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REV 5

MOTOROLA

Sensor
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4th Edition

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The Sensor Data Book does not contain any
“Not Recommended for New Design” devices.

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Section One

General Information

Introduction:

This version of the Sensor Products Device Data Handbook is organized to provide easy reference to sensor device information. We have reorganized the book based upon your recommendations with our goal to make designing in pressure, acceleration and smoke ICs easy, and if you do have a question, you'll have access to the technical support you need.

The handbook is organized by product line, acceleration, pressure and smoke ICs. Once in a section, you'll find a glossary of terms, a list of frequently asked questions or other relevant data. If you have recommendations for improvement, please complete the comment card and return it to us or, feel free to call our Sensor Device Data Handbook hot line and we'll personally record your comments. The hot line number is 602/244–5568. We look forward to hearing from you!

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We want to make this website entertaining as well as informative with a variety of information available. You'll find information on each sensor product (acceleration, pressure and smoke ICs) as well as access to data sheets, pricing, SPICE models as available, product and applications photography, new product information and news about our growing sensor family. Information is continuously added to improve the value of our website as we envision it as a tool in your library of product and design references. We encourage your comments and suggestions. To let us know your feed back, simply email Carol Smith, (R27828@email.SPS.mot.com).

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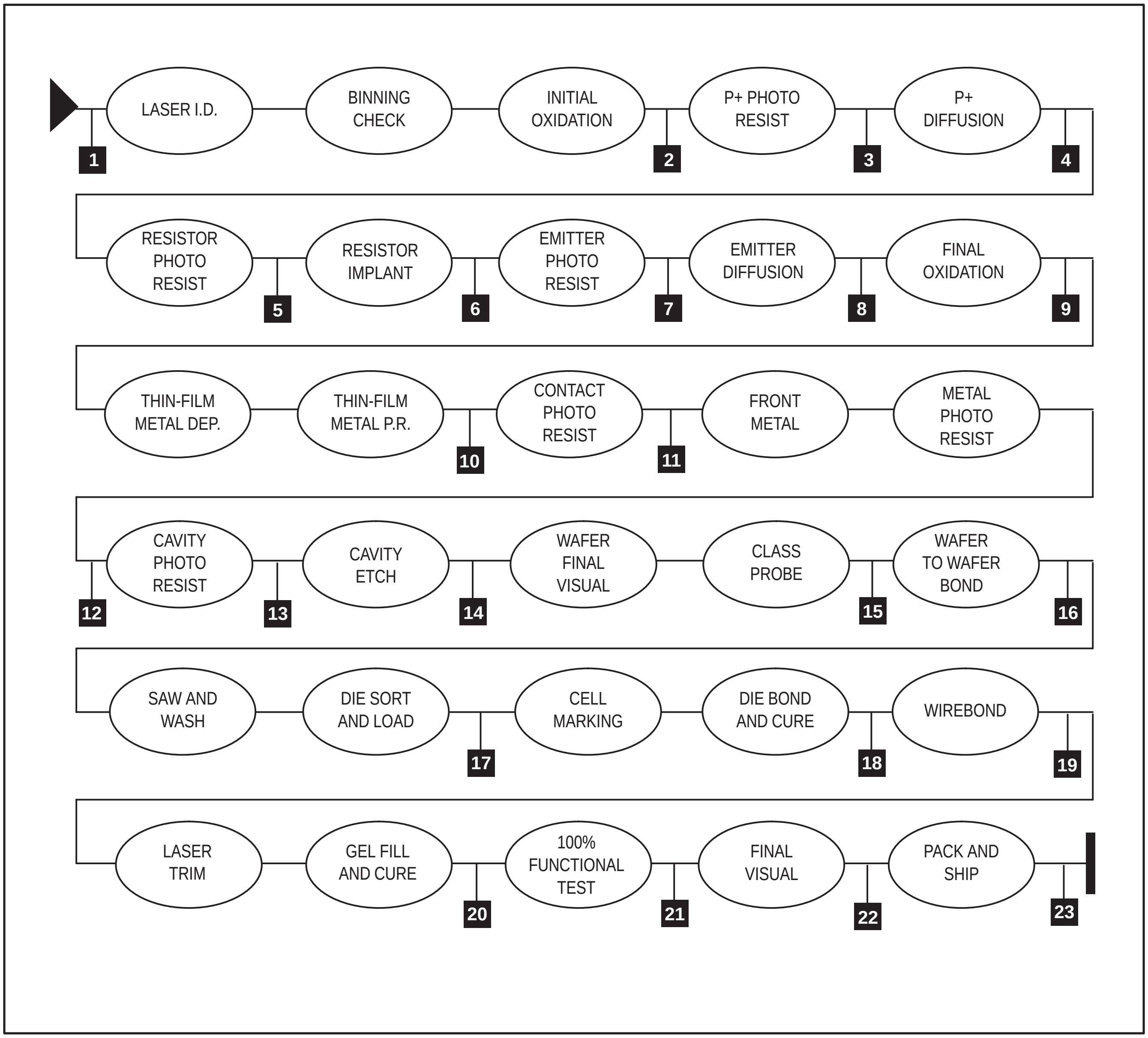
Compensated Sensor Flow Chart



Reliability Issues for Silicon Pressure Sensors

by Theresa Maudie and Bob Tucker
Sensor Products Division

Revised June 9, 1997

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. 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 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 15 years for automotive 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. The relationship between failure rate and the chi-square distribution is as follows:

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

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 = 2 (r + 1)
r = number of failures
t = device hours

Chi-square values for 60% and 90% confidence intervals for up to 12 failures is 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

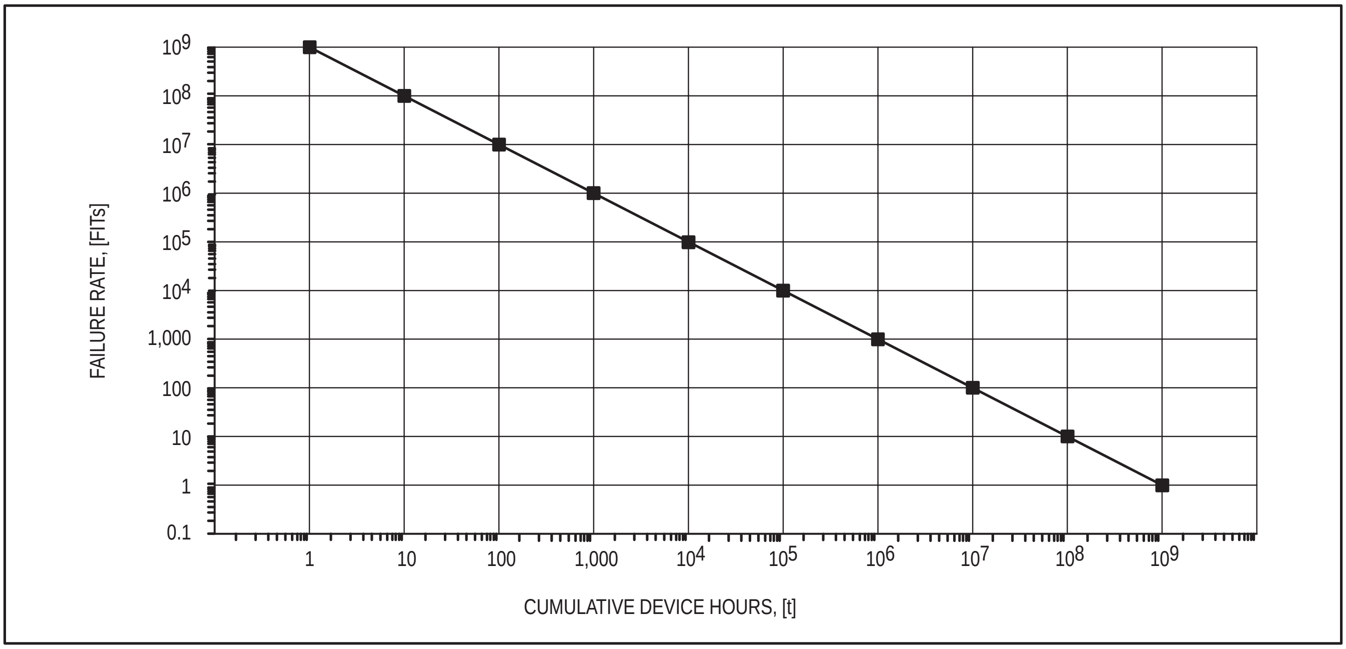


Figure 1. Depiction of the influence on the cumulative device hours with no failures and the Failure Rate as measured in FITs.

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. Testing to failure and determination of the lifetime statistics is beyond the scope of this paper and presented elsewhere [2].

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) [3]. 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" [4].

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 causes are developed by allowing tests to run beyond the normal test times, thus stressing to destruction. The typical reliability test matrix used to insure conformance to customers end usage is as follows [5]:

PULSED PRESSURE TEMPERATURE CYCLING WITH BIAS (PPTCB)

This test is an environmental stress test combined with cyclic pressure loading in which the devices are alternately subjected to a low and high temperature while operating under bias 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 the die, die bond, wire bond and package integrity.

Typical Test Conditions: Temperature per specified operating limits (i.e., Ta = –40 to 125°C for an automotive application). Dwell time ≥ 15 minutes, transfer time ≤ 5 minutes, bias = 100% rated voltage. Pressure = 0 to full scale, pressure frequency = 0.05 Hz, test time = up to 1000 hours.

Potential Failure Modes: Open, short, parametric shift.

Potential Failure Mechanisms: Die defects, wire bond fatigue, die bond fatigue, port adhesive failure, volumetric gel changes resulting in excessive package stress. Mechanical creep of packaging material.

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 under bias. The test is useful for evaluating package integrity as well as detecting surface contamination and processing flaws.

Typical Test Conditions: Temperature between 60 and 85°C, relative humidity between 85 and 90%, rated voltage, test time = up to 1000 hours.

Potential Failure Modes: Open, short, parametric shift.

Potential Failure Mechanisms: Shift from ionic affect, parametric instability, moisture ingress resulting in excessive package stress, corrosion.

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. The test is useful for evaluating the integrity of the interfaces on the die and thin film stability.

Typical Test Conditions: Temperature per specified operational maximum, bias = 100% rated voltage, test time = up to 1000 hours.

Potential Failure Modes: Parametric shift in offset and/or sensitivity.

Potential Failure Mechanisms: Bulk die or diffusion defects, film stability and ionic contamination.

HIGH AND LOW TEMPERATURE STORAGE LIFE (HTSL, LTSL)

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

Typical Test Conditions: Temperature per specified storage maximum and minimum, no bias, test time = up to 1000 hours.

Potential Failure Modes: Parametric shift in offset and/or sensitivity.

Potential Failure Mechanisms: Bulk die or diffusion defects, mechanical creep in packaging components due to thermal mismatch.

TEMPERATURE CYCLING (TC)

This is an 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. The test will stress the devices by generating thermal mismatches between materials.

Typical Test Conditions: Temperature per specified storage maximum and minimum (i.e., –40 to +125°C for automotive applications). Dwell time ≥ 15 minutes, transfer time ≤ 5 minutes, no bias. Test time up to 1000 cycles.

Potential Failure Modes: Open, parametric shift in offset and/or sensitivity.

Potential Failure Mechanisms: Wire bond fatigue, die bond fatigue, port adhesive failure, volumetric gel changes resulting in excessive package stress. Mechanical creep of packaging material.

MECHANICAL SHOCK

This is an environmental test where the sensor device is evaluated 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, shipping or actual use. MIL STD 750, Method 2016 Reference.

Typical Test Conditions: Acceleration = 1500 g’s, orientation = X, Y, Z planes, time = 0.5 milliseconds, 5 blows.

Potential Failure Modes: Open, parametric shift in offset and/or sensitivity.

Potential Failure Mechanisms: Diaphragm fracture, mechanical failure of wire bonds or package.

VARIABLE FREQUENCY VIBRATION

A test to examine the ability of the pressure sensor device to withstand deterioration due to mechanical resonance. MIL STD 750, Method 2056 Reference.

Typical Test Conditions: Frequency – 10 Hz to 2 kHz, 6.0 G’s max, orientation = X, Y, Z planes, 8 cycles each axis, 2 hrs. per cycle.

Potential Failure Modes: Open, parametric shift in offset and/or sensitivity.

Potential Failure Mechanisms: Diaphragm fracture, mechanical failure of wire bonds or package.

SOLDERABILITY

In this reliability test, the lead/terminals are evaluated for their ability to solder after an extended time period of storage (shelf life). MIL STD 750, Method 2026 Reference.

Typical Test Conditions: Steam aging = 8 hours, Flux= R, Solder = Sn63, Pb37.

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

Potential Failure Mechanisms: Poor plating, contamination.

OVER PRESSURE

This test is performed to measure the ability of the pressure sensor to withstand excessive pressures that may be encountered in the application. The test is performed from either the front or back side depending on the application.

Typical Test Conditions: Pressure increase to failure, record value.

Potential Failure Modes: Open.

Potential Failure Mechanisms: Diaphragm fracture, adhesive or cohesive failure of die attach.

A pressure sensor may be placed in an application where it will be exposed to various media that may chemically attack the active circuitry, silicon, interconnections and/or packaging material. The focus of media compatibility is to understand the chemical impact with the other environmental factors such as temperature and bias and determine the impact on the device lifetime. The primary driving mechanism to consider is permeation which quantifies the time for a chemical to permeate across a membrane or encapsulant corrosion can result.

Media related product testing is generally very specific to the application since the factors that relate to the product lifetime are very numerous and varied. An example is solution pH where the further from neutral will drive the chemical reaction, generally to a power rule relationship. The pH alone does not always drive the reaction either, the non–desired products in the media such as strong acids in fuels as a result of acid rain can directly influence the lifetime. It is recommended the customer and/or vendor perform application specific testing that best represents the environment. This testing should be performed utilizing *in situ* monitoring of the critical device parameter to insure the device survives while exposed to the chemical. The Sensor Products Division within Motorola has a wide range of media specific test capabilities and under certain circumstances will perform application specific media testing.

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.

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 considered the standard sensor operational life test.

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 assess 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.

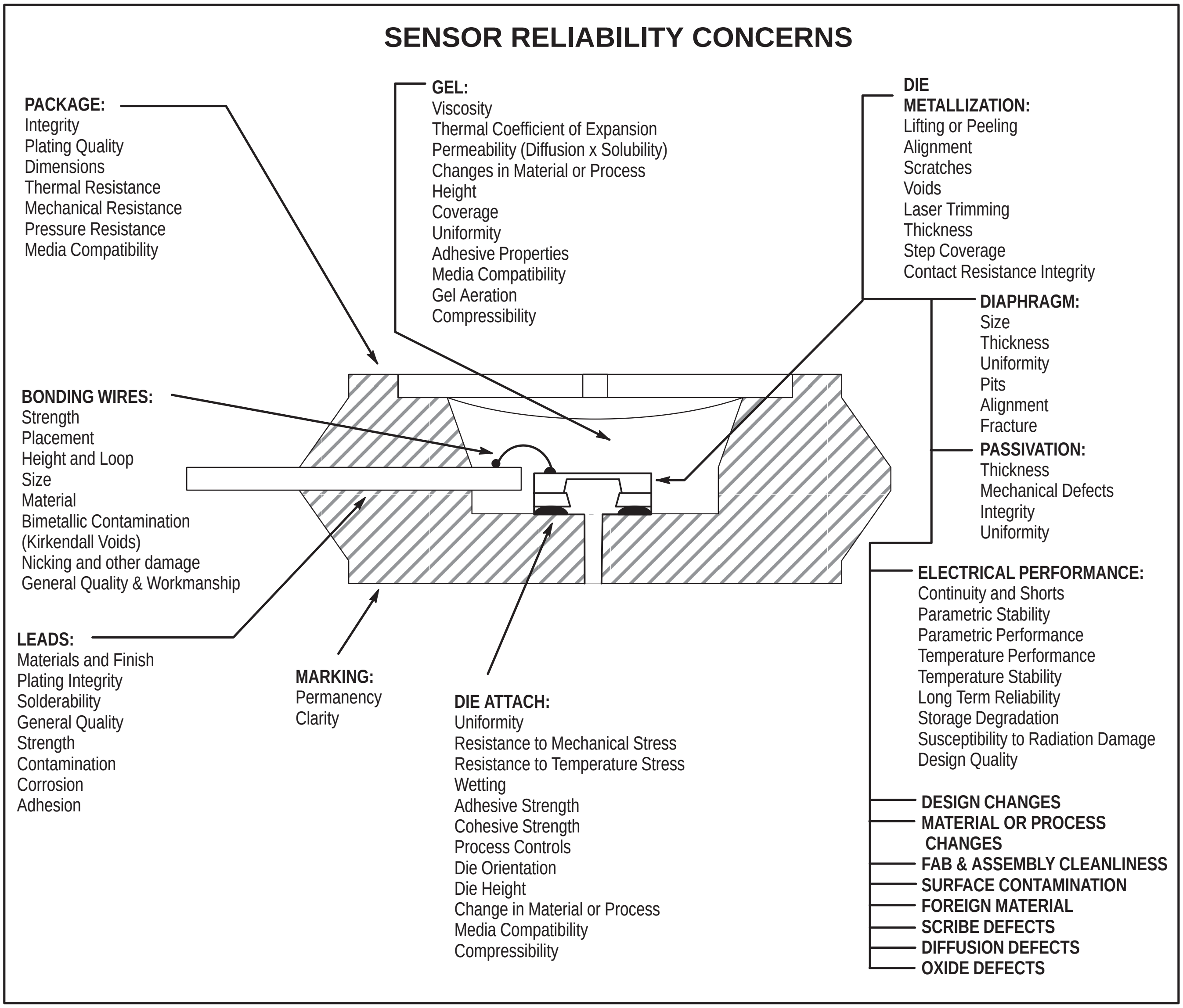


Figure 2. Process and Product Variability Concerns During Reliability Testing

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:

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

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

Where:

AF	=	Acceleration Factor
R_T	=	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 [6] and [7].

An example using the Arrenhius equation will be demonstrated. A 32 device HTB test for 500 hours total and no failure was performed. The 125°C, 100% rated voltage test resulted in no failures. If a customer's actual usage conditions was 55°C at full rated voltage, an estimate of the lower one side confidence limit can be calculated. An assumption is made that the failure rate is constant thus implying the exponential distribution. 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,

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

Where:

eA = 0.7eV/°K (assumed)

T_{LS} = 55°C + 273.16 = 328.16°K

T_{HS} = 125°C + 273.16 = 398.16°K

then;

AF = 77.64

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

t_{LS} = AF x t_{HS} = $(32 \cdot 500) \cdot 77.64$

or

t_{LS} = 1,242,172 device hours

Computing the lower one sided failure rate with a 90% confidence level and no failures:

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

or

λ = 1.853E–06 failures per hour

or

λ = 1,853 FITs

The inverse of the failure, λ, or the Mean Time To Failure (MTTF) is:

$$MTTF = \frac{1}{\lambda}$$

or

MTTF = 540,000 device hours

CONCLUSION

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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[4] “Interchangeability and Performance of Resistive Bridge Type Blood Pressure Transducers,” AAMI Guideline, Blood Pressure Monitoring Committee, latest revision.

[5] “Motorola D.M.T.G. Reliability Audit Report,” Q191.

[6] Wayne Nelson, “Accelerated Testing: Statistical Models,” *Test Plans, and Data Analyses,* John Wiley & Sons, Inc., New York, N.Y., 1990.

[7] D.S. Peck and O.D. Trapp, (1978), “Accelerated Testing Handbook,” Technology Associates, revised 1987.

SOLDERING PRECAUTIONS

The melting temperature of solder is higher than the rated temperature of the device. When the entire device is heated to a high temperature, failure to complete soldering within a short time could result in device failure. Therefore, the following items should always be observed in order to minimize the thermal stress to which the devices are subjected.

- Always preheat the device.
- The delta temperature between the preheat and soldering should be 100°C or less.*
- For pressure sensor devices, a no–clean solder is recommended unless the silicone die coat is sealed and unexposed. Also, prolonged exposure to fumes can damage the silicone die coat of the device during the solder reflow process.
- When preheating and soldering, the temperature of the leads and the case must not exceed the maximum temperature ratings as shown on the data sheet. When using infrared heating with the reflow soldering method, the difference should be a maximum of 10°C.
- The soldering temperature and time should not exceed 260°C for more than 10 seconds.
- When shifting from preheating to soldering, the maximum temperature gradient shall be 5°C or less.
- After soldering has been completed, the device should be allowed to cool naturally for at least three minutes. Gradual cooling should be used since the use of forced cooling will increase the temperature gradient and will result in latent failure due to mechanical stress.
- Mechanical stress or shock should not be applied during cooling.

* Soldering a device without preheating can cause excessive thermal shock and stress which can result in damage to the device.

TYPICAL SOLDER HEATING PROFILE

For any given circuit board, there will be a group of control settings that will give the desired heat pattern. The operator must set temperatures for several heating zones and a figure for belt speed. Taken together, these control settings make up a heating “profile” for that particular circuit board. On machines controlled by a computer, the computer remembers these profiles from one operating session to the next. Figure 3 shows a typical heating profile for use when soldering a surface mount device to a printed circuit board. This profile will vary among soldering systems, but it is a good starting point. Factors that can affect the profile include the type of soldering system in use, density and types of components on the board, type of solder used, and the type of board or substrate material being used. This profile shows temperature versus time. The line on the graph shows the actual temperature that might be experienced on the surface of a test board at or near a central solder joint. The two profiles are based on a high density and a low density board. The Vitronics SMD310 convection/infrared reflow soldering system was used to generate this profile. The type of solder used was 62/36/2 Tin Lead Silver with a melting point between 177–189°C. When this type of furnace is used for solder reflow work, the circuit boards and solder joints tend to heat first. The components on the board are then heated by conduction. The circuit board, because it has a large surface area, absorbs the thermal energy more efficiently, then distributes this energy to the components. Because of this effect, the main body of a component may be up to 30 degrees cooler than the adjacent solder joints.

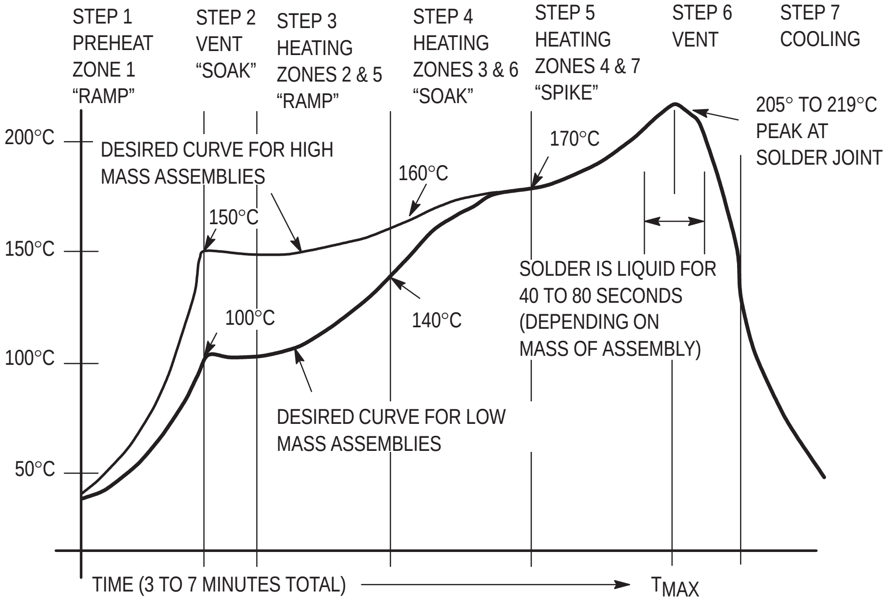


Figure 3. Typical Solder Heating Profile

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	XL0010V1	344–15	3–SEN	Uncompensated
MPX10DP	XL0010V1	344C–01	3–SEN	Uncompensated
MPX10GP	XL0010V1	344B–01	3–SEN	Uncompensated
MPX12D	XL0012V1	344–15	3–SEN	Uncompensated
MPX12DP	XL0012V1	344C–01	3–SEN	Uncompensated
MPX12GP	XL0012V1	344B–01	3–SEN	Uncompensated
MPX50D	XL0050V3	344–15	3–SEN	Uncompensated
MPX50GP	XL0050V3	344B–01	3–SEN	Uncompensated
MPX100A	XL0100V2	344–15	3–SEN	Uncompensated
MPX100AP	XL0100V2	344B–01	3–SEN	Uncompensated
MPX100AS	XL0100V2	344B–01	3–SEN	Uncompensated
MPX100ASX	XL0100V2	344F–01	3–SEN	Uncompensated
MPX100D	XL0100V3	344–15	3–SEN	Uncompensated
MPX100DP	XL0100V3	344C–01	3–SEN	Uncompensated
MPX100GP	XL0100V3	344B–01	3–SEN	Uncompensated
MPX200D	XL0200V3	344–15	3–SEN	Uncompensated
MPX200DP	XL0200V3	344C–01	3–SEN	Uncompensated
MPX200GP	XL0200V3	344B–01	3–SEN	Uncompensated
MPX2010D	XL2010V5	344–15	1–SEN	Temperature Compensated/Calibrated
MPX2010DP	XL2010V5	344C–01	1–SEN	Temperature Compensated/Calibrated
MPX2010GP	XL2010V5	344B–01	1–SEN	Temperature Compensated/Calibrated
MPX2010GS	XL2010V5	344E–01	1–SEN	Temperature Compensated/Calibrated
MPX2010GSX	XL2010V5	344F–01	1–SEN	Temperature Compensated/Calibrated
MPX2050D	XL2050V3	344–15	1–SEN	Temperature Compensated/Calibrated
MPX2050DP	XL2050V3	344C–01	1–SEN	Temperature Compensated/Calibrated
MPX2050GP	XL2050V3	344B–01	1–SEN	Temperature Compensated/Calibrated

DEVICE	LINE	CASE	CLASS	PRODUCT DESCRIPTION
MPX2300DT1	XL2300C1,01C1	423–04	1–SEN	Temperature Compensated/Calibrated
MPX4100A	XL4101S2	867–08	1–SEN	Signal–Conditioned
MPX4100AP	XL4101S2	867B–04	1–SEN	Signal–Conditioned
MPX4100AS	XL4101S2	867E–03	1–SEN	Signal–Conditioned
MPX4101A	XL4101S2	867–08	1–SEN	Signal–Conditioned
MPX4115A	XL4101S2	867–08	1–SEN	Signal–Conditioned
MPX4115AP	XL4101S2	867B–04	1–SEN	Signal–Conditioned
MPX4115AS	XL4101S2	867E–03	1–SEN	Signal–Conditioned
MPX4250A	XL4101S2	867–08	1–SEN	Signal–Conditioned
MPX4250AP	XL4101S2	867B–04	1–SEN	Signal–Conditioned
MPX5010D	XL4010S5	867–08	1–SEN	Signal–Conditioned
MPX5010DP	XL4010S5	867C–05	1–SEN	Signal–Conditioned
MPX5010GP	XL4010S5	867B–04	1–SEN	Signal–Conditioned
MPX5010GS	XL4010S5	867E–03	1–SEN	Signal–Conditioned
MPX5010GSX	XL4010S5	867F–03	1–SEN	Signal–Conditioned
MPX5050D	XL4051S1	867–08	1–SEN	Signal–Conditioned
MPX5050DP	XL4051S1	867C–05	1–SEN	Signal–Conditioned
MPX5050GP	XL4051S1	867B–04	1–SEN	Signal–Conditioned
MPX5100D	XL4101S1	867–08	1–SEN	Signal–Conditioned
MPX5100DP	XL4101S1	867C–05	1–SEN	Signal–Conditioned
MPX5100GP	XL4101S1	867B–04	1–SEN	Signal–Conditioned
MPX5700D	XL4701S1	867–08	1–SEN	Signal–Conditioned
MPX5700DP	XL4701S1	867C–05	1–SEN	Signal–Conditioned
MPX5700GP	XL4701S1	867B–04	1–SEN	Signal–Conditioned
MPX5999D	XL4999S1	867–08	1–SEN	Signal–Conditioned
PMMA2001D	XL040X8B	475–01	1–SEN	50g Accelerometer
PMMA2500D	XL040DAF(J)	475–01	1–SEN	15g Accelerometer

Statistical Process Control

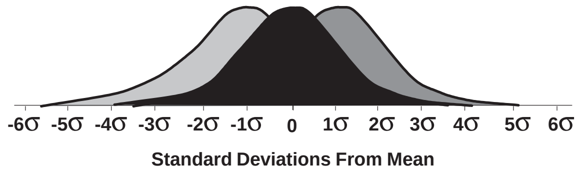
Motorola's Semiconductor Products Sector is continually pursuing new ways to improve product quality. Initial design improvement is one method that can be used to produce a superior product. Equally important to outgoing product quality is the ability to produce product that consistently conforms to 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 produces 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 1, 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 1. 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 2 shows the impact on predictability that assignable cause can have. Figure 3 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 = | closest specification $-\bar{X}/3\sigma$.

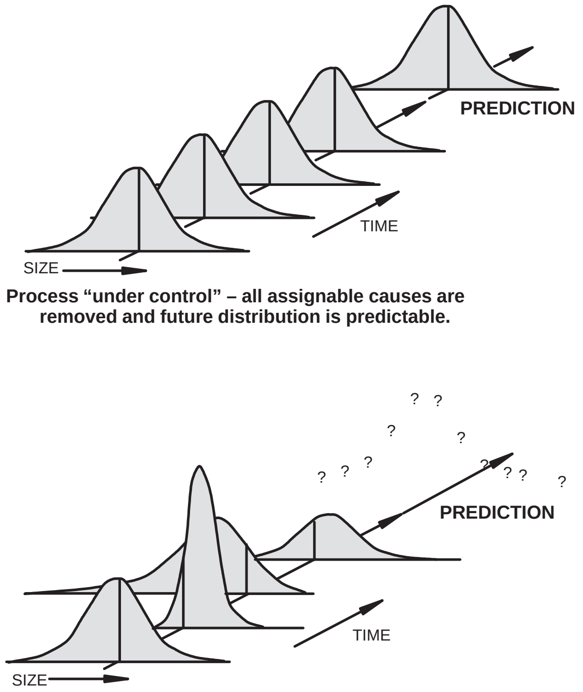


Figure 2. Impact of Assignable Causes on Process Predictable

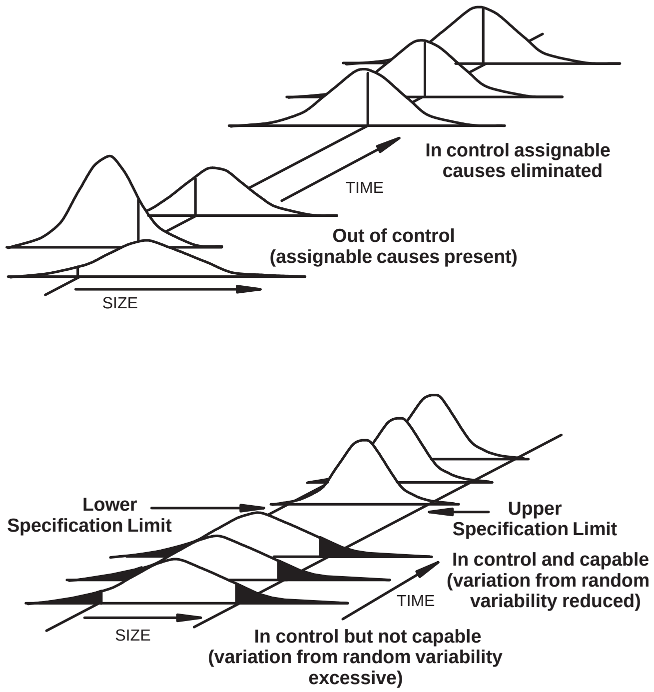


Figure 3. Difference Between Process Control and Process Capability

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 $\overline{X}$ and R values that are plotted with respect to time. $\overline{X}$ 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 $\overline{X}$ and R values have been generated, the average of these values is computed as follows:

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

where K = the number of subgroups measured.

The values of $\overline{\overline{X}}$ and $\overline{R}$ are used to create the process control chart. Control charts are the primary SPC tool used to signal a problem. Shown in Figure 4, process control charts show $\overline{X}$ and R values with respect to time and concerning reference to upper and lower control limit values. Control limits are computed as follows:

$$\text{R upper control limit} = UCL_R = D4\ \overline{R}$$
$$\text{R lower control limit} = LCL_R = D3\ \overline{R}$$
$$\overline{X}\ \text{upper control limit} = UCL_{\overline{X}} = \overline{\overline{X}} + A2\ \overline{R}$$
$$\overline{X}\ \text{lower control limit} = LCL_{\overline{X}} = \overline{\overline{X}} - A2\ \overline{R}$$

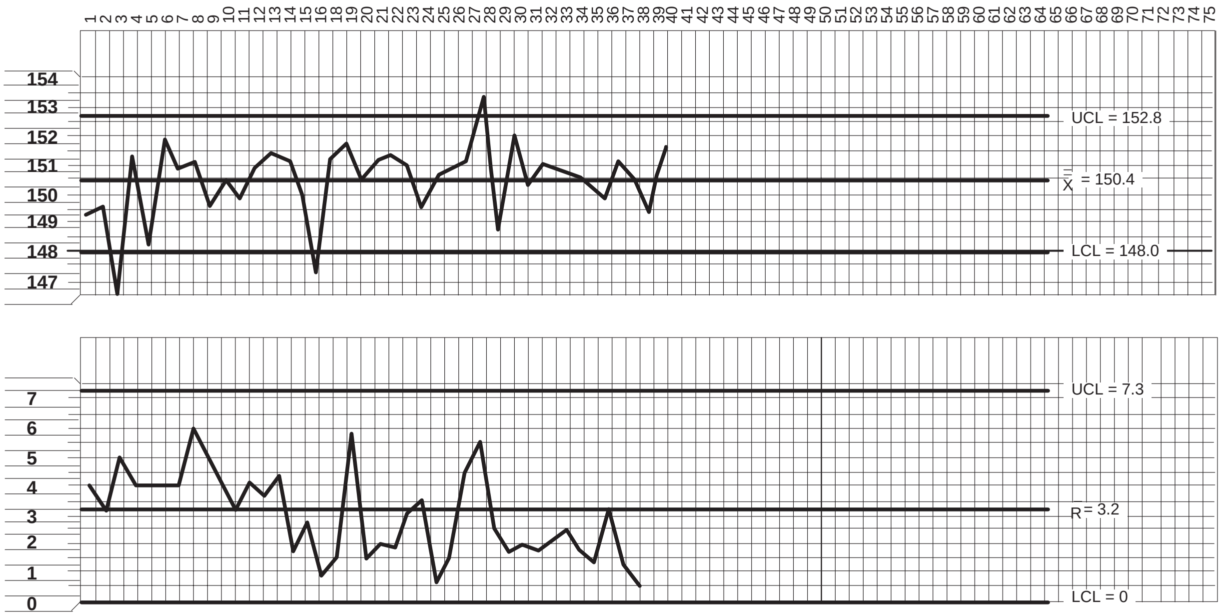


Figure 4. Example of Process Control Chart Showing Oven Temperature Data

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 5 shows a control chart subdivided into zones A, B, and C corresponding to 3 sigma, 2 sigma, and 1 sigma limits respectively. In Figure 6 through Figure 9 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.

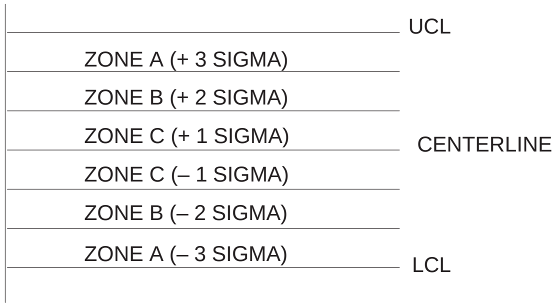


Figure 5. Control Chart Zones

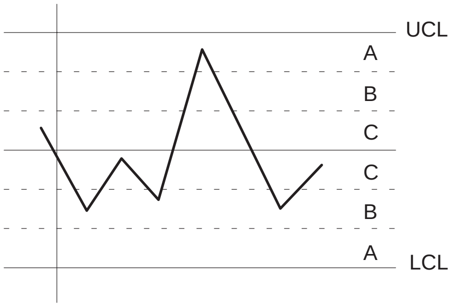


Figure 6. One Point Outside Control Limit Indicating Excessive Variability

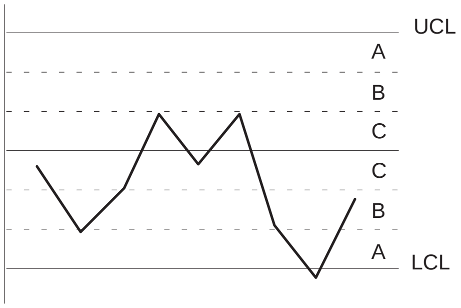


Figure 7. Two Out of Three Points in Zone A or Beyond Indicating Excessive Variability

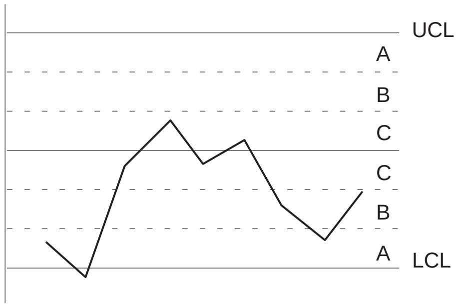


Figure 8. Four Out of Five Points in Zone B or Beyond Indicating Excessive Variability

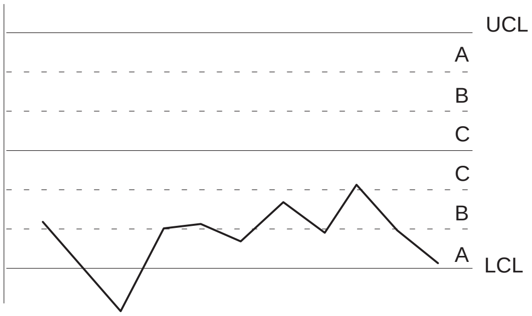


Figure 9. Seven Out of Eight Points in Zone C or Beyond Indicating Excessive Variability

SUMMARY

Motorola's commitment to STATISTICAL PROCESS CONTROLS has resulted in many significant improvements to processes. Continued dedication to the SPC culture will allow Motorola to reach beyond Six Sigma and zero defect capability goals. SPC will further enhance the commitment to **TOTAL CUSTOMER SATISFACTION**.

Micromachined Accelerometer Reliability Testing Results

LIFE AND ENVIRONMENTAL TESTING RESULTS

STRESS TEST	CONDITIONS	RESULTS FAILED/PASS
High Temperature Bias	T_A = 90°C, V_{DD} = 5.0 V t = 1000 hours, 12 minutes on, 8 seconds off	0/32
High Temperature/High Humidity Bias	T_A = 85°C, R_H = 85%, V_{DD} = 5.0 V, t = 2016	0/38
High Temperature Storage (Bake)	T_A = 105°C, t = 1000 hours	0/35
Temperature Cycle	–40 to 105°C, Air to Air, 15 minutes at extremes, ≤ 5 minutes transfer, 1000 cycles	0/23
Mechanical Shock	5 blows X1, X2, Y1, Y2, Z1, Z2 2.0 G's, 0.5 mS, T_A = –40°C, 25°C, 90°C	0/12
Vibration Variable Frequency with Temperature Cycle	10 – 1 Khz @ 50 G's max, 24 hours each axis, X1, X2, Y1, Y2, Z1, Z2, T_A = –40 to 90°C, Dwell = 1 Hour, transfer = 65 minutes	0/12
Autoclave	T_A = 121°C, R_H = 100% 15 P_{SIG}, t = 240 hours	0/71
Drop Test	10 Drops from 1.0 meters onto concrete, any orientation	0/12

PARAMETERS MONITORED

		LIMITS			
		INITIAL		END POINTS	
PARAMETER	CONDITIONS	MIN	MAX	MIN	MAX
Offset	V_{DD} = 5.0 V, 25, –40 & 90°C	2.15 V	2.95 V	2.15 V	2.95V
Self Test	V_{DD} = 5.0 V, 25, –40 & 90°C	20G	30 G	20 G	30 G
Sensitivity	V_{DD} = 5.0 V, 25, –40 & 90°C	45 mV/G	55 mV/G	45 mV/G	55 mV/G

Media Compatibility Disclaimer

Motorola has tested media tolerant sensor devices in selected solutions or environments and test results are based on particular conditions and procedures selected by Motorola. Customers are advised that the results may vary for actual services conditions. Customers are cautioned that they are responsible to determine the media compatibility of sensor devices in their applications and the foreseeable use and misuses of their applications.

Sensor Media Compatibility: Issues and Answers

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ABSTRACT

As sensors and actuators are embedded deeper into electronic systems, the issue of media compatibility as well as sensor and actuator performance and survivability becomes increasingly critical. With a large number of definitions and even more explanations of what media compatibility is, there is a ground swell of confusion not only within the industry, but among end users as well. The sensor industry must respond to create a clear definition of what media compatibility is, then strive to provide a comprehensive understanding and industry wide agreement on what is involved in assessing media tolerance and compatibility. Finally, the industry must create a standard set of engineering parameters to design, evaluate, test, and ultimately qualify sensor and actuators functioning in various media conditions. This paper defines media compatibility, identifies pertinent compatibility issues, and recommends a path to industry standardization.

INTRODUCTION

Microelectromechanical System (MEMS) reliability in various media is a subject that has not yet received much attention in the literature yet [1–3], but does bring up many potential issues. The effects of long term media exposure to the silicon MEMS device and material still need answers [4]. Testing can result in predictable silicon or package related failures, but due to the complexity of the mechanisms, deleterious failures can be observed. The sensor may be exposed to diverse media in markets such as automotive, industrial, and medical. This media may include polar or nonpolar organic liquids, acids, bases, or aqueous solutions. Integrated circuits (ICs) have long been exposed to temperature extremes, humid environments, and mechanical tests to demonstrate or predict the reliability of the device for the application. Unlike a typical IC, a sensor often must exist in direct contact with a harsh environment. The lack of harsh media simulation test standardization for these direct contact situations necessitates development of methods and hardware to perform reliability tests.

The applicability of media compatibility affects all sensors to some degree, but perhaps none more dramatically than a piezoresistive pressure sensor. In order to provide an accurate, linear output with applied pressure, the media should come in direct contact with the silicon die. Any barrier provided between the die and the media, limits the device performance. A typical piezoresistive diaphragm pressure sensor manufactured using bulk micromachining techniques is shown in Figure 1. A definition for a media compatible pressure sensor will be proposed.

To ensure accurate media testing, the requirements and methods need to be understood, as well as what constitutes a failure. An understanding of the physics of failure can significantly reduce the development cycle time and produce a higher quality product [5,6]. The focus of the physics–of–failure approach includes the failure mechanism, accelerating environment, and failure mode. The requirement for a typical pressure sensor application involves long term exposure to a variety of media at an elevated temperature and may include additional acceleration components such as static or cyclic temperature and pressure.

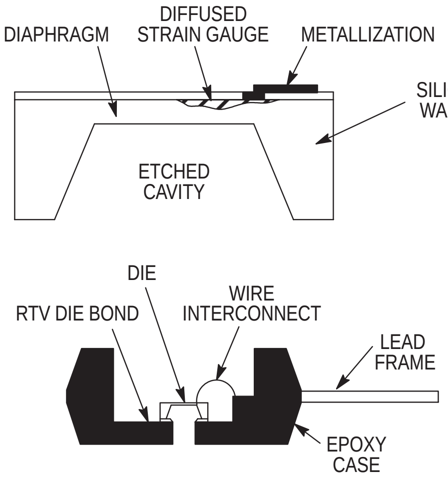

Figure 1. Typical bulk micromachined silicon piezoresistive pressure sensor device and package configuration.

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The failure mechanisms that may affect a sensor or actuator will be discussed along with the contributors and acceleration means. Failure mechanisms of interest during media testing of semiconductor MEMS devices are shown in Table 1. MEMS applications may involve disposable applications such as a blood pressure monitor whose lifetime is several days. General attributes to consider during testing include: lifetime expectations, cost target, quality level, size, form, and functionality.

Table 1. Typical Failure Mechanisms for Sensors and Actuators [6–10]

Failure Mechanism
Uniform Corrosion
Localized Corrosion
Galvanic Corrosion
Silicon Etching
Polymer Swelling or Dissolution
Interfacial Permeability
Adhesive Strength
Fatigue Crack Initiation
Fatigue Crack Propagation
Environment Assisted Cracking
Creep

Methods for performing media compatibility testing to determine the potential for the various failure mechanisms will be presented. Attributes of the testing need to be well understood so that proper assessment of failure and lifetime approximation can be made. The lifetime modeling is key for determination of the ability of a sensor device to perform its intended function. Reliability modeling and determination of activation energies for the models will provide the customer with an understanding of the device performance. The definition of an electrical failure can range from catastrophic, to exceeding a predetermined limit, to just a small shift. The traditional pre to post electrical characterization (before and after the test interval) can be enhanced by *in situ* monitoring. *In situ* monitoring may expose a problem with a MEMS device during testing that might have gone undetected once the media or another environmental factor is removed. This is a common occurrence for a failure mechanism, such as swelling, that may result in a shift in the output voltage of the sensor. Response variables during environmental testing can include: electrical, visual, analytical, or physical characteristics such as swelling or weight change.

DEFINITIONS & UNDERLYING CAUSES

The definition of a media compatible pressure sensor is as follows:

The ability of a pressure sensor to perform its specified electromechanical function over an intended lifetime in the chemical, electrical, mechanical, and thermal environments encountered in a customer's application.

The key elements of the definition are perform, function, lifetime, environment, and application. All of these elements are critical to meet the media compatibility needs. The underlying causes of poor media compatibility is the hostile environment and permeability of the environment. The environment may consist of media or moisture with ionics, organics, and/or aqueous solutions, extreme temperatures, voltage, and stress.

Permeability is the product of diffusivity and solubility. Contributors to permeability include materials (e.g. polymeric structures), geometry, processing, and whether or not the penetration is in the bulk or at an interface. The environment can also accelerate permeation if a concentration gradient, elevated temperature and/or pressure exist. An example of material dependence of permeation is shown in Figure 2. Organic materials such as silicone can permeate 50% of the relative moisture from the exterior within minutes where inorganic materials such as glass takes years for the same process to occur.

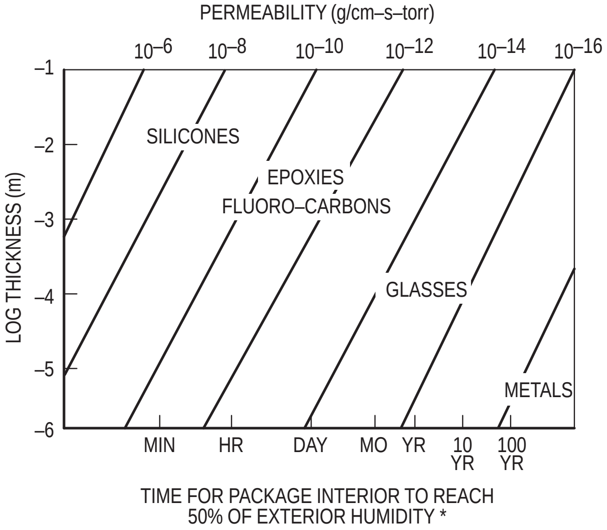

Figure 2. Permeation relationship for various materials.

** Richard K. Traeger, "Nonhermiticity of Polymeric Lid Sealants, IEEE Transactions on Parts, Hybrids, and Packaging, Vol. PHP–13, No. 2, June 1977.*

Gasoline and aqueous alkaline solutions represent two relatively diverse applications that are intended for use with a micromachined pressure sensor. The typical automotive temperature range is from –40° to 150°C. This not only makes material selection more difficult but also complicates the associated hardware to perform the media related testing [11]. A typical aqueous alkaline solution application would be found in the appliance industry. This industry typically has a narrower temperature extreme then the automotive market, but the solutions and the level of ions provide a particular challenge to MEMS device reliability.

Gasoline contains additives such as: antiknock, anti–preignition agents, dyes, antioxidants, metal deactivators, corrosion inhibitors, anti–icers, injector or carburetor detergents, and intake valve deposit control additives [12]**.** To develop a common test scheme for the liquid, a mixture table was developed for material testing in gasoline/methanol mixtures. The gasoline/methanol mixtures developed were intended for accelerated material testing with a gasoline surrogate of ASTM Fuel Reference "C" (50% toluene and 50% iso–octane) [13]. Material testing is performed with samples either immersed in the liquid or exposed to the vapor over the liquid. The highly aromatic Fuel

"C" is intended to swell polymeric materials. Contaminants in actual gasoline can result in corrosion or material degradation, so chloride ions or formic acid with distilled water are added to create an aggressive fuel media. Gasoline can decompose by a process called auto–oxidation that will form aggressive substances that can dissolve polymers or corrode metal. Copper is added as a trace metal to accelerate the formation of free radicals from the hydroperoxides. Table 2 details the various gasoline/methanol mixtures with additives recommended by the task force from Chrysler, Ford, and General Motors.

Table 2. Fuel Testing Methods

	Elastomer	Polymer	Metal
Alcohol/Fuel Blends	CMO	CMO	
	CM15	CM15	CM15
	CM30	CM30	
	CM50	CM50	
	CM85	CM85	CM85
Aggressive Fuel, Add		Chloride ion	Distilled water
		Formic Acid	Chloride ion
		Sodium Chloride	Formic Acid
Auto Oxidized Fuels, Add		t–Butyl Hydroperoxide	t–Butyl Hydroperoxide
		Cu^+	

Recommended gasoline/methanol mixtures for material testing. The recommended testing for metals should include immersion in the liquid as well as exposure to the vapor. The coding for the alcohol/fuel blends, CMxx is: C for Fuel C; M for methanol; and xx indicating the percentage of methanol in the mixture.

The general question for the appliance industry compatibility issues is not whether the media will contain ions (as it most assuredly will) but at what concentration. Tap water with no alkali additives contains ions capable of contributing to a corrosive reaction [14]. A typical application of a pressure sensor in the appliance industry is sensing the water level in a washing machine. The primary ingredients of detergent used in a washing machine are: surfactants, builders, whitening agents and enzymes [15]. The surfactants dissolve dirt and emulsify oil, grease and dirt. They can be anionic or cationic. Cationic surfactants are present in detergent–softener combinations. Builders or alkaline water conditioning agents are added to the detergent to soften the water, thus increasing the efficiency of the surfactant. These builders maintain alkalinity that results in improved cleaning. Alkaline solutions at temperatures indicated by the appliance industry range can etch bare silicon similar to the bulk micromachining process. Thus bare silicon could be adversely affected by exposure to these liquids [16].

FAILURE MECHANISMS

The failure mechanisms that can affect sensors and actuators are similar to that for electronic devices. These failure mechanisms provide a means of categorizing the various effects caused by chemical, mechanical, electrical, and thermal environments encountered. An understanding of the potential failure mechanisms should be determined before media testing begins. The typical industry scenario has been to follow a set boiler plate of tests and then determine reliability. This may have been acceptable for typical electronic devices, but the applications for sensors are more demanding of a thorough understanding before testing begins. The sensitivity of the device to its physical environment is heightened for a pressure sensor. Any change in the material properties results in a change of the sensor performance. Failure mechanisms for pressure sensors in harsh media application are listed below. The pressure sensor allows a format for discussion, though the mechanisms discussed are applicable in some degree to all sensor and actuator devices.

Corrosion

Corrosion has been defined as any destructive result of a chemical reaction between a metal or metal alloy and its environment [17]. Several metal surfaces exist within a pressure sensor package: metallic lines on the die, trimmable resistors, bonding pads, wires, leadframes, etc. Much of the die–level metal is protected by an overlying inorganic passivation material (e.g., PECVD silicon nitride); however, unless some package–level encapsulant is used, bondpads, wires, and leadframes are exposed to the harsh media and are potential corrosion sites. Furthermore, an energized pressure sensor has a voltage difference between these exposed metallic surfaces, which compounds the corrosion problem. Generally, corrosion problems are organized into the following categories: uniform corrosion; galvanic corrosion, and localized corrosion (including, crevice corrosion, pitting corrosion, etc.) [17]. The factors that contribute to corrosion are: the substrate (metallic) material and its surface structure and composition; the influence of a barrier coating, its processing conditions and/or adhesion promotion; the cleanliness of the surface, adhesion between a coating and the surface, solution concentration, solution components (especially impurities and/or oxidizers); localized geometry and applied potential. In addition, galvanic corrosion is influenced by specific metal–to–metal connections.

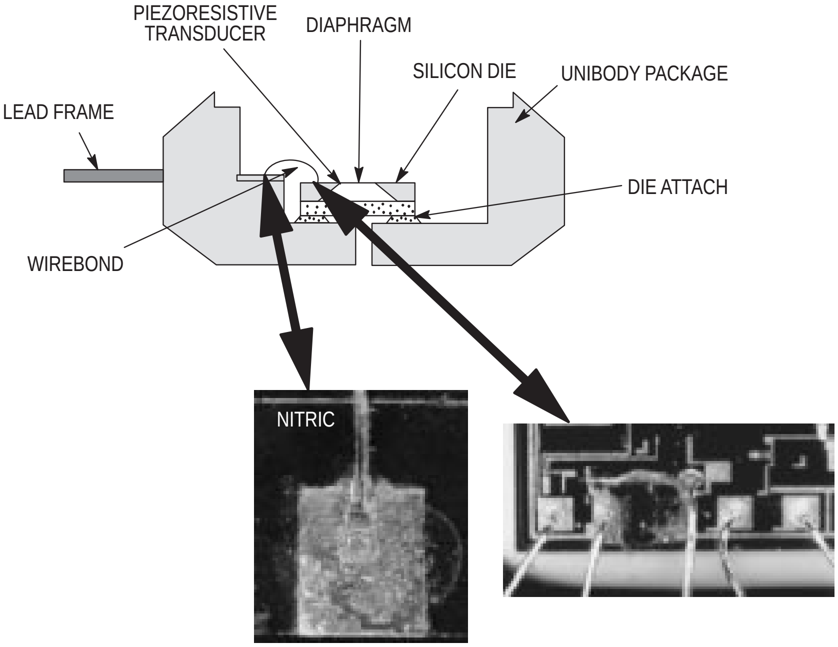

Figure 3. Examples of uniform corrosion of a gold leadframe in nitric acid at 5 Vdc and galvanic corrosion on an unbiased device at the gold wire/aluminum bondpad interface in commercial detergent.

Part of figure 3 shows an example of what we have described as electrolytic corrosion (i.e., corrosion of similar metallic surfaces in an electrolytic solution caused by a sufficient difference in potential between the two surfaces). This appears to be uniform corrosion of the gold leadframe surface. It should be noted that this type of failure is observed even on 'noble' metals like gold. Applied potential is the driving force for the reaction. All metals can corrode in this fashion depending on the solution concentration (pH) and the applied potential. Pourbaix diagrams describe these thermodynamic relationships [18].

Figure 3 shows an example of galvanic corrosion. The figure illustrates that corrosion can also occur because of dissimilar metals that are connected electrically and are immersed in an electrolytic solutions. A difference in the corrosion potential between the two metals is the driving force for the reaction. Localized corrosion examples are prevalent as well. Often they may be the precursor to what appears on a macro scale to be uniform or galvanic corrosion. *In situ* monitoring of devices in electrolytic media will allow better diagnosis of this failure mechanism. Typical *ex situ* or interval reliability testing may not allow diagnosis of the root cause to the failure, thus limiting the predictive power of any resulting reliability models.

Silicon Etching

Figure 4 shows the result of an accelerated test of a pressure sensor die to a high temperature detergent solution. The detergent used was a major consumer brand and resulted in dramatic etching of the silicon. Alkaline solutions that undergo a hydrolysis reaction may result in etching of the silicon similar to a bulk micromaching operation. This failure mechanism can cause a permanent change in the sensitivity of the device because the sensitivity is proportional to the inverse square of the silicon thickness. Moreover, it can lead to loss in bond integrity between wafers (Fig. 4). Silicon etching [19–20], like corrosion reactions, is a chemical reaction, so the contributing factors include the silicon material, its crystal orientation and its doping level, the solution type, concentration and pH, and the applied potential. Temperature, concentration (i.e., pH), and voltage all act to accelerate this process. Figure 5 shows an example of modeling results that illustrates two of these variables.

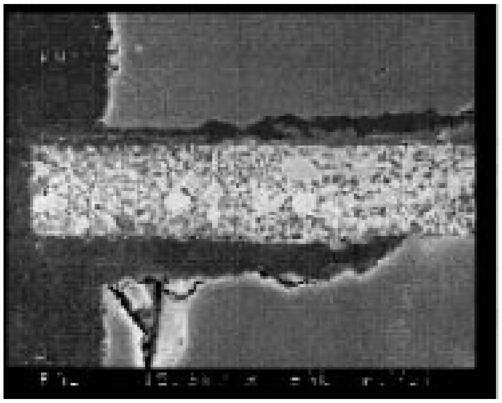

Figure 4. Photograph of silicon etching after exposure to an aqueous detergent solution at elevated temperature for an extended time. A frit layer, horizontally in the middle, adheres to silicon on either side. The amount of etching is evident by referencing the glass frit edge on the far left. These two silicon edges were aligned to the frit edge when the die was sawn.

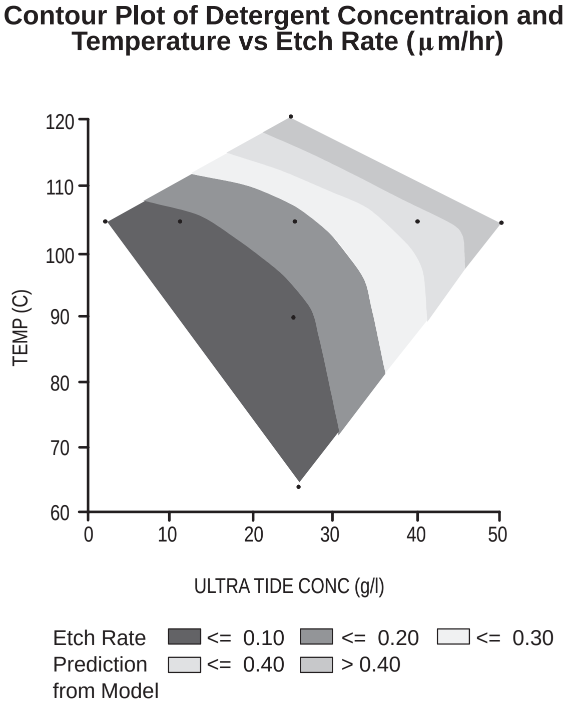

Figure 5. Experimental results for the etching of (100) silicon with approximately $5\text{x}10^{-5}$ cm^{-3} boron doping density in a commercially available detergent as a function of temperature and detergent concentration (which is proportional to pH).

Polymer Swelling or Dissolution

Swelling or dissolution affects those polymers typically employed to package the micromachined structure and depending on the nature of the media, may have a degrading effect on device performance. These two related phenomena are caused by solvent diffusing into the material and occupying free volume within the polymer. The solubility parameter gives a quantitative measure of the potential for swelling [21]: i.e., it provides a quantitative measure of “like dissolves like” (Fig. 6). Both the polymer and the solution contribute to this failure mechanism, while the media (specifically, the solubility parameter), the temperature, and the pressure can be used as acceleration factors.

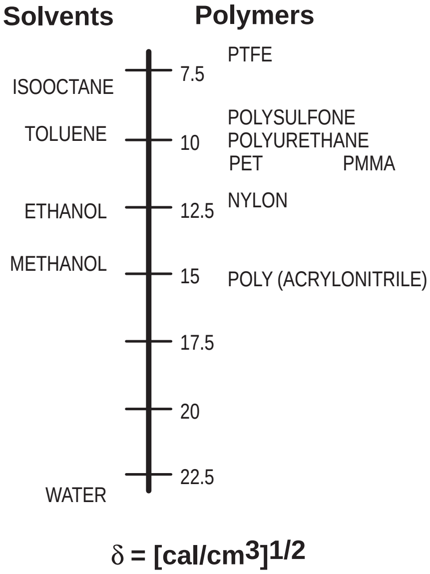

Figure 6. Typical values of solubility parameter (δ [cal/cm^3]$^{1/2}$) for solvents and polymers.

Figure 7 shows a photograph of a device after exposure to a harsh fuel containing corrosive water solution. This corrosion and evidence of swelling of the gel demonstrates the vital importance the package has on the reliability of the pressure sensor device. Also, it has been observed that corrosion occurs more readily following swelling of a polymeric encapsulant.

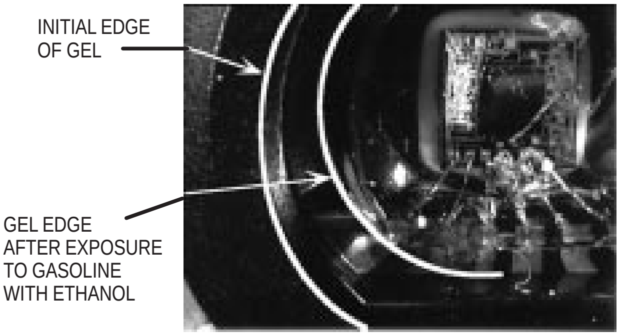

Figure 7. Photograph of a pressure sensor device after extended exposure to harsh fuel containing corrosive water, followed by exposure to a strong acid. Evidence of the gel swelling during the test, and corresponding shrinkage after removal from the test media can be seen by the gel retracting away from the sidewall of the package.

Interfacial Permeability

Lead leakage is a specific example of interfacial permeability. It is pressure leakage through the polymer housing material/metallic leadframe material interface from the inside of the pressure sensor package to the outside of the pressure sensor package or vice versa [22]. In addition, other material interfaces can result in leakage. We describe another specific example of this in the next section. Lead leakage is like polymer swelling in that it may allow another failure mechanism, like corrosion, to occur more readily. It also causes a systematic pressure measurement error. Figure 8 shows the result of lead leakage measurements as a function of temperature cycling. The polymer housing material (and its CTE as a function of temperature), the leadframe material (and its CTE), surface preparation and contamination, the polymer matrix composition, and polymer processing all contribute to this effect. It is accelerated by media, temperature cycling, and applied pressure.

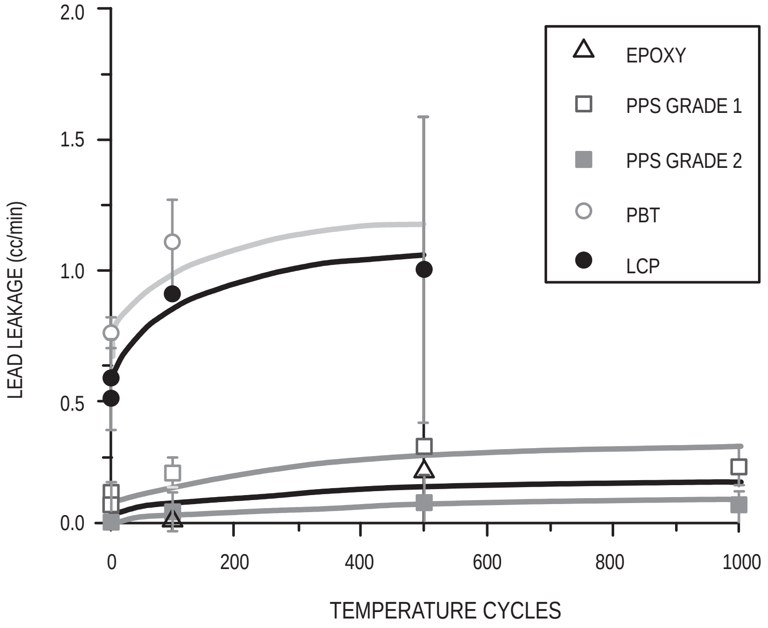

Figure 8. Pressure leakage measurements through the metallic leadframe/polymeric housing material interface on a pressure sensor as a function of temperature cycles between –40 and 125°C.

Adhesive Strength

Packaging of the sensor relies on adhesive material to maintain a seal but not impart stress on the piezoresistive element. Polymeric materials are the primary adhesive materials which can range from low modulus material such as silicone to epoxy with a high modulus. An example of a typical joint is shown in Figure 9. The joint has three possible failure locations with the preferred break being cohesive. Contributors to a break include whether the joint is in tension or compression, residual stresses, the adhesive material, surface preparation, and contamination. An adhesive failure is accelerated by media contact, cyclic or static temperature, and cyclic or static stress (e.g. pressure).

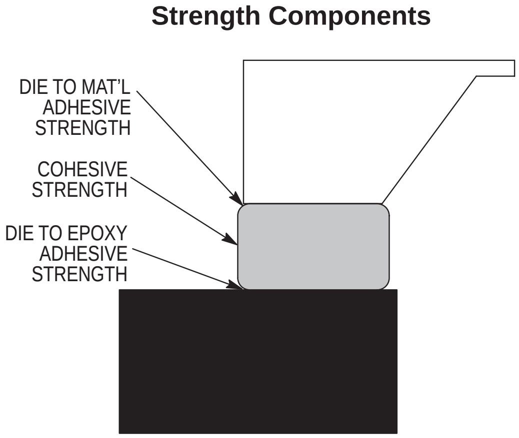

Figure 9. Failure locations for an adhesive bond of dissimilar materials.

Mechanical Failures

The occurrence of mechanical failures include components of fatigue, environment assisted cracking, and creep. Packaging materials, process, and residual stresses are all contributors to mechanical failure. A summary of acceleration stresses is shown in Table 3. Contact with harsh media is an accelerating stress for all of the mechanical failure mechanisms.

Table 3. Mechanical Failure Mechanisms

Failure Mechanism	Acceleration Stresses
Fatigue crack initiation	Mechanical stress/strain range Cyclic temperature range Frequency Media
Fatigue crack propagation	Mechanical stress range Cyclic temperature range Frequency Media
Environment assisted cracking	Mechanical stress Temperature Media
Creep	Mechanical stress Temperature Media

PRESSURE SENSOR SOLUTIONS

The range of solutions for pressure sensors to media compatibility is very diverse. Mechanical pressure sensors still occupy a number of applications due to this media compatibility concern. These devices typically operate on a variable inductance method and are typically not as linear as a piezoresistive element. Figure 10 shows a comparison between a mechanical pressure sensor and a piezoresistive element for a washing machine level sensing application. The graph shows a nonlinear response for the mechanical sensor and a corresponding straight line for the piezoresistive element.

A common method of obtaining media compatibility is to place a barrier coating over the die and wire interconnection. This organic encapsulant provides a physical barrier between the harsh environment and the circuitry. The barrier coating can range from silicone to parylene or other dense films that are typically applied as a very thin layer. This technique offers limited protection to some environments due to swelling and/or dissolution of the encapsulant material when in contact with media with a similar solubility. When a polymeric material has a solubility parameter of the same value as the corresponding media, swelling or dissolution will occur.

Stainless steel diaphragms backfilled with silicone oil provide a rugged barrier to most media environments, but generally are very costly and limit the sensitivity of the device. The silicone oil is used to transmit the stress from the diaphragm to the piezoresistive element. If a polymeric material is used as the die attach, the silicone oil will permeate out of the package. This concern requires a die attach that is typically of higher modulus than a silicone and may not adequately isolate the package stress from the die.

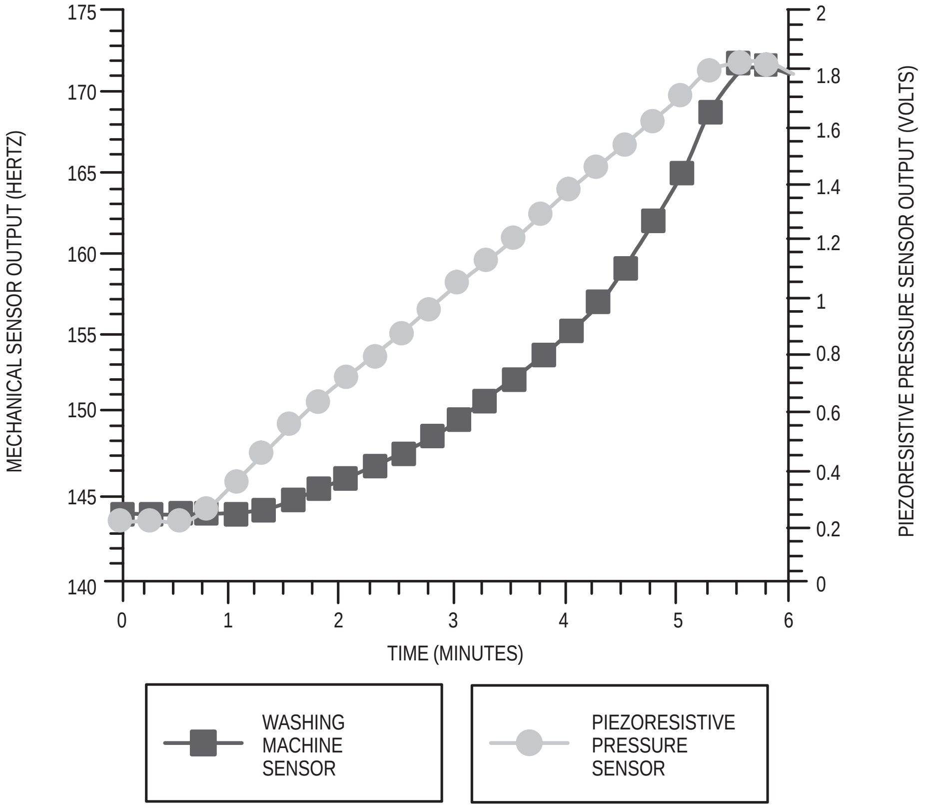

Figure 10. Graphical comparison of the output from a mechanical pressure sensor compared to a piezoresistive sensor during a washing machine fill cycle.

MEDIA TEST METHODS

Figures 11 and 12 show a test apparatus specifically intended for use with solvents and Figure 13 an apparatus for aqueous solutions. This test system has resulted in a realistic test environment that provides electrical bias, *in situ* measurements, consistent stoichiometry, and temperature control all within a safe environment. The safety aspects of the testing were obtained by creating an environment free of oxygen to eliminate the possibility of a fire. Results from the testing have included swelling of silicone materials, corrosion, and adhesive failures.

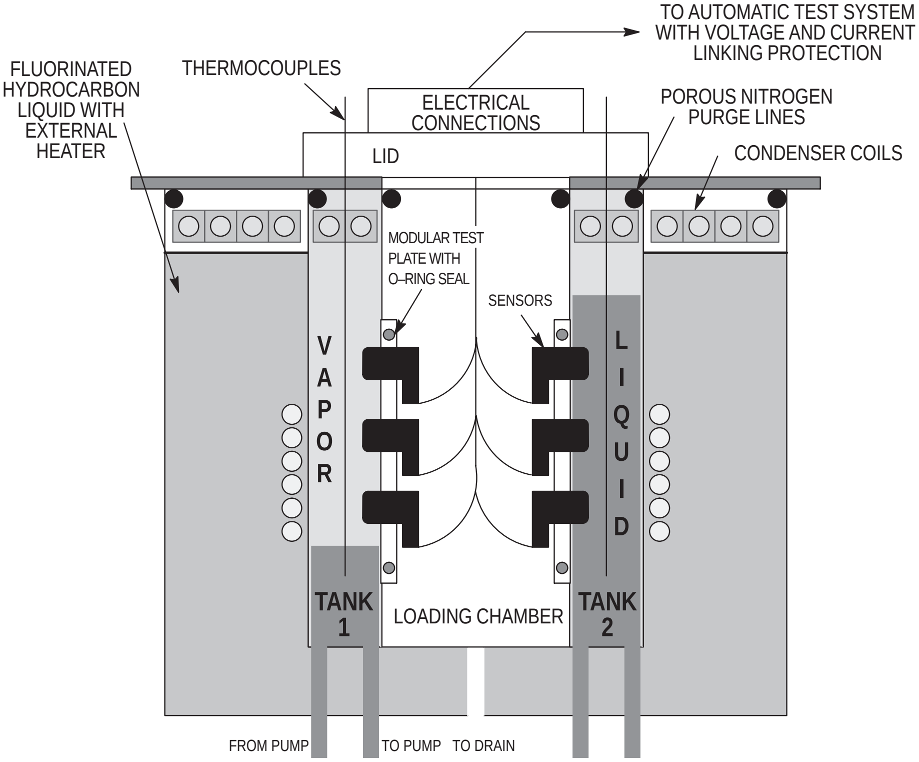

Figure 11. Graphical depiction of the sensor media tester used for liquid or vapor exposure of the device to the harsh media to accelerate the failure mechanisms or demonstrate compatibility.

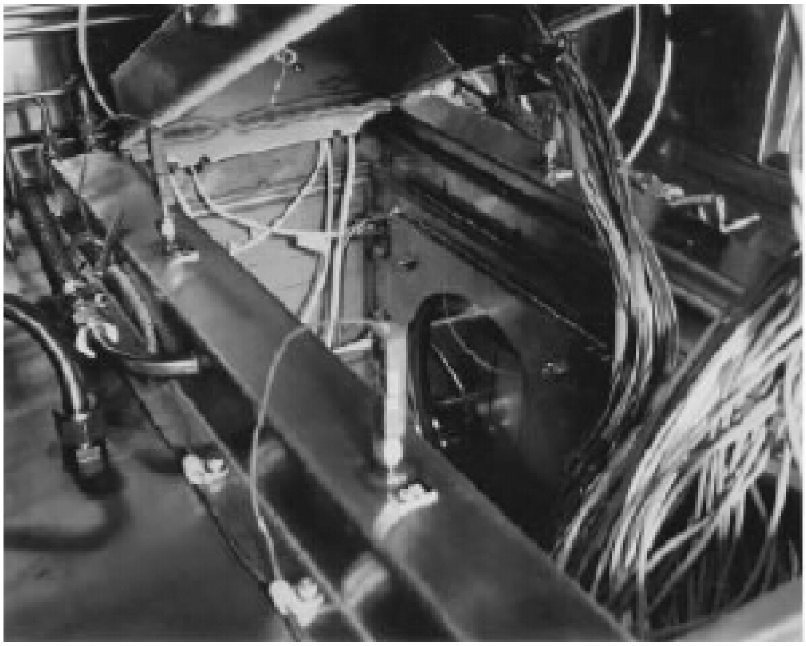

Figure 12. Photograph of the load chamber area of the Media Test System allowing for fuel or solvent testing at temperature with *in situ* monitoring of the devices under test (DUT's) output.

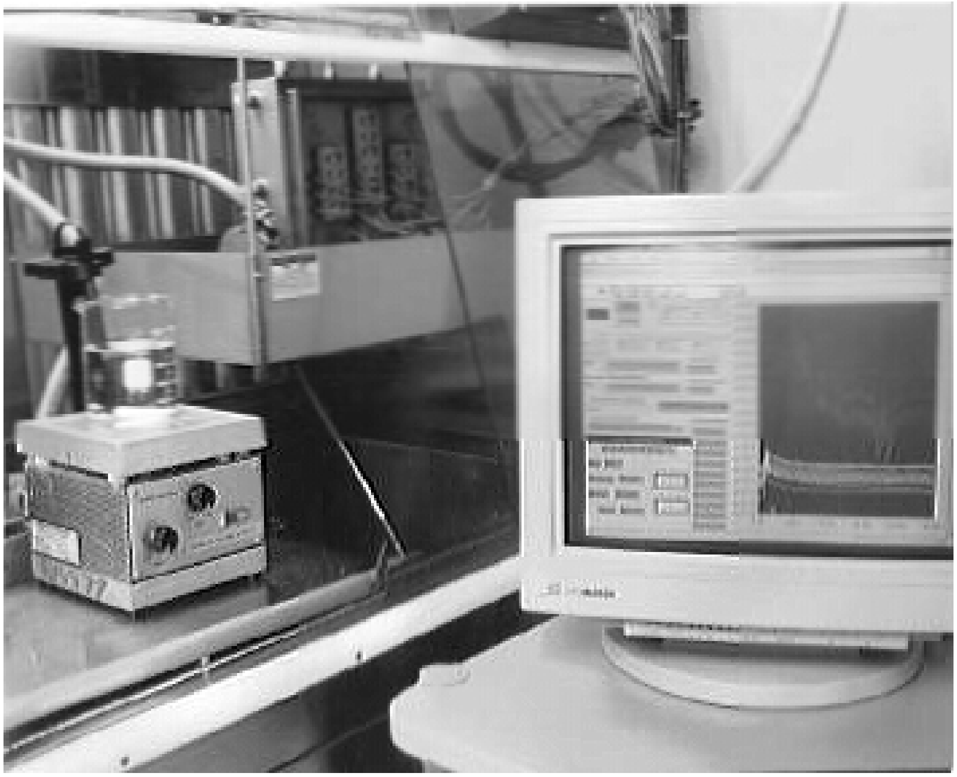

Figure 13. Photograph of the aqueous alkaline solution test system and the data acquisition system for *in situ* monitoring of the MEMS devices.

LIFETIME MODELING

Reliability techniques provide a means to analyze media test results and equate the performance to a lifetime [23–24]. The primary reliability techniques involve an understanding of the failure rate, life distributions, and acceleration modeling. The failure rate for a product's lifetime follows the bathtub curve. This curve, as shown in Figure 14, has an early life period with a decreasing failure rate. Manufacturing defects would be an example of failures during this portion of the curve. The second portion of the curve, often described as the useful life region has a constant failure rate. The last section has an increasing failure rate and is referred to as the wearout region. This wearout region would include failure mechanisms such as corrosion or fatigue.

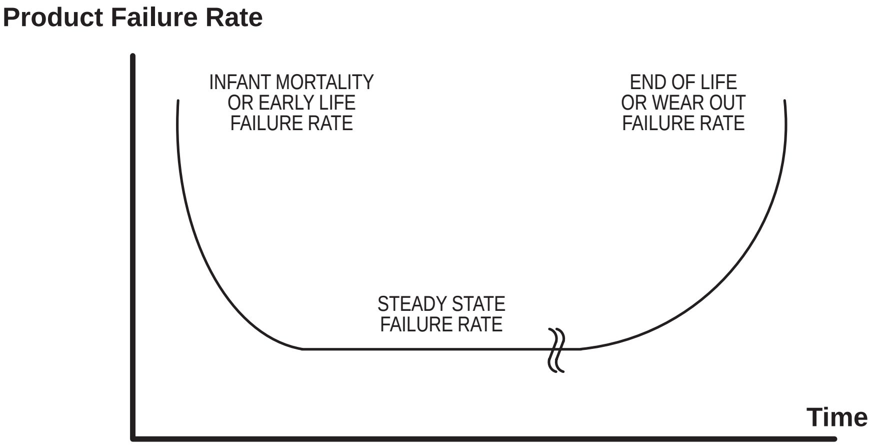

Figure 14. Bathtub curve showing various failure rate regions.

Lifetime distributions provide a theoretical model to describe device lifetimes. Common lifetime distributions include the exponential, Weibull, lognormal, and extreme value. The exponential distribution models a lifetime with a constant failure rate An example of the exponential distribution is a glass which has an equal probability of failing the moment after it is manufactured, or when its ten years old. The Weibull and lognormal distribution are all right, or positively skewed distributions. A right skewed distribution will be a good model for data in a histogram with an extended right tail. The Weibull distribution is sometimes referred to as a distribution of minima. An example of a Weibull distribution is the strength to break a chain where the weakest link describes the strength of the chain. The extreme value distribution is a distribution of maxima. It is the least utilized of the four life distributions.

For means of example, the Weibull distribution will be used. The Weibull lifetime distribution has the form:

$$F(t, \theta, \beta) = 1 - e^{-\left(\frac{t}{\theta}\right)^{\beta}}. \qquad (1)$$

The two parameters for the Weibull distribution are q and b. Theta is the scale parameter, or characteristic life. It represents the 63.2 percentile of the life distribution. Beta is the shape parameter. In order to determine the parameters for the Weibull distribution, testing must be performed produce failure on the devices. The failure data can be used to calculate the maximum likelihood estimates or determined graphically. It has not always been customary to perform reliability demonstration testing until failures occur. In regards to media testing, this seems to be the only method to derive lifetime estimates that reflect a true understanding of the device capability.

$$AF = e^{\left[\frac{Ea}{k}\left(\frac{1}{T_{low}} - \frac{1}{T_{high}}\right)\right]} \bullet \left(\frac{RH_{high}}{RH_{low}}\right)^{n}, \qquad (2)$$

A media test typically needs to take results received in weeks or months to predict lifetime in years. Acceleration models are used to determine the relationship between the accelerated test and the normal lifetime. Literature has reported numerous models to equate testing to lifetime including the Peck model for temperature and humidity [25]. The acceleration equation based on Peck's model is where Ea is 0.9eV and n is –3.0. The value K is Boltzmann's constant which is equal to 8.6171×10^{-5} eV/K. The relative humidity is entered as a whole number, i.e. 85 for 85%. Using this sample model, test results from humidity testing can be related to the lifetime. The methods to equate test time to lifetime first involves fitting the failure data to a lifetime distribution. For an example, humidity data at 60°C, 90% relative humidity and bias was tested to failure. The failure data fit a Weibull distribution with a characteristic life of 40,000 hours. By applying the acceleration factor equation shown above, quantification of the lifetime in the use conditions can be calculated. Figure 15 shows the cumulative failure distribution for the test and use conditions for a 15 year lifetime. This technique is key for media testing since the range of use conditions is very broad. The consumer can determine the attributes for the sensor to use for the application. The attributes might include cost, performance, and possibility for replacement.

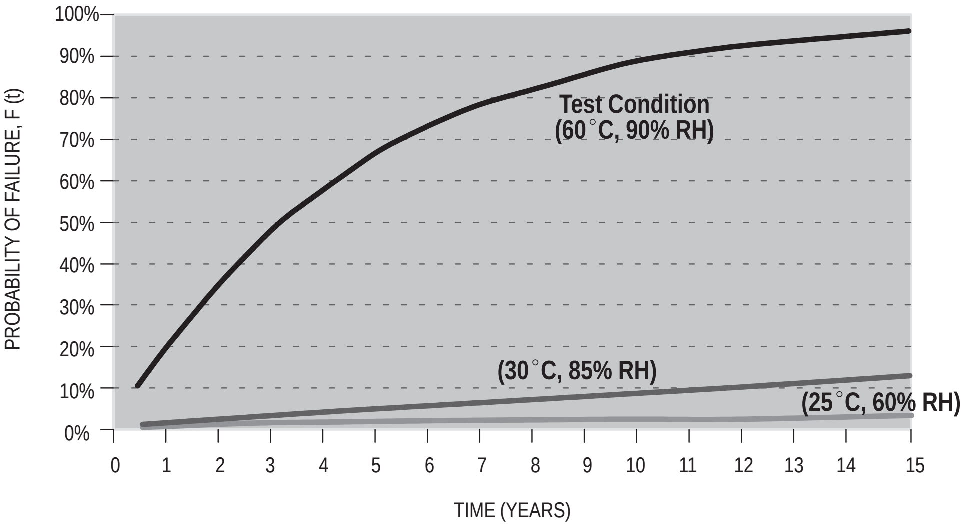

Figure 15. Probability of failure versus time for humidity testing with bias on an integrated sensor device.

The failure distribution example shown typically represents one failure mechanism. The failure mechanism that typifies humidity testing is mobile ions. An elevated test temperature, humidity and bias contributes to the mobility of the ions and the ability to create a surface charge. By lowering the temperature, humidity or switching the bias, an improvement in the lifetime can be obtained. If a device manufacturer would test to failure and report the lifetimes, the customer could select the appropriate product for their application. Following a template of reliability tests that have not been verified and do not coincide with the applicable failure mechanism may put the application at risk for surviving.

Humidity testing was used as an example above, but a similar case could be made of other attributes involved with media testing. Other attributes of the media test may include the bias level and duty cycle, the pH or conductivity of the solution, and any stress such as a pressure differential. By modeling these attributes against the various solutions, models for media compatibility can be developed.

INDUSTRY STANDARDIZATION

Why an industry standard? The increasing use of electronic sensors in everyday life has designers wrestling with the complexity of defining the compatibility of a sensor with the media they are measuring. A designer may decide to solve the question of media compatibility by choosing to isolate the sensor from the media via a stainless steel diaphragm. While this solution provides very good media isolation, it is not without some drawbacks such as cost, size of packaging, decreased sensitivity and long term drift. Without a recognized standard for defining media compatibility, the designer is left to a series of ad hoc test methods and conflicting specifications.

An industry media compatibility standard will provide the designer with a method of evaluating sensor performance. The designer could match an application's requirements, for media compatibility, with the available sensor products thus taking price and performance into account. This will enable the designer to minimize the total cost of an application. A standard will also enable suppliers to provide products warranted to defined criteria. Once a standard is adopted, the suppliers may rationalize their test efforts and pass the savings on to their customers.

A standard should provide a designer with a simple, coherent, complete definition of a media's effects on a sensor. The standard should included an accepted test methodology, test equipment guidelines, life time model, acceleration factors model, and a definition of failures. A proposed list of criteria to include in a model are shown in table 4.

Table 4. Suggested Criteria for Media Compatibility

Media Contact — Front or Back	Supply Voltage	Solubility Parameter
Pressure Range	Supply Voltage Duty Cycle	Conductivity of Media
Temperature Range	Voltage Potential within Media	pH
Recipe of Media and Contaminants	Frequency Output is Measured	Lifetime Expectancy
Sensor to Media Interconnection	Relative Motion of Media (e.g., Flow)	

These criteria must be included not only for the media, but also for the contaminants in the media. An example is a washing machine level sensor which must be compatible with water vapor (the media) and detergent and chlorine (the contaminant). To create a standard, a series of tests which benchmark the criteria must be designed and performed. The results would form the basis of the life time and acceleration factor models.

There are several ways to create a standard, each of which have their own associated pros and cons. Three possible ways to create a standard are: an industry association committee, a panel of industry representatives, or a de facto standard set by one or more industry suppliers. To define a standard for media compatibility may require more than one of these methods. An industry leader may define a standard form to which they deliver product. This may stimulate the formation of a committee which defines a broader standard for the industry. As this standard becomes more accepted by the industry, the committee may work with an industry association to “legitimize” the de facto standard. No matter how the standard is formulated, receiving broad industry acceptance will require meeting the customers' needs.

CONCLUSION

Investigation of media compatibility for pressure sensors has been presented from a physics–of–failure approach. We have developed a set of internal standard test and reliability lifetime analysis procedures to simulate our customers' requirements. These activities have incorporated information from several fields beyond sensors and/or electronics, including: electrochemistry and corrosion, polymers, safety and environmental, automotive and appliance industry standards, and reliability. The next critical step to elevating the awareness of this problem, in our opinion, is to develop an industry–wide set of standards, driven by customer applications, that include media testing experimental procedures, reliability lifetime analysis, and media compatibility reporting to allow easier customer interpretation of results.

ACKNOWLEDGMENTS

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Section Two

Acceleration Sensor Products

Accelerometer Overview:

Motorola's series of acceleration sensors incorporate a surface micromachined structure. The force of acceleration moves the seismic mass, thereby changing the g–cell's capacitance. Coupled with the g–cell is a control chip to provide the accelerometer with signal amplification, signal conditioning, low pass filter and temperature compensation. With Zero–g offset, sensitivity and filter roll–off that is factory set, the device requires only a few external passives. In fact, this acceleration sensor device offers a calibrated self–test feature that mechanically displaces the seismic mass with the application of a digital self–test signal. The g–cell is hermetically sealed at the die level, creating a particle–free environment with features such as built in damping and over–range stops to protect it from mechanical shock. These acceleration sensors are rugged, highly accurate and sense in the X–lateral direction.

Motorola's acceleration sensors are economical, accurate and highly reproducible for the ideal sensing solution in automotive, industrial, computer and consumer applications.

Data Sheets

Application Notes

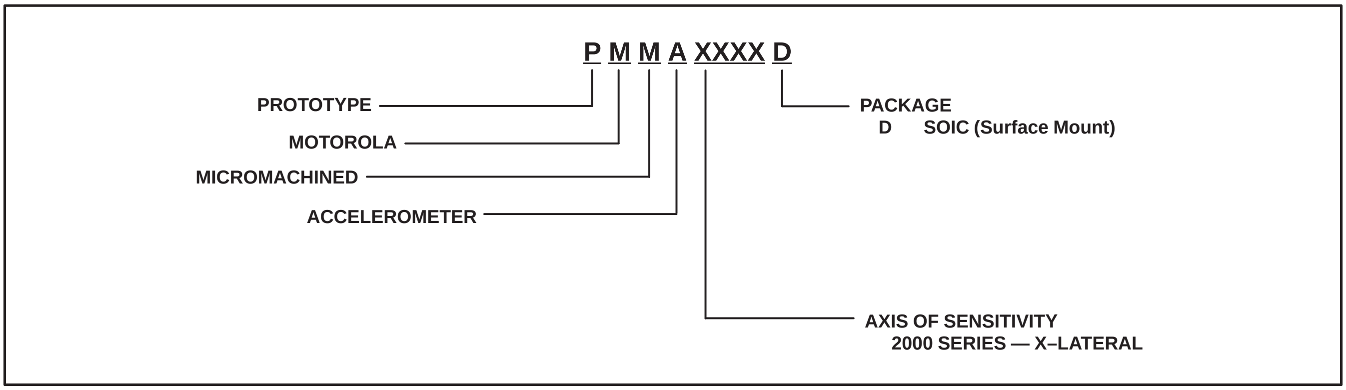
Reference Information

Mini Selector Guide

Accelerometer Sensor

Device	Range	Sensitivity	Frequency/ Bandwidth (Hz)	Sensing Direction	Supply Current (mA)	Zero Acceleration Output
PMMA2001D Series	±50g	40 mV/g	400	X–lateral	5	2.5

Device Numbering System for Accelerometers



Acceleration Sensor FAQ's

We've discovered that many of our customers have similar questions about certain aspects of our accelerometer's technology and operation. Here are the most frequently asked questions and answers that have been explained in relatively non–technical terms.

Q. What is the g–cell?

A. *The g–cell is the acceleration transducer within the accelerometer device. It is hermetically sealed at the wafer level to ensure a contaminant free environment, resulting in superior reliability performance.*

Q. What does the output typically interface with?

A. *The accelerometer device is designed to interface with an analog to digital converter available on most microcontrollers. The output has a 2.5 V DC offset, therefore positive and negative acceleration is measurable. For unique customer applications, the output voltage can be scaled and shifted to meet requirements using external circuitry.*

Q. What is the polarity of the g force in relation to the output voltage?

A. *Refer to the sensing direction diagram below.*

Q. What is the resonant frequency of the g–cell?

A. *The resonant frequency of the g–cell is much higher than the cut–off frequency of the internal filter. Therefore, the resonant frequency of the g–cell does not play a role in the accelerometer response.*

Q. What is ratiometricity?

A. *Ratiometricity simply means that the output offset voltage and sensitivity scales linearly with applied supply voltage. That is, as you increase supply voltage the sensitivity and offset increase linearly; as supply voltage decreases, offset and sensitivity decrease linearly. This is a key feature when interfacing to a microcontroller or an A/D converter. Ratiometricity allows for system level cancellation of supply induced errors in the analog to digital conversion process. Refer to the Special Features section under the Principle of Operation for more information.*

Q. What is the "noise" on the 40 G accelerometer?

A. *In the 40 g part, maximum noise is equivalent to a 0.25 g signal.*

Q. Is the accelerometer device sensitive to electro static discharge (ESD)?

A. *Yes . . . the accelerometer should be handled like other CMOS technology devices.*

Q. Can the g–cell part "latch"?

A. *No . . . overrange stops have been designed into the g–cell to prevent latching. (Latching is when the middle plate of the g–cell sticks to the top or bottom plate.)*

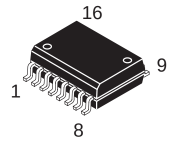
MOTOROLA
SEMICONDUCTOR TECHNICAL DATA

Product Preview

±50g Micromachined Accelerometer

PMMA2001D

PMMA2001D: X AXIS SENSITIVITY
MICROMACHINED
ACCELEROMETER
±50g



16 LEAD SOIC
CASE 475–01

The PMMA series of silicon micromachined, capacitive accelerometers features signal conditioning, a 4–pole low pass filter and temperature compensation. Zero–g offset, sensitivity, and filter cut–off are factory set and require no external devices. A component self–test capability verifies device functionality.

Features

- Integral Signal Conditioning
- Linear Output
- Ratiometric Performance
- 4th Order Bessel Filter Preserves Pulse Shape Integrity
- Calibrated Self–Test
- Transducer Hermetically Sealed at Wafer Level for Superior Reliability
- Robust Design, High Shock Survivability

Typical Applications

- Vibration Monitoring and Recording
- Appliance Control
- Mechanical Bearing Monitoring
- Computer Hard Drive Protection
- Computer Mouse and Joysticks
- Virtual Reality Input Devices
- Sports Diagnostic Devices and Systems

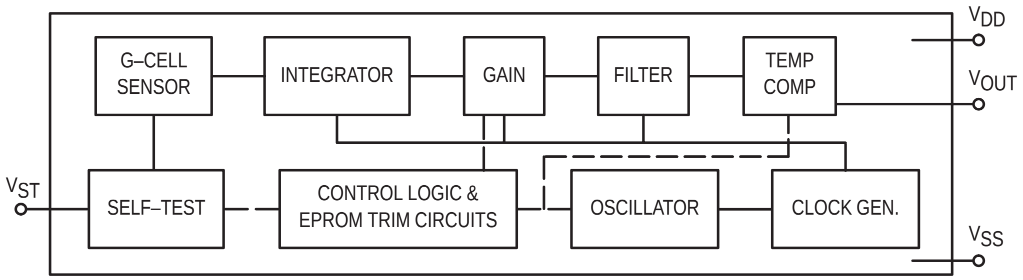


Figure 1. Simplified Accelerometer Functional Block Diagram

MAXIMUM RATINGS (Maximum ratings are the limits to which the device can be exposed without causing permanent damage.)

Rating	Symbol	Value	Unit
Powered Acceleration (all axes)	G_{pd}	500	g
Unpowered Acceleration (all axes)	G_{upd}	2000	g
Supply Voltage	V_{DD}	–0.3 to +7.0	V
Drop Test(1)	D_{drop}	1.2	m
Storage Temperature Range	T_{stg}	–40 to +105	°C

ELECTRO STATIC DISCHARGE (ESD)

WARNING: This device is sensitive to electrostatic discharge.

Although the Motorola accelerometers contain internal 2kV ESD protection circuitry, extra precaution must be taken by the user to protect the chip from ESD. A charge of over 2000 volts can accumulate on the human body or associated test equipment. A charge of this magnitude can alter the performance or cause failure of the chip. When handling the accelerometer, proper ESD precautions should be followed to avoid exposing the device to discharges which may be detrimental to its performance.

OPERATING CHARACTERISTICS

(Unless otherwise noted: 0°C ≤ T_A ≤ +70°C, 4.75 ≤ V_{DD} ≤ 5.25, Acceleration = 0g, Loaded output(2))

Characteristic	Symbol	Min	Typ	Max	Unit
Operating Range(3)					
Supply Voltage(4)	V_{DD}	4.75	5.00	5.25	V
Supply Current	I_{DD}	4.0	5.0	6.0	mA
Operating Temperature Range	T_A	– 40	—	+105	°C
Acceleration Range	g_{FS}	—	50	—	g
Output Signal					
Zero g (V_{DD} = 5.0 V)(5)	V_{OFF}	2.2	2.5	2.8	V
Zero g	$V_{OFF,V}$	0.44 V_{DD}	0.50V_{DD}	0.56 V_{DD}	V
Sensitivity (T_A = 25°C, V_{DD} = 5.0 V)(6)	S	37.2	40	42.8	mV/g
Sensitivity	S_V	7.36	8.0	8.64	mV/V/g
Bandwidth Response	f_{-3dB}	360	400	440	Hz
Nonlinearity	NL_{OUT}	– 1.0	—	+1.0	% FSO
Noise					
RMS (.01–1 kha)	n_{RMS}	—	—	2.8	mVrms
Power Spectral Density	n_{PSD}	—	300	—	μV/(Hz$^{1/2}$)
Clock Noise (without RC load on output)(7)	n_{CLK}	—	2.0	—	mVpk
Self–Test					
Output Response	g_{ST}	10	—	14	g
Input Low	V_{IL}	V_{SS}	—	0.3 x V_{DD}	V
Input High	V_{IH}	0.7 x V_{DD}	—	V_{DD}	V
Input Loading(8)	I_{IN}	– 30	– 110	– 300	μA
Response Time(9)	t_{ST}	—	2.0	—	ms
Output Stage Performance					
Electrical Saturation Recovery Time(10)	t_{DELAY}	—	0.2	—	ms
Full Scale Output Range (I_{OUT} = 200 μA)	V_{FSO}	0.3	—	V_{DD} – 0.3	V
Capacitive Load Drive(11)	C_L	—	—	100	pF
Output Impedance	Z_O	—	300	—	Ω
Mechanical Characteristics					
Alignment Error	θ_A	—	+/ – 3	—	degrees
Transverse Sensitivity(12)	$V_{ZX,YX}$	—	—	5.0	% FSO
Package Resonance	f_{PKG}	—	10	—	kHz

NOTES:

1. Dropped onto concrete surface from any axis.
2. For a loaded output the measurements are observed after an RC filter consisting of a 1 kΩ resistor and a 0.01 μF capacitor to ground.
3. These limits define the range of operation for which the part will meet specification.
4. Within the supply range of 4.75 and 5.25 volts, the device operates as a fully calibrated linear accelerometer. Beyond these supply limits the device may operate as a linear device but is not guaranteed to be in calibration.
5. The device can measure both + and – acceleration. With no input acceleration the output is at midsupply. For positive acceleration the output will increase above $V_{DD}/2$ and for negative acceleration the output will decrease below $V_{DD}/2$.
6. The device is calibrated at 20g.
7. At clock frequency ≅ 70 kHz.
8. The digital input pin has an internal pull–down current source to prevent inadvertent self test initiation due to external board level leakages.
9. Time for the output to reach 90% of its final value after a self–test is initiated.
10. Time for amplifiers to recover after an acceleration signal causing them to saturate.
11. Preserves phase margin (60°) to guarantee output amplifier stability.
12. A measure of the device’s ability to reject an acceleration applied 90° from the true axis of sensitivity.

PRINCIPLE OF OPERATION

The Motorola accelerometer is a surface–micromachined integrated–circuit accelerometer.

The device consists of a surface micromachined capacitive sensing cell (g–cell) and a CMOS signal conditioning ASIC contained in a single integrated circuit package. The sensing element is sealed hermetically at the wafer level using a bulk micromachined “cap’’ wafer.

The g–cell is a mechanical structure formed from semiconductor materials (polysilicon) using semiconductor processes (masking and etching). It consists of interdigitated finger structures (comb patterns) which can be modeled as two stationary plates with a moveable plate in–between. The center plate can be deflected from its rest position by subjecting the system to an acceleration (Figure 2).

When the center plate deflects, the distance from it to one fixed plate will increase by the same amount that the distance to the other plate decreases. The change in distance is a measure of acceleration.

The g–cell plates form two back–to–back capacitors (Figure 3). As the center plate moves with acceleration, the distance between the plates changes and each capacitor’s value will change, ($C = A\varepsilon/D$). Where A is the area of the plate, ε is the dielectric constant, and D is the distance between the plates.

The CMOS ASIC uses switched capacitor techniques to measure the g–cell capacitors and extract the acceleration data from the difference between the two capacitors. The ASIC also signal conditions and filters (switched capacitor) the signal, providing a high level output voltage that is ratiometric and proportional to acceleration.

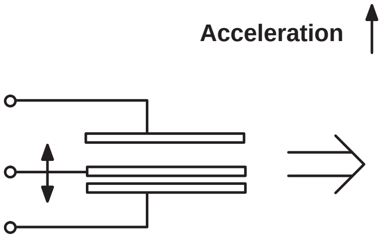


Figure 2. Transducer Physical Model

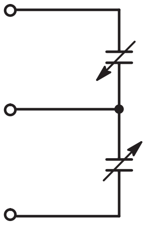


Figure 3. Equivalent Circuit Model

SPECIAL FEATURES

Filtering

The Motorola accelerometers contain an onboard 4–pole switched capacitor filter. A Bessel implementation is used because it provides a maximally flat delay response (linear phase) thus preserving pulse shape integrity. Because the filter is realized using switched capacitor techniques, there is no requirement for external passive components (resistors and capacitors) to set the cut–off frequency.

Self–Test

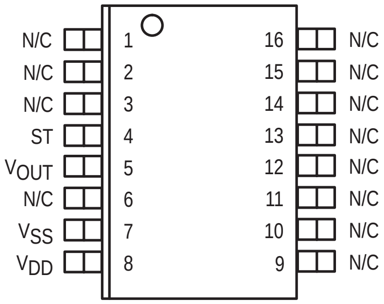
The sensor provides a self–test feature that allows the verification of the mechanical and electrical integrity of the accelerometer at any time before or after installation. This feature is critical in applications such as automotive airbag systems where system integrity must be ensured over the life of the vehicle. A fourth “plate’’ is used in the g–cell as a self–test plate. When the user applies a logic high input to the self–test pin, a calibrated potential is applied across the self–test plate and the moveable plate. The resulting electrostatic force ($Fe = {}^{1}/_{2}\, AV^{2}/d^{2}$) causes the center plate to deflect. The resultant deflection is measured by the accelerometer’s control ASIC and a proportional output voltage results. This procedure assures that both the mechanical (g–cell) and electronic sections of the accelerometer are functioning.

Ratiometricity

Ratiometricity simply means that the output offset voltage and sensitivity will scale linearly with applied supply voltage. That is, as you increase supply voltage the sensitivity and offset increase linearly; as supply voltage decreases, offset and sensitivity decrease linearly. This is a key feature when interfacing to a microcontroller or an A/D converter because it provides system level cancellation of supply induced errors in the analog to digital conversion process.

BASIC CONNECTIONS

Pinout Description



Pin No.	Pin Name	Description
1 thru 3	—	No internal connection. Leave unconnected.
4	**ST**	**Logic input pin used to initiate self–test.**
5	**V_{OUT}**	**Output voltage of the accelerometer.**
6	—	No internal connection. Leave unconnected.
7	**V_{SS}**	**The power supply ground.**
8	**V_{DD}**	**The power supply input.**
9 thru 13	Trim pins	Used for factory trim. Leave unconnected.
14 thru 16	—	No internal connection. Leave unconnected.

Circuit Schematic

Figure 4 shows the recommended connection diagram for operating the accelerometer. Pins 1, 2, 3, 6, 14, 15, and 16 have no internal connections, and pins 9 through 13 are used for calibration and trimming in the factory. These pins should all be left unconnected.

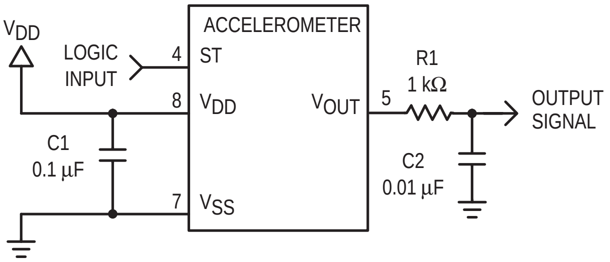


Figure 4. Accelerometer with Recommended Connection Diagram

PCB Layout

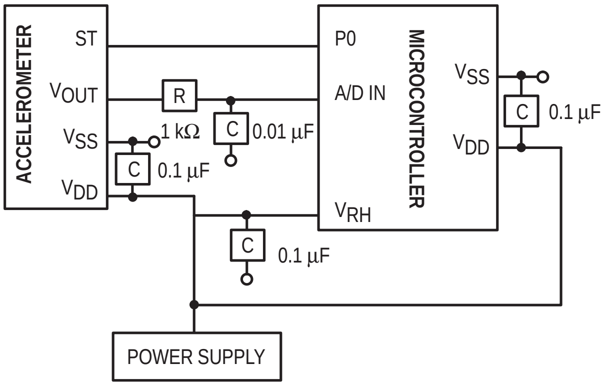
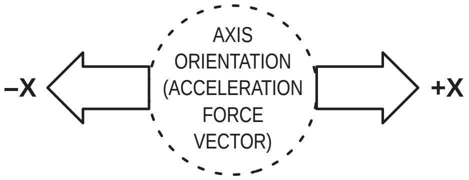


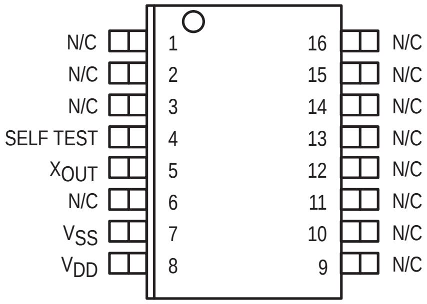
Figure 5. Recommend PCB Layout for Interfacing Accelerometer to Microcontroller

NOTES:

- Use a .1 µF capacitor on V_{DD} to decouple the power source.
- Physical coupling distance of the accelerometer to the microcontroller should be minimal.
- Place a ground plane beneath the accelerometer to reduce noise, the ground plane should be attached to all of the open ended terminals shown above.
- Use an RC filter of 1 kΩ and 0.01 µF on the output of the accelerometer to minimize clock noise (from the switched capacitor filter circuit).
- Accelerometer and microcontroller should not be supplied by a trace that is connected to a high current path.
- A/D sampling rate and any external power supply switching frequency should be selected such that they do not interfere with the internal accelerometer sampling frequency. This will prevent aliasing errors.

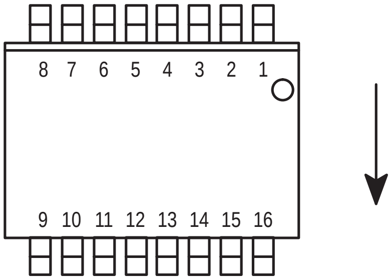
Positive Acceleration Sensing Direction





16–Pin SOIC Package

N/C pins are recommended to be left FLOATING



Direction of Earth's gravity field.*

* When positioned as shown, the Earth's gravity will result in a positive 1g output

ORDERING INFORMATION

Device	Temperature Range	Case No.	Package
PMMA2001D	– 40 to +105°C	Case 475–01	16 Lead SOIC

AN1559

Application Considerations for a Switched Capacitor Accelerometer

By Wayne Chavez

INTRODUCTION

Today's low cost accelerometers are highly integrated devices employing features such as signal conditioning, filtering, offset compensation and self test. Combining this feature set with economical plastic packaging requires that the signal conditioning circuitry be as small as possible. One approach is to implement sampled data system and switched capacitor techniques as in the Motorola accelerometer.

As in all sampled data systems, precautions should be taken to avoid signal aliasing errors. This application note describes the Motorola accelerometer and how signal aliasing can be introduced and more importantly minimized.

BACKGROUND

What is aliasing? Simply put, aliasing is the effect of sampling a signal at an insufficient rate, thus creating another signal at a frequency that is the difference between the original signal frequency and the sampling rate. A graphical explanation of aliasing is offered in Figure 1. In this figure, the upper trace shows a 50 kHz sinusoidal waveform. Note that when sampled at a 45 kHz rate, denoted by the boxes, a sinusoidal pattern is formed. Lowpass filtering the sampled points, to create a continuous signal, produces the 5 kHz waveform shown in Figure 1 (lower). (The phase shift in the lower figure is due to the low–pass filter).

Aliased signals, like the one in Figure 1 (lower) are often unintentionally produced. Signal processing techniques are well understood and sampling rates are chosen appropriately (i.e. Nyquist criteria). However, the assumption is that the signals of interest are well characterized and have a limited bandwidth. This assumption is not always true, as in the case of wideband noise.

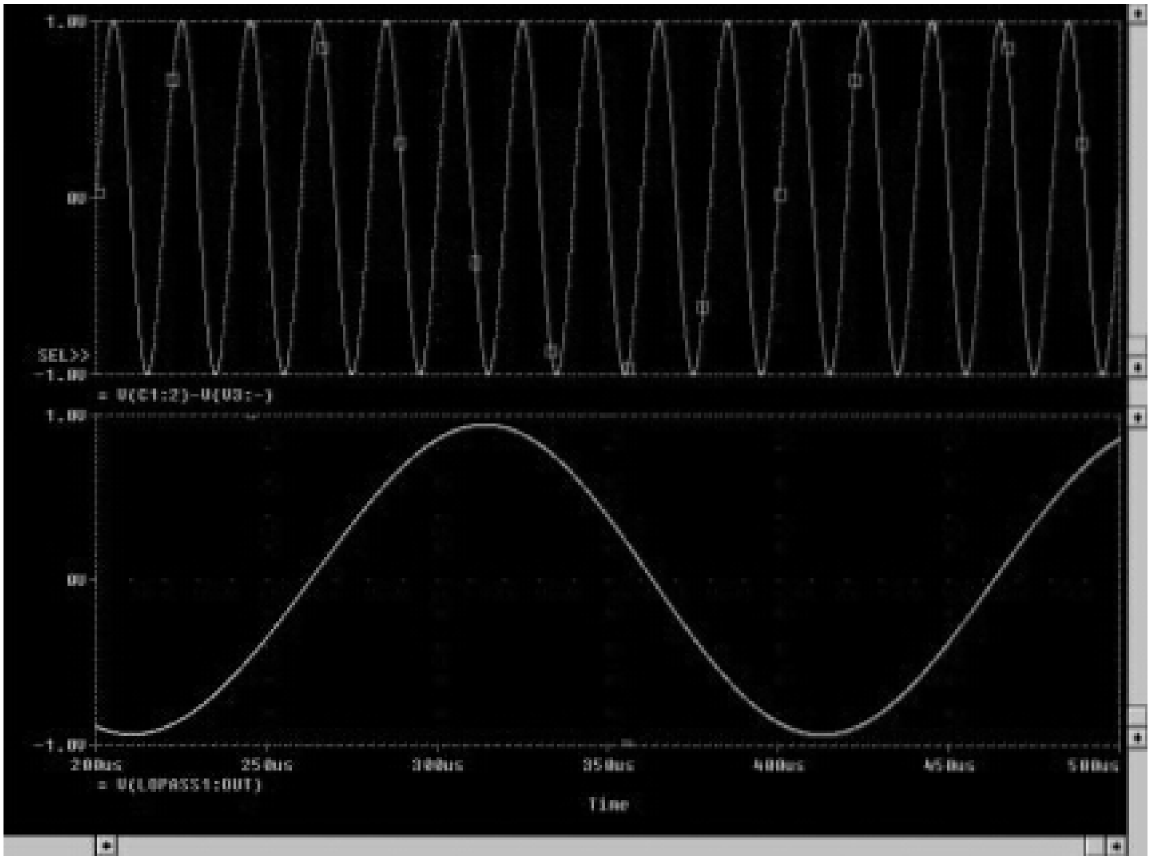


Figure 1. Aliased Signals

REV 1

Given the brief example on how aliasing can occur, how does the accelerometer relate to aliasing? To answer this question, a brief summary on how the accelerometer works is in order.

The accelerometer is a two chip acceleration sensing solution. The first chip is the acceleration transducer, termed G–Cell, constructed by Micro Electro–Mechanical Systems (MEMS) technology. The G–Cell is a two capacitor element where the capacitors are in series and share a common center plate. The deflection in the center plate changes the capacitance of each capacitor which is measured by the second chip, termed control chip.

The control chip performs the signal conditioning (amplification, filtering, offset level shift) function in the system. This chip measures the G–Cell output using switched capacitor techniques. By the nature of switched cap techniques, the system is a sampled data system operating at sampling frequency f_S. The filter is switched capacitor, 4–pole Bessel implementation with a –3 dB frequency of 400 Hz.

As a sampled data system, the accelerometer is not immune to signal aliasing. However, given the accelerometer's internal filter, aliased signals will only appear in the output passband when input signals are in the range $| n \bullet f_S - f_{signal} | \le f_{BW}$. Where f_S is the sampling rate, f_{Signal} is the input signal frequency, f_{BW} is the filter bandwidth and n is a positive integer to account for all harmonics. The graphical representation is shown in Figure 2. The bounds can be extended beyond f_{BW} to ensure an alias free output.

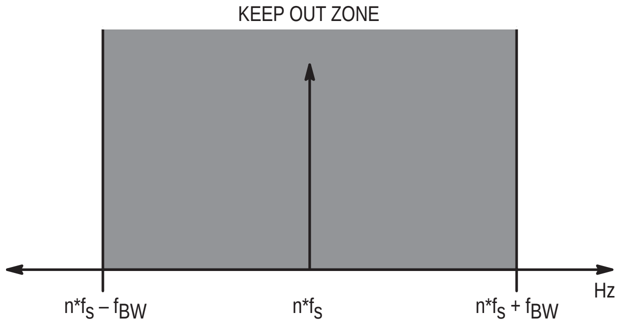


Figure 2. Input signal frequency range where a signal will be produced in the output passband.

ACCELEROMETER INPUT SIGNALS

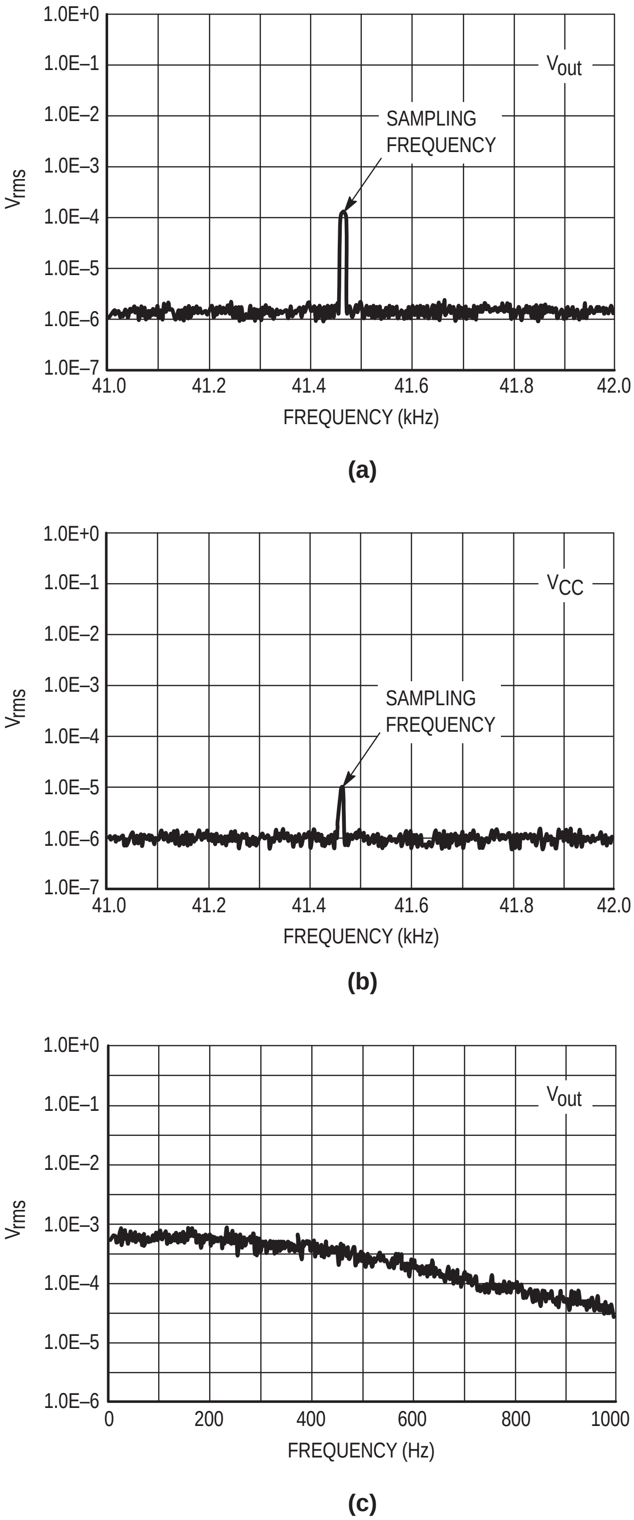
The accelerometer is a ratiometric electro–mechanical transducer. Therefore, the input signals to the device are the acceleration and the input power source.

The acceleration input is limited in frequency bandwidth by the geometry of the sensing, packaging, and mounting structures that define the resonant frequency and response. This response is in the range of 10 kHz, however, the practical range is less than 600 Hz for most mechanical systems. Therefore, aliasing an acceleration signal is unlikely.

The power input signal is ideally dc. However, depending on the application system architecture, the power supply line can be riddled with high frequency components. For example, dc to dc converters can operate with switching frequencies between 20 kHz and 200 kHz. This range encompasses the sampling rate of the accelerometer and point to the power source as the culprit in producing aliased signal.

DEMONSTRATION OF ALIASING

Under zero acceleration conditions a 100 mV_{rms} signal was injected onto the power supply line of 5.0 Vdc. The frequency of the injected signal was tuned in to produce an alias in the accelerometer's passband. Figures 3 and 4 show the difference in output when a high frequency signal is not and is present on the V_{CC} pin of the accelerometer.

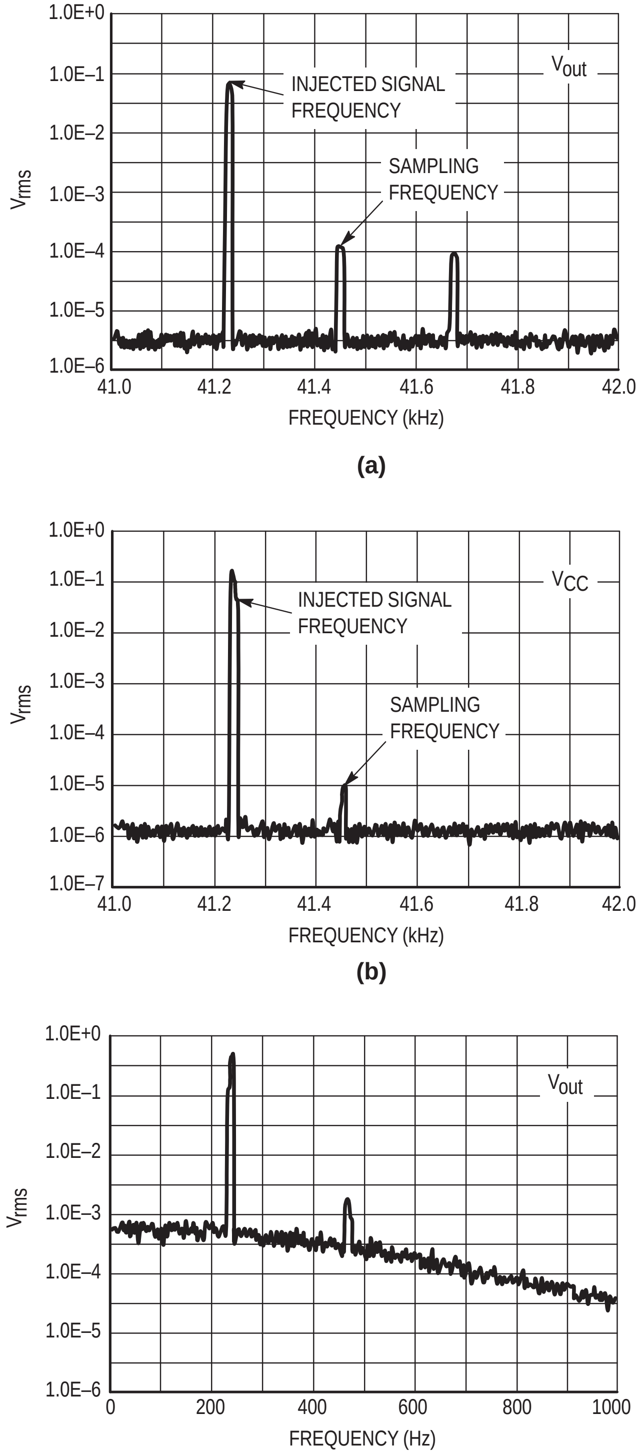


(a)

(b)

(c)

Figure 3. Normal Waveforms



(a)

(b)

(c)

Figure 4. Aliasing Comparison

Points to note:

- Under clean dc bias, V_{out} and V_{CC}, Figures 3a and 3b have a signal component at the sampling rate. This is due to switched capacitor currents coupling through finite power supply source impedances and PCB paracitics.
- The low frequency output spectrum, Figure 3c, displays the internal lowpass filter characteristics. (The filter and sampling characteristics are sometimes useful in system debugging.)
- When an ac component is superimposed onto V_{CC} near the sampling frequency, as shown in Figure 4b, the output will contain the original signal plus a mirrored signal about the sampling frequency, shown in Figure 4a. Signals on the V_{CC} line will appear at the output due to the ratiometric characteristic of the accelerometer and will be one half the amplitude.
- As a result of sampling, the output waveform of Figure 4c is produced where the injected high frequency signal has now produced a signal in the passband.
- Harmonics of the aliased signal in the pass band are also shown in Figure 4c.
- Aliased signals in the passband will be amplified versions of the injected signals. This is due to the signal conditioning circuitry in the accelerometer that includes gain.

ALIASING AVOIDANCE KEYS

- Use a linear regulated power source when feasible. Linear regulators have excellent power supply rejection offering a stable dc source.
- If using a switching power supply, ensure that the switching frequency is not close to the accelerometer sampling frequency or its harmonics. Noting that the accelerometer will gain the aliasing signal, it is desirable to keep frequencies at least 4 kHz away from the sampling frequency and its harmonics. 4 kHz is one decade from the –3 dB frequency, therefore any signals will be sufficiently attenuated by the internal 4–pole lowpass filter.
- Proper bias decoupling will aid in noise reduction from other sources. With dense surface mount PCB assemblies, it is often difficult to place and route decoupling components. However, the accelerometer is not like a typical logic device. A little extra effort on decoupling goes a long way.
- Good PCB layout practices should always be followed. Proper system grounding is essential. Parasitic capacitance and inductance could prove to be troublesome, particularly during EMC testing. Signal harmonics and sub–harmonics play a significant role in introducing aliased signals. Clean layouts minimize the effects of parasitics and thus signal harmonics and sub–harmonics.

AN1635

Baseball Pitch Speedometer

**Prepared by: Carlos Miranda, Systems and Applications Engineer and
David Heeley, Systems and Applications Mechanical Engineer**

INTRODUCTION

The Baseball Pitch Speedometer, in its simplest form, consists of a target with acceleration sensors mounted on it, an MCU to process the sensors' outputs and calculate the ball speed, and a display to show the result. The actual implementation, shown in Figure 1, resembles a miniature pitching cage, that can be used for training and/or entertainment. The cage is approximately 6 ft. tall by 3 ft. wide by 6 ft. deep. The upper portion is wrapped in a nylon net to retain the baseballs as they rebound off the target. A natural rubber mat, backed by a shock resistant acrylic plate, serve as the target. Accelerometers, used to sense the ball impact, and buffers, used to drive the signal down the transmission line, are mounted on the back side of the target. The remainder of the electronics is contained in a display box on the top front side of the cage.

Accelerometers are sensors that measure the acceleration exerted on an object. They convert a physical quantity into an electrical output signal. Because acceleration is a vector quantity, defined by both magnitude and direction, an accelerometer's output signal typically has an offset voltage and can swing positive and negative relative to the offset, to account for both positive and negative acceleration. An example acceleration profile is shown in Figure 2. Because acceleration is defined as the rate of change of velocity with respect to time, the integration of acceleration as a function of time will yield a net change in velocity. By digitizing and numerically integrating the output signal of an accelerometer through the use of a microcontroller, the "area under the curve" could be computed. The result corresponds to the net change in velocity of the object under observation. This is the basic principle behind the Baseball Pitch Speedometer.

Figure 1. David Heeley, mechanical designer of the Baseball Pitch Speedometer Demo, tests his skills at Sensors Expo Boston '97.

REV 1

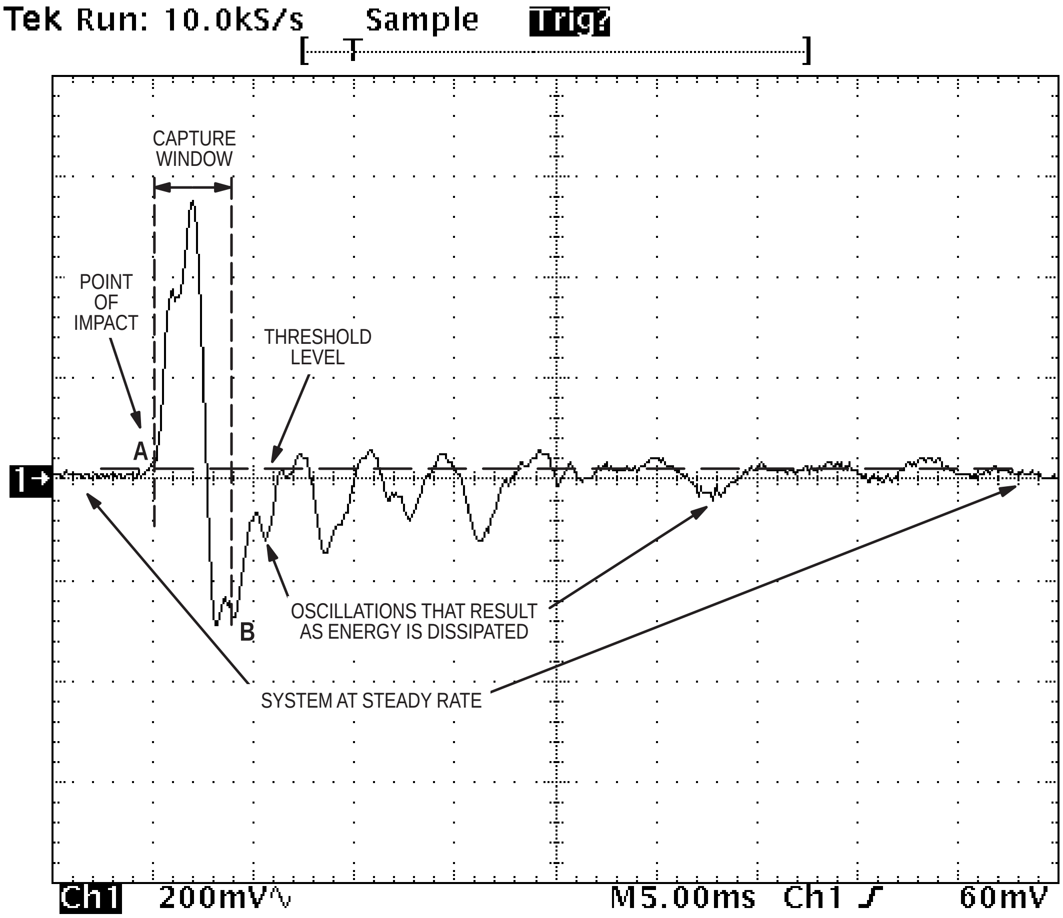


Figure 2. Typical Crash Pattern for the Baseball Pitch Speedometer Demo

THEORY OF OPERATION

When a ball is thrown against the target, the accelerometer senses the impact and produces an analog output signal, proportional to the acceleration measured, resulting in a crash signature. The amplitude and duration of the crash signature is a function of the velocity of the ball. How can this crash signature be correlated to the velocity of the baseball? By making use of the principle of conservation of momentum (see Equation 1). The principle of conservation of momentum states that the total momentum within a closed system remains constant. In our case, the system consists of the thrown ball and the target.

$$m_{ball} * V_{ball,initial} + m_{target} * V_{target,initial} = m_{ball} * V_{ball,final} + m_{target} * V_{target,final} \qquad \text{Eq. 1}$$

When the ball is thrown, it has a momentum equivalent to $m_{ball} * V_{ball,initial}$. The target initially has zero momentum since it is stationary. When the ball collides with the target, part of the momentum of the ball is transferred to the target, and the target will momentarily experience acceleration, velocity, and some finite, though small, displacement before dissipating the momentum and returning to a rest state. The other portion of momentum is retained by the ball as it bounces off the target, due to the elastic nature of the collision. By measuring the acceleration imparted on the target, its velocity is computed through integration. Ideally, if the mass of the ball, the mass of the target, and the final velocity of the ball are known, then the problem could be solved analytically and the initial velocity of the baseball determined.

The analysis of the crash phenomenon is, however, actually quite complex. Some factors that must be taken into account and that complicate the analysis greatly, are the spring constant and damping coefficient of the target. The target will be displaced during impact because it is anchored to the frame by a thick rubber mat. This action effectively causes the system to have a certain amount of spring. Also, though the mat is very dense, it will deform somewhat during impact and will act as shock absorber. In addition, the ball itself also has a spring constant and damping coefficient associated with it, since it bounces off the target and, though not noticeable by the naked eye, will deform during the impact. Finally, and of even greater significance, the mass of the ball, the mass of the target, and the final velocity of the ball are neither known nor measured. So how can the system work?

The Baseball Pitch Speedometer works by exploiting the fact that the final velocity of the target will be, according to Eq. 1, linearly proportional to the initial velocity of the thrown ball. Therefore, by measuring the acceleration response of the system to various ball velocities, which can be measured by independent means such as a radar gun, the system could be calibrated and a linear model developed. To facilitate the characterization and calibration of the system, a pitching machine was used to ensure that the incident ball speed would be repeatable. It also eliminated potential error caused by the variability of location of impact on the target that would inevitably result from several manual throws. Figure 3 shows a linear regression plot of the response of the system as a function of incident velocity. As is indicated by the plot, just a simple constant of proportionality could be used to correlate the measured acceleration response to the incident velocity of the ball, with fairly accurate results.

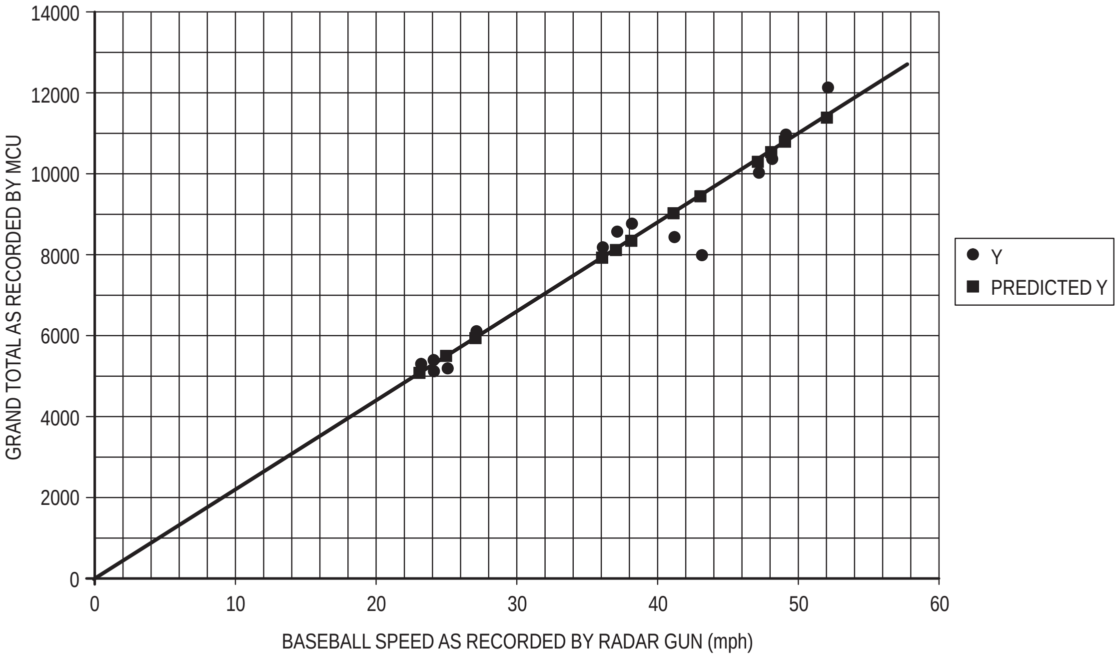


Figure 3. Baseball Pitch Speedometer Characterization Data

IMPLEMENTATION — HARDWARE

The target mat of the Baseball Pitch Speedometer has an area of approximately 9 ft^2 (3 by 3). Even though the rubber material used to construct the target is quite dense and heavy, the transmission of an impact is very poor if the ball strikes the target too far from the sensor. Therefore, to cover such a relatively large area it is necessary to use at least four devices; one centered in each quadrant of the square target. In addition, a shock resistant plate about a quarter inch thick is mounted behind the rubber mat. These features help make the response of the system more uniform and reduce errors that result from the variability of where the ball strikes the target.

The bulk of the circuit hardware is contained in a display box mounted on the top front side of the cage. Since the accelerometers are physically located far away from the mother board (about 10 feet of wiring), op–amps were used to buffer the accelerometers' output and drive the transmission line. The four accelerometer signals are then simultaneously fed into a comparator network and four of the ADC inputs on an MC68HC11 microcontroller. The MC68HC11 was selected because it has the capability of converting four A/D channels in one conversion sequence and operates at a higher clock speed. These two features reduce the overall time interval between digitizations of the analog signal (that result from the minimum required time for proper A/D conversion and from software latency) thus allowing a more accurate representation of the acceleration waveform to be captured. The comparator network serves a similar purpose by eliminating the additional software algorithm and execution time that would be required to continually monitor the outputs of all four accelerometers and determine whether impact has occurred or not. By minimizing this delay (some is still present since the output signal must exceed a threshold, and a finite amount of time is required for this) more of the initial and more significant part of the signal is captured.

The comparator network employs four LM311's configured to provide an OR function, and a single output is fed into an input capture pin on the MCU. A potentiometer and filter capacitor are used to provide a stable reference threshold voltage to the comparator network. The threshold voltage is set as close as possible to the accelerometers' offset voltage to minimize the delay between ball impact and the triggering of the conversion sequence, but enough clearance must be provided to prevent false triggering due to noise. Because the comparator network is wired such that any one of the accelerometer outputs can trigger it, the threshold voltage must be higher than the highest accelerometer offset voltage. Hysteresis is not necessary for the comparator network, because once the MCU goes into the conversion sequence it ignores the input capture pin.

The system is powered using a commercially available 9 V supply. A Motorola MC7805 voltage regulator is used to provide a steady 5 Volt supply for the operation of the MCU, the accelerometers, the comparator network, and the op–amp buffers. The 9 V supply is directly connected to the common anode 8–segment LED displays. Each segment can draw as much as 30 mA of current. Therefore, to ensure proper operation, the power supply selected to build this circuit should be capable of supplying at least 600 mA. Ports B and C on the MCU are used to drive the LED displays. Each port output pin is connected via a resistor to the base of a BJT, which has the emitter tied to ground. A current limiting resistor is connected between the collector of each BJT and the cathode of the corresponding segment on the display. To minimize the amount of board space consumed by the output driving circuitry, MPQ3904s (quad packaged 2N3904s) were selected instead of the standard discrete 2N3904s. The zero bit on Port C is connected to a combination BJT and MOSFET circuit that drives the “Your Speed” and “Best Speed” LED's. The circuit is wired so that the LED's toggle, and only one can be ON at a time.

Figure 4 shows a schematic of the circuit used. Part (a) shows the accelerometers, the op–amps used to buffer the outputs and drive the transmission lines, the comparator network and the potentiometer used to set the detection threshold. Part (b) shows the MCU, with its minimal required supporting circuitry. Part (c) shows the voltage regulator, a mapping of the cathodes to the corresponding segments on the LED displays, the BJT switch circuitry used to drive the seven segment display LEDs (although not shown on the schematic, this circuit block is actually repeated 15 times), and finally, the circuitry used to drive the “Your Speed”/“Best Speed” LEDs.

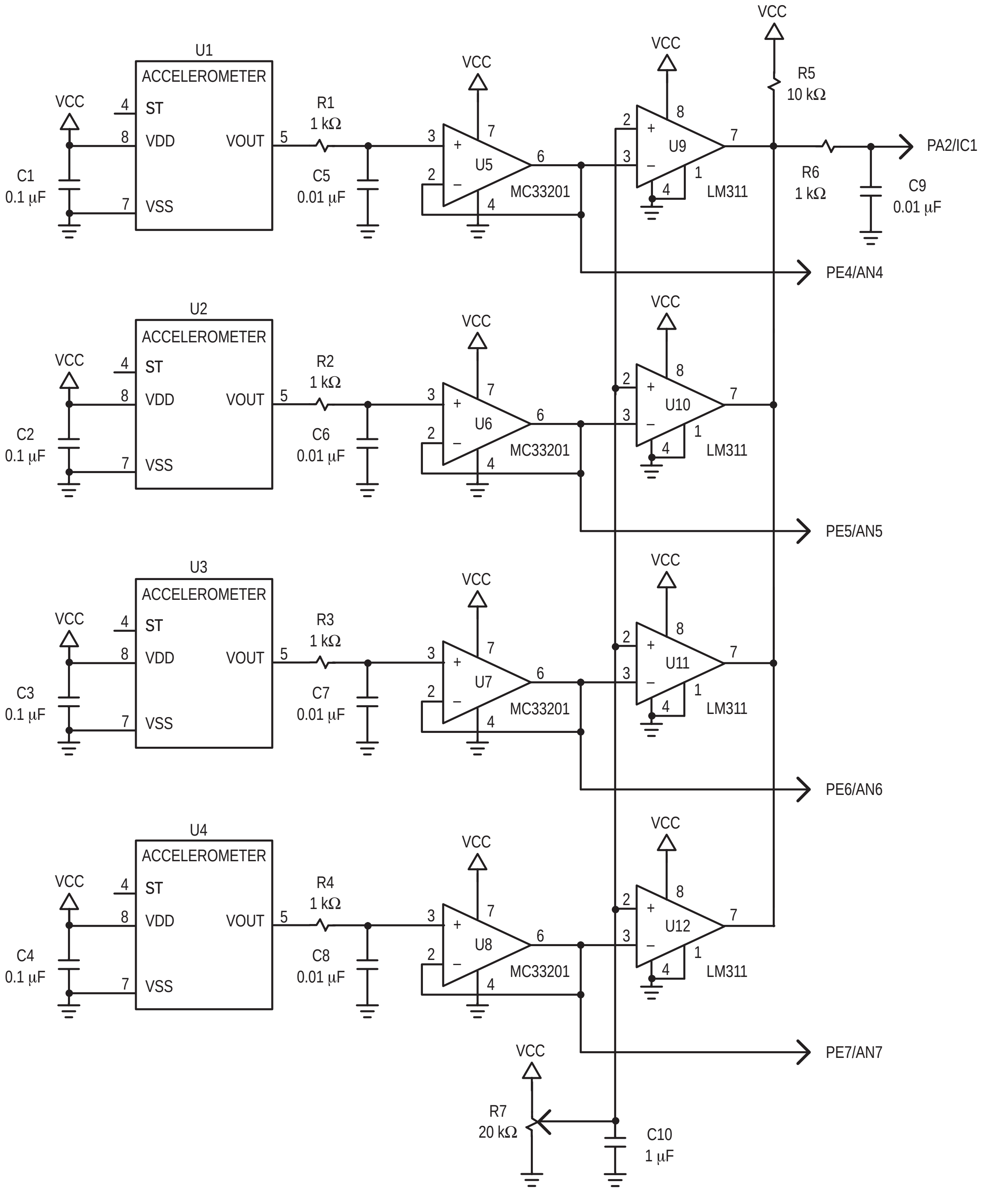


Figure 4a. Accelerometers, Buffer Op–Amps, and Comparator Network

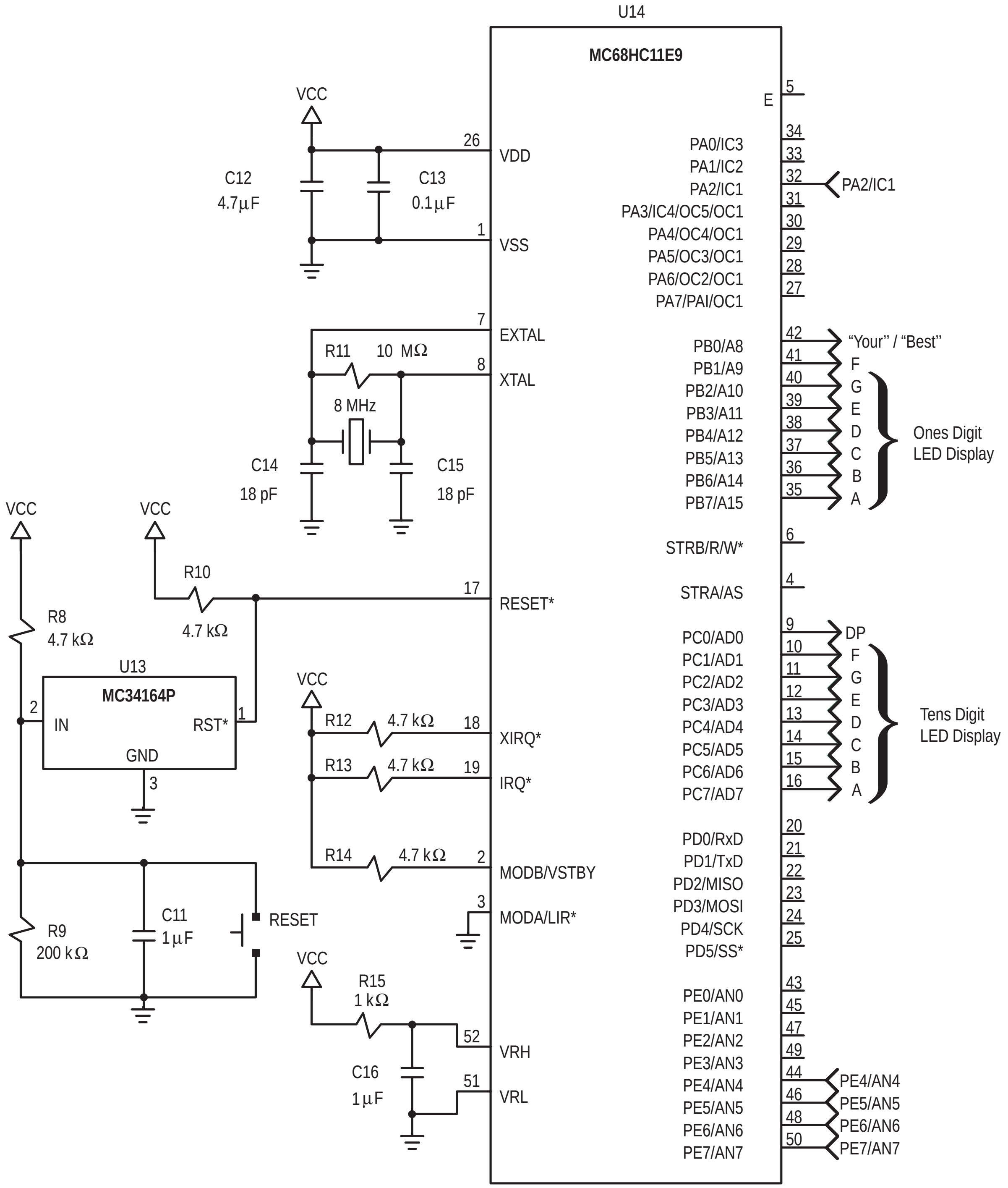


Figure 4b. MC68HC11E9 MCU with Supporting Circuitry

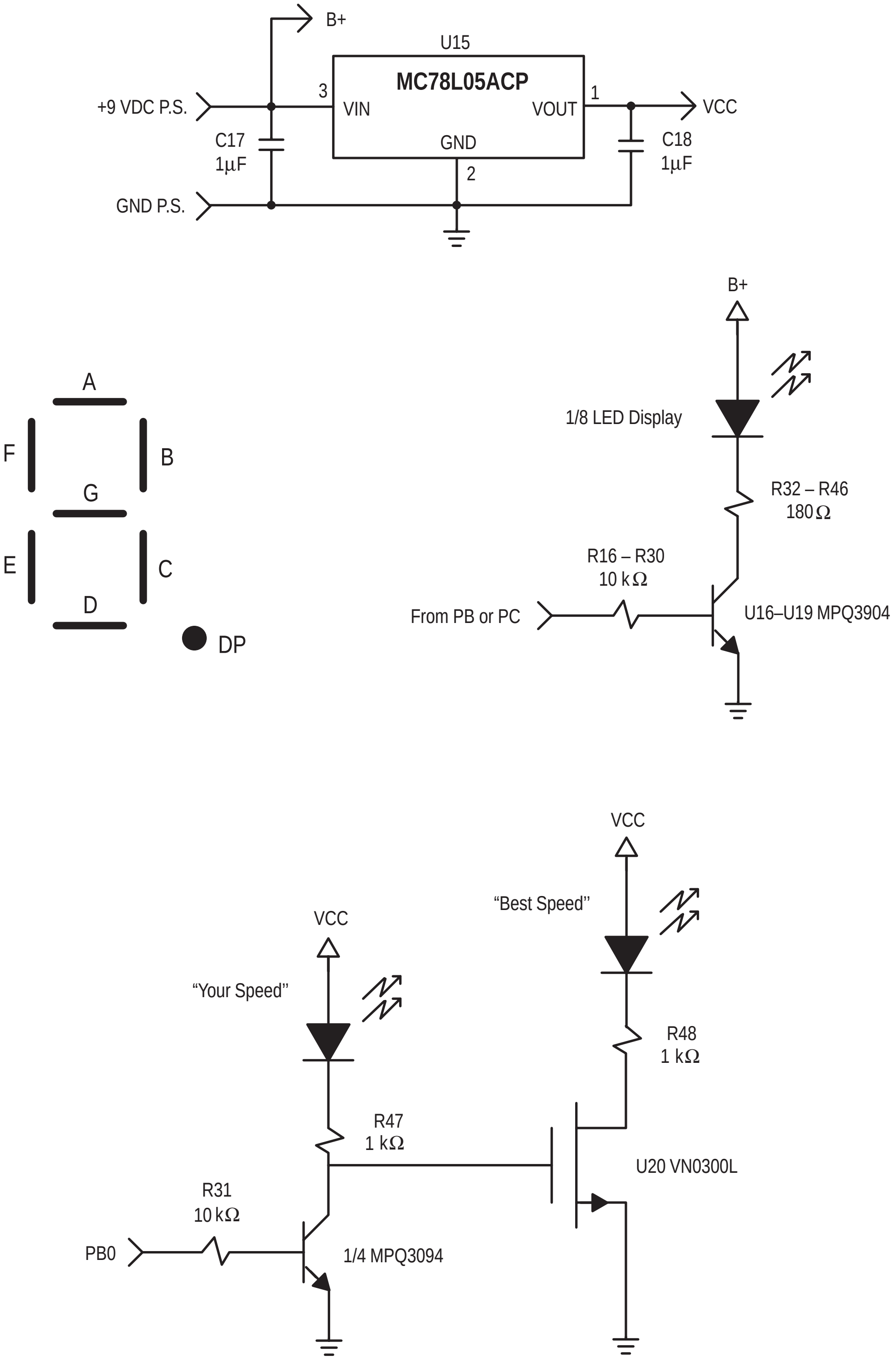


Figure 4c. Voltage Regulator, LED Segment Mapping, and LED Driving Circuitry

IMPLEMENTATION — SOFTWARE

The operation of the Baseball Pitch Speedometer is very simple. Upon power on reset, the output LEDs are initialized to display “00” and “Best Speed.” The analog to digital converter is turned on and the offset voltages of the accelerometers are measured and stored. Finally, all the variables are initialized and the MCU goes into a dormant state, where it will wait for a negative edge input capture pulse to trigger it to begin processing the crash signal.

Once the input capture flag is set, the MCU will immediately begin the analog to digital conversion sequence. As it digitizes the crash signature, it will calculate the absolute difference between the current value and the stored offset voltage value. It will integrate by summing up all the differences. Figure 2 shows a typical crash signature of the Baseball Pitch Speedometer. As illustrated, starting at the point of impact (A), the acceleration will initially ramp up, reaching a maximum, then decrease as the target is displaced. Because the target is constrained to the frame structure, the acceleration will continue to decrease until it reaches a minimum (point B), which correspond to the travel stop of the target. It is difficult to determine exactly when point B will occur, because the amplitude and duration of the initial acceleration pulse will vary with ball speed. Therefore, the capture window duration is set so that it will encompass most typical crash signatures, while rejecting most of the secondary ripples that result as the energy is dissipated by the system.

After integrating the four signals, the results are added together to produce an overall sum. This procedure averages out the individual responses and reduces measurement error due to the variability of where the ball lands on the target. The MCU then divides the grand sum by an empirically predetermined constant of proportionality. The result will then go through a binary to BCD conversion algorithm. A look–up table is used to match the BCD numbers to their corresponding 7–segment display codes. The calculated speed is displayed on the two digit 8–segment displays (one segment corresponds to the decimal point), and the “Your Speed” LED is turned on while the “Best Speed” LED is turned off. After a duration of approximately five seconds, the LEDs are toggled and stored best speed is redisplayed. The five second delay is used to provide enough time for the user to check his/her speed and also to allow the target to return to a rest state. The system is now ready for another pitch. A complete listing of the software is presented in the Appendix.

CONCLUSION

The Baseball Pitch Speedometer works fairly well, with an accuracy of +/– 5 mph. The dynamic range of the system is also worthy of note, measuring speeds from less than 10 mph up to well above the 70 mph range. One key point to emphasize, is that the system is empirically calibrated, and so to maintain good accuracy the system should only be used with balls of mass equal to those used during calibration.

Although intended mainly for training and recreational purposes, the Baseball Pitch Speedometer demonstrates a very important concept concerning the use of accelerometers. Accelerometers can be used not only to detect that an event such as impact or motion has occurred, but more importantly they measure the intensity of such events. They can be used to discern between different crash levels and durations. This is very useful in applications where it is desired to have the system respond in accord with the magnitude of the input being monitored. An example application would be a smart air bag system, where the speed at which the bag inflates is proportional to the severity of the crash. The deployment rate of the airbag would be controlled so that it does not throw the occupant back against the seat, thus minimizing the possibility of injury to the occupant. Another application where this concept may be utilized is in car alarms, where the response may range from an increased state of readiness and monitoring, to a full alarm sequence depending on the intensity of the shock sensed by the accelerometer. This could be used to prevent unnecessary firing of the alarm in the event that an animal or person were to inadvertently bump or brush against the automobile.

APPENDIX — ASSEMBLY CODE LISTING FOR BASEBALL PITCH SPEEDOMETER

```
* Baseball Pitch Speedometer – Rev. 1.0
*
* Program waits for detection of impact via the input capture pin and then reads four A/D channels.
* The area under the Acceleration vs. Time curve is found by subtracting the steady state offsets
* from the digitized readings and summing the results.  The sum is then divided by an empirically
* determined constant of proportionality, and the speed of the ball is displayed.
*
* Written by Carlos Miranda
* Systems and Applications
* Sensor Products Division
* Motorola Semiconductor Products Sector
* May 6, 1997
*
*
********************************************************************************************************
*       Although the information contained herein, as well as any information provided relative        *
*       thereto, has been carefully reviewed and is believed accurate, Motorola assumes no             *
*       liability arising out of its application or use, neither does it convey any license under      *
*       its patent rights nor the rights of others.                                                    *
********************************************************************************************************
* These equates assign memory addresses to variables.
EEPROM           EQU              $B600
CODEBGN          EQU              $B60D
REGOFF           EQU              $1000    ;Offset to access registers beyond direct addressing range.
PORTC            EQU              $03
PORTB            EQU              $04
DDRC             EQU              $07
TCTL2            EQU              $21
TFLG1            EQU              $23
ADCTL            EQU              $30
ADR1             EQU              $31
ADR2             EQU              $32
ADR3             EQU              $33
ADR4             EQU              $34
OPTION           EQU              $39
STACK            EQU              $01FF    ;Starting address for the Stack Pointer.
RAM              EQU              $0000
* These equates assign specific masks to variables to facilitate bit setting, clearing, etc.
ADPU             EQU              $80      ;Power up the analog to digital converter circuitry.
CSEL             EQU              $40      ;Select the internal system clock.
CCF              EQU              $80      ;Conversion complete flag.
IC1F             EQU              $04      ;Input Capture 1 flag.
IC1FLE           EQU              $20      ;Configure Input Capture 1 to detect falling edges only.
IC1FCLR          EQU              $FB      ;Clear the Input Capture 1 flag.
CHNLS47          EQU              $14      ;Select channels 4 through 7 with MULT option ON.
SAMPLES          EQU              $0200    ;Number of A/D samples taken.
OC1F             EQU              $80      ;Output Compare 1 flag.
OC1FCLR          EQU              $7F      ;Clear the Output Compare flag.
CURDLY           EQU              $0098    ;Timer cycles to create delay for displaying ”Your Speed.”
RAMBYTS          EQU              $19      ;Number of RAM variables to clear during initialization.
ALLONES          EQU              $FF
YOURSPD          EQU              $01
PRPFCTR          EQU              $00AD    ;This constant of proportionality was empirically determined.
* Variables used for computation.
                 ORG              RAM
OFFSET1          RMB              1        ;One for each accelerometer.
OFFSET2          RMB              1
OFFSET3          RMB              1
OFFSET4          RMB              1
SUM1             RMB              2        ;Area under the acceleration vs. time curve.
SUM2             RMB              2
SUM3             RMB              2
SUM4             RMB              2
GRNDSUM          RMB              2
COUNT            RMB              2
CURBIN           RMB              1
TEMPBIN          RMB              1
BCD              RMB              2
CURDSPL          RMB              2
MAXBIN           RMB              1
MAXDSPL          RMB              2
* LED seven segment display patterns table.
                 ORG              EEPROM
                 JMP              START
SEVSEG           FCB              %11111010
                 FCB              %01100000
                 FCB              %11011100
                 FCB              %11110100
                 FCB              %01100110
                 FCB              %10110110
                 FCB              %10111110
                 FCB              %11100000
                 FCB              %11111110
                 FCB              %11100110
```

```
* This is the main program loop.
                 ORG              CODEBGN
START            LDS              #STACK
                 LDX              #REGOFF
                 JSR              LEDINIT
                 JSR              ADCINIT
                 JSR              VARINIT
MAIN             JSR              CAPTURE
                 JSR              COMPUTE
                 JSR              BINTBCD
                 JSR              OUTPUT
                 BRA              MAIN
* This subroutine initializes ports B & C, and the LED display.
LEDINIT          PSHX
                 PSHA
                 LDX              #REGOFF
                 BSET             DDRC,X,ALLONES            ;Configure port C as an output.
                 LDAA             SEVSEG
                 STAA             PORTB,X
                 STAA             PORTC,X
                 PULA
                 PULX
                 RTS
* This subroutine initializes the analog to digital converter.
ADCINIT          PSHX
                 PSHA
                 LDX              #REGOFF
                 BSET             OPTION,X,ADPU             ;Turn on A/D converter via ADPU bit.
                 BCLR             OPTION,X,CSEL             ;Select system e clock via CSEL bit.
                 CLRA
DELAY            INCA
                 BNE              DELAY
                 PULA
                 PULX
                 RTS
* This subroutine clears all the memory variables.
VARINIT          PSHX
                 LDX              #$0000
CLRVAR           CLR              OFFSET1,X
                 INX
                 CPX              #RAMBYTS                  ;Number of RMB bytes.
                 BLO              CLRVAR
DONECLR          LDX              #REGOFF
                 LDAA             #CHNLS47                  ;Measure the offset.
                 STAA             ADCTL,X
OFSWAIT          BRCLR            ADCTL,X,CCF,OFSWAIT
                 LDD              ADR1,X
                 STD              OFFSET1
                 LDD              ADR3,X
                 STD              OFFSET3
                 PULX
                 RTS
* This subroutine waits for impact and computes the area under the curve.
CAPTURE          PSHX
                 PSHA
                 PSHB
                 LDX              #REGOFF
                 BSET             TCTL2,X,IC1FLE            ;Set IC1 to detect falling edge only.
                 BCLR             TFLG1,X,IC1FCLR
MONITOR          BRCLR            TFLG1,X,IC1F,MONITOR
ADCREAD          LDAA             #CHNLS47                  ;Select channels 4 – 7 for conversion.
                 STAA             ADCTL,X
ADCWAIT          BRCLR            ADCTL,X,CCF,ADCWAIT
CALDLT1          LDAB             ADR1,X
                 SUBB             OFFSET1
                 BPL              ADDSUM1
                 COMB
                 INCB
ADDSUM1          CLRA
                 ADDD             SUM1
                 STD              SUM1
CALDLT2          LDAB             ADR2,X
                 SUBB             OFFSET2
                 BPL              ADDSUM2
                 COMB
                 INCB
ADDSUM2          CLRA
                 ADDD             SUM2
                 STD              SUM2
CALDLT3          LDAB             ADR3,X
                 SUBB             OFFSET3
                 BPL              ADDSUM3
                 COMB
                 INCB
```

```
ADDSUM3          CLRA
                 ADDD             SUM3
                 STD              SUM3
CALDLT4          LDAB             ADR4,X
                 SUBB             OFFSET4
                 BPL              ADDSUM4
                 COMB
                 INCB
ADDSUM4          CLRA
                 ADDD             SUM4
                 STD              SUM4
                 LDD              COUNT
                 ADDD             #$0001
                 STD              COUNT
                 CPD              #SAMPLES
                 BLO              ADCREAD
                 PULB
                 PULA
                 PULX
                 RTS
* This subroutine computes the ball speed by dividing the overall sum by a constant.
COMPUTE          PSHX
                 PSHA
                 PSHB
                 LDD              SUM1
                 ADDD             SUM2
                 ADDD             SUM3
                 ADDD             SUM4
                 STD              GRNDSUM
                 LDX              #PRPFCTR
                 IDIV
                 XGDX
                 STAB             CURBIN
                 PULB
                 PULA
                 PULX
                 RTS
* This subroutine converts from binary to BCD. (Limited to number up to 99 decimal.)
BINTBCD          PSHX
                 PSHA
                 PSHB
                 LDX              #$0000
                 LDAA             CURBIN
                 STAA             TEMPBIN
                 CLRA
                 CLRB
BINSHFT          LSL              TEMPBIN
                 ROLB
                 LSLA
                 CMPB             #$10
                 BLO              CHKDONE
                 INCA
                 ANDB             #$0F
CHKDONE          INX
                 CPX              #$0008
                 BEQ              RAILAT9
CHKFIVE          CMPB             #$05
                 BLO              BINSHFT
                 ADDB             #$03
                 BRA              BINSHFT
RAILAT9          CMPA             #$09             ;Force the display to “99” if speed > 100 mph.
                 BLS              DONE
                 LDD              #$0909
DONE             STD              BCD
                 LDX              #SEVSEG          ;This part finds the seven segment display codes.
                 XGDX
                 ADDB             BCD
                 XGDX
                 LDAA             $00,X
                 STAA             CURDSPL
                 LDX              #SEVSEG
                 XGDX
                 ADDB             BCD+1
                 XGDX
                 LDAA             $00,X
                 STAA             CURDSPL+1
                 PULB
                 PULA
                 PULX
                 RTS
* This subroutine displays the current speed for 5 seconds & then displays the maximum.
OUTPUT           PSHX
                 PSHA
                 PSHB
```

```
                LDX             #REGOFF
                LDAA            CURBIN
                CMPA            MAXBIN
                BLS             OLDMAX
                STAA            MAXBIN
                LDD             CURDSPL
                STD             MAXDSPL
OLDMAX          LDD             CURDSPL
                STD             PORTC,X
                BSET            PORTB,X,YOURSPD           ;Toggle the ”YOUR”/“BEST” LEDs.
                LDD             #$0000
LEDWAIT         BCLR            TFLG1,X,OC1FCLR           ;Clear output compare 1 flag.
DSPLDLY         BRCLR           TFLG1,X,OC1F,DSPLDLY
                ADDD            #$0001
                CPD             #CURDLY                   ;Decimal 152. (152 * 33ms = 5.0 sec)
                BLO             LEDWAIT
                LDX             #$0000
RECLEAR         CLR             SUM1,X          ;Clear 12 RAM bytes beginning at address ”SUM1”.
                INX                             ;Clears SUM1 thru SUM4, GRNDSUM, and COUNT.
                CPX             #$000C
                BLO             RECLEAR
                LDX             #REGOFF
                LDD             MAXDSPL
                STD             PORTC,X         ;The ”YOUR”/“BEST” LEDS are automatically toggled.
                PULB
                PULA
                PULX
                RTS
```

AN1640

Reducing Accelerometer Susceptibility to BCI

Prepared by Brandon Loggins

Automobile manufacturers require all system electronics to pass stringent electromagnetic compatibility (EMC) tests. Airbag systems are one of the systems that must perform adequately under EMC tests. There are different types of tests for EMC, one of which is testing the tolerance of the system to high frequency conducted emissions. One of the most stringent methods for EMC evaluation is the Bulk Current Injection (BCI) test. The entire airbag system must continue to function normally throughout the BCI test. This application note will discuss how to reduce susceptibility to BCI for the Motorola accelerometer but the information presented here can be applied to other electronic components in the system.

BCI TEST SETUP

The BCI test procedure follows a published SAE engineering standard, “Immunity to Radiated Electric Fields ~ Bulk Current Injection (BCI)”, or SAE J 1113/401. For an airbag module, this involves injecting the desired current into the wiring harness by controlling current in the injection probe. The test frequency can vary from one to several hundred MHz. There are at least 20 frequency steps per octave required for the test, but as many as 50 steps per octave can be used. The injection probe is placed on the harness in one of three distances from the airbag module connector: 120, 450 and 750 mm. There is a monitor pickup probe present to measure the amount of current being injected. It is placed 50 mm from the airbag module. This feeds back to the system to ensure that the desired test current is being injected on to the wiring harness. Figure 1 shows the setup for the BCI test. (For more details, see the SAE J 1113/401 Test Procedure).

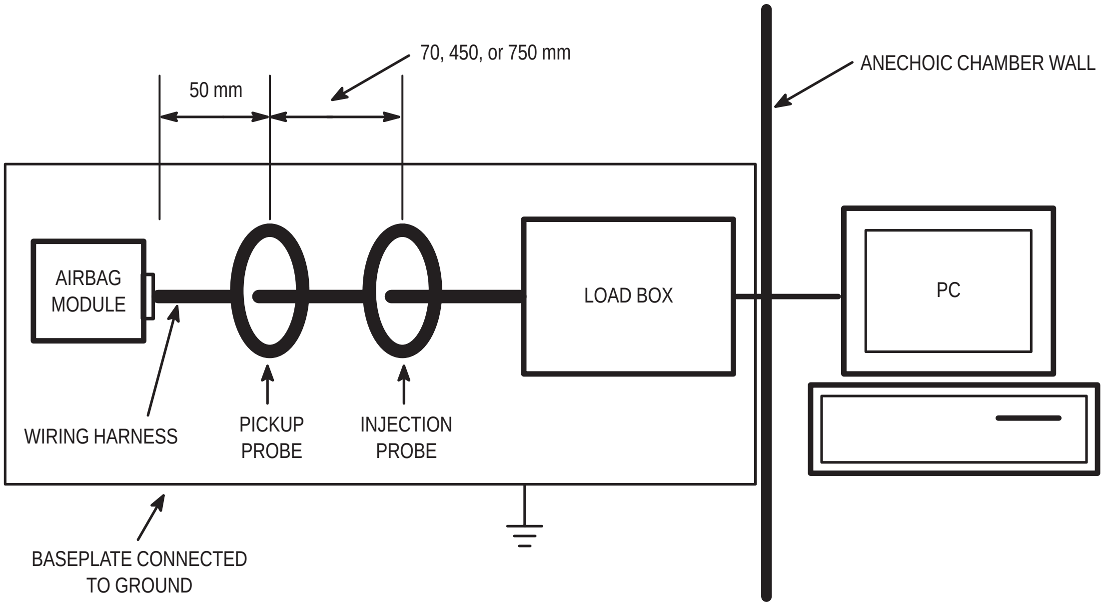


Figure 1. BCI Test Setup

The harness connects the airbag module to a load box. This load box provides simulated loads for terminating the remainder of the airbag system (firing ignitors, etc.). The data coming back is translated from J1850 to RS232 to be communicated to a dummy terminal on a PC. For safety reasons, this test is typically performed inside an anechoic chamber to shield high frequency emissions from equipment and humans.

BCI TEST PROCEDURE FOR THE PMMA1000 ACCELEROMETER

The accelerometer is evaluated in the following manner. In an airbag system, the microcontroller’s A/D converter digitizes the accelerometer output. The microcontroller sends this value to the communication ASIC which translates the logic from board level logic to RS232, then sends the value back

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along the wiring harness. Once through the chamber wall, the data is translated to RS232 and fed to a dummy terminal. On the terminal screen, the A/D codes for the accelerometer can be monitored for unexpected performance.

Ideally, when the accelerometer is at rest (no acceleration applied), the output should be at 0*g*, regardless of what EMC testing the system may be subjected to. Depending on the crash algorithm of the airbag module software, there is some allowable offset shift that can be tolerated. Higher shift in output could create errors in the crash analysis software, perhaps causing the airbags to unnecessarily deploy when there is not a crash or not deploy when there is a crash.

The Motorola accelerometer must be able to meet the airbag system requirements throughout BCI exposure. It has a sensitivity of 40 mV/g and an offset (0*g* output) of 2.50 V. During the BCI test, the accelerometer output should be 2.50 V at 0*g* with as little drift as possible. A typical airbag system may have software that can tolerate from as little as 0.5 *g* up to 2.0 *g*. of deviation from the offset. The system would then expect the accelerometer output to be within 40 mV of the offset during the entire BCI test. Therefore, at any given frequency of the BCI test, if the output deviates outside this expected window of drift, it fails the test.

PMMA1000 ACCELEROMETER BCI TEST RESULTS

If a system has not been well designed for electromagnetic compatibility, the accelerometer, as well as other devices, can have performance problems. What has been found for the accelerometer is that in some system applications, it suffers from an offset shift when certain frequencies of BCI are applied. For example, in one airbag system being tested at a certain frequency, with the desired BCI current applied, the offset is found to shift down by 60 mV. This would equate to an error of 1.5 *g*. See Figure 2. At other frequencies, this shift is even higher. This DC shift plot was taken with an oscilloscope using a 20 MHz filter to remove the high frequency component of the signal. Probes are placed at the accelerometer in the system application. The plot shows the accelerometer output before and after BCI was applied (before and after the RF generator creating the high frequency signal was turned on).

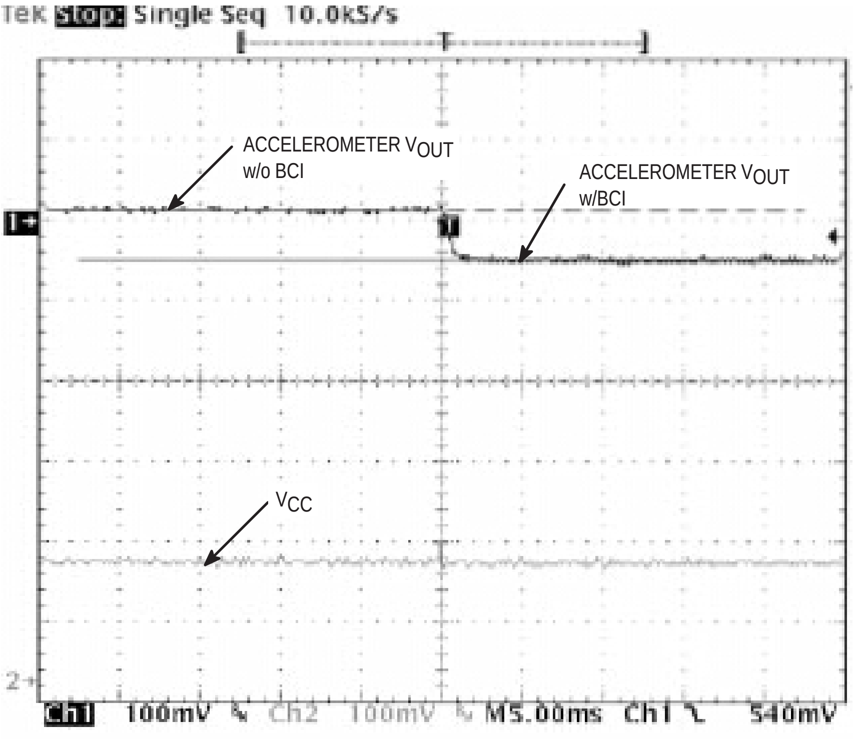

Figure 2. Accelerometer Tested Under High Frequency BCI

This phenomenon has been determined to be system level related. PCB layout and grounding for the accelerometer will affect its performance. This was found by testing the accelerometer outside of the airbag module. The device was put on a test board by itself with only the supply decoupling capacitor of 0.1 μF connected to it. To simulate the effect of BCI on Vcc, a frequency generator was used to inject a known high frequency sinusoid that caused BCI failure on to the 5.0 V supply voltage. The device was first tested in small test board with ground provided by one wire back to the supply. This grounding reproduced the failure due to BCI seen at the module level. The test board was then mounted down to a ground plane provided by a copper plate and the accelerometer ground was soldered to the plate (providing a low impedance path to ground). With this setup, the offset shift did not occur.

If a system does not incorporate a good PCB layout providing a low impedance to ground, the accelerometer output may shift at certain high frequencies. This output offset shift was caused by a shift in the 0–5 V supply window. Because the accelerometer has a ratiometric output, its offset is dependent on the supply voltage. Any change in the supply voltage will result in the same proportional change in the output. For example, if the 5 V supply were to change by 10%, from 5.0 V to 5.5 V, the accelerometer offset will change by 10% also, from 2.5 V to 2.75 V. This phenomena would also occur if the ground were to shift. A 100 mV change in ground would result in a 50 mV change in the output. If the accelerometer does not have low impedance path to ground and parasitics from a poor ground are present as a result, the ground seen by the accelerometer may change over frequency. So, during a BCI test, if the 5.0 V supply does not shift but the output of the accelerometer does, the ground to the accelerometer may be moving.

It was found with some experimentation that the offset shift can be eliminated with proper board layout techniques as described below.

PROPER LAYOUT TECHNIQUES

Since the Motorola accelerometer is a sensitive analog device that relies on a clean supply to function within established parameters, there are some techniques that can be employed to minimize the effects of BCI on the accelerometer performance. PCB layout is paramount to reducing susceptibility to BCI.

- A low impedance path to ground will provide shunting of the high frequency interference and minimize its effect on the accelerometer. The best way to provide a good path is by putting a solid, unbroken ground plane in the PCB. This ground plane should be shunted to chassis ground at the module connector. This will ensure that the high frequency BCI will be shunted before interfering with accelerometer performance.
- All accelerometer pins that require ground connection should be tied together to a common ground.
- Traces attached directly to the connector pins can receive high RF noise, which can couple to nearby traces and components. Increasing series impedance of the traces helps reduce the couple or conducted noise. High frequency filters on the supply line and other susceptible lines may be required to filter out high frequency interference introduced by the BCI test. Signal lines that carry low current can tolerate series resistances of 100–200 Ω.
- Decoupling capacitors on every input line to the common ground plane will help shunt the high frequency away from the system. These should be placed near the connector.
- Signal trace lengths to and from the accelerometer should be kept at a minimum. The shorter the trace, the less chance it has of picking up high frequency BCI signals as it crosses the board. Trace lengths can be reduced by placing the accelerometer and the microcontroller as close together as possible. Signal and ground traces looping should be minimized.
- A decoupling capacitor on the accelerometer Vcc pin will also help minimize BCI effects. The recommended value is 0.1 μF. This capacitor should be placed as close as possible to the accelerometer to achieve the best results.
- To maximize ratiometricity, the accelerometer Vcc and the microcontroller A/D reference pin should be on the same trace. The accelerometer ground and the microcontroller ground should also share the same ground point. Therefore, when there is signal interference due to BCI, the A/D converter and the accelerometer will see the interference at the same level. This will result in the same digital code representation of acceleration without signal interference.
- A clean power supply to both the accelerometer and the microcontroller should be provided. Supply traces should avoid high current traces that might carry high RF currents during the BCI test. The traces should be as short as possible.
- The accelerometer should be placed on the opposite end of the PCB away from the connector. The farther the distance, the lower the chance high frequency RF from BCI will interfere with the accelerometer.
- The accelerometer should be placed away from high current paths that may carry high RF currents during the BCI test.

Automotive customers will continue to require airbag systems to have high standards for EMC. One way to test for EMC is perform the Bulk Current Injection test. Because of the high current involved, BCI is one of the most difficult EMC tests to pass. Being part of the airbag system, the accelerometer must continue to function normally under application of high frequency BCI. The accelerometer is highly sensitive to placement on the board and its connection to ground. Poor design will caused the device to fail the BCI test. The practice of good PCB layout, device placement and good grounding will allow the accelerometer to function within specification and pass the BCI test.

AN4004

±2g Acceleration Sensing Module Based on a ±40g Integrated Accelerometer

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and
Brandon Loggins
Application Engineer, Phoenix, USA

INTRODUCTION

Micromachined accelerometers, with built–in signal conditioning and calibration are widely used in automotive safety devices such as airbag modules. Automotive applications for accelerometers also include comfort features such as active suspension. For such an application, a ±2g accelerometer is required. But most accelerometers offered today that are able to provide sufficient sensitivity are expensive and/or unavailable in production volumes. With the circuitry described herein, the accelerometer can be used for sensing acceleration in the range of ±2g, with performance in line with the technical requirements of this application.

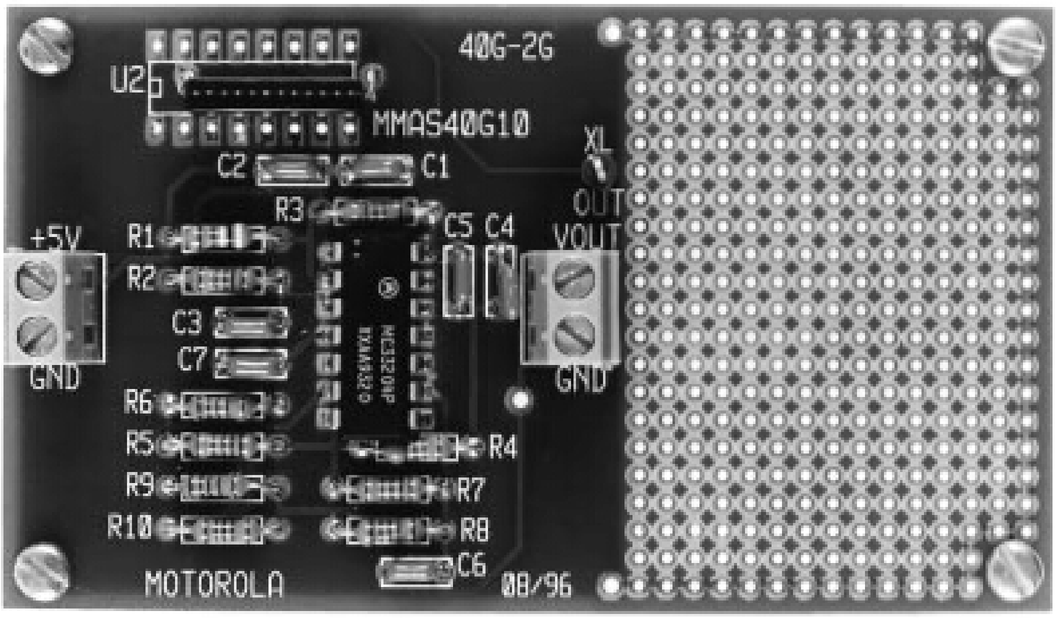


Figure 1. 40G–2G ±2g Sensing Module Evaluation Board

REV 4

EVALUATION BOARD DESCRIPTION

The information required to use evaluation board "40G–2G" follows and a discussion of the design appears in the Design Considerations section.

Function

The evaluation board shown in Figure 1, when supplied with an accelerometer, provides a ±2g full scale acceleration measurement.

The output is an analog signal. It nominally supplies 2.1 volts at zero g and has a sensitivity of 1000 mV/g. It is easily interfaced with a microcontroller's A/D input.

A through–hole area is provided on the PCB for the designer to add other circuitry as needed.

Electrical Characteristics

The following electrical characteristics are included as a guide to operation.

Characteristics	Symbol	Min	Typ	Max	Units
Supply Voltage	V_{CC}	4.75	5.0	5.25	Volts
Supply Current	I_O	—	7.0	—	mA
Acceleration Range	G	–2.0	—	+2.0	g
Zero G Output	V_{off}	2.0	2.1	2.2	Volts
Sensitivity	$\Delta V/\Delta G$	850	1000	1150	mV/g
Low Cutoff Frequency	—	0.8	0.9	1.0	Hz
High Cutoff Frequency	—	4.0	5.0	6.0	Hz
Operating Temperature	Ta	–40	—	+85	°C

Table 1. Electrical Characteristics

Frequency Response

Below is the simulated typical output frequency response using the devices listed in the parts list below. The system provides a gain of 25 over a 5 Hz bandwidth.

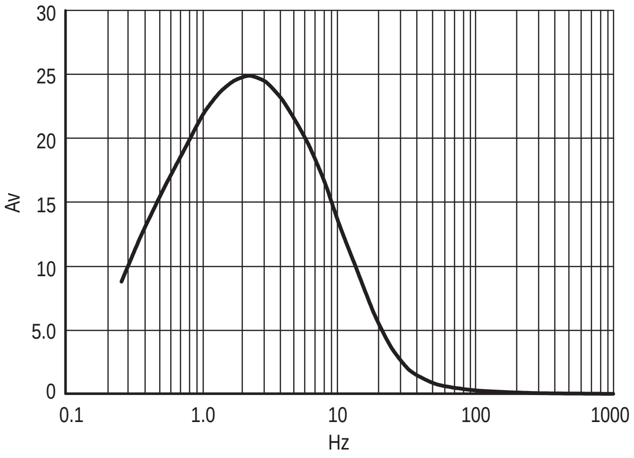


Figure 2. ±2g Biquad Filter with Additional Gain Stage Frequency Response

Evaluation Board Content

Board contents are described in the parts list shown in Table 2. A schematic and silk screen plot are shown in Figures 4 and 5.

Designator	Qty.	Description	Value/Part Number
R1	1	1/4 Watt Resistor	90.9 K
R2, R8	2	1/4 Watt Resistor	162 K
R5, R6, R7, R9, R10	5	1/4 Watt Resistor	11 K
R3, R4	2	1/4 Watt Resistor	432 K
C1–C6	6	Ceramic Capacitor	0.1 μF
U1	1	Quad Rail–to–Rail Op Amp	MC33204P
U2	1	40g Accelerometer	PMMA2000 Series

Table 2. Parts List

DESIGN CONSIDERATIONS

Using a 40g accelerometer to measure ±2g of acceleration can be tricky. Motorola's accelerometer provides a wide bandwidth of 400 Hz for acceleration sensing. In many low g applications, such as active suspension, the bandwidth requirements are considerably lower. Limiting the bandwidth of the accelerometer can reduce noise. After reducing the bandwidth, gain can be applied to provide higher sensitivity for low g acceleration measurements.

The design challenge is how to bandpass filter the accelerometer's output with gain using a few low cost components. To accommodate the accelerometer's wide dynamic range, since the supply voltage is limited to 5 volts, it is necessary to use rail to rail operational amplifiers, such as Motorola's MC33204P.

In this design, the output signal passes through a biquad filter stage, then through an additional low–pass gain stage to provide ±2g sensing capability. The biquad filter, shown in Figure 3, with some gain, is a good choice for bandpass filtering the accelerometer output when a high quotient factor, Q, is desired. The gain is set by Rg and Rb with the high cutoff frequency being set by Rb and C1. The low cutoff frequency is set by Rf and C2.

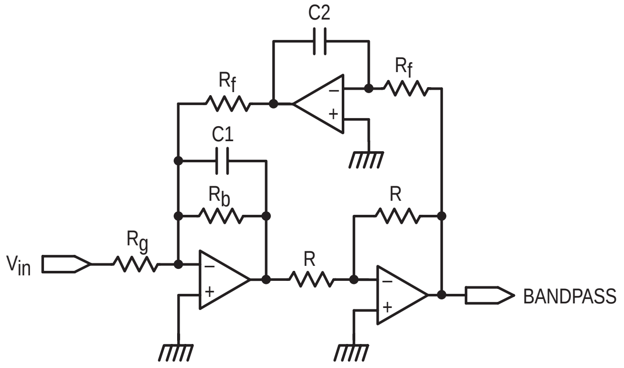


Figure 3. Biquad Active Filter

APPLICATION

Integrating the accelerometer with the biquad amplifier is quite simple. First, in order to minimize the noise level, the accelerometer is properly bypassed, as indicated in the data sheet, with one 0.1 μF ceramic capacitor between V_{CC} (pin 8) and Ground (pin 7). The self–test feature remains unused in this design. Pin 11 is tied to V_{CC}, as indicated in the data sheet. The output signal is taken on pin 5. The remaining pins of the accelerometer are unused.

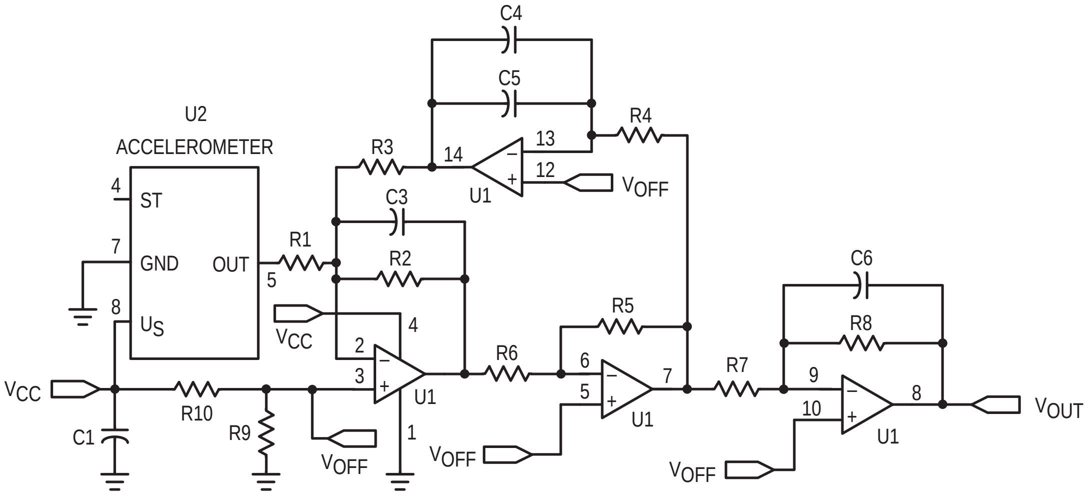


Figure 4. ±2g Acceleration Sensing Module EVB Schematic

In this design, the biquad filter stage gain is set to 1.76 with R2 (160 kΩ) and R1 (91 kΩ). A higher gain cannot be set for this stage, otherwise some operational amplifiers saturate when the accelerometer output drifts over temperature. The upper cutoff frequency is set with R2 (160 kΩ) and C3 (0.1 μF). Two capacitors, C4 (0.1 μF) and C5 (0.1 μF), are needed to set the lower cutoff frequency.

A final low pass filter stage, with a gain of 14.55, brings the overall gain to 25. Resistors R8 (160 kΩ) and R7 (11 kΩ) set the gain. The amplifier is low passed with C6 (0.1 μF) to remove any high frequency noise in the signal. The output can then be connected to a microcontroller's A/D converter by a simple direct connection from the evaluation board analog output V_{OUT} to the A/D input. Using the MC68HC11 as an example, the output is connected to any of the E ports.

Since the accelerometer signal passes through 3 inverter stages, the positive direction of acceleration is reversed.

CONCLUSION

Perhaps the most noteworthy aspect to the ±2g sensing module described here is the ease with which it can be designed. Only two dual, or one quad, operational amplifier and a few resistors and capacitors are required. The result is a simple and inexpensive circuit that is capable to measure acceleration within the range of ±2g with an analog output that can be directly interfaced to a microcontroller.

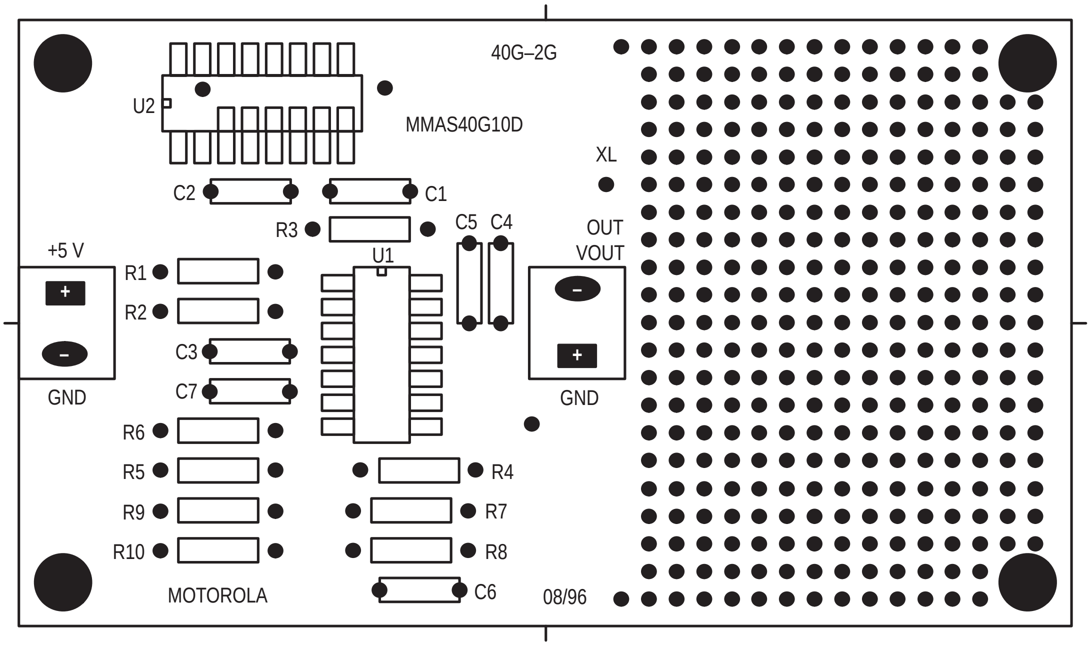
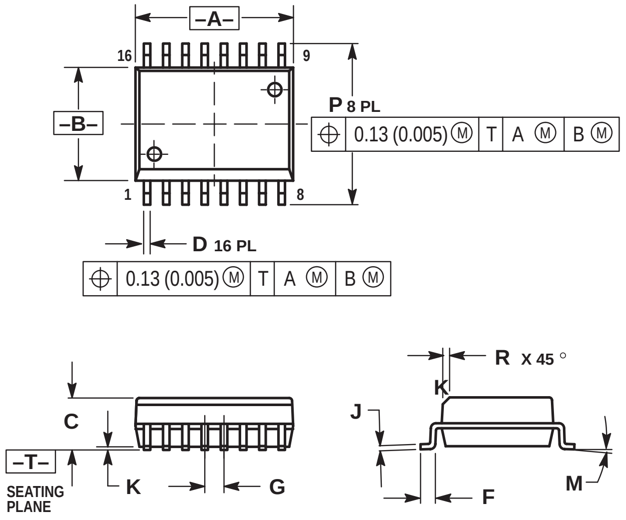


Figure 5. Silk Screen

Case Outlines



NOTES:

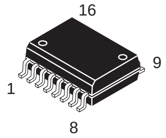
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: MILLIMETER.
3. DIMENSIONS A AND B DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION 0.15 (0.006) PER SIDE.
5. DIMENSION D DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.13 (0.005) TOTAL IN EXCESS OF D DIMENSION AT MAXIMUM MATERIAL CONDITION.

	MILLIMETERS		INCHES	
DIM	MIN	MAX	MIN	MAX
A	10.15	10.45	0.400	0.411
B	7.40	7.60	0.292	0.299
C	3.30	3.55	0.130	0.140
D	0.35	0.49	0.014	0.019
F	0.76	1.14	0.030	0.045
G	1.27 BSC		0.050 BSC	
J	0.25	0.32	0.010	0.012
K	0.10	0.25	0.004	0.009
M	0 °	7 °	0 °	7 °
P	10.16	10.67	0.400	0.420
R	0.25	0.75	0.010	0.029

CASE 475–01
ISSUE A
16 LEAD SOIC

Reference Information

Pinout Diagrams for Accelerometer Sensors



16 LEAD SOIC
CASE 475–01

ACCELEROMETER

Case Type	Package Style	PIN 1	PIN 2	PIN 3	PIN 4	PIN 5	PIN 6	PIN 7
475–01	SOIC	N/C (1)	N/C (1)	N/C (1)	Self–Test	Output	N/C (1)	Ground

PIN 8	PIN 9	PIN 10	PIN 11	PIN 12	PIN 13	PIN 14	PIN 15	PIN 16
V_S (2)	N/C (1)	N/C (1)	N/C (1)	N/C (1)	N/C (1)	N/C (1)	N/C (1)	N/C (1)

Notes:
1. Internal connections. All N/C must remain floating.
2. Connect to ground.

Accelerometer Glossary of Terms

Acceleration	Change in velocity per unit time.
Acceleration Vector	Vector describing the net acceleration acting upon the device.
Frequency Bandwidth	The accelerometer output frequency range.
g	A unit of acceleration equal to the average force of gravity occurring at the earth's surface. A g is approximately equal to 32.17 ft/s^2 or 9.807 m/s^2.
Nonlinearity	The maximum deviation of the accelerometer output from a point–to–point straight line fitted to a plot of acceleration vs. output voltage. This is determined as the percentage of the full–scale output (FSO) voltage at full–scale acceleration (40g).
Ratiometric	The variation of the accelerometer's output offset and sensitivity linearly proportional to the variation of the power supply voltage.
Sensitivity	The change in output voltage per unit g of acceleration applied. This is specified in mV/g.
Sensitive Axis	The most sensitive axis of the accelerometer. On the DIP package, acceleration is in the direction perpendicular to the top of the package (positive acceleration going into the device). On the SIP package, acceleration is in the direction perpendicular to the pins.
Transverse Acceleration	Any acceleration applied 90° to the axis of sensitivity.
Transverse Sensitivity Error	The percentage of a transverse acceleration that appears at the output. For example, if the transverse sensitivity is 1%, then a +40 g transverse acceleration will cause a 0.4 g signal to appear on the output. Transverse sensitivity can result from sensitivity of the g–cell to transverse forces.

Section Three

Pressure Sensor Products

General Information:

Pressure Sensor Overview

Motorola's pressure sensors are silicon micromachined, electromechanical devices featuring device uniformity and consistency, high reliability, accuracy and repeatability at competitively low costs. With more than 15 years in pressure sensor engineering, technology development and manufacturing, these pressure sensors have been designed into automotive, industrial, medical, commercial and consumer products worldwide.

Pressure sensors operate in pressures ranging from 10 to 1000 kPa (1.45psi to 150psi). For maximum versatility, Motorola pressure sensors are single silicon, piezoresistive devices with three levels of device sophistication. The basic sensor device provides uncompensated sensing, the next level adds device compensation and the third and most value added pressure sensors are the integrated devices. Compensated sensors are available in temperature compensated and calibrated configurations; integrated devices are available in temperature compensated, calibrated and signal conditioned (or amplified) configurations. Each sensor family is available in gauge, absolute and differential pressure references in a variety of packaging and porting options.

Pressure Sensor Overview

Reference Information

Mini Selector Guide

Pressure Sensors

Part #	Description	Supply Voltage	Max Pressure Rating	Packages
MPX10 Series	Uncompensated	10 V max	1.45 psi	4 pin — epoxy, ported
MPX50 Series	Uncompensated	10 V max	7.3 psi	4 pin — epoxy, ported
MPX100 Series	Uncompensated	10 V max	14.5 psi	4 pin — epoxy, ported
MPX2010 Series	Temperature Compensated/Calibrated	16 V max	1.45 psi	4 pin — epoxy, ported
MPXT2010G Series	Temperature Compensated/Calibrated	16 V max	1.45 psi	8 pin — top piston fit
MPX2050 Series	Temperature Compensated/Calibrated	16 V max	7.3 psi	4 pin — epoxy, ported
MPX2300DT1	Disposable, Temperature Compensated/Calibrated	10 V max	300 mmHg	chip pak, tape and reel
MPX4100A Series	Signal Conditioned	5.35 V max	15.2 psi	6 pin — epoxy, ported
MPX4101A Series	Signal Conditioned	5.35 V max	14.7 psi	6 pin — epoxy, ported
MPXS4100A Series	Signal Conditioned	5.35 V max	15.2 psi	8 pin — surface mount
MPX4115A Series	Signal Conditioned	5.35 V max	16.6 psi	6 pin — epoxy, ported
MPXS4115A Series	Signal Conditioned	5.35 V max	16.6 psi	8 pin — surface mount
MPX4250A Series	Signal Conditioned	5.35 V max	36.2 psi	6 pin — epoxy, ported
MPX5010 Series	Signal Conditioned	5.25 V max	1.45 psi	6 pin — epoxy, ported
MPX5050 Series	Signal Conditioned	5.25 V max	7.3 psi	6 pin — epoxy, ported
MPX5100 Series	Signal Conditioned	5.25 V max	14.5 psi	6 pin — epoxy, ported
MPX5500 Series	Signal Conditioned	5.25 V max	72.5 psi	6 pin — epoxy, ported
MPX5700 Series	Signal Conditioned	5.25 V max	100 psi	6 pin — epoxy, ported
MPX5999D	Signal Conditioned	5.25 V max	150 psi	6 pin — epoxy

General Product Information

Performance, competitive price and application versatility are just a few of the Motorola pressure sensor advantages.

PRESSURE SENSOR APPLICATIONS VERSATILITY

For Motorola's pressure sensors, new applications emerge every day as engineers and designers realize that they can convert their expensive mechanical pressure sensors to Motorola's lower–cost, semiconductor–based devices. Applications include automotive and aviation, industrial, healthcare and medical products and systems.

PERFORMANCE

The performance of Motorola's MPX pressure sensors is based on its patented strain gauge design. Unlike the more conventional pressure sensors which utilize four closely matched resistors in a distributed 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 sensors 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:

Motorola's pressure sensors are available in pressure ranges to fit a wide variety of automotive, medical, consumer and industrial applications.

Choice of Measurement:

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

Choice of Chip Complexity:

Motorola's pressure sensors are available as the basic sensing element, with temperature compensation and calibration, or with full signal conditioning circuitry included on the chip. Uncompensated devices permit external compensation to any degree desired.

Choice of Packaging:

Available as a basic element for custom mounting, or in conjunction with Motorola's designed ports, printed circuit board mounting is easy. Our Next Generation and Small Outline packaging options provide surface mount, low profile, and top piston fit package selections. Alternate packaging material, which has been designed to meet biocompatibility requirements, is also available.

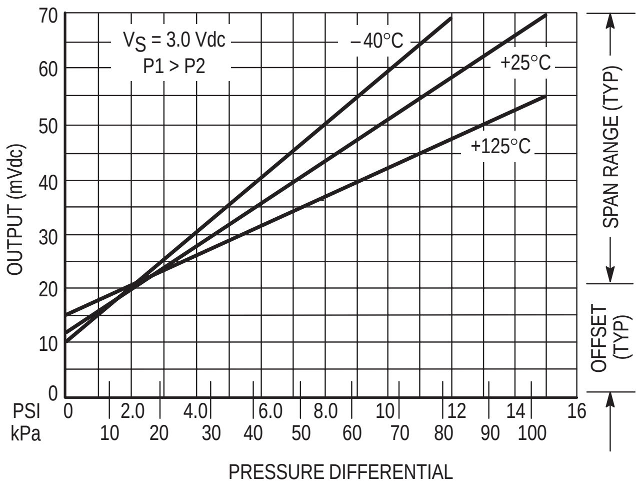
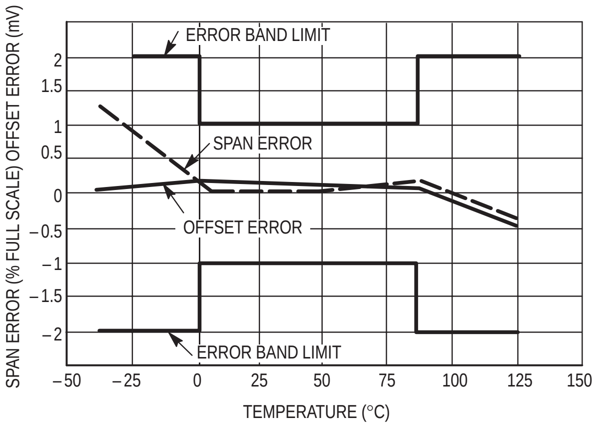


Figure 1. Typical Output versus Pressure Differential



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

Figure 2. Temperature Error Band Limit and Typical Span and Offset Errors

Motorola Pressure Sensors

INTRODUCTION

Motorola pressure sensors combine advanced piezoresistive sensor architecture with integrated circuit technology to offer a wide range of pressure sensing devices for automotive, medical, consumer and industrial applications. Selection versatility includes choice of:

Pressure Ranges in PSI

0 to 1.45, 0 to 6, 0 to 7.3, 0 to 14.5, 0 to 29, 0 to 75, 0 to 100, 0 to 150 psi.

Application Measurements

Absolute, Differential, Gauge

Sensing Options

Uncompensated, Temperature Compensated/Calibrated, and Signal Conditioned (with on–chip amplifiers)

Package Options

- Basic Element, Ported Elements for specific measurements
- Surface Mount, Low Profile and Top Piston fit packages

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 LOCALIZED SENSING ELEMENTS

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 (Figure 3a).

The transducer (Figure 3) uses a single element eliminating the need to closely match the four stress and temperature sensitive resistors that form a distributed 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.

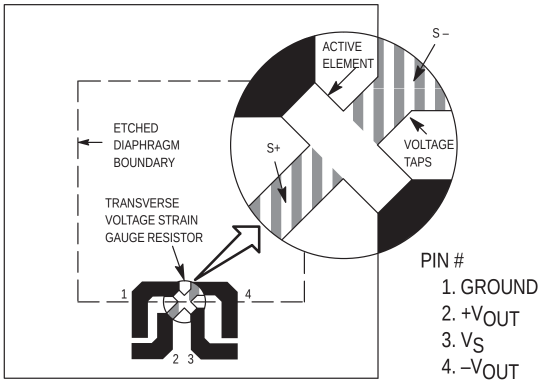


Figure 3. X–ducer™ Sensor Element — Top View

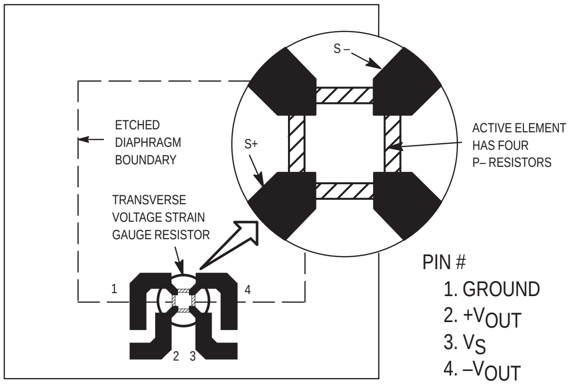


Figure 3a. Localized Sensing Element

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 4) 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.

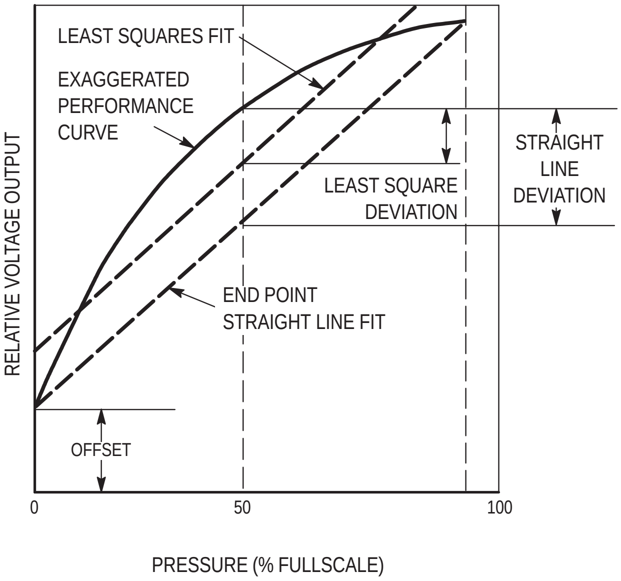


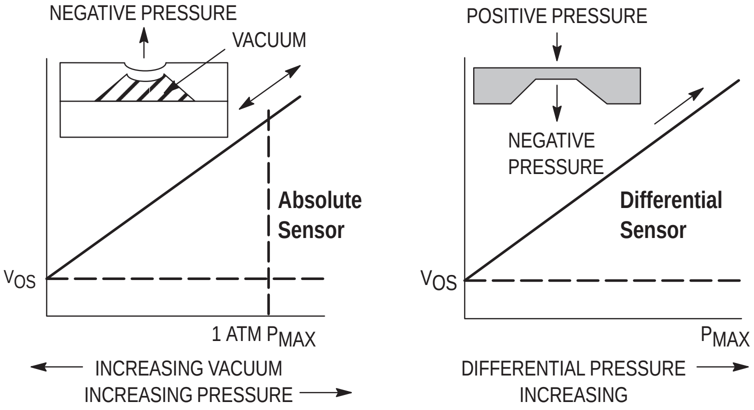
Figure 4. Linearity Specification Comparison

OPERATION

Motorola pressure sensors provide three types of pressure measurement: 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 14.5 psi (one atmosphere), generating a quiescent full–scale output for the MPX100A (14.5 psi) sensor, and a half–scale output for the MPX200A (29 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 is immediately restored.

Figure 5. 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.

Typical Electrical Characteristic Curves

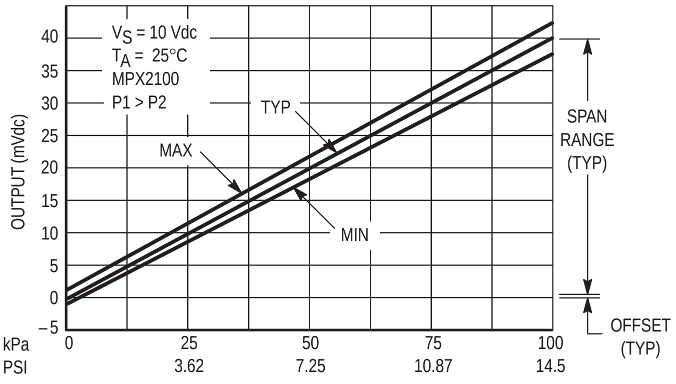


Figure 6. Output versus Pressure Differential

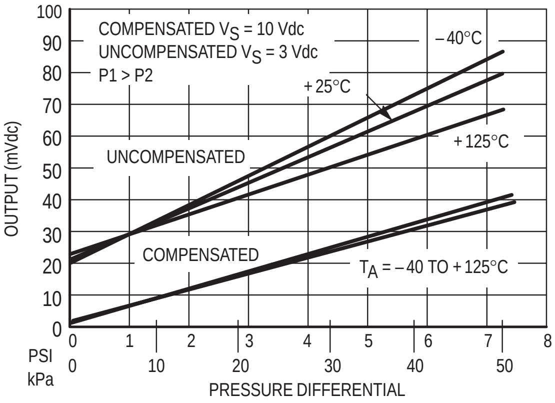


Figure 7. Typical–Output Voltage versus Pressure and Temperature for Compensated and Uncompensated Devices

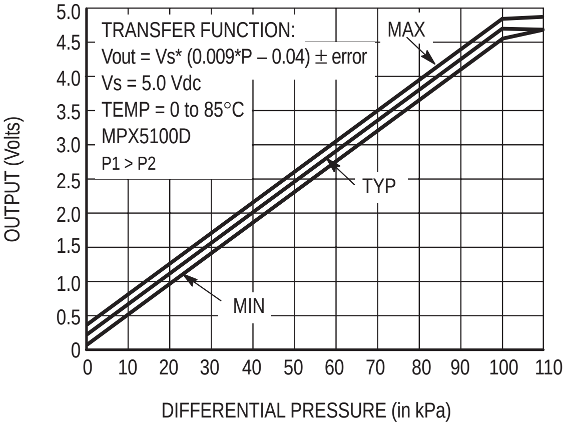


Figure 8. Signal Conditioned MPX5100

Unibody Cross–sectional Drawings

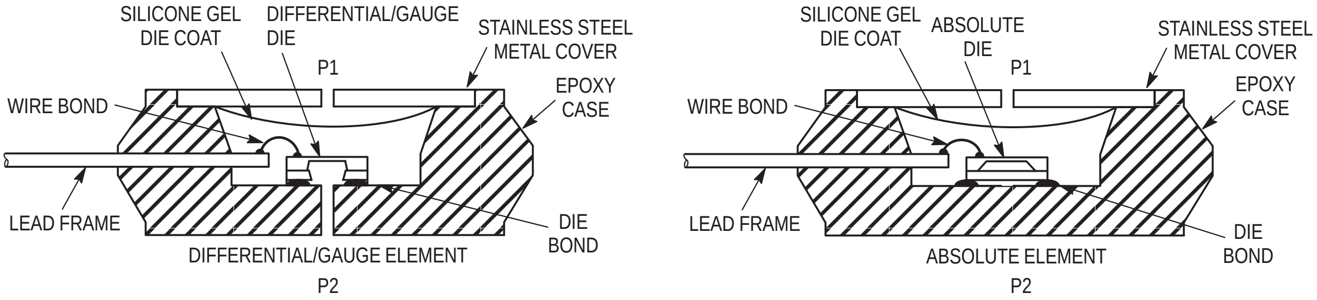


Figure 9. Cross–Sectional Diagrams (not to scale)

Figure 9 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 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.

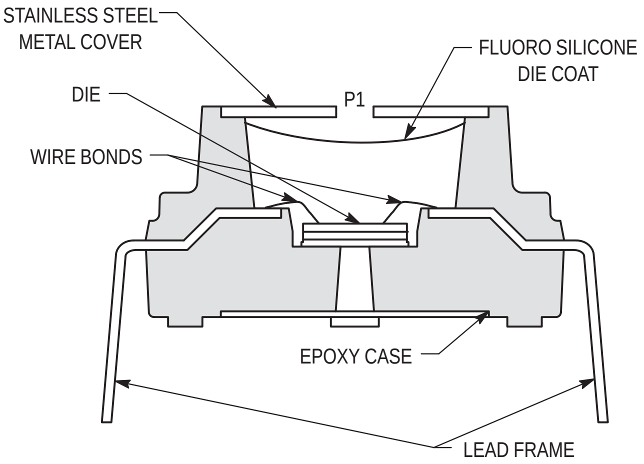


Figure 10. Cross–Sectional Diagram (not to scale)

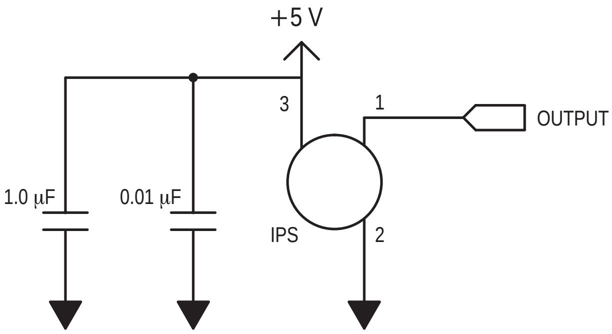
Figure 10 illustrates the differential/gauge die in the basic chip carrier (Case 473). A silicone gel isolates the die surface and wirebonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm.

Integration

ON-CHIP SIGNAL CONDITIONING

To make the designer's job even easier, Motorola's integrated devices carry sensor technology one step further. In addition to 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.



Recommended Power Supply Decoupling. For output filtering recommendations, please refer to Application Note AN1646.

Design Considerations for Different Levels of Sensor Integration

	DESIGN ADVANTAGES	DESIGN CONSIDERATIONS
Uncompensated Sensors	High Sensitivity	Device–to–Device Variation in Offset and Span
	Lowest Device Cost	Temperature Compensation Circuitry Required
	Low–Level Output Allows Flexibility of Signal Conditioning	Requires Signal Conditioning/ Amplification of Output Signal
		Relatively Low Input Impedance (400 Ω Typical)
Temperature Compensated & Calibrated (MPX2000 Series)	Reduced Device–to–Device Variations in Offset and Span	Lower Sensitivity Due to Span Compensation (Compared to Uncompensated)
	Reduced Temperature Drift in Offset and Span	Priced Higher than Uncompensated Device
	Reasonable Input Impedance (2K Ω Typical)	Requires Signal Conditioning/ Amplification of Output Signal
	Low Level Output Allows Flexibility in Signal Conditioning	
Integrated Pressure Sensors (MPX4000 and MPX5000 Series)	No Amplification Needed Direct Interface to MPU	Priced Higher than Compensated/ Uncompensated Device
	Signal Conditioning, Calibration of Span and Offset, Temperature Compensation Included On–Chip	

Sensor Applications

AUTOMOTIVE/AVIATION APPLICATIONS

- Fuel Level Indicator
- Altimeters (for backpackers also)
- Air Speed Indicator
- Ejection Seat Control
- Turbo Boost Control
- Manifold Vacuum Control
- Fuel Flow Metering
- Oil Filter Flow Indicator
- Oil Pressure Sensor
- Air Flow Indicators
- Anti–Start
- Breathalizer Systems
- Smart Suspension Systems
- Variometer–Hangglider & Sailplanes
- Automotive Speed Control

MEDICAL APPLICATIONS

- Blood Pressure
- Esophagus Pressure
- Heart Monitor
- Interoccular Pressure
- Saline Pumps
- Kidney Dialysis
- Blood Gas Analysis
- Blood Serum Analysis
- Seating Pressure (Paraplegic)
- Respiratory Control
- Intravenous Infusion Pump Control
- Hospital Beds

INDUSTRIAL/COMMERCIAL APPLICATIONS

- Electronic Fire Fighting Control
- Flow Control
- Barometer
- Weather Stations (Wind Speed, Barometric Pressure)
- Cow Milker
- Shift Point Indicators
- HVAC Systems
- Building Air Flow Control
- Electronic Tire Pressure Gauge
- Water Filtered Systems (Flow Rate Indicator)
- Air Filtered Systems (Flow Rate Indicator)
- Tactile Sensing for Robotic Systems
- Boiler Pressure Indicators
- End of Tape Readers
- Automatic Parts Counter
- Disc Drive Control/Protection Systems
- Ocean Wave Measurement
- Diving Regulators
- Oil Well Logging
- Building Automation (Balancing, Load Control, Windows)
- Fluid Dispensers
- Explosion Sensing — Shock Wave Monitors
- Load Cells
- Autoclave Release Control
- Soil Compaction Monitor — Construction
- Wind Tunnel Pressure Measurement
- Water Depth Finders (Industrial, Sport Fishing/Diving)
- Pneumatic Controls — Robotics
- Pinch Roller Pressure — Paper Feed
- Blower Failure Safety Switch — Computer
- Vacuum Cleaner Control
- Electronic Drum
- Pressure Controls Systems — Building, Domes
- Engine Dynamometer

Motorola has tested media tolerant sensor devices in selected solutions or environments and test results are based on particular conditions and procedures selected by Motorola. Customers are advised that the results may vary for actual services conditions. Customers are cautioned that they are responsible to determine the media compatibility of sensor devices in their applications and the foreseeable use and misuses of their applications.

PRESSURE SENSOR PRODUCTS

Uncompensated*

Device Series	Max Pressure Rating		Over Pressure (kPa)	Offset mV (Typ)	Full Scale Span mV (Typ)	Sensitivity (mV/kPa)	Linearity % of FSS(1)	
	psi	kPa					(Min)	(Max)
MPX10	1.45	10	75	20	35	3.5	–1.0	1.0
MPXL10	1.45	10	75	20	35	3.5	–1.0	1.0
MPX12	1.45	10	75	20	35	3.5	–1.0	1.0
MPX50	7.3	50	200	20	60	1.2	–0.25	0.25
MPX100	14.5	100	200	20	60	0.6	–0.25	0.25
MPX200	29	200	400	20	60	0.3	–0.25	0.25

Compensated and Calibrated (On–Chip)*

MPX2010	1.45	10	75	±1.0	25	2.5	–1.0	1.0
MPX2050	7.3	50	200	±1.0	40	0.8	–0.25	0.25
MPX2100	14.5	100	400	±2.0	40	0.4	–1.0	1.0
MPX2200	29	200	400	±1.0	40	0.2	–1.0	1.0

Compensated and Calibrated (On–Chip) Medical Grade

Device Series	Max Pressure Rating		Supply Voltage (Vdc)	Offset mV (Max)	Sensitivity (µV/V/mmHg)	Output Impedance Ohms (Max)	Linearity % of FSS(1)	
	psi	kPa					(Min)	(Max)
MPX2300 DT1	5.8	40	6.0	0.75	5.0	330	–2.0	2.0

(1) Based on end point straight line fit method. Best fit straight line linearity error is approximately 1/2 of listed value.

Refer to Pressure Packaging options for preferred package selections, marked with an "".

Signal Conditioned (On–Chip)

Device Series	Max Pressure Rating		Over Pressure (kPa)	Full Scale Span V (Typ)	Sensitivity (mV/kPa)	Accuracy (0 – 85°C) % of V_{FSS}
	psi	kPa				
MPX4100	15.2	105	400	4.59	54	±1.8
MPXA4100*	15.2	105	400	4.59	54	±1.8
MPXS4100	15.2	105	400	4.59	54	±1.8
MPX4101	14.8	102	400	4.59	54	±1.8
MPX4105	15.2	105	400	4.59	54	±1.8
MPX4115	16.7	115	400	4.59	45.9	±1.5
MPXA4115*	16.7	115	400	4.59	45.9	±1.5
MPXS4115	16.7	115	400	4.59	45.9	±1.5
MPX4200	29	200	400	4.59	25.5	±1.5
MPX4250	36.3	250	400	4.6	20	±1.5
MPXT5006	0.87	6	1000	4.6	7.5	±3.0
MPX5010	1.45	10	75	4.5	450	±5.0
MPXL5010	1.45	10	75	4.5	450	±5.0
MPX5050	7.3	50	200	4.5	90	±2.5
MPX5100	14.5	100	400	4.5	45	±2.5
MPX5500	72.5	500	2000	4.5	9.0	±2.5
MPX5700	100	700	2800	4.5	6.4	±2.5
MPX5999	150	1000	4000	4.5	4.5	±2.5

Refer to Pressure Packaging options for preferred package selections, marked with an "".

Pressure Sensors by Pressure Range

Device Series	Maximum Pressure Rating		Device Type
	psi	kPa	
MPXT5006	.87	6	Signal Conditioned (On–chip)
MPX10D	1.45	10	Uncompensated
MPXL10G	1.45	10	Uncompensated — Low Profile Package
MPX12D	1.45	10	Uncompensated
MPX2010D	1.45	10	Compensated and Calibrated (On–chip)
MPX5010D	1.45	10	Integrated with Signal Conditioning (On–chip)
MPXL5010G	1.45	10	Integrated with Signal Conditioning (On–chip) — Low Profile Package
MPX2300D	5.80	40	Compensated and Calibrated — Medical Grade
MPX50D	7.30	50	Uncompensated
MPXV50*	1.3	50	Uncompensated
MPX2050D	7.30	50	Compensated and Calibrated (On–chip)
MPX5050D	7.30	50	Signal Conditioned (On–chip)
MPX100A,D	14.50	100	Uncompensated
MPX2100A,D	14.50	100	Compensated and Calibrated (On–chip)
MPXA4100A*	14.50	100	Compensated and Calibrated (On–chip) — Small Outline Package
MPXS4100A	15.20	105	Signal Conditioned (On–chip)
MPXA4100A	15.20	105	Signal Conditioned (On–chip) — Small Outline Package
MPX4101A	14.80	102	Signal Conditioned (On–chip)
MPX4105A	15.20	105	Signal Conditioned (On–chip)
MPX4115A	16.70	115	Signal Conditioned (On–chip)
MPXA4115A*	16.70	115	Signal Conditioned (On–chip) — Small Outline Package
MPXS4115A	16.70	115	Signal Conditioned (On–chip) — Surface Mount Package
MPX5100A,D	16.70	115	Signal Conditioned (On–chip)
MPX200D	29.00	200	Uncompensated
MPX2200A,D	29.00	200	Compensated and Calibrated (On–chip)
MPX4200A	29.00	200	Signal Conditioned, Temperature Compensated and Calibrated (On–chip)
MPX4250A,D	36.30	250	Signal Conditioned, Temperature Compensated and Calibrated (On–chip)
MPX5999	150	1000	Signal Conditioned (On–chip)

Refer to Pressure Packaging options for preferred package selections, marked with an “”.

MPX10/50/100/200/700 Series (Uncompensated)

Device Type	Measurement/Porting Options	Package Options	Pressure Range				
			0 to 1.45 PSI (0 to 10 kPa)	0 to 7.3 PSI (0 to 50 kPa)	0 to 14.5 PSI (0 to 100 kPa)	0 to 29 PSI (0 to 200 kPa)	0 to 100 PSI (0 to 700 kPa)
4–Pin Basic Elements	Absolute	Case 344–15	—	—	MPX100A	—	—
	Differential	Case 344–15	MPX10D, MPX12D	MPX50D	MPX100D	MPX200D	—
Ported Elements	Absolute Port	Case 344B–01	—	—	MPX100AP	—	—
	Absolute Stovepipe	Case 344E–01	—	—	MPX100AS	—	—
	Absolute Axial	Case 344F–01	—	—	MPX100ASX	—	—
	Differential Port	Case 344C–01	MPX10DP, MPX12DP	—	MPX100DP	MPX200DP	—
	Gauge	Case 344B–01	MPX10GP, MPX12GP	MPX50GP	MPX100GP	MPX200GP	—
	Gauge Stovepipe	Case 344E–01	MPX10GS	—	—	—	—
8–Pin Basic Elements	Differential	Case 472B–01	—	—	—	—	—
	Absolute (Small Outline)	Case 482–01	—	—	—	—	—
	Gauge	Case 472B–01	MPXL10	—	—	—	—
Ported Elements	Absolute (Small Outline)	Case 482A–01	—	—	—	—	—

MPX2000 Series (Temperature Compensated and Calibrated On–Chip)

Device Type	Measurement Options	Package Options	Pressure Range				
			0 to 1.45 PSI (0 to 10 kPa)	0 to 7.3 PSI (0 to 50 kPa)	0 to 14.5 PSI (0 to 100 kPa)	0 to 29 PSI (0 to 200 kPa)	0 to 100 PSI (0 to 700 kPa)
4–Pin Basic Elements	Absolute	Case 344–15	—	—	MPX2100A	MPX2200A	—
	Differential	Case 344–15	MPX2010D	MPX2050D	MPX2100D	MPX2200D	—
Ported Elements	Absolute Port	Case 344B–01	—	—	MPX2100AP	MPX2200AP	—
	Absolute Axial	Case 344F–01	—	—	MPX2100ASX	—	—
	Differential Port	Case 344C–01	MPX2010DP	MPX2050DP	MPX2100DP	MPX2200DP	—
	Gauge	Case 344B–01	MPX2010GP	MPX2050GP	MPX2100GP	MPX2200GP	—
	Gauge Vacuum	Case 344D–01	—	—	—	—	—
	Gauge Stovepipe	Case 344E–01	MPX2010GS	—	—	—	—
	Gauge Axial	Case 344F–01	MPX2010GSX	MPX2050GSX	MPX2100GSX	—	—
8–Pin Basic Elements	Gauge	Case 473A–01	—	—	—	—	—

MPX4000 Series (Signal Conditioned On–Chip)

Device Type	Measurement Options	Package Options	Pressure Range			
			3 to 15 PSI (20 to 105 kPa)	2.3 to 14.7 PSI (15 to 102 kPa)	2.3 to 16.6 PSI (15 to 115 kPa)	3 to 36.2 PSI (20 to 250 kPa)
6–Pin Basic Elements	Absolute	Case 867–08	MPX4100A, MPX4105A	MPX4101A	MPX4115A	MPX4200A, MPX4250A MPX4250D
Ported Elements	Absolute Port	Case 867B–04	MPX4100AP	—	MPX4115AP	MPX4250AP MPX4250DP MPX4250GP
	Absolute Stovepipe	Case 867E–03	MPX4100AS	—	MPX4115AS	—
	Absolute Axial	Case 867F–03	—	—	—	—
8–Pin Basic Elements	Absolute	Case 471–01	MPXS4100A	—	—	—
	Absolute	Case 473A–01	—	—	—	—
	Absolute	Case 473A–01	—	—	—	—
	Absolute (Small Outline)	Case 482–01	MPX4100A	—	MPXA4115A	—
	Absolute	Case 473A–01	—	—	—	—
Ported Elements	Absolute Axial	Case 471B–01	—	—	MPXS4115A	—
	Absolute (Small Outline)	Case 482A–01	MPXA4100A	—	MPXA4115A	—

MPX5000 Series (Signal Conditioned On–Chip)

Device Type	Measurement Options	Package Options	Pressure Range						
			0 to 1.45 PSI (0 to 10 kPa)	0 to 7.3 PSI (0 to 50 kPa)	0 to 14.5 PSI (0 to 100 kPa)	2.3 to 16.6 PSI (15 to 115 kPa)	0 to 75 PSI (0 to 500 kPa)	0 to 100 PSI (0 to 700 kPa)	0 to 150 PSI (0 to 1000 kPa)
6–Pin	Absolute	Case 867–08	—	—	—	MPX5100A	—	—	—
Basic Element	Differential	Case 867–08	MPX5010D	MPX5050D	MPX5100D	—	MPX5500D	MPX5700D	MPX5999D
Ported Element	Absolute Port	Case 867B–04	—	—	—	MPX5100AP	—	—	—
	Differential Port	Case 867C–05	MPX5010DP	MPX5050DP	MPX5100DP	—	MPX5500DP	MPX5700DP	—
	Gauge	Case 867B–04	MPX5010GP	MPX5050GP	MPX5100GP	—	MPX5500GP	MPX5700GP	—
	Gauge Stovepipe	Case 867E–03	MPX5010GS	—	—	—	—	—	—
	Gauge Axial	Case 867F–03	MPX5010GSX	—	—	—	—	—	—
8–Pin Basic Element	Differential	Case 473–01	MPXT5006D MPXT5006DF	—	—	—	—	—	—
	Absolute (Small Outline)	Case 482–01	MPXV5010	—	—	—	—	—	—
	Gauge	Case 472–01	MPXL5010G	—	—	—	—	—	—
Ported Element	Absolute (Small Outline)	Case 482A–01	MPXV5010	—	—	—	—	—	—

Pressure Side Identification

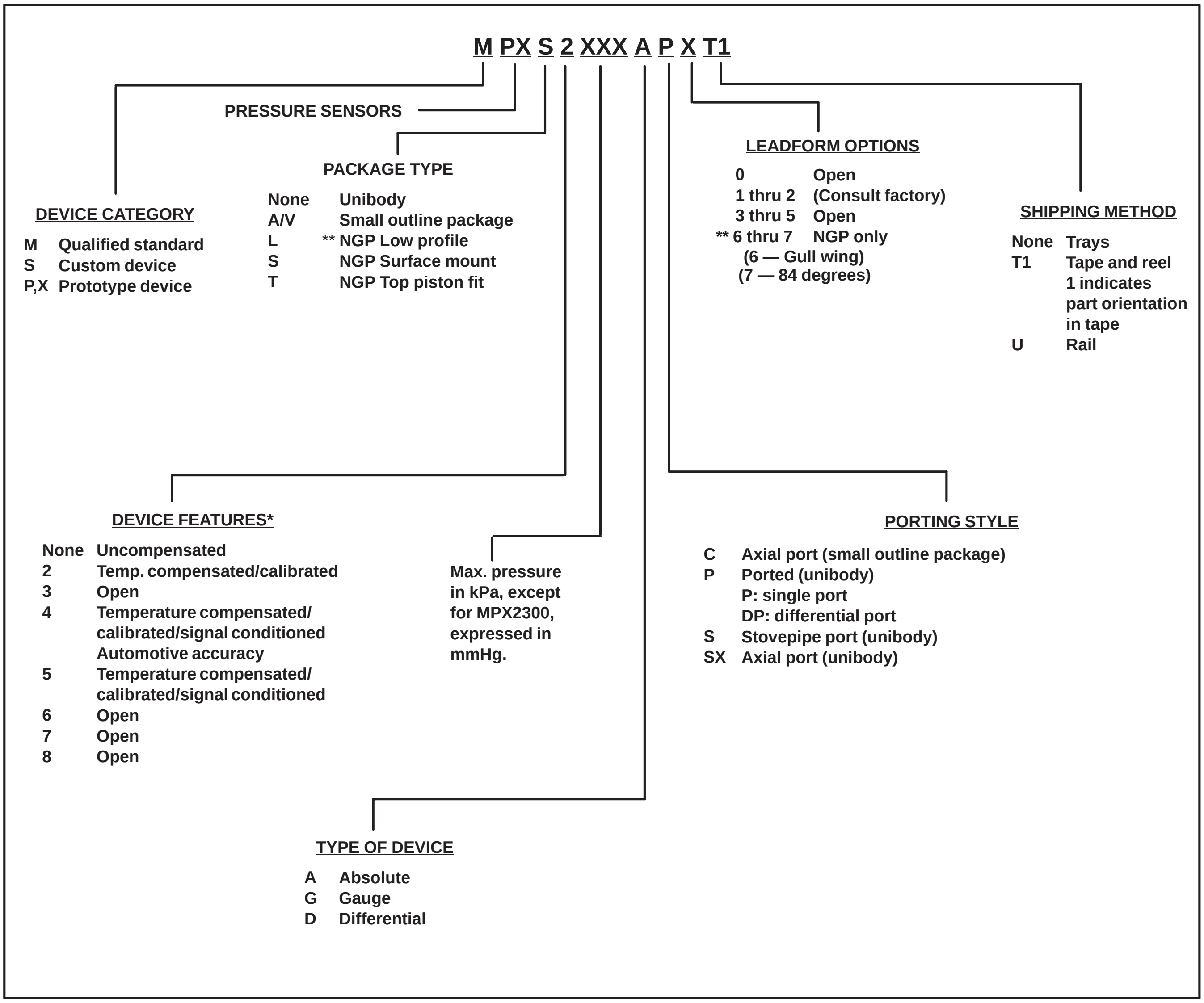
Motorola designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing the silicon gel which protects the die. The differential or gauge sensor is designed to operate with positive differential pressure applied, P1 > P2. The absolute sensor is designed for vacuum applied to P1 side.

The Pressure (P1) side may be identified by using the table below.

Pressure (P1) / Vacuum (P2) Side Identification

Part Number	Case Type 4 PIN	Positive Pressure Side Identifier
MPXxxxxA MPXxxxxD	344–15	Stainless Steel Cap
MPXxxxxDP	344C–01	Side with Part Marking
MPXxxxxAP MPXxxxxGP	344B–01	Side with Port Attached
MPXxxxxAS MPXxxxxGS	344E–01	Side with Port Attached
Part Number	**Case Type 6 PIN**	**Positive Pressure Side Identifier**
MPXxxxxA MPXxxxxD	867–08	Stainless Steel Cap
MPXxxxxDP	867C–05	Side with Part Marking
MPXxxxxAP MPXxxxxGP	867B–04	Side with Port Attached
MPXxxxxAS MPXxxxxGS	867E–03	Side with Port Attached

Device Numbering System for Pressure Sensors



M PX S 2 XXX A P X T1

PRESSURE SENSORS

DEVICE CATEGORY

M	**Qualified standard**
S	**Custom device**
P,X	**Prototype device**

PACKAGE TYPE

None	**Unibody**
A/V	**Small outline package**
L	** **NGP Low profile**
S	**NGP Surface mount**
T	**NGP Top piston fit**

LEADFORM OPTIONS

0	**Open**
1 thru 2	**(Consult factory)**
3 thru 5	**Open**
**** 6 thru 7**	**NGP only**

(6 — Gull wing)
(7 — 84 degrees)

SHIPPING METHOD

None	**Trays**
T1	**Tape and reel 1 indicates part orientation in tape**
U	**Rail**

DEVICE FEATURES*

None	**Uncompensated**
2	**Temp. compensated/calibrated**
3	**Open**
4	**Temperature compensated/ calibrated/signal conditioned Automotive accuracy**
5	**Temperature compensated/ calibrated/signal conditioned**
6	**Open**
7	**Open**
8	**Open**

Max. pressure in kPa, except for MPX2300, expressed in mmHg.

PORTING STYLE

C	**Axial port (small outline package)**
P	**Ported (unibody) P: single port DP: differential port**
S	**Stovepipe port (unibody)**
SX	**Axial port (unibody)**

TYPE OF DEVICE

A	**Absolute**
G	**Gauge**
D	**Differential**

Note: Actual device marking may be abbreviated due to space constraints but packaging label will reflect full part number.

*Only applies to qualified and prototype devices. This does not apply to custom devices.

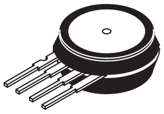
Examples:		
	MPX100AP	100 kPa uncompensated, absolute device in unibody package with one port (topside), no leadform, shipped in trays.
	MPXS4100A6U	100 kPa automotive temp. compensated and calibrated device with signal conditioning, NGP surface mount with gull wing leadform, shipped in rails

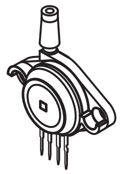
**NGP – Next Generation Package

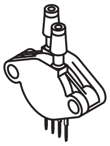
What Are the Pressure Packaging Options?

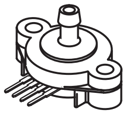
4–PIN

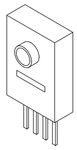
(Sizes not to scale)

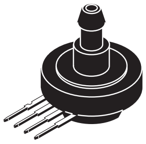

BASIC ELEMENT*
CASE 344–15
SUFFIX A / D

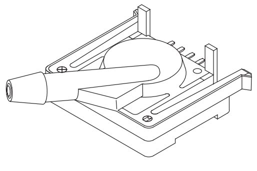

GAUGE PORT*
CASE 344B–01
SUFFIX AP / GP


DUAL PORT*
CASE 344C–01
SUFFIX DP

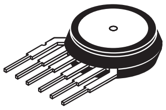

AXIAL PORT
CASE 344F–01
SUFFIX ASX / GSX

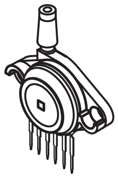

MEDICAL CHIP PAK*
CASE 423A–03

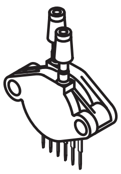

STOVEPIPE PORT
CASE 344E–01
SUFFIX AS/GS

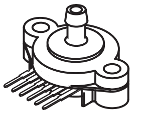

SNAP–FIT
CASE 473B–01
SUFFIX DF

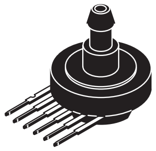
6–PIN


BASIC ELEMENT*
CASE 867–08
SUFFIX A / D

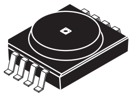

GAUGE PORT*
CASE 867B–04
SUFFIX AP / GP

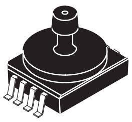

DUAL PORT*
CASE 867C–05
SUFFIX DP

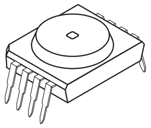

AXIAL PORT
CASE 867F–03
SUFFIX ASX / GSX

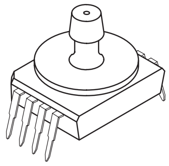

STOVEPIPE PORT
CASE 867E–03
SUFFIX AS / GS

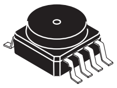
8–PIN

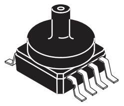

SURFACE MOUNT*
CASE 471–01

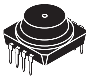

SURFACE MOUNT*
AXIAL PORT
CASE 471B–01

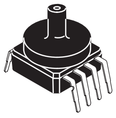

LOW PROFILE*
CASE 472–01


LOW PROFILE*
CASE 472B–01


SMALL OUTLINE (SURFACE MOUNT)*
CASE 482–01

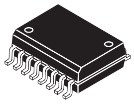

SMALL OUTLINE
(SURFACE MOUNT/PORTED)
CASE 482A–01


SMALL OUTLINE (DIP)
CASE 473A–01


SMALL OUTLINE (PORTED/DIP)
CASE 482C–03

*Indicates preferred packing options

ACCELEROMETER PACKAGING


16 LEAD SOIC
CASE 475–01

MPX10
MPXL10
SERIES

0 to 10 kPa (0 – 1.45 psi)
35 mV FULL SCALE SPAN
(TYPICAL)

10 kPa Uncompensated Silicon Pressure Sensors

The MPX10 and MPXL10 series devices are silicon piezoresistive pressure sensors providing a very accurate and linear voltage output — directly proportional to the applied pressure. These standard, low cost, uncompensated sensors permit manufacturers to design and add their own external temperature compensation and signal conditioning networks. Compensation techniques are simplified because of the predictability of Motorola's single element strain gauge design.

Features

- Low Cost
- Patented Silicon Shear Stress Strain Gauge Design
- Ratiometric to Supply Voltage
- Easy to Use Chip Carrier Package Options
- Differential and Gauge Options

Application Examples

- Air Movement Control
- Environmental Control Systems
- Level Indicators
- Leak Detection
- Medical Instrumentation
- Industrial Controls
- Pneumatic Control Systems
- Robotics

Figure 1 shows a schematic of the internal circuitry on the stand–alone pressure sensor chip.

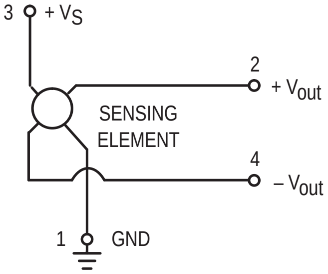
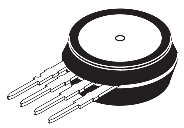


Figure 1. Uncompensated Pressure Sensor Schematic

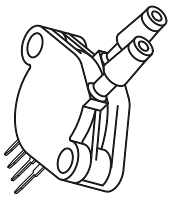
VOLTAGE OUTPUT versus APPLIED DIFFERENTIAL PRESSURE

The output voltage of the differential or gauge sensor increases with increasing pressure applied to the pressure side (P1) relative to the vacuum side (P2). Similarly, output voltage increases as increasing vacuum is applied to the vacuum side (P2) relative to the pressure side (P1).

UNIBODY PACKAGES
MPX10



BASIC CHIP
CARRIER ELEMENT
CASE 344–15, STYLE 1

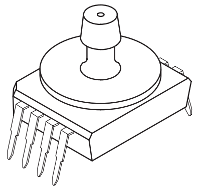


DIFFERENTIAL
PORT OPTION
CASE 344C–01, STYLE 1

NOTE: Pin 1 is the notched pin.

PIN NUMBER			
1	Gnd	3	V_S
2	$+V_{out}$	4	$-V_{out}$

LOW PROFILE PACKAGE
MPXL10



CASE 472B–01, STYLE 2

PIN NUMBER			
1	Gnd	5	N/C
2	$+V_{out}$	6	N/C
3	V_S	7	N/C
4	$-V_{out}$	8	N/C

NOTE: Pins 5, 6, 7, and 8 are not device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the Lead.

REV 7

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Overpressure(8) (P1 > P2)	P_{max}	75	kPa
Burst Pressure(8) (P1 > P2)	P_{burst}	100	kPa
Storage Temperature	T_{stg}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C

OPERATING CHARACTERISTICS (V_S = 3.0 Vdc, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic	Symbol	Min	Typ	Max	Unit
Differential Pressure Range(1)	P_{OP}	0	—	10	kPa
Supply Voltage(2)	V_S	—	3.0	6.0	Vdc
Supply Current	I_o	—	6.0	—	mAdc
Full Scale Span(3)	V_{FSS}	20	35	50	mV
Offset(4)	V_{off}	0	20	35	mV
Sensitivity	$\Delta V/\Delta P$	—	3.5	—	mV/kPa
Linearity(5)	—	–1.0	—	1.0	%V_{FSS}
Pressure Hysteresis(5) (0 to 10 kPa)	—	—	± 0.1	—	%V_{FSS}
Temperature Hysteresis(5) (–40°C to +125°C)	—	—	± 0.5	—	%V_{FSS}
Temperature Coefficient of Full Scale Span(5)	TCV_{FSS}	–0.22	—	–0.16	%V_{FSS}/°C
Temperature Coefficient of Offset(5)	TCV_{off}	—	±15	—	µV/°C
Temperature Coefficient of Resistance(5)	TCR	0.21	—	0.34	%Z_{in}/°C
Input Impedance	Z_{in}	400	—	550	Ω
Output Impedance	Z_{out}	750	—	1250	Ω
Response Time(6) (10% to 90%)	t_R	—	1.0	—	ms
Warm–Up	—	—	20	—	ms
Offset Stability(9)	—	—	±0.5	—	%V_{FSS}

MECHANICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Common Mode Line Pressure(7)	—	—	—	690	kPa

NOTES:

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range. Operating the device above the specified excitation range may induce additional error due to device self–heating.
3. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
4. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
5. Accuracy (error budget) consists of the following:

• Linearity:	Output deviation from a straight line relationship with pressure, using end point method, over the specified pressure range.
• Temperature Hysteresis:	Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
• Pressure Hysteresis:	Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
• TcSpan:	Output deviation at full rated pressure over the temperature range of 0 to 85°C, relative to 25°C.
• TcOffset:	Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
• TCR:	Z_{in} deviation with minimum rated pressure applied, over the temperature range of –40°C to +125°C, relative to 25°C.

6. Response Time is defined as the time 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.
7. Common mode pressures beyond specified may result in leakage at the case–to–lead interface.
8. Exposure beyond these limits may cause permanent damage or degradation to the device.
9. Offset stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

TEMPERATURE COMPENSATION

Figure 2 shows the typical output characteristics of the MPX10 and MPXL10 series over temperature.

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 by designing your system using the MPX2010D series sensor.

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.

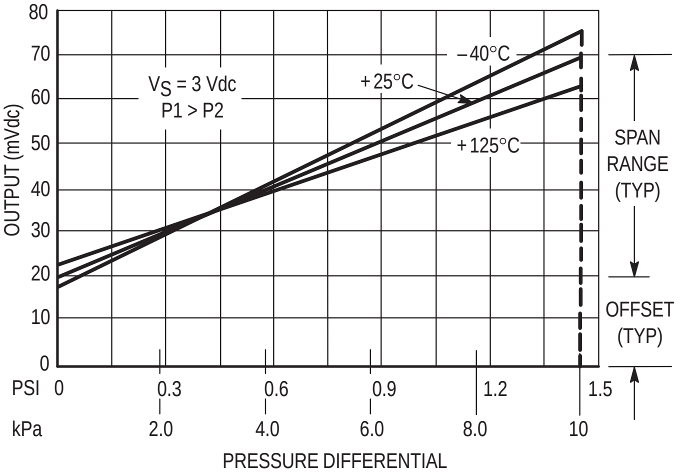


Figure 2. Output versus Pressure Differential

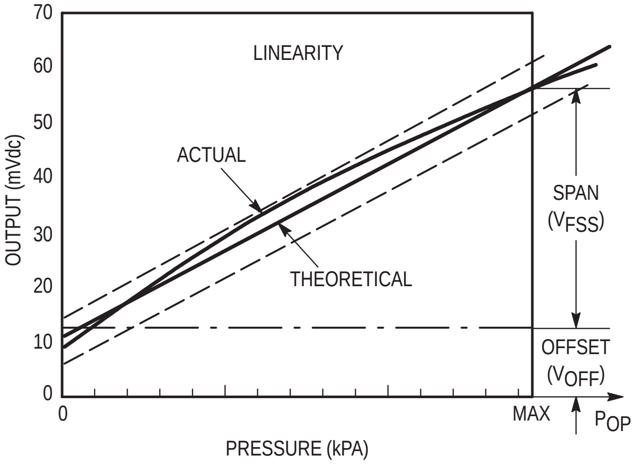


Figure 3. Linearity Specification Comparison

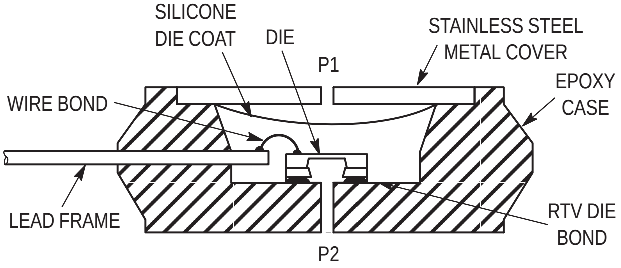


Figure 4. Unibody Package — Cross–Sectional Diagram (not to scale)

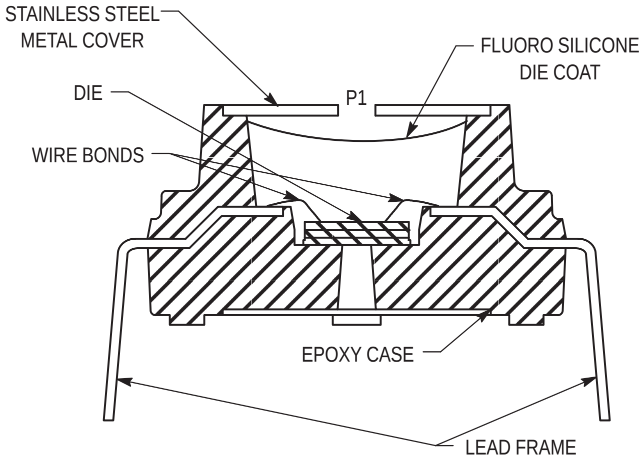


Figure 5. Low Profile Package — Cross–Sectional Diagram (not to scale)

Figure 4 illustrates the differential or gauge configuration in the basic chip carrier (Case 344–15). Figure 5 illustrates the differential or gauge configuration in the basic Low Profile Package (Case 472B–01). A silicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm.

The MPX10 and MPXL10 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 reliability. Contact the factory for information regarding media compatibility in your application.

PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Motorola designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing silicone gel which isolates the die from the environment. The Motorola MPX pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using the table below:

Part Number	Case Type	Pressure (P1) Side Identifier
MPX10D	344–15	Stainless Steel Cap
MPX10DP	344C–01	Side with Part Marking
MPX10GP	344B–01	Side with Port Attached
MPXL10GC7U	472B–01	Side with Part Marking

ORDERING INFORMATION — UNIBODY PACKAGE

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 344–15	MPX10D	MPX10D
Ported Elements	Differential	Case 344C–01	MPX10DP	MPX10DP
	Gauge	Case 344B–01	MPX10GP	MPX10GP

ORDERING INFORMATION — LOW PROFILE PACKAGE

MPXL10 series pressure sensors are available in a gauge configuration.

			MPXL Series	
Device Type	Options	Case Type	Order Number	Device Marking
MPXL10GC7U	N/A	Case 472B–01	MPXL10GC7U	MPXL10G

MPX12 SERIES

10 kPa Uncompensated Silicon Pressure Sensors

The MPX12 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.

Features

- Low Cost
- Patented Silicon Shear Stress Strain Gauge Design
- Ratiometric to Supply Voltage
- Easy to Use Chip Carrier Package Options
- Differential and Gauge Options

Application Examples

- Air Movement Control
- Environmental Control Systems
- Level Indicators
- Leak Detection
- Medical Instrumentation
- Industrial Controls
- Pneumatic Control Systems
- Robotics

Figure 1 shows a schematic of the internal circuitry on the stand–alone pressure sensor chip.

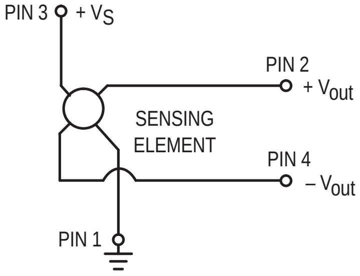
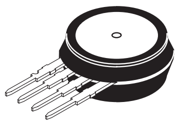


Figure 1. Uncompensated Pressure Sensor Schematic

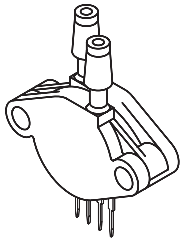
VOLTAGE OUTPUT versus APPLIED DIFFERENTIAL PRESSURE

The output voltage of the differential or gauge sensor increases with increasing pressure applied to the pressure side (P1) relative to the vacuum side (P2). Similarly, output voltage increases as increasing vacuum is applied to the vacuum side (P2) relative to the pressure side (P1).

0 to 10 kPa (0 – 1.45 psi)
35 mV FULL SCALE SPAN
(TYPICAL)



BASIC CHIP
CARRIER ELEMENT
CASE 344–15, STYLE 1



DIFFERENTIAL
PORT OPTION
CASE 344C–01, STYLE 1

NOTE: Pin 1 is the notched pin.

PIN NUMBER			
1	Gnd	3	V_S
2	$+V_{out}$	4	$-V_{out}$

REV 1

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Overpressure(8) (P1 > P2)	P_{max}	75	kPa
Burst Pressure(8) (P1 > P2)	P_{burst}	100	kPa
Storage Temperature	T_{stg}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C

OPERATING CHARACTERISTICS (V_S = 3.0 Vdc, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic	Symbol	Min	Typ	Max	Unit
Differential Pressure Range(1)	P_{OP}	0	—	10	kPa
Supply Voltage(2)	V_S	—	3.0	6.0	Vdc
Supply Current	I_o	—	6.0	—	mAdc
Full Scale Span(3)	V_{FSS}	45	55	70	mV
Offset(4)	V_{off}	0	20	35	mV
Sensitivity	$\Delta V/\Delta P$	—	5.5	—	mV/kPa
Linearity(5)	—	–0.5	—	5.0	$\%V_{FSS}$
Pressure Hysteresis(5) (0 to 10 kPa)	—	—	± 0.1	—	$\%V_{FSS}$
Temperature Hysteresis(5) (–40°C to +125°C)	—	—	± 0.5	—	$\%V_{FSS}$
Temperature Coefficient of Full Scale Span(5)	TCV_{FSS}	–0.22	—	–0.16	$\%V_{FSS}$/°C
Temperature Coefficient of Offset(5)	TCV_{off}	—	±15	—	μV/°C
Temperature Coefficient of Resistance(5)	TCR	0.21	—	0.27	$\%Z_{in}$/°C
Input Impedance	Z_{in}	400	—	550	Ω
Output Impedance	Z_{out}	750	—	1250	Ω
Response Time(6) (10% to 90%)	t_R	—	1.0	—	ms
Warm–Up	—	—	20	—	ms
Offset Stability(9)	—	—	±0.5	—	$\%V_{FSS}$

MECHANICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Weight (Basic Element, Case 344–15)	—	—	2.0	—	Grams
Common Mode Line Pressure(7)	—	—	—	690	kPa

NOTES:

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range. Operating the device above the specified excitation range may induce additional error due to device self–heating.
3. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
4. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
5. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure, using end point method, over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation at full rated pressure over the temperature range of 0 to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
   - TCR: Z_{in} deviation with minimum rated pressure applied, over the temperature range of –40°C to +125°C, relative to 25°C.
6. Response Time is defined as the time 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.
7. Common mode pressures beyond specified may result in leakage at the case–to–lead interface.
8. Exposure beyond these limits may cause permanent damage or degradation to the device.
9. Offset stability is the product’s output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

TEMPERATURE COMPENSATION

Figure 2 shows the typical output characteristics of the MPX12 series over temperature.

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 by designing your system using the MPX2010D series sensor.

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.

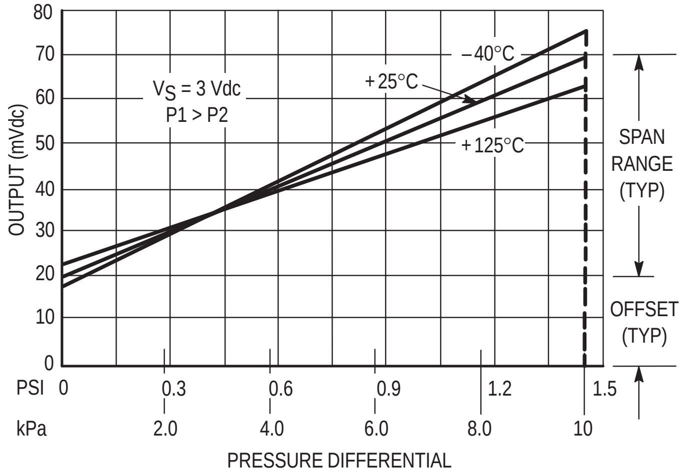


Figure 2. Output versus Pressure Differential

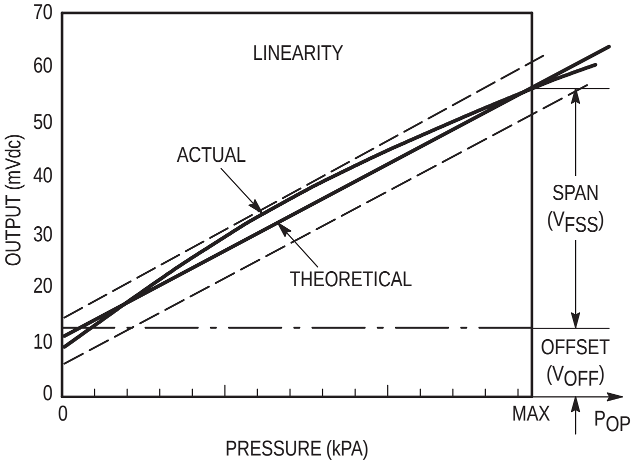


Figure 3. Linearity Specification Comparison

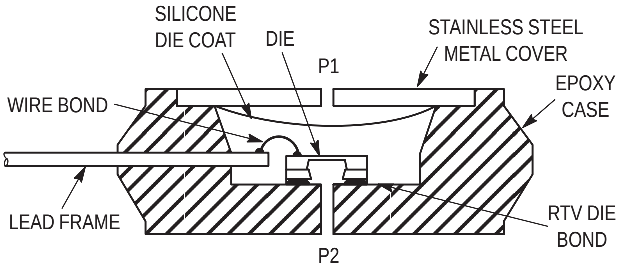


Figure 4. Cross–Sectional Diagram (not to scale)

Figure 4 illustrates the differential or gauge configuration in the basic chip carrier (Case 344–15). A silicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm.

The MPX12 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 reliability. Contact the factory for information regarding media compatibility in your application.

PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Motorola designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing silicone gel which isolates the die from the environment. The Motorola MPX pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using the table below:

Part Number	Case Type	Pressure (P1) Side Identifier
MPX12D	344–15	Stainless Steel Cap
MPX12DP	344C–01	Side with Part Marking
MPX12GP	344B–01	Side with Port Attached

ORDERING INFORMATION

MPX12 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 344–15	MPX12D	MPX12D
Ported Elements	Differential	Case 344C–01	MPX12DP	MPX12DP
	Gauge	Case 344B–01	MPX12GP	MPX12GP

MPX50
PPXV50G
SERIES

50 kPa Uncompensated Silicon Pressure Sensors

0 to 50 kPa (0 – 7.25 psi)
60 mV FULL SCALE SPAN
(TYPICAL)

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.

Features

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

Application Examples

- Air Movement Control
- Environmental Control Systems
- Level Indicators
- Leak Detection
- Medical Instrumentation
- Industrial Controls
- Pneumatic Control Systems
- Robotics

Figure 1 shows a schematic of the internal circuitry on the stand–alone pressure sensor chip.

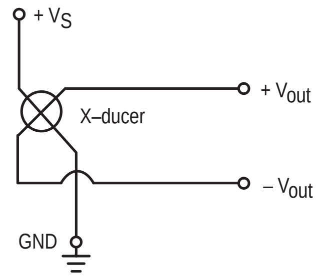
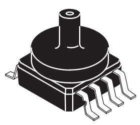
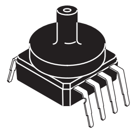


Figure 1. Uncompensated Pressure Sensor Schematic

SMALL OUTLINE PACKAGE

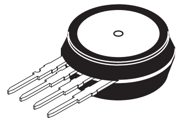


PPXV50GC6U
CASE 482A–01

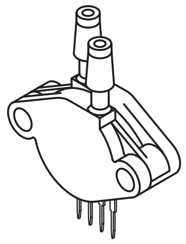


PPXV50GC7U
CASE 482C–03

PIN NUMBER			
1	Gnd	5	N/C
2	+V_{out}	6	N/C
3	V_S	7	N/C
4	–V_{out}	8	N/C



BASIC CHIP CARRIER ELEMENT
CASE 344–15, STYLE 1



DIFFERENTIAL PORT OPTION
CASE 344C–01, STYLE 1

NOTE: Pin 1 is the notched pin.

PIN NUMBER			
1	Gnd	3	V_S
2	+V_{out}	4	–V_{out}

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 or gauge sensor increases with increasing pressure applied to the pressure side (P1) relative to the vacuum side (P2). Similarly, output voltage increases as increasing vacuum is applied to the vacuum side (P2) relative to the pressure side (P1).

REV 7

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Overpressure(8) (P1 > P2)	P_{max}	200	kPa
Burst Pressure(8) (P1 > P2)	P_{burst}	500	kPa
Storage Temperature	T_{stg}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C

OPERATING CHARACTERISTICS (V_S = 3.0 Vdc, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic	Symbol	Min	Typ	Max	Unit
Pressure Range(1)	P_{OP}	0	—	50	kPa
Supply Voltage(2)	V_S	—	3.0	6.0	Vdc
Supply Current	I_o	—	6.0	—	mAdc
Full Scale Span(3)	V_{FSS}	45	60	90	mV
Offset(4)	V_{off}	0	20	35	mV
Sensitivity	$\Delta V/\Delta P$	—	1.2	—	mV/kPa
Linearity(5)	—	–0.25	—	0.25	$\%V_{FSS}$
Pressure Hysteresis(5) (0 to 50 kPa)	—	—	± 0.1	—	$\%V_{FSS}$
Temperature Hysteresis(5) (– 40°C to +125°C)	—	—	± 0.5	—	$\%V_{FSS}$
Temperature Coefficient of Full Scale Span(5)	TCV_{FSS}	–0.22	—	–0.16	$\%V_{FSS}/°C$
Temperature Coefficient of Offset(5)	TCV_{off}	—	± 15	—	µV/°C
Temperature Coefficient of Resistance(5)	TCR	0.28	—	0.34	$\%Z_{in}/°C$
Input Impedance	Z_{in}	400	—	550	Ω
Output Impedance	Z_{out}	750	—	1800	Ω
Response Time(6) (10% to 90%)	t_R	—	1.0	—	ms
Warm–Up	—	—	20	—	ms
Offset Stability(9)	—	—	± 0.5	—	$\%V_{FSS}$

MECHANICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Weight (Basic Element Case 344–15)	—	—	2.0	—	Grams
Common Mode Line Pressure(7)	—	—	—	690	kPa

NOTES:

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range. Operating the device above the specified excitation range may induce additional error due to device self–heating.
3. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
4. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
5. Accuracy (error budget) consists of the following:

• Linearity:	Output deviation from a straight line relationship with pressure, using end point method, over the specified pressure range.
• Temperature Hysteresis:	Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
• Pressure Hysteresis:	Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
• TcSpan:	Output deviation at full rated pressure over the temperature range of 0 to 85°C, relative to 25°C.
• TcOffset:	Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
• TCR:	Z_{in} deviation with minimum rated pressure applied, over the temperature range of –40°C to +125°C, relative to 25°C.

6. Response Time is defined as the time 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.
7. Common mode pressures beyond specified may result in leakage at the case–to–lead interface.
8. Exposure beyond these limits may cause permanent damage or degradation to the device.
9. Offset stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

TEMPERATURE COMPENSATION

Figure 2 shows the typical output characteristics of the MPX50 series over temperature.

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 by designing your system using the MPX2050 series sensors.

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.

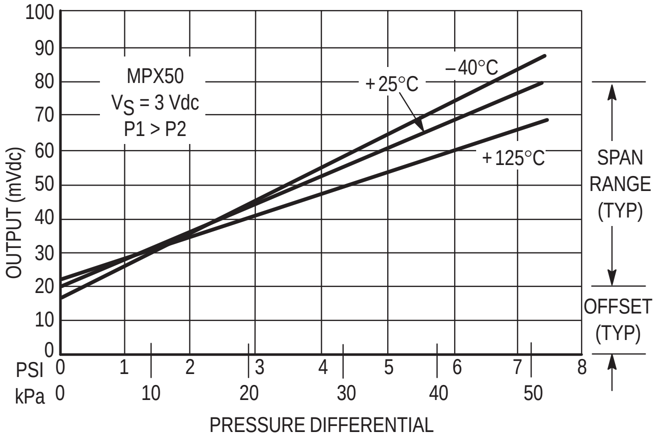


Figure 2. Output versus Pressure Differential

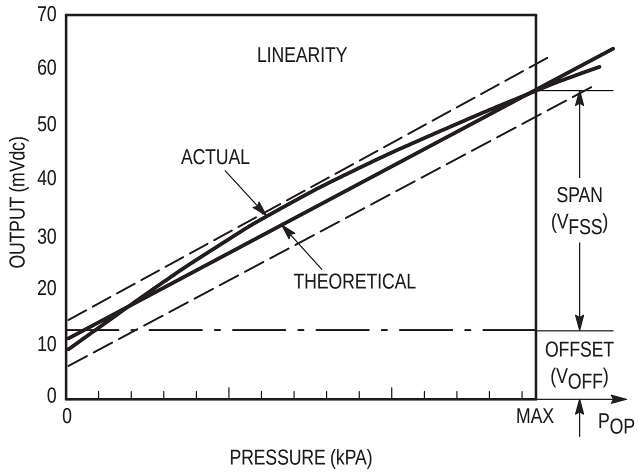


Figure 3. Linearity Specification Comparison

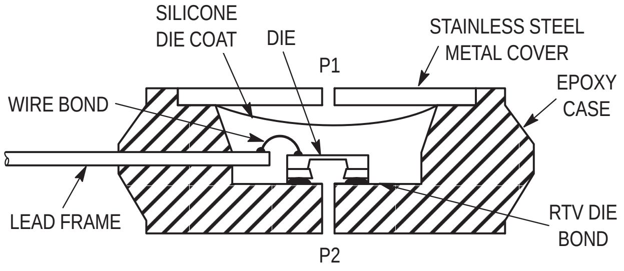


Figure 4. Cross–Sectional Diagram (not to scale)

Figure 4 illustrates the differential or gauge configuration in the basic chip carrier (Case 344–15). A silicone gel isolates the die surface and wire bonds from the environment, 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 reliability. Contact the factory for information regarding media compatibility in your application.

PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Motorola designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing silicone gel which isolates the die from the environment. The Motorola MPX pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using the table below:

Part Number	Case Type	Pressure (P1) Side Identifier
MPX50D	344–15	Stainless Steel Cap
MPX50DP	344C–01	Side with Part Marking
MPX50GP	344B–01	Side with Port Attached
MPX50GVP	344D–01	Stainless Steel Cap
MPX50GS	344E–01	Side with Port Attached
MPX50GVS	344A–01	Stainless Steel Cap
MPX50GSX	344F–01	Side with Port Attached
MPX50GVSX	344G–01	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 344–15	MPX50D	MPX50D
Ported Elements	Differential	Case 344C–01	MPX50DP	MPX50DP
	Gauge	Case 344B–01	MPX50GP	MPX50GP
	Gauge Vacuum	Case 344D–01	MPX50GVP	MPX50GVP
	Gauge Stovepipe	Case 344E–01	MPX50GS	MPX50D
	Gauge Vacuum Stovepipe	Case 344A–01	MPX50GVS	MPX50D
	Gauge Axial	Case 344F–01	MPX50GSX	MPX50D
	Gauge Vacuum Axial	Case 344G–01	MPX50GVSX	MPX50D

ORDERING INFORMATION — SMALL OUTLINE PACKAGE

Small outline package is currently available as a prototype status device. Please contact factory for more information or mechanical samples.

Device	Case No.	Packing Options	Marking
PPXV50GC6U	482A–01	Rails	PPXV50G
PPXV50GC7U	482C–03	Rails	PPXV50G

MOTOROLA
SEMICONDUCTOR TECHNICAL DATA

100 kPa Uncompensated 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.

Features

- Low Cost
- Patented, Silicon Shear Stress Strain Gauge Design
- Easy to Use Chip Carrier Package Options
- Ratiometric to Supply Voltage
- 60 mV Span (Typ)
- Absolute, Differential and Gauge Options
- ±0.25% Linearity (Max)

Application Examples

- Pump/Motor Controllers
- Robotics
- Level Indicators
- Medical Diagnostics
- Pressure Switching
- Barometers
- Altimeters

Figure 1 illustrates a schematic of the internal circuitry on the stand–alone pressure sensor chip.

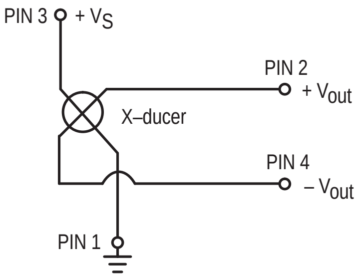


Figure 1. Uncompensated Pressure Sensor Schematic

VOLTAGE OUTPUT versus APPLIED DIFFERENTIAL PRESSURE

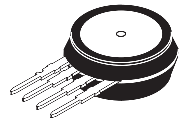
The differential voltage output of the X–ducer is directly proportional to the differential pressure applied.

The absolute sensor has a built–in reference vacuum. The output voltage will decrease as vacuum, relative to ambient, is drawn on the pressure (P1) side.

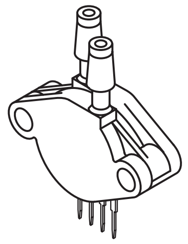
The output voltage of the differential or gauge sensor increases with increasing pressure applied to the pressure (P1) side relative to the vacuum (P2) side. Similarly, output voltage increases as increasing vacuum is applied to the vacuum (P2) side relative to the pressure (P1) side.

MPX100 SERIES

0 to 100 kPa (0 – 14.5 psi)
60 mV FULL SCALE SPAN
(TYPICAL)



BASIC CHIP
CARRIER ELEMENT
CASE 344–15, STYLE 1



DIFFERENTIAL
PORT OPTION
CASE 344C–01, STYLE 1

NOTE: Pin 1 is the notched pin.

PIN NUMBER			
1	Gnd	3	V_S
2	$+V_{out}$	4	$-V_{out}$

REV 6

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Overpressure(8) (P1 > P2)	P_{max}	200	kPa
Burst Pressure(8) (P1 > P2)	P_{burst}	1000	kPa
Storage Temperature	T_{stg}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C

OPERATING CHARACTERISTICS (V_S = 3.0 Vdc, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic	Symbol	Min	Typ	Max	Unit
Pressure Range(1)	P_{OP}	0	—	100	kPa
Supply Voltage(2)	V_S	—	3.0	6.0	Vdc
Supply Current	I_o	—	6.0	—	mAdc
Full Scale Span(3)	V_{FSS}	45	60	90	mV
Offset(4)	V_{off}	0	20	35	mV
Sensitivity	$\Delta V/\Delta P$	—	0.6	—	mV/kPa
Linearity(5)	—	–0.25	—	0.25	$\%V_{FSS}$
Pressure Hysteresis(5) (0 to 100 kPa)	—	—	±0.1	—	$\%V_{FSS}$
Temperature Hysteresis(5) (–40°C to +125°C)	—	—	±0.5	—	$\%V_{FSS}$
Temperature Coefficient of Full Scale Span(6)	TCV_{FSS}	–0.22	—	–0.16	$\%V_{FSS}/°C$
Temperature Coefficient of Offset(5)	TCV_{off}	—	±15	—	µV/°C
Temperature Coefficient of Resistance(5)	TC_R	0.21	—	0.27	$\%Z_{in}/°C$
Input Impedance	Z_{in}	400	—	550	Ω
Output Impedance	Z_{out}	750	—	1875	Ω
Response Time(6) (10% to 90%)	t_R	—	1.0	—	ms
Warm–Up	—	—	20	—	ms
Offset Stability(9)	—	—	±0.5	—	$\%V_{FSS}$

MECHANICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Weight (Basic Element Case 344–15)	—	—	2.0	—	Grams
Common Mode Line Pressure(7)	—	—	—	690	kPa

NOTES:

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range. Operating the device above the specified excitation range may induce additional error due to device self–heating.
3. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
4. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
5. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure, using end point method, over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation at full rated pressure over the temperature range of 0 to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
   - TCR: Z_{in} deviation with minimum rated pressure applied, over the temperature range of –40°C to +125°C, relative to 25°C.
6. Response Time is defined as the time 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.
7. Common mode pressures beyond specified may result in leakage at the case–to–lead interface.
8. Exposure beyond these limits may cause permanent damage or degradation to the device.
9. Offset stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

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 typical output characteristics of the MPX100 series over temperature.

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 by designing your system using the MPX2100 series sensors.

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.

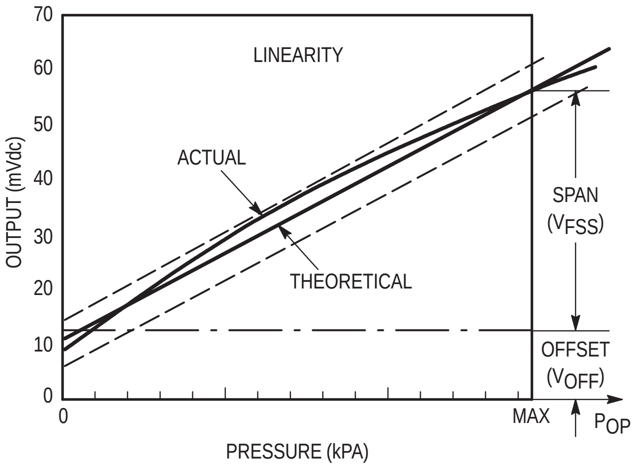


Figure 2. Linearity Specification Comparison

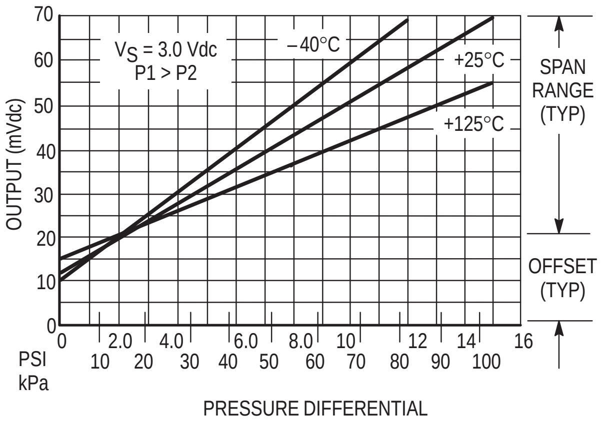


Figure 3. Output versus Pressure Differential

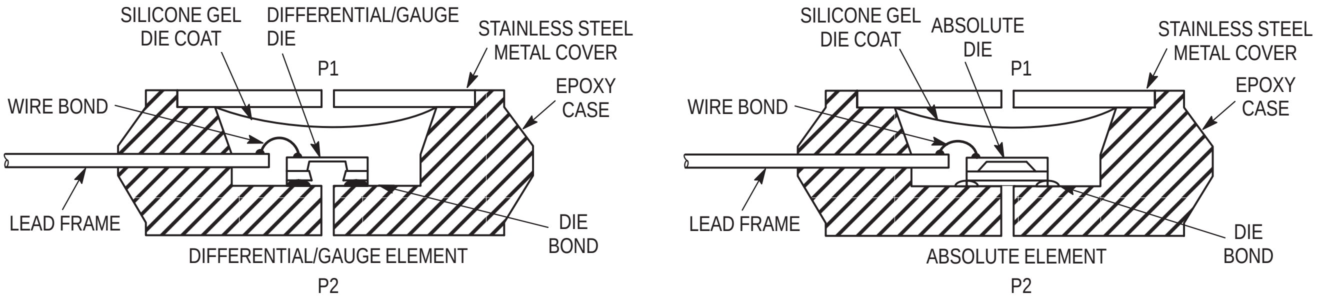


Figure 4. Cross–Sectional Diagrams (Not to Scale)

Figure 4 illustrates the absolute sensing configuration (right) and the differential or gauge configuration in the basic chip carrier (Case 344–15). A silicone gel helps protect the die surface and wire bond from the environment, 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 reliability. Contact the factory for information regarding media compatibility in your application.

PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Motorola designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing silicone gel which isolates the die from the environment. The differential or gauge sensor is designed to operate with positive differential pressure applied, P1 > P2. The absolute sensor is designed for vacuum applied to P1 side.

The Pressure (P1) side may be identified by using the table below:

Part Number	Case Type	Pressure (P1) Side Identifier
MPX100A, MPX100D	344–15	Stainless Steel Cap
MPX100DP	344C–01	Side with Part Marking
MPX100AP, MPX100GP	344B–01	Side with Port Attached
MPX100AS	344E–01	Side with Port Attached
MPX100ASX	344F–01	Side with Port Attached

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 344–15	MPX100A MPX100D	MPX100A MPX100D
Ported Elements	Differential	Case 344C–01	MPX100DP	MPX100DP
	Absolute, Gauge	Case 344B–01	MPX100AP MPX100GP	MPX100AP MPX100GP
	Absolute, Gauge Stove Pipe	Case 344E–01	MPX100AS MPX100GS	MPX100A MPX100D
	Absolute, Gauge Axial	Case 344F–01	MPX100ASX MPX100GSX	MPX100A MPX100D

MPX200 SERIES

200 kPa Uncompensated 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.

Features

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

Application Examples

- Pump/Motor Controllers
- Robotics
- Level Indicators
- Medical Diagnostics
- Pressure Switching
- Barometers
- Altimeters

Figure 1 illustrates a schematic of the internal circuitry on the stand–alone pressure sensor chip.

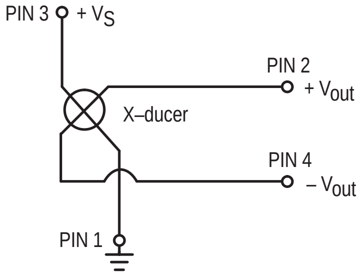


Figure 1. Uncompensated Pressure Sensor Schematic

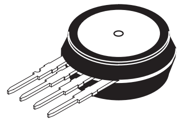
VOLTAGE OUTPUT versus APPLIED DIFFERENTIAL PRESSURE

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

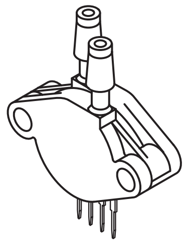
The absolute sensor has a built–in reference vacuum. The output voltage will decrease as vacuum, relative to ambient, is drawn on the pressure (P1) side.

The output voltage of the differential or gauge sensor increases with increasing pressure applied to the pressure (P1) side relative to the vacuum (P2) side. Similarly, output voltage increases as increasing vacuum is applied to the vacuum (P2) side relative to the pressure (P1) side.

**0 to 200 kPa (0 – 29 psi)
60 mV FULL SCALE SPAN
(TYPICAL)**



**BASIC CHIP
CARRIER ELEMENT
CASE 344–15, STYLE 1**



**DIFFERENTIAL
PORT OPTION
CASE 344C–01, STYLE 1**

NOTE: Pin 1 is the notched pin.

PIN NUMBER			
1	Gnd	3	V_S
2	$+V_{out}$	4	$-V_{out}$

REV 8

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Overpressure(8) (P1 > P2)	P_{max}	400	kPa
Burst Pressure(8) (P1 > P2)	P_{burst}	2000	kPa
Storage Temperature	T_{stg}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C

OPERATING CHARACTERISTICS (V_S = 3.0 Vdc, T_A = 25°C unless otherwise noted, P1 > P2)

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

MECHANICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Weight (Basic Element Case 344–15)	—	—	2.0	—	Grams
Common Mode Line Pressure(7)	—	—	—	690	kPa

NOTES:

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range. Operating the device above the specified excitation range may induce additional error due to device self–heating.
3. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
4. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
5. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure, using end point method, over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation at full rated pressure over the temperature range of 0 to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
   - TCR: Z_{in} deviation with minimum rated pressure applied, over the temperature range of –40°C to +125°C, relative to 25°C.
6. Response Time is defined as the time 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.
7. Common mode pressures beyond specified may result in leakage at the case–to–lead interface.
8. Exposure beyond these limits may cause permanent damage or degradation to the device.
9. Offset stability is the product’s output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

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 typical output characteristics of the MPX200 series over temperature. 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 by designing your system using the MPX2200 series sensors.

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.

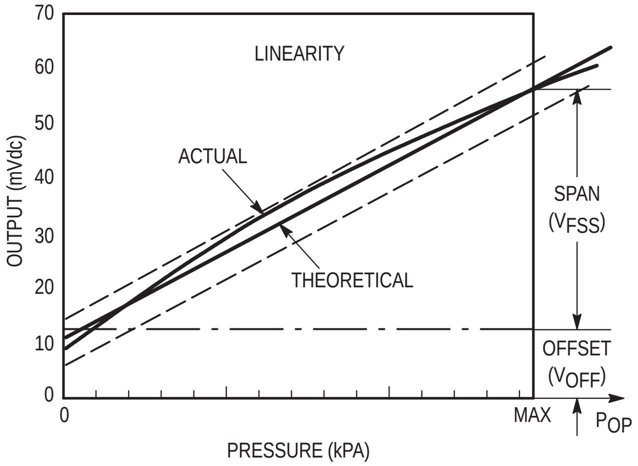


Figure 2. Linearity Specification Comparison

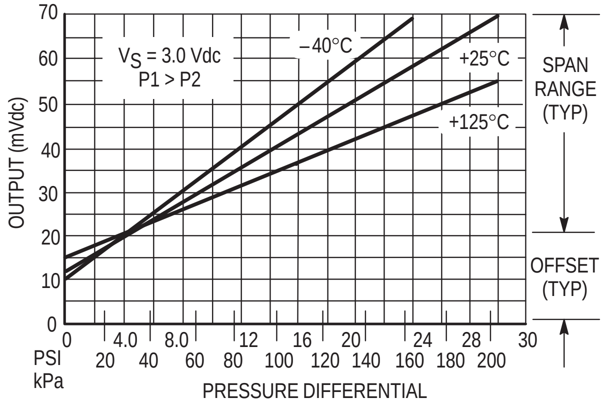


Figure 3. Output versus Pressure Differential

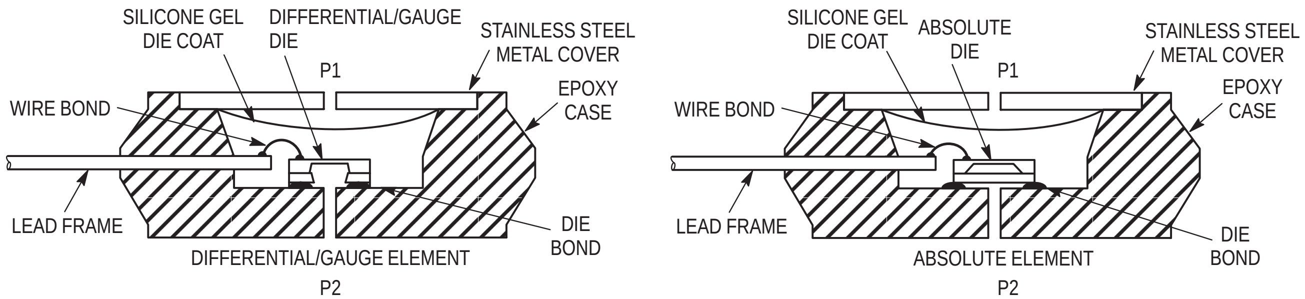


Figure 4. Cross–Sectional Diagrams (Not to Scale)

Figure 4 illustrates the absolute sensing configuration (right) and the differential or gauge configuration in the basic chip carrier (Case 344–15). A silicone gel isolates the die surface and wire bond from the environment, 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 reliability. Contact the factory for information regarding media compatibility in your application.

PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Motorola designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing the silicone gel which isolates the die from the environment. The differential or gauge sensor is designed to operate with positive differential pressure applied, P1 > P2. The absolute sensor is designed for vacuum applied to P1 side.

The Pressure (P1) side may be identified by using the table below:

Part Number	Case Type	Pressure (P1) Side Identifier
MPX200D	344–15	Stainless Steel Cap
MPX200DP	344C–01	Side with Part Marking
MPX200GP	344B–01	Side with Port Attached

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.

Device Type	Options	Case Type	MPX Series	
			Order Number	Device Marking
Basic Element	Absolute, Differential	Case 344–15	MPX200D	MPX200D
Ported Elements	Differential	Case 344C–01	MPX200DP	MPX200DP
	Absolute, Gauge	Case 344B–01	MPX200GP	MPX200GP

MPX2010
MPXT2010
SERIES

Motorola Preferred Device

10 kPa On-Chip Temperature Compensated & Calibrated Silicon Pressure Sensors

COMPENSATED PRESSURE SENSOR
0 to 10 kPa (0 to 1.45 psi)
FULL SCALE SPAN: 25 mV

The MPX2010/MPXT2010 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.

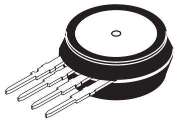
Features

- Temperature Compensated over 0°C to +85°C
- Unique Silicon Shear Stress Strain Gauge
- Ratiometric to Supply Voltage
- Differential and Gauge Options

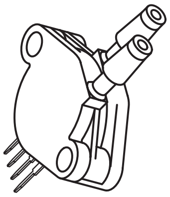
Application Examples

- Respiratory Diagnostics
- Air Movement Control
- Controllers
- Pressure Switching

UNIBODY PACKAGES
MPX2010



BASIC CHIP CARRIER ELEMENT
CASE 344–15, STYLE 1



DIFFERENTIAL PORT OPTION
CASE 344C–01, STYLE 1

PIN NUMBER			
1	2	3	4
Ground	$+V_{out}$	V_S	$-V_{out}$

NOTE: Pin 1 is the notched pin.

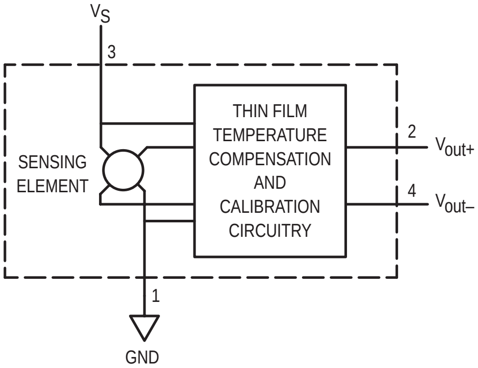
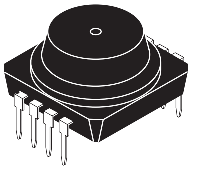


Figure 1. Temperature Compensated and Calibrated Pressure Sensor Schematic

TOP PISTON FIT PACKAGE
MPXT2010



BASIC ELEMENT
CASE 473A–01

PIN NUMBER			
1	Gnd	5	N/C
2	$+V_{out}$	6	N/C
3	V_S	7	N/C
4	$-V_{out}$	8	N/C

NOTE: Pins 5, 6, 7, and 8 are not device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the Lead.

VOLTAGE OUTPUT versus APPLIED DIFFERENTIAL PRESSURE

The output voltage of the differential or gauge sensor increases with increasing pressure applied to the pressure side (P1) relative to the vacuum side (P2). Similarly, output voltage increases as increasing vacuum is applied to the vacuum side (P2) relative to the pressure side (P1).

Figure 1 shows a block diagram of the internal circuitry on the stand–alone pressure sensor chip.

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

REV 7

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Overpressure(8) (P1 > P2)	P_{max}	75	kPa
Burst Pressure(8) (P1 > P2)	P_{burst}	100	kPa
Storage Temperature	T_{stg}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C

OPERATING CHARACTERISTICS (V_S = 10 Vdc, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic	Symbol	Min	Typ	Max	Unit
Pressure Range(1)	P_{OP}	0	—	10	kPa
Supply Voltage(2)	V_S	—	10	16	Vdc
Supply Current	I_o	—	6.0	—	mAdc
Full Scale Span(3)	V_{FSS}	24	25	26	mV
Offset(4) MPX2010 MPXT2010	V_{off}	–1.0 –1.0	— —	1.0 1.0	mV
Sensitivity	$\Delta V/\Delta P$	—	2.5	—	mV/kPa
Linearity(5)	—	–1.0	—	1.0	$\%V_{FSS}$
Pressure Hysteresis(5) (0 to 10 kPa)	—	—	±0.1	—	$\%V_{FSS}$
Temperature Hysteresis(5) (–40°C to +125°C)	—	—	±0.5	—	$\%V_{FSS}$
Temperature Effect on Full Scale Span(5)	TCV_{FSS}	–1.0	—	1.0	$\%V_{FSS}$
Temperature Effect on Offset(5)	TCV_{off}	–1.0	—	1.0	mV
Input Impedance	Z_{in}	1300	—	2550	Ω
Output Impedance	Z_{out}	1400	—	3000	Ω
Response Time(6) (10% to 90%)	t_R	—	1.0	—	ms
Warm–Up	—	—	20	—	ms
Offset Stability(9)	—	—	±0.5	—	$\%V_{FSS}$

MECHANICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Weight (Basic Element Case 344–15)	—	—	2.0	—	Grams
Weight (Basic Element Case 473A–01)	—	—	2.0	—	Grams
Common Mode Line Pressure(7)	—	—	—	690	kPa

NOTES:

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range. Operating the device above the specified excitation range may induce additional error due to device self–heating.
3. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
4. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
5. Accuracy (error budget) consists of the following:

• Linearity:	Output deviation from a straight line relationship with pressure, using end point method, over the specified pressure range.
• Temperature Hysteresis:	Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
• Pressure Hysteresis:	Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
• TcSpan:	Output deviation at full rated pressure over the temperature range of 0 to 85°C, relative to 25°C.
• TcOffset:	Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.

6. Response Time is defined as the time 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.
7. Common mode pressures beyond specified may result in leakage at the case–to–lead interface.
8. Exposure beyond these limits may cause permanent damage or degradation to the device.
9. Offset stability is the product’s output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

ON–CHIP TEMPERATURE COMPENSATION and CALIBRATION

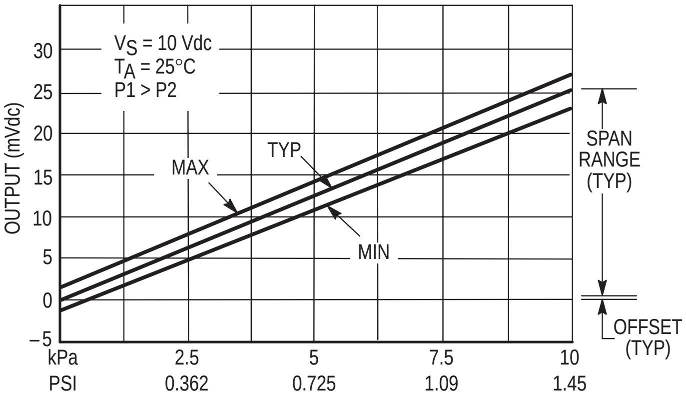


Figure 2. Output versus Pressure Differential

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.

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. Each chip is dynamically laser trimmed for precise span and offset calibration and temperature compensation.

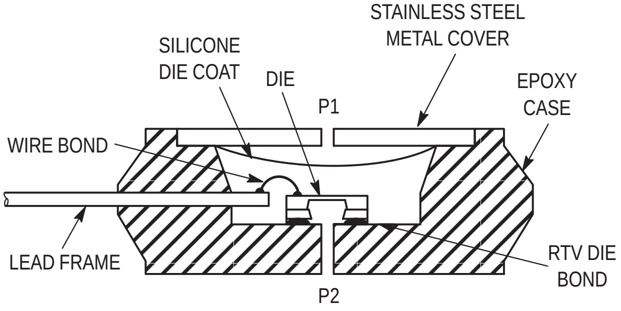


Figure 3. Unibody Package — Cross–Sectional Diagram (not to scale)

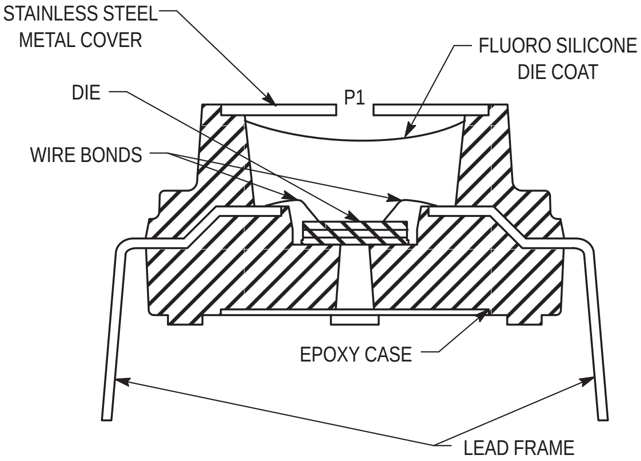


Figure 4. Top Piston Fit Package — Cross–Sectional Diagram (not to scale)

Figure 3 illustrates the differential/gauge die in the basic chip carrier (Case 344–15). Figure 4 illustrates the differential/gauge die in the top piston fit package (Case 473A). A silicone gel isolates the die surface and wire bonds from the environment, 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 reliability. Contact the factory for information regarding media compatibility in your application.

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 5) 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.

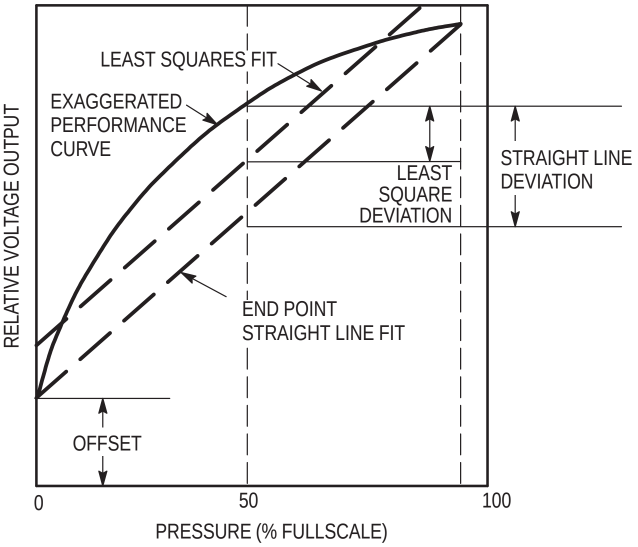


Figure 5. Linearity Specification Comparison

PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Motorola designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing silicone gel which isolates the die from the environment. The Motorola MPX pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using the table below:

Part Number	Case Type	Pressure (P1) Side Identifier
MPX2010D	344–15	Stainless Steel Cap
MPX2010DP	344C–01	Side with Part Marking
MPX2010GP	344B–01	Side with Port Attached
MPXT2010G7U	473A–01	Side with Part Marking

ORDERING INFORMATION — UNIBODY PACKAGE

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.

Device Type	Options	Case Type	MPX Series	
			Order Number	Device Marking
Basic Element	Differential	Case 344–15	MPX2010D MPX2012D	MPX2010D MPX2012D
Ported Elements	Differential	Case 344C–01	MPX2010DP MPX2012DP	MPX2010DP MPX2012DP

ORDERING INFORMATION — TOP PISTON FIT PACKAGE

The MPXT2010G7U pressure sensor is available to be shipped in Rails.

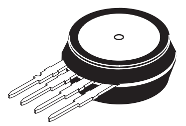
Packing Options	Port Options	Leadform	Case Type	MPXT Series Order No.	Marking
Rails	Element	84 degree	473A–01	MPXT2010G7U	MPXT2010G

MOTOROLA
SEMICONDUCTOR TECHNICAL DATA

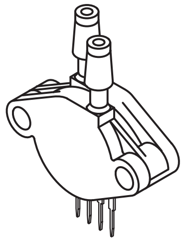
MPX2050
MPX2052
SERIES

Motorola Preferred Device

0 to 50 kPa (0 to 7.25 psi)
40 mV FULL SCALE SPAN
(TYPICAL)



BASIC CHIP
CARRIER ELEMENT
CASE 344–15, STYLE 1



DIFFERENTIAL
PORT OPTION
CASE 344C–01, STYLE 1

NOTE: Pin 1 is the notched pin.

PIN NUMBER			
1	Gnd	3	V_S
2	$+V_{out}$	4	$-V_{out}$

50 kPa
On-Chip Temperature Compensated & Calibrated Silicon Pressure Sensors

The MPX2050 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.

Features

- Temperature Compensated Over 0°C to +85°C
- Unique Silicon Shear Stress Strain Gauge
- Easy to Use Chip Carrier Package Options
- Ratiometric to Supply Voltage
- Differential and Gauge Options
- ±0.25% Linearity (MPX2050)

Application Examples

- Pump/Motor Controllers
- Robotics
- Level Indicators
- Medical Diagnostics
- Pressure Switching
- Non–Invasive Blood Pressure Measurement

Figure 1 shows a block diagram of the internal circuitry on the stand–alone pressure sensor chip.

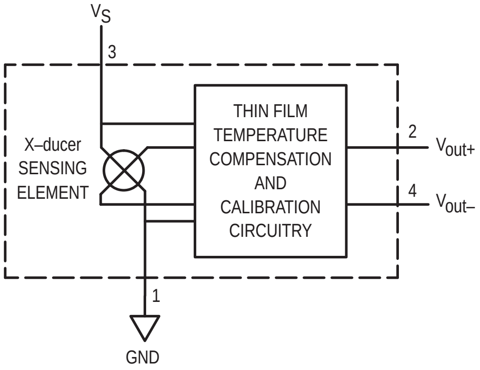


Figure 1. Temperature Compensated Pressure Sensor Schematic

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 or gauge sensor increases with increasing pressure applied to the pressure side (P1) relative to the vacuum side (P2). Similarly, output voltage increases as increasing vacuum is applied to the vacuum side (P2) relative to the pressure side (P1).

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

REV 6

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Overpressure(8) (P1 > P2)	P_{max}	200	kPa
Burst Pressure(8) (P1 > P2)	P_{burst}	500	kPa
Storage Temperature	T_{stg}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C

OPERATING CHARACTERISTICS (V_S = 10 Vdc, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range(1)		P_{OP}	0	—	50	kPa
Supply Voltage(2)		V_S	—	10	16	Vdc
Supply Current		I_o	—	6.0	—	mAdc
Full Scale Span(3)	MPX2050, MPX2052	V_{FSS}	38.5	40	41.5	mV
Offset(4)	MPX2050, MPX2052	V_{off}	–1.0	—	1.0	mV
Sensitivity		$\Delta V/\Delta P$	—	0.8	—	mV/kPa
Linearity(5)	MPX2050 MPX2052	— —	–0.25 –0.55	— —	0.25 0.25	$\%V_{FSS}$
Pressure Hysteresis(5) (0 to 50 kPa)		—	—	±0.1	—	$\%V_{FSS}$
Temperature Hysteresis(5) (–40°C to +125°C)		—	—	±0.5	—	$\%V_{FSS}$
Temperature Effect on Full Scale Span(5)		TCV_{FSS}	–1.0	—	1.0	$\%V_{FSS}$
Temperature Effect on Offset(5)		TCV_{off}	–1.0	—	1.0	mV
Input Impedance		Z_{in}	1000	—	2500	Ω
Output Impedance		Z_{out}	1400	—	3000	Ω
Response Time(6) (10% to 90%)		t_R	—	1.0	—	ms
Warm–Up		—	—	20	—	ms
Offset Stability(9)		—	—	±0.5	—	$\%V_{FSS}$

MECHANICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Weight (Basic Element Case 344–15)	—	—	2.0	—	Grams
Common Mode Line Pressure(7)	—	—	—	690	kPa

NOTES:

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range. Operating the device above the specified excitation range may induce additional error due to device self–heating.
3. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
4. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
5. Accuracy (error budget) consists of the following:
    - Linearity: Output deviation from a straight line relationship with pressure, using end point method, over the specified pressure range.
    - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
    - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
    - TcSpan: Output deviation at full rated pressure over the temperature range of 0 to 85°C, relative to 25°C.
    - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
6. Response Time is defined as the time 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.
7. Common mode pressures beyond specified may result in leakage at the case–to–lead interface.
8. Exposure beyond these limits may cause permanent damage or degradation to the device.
9. Offset stability is the product’s output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

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.

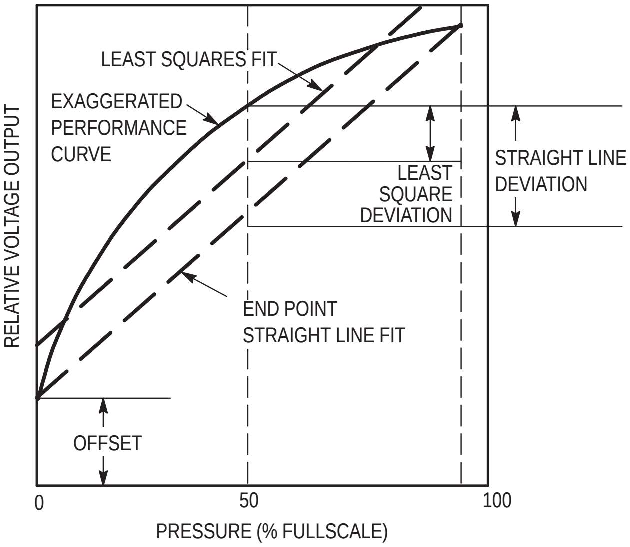


Figure 2. Linearity Specification Comparison

ON–CHIP TEMPERATURE COMPENSATION and CALIBRATION

Figure 3 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.

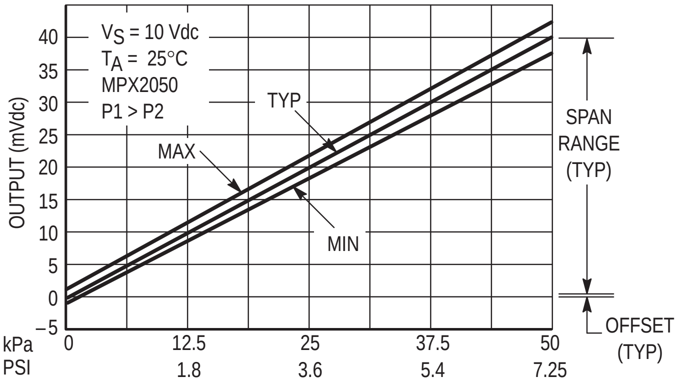


Figure 3. Output versus Pressure Differential

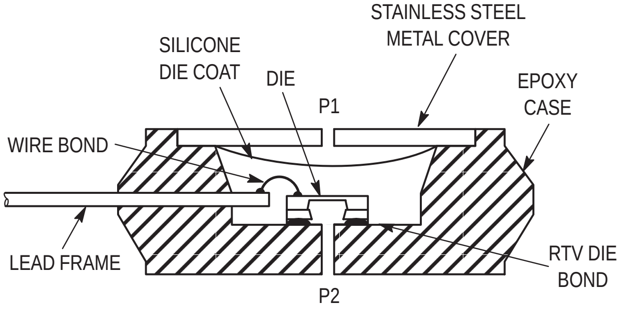


Figure 4. Cross–Sectional Diagram (not to scale)

Figure 4 illustrates the differential or gauge configuration in the basic chip carrier (Case 344–15). A silicone gel isolates the die surface and wire bonds from the environment, 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 reliability. Contact the factory for information regarding media compatibility in your application.

PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Motorola designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing the silicone gel which isolates the die. The Motorola MPX pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using the table below:

Part Number			Case Type	Pressure (P1) Side Identifier
MPX2050D	MPX2051D	MPX2052D	344–15	Stainless Steel Cap
MPX2050DP	MPX2051DP	MPX2052DP	344C–01	Side with Part Marking
MPX2050GP	MPX2051GP	MPX2052GP	344B–01	Side with Port Attached
MPX2050GVP	MPX2051GVP	MPX2052GVP	344D–01	Stainless Steel Cap
MPX2050GS		MPX2052GS	344E–01	Side with Port Attached
MPX2050GSX	MPX2051GSX	MPX2052GSX	344F–01	Side with Port Attached
MPX2050GVSX			344G–01	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	344–15	MPX2050D MPX2051D MPX2052D	MPX2050D MPX2051D MPX2052D
Ported Elements	Differential	344C–01	MPX2050DP MPX2051DP MPX2052DP	MPX2050DP MPX2051DP MPX2052DP
	Gauge	344B–01	MPX2050GP MPX2051GP MPX2052GP	MPX2050GP MPX2051GP MPX2052GP
	Gauge Vacuum	344D–01	MPX2050GVP MPX2051GVP MPX2052GVP	MPX2050GVP MPX2051GVP MPX2052GVP
	Gauge Stove Pipe	344E–01	MPX2050GS MPX2052GS	MPX2050D MPX2052D
	Gauge Axial	344F–01	MPX2050GSX MPX2051GSX MPX2052GSX	MPX2050D MPX2051D MPX2052D
	Gauge Vacuum Axial	344G–01	MPX2050GVSX	MPX2050D

MOTOROLA
SEMICONDUCTOR TECHNICAL DATA

MPX2100
MPX2101
SERIES

Motorola Preferred Device

100 kPa On-Chip Temperature Compensated & Calibrated Silicon Pressure Sensors

0 to 100 kPa (0 to 14.5 psi)
40 mV FULL SCALE SPAN
(TYPICAL)

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.

Features

- Temperature Compensated Over 0°C to +85°C
- Unique Silicon Shear Stress Strain Gauge
- Easy to Use Chip Carrier Package Options
- Available in Absolute, Differential and Gauge Configurations
- Ratiometric to Supply Voltage
- ±0.25% Linearity (MPX2100D)

Application Examples

- Pump/Motor Controllers
- Robotics
- Level Indicators
- Medical Diagnostics
- Pressure Switching
- Barometers
- Altimeters

Figure 1 illustrates a block diagram of the internal circuitry on the stand–alone pressure sensor chip.

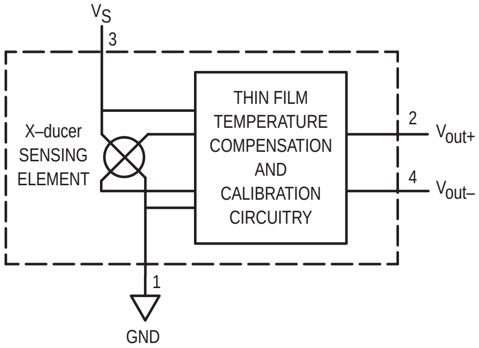


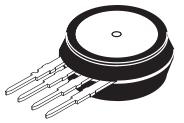
Figure 1. Temperature Compensated Pressure Sensor Schematic

VOLTAGE OUTPUT versus APPLIED DIFFERENTIAL PRESSURE

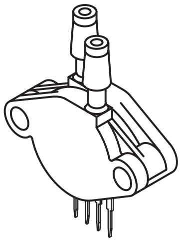
The differential voltage output of the X–ducer is directly proportional to the differential pressure applied.

The absolute sensor has a built–in reference vacuum. The output voltage will decrease as vacuum, relative to ambient, is drawn on the pressure (P1) side.

The output voltage of the differential or gauge sensor increases with increasing pressure applied to the pressure (P1) side relative to the vacuum (P2) side. Similarly, output voltage increases as increasing vacuum is applied to the vacuum (P2) side relative to the pressure (P1) side.



BASIC CHIP
CARRIER ELEMENT
CASE 344–15, STYLE 1



DIFFERENTIAL
PORT OPTION
CASE 344C–01, STYLE 1

NOTE: Pin 1 is the notched pin.

PIN NUMBER			
1	Gnd	3	V_S
2	$+V_{out}$	4	$-V_{out}$

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

REV 7

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Overpressure(8) (P1 > P2)	P_{max}	200	kPa
Burst Pressure(8) (P1 > P2)	P_{burst}	1000	kPa
Storage Temperature	T_{stg}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C

OPERATING CHARACTERISTICS (V_S = 10 Vdc, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range(1)		P_{OP}	0	—	100	kPa
Supply Voltage(2)		V_S	—	10	16	Vdc
Supply Current		I_o	—	6.0	—	mAdc
Full Scale Span(3)	MPX2100A, MPX2100D, MPX2101D Series MPX2101A Series	V_{FSS}	38.5 37.5	40 40	41.5 42.5	mV
Offset(4)	MPX2100D, MPX2101D Series MPX2100A Series MPX2101A Series	V_{off}	–1.0 –2.0 –3.0	— — —	1.0 2.0 3.0	mV
Sensitivity		ΔV/ΔP	—	0.4	—	mV/kPa
Linearity(5)	MPX2100D Series MPX2100A Series MPX2101D Series MPX2101A Series	— —	–0.25 –1.0 –0.5 –2.0	— — — —	0.25 1.0 0.5 2.0	%V_{FSS}
Pressure Hysteresis(5) (0 to 100 kPa)		—	—	±0.1	—	%V_{FSS}
Temperature Hysteresis(5) (–40°C to +125°C)		—	—	±0.5	—	%V_{FSS}
Temperature Effect on Full Scale Span(5)		TCV_{FSS}	–1.0	—	1.0	%V_{FSS}
Temperature Effect on Offset(5)		TCV_{off}	–1.0	—	1.0	mV
Input Impedance		Z_{in}	1000	—	2500	Ω
Output Impedance		Z_{out}	1400	—	3000	Ω
Response Time(6) (10% to 90%)		t_R	—	1.0	—	ms
Warm–Up		—	—	20	—	ms
Offset Stability(9)		—	—	±0.5	—	%V_{FSS}

MECHANICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Weight (Basic Element Case 344–15)	—	—	2.0	—	Grams
Common Mode Line Pressure(7)	—	—	—	690	kPA

NOTES:

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range. Operating the device above the specified excitation range may induce additional error due to device self–heating.
3. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
4. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
5. Accuracy (error budget) consists of the following:
    - Linearity: Output deviation from a straight line relationship with pressure, using end point method, over the specified pressure range.
    - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
    - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
    - TcSpan: Output deviation at full rated pressure over the temperature range of 0 to 85°C, relative to 25°C.
    - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
6. Response Time is defined as the time 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.
7. Common mode pressures beyond specified may result in leakage at the case–to–lead interface.
8. Exposure beyond these limits may cause permanent damage or degradation to the device.
9. Offset stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

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.

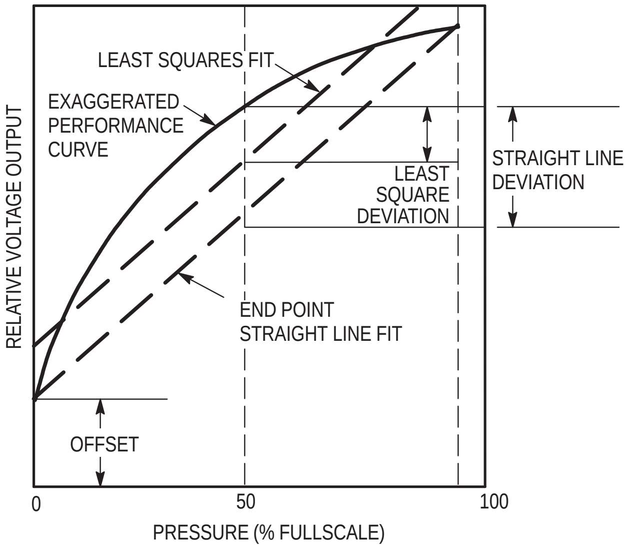


Figure 2. Linearity Specification Comparison

ON–CHIP TEMPERATURE COMPENSATION and CALIBRATION

Figure 3 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.

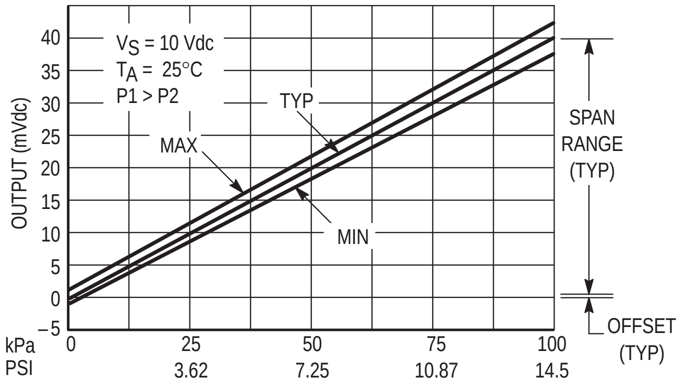


Figure 3. Output versus Pressure Differential

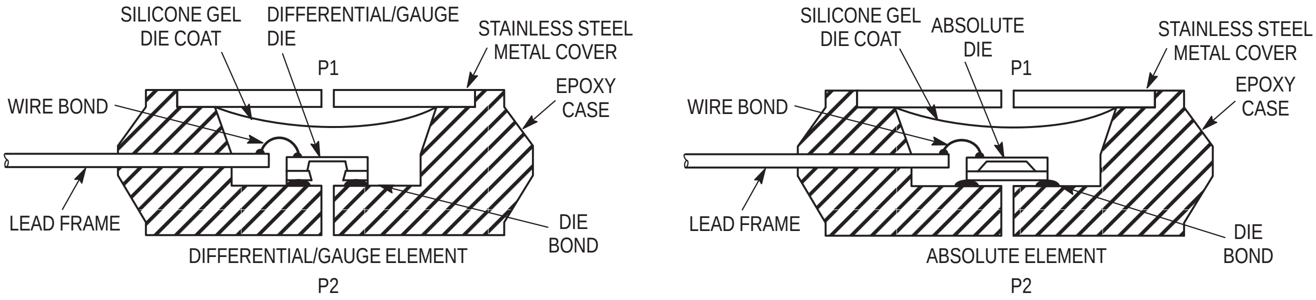


Figure 4. Cross–Sectional Diagrams (Not to Scale)

Figure 4 illustrates the absolute sensing configuration (right) and the differential or gauge configuration in the basic chip carrier (Case 344–15). A silicone gel isolates the die surface and wire bonds from the environment, 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 reliability. Contact the factory for information regarding media compatibility in your application.

PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Motorola designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing the silicone gel which isolates the die. The differential or gauge sensor is designed to operate with positive differential pressure applied, P1 > P2. The absolute sensor is designed for vacuum applied to P1 side.

The Pressure (P1) side may be identified by using the table below:

Part Number				Case Type	Pressure (P1) Side Identifier
MPX2100A	MPX2100D	MPX2101A		344–15	Stainless Steel Cap
MPX2100DP		MPX2101DP		344C–01	Side with Part Marking
MPX2100AP	MPX2100GP	MPX2101AP	MPX2101GP	344B–01	Side with Port Attached
MPX2100AS				344E–01	Side with Port Attached
MPX2100ASX	MPX2100GSX			344F–01	Side with Port Attached

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 344–15	MPX2100A MPX2100D MPX2101A	MPX2100A MPX2100D MPX2101A
Ported Elements	Differential	Case 344C–01	MPX2100DP MPX2101DP	MPX2100DP MPX2101DP
	Absolute, Gauge	Case 344B–01	MPX2100AP MPX2100GP MPX2101AP MPX2101GP	MPX2100AP MPX2100GP MPX2101AP MPX2101GP
	Absolute, Gauge Stove Pipe	Case 344E–01	MPX2100AS MPX2100GS	MPX2100A MPX2100D
	Gauge Vacuum Stove Pipe	Case 344A–01	MPX2100GVS	MPX2100D
	Absolute, Gauge Axial	Case 344F–01	MPX2100ASX MPX2100GSX	MPX2100A MPX2100D

MPX2200
MPX2201
SERIES

Motorola Preferred Device

200 kPa On-Chip Temperature Compensated & Calibrated Pressure Sensors

**0 to 200 kPa (0 to 29 psi)
40 mV FULL SCALE SPAN
(TYPICAL)**

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.

Features

- Temperature Compensated Over 0°C to +85°C
- Patented Silicon Shear Stress Strain Gauge
- ±0.25% Linearity (MPX2200D)
- Easy to Use Chip Carrier Package
- Available in Absolute, Differential and Gauge Configurations

Application Examples

- Pump/Motor Controllers
- Robotics
- Level Indicators
- Medical Diagnostics
- Pressure Switching
- Barometers
- Altimeters

Figure 1 illustrates a block diagram of the internal circuitry on the stand–alone pressure sensor chip.

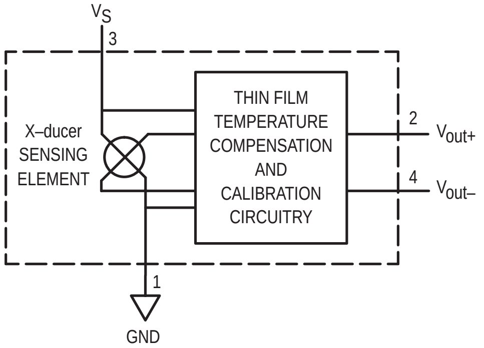
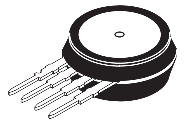
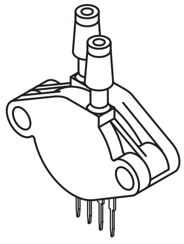


Figure 1. Temperature Compensated Pressure Sensor Schematic



**BASIC CHIP
CARRIER ELEMENT
CASE 344–15, STYLE 1**



**DIFFERENTIAL
PORT OPTION
CASE 344C–01, STYLE 1**

NOTE: Pin 1 is the notched pin.

PIN NUMBER			
1	Gnd	3	V_S
2	$+V_{out}$	4	$-V_{out}$

VOLTAGE OUTPUT versus APPLIED DIFFERENTIAL PRESSURE

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

The absolute sensor has a built–in reference vacuum. The output voltage will decrease as vacuum, relative to ambient, is drawn on the pressure (P1) side.

The output voltage of the differential or gauge sensor increases with increasing pressure applied to the pressure (P1) side relative to the vacuum (P2) side. Similarly, output voltage increases as increasing vacuum is applied to the vacuum (P2) side relative to the pressure (P1) side.

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

REV 8

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Overpressure(8) (P1 > P2)	P_{max}	400	kPa
Burst Pressure(8) (P1 > P2)	P_{burst}	2000	kPa
Storage Temperature	T_{stg}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C

OPERATING CHARACTERISTICS (V_S = 10 Vdc, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristics		Symbol	Min	Typ	Max	Unit
Pressure Range(1)		P_{OP}	0	—	200	kPa
Supply Voltage		V_S	—	10	16	Vdc
Supply Current		I_o	—	6.0	—	mAdc
Full Scale Span(3)		V_{FSS}	38.5	40	41.5	mV
Offset(4)		V_{off}	–1.0	—	1.0	mV
Sensitivity		ΔV/ΔP	—	0.2	—	mV/kPa
Linearity(5)	MPX2200D Series	—	–0.25	—	0.25	$\%V_{FSS}$
	MPX2200A Series		–1.0	—	1.0	
	MPX2201GP		–0.5	—	0.5	
Pressure Hysteresis(5) (0 to 200 kPa)		—	—	± 0.1	—	$\%V_{FSS}$
Temperature Hysteresis(5) (–40°C to +125°C)		—	—	± 0.5	—	$\%V_{FSS}$
Temperature Effect on Full Scale Span(5)		TCV_{FSS}	–1.0	—	1.0	$\%V_{FSS}$
Temperature Effect on Offset(5)		TCV_{off}	–1.0	—	1.0	mV
Input Impedance		Z_{in}	1300	—	2500	Ω
Output Impedance		Z_{out}	1400	—	3000	Ω
Response Time(6) (10% to 90%)		t_R	—	1.0	—	ms
Warm–Up		—	—	20	—	ms
Offset Stability(9)		—	—	±0.5	—	$\%V_{FSS}$

MECHANICAL CHARACTERISTICS

Characteristics	Symbol	Min	Typ	Max	Unit
Weight, (Basic Element Case 344–15)	—	—	2.0	—	Grams
Common Mode Line Pressure(7)	—	—	—	690	kPa

NOTES:

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range. Operating the device above the specified excitation range may induce additional error due to device self–heating.
3. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
4. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
5. Accuracy (error budget) consists of the following:
    - Linearity: Output deviation from a straight line relationship with pressure, using end point method, over the specified pressure range.
    - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
    - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
    - TcSpan: Output deviation at full rated pressure over the temperature range of 0 to 85°C, relative to 25°C.
    - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
6. Response Time is defined as the time 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.
7. Common mode pressures beyond specified may result in leakage at the case–to–lead interface.
8. Exposure beyond these limits may cause permanent damage or degradation to the device.
9. Offset stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

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.

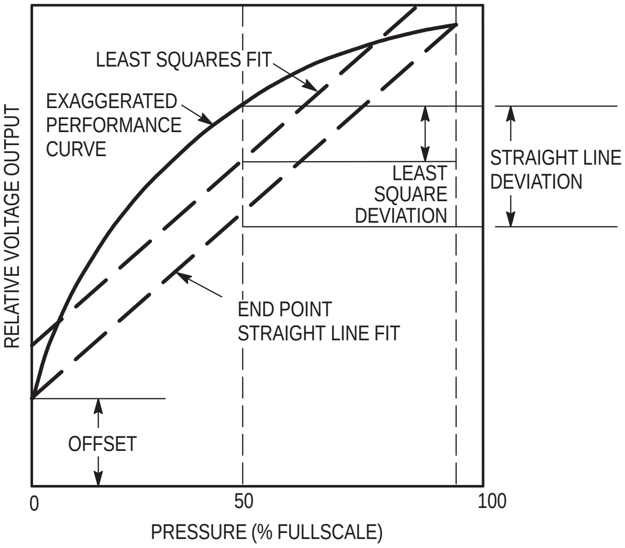


Figure 2. Linearity Specification Comparison

ON–CHIP TEMPERATURE COMPENSATION and CALIBRATION

Figure 3 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.

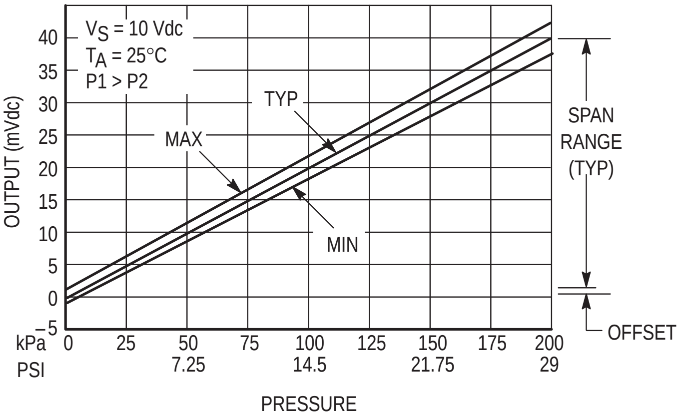


Figure 3. Output versus Pressure Differential

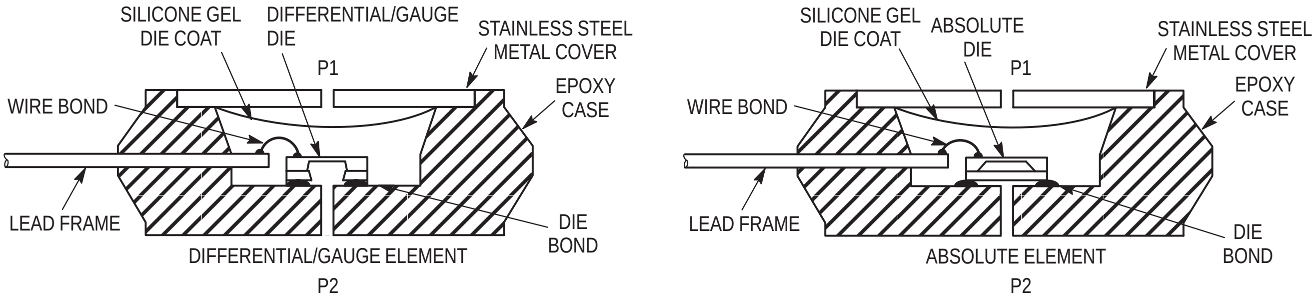


Figure 4. Cross–Sectional Diagrams (Not to Scale)

Figure 4 illustrates an absolute sensing die (right) and the differential or gauge die in the basic chip carrier (Case 344–15). A silicone gel isolates the die surface and wire bonds from the environment, 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 reliability. Contact the factory for information regarding media compatibility in your application.

PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Motorola designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing the silicone gel which isolates the die from the environment. The differential or gauge sensor is designed to operate with positive differential pressure applied, P1 > P2. The absolute sensor is designed for vacuum applied to P1 side.

The Pressure (P1) side may be identified by using the table below:

Part Number				Case Type	Pressure (P1) Side Identifier
MPX2200A	MPX2200D			344–15	Stainless Steel Cap
MPX2200DP				344C–01	Side with Part Marking
MPX2200AP	MPX2200GP		MPX2201GP	344B–01	Side with Port Attached

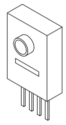
ORDERING INFORMATION

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 Marking
Basic Element	Absolute, Differential	Case 344–15	MPX2200A MPX2200D	MPX2200A MPX2200D
Ported Elements	Differential	Case 344C–01	MPX2200DP	MPX2200DP
	Absolute, Gauge	Case 344B–01	MPX2200AP MPX2200GP MPX2201GP	MPX2200AP MPX2200GP MPX2201GP

MPX2300DT1

PRESSURE SENSORS



CHIP PAK ELEMENT
CASE 423A–03

PIN NUMBER			
1	V_S	3	S–
2	S+	4	Gnd

Chip Pak High Volume Pressure Sensor for Disposable, Backside Pressure Applications

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:

- Low Cost
- 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 package. Application–specific parts will have an "SPX" prefix, followed by a four digit number, unique to the specific customer. Devices will be shipped in a tape and reel packaging.

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

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Overpressure (Backside)	P_{max}	125	PSI
Burst Pressure	P_{burst}	1000	kPa
Supply Voltage	V_{Smax}	10	Vdc
Storage Temperature	T_{stg}	– 25 to + 85	°C
Operating Temperature	T_A	+ 15 to + 40	°C

Motorola's MPX2300DT1 Pressure Sensors. Motorola's MPX2300DT1 pressure sensor has been designed for medical usage by combining the performance of Motorola's shear stress pressure sensor design and the use of biomedically approved materials. Materials with a proven history in medical situations have been chosen to provide a sensor that can be used with confidence in applications, such as invasive blood pressure monitoring. It can be sterilized using ethylene oxide. The portions of the pressure sensor that are required to be biomedically approved are the rigid housing and the gel coating.

The rigid housing is molded from a white, medical grade polysulfone that has passed extensive biological testing including: tissue culture test, rabbit implant, hemolysis, intracutaneous test in rabbits, and system toxicity, USP.

A silicone dielectric gel that has been used extensively in implants covers the silicon piezoresistive sensing element. The gel is a nontoxic, nonallergenic polymer system which passes pyrogen testing, as well as meeting all USP XX Biological Testing Class VI requirements. The properties of the gel allow it to transmit pressure uniformly to the diaphragm surface, while isolating the internal electrical connections from the corrosive effects of fluids, such as saline solution. The gel provides electrical isolation sufficient to withstand defibrillation testing, as specified in the proposed Association for the Advancement of Medical Instrumentation (AAMI) Standard for blood pressure transducers. A biomedically approved opaque filler in the gel prevents bright operating room lights from affecting the performance of the sensor.

REV 2

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

Characteristics	Symbol	Min	Typ	Max	Unit
Pressure Range	P_{OP}	0	—	300	mmHg
Supply Voltage(8)	V_S	—	6.0	10	Vdc
Supply Current	I_o	—	1.0	—	mAdc
Zero Pressure Offset	V_{off}	–0.75	—	0.75	mV
Sensitivity	—	4.95	5.0	5.05	μV/V/mmHg
Full Scale Span(1)	V_{FSS}	2.976	3.006	3.036	mV
Linearity + Hysteresis(2)	—	– 2.0	—	2.0	
Temperature Effect on Sensitivity	TCS	–0.1	—	+0.1	%/°C
Temperature Effect on Full Scale Span(3)	TCV_{FSS}	–0.1	—	+0.1	%/°C
Temperature Effect on Offset(4)	TCV_{off}	–9.0	—	+9.0	μV/°C
Input Impedance	Z_{in}	1800	—	4500	Ω
Output Impedance	Z_{out}	270	—	330	Ω
R_{CAL} (150 kΩ)(9)	R_{CAL}	97	100	103	mmHg
Response Time(5) (10% to 90%)	t_R	—	1.0	—	ms
Temperature Error Band	—	0	—	85	°C
Stability(6)	—	—	±0.5	—	%V_{FSS}

MECHANICAL CHARACTERISTICS

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

NOTES:

1. Measured at 6.0 Vdc excitation for 100 mmHg 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 300 mmHg.
3. Slope of end–point straight line fit to full scale span at 15°C and +40°C relative to +25°C.
4. Slope of end–point straight line fit to zero pressure offset at 15°C and +40°C relative to +25°C.
5. For a 0 to 300 mmHg 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 300 mmHg.
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.
9. Offset measurement with respect to the measured sensitivity when a 150k ohm resistor is connected to V_S and S+ output.

ORDERING INFORMATION

The MPX2300DT1 silicon pressure sensors are available in tape and reel.

Device Type Options	Case No.	MPX Series Order No.	Marking
Tape and Reel	423A–03		Date Code, Lot ID

Device	Reel Size	Tape Width	Quantity
MPX2300DT1	330 mm	24 mm	1000 pc/reel

Integrated Silicon Pressure Sensor Manifold Absolute Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

MPX4100A
MPXS4100A
MPXT4100A
PPXA4100A
SERIES

INTEGRATED
PRESSURE SENSOR
20 to 105 kPa (2.9 to 15.2 psi)
0.3 to 4.9 V Output

The Motorola MPX4100A/MPXS4100A/MPXT4100A 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. The small form factor and high reliability of on–chip integration makes the Motorola MAP sensor a logical and economical choice for automotive system designers.

Features

- 1.8% Maximum Error Over 0° to 85°C
- Specifically Designed for Intake Manifold Absolute Pressure Sensing in Engine Control Systems
- Ideally Suited for Microprocessor Interfacing
- Temperature Compensated Over –40°C to +125°C
- Durable Epoxy Unibody Element or Surface Mount Package
- Also Ideal for Non–Automotive Applications

Application Examples

- Manifold Sensing for Automotive Systems

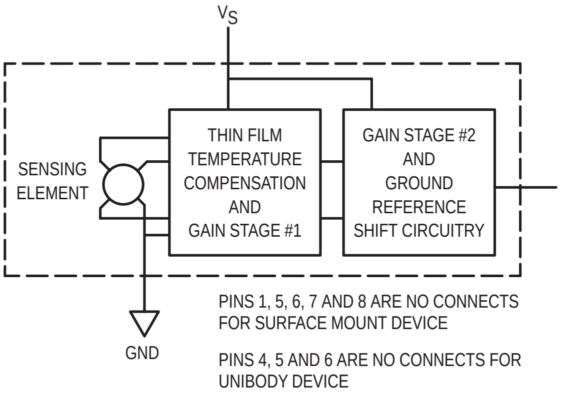
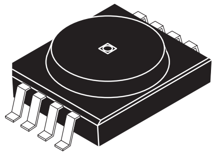


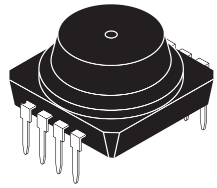
Figure 1. Fully Integrated Pressure Sensor Schematic

SURFACE MOUNT PACKAGE



MPXS4100A
CASE 471–01, STYLE 1

TOP PISTON FIT PACKAGE

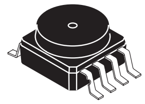


MPXT4100A
BASIC ELEMENT
CASE 473A–01, STYLE 2

PIN NUMBER							
1	N/C	3	Gnd	5	N/C	7	N/C
2	V_S	4	V_{out}	6	N/C	8	N/C

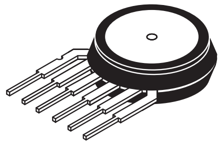
NOTE: Pins 1, 5, 6, 7, and 8 are not device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the Lead.

SMALL OUTLINE PACKAGE



PPXA4100A
CASE 482–01

UNIBODY PACKAGE



MPX4100A
BASIC CHIP CARRIER ELEMENT
CASE 867–08, STYLE 1

PIN NUMBER			
1	N/C	5	N/C
2	V_S	6	N/C
3	Gnd	7	N/C
4	V_{out}	8	N/C

NOTE: Pins 1, 5, 6, 7, and 8 are not device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the Lead.

PIN NUMBER			
1	V_{out}	4	N/C
2	Gnd	5	N/C
3	V_S	6	N/C

NOTE: Pins 4, 5, and 6 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the Lead.

The MPX4100A/MPXS4100A/MPXT4100A series piezoresistive transducer is a state–of–the–art, monolithic, signal conditioned, silicon pressure sensor. This sensor 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 block diagram of the internal circuitry integrated on a pressure sensor chip.

REV 1

MAXIMUM RATINGS(1)

Parametric	Symbol	Value	Unit
Overpressure(2) (P1 > P2)	P_{max}	400	kPa
Burst Pressure(2) (P1 > P2)	P_{burst}	1000	kPa
Storage Temperature	T_{stg}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C

1. T_C = 25°C unless otherwise noted.
2. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

OPERATING CHARACTERISTICS (V_S = 5.1 Vdc, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range(1)		P_{OP}	20	—	105	kPa
Supply Voltage(1)		V_S	4.85	5.1	5.35	Vdc
Supply Current		I_o	—	7.0	10	mAdc
Minimum Pressure Offset(3) @ V_S = 5.1 Volts	(0 to 85°C)	V_{off}	0.225	0.306	0.388	Vdc
Full Scale Output(4) @ V_S = 5.1 Volts	(0 to 85°C)	V_{FSO}	4.870	4.951	5.032	Vdc
Full Scale Span(5) @ V_S = 5.1 Volts	(0 to 85°C)	V_{FSS}	—	4.59	—	Vdc
Accuracy(6)	(0 to 85°C)	—	—	—	±1.8	$\%V_{FSS}$
Sensitivity		V/P	—	54	—	mV/kPa
Response Time(7)		t_R	—	1.0	—	ms
Output Source Current at Full Scale Output		I_{o+}	—	0.1	—	mAdc
Warm–Up Time(8)		—	—	20	—	ms
Offset Stability(9)		—	—	±0.5	—	$\%V_{FSS}$

Decoupling circuit shown in Figure 3 required to meet electrical specifications.

MECHANICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Weight, Basic Element (Case 473)	—	—	2.0	—	Grams
Weight, Basic Element (Case 867)	—	—	4.0	—	Grams
Common Mode Line Pressure(10)	—	—	—	690	kPa

NOTES:

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation over the temperature range of 0 to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.
7. Response Time is defined as the time 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.
8. Warm–up is defined as the time required for the product to meet the specified output voltage after the Pressure has been stabilized.
9. Offset stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.
10. Common mode pressures beyond specified may result in leakage at the case–to–lead interface.

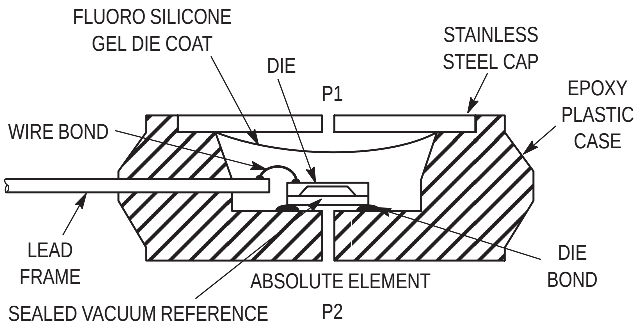


Figure 2. Cross Sectional Diagram (not to scale)

Figure 2 illustrates an absolute sensing chip in the basic chip carrier (Case 867).

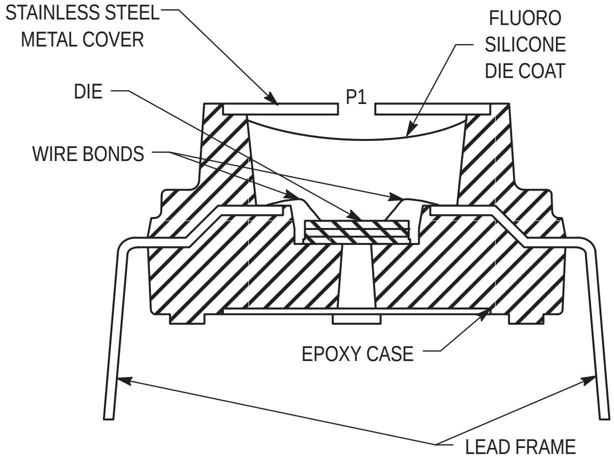


Figure 3. Cross–Sectional Diagram (not to scale)

Figure 3 illustrates an absolute sensing chip in surface mount carrier (Case 473).

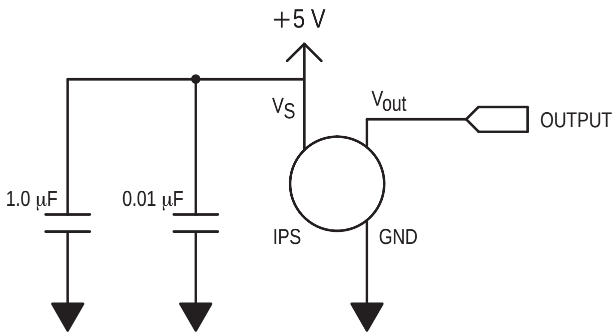


Figure 4. Recommended Power Supply Decoupling. For output filtering recommendations, please refer to Application Note AN1646.

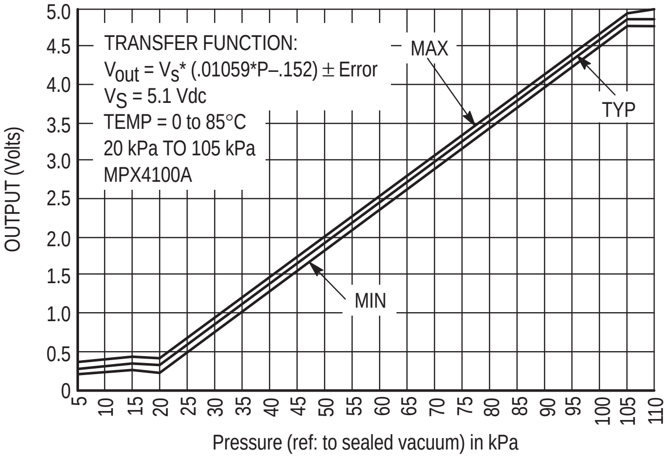


Figure 5. Output versus Absolute Pressure

Figure 5 shows the sensor output signal relative to pressure input. Typical, minimum, and maximum output curves are shown for operation over a temperature range of 0° to 85°C. (The output will saturate outside of the specified pressure range.)

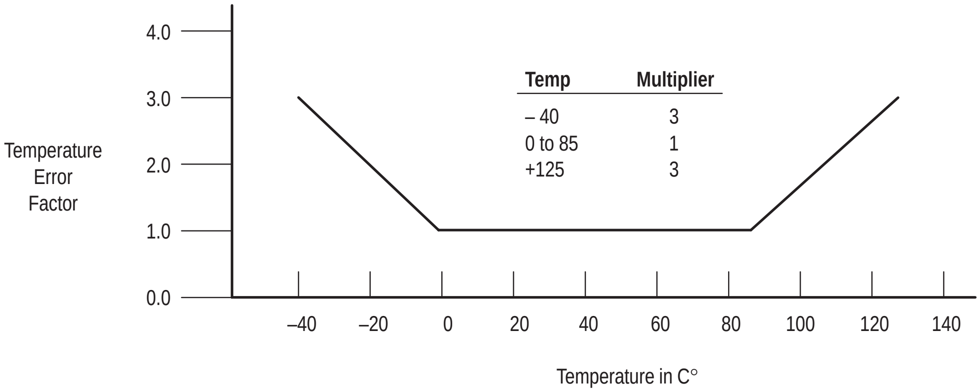
A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the sensor diaphragm. The MPX4100A/MPXS4100A/MPXT4100A series pressure sensor operating characteristics, and internal reliability and qualification tests are based on use of dry air as the pressure media. Media, other than dry air, may have adverse effects on sensor performance and long–term reliability. Contact the factory for information regarding media compatibility in your application.

Transfer Function (MPX4100A, MPXS4100A, MPXT4100A)

Nominal Transfer Value: $V_{out} = V_S$ (P x 0.01059 – 0.1518)
+/– (Pressure Error x Temp. Factor x 0.01059 x V_S)
V_S = 5.1 V ± 0.25 Vdc

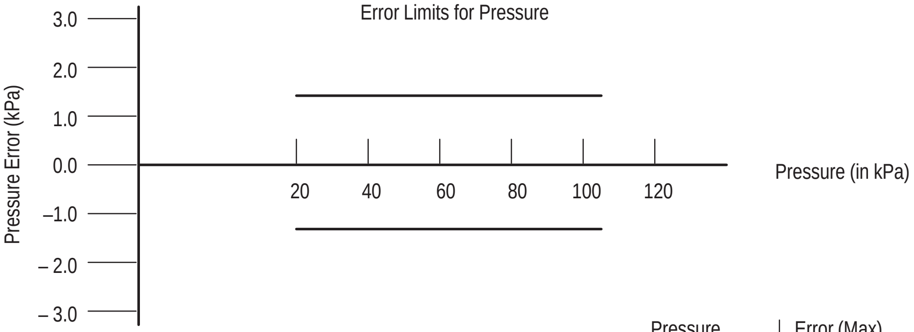
Temperature Error Band

MPX4100A, MPXS4100A, MPXT4100A Series



Temp	Multiplier
– 40	3
0 to 85	1
+125	3

Pressure Error Band



Pressure	Error (Max)
20 to 105 (kPa)	± 1.5 (kPa)

PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Motorola designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing fluorosilicone gel which protects the die from harsh media. The Motorola MPX pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using the table below:

Part Number	Case Type	Pressure (P1) Side Identifier
MPX4100A	867–08	Stainless Steel Cap
MPX4100AP	867B–04	Side with Port Marking
MPX4100AS	867E–03	Side with Port Attached
MPX4100ASX	867F–03	Side with Port Attached

ORDERING INFORMATION — UNIBODY PACKAGE

The MPX4100A series MAP silicon pressure sensors are available in the Basic Element, or with pressure port fittings that provide mounting ease and barbed hose connections.

Device Type	Options	Case Type	MPX Series	
			Order Number	Device Marking
Basic Element	Absolute, Element Only	867–08	MPX4100A	MPX4100A
Ported Elements	Absolute, Ported	867B–04	MPX4100AP	MPX4100AP
	Absolute, Stove Pipe Port	867E–03	MPX4100AS	MPX4100A
	Absolute, Axial Port	867F–03	MPX4100ASX	MPX4100A

ORDERING INFORMATION — SURFACE MOUNT PACKAGE

The MPXS4100A series BAP silicon pressure sensors are available shipped in sleeves or tape and reeled.

Device Type Options	Case No.	MPX Series Order No.	Marking
Sleeve Pack	471–01	MPXS4100A6U	MPXS4100A
Tape and Reel	471–01	MPXS4100A6T1	MPXS4100A

Device	Reel Size	Tape Width	Quantity
MPXS4100A6T1	13” dia.	44 mm	250

ORDERING INFORMATION — TOP PISTON FIT PACKAGE

The MPXT4100A series MAP silicon pressure sensors are available to be shipped in rails.

Packing Options	Port Options	Leadform	Case No.	MPXT Series Order No.	Marking
Rails	Element	84°	473A–01	MPXT4100A7U	MPXT4100A

ORDERING INFORMATION — SMALL OUTLINE PACKAGE

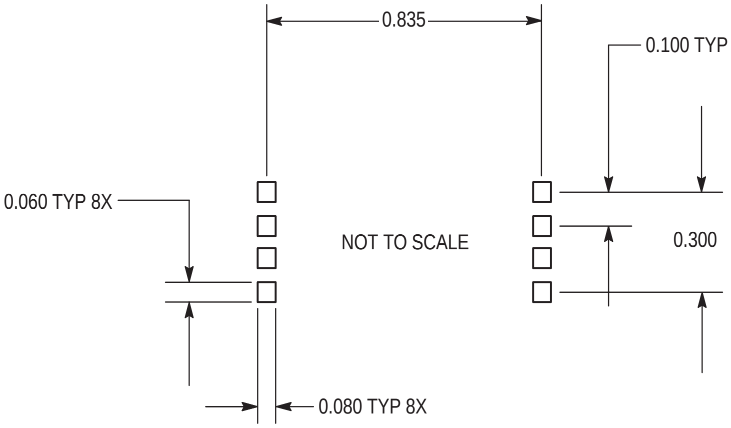
Small outline package is currently available as a prototype status device. Please contact factory for more information or mechanical samples.

Device	Case No.	Packing Options	Marking
PPXA4100A6U	482–01	Rails	PPXA4100A

INFORMATION FOR USING THE SURFACE MOUNT PACKAGE

MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the semiconductor packages must be the correct size to ensure proper solder connection interface between the board and the package. With the correct pad geometry, the packages will self align when subjected to a solder reflow process.



MPX4101A
MPXT4101A
SERIES

Integrated Silicon Pressure Sensor Manifold Absolute Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

INTEGRATED
PRESSURE SENSOR
15 to 102 kPa
(2.18 to 14.8 psi)
0.25 to 4.95 V Output

The Motorola MPX4101A/MPXT4101A 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. The small form factor and high reliability of on–chip integration makes the Motorola MAP sensor a logical and economical choice for automotive system designers.

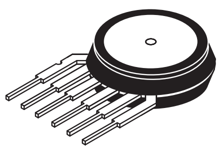
Features

- 1.72% Maximum Error Over 0° to 85°C
- Specifically Designed for Intake Manifold Absolute Pressure Sensing in Engine Control Systems
- Ideally Suited for Microprocessor Interfacing
- Temperature Compensated Over –40°C to +125°C
- Durable Epoxy Unibody Element or Surface Mount Package
- Also Ideal for Non–Automotive Applications

Application Examples

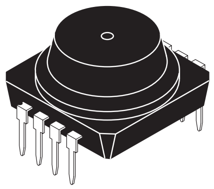
- Manifold Sensing for Automotive Systems

UNIBODY PACKAGE



MPX4101A
BASIC CHIP CARRIER
ELEMENT
CASE 867–08, STYLE 1

TOP PISTON FIT PACKAGE



MPXT4101A
BASIC ELEMENT
CASE 473A–01, STYLE 2

PIN NUMBER			
1	V_{out}	4	N/C
2	Gnd	5	N/C
3	V_S	6	N/C

NOTE: Pins 4, 5, and 6 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the Lead.

PIN NUMBER			
1	N/C	5	N/C
2	V_S	6	N/C
3	Gnd	7	N/C
4	V_{out}	8	N/C

NOTE: Pins 1, 5, 6, 7, and 8 are not device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the Lead.

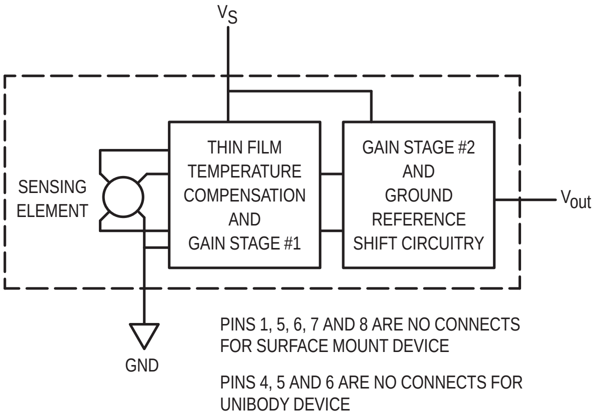


Figure 1. Fully Integrated Pressure Sensor Schematic

The MPX4101A/MPXT4101A series piezoresistive transducer is a state–of–the–art, monolithic, signal conditioned, silicon pressure sensor. This sensor 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 block diagram of the internal circuitry integrated on a pressure sensor chip.

REV 1

MAXIMUM RATINGS(1)

Parametric	Symbol	Value	Unit
Overpressure(2) (P1 > P2)	P_{max}	400	kPa
Burst Pressure(2) (P1 > P2)	P_{burst}	1000	kPa
Storage Temperature	T_{stg}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C

1. T_C = 25°C unless otherwise noted.
2. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

OPERATING CHARACTERISTICS (V_S = 5.1 Vdc, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range(1)		P_{OP}	15	—	102	kPa
Supply Voltage(1)		V_S	4.85	5.1	5.35	Vdc
Supply Current		I_o	—	7.0	10	mAdc
Minimum Pressure Offset(3) @ V_S = 5.1 Volts	(0 to 85°C)	V_{off}	0.171	0.252	0.333	Vdc
Full Scale Output(4) @ V_S = 5.1 Volts	(0 to 85°C)	V_{FSO}	4.870	4.951	5.032	Vdc
Full Scale Span(5) @ V_S = 5.1 Volts	(0 to 85°C)	V_{FSS}	—	4.7	—	Vdc
Accuracy(6)	(0 to 85°C)	—	—	—	±1.72	$\%V_{FSS}$
Sensitivity		V/P	—	54	—	mV/kPa
Response Time(7)		t_R	—	15	—	ms
Output Source Current at Full Scale Output		I_{o+}	—	0.1	—	mAdc
Warm–Up Time(8)		—	—	20	—	ms
Offset Stability(9)		—	—	±0.5	—	$\%V_{FSS}$

Decoupling circuit shown in Figure 3 required to meet electrical specifications.

MECHANICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Weight, Basic Element (Case 473)	—	—	2.0	—	Grams
Weight, Basic Element (Case 867)	—	—	4.0	—	Grams
Common Mode Line Pressure(10)	—	—	—	690	kPa

NOTES:

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:

• Linearity:	Output deviation from a straight line relationship with pressure over the specified pressure range.
• Temperature Hysteresis:	Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
• Pressure Hysteresis:	Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
• TcSpan:	Output deviation over the temperature range of 0 to 85°C, relative to 25°C.
• TcOffset:	Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
• Variation from Nominal:	The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.

7. Response Time is defined as the time 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.
8. Warm–up is defined as the time required for the product to meet the specified output voltage after the Pressure has been stabilized.
9. Offset stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.
10. Common mode pressures beyond specified may result in leakage at the case–to–lead interface.

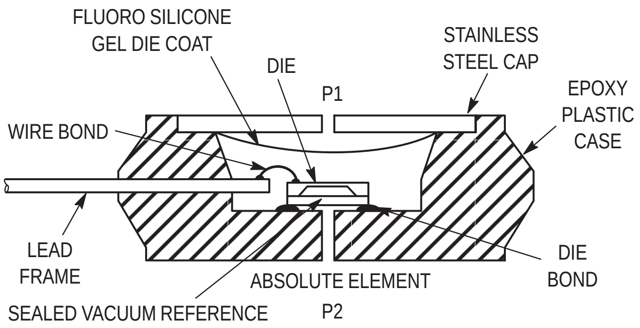


Figure 2. Cross Sectional Diagram (not to scale)

Figure 2 illustrates an absolute sensing chip in the basic chip carrier (Case 867).

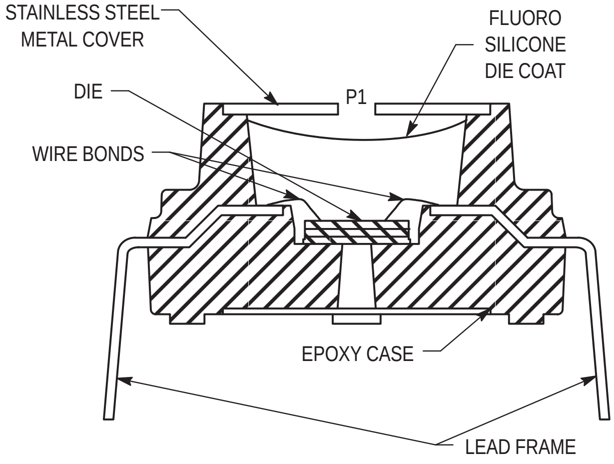


Figure 3. Cross–Sectional Diagram (not to scale)

Figure 3 illustrates an absolute sensing chip in the surface mount carrier (Case 473).

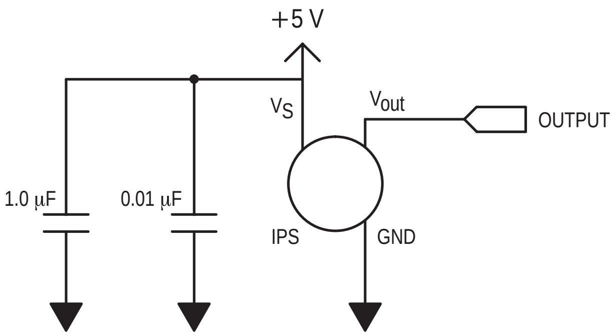


Figure 4. Recommended Power Supply Decoupling. For output filtering recommendations, please refer to Application Note AN1646.

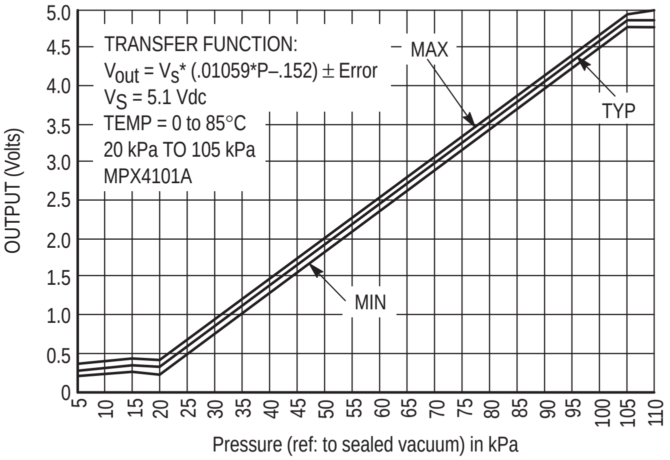


Figure 5. Output versus Absolute Pressure

Figure 5 shows the sensor output signal relative to pressure input. Typical, minimum, and maximum output curves are shown for operation over a temperature range of 0° to 85°C. (The output will saturate outside of the specified pressure range.)

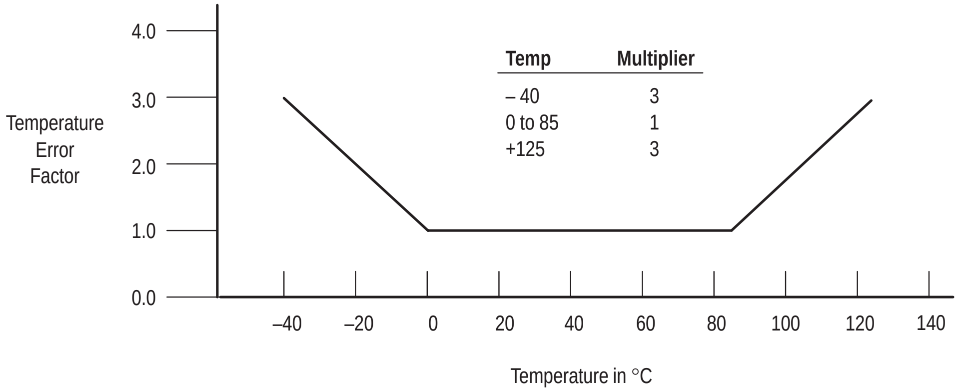
A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the sensor diaphragm. The MPX4101A/MPXT4101A series pressure sensor operating characteristics, and internal reliability and qualification tests are based on use of dry air as the pressure media. Media, other than dry air, may have adverse effects on sensor performance and long–term reliability. Contact the factory for information regarding media compatibility in your application.

Transfer Function (MPX4101A, MPXT4101A)

Nominal Transfer Value: $V_{out} = V_S\,(P \times 0.01059 - 0.10941)$
$\pm$ (Pressure Error x Temp. Factor x 0.01059 x V_S)
$V_S = 5.1\ V \pm 0.25\ Vdc$

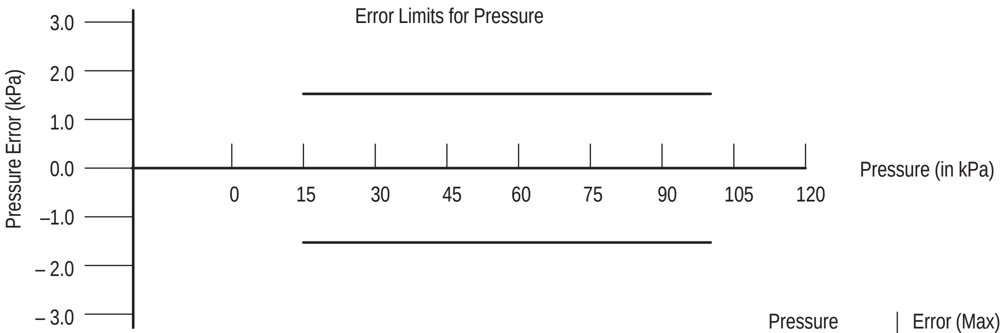
Temperature Error Band

MPX4101A, MPXT4101A Series



NOTE: The Temperature Multiplier is a linear response from 0° to –40°C and from 85° to 125°C.

Pressure Error Band



Pressure	Error (Max)
15 to 102 (kPa)	± 1.5 (kPa)

PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Motorola designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing fluorosilicone gel which protects the die from harsh media. The Motorola MPX pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using the table below:

Part Number	Case Type	Pressure (P1) Side Identifier
MPX4101A	867–08	Stainless Steel Cap
MPX4101AP	867B–04	Side with Port Marking
MPX4101AS	867E–03	Side with Port Attached
MPX4101ASX	867F–03	Side with Port Attached

ORDERING INFORMATION — UNIBODY PACKAGE

The MPX4101A series MAP silicon pressure sensors are available in the Basic Element, or with pressure port fittings that provide mounting ease and barbed hose connections.

Device Type	Options	Case Type	MPX Series	
			Order Number	Device Marking
Basic Element	Absolute, Element Only	867–08	MPX4101A	MPX4101A
Ported Elements	Absolute, Ported	867B–04	MPX4101AP	MPX4101AP
	Absolute, Stove Pipe Port	867E–03	MPX4101AS	MPX4101A
	Absolute, Axial Port	867F–03	MPX4101ASX	MPX4101A

ORDERING INFORMATION — TOP PISTON FIT PACKAGE

The MPXT4101A series MAP silicon pressure sensors are available to be shipped in rails.

Packing Options	Port Options	Leadform	Case No.	MPXT Series Order No.	Marking
Rails	Element	84°	473A–01	MPXT4101A7U	MPXT4101A

MOTOROLA
SEMICONDUCTOR TECHNICAL DATA

MPX4105A
MPXT4105A
SERIES

Motorola Preferred Device

Manifold Absolute Pressure Sensor On-Chip Signal Conditioned, 0.3 V to 4.9 V Output, Temperature Compensated & Calibrated

SILICON
PRESSURE SENSOR
15 to 105 kPa

The Motorola MPX4105A/MPXT4105A 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, bipolar 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.

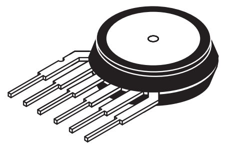
Features

- 1.8% Maximum Error Over 0° to 85°C
- Specifically Designed for Intake Manifold Absolute Pressure Sensing in Engine Control Systems
- Ideally Suited for Direct Microprocessor Interfacing
- Temperature Compensated Over –40 to +125°C
- Durable Epoxy Unibody Element or Surface Mount Package
- Also Ideal for Non–Automotive Applications

Application Examples

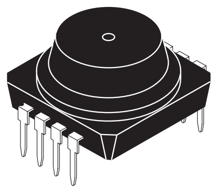
- Manifold Sensing for Automotive Systems

UNIBODY PACKAGE



MPX4105A
BASIC CHIP CARRIER ELEMENT
CASE 867–08, STYLE 1

TOP PISTON FIT PACKAGE



MPXT4105A
BASIC ELEMENT
CASE 473A–01, STYLE 2

PIN NUMBER

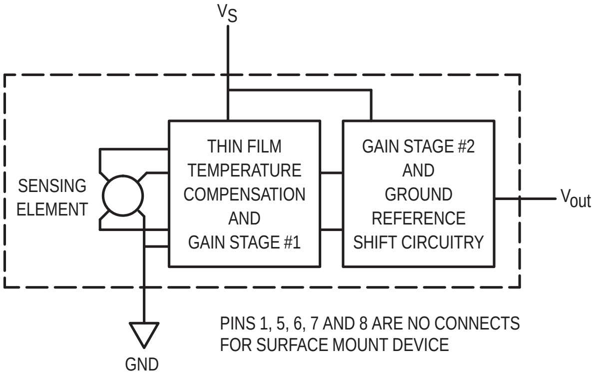
1	V_{out}	4	N/C
2	Gnd	5	N/C
3	V_S	6	N/C

NOTE: Pins 4, 5, and 6 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the Lead.

PIN NUMBER

1	N/C	5	N/C
2	V_S	6	N/C
3	Gnd	7	N/C
4	V_{out}	8	N/C

NOTE: Pins 1, 5, 6, 7, and 8 are not device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the Lead.



PINS 1, 5, 6, 7 AND 8 ARE NO CONNECTS FOR SURFACE MOUNT DEVICE

PINS 4, 5 AND 6 ARE NO CONNECTS FOR UNIBODY DEVICE

Figure 1. Fully Integrated Pressure Sensor Schematic

The MPX4105A/MPXT4105A series piezoresistive transducer is a state–of–the–art, monolithic, signal conditioned, silicon pressure sensor. This sensor 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 block diagram of the internal circuitry integrated on a pressure sensor chip.

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

MPX4105A, MPXT4105A SERIES OPERATING CHARACTERISTICS (V_S = 5.1 Vdc, T_A = 25°C unless otherwise noted)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range		P_{OP}	15	—	105	kPa
Supply Voltage(2)		V_S	4.85	5.1	5.35	Vdc
Supply Current		I_o	—	7.0	10	mAdc
Minimum Pressure Offset(3)	(0 to 85°C)	V_{off}	0.184	0.306	0.428	Vdc
Full Scale Output(4)	(0 to 85°C)	V_{FSO}	4.804	4.896	4.988	Vdc
Full Scale Span(5)	(0 to 85°C)	V_{FSS}	—	4.590	—	Vdc
Accuracy(6)	(0 to 85°C)	—	—	—	±1.8	$\%V_{FSS}$
Sensitivity		$\Delta V/\Delta P$	—	51	—	mV/kPa
Response Time(7)		t_R	—	1.0	—	ms
Output Source Current at Full Scale Output		I_{o+}	—	0.1	—	mAdc
Warm–up Time(8)		—	—	15	—	ms
Offset Stability(9)		—	—	±0.65	—	$\%V_{FSS}$

MECHANICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Weight, Basic Element (Case 867)	—	—	4.0	—	Grams
Weight, Basic Element (Case 473)	—	—	2.0	—	Grams
Cavity Volume	—	—	—	0.01	IN^3
Volumetric Displacement	—	—	—	0.001	IN^3
Common Mode Line Pressure	—	—	—	690	kPa

NOTES:

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy is the deviation in actual output from nominal output over the entire pressure range and temperature range as a percent of span at 25°C due to all sources of error including the following:

• Linearity:	Output deviation from a straight line relationship with pressure over the specified pressure range.
• Temperature Hysteresis:	Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with minimum specified pressure applied.
• Pressure Hysteresis:	Output deviation at any pressure within the specified range, when this pressure is cycled to and from minimum or maximum rated pressure at 25°C.
• TcSpan:	Span deviation per °C over the temperature range of 0° to 85°C, as a percent of span at 25°C.
• TcOffset:	Output deviation per °C with minimum pressure applied, over the temperature range of 0° to 85°C.

7. Response Time is defined as the time 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.
8. Warm–up Time is defined as the time required for the product to meet the specified output voltage.
9. Offset Stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.
10. Decoupling circuit shown in Figure 2 required to meet specification.

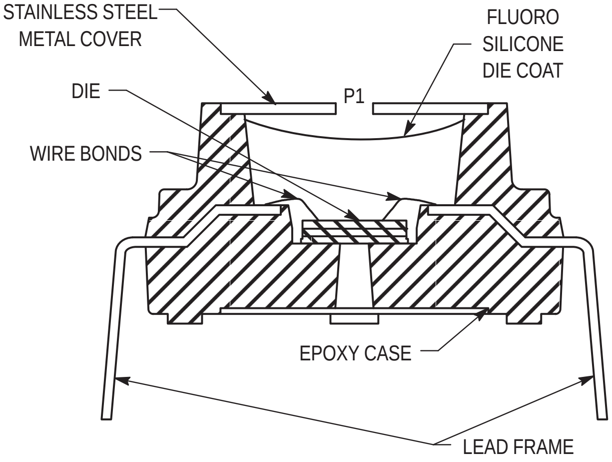


Figure 2. Cross–Sectional Diagram (not to scale)

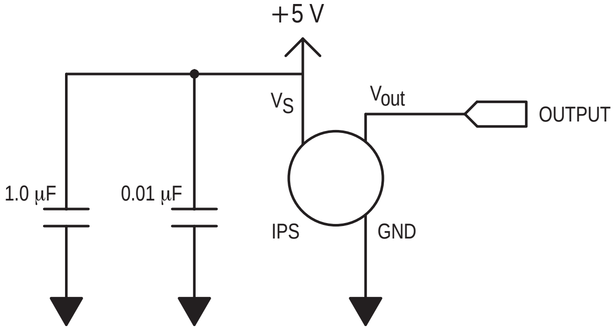


Figure 3. Recommended Power Supply Decoupling. For output filtering recommendations, please refer to Application Note AN1646.

Figure 2 illustrates an absolute sensing chip in the basic chip carrier (Case 473).

A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the sensor diaphragm. The MPX4105A/MPXT4105A series pressure sensor operating characteristics, 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 reliability. Contact the factory for information regarding media compatibility in your application.

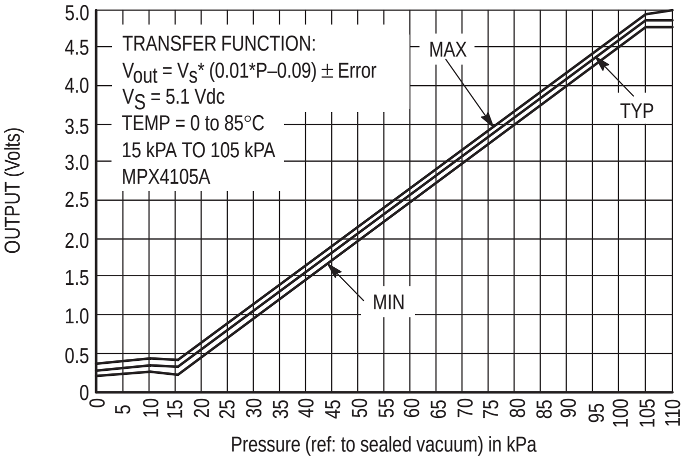


Figure 4. Output versus Absolute Pressure

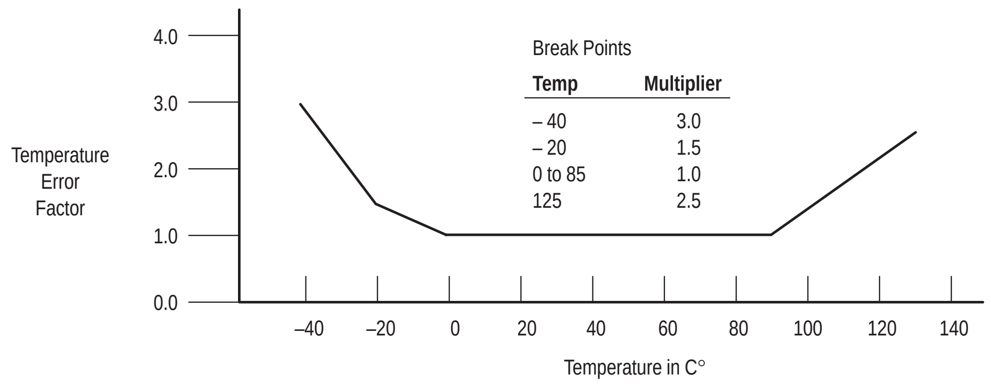
Figure 4 shows the sensor output signal relative to pressure input. Typical, minimum, and maximum output curves are shown for operation over a temperature range of 0° to 85°C. (The output will saturate outside of the specified pressure range.)

Transfer Function (MPX4105A, MPXT4105A)

Nominal Transfer Value: $V_{out} = V_S$ (P x 0.01 – 0.09)
+/– (Pressure Error x Temp. Factor x 0.01 x V_S)
V_S = 5.1 V ± 0.25 Vdc

Temperature Error Band

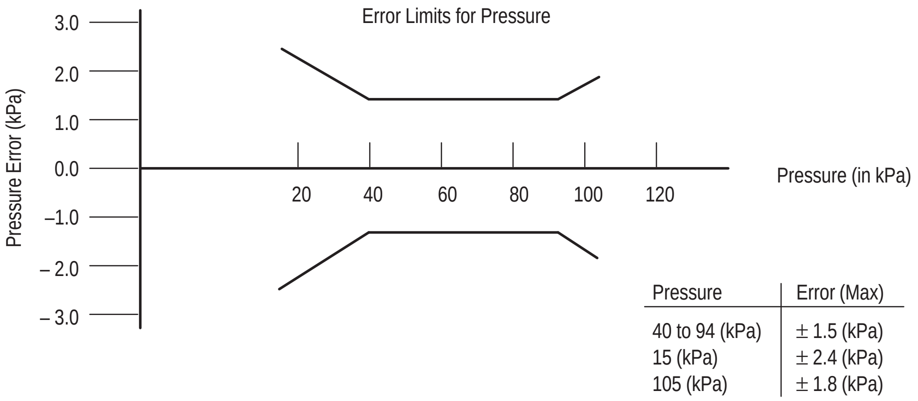
MPX4105A Series



Temp	Multiplier
– 40	3.0
– 20	1.5
0 to 85	1.0
125	2.5

NOTE: The Temperature Multiplier is a linear response from –40°C to –20°C, –20°C to 0°C, and from 85°C to 125°C

Pressure Error Band



Pressure	Error (Max)
40 to 94 (kPa)	± 1.5 (kPa)
15 (kPa)	± 2.4 (kPa)
105 (kPa)	± 1.8 (kPa)

ORDERING INFORMATION — UNIBODY PACKAGE

The MPX4105A series MAP silicon pressure sensors are available in the basic element package that provide printed circuit board mounting ease.

Device Type	Options	Case No.	MPX Series Order No.	Marking
Basic Element	Absolute, Element	867–08	MPX4105A	MPX4105A

ORDERING INFORMATION — TOP PISTON FIT PACKAGE

The MPXT4105A series MAP silicon pressure sensors is available to be shipped in rails.

Packing Options	Port Options	Leadform	Case No.	MPXT Series Order No.	Marking
Rails	Element	84°	473A–01	MPXT4105A7U	MPXT4105A

MOTOROLA
SEMICONDUCTOR TECHNICAL DATA

MPX4115A
MPXS4115A
PPXA4115A
SERIES

OPERATING OVERVIEW
INTEGRATED
PRESSURE SENSOR
15 to 115 kPa (2.2 to 16.7 psi)
0.2 to 4.8 Volts Output

Preliminary Information

Altimeter or Barometer Applications Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

The Motorola MPX4115A/MPXS4115A series Manifold Absolute Pressure (MAP) sensor for engine control is designed to sense absolute air pressure.

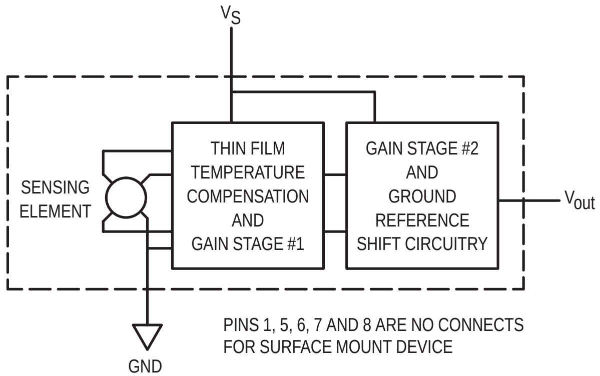
Motorola's MAP sensor integrates on–chip, bipolar op amp circuitry and thin film resistor networks to provide a high output signal and temperature compensation. The small form factor and high reliability of on–chip integration make the Motorola MAP sensor a logical and economical choice for the automotive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

Features

- 1.5% Maximum Error over 0° to 85°C
- Ideally suited for Microprocessor or Microcontroller–Based Systems
- Temperature Compensated from –40° to +125°C
- Durable Epoxy Unibody Element or Surface Mount Package

Application Examples

- Aviation Altimeters
- Industrial Controls
- Engine Control
- Weather Stations and Weather Reporting Devices

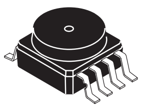


PINS 1, 5, 6, 7 AND 8 ARE NO CONNECTS FOR SURFACE MOUNT DEVICE

PINS 4, 5 AND 6 ARE NO CONNECTS FOR UNIBODY DEVICE

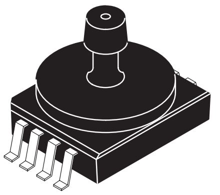
Figure 1. Fully Integrated Pressure Sensor Schematic

SMALL OUTLINE PACKAGE



PPXA4115A
CASE 482–01

SURFACE MOUNT PACKAGE

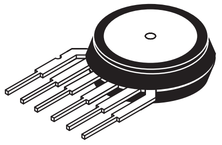


MPXS4115A
AXIAL PORT OPTION
CASE 471B–01, STYLE 1

PIN NUMBER							
1	N/C	3	Gnd	5	N/C	7	N/C
2	V_S	4	V_{out}	6	N/C	8	N/C

NOTE: Pins 1, 5, 6, 7, and 8 are internal device connections. Do not connect to external circuitry or ground.

UNIBODY PACKAGE



MPX4115A
BASIC CHIP CARRIER ELEMENT
CASE 867–08, STYLE 1

PIN NUMBER			
1	V_{out}	4	N/C
2	Gnd	5	N/C
3	V_S	6	N/C

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

The MPX4115A/MPXS4115A series piezoresistive transducer is a state–of–the–art, monolithic, signal conditioned, silicon pressure sensor. This sensor 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 block diagram of the internal circuitry integrated on a pressure sensor chip.

REV 1

MAXIMUM RATINGS(1)

Parametrics	Symbol	Value	Units
Overpressure(9) (P1 > P2)	P_{max}	400	kPa
Burst Pressure(9) (P1 > P2)	P_{burst}	1000	kPa
Storage Temperature	T_{stg}	–40° to +125°	°C
Operating Temperature	T_A	–40° to +125°	°C

1. T_C = 25°C unless otherwise noted.
2. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

OPERATING CHARACTERISTICS (V_S = 5.1 Vdc, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range		P_{OP}	15	—	115	kPa
Supply Voltage(1)		V_S	4.85	5.1	5.35	Vdc
Supply Current		I_o	—	7.0	10	mAdc
Minimum Pressure Offset(2) @ V_S = 5.1 Volts	(0 to 85°C)	V_{off}	0.135	0.204	0.273	Vdc
Full Scale Output(3) @ V_S = 5.1 Volts	(0 to 85°C)	V_{FSO}	4.725	4.794	4.863	Vdc
Full Scale Span(4) @ V_S = 5.1 Volts	(0 to 85°C)	V_{FSS}	4.521	4.590	4.659	Vdc
Accuracy(5)	(0 to 85°C)	—	—	—	±1.5	$\%V_{FSS}$
Sensitivity		V/P	—	45.9	—	mV/kPa
Response Time(6)		t_R	—	1.0	—	mS
Output Source Current at Full Scale Output		I_{o+}	—	0.1	—	mAdc
Warm–Up Time(7)		—	—	20	—	mSec
Offset Stability(8)		—	—	±0.5	—	$\%V_{FSS}$

Decoupling circuit shown in Figure 2 required to meet Electrical Specifications.

MECHANICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Weight, Basic Element (Case 471)	—	—	1.5	—	Grams
Weight, Basic Element (Case 867)	—	—	4.0	—	Grams

NOTES:

1. Device is ratiometric within this specified excitation range.
2. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
3. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
4. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
5. Accuracy is the deviation in actual output from nominal output over the entire pressure range and temperature range as a percent of span at 25°C due to all sources of error including the following:

• Linearity:	Output deviation from a straight line relationship with pressure over the specified pressure range.
• Temperature Hysteresis:	Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
• Pressure Hysteresis:	Output deviation at any pressure within the specified range, when this pressure is cycled to and from minimum or maximum rated pressure at 25°C.
• TcSpan:	Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
• TcOffset:	Output deviation with minimum pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.

6. Response Time is defined as the time 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.
7. Warm–up is defined as the time required for the product to meet the specified output voltage after the pressure has been stabilized.
8. Offset stability is the product's output deviation when subjected to 1000 cycles of Pulsed Pressure, Temperature Cycling with Bias Test.
9. Exposure beyond these limits may cause permanent damage or degradation to the device.

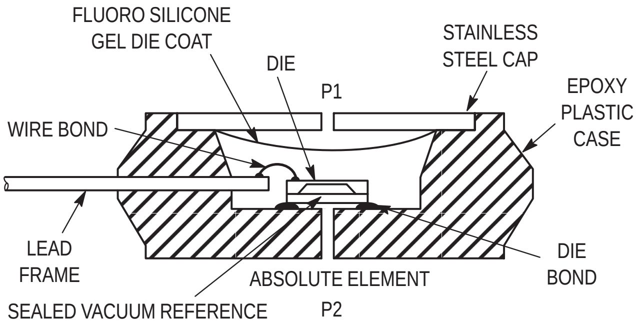


Figure 2. Cross Sectional Diagram (not to scale)

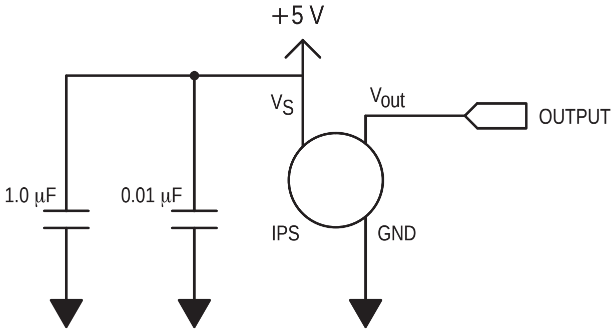


Figure 3. Recommended Power Supply Decoupling. For output filtering recommendations, please refer to Application Note AN1646.

Figure 2 illustrates the absolute sensing chip in the basic chip carrier (Case 867).

This surface mount package (Case 471–01) is an absolute sensing configuration package.

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

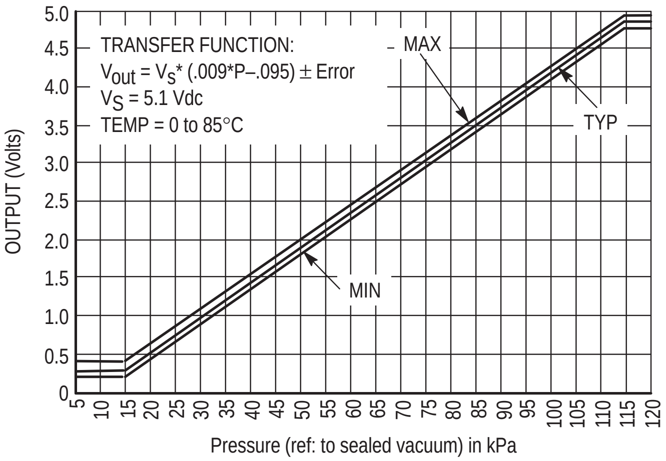


Figure 4. Output versus Absolute Pressure

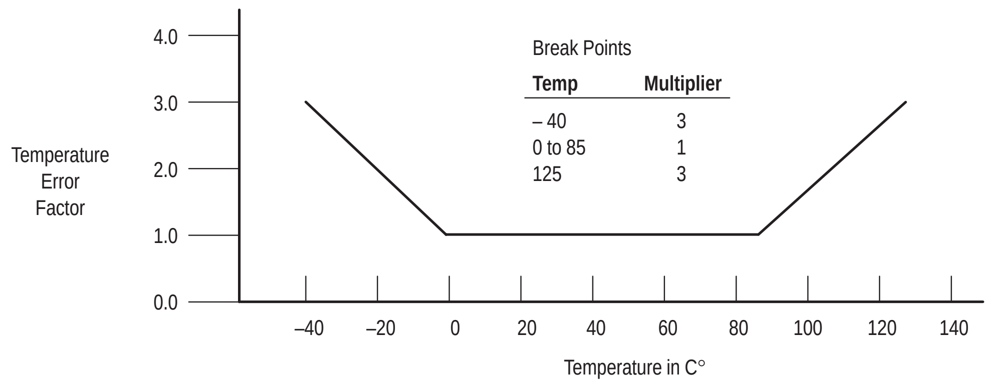
Figure 4 shows the sensor output signal relative to pressure input. Typical minimum and maximum output curves are shown for operation over 0 to 85°C temperature range. (Output will saturate outside of the rated pressure range.)

A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm. The MPX4115A/MPXS4115A series pressure sensor operating characteristics, 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 reliability. Contact the factory for information regarding media compatibility in your application.

Transfer Function (MPX4115A, MPXS4115A)

Nominal Transfer Value: $V_{out} = V_S \times (0.009 \times P - 0.095)$
$\pm$ (Pressure Error x Temp. Factor x $0.009 \times V_S$)
$V_S = 5.1 \pm 0.25$ Vdc

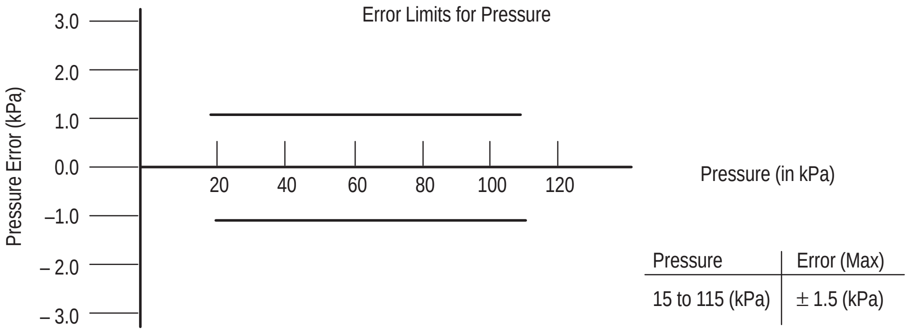
Temperature Error Band



Temp	Multiplier
– 40	3
0 to 85	1
125	3

NOTE: The Temperature Multiplier is a linear response from 0°C to –40°C and from 85°C to 125°C

Pressure Error Band



Pressure	Error (Max)
15 to 115 (kPa)	± 1.5 (kPa)

ORDERING INFORMATION — SURFACE MOUNT PACKAGE

The MPX4115A BAP Sensor is available in the Basic Element package or with pressure port fittings that provide mounting ease and barbed hose connections.

Depending upon the Options, the MPXS4115A pressure sensors are available shipped in Sleeves, Tape and Reel, and Trays.

Packing Options	Port Options	Leadform	Case No.	MPXS Series Order No.	Marking
Sleeve Pack	Axial	Gull Wing	471B–01	MPXS4115AC6U	MPXS4115A
Sleeve Pack	—	Gull Wing	471–01	MPXS4115A6U	MPXS4115A
Tape and Reel	—	Gull Wing	471–01	MPXS4115A6T1	MPXS4115A

ORDERING INFORMATION — UNIBODY PACKAGE

Device Type	Options	Case No.	MPX Series Order No.	Marking
Basic Element	Absolute, Element Only	867–08	MPX4115A	MPX4115A
Ported Elements	Absolute, Ported	867B–04	MPX4115AP	MPX4115AP
	Absolute, Stove Pipe Port	867E–03	MPX4115AS	MPX4115A
	Absolute, Axial Port	867F–03	MPX4115ASX	MPX4115A

ORDERING INFORMATION — SMALL OUTLINE PACKAGE

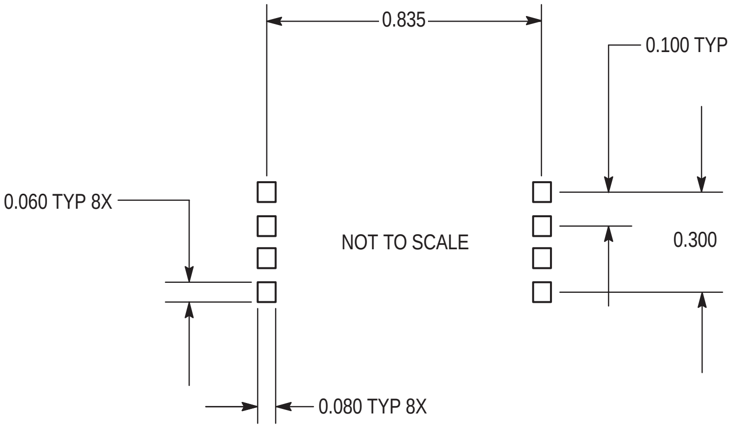
Small outline package is currently available as a prototype status device. Please contact factory for more information or mechanical samples.

Device	Case No.	Packing Options	Marking
PPXA4115A6U	482–01	Rails	PPXA4115A
PPXA4115AC6U	482A–01	Rails	PPXA4115A

INFORMATION FOR USING THE SURFACE MOUNT PACKAGE

MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the semiconductor packages must be the correct size to ensure proper solder connection interface between the board and the package. With the correct pad geometry, the packages will self align when subjected to a solder reflow process.



MOTOROLA
SEMICONDUCTOR TECHNICAL DATA

MPX4200 SERIES

INTEGRATED PRESSURE SENSOR
20 to 200 kPa (2.9 to 29 psi)
0.3 to 4.9 V OUTPUT

Integrated Silicon Pressure Sensor Manifold Absolute Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

The Motorola MPX4200 series Manifold Absolute Pressure (MAP) sensor for turbo boost 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.

The MPX4200 series sensor integrates on–chip, bipolar op amp circuitry and thin film resistor networks to provide a high level analog output signal and temperature compensation. The small form factor and reliability of on–chip integration make the Motorola MAP sensor a logical and economical choice for automotive system designers.

Features

- 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 Reduction in Weight and Volume Compared to Existing Hybrid Modules
- Durable Epoxy Unibody Element
- Ideal for Non–Automotive Applications

Application Examples

- Manifold Sensing for Automotive Systems

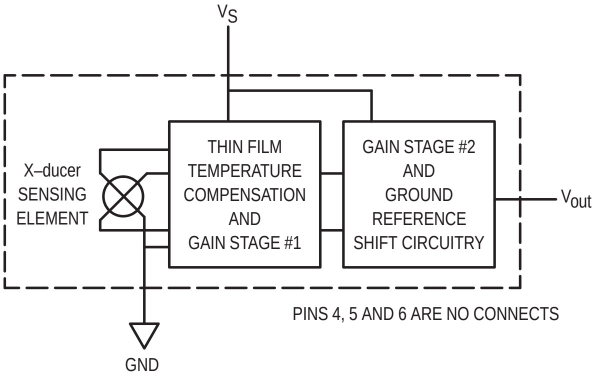
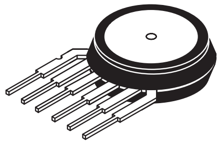
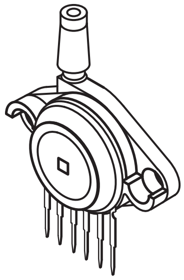


Figure 1. Fully Integrated Pressure Sensor Schematic



BASIC CHIP CARRIER ELEMENT
CASE 867–08, STYLE 1



PORT OPTION
CASE 867B–04, STYLE 1

PIN NUMBER			
1	V_{out}	4	N/C
2	Gnd	5	N/C
3	V_S	6	N/C

NOTE: Pins 4, 5, and 6 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the Lead.

REV 1

MAXIMUM RATINGS(1)

Parametrics	Symbol	Value	Unit
Overpressure(2) (P1 > P2)	P_{max}	400	kPa
Burst Pressure(2) (P1 > P2)	P_{burst}	1000	kPa
Storage Temperature	T_{stg}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C

1. T_C = 25°C unless otherwise noted.
2. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

OPERATING CHARACTERISTICS (V_S = 5.1 Vdc, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range(1)		P_{OP}	20	—	200	kPa
Supply Voltage(2)		V_S	4.85	5.1	5.35	Vdc
Supply Current		I_o	—	7.0	10	mAdc
Minimum Pressure Offset(3) @ V_S = 5.1 Volts	(0 to 85°C)	V_{off}	0.199	0.306	0.413	Vdc
Full Scale Output(4) @ V_S = 5.1 Volts	(0 to 85°C)	V_{FSO}	4.725	4.896	4.978	Vdc
Full Scale Span(5) @ V_S = 5.1 Volts	(0 to 85°C)	V_{FSS}	—	4.590	—	Vdc
Accuracy(6)	(0 to 85°C)	—	—	—	±1.5	$\%V_{FSS}$
Sensitivity		V/P	—	25.5	—	mV/kPa
Response Time(7)		t_R	—	1.0	—	ms
Output Source Current at Full Scale Output		I_o+	—	0.1	—	mAdc
Warm–Up Time(8)		—	—	20	—	ms
Offset Stability(9)		—	—	±0.5	—	$\%V_{FSS}$

Decoupling circuit shown in Figure 3 required to meet electrical specifications.

MECHANICAL CHARACTERISTICS

Characteristics	Symbol	Min	Typ	Max	Unit
Weight, Basic Element (Case 867)	—	—	4.0	—	Grams
Common Mode Line Pressure(10)	—	—	—	690	kPa

NOTES:

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:

• Linearity:	Output deviation from a straight line relationship with pressure over the specified pressure range.
• Temperature Hysteresis:	Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
• Pressure Hysteresis:	Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
• TcSpan:	Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
• TcOffset:	Output deviation with minimum rated pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
• Variation from Nominal:	The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS} at 25°C.

7. Response Time is defined as the time 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.
8. Warm–up is defined as the time required for the product to meet the specified output voltage after the Pressure has been stabilized.
9. Offset stability is the product’s output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.
10. Common mode pressures beyond what is specified may result in leakage at the case–to–lead interface.

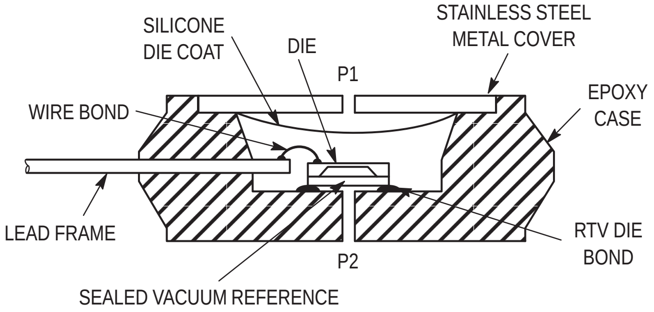


Figure 2. Cross–Sectional Diagram
(Not to Scale)

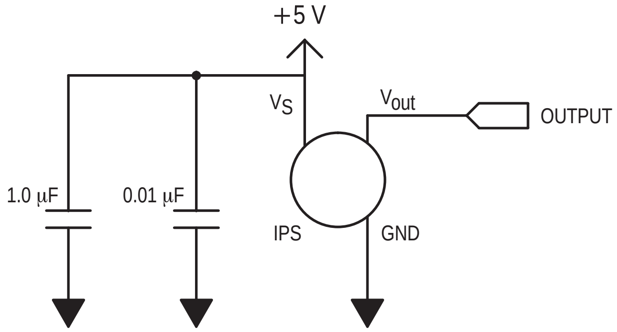


Figure 3. Recommended Power Supply Decoupling.
For output filtering recommendations, please refer
to Application Note AN1646.

Figure 2 illustrates the absolute sensing chip in the basic chip carrier (Case 867). A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the sensor diaphragm. The MPX4200A 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 reliability. Contact the factory for information regarding media compatibility in your application.

Figure 4 shows the sensor output signal relative to pressure input. Typical, minimum, and maximum output curves are shown for operation over temperature range of 0° to 85°C. (The output will saturate outside of the specified pressure range.)

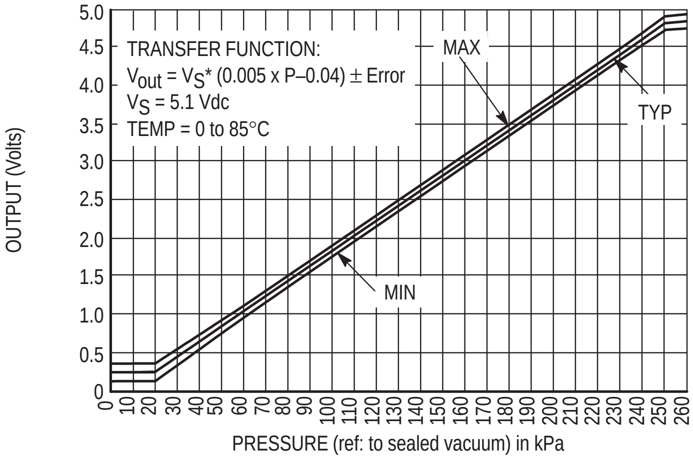


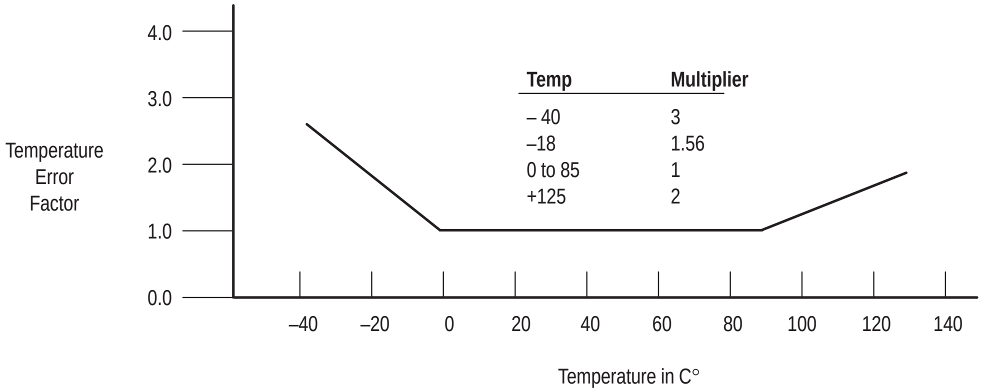
Figure 4. Output versus Absolute Pressure

Transfer Function (MPX4200A)

Nominal Transfer Value: $V_{out} = V_S \times (0.005 \times P - 0.04)$
$\pm$ (Pressure Error x Temp. Factor x 0.005 x V_S)
$V_S = 5.1 \pm 0.25$ Vdc

Temperature Error Band

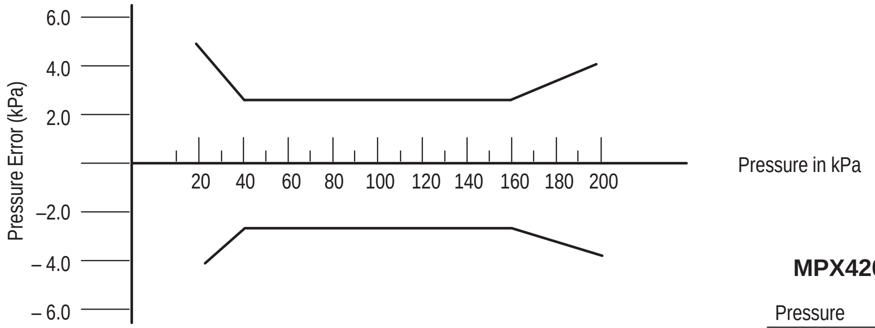
MPX4200A Series



Temp	Multiplier
– 40	3
–18	1.56
0 to 85	1
+125	2

NOTE: The Temperature Multiplier is a linear response.

Pressure Error Band



MPX4200A Series

Pressure	Error (Max)
20 kPa	± 4.2 (kPa)
40 kPa	± 2.4 (kPa)
160 kPa	± 2.4 (kPa)
200 kPa	± 3.2 (kPa)

ORDERING INFORMATION

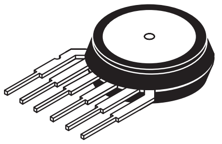
The MPX4200A series Turbo MAP silicon pressure sensors are available in the basic element package or with pressure port fittings that provide mounting ease and barbed hose connections.

Device Type	Options	Case No.	MPX Series Order No.	Marking
Basic Element	Absolute, Element	Case 867–08	MPX4200A	MPX4200A
Ported Elements	Absolute, Ported	Case 867B–04	MPX4200AP	MPX4200AP
	Absolute, Stove Pipe Port	Case 867E–03	MPX4200AS	MPX4200A
	Absolute, Axial Port	Case 867F–03	MPX4200ASX	MPX4200A

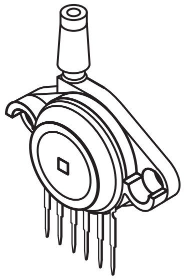
**MPX4250A
SERIES**

Integrated Silicon Pressure Sensor Manifold Absolute Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

**INTEGRATED
PRESSURE SENSOR
20 to 250 kPa (2.9 to 36.3 psi)
0.2 to 4.9 V OUTPUT**



**BASIC CHIP
CARRIER ELEMENT
CASE 867–08, STYLE 1**



**PORT OPTION
CASE 867B–04, STYLE 1**

PIN NUMBER			
1	V_{out}	4	N/C
2	Gnd	5	N/C
3	V_S	6	N/C

NOTE: Pins 4, 5, and 6 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the Lead.

The Motorola MPX4250A series Manifold Absolute Pressure (MAP) sensor for turbo boost 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.

The MPX4250A series sensor integrates on–chip, bipolar op amp circuitry and thin film resistor networks to provide a high level analog output signal and temperature compensation. The small form factor and reliability of on–chip integration make the Motorola MAP sensor a logical and economical choice for automotive system designers.

Features

- 1.5% Maximum Error Over 0° to 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 Reduction in Weight and Volume Compared to Existing Hybrid Modules
- Durable Epoxy Unibody Element
- Ideal for Non–Automotive Applications

Application Examples

- Manifold Sensing for Automotive Systems

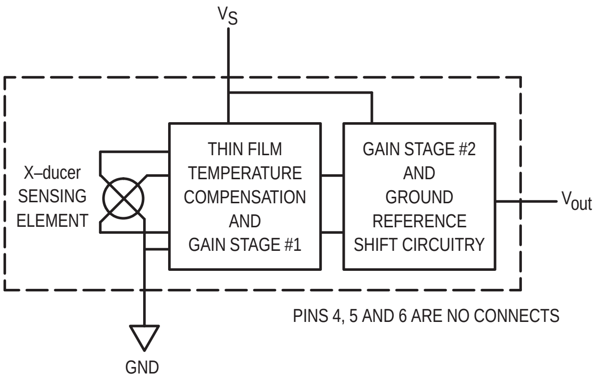


Figure 1. Fully Integrated Pressure Sensor Schematic

(Replaces MPX4250)

MAXIMUM RATINGS(1)

Parametrics	Symbol	Value	Unit
Overpressure(2) (P1 > P2)	P_{max}	400	kPa
Burst Pressure(2) (P1 > P2)	P_{burst}	1000	kPa
Storage Temperature	T_{stg}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C

1. T_C = 25°C unless otherwise noted.
2. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

OPERATING CHARACTERISTICS (V_S = 5.1 Vdc, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range(1)		P_{OP}	20	—	250	kPa
Supply Voltage(2)		V_S	4.85	5.1	5.35	Vdc
Supply Current		I_o	—	7.0	10	mAdc
Minimum Pressure Offset(3) @ V_S = 5.1 Volts	(0 to 85°C)	V_{off}	0.133	0.204	0.274	Vdc
Full Scale Output(4) @ V_S = 5.1 Volts	(0 to 85°C)	V_{FSO}	4.826	4.896	4.966	Vdc
Full Scale Span(5) @ V_S = 5.1 Volts	(0 to 85°C)	V_{FSS}	—	4.692	—	Vdc
Accuracy(6)	(0 to 85°C)	—	—	—	±1.5	$\%V_{FSS}$
Sensitivity		$\Delta V/\Delta P$	—	20	—	mV/kPa
Response Time(7)		t_R	—	1.0	—	ms
Output Source Current at Full Scale Output		I_o+	—	0.1	—	mAdc
Warm–Up Time(8)		—	—	20	—	ms
Offset Stability(9)		—	—	±0.5	—	$\%V_{FSS}$

Decoupling circuit shown in Figure 3 required to meet electrical specifications.

MECHANICAL CHARACTERISTICS

Characteristics	Symbol	Min	Typ	Max	Unit
Weight, Basic Element (Case 867)	—	—	4.0	—	Grams
Common Mode Line Pressure(10)	—	—	—	690	kPa

NOTES:

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:
    - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
    - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
    - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
    - TcSpan: Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
    - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
    - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.
7. Response Time is defined as the time 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.
8. Warm–up is defined as the time required for the product to meet the specified output voltage after the Pressure has been stabilized.
9. Offset stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.
10. Common mode pressures beyond what is specified may result in leakage at the case–to–lead interface.

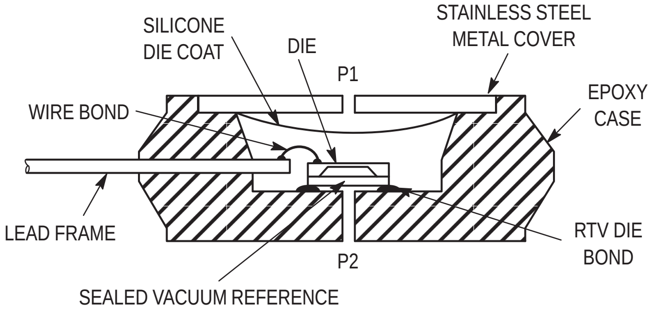


Figure 2. Cross–Sectional Diagram (Not to Scale)

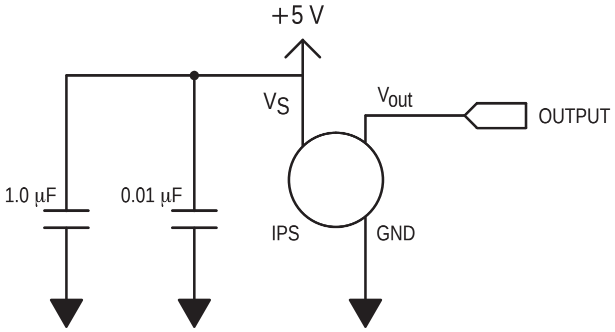


Figure 3. Recommended Power Supply Decoupling. For output filtering recommendations, please refer to Application Note AN1646.

Figure 2 illustrates the absolute sensing chip in the basic chip carrier (Case 867). A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the sensor diaphragm. The MPX4250A 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 reliability. Contact the factory for information regarding media compatibility in your application.

Figure 4 shows the sensor output signal relative to pressure input. Typical, minimum, and maximum output curves are shown for operation over temperature range of 0° to 85°C. (The output will saturate outside of the specified pressure range.)

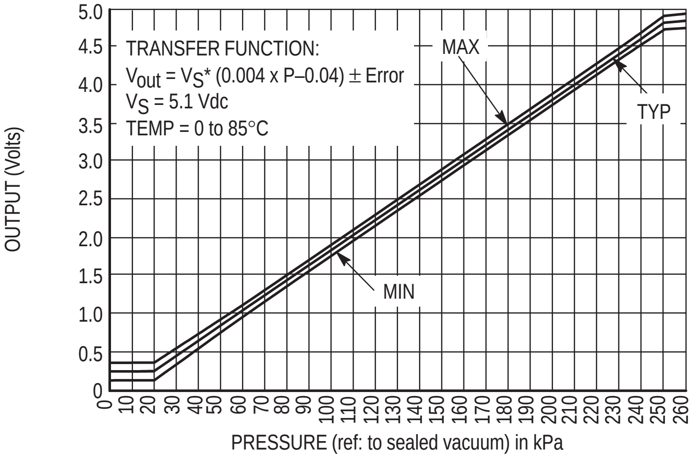


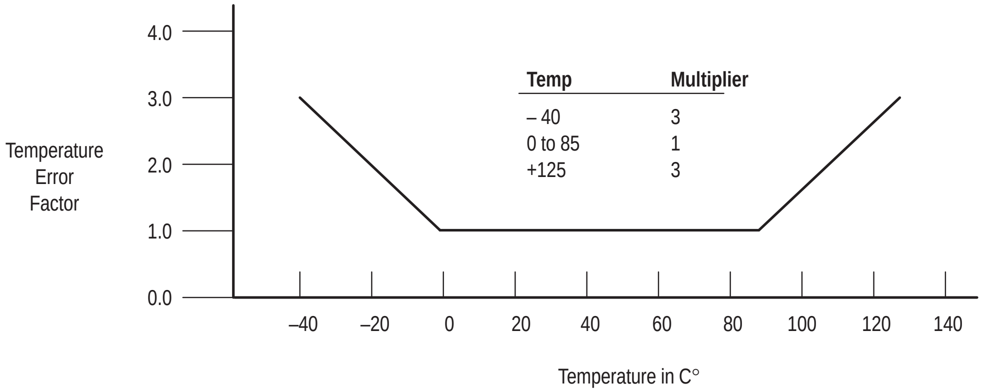
Figure 4. Output versus Absolute Pressure

Transfer Function

Nominal Transfer Value: $V_{out} = V_S\,(P \times 0.004 - 0.04)$
$\pm\,(\text{Pressure Error} \times \text{Temp. Factor} \times 0.004 \times V_S)$
$V_S = 5.1\ \text{V} \pm 0.25\ \text{Vdc}$

Temperature Error Band

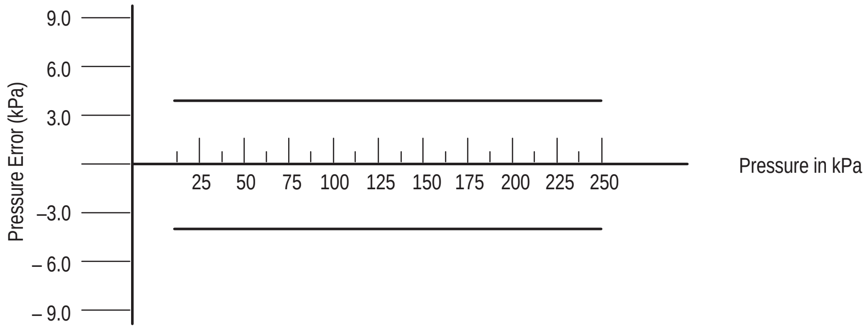
MPX4250A Series



Temp	Multiplier
– 40	3
0 to 85	1
+125	3

NOTE: The Temperature Multiplier is a linear response from 0° to –40°C and from 85° to 125°C.

Pressure Error Band



Pressure	Error (Max)
20 to 250 kPa	± 3.45 (kPa)

ORDERING INFORMATION

The MPX4250A series Turbo MAP 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	Case 867–08	MPX4250A	MPX4250A
Ported Elements	Absolute, Ported	Case 867B–04	MPX4250AP	MPX4250AP
	Absolute, Stove Pipe Port	Case 867E–03	MPX4250AS	MPX4250A
	Absolute, Axial Port	Case 867F–03	MPX4250ASX	MPX4250A

MOTOROLA
SEMICONDUCTOR TECHNICAL DATA

MPX4250D SERIES

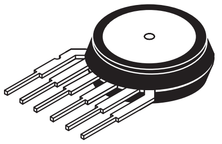
Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

The MPX4250D 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 transducer combines advanced micromachining techniques, thin–film metallization, and bipolar processing to provide an accurate, high level analog output signal that is proportional to the applied pressure.

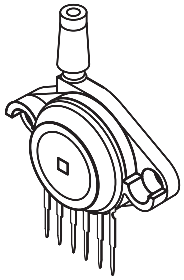
Features

- Differential and Gauge Applications Only
- 1.4% Maximum Error Over 0° to 85°C
- Ideally suited for Microprocessor Interfacing
- Patented Silicon Shear Stress Strain Gauge
- Temperature Compensated Over –40° to +125°C
- Offers Reduction in Weight and Volume Compared to Existing Hybrid Modules
- Durable Epoxy Unibody Element

OPERATING OVERVIEW
INTEGRATED
PRESSURE SENSOR
0 to 250 kPa (0 to 36.3 psi)
0.2 to 4.9 Volts Output



BASIC CHIP
CARRIER ELEMENT
CASE 867–08, STYLE 1



PORT OPTION
CASE 867B–04, STYLE 1

PIN NUMBER			
1	V_{out}	4	N/C
2	Gnd	5	N/C
3	V_S	6	N/C

NOTE: Pins 4, 5, and 6 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the Lead.

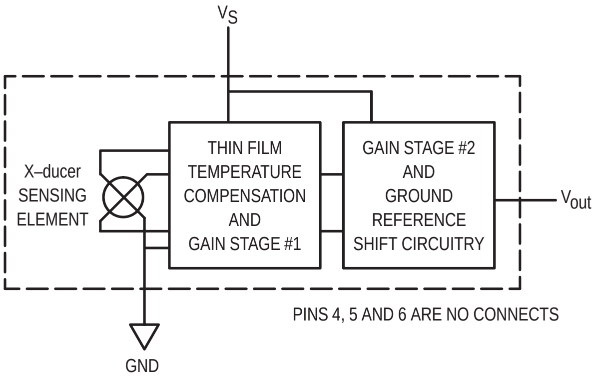


Figure 1. Fully Integrated Pressure Sensor Schematic

MAXIMUM RATINGS(1)

Parametrics	Symbol	Value	Unit
Overpressure(2) (P1 > P2)	P_{max}	400	kPa
Burst Pressure(2) (P1 > P2)	P_{burst}	1000	kPa
Storage Temperature	T_{stg}	–40° to +125°	°C
Operating Temperature	T_A	–40° to +125°	°C

1. T_C = 25°C unless otherwise noted.
2. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

REV 2

OPERATING CHARACTERISTICS (V_S = 5.1 Vdc, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range(1)		P_{OP}	0	—	250	kPa
Supply Voltage(2)		V_S	4.85	5.1	5.35	Vdc
Supply Current		I_o	—	7.0	10	mAdc
Minimum Pressure Offset(3) @ V_S = 5.1 Volts	(0 to 85°C)	V_{OFF}	0.139	0.204	0.269	Vdc
Full Scale Output(4) @ V_S = 5.1 Volts	(0 to 85°C)	V_{FSO}	4.844	4.909	4.974	Vdc
Full Scale Span(5) @ V_S = 5.1 Volts	(0 to 85°C)	V_{FSS}	—	4.705	—	Vdc
Accuracy(6)	(0 to 85°C)	—	—	—	±1.4	$\%V_{FSS}$
Sensitivity		$\Delta V/\Delta P$	—	18.8	—	mV/kPa
Response Time(7)		t_R	—	1.0	—	ms
Output Source Current at Full Scale Output		I_o+	—	0.1	—	mAdc
Warm–Up Time(8)		—	—	20	—	mSec
Offset Stability(9)		—	—	±0.5	—	$\%V_{FSS}$

MECHANICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Weight, Basic Element (Case 867)	—	—	4.0	—	Grams
Common Mode Line Pressure(10)	—	—	—	690	kPa

NOTES:

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:

Linearity:	Output deviation from a straight line relationship with pressure over the specified pressure range.
Temperature Hysteresis:	Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
Pressure Hysteresis:	Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
TcSpan:	Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
TcOffset:	Output deviation with minimum rated pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
Variation from Nominal:	The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.

7. Response Time is defined as the time 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.
8. Warm–up is defined as the time required for the product to meet the specified output voltage after the Pressure has been stabilized.
9. Offset stability is the product’s output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.
10. Common mode pressures beyond what is specified may result in leakage at the case–to–lead interface.

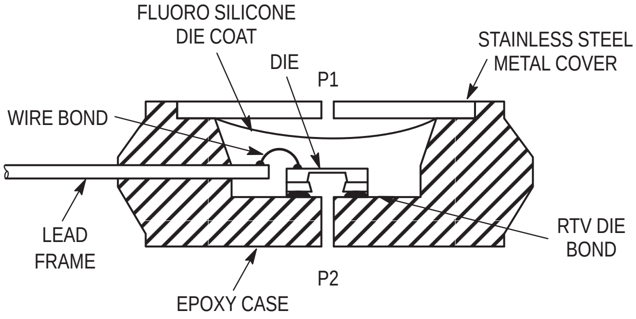


Figure 2. Cross–Sectional Diagram (Not to Scale)

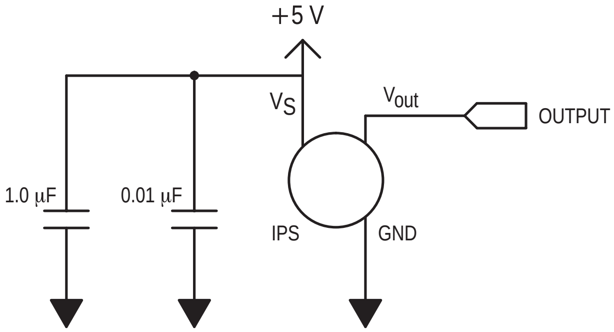


Figure 3. Recommended Power Supply Decoupling. For output filtering recommendations, please refer to Application Note AN1646.

Figure 2 illustrates the Differential/Gauge Pressure Sensing Chip in the basic chip carrier (Case 867). A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the sensor diaphragm.

The MPX4250D 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 reliability. Contact the factory for information regarding media compatibility in your application.

Figure 4 shows the sensor output signal relative to pressure input. Typical, minimum, and maximum output curves are shown for operation over a temperature range of 0° to 85°C using the decoupling circuit below. (The output will saturate outside of the specified pressure range.)

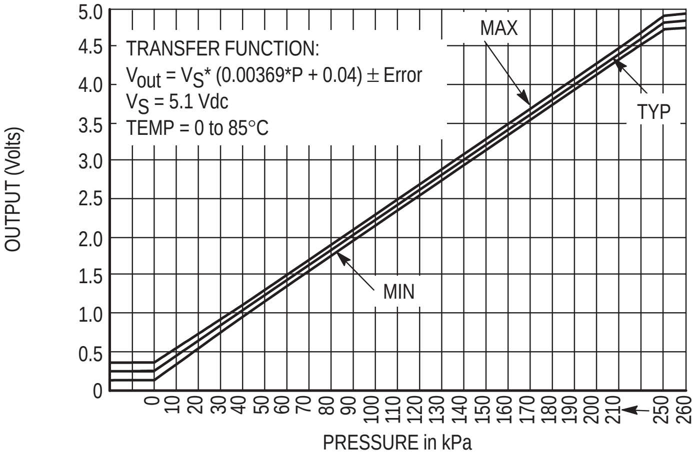
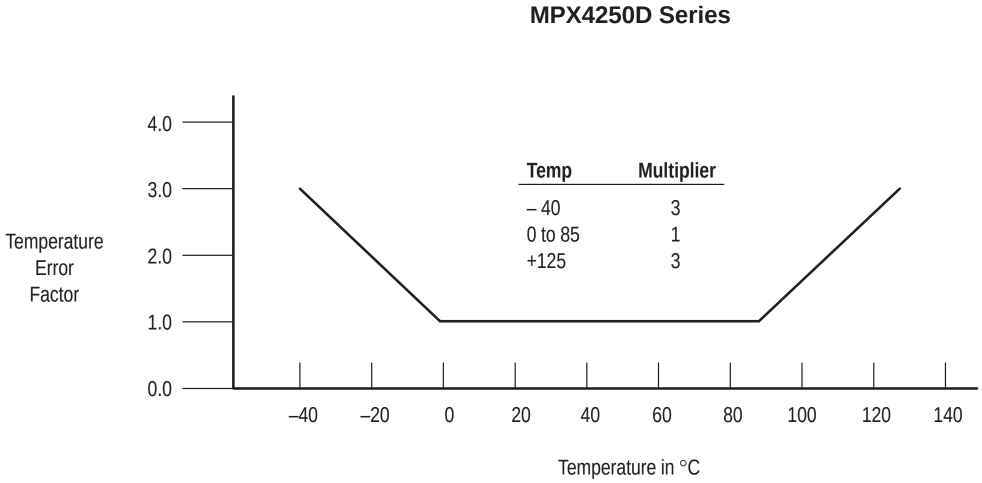


Figure 4. Output versus Differential Pressure

Transfer Function (MPX4250D)

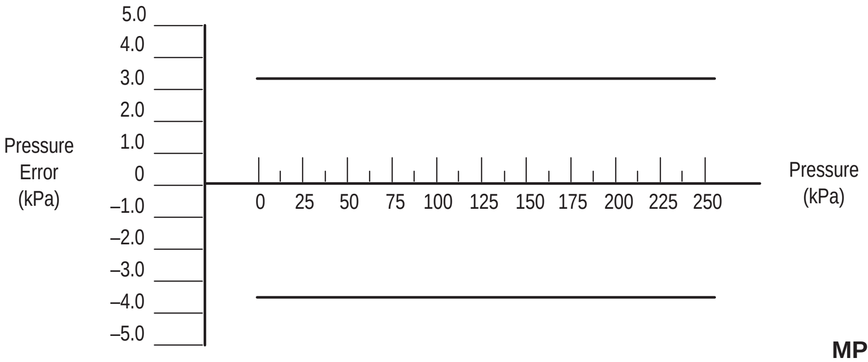
Nominal Transfer Value: $V_{out} = V_S \times (0.00369 \times P + 0.04)$
$\pm$ (Pressure Error x Temp. Factor x 0.00369 x V_S)
$V_S = 5.1 \pm 0.25$ Vdc

Temperature Error Band



NOTE: The Temperature Multiplier is a linear response from 0° to –40°C and from 85° to 125°C.

Pressure Error Band



MPX4250D Series

Pressure	Error (max)
0 to 250 kPa	± 3.45 kPa

ORDERING INFORMATION

The MPX4250D series 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	Differential/Gauge, Element	Case 867–08	MPX4250D	MPX4250D
Ported Elements	Differential/Gauge, Ported	Case 867B–04	MPX4250DP	MPX4250DP
	Differential/Gauge, Stove Pipe Port	Case 867E–03	MPX4250GS	MPX4250D
	Differential/Gauge, Axial Port	Case 867F–03	MPX4250GSX	MPX4250D

MPXT5006D SERIES

INTEGRATED PRESSURE SENSOR
0 to 6 kPa (0 to 0.87 psi)
0.2 to 4.7 V OUTPUT

Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

The MPXT5006D 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 sensor combines a highly sensitive implanted strain gauge with advanced micromachining techniques, thin–film metallization, and bipolar processing to provide an accurate, high level analog output signal that is proportional to the applied pressure.

Features

- Temperature Compensated over 10° to 60°C
- Ideally Suited for Microprocessor or Microcontroller–Based Systems
- Available in Gauge Configurations

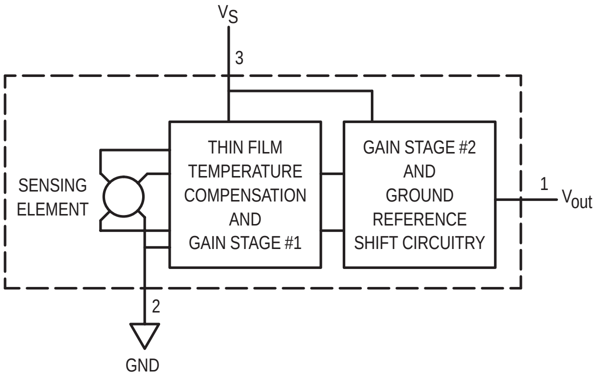
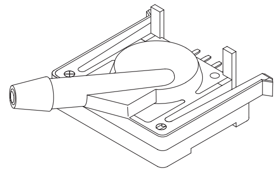
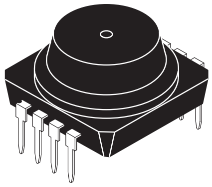


Figure 1. Fully Integrated Pressure Sensor Schematic



SNAP PORT
CASE 473B–01, STYLE 1
(MPX5006DF)



TOP PISTON FIT PACKAGE
CASE 473A–01, STYLE 3

PIN NUMBER			
1	V_{out}	3	V_S
2	Gnd	4	N/C

NOTE: Pin 4 is an internal device connection. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the Lead.

MAXIMUM RATINGS(1)

Parametrics	Symbol	Value	Unit
Overpressure(2) (P1 > P2)	P_{max}	10	kPa
Burst Pressure(2) (P1 > P2)	P_{burst}	60	kPa
Storage Temperature	T_{stg}	–30 to +100	°C
Operating Temperature	T_A	+10 to +60	°C

1. T_C = 25°C unless otherwise noted.
2. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

REV 2

OPERATING CHARACTERISTICS (V_S = 5.0 Vdc, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range		P_{OP}	0	—	6.0	kPa
Supply Voltage[1]		V_S	4.75	5.0	5.25	Vdc
Supply Current		I_S	—	—	10	mAdc
Full Scale Span[2]	(RL = 51kΩ)	V_{FSS}	4.5	4.6	4.7	V
Offset[3][5]	(RL = 51kΩ)	V_{off}	0.100	0.225	0.430	V
Sensitivity		V/P	—	766	—	mV/kPa
Accuracy[4][5]	(10 to 60°C)	—	—	—	±3.0	$\%V_{FSS}$

NOTES:

1. Device is ratiometric within this specified excitation range.
2. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Accuracy (error budget) consists of the following:

• Linearity:	Output deviation from a straight line relationship with pressure over the specified pressure range.
• Temperature Hysteresis:	Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
• Pressure Hysteresis:	Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
• Offset Stability:	Output deviation, after 1000 temperature cycles, – 30 to 100°C, and 1.5 million pressure cycles, with minimum rated pressure applied.
• TcSpan:	Output deviation over the temperature range of 10 to 60°C, relative to 25°C.
• TcOffset:	Output deviation with minimum rated pressure applied, over the temperature range of 10 to 60°C, relative to 25°C.
• Variation from Nominal:	The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.

5. Auto Zero at Factory Installation: Due to the sensitivity of the MPXT5006D, external mechanical stresses and mounting position can affect the zero pressure output reading. To obtain the 3% FSS accuracy, the device output must be “autozeroed” after installation. Autozeroing is defined as storing the zero pressure output reading and subtracting this from the device’s output during normal operations.

ON–CHIP TEMPERATURE COMPENSATION, CALIBRATION AND SIGNAL CONDITIONING

The 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 illustrates the gauge configuration in the basic chip carrier (Case 473). A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm.

The MPXT5006D series sensor operating characteristics are based on use of dry air as pressure media. Media, other than dry air, may have adverse effects on sensor performance and long–term reliability. Internal reliability and qualification test for dry air, and other media, are available from the factory. Contact the factory for information regarding media tolerance in your application.

Figure 3 shows a typical decoupling circuit for interfacing the output of the MPXT5006D to the A/D microprocessor. Proper decoupling of the power supply is recommended.

Figure 4 shows the sensor output signal relative to pressure input. Typical, minimum and maximum output curves are shown for operation over 10°C to 60°C. (Device output may be nonlinear outside of the rated pressure range.)

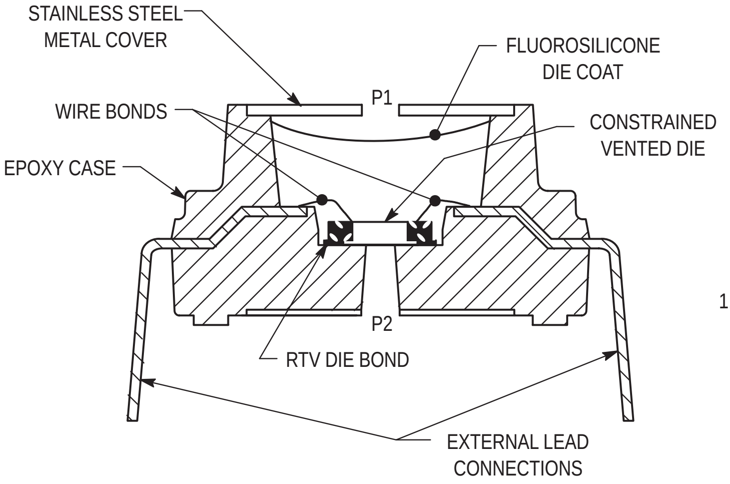


Figure 2. Cross–Sectional Diagram (Not to Scale)

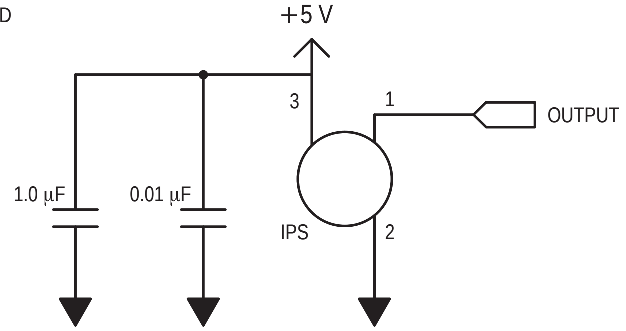


Figure 3. Recommended Power Supply Decoupling. For output filtering recommendations, please refer to Application Note AN1646.

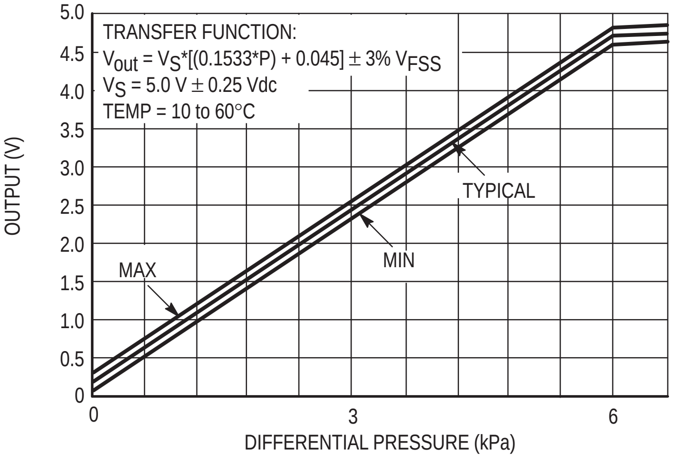


Figure 4. Output versus Pressure Differential

(See Note 5 in Operating Characteristics)

PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Motorola designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing silicone gel which isolates the die from the environment. The Motorola pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using the table below:

Part Number	Case Type	Pressure (P1) Side Identifier
MPXT5006D	473A–01	Stainless Steel Cap
MPXT5006DF	473B–01	Side with Port Attached

ORDERING INFORMATION

MPXT5006D series pressure sensors are available in two gauge configurations. Devices are available in the basic element package or with a pressure port fitting which provides printed circuit board mounting ease and a barbed hose pressure connection.

			MPX Series	
Device Type	Options	Case Type	Order Number	Device Marking
Basic Element	Gauge	Case 473A–01	MPXT5006D	MPXT5006D
Ported Element	Gauge	Case 473B–01	MPXT5006DF	MPXT5006DF

MOTOROLA
SEMICONDUCTOR TECHNICAL DATA

MPX5010
MPXL5010
SERIES

Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

INTEGRATED
PRESSURE SENSOR
0 to 10 kPa (0 to 1.45 psi)
0.2 to 4.7 V Output

The MPX5010 and MPXL5010 series piezoresistive transducers are state–of–the–art monolithic silicon pressure sensors designed for a wide range of applications, but particularly those employing a microcontroller or microprocessor with A/D inputs. This transducer combines advanced micromachining techniques, thin–film metallization, and bipolar processing to provide an accurate, high level analog output signal that is proportional to the applied pressure.

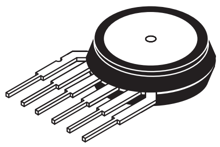
Features

- 5.0% Maximum Error over 0° to 85°C
- Ideally Suited for Microprocessor or Microcontroller–Based Systems
- Durable Epoxy Unibody Package
- Temperature Compensated over −40° to +125°C
- Patented Silicon Shear Stress Strain Gauge
- Available in Differential and Gauge Configurations

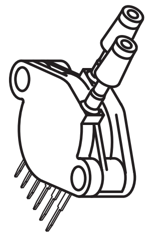
Application Examples

- Hospital Beds
- HVAC
- Respiratory Systems
- Process Control

UNIBODY PACKAGE
MPX5010



BASIC CHIP
CARRIER ELEMENT
CASE 867–08, STYLE 1

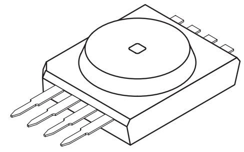


DIFFERENTIAL
PORT OPTION
CASE 867C–05, STYLE 1

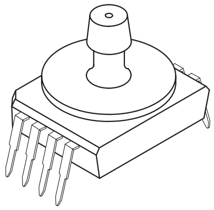
PIN NUMBER			
1	V_{out}	4	N/C
2	Gnd	5	N/C
3	V_S	6	N/C

NOTE: Pins 4, 5, and 6 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the Lead.

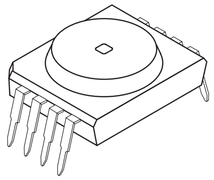
LOW PROFILE PACKAGE
MPXL5010



CASE 469–01, STYLE 1



CASE 472B–01, STYLE 1



CASE 472–01, STYLE 1

PIN NUMBER			
1	N/C	5	N/C
2	V_S	6	N/C
3	Gnd	7	N/C
4	V_{out}	8	N/C

NOTE: Pins 1, 5, 6, 7, and 8 are internal device connections. Do not connect to external circuitry or ground.

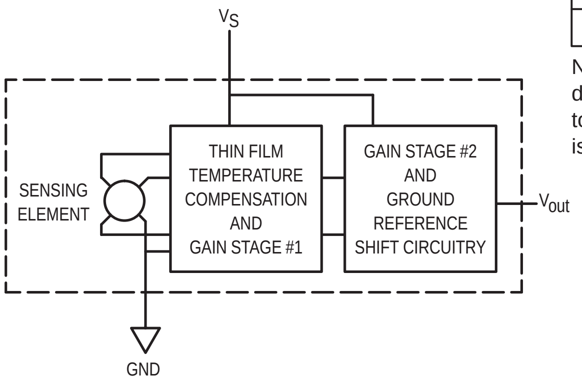


Figure 1. Fully Integrated Pressure Sensor Schematic
(Refer to pin number tables for appropriate pin connections)

REV 4

MAXIMUM RATINGS(1)

Parametrics	Symbol	Value	Unit
Overpressure(2) (P1 > P2)	P_{max}	75	kPa
Burst Pressure(2) (P1 > P2)	P_{burst}	100	kPa
Storage Temperature	T_{stg}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C

1. T_C = 25°C unless otherwise noted.
2. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

OPERATING CHARACTERISTICS (V_S = 5.0 Vdc, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range(1)		P_{OP}	0	—	10	kPa
Supply Voltage(2)		V_S	4.75	5.0	5.25	Vdc
Supply Current		I_o	—	7.0	10	mAdc
Minimum Pressure Offset(3) @ V_S = 5.0 Volts	(0 to 85°C)	V_{off}	0	0.2	0.425	Vdc
Full Scale Output(4) @ V_S = 5.0 Volts	(0 to 85°C)	V_{FSO}	4.475	4.7	4.925	Vdc
Full Scale Span(5) @ V_S = 5.0 Volts	(0 to 85°C)	V_{FSS}	—	4.5	—	Vdc
Accuracy(6)	(0 to 85°C)	—	—	—	±5.0	$\%V_{FSS}$
Sensitivity		V/P	—	450	—	mV/kPa
Response Time(7)		t_R	—	15	—	ms
Output Source Current at Full Scale Output		I_{O+}	—	0.1	—	mAdc
Warm–Up Time(8)		—	—	20	—	ms
Offset Stability(9)		—	—	±0.5	—	$\%V_{FSS}$

MECHANICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Weight, Basic Element (Case 867)	—	—	4.0	—	Grams
Weight, Basic Element (Case 469)	—	—	1.5	—	Grams
Common Mode Line Pressure(10)	—	—	—	690	kPa

NOTES:

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:

• Linearity:	Output deviation from a straight line relationship with pressure over the specified pressure range.
• Temperature Hysteresis:	Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
• Pressure Hysteresis:	Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
• TcSpan:	Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
• TcOffset:	Output deviation with minimum rated pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
• Variation from Nominal:	The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.

7. Response Time is defined as the time 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.
8. Warm–up is defined as the time required for the product to meet the specified output voltage after the Pressure has been stabilized.
9. Offset stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.
10. Common mode pressures beyond what is specified may result in leakage at the case–to–lead interface.

ON–CHIP TEMPERATURE COMPENSATION, CALIBRATION AND SIGNAL CONDITIONING

Figure 2 illustrates the Differential/Gauge Sensing Chip in the basic chip carrier (Case 867). Figure 3 illustrates the Differential/Gauge Sensing Chip in the basic Low Profile Package (Case 469). A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the sensor diaphragm.

The MPX5010 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 reliability. Contact the factory for information regarding media compatibility in your application.

Figure 4 shows a typical power supply decoupling. Proper decoupling of the power supply is recommended.

Figure 5 shows the sensor output signal relative to pressure input. Typical, minimum, and maximum output curves are shown for operation over a temperature range of 0° to 85°C using the decoupling circuit below. (The output will saturate outside of the specified pressure range.)

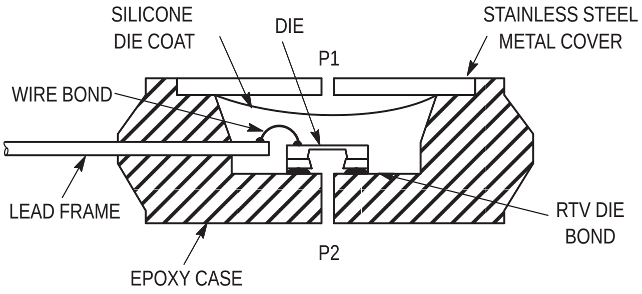


Figure 2. Unibody Package Cross–Sectional Diagram (not to scale)

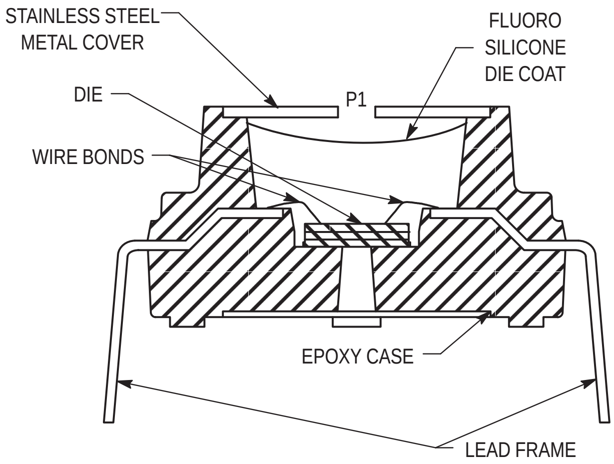


Figure 3. Low Profile Package Cross–Sectional Diagram (not to scale)

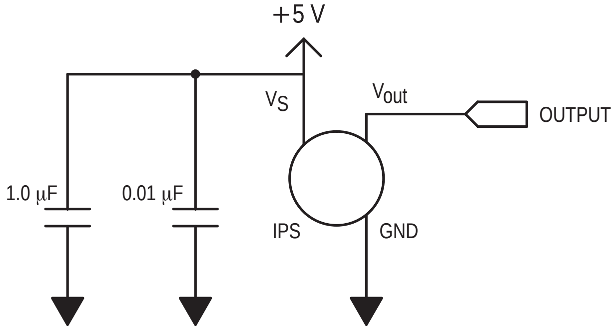


Figure 4. Recommended Power Supply Decoupling. For output filtering recommendations, please refer to Application Note AN1646.

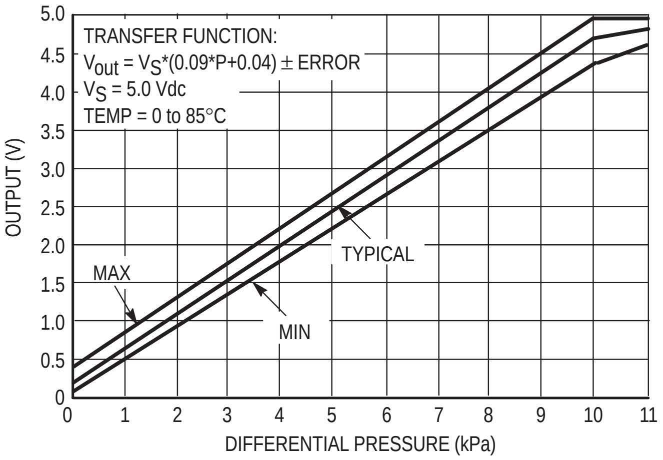


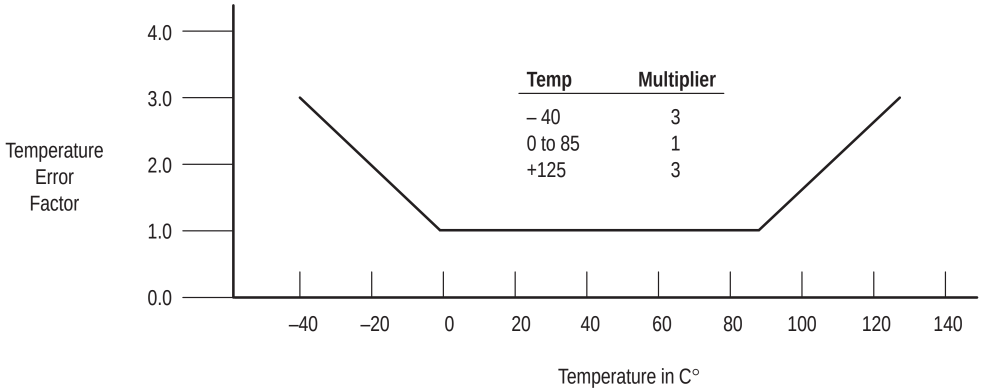
Figure 5. Output versus Pressure Differential

Transfer Function (MPX5010, MPXL5010)

Nominal Transfer Value: $V_{out} = V_S \times (0.09 \times P + 0.04)$
$\pm$ (Pressure Error x Temp. Factor x 0.09 x V_S)
$V_S = 5.0\ V \pm 0.25$ Vdc

Temperature Error Band

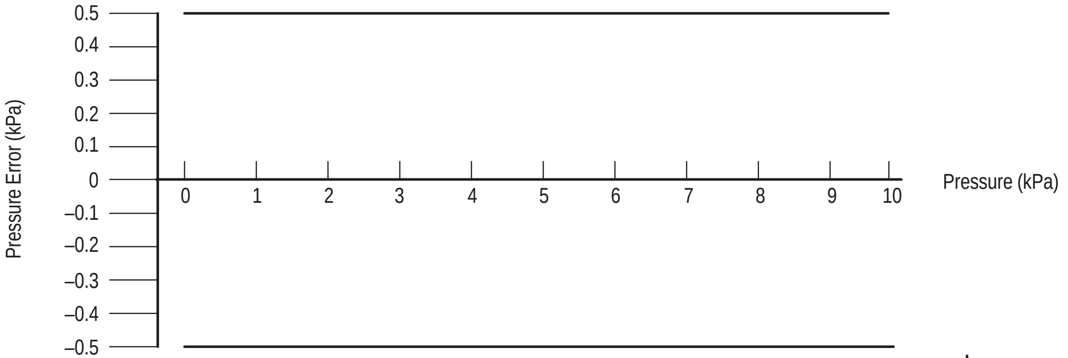
MPX5010, MPXL5010 Series



Temp	Multiplier
– 40	3
0 to 85	1
+125	3

NOTE: The Temperature Multiplier is a linear response from 0° to –40°C and from 85° to 125°C.

Pressure Error Band



Pressure	Error (Max)
0 to 10 kPa	± 0.5 kPa

PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Motorola designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing silicone gel which isolates the die from the environment. The Motorola MPX pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using the table below:

Part Number	Case Type	Pressure (P1) Side Identifier
MPX5010D	867–08	Stainless Steel Cap
MPX5010DP	867C–05	Side with Part Marking
MPX5010GP	867B–04	Side with Port Attached
MPXL5010G7U	472–01	Side with Part Marking
MPXL5010G8U	469–01	Side with Part Marking
MPXL5010GC7U	472B–01	Side with Part Marking

ORDERING INFORMATION — UNIBODY PACKAGE

The MPX5010 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	867–08	MPX5010D	MPX5010D
Ported Elements	Differential Dual Ports	867C–05	MPX5010DP	MPX5010DP
	Gauge	867B–04	MPX5010GP	MPX5010GP

ORDERING INFORMATION — LOW PROFILE PACKAGE

The MPXL5010 pressure sensor is available in differential and gauge configurations. Devices are available in the basic element package or with pressure port fittings.

Packing Options	Port Options	Leadform	Case Type	MPXL Series	
				Order Number	Device Marking
Rails	No Port	84° Lead Bend	472–01	MPXL5010G7U	MPXL5010G
Rails	No Port	4–Straight Leads	469–01	MPXL5010G8U	MPXL5010G
Rails	Axial Port	84° Lead Bend	472B–01	MPXL5010GC7U	MPXL5010G

Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

The MPX5050 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 transducer combines advanced micromachining techniques, thin–film metallization, and bipolar processing to provide an accurate, high level analog output signal that is proportional to the applied pressure.

Features

- 2.5% Maximum Error over 0° to 85°C
- Ideally suited for Microprocessor or Microcontroller–Based Systems
- Temperature Compensated Over – 40° to +125°C
- Patented Silicon Shear Stress Strain Gauge
- Durable Epoxy Unibody Element
- Easy–to–Use Chip Carrier Option

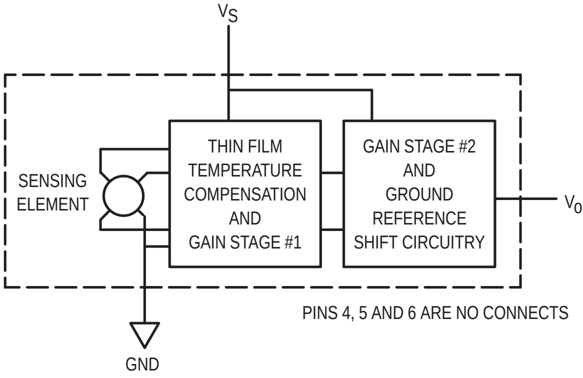


Figure 1. Fully Integrated Pressure Sensor Schematic

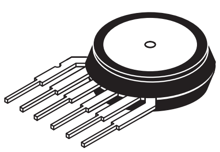
MAXIMUM RATINGS(1)

Parametrics	Symbol	Value	Unit
Overpressure(2) (P1 > P2)	P_{max}	200	kPa
Burst Pressure(2) (P1 > P2)	P_{burst}	700	kPa
Storage Temperature	T_{stg}	–40° to +125°	°C
Operating Temperature	T_A	–40° to +125°	°C

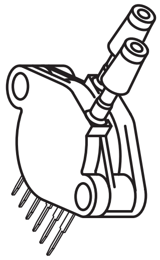
1. T_C = 25°C unless otherwise noted.
2. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

MPX5050 SERIES

**OPERATING OVERVIEW
INTEGRATED
PRESSURE SENSOR
0 to 50 kPa (0 to 7.25 psi)
0.2 to 4.7 Volts Output**



**BASIC CHIP CARRIER
ELEMENT
CASE 867–08, STYLE 1**



**DIFFERENTIAL PORT OPTION
CASE 867C–05, STYLE 1**

NOTE: Pin 1 is the notched pin.

PIN NUMBER			
1	V_{out}	4	N/C
2	Grd	5	N/C
3	V_S	6	N/C

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

REV 4

OPERATING CHARACTERISTICS (V_S = 5.0 Vdc, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic	Symbol	Min	Typ	Max	Unit
Pressure Range(1)	P_{OP}	0	—	50	kPa
Supply Voltage(2)	V_S	4.75	5.0	5.25	Vdc
Supply Current	I_o	—	7.0	10.0	mAdc
Minimum Pressure Offset(3) (0 to 85°C) @ V_S = 5.0 Volts	V_{off}	0.088	0.20	0.313	Vdc
Full Scale Output(4) (0 to 85°C) @ V_S = 5.0 Volts	V_{FSO}	4.587	4.70	4.813	Vdc
Full Scale Span(5) (0 to 85°C) @ V_S = 5.0 Volts	V_{FSS}	—	4.50	—	Vdc
Accuracy(6)	—	—	—	± 2.5	$\%V_{FSS}$
Sensitivity	V/P	—	90	—	mV/kPa
Response Time(7)	t_R	—	1.0	—	mS
Output Source Current at Full Scale Output	I_o+	—	0.1	—	mAdc
Warm–Up Time(8)	—	—	20	—	mSec
Offset Stability(9)	—	—	± 0.5	—	$\%V_{FSS}$

Decoupling circuit shown in Figure 4 required to meet electrical specifications.

MECHANICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Weight, Basic Element (Case 867)	—	—	4.0	—	Grams
Common Mode Line Pressure(10)	—	—	—	690	kPa

NOTES:

1. 1.0kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from minimum or maximum rated pressure at 25°C.
   - TcSpan: Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS} at 25°C.
7. Response Time is defined as the time 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.
8. Warm–up is defined as the time required for the product to meet the specified output voltage after the Pressure has been stabilized.
9. Offset stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.
10. Common mode pressures beyond what is specified may result in leakage at the case–to–lead interface.

Figure 3 illustrates the Differential/Gauge Sensing Chip in the basic chip carrier (Case 867). A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the sensor 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 reliability. Contact the factory for information regarding media compatibility in your application.

Figure 2 shows the sensor output signal relative to pressure input. Typical, minimum, and maximum output curves are shown for operation over a temperature range of 0° to 85°C using the decoupling circuit below. (The output will saturate outside of the specified pressure range.)

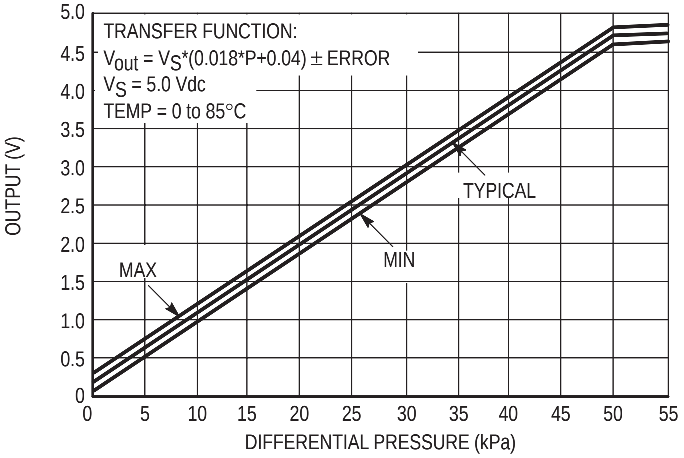


Figure 2. Output versus Pressure Differential

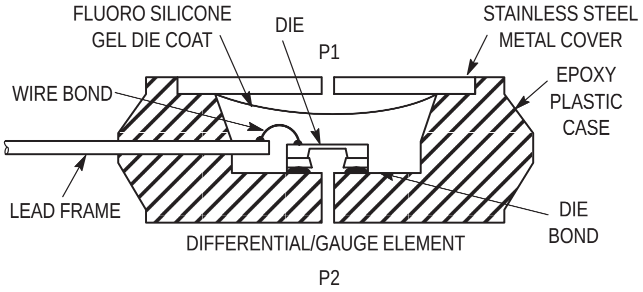


Figure 3. Cross–Sectional Diagram (Not to Scale)

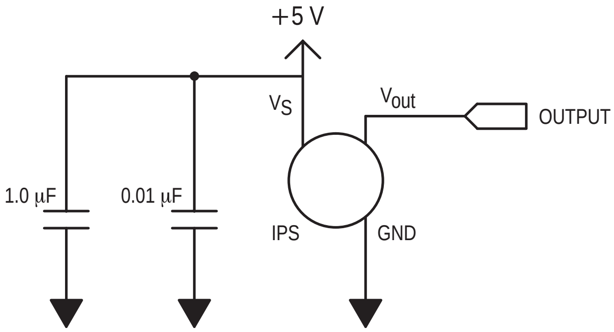


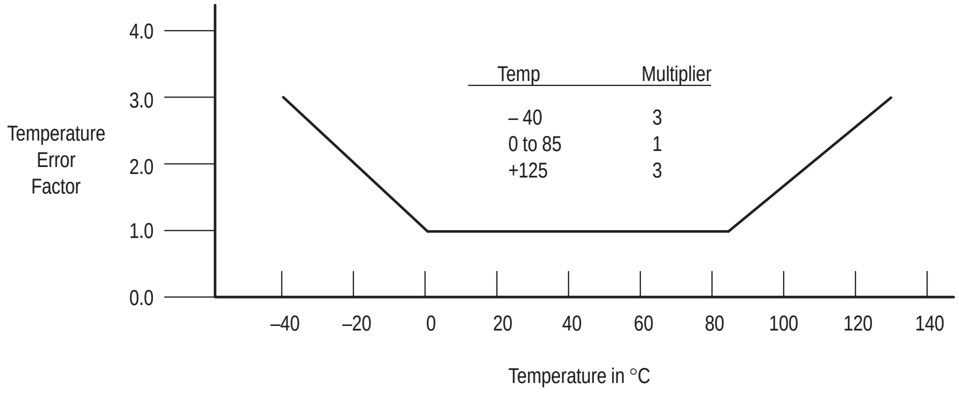
Figure 4. Recommended Power Supply Decoupling. For output filtering recommendations, please refer to Application Note AN1646.

Transfer Function

Nominal Transfer Value: $V_{out} = V_S\ (P \times 0.018 + 0.04)$
$\pm$ (Pressure Error x Temp. Factor x 0.018 x V_S)
$V_S = 5.0\ V \pm 0.25$ Vdc

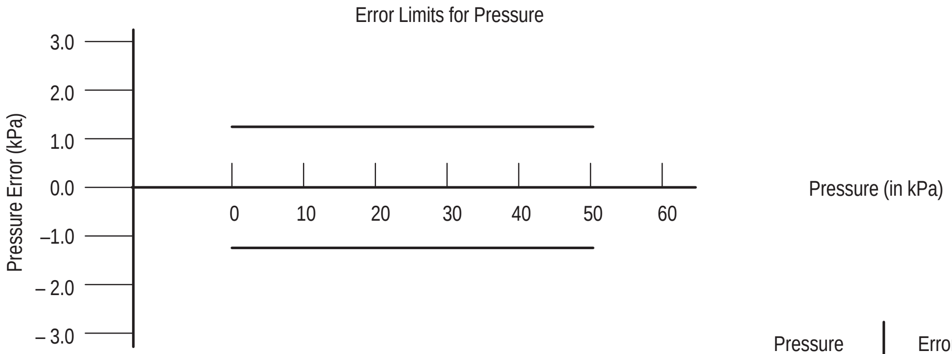
Temperature Error Band

MPX5050D Series



NOTE: The Temperature Multiplier is a linear response from 0° to –40°C and from 85° to 125°C.

Pressure Error Band



Pressure	Error (Max)
0 to 50 kPa	± 1.25 kPa

PRESSURE (P1) / VACUUM (P2) SIDE IDENTIFICATION TABLE

Motorola designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing fluorosilicone gel which protects the die from harsh media. The Motorola MPX pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using the table below:

Part Number	Case Type	Pressure (P1) Side Identifier
MPX5050D	867–08	Stainless Steel Cap
MPX5050DP	867C–05	Side with Part Marking
MPX5050GP	867B–04	Side with Port Attached
MPX5050GVP	867D–04	Stainless Steel Cap
MPX5050GS	867E–03	Side with Port Attached
MPX5050GVS	867A–04	Stainless Steel Cap
MPX5050GSX	867F–03	Side with Port Attached
MPX5050GVSX	867G–03	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	867–08	MPX5050D	MPX5050D
Ported Elements	Differential Dual Ports	867C–05	MPX5050DP	MPX5050DP
	Gauge	867B–04	MPX5050GP	MPX5050GP
	Gauge Vacuum Port	867D–04	MPX5050GVP	MPX5050GVP
	Gauge, Axial	867E–03	MPX5050GS	MPX5050D
	Gauge Vacuum Axial	867A–04	MPX5050GVS	MPX5050D
	Gauge, Axial PC Mount	867F–03	MPX5050GSX	MPX5050D
	Gauge Vacuum Axial PC Mount	867G–03	MPX5050GVSX	MPX5050D

MOTOROLA
SEMICONDUCTOR TECHNICAL DATA

MPX5100 SERIES

Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

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 transducer combines advanced micromachining techniques, thin–film metallization, and bipolar processing to provide an accurate, high level analog output signal that is proportional to the applied pressure.

Features

- 2.5% Maximum Error over 0° to 85°C
- Ideally suited for Microprocessor or Microcontroller–Based Systems
- Patented Silicon Shear Stress Strain Gauge
- Available in Absolute, Differential and Gauge Configurations
- Durable Epoxy Unibody Element
- Easy–to–Use Chip Carrier Option

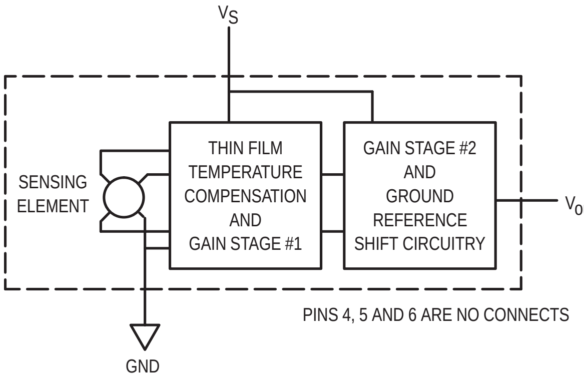


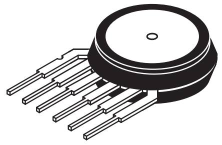
Figure 1. Fully Integrated Pressure Sensor Schematic

MAXIMUM RATINGS(1)

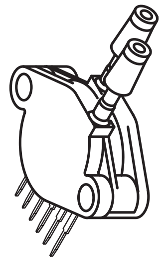
Parametrics	Symbol	Value	Unit
Overpressure(2) (P1 > P2) (P2 > P1)	P_{max}	400 400	kPa
Burst Pressure(2) (P1 > P2)	P_{burst}	1000	kPa
Storage Temperature	T_{stg}	–40° to +125°	°C
Operating Temperature	T_A	– 40° to +125°	°C

1. T_C = 25°C unless otherwise noted.
2. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

OPERATING OVERVIEW INTEGRATED PRESSURE SENSOR
0 to 100 kPa (0 to 14.5 psi)
15 to 115 kPa
(2.18 to 16.68 psi)
0.2 to 4.7 Volts Output



BASIC CHIP CARRIER ELEMENT
CASE 867–08, STYLE 1



DIFFERENTIAL PORT OPTION
CASE 867C–05, STYLE 1

NOTE: Pin 1 is the notched pin.

PIN NUMBER			
1	V_{out}	4	N/C
2	Gnd	5	N/C
3	V_S	6	N/C

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

REV 6

OPERATING CHARACTERISTICS (V_S = 5.0 Vdc, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic	Symbol	Min	Typ	Max	Unit
Pressure Range(1) Gauge, Differential: MPX5100D Absolute: MPX5100A Vacuum: MPX5100GV(11)	P_{OP}	0 15 0	— — —	100 115 100	kPa
Supply Voltage(2)	V_S	4.75	5.0	5.25	Vdc
Supply Current	I_o	—	7.0	10	mAdc
Minimum Pressure Offset(3) (0 to 85°C) @ V_S = 5.0 Volts	V_{off}	0.088	0.20	0.313	Vdc
Full Scale Output(4) Differential and Absolute (0 to 85°C) @ V_S = 5.0 Volts Vacuum(11)	V_{FSO}	4.587 3.688	4.700 3.800	4.813 3.913	Vdc
Full Scale Span(5) Differential and Absolute (0 to 85°C) @ V_S = 5.0 Volts Vacuum(11)	V_{FSS}	— —	4.500 3.600	— —	Vdc
Accuracy(6)	—	—	—	±2.5	$\%V_{FSS}$
Sensitivity	V/P	—	45	—	mV/kPa
Response Time(7)	t_R	—	1.0	—	mS
Output Source Current at Full Scale Output	I_{o+}	—	0.1	—	mAdc
Warm–Up Time(8)	—	—	20	—	mSec
Offset Stability(9)	—	—	±0.5	—	$\%V_{FSS}$

Decoupling circuit shown in Figure 4 required to meet electrical specifications.

MECHANICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Weight, Basic Element (Case 867)	—	—	4.0	—	Grams
Common Mode Line Pressure(10)	—	—	—	690	kPa

NOTES:

1. 1.0kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:

• Linearity:	Output deviation from a straight line relationship with pressure over the specified pressure range.
• Temperature Hysteresis:	Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
• Pressure Hysteresis:	Output deviation at any pressure within the specified range, when this pressure is cycled to and from minimum or maximum rated pressure at 25°C.
• TcSpan:	Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
• TcOffset:	Output deviation with minimum pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
• Variation from Nominal:	The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS} at 25°C.

7. Response Time is defined as the time 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.
8. Warm–up is defined as the time required for the product to meet the specified output voltage after the Pressure has been stabilized.
9. Offset stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.
10. Common mode pressures beyond what is specified may result in leakage at the case–to–lead interface.
11. Pressure Range: Vacuum sensor is rated to 100 kPa; part is tested to a vacuum pressure equivalent to 80 kPa.

ON–CHIP TEMPERATURE COMPENSATION, CALIBRATION and SIGNAL CONDITIONING

Figure 2 shows the sensor output signal relative to pressure input. Typical, minimum, and maximum output curves are shown for operation over a temperature range of 0° to 85°C using the decoupling circuit below. (The output will saturate outside of the specified pressure range.)

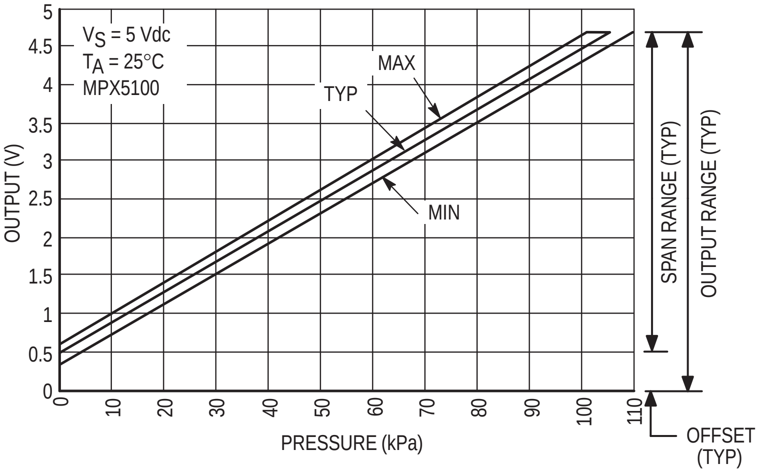


Figure 2. Output versus Pressure Differential

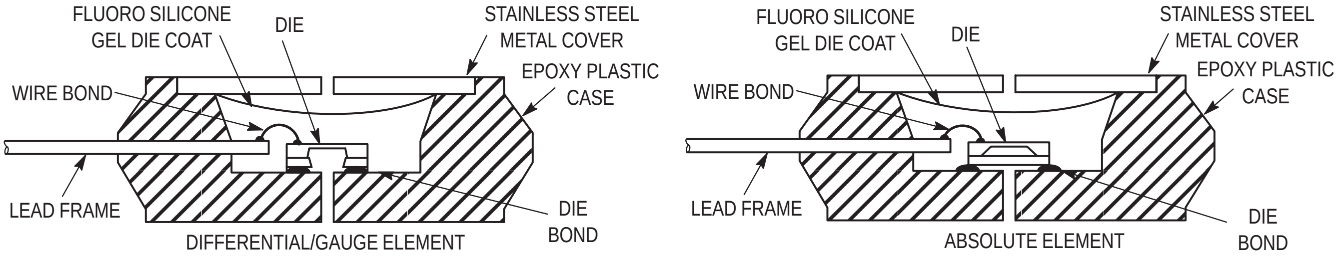


Figure 3. Cross–Sectional Diagrams
(Not to Scale)

Figure 3 illustrates both the Differential/Gauge and the Absolute Sensing Chip in the basic chip carrier (Case 867). A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the sensor diaphragm.

The MPX5100 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 reliability. Contact the factory for information regarding media compatibility in your application.

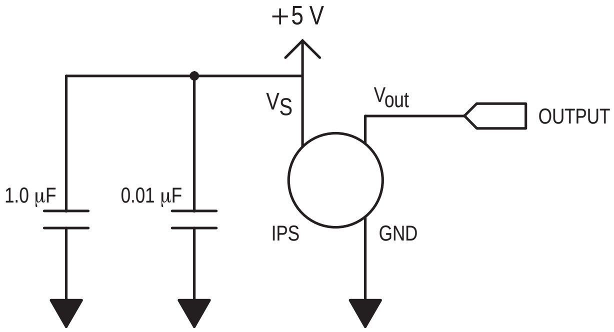
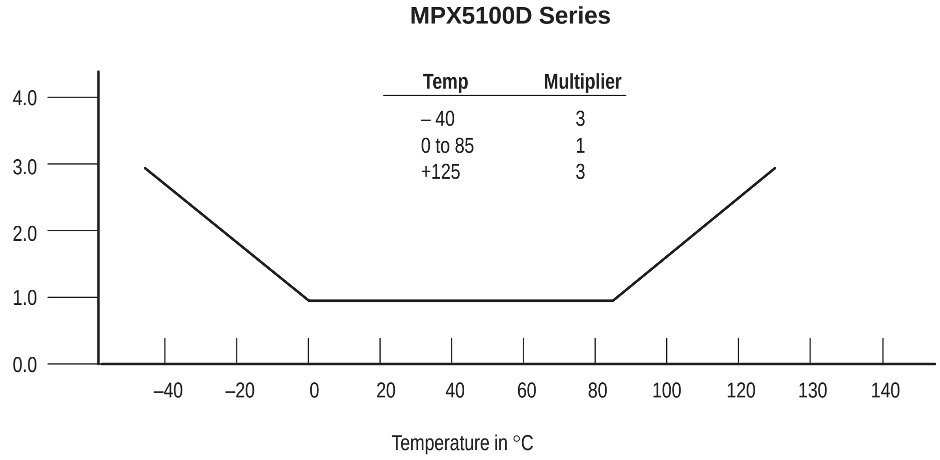


Figure 4. Recommended Power Supply Decoupling.
For output filtering recommendations, please refer to
Application Note AN1646.

Transfer Function (MPX5100D, MPX5100GV)

Nominal Transfer Value: $V_{out} = V_S$ (P x 0.009 + 0.04)
+/– (Pressure Error x Temp. Mult. x 0.009 x V_S)
V_S = 5.0 V ±5% P kPa

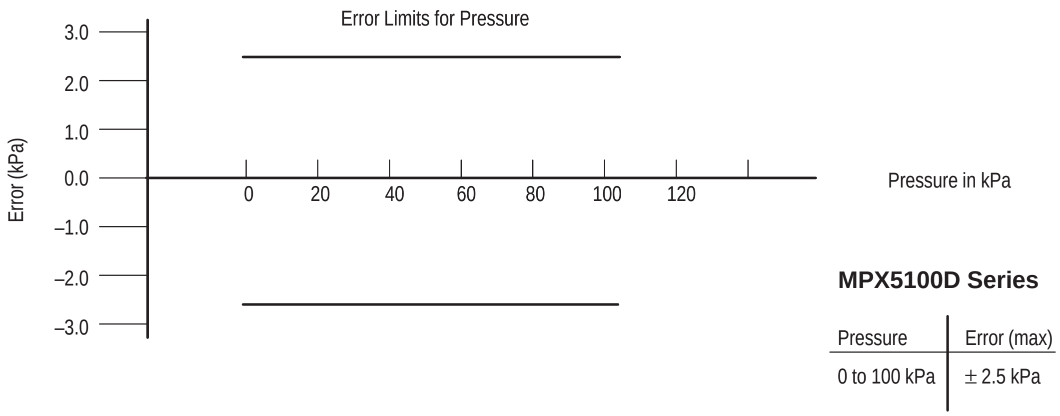
Temperature Error Multiplier



Temp	Multiplier
– 40	3
0 to 85	1
+125	3

NOTE: The Temperature Multiplier is a linear response from 0° to –40°C and from 85° to 125°C.

Pressure Error Band



MPX5100D Series

Pressure	Error (max)
0 to 100 kPa	± 2.5 kPa

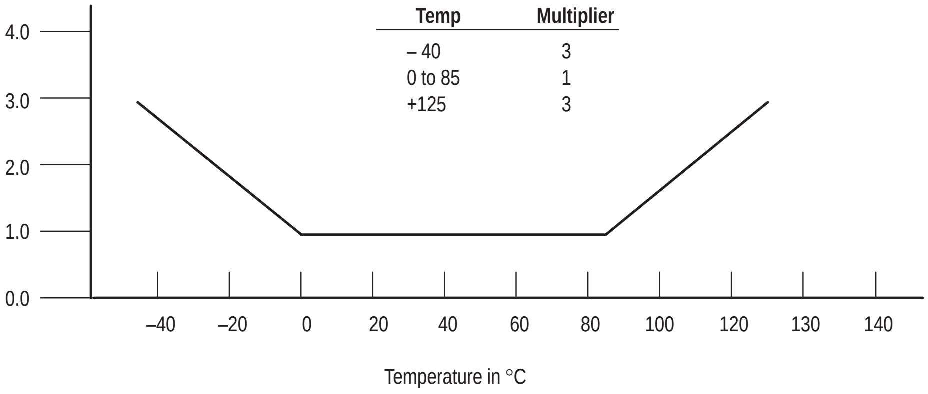
NOTE: For vacuum type parts (5100GV), Transfer Function is the same as that for 5100D Series.

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

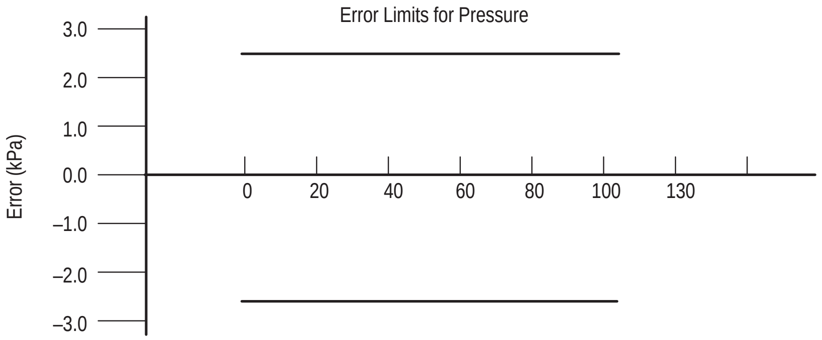
MPX5100A Series



Temp	Multiplier
– 40	3
0 to 85	1
+125	3

NOTE: The Temperature Multiplier is a linear response from 0° to –40°C and from 85° to 125°C.

Pressure Error Band



MPX5100A Series

Pressure	Error (max)
15 to 115 kPa	± 2.5 kPa

PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Motorola designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) 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, P1 > P2.

The Pressure (P1) side may be identified by using the Table below:

Part Number	Case Type	Pressure (P1) Side Identifier
MPX5100A, MPX5100D	867–08	Stainless Steel Cap
MPX5100DP	867C–05	Side with Part Marking
MPX5100AP, MPX5100GP	867B–04	Side with Port Attached
MPX5100GVP	867D–04	Stainless Steel Cap
MPX5100AS, MPX5100GS	867E–03	Side with Port Attached
MPX5100GVS	867A–04	Stainless Steel Cap
MPX5100ASX, MPX5100GSX	867F–03	Side with Port Attached
MPX5100GVSX	867G–03	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 Name	Options	Case Type	MPX Series	
			Order Number	Device Marking
Basic Element	Absolute	867–08	MPX5100A	MPX5100A
	Differential	867–08	MPX5100D	MPX5100D
Ported Elements	Differential Dual Ports	867C–05	MPX5100DP	MPX5100DP
	Absolute, Single Port	867B–04	MPX5100AP	MPX5100AP
	Gauge, Single Port	867B–04	MPX5100GP	MPX5100GP
	Gauge, Vacuum Port	867D–04	MPX5100GVP	MPX5100GVP
	Absolute, Axial	867E–03	MPX5100AS	MPX5100A
	Gauge, Axial	867E–03	MPX5100GS	MPX5100D
	Gauge, Vacuum Axial	867A–04	MPX5100GVS	MPX5100D
	Absolute, Axial PC Mount	867F–03	MPX5100ASX	MPX5100A
	Gauge, Axial PC Mount	867F–03	MPX5100GSX	MPX5100D
	Gauge Vacuum Axial PC Mount	867G–03	MPX5100GVSX	MPX5100D

MPX5500 SERIES

Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

OPERATING OVERVIEW INTEGRATED PRESSURE SENSOR
0 to 500 kPa (0 to 72.5 psi)
0.2 to 4.7 Volts Output

The MPX5500 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 transducer combines advanced micromachining techniques, thin–film metallization, and bipolar processing to provide an accurate, high level analog output signal that is proportional to the applied pressure.

Features

- 2.5% Maximum Error over 0° to 85°C
- Ideally suited for Microprocessor or Microcontroller–Based Systems
- Patented Silicon Shear Stress Strain Gauge
- Durable Epoxy Unibody Element
- Available in Differential and Gauge Configuration

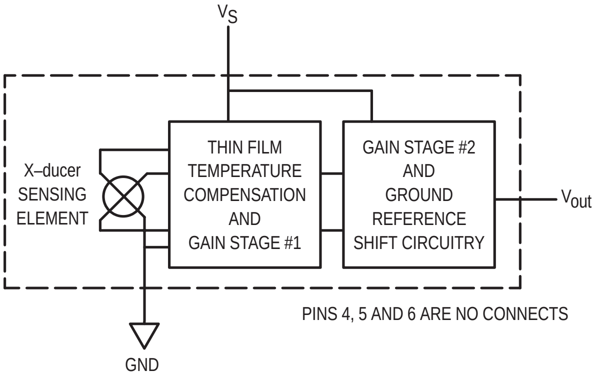
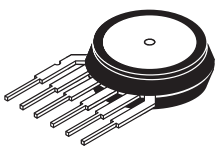
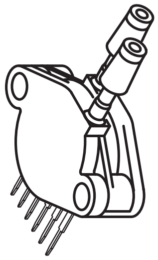


Figure 1. Fully Integrated Pressure Sensor Schematic



BASIC CHIP CARRIER ELEMENT
CASE 867–08, STYLE 1



DIFFERENTIAL PORT OPTION
CASE 867C–05, STYLE 1

NOTE: Pin 1 is the notched pin.

PIN NUMBER			
1	V_{out}	4	N/C
2	Gnd	5	N/C
3	V_S	6	N/C

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

MAXIMUM RATINGS[1]

Parametrics	Symbol	Value	Unit
Overpressure[2] (P2 ≤ 1 Atmosphere)	P_{max}	2000	kPa
Burst Pressure[2] (P2 ≤ 1 Atmosphere)	P_{burst}	3500	kPa
Storage Temperature	T_{stg}	–40° to +125°	°C
Operating Temperature	T_A	–40° to +125°	°C

1. T_C = 25°C unless otherwise noted. Maximum Ratings apply to Case 867–08 only.
2. Extended exposure at the specified limits may cause permanent damage or degradation to the device.
3. This sensor is designed for applications where P1 is always greater than, or equal to P2.

REV 3

OPERATING CHARACTERISTICS (V_S = 5.0 Vdc, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range(1)		P_{OP}	0	—	500	kPa
Supply Voltage(2)		V_S	4.75	5.0	5.25	Vdc
Supply Current		I_o	—	7.0	10.0	mAdc
Zero Pressure Offset(3)	(0 to 85°C)	V_{off}	0.088	0.20	0.313	Vdc
Full Scale Output(4)	(0 to 85°C)	V_{FSO}	4.587	4.70	4.813	Vdc
Full Scale Span(5)	(0 to 85°C)	V_{FSS}	—	4.50	—	Vdc
Accuracy(6)		—	—	—	±2.5	$\%V_{FSS}$
Sensitivity		V/P	—	9.0	—	mV/kPa
Response Time(7)		t_R	—	1.0	—	mS
Output Source Current at Full Scale Output		I_o+	—	0.1	—	mAdc
Warm–Up Time(8)		—	—	20	—	mSec

Decoupling circuit shown in Figure 4 required to meet electrical specifications.

MECHANICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Weight, Basic Element (Case 867)	—	—	4.0	—	Grams
Cavity Volume	—	—	—	0.01	IN^3
Volumetric Displacement	—	—	—	0.001	IN^3

NOTES:

1. 1.0kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from minimum or maximum rated pressure at 25°C.
   - TcSpan: Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS} at 25°C.
7. Response Time is defined as the time 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.
8. Warm–up is defined as the time required for the device to meet the specified output voltage after the pressure has been stabilized.
9. P2 max is 500 kPa.

Figure 3 illustrates both the Differential/Gauge and the Absolute Sensing Chip in the basic chip carrier (Case 867). A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the sensor diaphragm. (For use of the MPX5500D in a high pressure, cyclic application, consult the factory.)

The MPX5500 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 reliability. Contact the factory for information regarding media compatibility in your application.

Figure 2 shows the sensor output signal relative to pressure input. Typical, minimum, and maximum output curves are shown for operation over a temperature range of 0° to 85°C using the decoupling circuit below. (The output will saturate outside of the specified pressure range.)

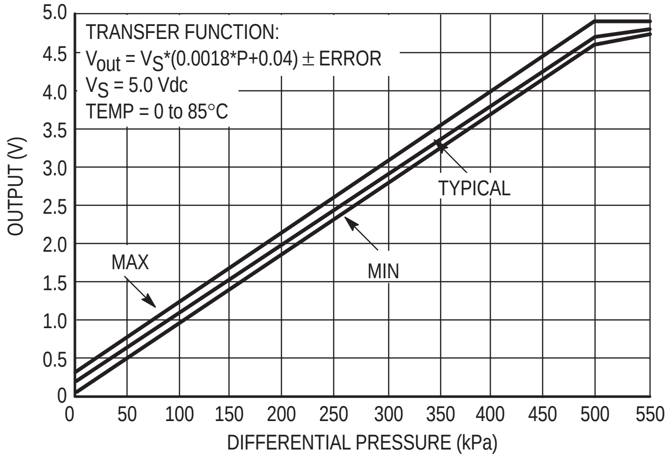


Figure 2. Output versus Pressure Differential

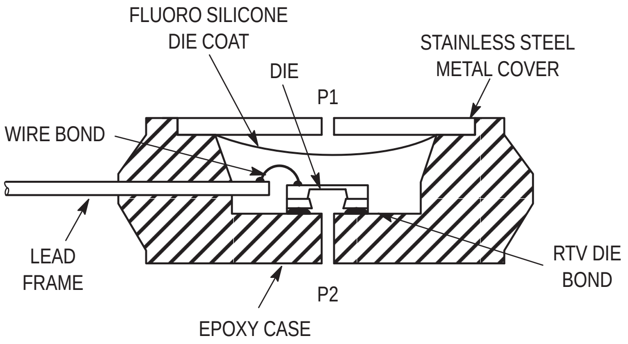


Figure 3. Cross–Sectional Diagram (Not to Scale)

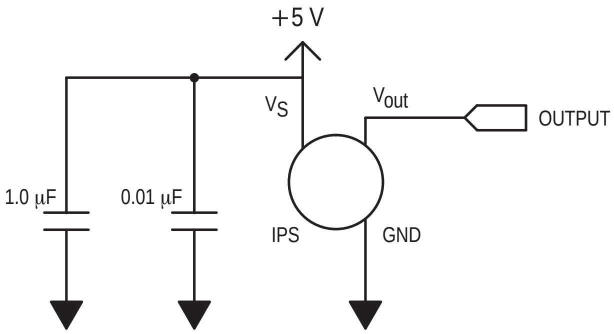


Figure 4. Recommended Power Supply Decoupling. For output filtering recommendations, please refer to Application Note AN1646.

PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Motorola designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing fluorosilicone gel which protects the die from the environment. The Motorola MPX pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using the Table below:

Part Number	Case Type	Pressure (P1) Side Identifier
MPX5500D	867–08	Stainless Steel Cap
MPX5500DP	867C–05	Side with Part Marking
MPX5500GP	867B–04	Side with Port Attached
MPX5500GS	867E–03	Side with Port Attached
MPX5500GSX	867F–03	Side with Port Attached

ORDERING INFORMATION

The MPX5500 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 Name	Options	Case Type	MPX Series	
			Order Number	Device Marking
Basic Element	Differential	867–08	MPX5500D	MPX5500D
Ported Elements	Differential Dual Ports	867C–05	MPX5500DP	MPX5500DP
	Gauge	867B–04	MPX5500GP	MPX5500GP
	Gauge, Axial	867E–03	MPX5500GS	MPX5500D
	Gauge, Axial PC Mount	867F–03	MPX5500GSX	MPX5500D

MOTOROLA
SEMICONDUCTOR TECHNICAL DATA

MPX5700 SERIES

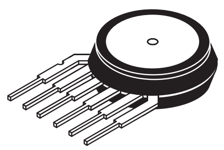
Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

INTEGRATED
PRESSURE SENSOR
0 to 700 kPa (0 to 101.5 psi)
0.2 to 4.7 V OUTPUT

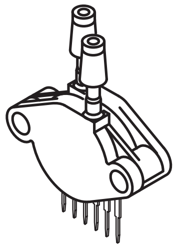
The MPX5700 series piezoresistive transducer is a state–of–the–art monolithic silicon pressure sensor designed for a wide range of applications, but particularly those employing a microcontroller or microprocessor with A/D inputs. This patented, single element transducer combines advanced micromachining techniques, thin–film metallization, and bipolar processing to provide an accurate, high level analog output signal that is proportional to the applied pressure.

Features

- 2.5% Maximum Error over 0° to 85°C
- Ideally Suited for Microprocessor or Microcontroller–Based Systems
- Available in Differential and Gauge Configurations
- Patented Silicon Shear Stress Strain Gauge
- Durable Epoxy Unibody Element



BASIC CHIP
CARRIER ELEMENT
CASE 867–08, STYLE 1



DIFFERENTIAL
PORT OPTION
CASE 867C–05, STYLE 1

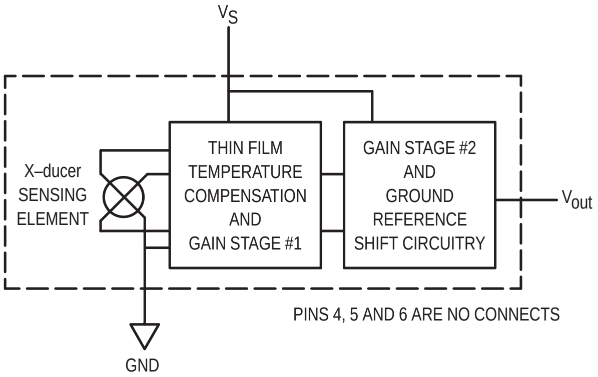


Figure 1. Fully Integrated Pressure Sensor Schematic

PIN NUMBER			
1	V_{out}	4	N/C
2	Gnd	5	N/C
3	V_S	6	N/C

NOTE: Pins 4, 5, and 6 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the Lead.

MAXIMUM RATINGS(1)

Parametrics	Symbol	Value	Unit
Overpressure (P2 ≤ 1 Atmosphere)	$P1_{max}$	2800	kPa
Burst Pressure (P2 ≤ 1 Atmosphere)	$P1_{burst}$	5000	kPa
Storage Temperature	T_{stg}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C

1. T_C = 25°C unless otherwise noted. Maximum Ratings apply to Case 867–08 only.
2. Extended exposure at the specified limits may cause permanent damage or degradation to the device.
3. This sensor is designed for applications where P1 is always greater than, or equal to P2.

REV 3

OPERATING CHARACTERISTICS (V_S = 5.0 Vdc, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range(1)		P_{OP}	0	—	700	kPa
Supply Voltage(2)		V_S	4.75	5.0	5.25	Vdc
Supply Current		I_o	–	7.0	10	mAdc
Zero Pressure Offset(3)	(0 to 85°C)	V_{off}	0.088	0.2	0.313	Vdc
Full Scale Output(4)	(0 to 85°C)	V_{FSO}	4.587	4.7	4.813	Vdc
Full Scale Span(5)	(0 to 85°C)	V_{FSS}	—	4.5	—	Vdc
Accuracy(6)	(0 to 85°C)	—	—	—	± 2.5	$\%V_{FSS}$
Sensitivity		V/P	—	6.4	—	mV/kPa
Response Time(7)		t_R	—	1.0	—	ms
Output Source Current at Full Scale Output		I_{O+}	—	0.1	—	mAdc
Warm–Up Time(8)		—	—	20	—	ms

Decoupling circuit shown in Figure 4 required to meet electrical specifications.

MECHANICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Weight, Basic Element (Case 867)	—	—	4.0	—	Grams
Cavity Volume	—	—	—	0.01	IN^3
Volumetric Displacement	—	—	—	0.001	IN^3

NOTES:

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:

• Linearity:	Output deviation from a straight line relationship with pressure over the specified pressure range.
• Temperature Hysteresis:	Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
• Pressure Hysteresis:	Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
• TcSpan:	Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
• TcOffset:	Output deviation with minimum rated pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
• Variation from Nominal:	The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.

7. Response Time is defined as the time 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.
8. Warm–up is defined as the time required for the device to meet the specified output voltage after the pressure has been stabilized.
9. P2 max is 500 kPa.

ON–CHIP TEMPERATURE COMPENSATION, CALIBRATION AND SIGNAL CONDITIONING

Figure 3 illustrates both the Differential/Gauge and the Absolute Sensing Chip in the basic chip carrier (Case 867). A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the sensor diaphragm. (For use of the MPX5700D in a high pressure, cyclic application, consult the factory.)

The MPX5700 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 reliability. Contact the factory for information regarding media compatibility in your application.

Figure 2 shows the sensor output signal relative to pressure input. Typical, minimum, and maximum output curves are shown for operation over a temperature range of 0° to 85°C using the decoupling circuit below. (The output will saturate outside of the specified pressure range.)

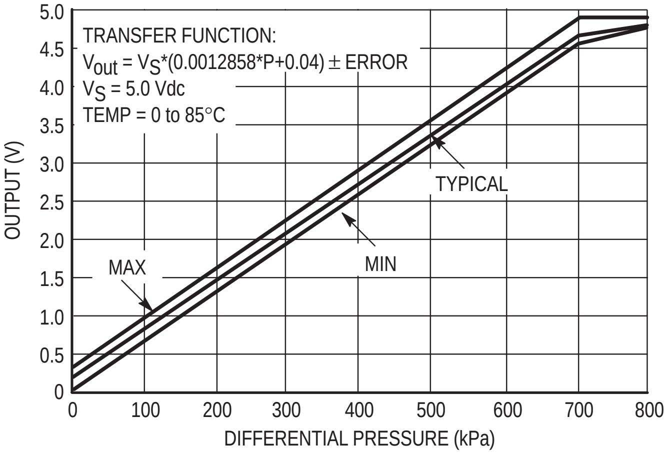


Figure 2. Output versus Pressure Differential

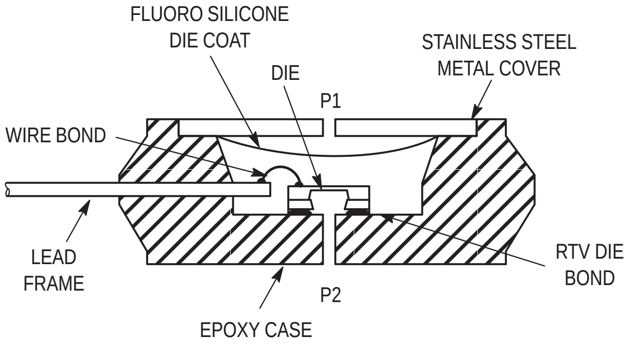


Figure 3. Cross–Sectional Diagram (Not to Scale)

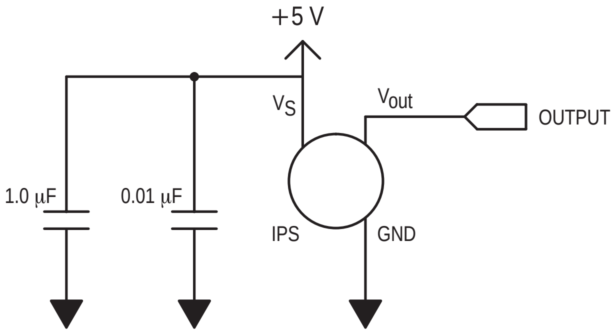


Figure 4. Recommended Power Supply Decoupling. For output filtering recommendations, please refer to Application Note AN1646.

PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Motorola designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) 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, P1 > P2.

The Pressure (P1) side may be identified by using the table below:

Part Number	Case Type	Pressure (P1) Side Identifier
MPX5700D	867–08	Stainless Steel Cap
MPX5700DP	867C–05	Side with Part Marking
MPX5700GP	867B–04	Side with Port Attached
MPX5700GS	867E–03	Side with Port Attached
MPX5700GSX	867F–03	Side with Port Attached

ORDERING INFORMATION

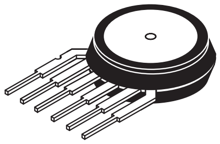
The MPX5700 pressure sensor is available in differential and gauge configurations. Devices are available in the basic element package or with pressure port fittings that provide printed circuit board mounting ease and barbed hose pressure connections.

Device Type	Options	Case Type	MPX Series	
			Order Number	Device Marking
Basic Element	Differential	867–08	MPX5700D	MPX5700D
Ported Elements	Differential Dual Ports	867C–05	MPX5700DP	MPX5700DP
	Gauge	867B–04	MPX5700GP	MPX5700GP
	Gauge, Axial	867E–03	MPX5700GS	MPX5700D
	Gauge, Axial PC Mount	867F–03	MPX5700GSX	MPX5700D

MPX5999D

0 to 1000 kPa (0 to 150 PSI) On-Chip Signal Conditioned, 0.2 V to 4.7 V Output, Temperature Compensated and Calibrated, Silicon Pressure Sensor

X–ducer™
SILICON
PRESSURE SENSORS



BASIC CHIP
CARRIER ELEMENT
CASE 867–08, STYLE 1

PIN NUMBER			
1	V_{out}	4	N/C
2	Gnd	5	N/C
3	V_S	6	N/C

NOTE: Pins 4, 5, and 6 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the Lead.

The MPX5999D piezoresistive transducer is a state–of–the–art 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 block diagram of the internal circuitry integrated on the stand–alone sensing chip.

Features

- Temperature Compensated Over 0 to 85°C
- Ideally Suited for Microprocessor or Microcontroller–Based Systems
- Patented Silicon Shear Stress Strain Gauge
- Durable Epoxy Unibody Element

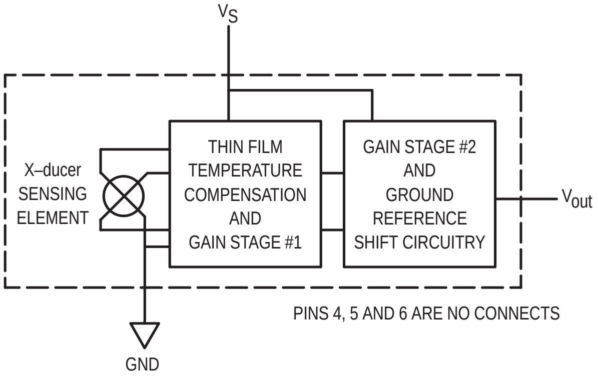


Figure 1. Fully Integrated Pressure Sensor Schematic

MAXIMUM RATINGS(1)

Parametrics	Symbol	Value	Unit
Overpressure(2) (P1 > P2)	P_{max}	4000	kPa
Burst Pressure(2) (P1 > P2)	P_{burst}	6000	kPa
Storage Temperature	T_{stg}	–40° to +125	°C
Operating Temperature	T_A	–40° to +125	°C

1. T_C = 25°C unless otherwise noted. Maximum Ratings apply to Case 867–08 only.
2. Extended exposure at the specified limits may cause permanent damage or degradation to the device.
3. This sensor is designed for applications where P1 is always greater than, or equal to P2.

(Replaces MPX5999)

REV 1

OPERATING CHARACTERISTICS (V_S = 5.0 Vdc, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic	Symbol	Min	Typ	Max	Unit
Pressure Range(1)	P_{OP}	0	—	1000	kPa
Supply Voltage(2)	V_S	4.75	5.0	5.25	Vdc
Supply Current	I_o	—	7.0	10	mAdc
Zero Pressure Offset(3) (0 to 85°C)	V_{off}	0.088	0.2	0.313	Vdc
Full Scale Output(4) (0 to 85°C)	V_{FSO}	4.587	4.7	4.813	Vdc
Full Scale Span(5) (0 to 85°C)	V_{FSS}	—	4.5	—	Vdc
Sensitivity	V/P	—	4.5	—	mV/kPa
Accuracy(6) (0 to 85°C)	—	—	—	± 2.5	%V_{FSS}
Response Time(7)	t_R	—	1.0	—	ms
Output Source Current at Full Scale Output	I_{O+}	—	0.1	—	mA
Warm–Up(8)	—	—	20	—	Sec

MECHANICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Weight, Basic Element (Case 867)	—	—	4.0	—	Grams
Cavity Volume	—	—	—	0.01	IN^3
Volumetric Displacement	—	—	—	0.001	IN^3

NOTES:

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:

• Linearity:	Output deviation from a straight line relationship with pressure over the specified pressure range.
• Temperature Hysteresis:	Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
• Pressure Hysteresis:	Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
• TcSpan:	Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
• TcOffset:	Output deviation with minimum rated pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
• Variation from Nominal:	The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.

7. Response Time is defined as the time 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.
8. Warm–up is defined as the time required for the device to meet the specified output voltage after the pressure has been stabilized.
9. P2 max is 500 kPa.

ON–CHIP TEMPERATURE COMPENSATION, CALIBRATION AND SIGNAL CONDITIONING

Figure 2 shows the sensor output signal relative to pressure input. Typical, minimum and maximum output curves are shown for operation over 0°C to 85°C. (Device output may be nonlinear outside of the rated pressure range.)

The 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 MPX5999D 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 reliability. Contact the factory for information regarding media compatibility in your application.

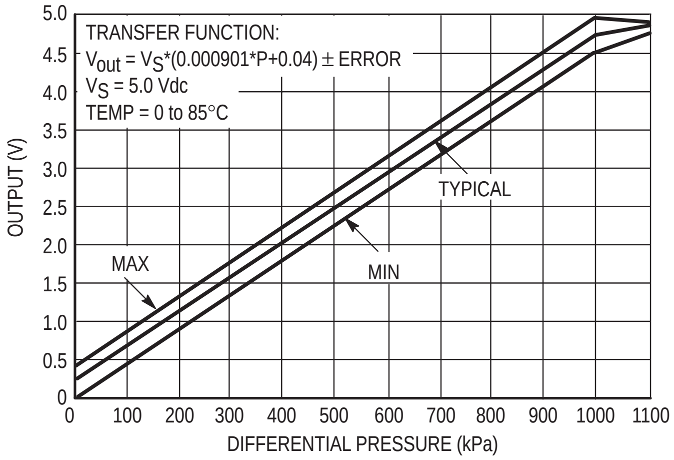


Figure 2. Output versus Pressure Differential

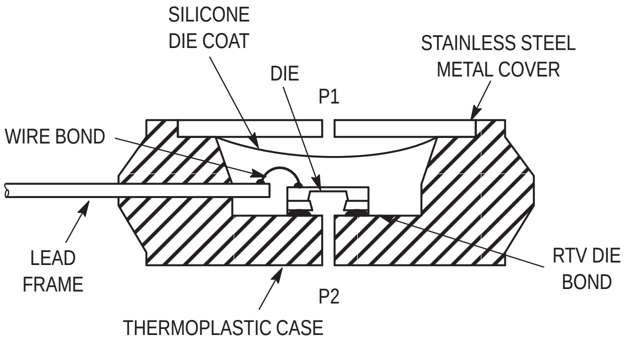


Figure 3. Cross–Sectional Diagram
(Not to Scale)

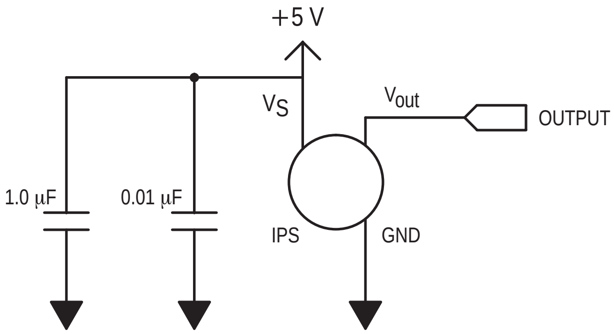


Figure 4. Recommended Power Supply Decoupling. For output filtering recommendations, please refer to Application Note AN1646.

PRESSURE (P1) / VACUUM (P2) SIDE IDENTIFICATION TABLE

Motorola designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) 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, P1 > P2.

The Pressure (P1) side may be identified by using the table below:

Part Number	Case Type	Pressure (P1) Side Identifier
MPX5999D	867–08	Stainless Steel Cap

ORDERING INFORMATION

The MPX5999D pressure sensor is available as an element only.

Device Type	Options	Case Type	MPX Series	
			Order Number	Device Marking
Basic Element	Differential	867–08	MPX5999D	MPX5999D

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 (i.e., MPX10, MPX11, and MPX12 pressure sensors) 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.

REV 1

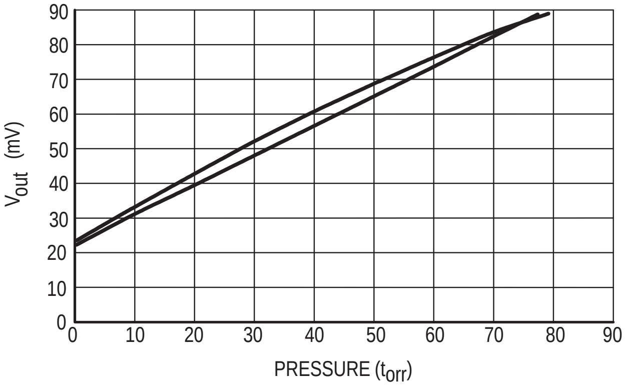


Figure 1. MPX12 Linearity Analysis Raw Data

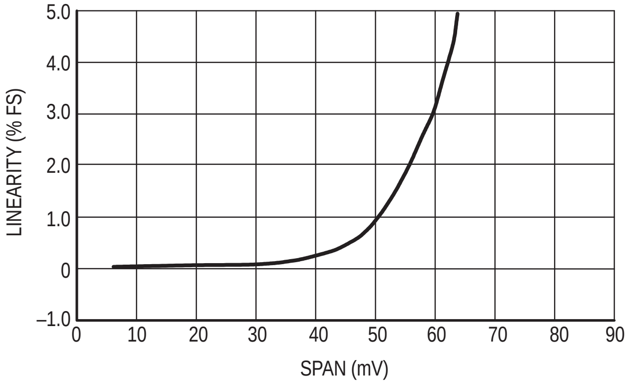


Figure 2. MPX10 Series Span versus Linearity

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:

$$V_{out} = V_{off} + \text{sens}^*P \qquad [1]$$

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.

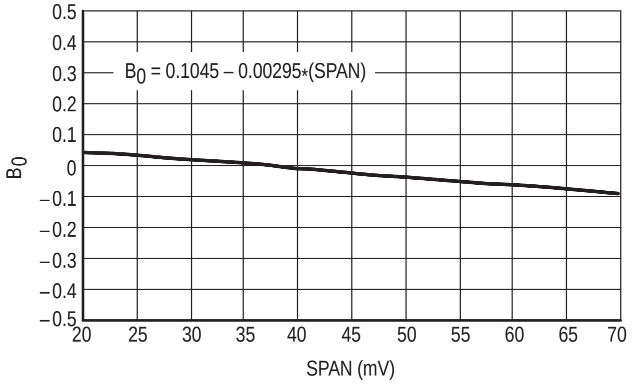


Figure 3. MPX10 Linearity Analysis — Correlation of B_0 $V_{out} = B_0 + B_1\,(P) + B_2\,(P)^2$

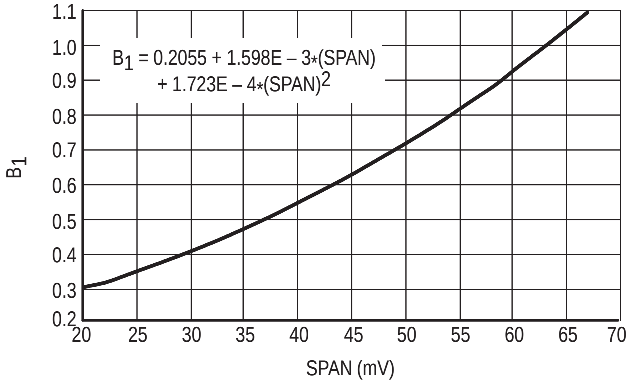


Figure 4. MPX10 Linearity Analysis — Correlation of B_1 $V_{out} = B_0 + B_1\,(P) + B_2\,(P)^2$

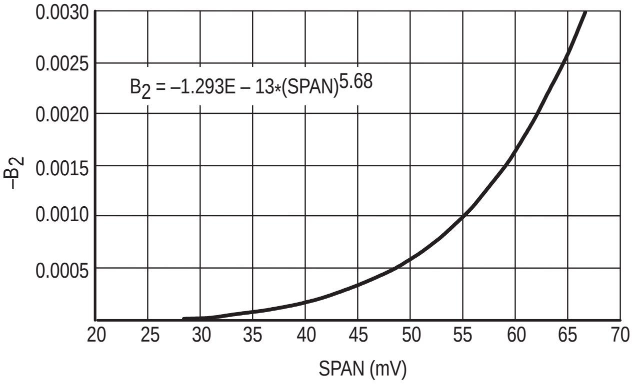


Figure 5. MPX10 Linearity Analysis — Correlation of B_2 $V_{out} = B_0 + B_1\,(P) + B_2\,(P)^2$

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.

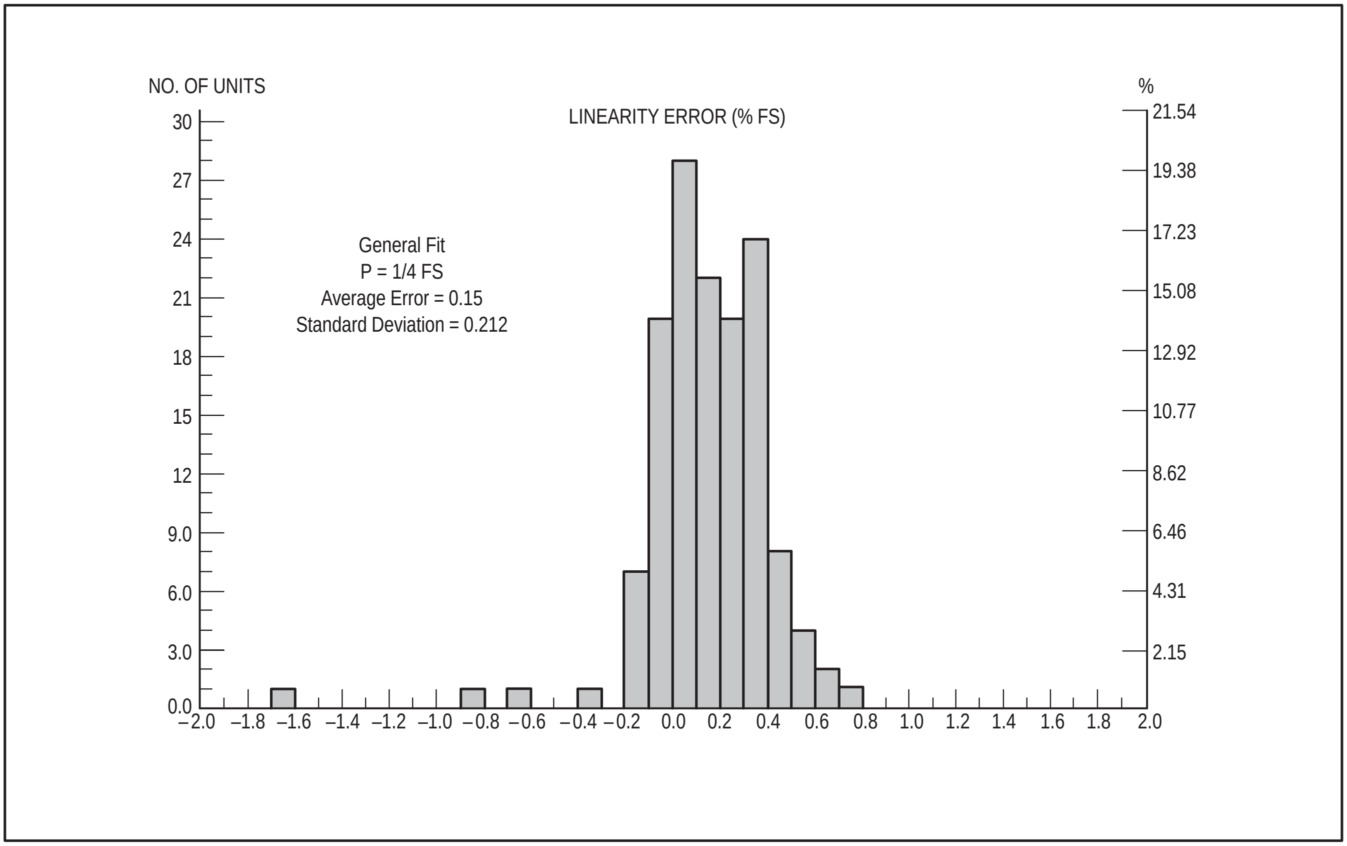


Figure 6. Linearity Error of General Fit Equation at 1/4 FS

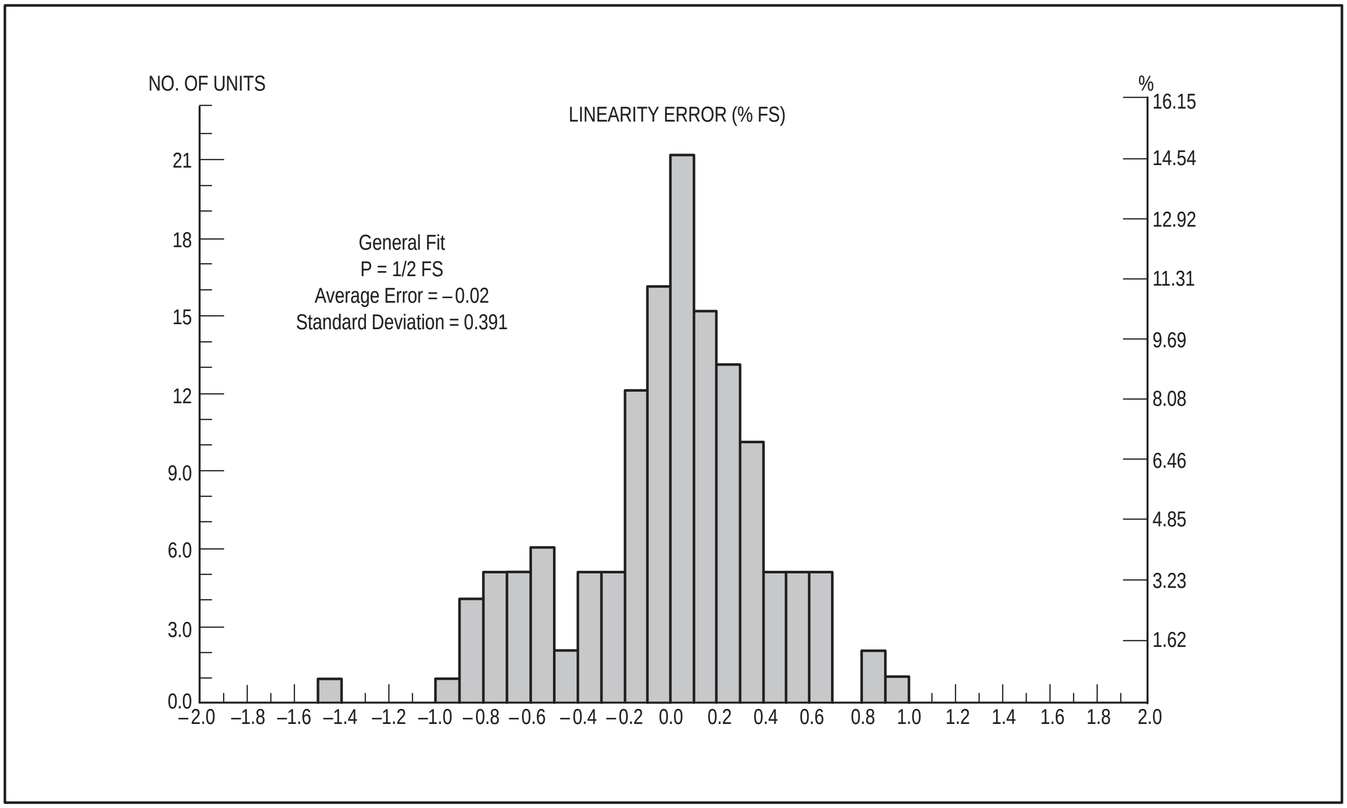


Figure 7. Linearity Error of General Fit Equation at 1/2 FS

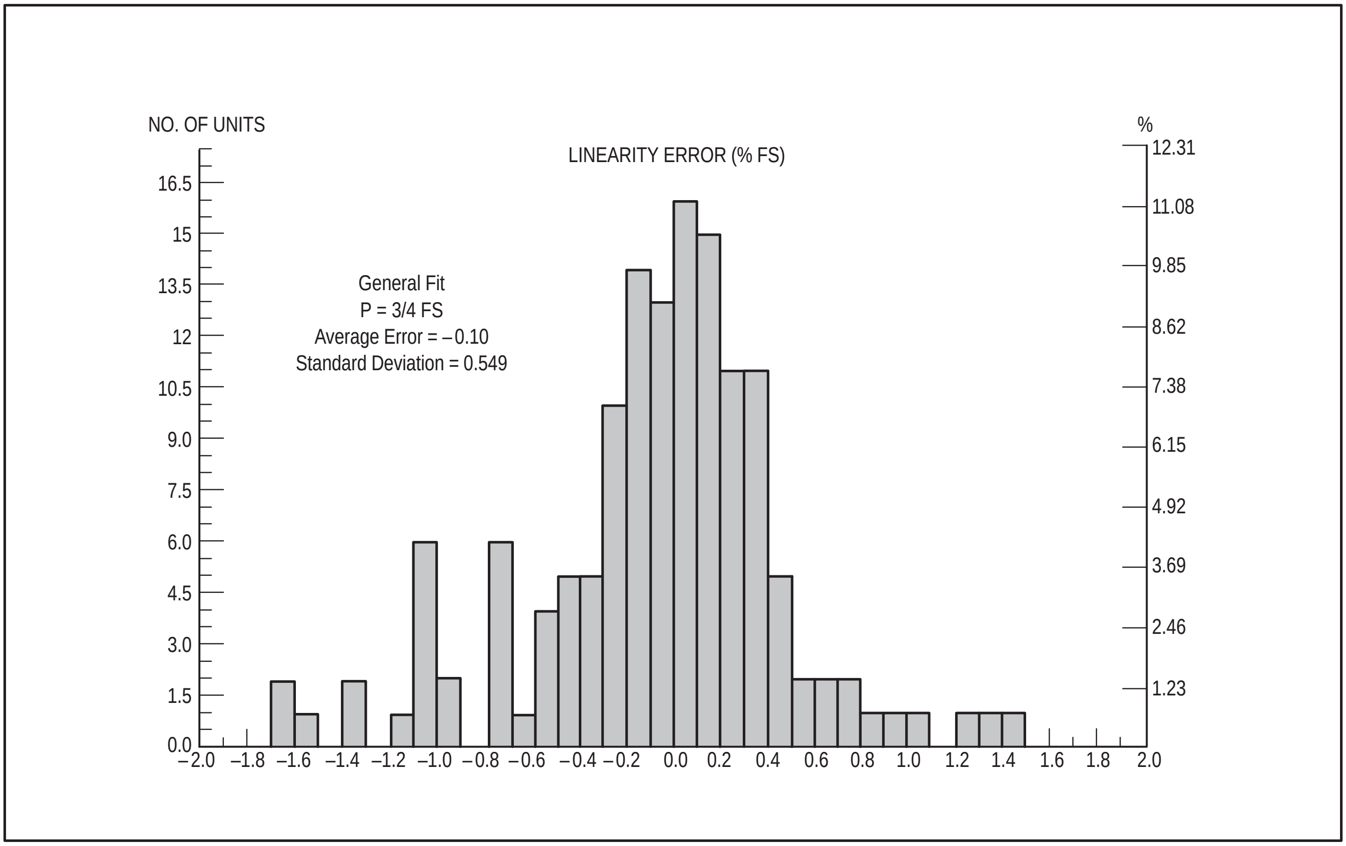


Figure 8. Linearity Error of General Fit Equation at 3/4 FS

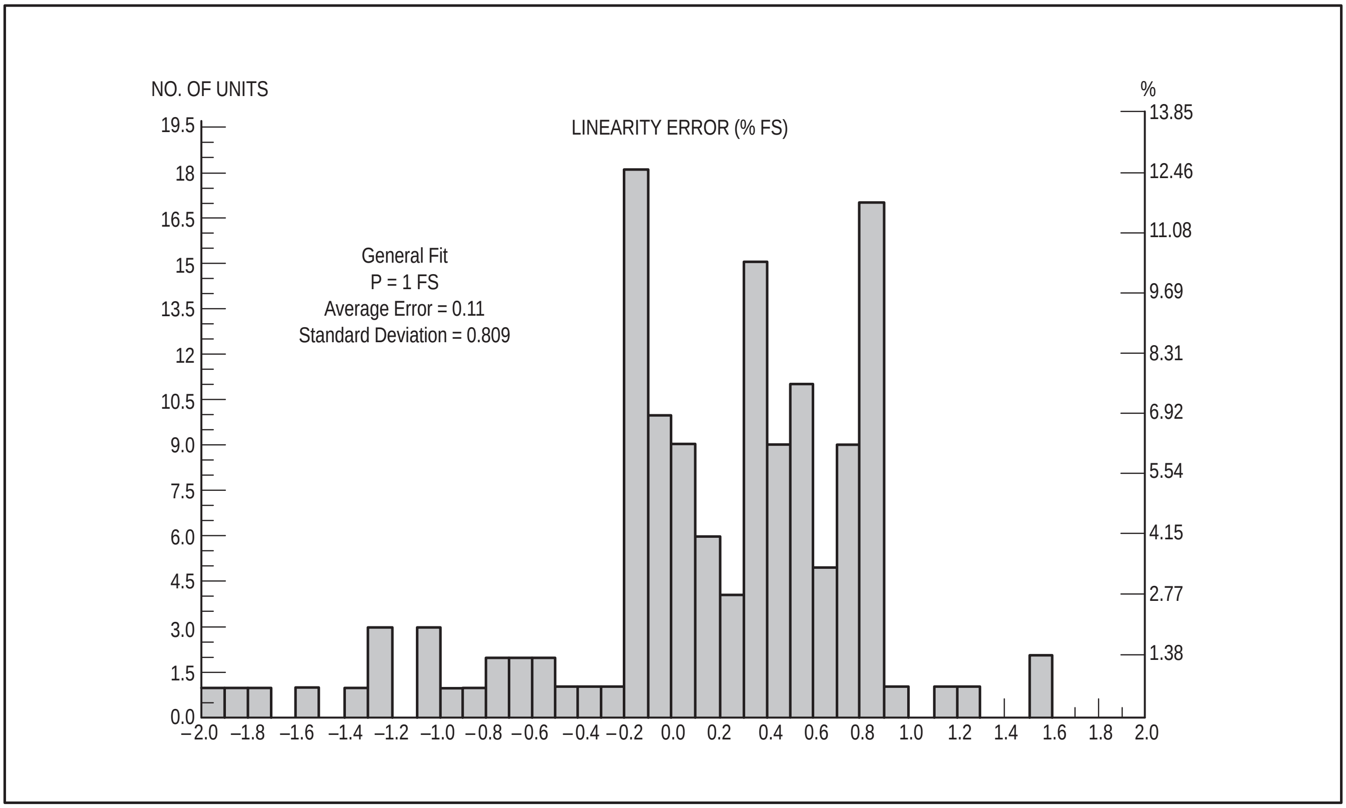


Figure 9. Linearity Error of General Fit Equation at FS

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.

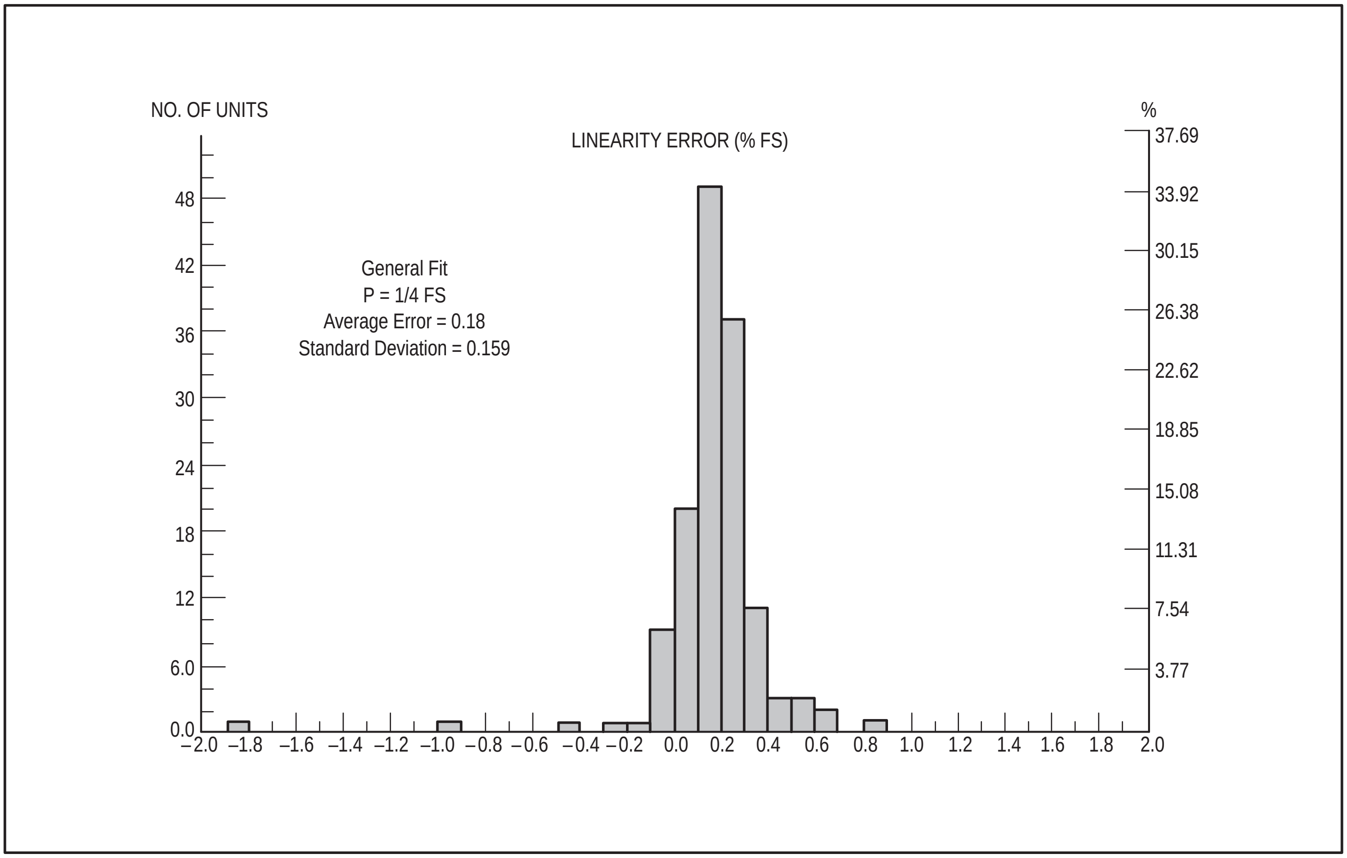


Figure 10. Linearity Error of Piece–Wise Linear Fit at 1/4 FS

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 – 13$X^{5.681}$
	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

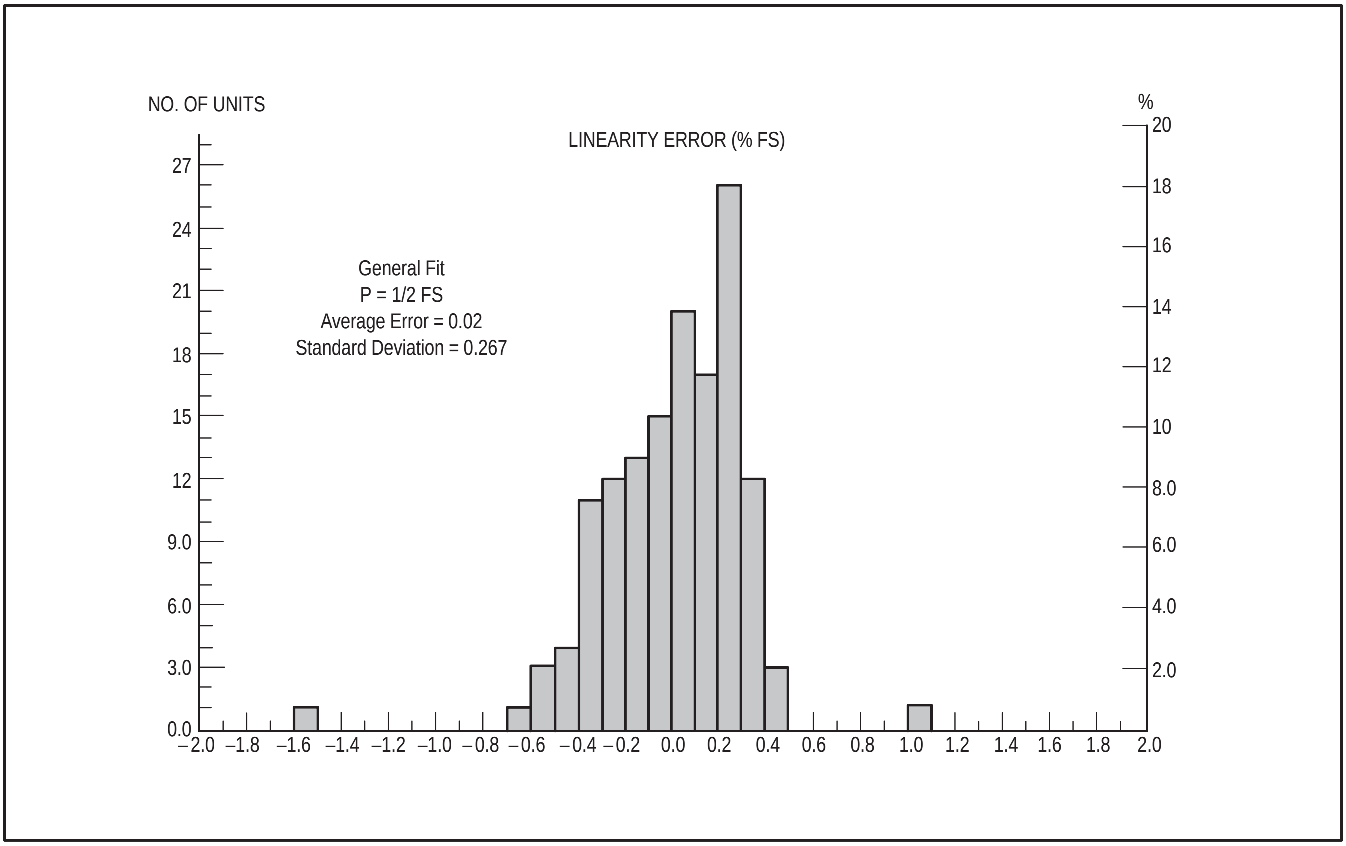


Figure 11. Linearity Error of Piece–Wise Linear Fit at 1/2 FS

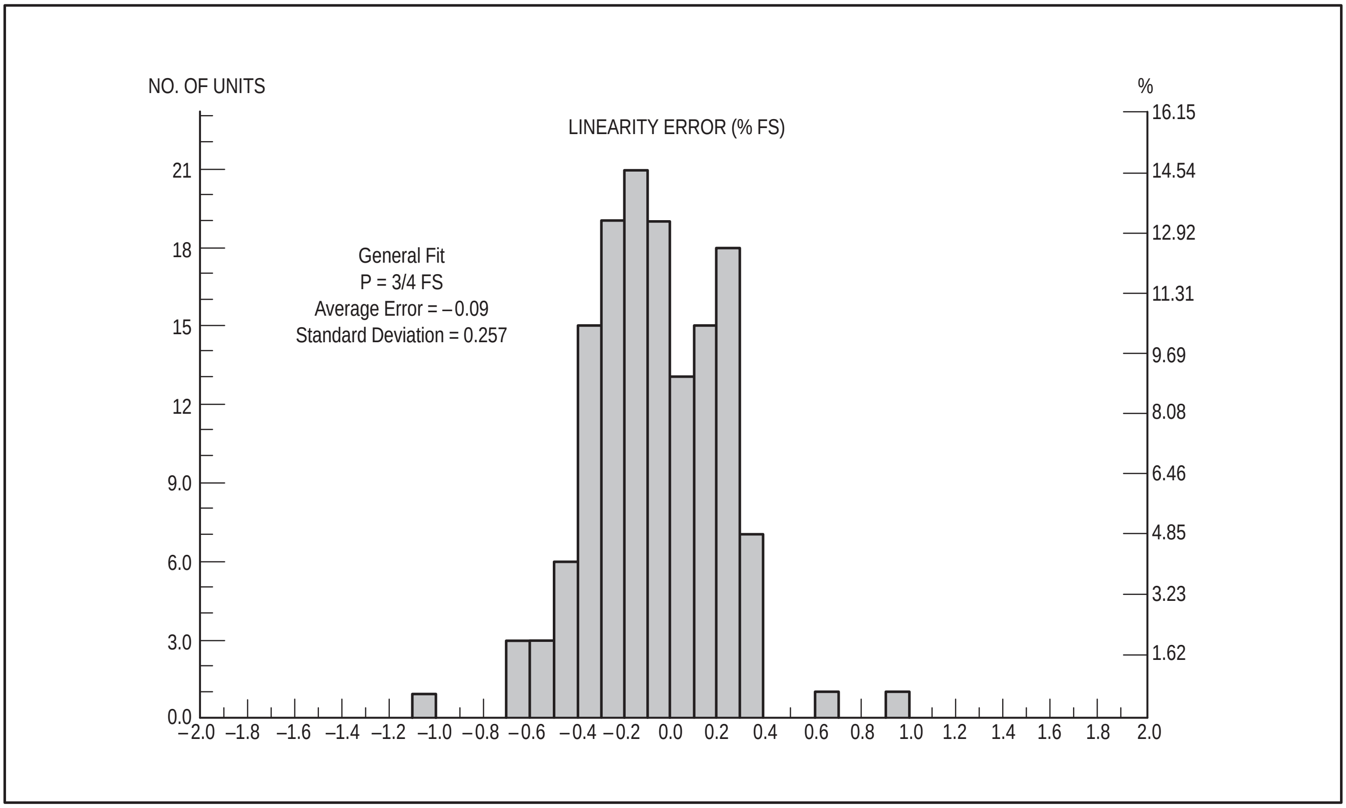


Figure 12. Linearity Error of Piece–Wise Linear Fit at 3/4 PS

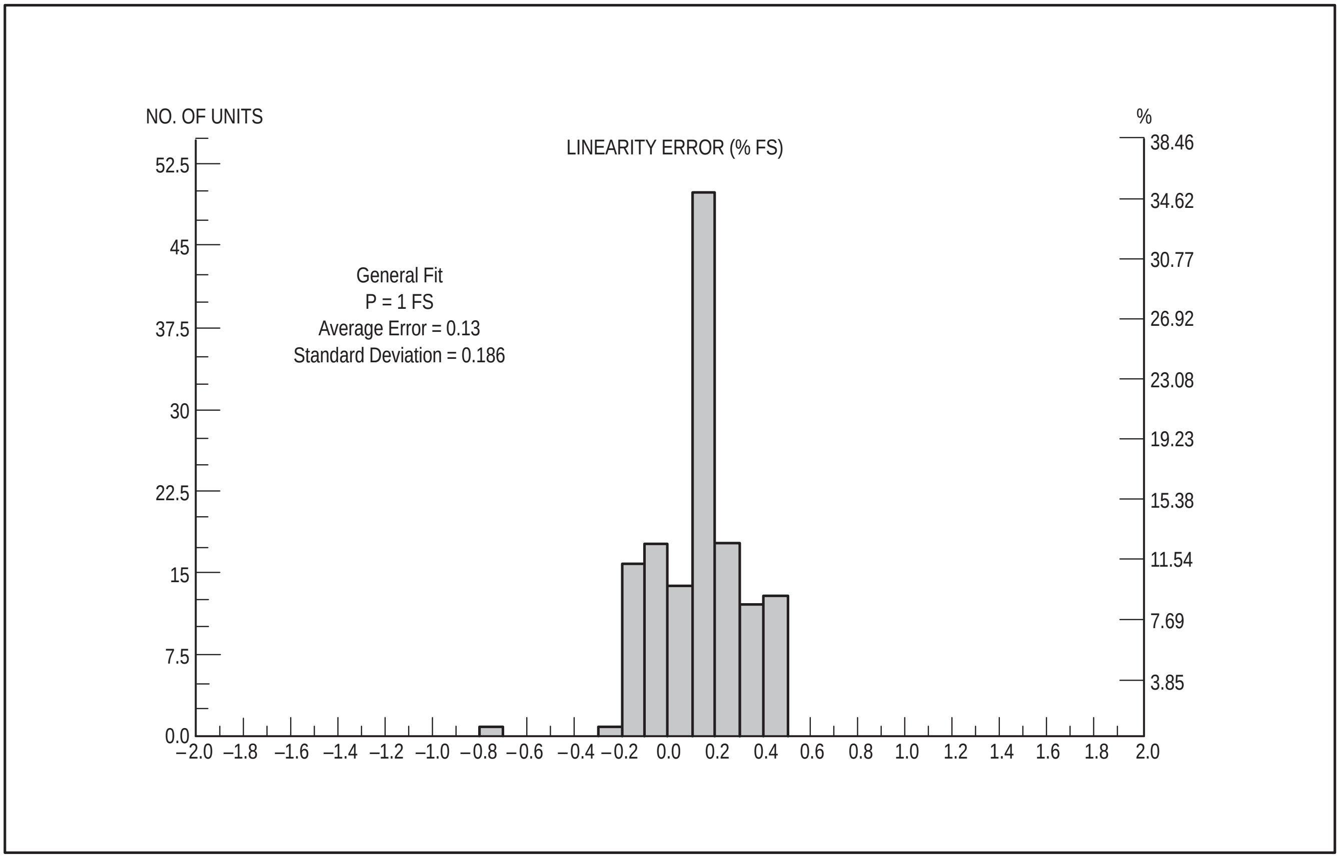


Figure 13. Linearity Error of Piece–Wise Linear Fit at FS

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.

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.

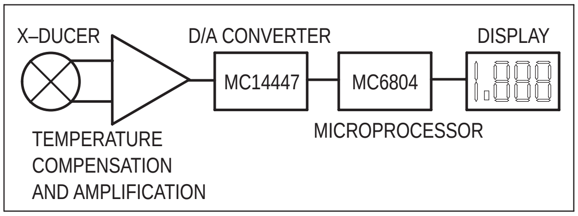


Figure 14. Linearization System Block Diagram

MOTOROLA
SEMICONDUCTOR APPLICATION NOTE

AN936

Mounting Techniques, Lead Forming and Testing of Motorola's MPX Series Pressure Sensors

Prepared by: Randy Frank
Motorola Inc., Semiconductor Products Sector
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.

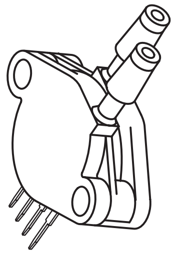

DIFFERENTIAL
PORT OPTION
CASE 344C–01

Figure 1. MPX Pressure Sensor In Chip Carrier Package Shown with Port Options

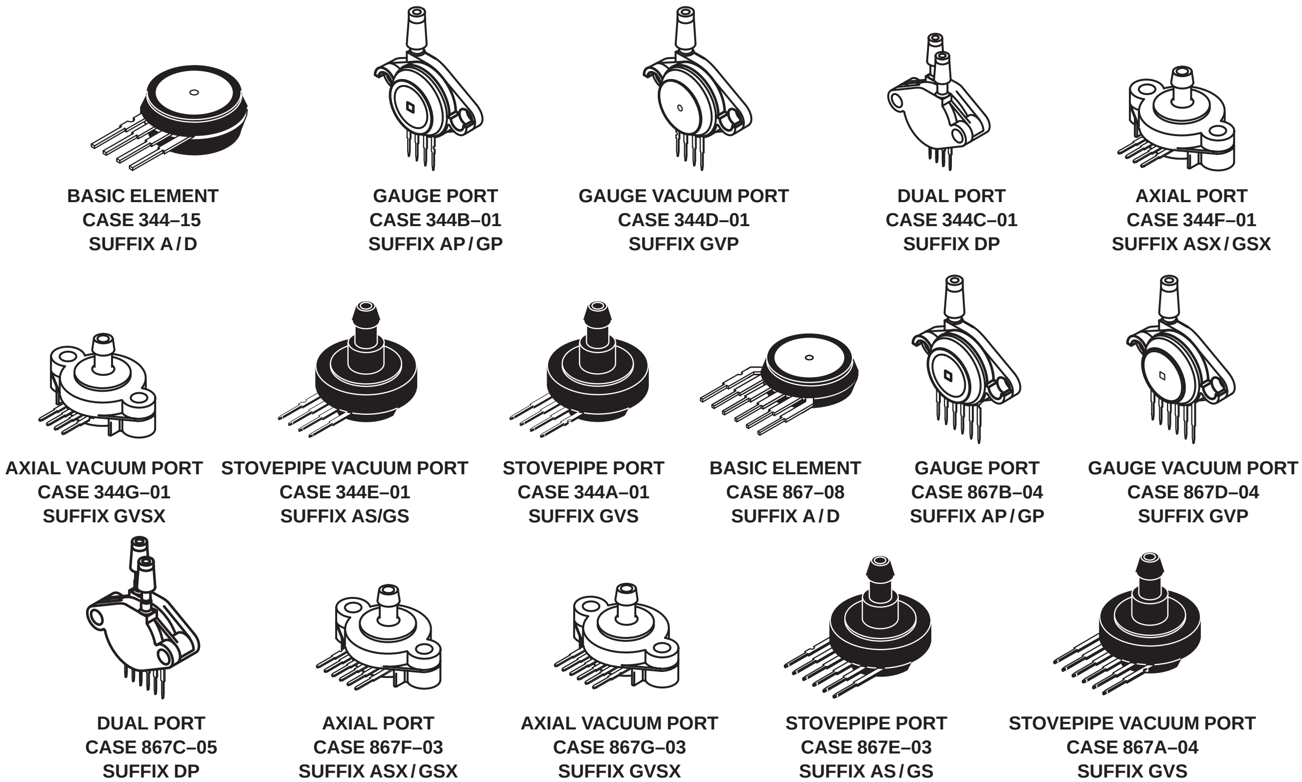


Figure 2. Chip Carrier and Available Ported Packages

REV 2

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.

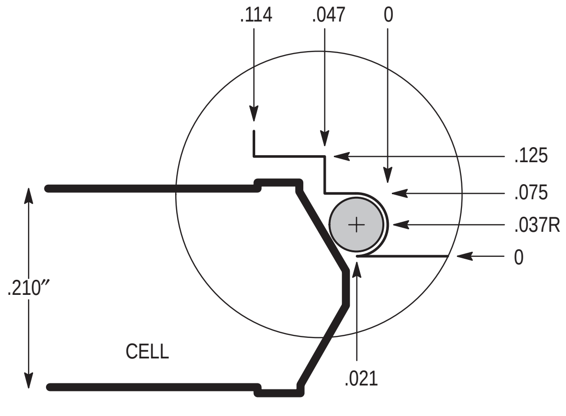


Figure 3. Examples of Motorola Sensors in Custom Housings

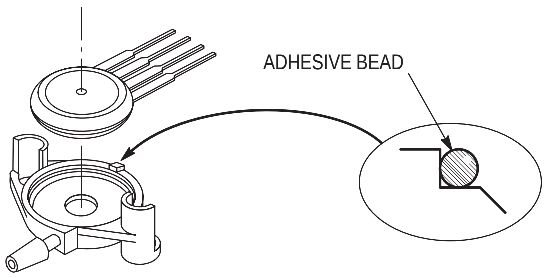


Figure 4. Port Adapter Dimensions

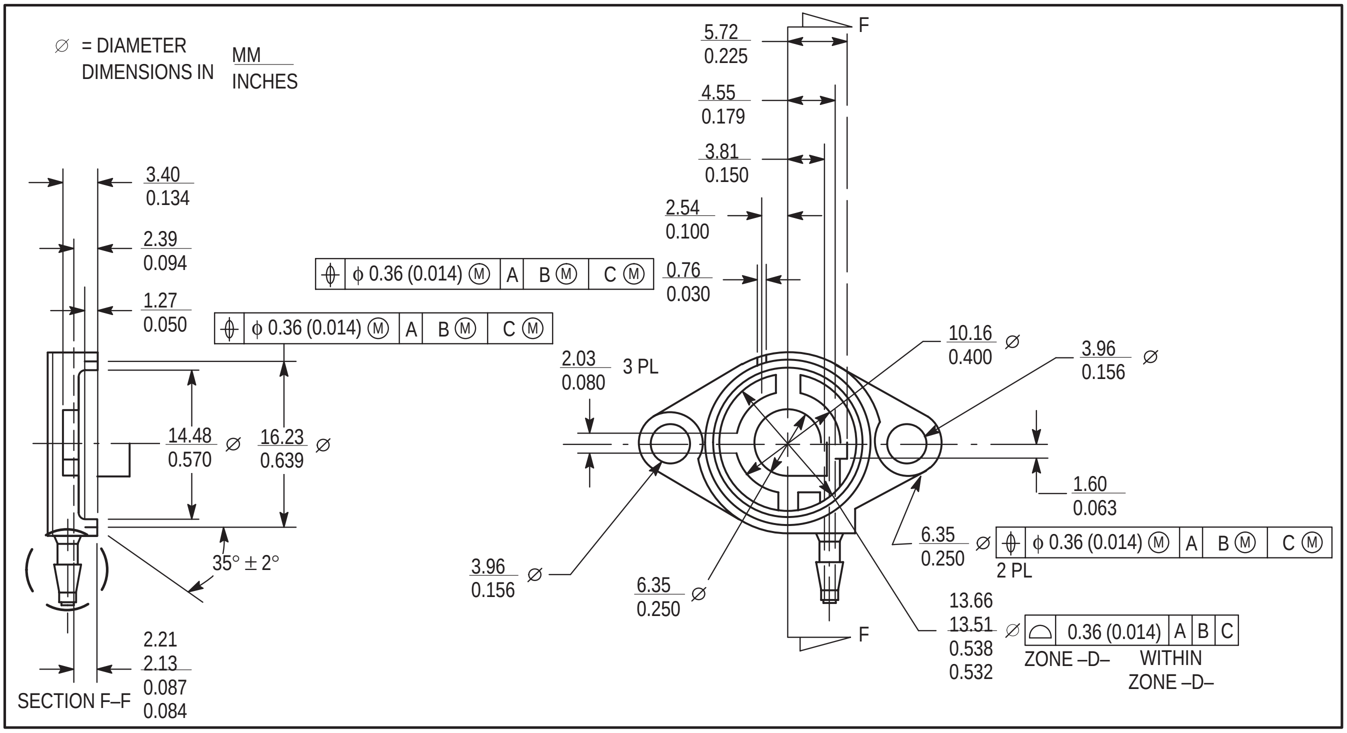
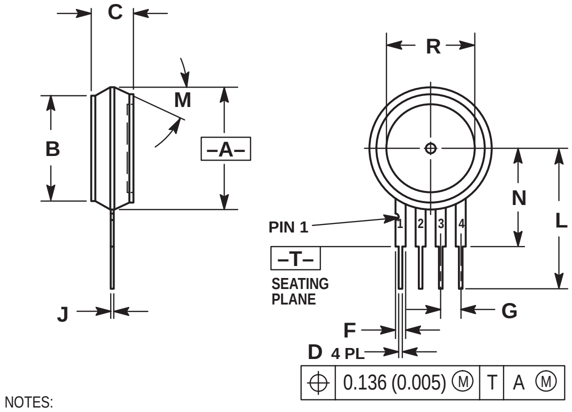


Figure 5. Port Adapter Dimensions



NOTES:

1. DIMENSIONING AND TOLERANCING PER ASME Y14.5M, 1994.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION –A– IS INCLUSIVE OF THE MOLD STOP RING. MOLD STOP RING NOT TO EXCEED 16.00 (0.630).

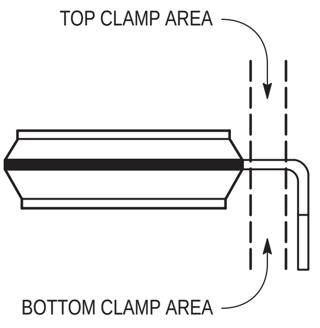
STYLE 1:
PIN 1. GROUND
2. + OUTPUT
3. + SUPPLY
4. – OUTPUT

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.595	0.630	15.11	16.00
B	0.514	0.534	13.06	13.56
C	0.200	0.220	5.08	5.59
D	0.016	0.020	0.41	0.51
F	0.048	0.064	1.22	1.63
G	0.100 BSC		2.54 BSC	
J	0.014	0.016	0.36	0.40
L	0.695	0.725	17.65	18.42
M	30° NOM		30° NOM	
N	0.475	0.495	12.07	12.57
R	0.430	0.450	10.92	11.43

CASE 344–15

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. 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

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

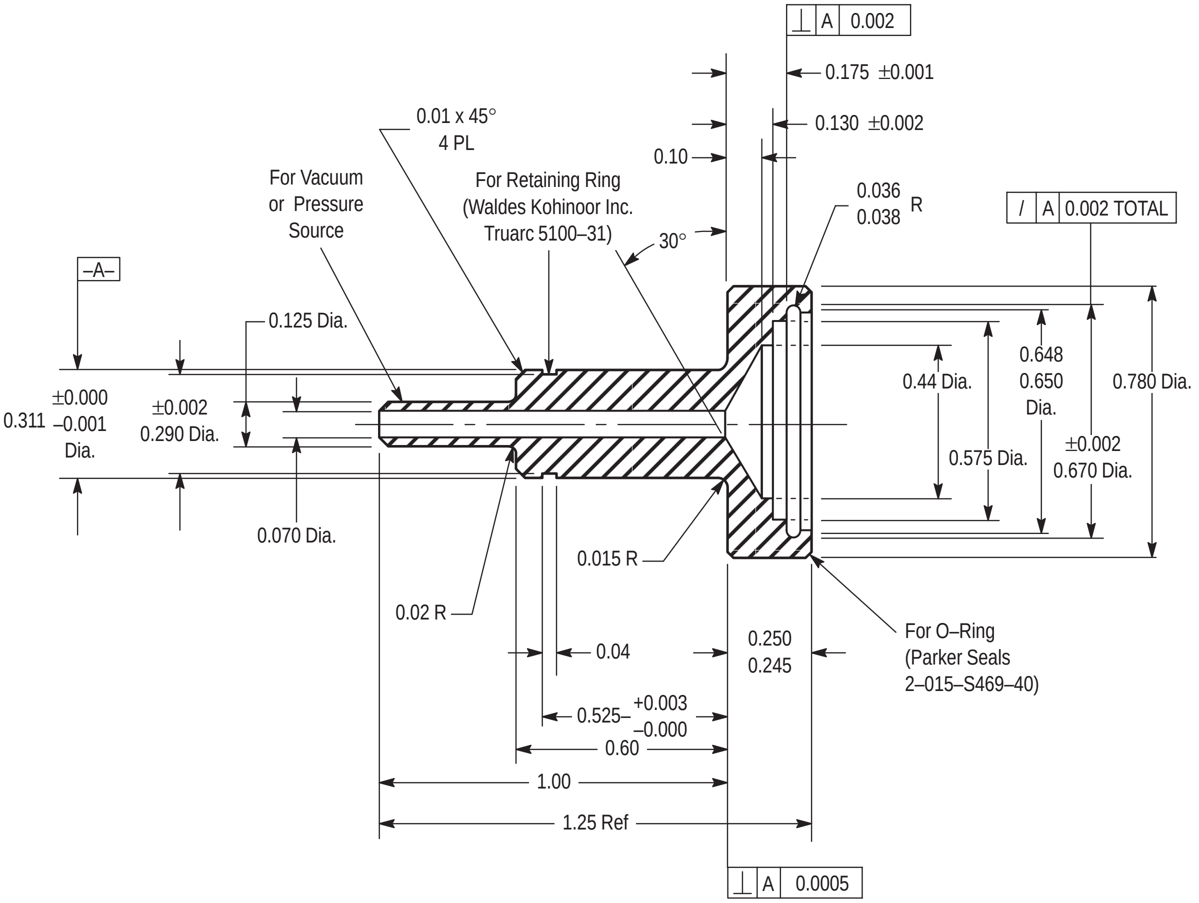


Figure 8. O–Ring Test Fixture

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).

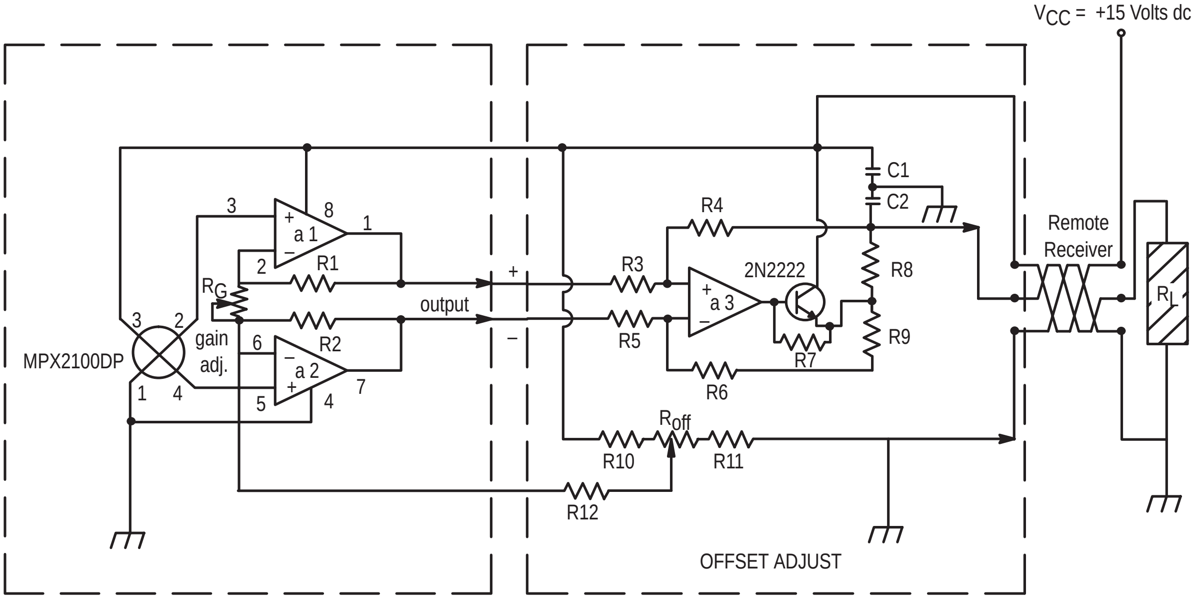
The high pressure is connected to the pressure port and the low pressure (if using a differential pressure sensor), is connected to the vacuum port.

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.

REV 1



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. R7 = 1 K
R_{off} = 1 M Pot. R10 = 110 K
* R1 = R2 = 330 K R11 = 1 M
* R3 = R4 = 27 K R12 = 330 K
* R5 = R6 = 27 K C1 = C2 = 0.1 µF
* R8 = R9 = 150 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

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.

When using a Motorola MC78L12AC voltage regulator, the circuit can be used with power voltage variation from 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.

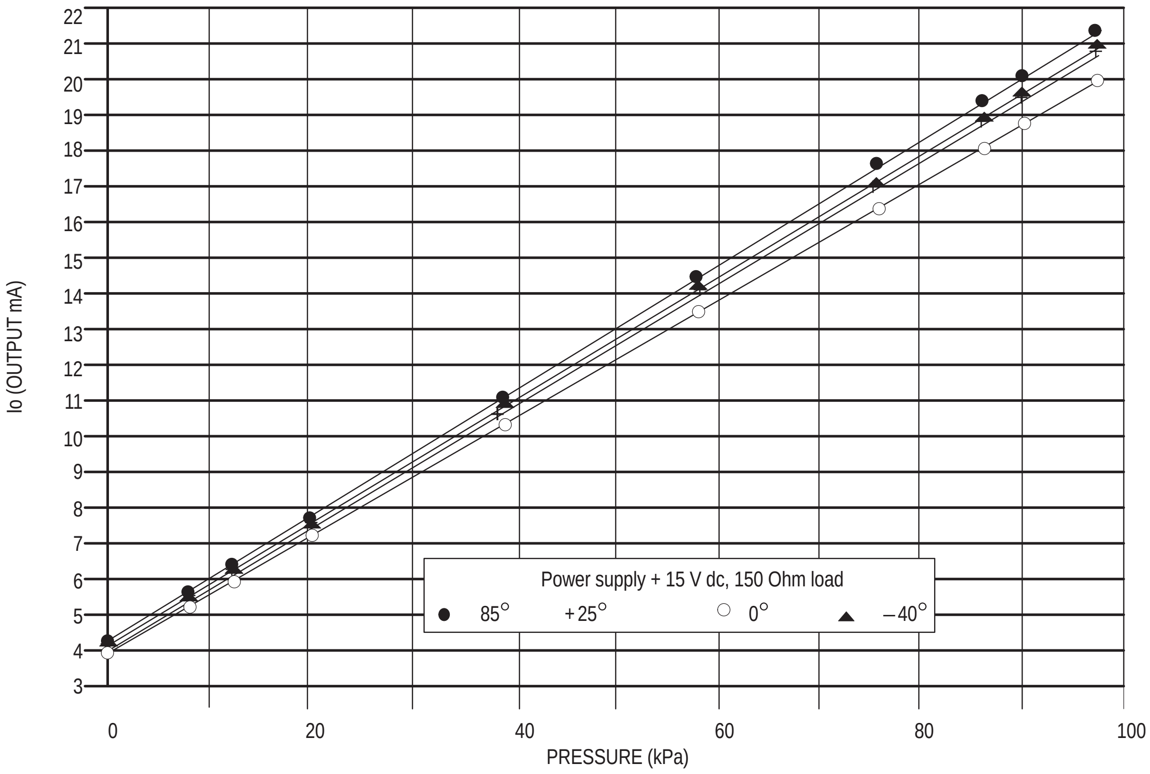
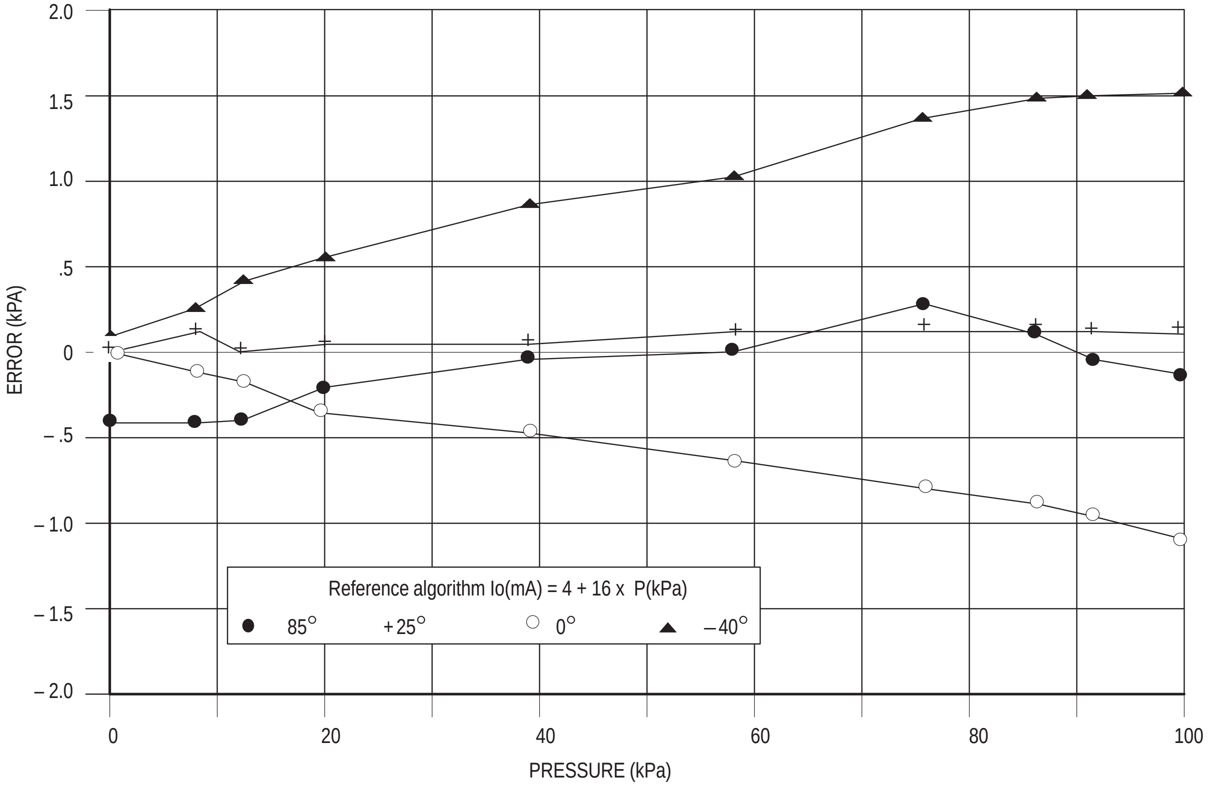


Figure 2. Output versus Pressure



Reference algorithm is the straight from output at 255 0 pressure and output at full pressure

Figure 3. Absolute Error Reference to Algorithm

MOTOROLA
SEMICONDUCTOR 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.

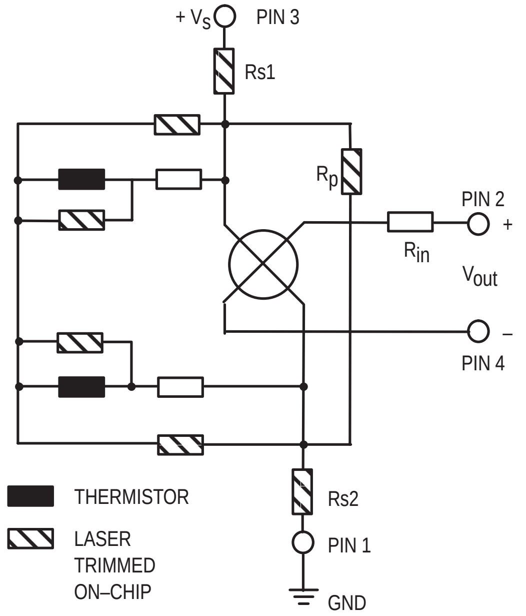


Figure 1. Seven Laser–Trimmed Resistors and Two Thermistors Calibrate the Sensor for Offset, Span, Symmetry and Temperature Compensation

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.

REV 1

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.

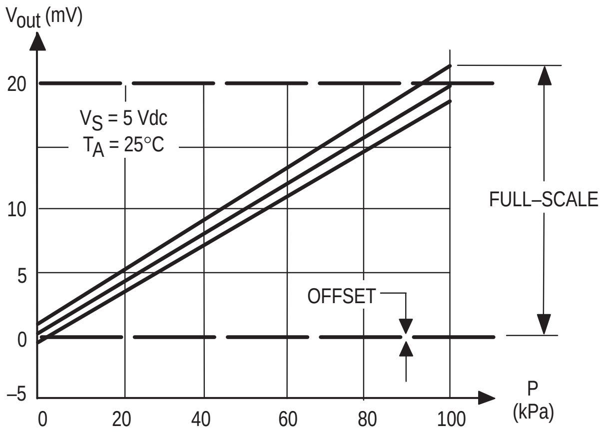


Figure 2. Spread of the Output Voltage versus the Applied Pressure at 25°C

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.

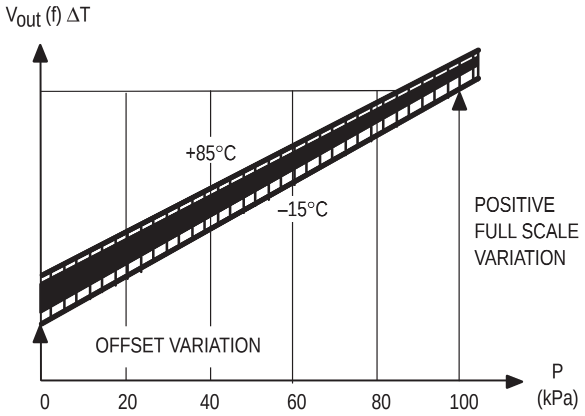


Figure 3. Output Voltage versus Temperature. The Dark Area Shows the Trend of the Compensation

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:

$$Avd = \frac{V1-V2}{Vs2-Vs4} = \left(1 + \frac{2\,R_f}{R_g}\right) \qquad (1)$$

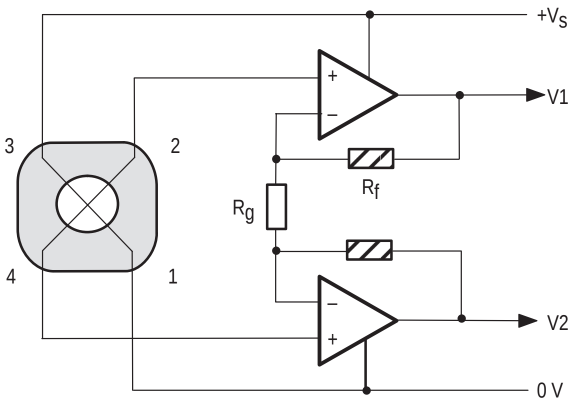


Figure 4. One Power Supply to Excite the Bridge and to Develop a Differential Output Voltage

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.

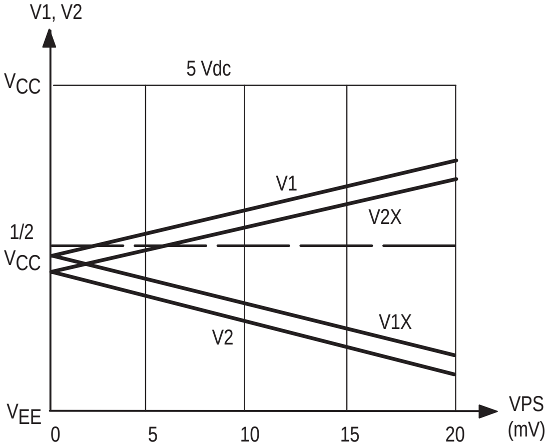


Figure 5. Instrument Amplifier Transfer Function with Spread of the Device to Device Offset Variation

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.

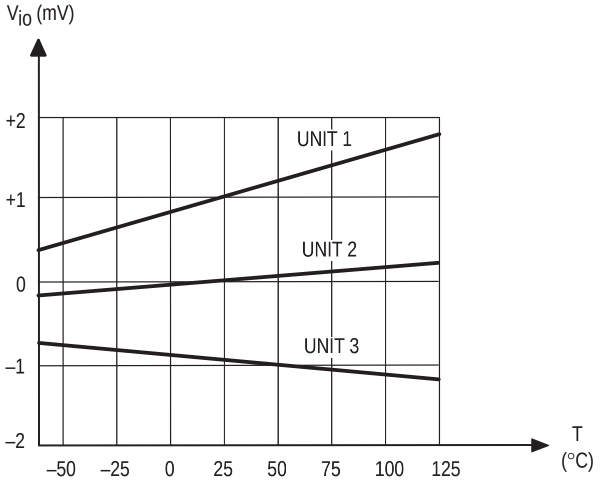


Figure 6. Input Offset Voltage versus Temperature

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.

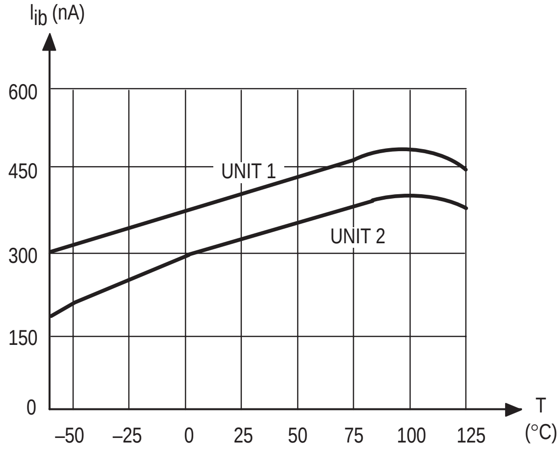


Figure 7. Input Bias Current versus Temperature

MCU CONTRIBUTION

As shown in Figure 5, crossing the instrument amplifier inputs generated their mutual differences which can be computed by the MCU.

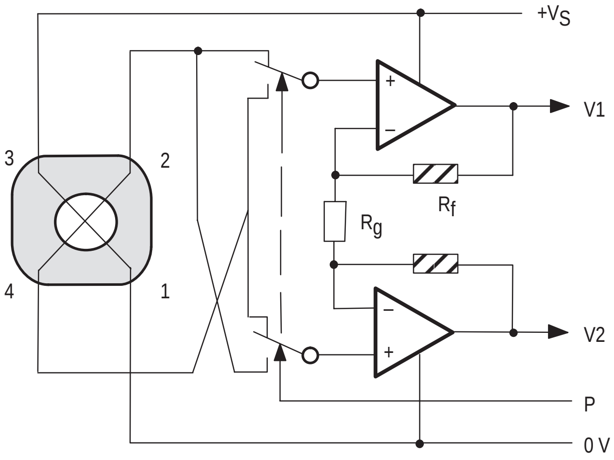


Figure 8. Crossing of the Instrument Amplifier Input Using a Port of the MCU

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.

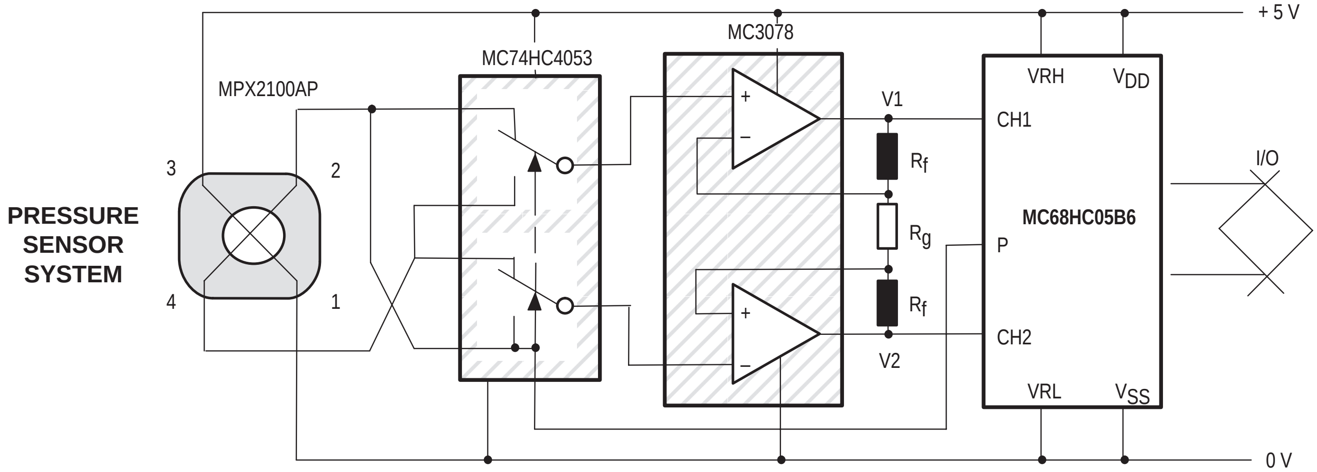


Figure 9. Two Channel Input and One Output Port Are Used by the MCU

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
$V1x = Avd (Vs4 + OF1)$ $V2x = Avd (Vs2 + OF2)$

$Delta = V1–V2$ 1st differential result
$= Avd * (Vs2 of OF1) – Avd * (Vs4 + OF2)$

$Deltax = V2x–V1x$ 2nd differential result
$= Avd * (Vs2 + OF2) – Vdc * (Vs4 + OF1)$

Adding of the two differential results

$$\begin{aligned} VoutV &= Delta + Deltax \\ &= Avd*Vs2 + Avd*OF2 + Avd*OF2 – Avd*OF1 \\ &+ Avd*OF1 – Avd*OF2 + Avd*OF2 – Avd*OF1 \\ &= 2 * Avd * (Vs2 – Vs4) \\ &= 2 * Avd * [(a (P) + of2) – (b (P) + of4)] \\ &= 2 * Avd * [V(P) + Voffset] \end{aligned}$$

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:

$$count = 2 * Avd * V(P) * 51/V \text{ where:}$$

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 = $\underline{113}$.

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.

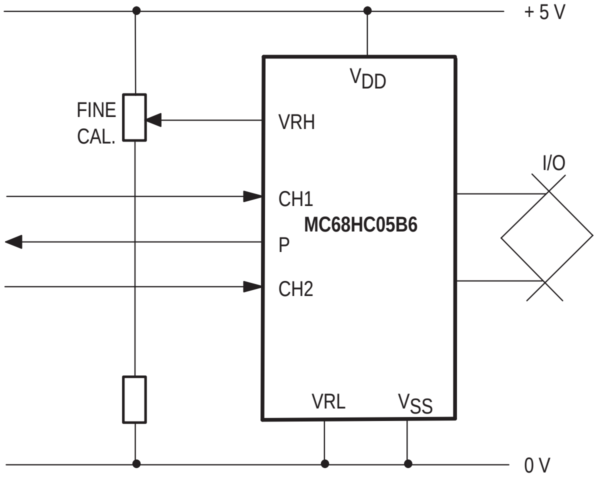


Figure 10. Full Scale Output Calibration Using the Reference Voltage VRH–VRL

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.

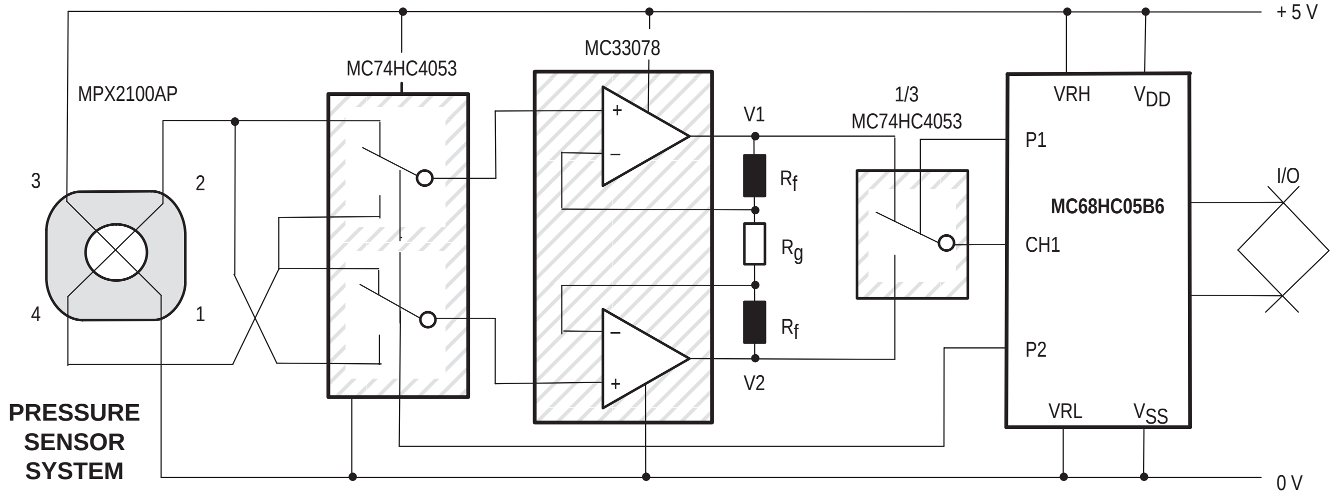


Figure 11. One Channel Input and Two Output Ports are used by the MCU

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.

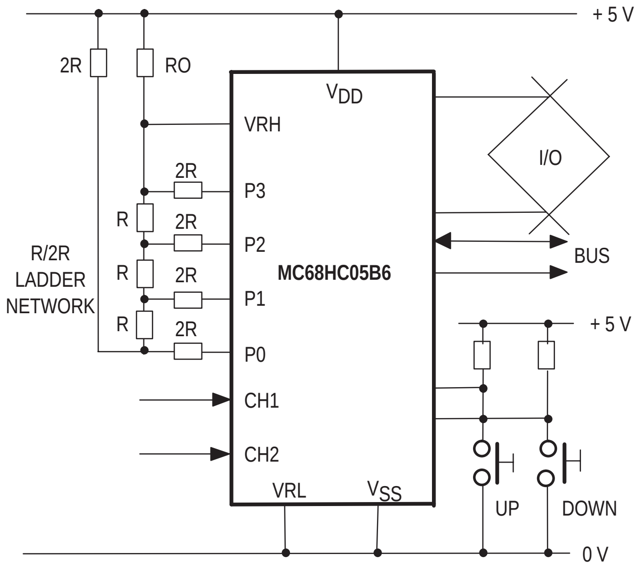


Figure 12.

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:/

$$\begin{aligned} S &= 4.5\ \mathrm{V}/200\mathrm{kPa} && (1)\\ &= 0.0225\ \mathrm{V}/\mathrm{kPa} &&\\ \text{or}\quad S &= 22.5\ \mathrm{mV}/\mathrm{kPa} && \end{aligned}$$

If an 8–bit A/D is used with 0 and 5 Volt low and high references, respectively, then the resolution would be:

$$\begin{aligned} S &= 5\mathrm{V}/\left(2^8 - 1 = 5\mathrm{V}/255\right) && (2)\\ &= 0.01961\ \mathrm{V} &&\\ \text{or}\quad R_V &= 19.60\ \mathrm{mV\ per\ bit} && \end{aligned}$$

This corresponds to a pressure resolution of:

$$\begin{aligned} R_P &= 5\mathrm{V}/\ (19.60\ \mathrm{mV/bit})\ /(22.5\ \mathrm{mV/kPa}) && (3)\\ &= 0.871\ \mathrm{kPa\ per\ bit} && \end{aligned}$$

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):

$$\begin{aligned} V_m(\text{measured}) &= 4.5\ (\text{Papp})\ \mathrm{x}\ (S) && (4)\\ &= (124\ \mathrm{kPa})\ \mathrm{x}\ (22.5\ \mathrm{mV/kPa}) &&\\ &= 2790\ \mathrm{mV}, && \end{aligned}$$

where Papp is the pressure applied to the sensor.

Due to the resolution of the A/D, the microprocessor receives the following conversion:

$$\begin{aligned} M &= (2790\ \mathrm{mV})/\ (19.60\ \mathrm{mV/bit}) && (5)\\ &= 142.35 &&\\ &= 142\ (\text{truncated to integer}) && \end{aligned}$$

The calculated voltage for this stored value is:

$$\begin{aligned} V_c\ (\text{calculated}) &= (142\ \text{count})\ \mathrm{x}\ (19.60\mathrm{mV}/\ \text{count}) && (6)\\ &= 2783\ \mathrm{mV} && \end{aligned}$$

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:

$$\begin{aligned} P_c\ (\text{calculated}) &= (2783\ \mathrm{mV})/\ (22.5\ \mathrm{mV/kPa}) && (7)\\ &\ 123.7\ \mathrm{kPa} && \end{aligned}$$

Thus, the error would be:

$$\begin{aligned} E &= \text{Papp}–\text{Pc} && (8)\\ &= 124\ \mathrm{kPa}–123.7\ \mathrm{kPa} &&\\ &= 0.3\ \mathrm{kPa} && \end{aligned}$$

This is greater than the 0.1 kPa resolution requirement.

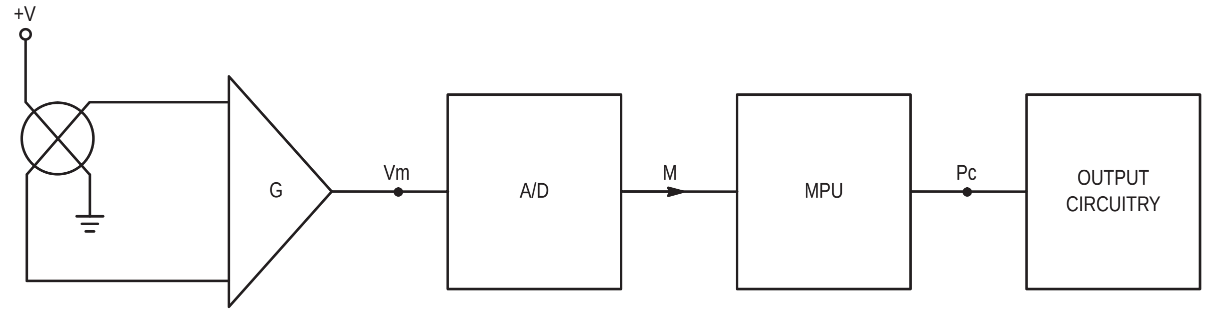


Figure 1. Block Diagram

REV 1

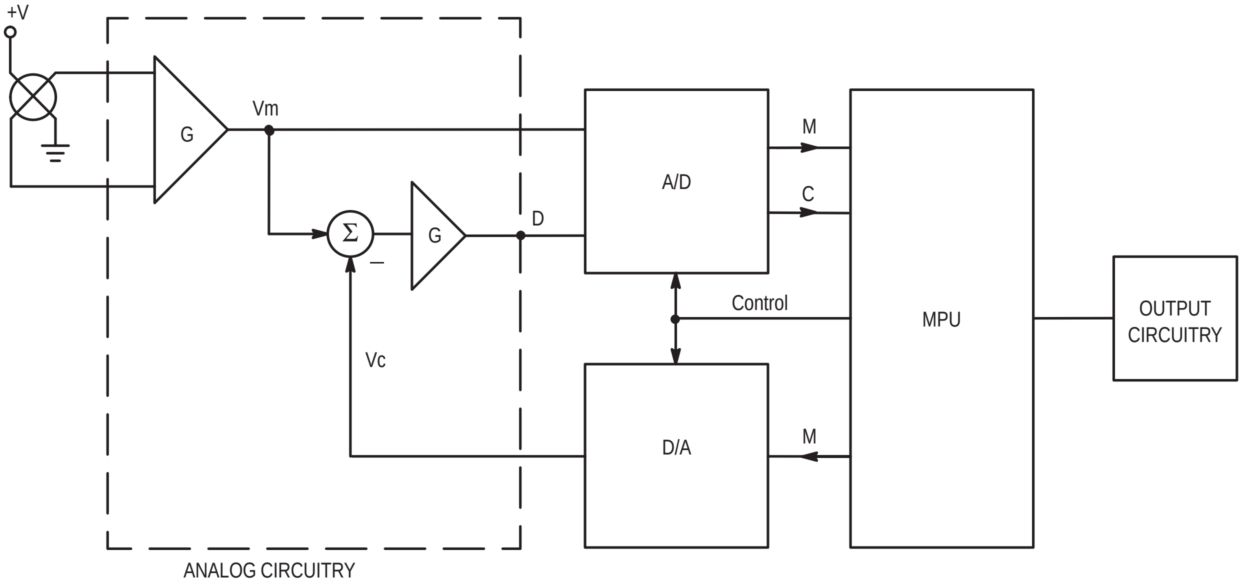


Figure 2. Expanded Block Diagram

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:

$$\begin{aligned} D &= (Vm - Vc) \times G && (9) \\ &= (2790\ \text{mV} - 2783\ \text{mV}) \times 10 \\ &= 70\ \text{mV} \end{aligned}$$

The microprocessor will receive the following count from the A/D:

$$\begin{aligned} C &= 70\text{mV}/(19.60\ \text{mV/count}) && (10) \\ &= 3.6 \\ &= 3\ \text{full counts} \end{aligned}$$

The microprocessor then computes the actual pressure with the following equations:

$$\begin{aligned} \text{Expanded Voltage} &= Vc + ((C \times R)/G) && (11) \\ &= 2783 + ((3 \times 19.60)/10) \\ &= 2789\ \text{mV}, \end{aligned}$$

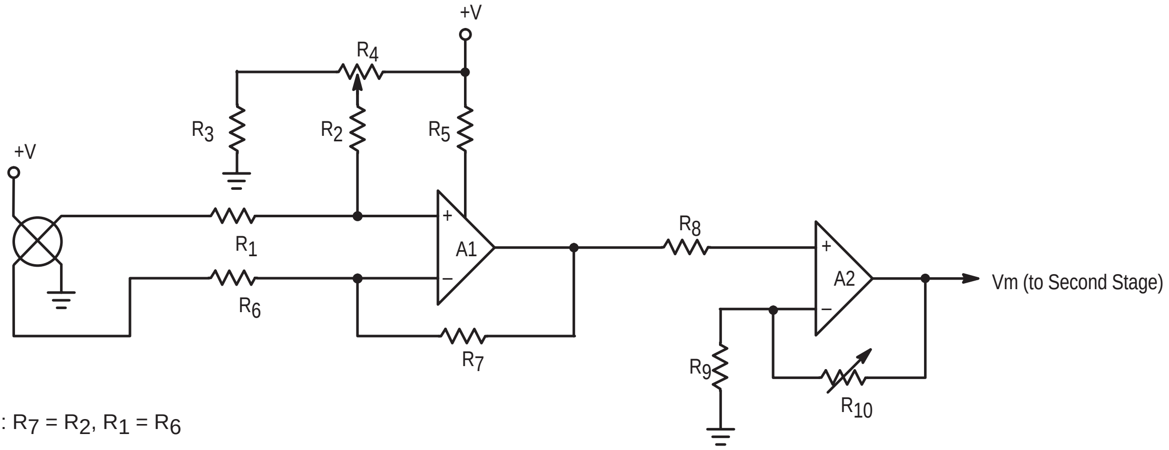
NOTE: R is resolution of 8-bit d/A

$$\begin{aligned} \text{Corresponding Pressure} &= 2789\ \text{mV}/ && (12) \\ &= 22.5\ \text{mV/kPa} \\ &= 123.9\ \text{kPa} \end{aligned}$$

Thus the error is:

$$\begin{aligned} \text{Pressure Error} &= \text{Actual} - \text{Measured} && (13) \\ &= 124\ \text{kPa} - 123.9\ \text{kPa} \\ &= 0.1\ \text{kPa} \end{aligned}$$

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

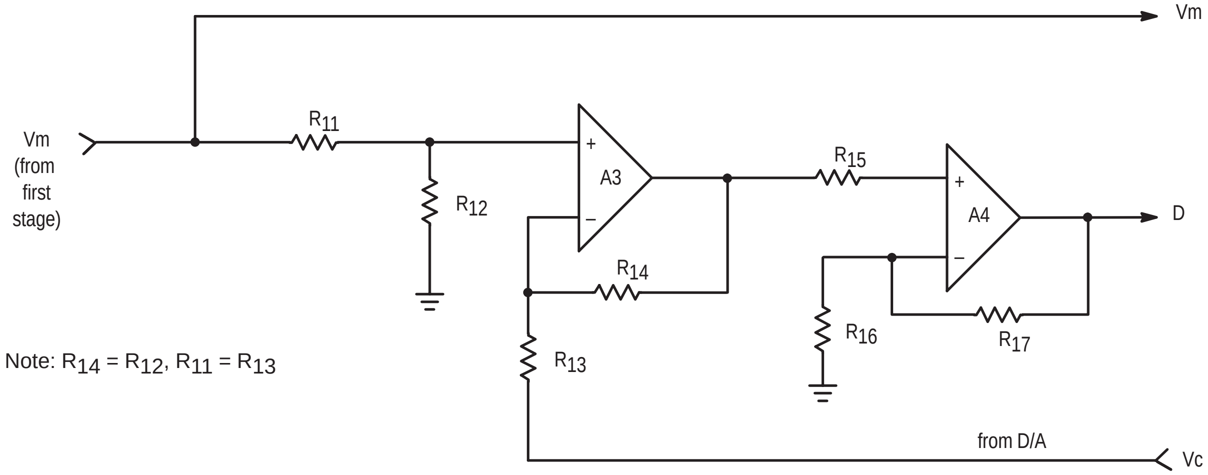


Figure 4. Second Stage — Difference Amplifier and Gain

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:

$$D = (Vm - V_c) \times G3$$

$$G3 = (R14/\ R13)\left(1 + \frac{R17}{R16}\right)$$

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. $V_{expanded}$ 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:

$$V_{expanded} = V_c + D/G3$$

$$\text{therefore,}\ PV_{expanded} = V_{expanded}/S.$$

$P_{expanded}$ 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.

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.

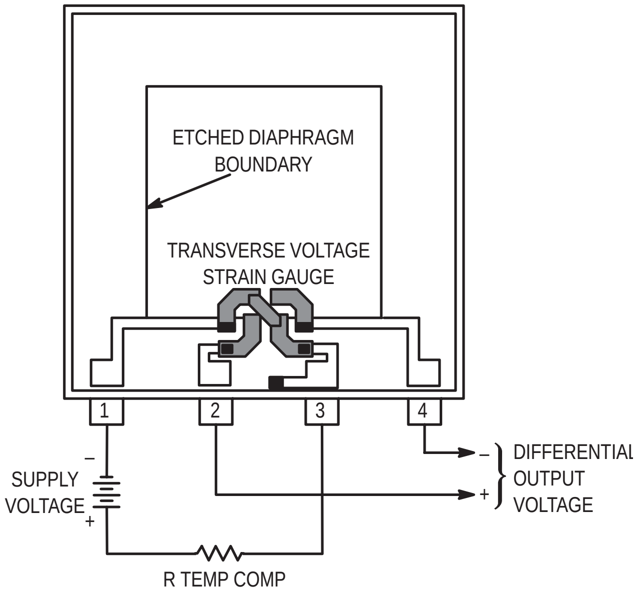


Figure 1. Sensor Construction Showing Electrical Connections

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.

REV 1

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 advantage of reducing the power supply voltage, 15 volts, to the desired 3 volt level.

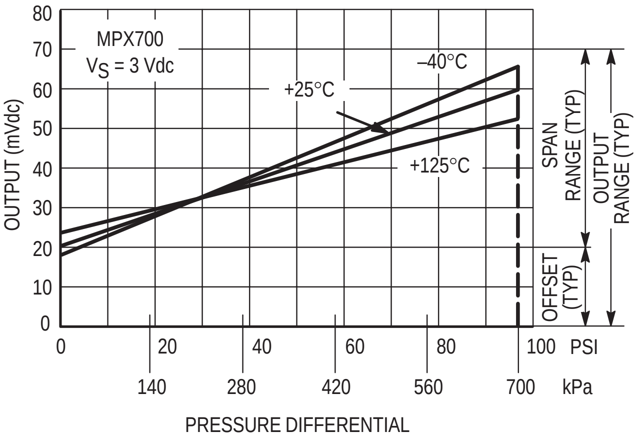


Figure 2. Output versus Pressure Differential

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

$$A = 2(1 + 100K/R)$$

where A = circuit gain
R = the total resistance composed of R6 plus R7
100K = the circuit value represented by R8, R9, R10 and R12.

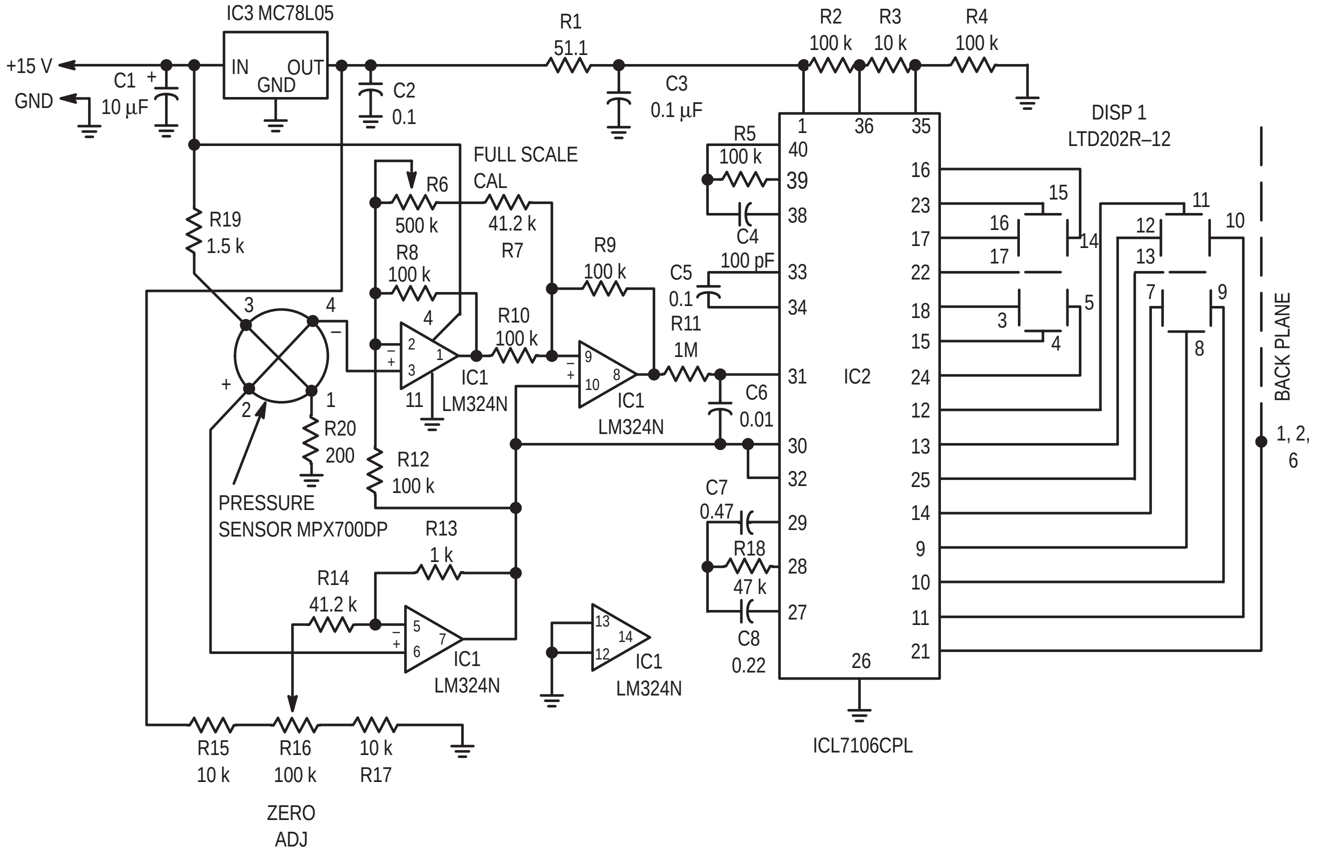


Figure 3. Schematic Diagram of Digital Pressure Gauge

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.

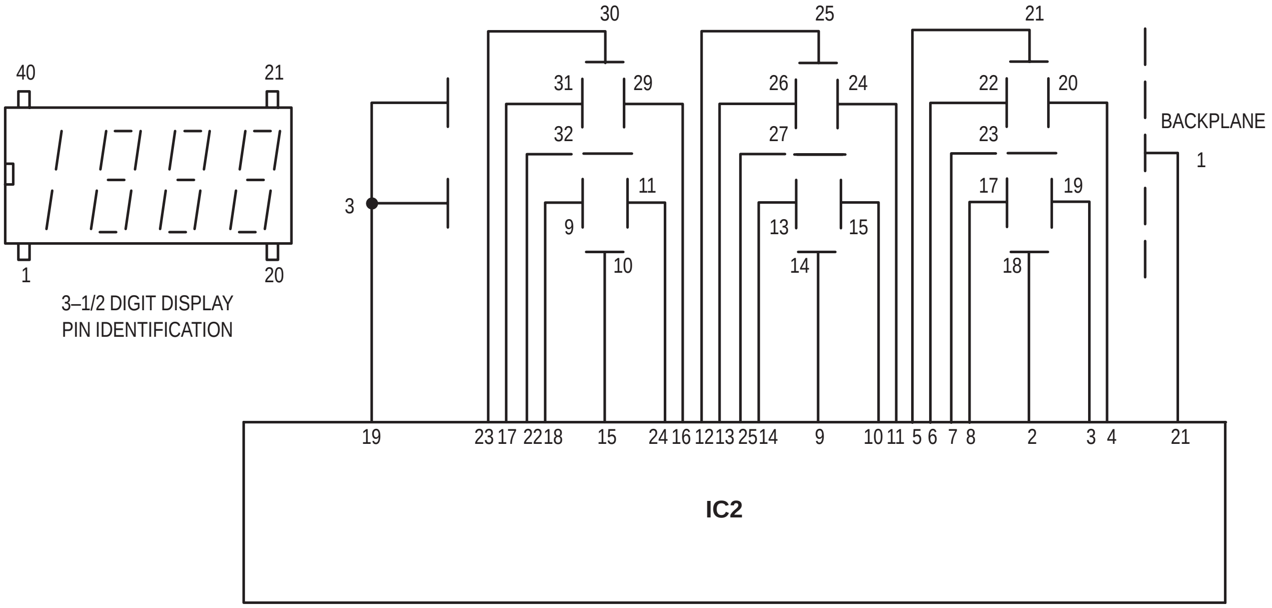


Figure 4. IC2 Driving Optional 3–1/2 Digit LCD Display

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.

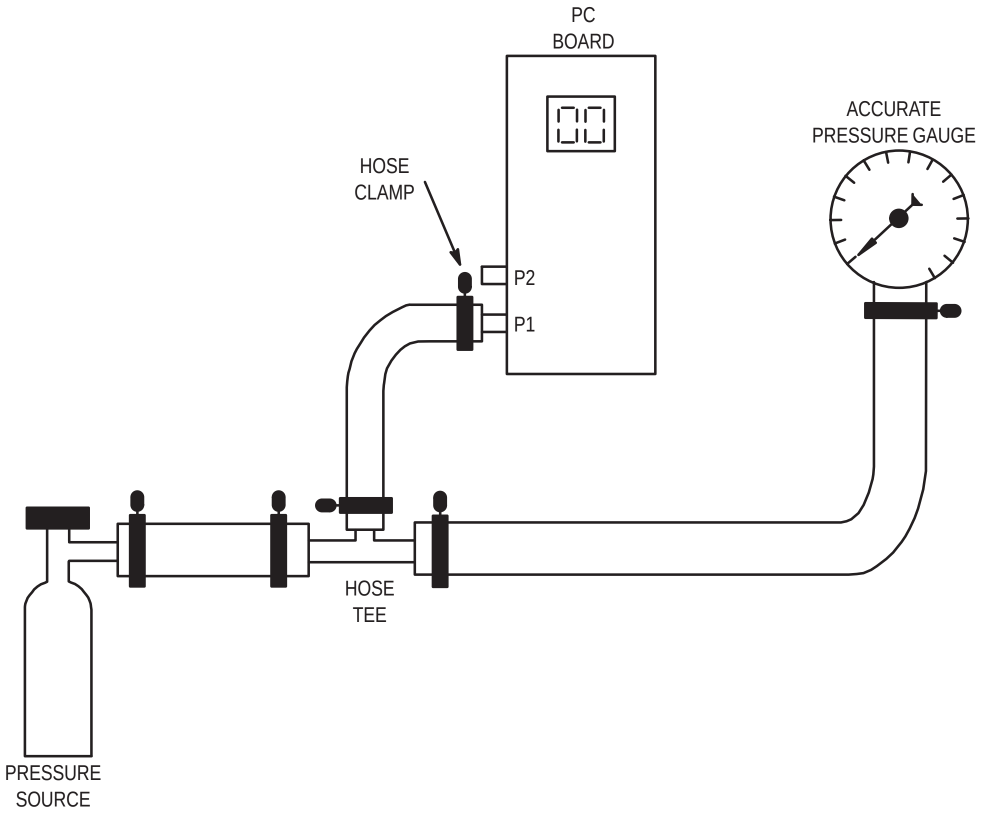


Figure 5. Setup to Calibrate Circuit Against a Known Accurate Pressure Gauge

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

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.

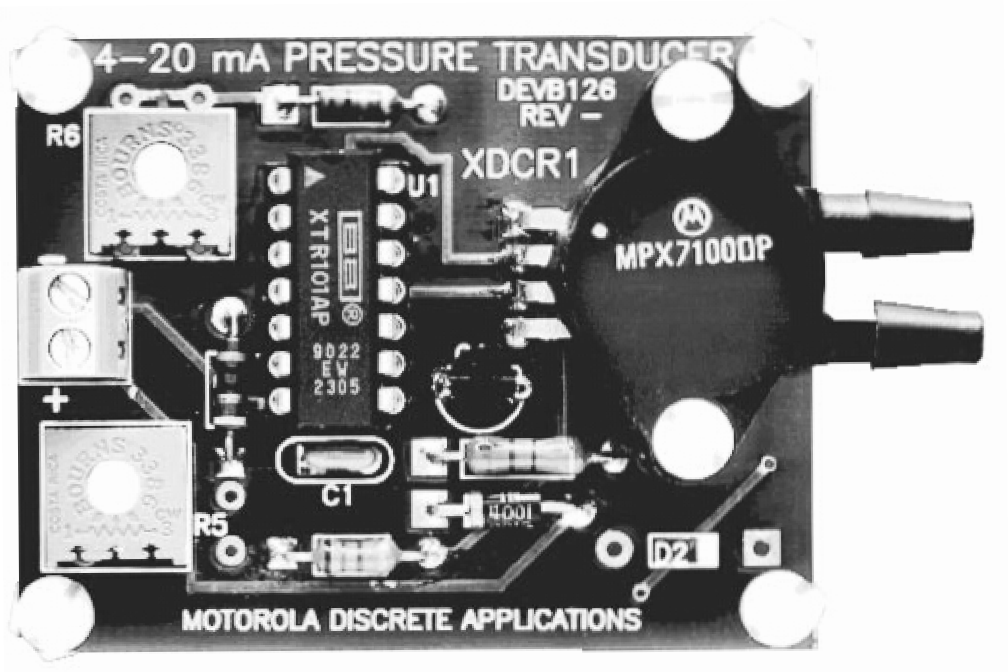


Figure 1. 4–20 mA Pressure Transducer Evaluation Board

REV 2

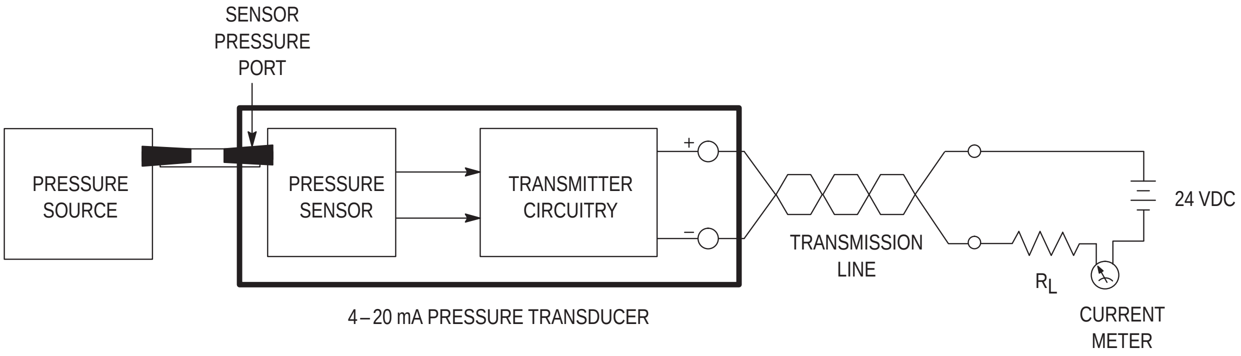


Figure 2. System Block Diagram

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.

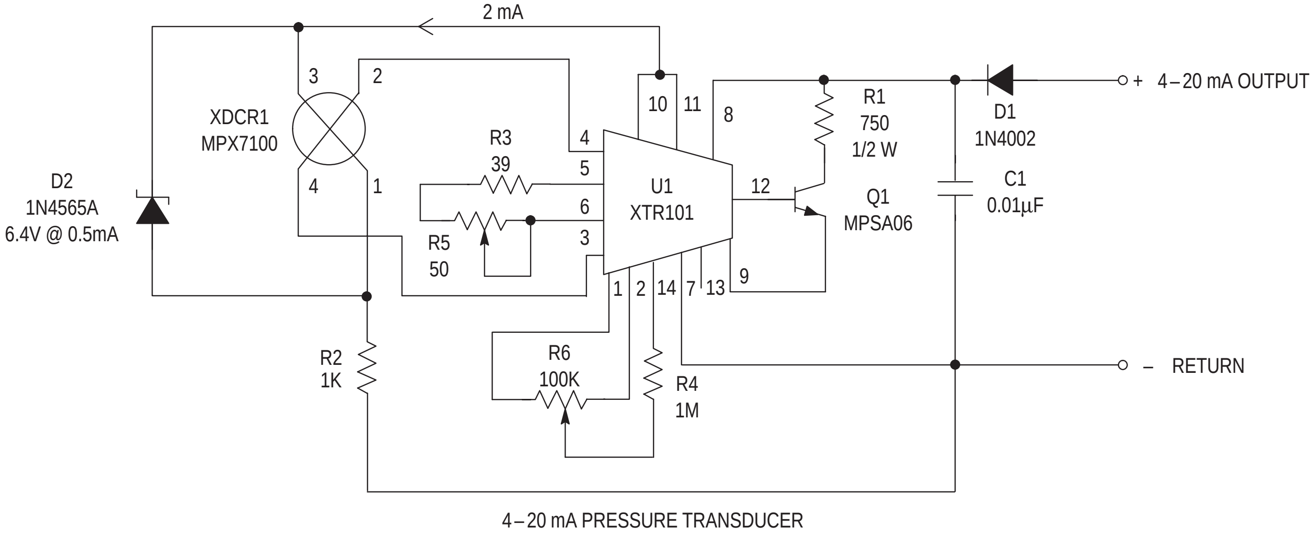


Figure 3. Schematic Diagram

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.

$$\begin{aligned} R_{span} &= 40/\left[(16\ \mathrm{mA}\ /\ \Delta\mathrm{Vin}) - 0.016\ \mathrm{mhos}\right] \\ &= 64\ \Omega \end{aligned}$$

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	PC Board (see Figure 3)		Motorola	DEVB126
	1	Input/Output Terminals		PHX CONT	#1727010
	4	1/2″ standoffs, Nylon threaded			
	4	1/2″ screws, Nylon			
	2	5/8″ screws, Nylon			
	2	4–40 nuts, Nylon			
		Capacitor			
C1	1	0.01 µF	50 V		
		Diodes			
D1	1	100 V Diode	1 A		1N4002
D2	1	6.4 V Zener			1N4565A
		Transistor			
Q1	1	NPN Bipolar		Motorola	MPSA06
		Resistors, Fixed			
R1	1	750 Ω	1/2 W		
R2	1	1 kΩ			
R3	1	39 Ω			
R4	1	1 MΩ			
		Resistors, Variable			
R5	1	50 Ω, one turn		Bourns	#3386P–1–500
R6	1	100 KΩ, one turn		Bourns	#3386P–1–104
		Integrated Circuit			
U1	1	Two wire current transmitter		Burr–Brown	XTR101
		Sensor			
XDCR1	1	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.

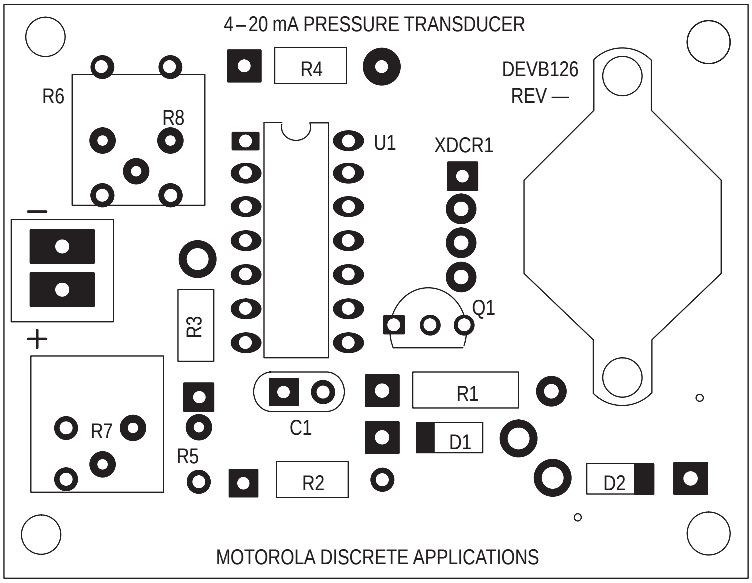


Figure 4a. Component Layout

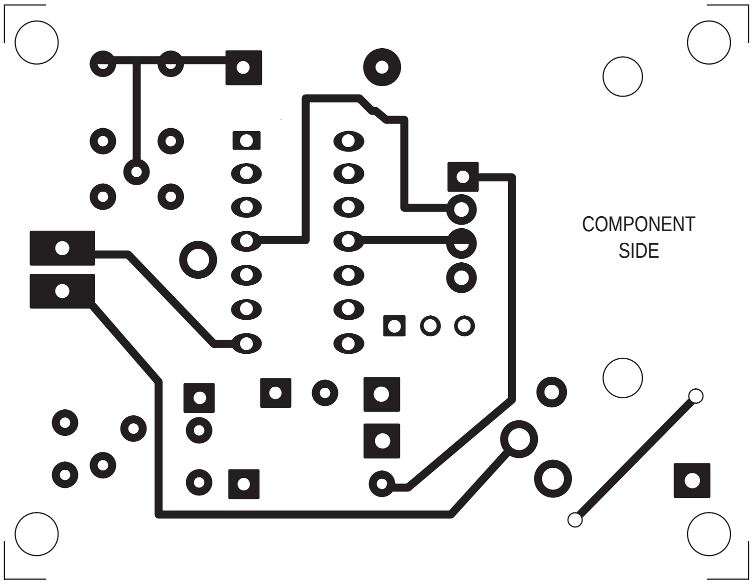


Figure 4b. Board Layout Component Side

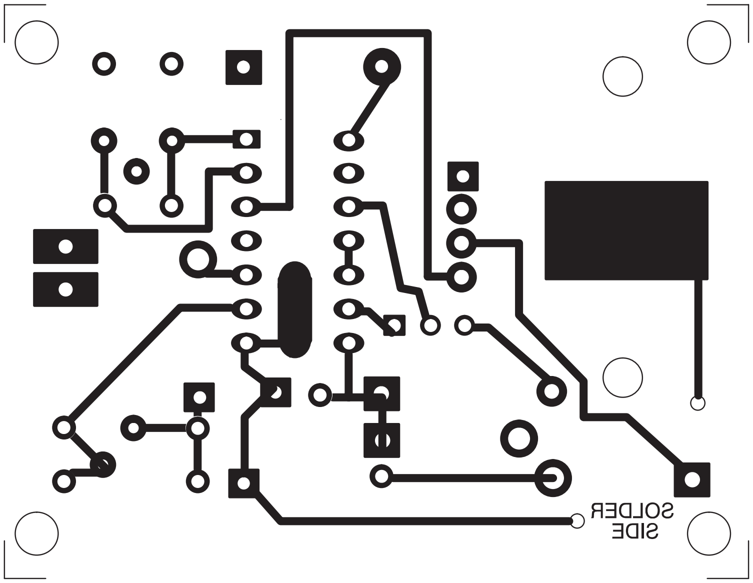


Figure 4c. Board Layout Solder Side

(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.

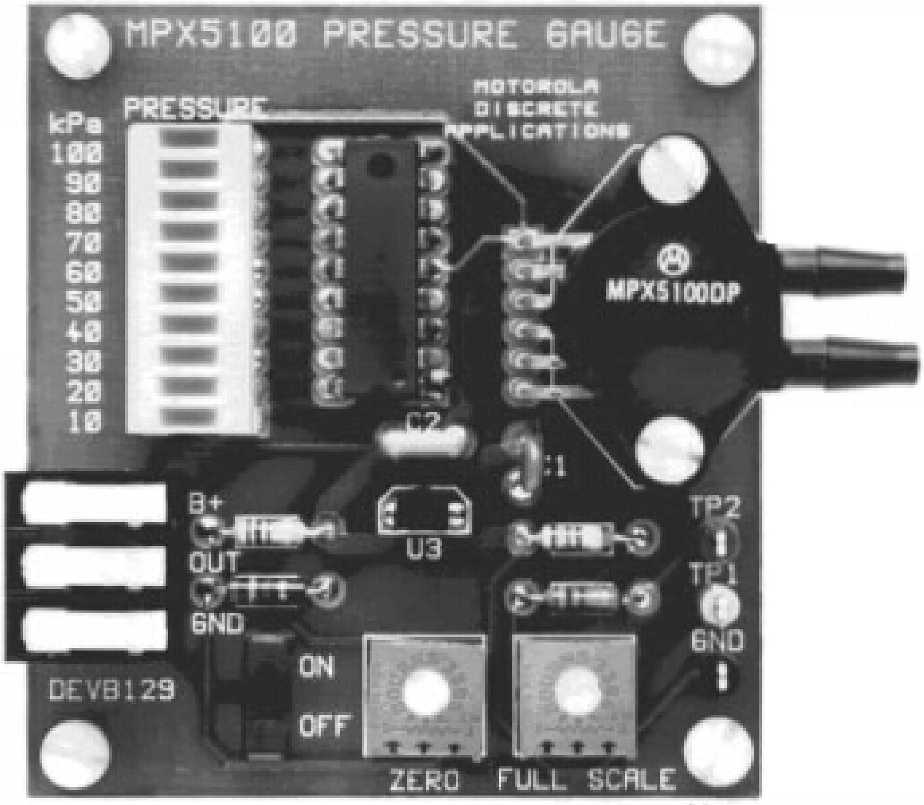


Figure 1. DEVB129 MPX5100 Bar Graph Pressure Gauge

REV 1

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.

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* 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.

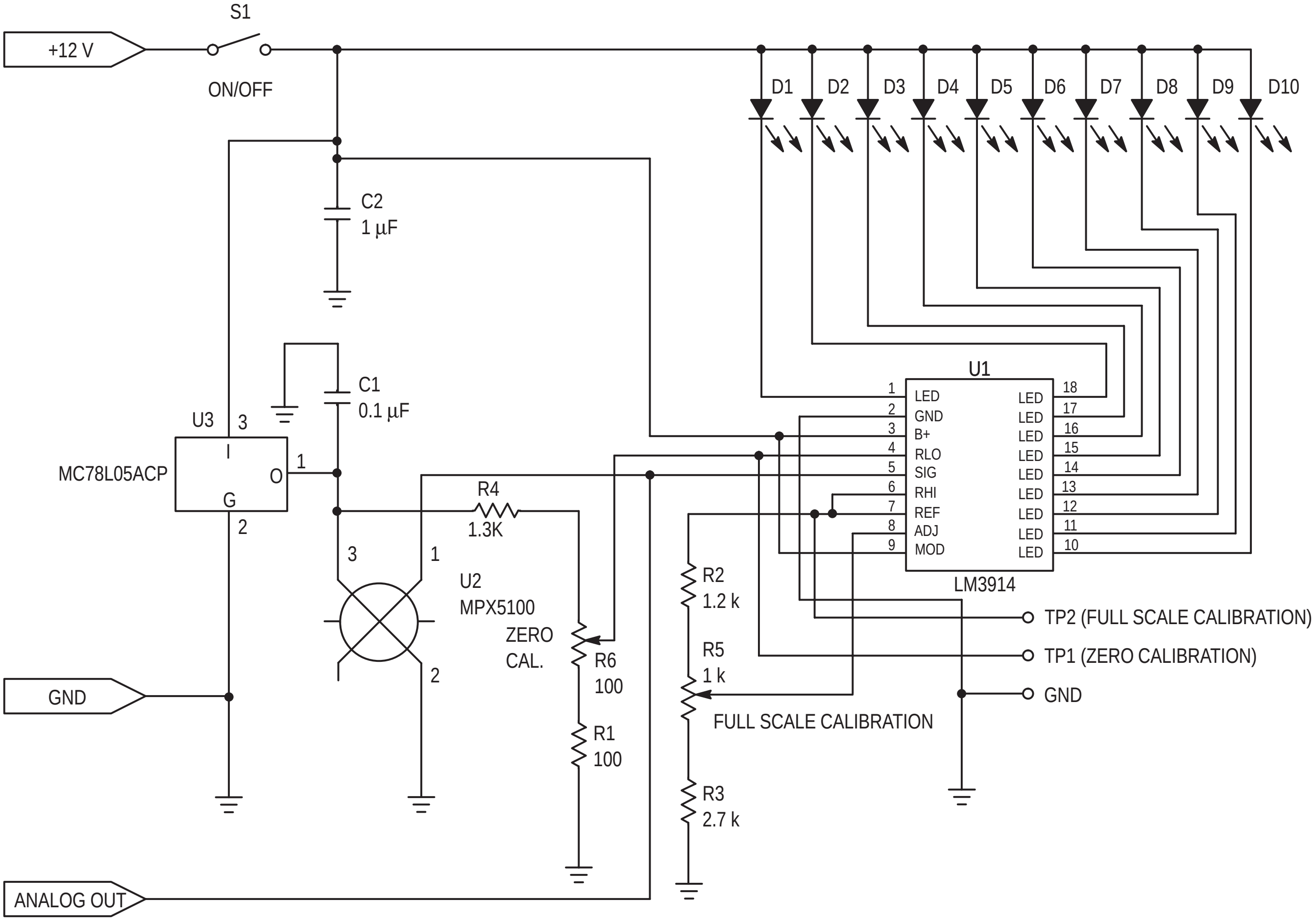


Figure 2. MPX5100 Pressure Gauge

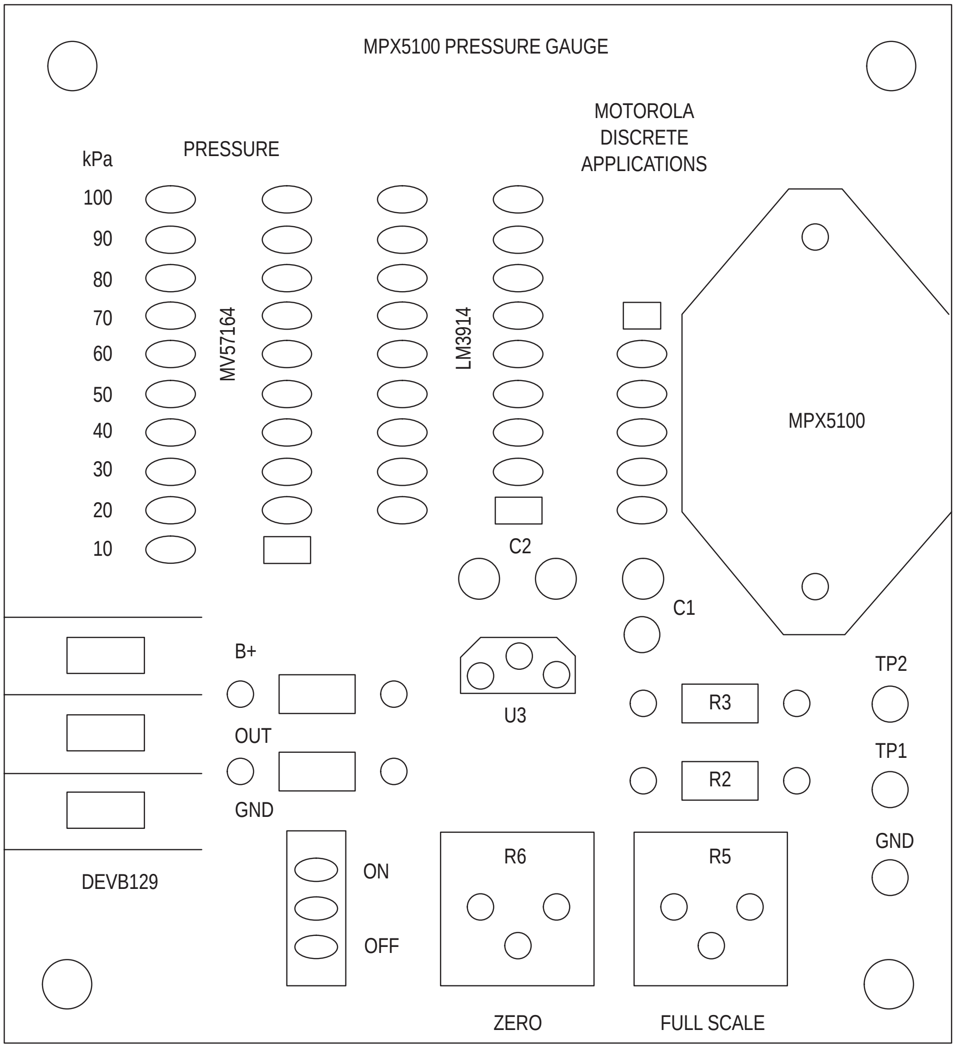


Figure 3. Silk Screen 2X

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.

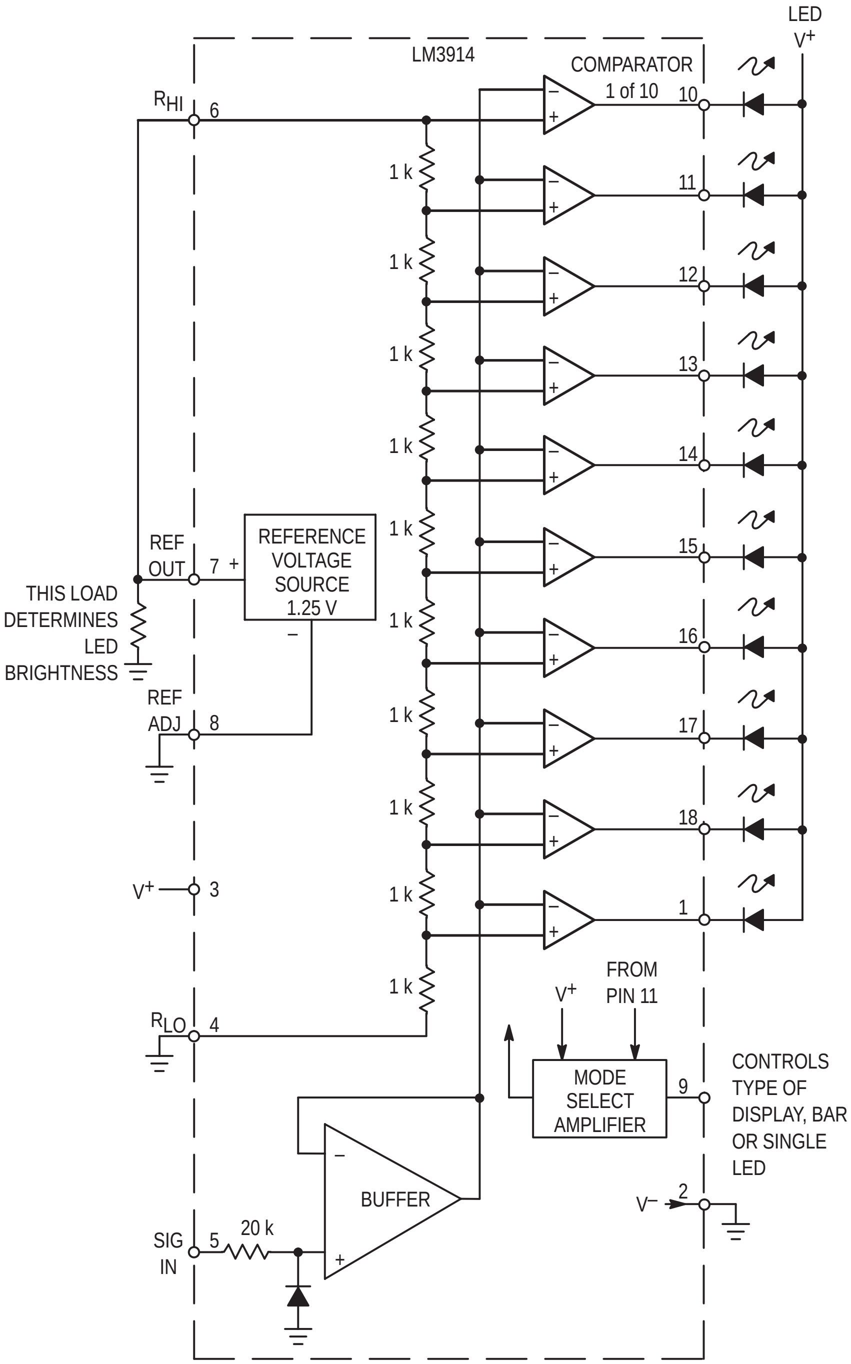


Figure 4. LM3914 Block Diagram

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.

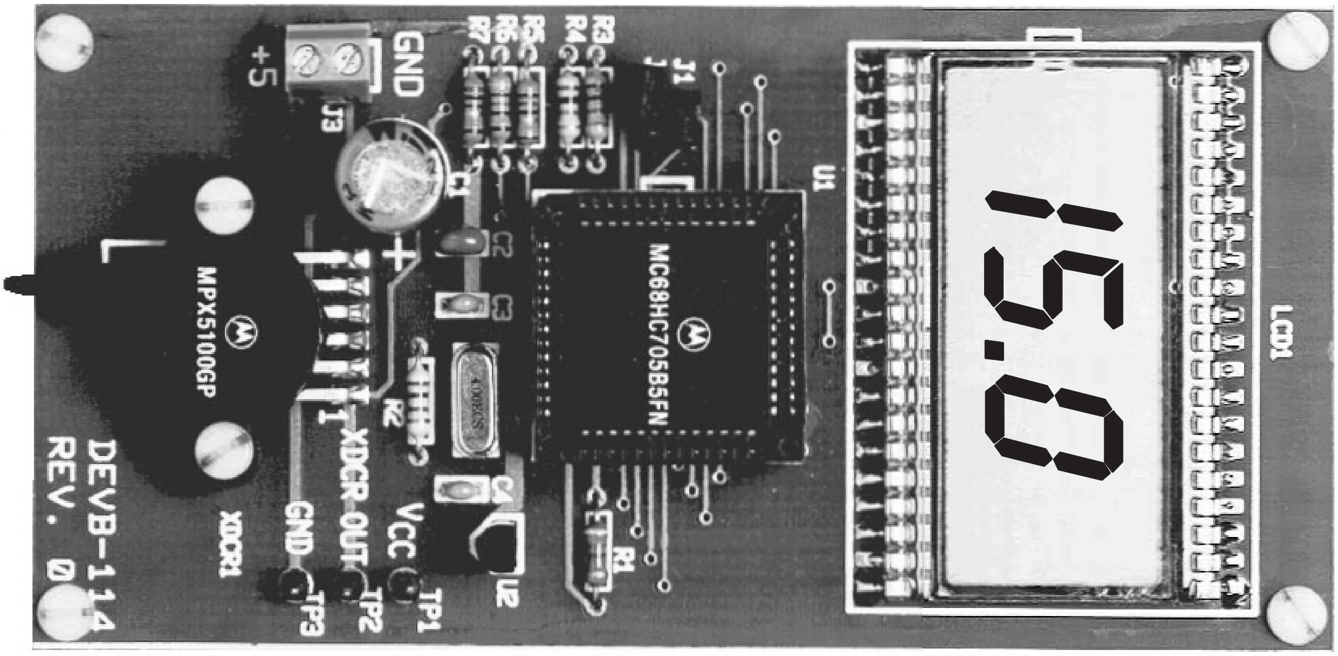


Figure 1. DEVB–114 MPX5100 Evaluation Module

REV 1

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.

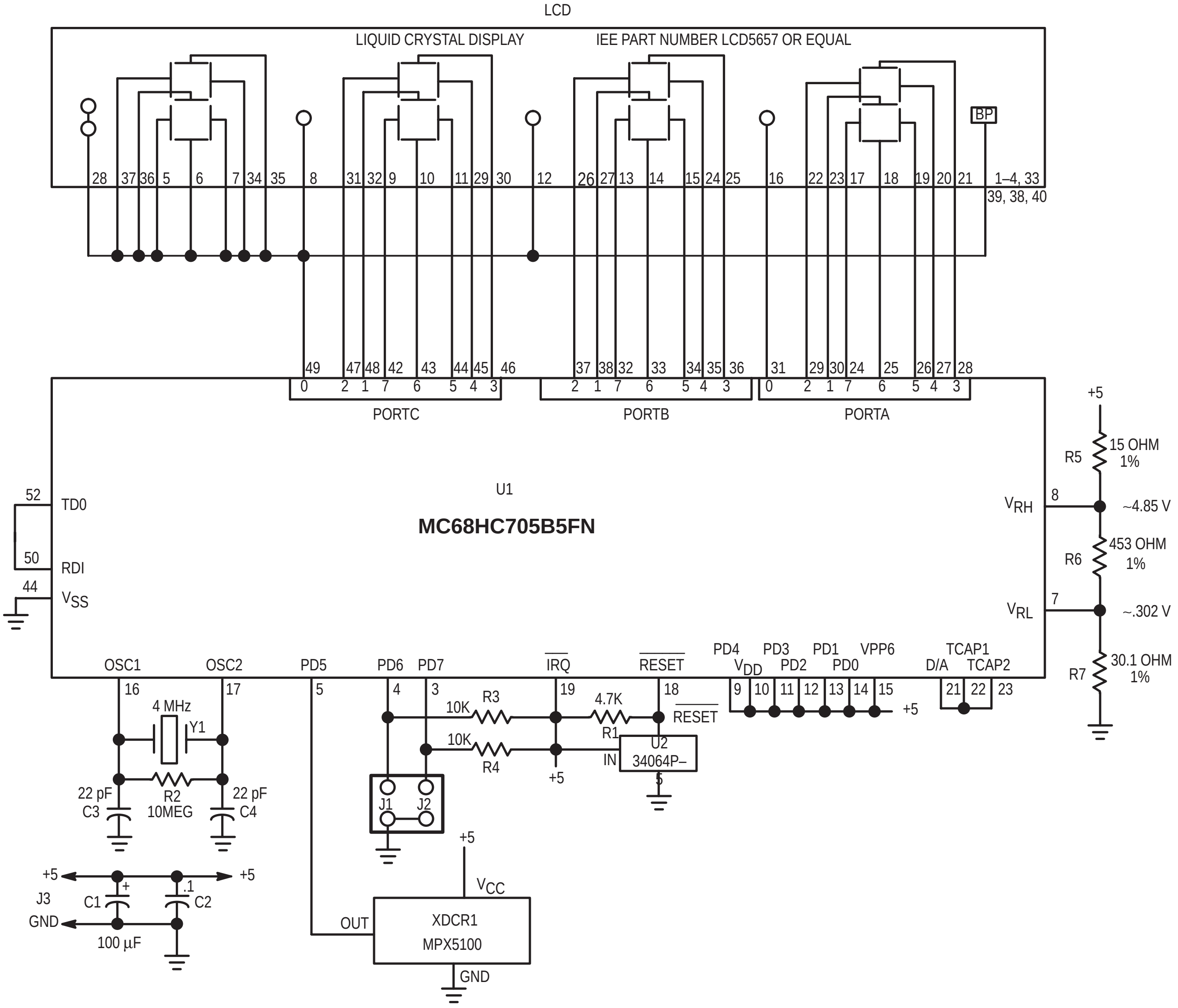


Figure 2. DEVB–114 System Schematic

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.

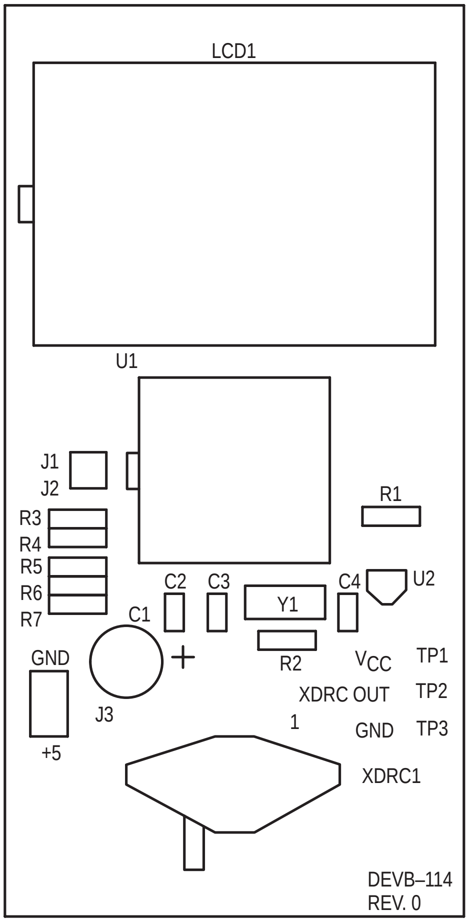


Figure 3. Silk Screen

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.

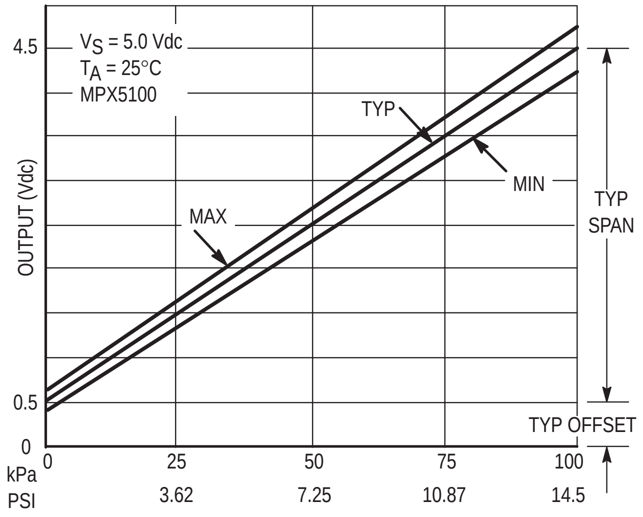


Figure 4. MPX5100 Output versus Pressure Input

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.

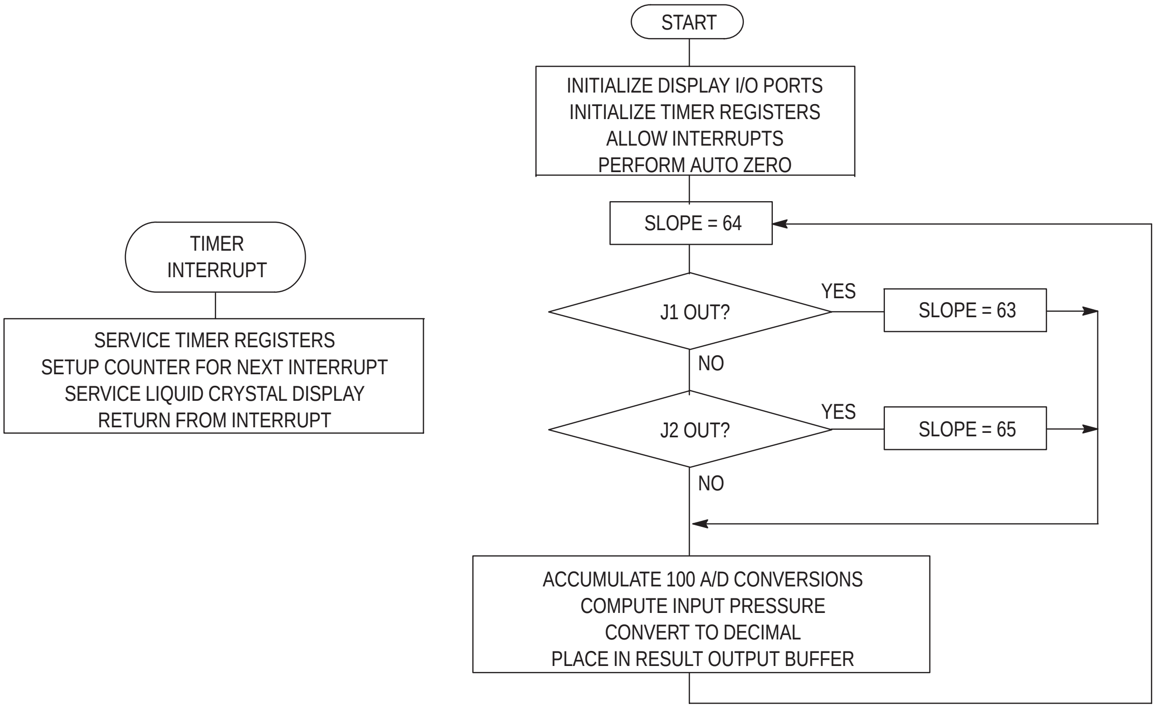


Figure 5. DEVB–114 Software Flowchart

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 / l;
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] * l);
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
```

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.

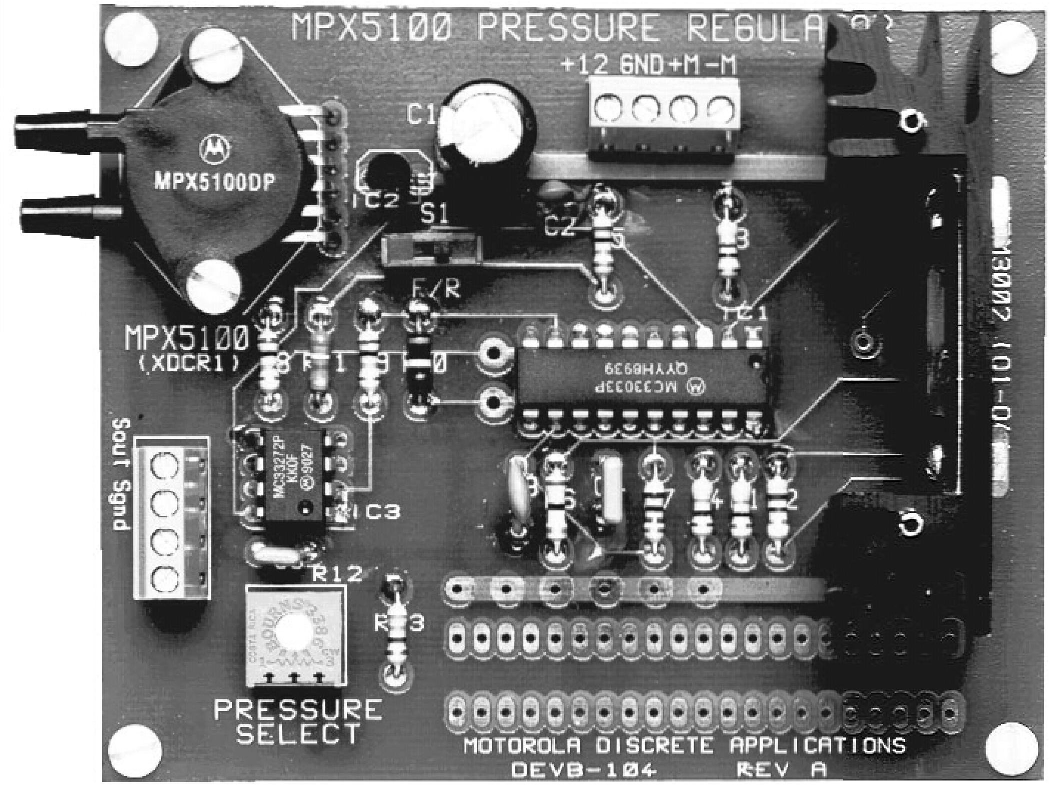


Figure 1. DEVB–104 MPX5100 Pressure Regulator

REV 1

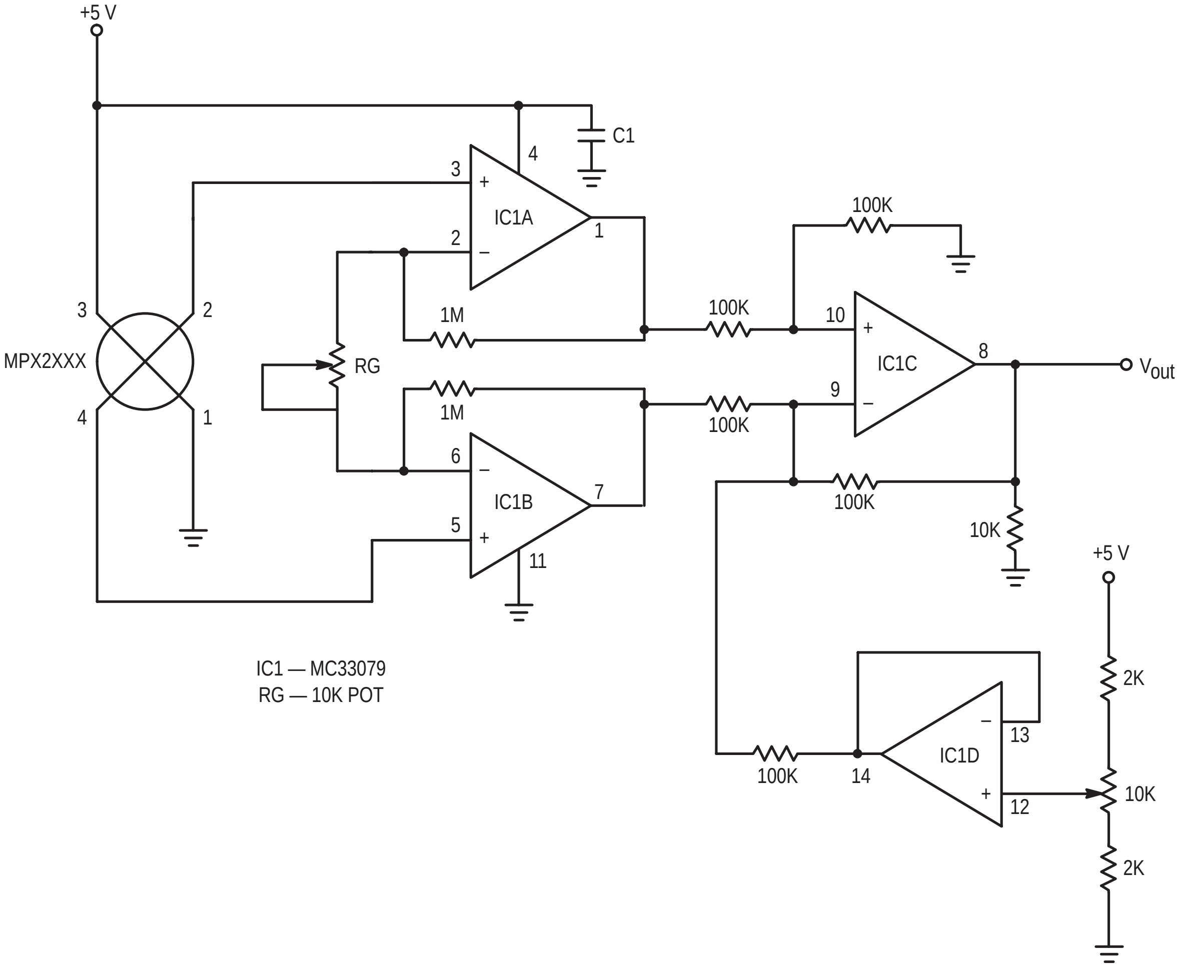


Figure 2. High Level, Ground Referenced Output Using an MPX2000 Series Transducer

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 1.0 msec.

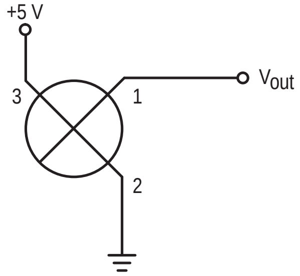


Figure 3. High Level, Ground Referenced Output Using an MPX5100

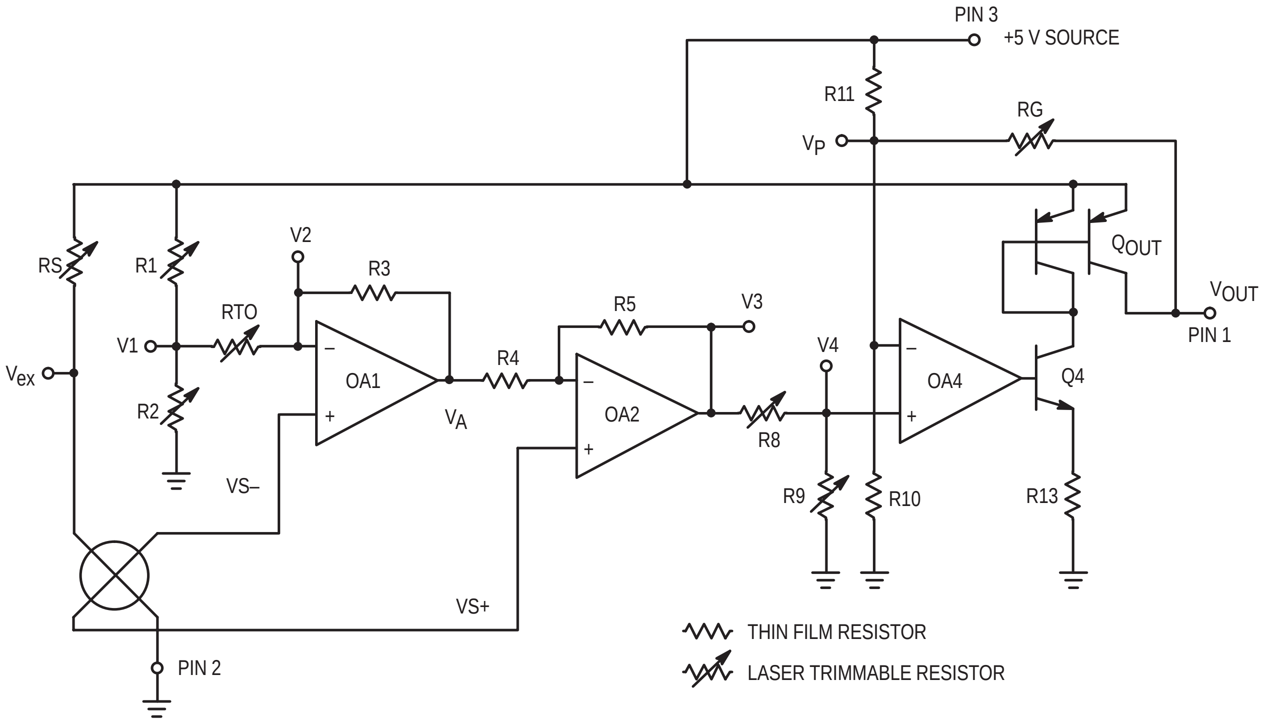


Figure 4. Fully Integrated Pressure Sensor Schematic

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.

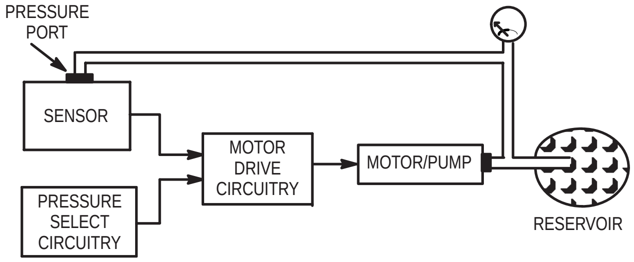


Figure 5. System Block Diagram

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.

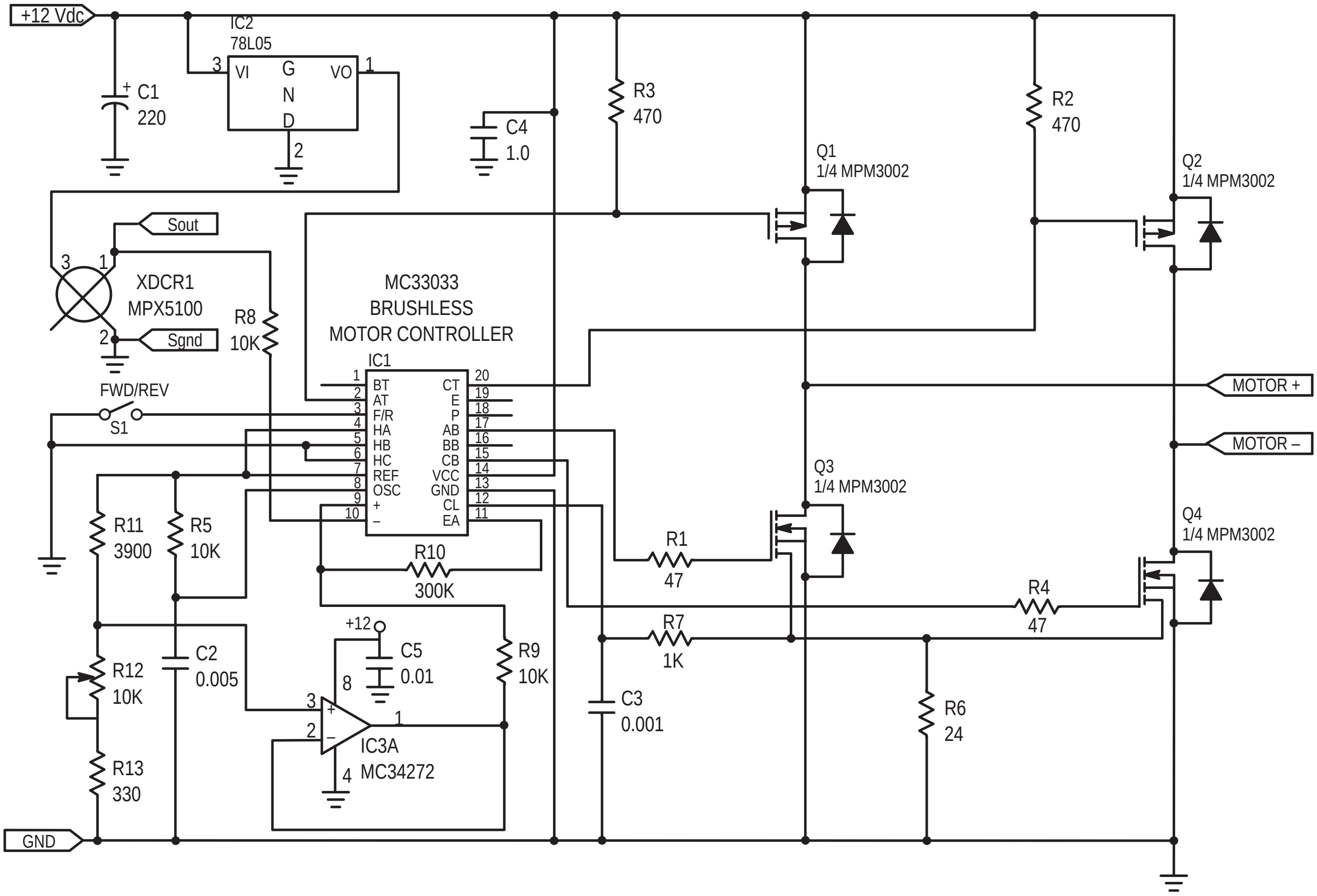


Figure 6. MPX5100 Pressure Regulator

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

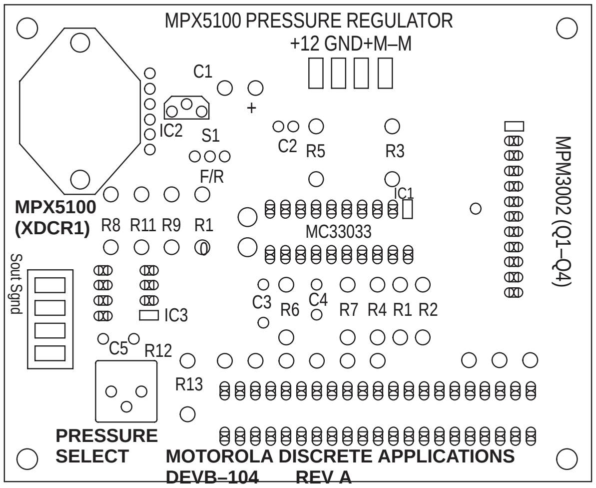


Figure 7. PCB Component Layout

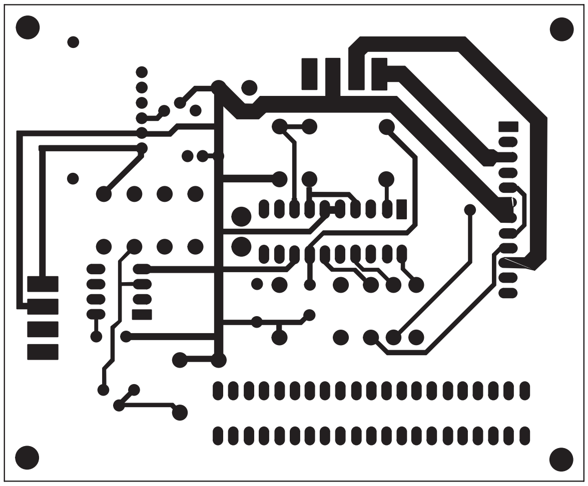


Figure 8. PCB Component Side Artwork

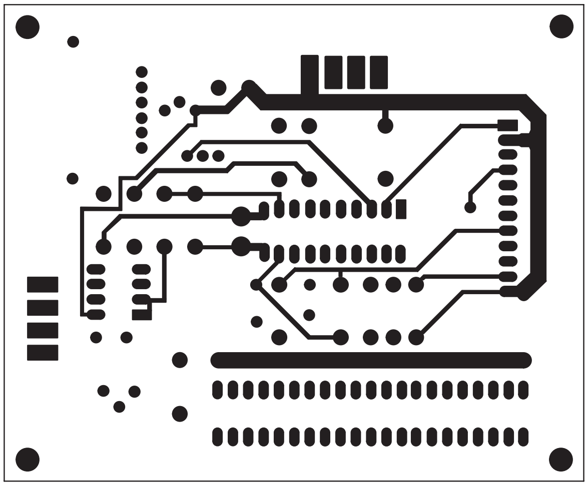


Figure 9. PCB Solder Side Artwork

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.

Figures 7, 8, and 9 show 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 Figures 7–9
	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.

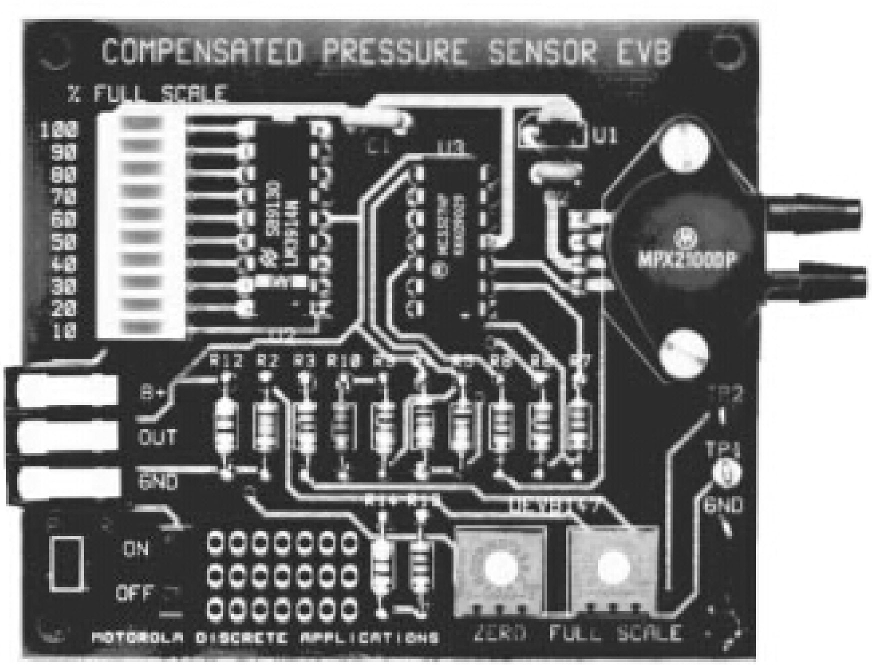


Figure 1. DEVB147 Compensated Pressure Sensor Evaluation Board

REV 1

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 and 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.

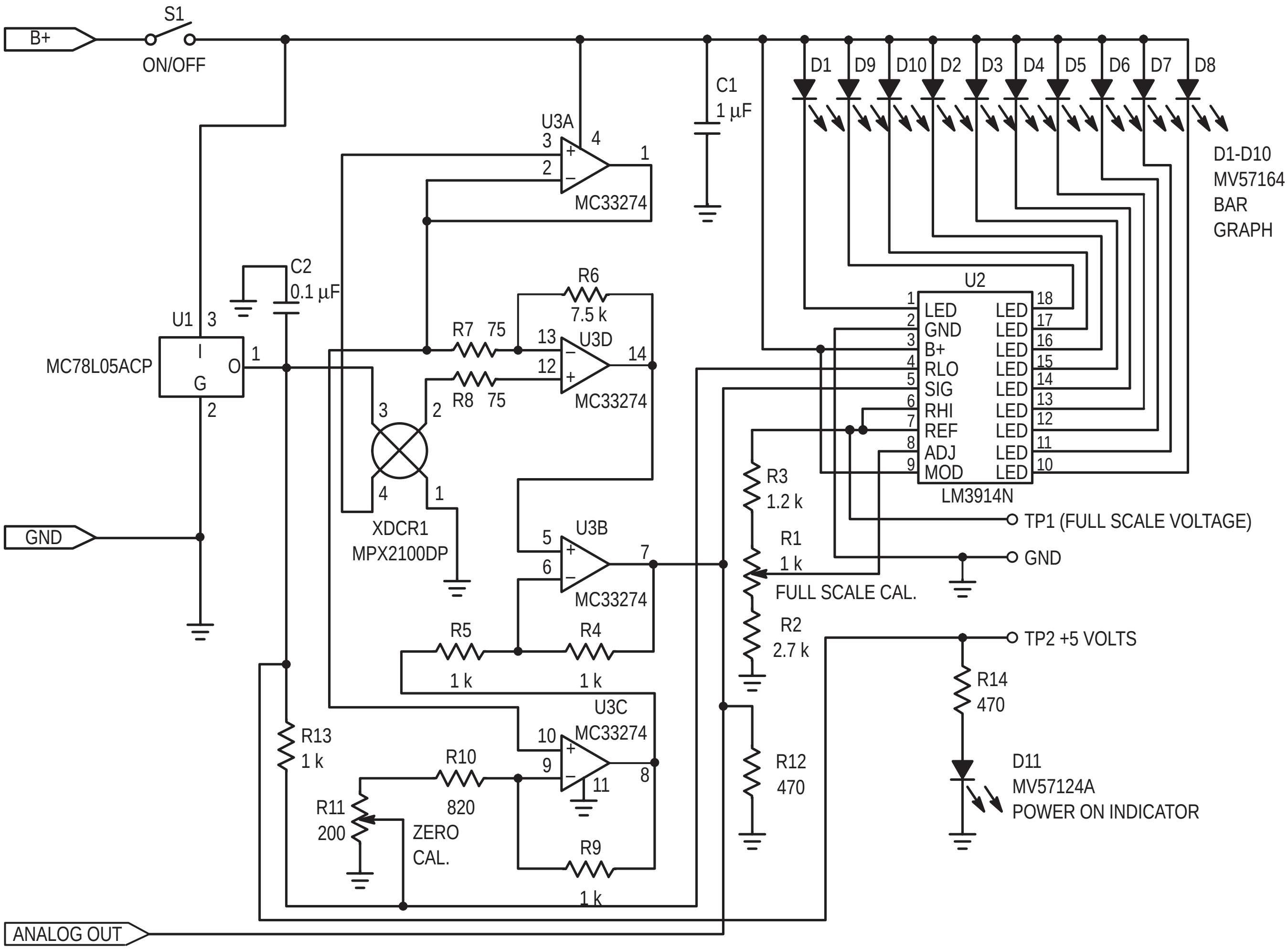
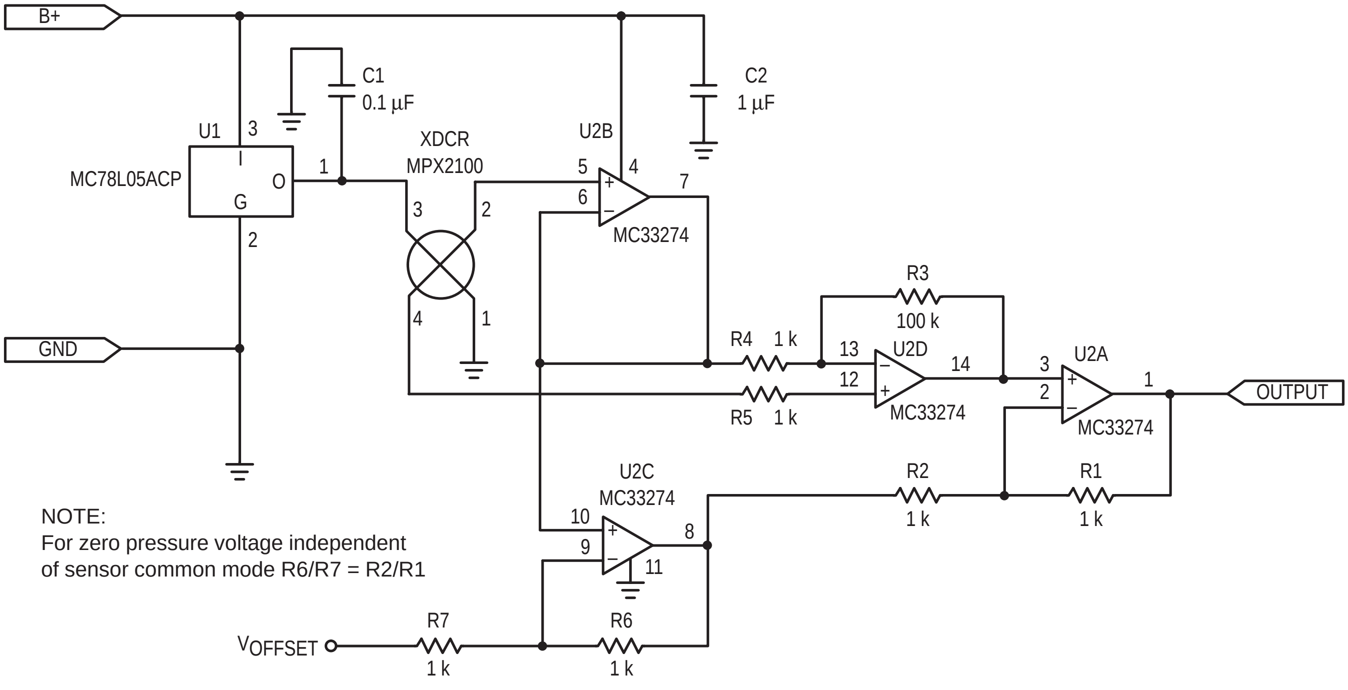


Figure 2. Compensated Pressure Sensor EVB Schematic



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 and 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.

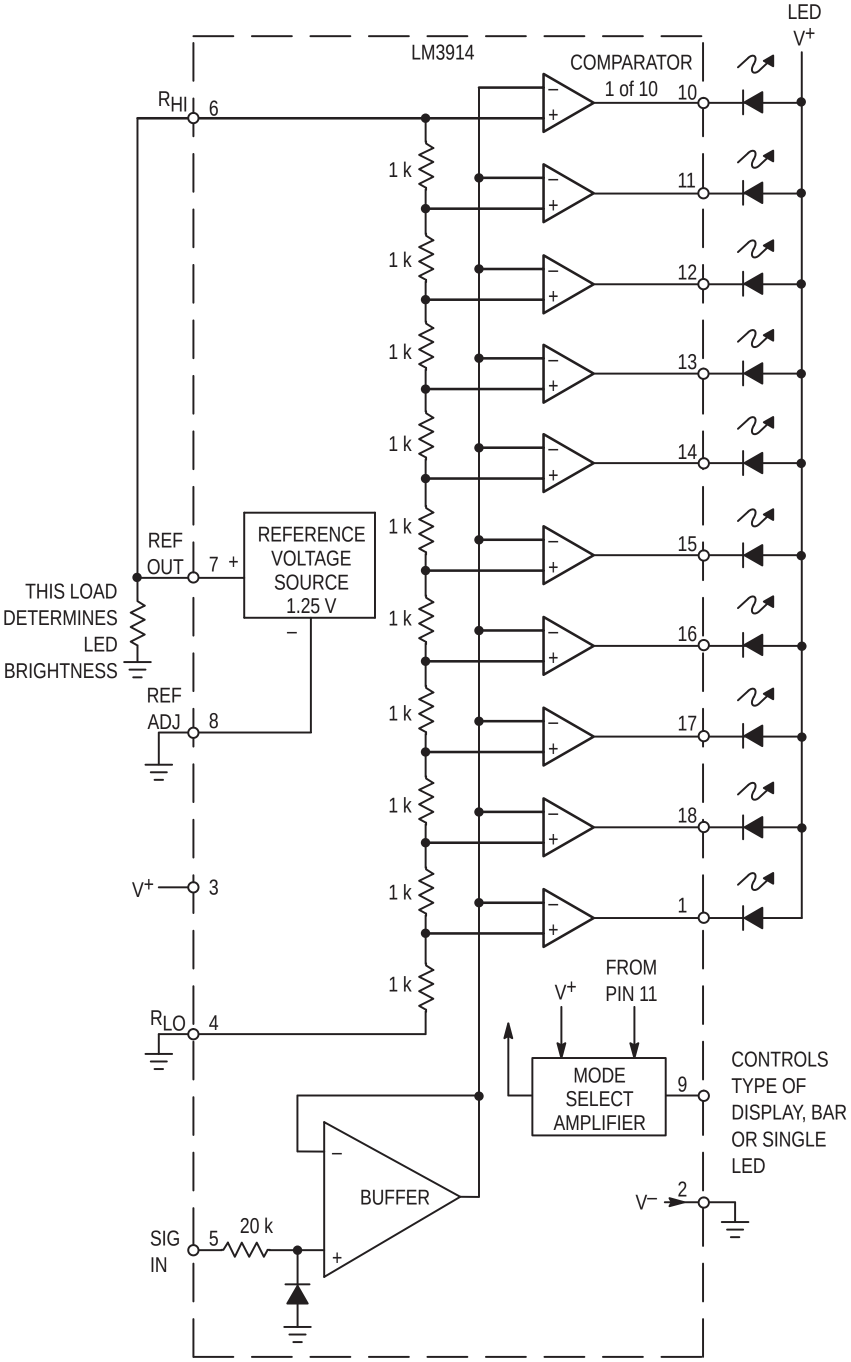


Figure 4. LM3914 Block Diagram

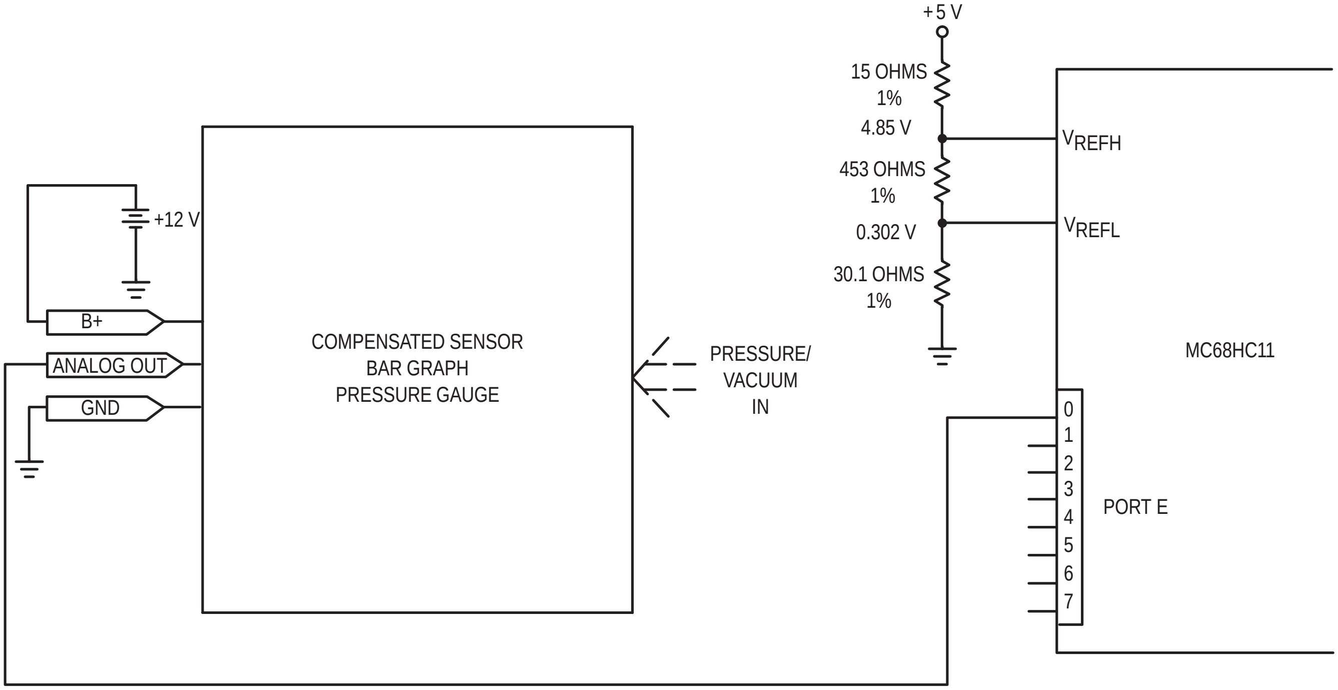


Figure 5. Application Example

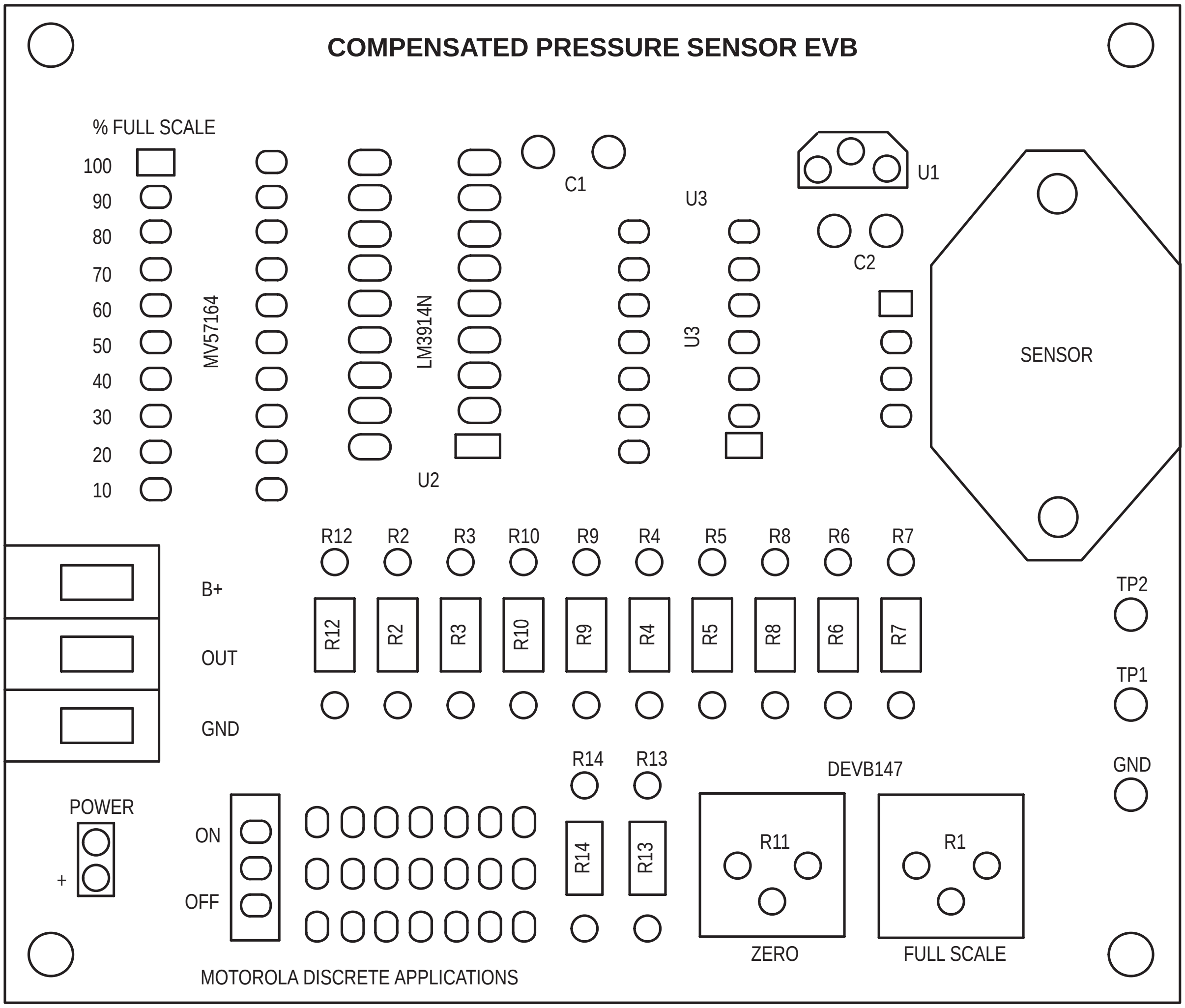


Figure 6. Silk Screen

Table 1. Parts List

Designator	Qty.	Description	Value	Vendor	Part
C1 C2	1 1	Ceramic Capacitor Ceramic Capacitor	1.0 µF 0.1 µF		
D1-D10 D11	1 1	Bar Graph LED LED		GI GI	MV57164 MV57124A
R2 R3 R4, R5, R9, R13 R6 R7, R8 R10 R12, R14 R1 R11	1 1 4 1 2 1 2 1 1	1/4 Watt Film Resistor 1/4 Watt Film Resistor 1/4 Watt Film Resistor 1/4 Watt Film Resistor 1/4 Watt Film Resistor 1/4 Watt Film Resistor 1/4 Watt Film Resistor Trimpot Trimpot	2.7K 1.2K 1.0K 7.5K 75 820 470 1.0K 200	Bourns Bourns	3386P-1-102 3386P-1-201
S1	1	Switch		NKK	12SDP2
U1 U2 U3	1 1 1	5.0 V Regulator Bar Graph IC Op Amp		Motorola National Motorola	MC78L05ACP LM3914N MC33274P
XDCR1	1	Pressure Sensor		Motorola	MPX2100DP
— — — —	1 1 1 1	Terminal Block Test Point Terminal (Black) Test Point Terminal (Red) Test Point Terminal (Yellow)		Augat Components Corp. Components Corp. Components Corp.	2SV03 TP1040100 TP1040102 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.

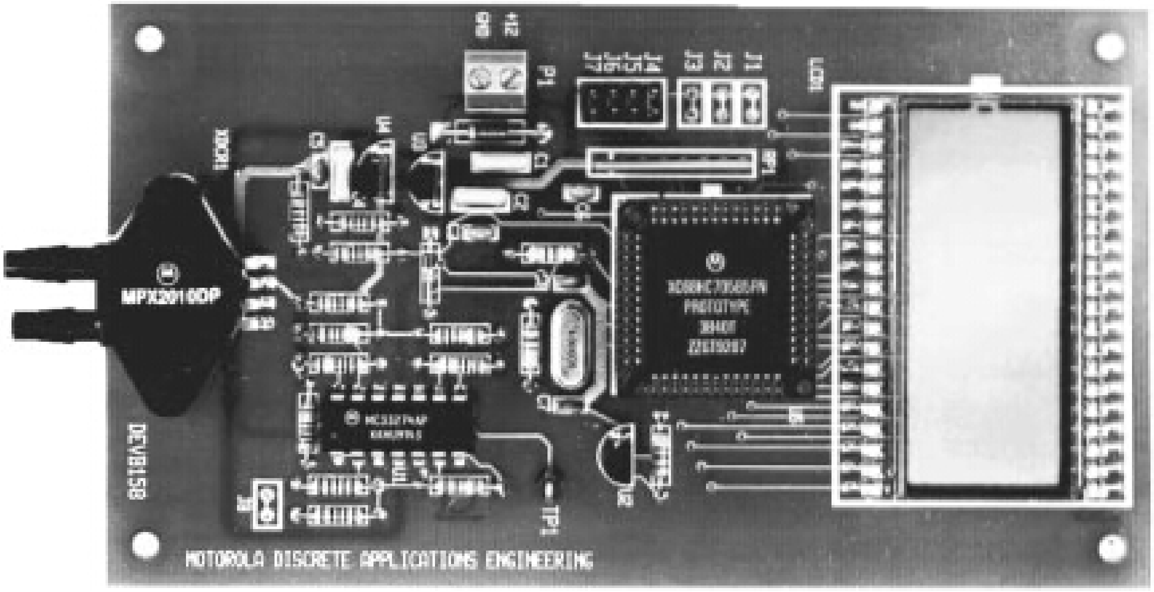


Figure 1. DEVB158 2000 Series LCD Pressure Gauge EVB

REV 1

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.

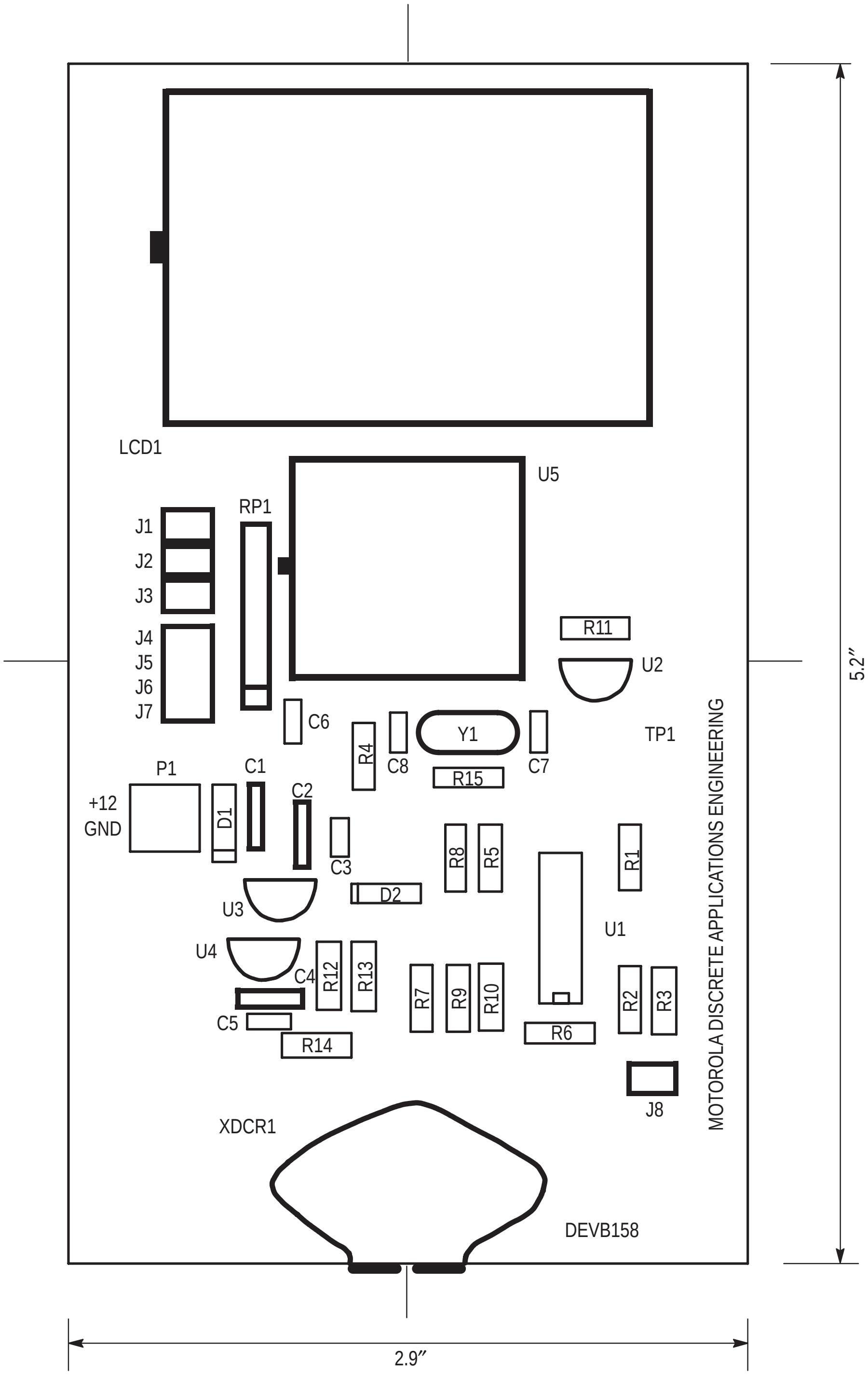


Figure 2. Printed Circuit Silkscreen

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	0.1 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 0.1″ 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.

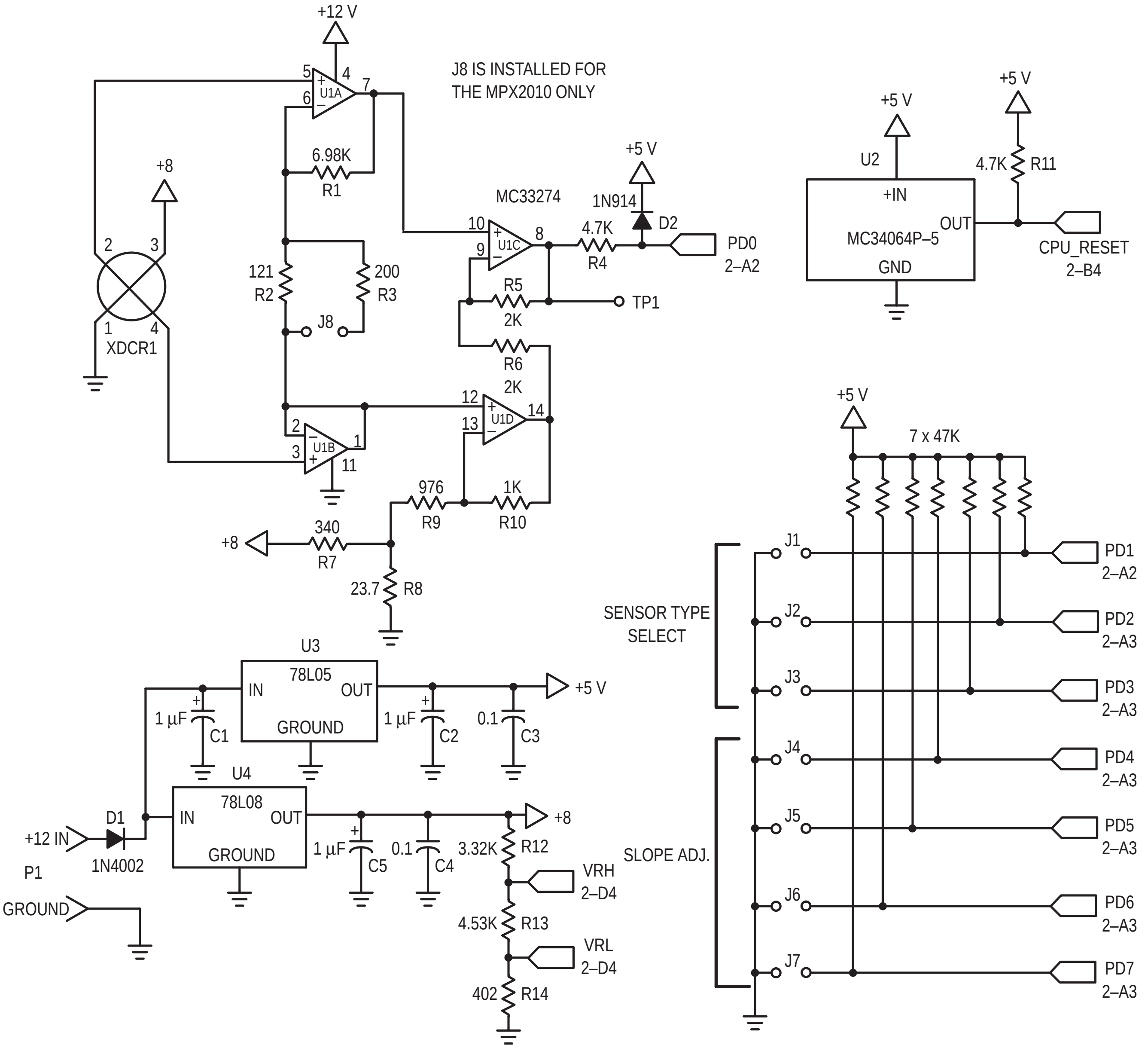


Figure 3c. Schematic

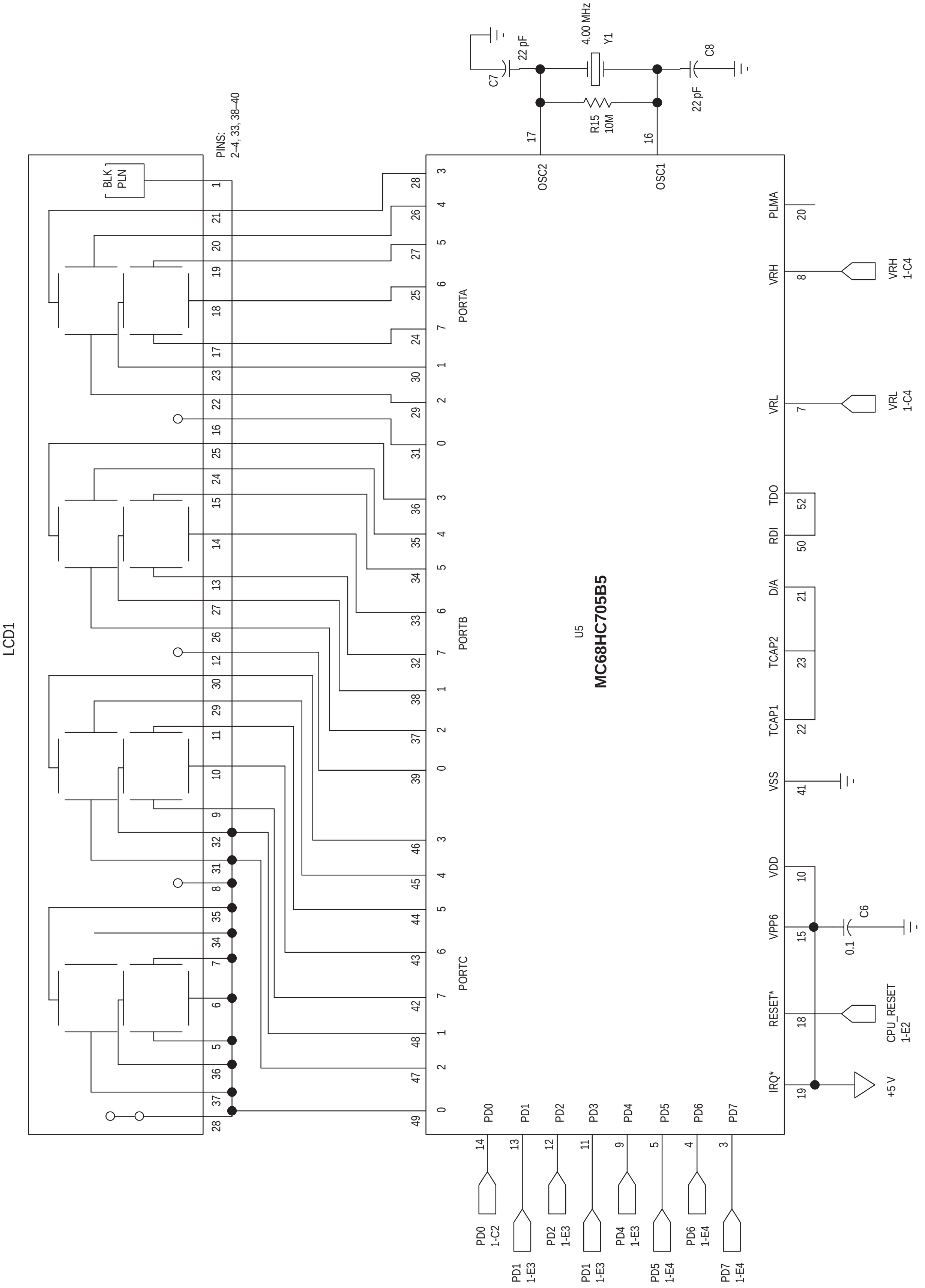


Figure 3d. Schematic

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 Ports 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).

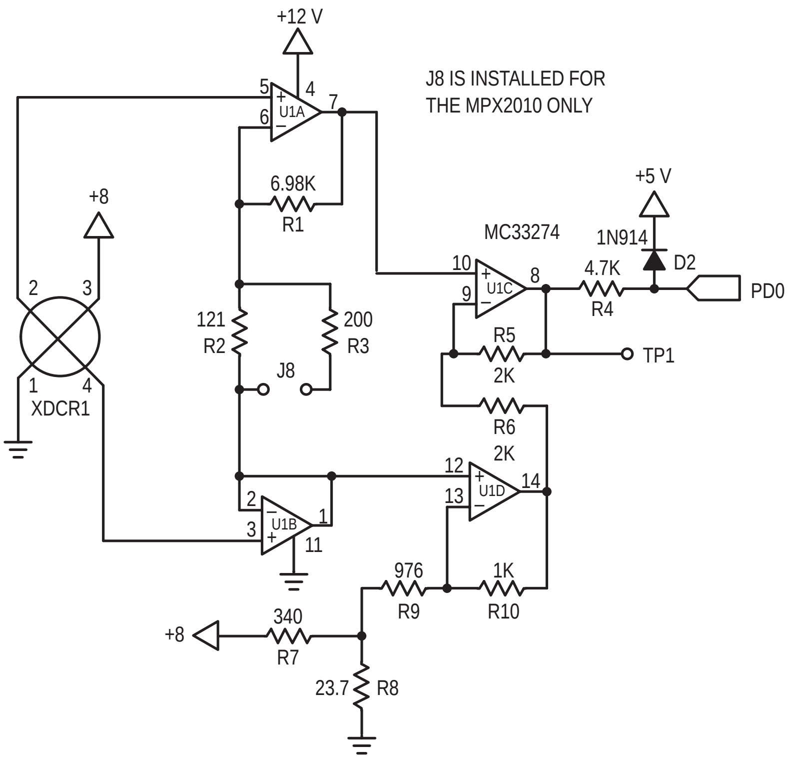


Figure 4. Analog Interface

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 × 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 × 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.

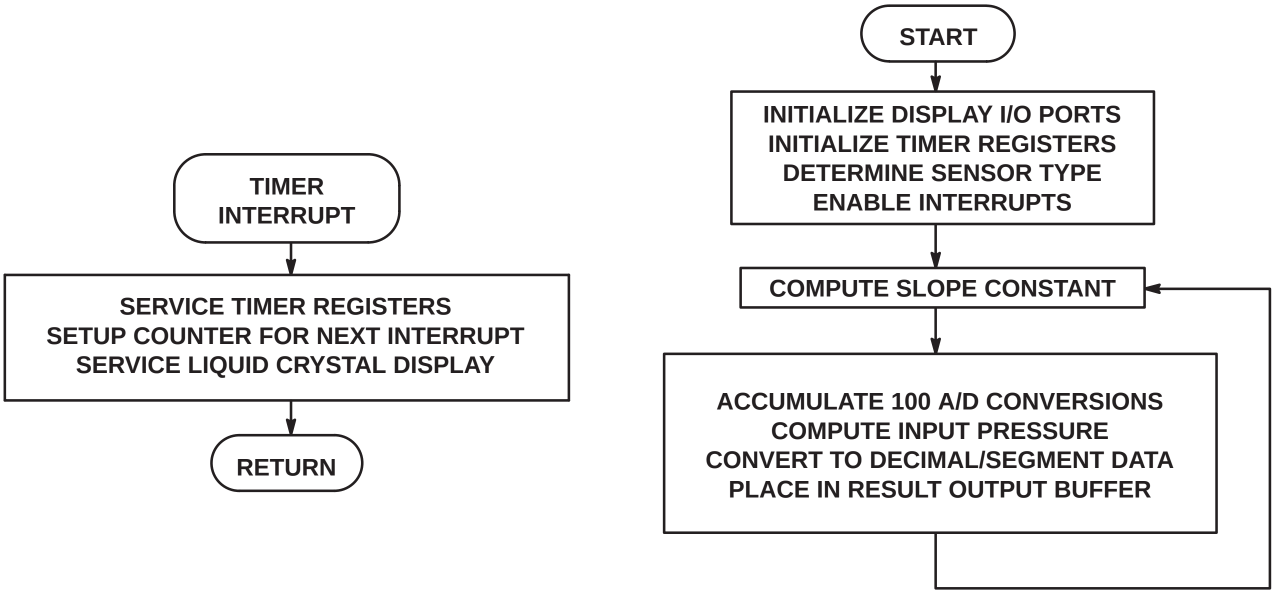


Figure 5. DEVB–158 Software Flowchart

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
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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.

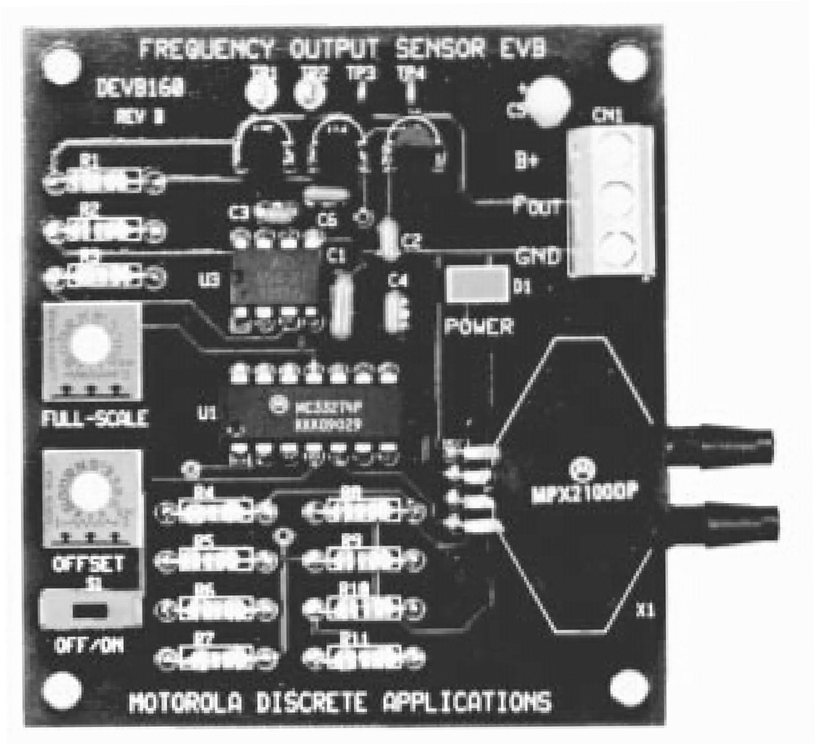


Figure 1. DEVB160 Frequency Output Sensor EVB

REV 1

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 and 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.

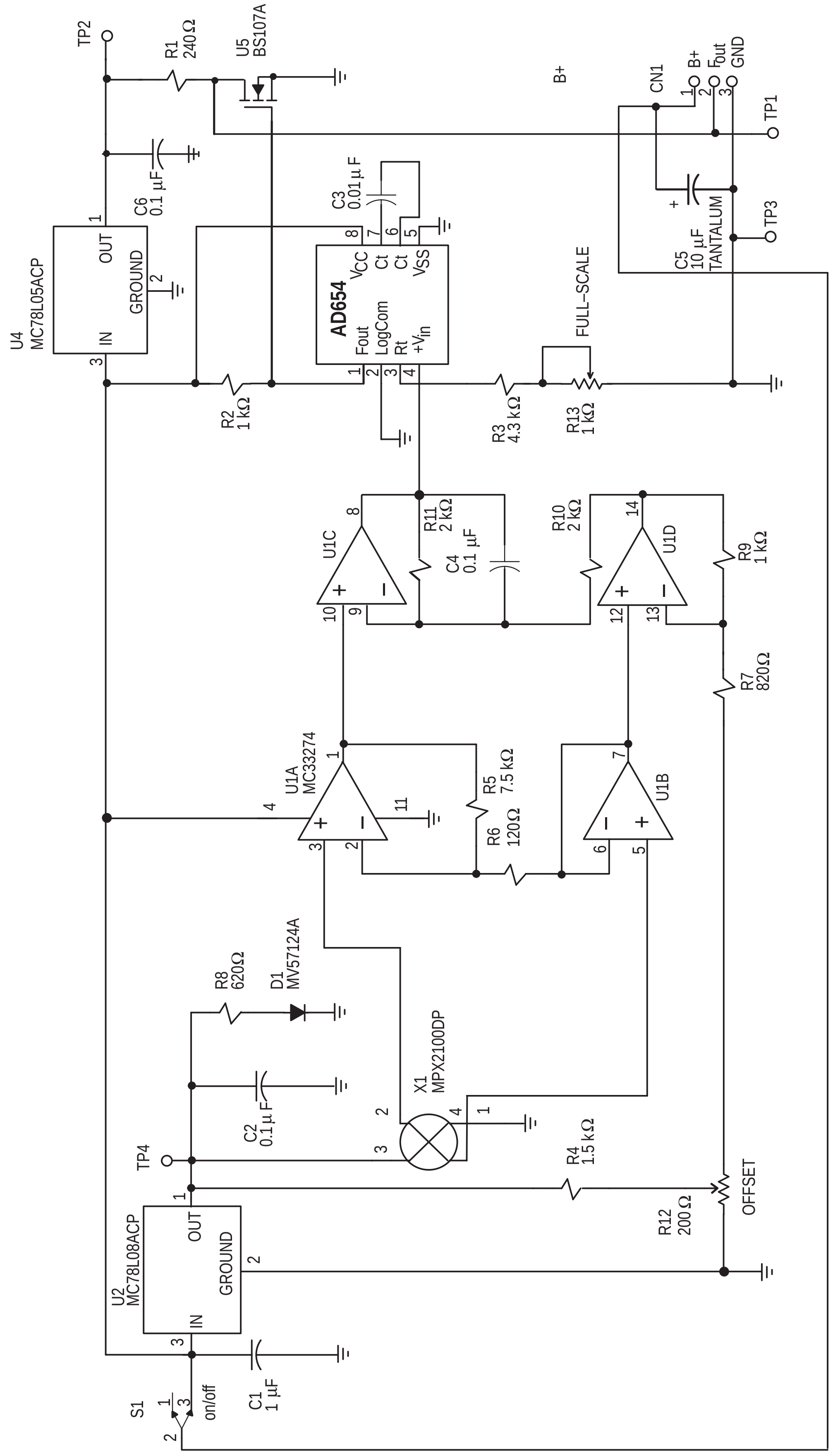


Figure 2. DEVB160 Frequency Output Sensor Evaluation Board

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	0.1 µF Capacitor		
C3	1	0.01 µF Capacitor		
C4	1	0.1 µF Capacitor		
C5	1	10 µF Cap+		tantalum
C6	1	0.1 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.

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.

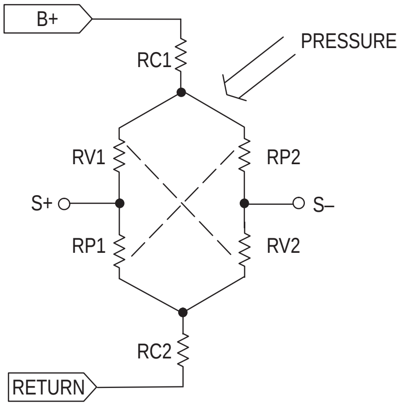


Figure 1. Sensor Equivalent Circuit

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%.

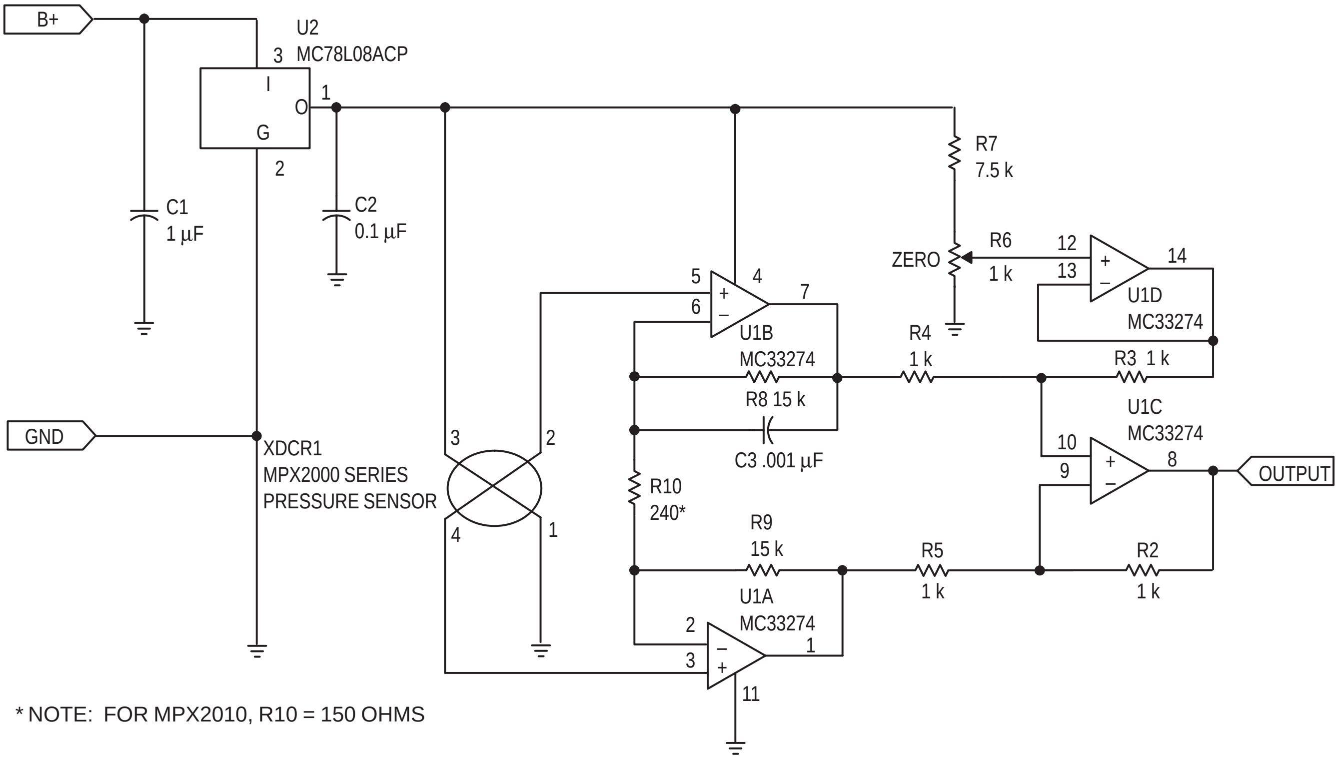


Figure 2. Instrumentation Amplifier Interface

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.

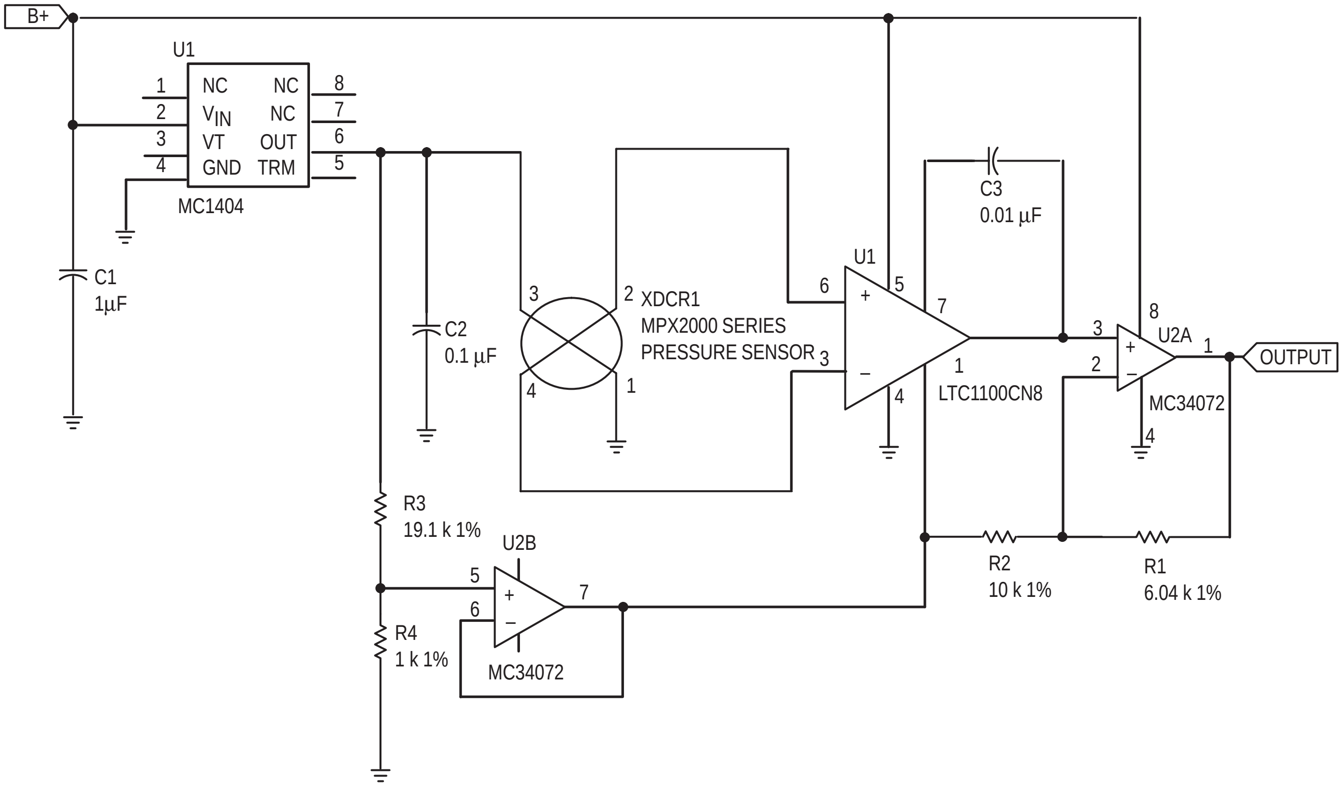
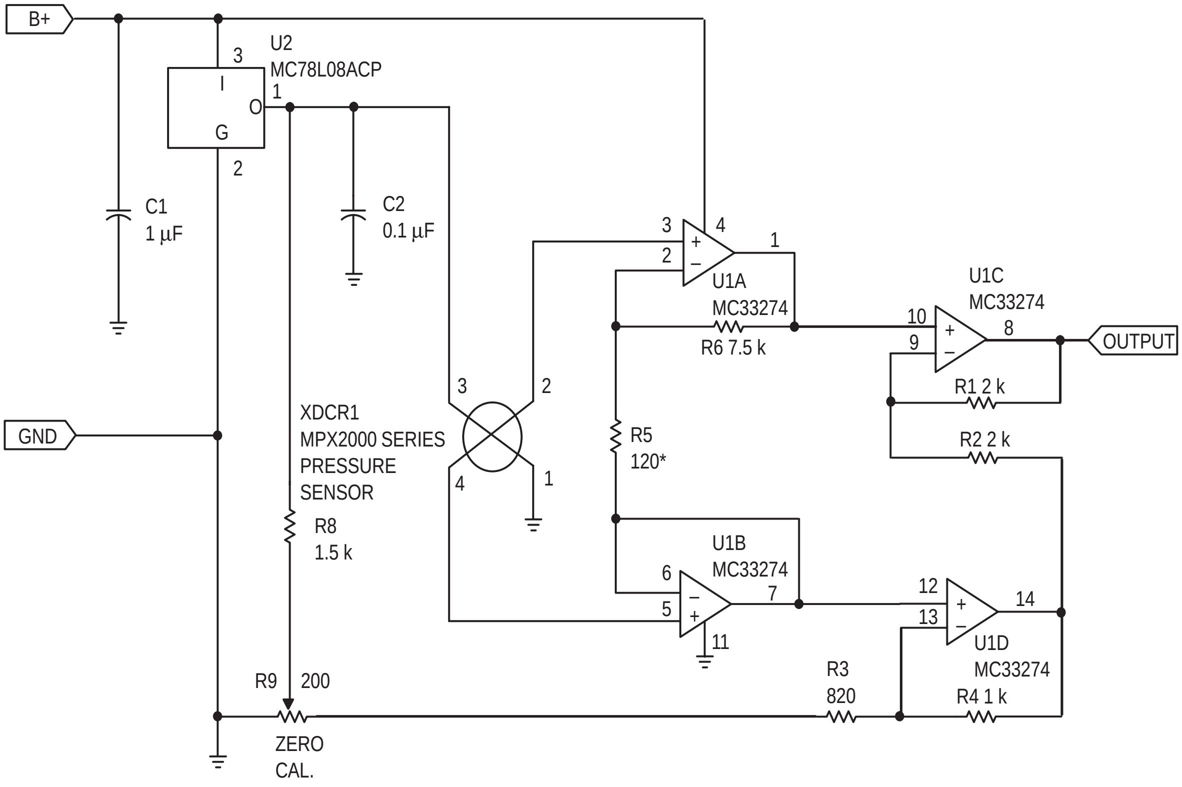


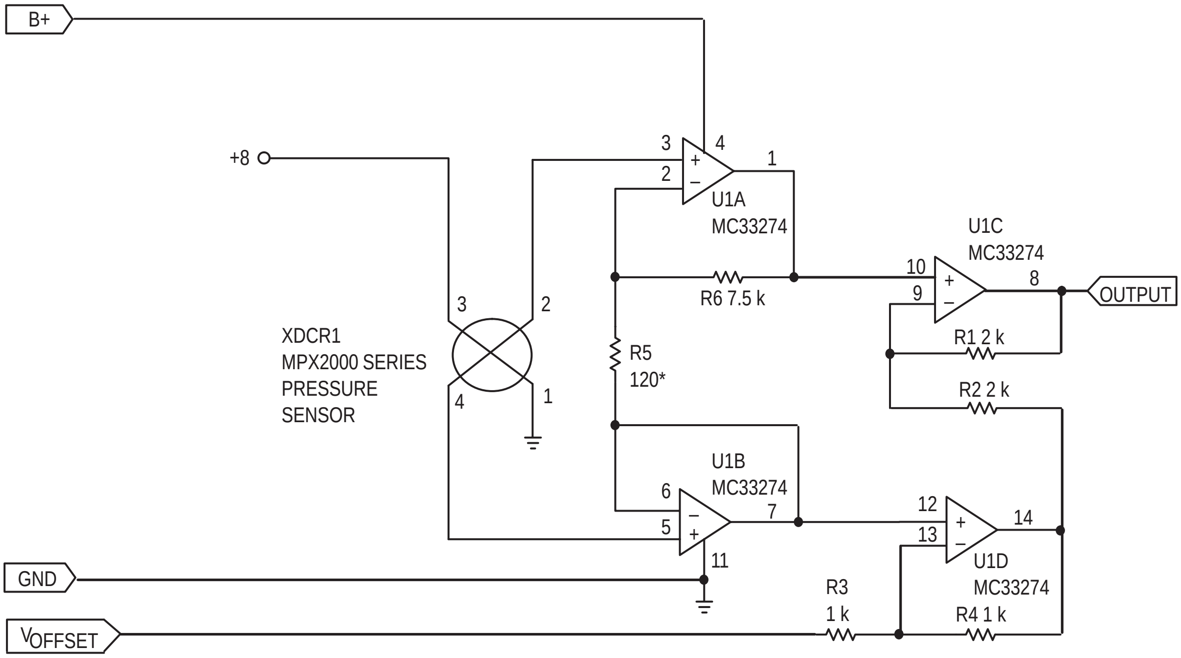
Figure 3. Precision Instrument Amplifier Interface



* 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.

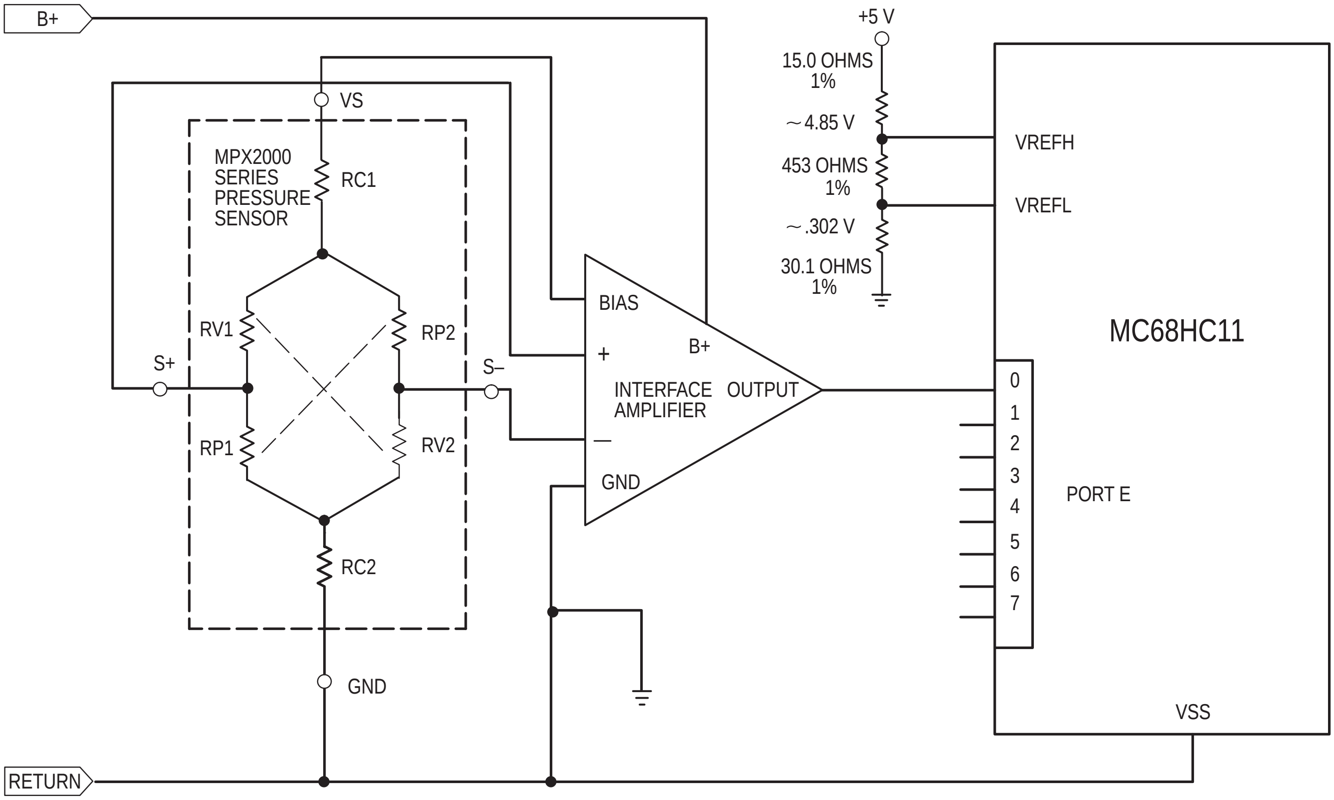


Figure 6. Application Example

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.

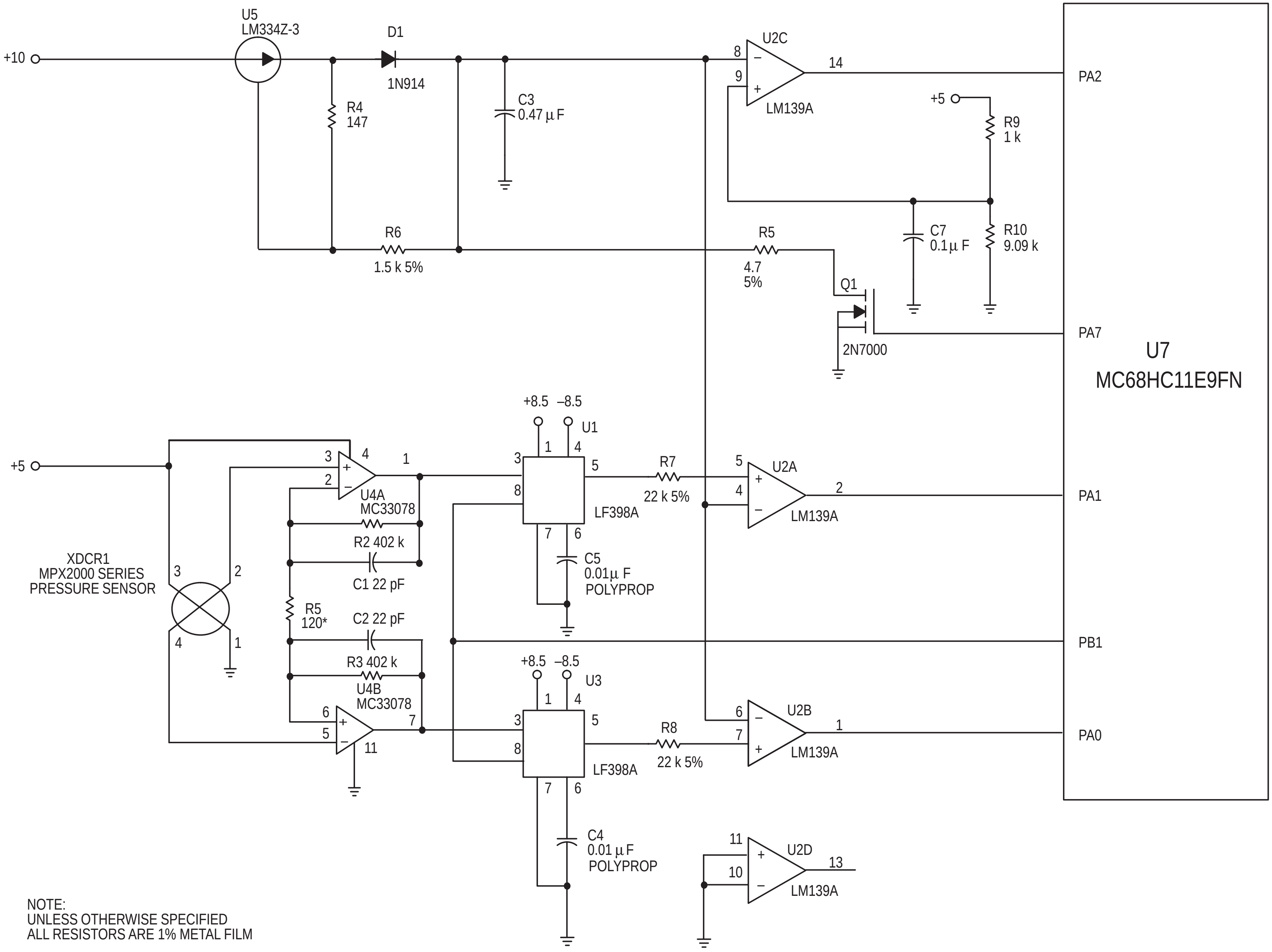
In this circuit, U4A and U4B form the front end of an instrument amplifier. They differentially amplify the sensor's output. The resulting amplified differential signal is then sampled and held in U1 and U3. The sample and hold function is performed in order to keep input data constant during the conversion 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.

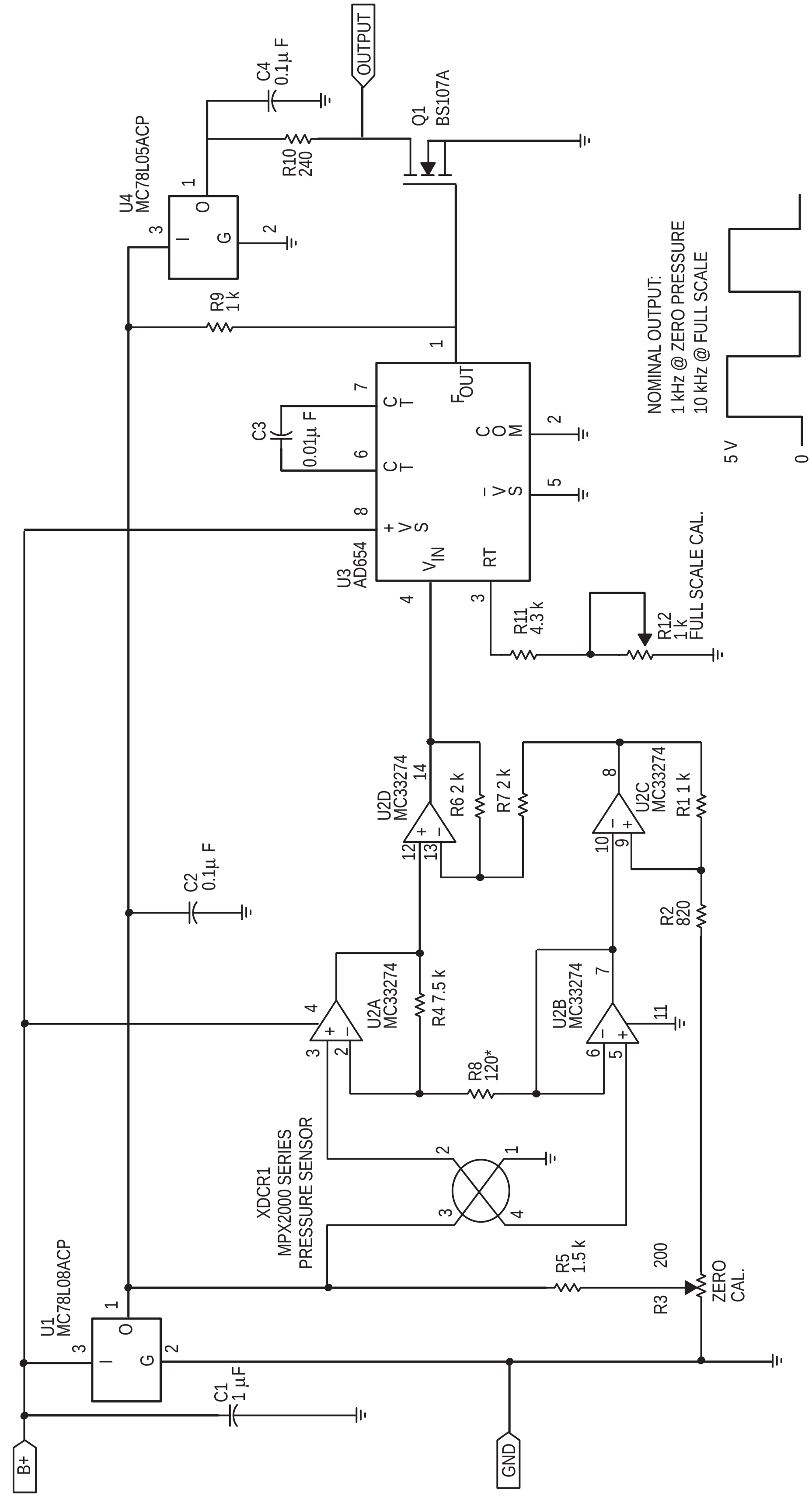
LONG DISTANCE INTERFACES

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.



NOTE:
UNLESS OTHERWISE SPECIFIED
ALL RESISTORS ARE 1% METAL FILM

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.

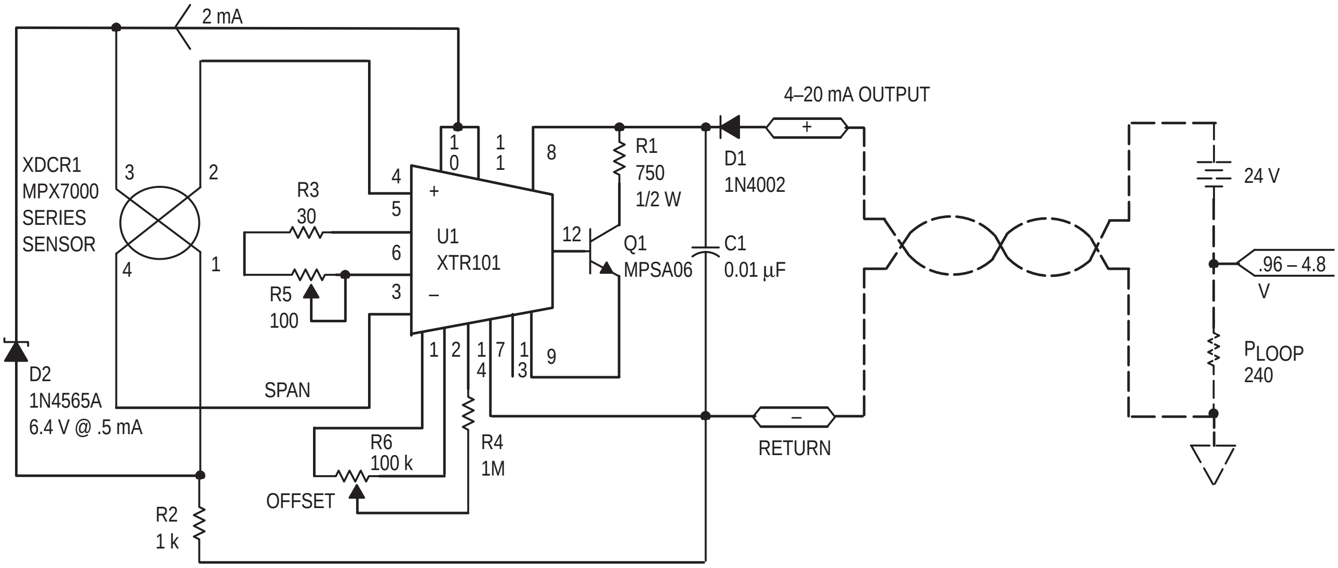


Figure 9. 4–20 mA Pressure Transducer

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.

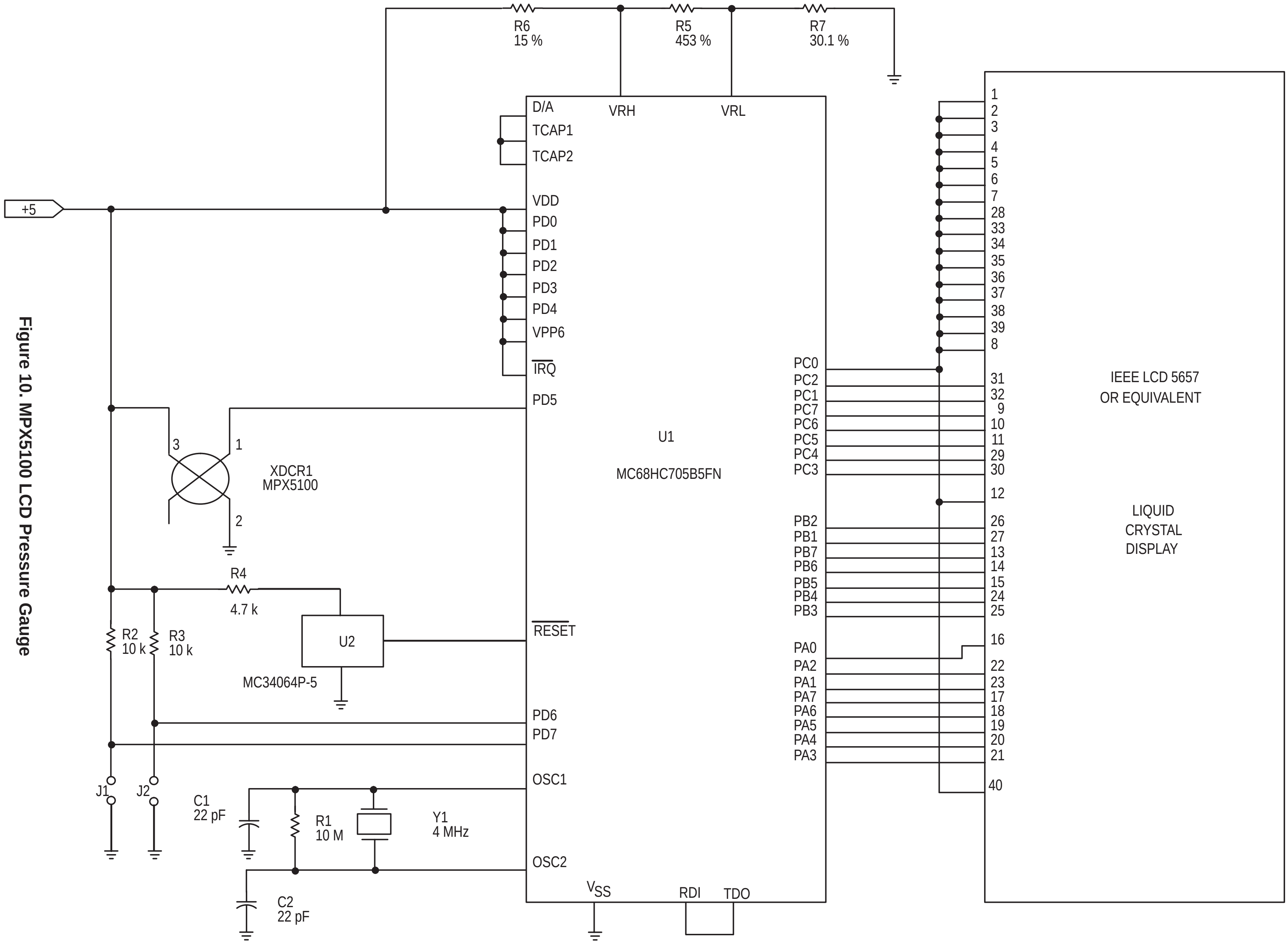


Figure 10. MPX5100 LCD Pressure Gauge

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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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 0.5 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 and 4 of the sensor is 4.0 V, then pin 2 of U2A and pin 6 of U2B are also at 4.0 V. This puts 4.0 V across R6. 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 0.5 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.

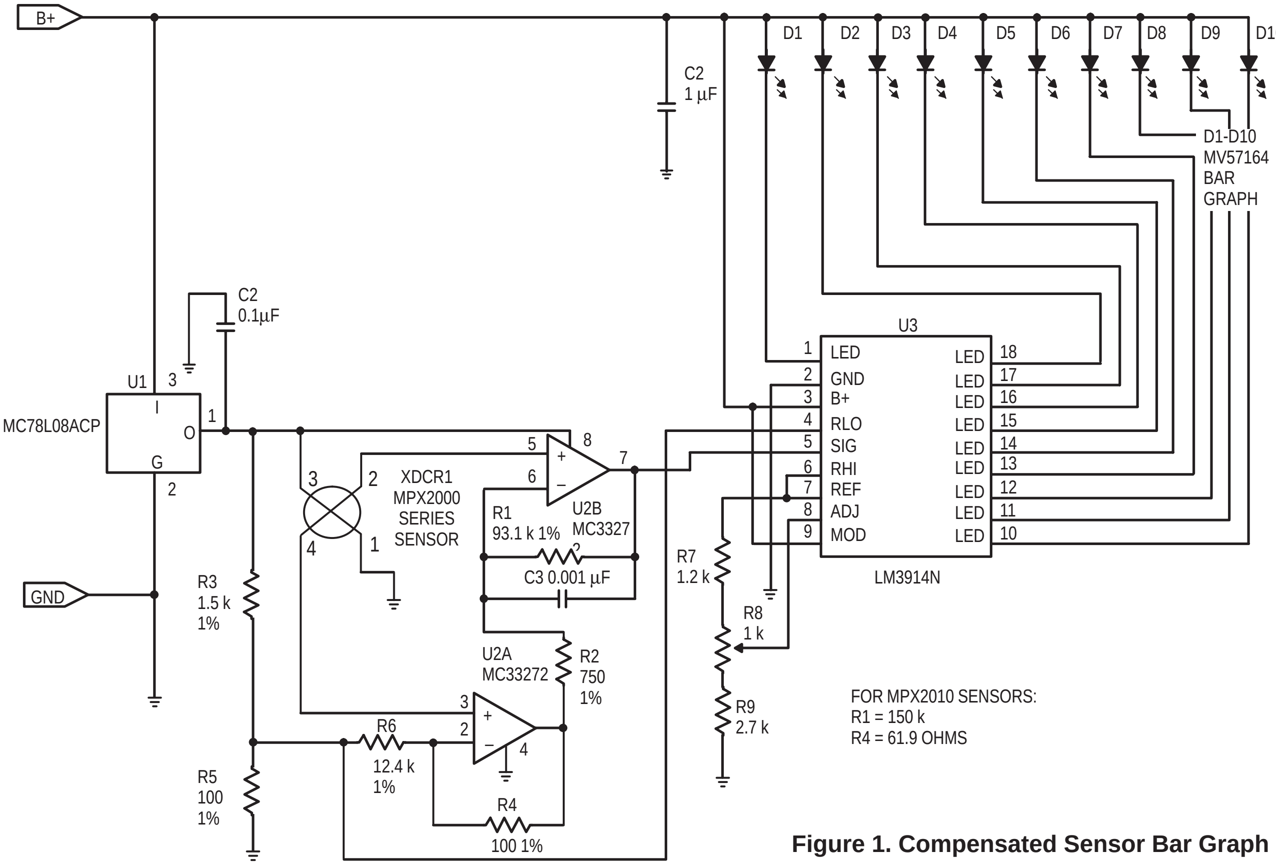
Again looking at Figure 1, full scale is set by adjusting the upper comparator's reference voltage to match the sensor's output at full pressure. An internal regulator on the LM3914 sets this voltage with the aid of resistors R7, R9, and adjustment pot R8.

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%).

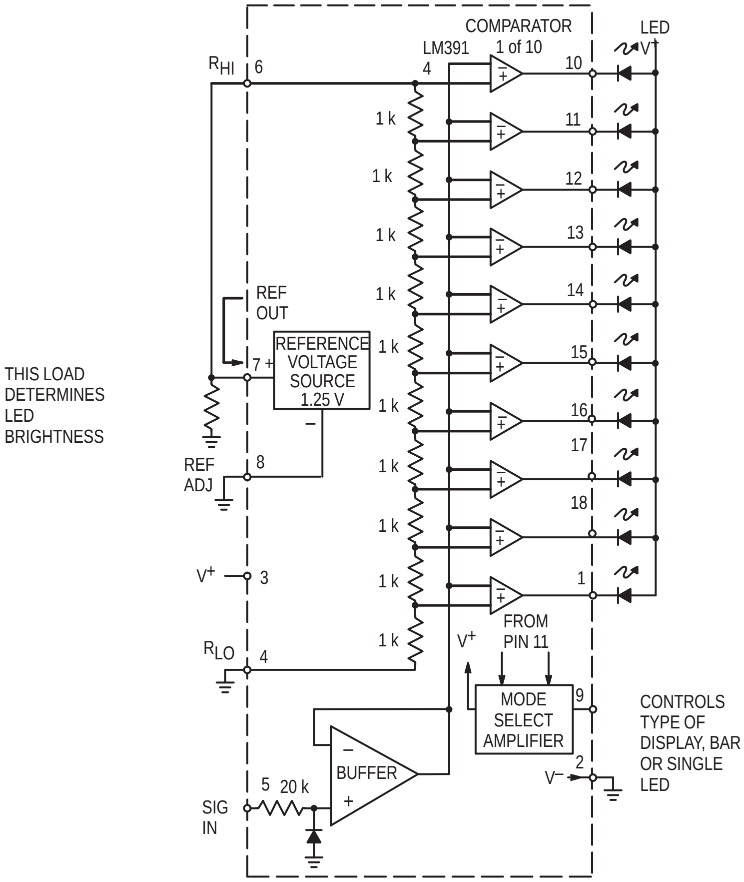
This circuit can be simplified by substituting an MPX5100 integrated sensor for the MPX2100 and the op amp interface. The resulting schematic is shown in Figure 3. In this case zero reference for the bar graph is provided by dividing down the 5 V regulator with R4, R1 and adjustment pot R6. The voltage 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.

REV 1



FOR MPX2010 SENSORS:
R1 = 150 k
R4 = 61.9 OHMS

Figure 1. Compensated Sensor Bar Graph Pressure Gauge



THIS LOAD
DETERMINES
LED
BRIGHTNESS

Figure 2. LM3914 Block Diagram

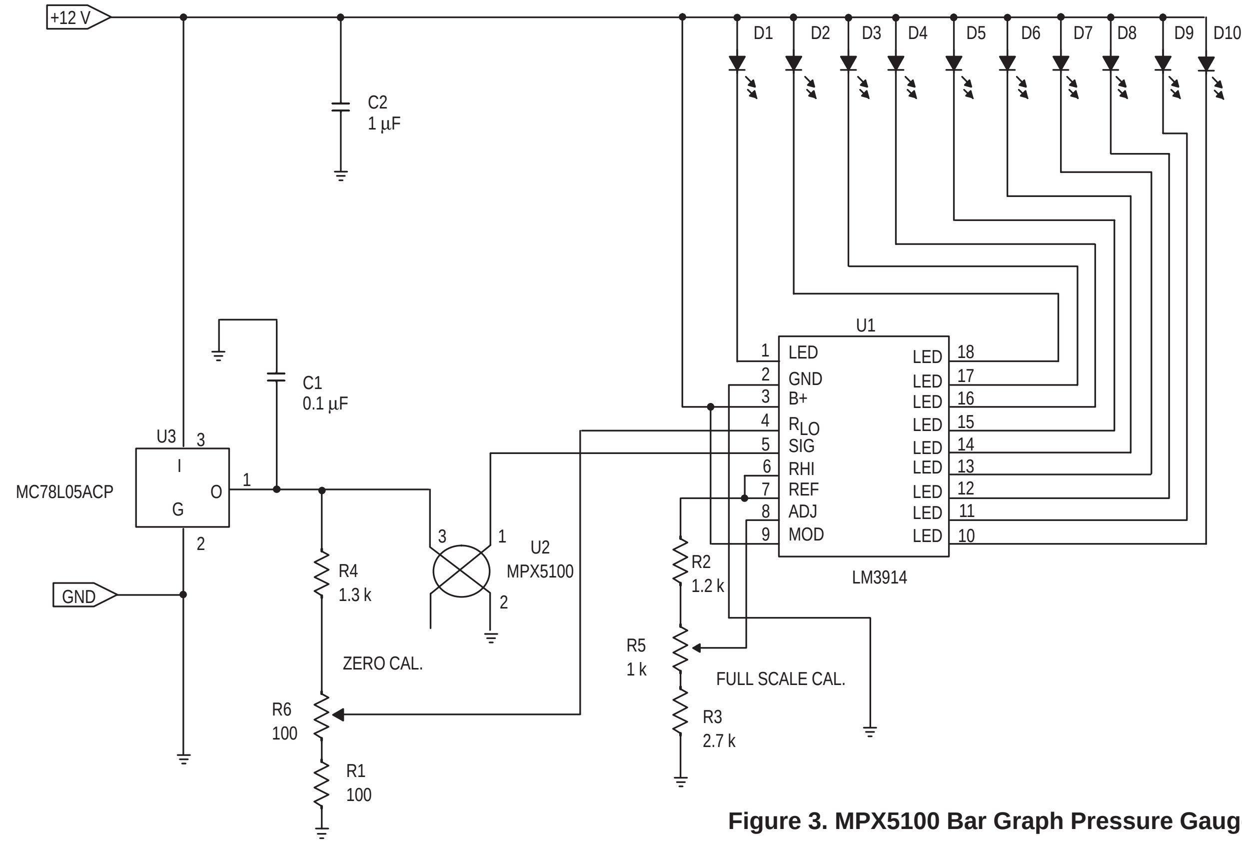


Figure 3. MPX5100 Bar Graph Pressure Gauge

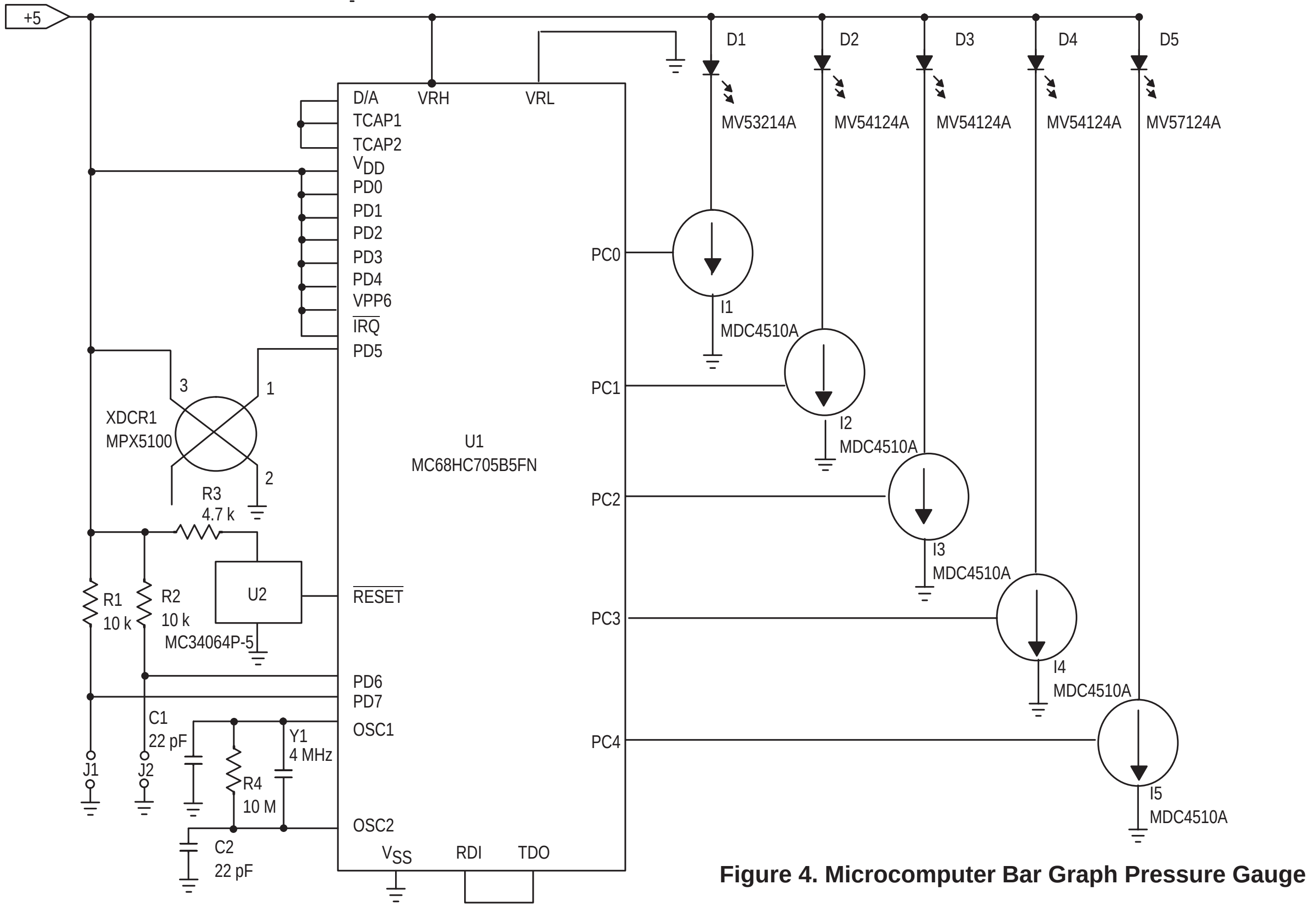


Figure 4. Microcomputer Bar Graph Pressure Gauge

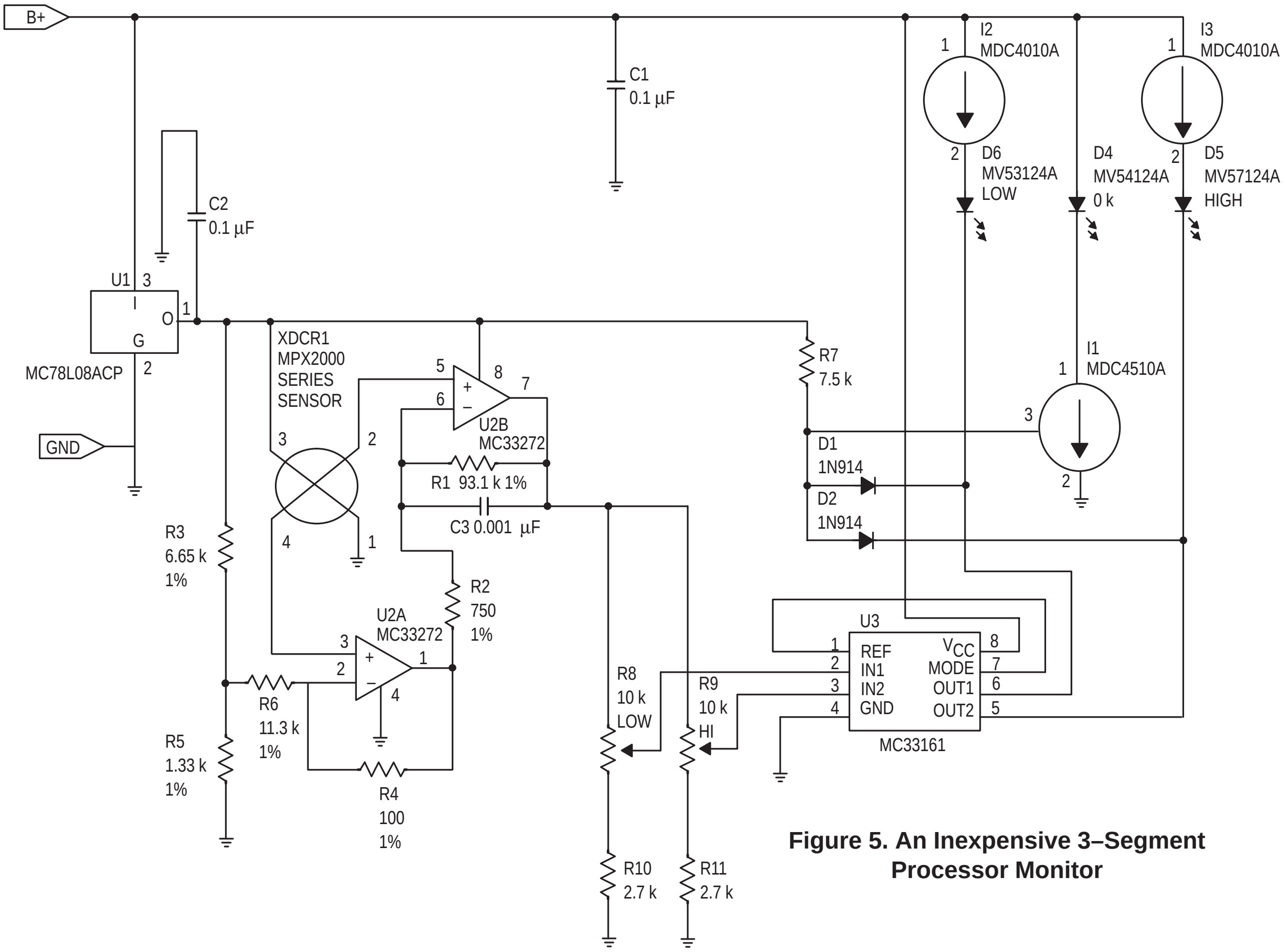


Figure 5. An Inexpensive 3–Segment Processor Monitor

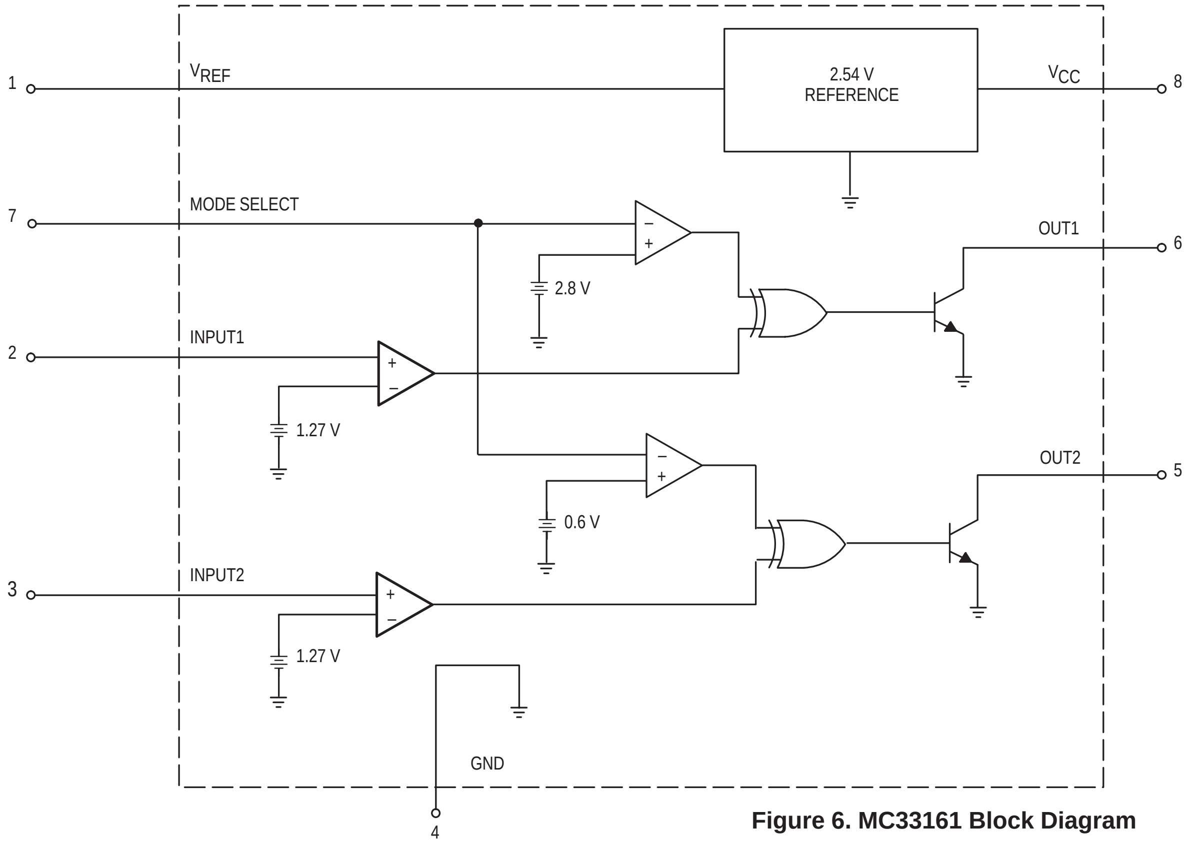


Figure 6. MC33161 Block Diagram

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 and 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 and 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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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.

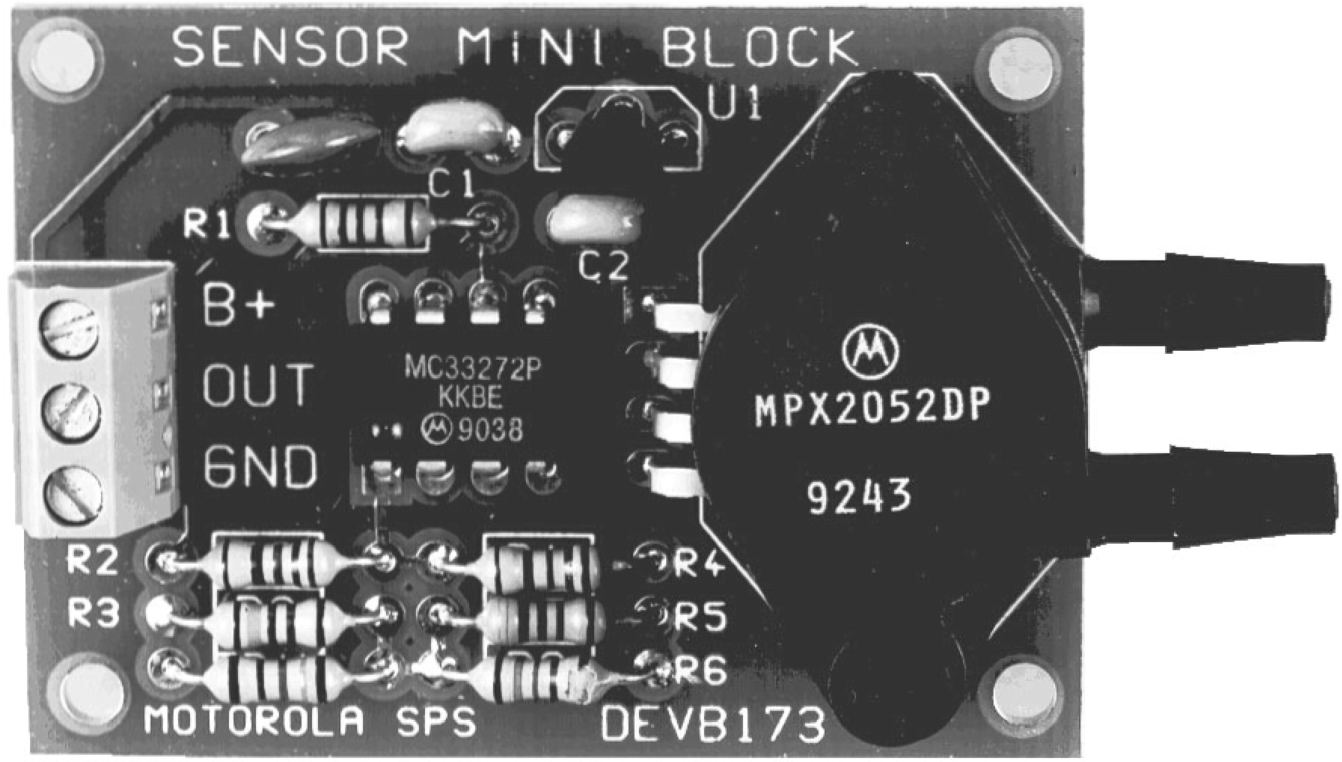


Figure 1. DEVB173 Sensor Building Block Evaluation Board

REV 1

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	P_{FS}				kPa
MPX2010		—	—	10	
MPX2050		—	—	50	
MPX2100		—	—	100	
MPX2200		—	—	200	
MPX2700		—	—	700	
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:

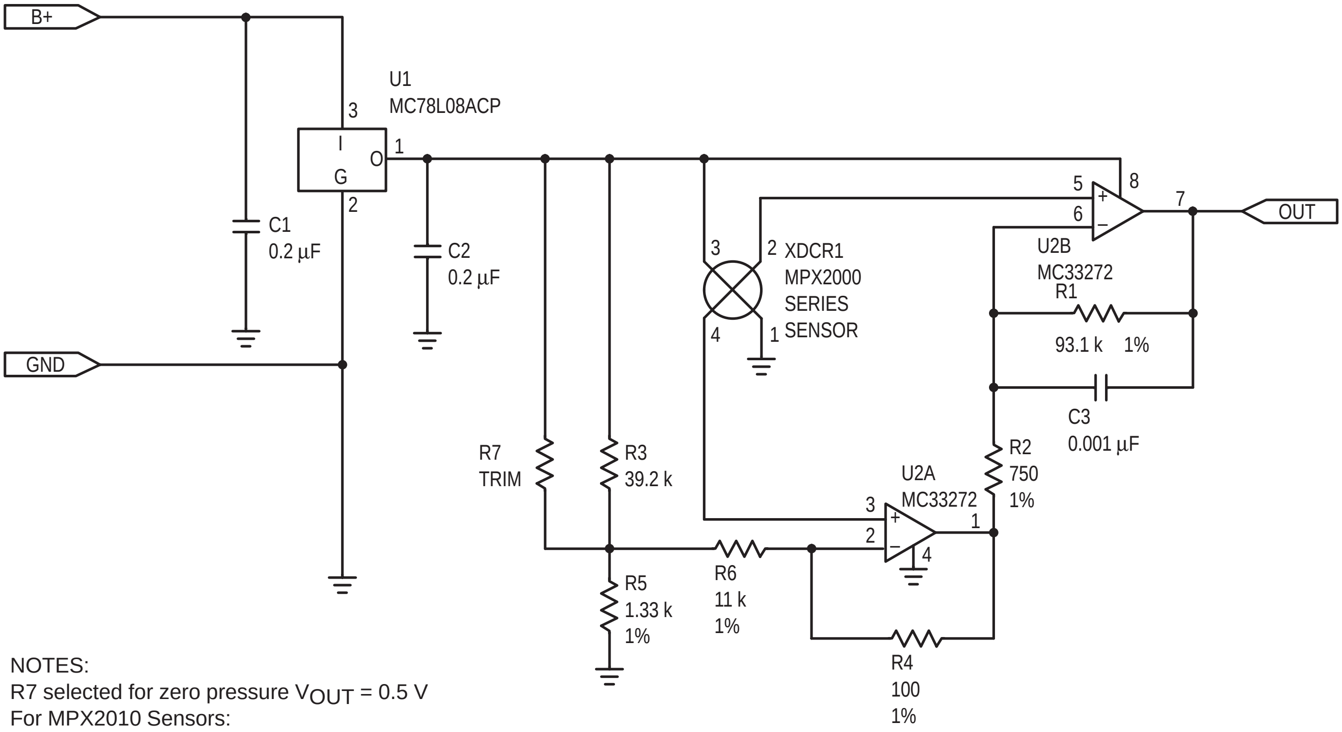
An analog output is supplied at the OUT terminal. The signal it provides is nominally 0.5 V at zero pressure and 4.5 V at full scale. This output is designed to be directly connected to a microcomputer A/D channel, such as one of the E ports on an MC68HC11.

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 and 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

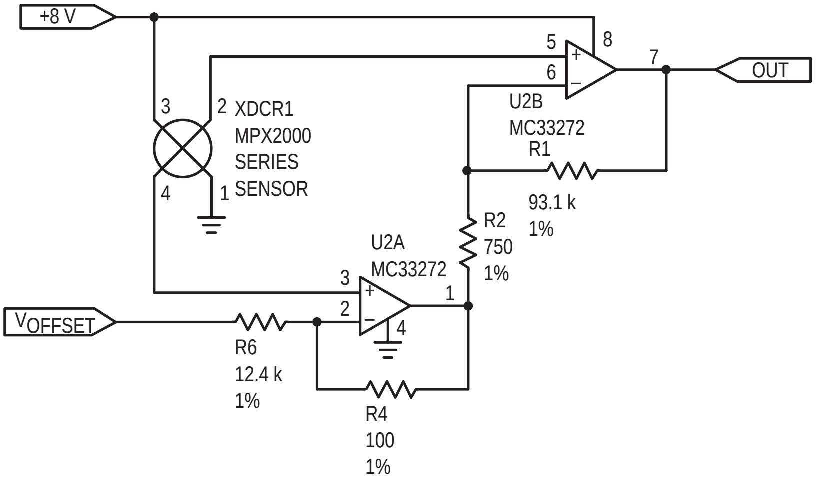


Figure 3. Simplified Schematic

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 and 4 of the sensor is 4.0 V, then pin 2 of U2A and pin 6 of U2B are also at 4.0 V. This puts 4.0 V across R6. Assuming that the current in R4 is equal 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 and 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.

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 0.3 – 1.0 V. Typical design targets are 0.5 V at zero pressure and enough gain to produce 4.5 V at full scale. The 0.5 V zero pressure offset allows for output saturation voltage in op amps operated with a single supply ($V_{EE} = 0$). At the other end, 4.5 V full scale keeps the output within an A/D converter's 5 V range with a comfortable margin for component tolerances. The resulting 0.5 to 4.5 V single–ended analog signal is also quite suitable for a variety of other applications such as bar graph pressure gauges and process monitors.

CLASSIC INSTRUMENTATION AMPLIFIER

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

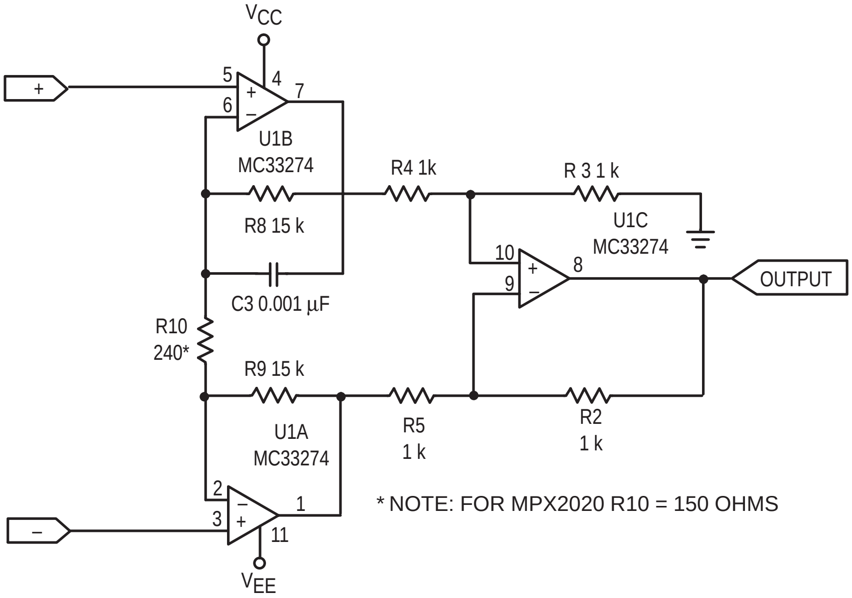
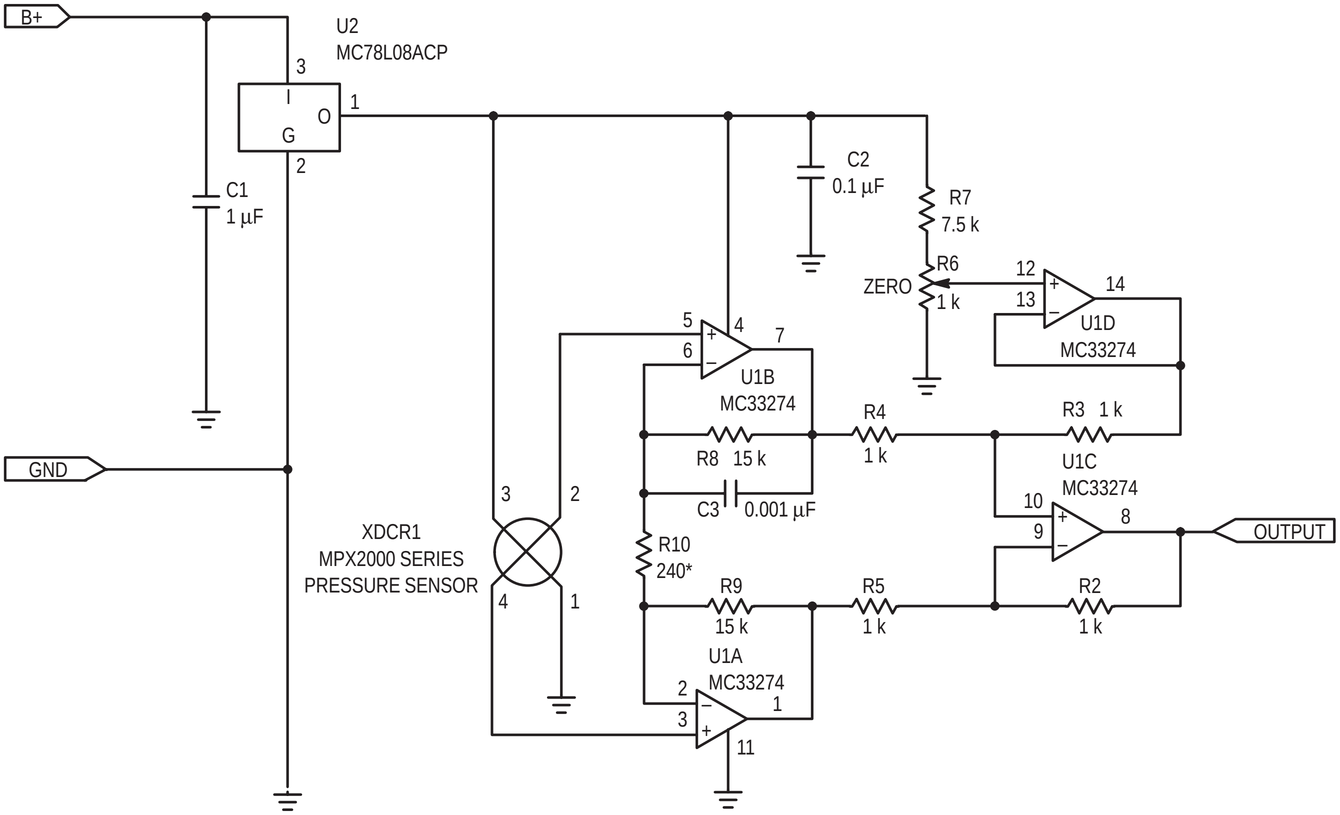


Figure 1. Classic Instrumentation Amplifier

REV 2



* NOTE: FOR MPX2010 R10 = 150 OHMS

Figure 2. Instrumentation Amplifier Interface

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

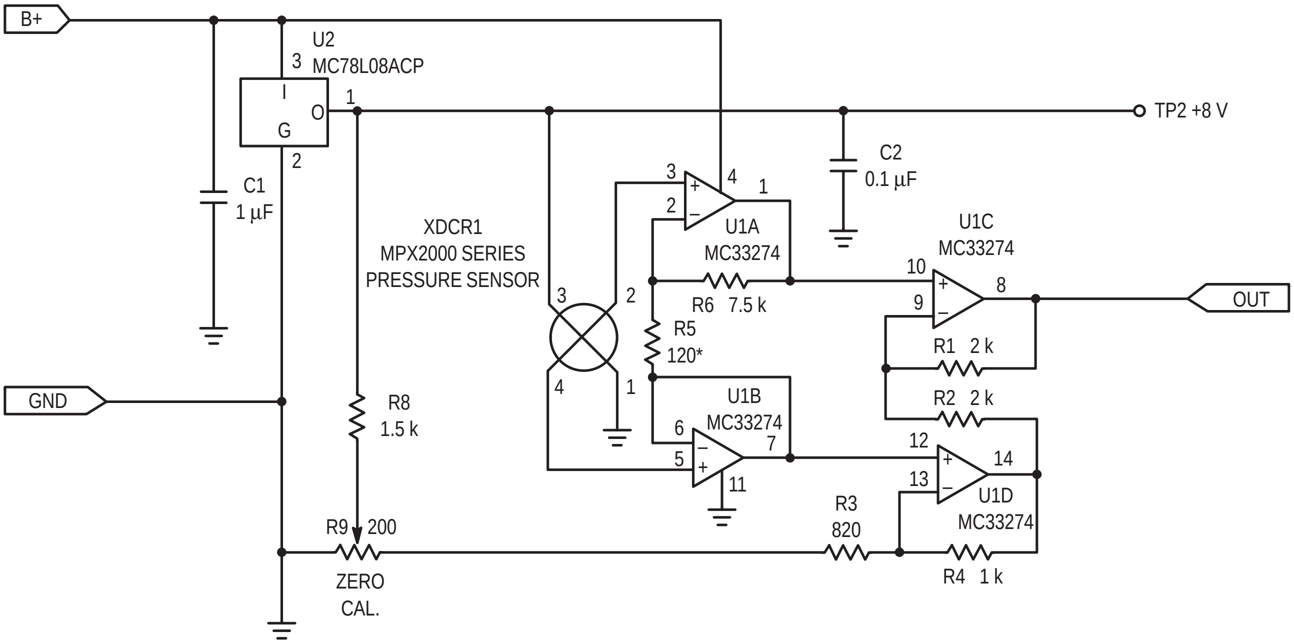
With R10 at 240 Ω gain is set for a nominal value of 125, providing a 4 V span for 32 mV of full scale sensor output. Setting the offset voltage to 0.75 V, results in a 0.75 V to 4.75 V output that is directly compatible with microprocessor A/D inputs.

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

SENSOR SPECIFIC AMPLIFIER

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

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



* NOTE: FOR MPX2010 R5 = 75 OHMS

Figure 3. Sensor Specific Amplifier

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

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

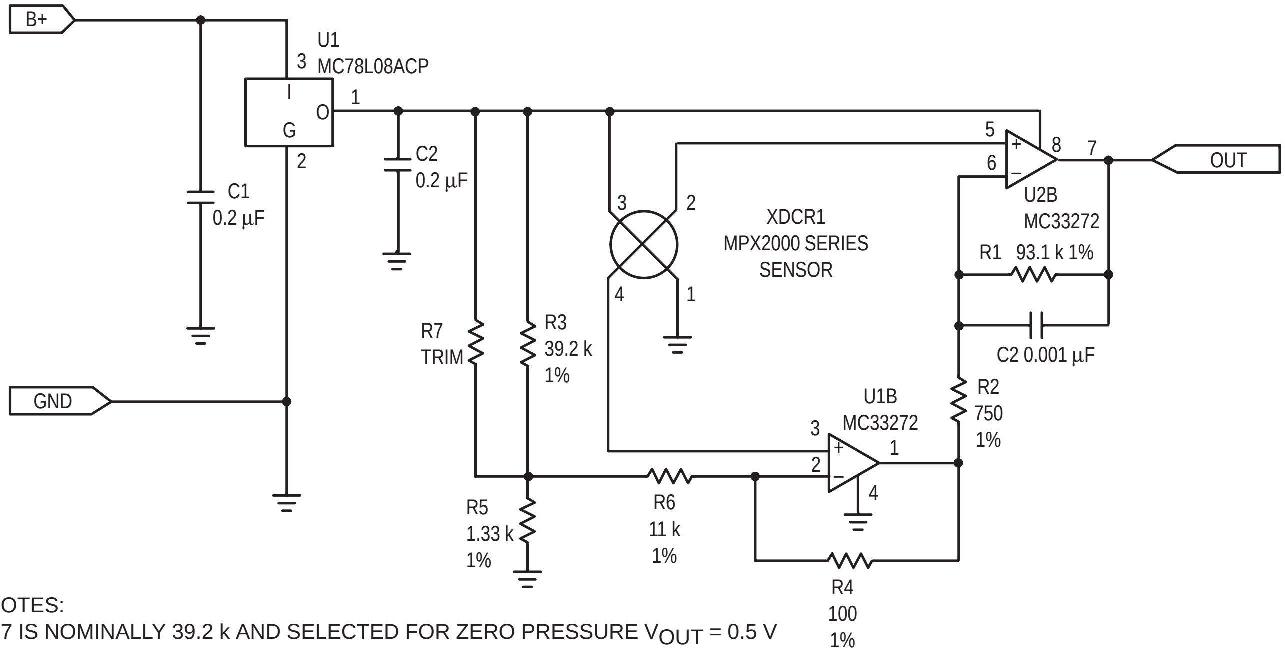
This approach to interface amplifier design is an improvement over the classic instrument amplifier in that it uses fewer resistors, is inherently more stable, and provides a zero pressure output voltage that can be targeted at .5 V. It has the same tolerance problem from matching discrete resistors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

SENSOR MINI AMP

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

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

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



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

Figure 4. Sensor Mini Amp

PERFORMANCE

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

CONCLUSION

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

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.

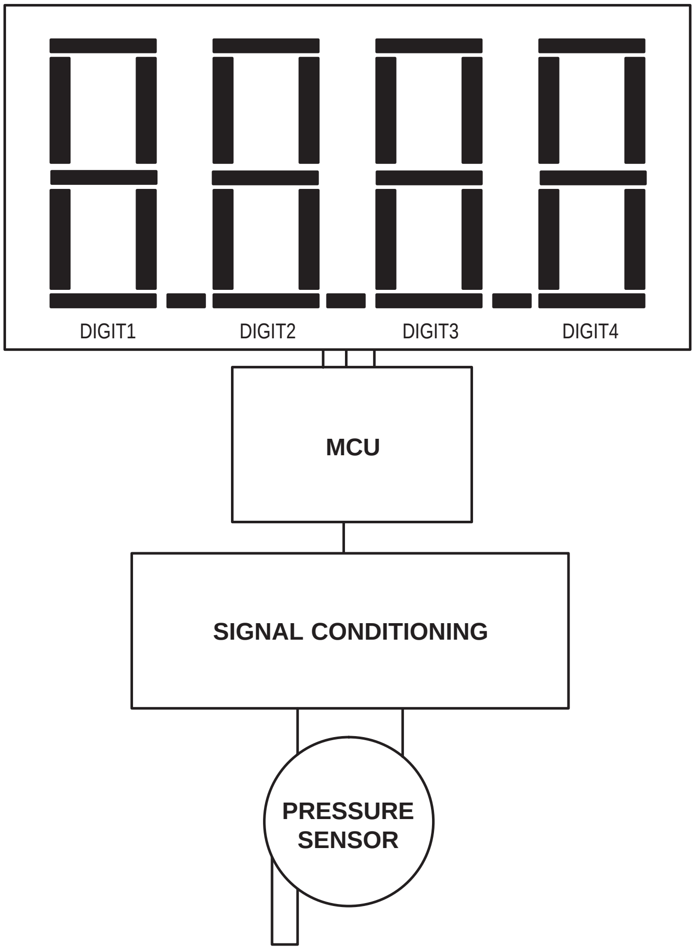


Figure 1. Barometer System

REV 1

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.

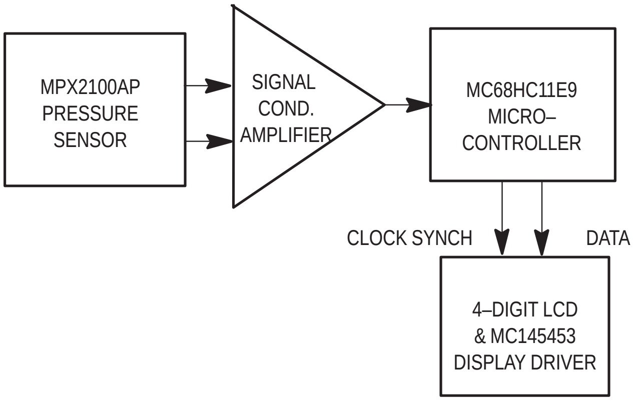


Figure 2. Barometer System Block Diagram

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.

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

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.

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.

$$\left(\frac{8}{10} \times 40\ \text{mV}\right)$$

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

$$\text{Gain} = \frac{3.04\ \text{V}}{\Delta\text{SO}} = 187$$

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:

$$R_1 \approx R_3 = 121\ \Omega$$
$$R_2 \approx R_4 = 22.6\ \text{k}\ \Omega.$$

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.

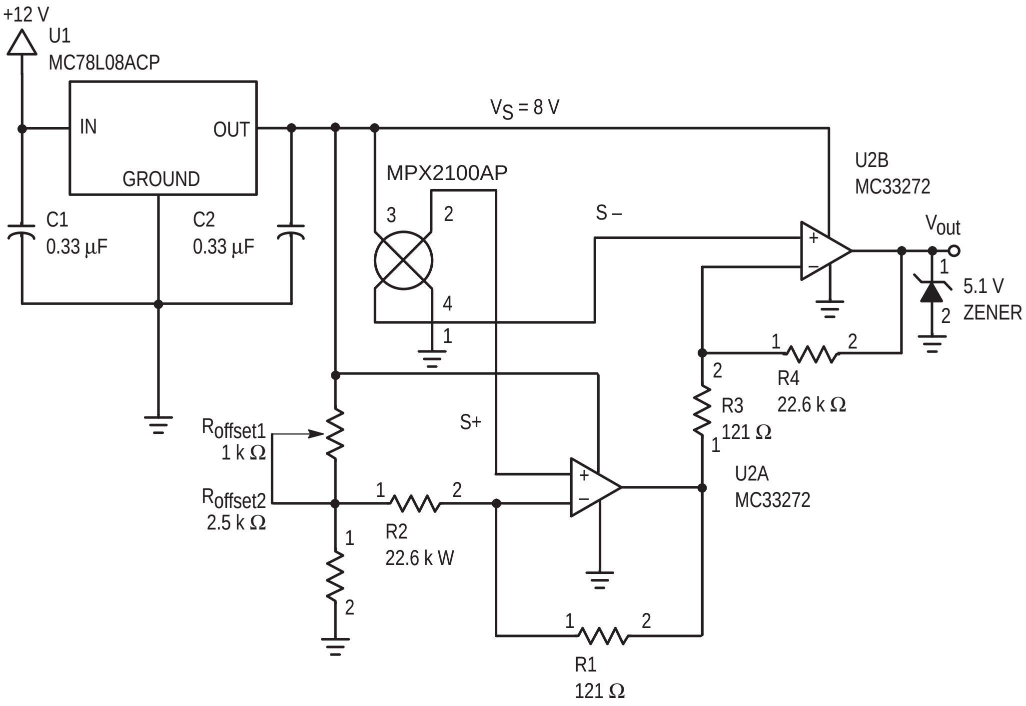


Figure 3. Signal Conditioning Circuit

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.

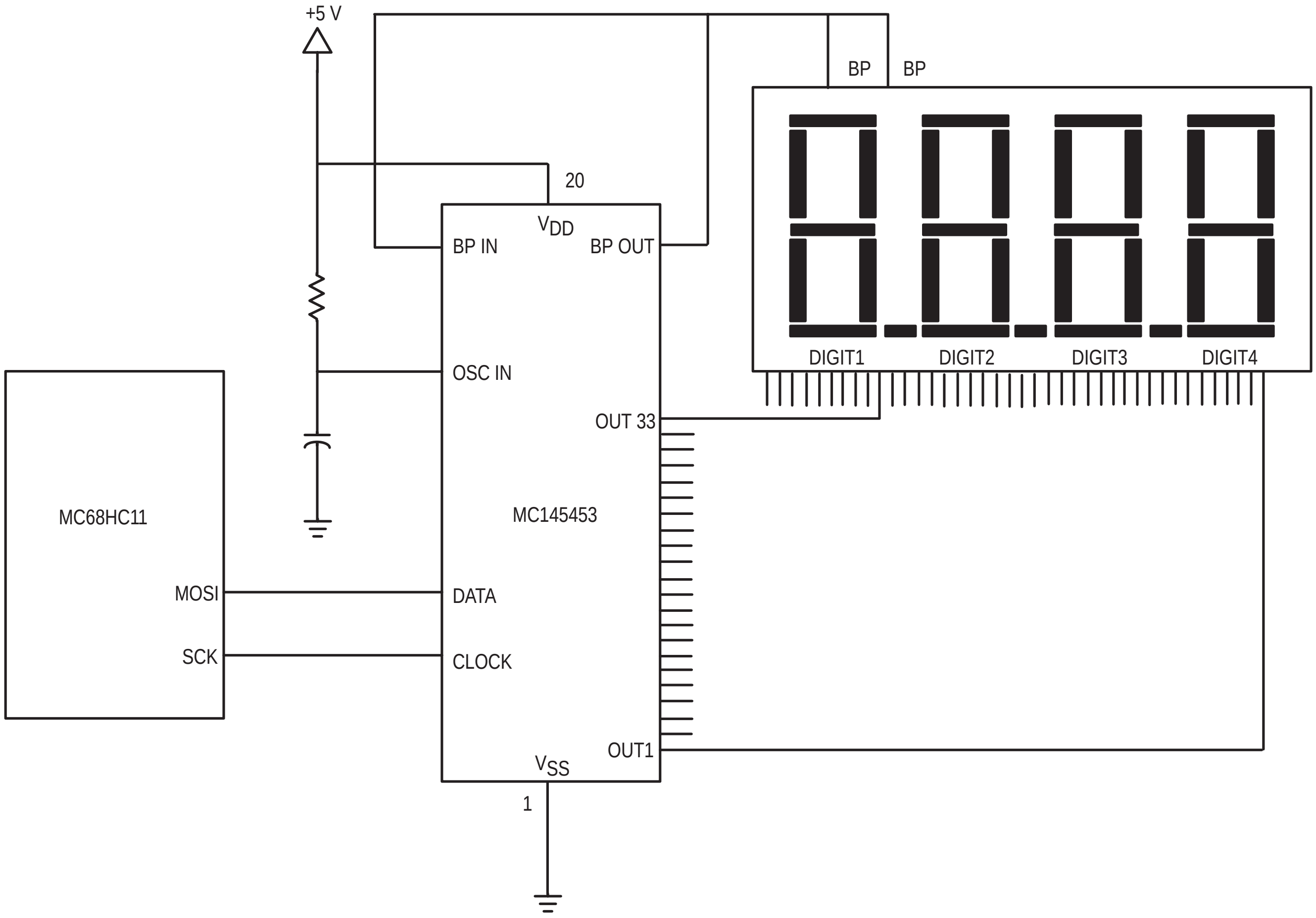


Figure 4. LCD Display Interface Diagram

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.

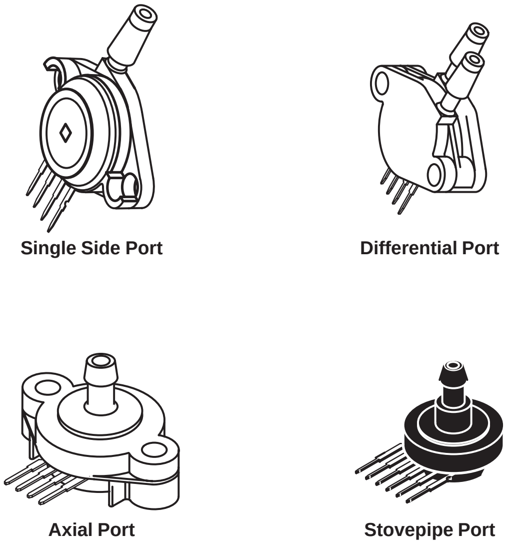

Single Side Port
Differential Port
Axial Port
Stovepipe Port

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.

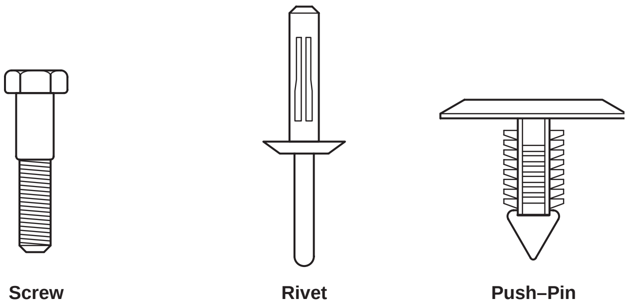
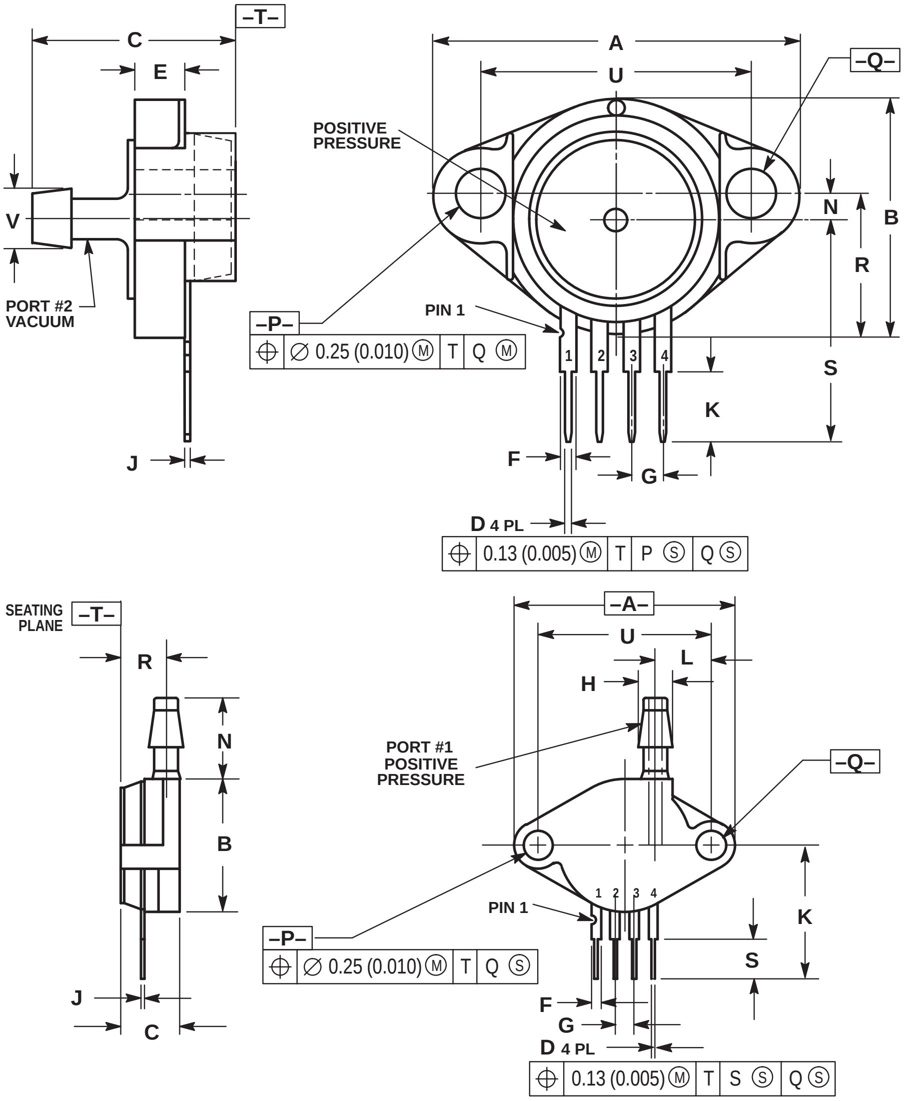

Screw
Rivet
Push–Pin

Figure 2. Mounting Hardware

REV 1



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.

DIM	INCHES MIN	INCHES MAX	MILLIMETERS MIN	MILLIMETERS 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

NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5, 1982.
2. CONTROLLING DIMENSION: INCH.

DIM	INCHES MIN	INCHES MAX	MILLIMETERS MIN	MILLIMETERS MAX
A	1.140	1.180	28.95	29.97
B	0.685	0.751	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	

Figure 3. Case Outline Drawings
Top: Case 371D–02, Issue B
Bottom: Case 350–03, Issue H

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.

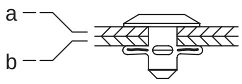
Tightening beyond these recommendations may damage the package, or affect the performance of the device.

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.

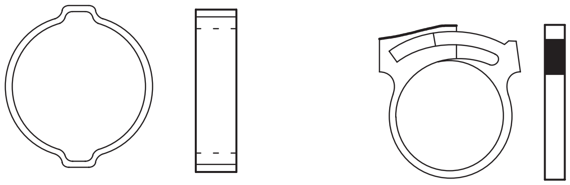
Two brands of urethane hose are:

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).

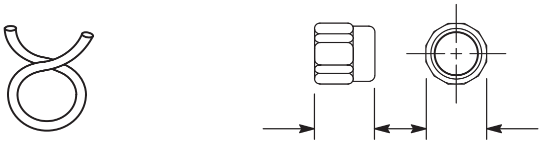
HOSE CLAMPS

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
Telex: 710–988–5834
USA
P.O. Box 3660, Akron, OH 44309–3660
USA
(216) 798–9240
FAX: (216) 798–0358

Clippard Instrument Laboratory, Inc.
7390 Colerain Rd.
Cincinnati, Ohio 45239, USA
(513) 521–4261
FAX: (513) 521–4464

Ryan Herco Products Corporation
P.O. Box 588
Burbank, CA 91503
1–800–423–2589
FAX: (818) 842–4488

Spring Wire Clamps

RotorClip, Inc.
187 Davidson Avenue
Somerset, NJ 08875–0461
1–800–631–5857 Ext. 255

Rivets and Push–Pins

ITW FasTex
195 Algonquin Road
Des Plaines, IL 60016
(708) 299–2222
FAX: (708) 390–8727

Bolts

Quality Screw and Nut Company
1331 Jarvis Avenue
Elk Grove Village, IL 60007
(312) 593–1600

Crimp–on and Nylon Clamps

Ryan Herco Products Corporation
P.O. Box 588
Burbank, CA 91503
1–800–423–2589
FAX: (818) 842–4488

Crimp–on and Screw–on Clamps

Clippard Instrument Laboratory, Inc.
7390 Colerain Rd.
Cincinnati, Ohio 45239, USA
(513) 521–4261
FAX: (513) 521–4464

MOTOROLA
SEMICONDUCTOR APPLICATION NOTE

AN1516

Liquid Level Control Using a Motorola Pressure Sensor

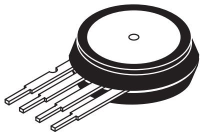
Prepared by: JC Hamelain
Toulouse Pressure Sensor Laboratory
Semiconductor Products Sector, Toulouse, France

INTRODUCTION

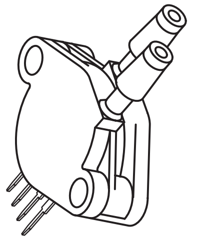
Motorola Discrete Products provides a complete solution for designing a low cost system for direct and accurate liquid level control using an ac powered pump or solenoid valve. This circuit approach which exclusively uses Motorola semiconductor parts, incorporates a piezoresistive pressure sensor with 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

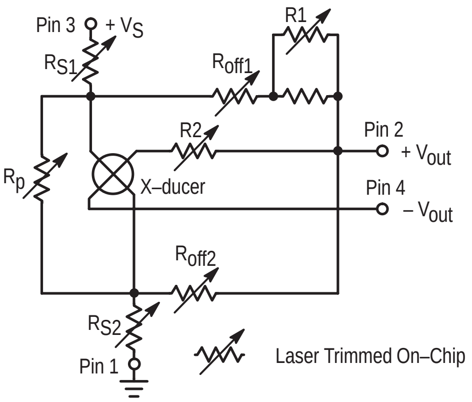
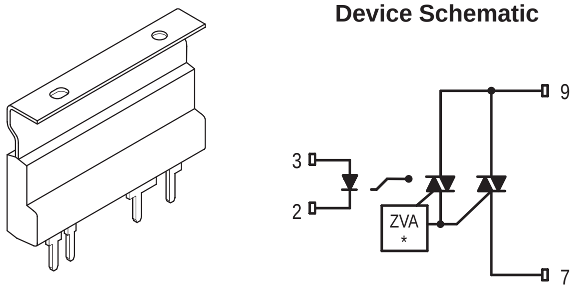


Figure 1. Pressure Sensor MPX2000 Series

REV 1

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).



Device Schematic

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.

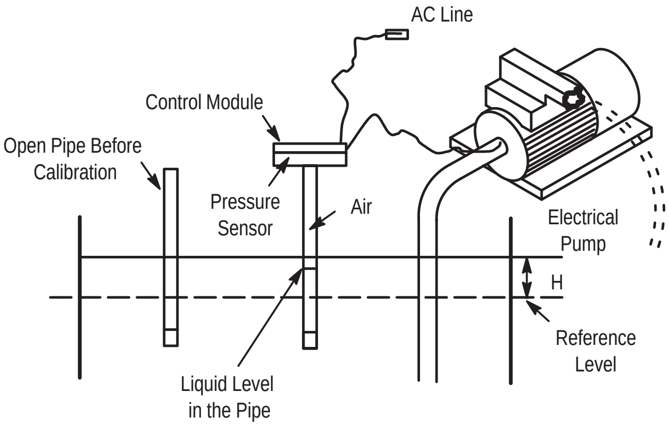


Figure 3. Liquid Level Monitoring

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.

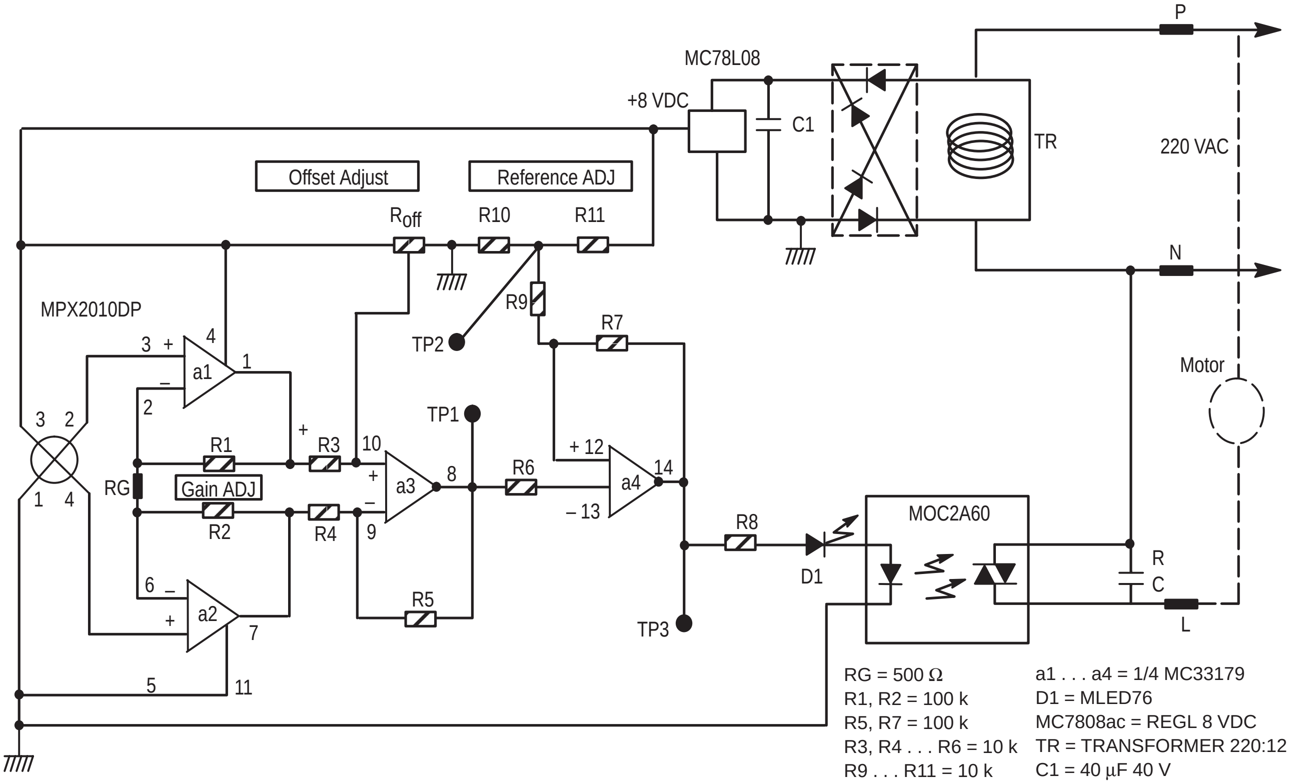
PRESSURE SENSOR CHOICE

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

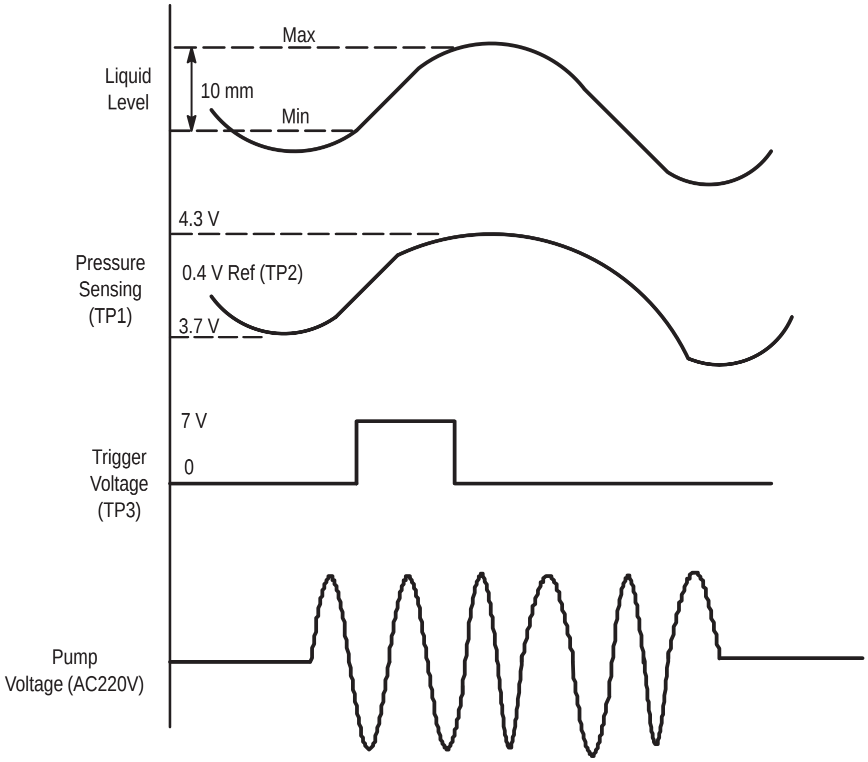
METHOD	SENSOR	ADVANTAGE	DISADVANTAGES
Liquid weight	Magnetoresitive	Low power, no active electronic	Low resolution, range limited
	Magnetoresitive	Very high resolution	Complex electronic
	Ultrasonic	Easy to install	Need high power, low accuracy
Liquid resistivity	No active electronic	No active electronic	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



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

Figure 4. Electrical Circuit



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.

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

REV 1

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:

$$\mathrm{GAIN} = 1 + \frac{R6}{R5}$$

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.

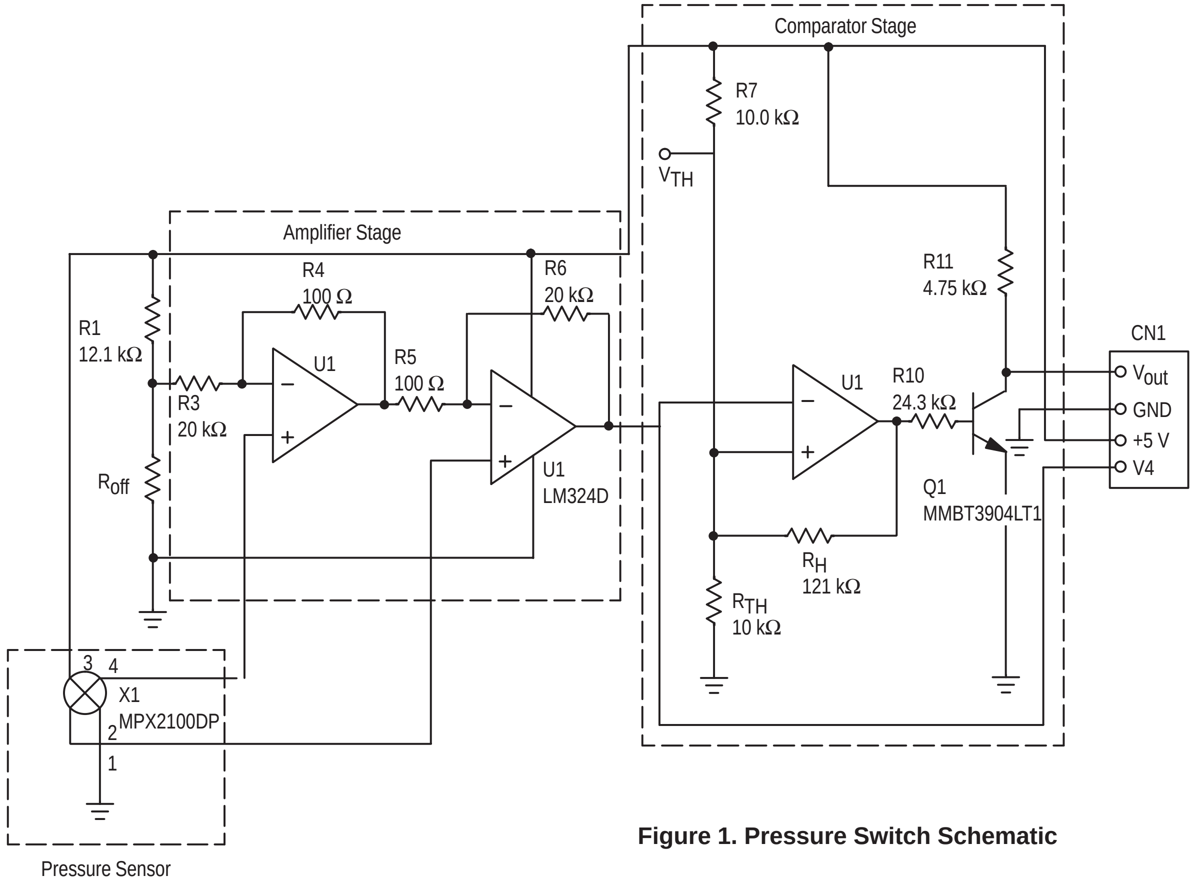

Figure 1. Pressure Switch Schematic

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**.**

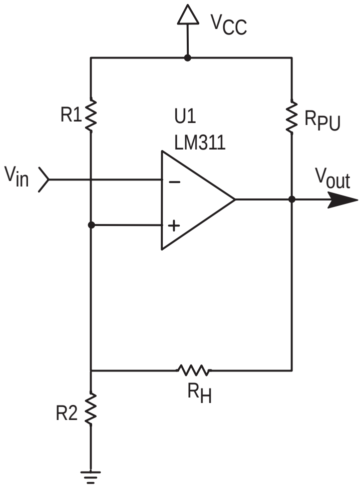

Figure 2. LM311 Comparator Circuit Schematic

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.

$$V_{REFH} = \frac{R1R2 + R2R_H}{R1R2 + R1R_H + R2R_H} V_{CC}$$

$$V_{REFL} = \frac{R2R_H}{R1R2 + R1R_H + R2R_H} V_{CC}$$

$$HYSTERESIS = V_{REF} - V_{REFL}$$

when the normal state is below V_{REF}, or

$$HYSTERESIS = V_{REFH} - V_{REF}$$

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.

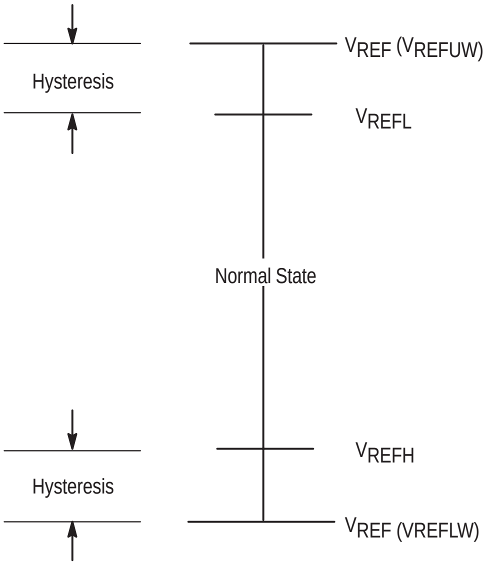

Figure 3. Setting the Reference Voltages

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.

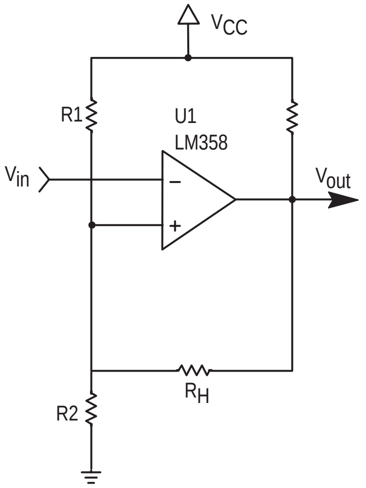

Figure 4. LM358 Comparator Circuit Schematic

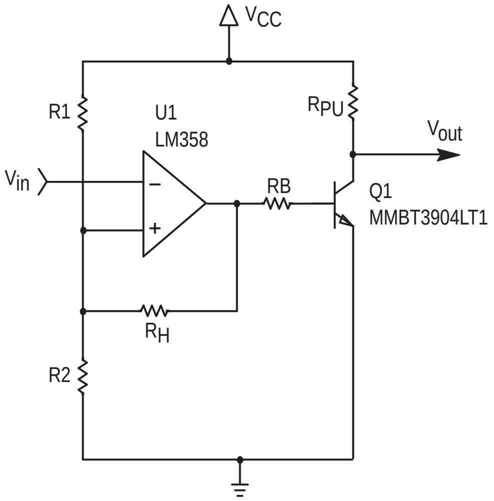

Figure 5. LM358 with a Transistor Output Stage Comparator Circuit Schematic

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.

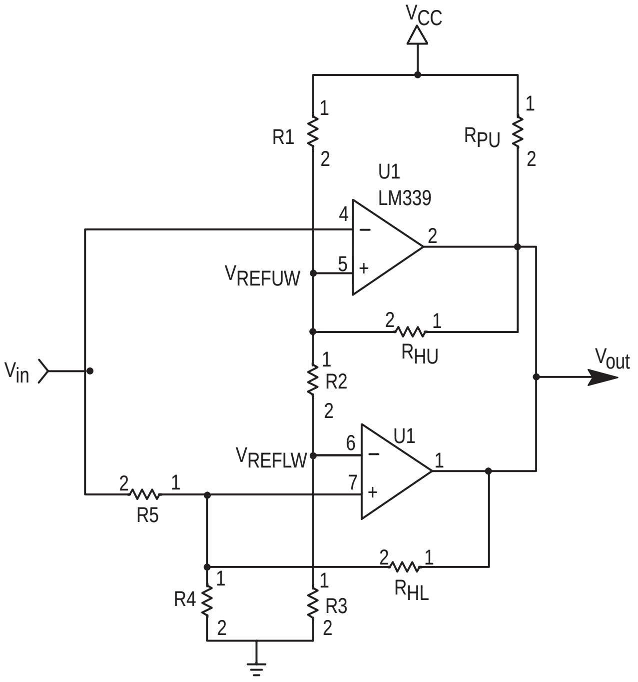

Figure 6. LM339 Window Comparator Circuit Schematic

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}istheupperwindowreferencevoltageandV_{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.

$$R_{HL} = \frac{R4R5\left(V_{REFLW} - V_{INL} - V_{CC}\right)}{(R4 + R5)\left(V_{INL} - V_{REFLW}\right)}$$

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

$$V_{off} = \frac{V_{off}}{R1 + R_{off}} V_{CC} .$$

Then, the amplified sensor voltage corresponding to a given pressure is calculated by

V_{sensor} = 201 x 0.0002 x 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

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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.

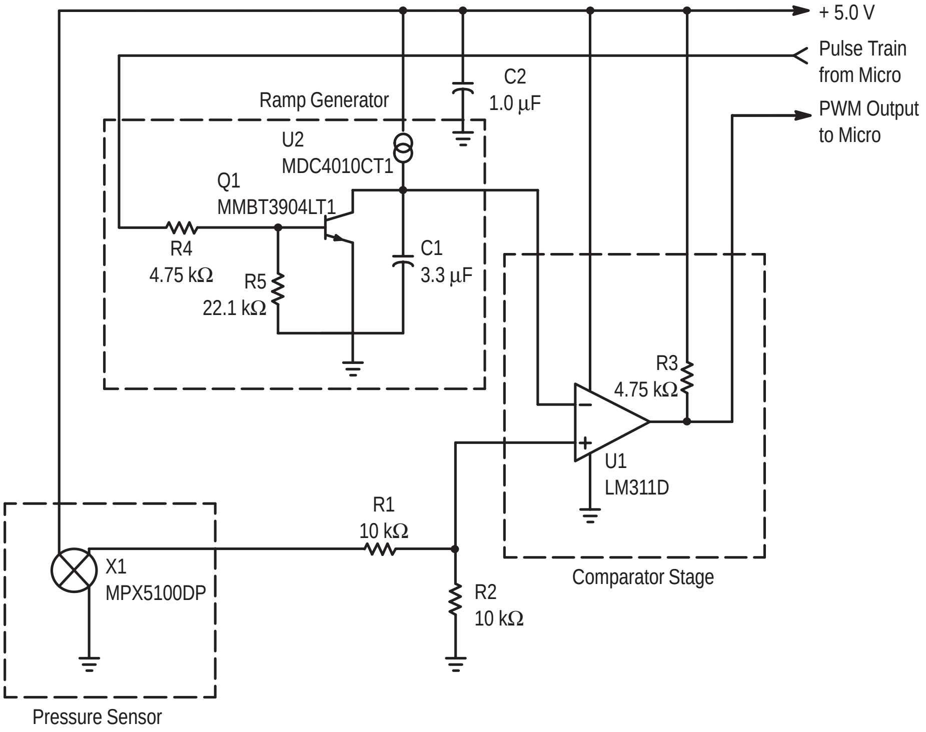

Figure 1. PWM Output Pressure Sensor Schematic

REV 1

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:

$$\Delta V = \frac{I\Delta t}{C} \qquad (1)$$

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.

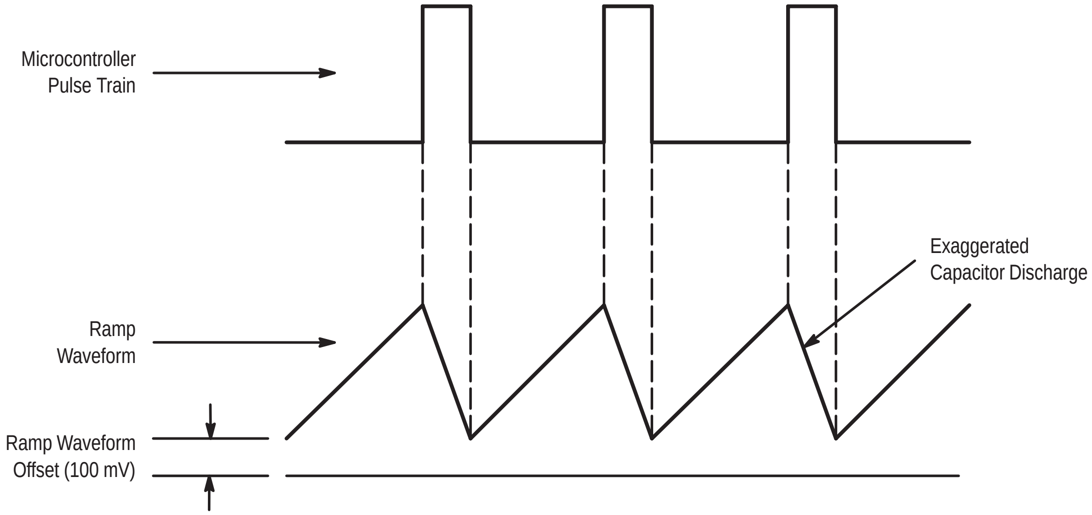

Figure 2. Ideal Ramp Waveform for the PWM Output Pressure Sensor

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.

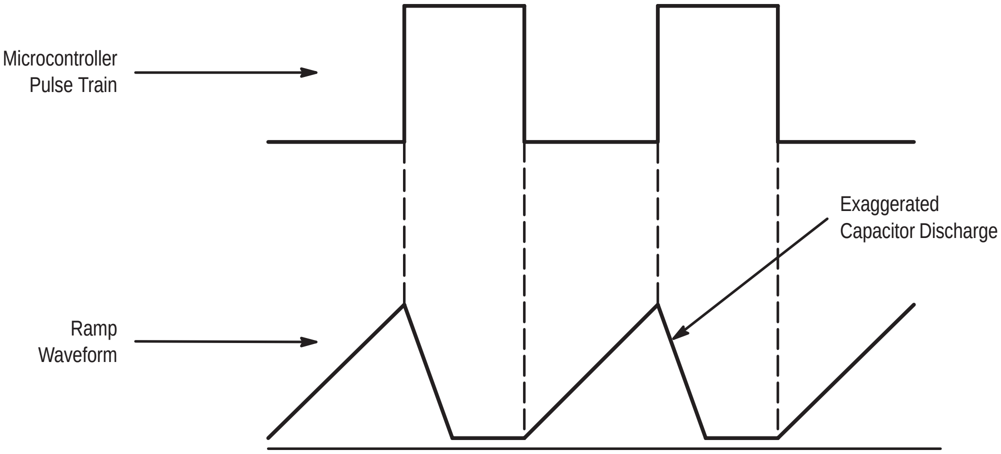

Figure 3. Non Ideal Ramp Waveform for the PWM Output Pressure Sensor

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).

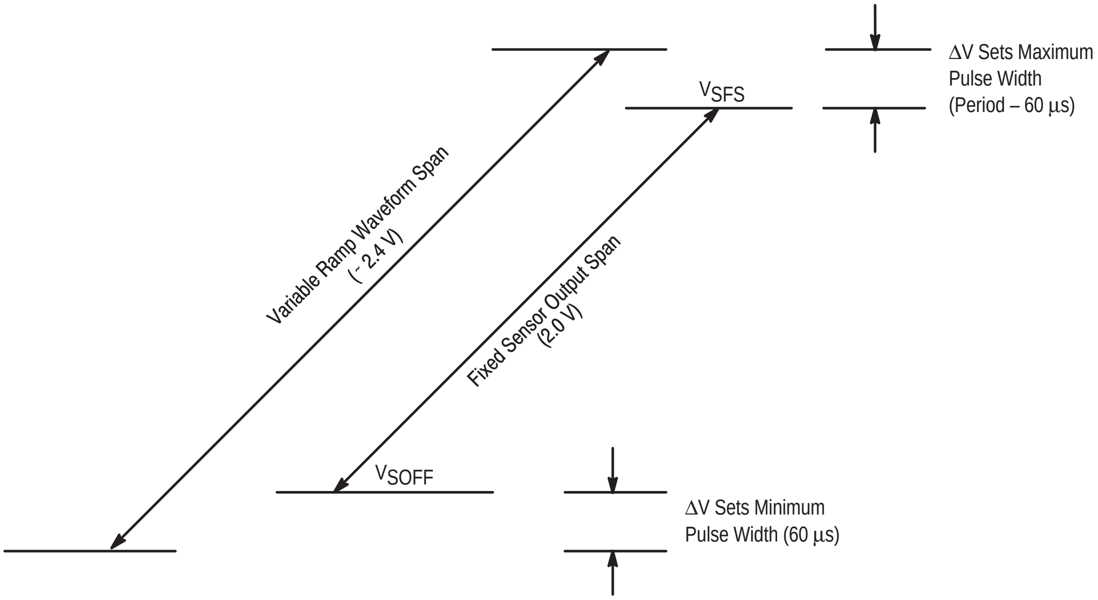

Figure 4. Desired Relationship Between the Ramp Waveform and Pressure Sensor Voltage Spans

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.

$$\frac{1}{2\ \text{MHz}} = \succ \frac{0.5\ \mu\text{s}}{\text{clock cycle}}$$

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.

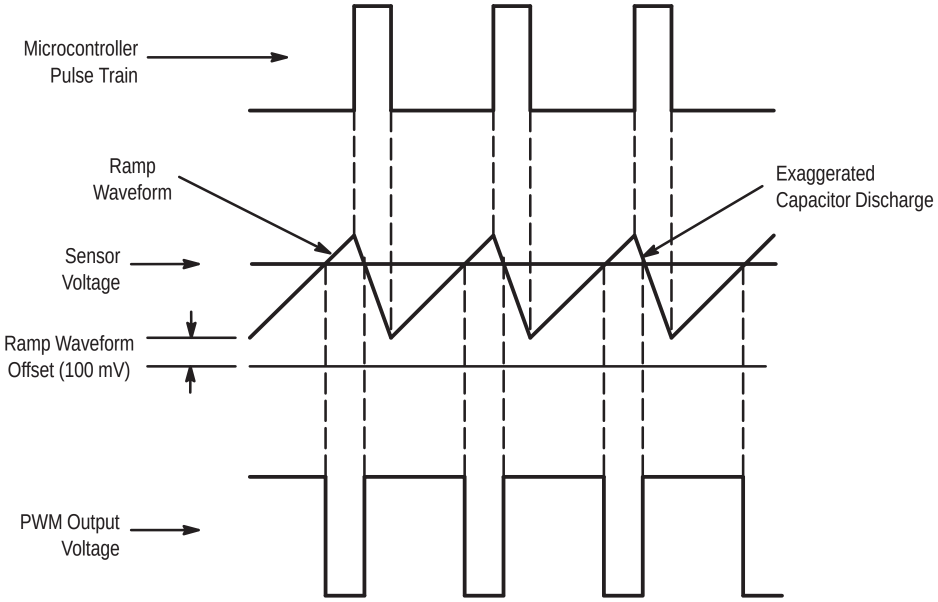

Figure 5. Relationships Between the PWM Output Pressure Sensor Voltages

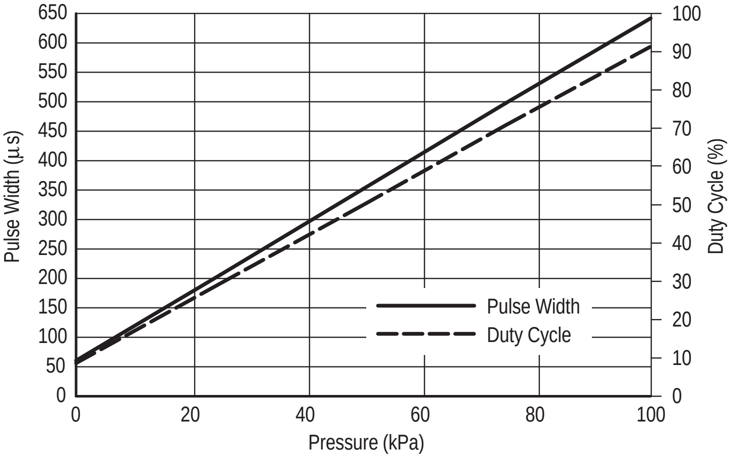

Figure 6. PWM Output Pressure Sensor Linearity Data

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.

AN1525

The A-B-C's of Signal-Conditioning Amplifier Design for Sensor Applications

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INTRODUCTION

Although fully signal–conditioned, calibrated, and temperature compensated monolithic sensor IC's are commercially available today, there are many applications where the flexibility of designing custom signal–conditioning is of great benefit. Perhaps the need for a versatile low–level sensor output is best illustrated by considering two particular cases that frequently occur: (1) the user is in a prototyping phase of development and needs the ability to make changes rapidly to the overall transfer function of the combined sensor/amplifier subsystem, (2) the specific desired transfer function does not exist in a fully signal–conditioned, precision–trimmed sensor product (e.g., a signal–conditioned device is precision trimmed over a different pressure range than that of the application of interest). In such cases, it is obvious that there will always be a need for low–level, nonsignal–conditioned sensors. Given this need, there is also a need for sensor interface amplifier circuits that can signal condition the "raw" sensor output to a usable level. These circuits should also be user friendly, simple, and cost effective.

Today's unamplified solid–state sensors typically have an output voltage of tens of millivolts (Motorola's basic 10 kPa pressure sensor, MPX10, has a typical full–scale output of 58 mV, when powered with a 5 V supply). Therefore, a gain stage is needed to obtain a signal large enough for additional processing. This additional processing may include digitization by a microcontroller's analog to digital (A/D) converter, input to a comparator, etc. Although the signal–conditioning circuits described here are applicable to low–level, differential–voltage output sensors in general, the focus of this paper will be on interfacing pressure sensors to amplifier circuits.

This paper presents a basic two operational–amplifier signal–conditioning circuit that provides the desired characteristics of an instrumentation amplifier interface:

- High input impedance
- Low output impedance
- Differential to single–ended conversion of the pressure sensor signal
- High gain capability

For this two op–amp circuit, additional modifications to the circuit allow (1) gain adjustment without compromising common mode rejection and (2) both positive and negative dc level shifts of the zero pressure offset. Varying the gain and offset is desirable since full–scale span and zero pressure offset voltages of pressure sensors will vary somewhat from unit to unit. Thus, a variable gain is desirable to fine tune the sensor's full–scale span, and a positive or negative dc level shift (offset adjustment) of the pressure sensor signal is needed to translate the pressure sensor's signal–conditioned output span to a specific level (e.g., within the high and low reference voltages of an A/D converter).

For the two op–amp gain stage, this paper will present the derivation of the transfer function and simplified transfer function for pressure sensor applications, the derivation and explanation of the gain stage with a gain adjust feature, and the derivation and explanation of the gain stage with the dc level shift modification.

Adding another amplifier stage provides an alternative method of creating a negative dc voltage level shift. This stage is cascaded with the output from the two op–amp stage (*Note:* gain of the two op–amp stage will be reduced due to additional gain provided by the second amplifier stage). For this three op–amp stage, the derivation of the transfer function, simplified transfer function, and the explanation of the negative dc level shift feature will be presented.

GENERAL NOTE ON OFFSET ADJUSTMENT

Pressure sensor interface circuits may require either a positive or a negative dc level shift to adjust the zero pressure offset voltage. As described above, if the signal–conditioned pressure sensor voltage is input to an A/D, the sensor's output dynamic range must be positioned within the high and low reference voltages of the A/D; i.e., the zero pressure offset voltage must be greater than (or equal to) the low reference voltage and the full–scale pressure voltage must be less than (or equal to) the high reference voltage (see Figure 1). Otherwise, voltages above the high reference will be digitally converted as 255 decimal (for 8–bit A/D), and voltages below the low reference will be converted as 0. This creates a nonlinearity in the analog–to–digital conversion.

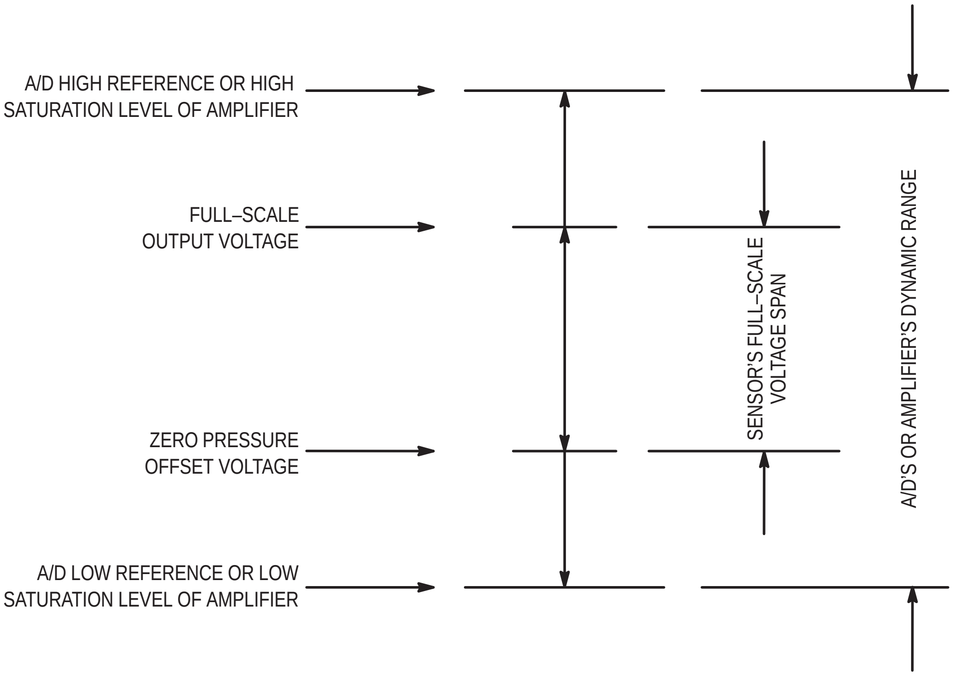


Figure 1. Positioning the Sensor's Full–Scale Span within the A/D's or Amplifier's Dynamic Range

A similar requirement that warrants the use of a dc level shift is the prevention of the pressure sensor's voltage from extending into the saturation regions of the operational amplifiers. This also would cause a nonlinearity in the sensor output measurements. For example, if an op–amp powered with a single–ended 5 V supply saturates near the low rail of the supply at 0.2 V, a positive dc level shift may be required to position the zero pressure offset voltage at or above 0.2 V. Likewise, if the same op–amp saturates near the high rail of the supply at 4.8 V, a negative dc level shift may be required to position the full–scale pressure voltage at or below 4.8 V. It should be obvious that if the gain of the amplifiers is too large, the span may be too large to be positioned within the 4.6 V window (regardless of ability to level shift dc offset). In such a case, the gain must be decreased to reduce the span.

THE TWO OP–AMP GAIN STAGE TRANSFER FUNCTION

The transfer function of the two op–amp signal–conditioning stage, shown in Figure 2, can be determined using nodal analysis at nodes 1 and 2. The analysis can be simplified by calculating the transfer function for each of the signals with the other two signals grounded (set to zero), and then employing superposition to realize the overall transfer function. As shown in Figure 2, V_{IN2} and V_{IN1} are the differential amplifier input signals (with $V_{IN2} > V_{IN1}$), and V_{REF} is the positive dc level adjust point. For a sensor with a small zero pressure offset and operational amplifiers powered from a single–ended supply, it may be necessary to add a positive dc level shift to keep the operational amplifiers from saturating near zero volts.

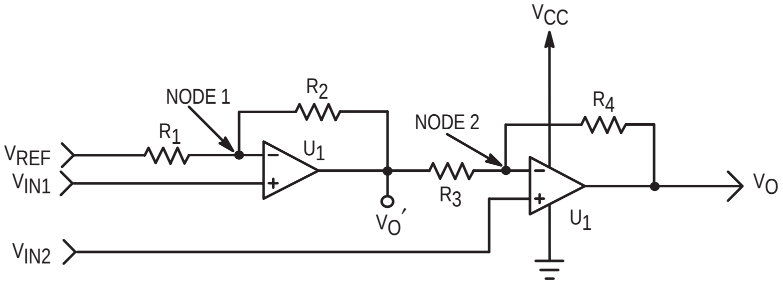


Figure 2. The Two Operational–Amplifier Gain Stage

First, the transfer function for V_{IN1} is determined by grounding V_{REF} and V_{IN2} at node 1:

$$\frac{V_{IN1}}{R_1} = \frac{V_O' - V_{IN1}}{R_2} \qquad (1)$$

and at node 2:

$$\frac{V_O'}{R_3} = -\frac{V_O}{R_4} \qquad (2)$$

By solving Equations (1) and (2) for V_O' and equating the results, Equation (3) is established:

$$\left(\frac{R_2}{R_1} + 1\right) V_{IN1} = -\frac{R_3}{R_4} V_O \qquad (3)$$

Solving for V_O yields

$$V_{O1} = -\frac{R_4}{R_3}\left(\frac{R_2}{R_1} + 1\right) V_{IN1} \qquad (4)$$

where V_{O1} represents the part of V_O that V_{IN1} contributes.

To determine the transfer function for V_{IN2}, V_{IN1} and V_{REF} are grounded, and a similar analysis is used, yielding

$$V_{O2} = \left(\frac{R_4}{R_3} + 1\right) V_{IN2} \qquad (5)$$

where V_{O2} represents the part of V_O that V_{IN2} contributes.

Finally, to calculate the transfer function between V_O and V_{REF}, V_{IN1} and V_{IN2} are grounded to obtain the following transfer function:

$$V_{OREF} = \frac{R_4R_2}{R_3R_1} V_{REF} \qquad (6)$$

where V_{OREF} represents the part of V_O that V_{REF} contributes.

Using superposition for the contributions of V_{IN1}, V_{IN2}, and V_{REF} gives the overall transfer function for the signal–conditioning stage.

$$V_O = V_{O1} + V_{O2} + V_{OREF}$$

$$V_O = -\frac{R_4}{R_3}\left(\frac{R_2}{R_1} + 1\right) V_{IN1} + \left(\frac{R_4}{R_3} + 1\right) V_{IN2} + \frac{R_4R_2}{R_3R_1} V_{REF} \qquad (7)$$

Equation (7) is the general transfer function for the signal–conditioning stage. However, the general form is not only cumbersome, but also if no care is taken to match certain resistance ratios, poor common mode rejection results. A simplified form of this equation that provides good common mode rejection is shown in the next section.

APPLICATION TO PRESSURE SENSOR CIRCUITS

The previous section showed the derivation of the general transfer function for the two op–amp signal–conditioning circuit. The simplified form of this transfer function, as applied to a pressure sensor application, is derived in this section.

For pressure sensors, V_{IN1} and V_{IN2} are referred to as S^- and S^+, respectively. The simplification is obtained by setting

$$\frac{R_4}{R_3} = \frac{R_1}{R_2}$$

Through this simplification, Equation (7) simplifies to

$$V_O = \left(\frac{R_4}{R_3} + 1\right)(S^+ - S^-) + V_{REF} \qquad (8)$$

By examining Equation (8), the differential gain of the signal– conditioning stage is:

$$G = \frac{R_4}{R_3} + 1 \qquad (9)$$

Also, since the differential voltage between S^+ and S^- is the pressure sensor's actual differential output voltage (V_{SENSOR}), the following equation is obtained for V_O:

$$V_O = \left(\frac{R_4}{R_3} + 1\right) V_{SENSOR} + V_{REF} \qquad (10)$$

Finally, the term V_{REF} is the positive offset voltage added to the amplified sensor output voltage. V_{REF} can only be positive when using a positive single–ended supply. This offset (dc level shift) allows the user to adjust the absolute range that the sensor voltage spans. For example, if the gain established by R_4 and R_3 creates a span of four volts and this signal swing is superimposed upon a dc level shift (offset) of 0.5 volts, then a signal range from 0.5 V to 4.5 V results.

V_{REF} is typically adjusted by a resistor divider as shown in Figure 3. A few design constraints are required when designing the resistor divider to set the voltage at V_{REF}.

- To establish a stable positive dc level shift (V_{REF}), V_{CC} should be regulated; otherwise, V_{REF} will vary as V_{CC} varies.
- When "looking" into the resistor divider from R_1, the effective resistance of the parallel combination of the resistors, R_{REF1} and R_{REF2}, should be at least an order of magnitude smaller than R_1's resistance. If the resistance of the parallel combination is not small in comparison to R_1, R_1's value will be significantly affected by the parallel combination's resistance. This effect on R_1 will consequently affect the amplifier's gain and reduce the common mode rejection.

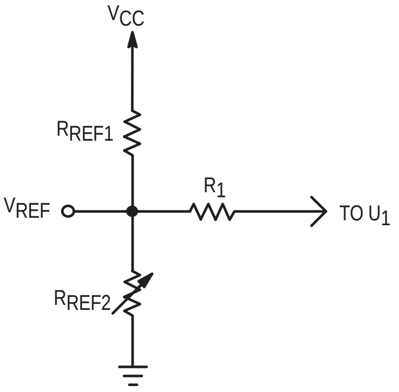


Figure 3. A Resistor Divider to Create V_{REF}

THE TWO OP–AMP GAIN STAGE WITH VARIABLE GAIN

Varying the gain of the two op–amp stage is desirable for fine–tuning the sensor's signal–conditioned output span. However, to adjust the gain in the two op–amp gain circuit in Figure 2 and to simultaneously preserve the common mode rejection, two resistors must be adjusted. To adjust the gain, it is more desirable to change one resistor. By adding an additional feedback resistor, R_G, the gain can be adjusted with this one resistor while preserving the common mode rejection. Figure 4 shows the two op–amp gain stage with the added resistor, R_G.

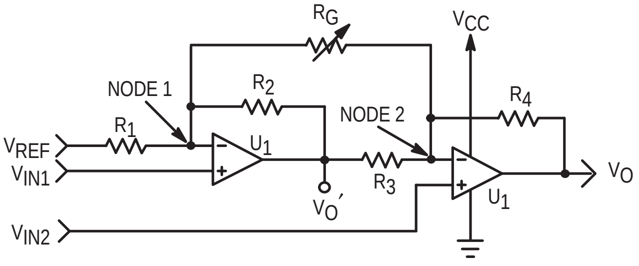


Figure 4. Two Operational–Amplifier Gain Stage with Variable Gain

As with the two op–amp gain stage, nodal analysis and superposition are used to derive the general transfer function for the variable gain stage.

$$V_O = \left(\frac{R_4}{R_3} + \frac{R_4}{R_G} + \frac{R_2R_4}{R_3R_G} + 1\right)V_{IN2} - \left(\frac{R_4}{R_3} + \frac{R_4}{R_G} + \frac{R_2R_4}{R_3R_G} + \frac{R_2R_4}{R_1R_3}\right)V_{IN1} + \left(\frac{R_2R_4}{R_1R_3}\right)V_{REF} \qquad (11)$$

This general transfer function also is quite cumbersome and is susceptible to producing poor common mode rejection without additional constraints on the resistor values. To obtain good common mode rejection, use a similar simplification as before; that is, set

$$R_1 = R_4$$

and

$$R_2 = R_3$$

Defining the voltage differential between V_{IN2} and V_{IN1} as V_{SENSOR}, the simplified transfer function is

$$V_O = \left(\frac{R_4}{R_3} + \frac{2R_4}{R_G} + 1\right)(V_{SENSOR}) + V_{REF} \qquad (12)$$

Thus, the gain is

$$G = \frac{R_4}{R_3} + \frac{2R_4}{R_G} + 1 \qquad (13)$$

and V_{REF} is the positive dc level shift (offset).

Use the following guidelines when determining the value for R_G:

- By examining the gain equation, R_G's resistance should be comparable to R_4's resistance. This will allow fine tuning of the gain established by R_4 and R_3. If R_G is too large (e.g., R_G approaches ∞), it will have a negligible effect on the gain. If R_G is too small (e.g., R_G approaches zero), the R_G term will dominate the gain expression, thus prohibiting fine adjustment of the gain established via the ratio of R_4 and R_3.
- Use a potentiometer for R_G that has a resistance range on the order of R_4 (perhaps with a maximum resistance equal to the value of R_4). If a fixed resistor is preferable to a potentiometer, use the potentiometer to adjust the gain, measure the potentiometer's resistance, and replace the potentiometer with the closest 1% resistor value.
- To maintain good common mode rejection while varying the gain, R_G should be the only resistor that is varied. R_G equally modifies both of the resistor ratios which need to be well–matched for good common mode rejection, thus preserving the common mode rejection.

THE TWO OP–AMP GAIN STAGE WITH VARIABLE GAIN AND NEGATIVE DC LEVEL SHIFT

The last two op–amp circuits both incorporate positive dc level shift capability. Recall that a positive dc level shift is required to keep the operational amplifiers from saturating near the low rail of the supply or to keep the zero pressure offset above (or equal to) the low reference voltage of an A/D. This two op–amp stage incorporates an additional resistor, R_{OFF}, to provide a negative dc level shift. A negative dc level shift is useful when the zero pressure offset voltage of the sensor is too high. In this case, the user may be required to level shift the zero pressure offset voltage down (toward zero volts). Now, for a specified amount of gain, the full–scale pressure output voltage does not saturate the amplifier at the high rail of the voltage supply, nor is it greater than the A/D's high reference voltage. Figure 5 shows the schematic for this amplifier circuit.

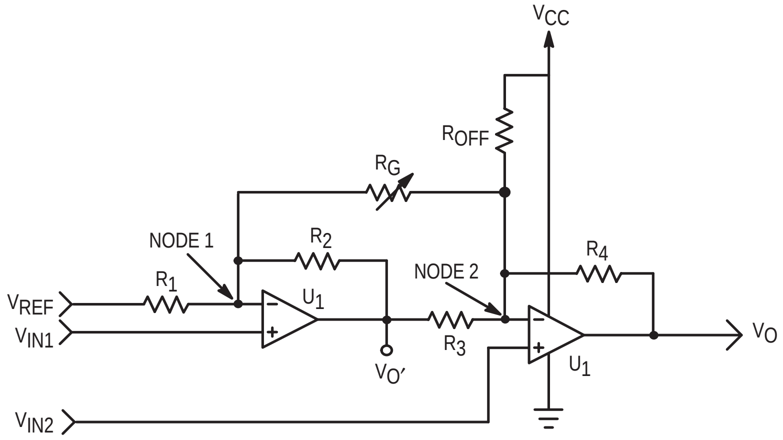


Figure 5. Two Op–Amp Signal–Conditioning Stage with Variable Gain and Negative Dc Level Shift Adjust

To derive the general transfer function, nodal analysis and superposition are used:

$$V_O = \left(\frac{R_4}{R_3} + \frac{R_4}{R_G} + \frac{R_2R_4}{R_3R_G} + 1\right)V_{IN2} - \left(\frac{R_4}{R_3} + \frac{R_4}{R_G} + \frac{R_2R_4}{R_1R_3} + \frac{R_2R_4}{R_3R_G}\right)V_{IN1} + \left(\frac{R_2R_4}{R_1R_3}\right)V_{REF} + \frac{R_4}{R_{OFF}}(V_{IN2} - V_{CC}) \quad (14)$$

As before, defining the sensor's differential output as V_{SENSOR}, defining V_{IN2} as S^+ for pressure sensor applications, and using the simplification that

$$R_1 = R_4$$

and

$$R_2 = R_3$$

obtains the following simplified transfer function:

$$V_O = \left(\frac{R_4}{R_3} + \frac{2R_4}{R_G} + 1\right)(V_{SENSOR}) + V_{REF} + \frac{R_4}{R_{OFF}}(S^+ - V_{CC}) \quad (15)$$

The gain is

$$G = \frac{R_4}{R_3} + \frac{2R_4}{R_G} + 1 \quad (16)$$

To adjust the gain, refer to the guidelines presented in the section on Two Op–Amp Gain Stage with Variable Gain**.**

V_{REF} is the positive dc level shift, and the negative dc level shift is:

$$V_{-shift} = \frac{R_4}{R_{OFF}}(S^+ - V_{CC}) \quad (17)$$

The following guidelines will help design the circuitry for the negative dc voltage level shift:

- To establish a stable negative dc level shift, V_{CC} should be regulated; otherwise, the amount of negative level shift will vary as V_{CC} varies.
- R_{OFF} should be the only resistor varied to adjust the negative level shift. Varying R_4 will change the gain of the two op–amp circuit and reduce the common mode rejection.
- To determine the value of R_{OFF}:
  1. Determine the amount of negative dc level shifting required (defined here as V_{-shift}).
  2. R_4 already should have been determined to set the gain for the desired signal–conditioned sensor output.
  3. Although V_{-shift} is dependent on S^+, S^+ changes only slightly over the entire pressure range. With Motorola's MPX10 powered at a 5 V supply, S^+ will have a value of approximately 2.51 V at zero pressure and will increase as high as 2.53 V at full–scale pressure. This error over the full–scale pressure span of the device is negligible when considering that many applications use an 8–bit A/D converter to segment the pressure range. Using an 8–bit A/D, the 20 mV (0.02 V) error corresponds to only 1 bit of error over the entire pressure range (1 bit / 255 bits x 100% = 0.4% error).
  4. R_{OFF} is then calculated by the following equation:

$$R_{OFF} = \frac{S^+ - V_{CC}}{V_{-shift}} R_4 \quad (18)$$

An alternative to using this equation is to use a potentiometer for R_{OFF} that has a resistance range on the order of R_4 (perhaps 1 to 5 times the value of R_4). Use the potentiometer to fine tune the negative dc level shift, while monitoring the zero pressure offset output voltage, V_O. As before, if a fixed resistor is preferable, then measure the potentiometer's resistance and replace the potentiometer with the closest 1% resistor value.

Important note: The common mode rejection of this amplifier topology will be low and perhaps unacceptable in some applications. (A SPICE model of this amplifier topology showed the common mode rejection to be 28 dB.) However, this circuit is presented as a solution for applications where only two operational amplifiers are available and the common mode rejection is not critical when considering the required system performance. Adding a third op–amp to the circuit for the negative dc level shifting capability (as shown in the next section) is a solution that provides good common mode rejection, but at the expense of adding an additional op–amp.

THE THREE OP–AMP GAIN STAGE FOR NEGATIVE DC LEVEL SHIFTING

This circuit adds a third op–amp to the output of the two op–amp gain block (see Figure 6). This op–amp has a dual function in the overall amplifier circuit:

- Its non–inverting configuration provides gain via the ratio of R_6 and R_5.
- It has negative dc voltage level shifting capability typically created by a resistor divider at $V_{–shift}$, as discussed in the section on Application to Pressure Sensor Circuits. Although this configuration requires a third op–amp for the negative dc level shift, it has no intrinsic error nor low common mode rejection associated with the negative level shift (as does the previous two op–amp stage). Depending on the application's accuracy requirement, this may be a more desirable configuration for providing the negative dc level shift.

First, use the same simplifications as before; that is, set

$$R_1 = R_4$$

and

$$R_2 = R_3$$

Defining the voltage differential between V_{IN2} and V_{IN1} as V_{SENSOR}, the simplified transfer function is

$$V_O = \left[1 + \frac{R_6}{R_5}\right]\left[\left(\frac{R_4}{R_3} + \frac{2R_4}{R_G} + 1\right)\left(V_{SENSOR}\right) + V_{REF}\right] - \frac{R_6}{R_5}V_{–shift} \qquad (20)$$

The gain is

$$G = \left[1 + \frac{R_6}{R_5}\right]\left[\frac{R_4}{R_3} + \frac{2R_4}{R_G} + 1\right] \qquad (21)$$

V_{REF} is the positive dc level shift (offset), and $V_{–shift}$ is the negative dc level shift.

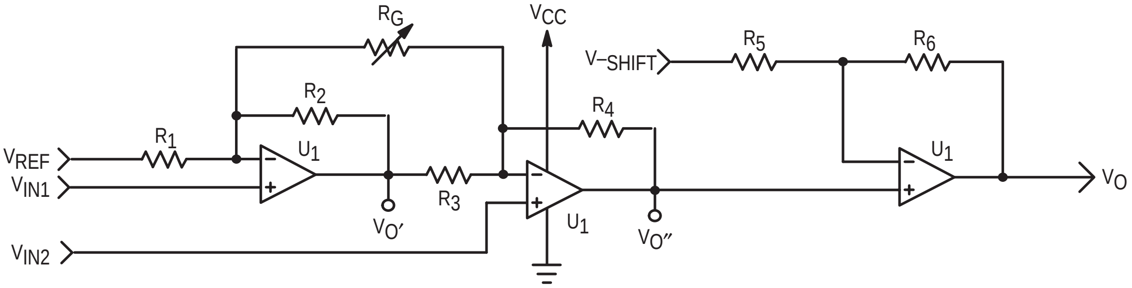


Figure 6. Three Op–Amp Gain Stage with Variable Gain and Negative Dc Level Shift

The transfer function for this stage will be similar to the chosen two op–amp gain stage configuration (either the fixed gain with positive dc level shift circuit or the variable gain with positive dc level shift circuit) with additional terms for the negative level shift and gain. As an example, the variable–gain two op–amp gain circuit is used here. All of the design considerations and explanations for the variable gain two op–amp circuit apply.

The transfer function may be derived with nodal analysis and superposition.

$$V_O = \left[1 + \frac{R_6}{R_5}\right]\left[\left(\frac{R_4}{R_3} + \frac{R_4}{R_G} + \frac{R_2R_4}{R_3R_G} + 1\right)V_{IN2} - \left(\frac{R_4}{R_3} + \frac{R_4}{R_G} + \frac{R_2R_4}{R_3R_G} + \frac{R_2R_4}{R_1R_3}\right)V_{IN1} + \left(\frac{R_2R_4}{R_1R_3}\right)V_{REF}\right] - \frac{R_6}{R_5}V_{–shift} \qquad (19)$$

The preceding simplifications have been performed in the previous sections, but by examining Equation 20, notice that the third op–amp's gain term also amplifies the positive and negative dc voltage level shifts, V_{REF} and $V_{–shift}$. If R_6 and R_5 are chosen to make an arbitrary contribution to the overall system gain, designing an appropriate amount of positive and negative dc level shift can be difficult. To simplify the transfer function, set $R_5 = R_6$, and the following equation for V_O results:

$$V_O = 2\left[\left(\frac{R_4}{R_3} + \frac{2R_4}{R_G} + 1\right)\left(V_{SENSOR}\right) + V_{REF}\right] - V_{–shift} \qquad (22)$$

Now the third op–amp's contribution to the overall system gain is a factor of two. When designing the overall system gain and the positive dc level shift, use the following guidelines:

- Since the third op–amp contributes a gain of two to the overall system, design the gain that the two op–amp circuit contributes to the system to be one–half the desired system gain. The gain term for the two op–amp circuit is:

$$G = \frac{R_4}{R_3} + \frac{2R_4}{R_G} + 1$$

which is the same as presented in Equation 16.

- Similarly, since the third op–amp also amplifies V_{REF} by two (refer to Equation 22), the resistor divider that creates V_{REF} should be designed to provide one–half the desired positive dc voltage level shift needed for the final output. When designing the voltage divider for V_{REF}, use the same design constraints as were given in the section on Application to Pressure Sensor Circuits.

With the above simplification of $R_5 = R_6$, the negative dc level shift, $V_{–shift}$, which is also created by a voltage divider, is now amplified by a factor of unity. When designing the voltage divider, use the same design constraints as were presented in the section on Application to Pressure Sensor Circuits.

CONCLUSION

The amplifier circuits discussed in this paper apply to pressure sensor applications, but the amplifier circuits can be interfaced to low–level, differential–voltage output sensors, in general. All of the circuits exhibit the desired instrumentation amplifier characteristics of high input impedance, low output impedance, high gain capability, and differential to single–ended conversion of the sensor signal. Each amplifier circuit provides positive dc level shift capability, while the last two circuit topologies presented are also able to provide a negative dc voltage level shift. This enables the user to position the sensor’s dynamic output within a specified range (e.g., within the high and low references of an A/D converter). Also detailed is a method of using an additional feedback resistor to adjust easily the differential voltage gain, while not sacrificing common mode rejection. Combining the appropriate sensor device and amplifier interface circuit provides sensor users with a versatile system solution for applications in which the ideal fully single–conditioned sensor does not exist or in which such signal flexibility is warranted.

MOTOROLA
SEMICONDUCTOR APPLICATION NOTE

AN1536

Digital Boat Speedometers

Prepared by: Bill Lucas
Industrial Technology Center

INTRODUCTION

This application note describes a Digital Boat Speedometer concept which uses a monolithic, temperature compensated silicon pressure sensor, analog signal–conditioning circuitry, microcontroller hardware/software and a liquid crystal display. This sensing system converts water head pressure to boat speed. This speedometer design using a 30 psi pressure sensor (Motorola P/N: MPX2200GP) yields a speed range of 5 mph to 45 mph. Calibration of the system is performed using data programmed into the microcontroller's internal memory.

A key advantage in all Motorola pressure sensors is the patented X–ducer™, a single piezoresistive implant that replaces the traditional Wheatstone bridge configuration used by competitors. In addition to the X–ducer, Motorola integrates on–chip all necessary temperature compensation, eliminating the need for separate substrates/hybrids. This state–of–the–art technology yields superior performance and reliability. Motorola pressure sensors are offered in several different port configurations to allow measurement of absolute, differential and gauge pressure. Motorola offers three pressure sensor types: uncompensated, temperature compensated and calibrated or fully signal conditioned.

WATER PRESSURE TO BOAT SPEED CONVERSION

A typical analog boat speedometer employs a pitot tube, a calibrated pressure gauge/speedometer and a hose to connect the two. The pitot tube, located at the boat transom, provides the pressure signal corresponding to boat speed. This pressure signal is transmitted to the gauge via the hose. Boat speed is related to the water pressure at the pitot tube as described by the following equation:

$$P \propto e * (V^2/2g)$$

where:

V = speed
P = pressure at pitot tube
e = specific weight of media
g = gravitational acceleration

For example, to calculate P in lb/in^2 for an ocean application use:

V = speed in mph
e = 63.99 lbs/ft^3 at 60°F, seawater
(e will be smaller for fresh water)
g = 32 ft/sec^2
15 mph = 22 ft/sec
1 ft^2 = 144 in^2

$$P = (63.99[\text{lb}/\text{ft}^3] \;/\; 144[\text{in}^2/\text{ft}^2]) \; (V^2[\text{mph}]^2 \; (22/15)^2[(\text{ft}/\text{sec})/\text{mph}]^2 \;/\; 2\;(32.2)[\text{ft}/\text{sec}^2])$$

$$P[\text{PSI}] = \left(\frac{V}{8.208}\right)^2$$

For example, if the boat is cruising at 30 mph, the impact pressure on the pitot tube is:

$$P = (30/8.208)^2 = 13.36 \text{ psi.}$$

DIGITAL BOAT SPEEDOMETER DESCRIPTION AND OPERATION

The MPX2200GP senses the impact water pressure against the pitot tube and outputs a proportional differential voltage signal. This differential voltage signal is then fed (via an analog switch and gain circuitry) to a single slope analog–to–digital converter (A/D) which is external to the microcontroller. The A/D circuit can complete two separate conversions as well as a reference conversion simultaneously. This A/D utilizes the microcontroller's internal timers as counters and software to properly manipulate the data. The analog switch provides a way to flip the sensor outputs after an A/D conversion step, which is necessary to null out the offset effects of the op–amps. This is accomplished by performing an analog conversion, reversing the sensor's differential output signal, performing another analog conversion, summing the two readings, then dividing this sum by two. Any op–amp offset present will be the same polarity regardless of the sensor output polarity, thus the op–amp offset can be mathematically nulled out. The digital representation of any analog signal is ratiometric to the reference voltages of the A/D converter. Also, the sensor's output is ratiometric to its excitation voltage. Therefore, if both the sensor and A/D reference voltages are connected to the same unregulated supply, the variations in sensor output will be nullified, and system accuracy will be maintained (i.e., systems in which both the A/D converter's digital value — due to variations in the A/D's reference voltages — and sensor's output voltage are ratiometric to the supply voltage so that a voltage regulator is not necessary).

Figure 1 shows the pressure sensor (XDCR) connected to the analog switches of the 74HC4053 which feeds the differential signal to the first stage of op–amps. An A/D conversion is performed on the two op–amp output signals, V_{out1} and V_{out2}. The difference ($V_{out1} - V_{out2}$) is computed and stored in microcontroller memory. The analog switch commutates (op–amp connections switch from Y_0 and Z_0 to Y_1 and Z_1), reversing the sensor output signals to the two op–amps, and another conversion is performed. This value is then also stored in the microcontroller memory. To summarize, via software, the following computation takes place:

Step 1: $V_{first} = V_{out1} - V_{out2}$

Step 2: $V_{second} = V_{out2} - V_{out1}$

Step 3: $V_{result} = (V_{first} + V_{second}) / 2$

Again, because any op–amp offset will remain the same polarity regardless of sensor output polarity, this routine will effectively cancel any amplifier offset. Any offset the sensor may introduce is compensated for by software routines that are invoked when the initial system calibration is done.

The single slope A/D provides 11 or more unsigned bits of resolution. This capability provides a water pressure resolution to at least 0.05 psi. This translates to a boat speed resolution of 0.1 mph over the entire speed range.

Figure 2 describes the pressure versus voltage transfer function of the first op–amp stage.

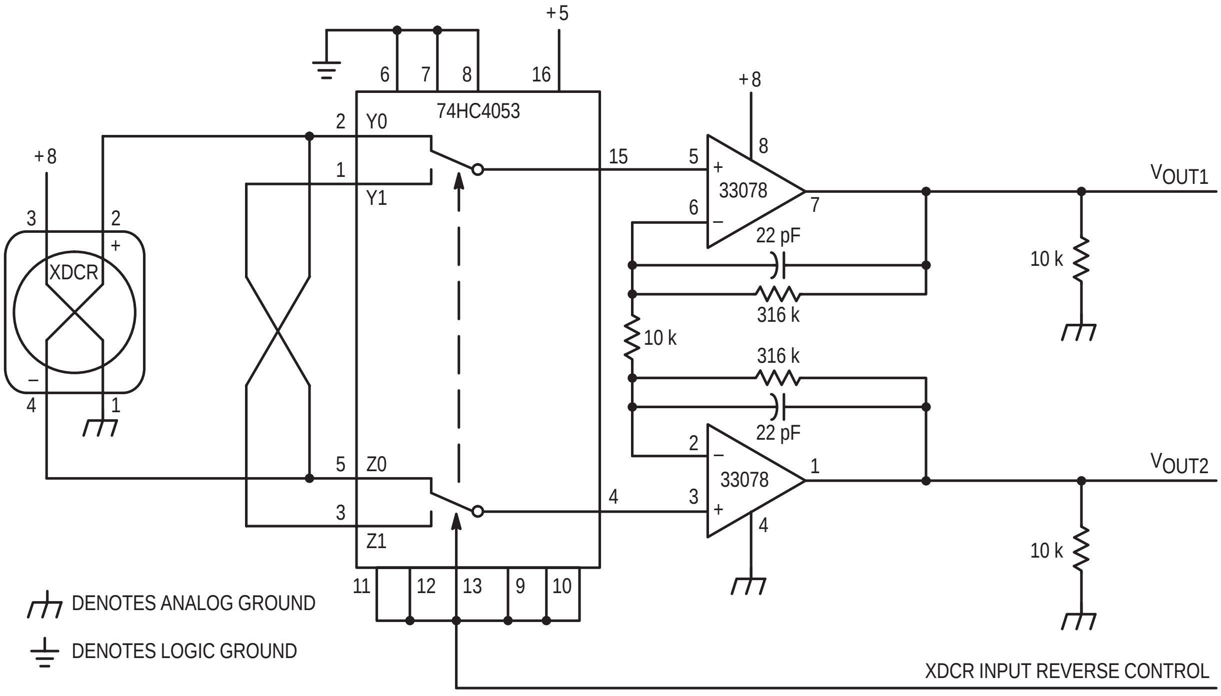


Figure 1. X–ducer, Instrument Amplifier and Analog Switch

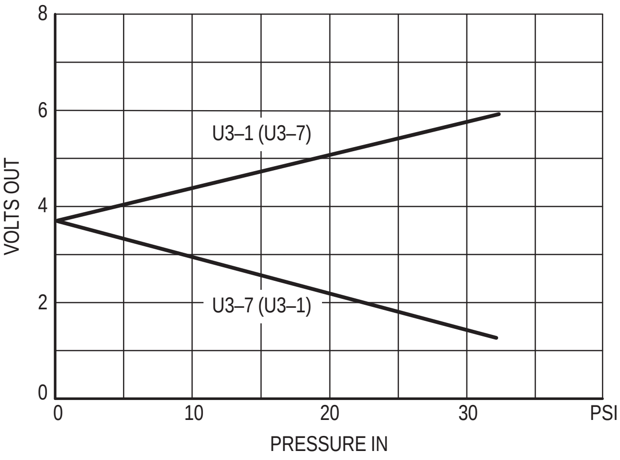


Figure 2. Instrument Amplifier Transfer Function

Figure 3 details the analog circuitry, microcontroller's timer capture registers and I/O port which comprise the single slope A/D. The microcontroller's 16–bit free running counter is also employed, but not shown in the figure.

Comparators U6A, U6B and U6D of the LM139A are used to provide the A/D function. Constant current source, U7, resistors R13 and R14 and diode D2 provide a linear voltage ramp to the inverting inputs of U6, with about 470 microamps charge current to capacitor C8, with transistor Q1 in the off state. C8 will charge to 5 volts in about 5 milliseconds at the given current. Q1 is turned on to provide a discharge path for C8 when required. The circuit is designed such that when the voltage to the inverting inputs of the comparators exceeds the voltage to the noninverting comparators, each comparator output will trip from a logic 1 to a logic 0.

One A/D conversion consists of the following steps: (1) setting the pressure sensor output polarity (via software and the analog switches of U4) to the amplifier inputs of the MC33078 (U3), (2) reading the value of the free running counter, (3) turning off Q1, and (4) charging C8 and waiting for the three (U6) comparator outputs to change from 1 to 0. When the comparator outputs change state, the microcontroller free running counter value is clocked into the microcontroller's input capture register. Contained in this register then is the number of counts required to charge C8 to a value large enough to trip the comparators. Via software, the voltage signal from U3 (corresponding to the applied pressure signal) can be compared to the "reference."

The boat speed display for this design employs an MC145453 LCD driver and four–digit liquid crystal display, of which three digits and a decimal point are used. Figure 4 shows the connections between the display driver and the display. The display driver is connected to the microprocessor's serial peripheral interface (SPI). The software necessary to initialize, format and drive the LCD is included in the software listing contained in this article.

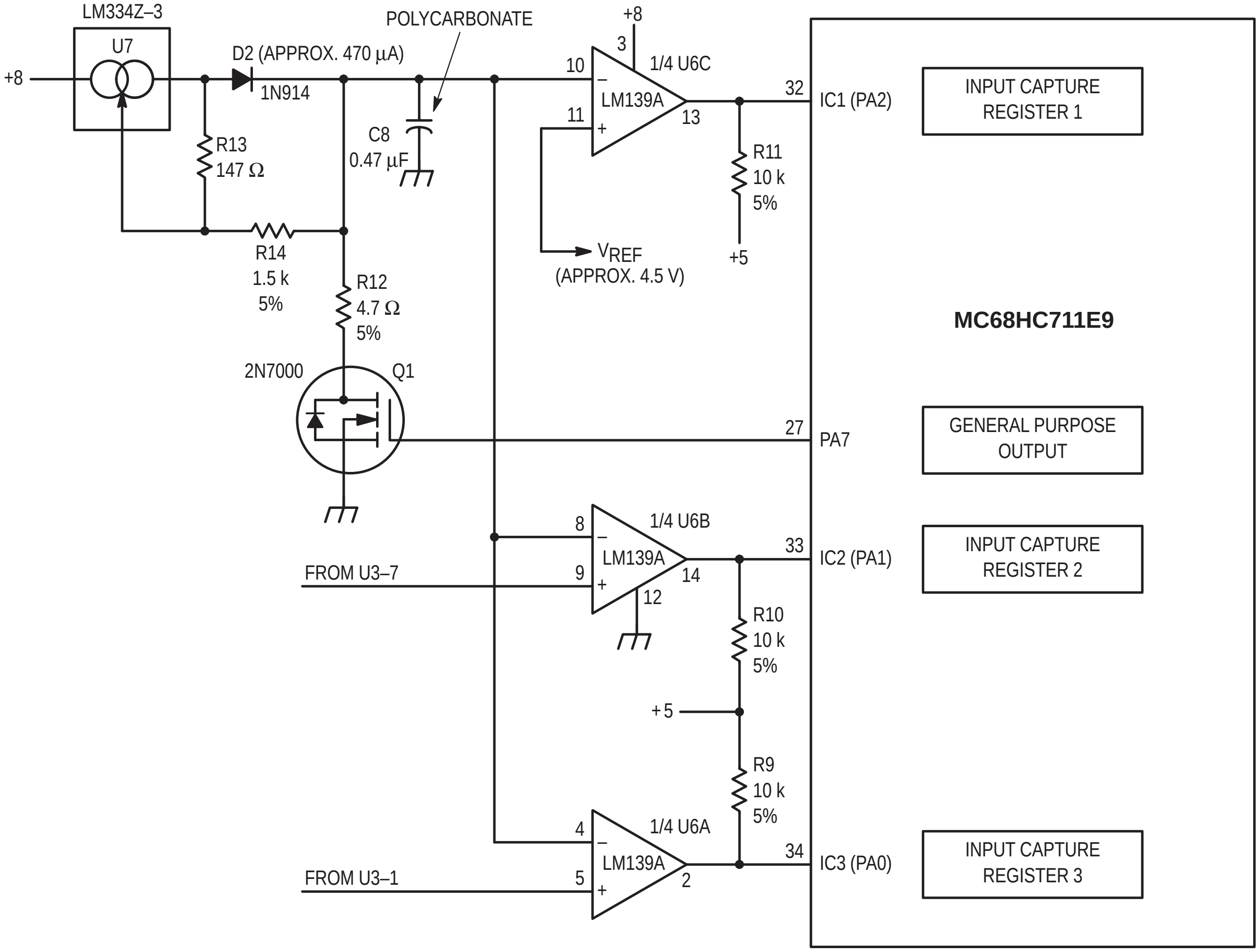


Figure 3. Analog–to–Digital Converter Front End with Microcontroller

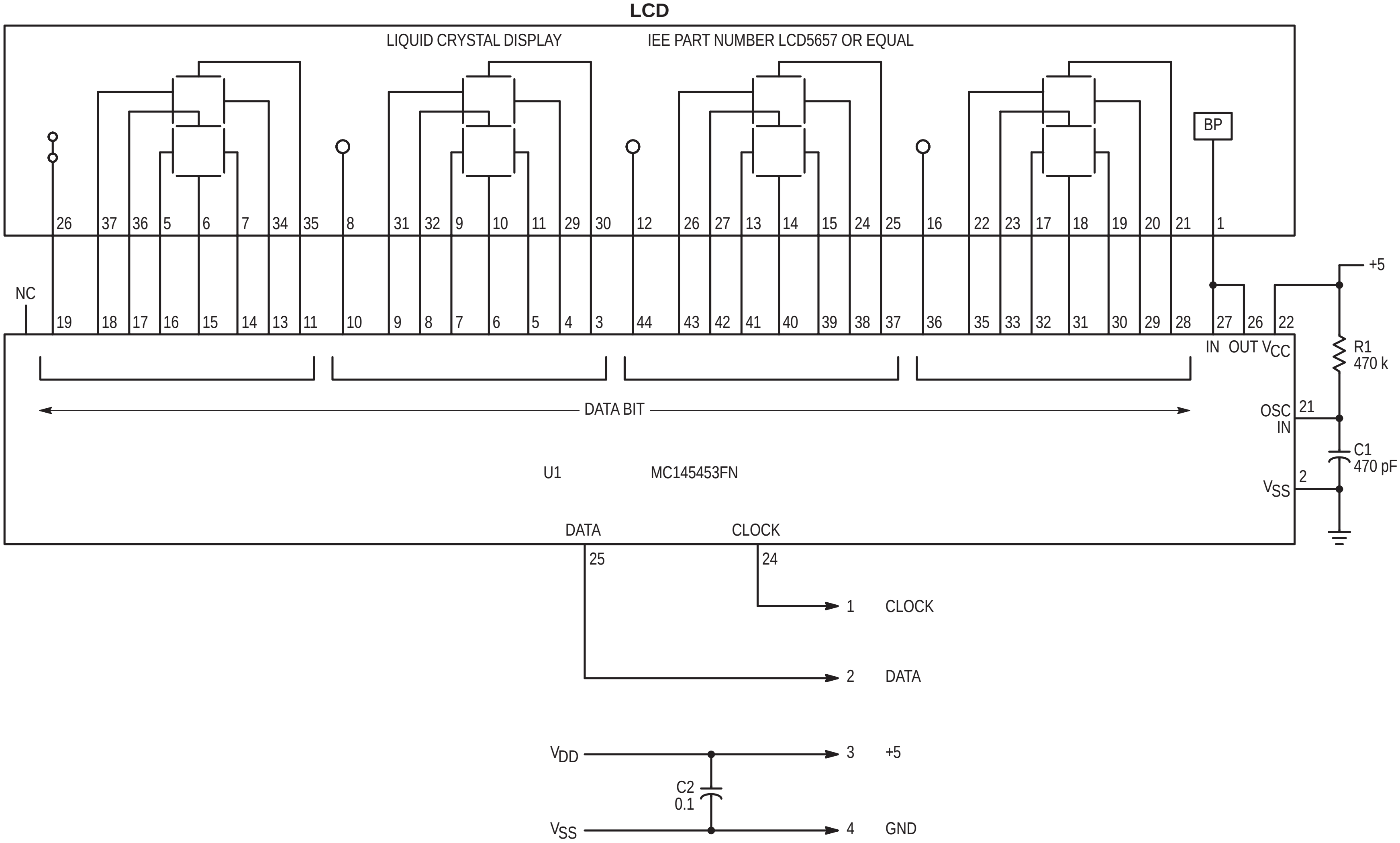
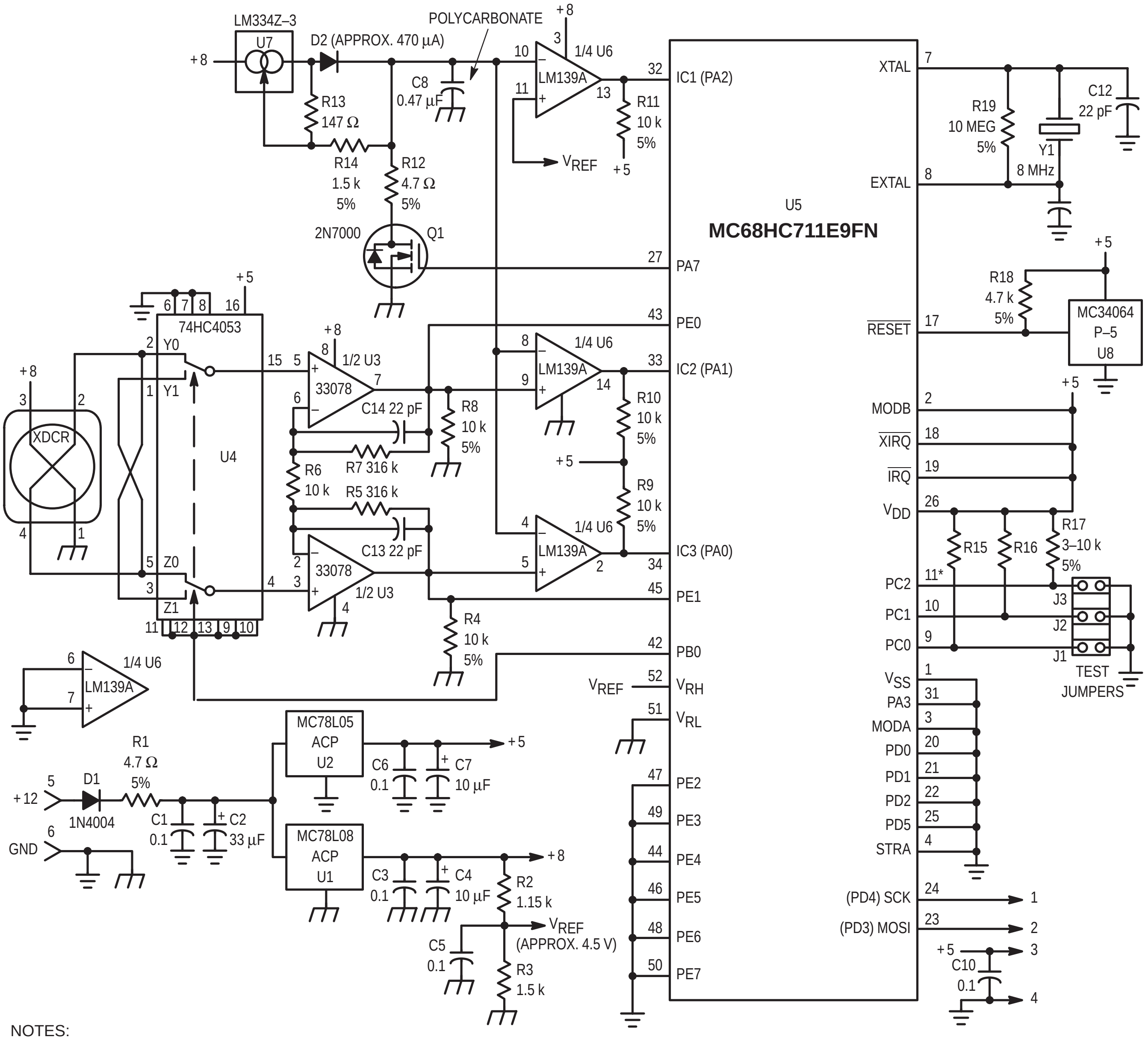


Figure 4. Boat Speedometer Display Board

Table 1 lists the jumper wire selections needed for calibration and operational modes. The jumper wire junction block (J1, J2, J3) is connected to the microprocessor, pins PC0, PC1 and PC2, respectively as shown in Figure 5.

Table 1.

J1	J2	J3	
OUT	OUT	OUT	Display speed in mph
OUT	OUT	IN	100 psi X–ducer installed
OUT	IN	OUT	30 psi X–ducer installed
OUT	IN	IN	15 psi X–ducer installed
IN	OUT	OUT	Full scale calibrate
IN	OUT	IN	Zero calibrate
IN	IN	OUT	Display pressure in psi
IN	IN	IN	Display speed in mph



NOTES:
UNLESS OTHERWISE NOTED, ALL RESISTORS 1% METAL FILM.

* U5 PINS 11–16 (PC2–PC7) ARE CONNECTED HERE FOR TERMINATION PURPOSES.

Figure 5. Boat Speedometer Processor Board

The calibration of this system is as follows. Refer to Table 1.

CAUTION: While installing or changing the proper jumpers described by each step, power must be off. Reapply power to read the display after jumpers have been installed in their proper location for each step. In each step there is a few seconds' delay after switching the power on and before an output is displayed. Steps 1 through 3 must be performed prior to system being operational.

Calibration

1. The pressure range of the system must be established. The present software installed in this design supports 15, 30 and 100 psi sensors. Using an MPX2200D sensor (30 psi) for example, only jumper J2 should be installed. After power is applied, the LCD should read "30." Power off the system prior to proceeding to step 2.
2. The total system offset, due to the sensor and A/D, must be established for the software routine to effectively calibrate. With power off, jumpers J1 and J3 should be installed. Reapply power, and the LCD should respond with "000." The offset value measured in this step is thus stored for use in circuit operation. Power off the system prior to proceeding to step 3.
3. In this step, the system full scale span is calibrated. With power off, install jumper J1 only. Now apply the full rated pressure (30 psi for MPX2200GP) to the sensor, power on and ensure the display reads "FFF." The full scale span measured in this step is thus stored for use in circuit operation. Power off the system prior to step 4.

Operation

4. Ensure power is off, and install jumpers J1, J2 and J3. The system is now ready for operation. Simply apply power and pressure to the sensor, and the LCD will display the proportional speed above 5 mph, up to the limits of the sensor.

REFERENCES

Burry, Michael (1989). "Calibration–Free Pressure Sensor System," Motorola Application Note AN1097.

```
NOTE. THIS  WAS COMPILED WITH A COMPILER COURTESY OF:
                INTROL CORP.
                9220 W. HOWARD AVE.
                MILWAUKEE, WI. 53228
                PHONE (414) 327–7734.
  SOME SOURCE CODE CHANGES MAY BE NECESSARY FOR COMPILATION WITH OTHER COMPILERS.
  THE HEADER FILE io6811.h HAS I/O PORT DEFINITIONS FOR THE I/O PORTS PARTICULAR TO THE MC68HC711E9. A TYPICAL ENTRY FOR
PORT A WILL FOLLOW. THE FIRST LINE ESTABLISHES A BASE ADDRESS BY WHICH ALL I/O FACILITIES AND COUNTERS ARE BIASED.
  REFER TO THE  MC68HC711E9 DATA FOR MORE INFORMATION RELATIVE TO I/O AND TIMER ADDRESSES.

  #define    IOBIAS 0x1000  /* BASE ADDRESS OF THE I/O FOR THE 68HC11 */
  #define PORTA (* (char *) (IOBIAS + 0))   /* PORT A */

  THE STARTUP ROUTINE NEED ONLY LOAD THE STACK TO THE TOP OF RAM, ZERO
  THE MICROCONTROLLER’S RAM AND PERFORM A BSR MAIN (BRANCH TO SUBROUTINE “MAIN”).
  THIS SOURCE CODE, HEADER FILE, COMPILED OBJECT CODE, AND LISTING FILES ARE AVAILABLE ON:
                                        THE MOTOROLA FREEWARE LINE
                                        AUSTIN, TX.
                                        (512) 891–3733.

Bill Lucas 6/21/90
THE CODE STARTS HERE  */

#include <io6811.h>  /*  I/O port definitions */

/* define locations in the eeprom to store calibration information */
#define EEPROM (char*)0xb600 /* used by calibration functions */
#define EEBASE 0xb600 /* start address of the eeprom */
#define ADZERO (* ( long int *)( EEBASE + 0 )) /* auto zero value */
#define HIATOD (* ( long int *)( EEBASE + 4 )) /* full scale measured input */
#define XDCRMAX (* ( char *)( EEBASE + 8 )) /* full scale input of the xdcr */
union bytes {
          unsigned long int l;
          char b[4];
            };  /* ADZERO.l for long word   ADZERO.b[0]; for byte */

const char lcdtab[] = { 95,  6,  59,  47, 102, 109, 125, 7, 127, 111,  0   };
/*   lcd pattern table   0   1    2    3   4    5    6   7   8    9  blank */

const int dectable[] = { 10000, 1000, 100, 10 };

char digit[5]; /* buffer to hold results from cvt_bin_dec function */

/* ################################################################### */

/* real time interrupt service routine  */

void real_time_interrupt (void) /* hits every 4.096 ms. */
   {
    TFLG2 = 0x40;  /* clear the interrupt flag */
   }

/* ################################################################### */

/* ################################################################### */

/*           write_eeprom(0xA5,EEPROM);   write A5h to first byte of EEPROM */
void write_eeprom(char data, char *address)
{
             PPROG = 0x16;             /* single–byte erase mode */
             *address = 0xff;     /* write anything */
             PPROG = 0x17;             /* turn on programming voltage */

             delay();
             PPROG = 0x0;        /* erase complete */

    /* now program the data */
    PPROG = 0x02;                 /* set eelat bit */
             *address = data;     /* write data */
             PPROG = 0x03;       /* set eelat and eepgm bits */
             delay();
             PPROG = 0;                /* read mode */
             /* programming complete */
}
/* ################################################################### */

long int convert(char polarity)
```

```
             {

unsigned int cntr;   /* free running timer system counter */
unsigned int r0;     /* difference between cntr and input capture 1 register */
unsigned int r1;     /* difference between cntr and input capture 2 register */
unsigned int r2;     /* difference between cntr and input capture 3 register */
unsigned long difference; /* the difference between the upper and lower
                     instrument amplifier outputs */
unsigned long int pfs; /* result defined as percent of full scale relative to
                          the reference voltage */

    if (polarity == 1)          /* set the hc4053 configuration */
        PORTB &= 0xfe;          /* polarity = 1 means + output of sensor */
         else  PORTB |= 0x1;    /* is connected to the upper opamp */

    delay();   /* this will allow the hc4053 to stabilize and the cap
                  to discharge from the previous conversion */
             TFLG1=0X07;                    /* clear the input capture flags */
                  cntr=TCNT;                    /* get the current count */
                   PORTA &= 0X7F;               /* turn the fet off */
                     while ((TFLG1 & 0X7) < 7); /* loop until all three input capture
                                                   flags are set */
              r0 = TIC1 – cntr;            /* reference voltage */
              r1 = TIC2 – cntr;            /* top side of the inst. amp */
              r2 = TIC3 – cntr;            /* lower side of the inst. amp */
              PORTA |= 0X80;              /* turn the fet on */
              if (polarity == 1)
                 difference = ( r1 + 1000 ) – r2;
                   else  difference = ( r2 + 1000 ) – r1;
                    pfs = (difference * 10000) / r0;
                      if (difference > 32767) /* this will cover up the case
                                                 where the a to d computes a
                                                 negative value */
                        pfs=0;
                                                  return ( pfs );
             }

atod()  /* computes the a/d value in terms of % full scale */
  {
unsigned long int x,y,z;
  x = convert(1);  /* normal */
   y = convert(0);  /* reversed */
    z = (x + y)>>1 ;  /* 2x difference / 2  */
     return(z);  /* z is percent of full scale */
  }

integrate() /* returns the a/d value in terms of % full scale and computes
               offset from calibration values */
{
unsigned long int j;
int i;
j=0;
for (i=0; i<20; ++i)
     j +=atod();
        j = (j/20) – ADZERO;  /* null out the xdcr zero input offset */
          return(j);
}

cala2d()   /* returns the average of 50 raw a/d conversions this is only
               used by the calibration functions */
{
unsigned long int j;
int i;
j=0;
for (i=0; i<50; ++i)
  { j +=atod(); }
    j=j/50;
    return(j);
}

/* ################################################################### */

cvt_bin_dec ( unsigned int arg )
{
char i;

  for ( i=0; i < 6; ++i )
```

```
    {
      digit[i] = 0;  /* put blanks in all digit positions */
    }

       for ( i=0; i < 4; ++i )
         {
             if ( arg  >= dectable [i] )
               {
                 digit[i] = arg /dectable[i];
                 arg = arg–(digit[i] * dectable[i]);
               }
          }
digit[i] = arg;
}

/* ################################################################### */

delay()
{
int i;
for (i=0; i<1000; ++i); /* delay about 15 ms. @ 8 mhz xtal */
}

/* ################################################################### */

/* set–up i/o for the single slope a/d, initialize the spi port, then
   initialize the MC145453 for output */

init_io(void)
{
char i;

/* set–up i/o for the a/d */
PACTL |= 0X80;   /* make pa7 an output */
PORTA |= 0X80;   /* turn the fet on */
PORTB &= 0X7F;   /* set–up the HC4053 in the Y0/Z0 connect mode */
TCTL2 = 0X2A;    /* capture on falling edge for timer capture 0,1,2 */
TFLG1 = 0X07;    /* clear any pending capture flags */

/* set–up the i/o for the spi subsystem */
PORTD=0x2f;  /* set output low before setting the direction register */
DDRD=0x38;   /* ss = 1, sck = 1, mosi = 1 */
SPCR=0x51;   /* enable spi, make the cpu the master, E clock /4  */

/* initialize the lcd driver */
  for (i=0; i<4; ++i)   /* four bytes of zeros */
       {
         write_spi(0);
       }
  write_spi (2);  /* this creates a start bit and data bit 1
                     for the next write to the mc145453 */
}

/* ################################################################### */

/* this is an attempt at the newton square root method */
sqrt(unsigned long b)
{

unsigned long x0,x1;

   if ( b < 4 ) { b=2; return (b); }
       else
     x0=4;
     x1=10;
        while (x0 != x1)
          {
            if( (x1–x0) ==1 ) break;
              x1=x0;
              x0=(( (b/x0) +x0 ) >> 1 );
          }
   b=x0;
   return (b);
}

/* ################################################################### */
```

```
write()
{
char i;
  digit[1]=10;
  if (digit[2]==0)
       {digit[2]=10;}
    if (  digit[2]==10 && digit[3]==0 )
         {digit[3]=10;}
   for ( i=1; i<5; ++i )
     {
      if (i==4)
       write_spi((lcdtab[digit[i]])+0x80);
        else
         write_spi(lcdtab[digit[i]]);
     }
 write_spi (2);      /* this creates a start bit and data bit 1
                        for the next write to the mc145453   */
}


write_spi( char a )  /* write a character to the spi port */

  {
    SPDR=a;
       while ( ! ( SPSR & 0x80 ) ) {}  /* loop until the spif = 1 */
  }

/* ################################################################### */

/*  This function is called at power–up and will determine the operation
    of the system. The user must complete the system configuration prior
    to setting the jumper in the first or last two configurations in the
    table or erroneous operation is guaranteed!
          test/operation jumper configuration:

           J3  J2  J1     1 = jumper removed

            1   1   1   display speed in mph
            1   1   0   reserved
            1   0   1   30 psi xdcr installed
            1   0   0   15 psi xdcr installed
            0   1   1   full scale calibrate
            0   1   0   zero calibrate
            0   0   1   display pressure in psi
            0   0   0   display speed in mph     */

setconfig()
{
char i;
for ( i=0; i<125; ++i )
    delay();   /* to let the charge pump come to life wll */
i = PORTC & 0x07;  /* and off the unused bits */
  if ( i == 7 )
    display_speed();
                if ( i == 6 )
                  setup_error();  /* non–valid pattern output –SE– on display*/
                  if ( i == 5 )
                         {write_eeprom(30,&XDCRMAX); /* xdcr is 30 psi */
                              display(30);
                             }
                                if ( i == 4 )
                                   {write_eeprom(15,&XDCRMAX); /* xdcr is 15 psi */
                                     display(15);
                                    }
                                      if ( i == 3 )
                                         fullscale_calibrate();
                                                                            if ( i == 2 )
                                                                              zero_calibrate();
                                                                                      if ( i == 1 )
                                               display_pressure();
                                                 else
                                                                                            display_speed();
}

/* ################################################################### */

display(char d)
```

```
{
if (d==30)
{
write_spi(0);    /* blank the upper digit */
write_spi(0);    /* blank the next to upper digit */
write_spi(47);   /* 3 */
write_spi(95);   /* 0 */
}
if (d==15)
{
write_spi(0);    /* blank the upper digit */
write_spi(0);    /* blank the next to upper digit */
write_spi(6);    /* 1 */
write_spi(109);  /* 5 */
}

write_spi(2);
while(1);
}

/* ################################################################### */

fullscale_calibrate()
{
int i;
long int temp;
union bytes average;
temp=0;
    average.l = cala2d();  /* get the average of 50 a/d conversions */
             for ( i=0; i<4; ++i)
                write_eeprom(average.b[i],EEPROM+i+4);


write_spi(0);    /* blank the upper digit */
write_spi(113);  /* F */
write_spi(113);  /* F */
write_spi(113);  /* F */
write_spi(2);
while(1);

}

/* ################################################################### */

zero_calibrate()
{
int i;
long int temp;
union bytes average;
temp=0;

    average.l = cala2d();  /* get the average of 50 a/d conversions */
             for ( i=0; i<4; ++i)
              write_eeprom(average.b[i],EEPROM+i);

write_spi(0);   /* blank the upper digit */
write_spi(95);  /* 0 */
write_spi(95);  /* 0 */
write_spi(95);  /* 0 */
write_spi(2);
while(1);
}

/* ################################################################### */

/* speed=8.208(square root(%full scale*transducer full scale)) */
display_speed()
{
long atod_result;
unsigned int j;
             while(1)
             {
                         atod_result = integrate(); /* read the a/d */
                           atod_result=( (atod_result*10000) / (HIATOD–ADZERO) ) * XDCRMAX;
           atod_result=sqrt(atod_result);
          atod_result=(atod_result*8208)/10000;
         j=atod_result;
```

```
          if (j<50)
            { j=0; }
  cvt_bin_dec ( j );
  write();

             }
}

/* ################################################################### */

/* pressure=%full scale*transducer max pressure */
display_pressure()
{
long atod_result;
int j;
             while(1)
             {
              atod_result = integrate(); /* read the a/d */
                atod_result=( (atod_result*1000) / (HIATOD–ADZERO) ) * XDCRMAX;
           j=atod_result/100;
  cvt_bin_dec ( j );
  write();

             }
}

/* ################################################################### */

setup_error()   /* write ”SE” on the display */
{
write_spi(0);
write_spi(109);  /* S */
write_spi(121);  /* E */
write_spi(0);
write_spi(2);
while(1);
}

/* ################################################################### */


main()
{
init_io();
setconfig();  /* determine how to function */
while(1);  /* should never return here except after calibration */
}
```

AN1571

Digital Blood Pressure Meter

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INTRODUCTION

This application note describes a Digital Blood Pressure Meter concept which uses an integrated pressure sensor, analog signal–conditioning circuitry, microcontroller hardware/software and a liquid crystal display. The sensing system reads the cuff pressure (CP) and extracts the pulses for analysis and determination of systolic and diastolic pressure. This design uses a 50 kPa integrated pressure sensor (Motorola P/N: MPX5050GP) yielding a pressure range of 0 mmHg to 300 mmHg.

CONCEPT OF OSCILLOMETRIC METHOD

This method is employed by the majority of automated non–invasive devices. A limb and its vasculature are compressed by an encircling, inflatable compression cuff. The blood pressure reading for systolic and diastolic blood pressure values are read at the parameter identification point.

The simplified measurement principle of the oscillometric method is a measurement of the amplitude of pressure change in the cuff as the cuff is inflated from above the systolic pressure. The amplitude suddenly grows larger as the pulse breaks through the occlusion. This is very close to systolic pressure. As the cuff pressure is further reduced, the pulsation increase in amplitude, reaches a maximum and then diminishes rapidly. The index of diastolic pressure is taken where this rapid transition begins. Therefore, the systolic blood pressure (SBP) and diastolic blood pressure (DBP) are obtained by identifying the region where there is a rapid increase then decrease in the amplitude of the pulses respectively. Mean arterial pressure (MAP) is located at the point of maximum oscillation.

HARDWARE DESCRIPTION AND OPERATION

The cuff pressure is sensed by Motorola's integrated pressure X–ducer™. The output of the sensor is split into two paths for two different purposes. One is used as the cuff pressure while the other is further processed by a circuit. Since MPX5050GP is signal–conditioned by its internal op–amp, the cuff pressure can be directly interfaced with an analog–to–digital (A/D) converter for digitization. The other path will filter and amplify the raw CP signal to extract an amplified version of the CP oscillations, which are caused by the expansion of the subject's arm each time pressure in the arm increases during cardiac systole.

The output of the sensor consists of two signals; the oscillation signal (≈ 1 Hz) riding on the CP signal (≤ 0.04 Hz). Hence, a 2–pole high pass filter is designed to block the CP signal before the amplification of the oscillation signal. If the CP signal is not properly attenuated, the baseline of the oscillation will not be constant and the amplitude of each oscillation will not have the same reference for comparison. Figure 1 shows the oscillation signal amplifier together with the filter.

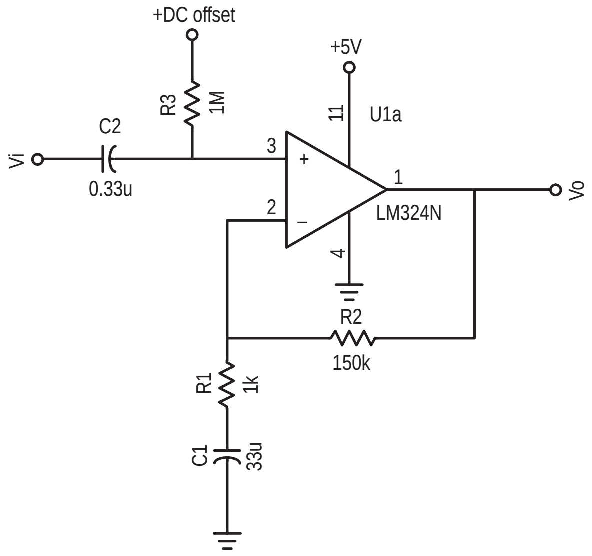

Figure 1. Oscillation Signal Amplifier

The filter consists of two RC networks which determine two cut–off frequencies. These two poles are carefully chosen to ensure that the oscillation signal is not distorted or lost. The two cut–off frequencies can be approximated by the following equations. Figure 2 describes the frequency response of the filter. This plot does not include the gain of the amplifier.

$$f_{P1} = \frac{1}{2\pi R_1 C_1}$$

$$f_{P2} = \frac{1}{2\pi R_3 C_2}$$

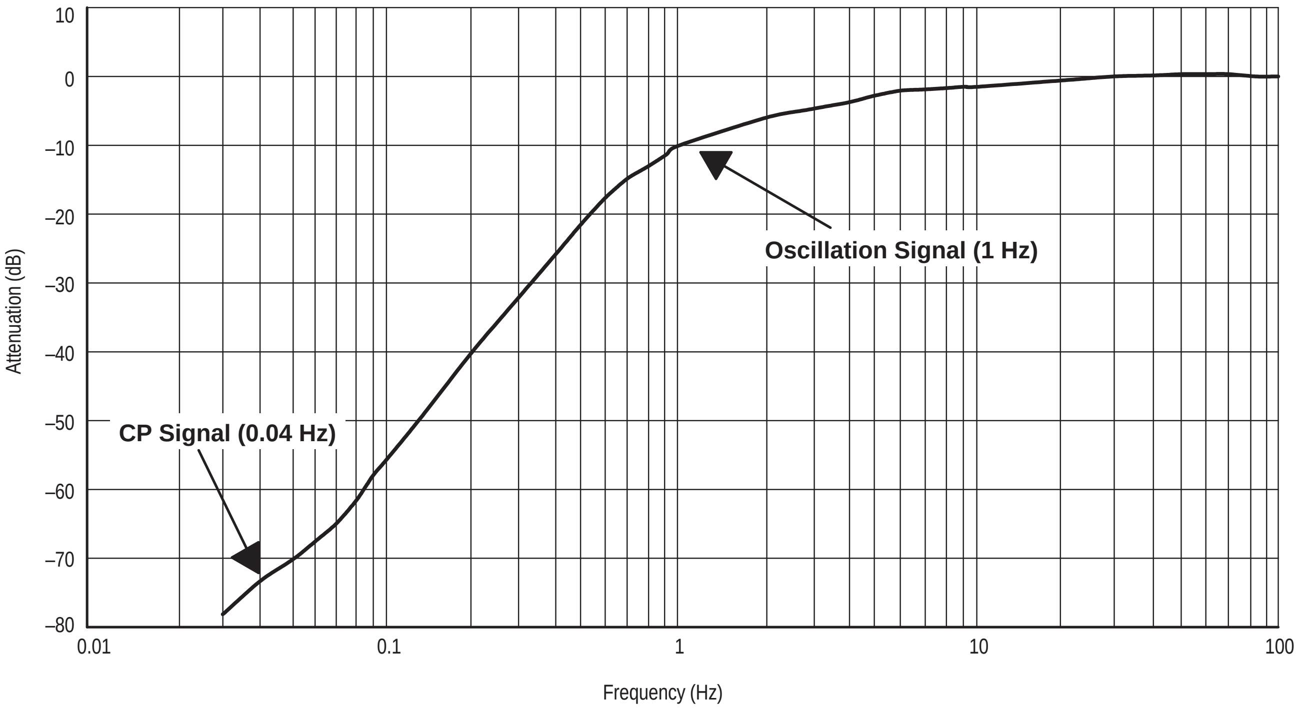

Figure 2. Filter Frequency Response

The oscillation signal varies from person to person. In general, it varies from less than 1 mmHg to 3 mmHg. From the transfer function of MPX5050GP, this will translate to a voltage output of 12 mV to 36 mV signal. Since the filter gives an attenuation of 10 dB to the 1 Hz signal, the oscillation signal becomes 3.8 mV to 11.4 mV respectively. Experiments indicate that, the amplification factor of the amplifier is chosen to be 150 so that the amplified oscillation signal is within the output limit of the amplifier (5 mV to 3.5 V). Figure 3(a) shows the output from the pressure sensor and Figure 3(b) shows the extracted oscillation signal at the output of the amplifier.

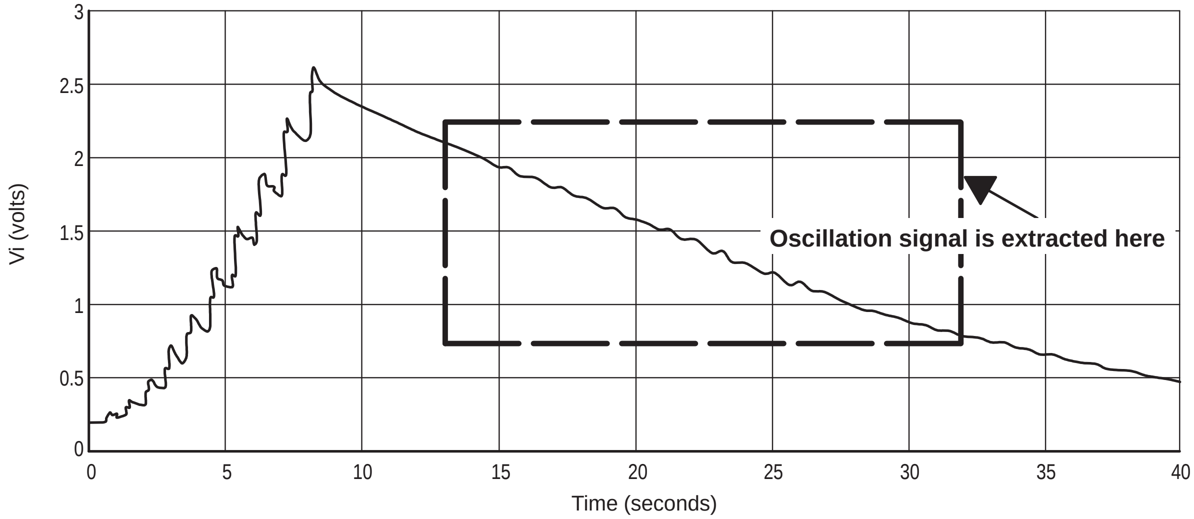

Figure 3. CP signal at the output of the pressure sensor

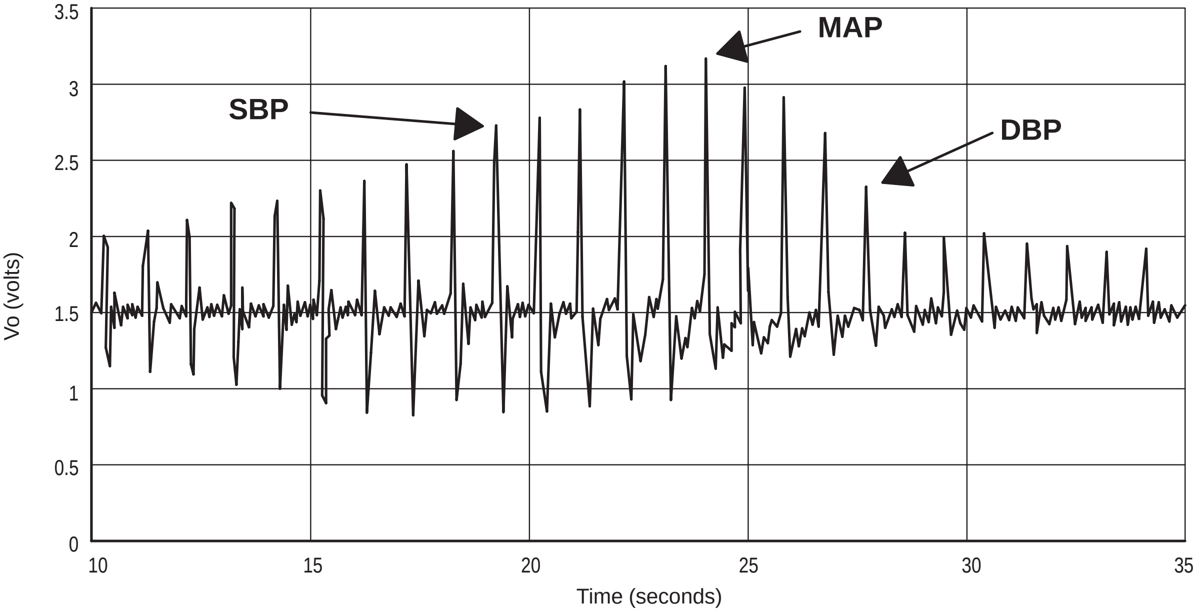

Figure 3b. Extracted oscillation signal at the output of amplifier

Referring to the schematic, Figure 4, the MPX5050GP pressure sensor is connected to PORT D bit 5 and the output of the amplifier is connected to PORT D bit 6 of the microcontroller. This port is an input to the on–chip 8–bit analog–to–digital (A/D) converter. The pressure sensor provides a signal output to the microprocessor of approximately 0.2 Vdc at 0 mmHg to 4.7 Vdc at 375 mmHg of applied pressure whereas the amplifier provides a signal from 0.005 V to 3.5 V. In order to maximize the resolution, separate voltage references should be provided for the A/D instead of using the 5 V supply. In this example, the input range of the A/D converter is set at approximately 0 Vdc to 3.8 Vdc. This compresses the range of the A/D converter around 0 mmHg to 300 mmHg to maximize the resolution; 0 to 255 counts is the range of the A/D converter. V_{RH} and V_{RL} are the reference voltage inputs to the A/D converter. The resolution is defined by the following:

$$\text{Count} = [(V_{Xdcr} - V_{RL})/(V_{RH} - V_{RL})] \times 255$$

The count at 0 mmHg = $[(0.2 - 0)/(3.8 - 0)] \times 255 \approx 14$

The count at 300 mmHg = $[(3.8 - 0)/(3.8 - 0)] \times 255 \approx 255$

Therefore the resolution = 255 – 14 = 241 counts. This translates to a system that will resolve to 1.24 mmHg.

The voltage divider consisting of R5 and R6 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 (LCD) is directly driven from I/O ports A, B, and C on the microcontroller. The operation of a LCD requires that the data and backplane (BP) 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.

Other than the LCD, there are two more I/O devices that are connected to the pulse length converter (PLM) of the microcontroller; a buzzer and a light emitting diode (LED). The buzzer, which connected to the PLMA, can produce two different frequencies; 122 Hz and 1.953 kHz tones. For instance when the microcontroller encounters certain error due to improper inflation of cuff, a low frequency tone is alarm. In those instance when the measurement is successful, a high frequency pulsation tone will be heard. Hence, different musical tone can be produced to differential each condition. In addition, the LED is used to indicate the presence of a heart beat during the measurement.

The microcontroller section of the system requires certain support hardware to allow it to function. The MC34064P–5 provides an undervoltage sense function which is used to reset the microprocessor at system power–up. The 4 MHz crystal provides the external portion of the oscillator function for clocking the microcontroller and provides a stable base for time based functions, for instance calculation of pulse rate.

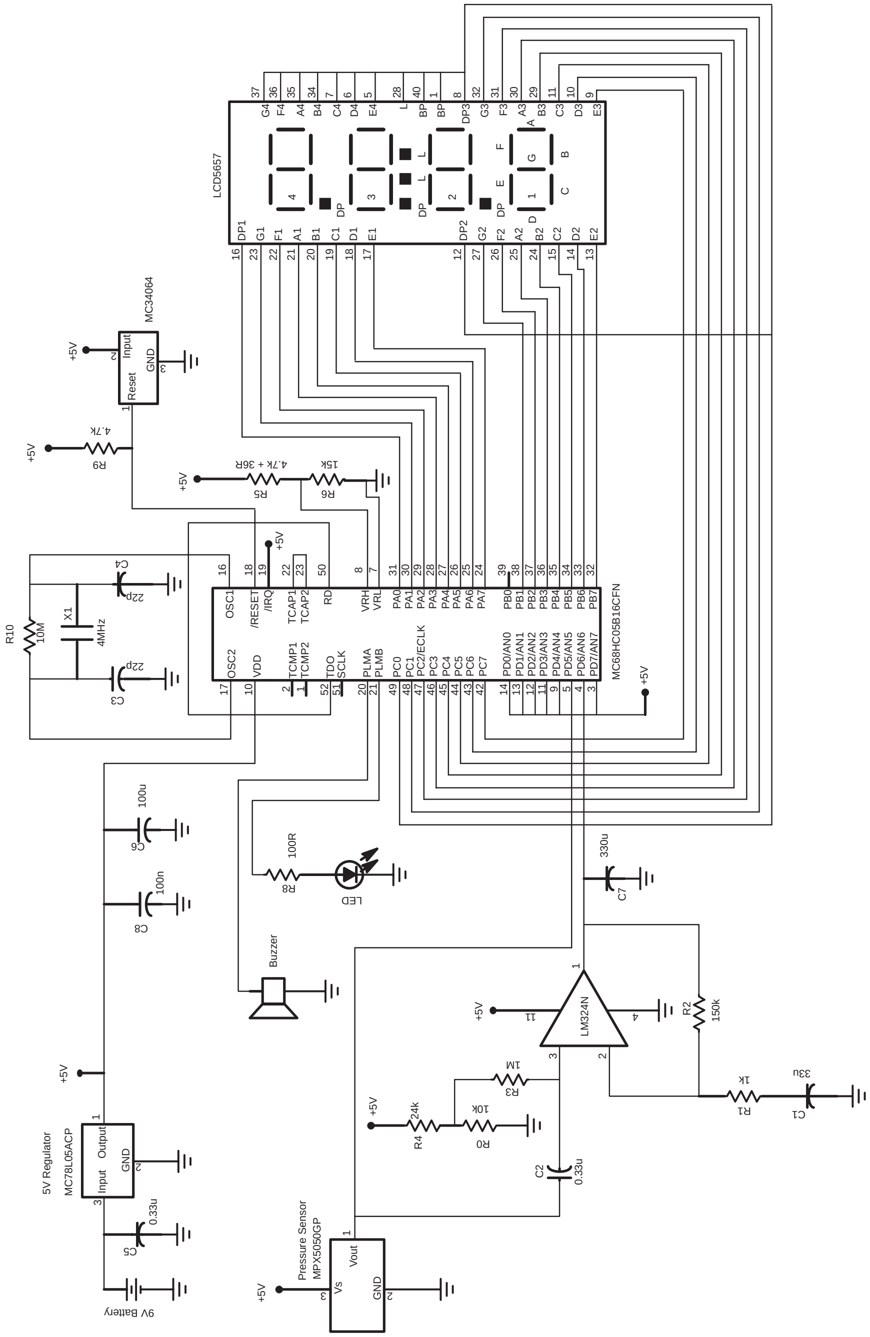

Figure 4. Blood Pressure Meter Schematic Drawing

SOFTWARE DESCRIPTION

Upon system power–up, the user needs to manually pump the cuff pressure to approximately 160 mmHg or 30 mmHg above the previous SBP. During the pumping of the inflation bulb, the microcontroller ignores the signal at the output of the amplifier. When the subroutine TAKE senses a decrease in CP for a continuous duration of more than 0.75 seconds, the microcontroller will then assume that the user is no longer pumping the bulb and starts to analyze the oscillation signal. Figure 5 shows zoom–in view of a pulse.

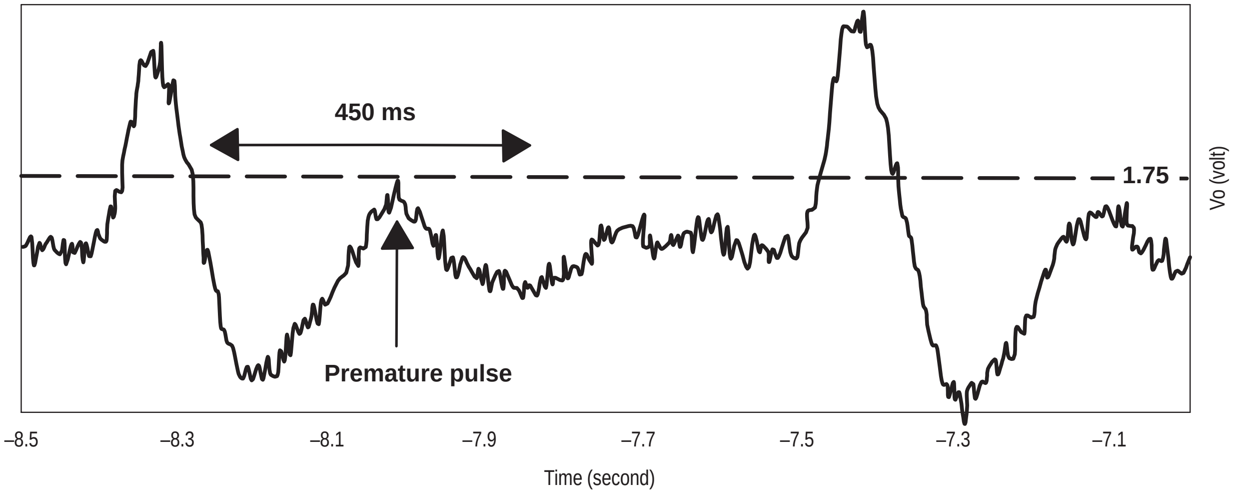

Figure 5. Zoom–in view of a pulse

First of all, the threshold level of a valid pulse is set to be 1.75 V to eliminate noise or spike. As soon as the amplitude of a pulse is identified, the microcontroller will ignore the signal for 450 ms to prevent any false identification due to the presence of premature pulse ”overshoot” due to oscillation. Hence, this algorithm can only detect pulse rate which is less than 133 beats per minute. Next, the amplitudes of all the pulses detected are stored in the RAM for further analysis. If the microcontroller senses a non–typical oscillation envelope shape, an error message (“Err”) is output to the LCD. The user will have to exhaust all the pressure in the cuff before re–pumping the CP to the next higher value. The algorithm ensures that the user exhausts all the air present in the cuff before allowing any re–pumping. Otherwise, the venous blood trapped in the distal arm may affect the next measurement. Therefore, the user has to reduce the pressure in the cuff as soon as possible in order for the arm to recover. Figure 6 is a flowchart for the program that controls the system.

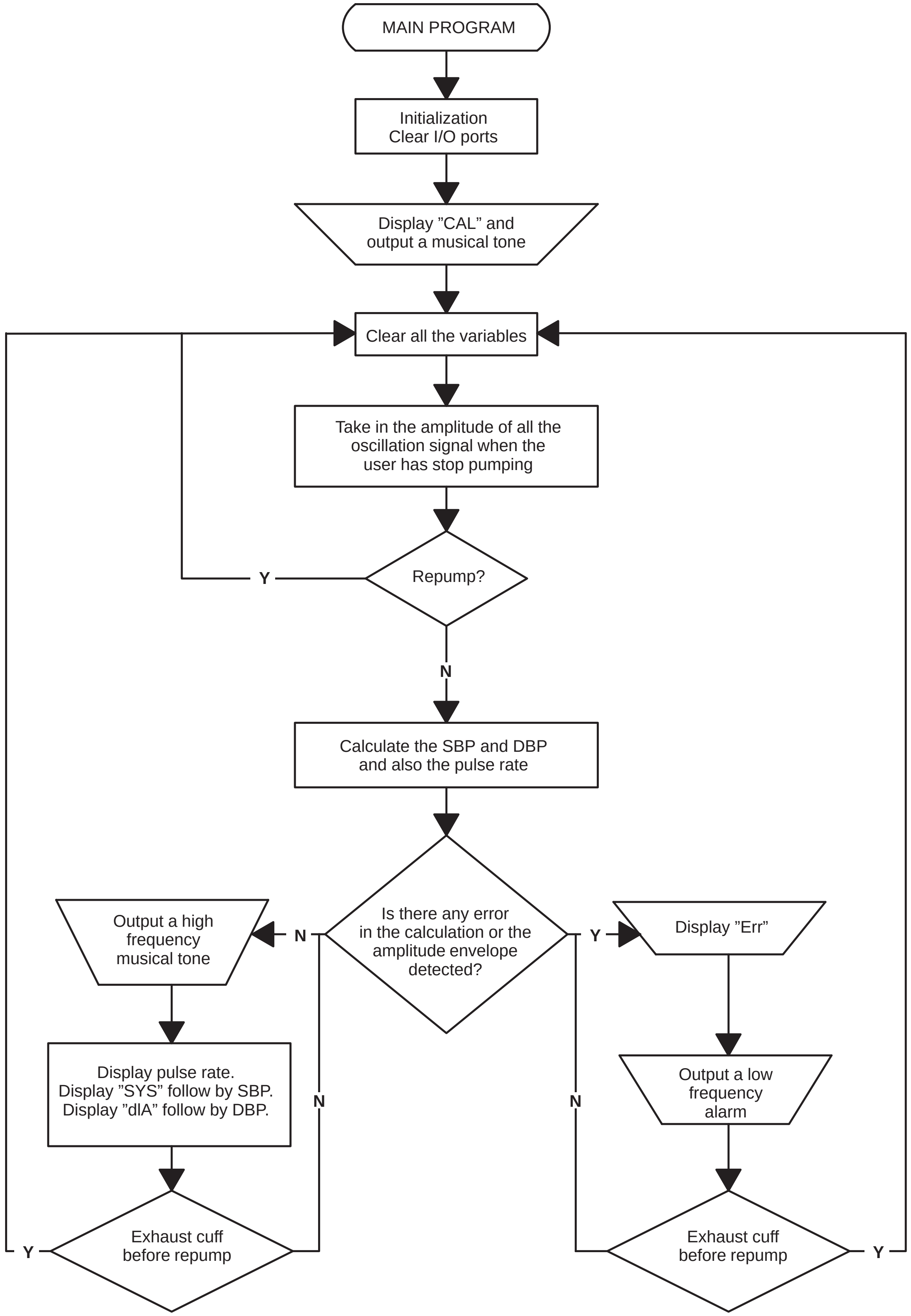

Figure 6. Main program flowchart

SELECTION OF MICROCONTROLLER

Although the microcontroller used in this project is MC68HC05B16, a smaller ROM version microcontroller can also be used. The table below shows the requirement of microcontroller for this blood pressure meter design in this project.

Table 1. Selection of microcontroller

On–chip ROM space 2 kilobytes
On–chip RAM space 150 bytes
2–channel A/D converter (min.)
16–bit free running counter timer
LCD driver
On–chip EEPROM space 32 bytes
Power saving Stop and Wait modes

CONCLUSION

This circuit design concept may be used to evaluate Motorola pressure sensors used in the digital blood pressure meter. This basic circuit may be easily modified to provide suitable output signal level. The software may also be easily modified to provide better analysis of the SBP and DBP of a person.

REFERENCES

Lucas, Bill (1991). “An Evaluation System for Direct Interface of the MPX5100 Pressure Sensor with a Microprocessor,” Motorola Application Note AN1305.

AN1573

Understanding Pressure and Pressure Measurement

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Introduction

Fluid systems, pressure and pressure measurements are extremely complex. The typical college curriculum for Mechanical Engineers includes at least two semesters in fluid mechanics. This paper will define and explain the basic concepts of fluid mechanics in terms that are easily understood while maintaining the necessary technical accuracy and level of detail.

Pressure and Pressure Measurement

What is fluid pressure? Fluid pressure can be defined as the measure of force per–unit–area exerted by a fluid, acting perpendicularly to any surface it contacts (a fluid can be either a gas or a liquid, fluid and liquid are not synonymous). The standard SI unit for pressure measurement is the Pascal (Pa) which is equivalent to one Newton per square meter (N/m^2) or the KiloPascal (kPa) where 1 kPa = 1000 Pa. In the English system, pressure is usually expressed in pounds per square inch (psi). Pressure can be expressed in many different units including in terms of a height of a column of liquid. The table below lists commonly used units of pressure measurement and the conversion between the units.

	kPa	mm Hg	millibar	in H2O	PSI
1 atm	101.325	760.000	1013.25	406.795	14.6960
1 kPa	1.000	7.50062	10.000	4.01475	0.145038
1 mm Hg	0.133322	1.000	1.33322	0.535257	0.0193368
1 millibar	0.1000	0.750062	1.000	0.401475	0.0145038
1 in H2O	0.249081	1.86826	2.49081	1.000	0.0361
1 PSI	6.89473	51.7148	68.9473	27.6807	1.000
1 mm H2O	0.009806	0.07355	9.8×10^{-8}	0.03937	0.0014223

Figure 1. Conversion Table for Common Units of Pressure

Pressure measurements can be divided into three different categories: *absolute pressure, gage pressure and differential pressure*. *Absolute pressure* refers to the absolute value of the force per–unit–area exerted on a surface by a fluid. Therefore the absolute pressure is the difference between the pressure at a given point in a fluid and the absolute zero of pressure or a perfect vacuum. *Gage pressure* is the measurement of the difference between the absolute pressure and the local atmospheric pressure. Local atmospheric pressure can vary depending on ambient temperature, altitude and local weather conditions. The U.S. standard atmospheric pressure at sea level and 59°F (20°C) is 14.696 pounds per square inch absolute (psia) or 101.325 kPa absolute (abs). When referring to pressure measurement, it is critical to specify what reference the pressure is related to. In the English system of units, measurement relating the pressure to a reference is accomplished by specifying pressure in terms of pounds per square inch absolute (psia) or pounds per square inch gage (psig). For other units of measure it is important to specify gage or absolute. The abbreviation 'abs' refers to an absolute measurement. A gage pressure by convention is always positive. A 'negative' gage pressure is defined as vacuum. Vacuum is the measurement of the amount by which the local atmospheric pressure exceeds the absolute pressure. A perfect vacuum is zero absolute pressure. Figure 2 shows the relationship between absolute, gage pressure and vacuum. *Differential pressure* is simply the measurement of one unknown pressure with reference to another unknown pressure. The pressure measured is the difference between the two unknown pressures. This type of pressure measurement is commonly used to measure the pressure drop in a fluid system. Since a differential pressure is a measure of one pressure referenced to another, it is not necessary to specify a pressure reference. For the English system of units this could simply be psi and for the SI system it could be kPa.

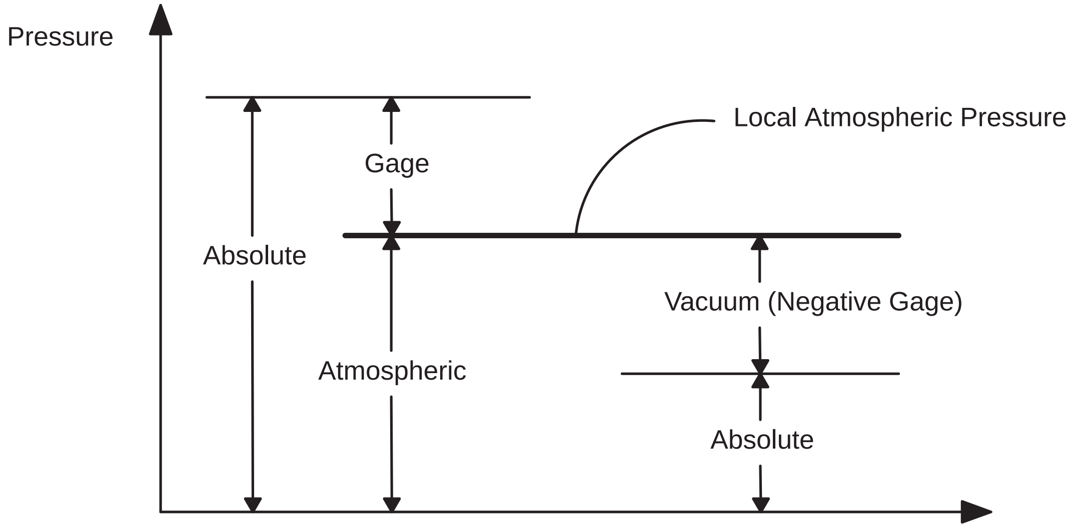


Figure 2. Pressure Term Relationships

In addition to the three types of pressure measurement, there are different types of fluid systems and fluid pressures. There are two types of fluid systems; *static systems* and *dynamic systems*. As the names imply, a static system is one in which the fluid is at rest and a dynamic system is on in which the fluid is moving.

Static Pressure Systems

The pressure measured in a static system is *static pressure*. In the pressure system shown in Figure 3, a uniform static fluid is continuously distributed with the pressure varying only with vertical distance. The pressure is the same at all points along the same horizontal plane in the fluid and is independent of the shape of the container. The pressure increases with depth in the fluid and acts equally in all directions. The increase in pressure at a deeper depth is essentially the effect of the weight of the fluid above that depth. Figure 4 shows two containers with the same fluid exposed to the same external pressure – **P** . At any equal depth within either tank the pressure will be the same . Note that the sides of the large tank are not vertical. The pressure is dependent only on depth and has nothing to do with the shape of the container. If the working fluid is a gas, the pressure increase in the fluid due to the height of the fluid is in most cases negligible since the density and therefore the weight of the fluid is much smaller than the pressure being applied to the system. However, this may not remain true if the system is large enough or the pressures low enough. One example considers how atmospheric pressure changes with altitude. At sea level the standard U.S. atmospheric pressure is 14.696 psia (101.325 kPa). At an altitude of 10,000 ft (3048 m) above sea level the standard U.S. atmospheric pressure is 10.106 psia (69.698 kPA) and at 30,000 ft (9144 m), the standard U.S. atmospheric pressure is 4.365 psia (30.101 kPa).

The pressure in a static liquid can be easily calculated if the density of the liquid is known. The absolute pressure at a depth H in a liquid is defined as:

$P_{abs} = P + (\rho \times g \times H)$

Where :

P_{abs} is the absolute pressure at depth H.
P is the external pressure at the top of the liquid. For most open systems this will be atmospheric pressure.
ρ is the density of the fluid.
g is the acceleration due to gravity (g = 32.174 ft/sec^2 (9.81 m/sec^2)).
H is the depth at which the pressure is desired.

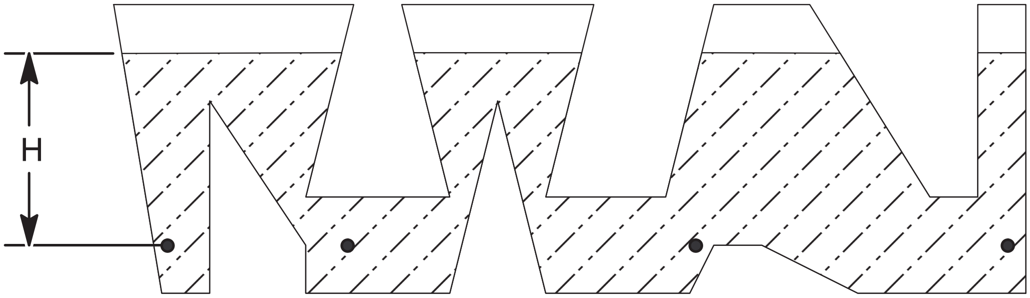


Figure 3. Continuous Fluid System

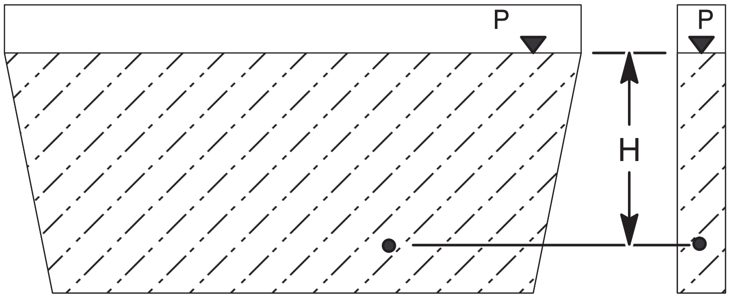


Figure 4. Pressure Measurement at a Depth in a Liquid

Dynamic Pressure Systems

Dynamic pressure systems are more complex than static systems and can be more difficult to measure. In a dynamic system, pressure typically is defined using three different terms. The first pressure we can measure is *static pressure*. This pressure is the same as the static pressure that is measured in a static system. Static pressure is independent of the fluid movement or flow. As with a static system the static pressure acts equally in all directions. The second type of pressure is what is referred to as the *dynamic pressure*. This pressure term is associated with the velocity or the flow of the fluid. The third pressure is *total pressure* and is simply the static pressure plus the dynamic pressure.

Steady–State Dynamic Systems

Care must be taken when measuring dynamic system pressures. For a dynamic system, under steady–state conditions, accurate static pressures may be measured by tapping into the fluid stream perpendicular to the fluid flow. For a dynamic system, steady–state conditions are defined as no change in the system flow conditions: pressure, flow rate, etc. Figure 5 illustrates a dynamic system with a fluid flowing through a pipe or duct. In this example a static pressure tap is located in the duct wall at point A. The tube inserted into the flow is called a Pitot tube. The Pitot tube measures the total pressure at point B in the system. The total pressure measured at this point is referred to as the *stagnation pressure*. The stagnation pressure is the value obtained when a flowing fluid is decelerated to zero velocity in an isentropic (frictionless) process. This process converts all of the energy from the flowing fluid into a pressure that can be measured. The stagnation or total pressure is the static pressure plus the dynamic pressure. It is very difficult to accurately measure dynamic pressures. When dynamic pressure measurement is desired, the total and static pressures are measured and then subtracted to obtain the dynamic pressure. Dynamic pressures can be used to determine the fluid velocities and flow rates in dynamic systems.

When measuring dynamic system pressures, care must be taken to ensure accuracy. For static pressure measurements, the pressure tap location should be chosen so that the measurement is not influenced by the fluid flow. Typically, taps are located perpendicular to the flow field. In Figure 5, the static pressure tap at point A is in the wall of the duct and perpendicular to the flow field. In Figures 6a and 6c the static taps (point A) in the pressure probes are also perpendicular to the flow field. These examples show the most common type of static pressure taps, however there are many different static pressure tap options. For total or stagnation pressure measurements, it is important that the Pitot or impact tube be aligned parallel to the flow field with the tip of the tube pointing directly into the flow. In Figures 6b and 6c, the Pitot tube is aligned parallel with the flow, with the tube opening pointing directly into the flow. Although the static pressure is independent of direction, the dynamic pressure is a vector quantity which depends on both magnitude and direction for the total measured value. If the Pitot tube is misaligned with the flow, accuracy of the total pressure measurement may suffer. In addition, for accurate pressure measurements the pressure tap holes and probes must be smooth and free from any burrs or obstructions that could cause disturbances in the flow. The location of the pressure taps and probes, static and total, must also be selected carefully. Any location in the system where the flow field may be disturbed should be avoided, both upstream and downstream. These locations include any obstruction or change such as valves, elbows, flow splits, pumps, fans, etc. To increase the accuracy of pressure measurement in a dynamic system, allow at least 10 pipe / duct diameters downstream of any change or obstruction and at least 2 pipe / duct diameters upstream. In addition the pipe / duct diameter should be much larger than the diameter of the Pitot tube. The pipe / duct diameter should be at least 30 times the Pitot tube diameter. Flow straighteners can also be used to minimize any variations in the direction of the flow. Also, when using a Pitot tube, it is recommended that the static pressure tap be aligned in the same plane as the total pressure tap. On the Pitot–static tube, the difference in location is assumed to be negligible.

Flow–through pipes and ducts will result in a velocity field and dynamic pressure field that are non–uniform. At the wall of any duct or pipe there exists a no–slip boundary due to friction. This means that at the wall itself the velocity of the fluid is zero. Figure 5 shows an imaginary velocity distribution in a duct. The shape of the distribution will depend on the fluid conditions, system flow and pressure. In order to accurately determine the average dynamic pressure across a duct section, a series of total pressure readings must be taken across the duct. These pressure measurements should be taken at different radii and clock positions across the cross section of a round duct or at various width and height locations for a rectangular duct. Once this characterization has been performed for the duct , a correlation can be easily made between the total pressure measurement at the center of the duct relative to the average duct total pressure. This technique is also used to determine the velocity profile within the duct.

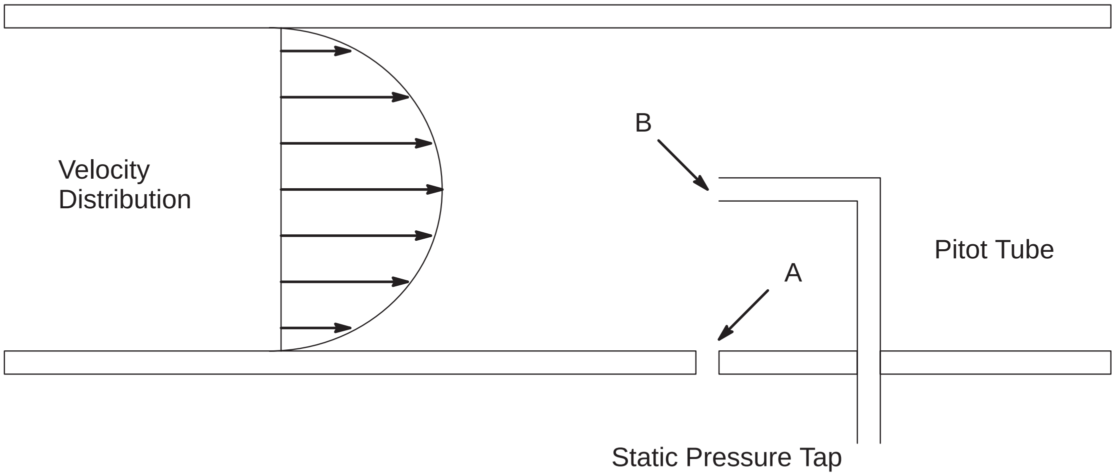
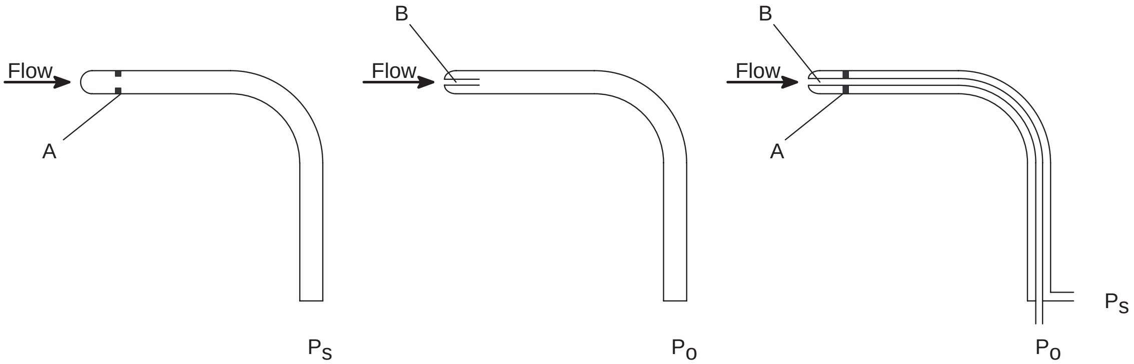


Figure 5. Static and Total Pressure Measurements Within a Dynamic Fluid System.



(A) Static Pressure
Probe

(B) Total Pressure
Pitot Tube

(C) Combination Static Pressure
and Total Pressure Pitot Tube
(Pitot–Static Tube)

Figure 6. Types of Pressure Probes

Transient Systems

Transient systems are systems with changing conditions such as pressures, flow rates, etc. Measurements in transient systems are the most difficult to accurately obtain. If the measurement system being used to measure the pressure has a faster response time than the rate of change in the system, then the system can be treated as quasi–steady–state. That is, the measurements will be about as accurate as those taken in the steady–state system. If the measurement of the system is assumed to be a snap shot of what is happening in the system, then you want to be able to take the picture faster than the rate of change in the system or the picture will be blurred. In other words, the measurement results will not be accurate. In a pressure measurement system, there are two factors that determine the overall measurement response: (1) the response of the transducer element that senses the pressure, and (2) the response of the interface between the transducer and the pressure system such as the pressure transmitting fluid and the connecting tube, etc. For Motorola pressure sensors, the second factor usually determines the overall frequency response of the pressure measurement system. The vast majority of pressure systems that require measurements today are quasi–steady–state systems where system conditions are changing relatively slowly compared to the response rate of the measurement system or the change happens instantaneously and then stabilizes.

Two transient system examples include washing machines and ventilation ducts in buildings. In a washing machine, the height of the water in the tub is measured indirectly by measuring the pressure at the bottom of the tub. As the tub fills the pressure changes. The rate at which the tub fills and the pressure changes is much slower than the response rate of the measurement system. In a ventilation duct, the pressure changes as the duct registers are opened and closed, adjusting the air movement within the building. As more registers are opened and closed, the system pressure changes. The pressure changes are virtually instantaneous. In this case, pressure changes are essentially incremental and therefore easy to measure accurately except at the instant of the change. For most industrial and building control applications, the lag in the pressure measurement system is negligible. As the control or measurement system becomes more precise, the frequency response of the measurement system must be considered.

Motorola Pressure Sensors

This application note has covered various types of pressures that are measured and how to tap into a system to measure the desired pressures. How are the actual pressure measurements made? There are many types of pressure measurement systems ranging from simple liquid tube manometers to bourdon–tube type gages to piezo–electric silicon based transducers. Today, as electronic control and measurement systems are replacing mechanical systems, silicon–based pressure transducers and sensors are becoming the sensors of choice. Silicon micromachined sensors offer very high accuracies at very low cost and provide an interface between the mechanical world and the electrical system. Motorola carries a complete line of silicon based pressure sensors which feature a wide range of pressures with various levels of integration on a single chip. These levels of integration start with the basic uncompensated, uncalibrated pressure sensor all the way to the fully integrated, temperature compensated, calibrated and signal conditioned pressure sensors. The response time of Motorola’s MPX series silicon pressure sensors is typically 1 millisecond or less. For static or dynamic systems, Motorola’s pressure sensors are an excellent solution for pressure measurement systems.

Conclusion

Pressures and pressure measurements can be extremely complex and complicated. However, for most systems it is relatively easy to obtain accurate pressure measurements if the proper techniques are used.

AN1583

Motorola's Next Generation Piston Fit Pressure Sensor Packages

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Sensor Products Division

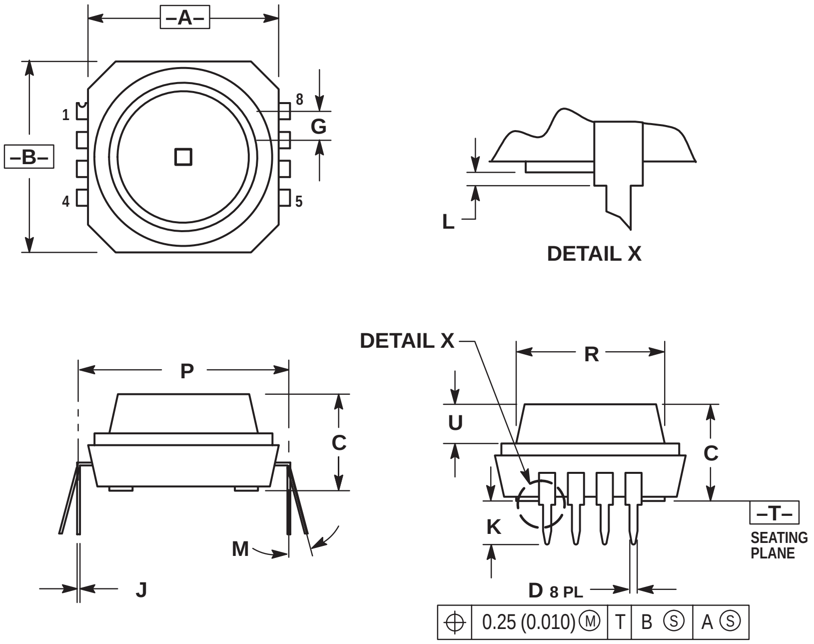
Motorola has introduced a new line of pressure sensor packages to satisfy the requirements of many of our customers. The advent of the silicon based pressure sensor has created a wide variety of new systems design approaches which were previously unavailable. More and more pressure sensor customers want to integrate silicon pressure sensors into their systems to provide not just measurement capabilities but also to provide information or feedback for a control loop. In addition, the low cost of silicon based pressure sensors has made it affordable and possible to incorporate pressure sensing into many more products. Of concern with these products is that the assembly costs be kept to a minimum. The 'next generation' piston fit packages were designed with this in mind. An additional concern when assembling a pressure sensor into a system is that a leak proof seal is obtained so that accurate pressure readings may be made and no loss of the system fluid is allowed. Also, the installation of the pressure sensor within the system should not affect the sensor's accuracy or output.

Motorola's new piston fit packages come in three different types — the top side piston fit, the dual piston fit and the backside piston fit, as shown in Figures 1 thru 3. These piston fit packages were designed to be installed into a customers housing using a standard O–ring to obtain a leak proof seal. The O–ring fits over the outside of the piston fit package like a piston ring fits over the outside of a piston. Hence the name — piston fit packages. The external geometry of the top side piston fit (TPF) and the back side piston fit (BPF) packages is the same. The differences between the packages are internal. The main difference is that for the TPF the piston fit is on the top side of the sensor die and on the BPF the piston fit is on the backside of the pressure die. The BPF is to be used mainly for vacuum measurement, where the vacuum is applied to the back side of the die, or for pressure sensors that use a backside pressure exposure for media compatibility as with the MPX906 series pressure sensors. The dual piston fit (DPF) package is designed for use in differential or gage pressure applications where two unknown pressures or an unknown pressure and local atmospheric pressure are applied to either side of the sensor die. The TPF is to be used for absolute or gage pressure measurements.

A silicon based pressure sensor is essentially a strain gage. It is designed to measure the strain in the silicon diaphragm or die when that diaphragm has a pressure applied to it. The higher the pressure difference across the diaphragm, the more the diaphragm deflects and, therefore, the larger the strain that is measured. If an external strain is applied directly to the die through the package or through thermal growth differences in the assembly, the sensor will have a shift in the output voltage even though there is no change in the pressures applied to the die. To minimize this phenomenon, the piston fit packages were designed to be very robust and to isolate the die from externally applied strains. An epoxy thermo–set plastic was chosen as the material for the piston fit package. This material offers high strength, good thermal stability and low moisture absorption — all important features to the operation of the device. The use of the piston fit package with an o–ring(s) further helps to isolate the package and the sensor die from system level stresses and strains that can be applied to the package. In addition, the o–ring allows for differences in the thermal growth of the assembled system while minimizing any transfer of stress or strain to the package. This means that if the housing that the sensor is assembled in is hotter than the sensor or grows due to temperature at a different rate than the sensor, the o–ring will accommodate these differences without passing the strain into the package.

O–RING SELECTION

The piston fit packages were designed to be used with standard o–rings. For the cavity geometries provided in Figures 5 thru 10, the standard o–ring size is 1/2″ ID x 5/8″ OD x 1/16″ cross section diameter. See Figure 4. Most o–ring manufacturers use a universal number system to specify o–ring size and type. These numbers can contain prefixes and suffixes that will indicate material types, tolerance class, durometer of the o–ring material (hardness of the elastomer), and application (static seal, dynamic seal, etc.). The universal dash number is typically the same between manufacturers. The dash number for the recommended o–ring for the piston fit packages is –014. When selecting an o–ring material the hardness of the material as well as the chemical resistance should be taken into account. An o–ring material should be compatible with the media it may come in contact with and should be as soft as possible to minimize stress or strain transfer from the system to the pressure sensor package and to maximize sealing. A softer material (lower durometer number) will flow into micro scratches and grooves in the mating parts more easily. For dry air, a good o–ring selection is a Parker Seal's P/N 2–014 S469–40. This is a silicon o–ring with a durometer of 40.



NOTES:

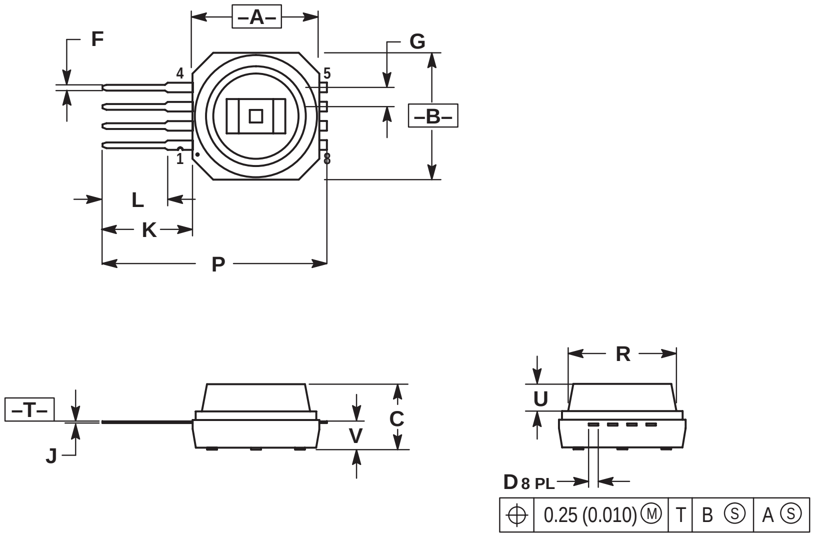
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION A AND B DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION 0.15 (0.006).
5. ALL VERTICAL SURFACES 5° TYPICAL DRAFT.
6. DIMENSION P TO CENTER OF LEAD WHEN FORMED PARALLEL.

DIM	INCHES MIN	INCHES MAX	MILLIMETERS MIN	MILLIMETERS MAX
A	0.658	0.668	16.71	16.97
B	0.658	0.668	16.71	16.97
C	0.329	0.357	8.36	9.07
D	0.026	0.034	0.660	0.864
G	0.100 BSC		2.54 BSC	
J	0.009	0.011	0.23	0.28
K	0.138	0.150	3.81	3.51
L	0.002	0.020	0.05	0.51
M	0°	15°	0°	15°
P	0.738	0.748	18.75	19.00
R	0.503	0.523	12.78	13.28
U	0.135	0.145	3.43	3.68

STYLE 1:
PIN 1. NC
2. VSUPPLY
3. GROUND
4. VOUT
5. NC
6. NC
7. NC
8. NC

STYLE 2:
PIN 1. GROUND
2. +VOUT
3. VSUPPLY
4. –VOUT
5. NC
6. NC
7. NC
8. NC

Figure 1. Top Piston Fit Package with 84° Lead Form

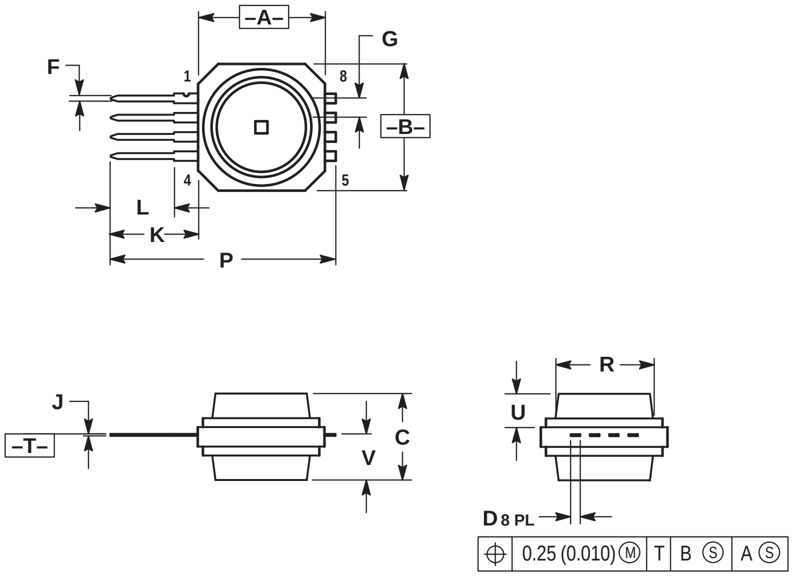


NOTES:

1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION A AND B DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION 0.15 (0.006).
5. VERTICAL SURFACES MAY BE UP TO 5° DRAFT.
6. DATUM –T– IS PARTING LINE PLANE.

DIM	INCHES MIN	INCHES MAX	MILLIMETERS MIN	MILLIMETERS MAX
A	0.658	0.668	16.71	16.97
B	0.658	0.668	16.71	16.97
C	0.327	0.337	8.30	8.56
D	0.046	0.054	1.17	1.37
F	0.026	0.034	0.660	0.864
G	0.100 BSC		2.54 BSC	
J	0.009	0.011	0.23	0.28
K	0.463	0.473	11.76	12.01
L	0.320	0.332	8.13	8.43
P	1.155	1.187	29.34	30.15
R	0.503	0.523	12.78	13.28
U	0.135	0.145	3.43	3.68
V	0.107	0.117	2.72	2.97

Figure 2. Backside Piston Fit Package with Straight 4–Lead, Lead Form



NOTES:

1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION A AND B DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION 0.15 (0.006).
5. VERTICAL SURFACES 5° TYPICAL DRAFT.
6. DATUM –T– IS PARTING LINE PLANE.

	INCHES		MILLIMETERS	
DIM	**MIN**	**MAX**	**MIN**	**MAX**
A	0.658	0.668	16.71	16.97
B	0.658	0.668	16.71	16.97
C	0.455	0.465	11.56	11.81
D	0.046	0.054	1.17	1.37
F	0.026	0.034	0.660	0.864
G	0.100 BSC		2.54 BSC	
J	0.009	0.011	0.23	0.28
K	0.463	0.473	11.76	12.01
L	0.320	0.332	8.13	8.43
P	1.155	1.187	29.34	30.15
R	0.503	0.523	12.78	13.28
U	0.135	0.145	3.43	3.68
V	0.235	0.245	5.97	6.22

STYLE 1:
PIN 1. NC
2. VSUPPLY
3. GROUND
4. VOUT
5. NC
6. NC
7. NC
8. NC

STYLE 2:
PIN 1. GROUND
2. +VOUT
3. VSUPPLY
4. –VOUT
5. NC
6. NC
7. NC
8. NC

Figure 3. Dual Piston Fit Package with Straight 4–Lead, Lead Form

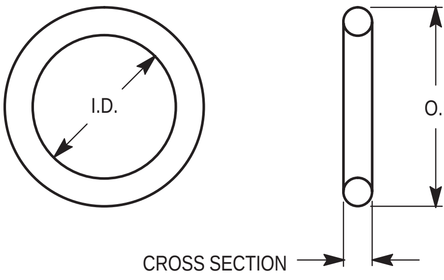


Figure 4. O–ring Geometry

PISTON AND CAVITY GEOMETRIES

The Piston Fit family of packages are available in a variety of lead form options. These options include 8–lead 84° lead form, straight 8–lead and 4–lead forms. The various lead forms need to be taken into account when designing a housing to enclose the sensor package. Figures 5 and 6 show how the dual piston fit package can be incorporated into a housing. Notice that in this particular example, the 84° 8–lead package option has been used. Figures 7 and 8 show a top side piston fit package with an 8–lead 84° lead form incorporated into a custom housing. Figures 9 thru 11 show the geometries used for the cavities that the sensor packages fit into. The top piston and the backside piston geometries for all three sensor packages are identical. Figure 11 shows the geometry for the cavity that will enclose the flat side of a TPF or BPF package.

Notice that these packages have four small circular bosses that need to have relief provided for. In this design, two of the bosses have a matching relief cavity in the housing while a cut out in the housing provides the clearance for the other two bosses. For an absolute pressure sensor in the TPF or BPF package, no pressure port is required on the flat side of the package. For a gage application, a pressure port or hole is required to allow ambient pressure to the sensor package. It should also be noted that clearance should be provided around the lead forms to prevent possible shorts across leads.

OPTIONAL MOUNTING METHODS

While the piston fit family of packages were designed to be used with an o–ring to provide sealing and ease of installation, other methods of mounting the devices can be done successfully. One such method is to use an adhesive compatible with the epoxy sensor package and whatever material that the housing is to be made from. These adhesives can be epoxy based or RTV based materials. When using epoxy materials, some consideration for the differences in the coefficients of thermal expansion between the different sensor, housing and adhesive materials should be made. The different rates of thermal expansion can create large thermal stresses in the assembly which can cause cracking and leaks in the assembly and can also cause shifts in the sensor output. RTV adhesive materials are generally lower in stiffness and act to reduce the transfer of stresses to the sensor. Because of this lower stiffness, RTV materials are not very good as a part of a rigid structural path. In other words, the RTV adhesive should be used in systems where there is no load applied to the RTV. This could include a system where the sensor is enclosed by a housing such as that shown in Figures 5 and 7.

CONCLUSION

The piston fit family of packages have been designed to meet customer needs and to be used in conjunction with a customer designed housing. This package is designed to be easily installed using standard O–rings. This package offers increased stress isolation for the sensing die and ease of installation. It is also possible to mount the package using adhesives to glue the sensor to a housing. This package was designed to compliment the existing family of ported and unported unibody pressure sensor packages. This package affords the customer the flexibility to easily add the sensor to a system design by incorporating some cavities into their system housing.

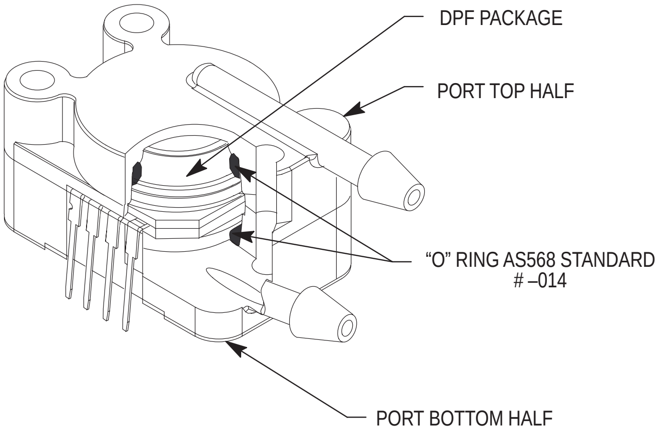


Figure 5. Dual Piston Fit Package Custom Housing

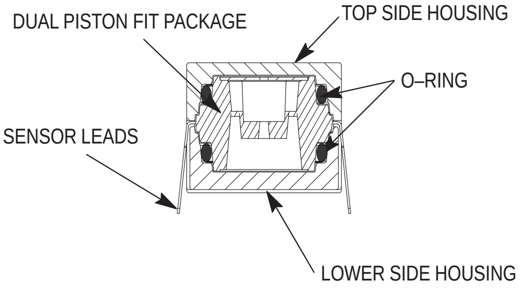


Figure 6. Dual Piston Fit Custom Housing Cross Section

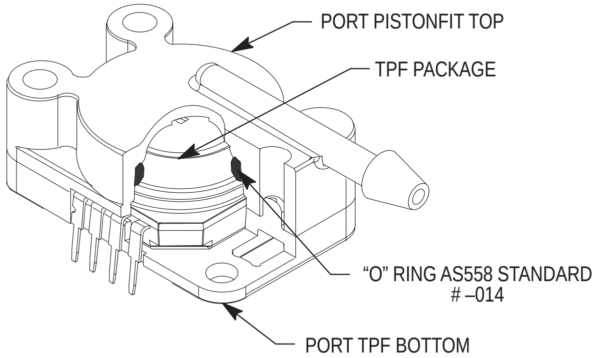


Figure 7. Top Side Piston Fit Custom Housing

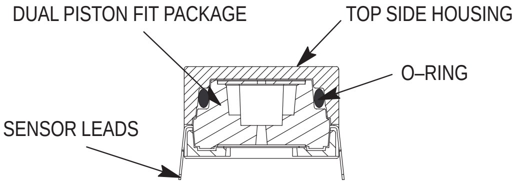


Figure 8. Top Side Piston Fit Custom Housing Cross Section

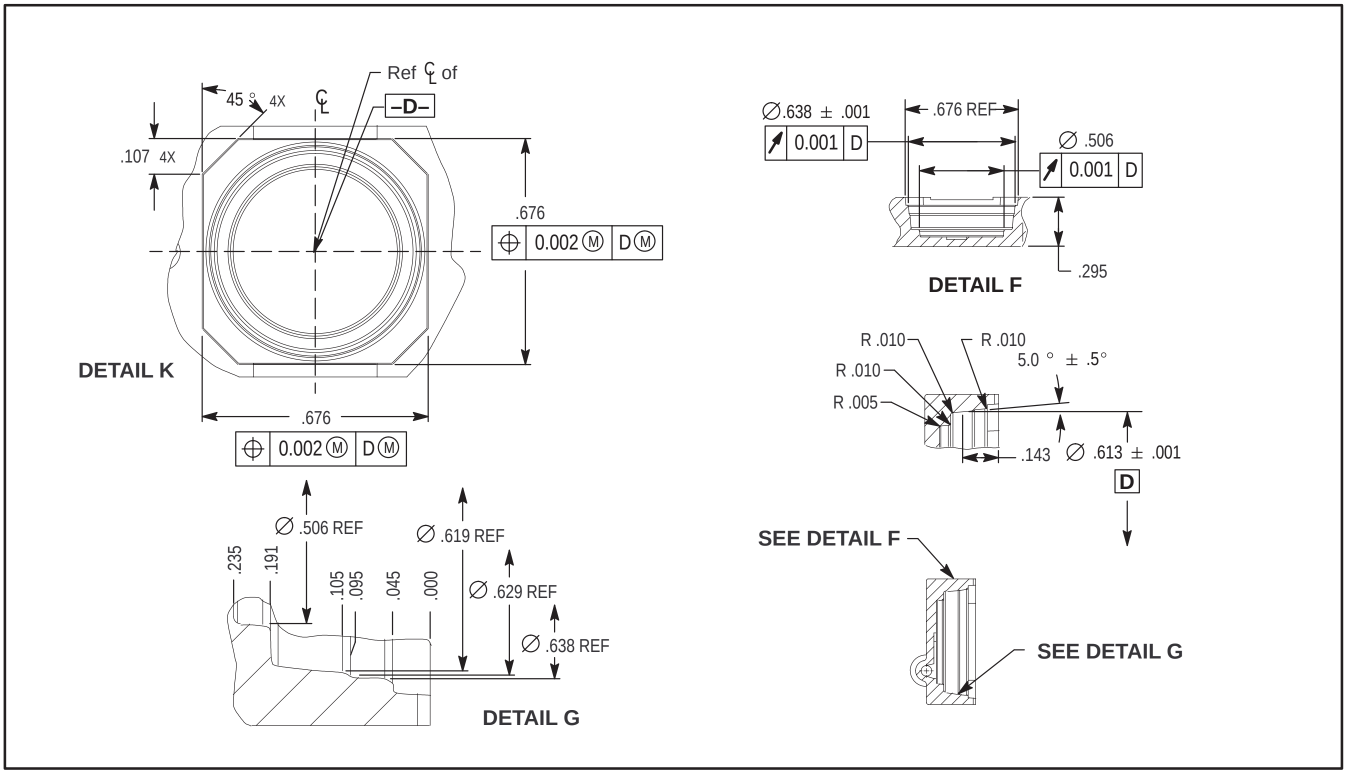


Figure 9. Top Cavity Geometry

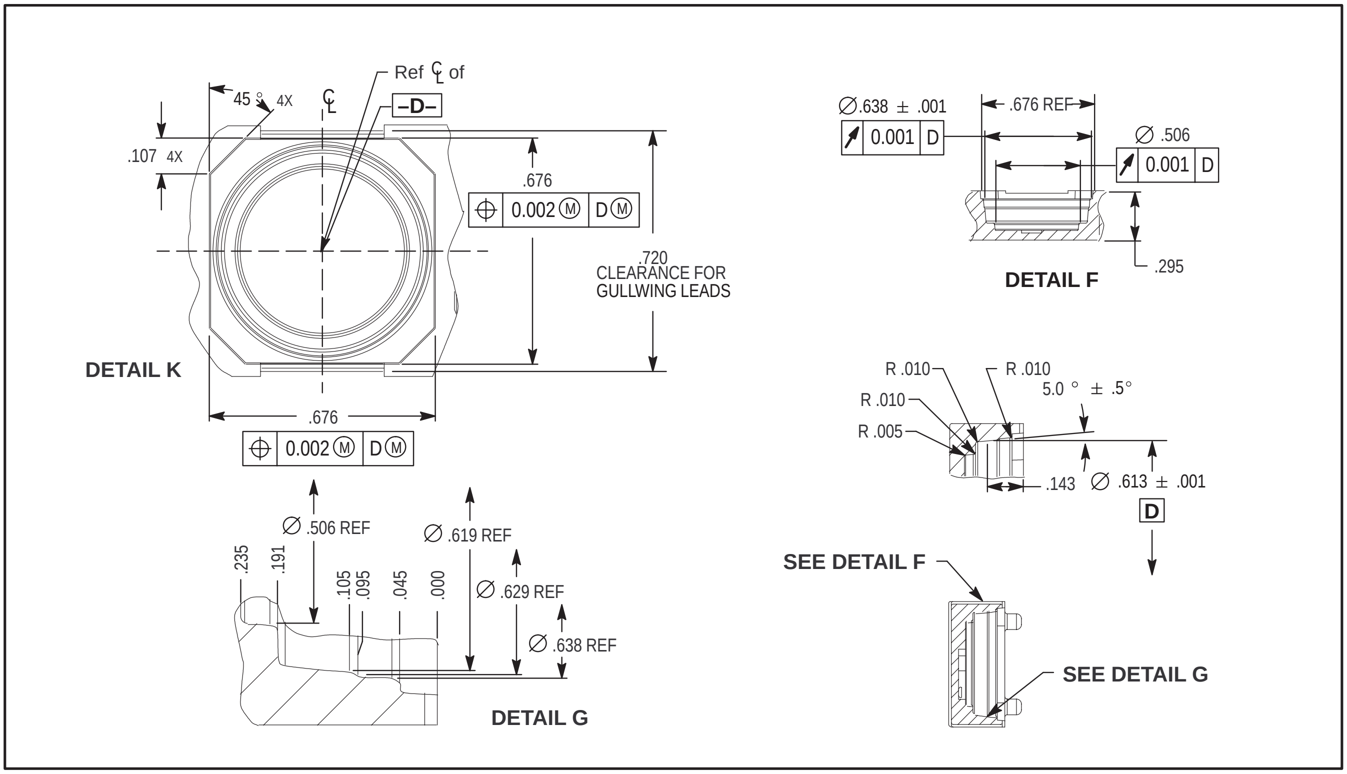


Figure 10. Dual Piston Fit Bottom Cavity Geometry

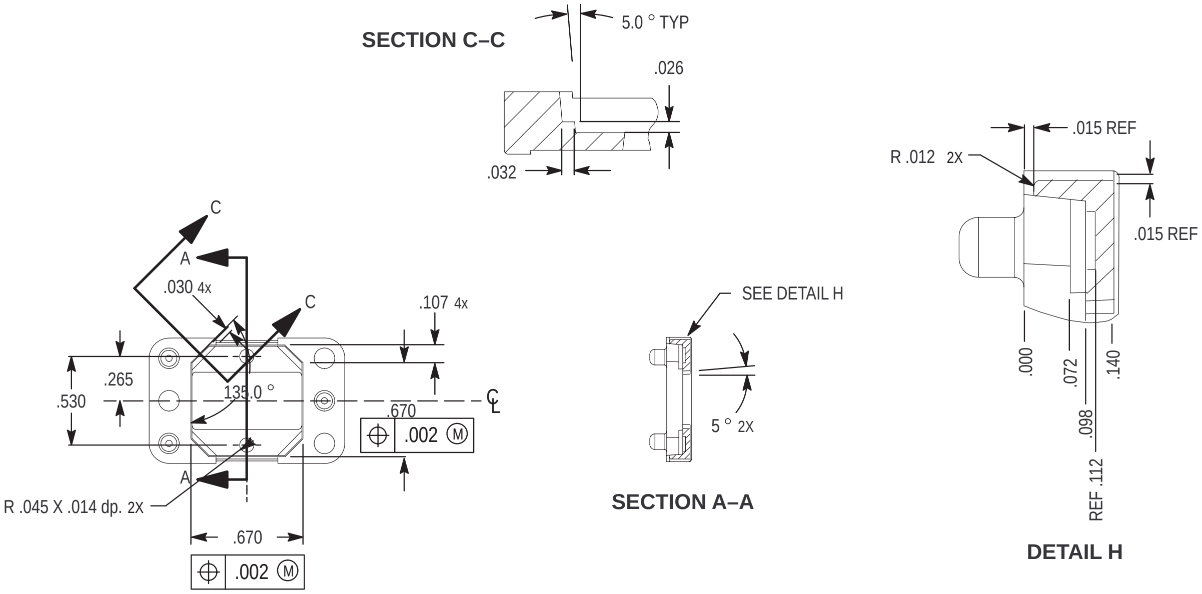


Figure 11. Top Side Piston Fit Bottom Cavity Geometry

AN1585

High-Performance, Dynamically-Compensated Smart Sensor System

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INTRODUCTION

The “front–end” sensor is the heart of any measuring system that requires a given physical condition to be transduced into an electrical variable. While the system presented in this paper has relevance to virtually all types of sensors, the case of converting a physical pressure to a voltage potential (via a micromachined semiconductor device), and subsequently to a numeric representation in the digital domain, will serve as the example presented here. Accuracy and resolution are the critical performance criteria that are native to such measuring systems.

Although all sources of measurement error cumulatively affect accuracy and resolution in a negative manner, sensor systems tend to obey the principle of “a chain only being as strong as its weakest link”. In the case of today’s sensor systems, it has become apparent that the overall system performance is typically limited by the less–than–ideal behaviors of the sensor devices. For piezoresistive pressure sensors, device–to–device variations in offset voltage and pressure sensitivity and temperature drift are the dominant sources of error.

The typical data acquisition system topology for most sensor applications includes a transducer, interface/signal conditioning circuitry associated with the transducer, an analog–to–digital converter (A/D), and a digital processing unit. In addressing the above sensor performance drawbacks, one could either pursue drastically improving the device design, semiconductor processing, and packaging of conventional sensor devices, or choose to accommodate and compensate these error–inducing variations via a radical departure from conventional signal conditioning and digital processing system designs. While the single goal of such a system design is to minimize the total measurement error, this objective has been accomplished by a three–fold approach. A system has been developed and demonstrated that eliminates device–to–device process variations, corrects for temperature dependencies of the sensor output, and optimizes the available resolution by means of a closed–loop, MCU–based, dynamic compensation system. This system philosophy and topology is presented as the final generation in an evolution that was directed at achieving a high–performance sensing system that is built around a low–cost, extremely non–ideal sensor device. In order to better facilitate an understanding of this, so–called, dynamic compensation system, a brief description of each of the prior generations of this evolution is also presented.

DEFINING RESOLUTION AND ACCURACY

Performance of a pressure sensor system is directly related to its resolution. Resolution is the smallest increment of pressure that the system can resolve — e.g. a system that measures pressure up to 10 kPa (full–scale) with a resolution of 1% of full–scale can resolve pressure increments of 0.1 kPa. Similarly, the resolution (smallest increment of voltage) of an 8–bit A/D converter (see Figure 1) with a 5 volt window (a high reference voltage of 5 V and a low reference voltage of 0 V) is

$$\text{Smallest Increment} = \frac{5.0\ \text{V}}{255\ \text{steps}} = 19.6\ \frac{\text{mV}}{\text{step}}$$

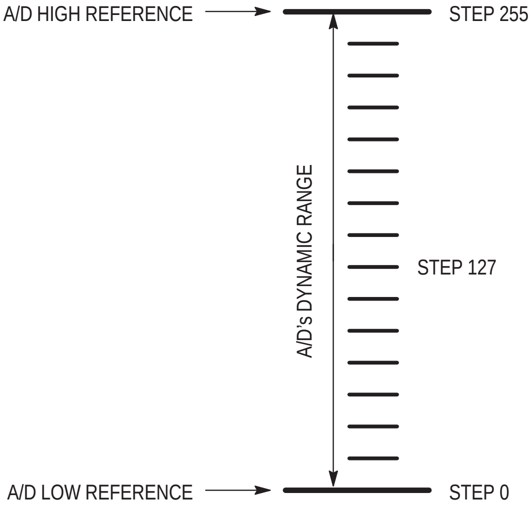

Figure 1. The 255 Digital Steps of an 8–Bit A/D

If the above system example requires 1% resolution when interfaced to an A/D, the pressure sensor signal’s span must be at least

$$\text{Signal Span} = \frac{19.6\ \text{mV}}{0.01} = 1.96\ \text{V}$$

Similarly, if the system resolution required is 0.5%, the pressure sensor signal’s span must be at least

$$\text{Signal Span} = \frac{19.6\ \text{mV}}{0.005} = 3.92\ \text{V}$$

From practical experience, an assumption is made that accuracy and resolution performance are related in the following manner:

$$\text{Accuracy} = 2 \bullet \text{Resolution}$$

This conservative relationship between accuracy and resolution is based on the fact that for an A/D, the digital quantization of the pressure signal can be plus or minus one step. Therefore, assume that it takes twice the number of steps previously determined to resolve a given minimum accuracy and incremental pressure.

HARDWARE CALIBRATION ONLY

One method of compensating a sensor's signal utilizes a customized amplifier design to position the sensor's zero–pressure offset and full–scale output at predetermined values (at a given temperature). For systems with a single regulated 5.0 V supply, the transfer function of the amplifier's output has historically and manually been adjusted for a 0.5 V zero–pressure offset and 4.5 V full–scale output (i.e. the amplifier's offset voltage pedestal and gain are modified) to "calibrate out" any of the device–to–device variations in the sensor's inherent zero–pressure offset and span. This amplified dynamic range allows for maximum static–temperature accuracy while also conservatively remaining within the linear output range of the amplifier (assuming a "rail–to–rail" op–amp is being used in the amplifier interface).

For this design, the number of A/D steps (bits) used is

$$\#\ \text{of A/D steps (bits)} = \frac{4.0\ \text{V}}{5.0\ \text{V}} \bullet 255\ \text{steps} = 200\ \text{steps}$$

Therefore the resolution is

$$\text{Resolution} = \frac{1}{200\ \text{steps}} = 0.5\%\ \text{full–scale}$$

Using the aforementioned criteria for calculating accuracy

$$\text{Accuracy} = 2 \bullet \text{Resolution} = 1.0\%\ \text{full–scale}$$

The system's resolution is depicted graphically in Figure 2, where the sensor's dynamic signal is shown to utilize 80% (4.0 V/5.0 V) of the A/D's bits.

Unfortunately, as mentioned previously, the above accuracy is defined only for static–temperature situations. Temperature fluctuations in the system can create large fluctuations and drift in the sensor signal, thereby degrading the overall sensor accuracy.

FIXED–HARDWARE INTERFACE WITH OPEN–LOOP SOFTWARE COMPENSATION

This technique performs both calibration (static–temperature) and temperature compensation of the sensor via software. Since the sensor's signal is compensated totally in software (no manual calibration of potentiometers, etc.), the fixed–value circuitry must be designed so that the sensor's signal is always within the high and low reference voltages of the A/D converter regardless of any sensor–to–sensor, component, or temperature variations in the system. To accomplish this goal a design methodology was established previously to determine the correct gain– and offset–setting resistors for the amplifier. This methodology works with the following criteria:

As discussed previously, to obtain the best signal resolution with an A/D, the sensor's amplified dynamic output voltage range should fill as much of the A/D window (difference between the A/D's high and low reference voltages) as possible without extending beyond the high and low reference voltages (i.e. the zero–pressure offset voltage must be greater than or equal to the low reference voltage, and the full–scale output voltage must be less than or equal to the high reference voltage).

The methodology designs a fixed–value circuit that optimizes performance (signal resolution) while taking into account all possible types of variation that may cause the sensor output to vary. Through this design methodology, the best sensor accuracy is achieved while ensuring through design, regardless of any system variation, that the sensor's amplified output will ALWAYS be within the saturation levels of the amplifier and the high and low reference voltages of the A/D converter.

Unfortunately, this restricts the sensor's true signal to a relatively small portion of the A/D's range since some of the bits are required for "headroom" to allow the sensor's signal to drift within the A/D window due to these sensor–to–sensor, component and temperature variations. Thus the resolution and overall accuracy are adversely affected.

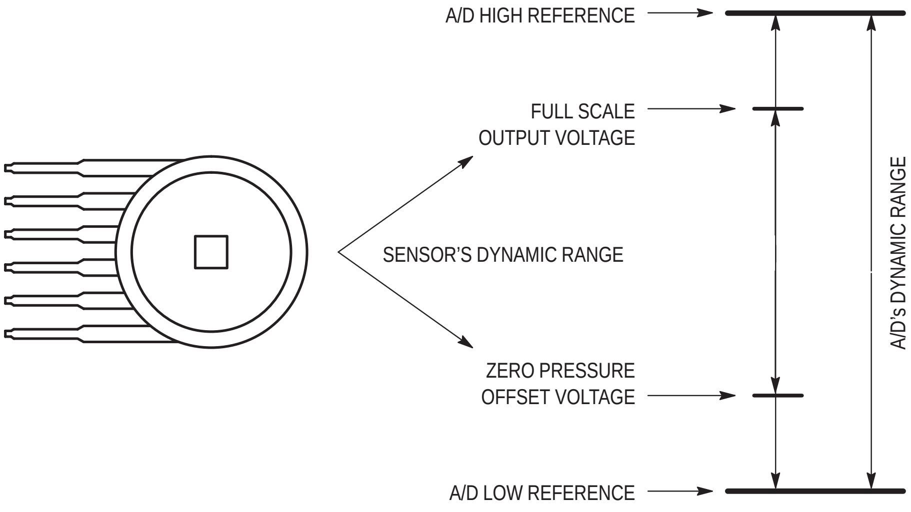

Figure 2. Sensor Dynamic Range with Hardware Calibration

However, by using the design methodology above, now the accurate open–loop software calibration and temperature compensation (with in–system temperature monitoring circuity) of the sensor's output is possible. By sampling the pressure sensor's zero–pressure offset and full–scale–pressure output and the temperature monitoring circuit's output at two different temperatures, all of the temperature, device–to–device, and circuit variations can be fairly well–compensated.

Via this technique, the same sensor used in Hardware Calibration yields a best case accuracy of 4.5% full–scale (resolution of 2.25% full–scale) over the system's operating temperature range. This translates to using 51% of the A/D's quantization intervals ("bits") for the sensor's dynamic signal (see Figure 3). The remaining 49% of the A/D's bits are used as signal drift margin ("headroom") to allow for various system tolerances (voltage regulator tolerance, resistor tolerances, etc.) and the sensor's device–to–device and temperature variations.

HYBRID SOLUTION

The previous two techniques may be combined to obtain a hybrid solution. This hybrid solution is manually–calibrated at room temperature as is the case for the Hardware Calibration. Additionally an open–loop software temperature compensation routine is implemented to maintain good accuracy over temperature. However, calculations must be performed to determine how much headroom is required to allow for temperature variations only (remember that sensor–to–sensor and component variations are eliminated with the manual calibration!) in the sensor's output to guarantee that the sensor's signal remains within the A/D window over temperature. Since headroom is required for these temperature variations, a 0.5 V to 4.5 V manual calibration may not be possible since it does not allow enough headroom for temperature drift (e.g. the zero pressure offset may be designed to be at 0.75 V and the full–scale output at 4.25 V to allow room for the sensor's signal to drift over temperature and still remain within the A/D's window). Thus, this hybrid technique will experience better accuracies over temperature than the Fixed–Hardware Interface with Open–loop Software Compensation (more bits are used for the true signal and fewer bits are used for headroom since the only headroom component is temperature variations) but will experience poorer accuracies for static–temperature cases compared to the Hardware Calibration (fewer bits are used for the sensor's dynamic range).

DYNAMIC COMPENSATION

Dynamic Compensation achieves what the other techniques cannot achieve. Dynamic Compensation allows the sensor signal to fill the entire A/D's range (Figure 4). By utilizing the entire A/D range, higher resolutions and accuracies are possible. Using Dynamic Compensation with a typical 8–bit A/D, over 90+% of the A/D's bits are used for the sensor's true signal span, resulting in accuracies better than 1% and a resolution as good as 0.4%.

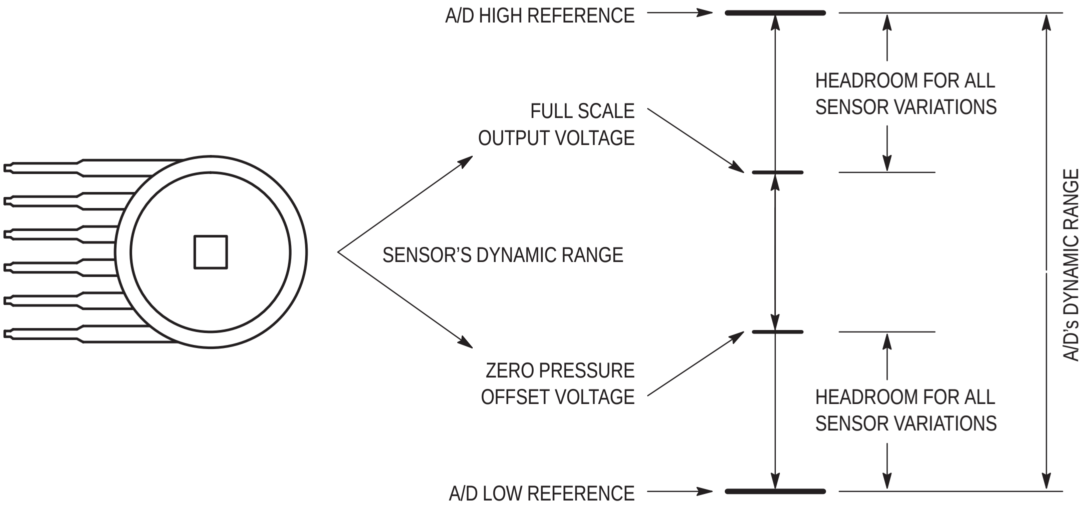

Figure 3. Sensor Dynamic Range for the Fixed–Hardware Interface with Open–Loop Software Compensation

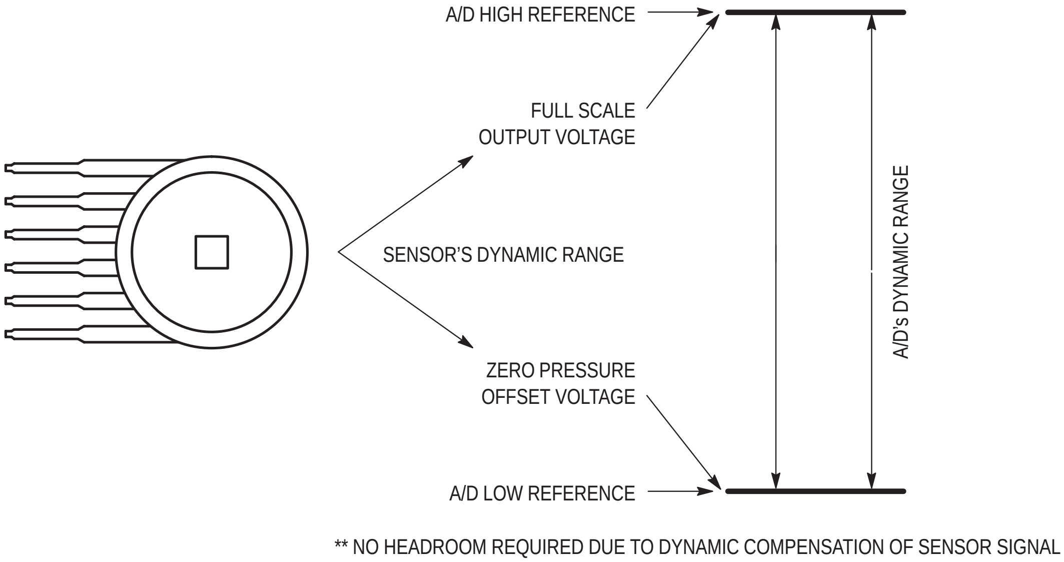

Figure 4. Sensor Dynamic Range with Dynamic Compensation

Dynamic Compensation uses a closed–loop topology to dynamically compensate the sensor signal to eliminate sensor–to–sensor and temperature variations in the sensor's output. Refer to the block diagram of the smart sensor system in Figure 5. Dynamic Compensation uses 3 digital–to–analog (D/A) feedback loops to dynamically (real–time) adjust the sensor's signal. Two D/A feedback loops dynamically maintain the desired zero–pressure offset level. The third D/A feedback loop provides dynamic gain control to adjust and maintain the desired sensor span. Because the sensor signal is dynamically compensated, no A/D bits are required to be reserved for sensor–to–sensor and temperature variations (i.e. headroom); consequently, nearly all the A/D's bits are available for the true sensor signal.

The actual circuit topology shown in Figure 6 is based around Motorola's MC68HC705P9 microcontroller. The "P9" is programmed with all the required mathematics routines to provide the dynamic compensation (the microcontroller is part of the feedback loop). The added benefits of a microcontroller–based system are the "smart sensor" features such as software calibration and temperature compensation (dynamic compensation), in–field recalibration capability, self–test and self–diagnostic features, dynamic zero (tare adjust), transducer electronic data sheet (TEDS), and serial communications interface.

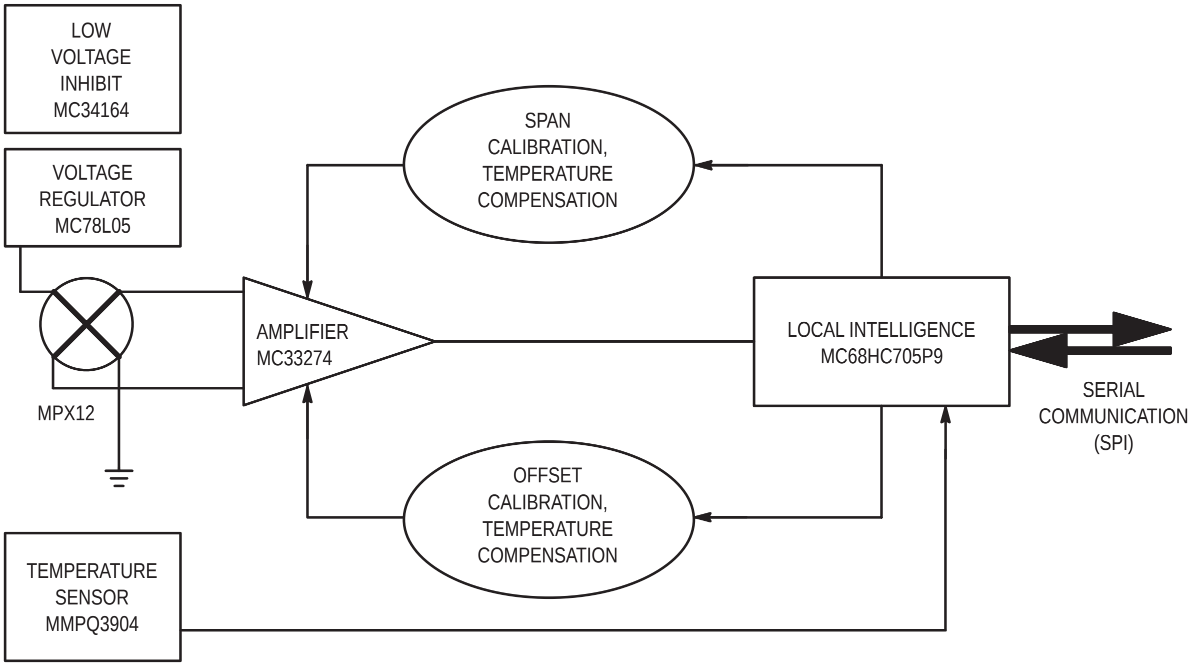

Figure 5. Dynamically–Compensated Smart Sensor Block Diagram

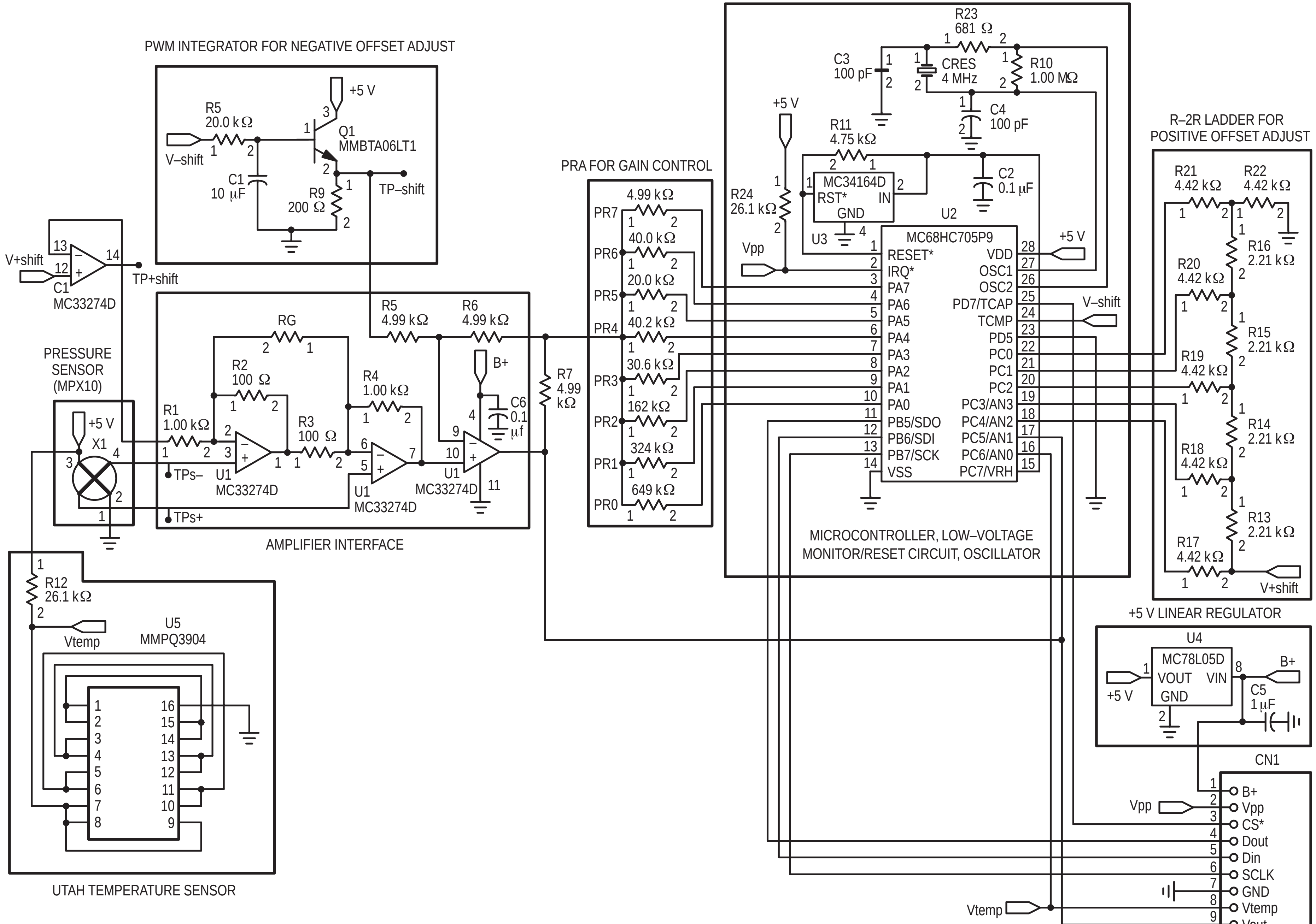

Figure 6. Dynamically–Compensated Smart Sensor Circuit Topology

SUMMARY

The three sensor calibration/compensation techniques have been discussed with the results shown in Table 1. The first technique, Hardware Calibration, uses a customized amplifier to eliminate sensor–to–sensor variations. It achieves good accuracy and resolution for static–temperature situations; however, large errors in the system result from temperature variations in the system (no temperature compensation performed). This technique also requires labor–intensive manufacturing to customize the amplifier's transfer function for a specific sensor offset and span.

The second technique, Fixed–Hardware Interface with Open–loop Software Compensation, uses fixed–value system circuitry that is designed such that the sensor's dynamic signal over all sensor–to–sensor and temperature variations will remain within the A/D's window. Then an open–loop software calibration and temperature compensation routine is implemented. The solution does provide decent compensation of the sensor signal over temperature; however, since many of the A/D's bits must be reserved for headroom, less of the A/D's bits are available for the sensor's true signal. Consequently, the accuracy and resolution capabilities of the sensor system are adversely affected.

The third technique, Dynamic Compensation, incorporates a closed–loop circuit topology to dynamically compensate the sensor signal (both the sensor's offset and sensitivity are dynamically adjusted to maintain them at their desired levels). Since the sensor signal is compensated in real–time, no headroom is required for sensor–to–sensor nor temperature variations in the system. All of the A/D's bits are available for the sensor's true signal. The result is superior resolution and accuracy.

Finally, in addition to the dynamic compensation, the system incorporates "smart sensor" features with the embedded microcontroller. These smart sensing functions include software calibration and temperature compensation (dynamic compensation), in–field recalibration capability, self–test and self–diagnostic features, dynamic zero (tare adjust), transducer electronic data sheet (TEDS), and serial communications interface.

Table 1. Results Summary

Compensation Method	**Accuracy (in % of full–scale)**	**Resolution (in % of full–scale)**
Hardware Calibration	1% (single temp. only)	0.5% (single temp. only)
Fixed–Hardware Interface	4.5%	2.25%
Dynamic Compensation	< 1%	0.4%

MOTOROLA
SEMICONDUCTOR APPLICATION NOTE

AN1586

Designing a Homemade Digital Output for Analog Voltage Output Sensors

by: Eric Jacobsen
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A digital output is more desirable than an analog output in noisy environments (e.g. automotive, washing machines, etc.) and remote sensing applications (building controls, industrial applications, etc.) because a digital signal inherently has better noise immunity compared to analog signals. Additional applications requiring a sensor with a digital output include microcontroller–based systems that have no A/D in the system or that have no A/D channels available for the sensing function. For these applications, there is no other option but a digital output to further process the signal.

Via a design example this paper shows how to easily convert an analog voltage output sensor to a digital output sensor. For the design example, each of the required circuit components is discussed in detail. While the design is applicable to analog voltage output sensors (differential or single–ended output) in general, the design example and following discussions will pertain specifically to semiconductor pressure sensors.

The digital output sensor in Figure 1. consists of the following:

- Motorola MPX2000 series pressure sensor
- A two op amp gain stage to amplify the sensor’s signal
- An integrator (i.e. a low pass filter consisting of one resistor and one capacitor)
- An LM311 comparator
- An MC68HC05P9 microcontroller with which only two pins are used: the output compare timer channel (TCMP) and one general I/O pin (the input capture timer channel, TCAP, can be used in place of the general I/O pin). Since only two of the MC68HC05P9’s pins are used, the remaining pins are available for other system functions.

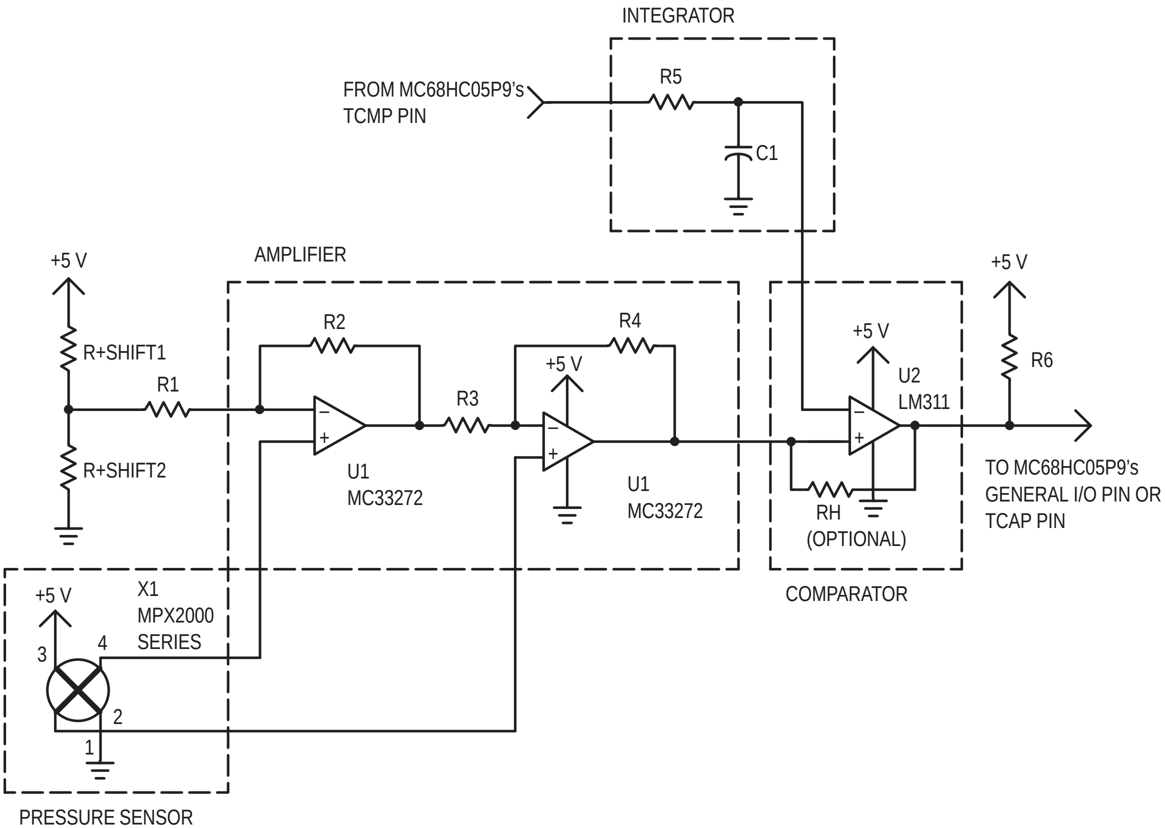

Figure 1. The Digital Output Sensor Schematic

After the discussion of the circuit components, the following system–related issues will be discussed simultaneously using the design example:

- How the system works
- Defining and designing the digital output for a desired signal resolution
- A step–by–step procedure that shows you how to digitize the signal
- A procedure to show you how to software calibrate the digital output
- Related software examples

This system, in addition to the benefits of a digital output (noise immunity, etc.), also has the following additional inherent benefits. These benefits will be addressed in more detail in the systems topics.

- The circuit topology and method of "digitizing" the sensor's analog output is very stable and accurate. The system uses the microcontroller's precise, internal, digital time base to digitize the analog signal.
- The signal resolution is user–programmable via software — i.e. the user can program whether the resolution is 8–bit, 10–bit, etc.
- The digital output is calibrated in software so that component tolerances can be nullified.
- The software required to digitize the signal requires very little CPU time and overhead.
- The required circuitry is minimal, simple, and cost–effective.

THE PRESSURE SENSOR

Motorola's MPX2000 series sensors are temperature compensated and calibrated (i.e. offset and 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 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 typically 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 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 largest output signal, it is evident that even the best case scenario will require some signal conditioning to obtain a usable signal (input to an A/D, etc.). For this specific design, an MPX2100 and 5.0 V supply are used, yielding a typical maximum sensor output of 20 mV (typical zero pressure offset is 0.0 mV and typical span is 20 mV). The sensor's output is then signal conditioned (amplified and level shifted) to provide a four volt span with a zero pressure offset of 0.5 V.

Table 1. MPX2100 Electrical Characteristics for V_S = 10 V, T_A = 25°C

Characteristic	Symbol	Min	Typ	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		1.0	mV
Sensitivity	$\Delta V/\Delta P$		0.4		mV/kPa
Linearity	—	–0.25		0.25	$\%V_{FSS}$
Temperature Effect on Span	TCV_{FSS}	–1.0		1.0	$\%V_{FSS}$
Temperature Effect on Offset	TCV_{off}	–1.0		1.0	mV

AMPLIFIER STAGE

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 amplifier incorporates level shifting capability. The amplifier has the following transfer function:

$$V_O = \left(1 + \frac{R4}{R3}\right) \bullet (V_{sensor}) + V + \text{shift}$$

where R1 = R4, R2 = R3, the gain is $1 + \frac{R4}{R3}$, V_{sensor} is the sensor's differential output ($S^+ - S^-$), and V+shift is the positive dc level shift voltage created by the resistor divider comprised of R+shift1 and R+shift2. V+shift is used to position the zero pressure offset at the desired level.

Table 2 summarizes the 1% resistor values used to obtain a four volt span with a zero pressure offset of 0.5 V (assuming the typical sensor offset and span values of 0.0 mV and 20 mV, respectively).

Table 2. Resistor Values for the MPX2100 Amplifier Design

R+shift1	R+shift2	R1	R2	R3	R4
4.99 kΩ	549 Ω	20.0 kΩ	100 Ω	100 Ω	20.0 kΩ

THE INTEGRATOR

As shown in Figure 1. , the integrator consists of a single resistor and single capacitor. A programmable duty cycle pulse train from the microcontroller is input to the integrator. Assuming that the RC time constant of the integrator is sufficiently long compared to the pulse train's frequency, the resulting output which is input to the inverting terminal of the comparator is a dc voltage that is linearly proportional to the pulse train's duty cycle, i.e.:

DC Output Voltage = Pulse Train's Duty Cycle (%) • 5 V

Where the Pulse Train's Duty Cycle is multiplied by the pulse train's logic–level one voltage value which is typically the same voltage as the microcontroller's 5 V supply.

Table 3 shows a few examples of Pulse Train Duty Cycles and the corresponding DC Output Voltage assuming a typical pulse train logic–level one value of 5 V.

Table 3. Example Pulse Train Duty Cycles and the Integrator's Corresponding dc Voltage Output

Pulse Train's Duty Cycle (%)	0	25	50	75	100
DC Output Voltage (V)	0	1.25	2.5	3.75	5

To establish a stable constant dc voltage at the integrator's output, its time constant must be sufficiently long compared to the frequency of the pulse train. However, the system resolution and thus performance are directly related to the pulse train's frequency. The design of the time constant and choice of the resistor and capacitor values is discussed in *System Design: Defining and designing for a desired signal resolution.*

COMPARATOR

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 (R6 = 5 kΩ) at the output is all that is needed to obtain a rail–to–rail output. As Figure 1. shows, the pressure sensor's amplified output voltage is input to the non–inverting terminal of the op amp and the integrator's dc output voltage is input to the inverting terminal. Therefore, when the pressure sensor's output voltage is greater than the integrator's dc output voltage, the comparator's output is high (logic–level one); conversely, when the pressure sensor's output voltage is less than the integrator's dc output voltage, the comparator's output is low (logic–level zero).

An optional resistor, RH is used as positive feedback around U2 in Figure 1 to provide a small amount of hysteresis to ensure a clean logic–level transition (prevents multiple transitions (squegging)) when the comparator's inputs are similar in value. The amount of hysteresis increases as the value of RH decreases. For this design, the value of RH is not critical but should be on the order of 100 kΩ.

THE MC68HC05P9 MICROCONTROLLER

The microcontroller for this application requires an output compare timer channel and one general I/O pin. The output compare pin is programmed to output the pulse train that is input to the integrator, and the general I/O pin is configured as an input to monitor the logic–level of the comparator's output. The remainder of this paper discusses the system and software requirements.

SYSTEM DESIGN: HOW THE SYSTEM WORKS

For any analog sensor voltage output, there's a pulse train with a duty cycle that when integrated will equal the sensor's output. Therefore, by incrementing via software the pulse train's duty cycle from 0% to 100%, there's a duty cycle that when integrated will be larger than the sensor's current voltage output. When the integrated pulse train voltage becomes larger than the sensor's output voltage, the comparator's output will change from a logic–level one to a logic–level zero. This logic–level, in turn, is monitored on the general I/O pin. The pulse train's duty cycle creating the integrated voltage that caused the comparator's logic–level transition is the digital representation of the sensor's voltage. Thus every sensor analog output voltage is mapped to a specific duty cycle. This design inherently has outstanding performance (very stable and accurate) since the digital representation of the sensor signal is created by the microcontroller's digital time base. Also the pressure measurement, made via software that first increments the pulse train's duty cycle and then determines if an edge transition occurred on the general I/O pin, is straightforward and easy.

In a calibration routine (discussed below) the sensor's output at two known pressures (e.g. zero and full–scale pressure) can be mapped to two corresponding pulse train duty cycles. Since the pressure sensor's output voltage is linear with the applied pressure, and the integrator's dc output voltage is linear with the input pulse train duty cycle, then the pulse train's duty cycle that causes the logic–level transition at the comparator's output will also be linear with the applied pressure. Thus by knowing the duty cycles for two known pressures, a linear interpolation of any duty cycle gives an accurate measurement of the current pressure. The following equation is used to interpolate the pressure measurement where the pressure units are in kPa:

$$\text{Current Pressure} = \frac{\text{Current Duty Cycle} - \text{Duty Cycle @ Zero Pressure}}{\text{Duty Cycle @ Full–Scale Pressure} - \text{Duty Cycle @ Zero Pressure}} \bullet \text{Full–Scale Pressure in kPa}$$

For example:

At zero pressure, if the pulse train's duty cycle required to cause a logic–level transition at the comparator's output is 25% and at full–scale pressure the pulse train's duty cycle is 75%, then the current pressure that corresponds to a duty cycle of 50% (required to obtain the logic–level one to logic–level zero transition at the comparator's output) is

$$\text{Current Pressure} = \frac{50\% - 25\%}{75\% - 25\%} \bullet 100\text{ kPa} = 50\text{ kPa}$$

Until now, the pulse train has been defined in terms of duty cycle. However, in practice duty cycle is calculated from the ratio of the high time to the total period of the pulse train. Therefore, there is a high time (typically in μs) of the pulse train that causes the logic–level transition of the comparator's output. The interpolation of the current pressure can then be calculated directly from the high time of the pulse train that is programmed by the user to be generated by the microcontroller's output compare pin. The equation is similar to the one above for Current Pressure:

$$\text{Current Pressure} = \frac{\text{Current High Time} - \text{High Time @ Zero Pressure}}{\text{High Time @ Full–Scale Pressure} - \text{High Time @ Zero Pressure}} \bullet \text{Full–Scale Pressure in kPa}$$

Via this equation, the digital nature of the design is revealed. The analog voltage signal has been translated into a signal in the time domain where the high time generated by the output compare pin is actually the digital time representation of the sensor's output. Since the user precisely controls the high time of the pulse train (and period) via software which is based on the accurate digital time base of the microcontroller, the digital representation of the signal is very stable and accurate. Additionally, the high accuracy of the digital representation is possible since all the user must do to digitize the signal is detect a single logic–level transition at the comparator's output.

SYSTEM DESIGN: DEFINING AND DESIGNING FOR A DESIRED SIGNAL RESOLUTION

The resolution is directly related to the period (and thus frequency) of the pulse train. In our design, the difference between the pulse train's high time at full scale pressure and the pulse train's high time and zero pressure must be 512 µs 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 MC68HC05P9 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 (discrete high–time time intervals or 8–bit resolution), the difference between the zero pressure and full scale pressure high times must be at least 2 µs x 256 = 512 µs.

To determine the pulse train's maximum frequency (or minimum period), the sensor's analog dynamic range (span) must be known. For this design, the span is 4 V. Thus the 4 V span of the sensor must translate to 512 µs of time for 8–bit resolution. But the pulse train typically has a logic–level high value of 5 V, indicating that for a 100% duty cycle or a period with all high time, the integrator's output would be 5 V; likewise for a duty cycle of 0% or a period with no high time, the output would be 0 V. Therefore 512 µs accounts for only 4 V/5 V (80%) of the pulse train's total period. See Figure 2. . To calculate the pulse train's total period, divide the 512 µs by 4/5 (0.8) to obtain the required minimum period for the pulse train of 640 µs. The reciprocal of this minimum period is the maximum frequency (1.56 kHz) of the pulse train to obtain at least 8–bit resolution.

To summarize:

The MC68HC05P9 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,

$$\frac{4\ \text{clock cycles}}{\text{timer count}} \bullet \frac{0.5\ \mu\text{s}}{\text{clock cycle}} = \frac{2\ \mu\text{s}}{\text{timer count}}$$

For 8–bit resolution,

$$\frac{2\ \mu\text{s}}{\text{timer count}} \bullet 256 \text{ timer counts} = 512\ \mu\text{s}$$

which is the required minimum time into which the sensor's 4 V span is translated.

To calculate the required period of the pulse train to yield the 0 to 5 V output (from 0% to 100% duty cycle based on the pulse train's logic–level high value of 5 V):

$$\text{Minimum Required Period} = \frac{512\ \mu\text{s for a 4 V sensor span}}{4/5 \text{ of integrator's output}} = 640\ \mu\text{s}$$

Translating this to frequency, the maximum pulse train frequency is thus

$$\frac{1}{640\ \mu\text{s}} = 1.56\ \text{kHz}.$$

The above procedure can be implemented easily for other resolution requirements (i.e. a resolution of 1%, 2%, etc.).

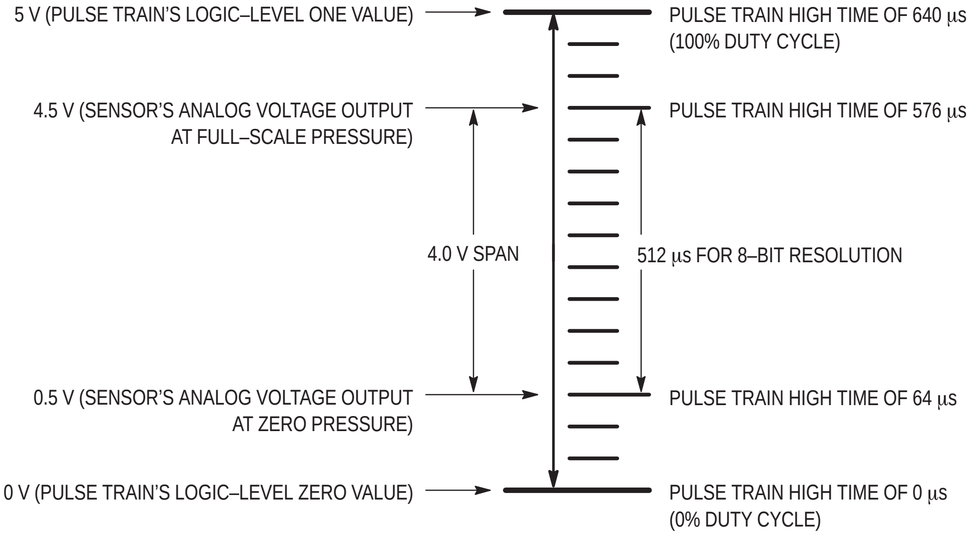

Figure 2. Designing the Pulse Train's Period for 8–Bit Resolution

Important Note:

Very small and very large high times (assuming a fixed period) are typically unattainable due to the finite amount of time it takes to generate the pulse train on the output compare pin. This amount of time will vary depending on the microcontroller's clock speed and the latency of the actual software routines implemented. Thus the sensor's analog voltage to which the integrator's dc voltage is compared must be within the possible ranges of voltages created by the integrator's input pulse train — i.e. the sensor's zero pressure offset voltage must be greater than the smallest voltage created by the integrator (corresponding to the pulse train's smallest possible high time) and the sensor's full scale output voltage must be less than the largest voltage created by the integrator (corresponding to the pulse train's largest possible high time).

After establishing the frequency of the pulse train, the RC time constant for the integrator can be determined and the resistor and capacitor value can be chosen. The RC time constant should be long compared to the period of the pulse train so that a stable dc voltage (very little ripple due to the capacitor's charging and discharging) is obtained at the output of the comparator.

Follow these steps to design the RC time constant and integrator's component values. The design example's calculations are presented simultaneously.

For the resolution desired, determine the number of volts (typically mV) that corresponds to the least significant bit (one timer count). For this design example, 8–bit resolution (256 timer counts) over the desired pressure sensor span corresponds to

$$\#\ \text{of}\ \frac{\text{mV}}{\text{timer count}}$$

$$= \frac{\text{Desired Pressure Sensor Span (V)}}{\text{Number of Timer Counts}}$$

$$= \frac{4\ \text{V}}{256\ \text{timer counts}} = \frac{15.6\ \text{mV}}{\text{timer count}}$$

Therefore the stability of the integrator's output voltage should be less than 15.6 mV (least significant bit). Choosing an RC time constant that allows a ripple of approximately one–fourth of the least significant bit is sufficient (approximately 3.9 mV).

The most ripple occurs at a 50% duty cycle pulse train. For this design the entire period is 640 µs. 50% duty cycle indicates a high time (and low time) of 320 µs. Furthermore, the capacitor should discharge no more than approximately 3.9 mV (defined as ΔV) over the 320 µs. The following equation is used to calculate the value for RC:

$$V(t) = V_{\text{initial}} - \Delta V = \text{Pulse Train Logic–level one value} \bullet \text{Duty Cycle} \bullet e^{\frac{t}{RC}}$$

where V_{initial} = Pulse Train Logic–level one value • Duty Cycle and ΔV is the voltage discharge of the capacitor.

Solving for RC:

$$RC = -\frac{t}{\ln\left(\dfrac{V(t)}{\text{Pulse Train Logic–level one value} \bullet \text{Duty Cycle}}\right)}$$

$$= \frac{320\ \mu\text{s}}{\ln\left(\dfrac{2.5\ \text{V} - 3.9\ \text{mV}}{5\ \text{V} \bullet 50\%}\right)} = 0.205\ \text{s}$$

Finally, choose the values of the resistor and capacitor. A typical resistor value is on the order of a tens of kΩ. The resistor's value can be higher (hundreds of kΩ) but care must be taken to avoid increased thermal noise.

For this design, the resistor value is chosen to be 49.9 kΩ (1% resistor). The capacitor's value is readily calculated to be

$$C = \frac{0.205\ \text{s}}{49.9\ \text{k}\Omega} = 4.1\ \mu\text{F}$$

Choose the values of the resistor and capacitor so that the actual time constant is equal to or greater than the calculated time constant.

Note: Be aware that temperature variations can create errors in the system (thus reducing system performance); therefore, be sure to use low temperature coefficient resistors, capacitors, etc.

SYSTEM DESIGN: STEP–BY–STEP PROCEDURE FOR PRESSURE MEASUREMENT AND CALIBRATION

To measure pressure (note: there are other measurement algorithms that can be performed that in some cases may be more acceptable (see below, Additional notes)):

1. Start with a pulse train with the minimum high time feasible with the system's microcontroller. Pulse train should run at a frequency equal to or less than the frequency calculated above.
2. Make sure the general I/O pin's input is high (sensor's output voltage is greater than the integrator's output voltage).
3. Increment the high time of the pulse train by one timer count.
4. Check the general I/O pin to see if its input is low (sensor's output voltage has become less than the integrator's output voltage).
5. If the general I/O pin is reading a logic–level zero, store in memory the high time of the pulse train as the current pressure high time reading that created the logic–level transition in the comparator's output.
6. If the general I/O pin is reading a logic–level one, go back to step 3 and repeat.
7. Using the equation "Current Pressure = ..." shown above, calculate the current pressure (assuming the system has already been calibrated).
8. Repeat steps 1 through 7 for additional pressure measurements.

To calibrate the system:

At zero and full scale pressures, perform the above 8 step pressure measurement routine. Store the appropriate pulse train high times corresponding to zero and full scale pressure. These high times will be used to calculate the current pressure as mentioned in Step 7 above.

SOFTWARE EXAMPLES TO GENERATE PULSE TRAIN ON OUTPUT COMPARE TIMER CHANNEL

The following software examples are written in assembly language for the MC68HC05P9 (the code is applicable to any HC05 series microcontroller with TCMP pin).

```
* GENERATES THE PULSE TRAIN ON TCMP
GEN
     LDA   PERIODL           * LOW BYTE OF THE PERIOD
     SUB   HIGHTIMEL         * LOW BYTE OF THE HIGHTIME
     STA   LOWTIMEL          * LOW BYTE OF THE LOWTIME
     LDA   PERIODH           * HIGH BYTE OF THE PERIOD
     SBC   HIGHTIMEH         * HIGH BYTE OF THE HIGHTIME
     STA   LOWTIMEH          * HIGH BYTE OF THE LOWTIME
     RTS

* INCREASE THE HIGH TIME (DUTY CYCLE) OF THE PULSE TRAIN
INCPW
     LDA   HIGHTIMEL
     ADD   #$01              * INCREMENT PULSE WIDTH BY 2 µs
     STA   HIGHTIMEL
     LDA   HIGHTIMEH
     ADC   #$0
     STA   HIGHTIMEH
     RTS

* DECREASE THE HIGH TIME (DUTY CYCLE) OF THE PULSE TRAIN
DECPW
     LDA   HIGHTIMEL
     SUB   #$01              * DECREMENT PULSE WIDTH BY 2 µs
     STA   HIGHTIMEL
     LDA   HIGHTIMEH
     SBC   #$0
     STA   HIGHTIMEH
     JSR   GEN
     RTS

* INCREASE THE PERIOD (DECREASE FREQUENCY) OF THE PULSE TRAIN
INCPER
     LDA   PERIODL
     ADD   #$05              * INCREMENT PERIOD BY 10 µs
     STA   PERIODL
     LDA   PERIODH
     ADC   #$0               * ADJUST HIGH BYTE OF PERIOD IF CARRY
     STA   PERIODH
     JSR   GEN
     RTS

* DECREASE THE PERIOD (INCREASE FREQUENCY) OF THE PULSE TRAIN
DECPER
     LDA   PERIODL
     SUB   #$05              * DECREMENT PERIOD BY 10 µs
     STA   PERIODL
     LDA   PERIODH
     SBC   #$0               * ADJUST HIGH BYTE OF PERIOD IF BORROW
     STA   PERIODH
     JSR   GEN
     RTS

TIMER                        * INTERRUPT SERVICE ROUTINE FOR TCMP
     LDA   TSR               * CLEAR OCF FLAG IN TSR
     LDA   TCMPL

     BRSET 0,TCR,ADDHIGH     * HIGH OR LOW PULSE TIME NEEDED?

ADDLOW
     BSET  0,TCR             * ADD LOW TIME TO THE PULSE TRAIN
     LDA   LOWTIMEL
     ADD   TCMPL
     TAX
     LDA   TCMPH
     ADC   LOWTIMEH
     STA   TCMPH
     STX   TCMPL
     RTI

ADDHIGH
     BCLR  0,TCR             * ADD HIGH TIME TO THE PULSE TRAIN
     LDA   HIGHTIMEL
     ADD   TCMPL
     TAX
     LDA   TCMPH
     ADC   HIGHTIMEH
     STA   TCMPH
     STX   TCMPL
     RTI
```

ADDITIONAL NOTES

This type of A/D conversion method (one type of A/D conversion) inherently takes a finite period of time to digitize the signal (incrementing the pulse train's high time while polling the general I/O pin); however, for most sensor applications the physical phenomenon being measured does not change quickly (<1 ms) enough to warrant an ultra–fast A/D conversion process.

An additional advantage of this design is that the measurement process may be performed only as necessary, keeping the CPU processing time and overhead minimal.

If an input capture timer channel (TCAP) is available, it may be configured to detect the logic–level one to logic–level zero transition of the comparator's output. When the edge transition occurs, an interrupt service routine is executed that stores the pulse train's high times, calculates the current pressure, etc. This is typically more convenient and eliminates the need to poll a general I/O pin every time the pulse train's high time is incremented (interrupt subroutine is executed only when the edge transition occurs).

SUMMARY

Shown above is a minimal component design that can convert an analog sensor's output into a digital output. Each major subsystem (sensor, amplifier, integrator, comparator, and microcontroller) is explained in detail simultaneously with a design example. Next the system operation is discussed including how it works and how to design a desired system resolution. Finally a flow chart for measuring and calibrating the sensor's output is presented.

MOTOROLA
SEMICONDUCTOR APPLICATION NOTE

AN1611

Impact and Tilt Measurement Using Accelerometer

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INTRODUCTION

This application note describes the concept of measuring impact and tilt of an object using an accelerometer, microcontroller hardware/software and a liquid crystal display. Due to the wide frequency response of the accelerometer from d.c. to 400Hz, the device is able to measure both the static acceleration from the Earth's gravity and the shock or vibration from an impact. This design uses a 40G accelerometer (Motorola P/N: MMAS40G10S) yields a minimum acceleration range of –40G to +40G.

CONCEPT OF TILT MEASUREMENT

To measure the tilt or orientation of an object, the accelerometer must be able to response to d.c. force. This is not possible for technology like piezoelectric which does not have any d.c. response. As shown in Figure 1, the accelerometer should be mounted in such a way that the axis of sensitivity is parallel to the surface of the Earth. In this way, the output of the accelerometer will vary from –1.0g to +1.0g when the angle θ is tilted from –90° to +90°. The relationship is shown by the equation below:

$$V_{OUT} = V_{off} + \left(\frac{\Delta V}{\Delta G} \times 1.0G \times \sin\theta\right)$$

where:

V_{OUT} = Output of accelerometer
V_{off} = Zero accelerometer
$\Delta V/\Delta G$ = Sensitivity
1.0G = Earth's gravity
θ = Tilt angle

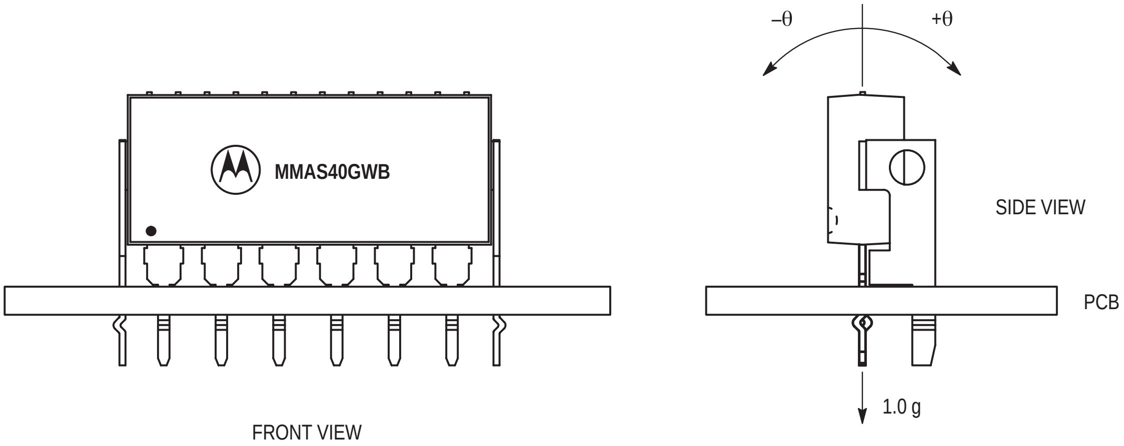

Figure 1. Orientation of Accelerometer

To measure this small changes (i.e. less than 1g over the full span of 40g) in tilt measurement, many sampling data are taken for averaging to eliminate the high frequency component because a tilt information is basically consisting of low frequency component in the order of a few hertz or less. Otherwise, an external low pass filter may be necessary to filter off the a.c. component in order to extract the dc component. In this design, the resolution is 0.5g due to the limitation of the 8–bit analog–to–digital converter which yields 19.6 mV/step. This is approximately equal to 0.5g as the sensitivity of MMAS40G is 40 mV/g. However, in the presence of an impact, the signal must be processed in a different way as the tilt measurement because peak impact information is a high frequency component.

To measure the tilt angle using the equation, we must first solve the sine function. In ‘C’ language programming, we could use the *asin()* function available in the libraries. However in assembly language, it could be solved via a look–up table or Trigonometric series given by the equation below.

$$\theta = \sin^{-1}\chi = \chi + \frac{\chi^3}{6} + \frac{1 \times 3}{2 \times 4}\frac{\chi^5}{5} + \frac{1 \times 3 \times 5}{2 \times 4 \times 6}\frac{\chi^7}{7} + \ldots\ldots$$

Alternatively, for tilt angle less than 10°, the following approximation can be used where θ is in radian.

$$\sin\theta = \theta$$

CONCEPT OF IMPACT MEASUREMENT

During an impact, the accelerometer will measure the deceleration experienced by the object from dc to 400Hz. Normally, the peak impact pulse is in the order of a few miniseconds. Figure 2 shows a typical crash waveform of a toy car having a stiff bumper.

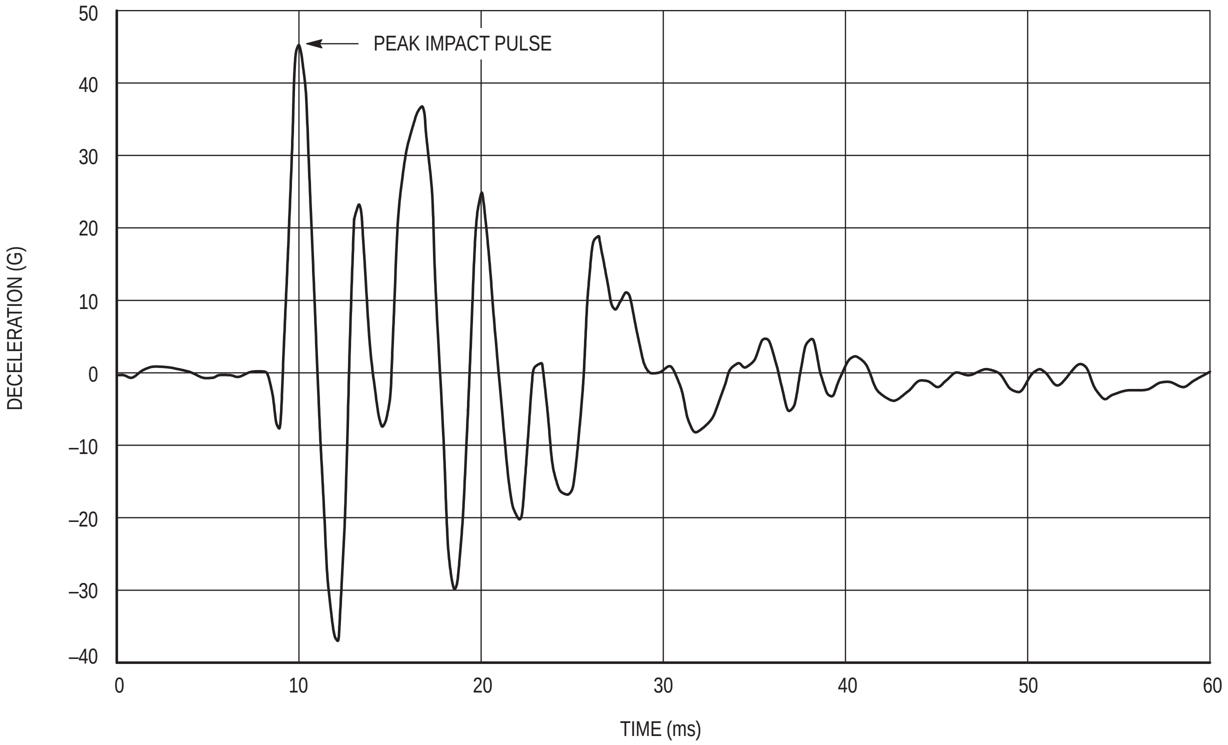

Figure 2. Typical Crash Pattern

To detect the peak of this signal, the sampling rate must be at least twice the signal frequency according to Nyquist Sampling Criterion. From the graph, the signal frequency is approximated to be 300Hz. This implies that the sampling rate must be at least 600Hz. In this design, 32 samples are taken for averaging to eliminate the random noise of the accelerometer. The total time taken for acquire 32 samples and averaging is about 650 µs which corresponds to 1.5 kHz of sampling frequency. Typically, the accelerometer sampling time is in the order of 500 µs.

In this design, the vehicle deceleration is measured and compared against a pre–set thresholds of 7g to determine if an LED is required to turn on or not. At the same time, the peak deceleration is display on the LCD for 3 seconds. Presently, most of the airbag system executes a crash discrimination once the threshold is exceeded. The software routine would then monitor the accelerometer to determine the severity of the crash and the need to deploy bags and/or seat belt pretentioners. The algorithm varies from design to design and is typically set to above certain energy threshold before it calls for a bag deployment. For instance, some design makes use of the equation below which integrates acceleration into velocity signal or jerk of the driver over a period of time. Many other parameters (e.g. change in energy of the vehicle) may also be used at the same time because one parameter is good for one type of crash while the other are good for other types of crashes.

$$\Delta V = \int_0^{T1} a(t)dt$$

HARDWARE DESCRIPTION AND OPERATION

Since MMAS40G is fully signal–conditioned by its internal op–amp and temperature compensation, the output of the accelerometer can be directly interfaced with an analog–to–digital (A/D) converter for digitization. A filter consists of one RC network should be added if the connection between the output of the accelerometer and the A/D converter is a long track or cable. This stray capacitance may change the position of the internal pole which would drive the output amplifier of the accelerometer into oscillation or unstability. In this design, the cut–off frequency is chosen to be 15.9 kHz which also acts as an anti–alias filter for the A/D converter. The 3dB frequency can be approximated by the following equation.

$$f_{-3dB} = \frac{1}{2\pi RC}$$

Referring to the schematic, Figure 3, the MMAS40G accelerometer is connected to PORT D bit 5 and the output of the amplifier is connected to PORT D bit 6 of the microcontroller. This port is an input to the on–chip 8–bit analog–to–digital (A/D) converter. Typically, the accelerometer provides a signal output to the microprocessor of approximately 0.3 Vdc at –55g to 4.7 Vdc at +55g of acceleration. However, Motorola only guarantees the accuracy within ±40g range. Using the same reference voltage for the A/D converter and accelerometer minimizes the number of additional components, but does sacrifice resolution. The resolution is defined by the following:

$$\text{count} = \frac{V_{out}}{5} \times 255$$

The count at 0g = [2.5/5] × 255 $\propto$ 128
The count at +25g = [3.5/5] × 255 $\propto$ 179
The count at –25g = [1.5/5] × 255 $\propto$ 77

Therefore the resolution 0.5g/count

The output of the accelerometer is ratiometric to the voltage applied to it. The accelerometer and the reference voltages 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 (LCD) is directly driven from I/O ports A, B, and C on the microcontroller. The operation of a LCD requires that the data and backplane (BP) 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. Other than the LCD, one light emitting diode (LED) are connected to the pulse length converter (PLM) of the microcontroller. This LED will lights up for 3 seconds when an impact greater or equal to 7g is detected.

The microcontroller section of the system requires certain support hardware to allow it to function. The MC34064P–5 provides an undervoltage sense function which is used to reset the microprocessor at system power–up. The 4 MHz crystal provides the external portion of the oscillator function for clocking the microcontroller and provides a stable base for time bases functions, for instance calculation of pulse rate.

SOFTWARE DESCRIPTION

Upon power–up the system, the LCD will display CAL for approximately 4 seconds. During this period, the output of the accelerometer are sampled and averaged to obtain the zero offset voltage or zero acceleration. This value will be saved in the RAM which is used by the equation below to calculate the impact in term of g–force. One point to note is that the accelerometer should remain stationary during the zero calibration.

$$\text{Impact} = [\text{count} - \text{count}_{offset}] \times \text{resolution}$$

In this software program, the output of the accelerometer is calculated every 650µs. During an impact, the peak deceleration is measured and displayed on the LCD for 3 seconds before resetting it to zero. In the mean time, if a higher impact is detected, the value on the LCD will be updated accordingly.

However, when a low g is detected (e.g. 1.0g), the value will not be displayed. Instead, more samples will be taken for further averaging to eliminate the random noise and high frequency component. Due to the fact that tilting is a low g and low frequency signal, large number of sampling is preferred to avoid unstable display. Moreover, the display value is not hold for 3 seconds as in the case of an impact.

Figure 4 is a flowchart for the program that controls the system.

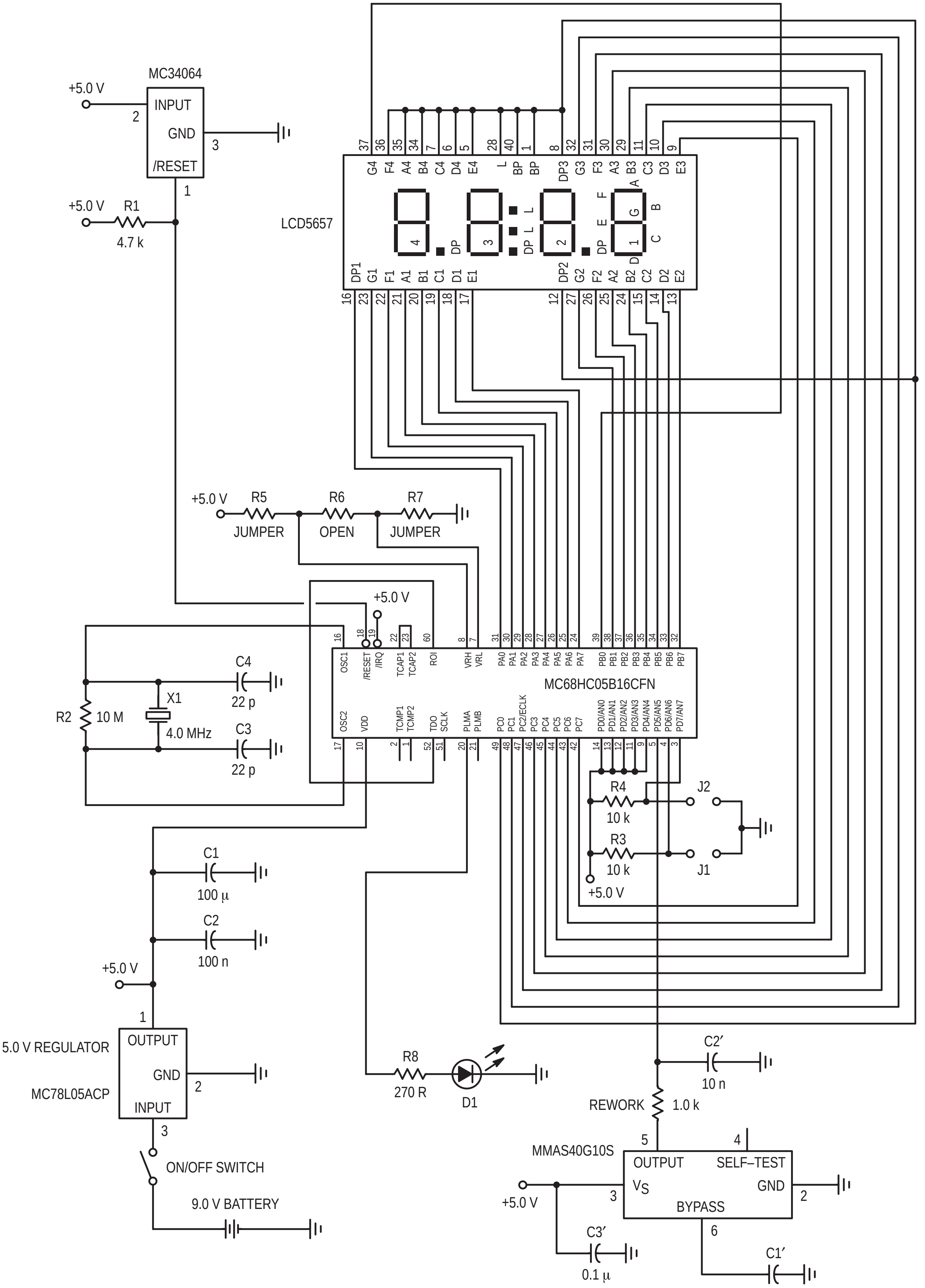

Figure 3. Impact Measurement Schematic Drawing

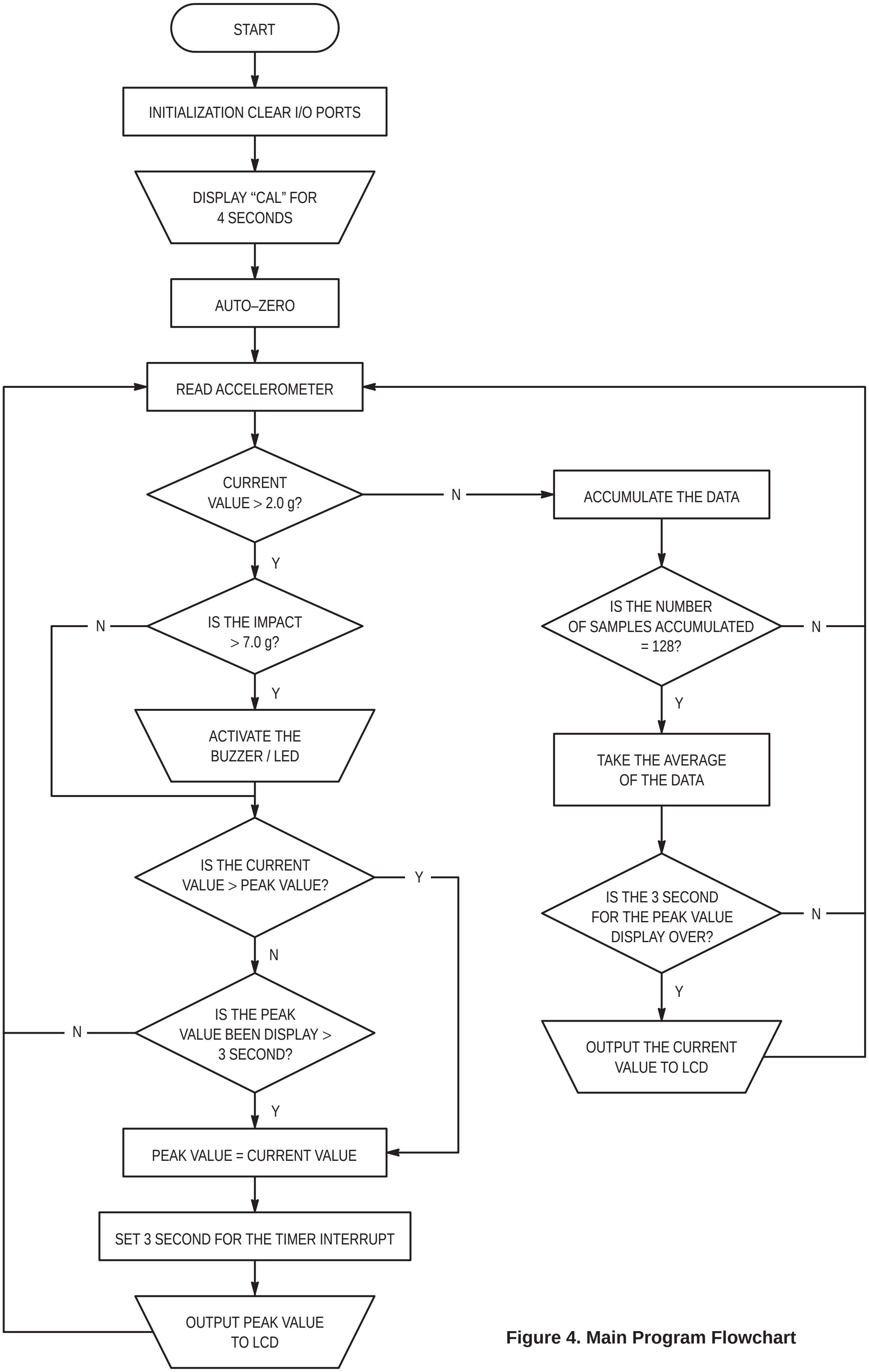

Figure 4. Main Program Flowchart

SOFTWARE SOURCE/ASSEMBLY PROGRAM CODE

```
******************************************************************************
*                                                                            *
*                   Accelerometer Demo Car Version 2.0                       *
*                                                                            *
*   The following code is written for MC68HC705B16 using MMDS05 software     *
*   Version 1.01                                                             *
*   CASM05 – Command line assembler Version 3.04                             *
*   P & E Microcomputer Systems, Inc.                                        *
*                                                                            *
*                         Written by : C.S. Chua                             *
*                             29 August 1996                                 *
*                                                                            *
*                                                                            *
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*   harmless against all claims, costs, damages, expenses and reasonable     *
*   attorney fees arising out of, directly or indirectly, any claim of       *
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*                                                                            *
******************************************************************************
******************************************************************************
*                                                                            *
*                           Software Description                             *
*                                                                            *
*   This software is used to read the output of the accelerometer MMAS40G    *
*   and display it to a LCD as gravity force. It ranges from –55g to +55g    *
*   with 0g as zero acceleration or constant velocity. The resolution is     *
*   0.5g.                                                                    *
*                                                                            *
*   The program will read from the accelerometer and hold the maximum        *
*   deceleration value for about 3.0 seconds before resetting. At the same   *
*   time, the buzzer/LED is activated if the impact is more than 7.0g.       *
*   However, if the maximum deceleration changes before 3.0 seconds, it      *
*   will update the display using the new value. Note that positive value    *
*   implies deceleration whereas negative value implies acceleration         *
*                                                                            *
******************************************************************************
******************************************
*                                        *
*            Initialisation              *
*                                        *
******************************************
PORTA        EQU     $00           ; Last digit
PORTB        EQU     $01           ; Second digit (and negative sign)
PORTC        EQU     $02           ; First digit (and decimal point)
ADDATA       EQU     $08           ; ADC Data
ADSTAT       EQU     $09           ; ADC Status
PLMA         EQU     $0A           ; Pulse Length Modulator (Output to Buzzer)
MISC         EQU     $0C           ; Miscellaneous Register (slow/fast mode)
TCONTROL     EQU     $12           ; Timer control register
TSTATUS      EQU     $13           ; Timer Status Register
OCMPHI1      EQU     $16           ; Output Compare Register 1 High Byte
```

```
OCMPLO1      EQU     $17           ; Output Compare Register 1 Low Byte
TCNTHI       EQU     $18           ; Timer Count Register High Byte
TCNTLO       EQU     $19           ; Timer Count Register Low Byte
OCMPHI2      EQU     $1E           ; Output Compare Register 2 High Byte
OCMPLO2      EQU     $1F           ; Output Compare Register 2 Low Byte
******************************************
*                                        *
*           User-defined RAM             *
*                                        *
******************************************
SIGN         EQU     $54           ; Acceleration (-) or deceleration (+)
PRESHI2      EQU     $55           ; MSB of accumulated acceleration
PRESHI       EQU     $56
PRESLO       EQU     $57           ; LSB of accumulated acceleration
PTEMPHI      EQU     $58           ; Acceleration High Byte (Temp storage)
PTEMPLO      EQU     $59           ; Acceleration Low Byte (Temp storage)
ACCHI        EQU     $5A           ; Temp storage of acc value (High byte)
ACCLO        EQU     $5B           ;                           (Low byte)
ADCOUNTER    EQU     $5C           ; Sampling Counter
AVERAGE_H    EQU     $5D           ; MSB of the accumulated data of low g
AVERAGE_M    EQU     $5E
AVERAGE_L    EQU     $5F           ; LSB of the accumulated data of low g
SHIFT_CNT    EQU     $60           ; Counter for shifting the accumulated data
AVE_CNT1     EQU     $61           ; Number of samples in the accumulated data
AVE_CNT2     EQU     $75
TEMPTCNTHI   EQU     $62           ; Temp storage for Timer count register
TEMPTCNTLO   EQU     $63           ; Temp storage for Timer count register
DECHI        EQU     $64           ; Decimal digit high byte
DECLO        EQU     $65           ; Decimal digit low byte
DCOFFSETHI   EQU     $66           ; DC offset of the output (high byte)
DCOFFSETLO   EQU     $67           ; DC offset of the output (low byte)
MAXACC       EQU     $68           ; Maximum acceleration
TEMPHI       EQU     $69
TEMPLO       EQU     $6A
TEMP1        EQU     $6B           ; Temporary location for ACC during delay
TEMP2        EQU     $6C           ; Temporary location for ACC during ISR
DIV_LO       EQU     $6D           ; No of sampling (low byte)
DIV_HI       EQU     $6E           ; No of sampling (high byte)
NO_SHIFT     EQU     $6F           ; No of right shift to get average value
ZERO_ACC     EQU     $70           ; Zero acceleration in no of ADC steps
HOLD_CNT     EQU     $71           ; Hold time counter
HOLD_DONE    EQU     $72           ; Hold time up flag
START_TIME   EQU     $73           ; Start of count down flag
RSHIFT       EQU     $74           ; No of shifting required for division
             ORG     $300          ; ROM space 0300 to 3DFE (15,104 bytes)
             DB      $FC           ; Display ”0”
             DB      $30           ; Display ”1”
             DB      $DA           ; Display ”2”
             DB      $7A           ; Display ”3”
             DB      $36           ; Display ”4”
             DB      $6E           ; Display ”5”
             DB      $EE           ; Display ”6”
             DB      $38           ; Display ”7”
             DB      $FE           ; Display ”8”
             DB      $7E           ; Display ”9”
HUNDREDHI    DB      $00           ; High byte of hundreds
HUNDREDLO    DB      $64           ; Low byte of hundreds
TENHI        DB      $00           ; High byte of tens
TENLO        DB      $0A           ; Low byte of tens
******************************************
*                                        *
*   Program starts here upon hard reset  *
*                                        *
******************************************
RESET        CLR     PORTC         ; Port C = 0
             CLR     PORTB         ; Port B = 0
             CLR     PORTA         ; Port A = 0
             LDA     #$FF
             STA     $06           ; Port C as output
             STA     $05           ; Port B as output
             STA     $04           ; Port A as output
             LDA     TSTATUS       ; Dummy read the timer status register
             CLR     OCMPHI2       ; so as to clear the OCF
             CLR     OCMPHI1
             LDA     OCMPLO2
             JSR     COMPRGT
             CLR     START_TIME
```

```
             LDA     #$40          ; Enable the output compare interrupt
             STA     TCONTROL
             CLI                   ; Interrupt begins here
             LDA     #$CC          ; Port C = 1100 1100   Letter ”C”
             STA     PORTC
             LDA     #$BE          ; Port B = 1011 1110   Letter ”A”
             STA     PORTB
             LDA     #$C4          ; Port A = 1100 0100   Letter ”L”
             STA     PORTA
             LDA     #16
IDLE         JSR     DLY20         ; Idling for a while (16*0.125 = 2 sec)
             DECA                  ; for the zero offset to stabilize
             BNE     IDLE          ; before perform auto–zero
             LDA     #$00          ; Sample the data 32,768 times and take
             STA     DIV_LO        ; the average 8000 H = 32,768
             LDA     #$80          ; Right shift of 15 equivalent to divide
             STA     DIV_HI        ; by 32,768
             LDA     #!15          ; Overall sampling time = 1.033 s)
             STA     NO_SHIFT
             JSR     READAD        ; Zero acceleration calibration
             LDX     #5            ; Calculate the zero offset
             LDA     PTEMPLO       ; DC offset = PTEMPLO * 5
             STA     ZERO_ACC
             MUL
             STA     DCOFFSETLO    ; Save the zero offset in the RAM
             TXA
             STA     DCOFFSETHI
             CLR     HOLD_CNT
             LDA     #$10         ; Sample the data 16 times and take
             STA     DIV_LO       ; the average 0100 H = 16
             LDA     #$00         ; Right shift of 4 equivalent to divide
             STA     DIV_HI       ; by 16
             LDA     #$4          ; Overall sampling time = 650 us
             STA     NO_SHIFT
             LDA     ZERO_ACC     ; Display 0.0g at the start
             STA     MAXACC
             JSR     ADTOLCD
             CLR     START_TIME
             CLR     AVE_CNT1
             CLR     AVE_CNT2
             CLR     SHIFT_CNT
             CLR     AVERAGE_L
             CLR     AVERAGE_M
             CLR     AVERAGE_H
REPEAT       JSR     READAD        ; Read acceleration from ADC
             LDA     ZERO_ACC
             ADD     #$04
             CMP     PTEMPLO
             BLO     CRASH         ; If the acceleration < 2.0g
             LDA     PTEMPLO       ; Accumulate the averaged results
             ADD     AVERAGE_L     ; for 128 times and take the averaging
             STA     AVERAGE_L     ; again to achieve more stable
             CLRA                  ; reading at low g
             ADC     AVERAGE_M
             STA     AVERAGE_M
             CLRA
             ADC     AVERAGE_H
             STA     AVERAGE_H
             LDA     #$01
             ADD     AVE_CNT1
             STA     AVE_CNT1
             CLRA
             ADC     AVE_CNT2
             STA     AVE_CNT2
             CMP     #$04
             BNE     REPEAT
             LDA     AVE_CNT1
             CMP     #$00
             BNE     REPEAT
SHIFTING     INC     SHIFT_CNT     ; Take the average of the 128 samples
             LSR     AVERAGE_H
             ROR     AVERAGE_M
             ROR     AVERAGE_L
             LDA     SHIFT_CNT
             CMP     #$0A
             BLO     SHIFTING
             LDA     AVERAGE_L
```

```
             STA     PTEMPLO
             LDA     HOLD_CNT      ; Check if the hold time of crash data
             CMP     #$00          ; is up
             BNE     NON–CRASH
             LDA     PTEMPLO       ; If yes, display the current acceleration
             STA     MAXACC        ; value
             JSR     ADTOLCD
             BRA     NON–CRASH
CRASH        LDA     ZERO_ACC
             ADD     #$0E          ; If the crash is more than 7g
             CMP     PTEMPLO       ; 7g = 0E H * 0.5
             BHS     NO_INFLATE
             LDA     #$FF          ; activate the LED
             STA     PLMA
NO_INFLATE   JSR     MAXVALUE      ; Display the peak acceleration
             JSR     ADTOLCD
NON–CRASH    CLR     SHIFT_CNT
             CLR     AVE_CNT1
             CLR     AVE_CNT2
             CLR     AVERAGE_L
             CLR     AVERAGE_M
             CLR     AVERAGE_H
             BRA     REPEAT        ; Repeat the whole process
******************************************
*                                        *
*            Delay Subroutine            *
*     (162 * 0.7725 ms = 0.125 sec)      *
*                                        *
******************************************
DLY20        STA     TEMP1
             LDA     #!162             ; 1 unit = 0.7725 ms
OUTLP        CLRX
INNRLP       DECX
             BNE     INNRLP
             DECA
             BNE     OUTLP
             LDA     TEMP1
             RTS
******************************************
*                                        *
*     Reading the ADC data X times       *
*        and take the average            *
*   X is defined by DIV_HI and DIV_LO    *
*                                        *
******************************************
READAD       LDA     #$25
             STA     ADSTAT           ; AD status = 25H
             CLR     PRESHI2
             CLR     PRESHI           ; Clear the memory
             CLR     PRESLO
             CLRX
             CLR     ADCOUNTER
LOOP128      TXA
             CMP     #$FF
             BEQ     INC_COUNT
             BRA     CONT
INC_COUNT    INC     ADCOUNTER
CONT         LDA     ADCOUNTER        ; If ADCOUNTER = X
             CMP     DIV_HI           ; Clear bit = 0
             BEQ     CHECK_X          ; Branch to END100
             BRA     ENDREAD
CHECK_X      TXA
             CMP     DIV_LO
             BEQ     END128
ENDREAD      BRCLR   7,ADSTAT,ENDREAD ; Halt here till AD read is finished
             LDA     ADDATA           ; Read the AD register
             ADD     PRESLO           ; PRES = PRES + ADDATA
             STA     PRESLO
             CLRA
             ADC     PRESHI
             STA     PRESHI
             CLRA
             ADC     PRESHI2
             STA     PRESHI2
             INCX                     ; Increase the AD counter by 1
             BRA     LOOP128          ; Branch to Loop128
END128       CLR     RSHIFT           ; Reset the right shift counter
```

```
DIVIDE       INC     RSHIFT           ; Increase the right counter
             LSR     PRESHI2
             ROR     PRESHI           ; Right shift the high byte
             ROR     PRESLO           ; Right shift the low byte
             LDA     RSHIFT
             CMP     NO_SHIFT         ; If the right shift counter >= NO_SHIFT
             BHS     ENDDIVIDE        ; End the shifting
             JMP     DIVIDE           ; otherwise continue the shifting
ENDDIVIDE    LDA     PRESLO
             STA     PTEMPLO
             RTS
******************************************
*                                        *
*       Timer service interrupt          *
*     Alternates the Port data and       *
*          backplane of LCD              *
*                                        *
******************************************
TIMERCMP     STA     TEMP2            ; Push Accumulator
             COM     PORTC            ; Port C = – (Port C)
             COM     PORTB            ; Port B = – (Port B)
             COM     PORTA            ; Port A = – (Port A)
             LDA     START_TIME       ; Start to count down the hold time
             CMP     #$FF             ; if START_TIME = FF
             BNE     SKIP_TIME
             JSR     CHECK_HOLD
SKIP_TIME    BSR     COMPRGT          ; Branch to subroutine compare register
             LDA     TEMP2            ; Pop Accumulator
             RTI
******************************************
*                                        *
*      Check whether the hold time       *
*        of crash impact is due          *
*                                        *
******************************************
CHECK_HOLD   DEC     HOLD_CNT
             LDA     HOLD_CNT
             CMP     #$00             ; Is the hold time up?
             BNE     NOT_YET
             LDA     #$00             ; If yes,
             STA     PLMA             ; stop buzzer
             LDA     #$FF             ; Set HOLD_DONE to FF indicate that the
             STA     HOLD_DONE        ; hold time is up
             CLR     START_TIME       ; Stop the counting down of hold time
NOT_YET      RTS
******************************************
*                                        *
*           Subroutine reset             *
*      the timer compare register        *
*                                        *
******************************************
COMPRGT      LDA     TCNTHI           ; Read Timer count register
             STA     TEMPTCNTHI       ; and store it in the RAM
             LDA     TCNTLO
             STA     TEMPTCNTLO
             ADD     #$4C             ; Add 1D4C H = 7500 periods
             STA     TEMPTCNTLO       ; with the current timer count
             LDA     TEMPTCNTHI       ; 1 period = 2 us
             ADC     #$1D
             STA     TEMPTCNTHI       ; Save the next count to the register
             STA     OCMPHI1
             LDA     TSTATUS          ; Clear the output compare flag
             LDA     TEMPTCNTLO       ; by access the timer status register
             STA     OCMPLO1          ; and then access the output compare
             RTS                      ; register
******************************************
*                                        *
*      Determine which is the next       *
*    acceleration value to be display    *
*                                        *
******************************************
MAXVALUE     LDA     PTEMPLO
             CMP     MAXACC           ; Compare the current acceleration with
             BLS     OLDMAX           ; the memory, branch if it is <= maxacc
             BRA     NEWMAX1
OLDMAX       LDA     HOLD_DONE        ; Decrease the Holdtime when
             CMP     #$FF             ; the maximum value remain unchanged
```

```
            BEQ     NEWMAX1          ; Branch if the Holdtime is due
            LDA     MAXACC           ; otherwise use the current value
            BRA     NEWMAX2
NEWMAX1     LDA     #$C8             ; Hold time = 200 * 15 ms = 3 sec
            STA     HOLD_CNT         ; Reload the hold time for the next
            CLR     HOLD_DONE        ; maximum value
            LDA     #$FF
            STA     START_TIME       ; Start to count down the hold time
            LDA     PTEMPLO          ; Take the current value as maximum
NEWMAX2     STA     MAXACC
            RTS
******************************************
*                                        *
*     This subroutine is to convert      *
*        the AD data to the LCD          *
*    Save the data to be diaplayed       *
*             in MAXACC                  *
*                                        *
******************************************
ADTOLCD     SEI                      ; Disable the Timer Interrupt !!
            LDA     #$00             ; Load 0000 into the memory
            STA     DECHI
            LDA     #$00
            STA     DECLO
            LDA     MAXACC
            LDX     #5
            MUL                      ; Acceleration = AD x 5
            ADD     DECLO            ; Acceleration is stored as DECHI
            STA     DECLO            ; and DECLO
            STA     ACCLO            ; Temporary storage
            LDA     #$00             ; Assume positive deceleration
            STA     SIGN             ; ”00” positive ; ”01” negative
            CLRA
            TXA
            ADC     DECHI
            STA     DECHI
            STA     ACCHI            ; Temporary storage
            LDA     DECLO
            SUB     DCOFFSETLO       ; Deceleration = Dec – DC offset
            STA     DECLO
            LDA     DECHI
            SBC     DCOFFSETHI
            STA     DECHI
            BCS     NEGATIVE         ; Branch if the result is negative
            BRA     SEARCH
NEGATIVE    LDA     DCOFFSETLO       ; Acceleration = DC offset – Dec
            SUB     ACCLO
            STA     DECLO
            LDA     DCOFFSETHI
            SBC     ACCHI
            STA     DECHI
            LDA     #$01             ; Assign a negative sign
            STA     SIGN
SEARCH      CLRX                     ; Start the search for hundred digit
LOOP100     LDA     DECLO            ; Acceleration = Acceleration – 100
            SUB     HUNDREDLO
            STA     DECLO
            LDA     DECHI
            SBC     HUNDREDHI
            STA     DECHI
            INCX                     ; X = X + 1
            BCC     LOOP100          ; if acceleration >= 100, continue the
            DECX                     ; loop100, otherwise X = X – 1
            LDA     DECLO            ; Acceleration = Acceleration + 100
            ADD     HUNDREDLO
            STA     DECLO
            LDA     DECHI
            ADC     HUNDREDHI
            STA     DECHI
            TXA                      ; Check if the MSD is zero
            AND     #$FF
            BEQ     NOZERO           ; If MSD is zero, branch to NOZERO
            LDA     $0300,X          ; Output the first second digit
            STA     PORTC
            BRA     STARTTEN
NOZERO      LDA     #$00             ; Display blank if MSD is zero
            STA     PORTC
```

```
STARTTEN     CLRX                      ; Start to search for ten digit
LOOP10       LDA     DECLO             ; acceleration = acceleration – 10
             SUB     TENLO
             STA     DECLO
             LDA     DECHI
             SBC     TENHI
             STA     DECHI
             INCX
             BCC     LOOP10            ; if acceleration >= 10 continue the
             DECX                      ; loop, otherwise end
             LDA     DECLO             ; acceleration = acceleration + 10
             ADD     TENLO
             STA     DECLO
             LDA     DECHI
             ADC     TENHI
             STA     DECHI
             LDA     $0300,X           ; Output the last second digit
             EOR     SIGN              ; Display the sign
             STA     PORTB
             CLRX                      ; Start to search for the last digit
             LDA     DECLO             ; declo = declo – 1
             TAX
             LDA     $0300,X           ; Output the last digit
             EOR     #$01              ; Add a decimal point in the display
             STA     PORTA
             CLI                       ; Enable Interrupt again !
             RTS
******************************************
*                                        *
*   This subroutine provides services    *
*    for those unintended interrupts     *
*                                        *
******************************************
SWI          RTI                       ; Software interrupt return
IRQ          RTI                       ; Hardware interrupt
TIMERCAP     RTI                       ; Timer input capture
TIMERROV     RTI                       ; Timer overflow
SCI          RTI                       ; Serial communication Interface
                                       ; Interrupt
             ORG     $3FF2             ; For 68HC05B16, the vector location
             FDB     SCI               ; starts at 3FF2
             FDB     TIMERROV          ; For 68HC05B5, the address starts
             FDB     TIMERCMP          ; 1FF2
             FDB     TIMERCAP
             FDB     IRQ
             FDB     SWI
             FDB     RESET
```

AN1612

Shock and Mute Pager Applications Using Accelerometer

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Singapore, A/P

INTRODUCTION

In the current design, whenever there is an incoming page, the buzzer will “beep” until any of the buttons is depressed. It can be quite annoying or embarrassing sometime when the button is not within your reach. This application note describes the concept of muting the “beeping” sound by tapping the pager lightly, which could be located in your pocket or handbag. This demo board uses an accelerometer, microcontroller hardware/software and a piezo audio transducer. Due to the wide frequency response of the accelerometer from d.c. to 400Hz, the device is able to measure both the static acceleration from the Earth’s gravity and the shock or vibration from an impact. This design uses a 40G accelerometer (Motorola P/N: MMA1000P) which yields a minimum acceleration range of –40G to +40G.

CONCEPT OF TAP DETECTION

To measure the tapping of a pager, the accelerometer must be able to respond in the range of hundreds of hertz. During the tapping of a pager at the top surface, which is illustrated in Figure 1, the accelerometer will detect a negative shock level between –15g to –50g of force depending on the intensity. Similarly, if the tapping action comes from the bottom of the accelerometer, the output will be a positive value. Normally, the peak impact pulse is in the order of a few milliseconds. Figure 2 shows a typical waveform of the accelerometer under shock.

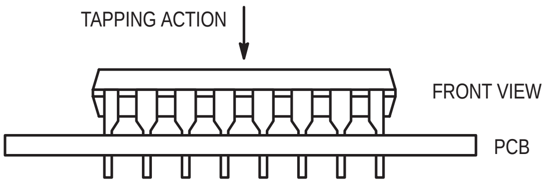

Figure 1. Tapping Action of Accelerometer

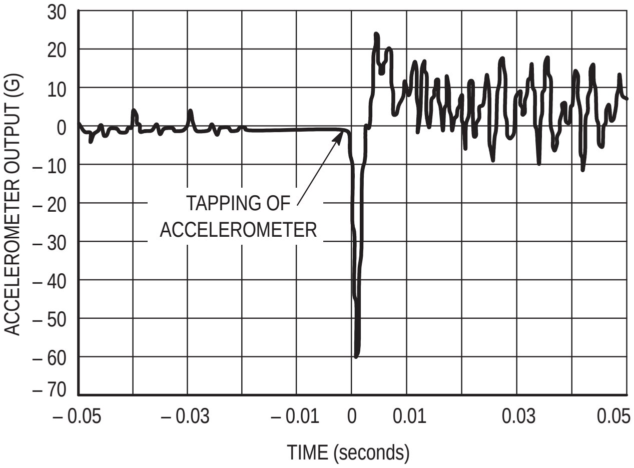

Figure 2. Typical Waveform of Accelerometer Under Tapping Action

Therefore, we could set a threshold level, either by hardware circuitry or software algorithm, to determine the tapping action and mute the “beeping”. In this design, a hardware solution is used because there will be minimal code added to the existing pager software. However, if a software solution is used, the user will be able to program the desire shock level.

HARDWARE DESCRIPTION AND OPERATION

Since MMA1000P is fully signal–conditioned by its internal op–amp and temperature compensation, the output of the accelerometer can be directly interfaced with a comparator. To simplify the hardware, only one direction (tapping on top of the sensor) is monitored. The comparator is configured in such a way that when the output voltage of the accelerometer is less than the threshold voltage or Vref (refer to Figure 3), the output of the comparator will give a logic “1” which is illustrated in Figure 4. To decrease the Vref voltage or increase the threshold impact in magnitude, turn the trimmer R2 anti–clockwise.

REV 2

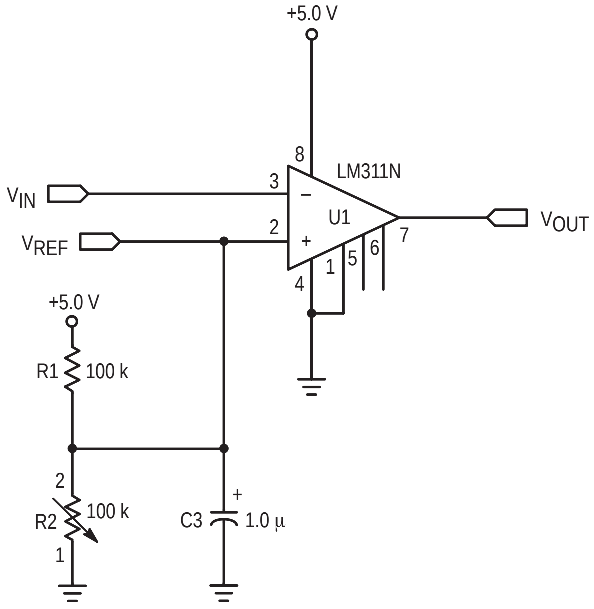

Figure 3. Comparator Circuitry

For instance, if the threshold level is to be set to –20g, this will correspond to a Vref voltage of 1.7 V.

$$
\begin{aligned}
V_{REF} &= V_{OFFSET} + \left(\frac{\Delta V}{\Delta G} \times G_{THRESHOLD}\right) \\
&= 2.5 + (0.04 \times [-20]) \\
&= 1.7\ \text{V}
\end{aligned}
$$

Under normal condition, Vin (which is the output of the accelerometer) is at about 2.5V. Since Vin is higher than Vref, the output of the comparator is at logic “0”. During any shock or impact which is greater than –20g in magnitude, the output voltage of the accelerometer will go below Vref. In this case, the output logic of the comparator changes from “0” to “1”.

When the pager is in silence mode, the vibrator produces an output of about ±2g. This will not trigger the comparator. Therefore, even in silence mode, the user can also tap the pager to stop the alert. Refer to Figure 5 for the vibrator waveform.

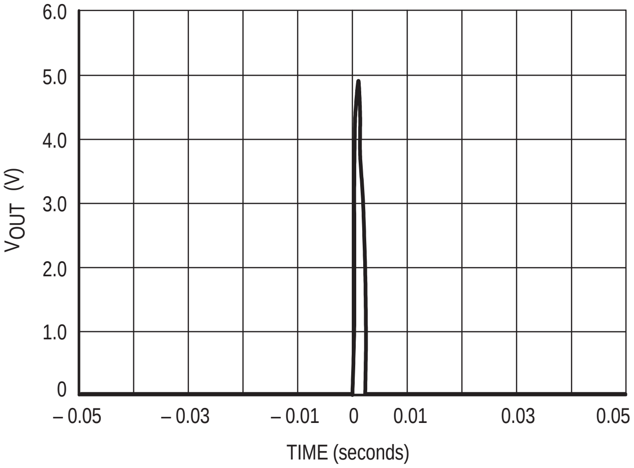

Figure 4. Comparator Output Waveform

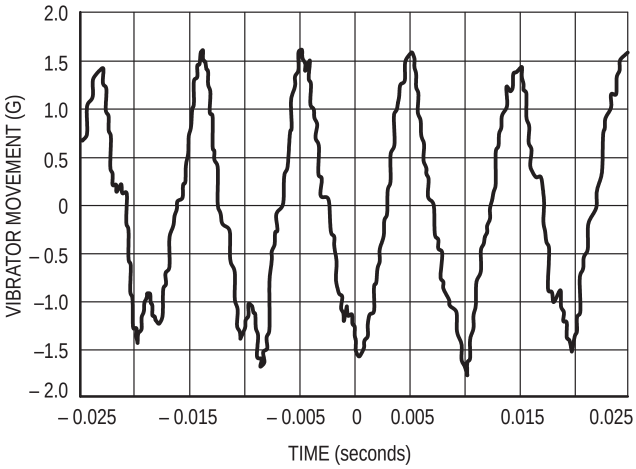

Figure 5. Vibrator Waveform

Figure 6 is a schematic drawing of the whole demo and Figures 7, 8, and 9 show the printed circuit board and component layout for the shock and mute pager. Table 1 is the corresponding part list.

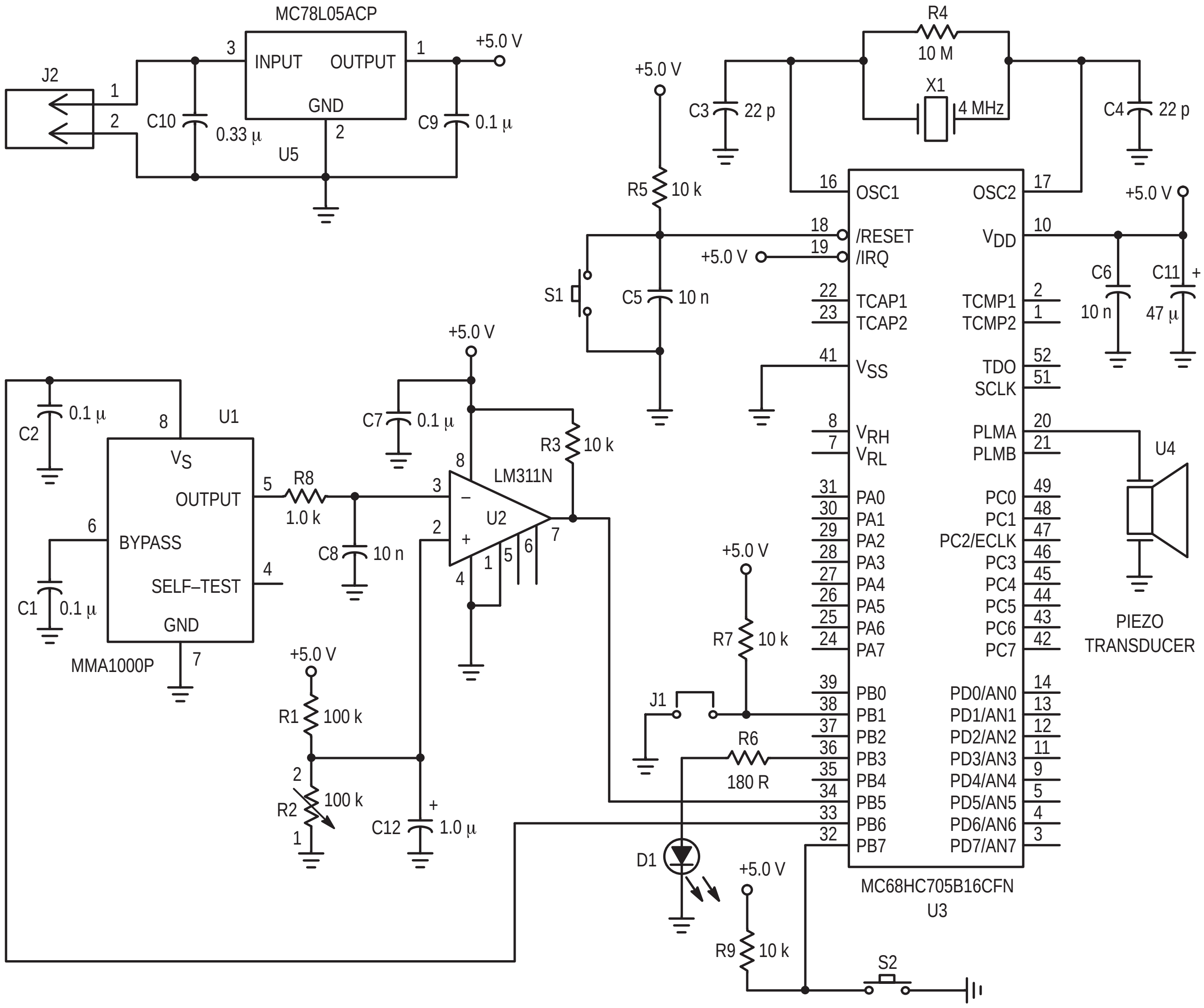

Figure 6. Overall Schematic Diagram of the Demo

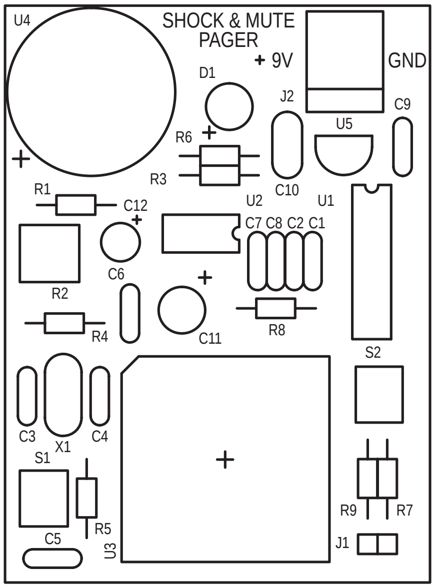

Figure 7. Silk Screen of the PCB

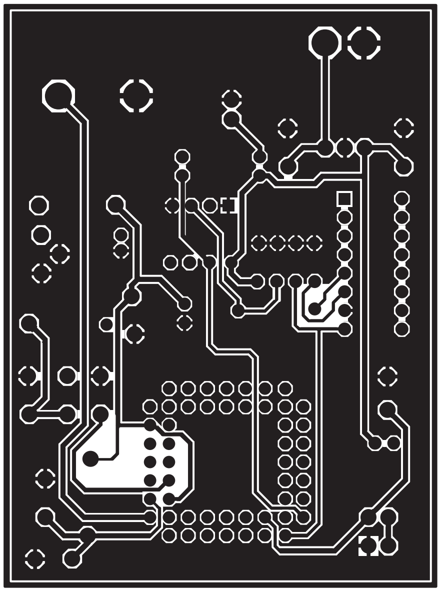

Figure 8. Solder Side of the PCB

Table 1. Bill of Material for the Shock and Mute Pager

Device Type	Qty.	Value	References
Ceramic Capacitor	4	0.1µ	C1, C2, C7, C9
Ceramic Capacitor	2	22p	C3, C4
Ceramic Capacitor	3	10n	C5, C6, C8
Solid Tantalum	1	0.33µ	C10
Electrolytic Capacitor	1	47µ	C11
Electrolytic Capacitor	1	1µ	C12
LED	1	5mm	D1
Header	1	2 way	J1
PCB Terminal Block	1	2 way	J2
Resistor ±5% 0.25W	1	100k	R1
Single Turn Trimmer	1	100k	R2
Resistor ±5% 0.25W	4	10k	R3, R5, R7, R9
Resistor ±5% 0.25W	1	10M	R4
Resistor ±5% 0.25W	1	180R	R6
Resistor ±5% 0.25W	1	1k	R8
Push Button	2	6mm	S1, S2
MMA1000P	1	—	U1
LM311N	1	—	U2
MC68HC705B16CFN	1	—	U3
Piezo Transducer	1	—	U4
MC78L05ACP	1	—	U5
Crystal	1	4MHz	X1

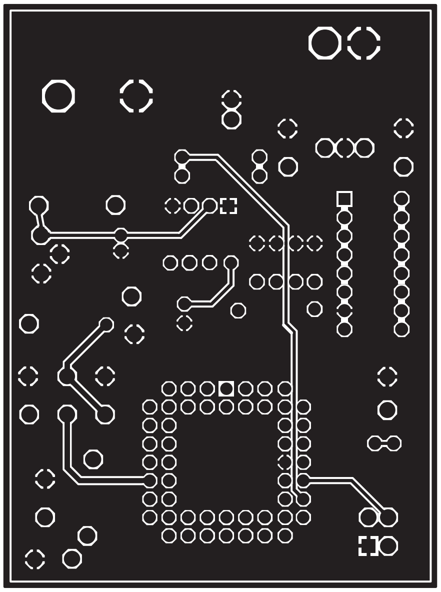

Figure 9. Component Side of the PCB

SOFTWARE DESCRIPTION

Upon powering up the system, the piezo audio transducer is activated simulating an incoming page, if the pager is in sound mode (jumper J1 in ON). Then, the accelerometer is powered up and the output of the comparator is sampled to obtain the logic level. The “beeping” will continue until the accelerometer senses an impact greater than the threshold level. Only then the alert is muted. However when the pager is in silence mode (jumper J1 is OFF), which is indicated by the blinking red LED, the accelerometer is not activated. To stop the alert, press the push–button S2.

To repeat the whole process, simply push the reset switch S1.

Figure 10 is a flowchart for the program that controls the system.

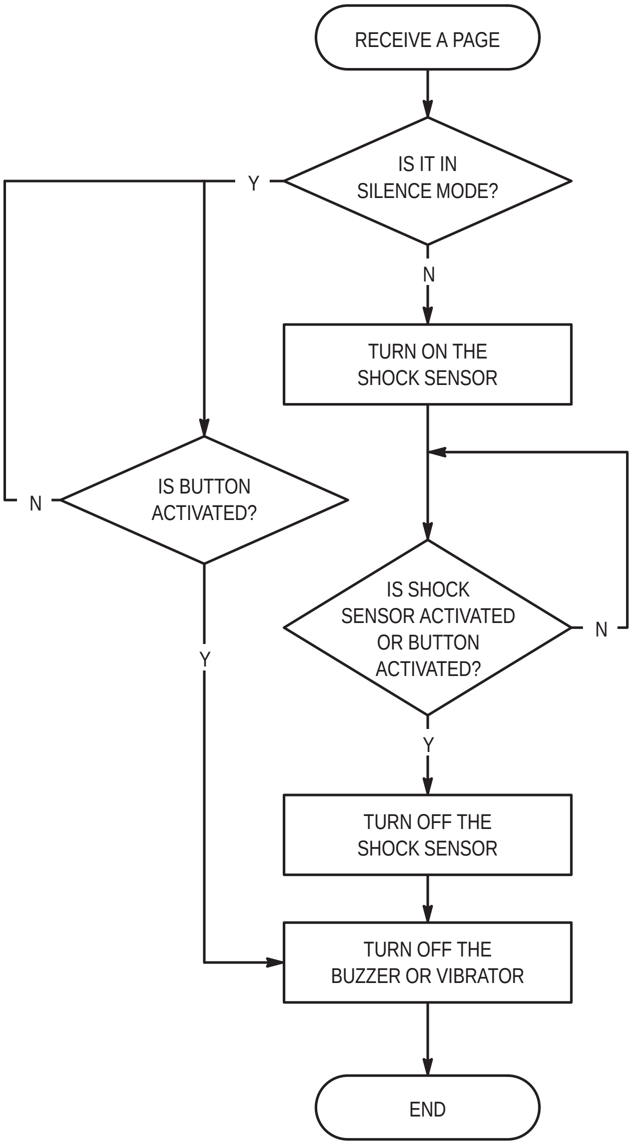

Figure 10. Main Program Flowchart

CONCLUSION

The shock and mute pager design uses a comparator to create a logic level output by comparing the accelerometer output voltage and a user–defined reference voltage. The flexibility of this minimal component, high performance design makes it compatible with many different applications, e.g. hard disk drive knock sensing, etc. The design presented here uses a comparator which yields excellent logic–level outputs and output transition speeds for many applications.

SOFTWARE SOURCE/ASSEMBLY PROGRAM CODE

```
******************************************************************************
*                                                                            *
*                 Pager Shock & Mute Detection Version 1.0                   *
*                                                                            *
*   The following code is written for MC68HC705B16 using MMDS05 software     *
*   Version 1.01                                                             *
*   CASM05 – Command line assembler Version 3.04                             *
*   P & E Microcomputer Systems, Inc.                                        *
*                                                                            *
*                         Written by : C.S. Chua                             *
*                             9th January 1997                               *
*                                                                            *
*                           Software Description                             *
*                                                                            *
*   J1 ON – Sound mode                                                       *
*   Buzzer will turn off if the accelerometer is tapped or switch S2 is      *
*   depressed.                                                               *
*                                                                            *
*   J1 OFF – Silence mode                                                    *
*   LED will turn off if and only if S2 is depressed                         *
*                                                                            *
******************************************************************************
******************************************
*                                        *
*            I/O Declaration             *
*                                        *
******************************************
PORTB        EQU     $01           ; Port B
PLMA         EQU     $0A           ; D/A to control buzzer
TCONTROL     EQU     $12           ; Timer control register
TSTATUS      EQU     $13           ; Timer Status Register
OCMPHI1      EQU     $16           ; Output Compare Register 1 High Byte
OCMPLO1      EQU     $17           ; Output Compare Register 1 Low Byte
TCNTHI       EQU     $18           ; Timer Count Register High Byte
TCNTLO       EQU     $19           ; Timer Count Register Low Byte
OCMPHI2      EQU     $1E           ; Output Compare Register 2 High Byte
OCMPLO2      EQU     $1F           ; Output Compare Register 2 Low Byte
******************************************
*                                        *
*        RAM Area ($0050 – $0100)        *
*                                        *
******************************************
             ORG     $50
STACK        RMB     4             ; Stack segment
TEMPTCNTLO   RMB     1             ; Temp. storage of timer result (LSB)
TEMPTCNTHI   RMB     1             ; Temp. storage of timer result (MSB)
******************************************
*                                        *
*        ROM Area ($0300 – $3DFD)        *
*                                        *
******************************************
             ORG     $300
******************************************
*                                        *
*   Program starts here upon hard reset  *
*                                        *
******************************************
RESET         CLR      PORTB             ; Initialise Ports
              LDA      #%01001000        ; Configure Port B
              STA      $05
              LDA      TSTATUS           ; Dummy read the timer status register so as to clear the OCF
              CLR      OCMPHI2
              CLR      OCMPHI1
              LDA      OCMPLO2
              JSR      COMPRGT
              LDA      #$40              ; Enable the output compare interrupt
              STA      TCONTROL
              LDA      #10               ; Idle for a while before ”beeping”
IDLE          JSR      DLY20
              DECA
              BNE      IDLE
              CLI                        ; Interrupt begins here
              BRSET    1,PORTB,SILENCE   ; Branch if J1 is off
              BSET     6,PORTB           ; Turn on accelerometer
              JSR      DLY20             ; Wait till the supply is stable
TEST          BRSET    5,PORTB,MUTE      ; Sample shock sensor for tapping
              BRCLR    7,PORTB,MUTE      ; Sample switch S2 for muting
              JMP      TEST
MUTE          BCLR     6,PORTB           ; Turn off accelerometer
              SEI
              CLR      PLMA              ; Turn off buzzer
```

```
DONE          JMP      DONE              ; End
SILENCE       BRSET    7,PORTB,SILENCE   ; Sample switch S2 for stopping LED
              SEI
              BCLR     3,PORTB           ; Turn off LED
              JMP      DONE              ; End
******************************************
*                                        *
*       Timer service interrupt          *
*       Alternates the PLMA data         *
*       and bit 3 of Port B              *
*                                        *
******************************************
TIMERCMP     BSR     COMPRGT             ; Branch to subroutine compare register
             BRSET   1,PORTB,SKIPBUZZER  ; Branch if J1 is OFF
             LDA     PLMA
             EOR     #$80                ; Alternate the buzzer
             STA     PLMA
             RTI
SKIPBUZZER   BRSET   3,PORTB,OFF_LED     ; Alternate LED supply
             BSET    3,PORTB
             RTI
OFF_LED      BCLR    3,PORTB
             RTI
******************************************
*                                        *
*           Subroutine reset             *
*      the timer compare register        *
*                                        *
******************************************
COMPRGT      LDA     TCNTHI           ; Read Timer count register
             STA     TEMPTCNTHI       ; and store it in the RAM
             LDA     TCNTLO
             STA     TEMPTCNTLO
             ADD     #$50             ; Add C350 H = 50,000 periods
             STA     TEMPTCNTLO       ; with the current timer count
             LDA     TEMPTCNTHI       ; 1 period = 2 us
             ADC     #$C3
             STA     TEMPTCNTHI       ; Save the next count to the register
             STA     OCMPHI1
             LDA     TSTATUS          ; Clear the output compare flag
             LDA     TEMPTCNTLO       ; by access the timer status register
             STA     OCMPLO1          ; and then access the output compare register
             RTS
******************************************
*                                        *
*       Delay Subroutine for 0.20 sec    *
*                                        *
*   Input: None                          *
*   Output: None                         *
*                                        *
******************************************
DLY20        STA     STACK+2
             STX     STACK+3
             LDA     #!40           ; 1 unit = 0.7725 mS
OUTLP        CLRX
INNRLP       DECX
             BNE     INNRLP
             DECA
             BNE     OUTLP
             LDX     STACK+3
             LDA     STACK+2
             RTS
******************************************
*                                        *
*   This subroutine provides services    *
*    for those unintended interrupts     *
*                                        *
******************************************
SWI          RTI                      ; Software interrupt return
IRQ          RTI                      ; Hardware interrupt
TIMERCAP     RTI                      ; Timer input capture
TIMERROV     RTI                      ; Timer overflow interrupt
SCI          RTI                      ; Serial communication Interface Interrupt
             ORG     $3FF2            ; For 68HC05B16, the vector location
             FDB     SCI              ; starts at 3FF2
             FDB     TIMERROV         ; For 68HC05B5, the address starts at 1FF2
             FDB     TIMERCMP
             FDB     TIMERCAP
             FDB     IRQ
             FDB     SWI
             FDB     RESET
```

AN1620

A Monolithic Integrated Solution for MAP Applications

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ABSTRACT

A monolithic sensing solution for manifold absolute pressure (MAP) is presented. This work includes examination of design, fabrication, temperature compensation, packaging and electromagnetic compatibility (EMC) testing of the fully integrated monolithic sensor. The circuit uses integrated bipolar electronics and conventional IC processing. The amplification circuit consists of three op–amps, seven laser trimmable resistors, and other active and passive components. Also discussed is a summary of an automotive application MAP sensor general specification, test methods, assembly, packaging, reliability and media testing for a single chip solution.

INTRODUCTION

Ever increasing requirements for better fuel economy, safety, and comfort in automobiles has put demand on the sensor industries to develop a high quality, more reliable, and lower cost sensor for use in high volume manufacturing. The stringent requirement of the Corporate Average Fuel Economy (CAFE) regulations makes it necessary for sensors to be incorporated into automotive electronics. There are several sensors used in today's automobile to fulfill the above needs [1,2,3], and among them are many silicon based sensors. One of these is a MAP application. The first silicon based MAP sensor was incorporated in automobiles in the 1980's [4].

Two of the technologies developed in early 80's for MAP application were capacitive and piezoresistive (PRT) pressure sensors. The capacitive pressure sensor known as SCAP (silicon capacitive absolute pressure sensor) was incorporated in Ford Motor Company vehicles, and the piezoresistive sensor was incorporated by a number of other automobile manufacturers. However, these technologies utilized sensing elements with no signal conditioning. In some cases the sensor included a resistor network for temperature compensation but did not incorporate signal conditioning on the same chip.

An integrated sensor offers a cost effective solution. A small die size offers an opportunity to reduce the package size, especially important where expensive materials are used for housing sensors [5]. In addition, an integrated sensor is less susceptible to outside interference where wire interconnects the transducer and control circuitry and introduces the coupling of EMI into the system. An integrated sensor also improves yield and reliability by having fewer connections where failures can occur [6]. The connections are usually exposed to harsh media environments and are more susceptible to corrosion and other potential failures [6].

To date, most silicon–based automotive pressure sensors do not have integrated circuitry on the same chip. The availability of reliable low cost integrated technology coupled with silicon micromachining has increased the number of potential applications for fully integrated pressure sensors. In recent years, development of new technologies for better media and environmental protection, along with better sensor fabrication techniques has resulted in a robust piezoresistive pressure sensors.

MAIN SECTION

PRINCIPLES OF OPERATION — MAP sensors measure the vacuum in the intake manifold. When the engine goes through an intake cycle, a given cylinder receives the fuel–air charge from the intake manifold. The pressure measurement from the intake manifold is provided to the engine control unit (ECU), which then calculates the MAF (mass air flow) rate from the pressure measurement using the following equation [7]

$$\text{Mass Air Flow} = \frac{N \bullet MAP \bullet \text{displacement} \bullet RPM}{T_{Charge}}$$

where N is an empirically determined factor, usually about 0.6, MAP is the intake manifold absolute pressure, displacement is the volume of the cylinders multiplied by the number of cylinders, RPM is the engine rotation in revolutions per minute, and T_{charge} is the temperature of the air/fuel charge. The data is used to adjust the vehicle's injector pulse width, thereby insuring optimum engine stoichiometry and preventing a lean burn.

The MAP sensor general specification and testing requirements varies for the different automakers. The specifications usually depend on their algorithm, technology, and system requirements. A typical MAP sensor specification and testing requirements is shown in Table 1. The typical pressure range for the MAP sensor is 105 kPa full scale. However, in the case of turbo charged engines, the pressure range is typically 250 kPaA full scale.

REV 1

Table 1. General MAP Requirements

Transfer Function	V_{out} = Vs (P • K_1 – K_2) ± Error, K_1 & K_2 are constants
Low pressure requirement (kPaA)	15
High pressure requirement (kPaA)	250
Ratiometricity	1% ± 0.5% for 1% Vs change
Power suppy (V)	Typically 5.0 ± regulated
Response time (ms)	≤15
Sink (mA)	.08 to 1
Source (mA)	.20 to 5
Thermal cycle — unpowered	200 to 700 cycles, –40/125°C, 60 min/cycle
Pressure/Temp Cycle	200 to 3000 cycles, –40/125°C, 0.5 to 1.5 hr/cycle
Hot Storage (Powered)	100 to 1000 hrs, 125°C
Hot Storage (Unpowered)	500 to 1000 hrs, 125°C
Cold Storage (Unpowered)	96 to 1000 hrs, –40°C
Humidity	96 to 1000 hrs, 60 to 85°C, 85 to 90% RH, with or without bias
Drop	1 to 5 drops of 1 meter
Mechanical Shock	5 to 100 g pulses of 10 msec
EMC/EMI (susceptibility)	50 to 200 V/M, 1 to 1000 MHz

MONOLITHIC DESIGN — Figure 1 shows the top view of an integrated pressure sensor. The monolithic sensor contains op–amps, and passive components including SiCr resistors for laser trimming. This is an analog device which uses bipolar integrated circuit technology. The single–chip MAP sensor uses a single series temperature compensation of span resistor which provides a varying common mode voltage for use in temperature compensation of offset trimming. A total of three op amps are used in the sensor design. The first two form an instrumentation amplifier to isolate the transducer output from the resistor network. The third is the output buffer with level shifting divider R_8 and R_9, and zero pressure offset pedestal set by R_{10} and R_{11} (see Figure 2). TC of offset is corrected by shifting the negative side of the transducer differential output with temperature. Zero pressure offset is trimmed at the divider (R_8 and R_9) and pull–up resistor to Vcc (R_7), which allows minor adjustments independent of gain.

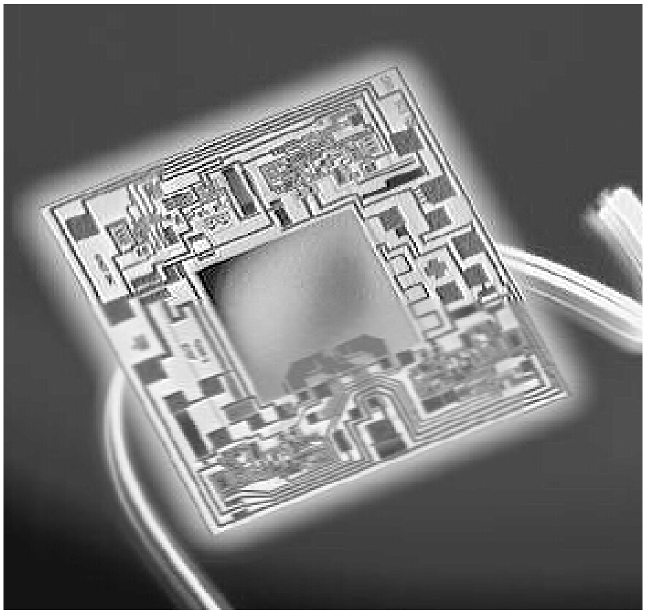


Figure 1. Top View of an Integrated Pressure Sensor

The sensing transducer design is a single piezoresistive element. It consists of a diaphragm and a piezoresistive element located near the edge of diaphragm at a 45% angle [8]. The diaphragm size is about 1000 microns and thickness is about 20 microns. The die size is approximately 3 mm^2..

SOURCE/SINK — The first single–chip MAP sensor was designed to interface directly with the A/D inputs of a microprocessor. The output signal encompasses the upper rail voltage minus a saturation voltage for the PNP output driver and ground plus a similar voltage to allow for a reasonable output leakage current across the load resistor for maximum resolution by the microprocessor A/D. The sensor output is ratiometric when µP Vref–hi supplies the positive supply voltage and Vref–lo is ground. The high input impedance of the microprocessor combined with the source only output of the sensor requires a filter of 51kΩ in parallel with 50pf to insure cancellation of high frequency noise.

Since the first single–chip MAP sensor was designed to drive only the high impedance input of a microprocessor, additional current requirements (for EMI suppression, corrosion prevention, or implementation of a logic function) require additional source current / sink current drive capability. This is easily accomplished by adding an op amp buffer at the sensor output. The change in current drain is minimal. Accuracy is not affected since the only error is the op amp input offset voltage of only a few millivolts over temperature. Any load, accuracy, and current drain can be accommodated by the choice of a suitable op amp for the buffer.

LASER TRIMMING — All system level resistors are SiCr which has a thermal coefficient of resistance (TCR) of near zero. The TCR is important for the series span compensation resistor (Rs) since span decreases with temperature (see Figure 2). Since the transducer input resistance increases with temperature, the series resistor will cause the voltage across the transducer to increase. This increase in voltage across the transducer counteracts a loss in sensitivity. The room temperature voltage must be set to a value which will cause the excitation voltage (Vex) to increase at a proper rate.

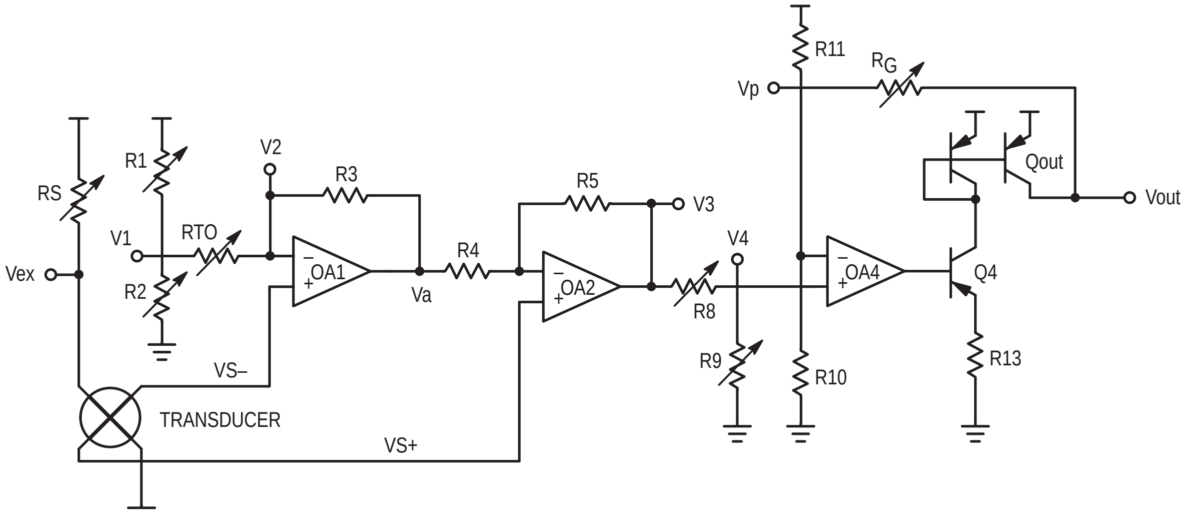
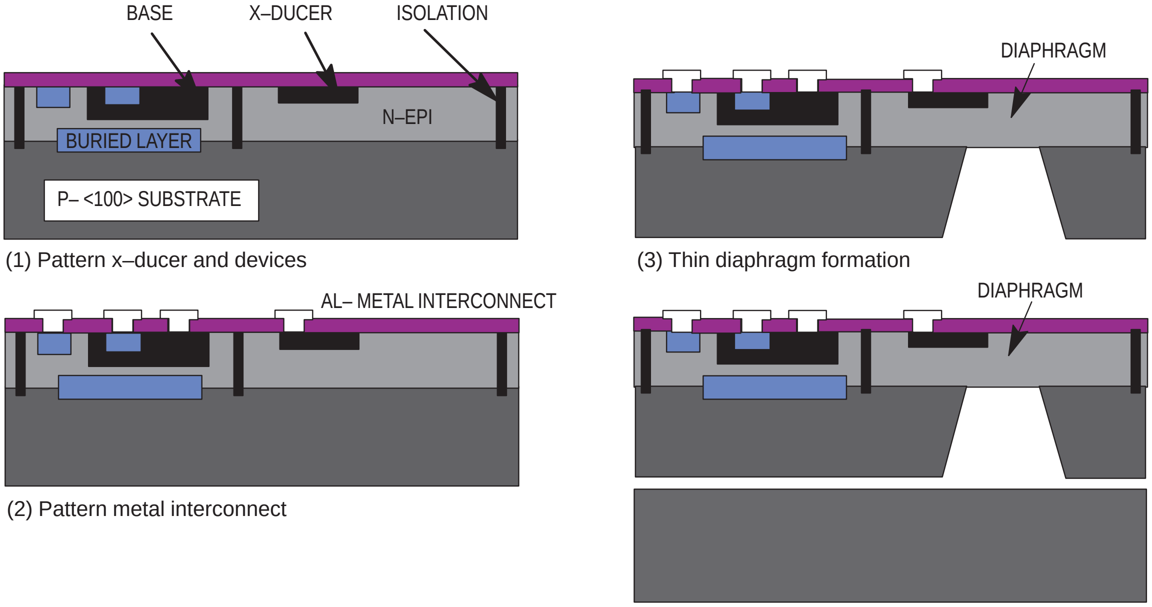


Figure 2. Signal Condition for Transducer

Next, the pressure to the device is set to the minimum level, R1 or R2 is trimmed to set V1=V2, and the offset is adjusted to 0.2V by adjusting the divider R8 or R9. The divider value is set to approximately cancel the transducer common mode voltage. With pressure applied, Rg is trimmed to set the desired sensitivity. The input network of OA4 allows gain to be adjusted without changing the previously trimmed offset.

The device must then be heated to trim TC of offset. At elevated temperature, V2 is now above V1, and current will flow into RTO. RTO is trimmed at the minimum pressure and elevated temperature to achieve the same offset voltage as set at room temperature, 0.2 V in this case.

PROCESS — The MAP sensor consists of bipolar integrated circuit and a micromachined sensing element on a single monolithic chip. Both bipolar processing and sensor fabrication are well established technologies. However, marrying these technologies presents some challenges, since the sensor fabrication requires non–conventional IC processing such as a deep etching of the silicon to form a thin diaphragm (see Figure 3).



(1) Pattern x–ducer and devices

(3) Thin diaphragm formation

(2) Pattern metal interconnect

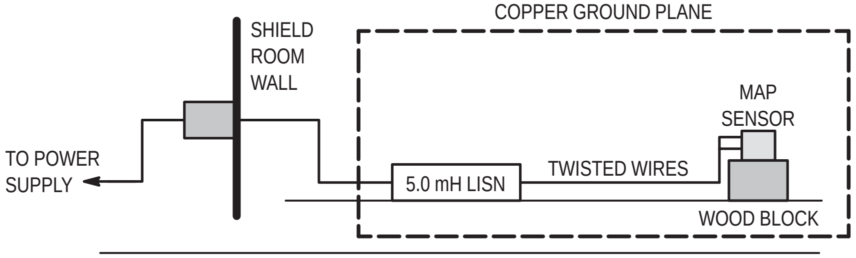
(4) Glass frit bonding for vaccum reference

Figure 3. Process Sequence for Generic Integrated Absolute Pressure Sensor

A typical sequence of fabrication steps illustrating the technique is shown in Figure 3 for a generic integrated piezoresistive sensor (IPS). The X–ducer™ and bipolar devices were fabricated using conventional IC diffusion processing. Following the diffusion, SiCr thin films and interconnect metalization is deposited and patterned. Aluminum is used as the interconnect metalization. Once the device fabrication is completed, a deep anisotropic cavity is etched into the silicon from the back side of the wafer to form the diaphragm. The active wafer is then frit bonded to a constraint in an evacuated chamber, forming an absolute reference cavity below the diaphragm.

EMC PERFORMANCE — Electromagnetic compatibility is a major issue for automotive applications. The specifications and bench test set up for EMI testing is not standardized across the industry. The test method discussed here is most severe and adequate enough to meet most of the requirements, i.e., device capable of lower susceptibility or greater resistance to the present electromagnetic (EM) signals.

Figure 4 describes the test setup. More detail of the setup, testing conditions and test results are described elsewhere [9]. The requirement for testing integrated sensor involves a 200 V/m radiated immunity test from 10 kHz to 1 Ghz. The test can be extended to higher frequency to evaluate influence of the 1–18 GHz signals.



(a) Located in Anechoically shielded room.
(b) Interface wires routed 5 cm over ground plane, 10 cm away from front edge.
(c) Sensor 10 cm above ground plane.

Figure 4. EMC Test Setup

Tested pressure sensors met the requirement and did not exceed the AC ripple or DC offset susceptibility criteria over the 200 MHz to 1GHz frequency range. Measurements were repeated several times over time periods as long as several days with the same test setups, and results show very similar values.

PACKAGING — One of the great challenges in semiconductor sensor manufacturing is the packaging. Unlike IC packaging, the pressure sensor can be directly exposed to harsh media. Thus, it requires more than the concepts that evolved out of conventional IC packaging technology. The suitable material and mounting techniques to provide include: (a) mechanical support, (b) electrical interface, (c) environmental protection, and (d) media interface (see Figure 5). Typical requirements for sensor packaging are discussed below.

– Media Compatibility
  – Fluro Silicone Gel
  – RTV Die Bond
  – Exposed Die

– External Package Stresses
  – Porting Stresses
  – Stresses From Lead Form
  – Direct Stresses on Package

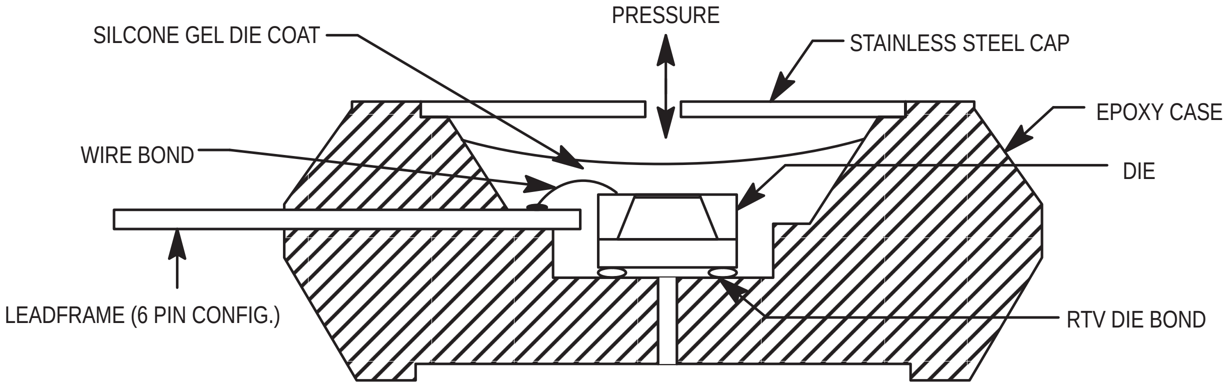


Figure 5. Basic Chip Carrier Package

The number of leads in sensor packaging varies according to the product and its application. The IPS package described here is designed with eight pins. The actual number of pins used by the customer is only three. The additional pins are used for laser trimming and are not connected in the application. The leads are designed with width of 1.27 mm (50 mil) and 2.54 mm (100 mil) spacing. For Surface Mount and other packages (Piston fit), the leads are formed to create a gull–wing shape or can be formed for a through hole solder joint. The piston fit package is designed to accept an O–ring to create either a radial pressure seal or a surface seal using a soft material such as silicone. Several versions of the piston fit package are shown in Figure 6. The size, spacing and the shape of the leads follow a standard practice, thus no special requirements for pad layout or via hole is required during PWB layout. The solder bond pad sizes and solder paste application will be same as other semiconductor components.

Conventional semiconductor components are typically shipped with leads that are solder dipped or tin plated after overmolding. This is not a major issue since the packages are not open to the atmosphere. For pressure sensor packages, there is always an opening for pressure interface. The lead configuration makes it difficult to perform solder dipping or tin plating. Without such a treatment, the underlying Ni layer may not pass the solderability requirement. An acceptable solution to the solderability issue is to provide a flash of Au on the solderable portion of the leads, which would protect the underlying Ni. In surface mount assembly with Sn–Pb solder, the presence of Au is known to form Au–Sn intermetallic. An

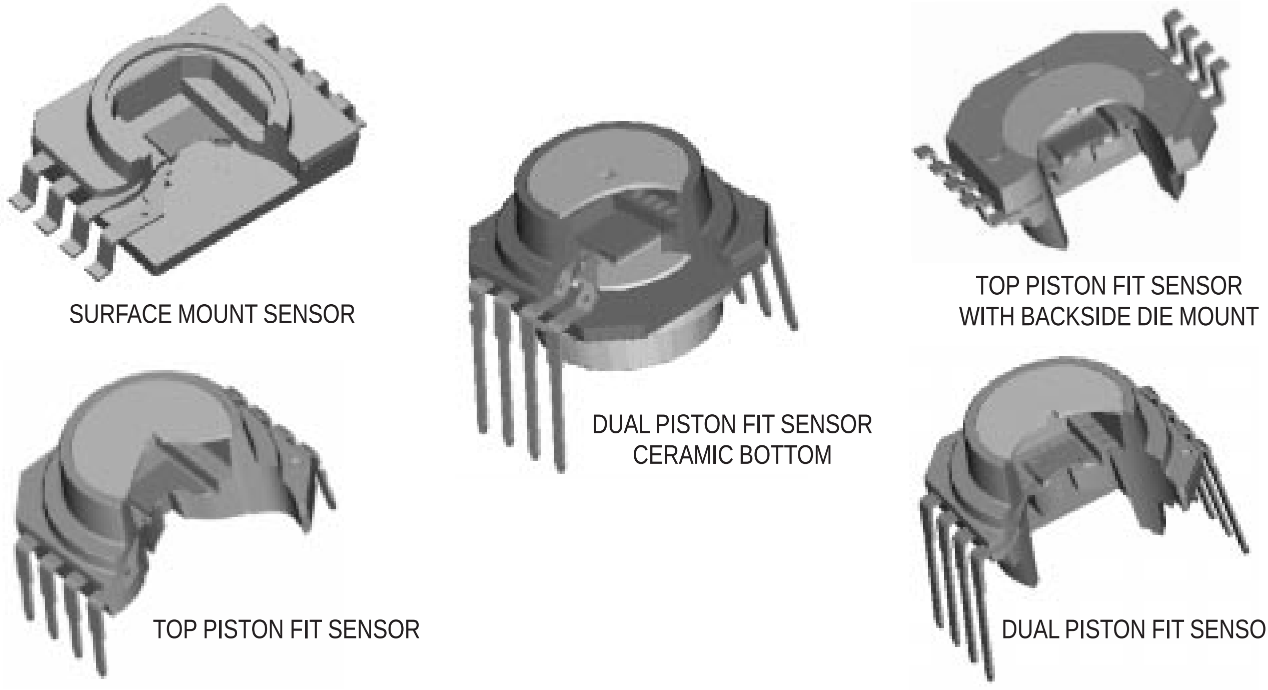


Figure 6. Surface mount and piston fit packages. The top and dual piston fit packages are designed to accept an o–ring for the pressure interconnect.

excessive amount of Au is likely to cause embrittlement of the solder joint, which will result in lower fatigue life. A solution adopted by Motorola and many other sensor manufacturers is to use a flash of Au on the lead frame, which would maintain solderability of the lead at the same time introduce fairly insignificant amount of Au in the Pb–Sn solder. In a typical solder joint, this amount of Au will result in approximately 1% of Au in the solder; which is significantly less than commonly acceptable 5% Au in the solder joint.

For a MAP application, the sensor needs to sense the manifold vacuum pressure. Therefore, it needs to have either a port which will be connected to vacuum hose, or it will be mounted in another housing with a port. These housings are either directly mounted to the manifold or externally mounted under the hood. The direct mount configuration is shown in Figure 7. The advantage of this technique is that the method does not require any hose to connect to the sensor thereby reducing the system cost. The draw back is that the sensor housing experiences significantly higher temperatures. This higher temperature may result in different housing materials and could influence the electrical specification.

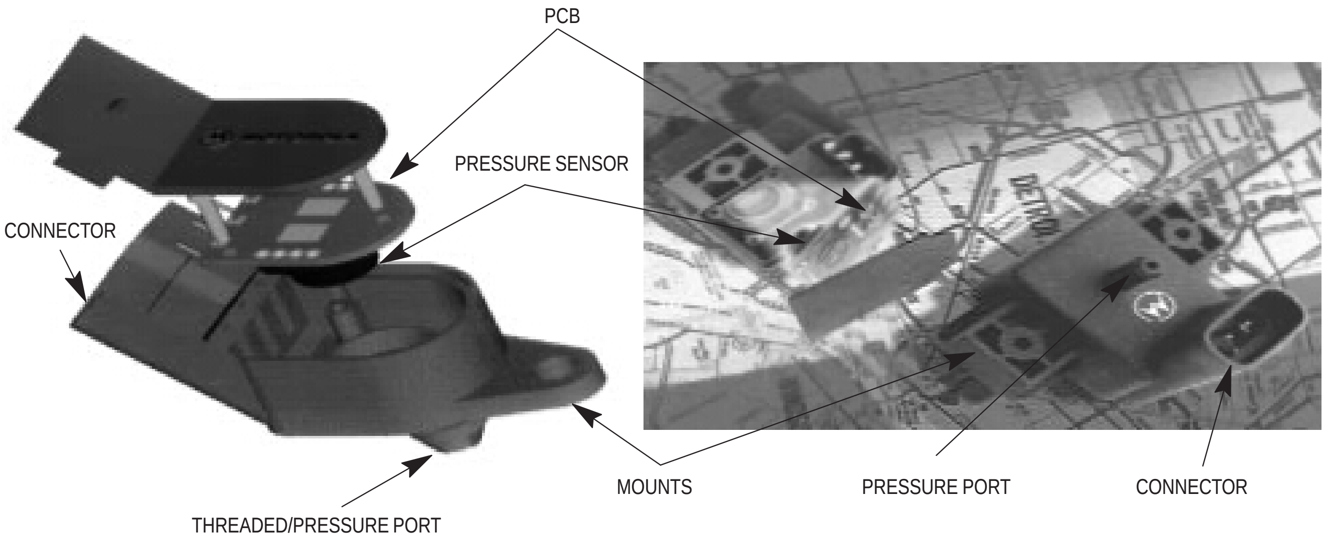


Figure 7. Conceptual Housing Options for User Implementation

The MAP sensor can also mounted direct on the ECU, eliminating the need for a wire harness and external connector. This will result in a lower system cost and less source and sink current requirements since the external connector is eliminated. For this configuration, the pressure hose needs to be extended from the manifold.

RELIABILITY AND MEDIA TESTING — To ensure accurate testing, knowledge of the application, lifetime requirements, and what constitutes a failure is crucial. A physics–of–failure approach can significantly reduce the development cycle time and produce a higher quality product [10]. The focus of the physics–of–failure approach includes an understanding of the application, lifetime expectation, failure mechanism(s), and lifetime models. The requirement for a typical MAP or BAP pressure sensor application involves testing to temperature extremes, thermal cycle, humidity, media exposure, vibration, shock, cyclic pressure, and overpressure testing [11]. Through reliability testing and knowledge of the environment, potential failure mechanisms are uncovered. A complete listing of potential failure mechanisms that may affect a pressure sensor device has been presented elsewhere [12].

The MAP application requires the sensor to survive in a fuel or aqueous solution. The fuel exposure typically is performed at elevated temperature to a wide variety of fuel types. A test matrix of several fuels based on ASTM guidelines that includes various additives such as methanol, water, or acids and a test procedure have been discussed elsewhere [13]. Acid testing either performed independent to the fuel or following exposure has proven to be an affective test scheme for product development. The nitric and sulfuric acid tests are a concern due to NO_X + water = HNO_3 and SO_X + water = H_2SO_4. A proposed test scheme for product development involves a variety of material types and environments. Not all materials from the same family will respond the same to the testing. Actual media test results will be published elsewhere.

A key aspect to reliability and media testing involves the determination of what constitutes a failure. The definition of an electrical failure can range from catastrophic, to exceeding a predetermined limit, to just a small shift. The traditional pre to post electrical characterization before and after the test interval can be enhanced by *in situ* monitoring. In situ monitoring may expose a problem with the sensor device during testing that may go undetected once the media or another environmental factor is removed. For example, swelling of polymeric materials when exposed to certain media or environment, may result in shift in the device output. Such a failure mechanism can only be detected by insitu monitoring. Response variables during environmental testing can include: electrical, visual, analytical, or a physical characteristic such as swelling or weight change. A typical definition of failure for the MAP and BAP application is to both be within the error budget after the exposure. In addition, the output voltage shift from the initial value needs to be within a predetermined value.

X–ducer is a trademark of Motorola, Inc.

CONCLUSION

A monolithic integrated pressure sensor has been developed for MAP applications. The integrated pressure sensor is small in size and provides better performance than its predecessors. The sensor can be directly mounted on the ECU PWB or underhood. It shows great resistance to harsh media thereby making it well suited for automotive applications. Additionally, the monolithic integrated pressure sensor shows very good immunity to surrounding electromagnetic fields since the need for an interconnect is eliminated.

ACKNOWLEDGMENT

The authors would like to thank John Trice, Randy Frank, Wendy Chan, Demetre Kondylis, Dan Wallace, Kelvin Blair, Aristide Tintikakis, Wayne Chavez, and Gary Beaudin for their encouragement and valuable inputs.

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MOTOROLA
SEMICONDUCTOR APPLICATION NOTE

AN1621

An Integrated Silicon Bulk Micromachined Barometric Pressure Sensor for Engine Control Unit and External Mount

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Motorola

ABSTRACT

An Integrated Barometric Absolute Pressure Sensor (IBAP) solution for barometric pressure sensing is presented here. The IBAP is a silicon bulk micromachined monolithic pressure sensor. This work includes an examination of the design, fabrication, temperature compensation, and testing aspects. In addition, options and issues related to the mounting of the IBAP device will be presented. Two techniques, including surface mounting the sensor on the engine control unit (ECU) PWB are discussed.

INTRODUCTION

Silicon–based sensors are utilized for multiple functions in automobiles, including the barometric absolute pressure (BAP) sensor [1]. BAP sensors are currently used in transmission and fuel systems to measure the ambient pressure based on the altitude. Turbo–diesel engines rely on the BAP sensor for glow plug timing alterations as a function of the ambient pressure. For higher altitudes, the glow plug timing must be increased to ensure proper starting. In transmissions, measurements of the ambient pressure improves shifting of the transmission.

The BAP sensor can be used in conjunction with a manifold absolute pressure (MAP) sensor. A MAP sensor measures the vacuum within the intake manifold which is monitored by the ECU. The ECU calculates the mass air flow (MAF) rate from the pressure measurement. The MAP sensor does not measure true mass air flow but indirectly measures air velocity by means of measuring manifold pressure. Thus, it will require an air density correction [2] to compute actual mass flow rate. The BAP sensor is used for this correction. Since both MAP and BAP applications require measuring absolute pressure in similar ranges, the same sensing die can be used for both applications.

The BAP sensor, in addition to a MAP sensor, is dependent upon the strategy and algorithm utilized by automobile manufacturer. Many automakers use the MAP sensor as a BAP sensor at key–in to determine the ambient pressure. This one sensor usage limits the dynamic changes due to ambient pressure changes in some terrain. The BAP sensor provides a cost effective solution for this application.

MAIN SECTION

BULK MICROMACHINED SENSORS — Micromachining technology provides a means to fabricate mechanical structures in high volume with fine dimensions. The silicon wafer with the mechanical structure can be enhanced with signal conditioning of the transducer through typical bipolar wafer processing onto a single chip [3]. The unit cost of the die is very economical due to size and batch fabrication techniques. The small die size offers an opportunity to reduce the package size, thus providing a cost effective means to packaging [4]. In addition, the single chip integrated sensor is less susceptible to outside interference. A dual chip solution with wire interconnects between the transducer and control circuitry can introduce the coupling of electromagnetic interference (EMI) into the system [5].

A capacitive or piezoresistive (PRT) transduction method to measure pressure is common for BAP applications. A predominant capacitive pressure sensor product, known as SCAP (silicon capacitive absolute pressure) sensor was developed by Ford for incorporation into their vehicles [6]. The piezoresistive transducer (PRT) was incorporated into other automotive markets. Both of these technologies produce a sense element with no temperature compensation or signal conditioning. In some cases, a resistor network is included on the same chip for temperature compensation, but not for signal conditioning. Cross–sections of SCAP and PRT sensor are shown in Figure 1.

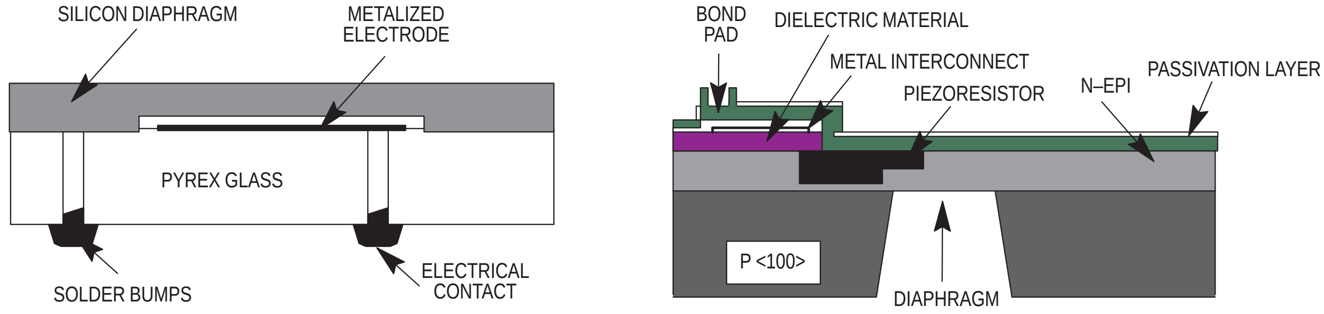
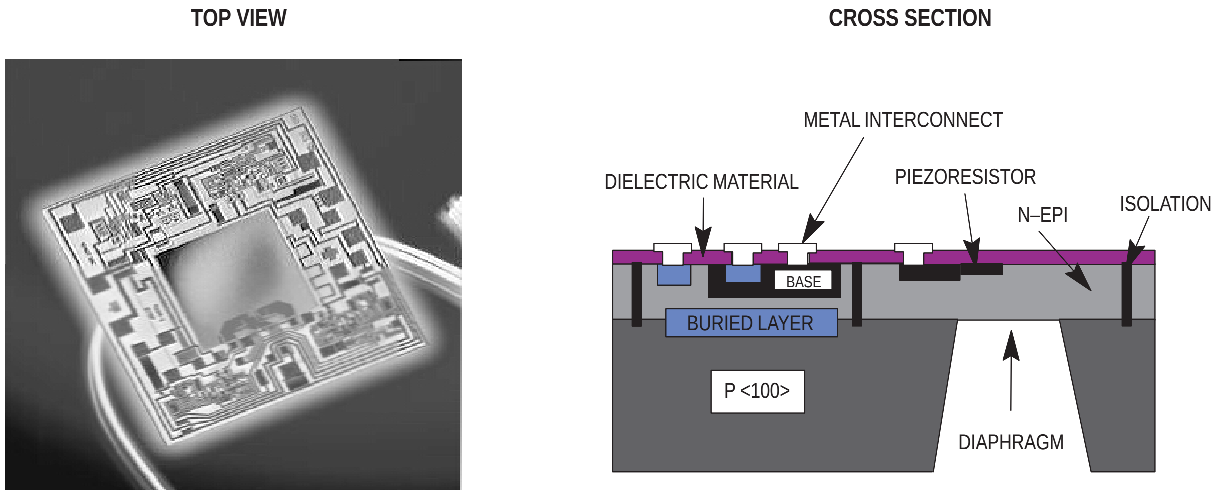


Figure 1. Cross section of a SCAP sensor on the left and a PRT element on the right.

REV 1

There are many acronyms used by sensor industry to describe the integrated sensor. The most common of which is a monolithic sensor. A fully–integrated monolithic sensor includes the amplification circuitry and temperature compensation resistor network on a single chip. This monolithic sensor, with a voltage output, is ideally suited for direct interfacing with a microprocessor. Examples of compensation networks used for monolithic sensors include laser trim, Therma–trim™ resistors, and Zener–Zap trim as well as electronic trim. All of these examples offer means to temperature compensate and calibrate the device. In contrast, a smart sensor describes a fully integrated sensor with a microprocessor, EPROM, A/D converters, and other components on a single chip. For this paper, the fully integrated monolithic pressure sensor is referred to as an integrated pressure sensor (IPS).

A typical integrated monolithic pressure sensor is shown in Figure 2. This monolithic sensor contains operational amplifiers (op amps), active, and passive components including SiCr resistors for calibration and compensation. This is an analog device and uses a bipolar integrated circuit technology.



TOP VIEW

CROSS SECTION

Figure 2. Photograph of a top view and cross–section of an integrated pressure sensor.

Table 1 describes the general specification for a BAP sensor. The specific output parameter as well as the testing requirements vary for different applications. Since the BAP is very similar to MAP, most of these parameters are similar.

Table 1. General BAP Requirements

Nominal Transfer Function	Vout = Vs (P x K1 – K2), K1 & K2 are constants
Low pressure requirement (kPa)	50
High pressure requirement (kPa)	115
Ratiometricity	1% ± 0.5% for 1% Vs change
Power suppy (V)	5 ± 0.5 volts typically
Response time (ms)	15 to 50 typically
Sink (mA)	.08 to 1
Source (mA)	.20 to 5
Thermal Shock (unpowered)	200 to 700 hrs, – 40/125°C, 60 min/cycle
Pressure/Temperature Cycling	200 to 3000 cycles, – 40/125°C, 0.5 to 1.5 hr per cycle
Hot Storage (Powered)	100 to 1000 hrs, 125°C
Hot Storage (Unpowered)	500 to 1000 hrs, 125°C
Cold Storage (Unpowered)	96 to 1000 hrs, – 40°C
Humidity	96 to 1000 hrs, 60 to 85°C, 85 to 90% RH, with or without bias
Drop	1 to 5 drops of 1 meter
Mechanical Shock	5 to 100 g pulses of 10 msec
EMC/EMI (susceptibility)	50 to 200 V/M, 1 to 1000 MHz

DESIGN — Since both BAP and MAP are absolute pressure sensors with similar ranges, the same circuit design can be utilized. One possible signal conditioning circuit for this application is shown in Figure 3. The only difference between the MAP and BAP sensors is the transfer function due to the different pressure ranges. In depth explanation of design and trim are explained elsewhere [5].

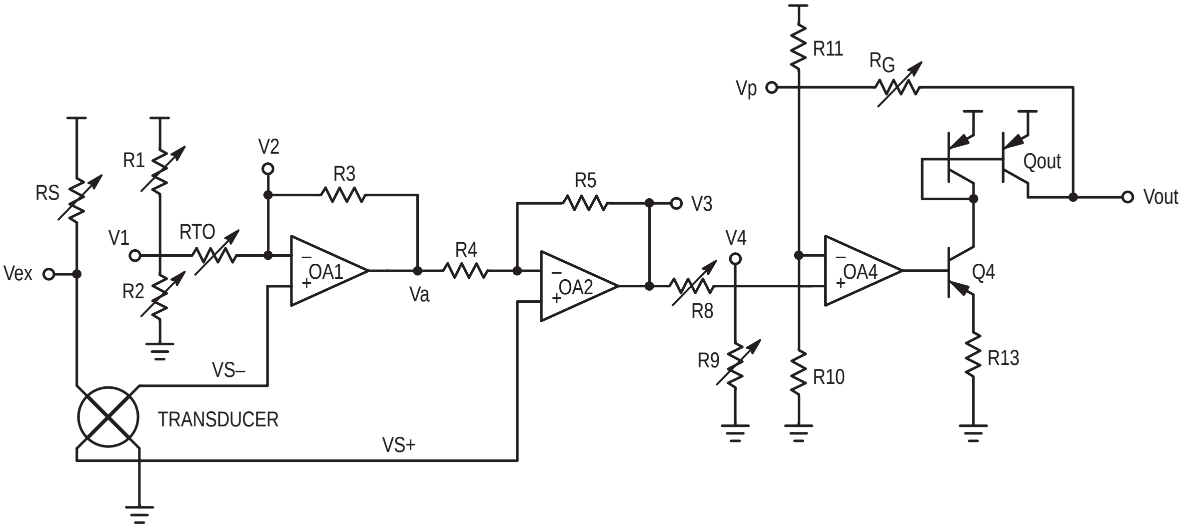


Figure 3. Signal Conditioning Circuit for Transducer

SOURCE/SINK OPTION — The source and sink requirement for BAP applications is based on system configuration inputs received from system designers. If the BAP is mounted on the ECU it may not require high source/sink capability. However, if the BAP sensor is mounted externally, a higher source or sink capability may be necessary to protect the connector from corrosion. If the device is not capable of producing source and sink, then (a) the connector pins may require corrosion protection such as gold plating and (b) the system may not be able to detect line faults.

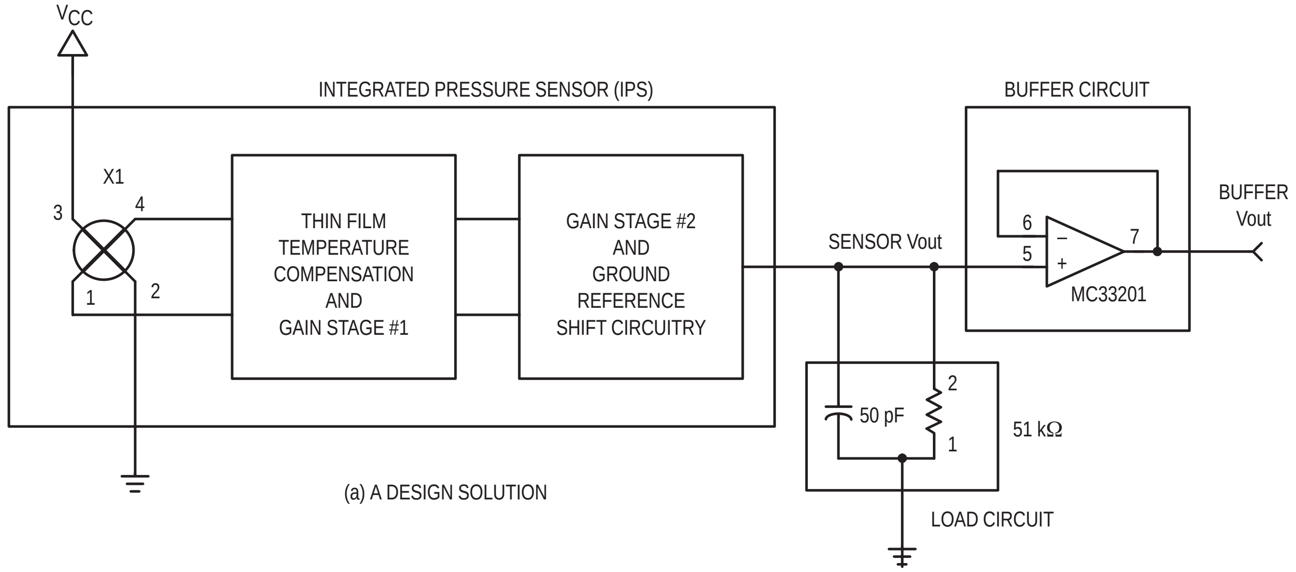
Figure 4a shows one potential solution achieving source and sink capability by adding external buffer circuitry. In the external buffer circuitry shown in Figure 4a, a MC33201 rail to rail operational amplifier is connected to the IPS Vout terminal. This configuration will provide the same output at the buffer circuit as the Vout from IPS. Output from the IPS sensor is fed through the noninverting input of the op–amp, and output of the op–amp is tied back to the inverting input of the op–amp. It should be noted that a load circuit connected to the Vout pin of the IPS is recommended. In order to test sink current test, simply (1) take a load resistor and tied from output of the buffer to the VCC, (2) put an ammeter in series with the load, and (3) repeat the same method for the source current, except this time, tie the load resistor to ground.

PROCESS — A monolithic BAP sensor consists of a bipolar integrated circuit and a sensing element on a single chip. The bipolar processing and sensor fabrication technique are well established technologies. However, marrying these technologies poses a great challenge since the sensor fabrication requires some non–conventional IC processing, such as deep etching of the silicon for forming a thin diaphragm (see Figure 5).

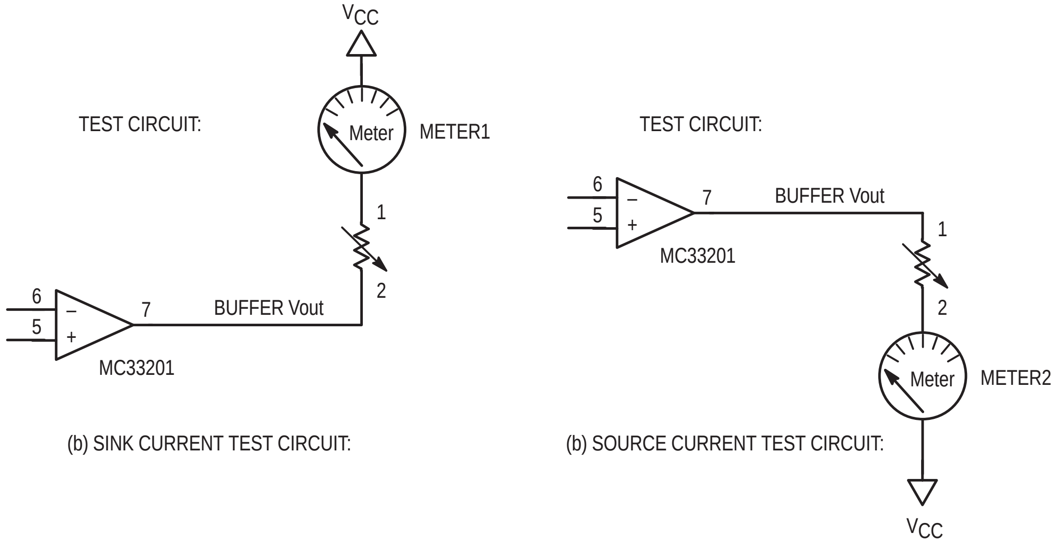
A typical sequence of fabrication steps illustrating the technique is shown in Figure 5 for the case of a generic IPS. In the process, all diffusion steps are performed to define the X–ducer™ and bipolar devices using conventional IC technology. Followed by diffusion, metal is deposited onto the wafer and patterned to interconnect the devices. Aluminum is used as an interconnect metalization. Once the device fabrication is completed, a deep cavity etch from the backside forms the thin diaphragm.

PACKAGING — As discussed above, semiconductor sensor technology is a combination of IC technology and micromachining. Thus, many of the bulk micromachining packaging concepts have evolved out of conventional IC packaging. Unlike IC packaging, the pressure sensor is directly exposed to the environment or media (see Figure 6). One of the great challenges in sensor packing is the ability to protect the device in harsh environments. The semiconductor package regulates that the package provide: (a) mechanical support; (b) electrical interface; (c) environmental protection; and (d) a media interface. Some of the specific requirements for sensor packaging are discussed below.

The number of leads in sensor packaging may vary according to the product and its application. The integrated pressure sensor package described here is designed with eight pins, though the actual pins used by customer is only three. The additional pins are used for trimming of the integrated sensor die. The leads are designed with a 1.27 mm (50 mil) width on a 2.54 mm (100 mil) spacing. For the Surface Mount and Top Piston Fit packages (Figure 7), the leads are formed to create a gull–wing shape for mounting to the PCB. The piston fit package is designed to accept an O–ring to create either a radial pressure seal or a surface seal using a soft material such as silicone. The size, spacing and the shape of the lead follows a standard practice, thus no special requirements for pad layout or via hole is required during the PWB layout. In short the solder bond pad sizes and solder paste application will be the same as other semiconductor components.



(a) A DESIGN SOLUTION



(b) SINK CURRENT TEST CIRCUIT:

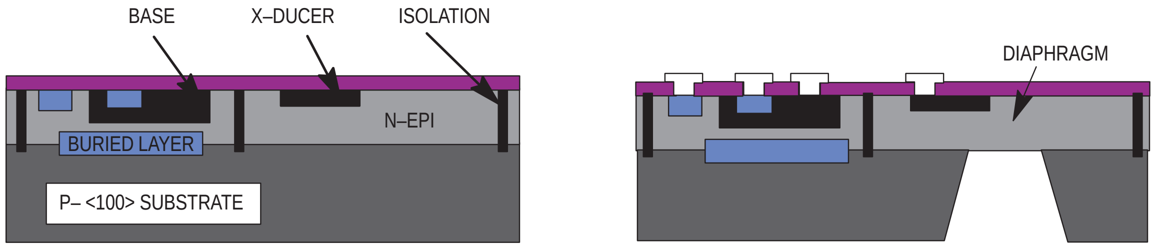
(b) SOURCE CURRENT TEST CIRCUIT:

Figure 4. Configuration of Source/Sink design solution and test circuits.

A pressure sensor package always incorporates an opening for the pressure interface. In such a case, it is difficult to perform solder dipping or tin plating. Without such treatment, the underlying Ni layer may not pass the solderability requirement. In such a case, an acceptable solution is to provide a flash of Au on the solderable portion of the leads, which would protect the underlying Ni and meet the solderability requirements. In surface mount assemblies using Sn–Pb solder, the presence of Au is known to form Au–Sn intermetallic. An excessive amount of Au is likely to cause embrittlement of the solder joint, which will result in lower fatigue life. A solution adopted by Motorola and many other sensor manufacturers is to use a flash of Au on the lead frame, which would maintain solderability of the lead at the same time introduce a fairly insignificant amount of Au in the Pb–Sn solder. In a typical solder joint, this amount of Au will result in approximately 1% of Au in the solder; which is significantly less than commonly acceptable 5% Au in the solder joint.

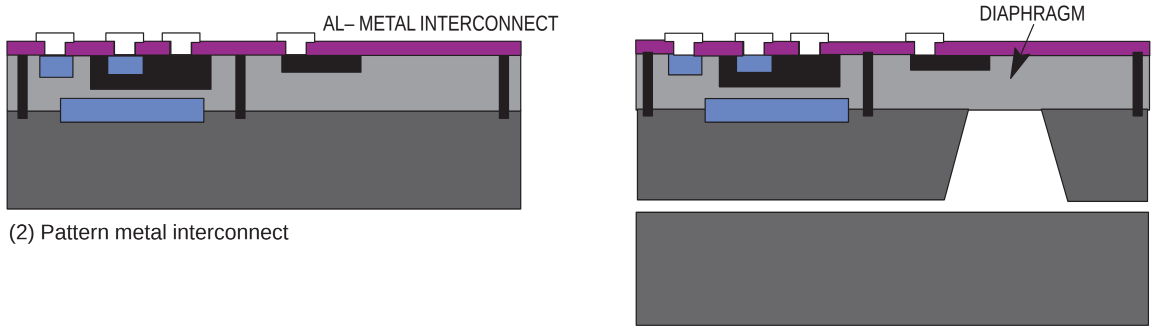
In the BAP application, the sensor needs to sense the atmospheric pressure. For this reason, it needs to have port open to the atmosphere. The sensor can be mounted either in the ECU or externally (see Figure 8). However for an external mounting, a housing is required. The direct mount is where the sensor is directly soldered on to PWB board in ECU. There are advantages and disadvantages of direct mounting the device in the ECU. One advantage of mounting directly on the ECU eliminates the need for a wiring harness, thus lowering the system cost. In addition, it requires less source and sink capability. The disadvantage is that the method requires protection of port during conformal coating. Two different techniques were used for conformal coating. These are dip–in, where the whole unit is immersed in the solution, and a protective spray.

In either case, the port of the sensor package has to be protected. If the port is left open during PWB manufacturing, the material, such as flux, solvents, and conformal coating will fill–in and interact with the silicone gel. The purpose of the silicon gel is to protect the sensor from environmental exposure. The interaction of these materials may alter or degrade the device performance. In addition, it may cause threat to long term reliability of the device. One solution to this problem is to cover the port temporarily during the assembly and remove it after the coating operation. A number of methods can be utilized for protective cover during conformal coating. These are: (a) attach a tape and detach or laser drill the tape after coating, (b) place a cap over the device and remove after coating. For the case (b) the housing should have a port that can facilitate the cap.



(1) Pattern x–ducer and devices

(3) Thin diaphragm formation

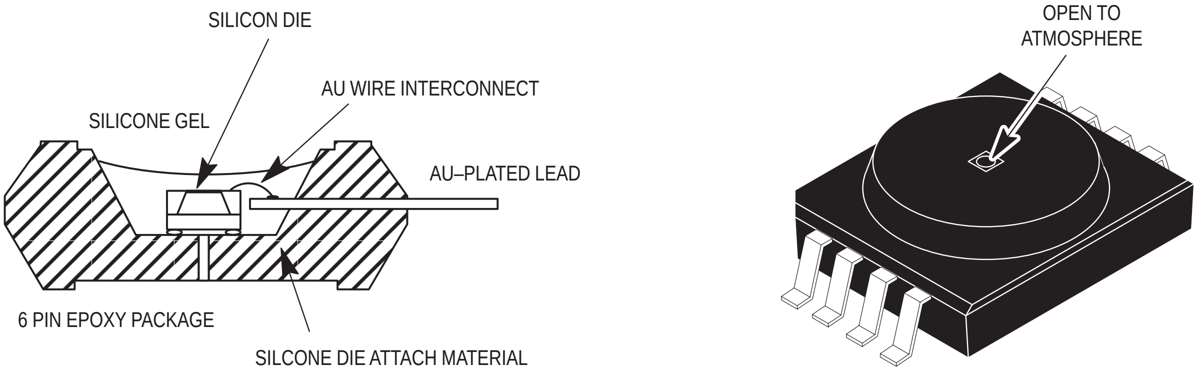


(2) Pattern metal interconnect

(4) Glass frit bonding for vaccum reference

Figure 5. Process sequence for generic integrated absolute pressure sensor.

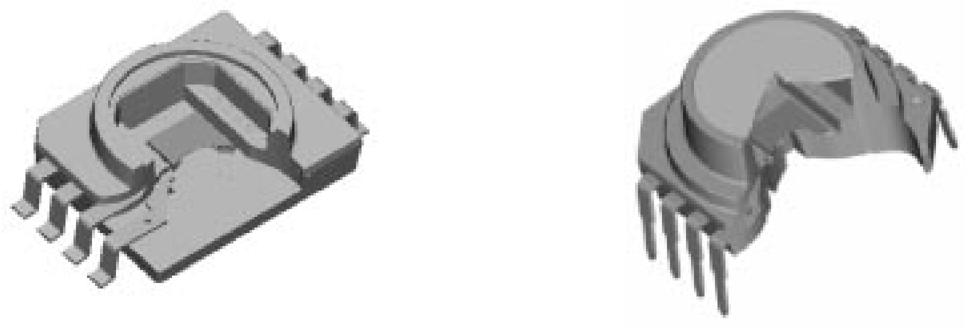
RELIABILITY AND MEDIA TESTING — To ensure accurate testing, knowledge of the application, lifetime requirements and what constitutes a failure is crucial. A physics–of–failure approach can significantly reduce the development cycle time and produce a higher quality product [7]. The focus of the physics–of–failure approach includes an understanding of the application, lifetime expectation, failure mechanism(s), and lifetime models. The requirement for a typical MAP or BAP pressure sensor application involves testing to temperature extremes, thermal shock, humidity, media exposure, vibration, shock, cyclic pressure, and overpressure testing [8]. Through reliability testing and knowledge of the environment, potential failure mechanisms are uncovered. A complete listing of potential failure mechanisms that may affect a pressure sensor device has been presented elsewhere [9].



Sample Package Detail

Package Part

Figure 6. General description of absolute pressure sensor for BAP application.



SURFACE MOUNT SENSOR

TOP PISTON FIT SENSOR

Figure 7. Surface Mount and Top Piston Fit Packages

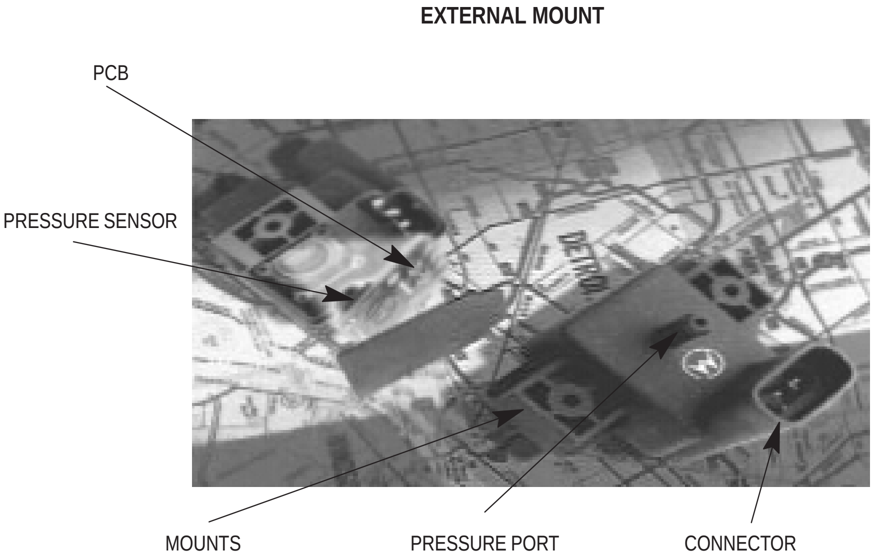


Figure 8. Conceptual housing options for user implementation. The direct ECU mount photograph only shows the IPS sensor, the remaining circuitry is removed.

CONCLUSION

A monolithic sensor has been developed for a BAP application. This pressure sensor is small in size and offers improved performance. The sensor can be mounted externally or directly on the ECU. The direct mount offers a lower system cost. A Au flash on the device leads enhance the solderability while staying below the Au limit to cause embrittlement of the solder joint. A capping operation is recommended during cleaning or conformal coating of the device.

ACKNOWLEDGMENTS

The authors would like to thank John Trice, Randy Frank, Demetre Kondylis, Dan Wallace, Kelvin Blair, Aristide Tintikakis, Wayne Chavez, and Gary Beaudin for the encouragement and valuable inputs.

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MOTOROLA
SEMICONDUCTOR APPLICATION NOTE

AN1622

EMC Considerations for Automotive Sensors

Prepared by: Dragan Mladenovic, Rajan Verma, and Randy Frank
Motorola Semiconductor Products Sector

ABSTRACT

Electro–Magnetic Compatibility (EMC) is a qualification requirement for automotive electronic components. Meeting this requirement can be a challenge, especially for devices in plastic packages with minimal shielding. EMC has a twofold meaning:

a) radiation of electromagnetic energy below a certain level in order to prevent negative impact on electrical performance of surrounding devices, and
b) lower susceptibility or greater resistance to the present electromagnetic (EM) signals.

Our concern in this paper is "b)" susceptibility of pressure sensors with integrated signal conditioning including amplification. Electrical performance of these sensors in an environment that is more and more contaminated with EM energy is very crucial for a number of automotive applications. The Integrated Pressure Sensors (IPS) will be used as an example for EMC testing. The EMC test setups and characterization results of the IPS will be discussed.

INTRODUCTION

Micromachined piezoresistive pressure sensors have been used successfully for over a decade in automotive manifold absolute pressure and barometric absolute pressure measurements. The EMC of these units was usually assured by shielding inside the module or the module housing itself. More recently, piezoresistive sensors with integrated signal conditioning have been qualified for automotive usage. A block diagram of a micromachined pressure sensor with integrated signal conditioning is shown in Figure 1 [1]. The key to the IPS is a single small silicon area with all of the calibration trims performed on the chip itself. This small die size allows the chip to be installed in a small surface mount package for subsequent assembly in an automotive electronics module. A metal can package offers improved immunity to radiated EM interference when the package is well grounded but is more costly and does not provide a surface mount assembly. It does not provide improvement for lead–conducted EMC.

A plastic chip carrier package designed for high volume, cost–sensitive pressure sensor applications is shown in Figure 2 [2]. A single mold forms both the body and back of the chip carrier. This surface mount package provides low cost with few process steps and is applicable to relatively high pressure range (up to 724 kPa or 105 psi). The leadframe assembly technique allows easy handling of several devices at one time and the automation of assembly operations such as die bond, wire bond and gel filling operations. Automation allows tight process controls to be implemented and still provides high throughput.

EMC is a major concern for the plastic–packaged IPS, especially when it is installed inside a module that can have high frequency switching such as ignition coil drivers. Addressing these concerns through repeatable EMC testing requires: a careful test setup, well–defined test method and a documented data measurement technique.

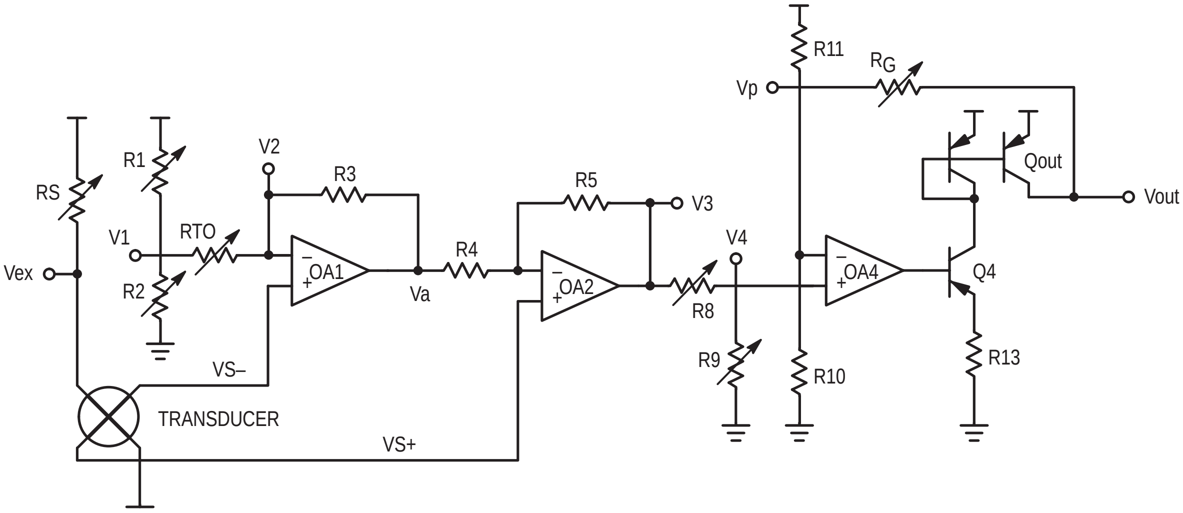

Figure 1. Integrated Pressure Sensor Block Diagram

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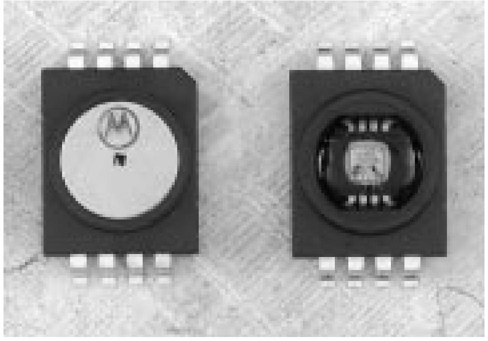


Figure 2. Plastic Package for Integrated Pressure Sensor. Shown with and without cover.

EMC TEST SETUP

One of the difficulties in EMC testing is ensuring that the test results can be repeated at different labs, conducted by different people and still give the same results. A test method which accomplishes this will be described in full detail. In the following section, where results will be discussed, other methods will be briefly mentioned and discussed as well.

Testing was performed within a USC–2 EMI anechoic shielded enclosure. The facility is a solid–wall shielded enclosure with filtered power. USC–2 is specifically designed with 1.2 meter (4–foot) anechoic cones to minimize shield room reflections.

The device under test (DUT) was mounted vertically in a socket on the top of the standard aluminum boxes (approximately 7.6cm x 10.2cm x 7.6cm or 3″ x 4″ x 3″) containing additional shielding (copper tape). The box is meant to reduce the effects of interface cabling and test the susceptibility only of the sensor package and die inside. SMA connectors are located at the side of the box to supply power and receive the sensor output. In the setup, semi–rigid cable was run directly to the SMA connectors (see Figure 3).

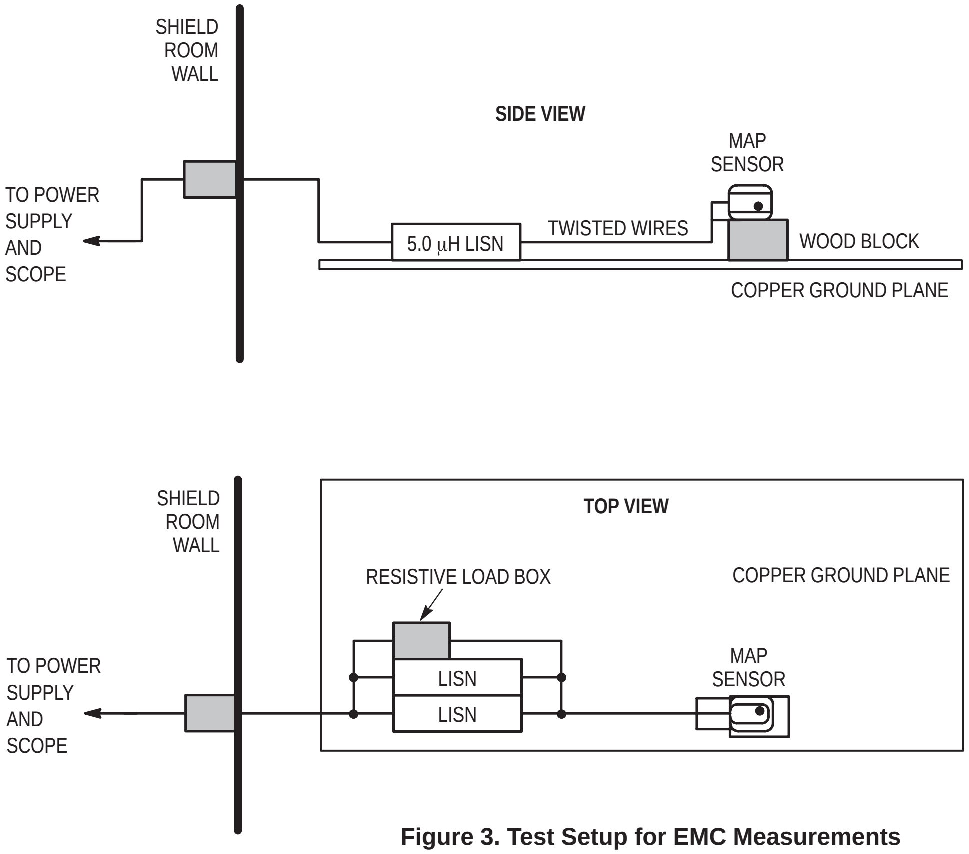
Qualification testing for the IPS required performance at 200 V/m radiated immunity — from 10 kHz to 1 GHz. This is one of the higher signal strength levels that is specified. However, required performance depends on the customer specification. Over thirty EMI specifications have been reported for engine control applications around the world — there is no common standard (3). The test was also extended to higher frequency to evaluate influence of the 1 to 18 GHz signals. The general test procedure selected was SAE J1113 AUG 87 — Electromagnetic Susceptibility Measurement Procedures for Vehicle Components (Except Aircraft).

Test Specification

The following field characteristics were defined:

Field Strength = 200 V/m
Frequency Range = 1 kHz to 1 GHz
Modulation = AM, 30% with 1 kHz sine wave.
Polarity = Vertical and horizontal

Criteria for acceptable performance of DUT:
AC ripple ≤ ±50 mV



Test Conditions:

a) Located in anechoically shielded room.
b) Interface wires routed 5 cm over ground plane, 10 cm away from front edge.
c) Interface wires twisted.
d) Sensor 10 cm above ground plane.

Figure 3. Test Setup for EMC Measurements

EMC TEST METHOD

From 10 kHz to 200 MHz the parallel strip line antenna was used to generate the required field strength. In the 30 MHz to 200 MHz region horizontal polarity was achieved by placing the components on their side.

From 200 MHz to 1 GHz the EMCO 3106 Double Ridged Guide antenna was used. Horizontal polarity was achieved in this range by changing the polarity of the antenna. From 1 GHz to 12 GHz the EMCO 3115 Double Ridged Guide antenna was used. From 12 GHz to 18 GHz a standard gain horn was used.

The incident field was measured using isotropic field monitoring probes (the IFI EFS–5 from 10 kHz to 200 MHz and the Narda 8719 from 200 MHz to 18 GHz) which were placed near the DUT and monitored in real time. Auto leveling was used to achieve a uniform field strength with respect to frequency.

DATA MEASUREMENT TECHNIQUE

Data collected from this test were as follows: (a) the amplitude of the ripple at the component output when the applied field strength is 200 V/m and (b) the DC output signal shift.

For the type (a) measurement, the component voltage output was run into a Tektronics 2440 oscilloscope, which was operated in the envelope detect and scroll mode. This enabled the oscilloscope to display the peak–to–peak Vout reading over a 50–second scan period. Since the scan frequency is directly related with time, the resulting plot showed an envelope of the output voltage with respect to scan frequency.

TEST RESULTS

Tested pressure sensors did not exceed either the AC ripple or DC offset susceptibility criteria over the 200 MHz to 1 GHz frequency range. Measurements were repeated several times over time periods as long as several days with the same test setup and results show very similar values. The DUT showed minor (< 300 mV) DC variances in the above frequency range. Figures 4 and 5 depict the common AC response in the frequency ranges 200 to 500 MHz and 500 to 1000 MHz, respectively. Figures 6 and 7 illustrate typical responses in lower gigahertz range of the same parts. Notice the scale of the vertical axis in Figure 6 is 500 mV per division, while in Figure 7 it is 50 mV per division. The samples did not show a susceptibility greater than +/– 50 mV for frequencies between 2.5 and 18 GHz.

These results verify that the plastic packaged integrated pressure sensors are not very susceptible to the surrounding electromagnetic field. However, the test setup plays a significant role in defining the device response and real susceptibility. Furthermore, due to the number of specifications that exist and to verify acceptable performance of product in the plastic package for two specific applications, additional tests were conducted. The results for these alternate techniques will be discussed in the next two sections. IPS devices were tested both in GTEM testing and with RF directly injected into their leads which is more appropriate for automotive applications. Direct injection is known to be a more demanding test for EMC performance and a narrower frequency range is normally specified by customers for this test.

GTEM GTEM testing was carried out at a field strength of 100V/m with a frequency sweep from 2 MHz to 1 GHz. Products from the same family but not necessarily the same DUTs in the previous tests were used for this testing. Each device was fitted with a 5 cm harness, which acts as the antenna for the RF signal into the device circuitry. This harness was taped in a secure position parallel to the E–field in all tests. A standard load was placed on each DUT. This load consists of a 51K resistor and a 2200pF capacitor attached in parallel from the sensor output to ground.

Performance during this test was very satisfactory from 2 MHz to 500 MHz. Beyond this point the output fluctuations began to increase until a maximum peak was reached at approximately 930 MHz. This result shows that with simple additional filter circuitry, a module using the IPS device can have susceptibility well below the limits, especially for frequencies lower than 500 MHz.

Direct RF Injection Direct RF injection is performed by soldering the harness to an impedance network. The same signal level (100 V/m) used in the GTEM testing was injected directly into the leads. Results from this test were not surprising. As would be expected from an unprotected (no additional filter) element, its output was not immune to the RF interference. Fluctuations of the output signal were significant. If the EM signal is radiated directly onto the device, susceptibility is very low for frequencies below 600 MHz and above 2 GHz. Between 600 MHz and 2 GHz some AC as well as DC shifts have been noticed.

To improve the performance when the EM signal is injected into the device leads, additional passive components, such as three–terminal capacitors, can stabilize the response and almost fully eliminate susceptibility. This is a significant result for further development of the integrated sensors. Figure 8 demonstrates the performance with the addition of these components using the method shown in Figure 3 and the higher 200V/m field strength.

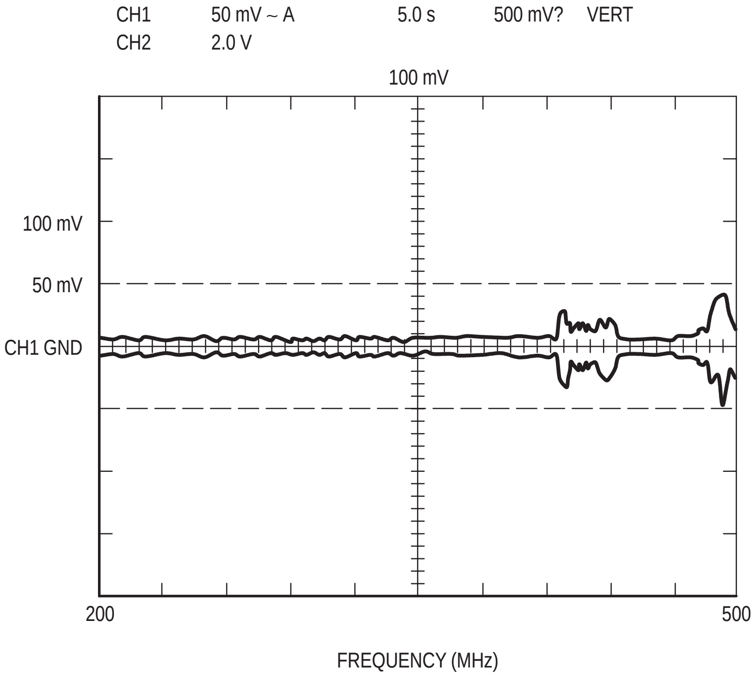


Figure 4. Common AC response in the 200 to 500 MHz frequency range.

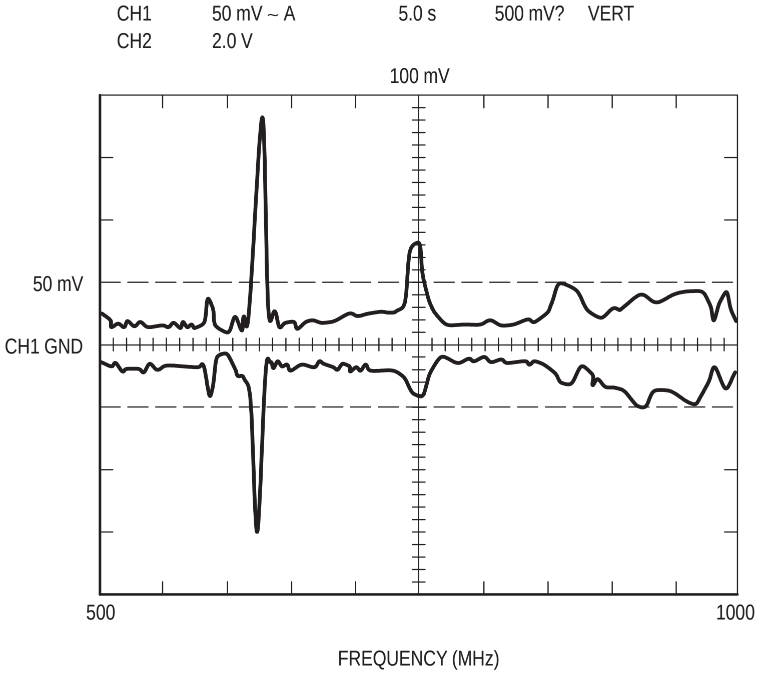


Figure 5. Common AC response in the 500 to 1000 MHz frequency range.

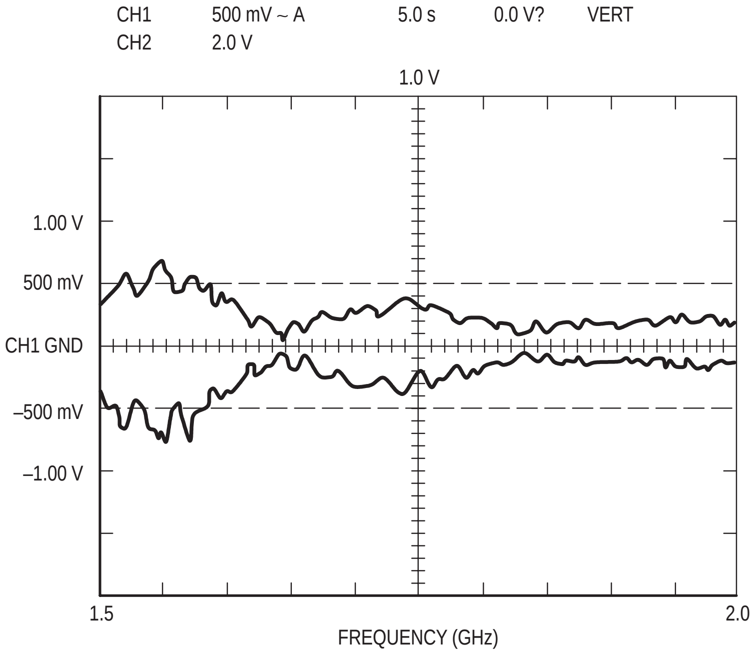


Figure 6. Typical responses in lower gigahertz range of the same parts. The scale of the vertical axis is 500 mV per division.

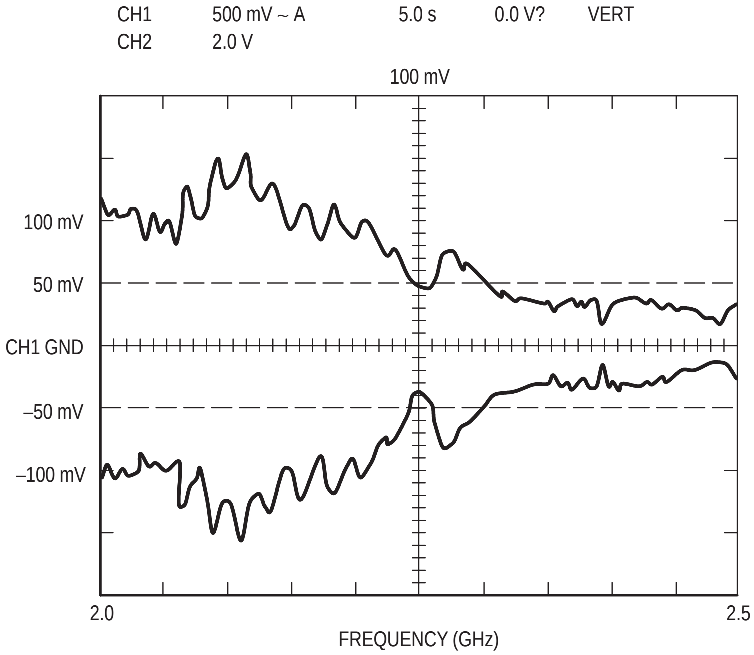


Figure 7. Typical responses in lower gigahertz range of the same parts. The scale of the vertical axis is 50 mV per division.

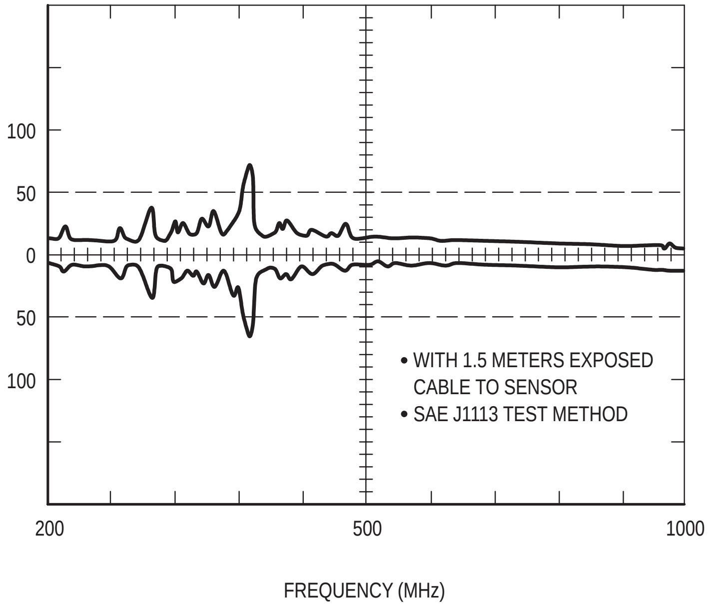


Figure 8. EMC results of MAP sensor with additional (external) filter.

CONCLUSION

The plastic–packaged integrated pressure sensor has demonstrated very good immunity to the surrounding electromagnetic field. The exact performance depends on the test setup. Due to the number of different EMC specifications, several tests may have to be performed to qualify a product for the same application but with different customers. A filter technique has been tested that greatly improves the IPS' performance even under the toughest testing including the direct RF injection test.

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MOTOROLA
SEMICONDUCTOR APPLICATION NOTE

AN1636

Implementing Auto Zero for Integrated Pressure Sensors

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INTRODUCTION

This application note describes how to implement an auto–zero function when using a Motorola integrated pressure sensor with a microcontroller and an analog to digital converter (MCU and an A/D). Auto–zero is a compensation technique based on sampling the offset of the sensor at reference pressure (atmospheric pressure is a zero reference for a gauge measurement) in order to correct the sensor output for long–term offset drift or variation.

Sources of offset errors are due to device to device offset variation (trim errors), mechanical stresses (mounting stresses), shifts due to temperature and aging. Performing auto–zero will greatly reduce these errors. The amount of error correction is limited by the resolution of the A/D.

In pressure sensing applications where a zero–pressure reference condition can exist, auto–zero can be implemented easily when an integrated pressure sensor is interfaced to an MCU.

EFFECTS OF OFFSET ERRORS

Figure 1 illustrates the transfer function of an integrated pressure sensor. It is expressed by the linear function:

$$\begin{aligned} V_{OUT} &= V_{OFF} + [(V_{FSO} - V_{OFF})/(P_{MAX} - P_{REF})]*P \\ &= V_{OFF} + S*P. \end{aligned}$$

Here, V_{OUT} is the voltage output of the sensor, V_{FSO} is the full–scale output, V_{OFF} is the offset, P_{MAX} is the maximum pressure and P_{REF} is the reference pressure. Note that $(V_{FSO} - V_{OFF}/P_{MAX} - P_{REF})$ can be thought of as the slope of the line and V_{OFF} as they y–intercept. The slope is also referred to as the sensitivity, S, of the sensor.

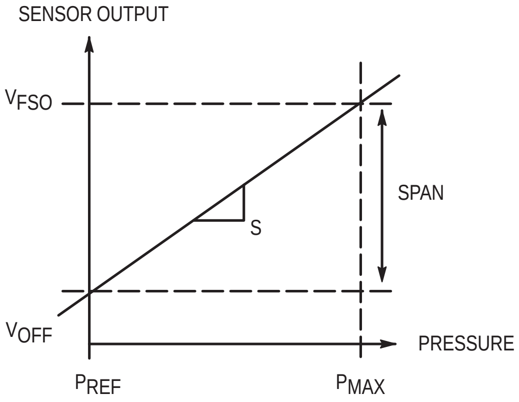

Figure 1. Definition of Span, Full–Scale Output, Offset and Sensitivity

REV 1

A two–point pressure calibration can be performed to accurately determine the sensitivity and get rid of the offset calibration errors altogether. However, this can be very expensive in a high volume production due to extra time and labor involved. The system designer therefore designs a pressure sensor system by relying on the sensitivity and offset data given in the data sheet and using a linear equation to determine the pressure. Using the later, the sensed pressure is easily determined by:

$$P = (V_{OUT} - V_{OFF})/S.$$

If an offset error is introduced due to device to device variation, mechanical stresses, or offset shift due to temperature (the offset has a temperature coefficient or TCO), those errors will show up as an error, ΔP, in the pressure reading:

$$P + \Delta P = [V_{OUT} - (V_{OFF} + \Delta V_{OFF})]/S.$$

As evident in Figure 2, offset errors, ΔV_{OFF}, have the effect of moving the intercept up and down *without* affecting the sensitivity. *We can therefore correct this error by sampling the pressure at zero reference pressure (atmosphere) and subtracting this from the sensor output.*

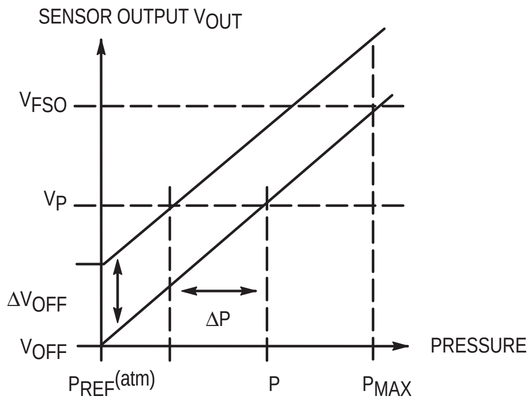

Figure 2. Effect of Offset Errors

AUTO–ZERO CONSIDERATIONS IN APPLICATIONS

There is an important consideration when implementing auto–zero. In order to use this technique, *a zero pressure reference condition must be known to exist in the system.*

There are a lot of applications that will lend themselves naturally to auto–zeroing. Typical applications are those that:

- experience a zero–pressure condition at system start up,
- are idle for a long time (zero pressure), take a pressure measurement then go back to idle again.

For example, in a water level measurement in a washing machine application, there is a zero pressure reference condition when the water in the tub is fully pumped out. Another application that is perfect for auto–zeroing is a beverage fill level measurement; a zero reference condition exists before the bottle is filled. HVAC air flow applications can also use auto–zeroing; before system start up, an auto–zero can be initiated. In other words, it can be used in applications where a zero pressure condition can exist in order to auto–zero the system.

An auto–zero command can be automated by the system or can be commanded manually. Each system will have a different algorithm to command an auto–zero signal. For example, using the beverage fill level measurement as an example, the system will auto zero the sensor before the bottle is filled.

IMPLEMENTATION OF AUTO–ZERO WITH A MICROCONTROLLER

Auto–zero can be implemented easily when the integrated sensor is interfaced to a microcontroller. The auto–zero algorithm is listed below:

1. Sample the sensor output when a known zero reference is applied to the sensor (atmospheric pressure is a zero reference for gauge type measurement). Store current zero pressure offset as CZPO.
2. Sample the sensor output at the current applied pressure. Call this SP.
3. Subtract the stored offset correction, CZPO, from SP. The pressure being measured is simply calculated as:

$$P_{MEAS} = (SP - CZPO)/S.$$

Note that the equation is simply a straight line equation, where S is the sensitivity of the sensor. The auto–zero algorithm is shown graphically in Figure 3.

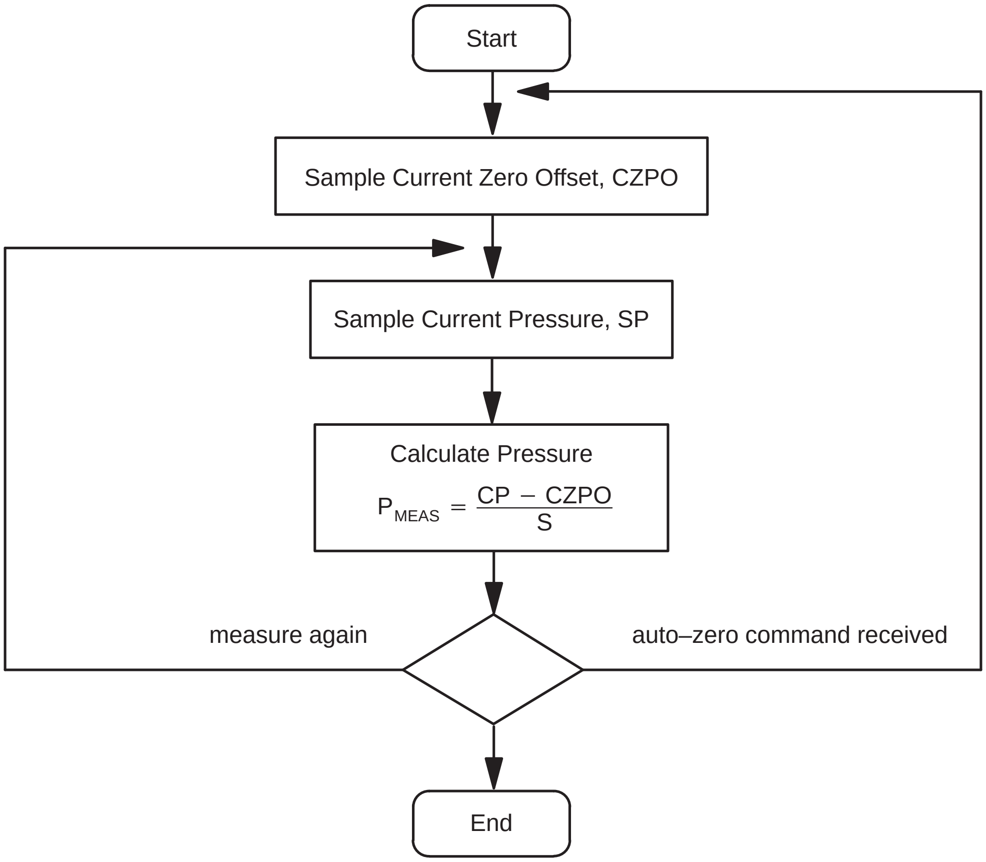

Figure 3. Flow–Chart of the Auto–Zero Algorithm

IMPROVEMENT ON OFFSET ERROR

In the following calculations, we will illustrate how auto–zero will improve the offset error contribution. We will use the MPX5006 interfaced to an 8–bit A/D as an example. When auto–zero is performed, the offset errors are reduced and the *resulting offset errors are replaced with the error (due to resolution) of the A/D.* We can categorize the offset error contributions into temperature and calibration errors.

Temperature Coefficient of Offset Error

The offset error due to temperature is due to Temperature Coefficient of Offset, or TCO. This parameter is the rate of change of the offset when the sensor is subject to temperature. It is defined as:

$TCO = (\Delta V_{OFF}/\Delta T)$.

The MPX5006 has a temperature coefficient of offset (normalized with the span at 25°C) of:

$\Delta TCO = (\Delta V_{OFF}/\Delta T)/V_{FS@25^\circ C} = 0.06\%\ FS/^\circ C$.

As an example, if the sensor is subjected to temperature range between 10°C and 60°C, the error due to TCO is:

$\Delta TCO = (0.06\%\ FS/C)*(60^\circ C - 10^\circ C) = \pm 3.0\%\ FS$.

Offset Calibration Errors

Even though the offset is laser trimmed, offset can shift due to packaging stresses, aging and external mechanical stresses due to mounting and orientation. This results in offset calibration error. For example, the MPX5006 data sheet shows this as:

$V_{OFF\ MIN} = 0.100$ V,
$V_{OFF\ TYPICAL} = 0.225$ V and $V_{OFF\ MAX} = 0.430$ V.

We can then calculate the offset calibration error with respect to the full scale span as:

$\Delta V_{OFF\ MIN,MAX} =$
$(V_{OFF\ TYPICAL} - V_{OFF\ MIN,MAX})/V_{FS}$.

This results in the following offset calibration error,

$\Delta V_{OFF\ MIN} = 2.7\%$ FS and
$\Delta V_{OFF\ MAX} = 4.5\%$ FS.

A/D Error

As mentioned above, we can reduce offset errors (calibration and TCO) when we perform auto–zero. These errors are replaced with the A/D error (due to its resolution),

$\Delta OFFSET_{AUTOZERO} = \Delta TCO + \Delta OFFSET = \Delta A/D$.

Typically, a sensor is interfaced to an 8–bit A/D. With the A/D reference tied to $V_{RH} = 5$ V and $V_{RL} = 0$ V, the A/D can resolve 19.6 mV/bit. For example, the MXP5006 has a sensitivity of 7.5 mV/mmH$_2$0, the resolution is therefore,

$$A/D_{RESOLUTION} = 19.6\ mV/bit)/(7.5\ mV/mmH_20)$$
$$= 2.6\ mmH_20/bit.$$

Assuming +/ – 1 LSB error, the error due to digitization *and* the resulting offset error is,

$$\Delta A/D = \Delta OFFSET_{AUTOZERO} = 2.6\ mmH_20/612\ mmH_20$$
$$= +/-\ 0.4\%\ FS.$$

It can be seen that with increasing A/D resolution, offset errors can be further reduced. For example, with a 10–bit A/D, the resulting offset error contribution is only 0.1% FS when auto–zero is performed.

If auto–zero is to be performed only once and offset correction data is stored in non–volatile memory, the TCO offset error and calibration error will not be corrected *if* the sensor later experiences a wide temperature range or later experience an offset shift. However, if auto–zero is performed *at* the operating temperature, TCO error will be compensated although subsequent offset calibration error will not be compensated. It is therefore best to auto–zero as often as possible in order to dynamically compensate the system for offset errors.

CONCLUSION

Auto–zero can be used to reduce offset errors in a sensor system. This technique can easily be implemented when an integrated pressure sensor is interfaced to an A/D and a microcontroller. With a few lines of code, the offset errors are effectively reduced; the resulting offset error reduction is limited only by the resolution of the A/D.

AN1638

Offset Calibration of Gauge Pressure Sensor Using Parallel I/O Ports

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INTRODUCTION

This application note describes the concept of calibrating the offset of a gauge pressure sensor using the parallel i/o ports of a microcontroller which includes the hardware/software, a liquid crystal display and some switches. External stresses and mounting position can affect the zero pressure output reading of a gauge pressure sensor especially low pressure sensor (high sensitivity), it is advisable to perform offset calibration after installation. In general, the offset value of the sensor can be stored in the ROM (read only memory), the EEPROM (electrical erasable programmable ROM) or the RAM (random access memory) of the microcontroller. The type of storage is restricted by the cost and applications of the system.

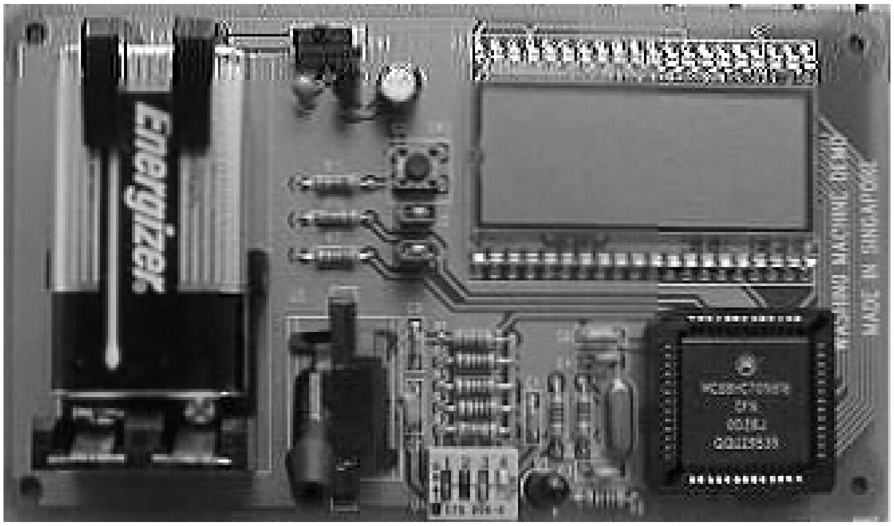

Figure 1. Offset Compensation Evaluation Board

CONCEPT OF OFFSET CALIBRATION USING PARALLEL I/O PORTS

In order to achieve better accuracy in a gauge pressure sensor, the output of the sensor is sampled at zero pressure (atmospheric pressure). This offset value will then be used to derive the actual pressure reading. Of all the methods used, the easiest way is to store the nominal offset value (given by the supplier) into the ROM. In other words, this value cannot be changed after the program code is implemented. Hence, the accuracy is affected by the part–to–part offset variation and temperature coefficient of offset (TCO).

The second method calibrates the offset value at the production and stores it in the EEPROM of the microcontroller. It eliminates the part–to–part offset variation. However, this method becomes expensive if the original system does not have any EEPROM.

The third method calibrates the offset value every time the system is power–up. The offset is then saved into the RAM of the microcontroller. This method is simple, low cost, and it can also compensate for the part–to–part variation and TCO of the sensor. It is an ideal method for offset calibration but it may not be applicable in certain systems. For instance, in a digital blood pressure monitor, the system experiences a zero pressure condition before the user starts pumping the bulb. In this case, the system can execute a command to save the offset value into the RAM. However, in a washing machine, the system may or may not experience zero pressure during start–up. This may occur when some users may start pouring water into the tub (for top loading washing machine) even before they switch on the power. However, for front loading washing machine, the method of offset calibration is possible because it is impossible for the user to pour water into the drum.

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During offset calibration, 1–byte or 8–bit of the data is used to represent the offset value for a 8–bit analog–to–digital converter (ADC). Since the offset voltage is very close to the lower rail of the supply, the 8–bit data string is not fully utilised i.e. only the lower 4 to 5 bits are used. The upper bits are all zeros.

Let's take the MPXT5006D as an example. The offset value ranges from a minimum of 0.1 V to a maximum of 0.43 V with the nominal value at 0.225 V. Hence, the variation of offset from the nominal value is –0.125 V and +0.205 V. Therefore, the offset is varied from the nominal value by –6 steps to +10 steps based on the 19.6 mV/step of ADC. In this application note, we defined this variation by a 4–bit data which is shown the Figure 2.

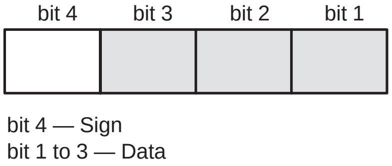

Figure 2. Data Format

In this way, the 4–bit data string can calibrate the offset value with variation of ±0.137 V from the nominal. This 4–bit data will be implemented using hardware (DIL switch is used in this case) through the parallel i/o ports of the microcontroller.

HARDWARE DESCRIPTION AND OPERATION

In this example, we use a 4–way DIL switch to represent the 4–bit data string. In an actual case, jumper wires should be used for lower cost. Figure 3 shows the interface between the DIL switch and microcontroller i/o ports. In this design, port D is used and is configured as standard input–only pins (can be read via port D data register) whenever the program reads the status of the DIL switch.

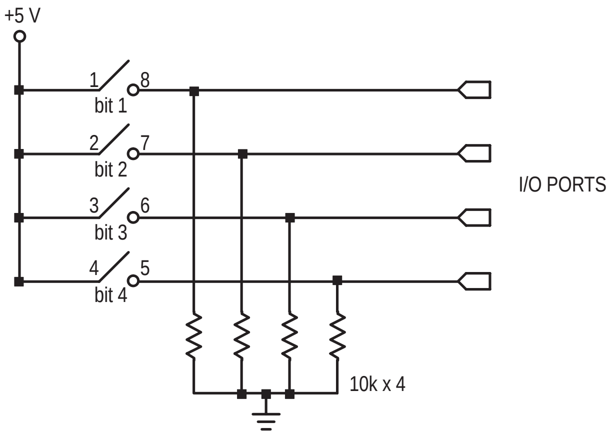

Figure 3. Interface of DIL Switch to Microcontroller

By closing the switch, the corresponding i/o pin will indicate a logic "1" and vice–versa. For a cheaper solution, the four switches are replaced by 4 jumper wires which represents "1111". To store a logical "0" during offset calibration, the corresponding wire will be removed or cut.

Offset (steps) = Nominal ± Data (3–bit)

where Nominal = 11 steps
Sign = plus if bit 4 is "0"
Sign = minus if bit 4 is "1"

The DIL switch is "1011", offset = 11 – 3 = 9 steps or 0.176 V
The DIL switch is "0100", offset = 11 + 4 = 15 steps or 0.294 V

Therefore, the higher the number of i/o pins used, the wider it can calibrate for the spread in sensor's offset. However, it has to depend on the availability of i/o ports in the system.

Besides performing offset calibration using i/o ports, the system also allows calibration through RAM and EEPROM. The type of storage mode for the offset value is determined by the two jumper settings i.e. J1 and J2.

	J1	J2
ROM	ON	ON
RAM	ON	OFF
EEPROM	OFF	ON
I/O Ports	OFF	OFF

The output of the integrated pressure sensor is ratiometric to the voltage applied to it. The sensor and the reference voltages 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 (LCD) is directly driven from I/O ports A, B, and C on the microcontroller. The operation of a LCD requires that the data and backplane (BP) 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. Other than the LCD, one light emitting diode (LED) is connected to the pulse length converter (PLM) of the microcontroller. This LED will light up whenever the pressure sensor's reading exceeded 600 mm of water level.

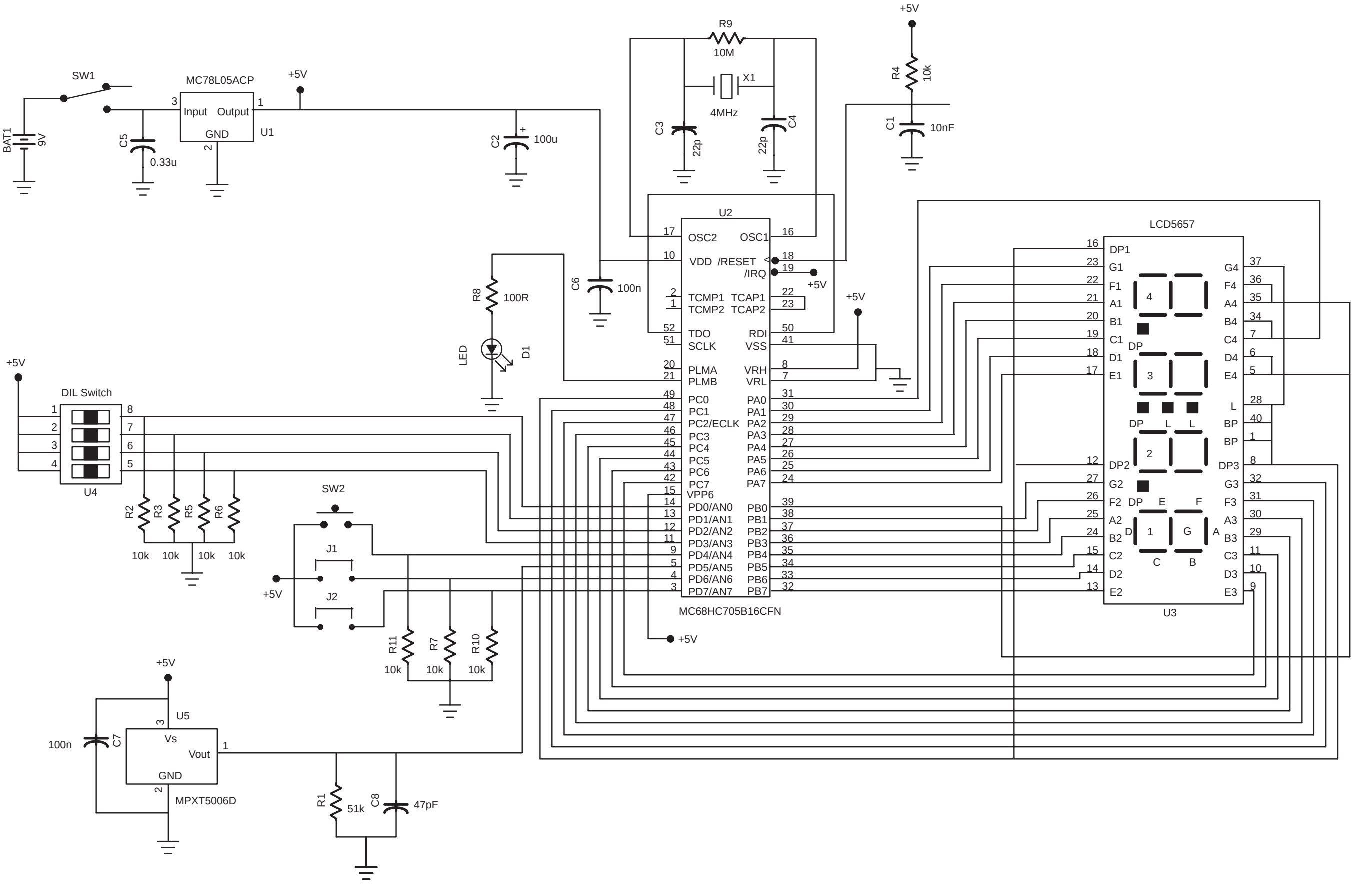

Figure 4. Offset Calibration Schematic Drawing

SOFTWARE DESCRIPTION

Upon power–up of the system, the microcontroller will sample the sensor's output and calculate the average value. Depending on the jumper settings, the calculation will retrieve the offset value from the respective location (RAM, ROM etc.) and convert the pressure to millimetre of water according to the equation below.

Pressure (mmH$_2$0) = ($V_{OUT} - V_{OFFSET}$) × Resolution

where V_{OUT} and V_{OFFSET} is in number of steps
Resolution is 2.6081 mm/step

This water level reading is then shown on the LCD. To calibrate the offset value, expose the sensor to atmospheric pressure and press the button SW2 after configured the desired jumper settings. The LCD will display "CAL" for 2 seconds before the microcontroller starts to sample and calculate average value for zero offset voltage. This value will then be saved in the respective location depending of the jumper settings. One point to note is that the sensor should remain at zero pressure during the calibration process.

For calibration using i/o ports, the program will determine the required compensation and display a 4–bit data on the LCD for 2 seconds after "CAL". You will need to change the configuration of the DIL switch from number 1 to number 4 according to display on the LCD from bit 0 to bit 3 respectively.

The LCD will automatically switch back to display water level immediately after the calibration.

Figure 5 is a flowchart for the program that controls the system.

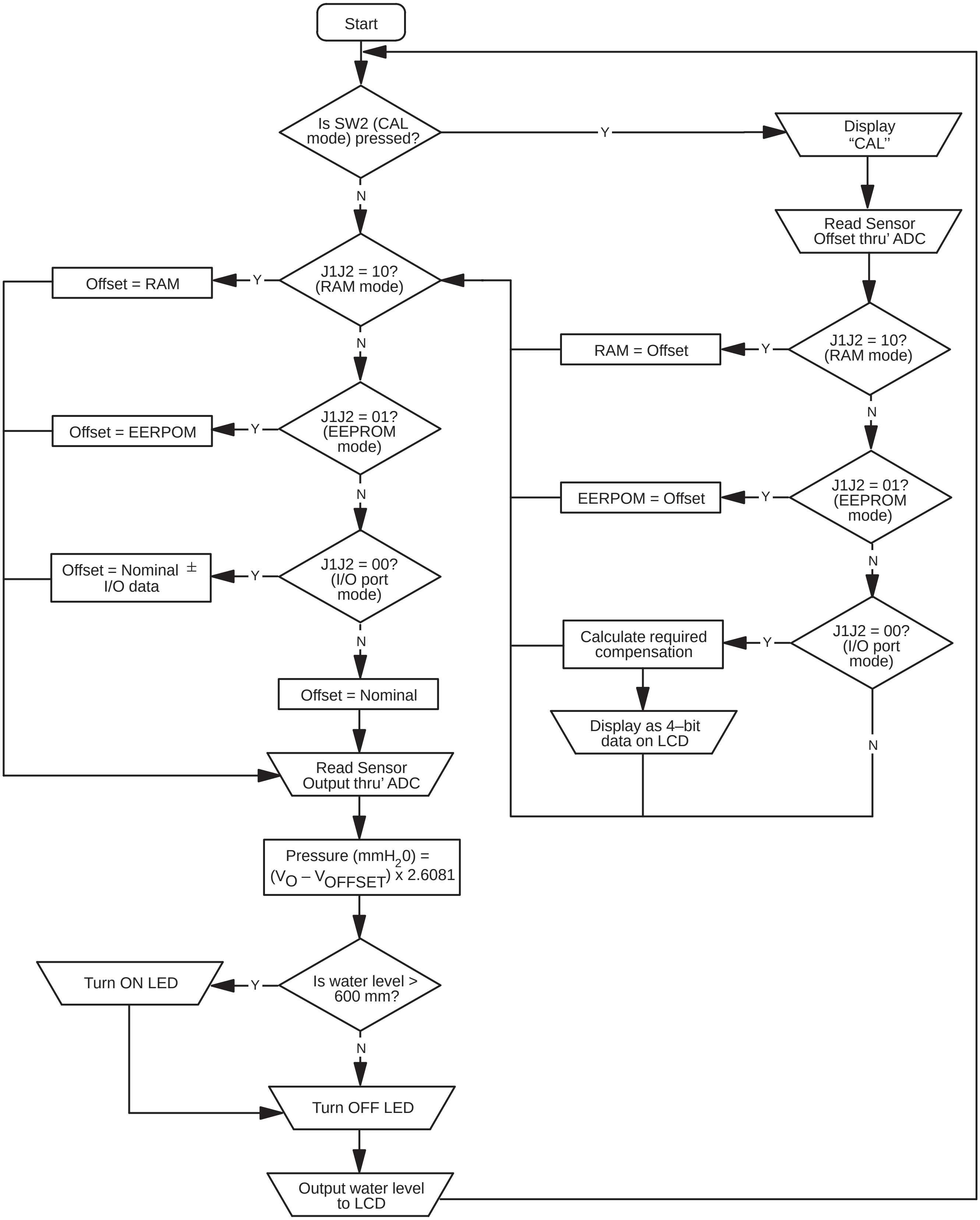

Figure 5. Main Program Flowchart

CONCLUSION

Offset calibration of a gauge pressure sensor can improve the accuracy of a system significantly. However, for a system that may not experience an atmospheric pressure during the start–up, the offset should be calibrated on the production floor. In this case, the offset value will have to be stored as non–volatile memory, either in the EEPROM or the i/o ports whichever is available.

REFERENCES

1. Ador Reodique, “Implementing Auto Zero for Integrated Pressure Sensors”, Motorola Application Note AN1636.
2. Bill Lucas, “An Evaluation System for Direct Interface of the MPX5100 Pressure Sensor with a Microprocessor”, Motorola Application Note AN1305.

SOFTWARE SOURCE/ASSEMBLY PROGRAM CODE

```
******************************************************************************
*                                                                            *
*                     Offset Calibration Version 1.0                         *
*                                                                            *
*   The following code is written for MC68HC705B16 using MMDS05 software     *
*   Version 1.01                                                             *
*   CASM05 – Command line assembler Version 3.04                             *
*   P & E Microcomputer Systems, Inc.                                        *
*                                                                            *
*                         Written by : C.S. Chua                             *
*                             21 October 1997                                *
*                                                                            *
*                                                                            *
*              Copyright Motorola Electronics Pte Ltd 1997                   *
*                          All rights Reserved                               *
*                                                                            *
******************************************************************************
******************************************************************************
*                                                                            *
*                           Software Description                             *
*                                                                            *
*   This software is used to demonstrate offset calibration of low pressure  *
*   sensor through RAM, ROM, EEPROM or i/o ports                             *
*   In addition, it displays the water level in millimetre.                  *
*                                                                            *
******************************************************************************
******************************************
*                                        *
*            Initialisation              *
*                                        *
******************************************
PORTA        EQU     $00           ; Last digit
PORTB        EQU     $01           ; Second digit (and negative sign)
PORTC        EQU     $02           ; First digit (and decimal point)
PORTD        EQU     $03           ; 7 digit inputs and 1 analog input
EESTAT       EQU     $07           ; EEPROM control register
ADDATA       EQU     $08           ; ADC Data
ADSTAT       EQU     $09           ; ADC Status
PLMB         EQU     $0B           ; Pulse Length Modulator (Output to LED)
MISC         EQU     $0C           ; Miscellaneous Register (slow/fast mode)
TCONTROL     EQU     $12           ; Timer control register
TSTATUS      EQU     $13           ; Timer Status Register
OCMPHI1      EQU     $16           ; Output Compare Register 1 High Byte
OCMPLO1      EQU     $17           ; Output Compare Register 1 Low Byte
TCNTHI       EQU     $18           ; Timer Count Register High Byte
TCNTLO       EQU     $19           ; Timer Count Register Low Byte
OCMPHI2      EQU     $1E           ; Output Compare Register 2 High Byte
OCMPLO2      EQU     $1F           ; Output Compare Register 2 Low Byte
******************************************
*                                        *
*           User–defined RAM             *
*                                        *
******************************************
             ORG     $50
ADCOUNTER    RMB     1             ; Sampling Counter
TEMPTCNTHI   RMB     1             ; Temp storage for Timer count register
TEMPTCNTLO   RMB     1             ; Temp storage for Timer count register
STACK        RMB     5             ; Push acc and x–register during interrupt
RSHIFT       RMB     1             ; No of shifting required for division
ADVALUE      RMB     2             ; Analog voltage
OFFSET       RMB     1             ; Offset value
RAM          RMB     1             ; Offset stored in RAM
IO_OFFSET    RMB     1             ; Offset stored in i/o
OFCNT        RMB     1             ; Timer overflow counter
LCD_STATUS   RMB     1             ; LCD status
NUMBER       RMB     4             ; 4 byte number to be converted to decimal
                                   ; number
ADDEND       RMB     4             ; Variables used in Addition subroutine
AUGEND       RMB     4
SUM          RMB     4
MINUE        RMB     4             ; Variables used in Subtraction subroutine
SUBTRA       RMB     4
DIFF         RMB     4
MTEMP        RMB     4             ; Variables used in Multiplication
MULCAN       RMB     4             ; subroutine
MULTP        RMB     4
CNT          RMB     1             ; Variables used in the Division subroutine
DVSOR        RMB     4
DVDND        RMB     4
QUO          RMB     4
```

```
*******************************************
*                                         *
*           User–defined EEPROM          *
*                                         *
*******************************************
             ORG     $120
EEPROM       RMB     1             ; Offset stored in EEPROM
EEREG        EQU     $100          ; Options register
             ORG     $300          ; ROM space 0300 to 3DFE (15,104 bytes)
             DB      $FC           ; Display ”0”
             DB      $30           ; Display ”1”
             DB      $DA           ; Display ”2”
             DB      $7A           ; Display ”3”
             DB      $36           ; Display ”4”
             DB      $6E           ; Display ”5”
             DB      $EE           ; Display ”6”
             DB      $38           ; Display ”7”
             DB      $FE           ; Display ”8”
             DB      $7E           ; Display ”9”
NOMINAL      DB      !11           ; Offset nominal value
*******************************************
*                                         *
*   Program starts here upon hard reset   *
*                                         *
*******************************************
RESET        CLR     PORTC                    ; Port C = 0
             CLR     PORTB                    ; Port B = 0
             CLR     PORTA                    ; Port A = 0
             LDA     #$FF
             STA     $06                      ; Port C as output
             STA     $05                      ; Port B as output
             STA     $04                      ; Port A as output
             LDA     TSTATUS                  ; Dummy read the timer status register
             CLR     OCMPHI2                  ; so as to clear the OCF
             CLR     OCMPHI1
             LDA     OCMPLO2
             JSR     COMPRGT
             LDA     #$60                     ; Enable the output compare interrupt
             STA     TCONTROL
             CLI                              ; Interrupt begins here
             CLR     OFFSET
             CLR     RAM
ALWAYS       BCLR    6,ADSTAT                 ; Switch off ADC
             BCLR    5,ADSTAT
             BRCLR   4,PORTD,NO_CAL           ; Check if SW2 is pressed
             JSR     CALIBRATE
NO_CAL       BCLR    6,ADSTAT                 ; Switch off ADC
             BCLR    5,ADSTAT
             LDA     PORTD
             AND     #%11000000               ; Check J1 J2 status
             EOR     #%01000000
             BNE     MEMORY1
             LDA     RAM                      ; Used RAM value for offset
             STA     OFFSET
             JMP     READ_SENSOR
MEMORY1      BCLR    6,ADSTAT                 ; Switch off ADC
             BCLR    5,ADSTAT
             LDA     PORTD
             AND     #%11000000               ; Check J1 J2 status
             EOR     #%10000000
             BNE     MEMORY2
             LDA     EEPROM                   ; Use EPROM value for offset
             STA     OFFSET
             JMP     READ_SENSOR
MEMORY2      BCLR    6,ADSTAT                 ; Switch off ADC
             BCLR    5,ADSTAT
             LDA     PORTD
             AND     #%11000000               ; Check J1 J2 status
             EOR     #%00000000
             BNE     MEMORY3
             LDA     PORTD                    ; Use i/o value for offset
             AND     #%00000111
             STA     OFFSET
             BRSET   3,PORTD,MINUS            ; If DIL switch 4 is OFF
             LDA     NOMINAL                  ; Offset = Nominal + Offset
             ADD     OFFSET
             STA     OFFSET
             JMP     READ_SENSOR
MINUS        LDA     NOMINAL                  ; If DIL switch 4 is ON
             SUB     OFFSET                   ; Offset = Nominal – Offset
             STA     OFFSET
             JMP     READ_SENSOR
MEMORY3      LDA     NOMINAL                  ; Use ROM/nominal value
             STA     OFFSET                   ; for offset
READ_SENSOR  JSR     READAD                   ; Read Vo of sensor
             LDA     ADVALUE+1
```

```
             CMP     OFFSET
             BHS     POSITIVE
             LDA     OFFSET                    ; Offset – Vo
             SUB     ADVALUE+1
             BSET    3,LCD_STATUS              ; Turn ON negative sign
             BRA     EQUATION
POSITIVE     SUB     OFFSET                    ; Vo – Offset
             BCLR    3,LCD_STATUS              ; Turn OFF negative sign
EQUATION     STA     MULTP+3
             CLRA
             STA     MULTP+2
             STA     MULTP+1
             STA     MULTP
             LDA     #$E1
             STA     MULCAN+3
             LDA     #$65
             STA     MULCAN+2
             CLRA
             STA     MULCAN+1
             STA     MULCAN
             JSR     CALMUL                    ; (Vo – Offset)*2.6081
             LDA     MULCAN+3
             STA     ADDEND+3
             LDA     MULCAN+2
             STA     ADDEND+2
             LDA     MULCAN+1
             STA     ADDEND+1
             LDA     MULCAN
             STA     ADDEND
             LDA     #$88                      ; Add 0.5000
             STA     AUGEND+3
             LDA     #$13
             STA     AUGEND+2
             CLRA
             STA     AUGEND+1
             STA     AUGEND
             JSR     CALADD
             LDA     SUM+3
             STA     DVDND+3
             LDA     SUM+2
             STA     DVDND+2
             LDA     SUM+1
             STA     DVDND+1
             LDA     SUM
             STA     DVDND
             LDA     #$10
             STA     DVSOR+3
             LDA     #$27
             STA     DVSOR+2
             CLRA
             STA     DVSOR+1
             STA     DVSOR
             JSR     CALDIV                    ; / 10000
             LDA     OFCNT                     ; No refresh of LCD if the
             CMP     #!1                       ; time elapse is too short
             BLS     NO_REFRESH
             CLR     OFCNT
             LDA     QUO+2                     ; Check if level > 600 mm
             CMP     #$02
             BHS     MAX_LIMIT
             BRA     IN_LIMIT
MAX_LIMIT    LDA     QUO+3
             CMP     #$58
             BLS     IN_LIMIT
             LDA     #$80                     ; LED ON if limit is exceeded
             STA     PLMB
             BRA     SHOW_LEVEL
IN_LIMIT     CLRA                             ; LED OFF if within limit
             STA     PLMB
SHOW_LEVEL   LDA     QUO+3                    ; Display water level
             STA     NUMBER+3
             LDA     QUO+2
             STA     NUMBER+2
             LDA     QUO+1
             STA     NUMBER+1
             LDA     QUO
             STA     NUMBER
             JSR     ADTOLCD
NO_REFRESH   JMP     ALWAYS
******************************************
*                                        *
*          Offset Calibration            *
*                                        *
*   Output: Offset                       *
*                                        *
******************************************
```

```
CALIBRATE    LDA     #$CC          ; Port C = 1100 1100   Letter ”C”
             STA     PORTC
             LDA     #$BE          ; Port B = 1011 1110   Letter ”A”
             STA     PORTB
             LDA     #$C4          ; Port A = 1100 0100   Letter ”L”
             STA     PORTA
             LDA     #16
IDLE         JSR     DLY20         ; Idling for a while (16*0.125 = 2 sec)
             DECA                  ; for the zero offset to stabilize
             BNE     IDLE          ; before perform auto–zero
             JSR     READAD
             BCLR    6,ADSTAT      ; Switch off ADC
             BCLR    5,ADSTAT
             LDA     PORTD
             AND     #%11000000    ; Check J1 J2 status
             EOR     #%01000000
             BNE     NON_RAM
             LDA     ADVALUE+1     ; Save the offset into RAM
             STA     RAM
             BRA     END_CAL
NON_RAM      LDA     PORTD
             AND     #%11000000    ; Check J1 J2 status
             EOR     #%10000000
             BNE     NON_EPROM
             JSR     LOAD_EPROM    ; Call EPROM subroutine
             BRA     END_CAL
NON_EPROM    LDA     PORTD
             AND     #%11000000    ; Check J1 J2 status
             EOR     #%00000000
             BNE     END_CAL
             JSR     IO_CAL        ; Call i/o CAL subroutine
END_CAL      RTS
*******************************************
*                                         *
*         I/O CAL Subroutine              *
*                                         *
*******************************************
IO_CAL       SEI
             CLRA
             STA     PORTA
             STA     PORTB
             STA     PORTC
             LDA     ADVALUE+1     ; If Voffset >= nominal
             CMP     NOMINAL
             BLO     NEGATIVE
             SUB     NOMINAL       ; Voffset – nominal
             STA     IO_OFFSET
             BRA     SHOW_DIL
NEGATIVE     LDA     NOMINAL       ; If Voffset < nominal
             SUB     ADVALUE+1     ; Nominal – Voffset
             STA     IO_OFFSET
             BSET    3,IO_OFFSET   ; Nominal > Voffset
SHOW_DIL     BRCLR   0,IO_OFFSET,BIT1_ZERO
             LDA     $301
             STA     PORTA         ; 1st digit shows ”1”
             BRA     BIT2
BIT1_ZERO    LDA     $300          ; 1st digit shows ”0”
             STA     PORTA
BIT2         BRCLR   1,IO_OFFSET,BIT2_ZERO
             LDA     $301
             STA     PORTB         ; 2nd digit shows ”1”
             BRA     BIT3
BIT2_ZERO    LDA     $300
             STA     PORTB         ; 2nd digit shows ”0”
BIT3         BRCLR   2,IO_OFFSET,BIT3_ZERO
             LDA     $301
             STA     PORTC         ; 3rd digit shows ”1”
             BRA     BIT4
BIT3_ZERO    LDA     $300
             STA     PORTC         ; 3rd digit shows ”0”
BIT4         BRCLR   3,IO_OFFSET,BIT4_ZERO
             BSET    0,PORTA       ; 4th digit shows ”1”
             BRA     END_IO_CAL
BIT4_ZERO    BSET    0,PORTA       ; 4th digit shows ”0”
             BSET    0,PORTB
END_IO_CAL   CLI
             LDA     #16
IDLE1        JSR     DLY20         ; Idling for a while (16*0.125 = 2 sec)
             DECA                  ; for the user to read the LCD
             BNE     IDLE1         ; before switching the DIL SW
             RTS
*******************************************
*                                         *
*         Save Offset into EEPROM         *
*                                         *
*******************************************
```

```
LOAD_EPROM   CLRA
             STA     EESTAT        ; Erase EEPROM
             BSET    1,EESTAT      ; Set E1LAT bit
             BSET    2,EESTAT      ; Set E1ERA bit
             STA     EEPROM        ; Save data to location to be erased
             BSET    0,EESTAT      ; Set E1PGM bit
             JSR     DLY20         ; Wait for T(ERA1)
             BCLR    1,EESTAT      ; Reset E1LAT
             CLRA
             STA     EESTAT
             BSET    1,EESTAT
             LDA     ADVALUE+1     ; Load value into EEPROM
             STA     EEPROM
             BSET    0,EESTAT
             JSR     DLY20
             BCLR    1,EESTAT
             CLRA
             STA     EESTAT        ; Enable read operation
             RTS
******************************************
*                                        *
*            Delay Subroutine            *
*     (162 * 0.7725 ms = 0.125 sec)      *
*                                        *
******************************************
DLY20        STA     STACK
             STX     STACK+1
             LDA     #!162         ; 1 unit = 0.7725 ms
OUTLP        CLRX
INNRLP       DECX
             BNE     INNRLP
             DECA
             BNE     OUTLP
             LDX     STACK+1
             LDA     STACK
             RTS
******************************************
*                                        *
*     Reading the ADC data 128 times     *
*         and take the average           *
*                                        *
*  Output: ADVALUE (Average ADC data)    *
*                                        *
******************************************
READAD       LDA     #$25              ; Enable PD5 as ADC
             STA     ADSTAT
             CLR     ADVALUE           ; Clear the memory
             CLR     ADVALUE+1
             CLR     ADCOUNTER
             CLR     RSHIFT
LOOP128      LDA     ADCOUNTER
             CMP     #$80             ; If ADCOUNTER >= 128
             BHS     DIVIDE           ; Branch to DIVIDE
ENDREAD      BRCLR   7,ADSTAT,ENDREAD ; Halt here till AD read is finished
             LDA     ADDATA           ; Read the AD register
             ADD     ADVALUE+1        ; ADVALUE = ADVALUE + ADDATA
             STA     ADVALUE+1
             LDA     ADVALUE
             ADC     #$00
             STA     ADVALUE
             INC     ADCOUNTER        ; Increase the AD counter by 1
             BRA     LOOP128          ; Branch to Loop128
DIVIDE       INC     RSHIFT           ; Increase the right counter
             LSR     ADVALUE          ; Right shift the high byte
             ROR     ADVALUE+1        ; Right shift the low byte
             LDA     RSHIFT
             CMP     #$07             ; if the right shift counter >= 7
             BHS     ENDDIVIDE        ; End the shifting
             JMP     DIVIDE           ; otherwise continue the shifting
ENDDIVIDE    RTS
******************************************
*                                        *
*       Timer service interrupt          *
*     Alternates the Port data and       *
*          backplane of LCD              *
*                                        *
******************************************
TIMERCMP     STA     STACK+2                 ; Push Accumulator
             COM     PORTC                   ; Port C = – (Port C)
             COM     PORTB                   ; Port B = – (Port B)
             COM     PORTA                   ; Port A = – (Port A)
             BSR     COMPRGT                 ; Branch to subroutine compare register
             LDA     STACK+2                 ; Pop Accumulator
             RTI
```

```
******************************************
*                                        *
*           Subroutine reset             *
*      the timer compare register        *
*                                        *
******************************************
COMPRGT      LDA     TCNTHI                  ; Read Timer count register
             STA     TEMPTCNTHI              ; and store it in the RAM
             LDA     TCNTLO
             STA     TEMPTCNTLO
             ADD     #$4C                    ; Add 1D4C H = 7500 periods
             STA     TEMPTCNTLO              ; with the current timer count
             LDA     TEMPTCNTHI              ; 1 period = 2 us
             ADC     #$1D
             STA     TEMPTCNTHI              ; Save the next count to the register
             STA     OCMPHI1
             LDA     TSTATUS                 ; Clear the output compare flag
             LDA     TEMPTCNTLO              ; by access the timer status register
             STA     OCMPLO1                 ; and then access the output compare
             RTS                             ; register
******************************************
*                                        *
*     This subroutine is to convert      *
*        the AD data to the LCD          *
*    LCD_STATUS:                         *
*    Bit 3 – Negative Sign               *
*    Bit 2 – 4th Digit                   *
*    Bit 0 – No zero suppression         *
*                                        *
******************************************
ADTOLCD      SEI                             ; Disable the Timer Interrupt !!
             BCLR    0,LCD_STATUS
             BCLR    1,LCD_STATUS
             BCLR    2,LCD_STATUS
             CLRA                            ; Clear the 3 ports to
             STA     PORTA                   ; prevent the segment to turn
             STA     PORTB                   ; ON partially
             STA     PORTC
FORTH_DIGIT  LDA     NUMBER+3
             STA     DVDND+3
             LDA     NUMBER+2
             STA     DVDND+2
             LDA     NUMBER+1
             STA     DVDND+1
             LDA     NUMBER
             STA     DVDND
             LDA     #$E8
             STA     DVSOR+3
             LDA     #$03
             STA     DVSOR+2
             CLRA
             STA     DVSOR+1
             STA     DVSOR
             JSR     CALDIV                  ; Number / 1000
             LDA     QUO+3
             CMP     #1
             BHI     END_LCD                 ; Exit if more than 2000
             BLO     NO_4_DIGIT
             BSET    2,LCD_STATUS            ; Turn ON bit–2 of LCD_status
             BSET    0,LCD_STATUS            ; No need to suppress zero
             BRA     THIRD_DIGIT
NO_4_DIGIT   BCLR    2,LCD_STATUS            ; Turn OFF bit–2 of LCD_status
THIRD_DIGIT  LDA     #$64
             STA     DVSOR+3
             CLRA
             STA     DVSOR+2
             STA     DVSOR+1
             STA     DVSOR
             JSR     CALDIV                  ; Remainder / 100
             LDA     QUO+3
             CMP     #0
             BNE     NON_ZERO
             BRSET   0,LCD_STATUS,NON_ZERO
             CLRA                            ; Zero suppression
             STA     PORTC                   ; Clear port C
             BRA     SECOND_DIGIT
NON_ZERO     LDX     QUO+3
             LDA     $0300,X
             STA     PORTC                   ; Display 3rd digit
             BSET    0,LCD_STATUS            ; No need to suppress zero
SECOND_DIGIT LDA     #$0A
             STA     DVSOR+3
             CLRA
             STA     DVSOR+2
             STA     DVSOR+1
             STA     DVSOR
```

```
             JSR     CALDIV                  ; Remainder / 10
             LDA     QUO+3
             CMP     #0
             BNE     NON_ZERO1
             BRSET   0,LCD_STATUS,NON_ZERO1
             CLRA                            ; Zero suppression
             STA     PORTB                   ; Clear port B
             BRA     FIRST_DIGIT
NON_ZERO1    LDX     QUO+3
             LDA     $0300,X
             STA     PORTB                   ; Display 2nd digit
             BRA     FIRST_DIGIT
FIRST_DIGIT  LDX     DVDND+3
             LDA     $0300,X
             STA     PORTA
             BRSET   2,LCD_STATUS,DIGIT4_ON  ; Jump if the 4th digit is ON
             BRA     END_LCD
DIGIT4_ON    BSET    0,PORTA                 ; ON the forth digit
             BRA     END_LCD
END_LCD      BRCLR   3,LCD_STATUS,NO_SIGN
             BSET    1,PORTC                 ; Turn ON negative sign
NO_SIGN      CLI                             ; Enable Interrupt again !
             RTS
******************************************
*                                        *
*       Add two 32–bit values            *
*                                        *
*  ADDEND + AUGEND = SUM                 *
*                                        *
******************************************
CALADD       LDA     ADDEND+3
             ADD     AUGEND+3
             STA     SUM+3
             LDA     ADDEND+2
             ADC     AUGEND+2
             STA     SUM+2
             LDA     ADDEND+1
             ADC     AUGEND+1
             STA     SUM+1
             LDA     ADDEND
             ADC     AUGEND
             STA     SUM
             RTS
******************************************
*                                        *
*     Subtract two 32–bit values         *
*                                        *
*  MINUE – SUBTRA = DIFF                 *
*                                        *
******************************************
CALSUB       LDA     MINUE+3
             SUB     SUBTRA+3
             STA     DIFF+3
             LDA     MINUE+2
             SBC     SUBTRA+2
             STA     DIFF+2
             LDA     MINUE+1
             SBC     SUBTRA+1
             STA     DIFF+1
             LDA     MINUE
             SBC     SUBTRA
             STA     DIFF
             RTS
******************************************
*                                        *
* Multiply 32–bit value by 32–bit value  *
*                                        *
*  MULTP * MULCAN = MTEMP:MULCAN         *
*                                        *
******************************************
CALMUL       LDX     #!32
             CLR     MTEMP
             CLR     MTEMP+1
             CLR     MTEMP+2
             CLR     MTEMP+3
             ROR     MULCAN
             ROR     MULCAN+1
             ROR     MULCAN+2
             ROR     MULCAN+3
MNEXT        BCC     ROTATE
             LDA     MTEMP+3
             ADD     MULTP+3
             STA     MTEMP+3
             LDA     MTEMP+2
             ADC     MULTP+2
             STA     MTEMP+2
```

```
             LDA     MTEMP+1
             ADC     MULTP+1
             STA     MTEMP+1
             LDA     MTEMP
             ADC     MULTP
             STA     MTEMP
ROTATE       ROR     MTEMP
             ROR     MTEMP+1
             ROR     MTEMP+2
             ROR     MTEMP+3
             ROR     MULCAN
             ROR     MULCAN+1
             ROR     MULCAN+2
             ROR     MULCAN+3                ; MTEMP,MULCAN
             DECX
             BNE     MNEXT
             RTS
******************************************
*                                        *
*       Divide 32–bit by 32–bit          *
*                                        *
*  DVDND / DVSOR = QUO + DVDND           *
*                                        *
******************************************
CALDIV       CLR     QUO
             CLR     QUO+1
             CLR     QUO+2
             CLR     QUO+3
             LDA     #1
             TST     DVSOR
             BMI     DIV153
DIV151       INCA
             ASL     DVSOR+3
             ROL     DVSOR+2
             ROL     DVSOR+1
             ROL     DVSOR
             BMI     DIV153
             CMP     #!33
             BNE     DIV151
DIV153       STA     CNT
DIV163       LDA     DVDND+3
             SUB     DVSOR+3
             STA     DVDND+3
             LDA     DVDND+2
             SBC     DVSOR+2
             STA     DVDND+2
             LDA     DVDND+1
             SBC     DVSOR+1
             STA     DVDND+1
             LDA     DVDND
             SBC     DVSOR
             STA     DVDND
             BCC     DIV165
             LDA     DVDND+3
             ADD     DVSOR+3
             STA     DVDND+3
             LDA     DVDND+2
             ADC     DVSOR+2
             STA     DVDND+2
             LDA     DVDND+1
             ADC     DVSOR+1
             STA     DVDND+1
             LDA     DVDND
             ADC     DVSOR
             STA     DVDND
             CLC
             BRA     DIV167
DIV165       SEC
DIV167       ROL     QUO+3
             ROL     QUO+2
             ROL     QUO+1
             ROL     QUO
             LSR     DVSOR
             ROR     DVSOR+1
             ROR     DVSOR+2
             ROR     DVSOR+3
             DEC     CNT
             BNE     DIV163
             RTS
******************************************
*                                        *
*   Overflow Interrupt Service Routine   *
*    Counting the number of overflow     *
*                                        *
******************************************
TIMERROV     STA     STACK+4
```

```
            INC     OFCNT                   ; Increase overflow counter
            LDA     TSTATUS                 ; Clear overflow flag
            LDA     TCNTLO
            LDA     STACK+4
            RTI
******************************************
*                                        *
*   This subroutine provides services    *
*    for those unintended interrupts     *
*                                        *
******************************************
SWI         RTI                             ; Software interrupt return
TIMERCAP    RTI                             ; Timer input capture
SCI         RTI                             ; Serial communication Interface
IRQ         RTI
            ORG     $3FF2                   ; For 68HC05B16, the vector location
            FDB     SCI                     ; starts at 3FF2
            FDB     TIMERROV                ; For 68HC05B5, the address starts
            FDB     TIMERCMP                ; 1FF2
            FDB     TIMERCAP
            FDB     IRQ
            FDB     SWI
            FDB     RESET
```

AN1645

Micromachined Electromechanical Sensors for Automotive Applications

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ABSTRACT

This application note is going to discuss typical requirements for micromachined sensors. The most common examples today are pressure and acceleration sensors. We will discuss the function and applications of pressure and acceleration sensors. There are two differences between accelerometers and pressure sensors: sensor technology and signal conditioning. Pressure sensors employ bulk micromachining techniques where accelerometers use surface micromachining. Pressure sensors are typically signal conditioned with bipolar circuitry. Acceleration sensors use CMOS signal conditioning. We will also explain the electrical characteristics of both pressure and acceleration sensors along with mechanical package styles. We will be focusing our effort on automotive based applications. Some typical applications for pressure sensors in the automotive environment are MAP, BAP, lumbar seat, air bag and tire pressure. The requirements of the MAP/BAP application will also be discussed in detail. Some typical applications for the acceleration sensor are front airbag, side airbag, yaw rate, active suspension and ABS. Parameter requirements for the accelerometer in a typical front airbag system will be presented.

INTRODUCTION

As the automobile enters its 2nd century of manufacture, technology continues to make it more reliable, clean and safe. Meeting tomorrow's challenges will require more sophistication. Electronics has replaced mechanical sensing with sensors that are low cost, robust and provide data to the engine control unit (ECU) that allows it to make the car fuel efficient, have low pollutant emissions and provide the occupants maximum protection in case of an accident.

There are many kinds of sensors being used to sample a larger cross–section of parameters than in the past. For example achieving optimum fuel efficiency requires mass airflow data such as temperature, barometric pressure, manifold partial vacuum, timing, and temperature but also requires correctly inflated tires.

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The increased computing power in automotive applications must be fed by sensors, unlike personal computers which utilize the keyboard and mouse. The air bag sensor must act quickly to determine if a crash is occurring. Other sensors monitor constant data streams to control some aspect of passenger comfort. In both cases, solid state sensors are the key to operation of the system.

MAIN SECTION

PRESSURE SENSORS

Electrical Characteristics

Pressure sensors are used to convert pressure, a physical parameter, to an electrical signal.

The MPX series pressure sensor manufactured by Motorola 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 pressure sensor utilizes monolithic silicon piezoresistors arranged in a Wheatstone bridge configuration. The piezoresistive bridge, which functions as a strain gauge is ion implanted on a thin silicon diaphragm. Applying pressure to the diaphragm applies stress to the various piezoresistors which then change value, 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 between 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 temperatures ranges, i.e., 0°C to 85°C.

Technology

The manifold absolute pressure sensor uses a bipolar IC technology which has been refined in the automotive and consumer market place. The combination of well–proven bulk–micromachined structures and piezoresistive strain gauge transducers form a foundation for a wide range of partnerships with system and subsystem builders. Experience gained in each technology yields superior reliability, lower risk, and lower cost than any other combination at this time.

The op amps are fabricated in a thick epitaxial layer, in a high voltage process which protects against unintentional over voltage and latch–up conditions. The die is protected against electrostatic discharge both during manufacturing and in operation. Short–circuit protection circuitry protects the output when shorted to either power rail.

The mechanical structure is formed by bulk micromachining with electrochemical etch–stop to produce well controlled diaphragm thickness and a tighter sensitivity distribution (see Figure 1). Thinner diaphragm targets allowed by this etch–stop have resulted in die size and attendant cost reduction. A closed bridge transducer configuration retains the process consistency of the X–ducer while providing an increased output signal. The absolute sensor vacuum reference cavity is enclosed by glass bonding a second wafer under the sensor wafer which provides additional mechanical isolation from the external package stress. Various vapor deposited films are applied to the sensor die to resist detrimental effects of the measured media and physical handling damage without creating excessive stress on the sensor diaphragm.

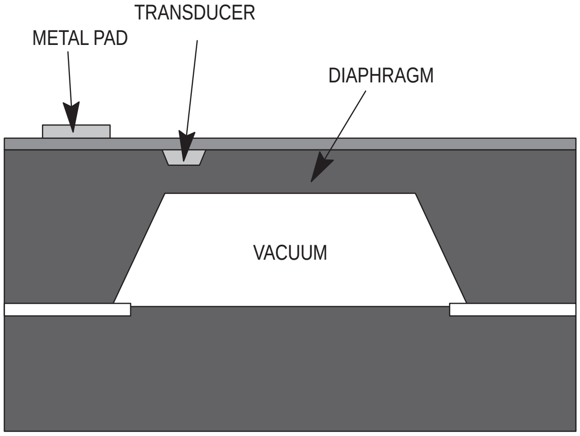


Figure 1. Pressure Sensor Cross Section

The temperature variations inherent in the piezoresistive strain gauge causes concern to the uninitiated. Some believe trim is required due to these effects. Actually, all components on bipolar integrated circuits vary with temperature. Examples are transistor betas, implanted resistor values, and junction capacitance. In fact, the base–emitter forward voltage of an IC transistor varies at a different rate with temperature if the current density is changed. Therefore, the temperature behavior of the piezoresistor is comparable to that of other IC components.

Unwanted stresses from the package, deposited films, and heavy diffusions are also suspected of requiring trim of the integrated pressure sensor.

Why do we trim pressure sensor systems? Only to remove the effects of variation. Temperature compensation of span, offset correction, ratiometricity, temperature compensation of offset and final sensitivity can all be accomplished to some degree without trim. The error is then the result of process variation. This is why pressure sensors are trimmed. Reduce the process variation and trim can be reduced or eliminated while quality, cost, and performance are improved in direct proportion.

The op amps on integrated MAP sensors are application specific. The nature of the piezoresistive strain gauge output places less stringent requirements on some parameters, while the high level of system accuracy places a premium on others. An example is bandwidth. Since the pressure signal is a variable DC voltage, characteristics present in a high–speed video amplifier are not needed. Another characteristic of a MAP sensor is that it is operated at a fixed voltage, for example 5 volts with a tolerance variation of ±7.5%. This is very different from a general purpose amplifier which may see supply voltages from 3 volts to 30 volts. The combined voltages of components between the power supply voltage and ground are not as critical nor are any internal parameters which vary with supply voltage, such as current drain.

One specification often ignored in the literature relating to the amplifier is ratiometricity. This is a measure of how closely the sensor output follows variations in the power supply voltage. It is a key parameter for the MAP sensor because the supply voltage also serves as the ADC Vref high voltage.

Package

Pressure sensors are offered in many different package styles, different porting options and mounting tab options. There are many types of packages available to the market, however, one of the latest package designs is the piston fit package. Piston fit packages come in three different types — the top side piston fit, the dual piston fit, as shown in Figure 2, and the backside piston fit. These packages were designed to be installed into a customer provided housing using a standard O–ring to obtain a leak proof seal. The O–ring fits over the outside of the piston fit package in the same way that a piston ring fits over the outside of a piston. Hence the name — piston fit packages. The external geometry of the top side piston fit (TPF) and the back side piston fit (BPF) packages is the same. The differences between the packages are internal. The main difference is that for the TPF, the piston fit is on the top side of the pressure die. The BPF package has the piston fit on the backside of the pressure die. The BPF is to used mainly for vacuum measurement, where the vacuum is applied to the back side of the die, or for pressure sensors that use a backside pressure exposure for media compatibility (see Figure 2–6). The dual piston fit (DPF) package is designed for use in differential or gauge pressure applications in which two unknown pressures or an unknown pressure and local atmospheric pressure are applied to either side of the sensor die.

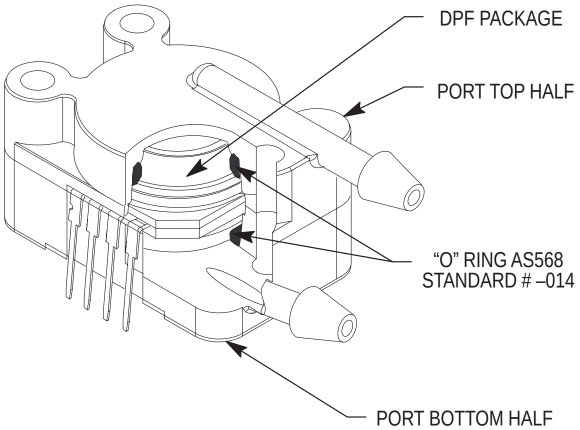


Figure 2. Dual Piston Fit Package Custom Housing

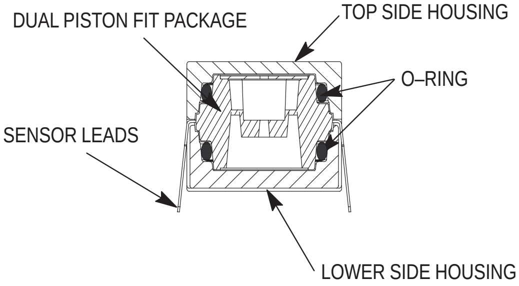


Figure 3. Dual Piston Fit Custom Housing Cross Section

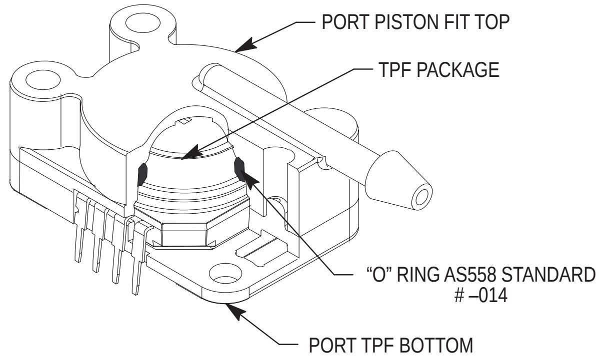


Figure 4. Top Side Piston Fit Custom Housing

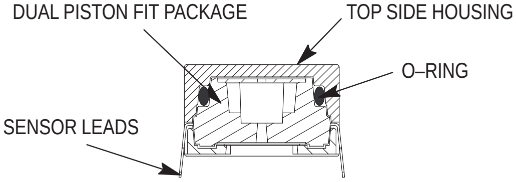


Figure 5. Top Side Piston Fit Custom Housing Cross Section

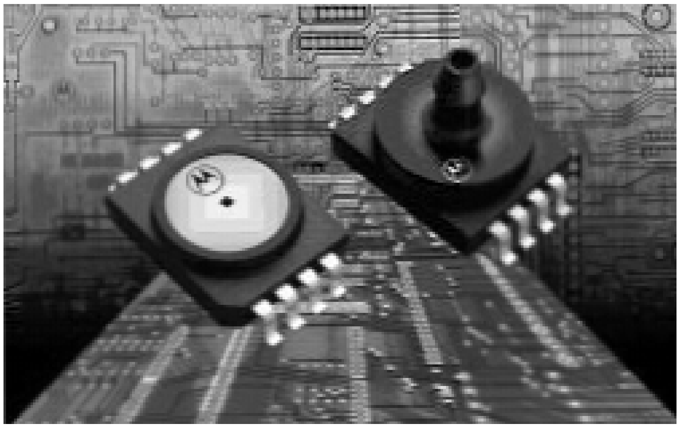
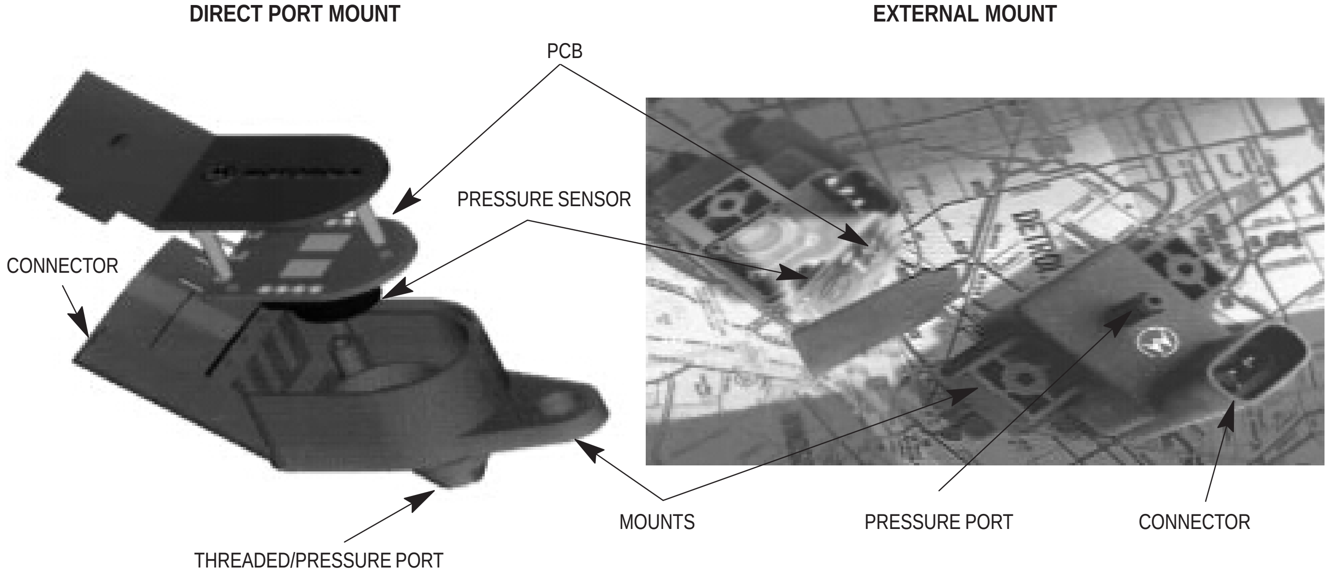


Figure 6. Piston Fit Packages
Top Piston Fit (l) & Top Piston Fit with Stove Pipe Port (r)

Typical Applications

There are three types of pressure sensors: differential, gauge, and absolute. Differential pressure sensors measure the difference in the simultaneous pressure applied to both sides of the sensor. A typical automotive application might be using pressure measurement to determine when an air cleaner is dirty. By measuring the difference in pressure from the air intake side of the filter to the outlet side, the resulting pressure drop indicates the condition of the filter. The gauge pressure sensor differs from the differential design because one side is in contact with the atmosphere. One example of gauge measurement is tire pressure.

In the absolute pressure sensor, only one side is accessible, measuring input pressure in relation to zero pressure (a total vacuum on one side of the diaphragm). Examples of applications for absolute pressure sensors include altimeters and manifold (MAP) and barometric (BAP) atmospheric pressure measurement. MAP sensors measure the partial vacuum in the intake manifold. When the engine goes through an intake cycle, a given cylinder receives the fuel–air charge from the intake manifold. The pressure measurement from the intake manifold is provided to the engine control unit, which then calculates the MAP(mass air flow) rate from the pressure measurement. As shown in Figure 7 below threaded port is installed directly in the manifold while the external mount requires the pressure hose to connect the vacuum to the sensor diaphragm.


DIRECT PORT MOUNT

EXTERNAL MOUNT

Figure 7. Direct Mount (l) and External Mount (r)

ACCELERATION SENSOR

Electrical Characteristics

Accelerometers are used to convert acceleration, a physical parameter, to an electrical signal. A microcontroller uses the signal to determine whether or not the automobile is in a crash and the intensity of the crash.

The CMOS control circuitry for surface micromachined acceleration sensors often use switched capacitor technology, extensive dynamic filtering, op amp gain stages, digital logic, and industry proven EPROM calibration.

An accelerometer typically uses a capacitive sensing technique to measure the amount of acceleration. A variable capacitor is created in silicon using surface micromachining. One type of variable capacitor consists of a movable mass suspended between two fixed capacitor plates. This mass moves according to acceleration of the device. The result is a change in capacitance that can be measured with a variety of methods.

One such method is using a switched capacitor technique to convert the change in capacitance to a change in voltage. Because of a such a small change in value (on the order of femto Farads), a custom control IC, either monolithic on the same silicon as the sensor or another chip housed in the same package with the sensor is necessary. Depending on the application, the custom control IC provides signal conditioning to set the output sensitivity, provides temperature compensation and a self test function.

In the case of an accelerometer, sensitivity is defined as what electrical signal unit, either digital or analog, that represents one g of acceleration. Many accelerometers have an analog voltage output whereby sensitivity would be defined as the amount of voltage that equates to 1 g. Most analog accelerometers specify their output in mV/g. Sensitivity is dependent on the full scale acceleration range needed in the application. Sensitivity and full scale range are closely related. Due to the limited dynamic range of the power supply, a high sensitivity accelerometer will have a lower full scale range than a lower sensitivity device. In the automotive world, accelerometer sensitivities range can vary from 1000 mV/g for low g applications such as ABS systems down to 8 mV/g for high g applications such as side impact airbag systems.

The signal conditioning circuitry provides gain for the sensitivity and low pass filter for the output. Most automotive grade accelerometers have this filter to ensure that the control IC clock frequency or mechanical resonance does not influence the output. This low pass filter’s cutoff frequency is set between 400 and 1000 Hz, depending on the application.

Because the sensor and its signal conditioning are sensitive to changes in temperature, compensation is required to correct the output. Self test is a function that allows the accelerometer to be checked for normal functionality. The self test mode applies a small voltage to the sensor, resulting an electrostatic charge that forces the capacitive plate to move. This movement is measured as a change in output that is of an expected value.

The resultant output signal is a linear voltage proportional to the acceleration applied to the accelerometer. This output is ready for input to an A/D converter. At 0g of acceleration, the output voltage is nominally 2.5 V, right between the ground and 5 V rails. At full scale, 40g, using a sensitivity of 40 mV/g, the output would be 4.1 V. A minus full scale, –40g, the output would be 0.9 V.

Technology

The micromachined accelerometer *can* take a variety of forms ranging from bulk micromachined structures with piezoresistive transducers, laser trimmed thin–film calibration, and bipolar analog circuitry to sophisticated surface micromachined structures with capacitive transducer, EPROM calibration, and CMOS mixed–signal control circuitry. The bulk micromachined version closely resembles the conventional integrated pressure sensor. The airbag accelerometer employs multiple layers of polycrystalline silicon over sacrificial oxide layers. When the oxide is etched away, the poly structure is suspended above a lower surface by a distance equal to the thickness of the oxide. Holes patterned into the oxide before depositing the poly provide anchor points to the lower structure. This method of fabrication allows multiple layers to be formed as required for a differential capacitive transducer working in the vertical–axis with 3 poly layers (see Figure 8) or cross–axis with 2 poly layers. The moveable structure incorporates plates for the capacitive transducer, the accelerometer mass, and self–test plates for electrostatic attraction.

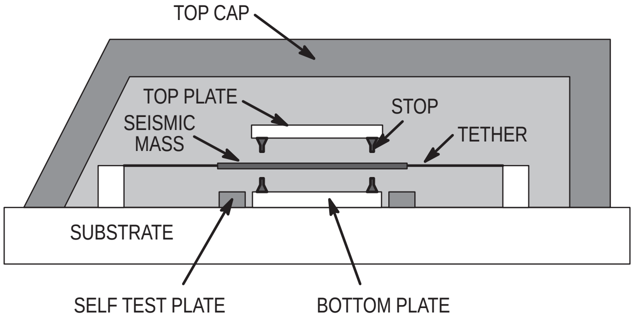


Figure 8. Accelerometer Cross Section

Packaging

Accelerometers are offered in many different packaging styles. They are offered in many standard IC packages: standard plastic DIP, plastic SOIC, ceramic DIP, ceramic SOIC and SIP. The different axis of sensing and type of sensor often dictate what package style is used. Z axis sensors are usually found in DIP or SOIC. For use as a X axis sensor, Z axis devices are sometimes turned sideways and placed into SIP packages. This requires lead frame reinforcement for mounting stability. See Figure 9. X lateral sensors are placed in DIP or SOIC devices and oriented on the PCB in the direction of desired sensing.

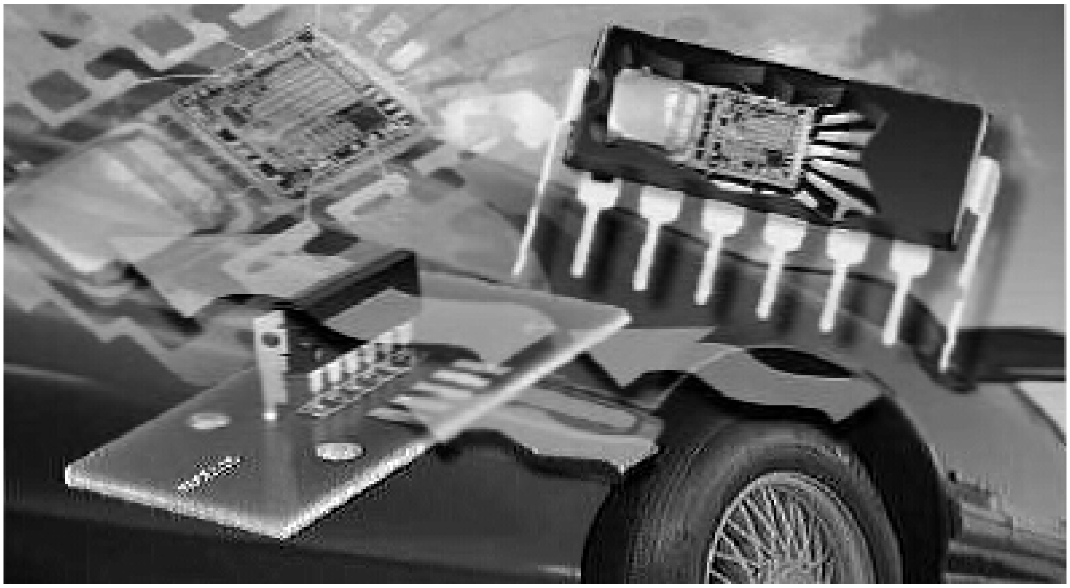


Figure 9. Automotive Accelerometer in SIP Package

Typical Applications

There are numerous automotive applications for accelerometers. The number one application today is the typical front airbag system. Airbag systems require accelerometers to determine crash severity. There are many collisions that do not require an air bag to deploy. Microcontrollers employ complex algorithms that use accelerometer data to determine the type and severity of an accident.

In a front airbag system, the accelerometer requirements are specific. The front airbag module is usually mounted in the passenger compartment. This results in a fairly large area of crush zone. In many frontal collisions, data has shown that between 20 and 40*g* of acceleration can be experienced in the passenger zone during a frontal collision. Thus, accelerometers with a +/– 40*g* full scale range are required.

Another accelerometer requirement is a low noise output. A device with less than 1 g of noise is best. In a system with an 8 bit A/D converter and an accelerometer with a sensitivity of 40 mV/g, noise above the level of 20 mV or one A/D bit is undesirable. Noise higher than that can make microcontroller algorithms more difficult to manage.

Ratiometricity is also an important requirement for the accelerometer in front airbag applications. The accelerometer output should fluctuate proportionally with the power supply. If the power supply were to dip 10%, the output should also dip 10%. The A/D converter in the system, on the same supply as the accelerometer, will also see the same variations. Its dynamic range will drop by that percentage. Therefore, if the supply were to move, the resultant digital A/D code for the acceleration at any given time would remain accurate. So even if the power supply were to fluctuate during a crash, the microcontroller could still make a decision to fire the airbags.

Another important requirement for the accelerometer is electromagnetic compatibility (EMC). The accelerometer must operate normally under certain levels of electromagnetic field exposure. Ideally, when the accelerometer is at rest (no acceleration applied), the output should be at 0*g*, regardless of what EMC conditions the system may be subjected to. During a duration of EMC exposure, a typical airbag system should be able to tolerate an output deviation of 1 to 3 *g*. A higher shift in output could create an abnormal accelerometer output, resulting in errors in the crash analysis software. This could cause the airbags to unnecessarily deploy when there is not a crash or not deploy when there is a crash.

Becoming more popular are the side–impact airbag systems. A side impact airbag system works in the same manner as frontal systems, but deals with collisions to the side of the vehicle. There are other non airbag applications in the automotive world. Accelerometers can be used to determine the amount of yaw, or vehicle movement during hard cornering or loss of traction. Accelerometers are mounted in the vehicle to track motion and direction of the car. During a loss of traction or control of the vehicle, microcontrollers use the accelerometer data to determine the direction and position of the car and correct it if necessary through application of the traction control, anti–lock brakes or adjustment of the suspension settings.

In order for an anti–lock braking system (ABS) to work, the braking system electronic control unit needs to know the forward speed of the vehicle. This can be accomplished by adding an accelerometer to the system. Additionally, wheel speed sensors at each wheel allow the velocity of each wheel to be accurately determined. In practice when a vehicle is subjected to panic stops, the car's wheel(s) may lose traction and begin to "lock" under hard braking. As wheel lock begins, a wheel's speed drops very quickly relative to the car's forward motion. This information along with a velocity mathematically derived from the accelerometer data allows the ABS electronic control unit to determine how to modulate the hydraulic pressure to each brake to minimize stopping distance.

An accelerometer provides accuracy improvements over traditional speed detection methods (an often mechanical and cumbersome interface) and allows for a lower system cost and improved reliability.

CONCLUSION

Semiconductor sensors continue to expand in importance as automotive electronics provide improved efficiency, comfort, and safety. Sensors are needed to convert mechanical phenomena into an electrical signal.

Two of the most common sensors in use today are pressure sensors and accelerometers. Both employ common micromachining practices and integrated circuit technology to form efficient data collection subsystems. A wide variety of packages and porting options exist for the pressure sensor due to the specific needs of the applications. Accelerometers are offered in standard plastic packages which makes it easy to integrate into the system. MAP sensors are the most common pressure sensor automotive application while the front airbag system is the most common accelerometer application.

ACKNOWLEDGMENT

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Noise Considerations for Integrated Pressure Sensors

Prepared by Ador Reodique, Sensor and Systems Applications Engineering and Warren Schultz, Field Engineering

INTRODUCTION

Motorola Integrated Pressure Sensors (IPS) have trimmed outputs, built–in temperature compensation and an amplified single–ended output which make them compatible with Analog to Digital converters (A/D's) on low cost micro–controllers. Although 8–bit A/D's are most common, higher resolution A/D's are becoming increasingly available. With these higher resolution A/D's, the noise that is inherent to piezo–resistive bridges becomes a design consideration.

The two dominant types of noise in a piezo–resistive integrated pressure sensor are shot (white) noise and 1/f (flicker noise). Shot noise is the result of non–uniform flow of carriers across a junction and is independent of temperature. The second, 1/f, results from crystal defects and also due to wafer processing. This noise is proportional to the inverse of frequency and is more dominant at lower frequencies[3].

Noise can also come from external circuits. In a sensor system, power supply, grounding and PCB layout is important and needs special consideration.

The following discussion presents simple techniques for mitigating these noise signals, and achieving excellent results with high resolution A/D converters.

EFFECTS OF NOISE IN SENSOR SYSTEM

The transducer bridge produces a very small differential voltage in the millivolt range. The on–chip differential amplifier amplifies, level shifts and translates this voltage to a single–ended output of typically 0.2 volts to 4.7 volts. Although the transducer has a mechanical response of about 500 Hz, its noise output extends from 500 Hz to 1 MHz. This noise is amplified and shows up at the output as depicted in Figure 1.

There is enough noise here to affect 1 count on an 8 bit A/D, and 4 or 5 counts on a 10 bit A/D. It is therefore important to consider filtering. Filtering options are discussed as follows.

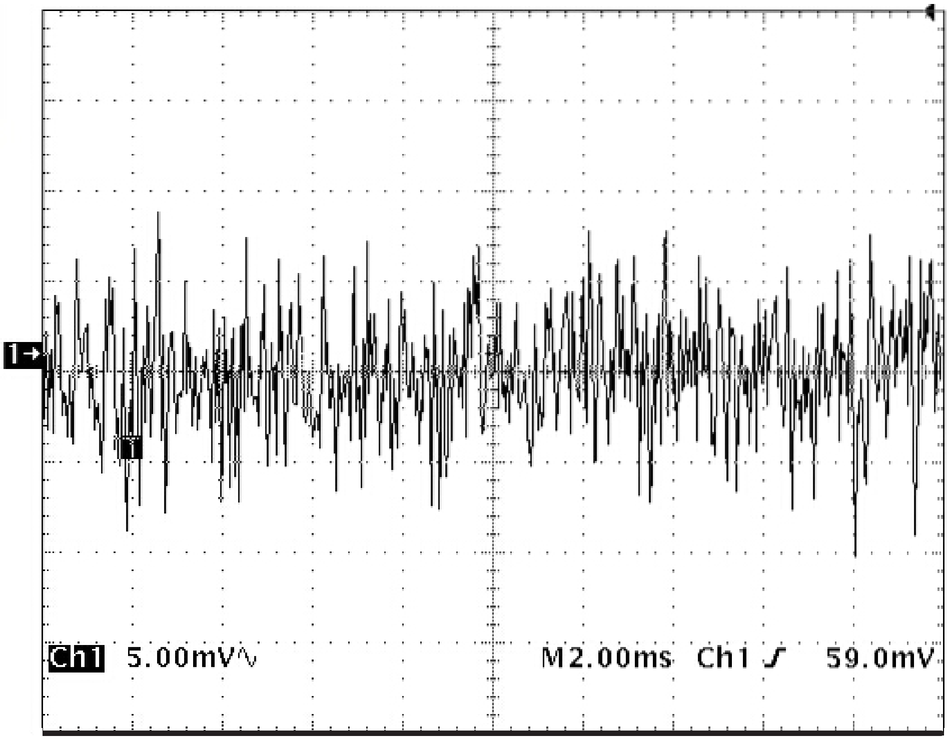

Figure 1. MPX5006 Raw Output

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NOISE FILTERING TECHNIQUES AND CONSIDERATIONS

For mitigating the effects of this sensor noise, two general approaches are effective, low pass filtering with hardware, and low pass filtering with software. When filtering with hardware, a low–pass RC filter with a cutoff frequency of 650 Hz is recommended. A 750 ohm resistor and a 0.33 µF capacitor have been determined to give the best results (see Figure 2) since the 750 ohm series impedance is low enough for most A/D converters.

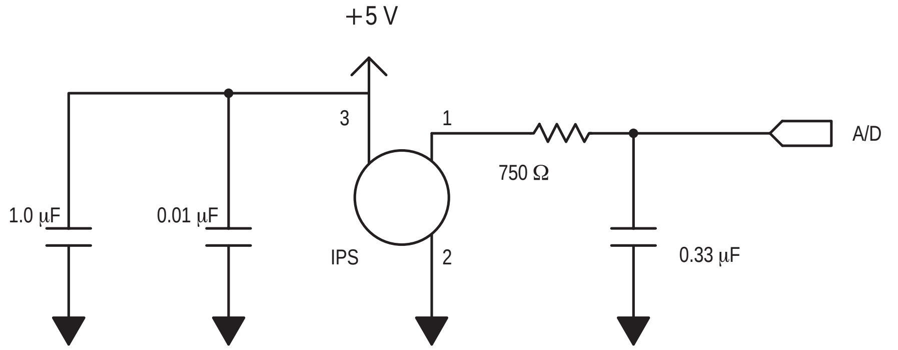


Figure 2. Integrated Pressure Sensor with RC LP Filter to Filter Out Noise

This filter has been tested with an MC68HC705P9 microcontroller which has a successive approximation A/D converter. Successive approximation A/D's are generally compatible with the DC source impedance of the filter in Figure 2. Results are shown in Figure 4.

Some A/D's will not work well with the source impedance of a single pole RC filter. Please consult your A/D converter technical data sheet if input impedance is a concern. In applications where the A/D converter is sensitive to high source impedance, a buffer should be used. The integrated pressure sensor has a rail–to–rail output swing, which dictates that a rail–to–rail operational amplifier (op amp) should be used to avoid saturating the buffer. A MC33502 rail–to–rail input and output op amp works well for this purpose (see Figure 3).

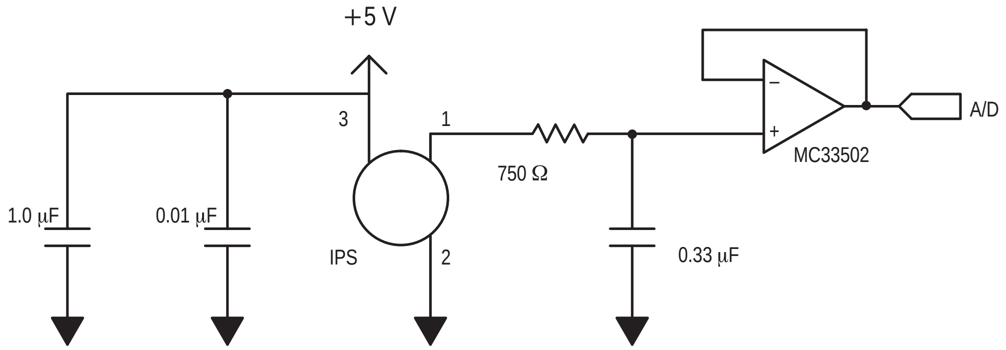


Figure 3. Use a Rail–to–Rail Buffer to Reduce Output Impedance of RC Filter

Averaging is also effective for filtering sensor noise. Averaging is a form of low pass filtering in software. A rolling average of 8 to 64 samples will clean up most of the noise. A 10 sample average reduces the noise to about 2.5 mV peak to peak and a 64 sample average reduces the noise to about 1 mV peak to peak (see Figures 5 and 6).

This method is simple and requires no external components. However, it does require RAM for data storage, extra computation cycles and code. In applications where the microcontroller is resource limited or pressure is changing relatively rapidly, averaging alone may not be the best solution. In these situations, a combination of RC filtering and a limited number of samples gives the best results. For example, a rolling average of 4 samples combined with the RC filter in Figure 2 results in a noise output on the order of 1 mV peak to peak.

Another important consideration is that the incremental effectiveness of averaging tends to fall off as the number of samples is increased. In other words, the signal–to–noise (S/N) ratio goes up more slowly than the number of samples. To be more precise, the S/N ratio improves as the square root of the number of samples is increased. For example, increasing the number of samples from 10, in Figure 5, to 64, in Figure 6, reduced noise by a factor of 2.5.

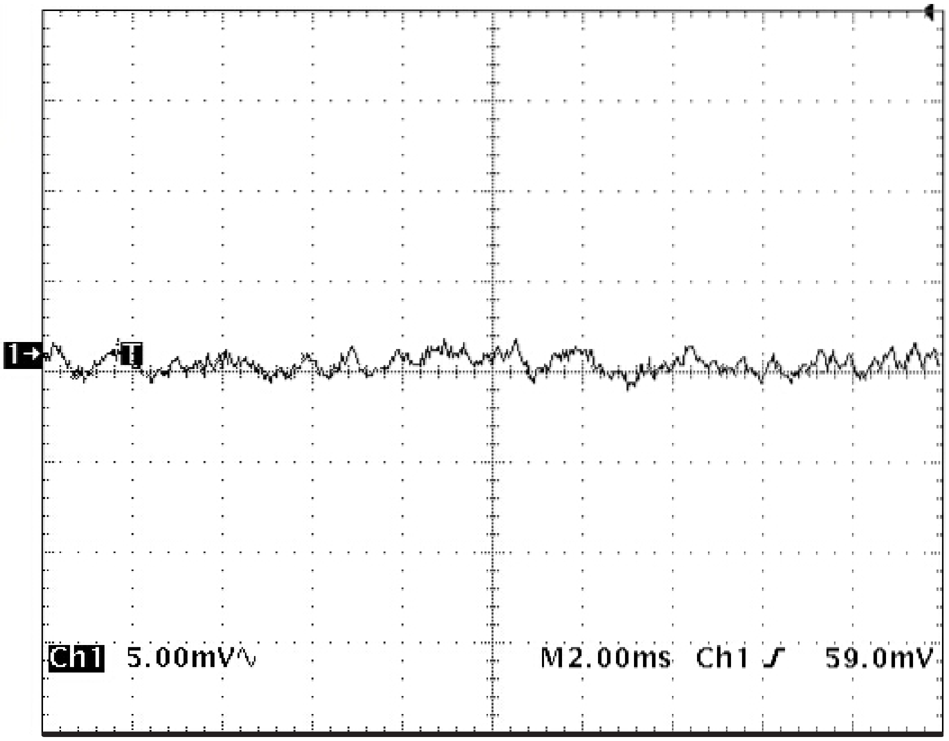


Figure 4. Output After Low Pass Filtering

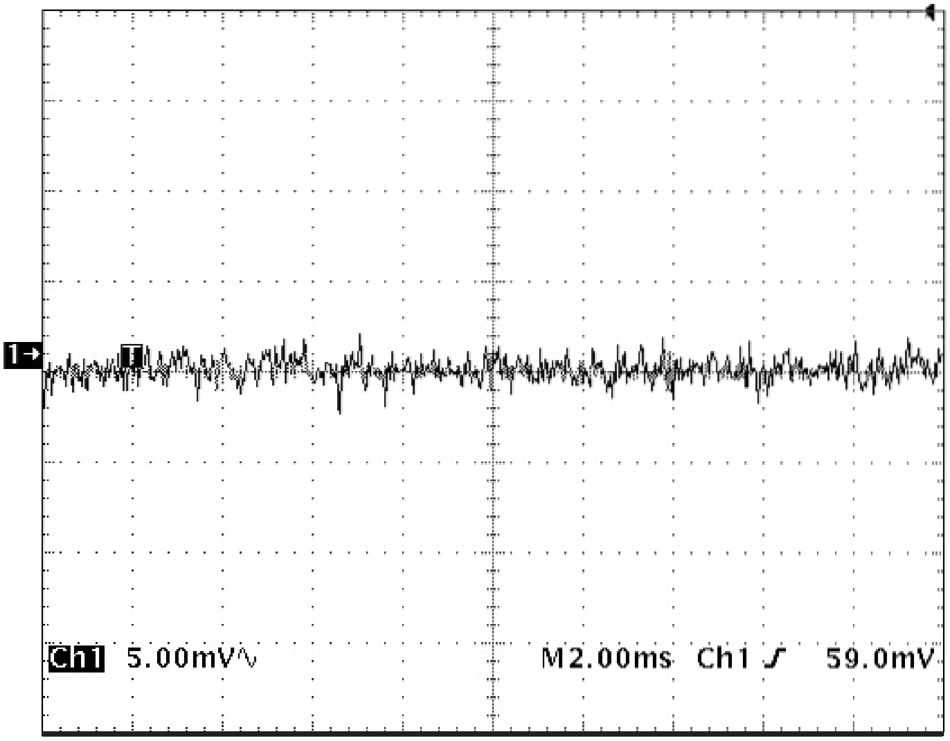


Figure 5. Output with 10 Averaged Samples

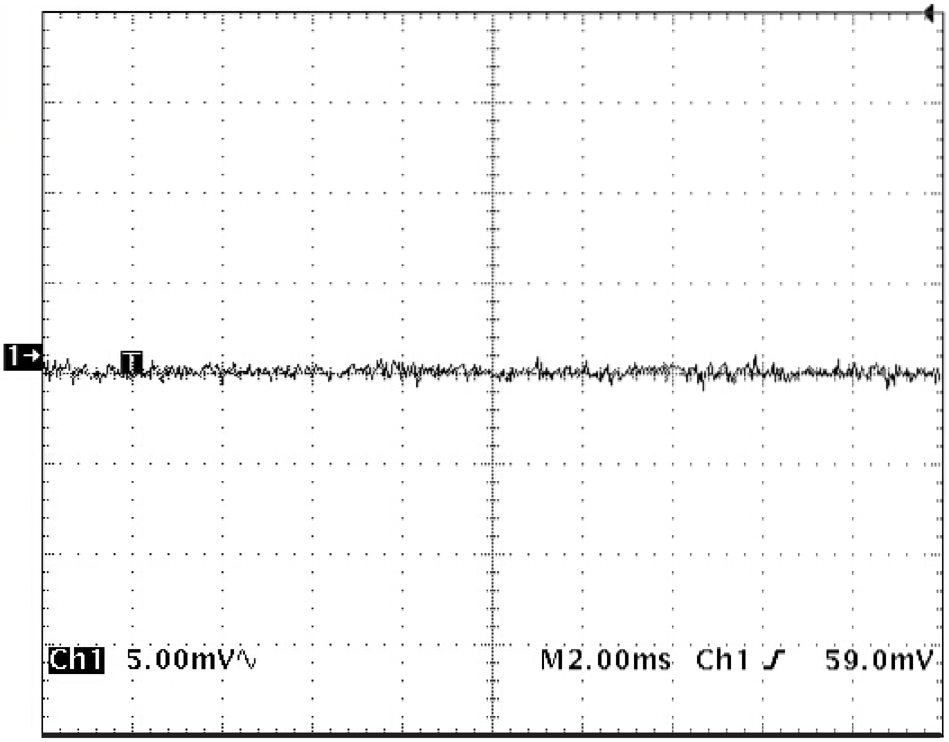


Figure 6. Output with 64 Averaged Samples

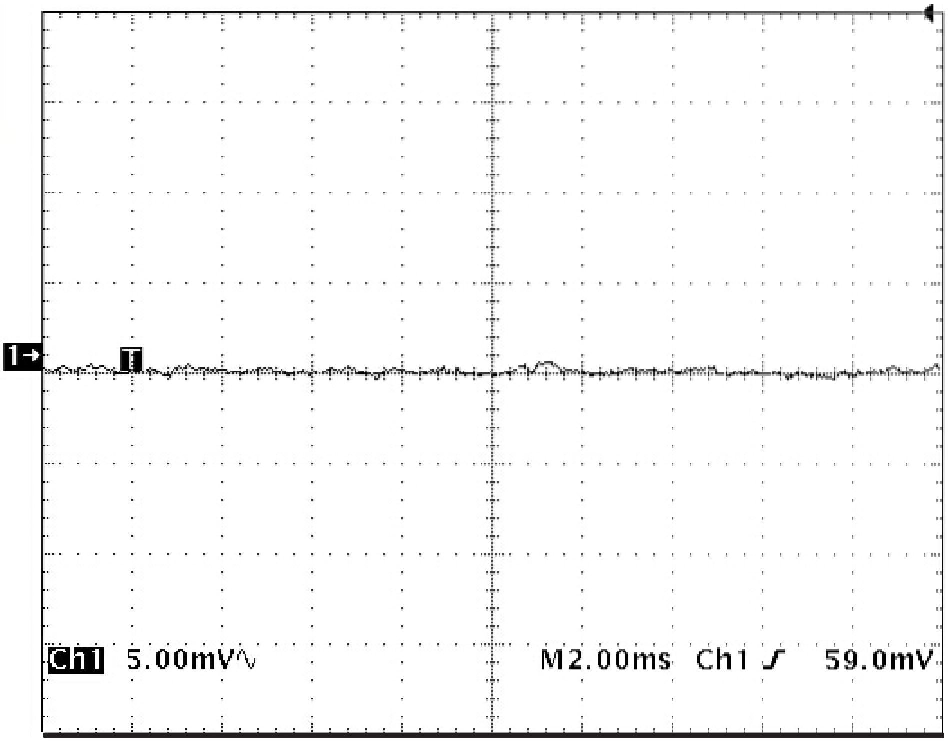


Figure 7. Filtered Sensor Output and Averaged Over 10 Samples

POWER SUPPLY

Since the sensor output is ratiometric with the supply voltage, any variation in supply voltage will also proportionally appear at the output of the sensor. The integrated pressure sensor is designed, characterized and trimmed to be powered with a 5 V +/– 5% power supply which can supply the maximum 10 mA current requirement of the sensor. Powering the integrated sensor at another voltage than specified is not recommended because the offset, temperature coefficient of offset (TCO) and temperature coefficient of span (TCS) trim will be invalidated and will affect the sensor accuracy.

From a noise point of view, adequate de–coupling is important. A 0.33 µF to 1.0 µF ceramic capacitor in parallel with a 0.01 µF ceramic capacitor works well for this purpose. Also, with respect to noise, it is preferable to use a linear regulator such as an MC78L05 rather than a relatively more noisy switching power supply 5 volt output. An additional consideration is that the power to the sensor and the A/D voltage reference should be tied to the same supply. Doing this takes advantage of the sensor output ratiometricity. Since the A/D resolution is also ratiometric to its reference voltage, variations in supply voltage will be canceled by the system.

LAYOUT OPTIMIZATION

In mixed analog and digital systems, layout is a critical part of the total design. Often, getting a system to work properly depends as much on layout as on the circuit design. The following discussion covers some general layout principles, digital section layout and analog section layout.

General Principles:

There are several general layout principles that are important in mixed systems. They can be described as five rules:

Rule 1: Minimize Loop Areas. This is a general principle that applies to both analog and digital circuits. Loops are antennas. At noise sensitive inputs, the area enclosed by an incoming signal path and its return is proportional to the amount of noise picked up by the input. At digital output ports, the amount of noise that is radiated is also proportional to loop area.

Rule 2: Cancel fields by running equal currents that flow in opposite directions as close as possible to each other. If two equal currents flow in opposite directions, the resulting electromagnetic fields will cancel as the two currents are brought infinitely close together. In printed circuit board layout, this situation can be approximated by running signals and their returns along the same path but on different layers. Field cancellation is not perfect due to the finite physical separation, but is sufficient to warrant serious attention in critical paths. Looked at from a different perspective, this is another way of looking at Rule # 1, i.e., minimize loop areas.

Rule 3: On traces that carry high speed signals avoid 90 degree angles, including "T" connections. If you think of high speed signals in terms of wavefronts moving down a trace, the reason for avoiding 90 degree angles is simple. To a high speed wavefront, a 90 degree angle is a discontinuity that produces unwanted reflections. From a practical point of view, 90 degree turns on a single trace are easy to avoid by using two 45 degree angles or a curve. Where two traces come together to form a "T" connection, adding some material to cut across the right angles accomplishes the same thing.

Rule 4: Connect signal circuit grounds to power grounds at only one point. The reason for this constraint is that transient voltage drops along the power grounds can be substantial, due to high values of di/dt flowing through finite inductance. If signal processing circuit returns are connected to power ground at multiple points, then these transients will show up as return voltage differences at different points in the signal processing circuitry. Since signal processing circuitry seldom has the noise immunity to handle power ground transients, it is generally necessary to tie signal ground to power ground at only one point.

Rule 5: Use ground planes selectively. Although ground planes are highly beneficial when used with digital circuitry, in the analog world they are better used selectively. A single ground plane on an analog board puts parasitic capacitance in places where it is not desired, such as at the inverting inputs of op amps. Ground planes also limit efforts to take advantage of field cancellation, since the return is distributed.

ANALOG LAYOUT

In analog systems, both minimizing loop areas and field cancellation are useful design techniques. Field cancellation is applicable to power and ground traces, where currents are equal and opposite. Running these two traces directly over each other provides field cancellation for unwanted noise, and minimum loop area.

Figure 8 illustrates the difference between a power supply de–coupling loop that has been routed correctly and one that has not. In this figure, the circles represent pads, the schematic symbols show the components that are connected to the pads, and the routing layers are shown as dark lines (top trace) or grey lines (bottom trace). Note that by routing the two traces one over the other that the critical loop area is minimized. In addition, it is important to keep de–coupling capacitors close to active devices such as MPX5000–series sensors and operational amplifiers. As a rule of thumb, when 50 mil ground and Vcc traces are used, it is not advisable to have more than 1 inch between a de–coupling capacitor and the active device that it is intended to be de–coupled.

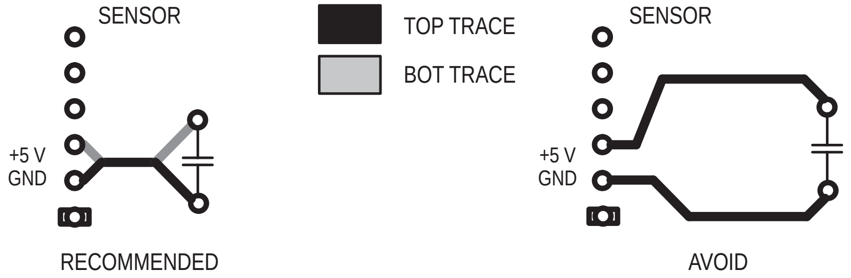


Figure 8. Minimizing Loop Areas

For similar reasons it is desirable to run sensor output signals and their return traces as close to each other as possible. Minimizing this loop area will minimize the amount of external noise that is picked up by making electrical connections to the sensor.

DIGITAL LAYOUT

The primary layout issue with digital circuits is ground partitioning. A good place to start is with the architecture that is shown in Figure 9. This architecture has several key attributes. Analog ground and digital ground are both separate and distinct from each other, and come together at only one point. For analog ground it is preferable to make the one point as close as possible to the analog to digital converter's ground reference (V_{REFL}). The power source ground connection should be as close as possible to the microcontroller's power supply return (V_{SS}). Note also that the path from V_{REFL} to V_{SS} is isolated from the rest of digital ground until it approaches V_{SS}.

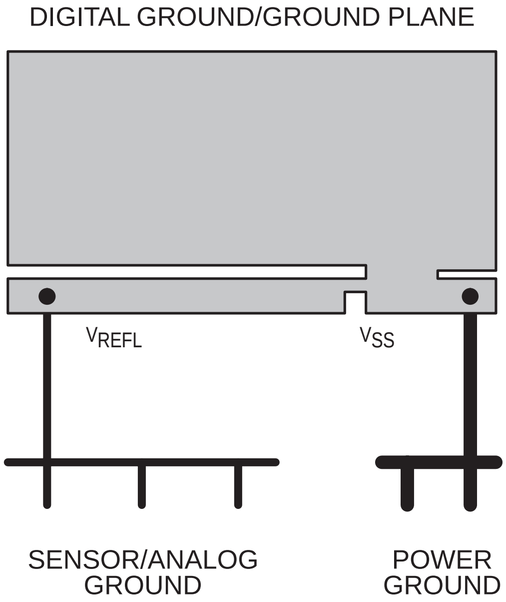


Figure 9. Ground Partitioning

In addition to grounding, the digital portion of a system benefits from attention to avoiding 90 degree angles, since there are generally a lot of high speed signals on the digital portion of the board. Routing with 45 degree angles or curves minimizes unwanted reflections, which increases noise immunity. Single traces are easy, two forty five degree angles or a curve easily accomplish a 90 degree turn. It is just as important to avoid 90 degree angles in T connections. Figure 10 illustrates correct versus incorrect routing for both cases.

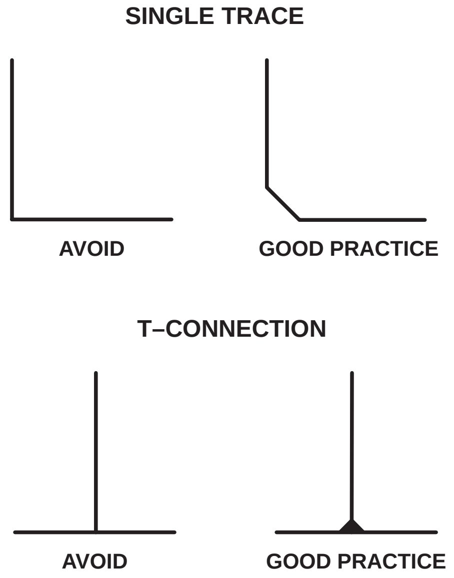


Figure 10. 90 Degree Angles

CONCLUSION

Piezo–resistive pressure sensors produce small amounts of noise that can easily be filtered out with several methods. These methods are low pass filtering with an RC filter, averaging or a combination of both which can be implemented with minimal hardware cost.

In a mixed sensor system, noise can be further reduced by following recommended power supply, grounding and layout techniques.

REFERENCES

[1] AN1626 Noise Management in Motor Drives, Warren Schultz, Motorola, Inc.

[2] Noise Reduction Techniques In Electronic Systems 2nd Edition, Henry W. Ott, John Wiley & Sons.

[3] Noise: Comparing Integrated Pressure Sensors and Op Amps, Ira Basket, Motorola Sensor Products Division internal paper.

AN1651

ASB201 — Uncompensated Series Sensor Module

Prepared by: Bill Lucas and Warren Schultz

A plug–in module that is part of a systems development tool set for pressure sensors is presented here. It provides an analog signal from an Uncompensated series sensor to a Motorola Sensor Development Controller, or can be used stand alone to provide power and signal conditioning for the sensor.

PLUG–IN MODULE DESCRIPTION

A summary of information for using systems development plug–in module ASB201 includes the schematic in Figure 2, connector pinout in Figure 3, a pin by pin description of functionality, specs in Tables 1–3, and a parts list in Table 4. Figure 4 in the Applications section provides a quick reference for making connections. A discussion of the design appears under the heading Design Considerations.

Function

The plug–in module shown in Figure 1 is designed to supply pressure and temperature inputs to a sensor development controller. The sensor output is amplified, level shifted, filtered, and converted to a single ended signal that fits within a zero to 5 volt window. Connections are made through a DB–9 connector, which allows this board to be plugged directly into its controller. If physical separation is desired, a standard 9 wire straight–through serial cable can be inserted between the two boards. Alternately, connections for B^+, 5 volts, ground, and the output signal can be made through screw terminals at the top of the board. A socket for sensor connections makes changing from one pressure range to another relatively easy.

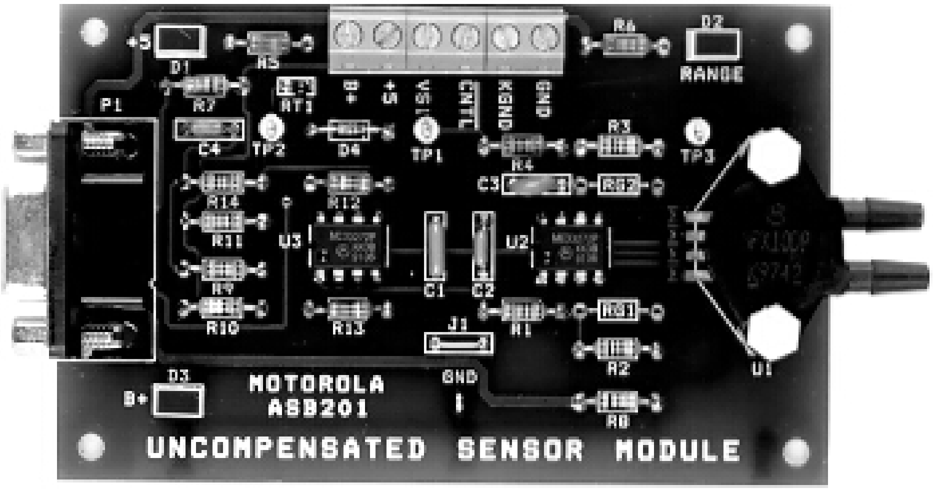


Figure 1. ASB201 — Uncompensated Series Sensor Module

REV 1

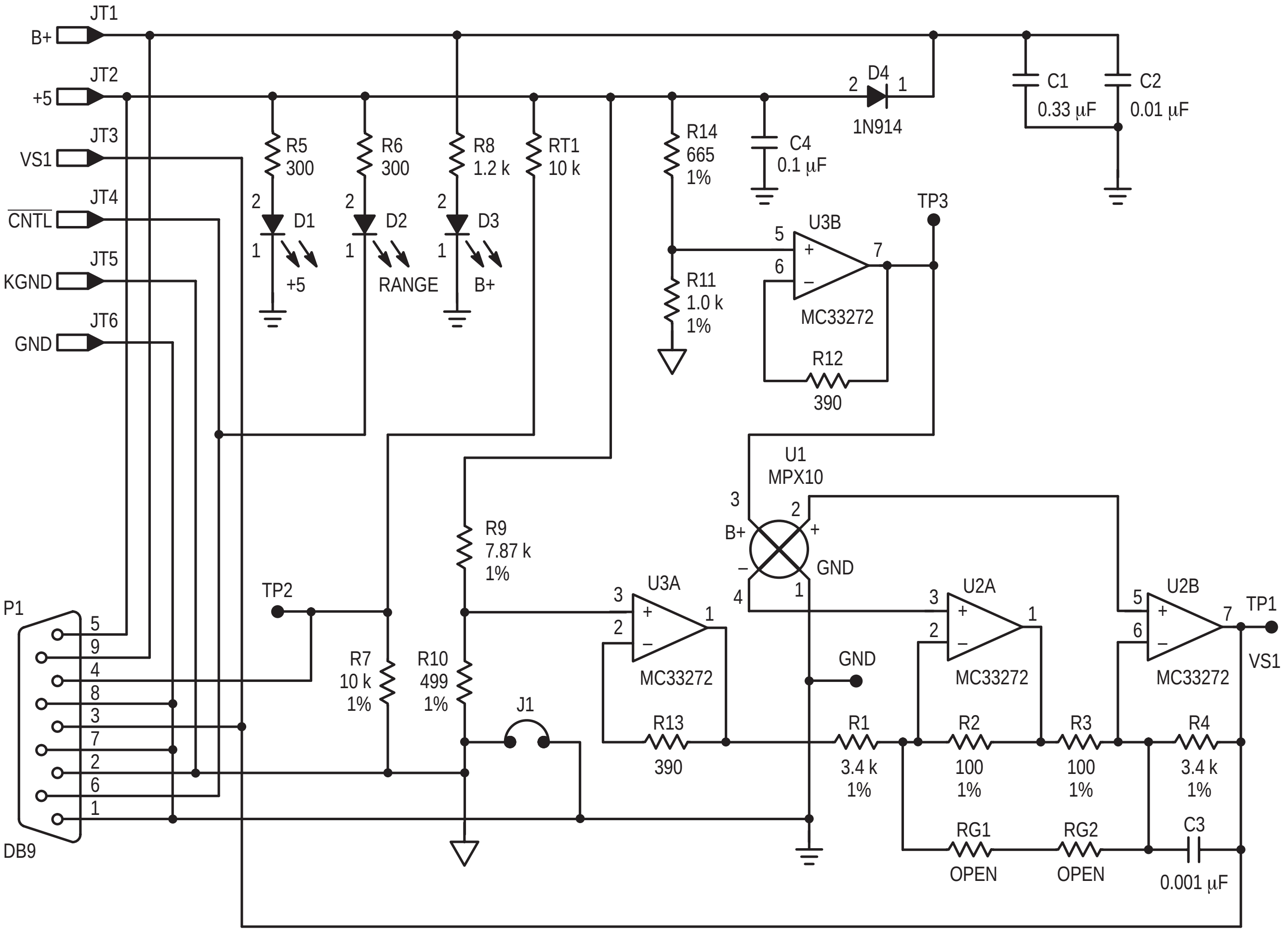


Figure 2. Schematic

Electrical Characteristics

Unless otherwise specified, the electrical characteristics in Tables 1, 2, & 3, apply to operation at 25 degrees Celsius, B^+ = 12.0 volts, and a +5 volt input of 5.00 volts. The values in Tables 2 and 3 are nominal values.

Table 1. Electrical Characteristics

Characteristic	Symbol	Min	Typ	Max	Units
DC Supply Voltage					
+5	+5	4.75	5.0	5.25	Volts
B^+	B^+	9.5	12	15.8	Volts
Pressure Sensor Output Voltage	VS1				
— Zero Pressure	—	—	1.0	—	Volt
— Full Scale (MPX10)	—	—	2.2	—	Volts
— Full Scale (MPX100)	—	—	3.1	—	Volts
Temp Sensor Output Voltage	VS2	—	2.5	—	Volts
Quiescent Current	I_{CC}	—	25	—	mA

Table 2. VS1 Versus Sensor Type

Sensor	Full Scale Pressure (kPa)	Sensitivity (mV/kPa)	Zero Pressure Offset (Volts)	Full Scale Output Voltage (Volts)	Full Scale Span (Volts)
MPX10*	10	120	1.0	2.2	1.2
MPX100*	100	21	1.0	3.1	2.1

*Included with ASB201 kit

Table 3. VS2 Versus Temperature

Temperature °C	R_T Ohms	VS2 Volts	Temperature °C	R_T Ohms	VS2 Volts
0	32773	1.17	40	5323	3.26
5	25456	1.41	45	4365	3.48
10	19932	1.67	50	3599	3.68
15	15725	1.94	55	2983	3.85
20	12497	2.22	60	2486	4.00
25	10000	2.50	65	2082	4.14
30	8055	2.77	70	1753	4.25
35	6528	3.03	75	1482	4.35

Content

Board contents are described by the following parts list and the schematic in Figure 2. A pin by pin circuit description follows in the next section.

Table 4. Parts List

Item	Quantity	Reference	Part
1	1	C1	.33 µF
2	1	C2	.01 µF
3	1	C3	.001 µF
4	1	C4	.1 µF
5	3	D1,D2,D3	LED (RED)
6	1	D4	IN914
7	1	P1	DB9
8	1	RT1	10K Thermistor
9	2	R1,R4	3.40K 1%
10	2	R2,R3	100 1%
11	2	R5,R6	300
12	1	R7	10K 1%
13	1	R8	1.2K
14	1	R9	7.87K 1%
15	1	R10	499 1%
16	1	R11	1K 1%
17	2	R12,R13	390
18	1	R14	665 1%
19	1	U1	MPX10
20	2	U2,U3	MC33272

Pin by Pin Description

Inputs and outputs are grouped into two connectors. A DB–9 connector provides a plug–in feature. If this connector is used, no other connections are necessary. Alternately, power, ground, and output connections can be made through screw terminals at the top of the board. The screw terminals and the DB–9 are wired in parallel. DB–9 connector pinouts are shown in Figure 3.

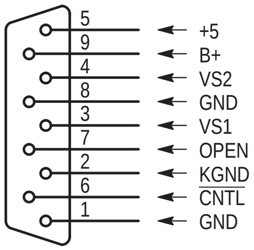


Figure 3. DB–9 Pinout

DB–9 Connector

B^+:
Power for the sensor and op amps is supplied through pin 9 on the DB–9 connector. This voltage is labeled B^+. It is specified from 9.5 VDC min to 15.8 VDC max.

+5:
5 volt power is supplied through pin 5. It is specified from 4.75 VDC min to 5.25 VDC max.

GND:
The ground connection is on pin one. It connects the sensor's analog ground to the controller's digital ground.

KGND:
An additional ground connection, labeled KGND, is made on pin 2. As shipped, KGND is tied to GND via jumper J1. If J1 is opened, KGND provides a separate signal ground return that does not carry the op amp and pressures sensor bias currents. This feature can be helpful if a cable is used between the sensor module and its controller.

VS1:
The pressure sensor output signal, VS1, is connected to pin 3. It is the output of a two op amp discrete instrumentation amplifier that has pressure sensor U1 as its input. Nominal output voltage is 1.0 volt at zero pressure and 2.2 volts at full scale with an MPX10 sensor. With an MPX100 sensor, nominal output voltage is 1.0 volts at zero pressure and 3.1 volts at full scale.

VS2:
A temperature dependent output signal is connected to pin 4. It is derived from a thermistor and has a nominal output voltage of 2.5 volts at 25 degrees C. The thermistor's output is a function of both ambient air temperature, and temperature rise on the board that is conducted through the leads. It will typically read several degrees higher than the temperature of still ambient air.

$\overline{\text{CNTL}}$:
A control signal is supplied on pin 6. It is normally high, and switches low to light the RANGE light when the sensor's full scale pressure is exceeded. With code modifications, the pressure at which this transition occurs can be changed, and the signal used to control an external device.

Board Code:
A board code that lets the controller know that this is an Uncompensated series module is supplied with a ground on pin 7 and a ground on pin 8.

Screw Terminals

Connections for B^+, +5, VS1, CNTL, $\overline{\text{KGND}}$, & GND are wired in parallel with the DB–9 connector. As shipped, KGND and GND are tied together with Jumper J1.

Test Points TP1–TP3, & GND

Test points TP1, TP2, & TP3 provide access to output and bias signals. TP1 is connected to the pressure output signal. TP2 is connected to the thermistor output signal. The sensor's 3 volt bias voltage, supplied from op amp U3B, appears on TP3. A test point for ground is also provided.

Indicator Lights

B^+:
The B^+ light is provided to indicate the presence of the B^+ power supply.

+5:
The +5 light is provided to indicate the presence of 5 volt power.

RANGE:
The RANGE indicator light turns on when the sensor's full scale pressure range is exceeded.

APPLICATION EXAMPLE

An application example shown in Figure 4 illustrates system connections to an ASB200 sensor development controller and a pressure source. This arrangement can be run stand alone, or the ASB200 can be connected to an MMDS or MMEVS system for code development. The two boards are designed such that the DB–9 connectors plug into each other. Once they are plugged in, it is only a matter of connecting a power supply and a pressure source to get a system up and running. If physical separation between the sensor location and the controller is desired, a standard 9 wire straight–through serial cable can be used between the two boards. Measuring different pressure ranges is facilitated by using a socket for the sensor that is supplied on the board.

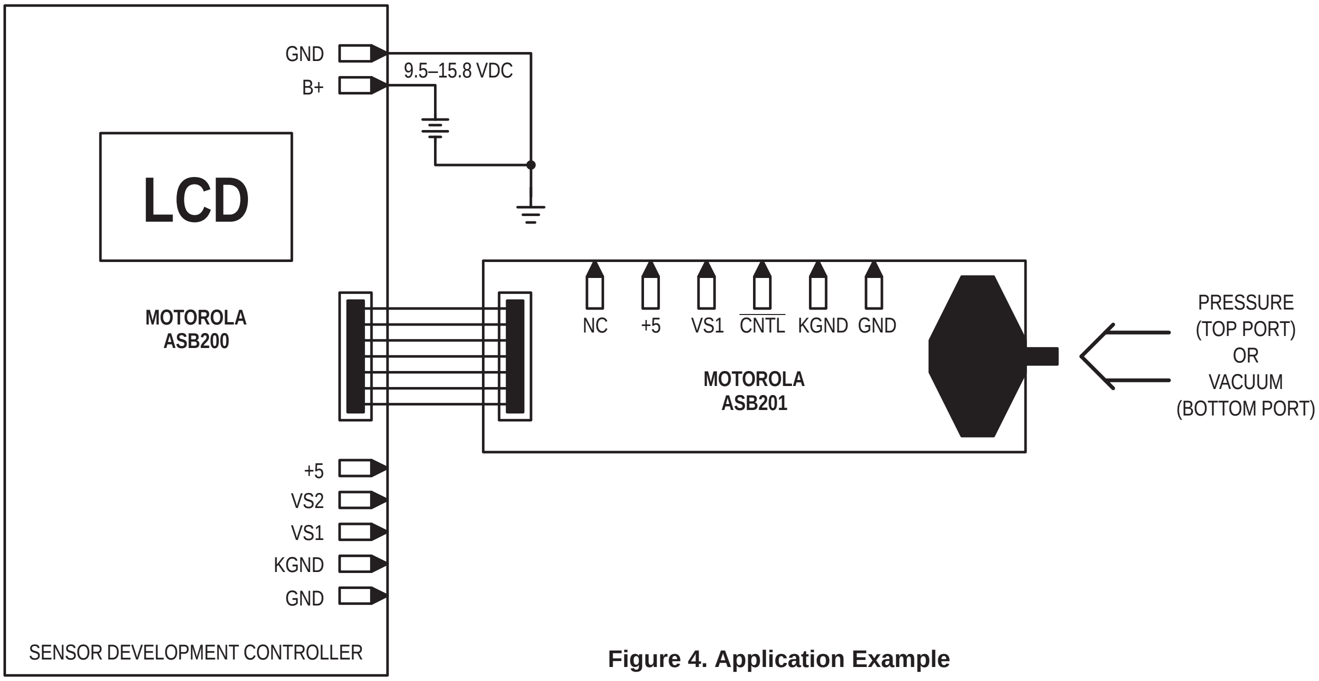
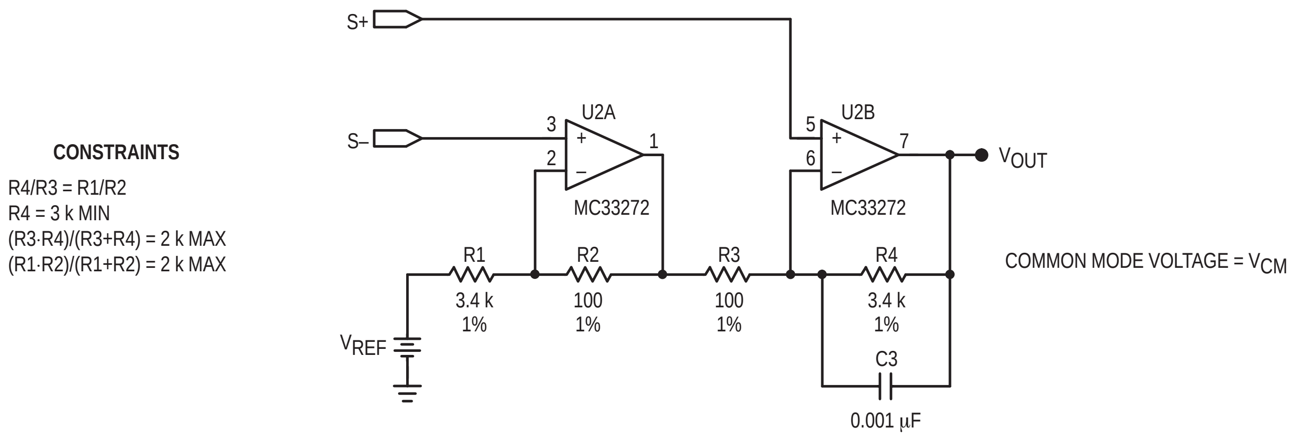


Figure 4. Application Example

DESIGN CONSIDERATIONS

When interfacing MPX10 & MPX100 pressure sensors to microcomputers, producing a ground referenced output that is suitable for driving A/D inputs from the sensor's relatively small differential signal is one of the design requirements. The circuit shown in Figure 2 provides a reference design performing this task.

To see how this amplifier works, let's simplify it in Figure 5, assume that the voltage source labeled V_{REF} is zero, and set the differential input voltage to zero. If the common mode voltage at sensor inputs S+ and S – is 1.5 volts, then pin 2 of U2A and pin 6 of U2B are also at 1.5 volts. This puts 1.5 volts across R1, generating 1.5V/3.40K = 441.176 µA of current. Assuming that the current in R2 is equal to the current in R1, 441.176 µA X 100 ohms produces a 41.176 mV drop across R2, which adds to the 1.5 volts at pin 2. The output voltage at pin 1 of U2A is, therefore, 1.541176 volts. This puts 1.541176 – 1.5 volts across R3, producing 41.176mV/1.00K = 41.176 µA. The same current flowing through R4 produces a voltage drop of (41.176 µA)X(3.40K) = 1.5 volts, which sets the output at zero. Substituting a value for V_{REF} other than zero into this calculation reveals that the zero pressure output voltage equals V_{REF}. 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 = R4/R3.



DIFFERENTIAL GAIN ≅ R4/R3 + 1
ZERO PRESSURE OFFSET ≅ V_{REF}(R2·R4)/(R1·R3) – V_{CM}((R2·R4)/(R1·R3) – 1)

Figure 5. Amplifier — Simplified Schematic

Signal gain can be determined by assuming a differential output at the sensor and going through the same calculation. To do this let's assume 100 mV of differential output and V_{REF} = 0. These values put pin 3 of U2A at 1.45 volts, and pin 5 of U2B at 1.55 volts. Therefore, 1.45 volts is applied to R1, generating 426.471 µA. This current flowing through R2 produces 42.647 mV, placing pin 1 of U2A at 1450 mV + 42.647 mV = 1492.647 mV. The voltage across R3 is then 1550mV – 1492.647 mV = 57.353 mV, which produces a current of 57.353mV/100 = 573.53 µA that flows into R4. The output voltage is then 1.55V + (573.53 µA · 3.40K) = 3.5 volts. Dividing 3.5 volts by the 100 mV input yields a gain of 35, which provides a 1.225 volt span for 35 mV of full scale sensor output.

Since the sensor output is nominally 20 mV at zero pressure, the differential gain times .02 Volts adds to V_{REF} to produce the ASB201's nominal zero pressure output voltage. Therefore, V_{REF} is set to .3 volts so that the nominal zero pressure offset, including the gained sensor's offset, is one volt.

The foregoing nodal analysis can be summarized by the following two equations, which are first order approximations. Equation (1) assumes that the zero pressure differential input between S+ and S – in Figure 5 is V_{OFFSET}, and that V_{CM} is the common mode voltage at S+ and S – .

(1) **ZERO PRESSURE OFFSET**

$$= \mathbf{V_{REF}\,(R2 \cdot R4)/(R1 \cdot R3) - V_{CM}((R2 \cdot R4)/(R1 \cdot R3) - 1) + (R4/R3 + 1)} \cdot V_{OFFSET}$$

$$= .3(3.40K \cdot 100)/(3.40K \cdot 100) - 1.5((3.40K \cdot 100)/(3.40K \cdot 100) - 1) + 35(.020)$$

$$= .3(3400K/3400K) - 1.5((3400K/3400K) - 1) + 35(.02) = .3 - 0 + .7 = 1 \text{ Volt}$$

(2) **DIFFERENTIAL GAIN = R4/R3 +1** = (3.40K/100 +1) = 34 + 1 = 35

These equations are based upon the same assumptions as the nodal analysis, namely high open loop gain, zero input offset voltage, zero input bias current, and that the resistor values are actual values as opposed to specified values. As is typical in discrete instrumentation amplifiers, the most troublesome assumption is the resistor values. A 1% variation in the ratio (R4 · R2)/(R1 · R3) causes an error that is 1% of the common mode voltage at the amplifier's input.

Returning to Figure 2, a .30 volt V_{REF} is generated by the divider consisting of R9 and R10. This divider is sourced from the same 5 volts as the controller's A/D converter reference, thereby minimizing power supply tolerance as a source of error. This divider is buffered by U3A in order to preserve the ratio R4/R3 = R1/R2. The power supply to the sensor is nominally 3.0 volts, and is also generated from the 5 volt reference to minimize power supply errors. The resulting 1 V to 3.1 V output from pin 7 of U2B is compatible with microprocessor A/D inputs.

CONCLUSION

The ASB201 plug–in module is part of a systems development tool set for pressure sensors. It provides pressure and temperature input signals to a Motorola Sensor Development Controller, or can be used stand alone to provide a signal conditioned output from MPX10 & MPX100 sensors.

MOTOROLA
SEMICONDUCTOR APPLICATION NOTE

AN1652

ASB202 — MPX2000 Series Sensor Module

Prepared by: Bill Lucas and Warren Schultz

A plug–in module that is part of a systems development tool set for pressure sensors is presented here. It provides an analog signal from an MPX2000 series sensor to a Motorola Sensor Development Controller, or can be used stand alone to provide power and signal conditioning for the sensor.

PLUG–IN MODULE DESCRIPTION

A summary of information for using systems development plug–in module ASB202 includes the schematic in Figure 2, connector pinout in Figure 3, a pin by pin description of functionality, specs in Tables 1–3, and a parts list in Table 4. Figure 4 in the Applications section provides a quick reference for making connections. A discussion of the design appears under the heading Design Considerations.

Function

The plug–in module shown in Figure 1 is designed to supply pressure and temperature inputs to a sensor development controller. The sensor output is amplified, level shifted, filtered, and converted to a single ended signal that fits within a zero to 5 volt window. Connections are made through a DB–9 connector, which allows this board to be plugged directly into its controller. If physical separation is desired, a standard 9 wire straight–through serial cable can be inserted between the two boards. Alternately, connections for B^+, 5 volts, ground, and the output signal can be made through screw terminals at the top of the board. A socket for sensor connections makes changing from one pressure range to another relatively easy.

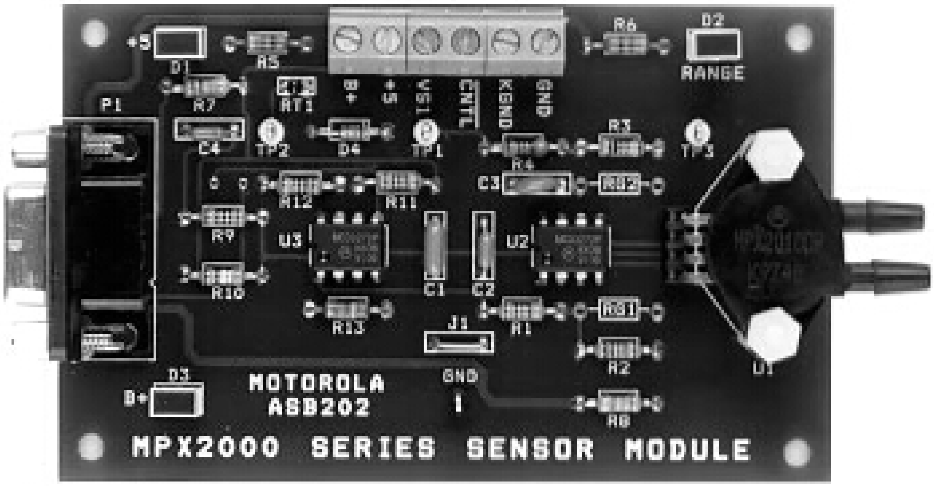


Figure 1. ASB202 — MPX2000 Series Sensor Module

REV 1

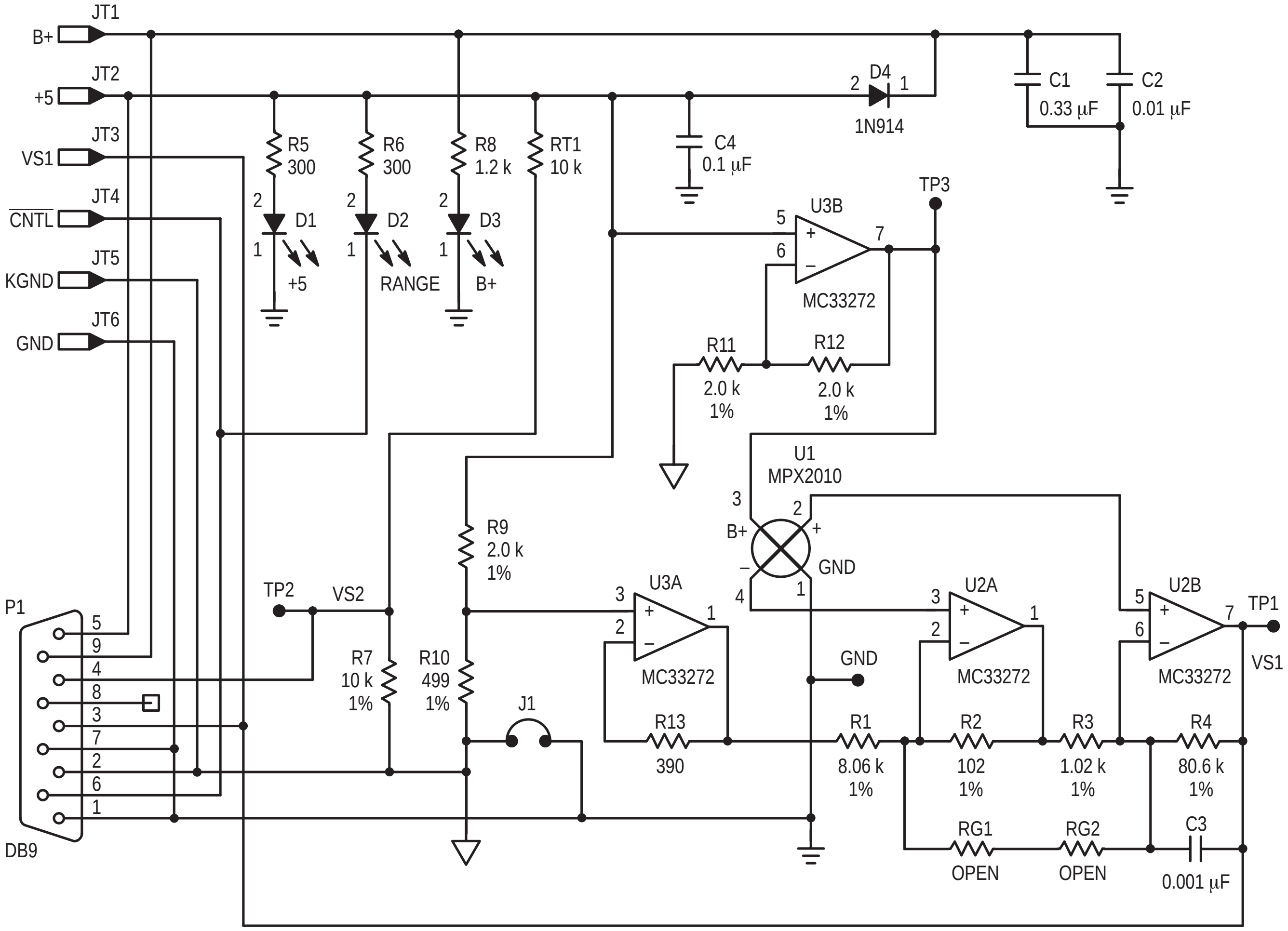


Figure 2. Schematic

Electrical Characteristics

Unless otherwise specified, the electrical characteristics in Tables 1, 2, & 3, apply to operation at 25 degrees Celsius, B^+ = 12.0 volts, and a +5 volt input of 5.00 volts. The values in Tables 2 and 3 are nominal values.

Table 1. Electrical Characteristics

Characteristic	Symbol	Min	Typ	Max	Units
DC Supply Voltage					
+5	+5	4.75	5.0	5.25	Volts
B^+	B^+	11.6	12	15.8	Volts
Pressure Sensor Output Voltage	VS1				
— Zero Pressure	—	—	1.0	—	Volt
— Full Scale (MPX2010)	—	—	3.0	—	Volts
— Full Scale (MPX2050–MPX2700)	—	—	4.2	—	Volts
Temp Sensor Output Voltage	VS2	—	2.5	—	Volts
Quiescent Current	I_{CC}	—	25	—	mA

Table 2. VS1 Versus Sensor Type

Sensor	Full Scale Pressure (kPa)	Sensitivity (mV/kPa)	Zero Pressure Offset (Volts)	Full Scale Output Voltage (Volts)	Full Scale Span (Volts)
MPX2010*	10	200	1.0	3.0	2.0
MPX2050	50	64	1.0	4.2	3.2
MPX2100*	100	32	1.0	4.2	3.2
MPX2200	200	16	1.0	4.2	3.2

*Included with ASB202 kit

Table 3. VS2 Versus Temperature

Temperature °C	R_T Ohms	VS2 Volts	Temperature °C	R_T Ohms	VS2 Volts
0	32773	1.17	40	5323	3.26
5	25456	1.41	45	4365	3.48
10	19932	1.67	50	3599	3.68
15	15725	1.94	55	2983	3.85
20	12497	2.22	60	2486	4.00
25	10000	2.50	65	2082	4.14
30	8055	2.77	70	1753	4.25
35	6528	3.03	75	1482	4.35

Content

Board contents are described by the following parts list and the schematic in Figure 2. A pin by pin circuit description follows in the next section.

Table 4. Parts List

Item	Quantity	Reference	Part
1	1	C1	.33 µF
2	1	C2	.01 µF
3	1	C3	.001 µF
4	1	C4	.1 µF
5	3	D1,D2,D3	LED (RED)
6	1	D4	IN914
7	1	P1	DB9
8	1	RT1	10K Thermistor
9	1	R1	8.06K 1%
10	1	R2	102 1%
11	1	R3	1.02K 1%
12	1	R4	80.6K 1%
13	2	R5,R6	300
14	1	R7	10K 1%
15	1	R8	1.2K
16	3	R9,R11,R12	2.00K 1%
17	1	R10	499 1%
18	1	R13	390
19	1	U1	MPX2010
20	2	U2,U3	MC33272

Pin by Pin Description

Inputs and outputs are grouped into two connectors. A DB–9 connector provides a plug–in feature. If this connector is used, no other connections are necessary. Alternately, power, ground, and output connections can be made through screw terminals at the top of the board. The screw terminals and the DB–9 are wired in parallel. DB–9 connector pinouts are shown in Figure 3.

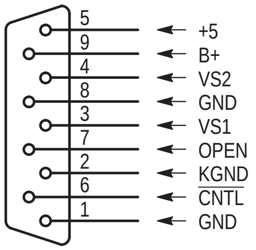


Figure 3. DB–9 Pinout

DB–9 Connector

B^+:
Power for the sensor and op amps is supplied through pin 9 on the DB–9 connector. This voltage is labeled B^+. It is specified from 11.6 VDC min to 15.8 VDC max.

+5:
5 volt power is supplied through pin 5. It is specified from 4.75 VDC min to 5.25 VDC max.

GND:
The ground connection is on pin one. It connects the sensor’s analog ground to the controller’s digital ground.

KGND:
An additional ground connection, labeled KGND, is made on pin 2. As shipped, KGND is tied to GND via jumper J1. If J1 is opened, KGND provides a separate signal ground return that does not carry the op amp and pressures sensor bias currents. This feature can be helpful if a cable is used between the sensor module and its controller.

VS1:
The pressure sensor output signal, VS1, is connected to pin 3. It is the output of a two op amp discrete instrumentation amplifier that has pressure sensor U1 as its input. Nominal output voltage is 1.0 volt at zero pressure and 3.0 volts at full scale with an MPX2010 sensor. With all of the other MPX2000 series sensors, nominal output voltage is 1.0 volts at zero pressure and 4.2 volts at full scale.

VS2:
A temperature dependent output signal is connected to pin 4. It is derived from a thermistor and has a nominal output voltage of 2.5 volts at 25 degrees C. The thermistor's output is a function of both ambient air temperature, and temperature rise on the board that is conducted through the leads. It will typically read several degrees higher than the temperature of still ambient air.

$\overline{\text{CNTL}}$:
A control signal is supplied on pin 6. It is normally high, and switches low to light the RANGE light when the sensor's full scale pressure is exceeded. With code modifications, the pressure at which this transition occurs can be changed, and the signal used to control an external device.

Board Code:
A board code that lets the controller know that this is an MPX2000 series module is supplied with a ground on pin 7 and an open on pin 8.

Screw Terminals

Connections for B$^+$, +5, VS1, CNTL, $\overline{\text{KGND}}$, & GND are wired in parallel with the DB–9 connector. As shipped, KGND and GND are tied together with Jumper J1.

Test Points TP1–TP3, & GND

Test points TP1, TP2, & TP3 provide access to output and bias signals. TP1 is connected to the pressure output signal. TP2 is connected to the thermistor output signal. The sensor's 10 volt bias voltage, supplied from op amp U3B, appears on TP3. A test point for ground is also provided.

Indicator Lights

B$^+$:
The B$^+$ light is provided to indicate the presence of the B$^+$ power supply.

+5:
The +5 light is provided to indicate the presence of 5 volt power.

RANGE:
The RANGE indicator light turns on when the sensor's full scale pressure range is exceeded.

APPLICATION EXAMPLE

An application example shown in Figure 4 illustrates system connections to an ASB200 sensor development controller and a pressure source. This arrangement can be run stand alone, or the ASB200 can be connected to an MMDS or MMEVS system for code development. The two boards are designed such that the DB–9 connectors plug into each other. Once they are plugged in, it is only a matter of connecting a power supply and a pressure source to get a system up and running. If physical separation between the sensor location and the controller is desired, a standard 9 wire straight–through serial cable can be used between the two boards. Measuring different pressure ranges is facilitated by using a socket for the sensor that is supplied on the board.

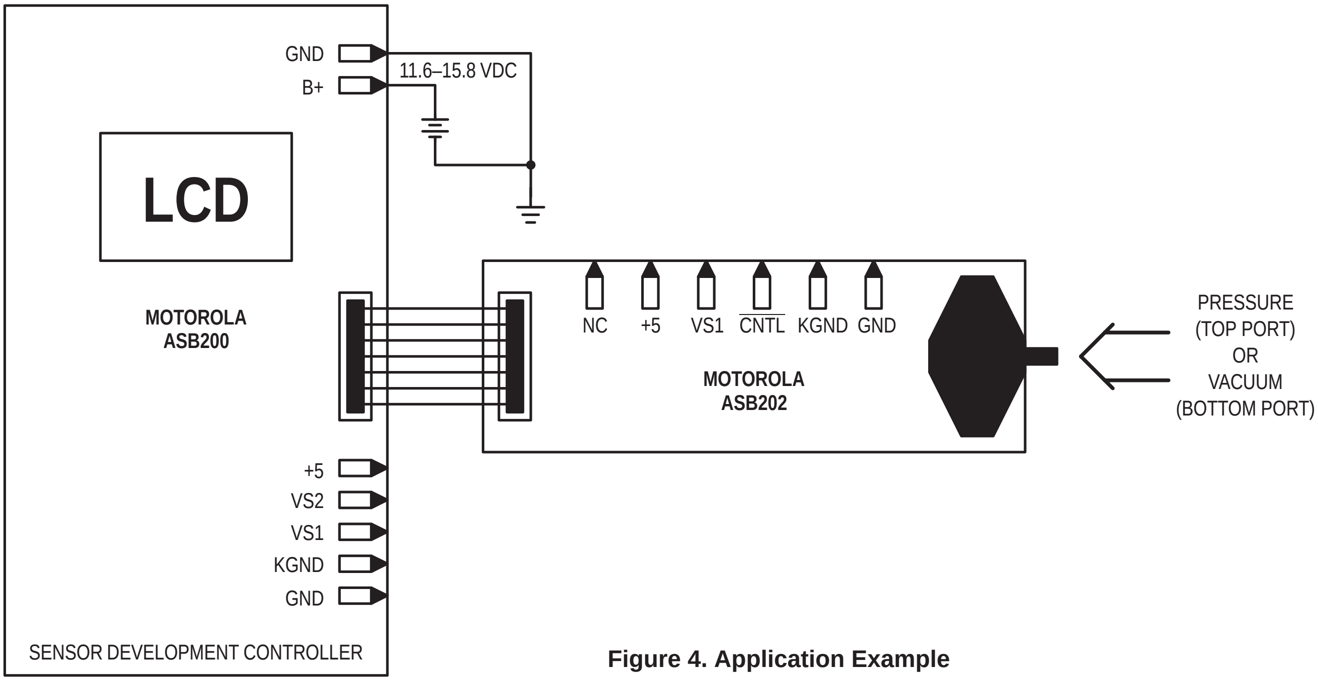


Figure 4. Application Example

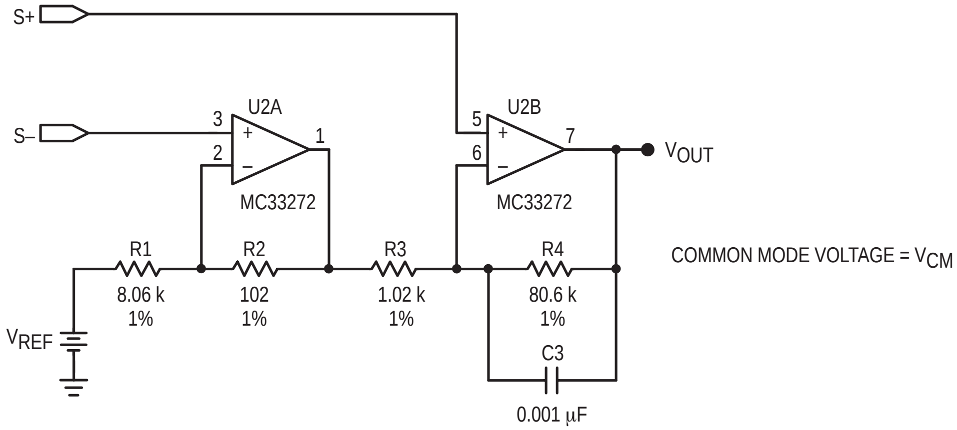
DESIGN CONSIDERATIONS

When interfacing MPX2000 series 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. The circuit shown in Figure 2 provides a reference design performing this task.

To see how this amplifier works, let's simplify it in Figure 5, assume that the voltage source labeled V_{REF} is zero, and set the differential input voltage to zero. If the common mode voltage at sensor inputs S+ and S – is 5.0 volts, then pin 2 of U2A and pin 6 of U2B are also at 5.0 volts. This puts 5.0 volts across R1, generating 5V/8.06K = 620 µA of current. Assuming that the current in R2 is equal to the current in R1, 620 µA X 102 ohms produces a 63.275 mV drop across R2, which adds to the 5.0 volts at pin 2. The output voltage at pin 1 of U2A is, therefore, 5.063275 volts. This puts 5.063275 – 5.0 volts across R3, producing 63.275mV/1.02K = 62.035 µA. The same current flowing through R4 produces a voltage drop of (62.035 µA)X(80.6K) = 5.0 volts, which sets the output at zero. Substituting a value for V_{REF} other than zero into this calculation reveals that the zero pressure output voltage equals V_{REF}. 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 = R4/R3.

CONSTRAINTS

R4/R3 = R1/R2
R4 = 10 k MIN
(R3·R4)/(R3+R4) = 2 k MAX
(R1·R2)/(R1+R2) = 2 k MAX
R3 ≅ R2 + SENSOR DELTA Z_{OUT}



DIFFERENTIAL GAIN ≅ R4/R3 + 1
ZERO PRESSURE OFFSET ≅ V_{REF}(R2·R4)/(R1·R3) – V_{CM}((R2·R4)/(R1·R3) – 1)

Figure 5. Amplifier — Simplified Schematic

Signal gain can be determined by assuming a differential output at the sensor and going through the same calculation. To do this let's assume 100 mV of differential output and V_{REF} = 0. These values put pin 3 of U2A at 4.95 volts, and pin 5 of U2B at 5.05 volts. Therefore, 4.95 volts is applied to R1, generating 614 µA. This current flowing through R2 produces 62.643 mV, placing pin 1 of U2A at 4950 mV + 62.6 mV = 5012.6 mV. The voltage across R3 is then 5050mV – 5012.6 mV = 37.4 mV, which produces a current of 37.4 mV/1.02K = 36.6 µA that flows into R4. The output voltage is then 5.05V + (36.6 µA · 80.6K) = 8.0 volts. Dividing 8.0 volts by the 100 mV input yields a gain of 80, which provides a 3.2 volt span for 40 mV of full scale sensor output.

The foregoing nodal analysis can be summarized by the following two equations, which are first order approximations. Equation (1) assumes that the differential input between S+ and S – in Figure 5 is zero, and that V_{CM} is the common mode voltage at S+ and S – .

(1) **ZERO PRESSURE OFFSET**

$$= V_{REF}\,(R2 \cdot R4)/(R1 \cdot R3) - V_{CM}((R2 \cdot R4)/(R1 \cdot R3) - 1)$$

$$= 1.0(80.6K \cdot 102)/(8.06K \cdot 1020) - 5.0((80.6K \cdot 102)/(8.06K \cdot 1020) - 1)$$

$$= 1.0(8220K/8220K) - 5.0((8220K/8220K) - 1) = 1.0 - 0 = 1 \text{ Volt}$$

(2) **DIFFERENTIAL GAIN = R4/R3 +1**

$$= (80.6K/1.02K + 1) = 79 + 1 = 80$$

These equations are based upon the same assumptions as the nodal analysis, namely high open loop gain, zero input offset voltage, zero input bias current, and that the resistor values are actual values as opposed to specified values. As is typical in discrete instrumentation amplifiers, the most troublesome assumption is the resistor values. A 1% variation in the ratio (R4 · R2)/(R1 · R3) causes an error that is 1% of the common mode voltage at the amplifier's input.

Returning to Figure 2, a 1.0 volt V_{REF} is generated by the divider consisting of R9 and R10. This divider is sourced from the same 5 volts as the controller's A/D converter reference, thereby minimizing power supply tolerance as a source of error. This divider is buffered by U3A in order to preserve the ratio R4/R3 = R1/R2. The power supply to the sensor is nominally 10.0 volts, and is also generated from the 5 volt reference to minimize power supply errors.

The resulting 1.0 V to 4.2 V output from pin 7 of U2B is compatible with microprocessor A/D inputs. Over a zero to 75 degree C temperature range combined accuracy for the sensor and interface is +/– 5%, provided that a provision for zero pressure offset calibration is made.

CONCLUSION

The ASB202 plug–in module is part of a systems development tool set for pressure sensors. It provides pressure and temperature input signals to a Motorola Sensor Development Controller, or can be used stand alone to provide a signal conditioned output from MPX2000 series sensors.

MOTOROLA
SEMICONDUCTOR APPLICATION NOTE

AN1653

ASB205 — MPX5000 Series Sensor Module

Prepared by: Bill Lucas and Warren Schultz

A plug–in module that is part of a systems development tool set for pressure sensors is presented here. It provides an analog signal from an MPX5000 series sensor to a Motorola Sensor Development Controller, or can be used stand alone to provide power and signal connections to the sensor.

PLUG–IN MODULE DESCRIPTION

A summary of information for using systems development plug–in module ASB205 includes the schematic in Figure 2, connector pinout in Figure 3, a pin by pin description of functionality, specs in Tables 1–3, and a parts list in Table 4. Figure 4 in the Applications section provides a quick reference for making connections. A discussion of the design appears under the heading Design Considerations.

Function

The plug–in module shown in Figure 1 is designed to supply pressure and temperature inputs to a sensor development controller. The sensor output is filtered and buffered with a unity gain rail to rail amplifier. If desired, jumpers on the board allow direct connection of the sensor output to the controller. Connections are made through a DB–9 connector, which allows this board to be plugged directly into its controller. If physical separation is desired, a standard 9 wire straight–through serial cable can be inserted between the two boards. Alternately, connections for 5 volts, ground, and the output signal can be made through screw terminals at the top of the board. A socket for sensor connections makes changing from one pressure range to another relatively easy.

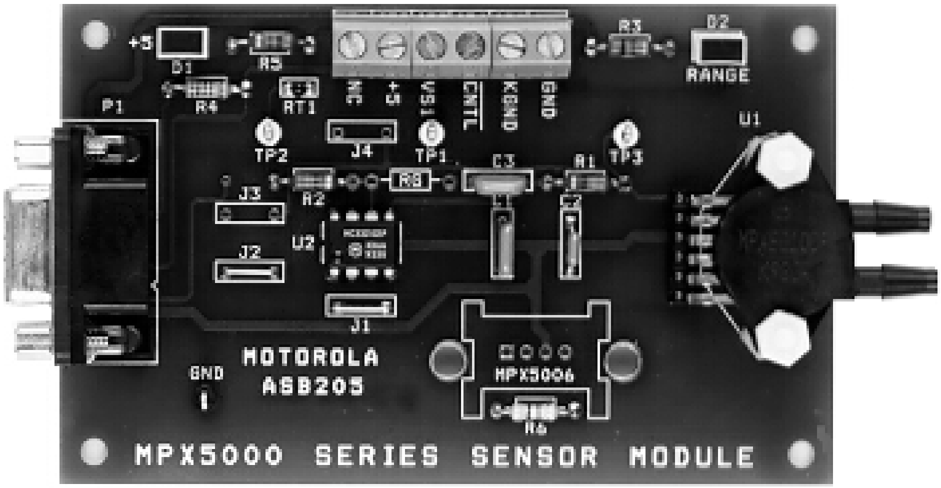


Figure 1. ASB205 — MPX5000 Series Sensor Module

REV 1

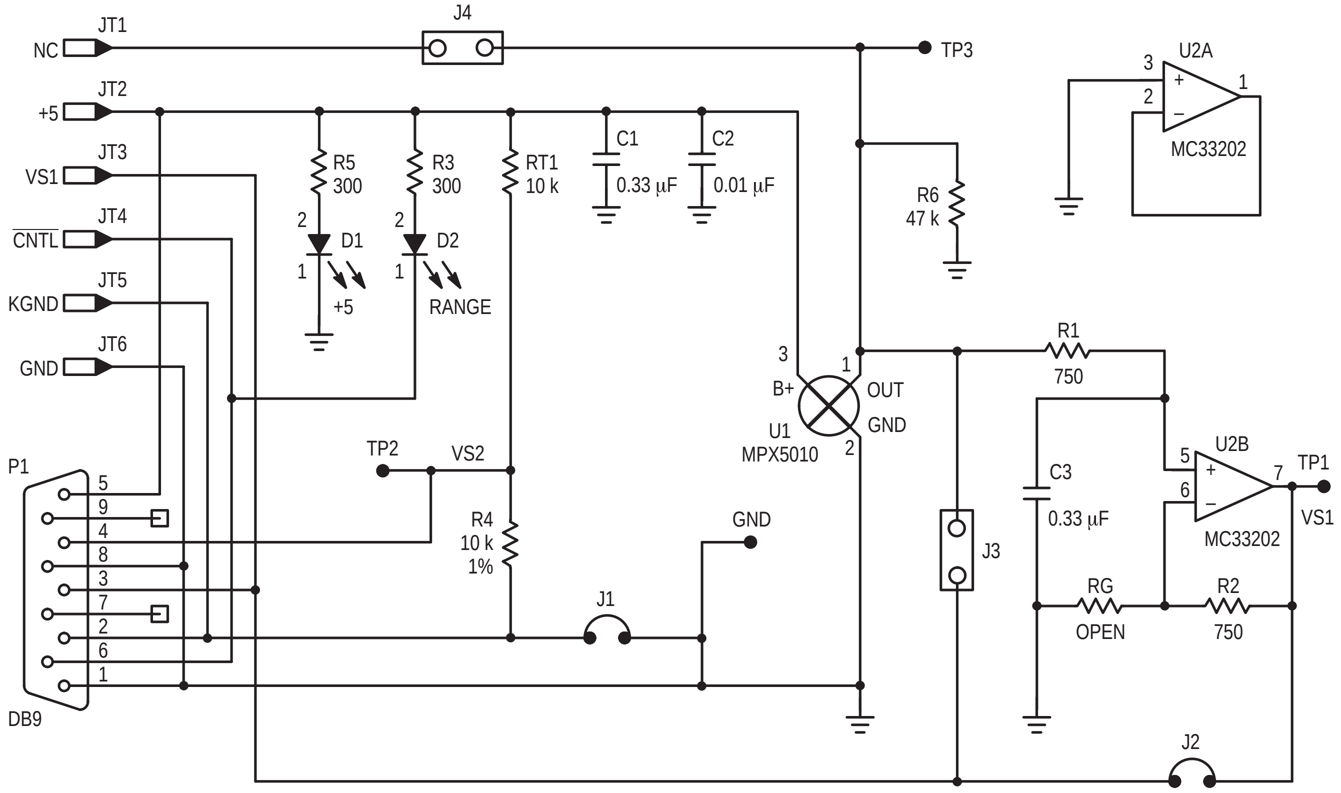


Figure 2. Schematic

Electrical Characteristics

The electrical characteristics in Tables 1, 2, & 3, apply to operation at 25 degrees Celsius, and unless otherwise specified a +5 volt input of 5.00 volts. The values in Tables 2 and 3 are nominal values.

Table 1. Electrical Characteristics

Characteristic	Symbol	Min	Typ	Max	Units
DC Supply Voltage	+5	4.75	5.0	5.25	Volts
Pressure Sensor Output Voltage	VS1				
— Zero Pressure	—	—	200	—	mV
— Full Scale	—	—	4.7	—	Volts
Temp Sensor Output Voltage	VS2	—	2.5	—	Volts
Quiescent Current	I_{CC}	—	25	—	mA

Table 2. Output Characteristics (VS1)

Sensor	Full Scale Pressure (kPa)	Sensitivity (mV/kPa)	Zero Pressure Offset (Volts)	Full Scale Output Voltage (Volts)	Full Scale Span (Volts)
MPX5006*	6	750	.2	4.7	4.5
MPX5010*	10	450	.2	4.7	4.5
MPX5050	50	90	.2	4.7	4.5
MPX5100*	100	45	.2	4.7	4.5
MPX5700*	700	6.43	.2	4.7	4.5
MPX5999	1000	4.5	.2	4.7	4.5

*Included with ASB205 kit

Table 3. VS2 Versus Temperature

Temperature °C	R_T Ohms	VS2 Volts	Temperature °C	R_T Ohms	VS2 Volts
0	32773	1.17	40	5323	3.26
5	25456	1.41	45	4365	3.48
10	19932	1.67	50	3599	3.68
15	15725	1.94	55	2983	3.85
20	12497	2.22	60	2486	4.00
25	10000	2.50	65	2082	4.14
30	8055	2.77	70	1753	4.25
35	6528	3.03	75	1482	4.35

Content

Board contents are described by the following parts list and the schematic in Figure 2. A pin by pin circuit description follows in the next section.

Table 4. Parts List

Item	Quantity	Reference	Part
1	2	C1,C3	.33 µF Ceramic
2	1	C2	.01 µF Ceramic
3	2	D1	LED (RED)
4	1	D2	LED (RED)
5	4	TP1,TP2,TP3,GND	Test Point
6	6	JT1–JT6	Screw Terminal
7	2	J1,J2	Jumper–Wire
8	1	P1	DB9 Connector
9	2	RT1	10K Thermistor
10	1	R4	10K 1%
11	2	R2,R1	750
12	2	R5,R3	300
13	1	R6	47K
14	1	U1	MPX5010
15	1	U2	MC33202

Pin by Pin Description

Inputs and outputs are grouped into two connectors. A DB–9 connector provides a plug–in feature. If this connector is used, no other connections are necessary. Alternately, power, ground, and sensor output connections can be made through screw terminals at the top of the board. The screw terminals and the DB–9 are wired in parallel. DB–9 connector pinouts are shown in Figure 3.

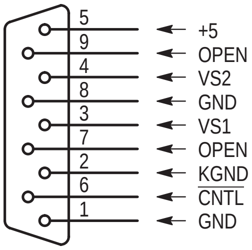


Figure 3. DB–9 Pinout

DB–9 Connector

+5:
5 volt power is supplied through pin 5 on the DB–9 connector.

GND:
The ground connection is on pin one. It connects the sensor's analog ground to the controller's digital ground.

KGND:
An additional ground connection, labeled KGND, is made on pin 2. As shipped, KGND is tied to GND via jumper J1. If J1 is opened, KGND provides a separate return for the temperature sensor. This feature can be helpful if a cable is used between the sensor module and its controller.

VS1:
The pressure sensor output signal, VS1, is on pin 3. This is the sensor's output, filtered and then buffered with a unity gain amplifier. If direct connection to the sensor's output is preferred, it will appear on this pin when Jumper J2 is open, and a wire is soldered into Jumper J3.

VS2:
A temperature dependent output signal is supplied on pin 4. It is supplied from a thermistor that has a nominal output voltage of 2.5 volts at 25 degrees C. This thermistor sees a temperature rise due to power dissipation on the board, and typically reads several degrees higher than ambient in still air.

$\overline{\text{CNTL}}$:
A control signal is supplied on pin 6. It is normally high, and switches low to light the RANGE light when the sensor's full scale pressure is exceeded. With code modifications, the pressure at which this transition occurs can be changed, and the signal used to control an external device.

Board Code:
A board code that lets the controller know that this is an MPX5000 series module is supplied with a ground on pin 8 and an open on pin 7.

Pin 9:
There is no connection made to Pin 9 on this board. However, power supply voltage B^+ will be present on this pin when plugged into a Motorola Sensor Development Controller.

Screw Terminals

Connections for +5, VS1, CNTL, $\overline{\text{KGND}}$, & GND are wired in parallel with the DB–9 connector. As shipped, KGND and GND are tied together with Jumper J1. A no connect terminal labeled, NC, is tied to Jumper J4 which is open. If a wire is placed in J4, this terminal is then connected to the sensor output.

Test Points TP1–TP3, & GND

Test points TP1, TP2, & TP3 provide access to output signals. TP1 is connected to the filtered and buffered pressure sensor output signal. TP2 is connected to the thermistor output signal, and TP3 is connected to sensor's output. A test point for ground is also provided.

Indicator Lights

+5:
The +5 light is provided to indicate the presence of 5 volt power.

RANGE:
The RANGE indicator light turns on when the sensor's full scale pressure range is exceeded.

APPLICATION EXAMPLE

An application example shown in Figure 4 illustrates system connections to an ASB200 control board and a pressure source. This arrangement can be run stand alone, or the ASB200 can be connected to an MMDS or MMEVS system for code development. The two boards are designed such that the DB–9 connectors plug into each other. Once they are plugged in it is only a matter of connecting a power supply and a pressure source to get a system up and running. If physical separation between the sensor location and the controller is desired, a standard 9 wire straight–through serial cable can be used between the two boards.

Measuring different pressure ranges is facilitated by using a socket for the sensor that is supplied on the board. Pads for an MPX5006 are also provided. To use the MPX5006, it is necessary to have the 6 pin socket empty, snap in the MPX5006, and then solder its leads to the pads that are provided. The correct orientation is with its marking facing the front of the board.

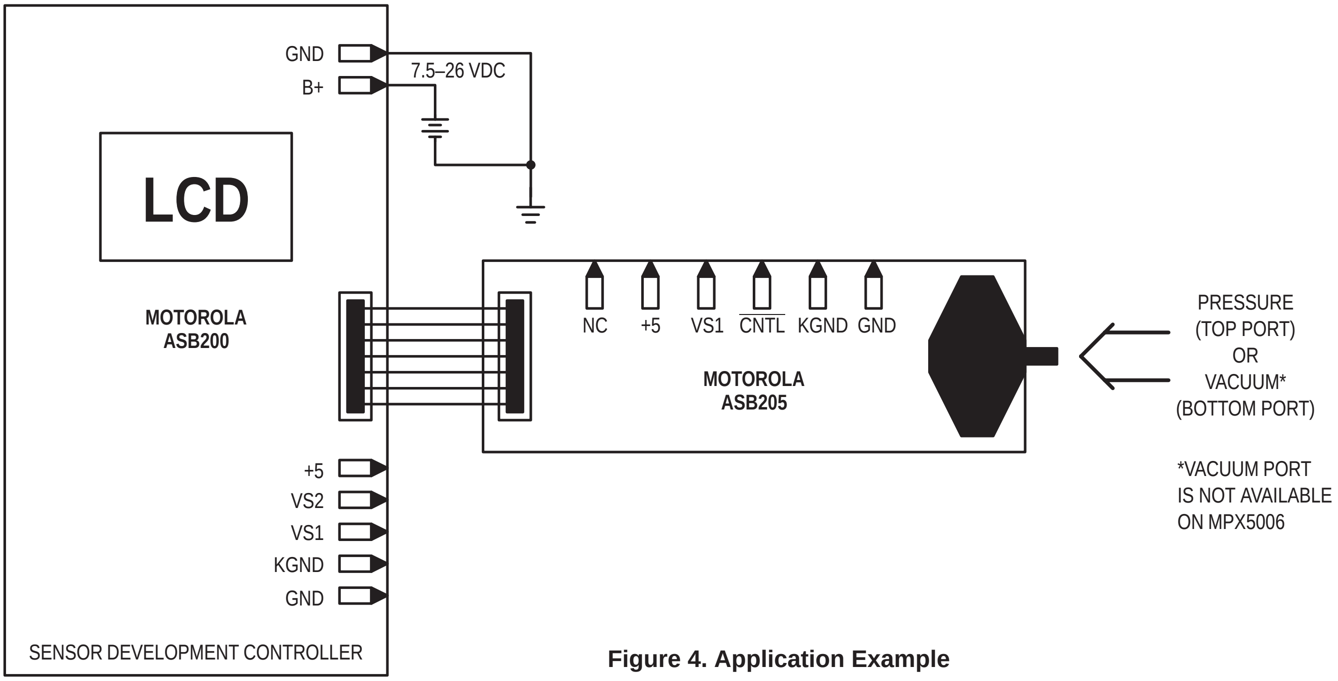


Figure 4. Application Example

DESIGN CONSIDERATIONS

MPX5000 sensors are plug and play devices in most applications, particularly when connected to a micro–controller with an 8 bit A/D converter. Although micro's with 8–bit A/D's are most common, higher resolution A/D's, such as the one on the 68HC705JP7 in this tool set, are becoming increasingly popular. With these higher resolution A/D's, the noise that is inherent to piezo–resistive bridges becomes a design consideration. For that reason, the sensor's output is filtered with a single pole filter, and then buffered with a unity gain buffer. An MC33202 rail to rail operational amplifier was chosen for its ability to drive cable capacitance, in the event that a cable is used between the plug–in module and controller. For applications where the sensor and micro–controller are on the same board, an MC33502 is a better choice, due to its lower offset voltage.

CONCLUSION

The ASB205 plug–in module is part of a systems development tool set for pressure sensors. It provides pressure and temperature input signals to a Motorola Sensor Development Controller, or can be used stand alone to provide power and signal connections to MPX5000 series sensors.

MOTOROLA
SEMICONDUCTOR APPLICATION NOTE

AN1654

ASB210 — 10″ H_2O Sensor Module

Prepared by: Bill Lucas and Warren Schultz

A plug–in module that is part of a systems development tool set for pressure sensors is presented here. It provides a pulsed analog signal from an MPX2010 sensor to a Motorola Sensor Development Controller. The pulsed architecture improves the sensitivity of MPX2010 sensors, providing a 0–10″ H_2O measurement range.

PLUG–IN MODULE DESCRIPTION

A summary of information for using systems development plug–in module ASB210 includes the schematic in Figure 2, connector pinout in Figure 3, a pin by pin description of functionality, specs in Tables 1 & 2, and a parts list in Table 3. Figure 4 in the Applications section provides a quick reference for making connections. A discussion of the design appears under the heading Design Considerations.

Function

The plug–in module shown in Figure 1 is designed to supply pressure and temperature inputs to a sensor development controller. The MPX2010 sensor is pulsed with a 20 volt bias to increase its sensitivity relative to operation at 10 volts DC. Its pulsed output is amplified, level shifted, filtered, and converted to a single ended signal that fits within a zero to 5 volt window. Connections are made through a DB–9 connector, which allows this board to be plugged directly into its controller. If physical separation is desired, a standard 9 pin straight– through serial cable can be inserted between the two boards.

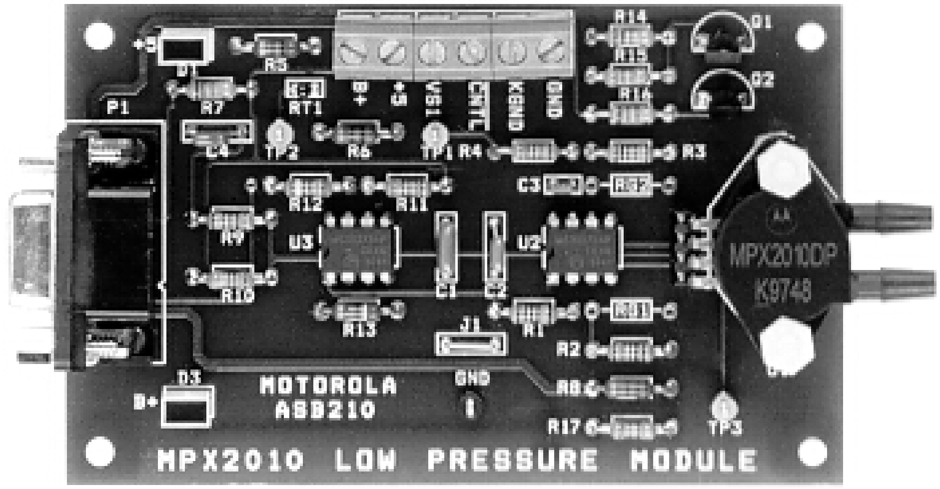


Figure 1. ASB210 — 10″ H_2O Sensor Module

REV 1

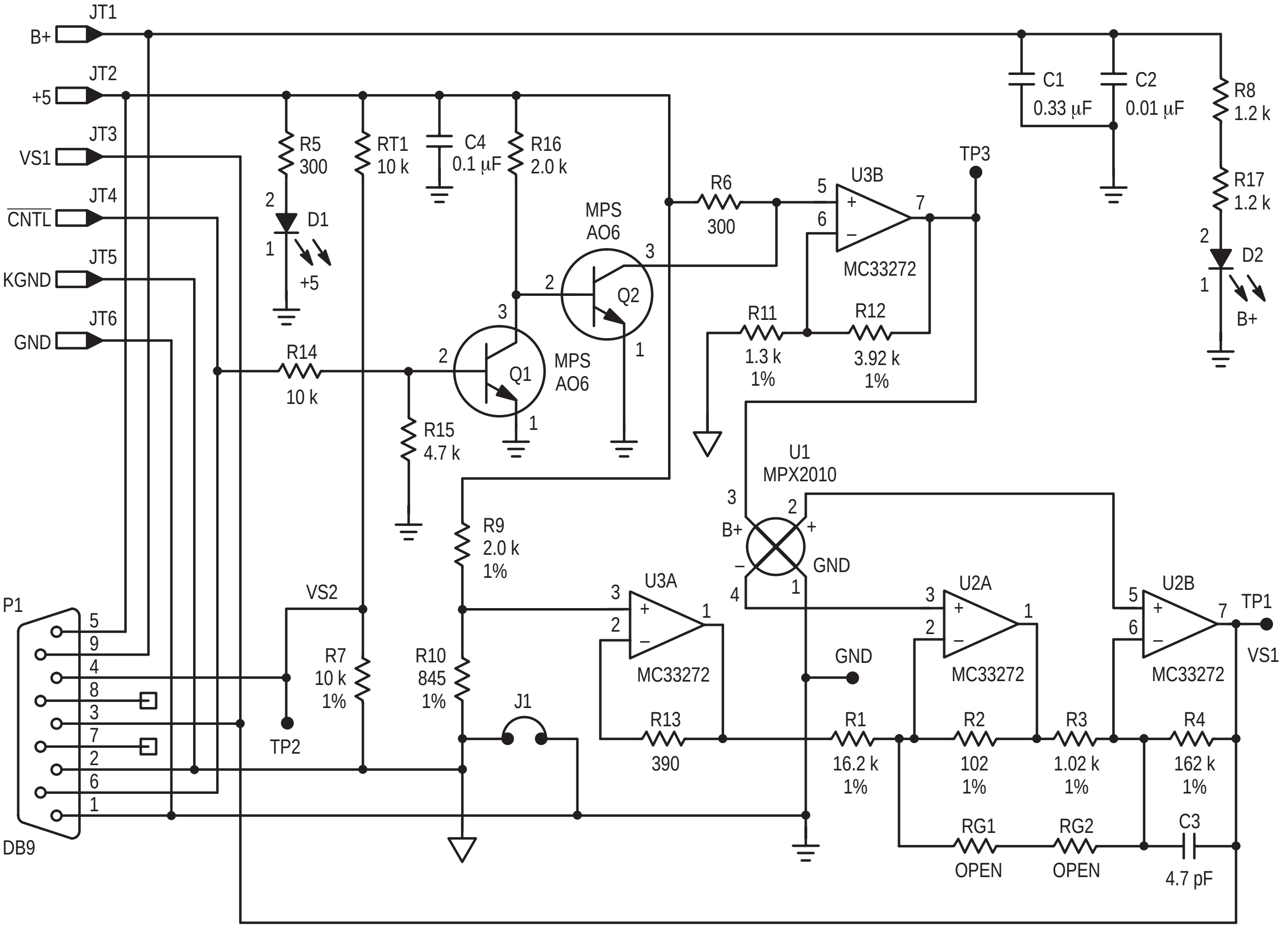


Figure 2. Schematic

Electrical Characteristics

Unless otherwise specified, the electrical characteristics in Tables 1, 2, & 3, apply to operation at 25 degrees Celsius, B^+ = 24.0 volts, and a +5 volt input of 5.00 volts. The values in Tables 2 and 3 are nominal values.

Table 1. Electrical Characteristics

Characteristic	Symbol	Min	Typ	Max	Units
DC Supply Voltage +5 B^+	 +5 B^+	 4.75 22	 5.0 24	 5.25 26	 Volts Volts
Pressure Sensor Output Voltage — Zero Pressure — Full Scale	VS1 — —	 — —	 1.5 3.5	 — —	 Volt Volts
Temp Sensor Output Voltage	VS2	—	2.5	—	Volts
Quiescent Current	I_{CC}	—	25	—	mA

Table 2. VS2 Versus Temperature

Temperature °C	R_T Ohms	VS2 Volts	Temperature °C	R_T Ohms	VS2 Volts
0	32773	1.17	40	5323	3.26
5	25456	1.41	45	4365	3.48
10	19932	1.67	50	3599	3.68
15	15725	1.94	55	2983	3.85
20	12497	2.22	60	2486	4.00
25	10000	2.50	65	2082	4.14
30	8055	2.77	70	1753	4.25
35	6528	3.03	75	1482	4.35

Content

Board contents are described by the following parts list and the schematic in Figure 2. A pin by pin circuit description follows in the next section.

Table 3. Parts List

Item	Quantity	Reference	Part
1	1	C1	.33 µF
2	1	C2	.01 µF
3	1	C3	.001 µF
4	1	C4	4.7 pF
5	2	D1,D2	LED (RED)
6	1	P1	DB9
7	1	RT1	10K Thermistor
8	1	R1	16.2K 1%
9	1	R2	102 1%
10	1	R3	1.02K 1%
11	1	R4	162K 1%
12	2	R5,R6	300
13	1	R7	10K 1%
14	2	R8,R17	1.2K
15	1	R9	2.00K 1%
16	1	R10	845 1%
17	1	R11	1.3K 1%
18	1	R12	3.92K 1%
19	1	R13	390
20	1	R14	10K
21	1	R15	4.7K
22	1	R16	2.0K
26	1	U1	MPX2010
27	2	U2,U3	MC33272

Pin by Pin Description

Inputs and outputs are grouped into two connectors. A DB–9 connector provides a plug–in feature. If this connector is used, no other connections are necessary. Alternately, power, ground, control signal, and output connections can be made through screw terminals at the top of the board. The screw terminals and the DB–9 are wired in parallel. DB–9 connector pinouts are shown in Figure 3.

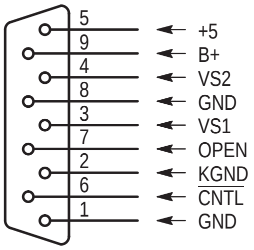


Figure 3. DB–9 Pinout

DB–9 Connector

B$^+$:
Power for the sensor and op amps is supplied through pin 9 on the DB–9 connector. This voltage is labeled B$^+$. It is specified from 22 VDC min to 26 VDC max.

+5:
5 volt power is supplied through pin 5. It is specified from 4.75 VDC min to 5.25 VDC max.

GND:
The ground connection is on pin one. It connects the sensor's analog ground to the controller's digital ground.

KGND:
An additional ground connection, labeled KGND, is made on pin 2. As shipped, KGND is tied to GND via jumper J1. If J1 is opened, KGND provides a separate signal ground return that does not carry the op amp and pressures sensor bias currents. This feature can be helpful if a cable is used between the sensor module and its controller.

VS1:
The pressure sensor output signal, VS1, is connected to pin 3. It is the output of a two op amp discrete instrumentation amplifier that has pressure sensor U1 as its input. Nominal output voltage is 1.5 volts at zero pressure and 3.5 volts at full scale, when the sensor is pulsed on.

VS2:
A temperature dependent output signal is connected to pin 4. It is derived from a thermistor and has a nominal output voltage of 2.5 volts at 25 degrees C. The thermistor's output is a function of both ambient air temperature, and temperature rise on the board that is conducted through the leads. It will typically read several degrees higher than the temperature of still ambient air.

$\overline{\text{CNTL}}$:
A control signal is supplied on pin 6. It switches high to apply a 20 volt bias to the sensor, with a duty cycle that is less than 10%. For the purposes of writing controller code, it is important to note that an inadvertent high on this pin will likely damage the sensor.

Board Code:
A board code that lets the controller know that this is an ASB210 module is supplied with an open on pin 7 and an open on pin 8.

Screw Terminals

Connections for B^+, +5, VS1, CNTL, KGND, & GND are wired in parallel with the DB–9 connector. As shipped, KGND and GND are tied together with Jumper J1.

Test Points TP1–TP3, & GND

Test points TP1, TP2, & TP3 provide access to output and bias signals. TP1 is connected to the pressure output signal. TP2 is connected to the thermistor output signal. The sensor's pulsed 20 volt bias voltage, supplied from op amp U3B, appears on TP3. A test point for ground is also provided.

Indicator Lights

B^+:
The B^+ light is provided to indicate the presence of the B^+ power supply.

+5:
The +5 light is provided to indicate the presence of 5 volt power.

APPLICATION EXAMPLE

An application example shown in Figure 4 illustrates system connections to an ASB200 sensor development controller and a pressure source. This arrangement can be run stand alone, or the ASB200 can be connected to an MMDS or MMEVS system for code development. The two boards are designed such that the DB–9 connectors plug into each other. Once they are plugged in, it is only a matter of connecting a power supply and a pressure source to get a system up and running. If physical separation between the sensor location and the controller is desired, a standard 9 wire straight–through serial cable can be used between the two boards.

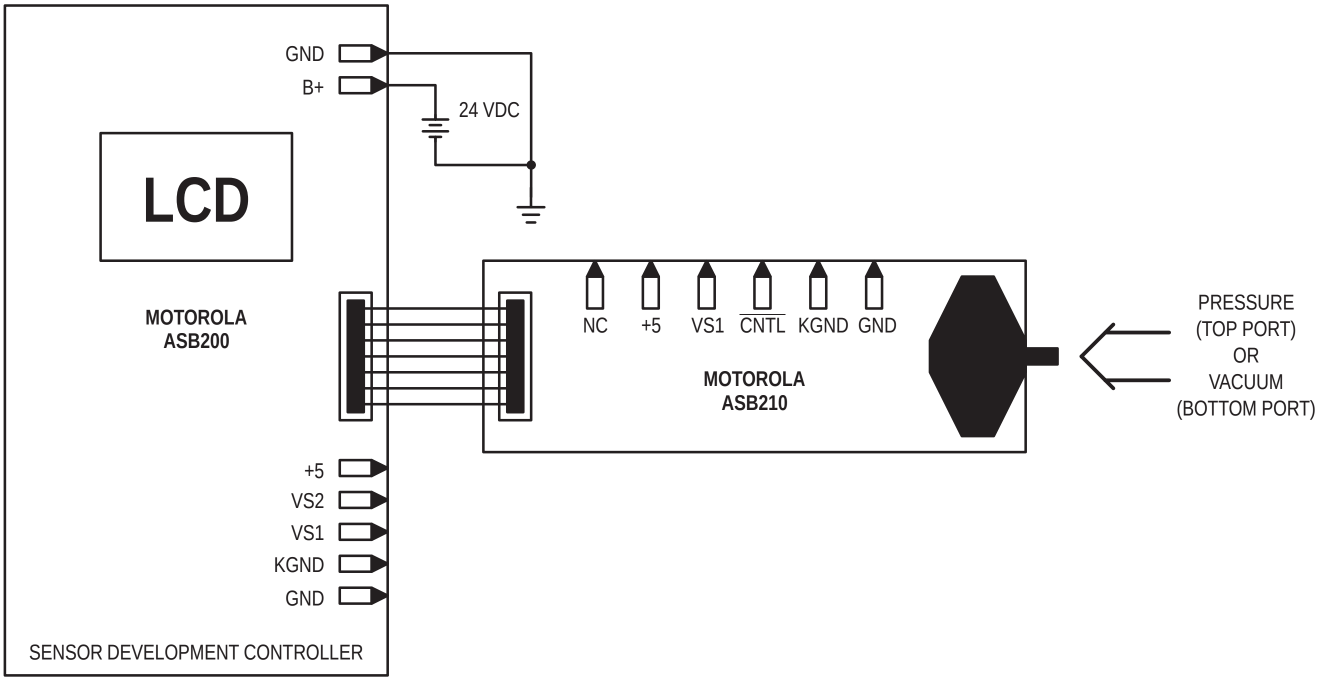


Figure 4. Application Example

DESIGN CONSIDERATIONS

MPX2010 sensors are designed with transducers that schematically look like Wheatstone bridges. Therefore, an increase in bias voltage produces a corresponding increase in sensitivity. The MPX2010's 10 volt DC bias spec is a compromise between the higher sensitivity that can be obtained with larger bias voltage, and better thermal stability with lower bias voltage. To measure 10″ of water full scale, it is necessary to use a higher bias voltage without incurring the thermal errors that a DC bias would produce. The reference design in Figure 2 does this by pulsing the bias voltage to the sensor.

With the exception of Q1 and Q2, this circuit has the same architecture as it would for DC operation. Q1 takes the control signal on pin 6 of DB–9 connector P1, and switches the base of Q2. With a logic high at the input, Q1 shuts off Q2, and U3B multiplies the 5 volt reference to 20 volts for biasing the sensor. When the input is low, Q2 is biased on. This condition switches the 5 volt reference at pin 5 of op amp U3B to ground, thereby removing bias to the sensor. Both op amps U2 and U3 are continuously powered from power supply B^+, so that they are biased and ready to respond when the sensor is switched on. For proper thermal management in the sensor, the input pulse should be less than 10% duty cycle, and last a maximum of 100 µsec.

The amplifier is a discrete two op amp instrumentation amplifier that has its gain described by equation 1.

(1) DIFFERENTIAL GAIN = R4/R3 +1 = 162K/1.02K +1 = 159 + 1 = 160.

Zero pressure offset voltage is established by divider R9/R10 which is buffered by U3A. The buffer is used to facilitate maintaining an impedance ratio R1/R2 = R4/R3, which maximizes the amplifier's common mode rejection characteristics. Both the zero pressure offset voltage and the bias voltage are referenced to the same 5 volt supply as the controller's A/D to minimize the effects of power supply tolerance. An expression for output voltage (V_{OUT}) that takes into account the differential input ($VS+ - VS-$), the common mode voltage (V_{CM}), and the zero pressure reference voltage (V_{REF}) appears in equation 2.

(2)
$$\begin{aligned} V_{OUT} = {} & ((R4/R3)+1)\cdot(VS+ - VS-) \\ & + (R2\cdot R4/R1\cdot R3)\cdot V_{REF} \\ & - V_{CM}\cdot((R2\cdot R4/R1\cdot R3) - 1) \end{aligned}$$

Note that when R1/R2 = R4/R3, $R2\cdot R4/R1\cdot R3 = 1$ and the last term is zero. A 1% mismatch in this ratio, however, adds an error term that equals −1% of the common mode voltage.

The dynamic characteristics of the circuit shown in Figure 2 produce a pulsed output waveform with a rather large spike on the leading edge. A representation of this waveform is shown in Figure 5. Time, on the horizontal axis is measured at 5 µsec per division, and voltage is measured vertically at 2 volts per division. From this figure, it is evident that in order to get an accurate reading, A/D conversions should be timed to start a minimum of 10 µsec after the sensor is turned on, and should be complete before the end of the pulse. When this timing relationship is observed, accuracy is superior to DC bias, even at lower bias voltages such as 5 or 10 volts.

The resulting 1.5 V to 3.5 V pulsed output from pin 7 of U2B is compatible with microcomputer A/D inputs. The 20 volt bias produces a 2 volt span at 10″ of water input pressure, using a gain of 160.

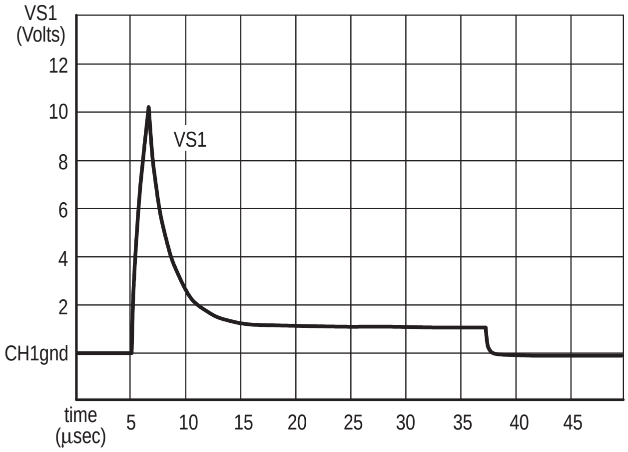


Figure 5. Pulsed Output Waveform

CONCLUSION

The ASB210 plug–in module is part of a systems development tool set for pressure sensors. Its pulsed architecture improves the sensitivity of MPX2010 sensors, providing a 0–10″ H_2O measurement range. It can be used as a reference design, and allows code to be developed without hardware fabrication.

AN1655

ASB200 — Motorola Sensor Development Controller Board

Prepared by: Bill Lucas and Warren Schultz

An MC68HC705JP7 based controller board that is part of a systems development tool set for pressure sensors is presented here. When used with a series of companion plug–in modules, it provides a complete systems solution for measuring pressure and developing code.

SENSOR DEVELOPMENT CONTROLLER DESCRIPTION

Function

The development board shown in Figure 1 is designed to receive signal inputs from a series of pressure sensor modules, receive command inputs via a dip switch or a terminal's keyboard, process the input signal, and send results to a terminal or liquid crystal display. Temperature display is an optional output of the system.

The ASB200 Sensor Development Controller will run in two configurations. As delivered, it will operate on its own with the pre–programmed microcontroller supplied with the board. Or, for code development, it will connect to an M68EM05JP7 emulator via an M68CBL05A cable and M68TA05JP7P28 target head adapter, when the microcontroller is removed. The emulator board may be run on either an MMDS05 or MMEVS05 system.

The input connector (P1) connects any one of several plug–in modules. At the time of this publication the following modules are supported by the system's hardware and software:

- **ASB 201: Uncompensated Series Sensor Module**
- **ASB 202: MPX2000 Compensated Series Sensor Module**
- **ASB 205: MPX5000 Integrated Series Sensor Module**
- **ASB 210: MPX2010 Low Pressure Module**

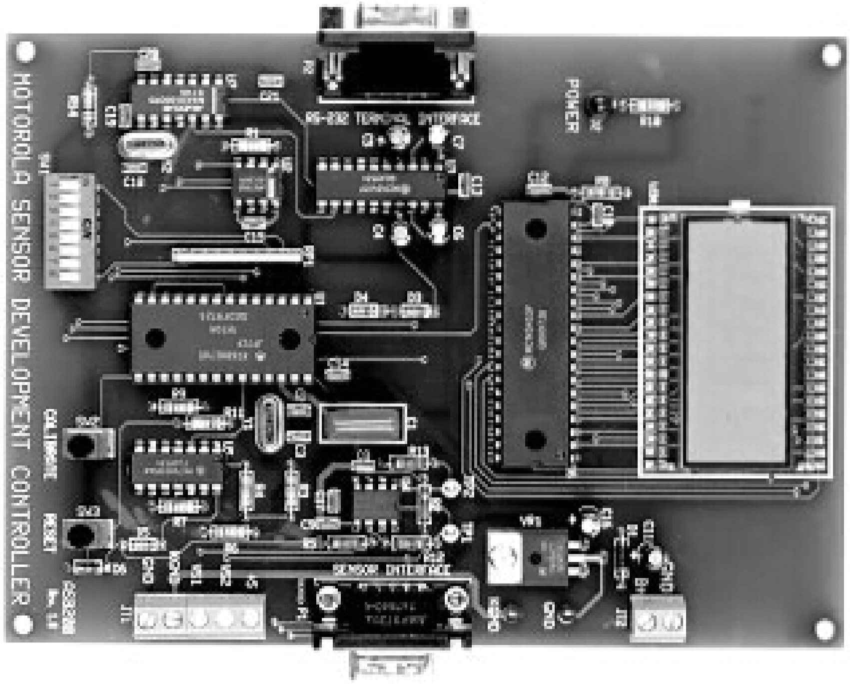


Figure 1. ASB200 — Development Controller Board

REV 1

Electrical Characteristics

The following electrical characteristics apply to operation at 25 degrees Celsius, and unless otherwise specified B+ = 12 volts.

Table 1. ASB200 Electrical Characteristics

Characteristic	Symbol	Min	Typ	Max	Units
Power Supply Voltage	B^+				
— Stand alone		7.5	12	26	Volts
— Connected to ASB201		9.5	12	15.8	Volts
— Connected to ASB202		11.6	12	15.8	Volts
— Connected to ASB205		7.5	12	26	Volts
— Connected to ASB210		22	24	26	Volts
Quiescent Current	I_{CC}	—	25	—	mA
Min Analog Input Voltage	$V_{IN(MIN)}$	50	—	—	mV
Max Analog Input Voltage	$V_{IN(MAX)}$	—	—	5.0	Volts
Buffer Gain					
— VS1 Input	A_{VS1}	—	1.0	—	—
— VS2 Input	A_{VS2}	—	1.0	—	—
Resolution	A/D_{RES}	10	10.5	—	Bits
Output Sink Current	I_{SINK}	—	25	—	mA

Content

The ASB200 controller includes an MC68HC705JP7 microcontroller, liquid crystal display (LCD), RS232 communications interface, EEPROM, a 5 volt regulator, and an analog input interface. Its contents are described in the following parts list, schematics, and pin by pin circuit description. Software is programmed into the microcontroller and is also supplied on an enclosed disk. The disk also includes PSPICE models for Uncompensated, MPX2000, and MPX5000 series sensors.

Table 2. Parts List

Designators	Qty	Description	Manufacturer	Part Number
C1	1	.12 µf Capacitor Polypropylene	Digi–Key	P3214
C2,3,9,18,19	5	22 pf Capacitor Cer	Digi–Key	P4841
C4,5,6,7,11,16	6	1 uF Electrolytic 50V Cap	Digi–Key	P5268
C8	1	.01 uF Cap	Digi–Key	P4904
C10	1	470 pf Capacitor	Digi–Key	P4808
C12,13,14,15,17,20	6	.1UF CAP	Digi–Key	P4910
D1	1	General Purpose Diode	Motorola	1N4002
D2	1	Red LED	Quality Tech	HLMP–4700
D3,D4,D5,D6	4	1N914	—	1N914
LCD1	1	4 DIGIT LCD	AND	FE0202W–DU
P1 SENSOR INTERFACE	1	DB–9 Connector (Male)	AMP	#177597–3
P2 TERMINAL INTERFACE	1	DB–9 Connector (Female)	Mouser	#152–3409
RP1	1	10K 10 PIN SIP Resistor	Digi–Key	770–101–R10K–ND
R1	1	47K Ohm Resistor	Yaego	47K CR–1/4W–B 5%
R2,R5,R12,R13	5	750 Ohm Resistor	Yaego	750 CR–1/4W–B 5%
R3,R4,R6,R7,R9,R11,R14	1	10K Ohm Resistor	Yaego	10K CR–1/4W–B 5%
R8	1	470K Ohm Resistor	Yaego	470K CR–1/4W–B 5%
R10	1	470 Ohm Resistor	Yaego	470 CR–1/4W–B 5%
SW1	1	8 POS DIP SWITCH	Digi–Key	CAN3007
SW2,3	1	SPST Pushbutton Switch	NKK	AB15AP–FA
TP1 V_{out}	1	Test Point Yellow	Components Corp.	TP–104–01–04
TP2 V_{temp}	1	Test Point Yellow	Components Corp.	TP–104–01–04
TP3 KGND, TP4 GND	2	Test Point Black	Components Corp.	TP–104–01–00
JT1	1	5 Screw Terminal Connector	Phoenix Contact	MKDSN 1,5/5–5,08
JT2	1	2 Screw Terminal Connector	Phoenix Contact	MKDSN 1,5/2–5,08
U1	1	Microprocessor MC68HC705JP7	Motorola	MC68HC705JP7
U1X	1	28 pin Socket	Digi–Key	AE7228–ND
U2	1	256 Bit Serial EEPROM	National	NM93C06N 8 PIN DIP
U3	1	RS–232 Driver/Receiver	Motorola	MC145407P
U4	1	Dual Op–Amp	Motorola	MC33502P
U5	1	Quad Bus Driver	Motorola	MC74HC125P
U6	1	32 Segment LCD Driver	Motorola	MC145453P
U7	1	SPI/Microware–Compatible UART	Maxuim	MAX3100CPD 14 PIN DIP
VR1	1	Voltage Regulator	Motorola	MC7805ACT
Y1	1	4.00 MHz Crystal	Digi–Key /CTS	X405–ND
Y2	1	3.6864 MHz Crystal	Digi–Key /CTS	X402–ND
—	2	Insulator for Y1 and Y2	Bivar	C1–192–028
—	1	4–40 x 1/4″ Screw for VR1	—	—
—	1	4–40 Nuts for VR1	—	—
—	6	Self stick rubber feet	Fastex	5033–01–00–5001
ASB200	1	Bare PCB	—	—
ASB200	—	—	—	—

Rev. 1.0

Note 1: All resistors are 1/4 W with a tolerance of 5% unless otherwise noted.

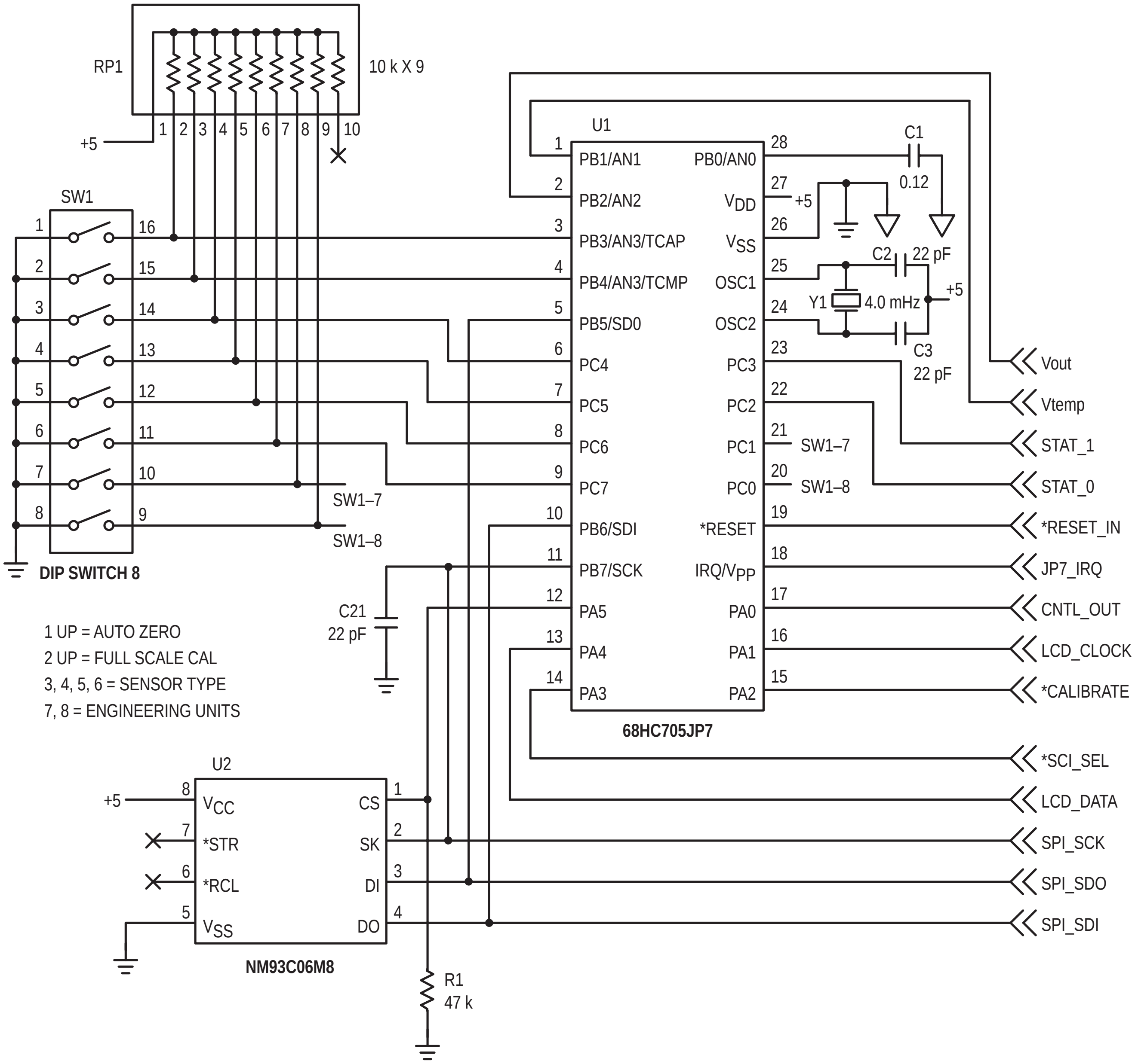


Figure 2a. Schematic

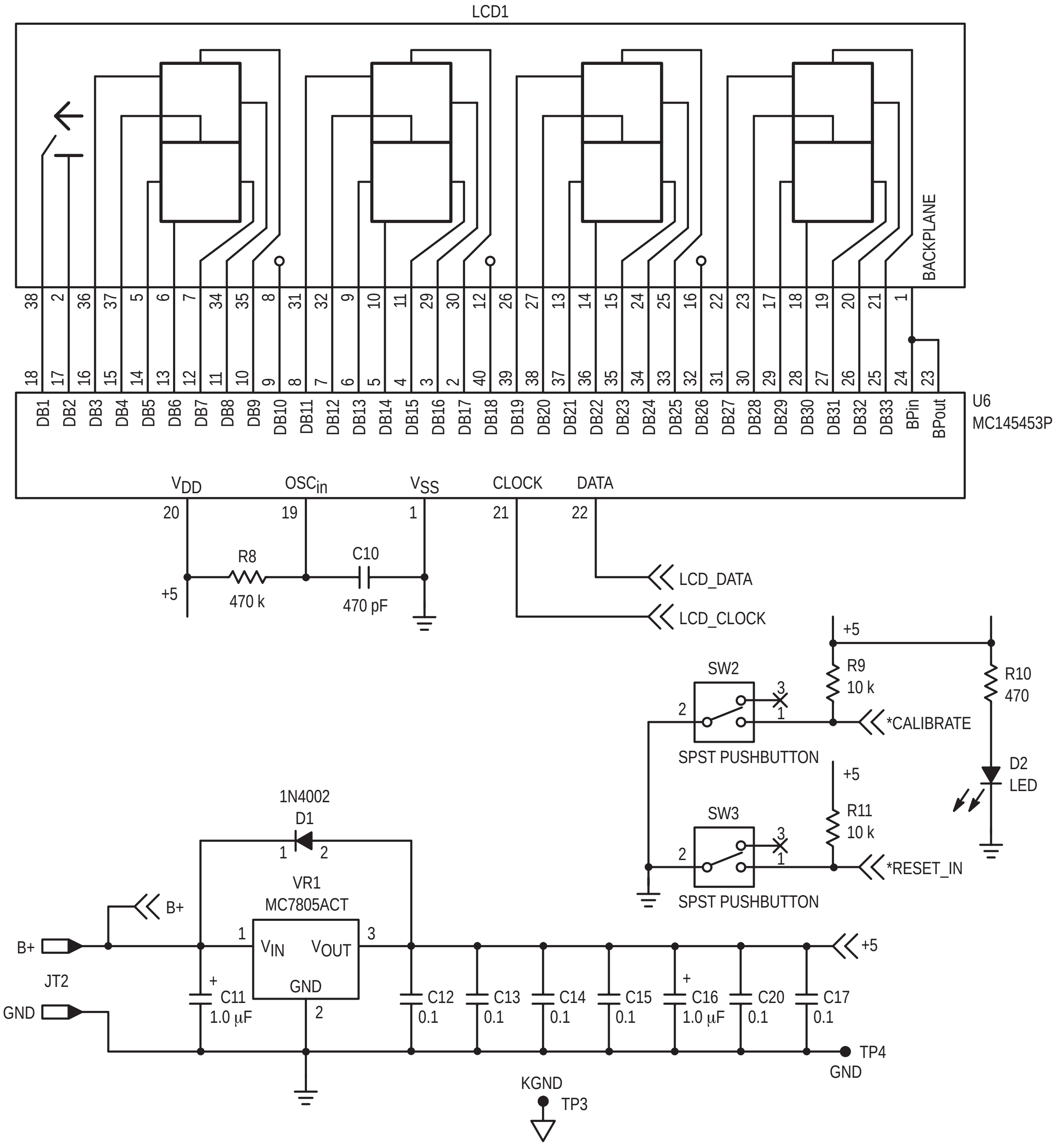
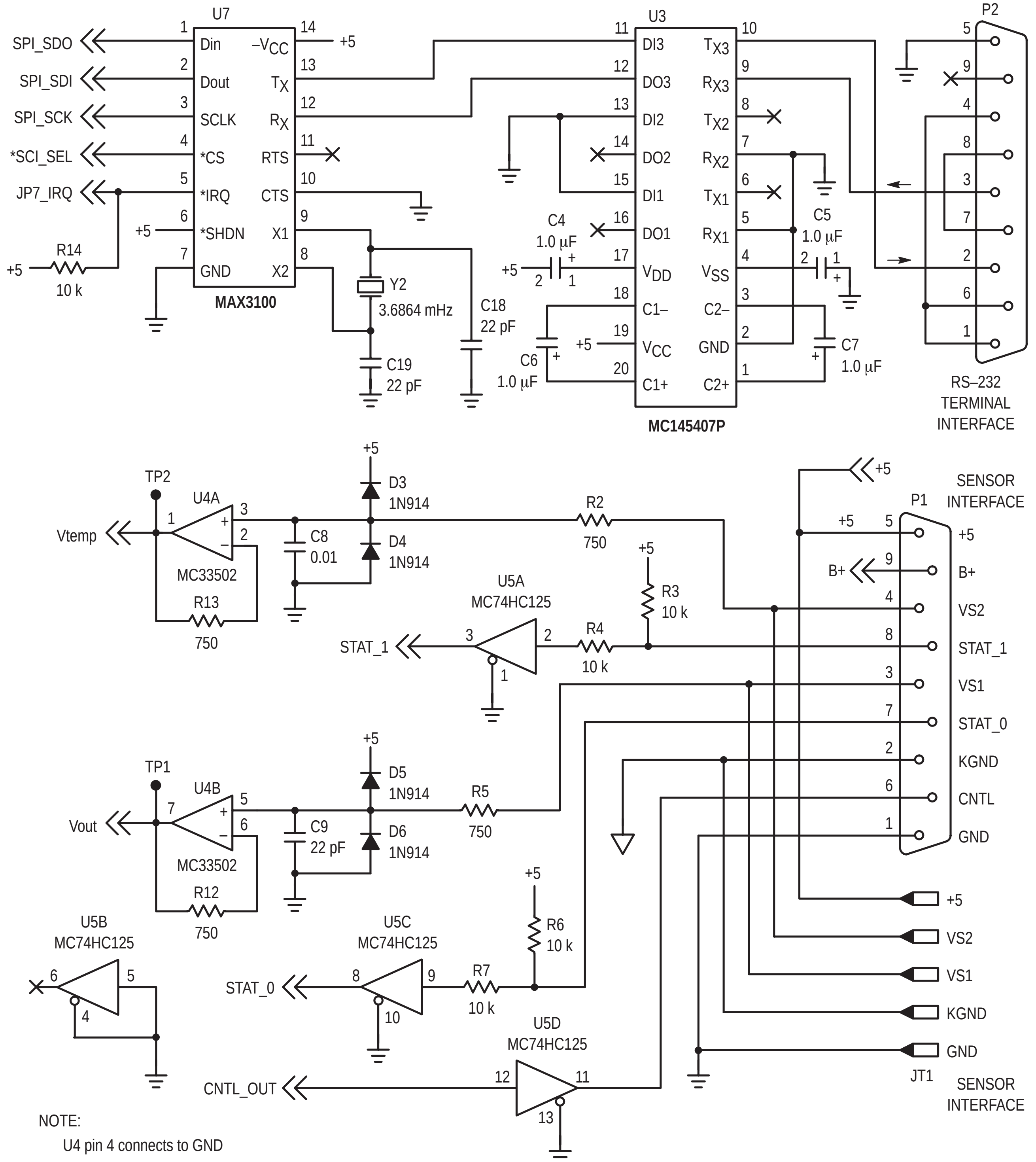


Figure 2b. Schematic



NOTE:
U4 pin 4 connects to GND
U4 pin 8 connects to +5
U5 pin 7 connects to GND
U5 pin 14 connects to +5

Figure 2c. Schematic

Pin by Pin Description

External inputs and outputs are grouped into two DB–9 connectors and two screw terminals. Connector P1 is the interface connection to ASB201, ASB202, ASB205, and ASB210 sensor plug–in modules. Screw terminal JT1, auxiliary sensor interface, is intended for stand alone operation with user supplied code. Screw terminal JT2 is the DC power input connector. Connector P2 is an RS–232 interface connection that allows optional 9600 baud communications with a terminal.

Screw Connector JT2

B^+:
B^+ is the power supply input. Power supply voltage varies with plug–in module, per Table 1. +12 VDC is the nominal input voltage, except for use with ASB210 plug–in modules, where it increases to +24 VDC.

GND:
The GND terminal on this connector is used as the return for power supply B^+.

DB–9 Male Sensor Module Interface Connector P1

P1–1:
Pin 1 is connected to Logic ground.

P1–2:
A connection to Analog Ground is made on Pin 2.

P1–3:
Analog input signal, VS1, is connected to pin 3. When connected to an ASB201, ASB202, ASB205, or ASB210 plug–in module, VS1 is the analog pressure signal. This signal is buffered and connected to A/D mux. AN2.

P1–4:
Analog input signal, VS2, is connected to pin 4. When connected to an ASB201, ASB202, ASB205, or ASB210 plug–in module, VS2 is the analog temperature signal. This signal is buffered and connected to A/D mux. AN1.

P1–5:
Regulated +5 VDC from linear regulator VR1 is supplied on pin 5.

P1–6:
A control signal, $\overline{\text{CNTL}}$, is supplied on pin 6. It is a logic level buffered output from the microprocessor's PORT A, bit 0.

P1–7:
An identification bit, STAT_0, is a logic input that is pulled up, buffered, and routed to the microprocessor's PORT C, bit 2. On plug–in modules ASB201 and ASB202 this bit is grounded. On plug–in modules ASB205 and 210 it is open, and pulled up to a logic 1.

P1–8:
An identification bit, STAT_1, is a logic input that is pulled up, buffered, and routed to the microprocessor's PORT C, bit 3. On plug–in modules ASB201 and ASB205 this bit is grounded. On plug–in modules ASB202 and 210 it is open, and pulled up to a logic 1.

P1–9:
B^+ from screw terminal JT2 is connected to pin 9.

Screw Connector JT1

Connections for +5, VS1, VS2, KGND, & GND are wired in parallel with DB–9 connector P1.

DB–9 Female RS–232 Connector P2

P2–1:
Pin 1 is connected to an RS–232 Handshake line, that is also connected to pins P2–4 and P2–6.

P2–2:
Pin 2 is routed to the RS–232 signal output.

P2–3:
Pin 3 is routed to the RS–232 signal input.

P2–4:
Pin 4 is connected to an RS–232 Handshake line, that is also connected to P2–1 and P2–6.

P2–5:
Pin 5 connects to ground.

P2–6:
Pin 6 is connected to an RS–232 Handshake line that is also connected to P2–4 and P2–1.

P2–7:
Pin 7 is connected to an RS–232 Handshake line, that is also connected to P2–8.

P2–8:
Pin 8 is connected to an RS–232 Handshake, that is also line connected to P2–7.

P2–9:
Not connected.

Test Points

Test points TP1 and TP2 provide access to buffered inputs VS1 and VS2, connected to A/D inputs AN2 and AN1 respectively. When connected to an ASB201, ASB202, ASB205, or ASB210 plug–in module, VS1 is the analog pressure signal, and VS2 is the analog temperature signal.

Switches

SW1:
SW1 is an 8 position dip switch that sets mode of operation. It controls autozero, full scale or zero calibration, inputs sensor type, selects Engineering units, and also has a position for restoring factory calibration. The operation section of this document explains switch settings in detail.

SW2:
SW2 is used for calibration and for restoring factory EEPROM calibration values.

SW3:
SW3 provides a processor RESET function to restart the program residing in the 68HC705JP7 microprocessor.

OPERATION

An example, shown in Figure 3, illustrates connections to an ASB202 plug–in module. This arrangement can be run stand alone, or the ASB200 can be connected to an MMDS05 or MMEVS05 emulator system for code development. The two boards are designed such that their P1 connectors mate directly. A short straight–through cable with male and female

DB–9 connectors on the ends may be used between the controller and the plug–in module. Once the two boards are connected together, power supply voltage B^+ should be set to the range referenced in Table 1 for the plug–in module that is being used. With switch SW1 set up as shipped, when power is turned on, “dLy” will appear on the display for a short time while autozeroing is performed. Once a zero appears, the system is ready for operation. The system has two modes of operation. They are non–terminal and terminal modes. Non–terminal mode is discussed first.

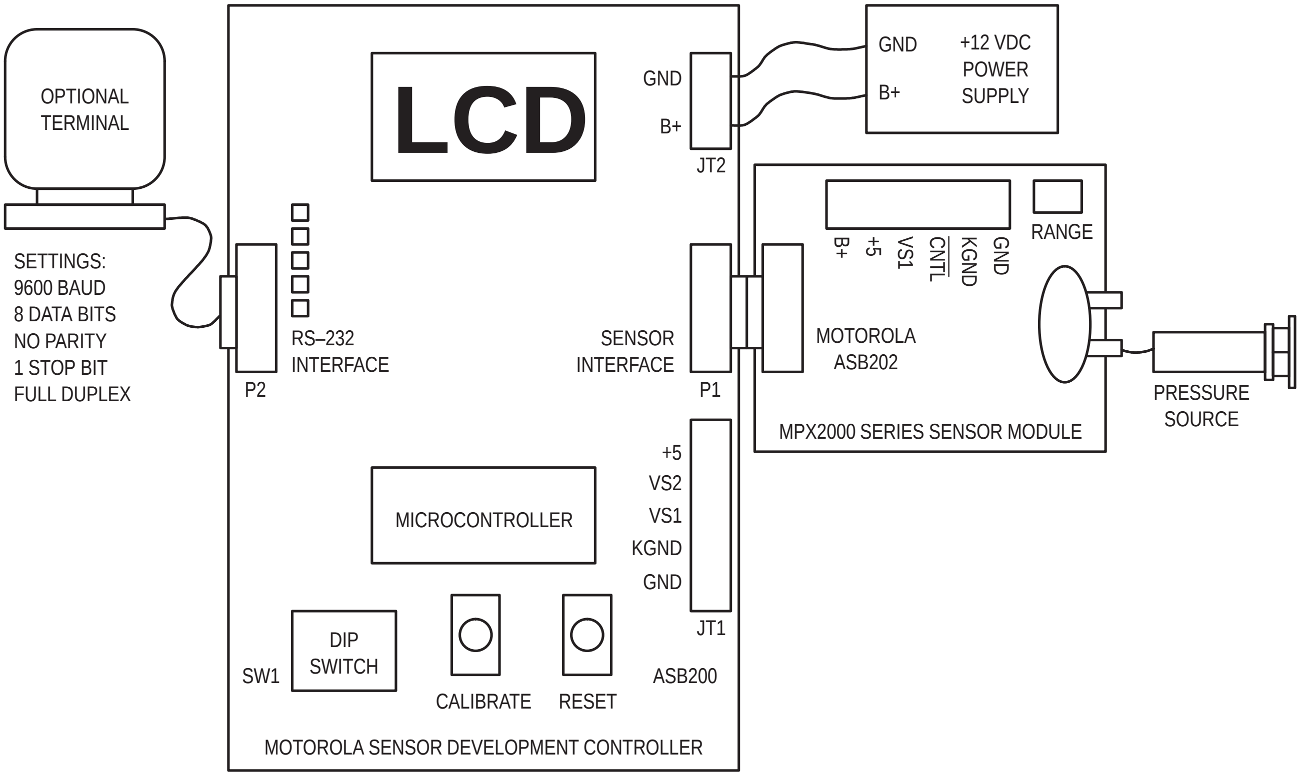


Figure 3. Connections

Non–Terminal Mode

The software looks for several pieces of information. In non–terminal mode, that information is picked–up from the dip–switch SW1. Figure 4 takes a close up look at switch SW1. Position 1 controls the autozero function. In the up position autozero is performed at reset, in the down position autozero is not performed. Switch position two controls calibration. In the up position, full scale is calibrated when the calibrate switch is pushed; and when down, zero is calibrated when the calibrate switch is pushed. Positions 3 through 6 select full scale pressure, select temperature, and contain a switch position for restoring factory calibration values. Positions 7 and 8 on switch SW1 set display units. The choices are inches of water column, kilo Pascals (kPa), and pounds per square inch. As shipped, switch positions are set for autozero, 10 kPa sensors, and kPa. It is not necessary to set switch positions for plug–in module type. The plug–in module is sensed from pins 7 & 8 on connector P1. Table 3 identifies switch SW1 settings.

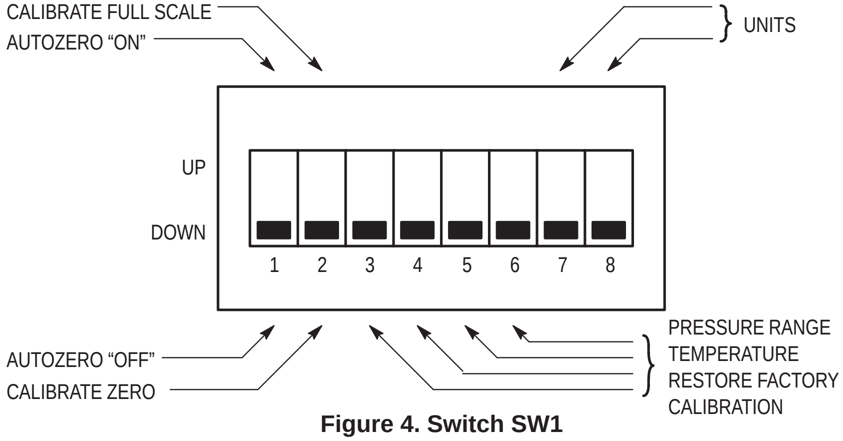


Figure 4. Switch SW1

Table 3A. DIP Switch SW1 Positions 1 & 2

SW1–1	SW1–2	Function
DOWN	—	AUTOZERO “OFF”
UP	—	AUTOZERO “ON”
—	DOWN	CALIBRATE ZERO
—	UP	CALIBRATE FULL SCALE

Table 3B. DIP Switch SW1 Positions 3–6

SW1–3	SW1–4	SW1–5	SW1–6	Sensor
DOWN	DOWN	DOWN	DOWN	6 kPa: MPX5006
DOWN	DOWN	DOWN	UP	10 kPa: MPX10, MPX2010, MPX5010
DOWN	DOWN	UP	DOWN	50 kPa: MPX50, MPX2050, MPX5050
DOWN	DOWN	UP	UP	100 kPa: MPX100, MPX2100, MPX5100
DOWN	UP	DOWN	DOWN	200 kPa: MPX200, MPX2200
DOWN	UP	DOWN	UP	700 kPa: MPX5700
DOWN	UP	UP	DOWN	1000 kPa: MPX5999
DOWN	UP	UP	UP	2.5 kPa: ASB210 with MPX2010 Sensor
UP	UP	UP	DOWN	Temperature
UP	UP	UP	UP	Restore Factory Calibration

Table 3C. DIP Switch SW1 Positions 7 & 8

SW1–7	SW1–8	Display Units
DOWN	DOWN	”H_2O
DOWN	UP	kPa
UP	DOWN	PSI

Calibration

Calibration is a simple process, once dip–switch SW1 is set up for the correct sensor and engineering units. To calibrate zero pressure, set dip–switch SW1 position 2 to the down position, apply zero pressure to the pressure sensor, and press and release the “CALIBRATE” push–button. The display will output “dLy” while the “CALIBRATE” switch is depressed. (Depressing the “CALIBRATE” switch more than once is OK). The EEPROM location, for that sensor family, now has a measured offset calibration value specific to the sensor and sensor module that is being used. When using MPX2000 or MPX5000 series sensors this procedure or autozero is all that is needed for a good measurement.

For the most accurate measurement, full scale can also be calibrated. To calibrate full scale pressure first calibrate zero pressure, then set dip–switch SW1 position 2 to the up position, apply full scale pressure to the pressure sensor, and press and release the “CALIBRATE” push–button. The display will output “dLy” while the “CALIBRATE” switch is depressed. (Again, depressing the “CALIBRATE” switch more than once is OK). The EEPROM location, for that sensor family, now has a measured full scale calibration value specific to the sensor and sensor module that is being used. Full scale is the full scale rating of the sensor type that has been selected, with the exception of ASB210 plug–in modules. For the ASB210, full scale is the full scale pressure rating of the module, which is 10 inches of water. Since calibration values are stored in EEPROM they are retained when power is removed. **NOTE, THAT FOR BEST RESULTS IT IS NECESSARY TO CALIBRATE ZERO PRESSURE BEFORE CALIBRATING FULL SCALE**. That’s all there is to it, calibration is complete at this point.

Autozero

Autozero is controlled by dip–switch SW1 position 1. That switch is read at RESET/POWER–UP time. In the up position autozero is performed at power up, in the down position it is not. With SW1 position 1 up at power up, the software will read the sensors output and store its analog value in the EEPROM. As long as SW1 position 1 is in the up position, that “auto–zero” value will be used as the sensor’s offset in lieu of any previously stored calibration values. When SW1 position 1 is placed in the down position, the value from the previously described calibration procedure will be used. To force a new “auto–zero” value into EEPROM, set SW1 position 1 up, and depress the “RESET” push–button, or power the system down and back up. A new “auto–zero” value will be written to the EEPROM. You will notice a delay in system start–up when the SW1–1 (auto–zero switch) is in the up position. The display will read “dLy” during the “auto–zero” sequence. If a terminal is connected to the system, it will output “Waiting for AUTO ZERO to complete”, followed by “DONE”. The display will then begin to function, based on the configuration of SW1.

Temperature Display

To display temperature, set dip switch SW1 positions 3 through 5 up and position 6 down. With this setting, analog voltage VS2 is used as the input, and degrees Celsius will be displayed. Table 4 contains input voltage, VS2, versus temperature in five degree Celsius increments from 0 to 75 degrees C. The software performs a segmented straight line interpolation of these values. The thermister used in plug–in modules ASB201, ASB202, ASB205, & ASB210 is a Keystone Thermometrics part number MS97 (also available through Digi–Key as part number KC003T).

Table 4. VS2 vs Temperature

Temperature °C	R_T Ohms	VS2 Volts	Temperature °C	R_T Ohms	VS2 Volts
0	32773	1.17	40	5323	3.26
5	25456	1.41	45	4365	3.48
10	19932	1.67	50	3599	3.68
15	15725	1.94	55	2983	3.85
20	12497	2.22	60	2486	4.00
25	10000	2.50	65	2082	4.14
30	8055	2.77	70	1753	4.25
35	6528	3.03	75	1482	4.35

Restoring Factory Calibration Constants/Troubleshooting

To restore default factory calibration constants, set dip switches SW1–1 and SW1–2 in the down position, and SW1–3 through SW1–6 in the up position. Press and release the “CALIBRATE” push–button, located in the lower right of the ASB200 PC board. The display will output “dLy” while the “CALIBRATE” switch is depressed. (Depressing the “CALIBRATE” switch more than once is OK.) The EEPROM now has factory calibration constants transferred to it. **Note that this is the first thing to do when readings don’t seem to make sense.** Other items to check include power supply voltage B^+, and display units setting. B^+ should be in spec, per Table 1, for the plug–in module that is being used. SW1–7 and SW1–8 should be set for the units that you are expecting per Table 3C.

Terminal Mode

The ASB200 serial port P2, labeled RS–232 TERMINAL INTERFACE is always enabled and monitored for activity. Terminal emulation software running on a Personal Computer (PC), will communicate with this port. Settings are listed in Table 5.

Table 5. Terminal Settings

Baud	Data Bits	Parity	Stop Bits	Duplex
9600	8	NO	1	FULL

When commanded to do so, via the terminal, the ASB200 can be switched to TERMINAL MODE, where most control of the system is performed by keyboard menu entries. When TERMINAL MODE is activated, the system continues to use dip switch SW1 position 1 for auto–zero and SW1 positions 3 through 6 for sensor type.

Connecting the ASB200 to an IBM Compatible PC

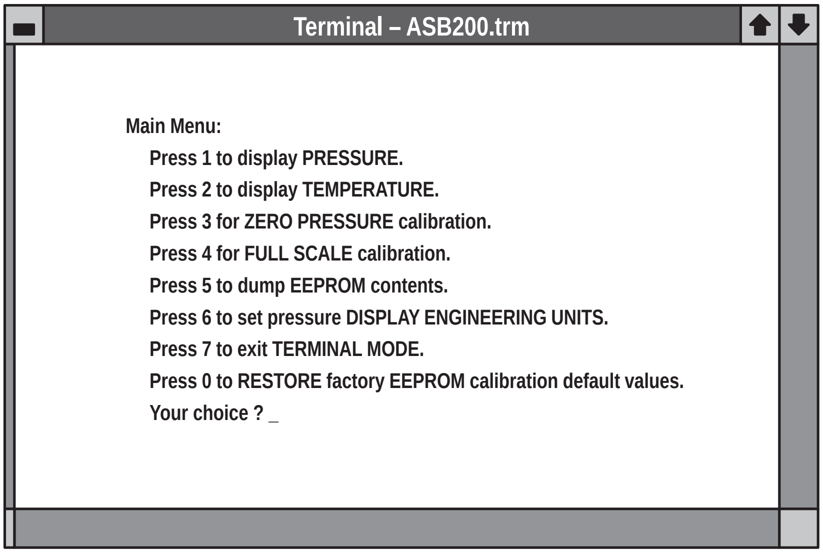
1. With power removed from the ASB200, and the PC powered off, connect a 9 conductor straight–through cable from the ASB200 connector P2, labeled “RS–232 TERMINAL INTERFACE” to the COM1 or COM2 serial port on the PC.
2. Restore power to the PC.
3. If you are using DOS based communications software such Procomm, set the COM port to COM1 or COM2 depending on which PC port you have cabled to ASB200 connector P2. Set the BAUD rate to 9600, the number of data bits to 8, the number of stop bits to 1 and the parity to NONE. Set the communications mode to full duplex.
4. Restore power to the ASB200 board. The system will start in the non–terminal mode. To activate terminal mode, depress any key on the terminal keyboard. (SW1 must be set per Table 3 when entering terminal mode or the display will display “Err”. The error will occur if SW1 was set to display temperature or in the restore factory calibration mode when the system was put in terminal mode). A “Main Menu” will appear on the terminal’s display. The menu is shown in Figure 5. Menu choices are driven by a single keystroke. Depressing the “Enter” key on the keyboard is unnecessary.

Follow the instructions on the PC’s display while in terminal mode.

Terminal Mode Main Menu

The main menu as shown in Figure 5 allows the following command options:

1. Display the pressure applied to the pressure sensor.
2. Display the temperature of the thermister, located on the pressure sensor plug–in module.
3. Calibrate the system for the sensor’s zero pressure offset calibration.
4. Calibrate the system for the sensor’s full scale input calibration.
5. Dump the contents of EEPROM. The EEPROM contains the calibration results of menu items 3 and 4, auto–zero values, as well as the display units used in terminal mode. The values displayed are in percent of full scale times 10, i.e., if the one of the values in the EEPROM reads 123, that value indicates an A/D value of 12.3% of V_{ref} or 12.3% of 5 volts.
6. The choices of engineering display units for the pressure sensor are pounds per square inch, kilo Pascal’s and inches of water column.
7. You can exit terminal mode by depressing the numeric 7 key on the terminal’s keyboard.
8. Factory calculated calibration constants can be reloaded into EEPROM by depressing the 0 numeric key. These constants are approximations of calibration values for the various pressure sensors supported by the system. These constants will overlay any user calibrations that have previously been performed.



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Main Menu:
   Press 1 to display PRESSURE.
   Press 2 to display TEMPERATURE.
   Press 3 for ZERO PRESSURE calibration.
   Press 4 for FULL SCALE calibration.
   Press 5 to dump EEPROM contents.
   Press 6 to set pressure DISPLAY ENGINEERING UNITS.
   Press 7 to exit TERMINAL MODE.
   Press 0 to RESTORE factory EEPROM calibration default values.
   Your choice ? _
```

Figure 5. ASB200 Main Menu

DESIGN CONSIDERATIONS

The MC68HC705JP7 microcontroller was chosen for a pressure measurement system reference design because of its 10+ bit A/D converter resolution and its low cost. From a hardware point of view, this microcontroller facilitates a relatively simple design.

Given the ASB200’s intended use as a development tool, all inputs and outputs, both analog and digital, are buffered. Analog inputs are buffered with MC33502 operational amplifiers configured for unity gain. These buffers provide a high input impedance, and also present a low source impedance to the JP7’s A/D converter inputs. Low impedance at the A/D converter inputs is an important consideration, since the A/D converter’s input impedance is nominally 120K ohms, as configured by the ASB200’s software. Digital buffering, to and from connector P1, is performed with an MC74HC125 bus driver IC.

The LCD driver, MC145453, is an SIOP compatible peripheral, however, it has no chip select. Due to the lack of a chip select on the LCD driver, a software emulated SIOP was constructed using two I/O lines from the microcontroller.

An SIOP/SPI compatible UART, MAX3100, was added for communications to an optional terminal. A UART could have been software generated by using two I/O lines from the microcontroller. However, due to the amount of interrupt driven functions in the A/D software driver, it made sense to add a true UART to the system.

A small EEPROM is included in the design as a convenient way to store calibration information for the system.

Last but not least, board layout is an important design consideration. In particular, how grounds are tied together influences noise immunity. In order to maximize noise immunity, two grounds are used. Digital ground (GND) is common to the power supply return and serves as a general purpose ground. An analog ground (KGND) ties the analog input return, op amp U1’s signal grounds, and C1’s ground together before connecting with digital ground at only one point. KGND also runs as a separate trace to P1–2 and the screw terminal labeled KGND on screw connector JT1.

SOFTWARE FUNCTIONAL OVERVIEW

Basic operating software is programmed into the microcontroller supplied with the ASB200 printed circuit board. The software, provides for calibration, reads pressure, reads temperature, and displays the results on a Liquid Crystal Display (LCD). It also provides an output signal, labeled $\overline{\text{CNTL}}$, that lights the "RANGE" light on ASB201, ASB202, and ASB205 plug–in modules when full scale pressure is exceeded. When the presence of an ASB210 low pressure module is detected with logic highs at pins 7 and 8 of DB–9 connector P1, this signal is used to control power to the sensor.

Three source modules, a link command file (ASB200.lnk), an I/O file (IO.h), a read me file, and a batch file (ASB200.bat) for compiling and linking the code are contained on a 3.5″ floppy diskette that is included with the ASB200 board. They are in a folder labeled, JP7code. The three source files are asb200.c, crt.s, and vector.c. File asb200.c is a single 'C' source file containing the code that operates the system. File crt.s is an assembly language file containing startup code required by the system, and vector.c is a 'C' source file containing reset and interrupt vector information. These modules are compiled by a compiler from:

Cosmic Software
100 Tower Office Park, Suite C
Woburn, MA 01801
(781) 932–2556

Some source code changes will likely be necessary for compilation with compilers from other vendors. To compile the files, consult the readme.doc file on the diskette. A brief description of each module follows:

crt.s
crt.s is an assembly startup module that zeros RAM, places an op–code in RAM that is used by the C' compiler's runtime support, and calls the main routine.

vector.c
vector.c is a C' source file, containing reset and interrupt vectors.

asb200.c
The following functions are contained in file asb200.c:

p_timer
p_timer is the interrupt service routine used by the input capture hardware. It serves as an A/D completion interrupt for the A/D subsystem. The ramp time for the integrating capacitor is computed here and saved for use by the interrupt routine, c_timer.

c_timer
c_timer is the CPU core's real time interrupt service routine. This routine sets–up the next analog multiplexer address, computes the unknown analog inputs on AN1 and AN2 based on the internal Vdd reference, initiates the next A/D conversion, and performs an infinite impulse filter on conversion results. It also handles analog time–out, if one occurs.

init_io
init_io sets–up the processors I/O ports, switches the oscillator to the external crystal, sets–up the processor's real time interrupt, powers–up the A/D comparators, sets–up the input capture edge, initializes the first A/D mux address, configures the UART driver, configures the LCD driver, and performs an auto zero if requested by dip switch SW1 position 1.

wr_write_siop
wr_write_siop writes a byte to the Simple Synchronous I/O Interface (SIOP) and returns the input data from that port.

write_siop
write_siop writes a byte to the Simple Synchronous I/O Interface (SIOP).

cvt_bin_dec
cvt_bin_dec formats and writes data to the liquid crystal display.

write_lcd
write_lcd writes 8 bits of clock and data to the MC145453 LCD driver IC.

read_temperature
read_temperature computes the temperature based upon the value of analog signal VS2 connected to A/D converter input AN1.

display
display determines which output device receives computed A/D results. The choice is the LCD, UART or both.

ee_wren
ee_wren sends a code enabling data writes to EEPROM.

ee_write
ee_write writes 16 bits of data to the EEPROM at a specified address.

ee_read
ee_read reads a 16 bit word from a specified address in the EEPROM.

config_uart
config_uart configures the UART for 9600 baud, no party, and 2 stop bits. The 2 stop bits are for slow terminals.

read_uart
read_uart reads a character from the terminal. If no character is available, 0 is returned.

write_uart
write_uart writes a character to the terminal.

out_2uart
out_2uart formats and writes integer data to the terminal.

read_pressure
read_pressure computes pressure from the analog voltage, VS1, connected to A/D converter input AN2. Scaling, based on display units and the sensor type, is computed here as well.

dump_eeprom
dump_eeprom outputs the contents of the EEPROM. Calibration contents for the various sensors are displayed as percent of full A/D scale times 10, i.e., the output 400 equals 40% full scale. All values are ratiometric to the +5 volts that is applied to the microcontroller.

print_text
print_text outputs a text string to the terminal until a null (0) character is detected in the string.

restore_eeprom
restore_eeprom transfers factory calibration constants from the program into the EEPROM. These factory constants are approximations of the analog output from the various sensor boards.

menu
menu reads the UART and parses terminal commands.

display_temperature
display_temperature directs temperature values to the terminal, LCD, or both, based on terminal or non–terminal mode.

display_pressure
display_pressure directs pressure values to the terminal, LCD, or both, based on terminal or non–terminal mode.

get_sensor_type
get_sensor_type parses the dip switch, SW1 positions 3 through 6, and returns a sensor type code.

get_eeprom_cal_address
get_eeprom_cal_address retrieves calibration values for the sensor type picked–up by get_sensor_type and the "board ID".

calibrate
calibrate saves the empirical value of the analog voltage from the pressure sensor to the address appropriate for that sensor and board type in EEPROM. This function is used in the non–terminal mode. The calculation for the address of the offset or full scale of the sensor is picked–up from dip switch SW1 position 2.

zero_cal
zero_cal saves the empirical value of the analog offset voltage to the address appropriate for that sensor and board type in EEPROM. This function is used in terminal mode.

full_scale_cal
full_scale_cal saves the empirical value of the full scale analog voltage to the address appropriate for that sensor and board type in EEPROM. This function is used in the terminal mode.

check_valid_config
check_valid_config uses the "board ID" and dip switch SW1 positions 3 through 6 to determine the validity of the combination. In other words, it looks for invalid sensor type and "board ID" combinations. If an error is detected, the LCD will display "Err" until the error is corrected.

write_lcd_text
write_lcd_text writes a limited text string to the LCD. The string is blank the LCD, "Err" , or "dLy".

main
main checks for a valid sensor type/"board ID" combination and outputs pressure or temperature to the LCD in non–terminal mode. In terminal mode, main outputs the menu message to the terminal, and passes control to the menu routine.

PSPICE Models

In addition to HC05 code, PSPICE models that describe Uncompensated, MPX2000, and MPX5000 pressure sensors are included in a folder labeled MODELS. These models use compound temperature coefficients to describe DC behavior over a –40 to +125 degree Celsius temperature range. Due to extensive use of PSPICE's .PARAMETER function, these models are specific to PSPICE. In addition to the sensors, the instrumentation amplifiers used in ASB201, ASB202, and ASB210 plug–in models are also modeled.

CONCLUSION

The ASB200 Sensor Development Controller is part of a systems development tool set for pressure sensors. It provides an HC05 based platform for reading pressure and developing code. Pressure signals are received from ASB201, ASB202, ASB205, and ASB210 plug–in modules. Together with MMDS & MMEVS software development tools, these products provide a comprehensive tool set that facilitates code development for pressure sensor systems without the necessity for building hardware.

AN1660

Compound Coefficient Pressure Sensor PSPICE Models

Prepared by: Warren Schultz

PSPICE models for Uncompensated, MPX2000 series, and MPX5000 series pressure sensors are presented here. These models use compound coefficients to improve modeling of temperature dependent behavior. The discussion begins with an overview of how the models are structured, and is followed by an explanation of compound coefficients. The emphasis is on how to use these models to estimate sensor performance. They can be found electronically on a disk included in ASB200 Motorola Sensor Development Controller kits, and on the WEB at:

http://www.mot–sps.com/home2/models/bin/sensor2.html

MODEL STRUCTURE

Models for all three sensors series share a common structure. They are complete models set up to run as is. To obtain output voltage versus pressure, it is only necessary to run the model and display V(2,4) or V(1,0). V(2,4) gives the output voltage for Uncompensated and MPX2000 series sensors. V(1,0) applies to MPX5000 sensors. In both cases, V(2,4) and V(1,0) correspond to the pin numbers where output voltage would be, if probed on an actual part.

These models are divided into five sections to facilitate ease of use. They are:

- **INPUT PARAMETERS**
- **LINEAR TO COMPOUND CONVERSION**
- **MODEL COEFFICIENTS**
- **TRANSDUCER**
- **STIMULUS**

Each of these sections is described in the following discussion.

INPUT PARAMETERS

This section contains input parameters that describe measurable sensor characteristics. Inputs such as full scale pressure (FSP), full scale span (FSS) offset voltage (VOFFSET), and temperature coefficient of offset voltage (TCOS) are made here. Characteristics that are specific to the transducer, such as bridge impedance (RBRIDGE), temperature coefficient of bridge resistance (TCRB), and temperature coefficient of span (TCSP) are also listed here.

Parameters such as VOFFSET that set an output value for the sensor are used to calculate resistance values that produce those outputs. For example, if you input 100 mV of offset voltage and a 10 µV/degree temperature coefficient of offset voltage, the model will calculate the bridge resistance values necessary to produce 100 mV of offset voltage and a 10 µV/degree temperature coefficient.

In the MPX2000 and MPX5000 models, temperature coefficient of span (TCSP) is handled differently than the other parameters. The non–linear behavior of span over temperature is calculated from the interaction of the transducer's temperature coefficient of span (TCSP), the transducer's temperature coefficient of resistance (TCRB), and the effects of inserting fixed resistance, RTCSPAN, in series with the bridge. The result is a temperature coefficient of span that closely resembles the real thing, but is not directly controlled by the user.

LINEAR TO COMPOUND CONVERSION

The compound coefficients used in these models are from equations of the form:

$$\textbf{(1)}\quad \mathrm{R(Temp)} = \mathrm{R}_{25}(1 + \mathrm{TCR})^{(\mathrm{Temp} - 25)}$$

where R_{25} is resistance at 25 degrees Celsius , TCR is temperature coefficient of resistance, Temp is an abbreviation for Temperature in degrees Celsius, and R(Temp) is the function resistance versus temperature.

The TCR (temperature coefficient of resistance) in equation (1) is a different number than a temperature coefficient that is stated in linear terms. The three statements in this section convert linear coefficients to the compound values that the models need. This conversion is based upon a 100 degree difference between the two points at which the linear coefficients have been measured.

MODEL COEFFICIENTS

In this section most of the calculation is performed. Values for the transducer bridge resistors are determined from pressure, temperature, offset, temperature coefficient of offset, span, temperature coefficient of span, and temperature coefficient of resistance inputs. A series of parameter statements are used, as much as is practical, to do calculations that will fit in an 80 character line without wraparounds. These calculations use PSPICE's .PARAMETER function, making the models specific to PSPICE. Parameters are described as follows:

KP — Pressure constant; translates pressure into a bridge resistance multiplier

KO — Offset constant; offset component of bridge resistance

DT — Delta temperature; Temperature – 25 degrees Celsius

KTCO — Temperature coefficient of offset constant; translates temperature coefficient of offset into bridge resistance

REV 1

TCR — Temperature coefficient of bridge resistance; shaped by a Table that accounts for cold temperature non–linearity's

TCR2 — Temperature coefficient of contact resistance; shaped by a Table that accounts for cold temperature non–linearity's

TCS — Temperature coefficient of Span; shaped by a Table that accounts for cold temperature non–linearity's

RPH — Bridge Resistance (RS1 and RS3) modified by pressure and temperature

ROH — Offset Component of Bridge Resistors RS1 and RS3

RPL — Bridge Resistance (RS2 and RS4) modified by pressure and temperature

ROL — Offset Component of Bridge Resistors RS2 and RS4

KB — Bias Constant; adjusts KP for bias voltage effects of span compensation network (MPX2000 and MPX5000 series sensors)

KBT — Bias Constant; adjusts KO for bias voltage effects of span compensation network (MPX2000 and MPX5000 series sensors)

GAIN — Instrumentation amplifier gain; differential gain (MPX5000 series)

ROFF — Offset resistance; determines value of RS13 (MPX5000 series)

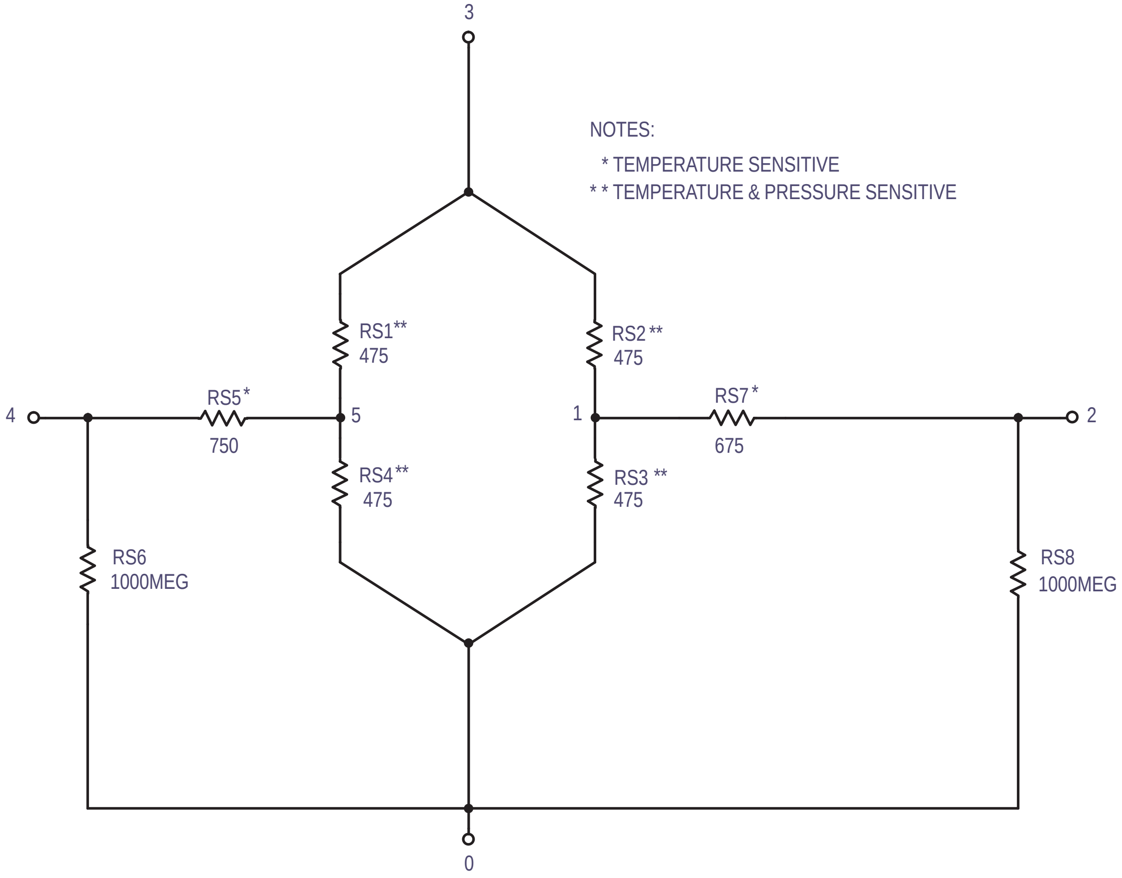
After these calculations are made, the final bridge resistance calculation is performed in the circuit section. The value for bridge resistors RS1 and RS3 is RPH + ROH. Bridge resistors RS2 and RS4 are equal to RPL–ROL.

CIRCUIT

Three circuits are used to model the three sensor families, one each for the Uncompensated series, MPX2000 series, and MPX5000 series sensors. Schematics that are derived from the circuit netlists are shown in Figures 1, 2, and 3. They are discussed beginning with the Uncompensated series, which is the least complex.

Uncompensated Series:

The Uncompensated Series sensors (MPX10, MPX50, and MPX100) are modeled as Wheatstone bridges. In the configuration that is shown in Figure 1, resistors RS2 and RS4 decrease in value as pressure is applied. Similarly, RS1 and RS3 increase in value as pressure is applied. Resistors RS5 and RS7 are contact resistors. They represent real physical resistors that are used to make contact to the bridge. Resistors RS6 and RS8 are included to satisfy PSPICE's requirement for no floating nodes. That's it. The netlist in this model is quite simple. The hard part is calculating the values for RS1, RS2, RS3, and RS4.



NOTES:
* TEMPERATURE SENSITIVE
** TEMPERATURE & PRESSURE SENSITIVE

Figure 1. MPX10 and 100 PSPICE Compound Coefficient Model

MPX2000 Series:

The MPX2000 Series sensors (MPX2010, MPX2050, MPX2100, and MPX2200) add span compensation and trim resistors to the Uncompensated model. These resistors are shown in Figure 2 as RS9, RS11, and RS10. The temperature coefficient of resistance (TCR) for the bridge resistors works against fixed resistors RS9 and RS11 to produce a bias to the bridge that increases with temperature. This increasing bias compensates for the temperature coefficient of span, which is negative.

Resistor RS12 is also added to the Uncompensated model. It represents additional impedance that is associated with the MPX2000 series sensors' offset trim network. Offset performance is modeled behaviorally. Inputs for offset (VOFFSET) and temperature coefficient of offset (TCOS) are translated into bridge resistance values that produce the specified performance. This behavioral approach was chosen in order to make it easy to plug in different values for VOFFSET and TCOS.

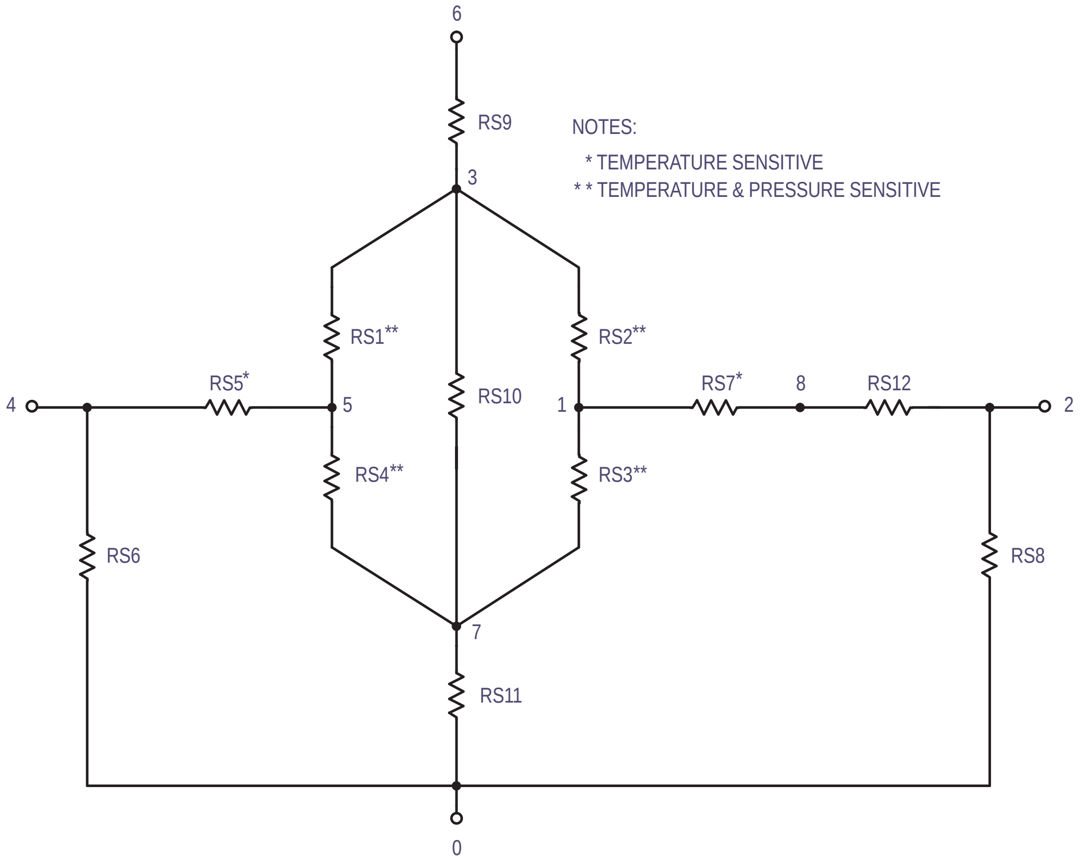
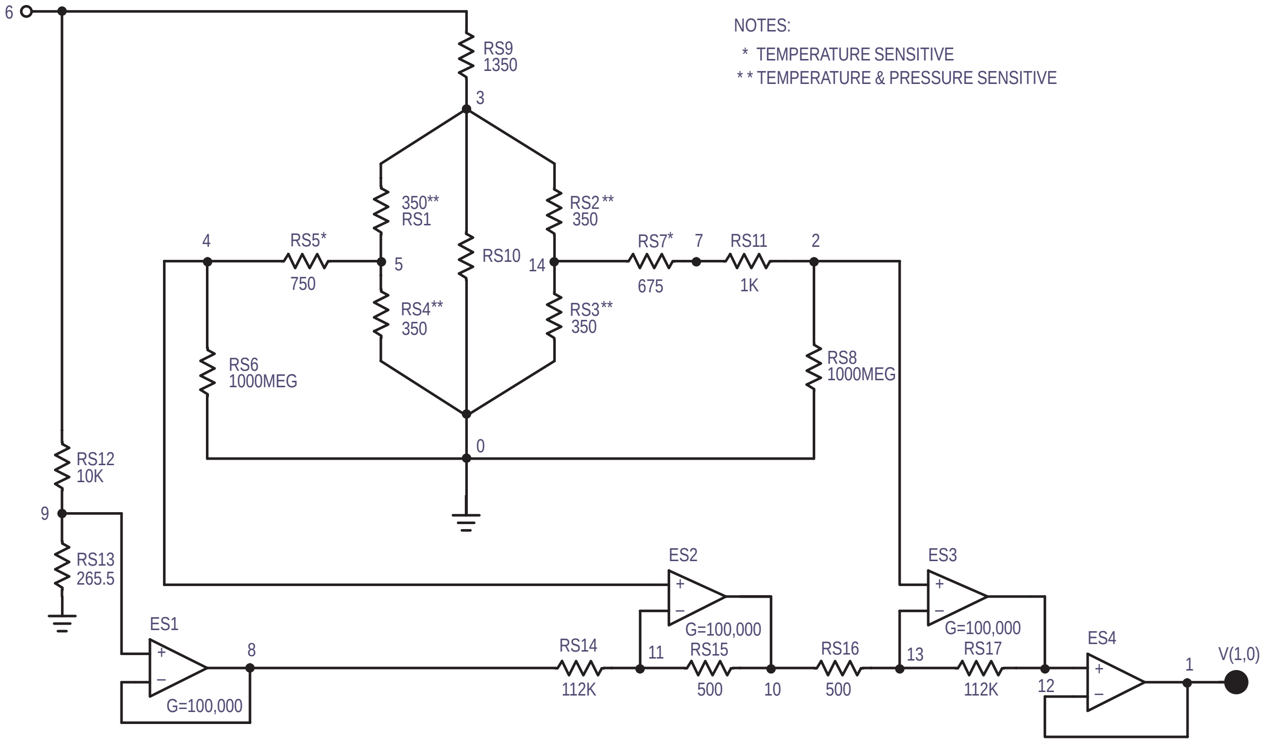


Figure 2. MPX2000 Series PSPICE Compound Coefficient Model

MPX5000 Series:

The MPX5000 Series sensors (MPX5010, MPX5050, MPX5100, MPX5700, and MPX5999) add an instrumentation amplifier to the MPX2000 series model. This amplifier is shown in Figure 3. It consists of operational amplifiers ES1, ES2, ES3, and ES4. Amplifiers ES1, ES2 and ES3 are modeled as voltage controlled voltage sources with gains of 100,000. Offset voltage, input bias current effects, etc. are taken into account with the values that are used to determine offset voltage and temperature coefficient of the sensor bridge. Amplifier ES4 models saturation voltage. Its output follows the output of ES3 with saturation limits at 75 millivolts and 4.9 volts.



NOTES:
* TEMPERATURE SENSITIVE
** TEMPERATURE & PRESSURE SENSITIVE

Figure 3. MPX5000 Series PSPICE Compound Coefficient Model

STIMULUS

The last section of these models is labeled STIMULUS. Bias voltage, pressure, and temperature are applied here. Nominal bias voltage (VCC) is 3.0 volts for Uncompensated sensors, 10.0 volts for MPX2000 sensors, and 5.0 volts for MPX5000 sensors. Pressure is selected on the second line. It is effective when the * on line 4 is removed to command a temperature sweep. Line 3 calls for a sweep of pressure and temperature. An * placed in front of Line 3 allows the temperature sweep on line 4 to be selected.

COMPOUND COEFFICIENTS

Applying temperature coefficients to variables such as resistance is an essential part of modeling. The linear approach, that is usually used, is based upon the assumption that changes are small, and can be modeled with a linear approximation. Using temperature coefficient of resistance as (TCR) as an example, the linear expression takes the form:

$$\text{(2)} \quad \mathbf{R(Temp) = R_{25}(1 + TCR(Temp - 25))}$$

Provided that the TCR in equation (2) is 100 parts per million per degree Celsius or less this approach works quite well. With sensor TCR's of several thousand parts per million per degree Celsius, however, the small change assumption does not hold. To accurately model changes of this magnitude, the mathematical expression has to describe a physical process where a unit change in temperature produces a constant percentage change in resistance. For example, a 1% per degree TCR applied to a 1 K Ohm resistor should add 10 ohms to the resistor's value going from 25 to 26 degrees. At 70 degrees, where the resistor has increased to 2006 Ohms, going from 70 to 71 degrees should add 20.06 Ohms to its value. The error in the linear expression comes from that fact that it adds 10 ohms to the resistor's value at all temperatures.

A physical process whereby a unit change in temperature produces a constant percentage change in resistance is easily modeled by borrowing an expression from finance. Compound interest is a direct analog of temperature coefficients. With compound interest, a unit change in time produces a constant percentage change in the value of a financial instrument. It can be described by the expression:

$$\text{(3)} \quad \mathbf{Future\ Value = Present\ Value\ (1 + i)^{n}}$$

where i is the interest rate and n is the number of periods. Substituting R_{25} for Present Value, R(Temp) for Future Value, TCR for i, and (Temp – 25) for n yields:

$$\text{(4)} \quad \mathbf{R(Temp) = R_{25}(1 + TCR)^{(Temp - 25)}}$$

Equation (4) works quite well, provided that TCR is constant over temperature. When modeling semiconductor resistors, it is also necessary to account for variable TCR's. At cold, the TCR for p type resistors changes with temperature. These changes are modeled using TABLE functions that have 3 values for TCR. Results of this modeling technique versus actual measurements and a linear model are summarized in Table 1.

Table 1. Actual versus Modeled R(Temp)

Temp	Measured R(Temp)	Compound Model	Linear Model
– 40	406	406	372
– 25	418	418	395
0	445	445	434
25	474	474	474
50	509	508	513
75	545	545	552
100	585	584	592
125	627	626	632
150	671	671	671

In Table 1, 25 and 150 degree Celsius data points were used to determine both linear and compound temperature coefficients. Therefore, measured values, linear model values and compound model values all match at these two temperatures. At other temperatures, the linear model exhibits errors that are significant when modeling piezoresistive pressure sensors. The compound model, however, tracks with measured values to within 1 Ohm out of 500 Ohms.

EXAMPLES

Two examples of what the model outputs look like are shown in Figures 4 and 5. Figure 4 shows a sweep of pressure versus output voltage (V_{OUT}) at 0, 25, and 85 degrees Celsius, for an MPX2010 sensor. It has the expected 0 to 25 mV output voltage, given a 0 to 10 kPa pressure input. At these three temperatures, compensation is sufficiently good that all three plots look like the same straight line.

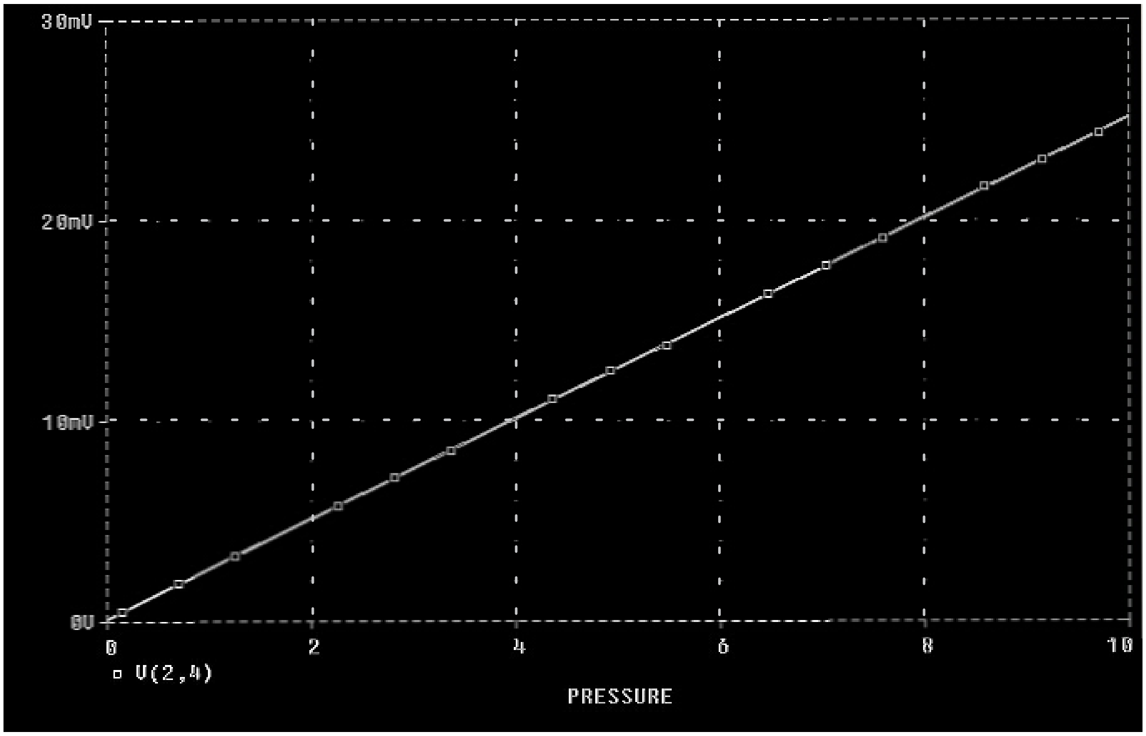


Figure 4. MPX2010 V_{OUT} versus Pressure and Temperature

To produce the plot in Figure 4, the stimulus section is set up as follows, and V(2,4) is probed.

```
***************************STIMULUS****************************
VCC 6 0 DC=10;     DC BIAS FROM PIN 3 TO PIN 1
.PARAM PRESSURE=0;    INPUT PRESSURE (kPa)
.DC PARAM PRESSURE 0_Kpa 10_Kpa .5_Kpa TEMP
LIST 0 25 85
*.DC PARAM TEMP –40 125 5
*
```

This is the default configuration with which the model is shipped. To change to a sweep of zero pressure voltage versus temperature, an asterisk is placed on line 3 and removed from line 4. The stimulus section then looks as follows:

```
****************************STIMULUS***************************
VCC 6 0 DC=10;     DC BIAS FROM PIN 3 TO PIN 1
.PARAM PRESSURE=0;    INPUT PRESSURE (kPa)
*.DC PARAM PRESSURE 0_Kpa 10_Kpa .5_Kpa TEMP
LIST 0 25 85
.DC PARAM TEMP –40 125 5
*
```

Again, V(2,4) is probed. The resulting output appears in Figure 5.

This plot shows offset versus temperature performance that is typical of MPX2000 series sensors. From – 40 to + 85 degrees Celsius, offset compensation is quite good. Above 85 degrees there is a hook in this curve, that is an important attribute of the sensor's performance.

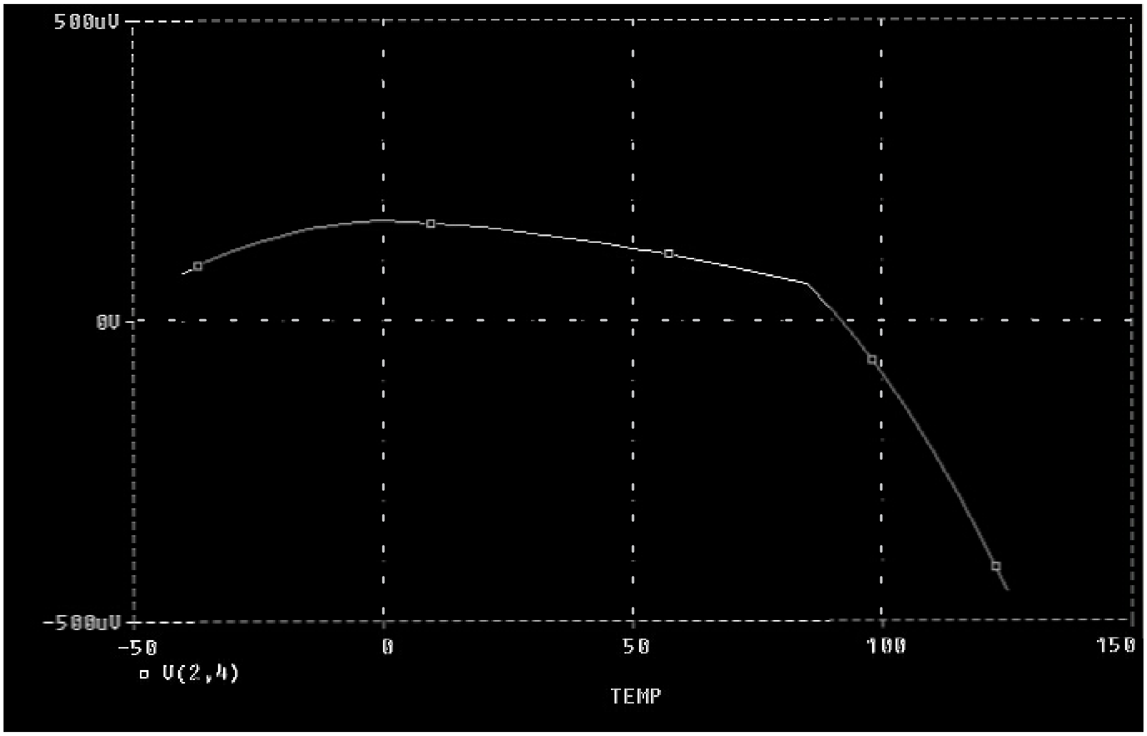


Figure 5. MPX2010 Offset versus Temperature

CONCLUSION

PSPICE models for Uncompensated, MPX2000 series, and MPX5000 series pressure sensors are available for estimating sensor performance. These models make use of the compounding concept that is used in finance to calculate compound interest. The resulting compound temperature coefficients do a better job than linear methods of modeling temperature dependent behavior. These models make extensive use of PSPICE's .PARAMETER statement, and are, therefore, specific to PSPICE. They are intended as references for determining typical sensor performance, and are structured for easy entry of alternate assumptions.

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AN1668

Washing Appliance Sensor Selection

Prepared by Ador Reodique
Sensor and Systems Applications Engineer

INTRODUCTION

North American washing machines currently in production use mechanical sensors for water level measurement function. These sensors are either purely mechanical pressure switch with discrete trip points or electromechanical pressure sensor with an on–board electronics for a frequency output.

High efficiency machines require high performance sensors (accuracy, linearity, repeatability) even at lower pressure ranges. Benchmarks indicate that these performance goals is difficult to achieve using current mechanical pressure sensors[1].

In Europe, where energy conservation is mandated, washing machine manufacturers have started to look at electronic solutions where accuracy, reliability, repeatability and additional functionality is to be implemented. North American and Asia Pacific manufacturers are also looking for better solutions.

From surveys of customer requirements, a typical vertical–axis machine calls for a sensor with 600 mmH_2O (24 “ H_2O ~ 6 kPa) sensor with a 5 % FS accuracy spec. Certain appliances call for a lower pressure range especially in Europe where horizontal axis machines are common.

SENSOR SOLUTIONS

For the typical 600 mmH_2O, 5 % FS spec, an off the shelf solution available today is the MPX10/MPX12, MXP2010 and the MPX5006 sensor. The MPX10 (or the MPX12) is 10 kPa (40 “ H_2O) full–scale pressure range device. It is uncompensated for temperature and untrimmed offset and full–scale span. This means that the end user must temperature compensate as well as calibrate the full–scale offset and span of the device. The output of the device must be amplified using a differential amplifier (see Figure 1) so it can be interfaced to an A/D and to obtain the desired range.

Since the MPX10/MPX12 sensors must be calibrated, the implications of this device being used in high–volume production is expensive. Because the offset and full–scale output can vary from part to part, a two–point calibration is required as a minimum. A two point calibration is a time consuming procedure as well as possible modification to the production line to accommodate the calibration process. The circuitry must also accommodate for trimming, i.e., via trimpots and/or EEPROM to store the calibration data. This adds extra cost to the system.

The MPX2010 is a 10kPa (40” H_2O), temperature compensated, offset and full–scale output calibrated device. A differential amplifier like the one shown in Figure 1 should be used to amplify its output. Unlike the MPX10 or MPX12, this device does not need a two–point calibration but auto–zeroing can improve its performance. This procedure is easily implemented using the system MCU.

The MPX5006 is a fully integrated pressure sensor specifically designed for appliance water level sensing application. This device has an on board amplification, temperature compensation and trimmed span. An auto–zero procedure should be implemented with this device (see Application Note AN1636). Because expensive and time consuming calibration, temperature compensation and amplification is already implemented, this device is more suitable for high volume production. The MPX5006 integrated sensor is guaranteed to be have an accuracy of +/–3 % FS over its pressure and temperature range.

For washing machine applications where low cost and high volume productions are involved, both the MPX2010 and MPX5006 are recommended. Both solutions can be used in current vertical axis machines where the water level in the 600 mmH_2O or 24 “ H_2O range. In the following, a comparison is made between MPX2010 and MPX5006 in terms of system and performance considerations to help the customer make a decision.

EXPECTED ACCURACY OF THE MPX2010 SYSTEM SOLUTION

The MPX2010 compensated sensor has an off the shelf overall RMS accuracy of +/–7.2 % FS over 0 to 85°C temperature range.

Auto–zeroing can improve the sensor accuracy to +/– 4.42 % FS. However, since this sensor does not have an integrated amplification, its amplifier section must be designed carefully in order to meet the target accuracy requirement. The MPX2010 compensated sensor has the following specifications shown on Table 1.

Table 1. MPX2010 Specifications

Characteristic	Min	Typ	Max	Unit
Pressure Range	0		10	kPa
Supply Voltage		10	16	Vdc
Supply Current		6		mA
Full Scale Span	24	25	26	mV
Offset	– 1		1	mV
Sensitivity		25		mV/kPa
Linearity	– 1		1	%V_{FSS}
Pressure Hysterisis		0.1		%V_{FSS}
Temperature Hysterisis (– 40 to 125°C)		0.5		%V_{FSS}
Temperature Effect on Span	– 1		1	%V_{FSS}
Temperature Effect Offset (0 to 85°C)	– 1		1	mV
Input Impedance	1300		2550	ohms
Output Impedance	1400		3000	ohms
Response Time (10% to 90%)		1		ms
Warm–Up		20		ms

The sensor system errors is made up of the sensor errors, amplifier errors and A/D errors. In other words,

$$\varepsilon System = \sqrt{\varepsilon Sensor^2 + \varepsilon Amplifier^2 + \varepsilon ADResolution^2} \quad (1)$$

Table 2 shows the MPX2010 with the errors converted to %V_{FSS}. The expected maximum root mean squared error of the sensor is

$$\varepsilon Sensor = \sqrt{SpanCal^2 + Lin^2 + Phys^2 + Thys^2 + Tcs^2 + OffCal^2 + Tco^2 + OffStab^2} \quad (2)$$

= +/– 7.19 % FS.

With auto–zeroing, the offset calibration, temperature effect on offset and offset stability is reduced or eliminated,

$$\varepsilon Sensor = \sqrt{SpanCal^2 + Lin^2 + Phys^2 + Thys^2 + Tcs^2} \quad (3)$$

= +/– 4.42 % FS.

The sensor error is calculated using the full–scale pressure range of the device, 0 to 85°C temperature and 10 V excitation.

In comparison with the MPX5006 solution, the expected accuracy of the system (MPX5006 + 8 bit A/D) with auto–zero is 3.1 % FS.

Table 2. MPX2010 span, offset and calculated maximum RMS error. *This assumes that the power supply is constant.

Span Errors (converted to %V_{FSS})	Symbol	Error Value	Note	Unit
Span Calibration	SpanCal	4		%V_{FSS}
Linearity	Lin	1		%V_{FSS}
Pressure Hysterisis	Phys	0.1		%V_{FSS}
Temperature Hysterisis	Thys	0.5		%V_{FSS}
Temperature Effect on Span	Tcs	1.5		%V_{FSS}

Offset Errors (converted to %V_{FSS})				
Offset Calibration	OffCal	4		%V_{FSS}
Temperature Effect on Offset	Tco	4		%V_{FSS}
Offset Stability	OffStab	0.5		%V_{FSS}

Calculated Maximum RMS Errors		RMS Error		
No Compensation*		7.19		%$_{FS}$
With auto–zero		4.42		%$_{FS}$

AMPLIFIER SELECTION AND AMPLIFIER INDUCED ERRORS

A differential amplifier is needed to convert the differential output of the MPX2010 sensor to a high level ground–referenced (single–ended). The classic three–op amp instrumentation amplifier can be used. However, it requires additional components (3 op–amps and possibly a split power supply). An instrumentation topology shown in Figure 1 requires only a single supply and only 2 op–amps and 1% resistors.

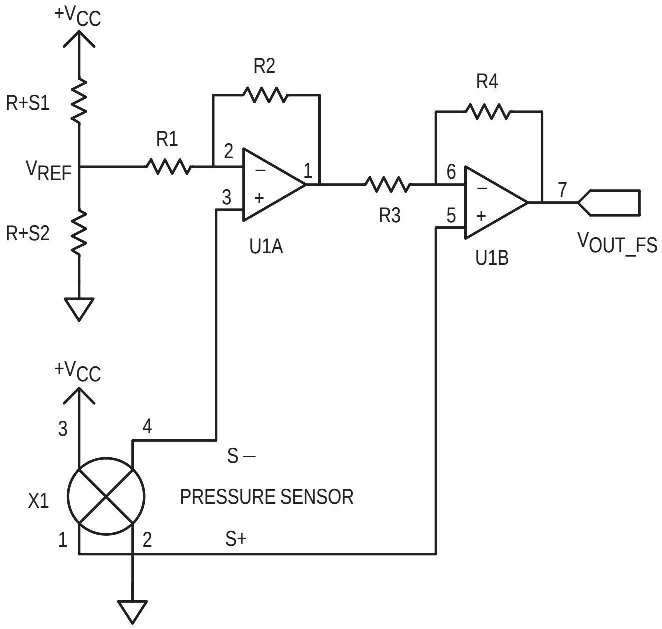


Figure 1. MPX2010 Amplifier Circuit

The circuit uses a voltage divider R+S1 and R+S2 to provide the reference (level shift), U1A and U1B are non–inverting amplifiers arranged in a differential configuration with gain resistors R1, R2, R3 and R4. Note that U1B is the main gain stage and it has the most gain. It is recommended to place a 0.015 μF capacitor in it's feedback loop (in parallel with R4) to reduce noise. The amplifier output can be characterized with the equation below:

$$\text{Gain} = \frac{R4}{R3} + 1 \tag{4}$$

$$\text{Voffset} = \text{VREF}\left(\frac{R2 \cdot R1}{R1 \cdot R3}\right) - \text{VSCM}\left[\left(\frac{R2 \cdot R4}{R1 \cdot R3}\right) - 1\right] \tag{5}$$

$$\text{Vout} = (S+ \; - \; S-)\ \text{Gain} + \text{Voffset} \tag{6}$$

$$\text{where } (S+ \; - \; S-) = \text{Sensor differential output} + \text{Sensor offset} \tag{7}$$

Equation 4 is the differential gain of the amplifier and equation 5 is the resulting offset voltage of the amplifier.

The above equations assume that the amplifier is close to ideal (high A_{OL} , low input offset voltage and low input offset bias currents). Since an ideal op–amp is hard to come by, the customer should select an op–amp based on cost and performance. Below are some points to keep in mind when selecting an op–amp and designing the amplifier circuit.

Note that the ratio R2*R4/R1*R3 controls the system offset as well as the common mode error of the amplifier. Mismatches in these resistors will result in an offset and common mode error which appear as offset. It is therefore recommended to use 1% metal film resistors to reduce these errors. Also, Vref source impedance should be minimized in comparison with R1 in order to reduce common mode error.

Amplifier input offset and input bias currents can induce errors. For example, an input offset (Vio) of the amplifier can become significant when the closed–loop gain of the amplifier is increased. Furthermore, there is also a temperature coefficient of the input voltage offset which contribute an additional error across temperature. If the input bias current of the amplifier is not taken into account in the design, it can also become a source of error. A technique to reduce this error is to match the impedance the source impedance of what the op–amp input pins sees.

It is important to note that high performance op–amps are more expensive. An MC33272 op–amp has a low input offset and low input bias current which is suitable for the two–op amp amplifier design. We can see that there is a tradeoff between accuracy and cost when designing a solution with the MPX2010.

When designing a system based on the MPX2010, it is important to take into account errors due to parametric variation of the sensor (i.e. offset calibration, span calibration, TcS, TcO), power supply and the inherent errors of the amplification circuit. The offset and span errors greatly determines the resolution of the system (which adds to the system error). Even though the system offset error can be nulled out by auto–zeroing, these errors must be accounted for when setting the system gain (see AN1556 for more details). This forces the total span of the system to be smaller, because we must reserve an extra headroom from the total span to account for amplifier and A/D variations (i.e. amp. sat. voltage, power supply variation, A/D quantization error, and gain errors). If these errors are not accounted for, it could, for example, result in non–linearity errors if the sensor span or offset error causes the amplified output of the sensor to reach the saturation voltage of the amplifier.

As an example, a MPX2010 sensor system is designed which has a range of 600 mmH_2O FS range with a +/– 5 % FS RMS error. The system uses a +5 V +/– 5% linear regulated power supply, a MC33272 dual op–amp and a 1% resistors.

Table 3 shows the resulting specification and component values for the system based on MPX2010 sensor.

Table 3. MPX2010 Sensor System Values

MPX2010 Sensor Design			
Parameter	**Description**	**Value**	**Units**
Vcc	Reg Power Supply	5	V
Differential Gain	Gain	433	V/V
Vout_FS	Full Scale Span	3.02	V
Vref	Offset Reference	0.66	V
Parts List			
U1A,U1B	MC33272 Op–amp		
R1	Gain Resistor	39.2K	Ohms
R2	Gain Resistor	90.9	Ohms
R3	Gain Resistor	909	Ohms
R4	Gain Resistor	392K	Ohms
R + S1	Level Shift Resistor	1K	Ohms
R + S2	Level Shift Resistor	150	Ohms
X1	MPX2010		

Table 4. Performance Comparison between MPX2010 and MPX5006 Solution

	MPX2010 Solution Error (FS = 600 mmH_2O)		MPX5006 Solution Error (FS = 612 mmH_2O)	
Error Contribution	**+/– % FS**	**+/– mmH_2O**	**+/– % FS**	**+/– mmH_2O**
Max Sensor Error	7.19	43	3.00	18
System Resolution (A/D + Amplification)	1.30	8	0.80	5
System Error (Sensor + A/D + Amplification)	7.3	44	3.10	19
System Error with Auto–Zero	4.6	28	<3	<19

Note that the error due to system resolution is higher for the MPX2010 solution (+/– 2 bit A/D accuracy). This is because the MPX2010 span is limited as discussed above. Also, this accuracy assumes that the amplifier does not induce significant errors. As noted MPX5006 sensor has better overall accuracy. The system resolution is very good because of its large span (4.6 V versus 3.0 V typical).

SUMMARY

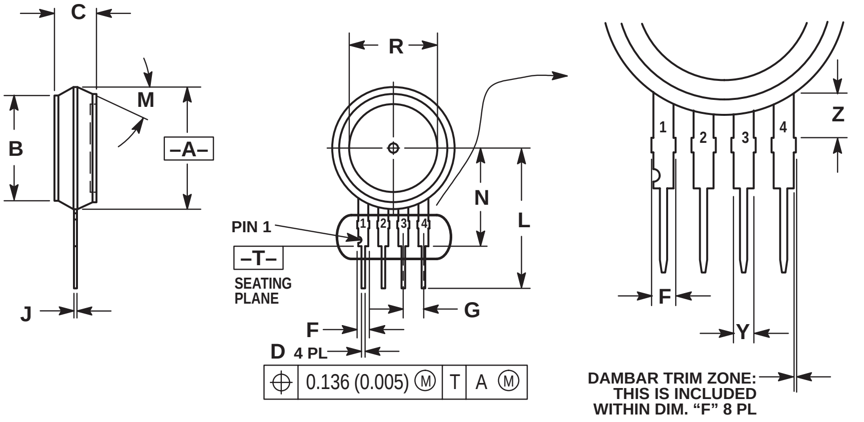
Several washing machine solutions were examined. The MPX10/12 solution can be expensive in terms of additional support circuitry and the added time and labor involved during the calibration procedure. The MPX2010 is good alternative for high volume manufacturing because is already calibrated. With this solution, however, the system amplifier design must be chosen and designed carefully in order to minimize the system error. This is a consideration when deciding to implement a high accuracy solution with the MPX2010 because the cost of the system will go up.

The MPX5006 solution is geared towards high volume manufacturing because trimming, compensation and amplification is already on board. Besides the system simplicity and using less component, the resolution and overall accuracy of this solution is better than the MPX2010 solution. In some cases, less components can actually improve the reliability and manufacturability the system.

REFERENCES

[1] Benchmark of Washing Machine Mechanical Sensor, Jack Rondoni, Motorola Internal Document.
[2] Mechanical Sensor Characterization, Ador Reodique, Motorola Internal Document.
[3] AN1551 Low Pressure Sensing with the MPX2010 Pressure Sensor, Jeff Baum, Motorola Application Note.
[4] AN1636 Implementing Auto–Zero for Integrated Pressure Sensors, Ador Reodique, Motorola Application Note.
[5] AN1556 Designing Sensor Performance Specifications for MCU–based Systems, Eric Jacobsen and Jeff Baum, Motorola Application Note.

Package Outline Dimensions



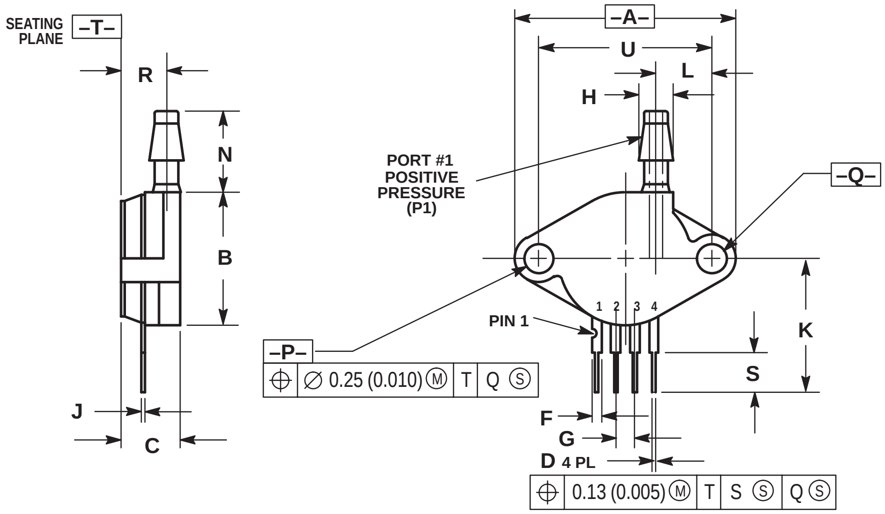
NOTES:

1. DIMENSIONING AND TOLERANCING PER ASME Y14.5M, 1994.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION –A– IS INCLUSIVE OF THE MOLD STOP RING. MOLD STOP RING NOT TO EXCEED 16.00 (0.630).

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.595	0.630	15.11	16.00
B	0.514	0.534	13.06	13.56
C	0.200	0.220	5.08	5.59
D	0.016	0.020	0.41	0.51
F	0.048	0.064	1.22	1.63
G	0.100 BSC		2.54 BSC	
J	0.014	0.016	0.36	0.40
L	0.695	0.725	17.65	18.42
M	30° NOM		30° NOM	
N	0.475	0.495	12.07	12.57
R	0.430	0.450	10.92	11.43
Y	0.048	0.052	1.22	1.32
Z	0.106	0.118	2.68	3.00

STYLE 1:
PIN 1. GROUND
2. + OUTPUT
3. + SUPPLY
4. – OUTPUT

CASE 344–15
ISSUE Z



NOTES:

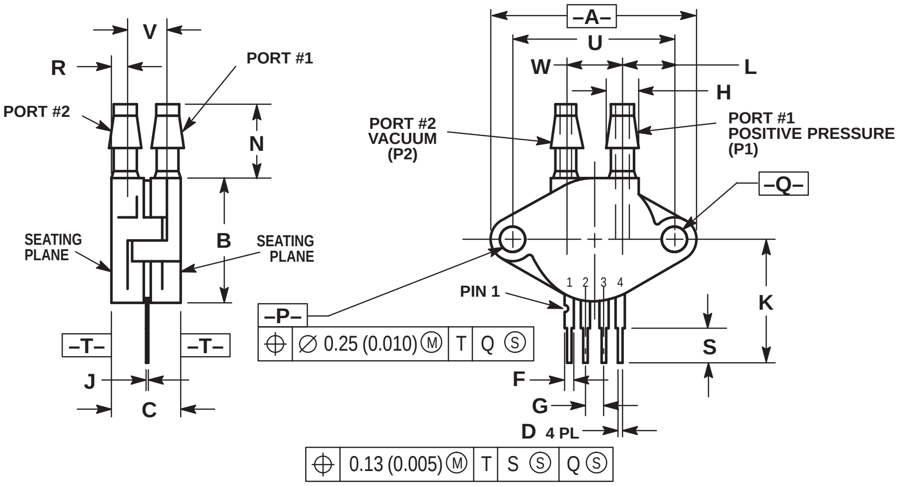
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5, 1982.
2. CONTROLLING DIMENSION: INCH.

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	1.145	1.175	29.08	29.85
B	0.685	0.715	17.40	18.16
C	0.305	0.325	7.75	8.26
D	0.016	0.020	0.41	0.51
F	0.048	0.064	1.22	1.63
G	0.100 BSC		2.54 BSC	
H	0.182	0.194	4.62	4.93
J	0.014	0.016	0.36	0.41
K	0.695	0.725	17.65	18.42
L	0.290	0.300	7.37	7.62
N	0.420	0.440	10.67	11.18
P	0.153	0.159	3.89	4.04
Q	0.153	0.159	3.89	4.04
R	0.230	0.250	5.84	6.35
S	0.220	0.240	5.59	6.10
U	0.910 BSC		23.11 BSC	

STYLE 1:
PIN 1. GROUND
2. + OUTPUT
3. + SUPPLY
4. – OUTPUT

CASE 344B–01
ISSUE B

PACKAGE OUTLINE DIMENSIONS (continued)

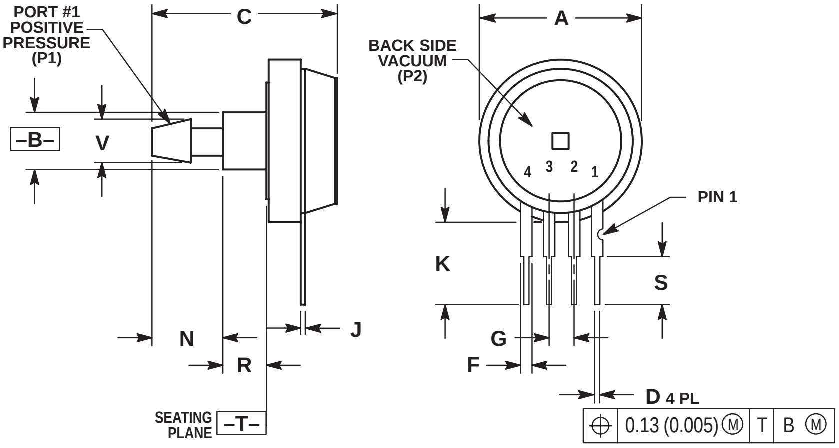


NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.

DIM	INCHES		MILLIMETERS	
	MIN	MAX	MIN	MAX
A	1.145	1.175	29.08	29.85
B	0.685	0.715	17.40	18.16
C	0.405	0.435	10.29	11.05
D	0.016	0.020	0.41	0.51
F	0.048	0.064	1.22	1.63
G	0.100 BSC		2.54 BSC	
H	0.182	0.194	4.62	4.93
J	0.014	0.016	0.36	0.41
K	0.695	0.725	17.65	18.42
L	0.290	0.300	7.37	7.62
N	0.420	0.440	10.67	11.18
P	0.153	0.159	3.89	4.04
Q	0.153	0.159	3.89	4.04
R	0.063	0.083	1.60	2.11
S	0.220	0.240	5.59	6.10
U	0.910 BSC		23.11 BSC	
V	0.248	0.278	6.30	7.06
W	0.310	0.330	7.87	8.38

STYLE 1:
PIN 1. GROUND
2. + OUTPUT
3. + SUPPLY
4. – OUTPUT

CASE 344C–01
ISSUE B



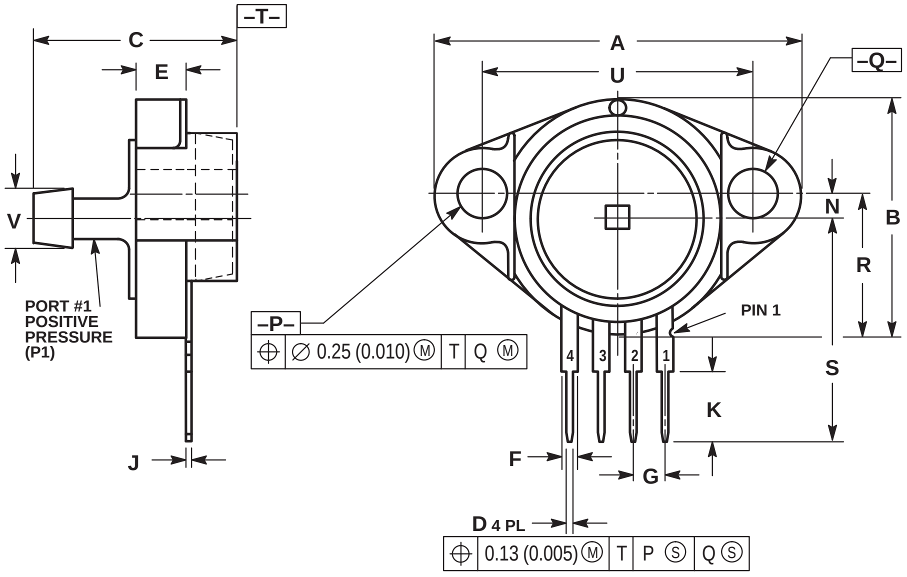
NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.

DIM	INCHES		MILLIMETERS	
	MIN	MAX	MIN	MAX
A	0.690	0.720	17.53	18.28
B	0.245	0.255	6.22	6.48
C	0.780	0.820	19.81	20.82
D	0.016	0.020	0.41	0.51
F	0.048	0.064	1.22	1.63
G	0.100 BSC		2.54 BSC	
J	0.014	0.016	0.36	0.41
K	0.345	0.375	8.76	9.53
N	0.300	0.310	7.62	7.87
R	0.178	0.186	4.52	4.72
S	0.220	0.240	5.59	6.10
V	0.182	0.194	4.62	4.93

STYLE 1:
PIN 1. GROUND
2. + OUTPUT
3. + SUPPLY
4. – OUTPUT

CASE 344E–01
ISSUE B

PACKAGE OUTLINE DIMENSIONS (continued)



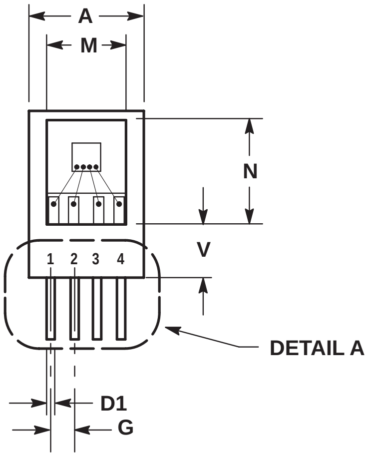
NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	1.080	1.120	27.43	28.45
B	0.740	0.760	18.80	19.30
C	0.630	0.650	16.00	16.51
D	0.016	0.020	0.41	0.51
E	0.160	0.180	4.06	4.57
F	0.048	0.064	1.22	1.63
G	0.100 BSC		2.54 BSC	
J	0.014	0.016	0.36	0.41
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	0.440	0.460	11.18	11.68
S	0.695	0.725	17.65	18.42
U	0.840	0.860	21.34	21.84
V	0.182	0.194	4.62	4.92

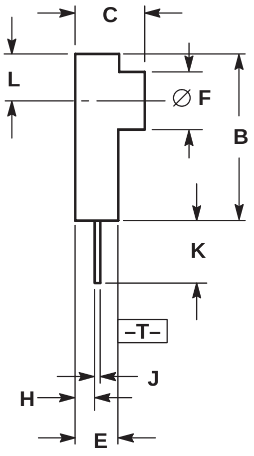
STYLE 1:
PIN 1. GROUND
2. V (+) OUT
3. V SUPPLY
4. V (–) OUT

CASE 344F–01
ISSUE B

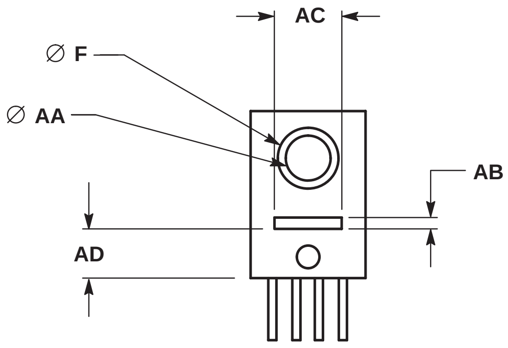
PACKAGE OUTLINE DIMENSIONS (continued)



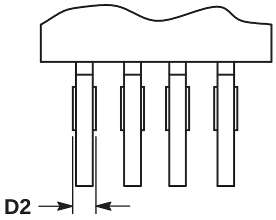
FRONT VIEW



END VIEW



BACK VIEW



DETAIL A

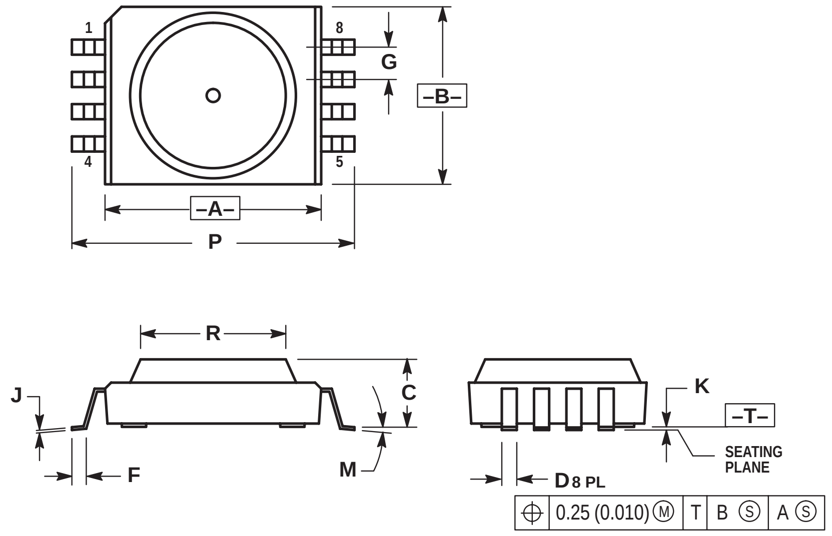
NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.

	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
D1	0.012	0.020	0.30	0.51
D2	0.014	0.022	0.36	0.56
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
V	0.105	0.115	2.67	2.92
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

STYLE 1:
PIN 1. V_{CC}
2. +OUT
3. –OUT
4. GROUND

CASE 423A–03
ISSUE C

PACKAGE OUTLINE DIMENSIONS (continued)

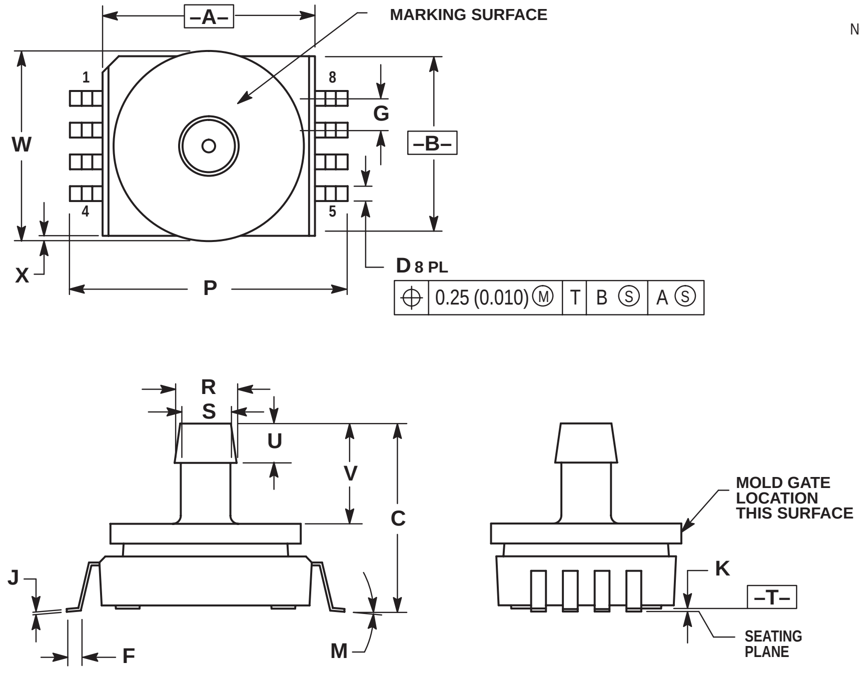


NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSIONS A AND B DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION 0.15 (0.006).
5. ALL VERTICAL SURFACES 5° TYPICAL DRAFT.

DIM	INCHES		MILLIMETERS	
	MIN	MAX	MIN	MAX
A	0.658	0.668	16.71	16.97
B	0.541	0.551	13.74	13.99
C	0.209	0.231	5.31	5.87
D	0.046	0.054	1.17	1.37
F	0.037	0.053	0.94	1.34
G	0.100 BSC		2.54 BSC	
J	0.009	0.011	0.23	0.28
K	0.002	0.010	0.05	0.25
M	0°	7°	0°	7°
P	0.856	0.880	21.74	22.35
R	0.503	0.523	12.78	13.28

STYLE 1:
PIN 1. NC
2. VSUPPLY
3. GROUND
4. VOUT
5. NC
6. NC
7. NC
8. NC

CASE 471–01
ISSUE O



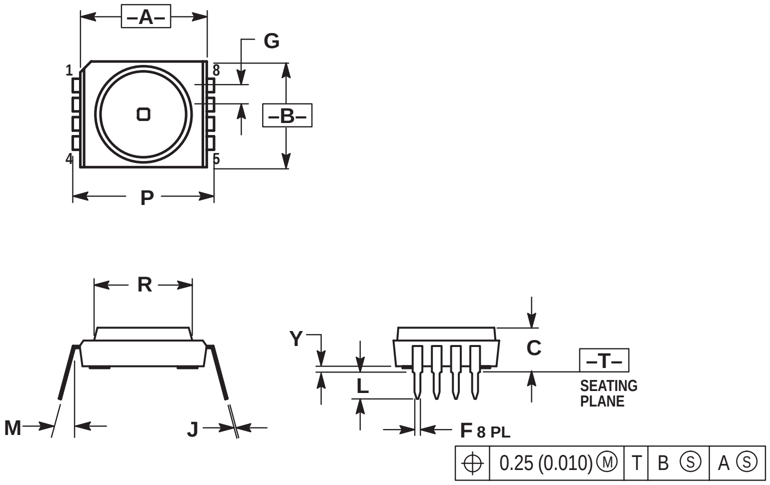
NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSIONS A AND B DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION 0.15 (0.006).
5. ALL VERTICAL SURFACES 5° TYPICAL DRAFT.

DIM	INCHES		MILLIMETERS	
	MIN	MAX	MIN	MAX
A	0.658	0.668	16.71	16.97
B	0.541	0.551	13.74	13.99
C	0.555	0.585	14.10	14.86
D	0.046	0.054	1.17	1.37
F	0.037	0.053	0.94	1.34
G	0.100 BSC		2.54 BSC	
J	0.009	0.011	0.23	0.28
K	0.002	0.010	0.05	0.25
M	0°	7°	0°	7°
P	0.856	0.880	21.74	22.35
R	0.185	0.195	4.69	4.95
S	0.155	0.165	3.94	4.19
U	0.120	0.130	3.05	3.30
V	0.305	0.315	7.75	8.00
W	0.561	0.571	14.25	14.50
X	0.010	0.025	0.25	0.63

STYLE 1:
PIN 1. NC
2. VSUPPLY
3. GROUND
4. VOUT
5. NC
6. NC
7. NC
8. NC

CASE 471B–01
ISSUE O

PACKAGE OUTLINE DIMENSIONS (continued)



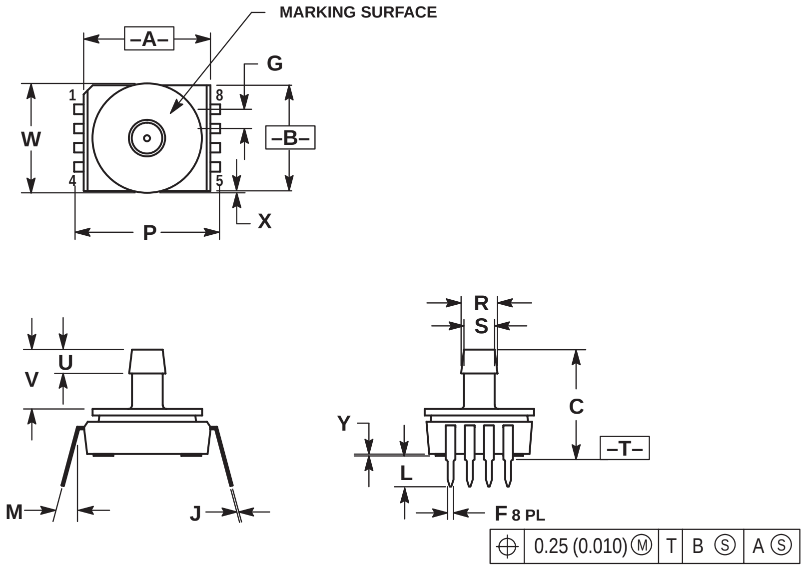
NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION A AND B DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION 0.15 (0.006).
5. VERTICAL SURFACES MAY BE UP TO 5° DRAFT.
6. DIMENSION P TO CENTER OF LEAD WHEN FORMED PARALLEL.

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.658	0.668	16.71	16.97
B	0.541	0.551	13.74	13.99
C	0.209	0.237	5.31	6.02
F	0.026	0.034	0.66	0.86
G	0.100 BSC		2.54 BSC	
J	0.009	0.011	0.23	0.28
L	0.138	0.150	3.50	3.81
Y	0.002	0.020	0.05	0.51
M	0 °	15 °	0 °	15 °
P	0.735	0.745	18.67	18.92
R	0.508	0.518	12.90	13.16

STYLE 1:
PIN 1. NC
2. VSUPPLY
3. GROUND
4. VOUT
5. NC
6. NC
7. NC
8. NC

STYLE 2:
PIN 1. GROUND
2. +VOUT
3. VSUPPLY
4. –VOUT
5. NC
6. NC
7. NC
8. NC

CASE 472–01
ISSUE O



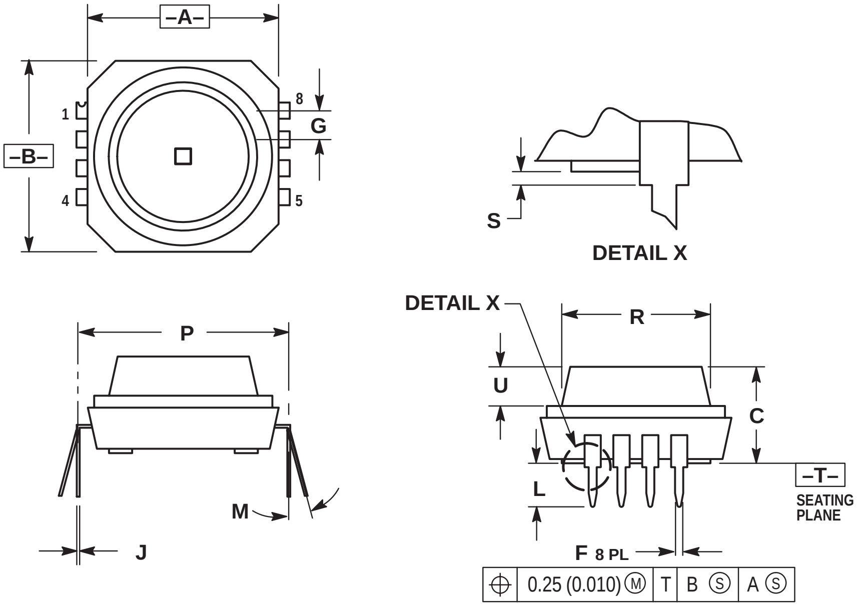
NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION A AND B DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION 0.15 (0.006).
5. VERTICAL SURFACES MAY BE UP TO 5° DRAFT.
6. DIMENSION P TO CENTER OF LEAD WHEN FORMED PARALLEL.

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.658	0.668	16.71	16.97
B	0.541	0.551	13.74	13.99
C	0.555	0.595	14.10	15.11
F	0.026	0.034	0.66	0.86
G	0.100 BSC		2.54 BSC	
J	0.009	0.011	0.23	0.28
L	0.138	0.150	3.50	3.81
M	0 °	15 °	0 °	15 °
P	0.735	0.745	18.67	18.92
R	0.185	0.195	4.69	4.95
S	0.155	0.165	3.94	4.19
U	0.120	0.130	3.05	3.30
V	0.305	0.315	7.75	8.00
W	0.561	0.571	14.25	14.50
X	0.010	0.025	0.25	0.63
Y	0.002	0.020	0.05	0.51

STYLE 1:
PIN 1. NC
2. VSUPPLY
3. GROUND
4. VOUT
5. NC
6. NC
7. NC
8. NC

CASE 472B–01
ISSUE O

PACKAGE OUTLINE DIMENSIONS (continued)



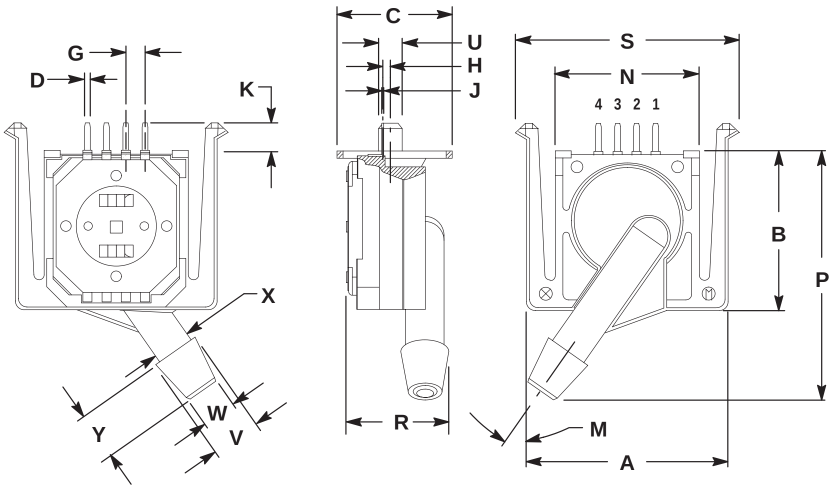
CASE 473A–01
ISSUE A

NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION A AND B DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION 0.15 (0.006).
5. ALL VERTICAL SURFACES 5° TYPICAL DRAFT.
6. DIMENSION P TO CENTER OF LEAD WHEN FORMED PARALLEL.

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.658	0.668	16.71	16.97
B	0.658	0.668	16.71	16.97
C	0.329	0.357	8.36	9.07
F	0.026	0.034	0.660	0.864
G	0.100 BSC		2.54 BSC	
J	0.009	0.011	0.23	0.28
L	0.138	0.150	3.81	3.51
M	0°	15°	0°	15°
P	0.738	0.748	18.75	19.00
R	0.503	0.523	12.78	13.28
S	0.002	0.020	0.05	0.51
U	0.135	0.145	3.43	3.68

STYLE 2:
PIN 1. GROUND
2. +VOUT
3. VSUPPLY
4. –VOUT
5. N/C
6. N/C
7. N/C
8. N/C

STYLE 3:
PIN 1. VOUT
2. GROUND
3. VSUPPLY
4. N/C
5. N/C
6. N/C
7. N/C
8. N/C



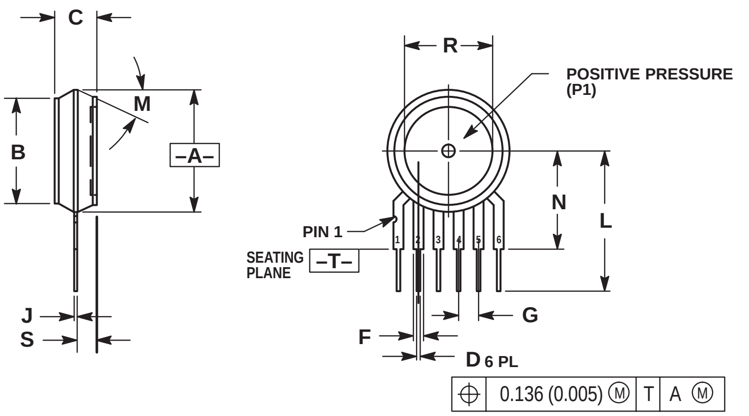
CASE 473B–01
ISSUE O

NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION –H– IS CENTER OF TINE TO CENTER OF LEAD. DIMENSION –J– IS LEAD THICKNESS.

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	1.035	1.065	26.29	27.05
B	0.813	0.833	20.65	21.16
C	0.593	0.623	15.06	15.82
D	0.026	0.034	0.66	0.86
G	0.090	0.110	2.29	2.79
H	0.027	0.059	0.68	1.50
J	0.008	0.012	0.20	0.30
K	0.130	0.150	3.30	3.56
M	30°	40°	30°	40°
N	0.735	0.765	18.67	19.43
P	1.285	1.315	32.64	33.40
R	0.510	0.540	12.95	13.72
S	1.195	1.225	30.35	31.11
U	0.105	0.135	2.67	3.43
V	0.245	0.255	6.22	6.48
W	0.173	0.183	4.39	4.65
X	0.195	0.205	4.95	5.21
Y	0.240	0.260	6.10	6.60

STYLE 1:
PIN 1. VOUT
2. GROUND
3. VCC
4. N/C

PACKAGE OUTLINE DIMENSIONS (continued)



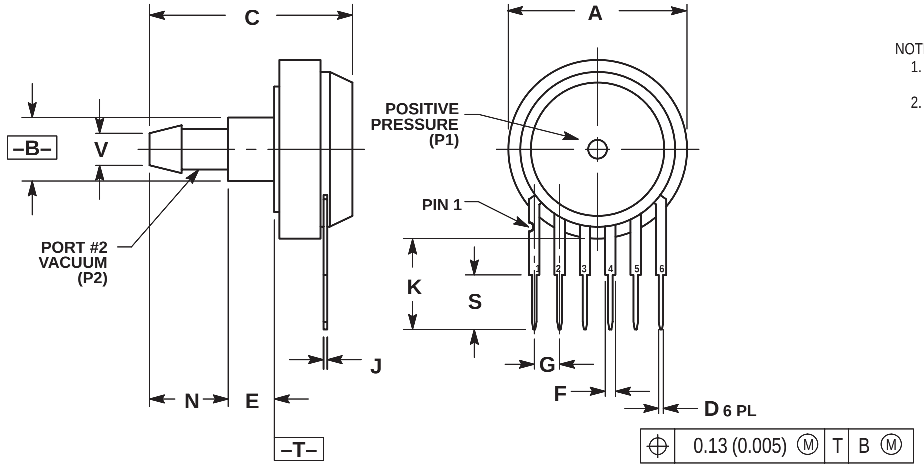
NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION –A– IS INCLUSIVE OF THE MOLD STOP RING. MOLD STOP RING NOT TO EXCEED 16.00 (0.630).

	INCHES		MILLIMETERS	
DIM	**MIN**	**MAX**	**MIN**	**MAX**
A	0.595	0.630	15.11	16.00
B	0.514	0.534	13.06	13.56
C	0.200	0.220	5.08	5.59
D	0.027	0.033	0.68	0.84
F	0.048	0.064	1.22	1.63
G	0.100 BSC		2.54 BSC	
J	0.014	0.016	0.36	0.40
L	0.695	0.725	17.65	18.42
M	30° NOM		30° NOM	
N	0.475	0.495	12.07	12.57
R	0.430	0.450	10.92	11.43
S	0.090	0.105	2.29	2.66

STYLE 1:
PIN 1. VOUT
2. GROUND
3. VCC
4. V1
5. V2
6. VEX

CASE 867–08
ISSUE N

BASIC ELEMENT (A, D)



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.

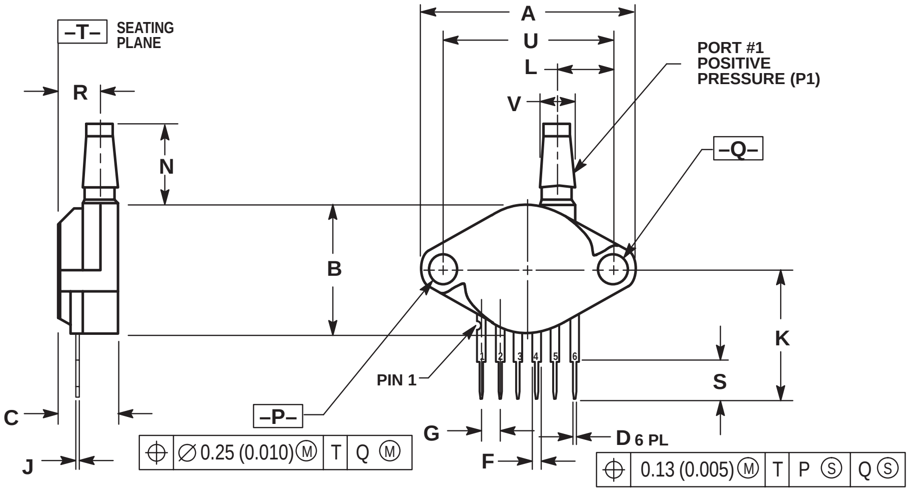
	INCHES		MILLIMETERS	
DIM	**MIN**	**MAX**	**MIN**	**MAX**
A	0.690	0.720	17.53	18.28
B	0.245	0.255	6.22	6.48
C	0.780	0.820	19.81	20.82
D	0.027	0.033	0.69	0.84
E	0.178	0.186	4.52	4.72
F	0.048	0.064	1.22	1.63
G	0.100 BSC		2.54 BSC	
J	0.014	0.016	0.36	0.41
K	0.345	0.375	8.76	9.53
N	0.300	0.310	7.62	7.87
S	0.220	0.240	5.59	6.10
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 867A–04
ISSUE E

VACUUM SIDE PORTED (GVS)

PACKAGE OUTLINE DIMENSIONS (continued)



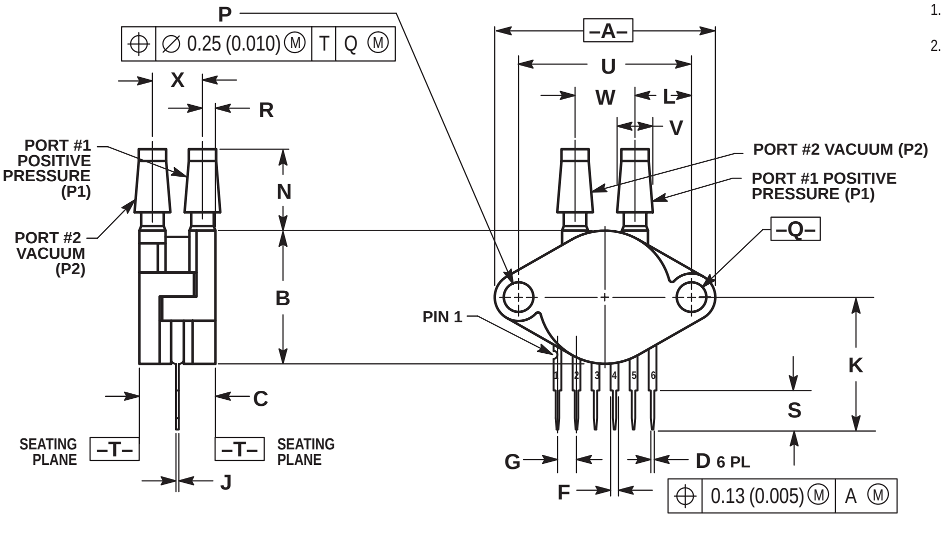
NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.

DIM	INCHES MIN	INCHES MAX	MILLIMETERS MIN	MILLIMETERS MAX
A	1.145	1.175	29.08	29.85
B	0.685	0.715	17.40	18.16
C	0.305	0.325	7.75	8.26
D	0.027	0.033	0.68	0.84
F	0.048	0.064	1.22	1.63
G	0.100 BSC		2.54 BSC	
J	0.014	0.016	0.36	0.41
K	0.695	0.725	17.65	18.42
L	0.290	0.300	7.37	7.62
N	0.420	0.440	10.67	11.18
P	0.153	0.159	3.89	4.04
Q	0.153	0.159	3.89	4.04
R	0.230	0.250	5.84	6.35
S	0.220	0.240	5.59	6.10
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–04
ISSUE E

PRESSURE SIDE PORTED (AP, GP)



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.

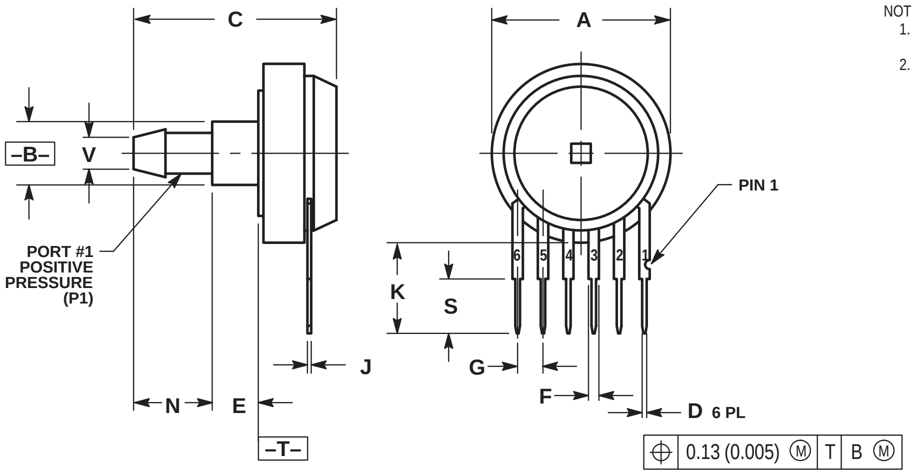
DIM	INCHES MIN	INCHES MAX	MILLIMETERS MIN	MILLIMETERS MAX
A	1.145	1.175	29.08	29.85
B	0.685	0.715	17.40	18.16
C	0.405	0.435	10.29	11.05
D	0.027	0.033	0.68	0.84
F	0.048	0.064	1.22	1.63
G	0.100 BSC		2.54 BSC	
J	0.014	0.016	0.36	0.41
K	0.695	0.725	17.65	18.42
L	0.290	0.300	7.37	7.62
N	0.420	0.440	10.67	11.18
P	0.153	0.159	3.89	4.04
Q	0.153	0.159	3.89	4.04
R	0.063	0.083	1.60	2.11
S	0.220	0.240	5.59	6.10
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–05
ISSUE F

PRESSURE AND VACUUM SIDES PORTED (DP)

PACKAGE OUTLINE DIMENSIONS (continued)



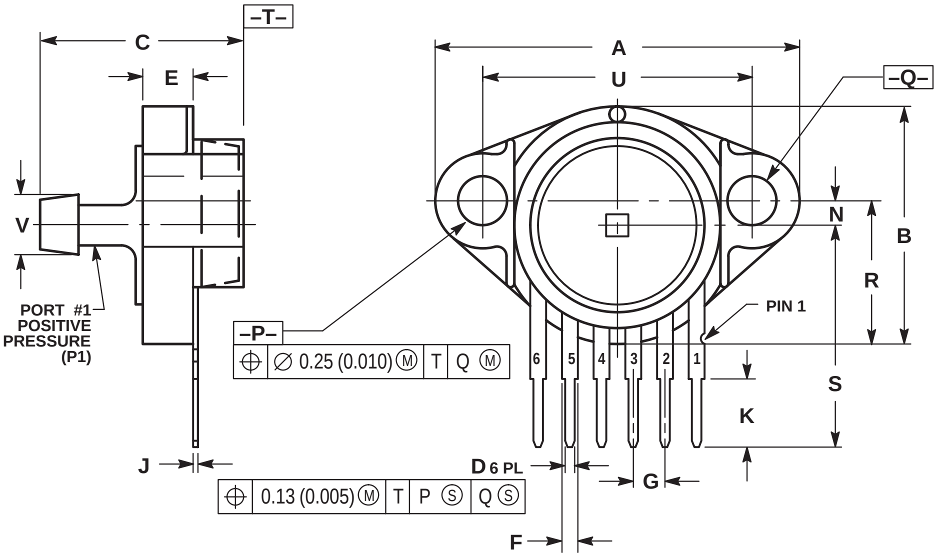
NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.690	0.720	17.53	18.28
B	0.245	0.255	6.22	6.48
C	0.780	0.820	19.81	20.82
D	0.027	0.033	0.69	0.84
E	0.178	0.186	4.52	4.72
F	0.048	0.064	1.22	1.63
G	0.100 BSC		2.54 BSC	
J	0.014	0.016	0.36	0.41
K	0.345	0.375	8.76	9.53
N	0.300	0.310	7.62	7.87
S	0.220	0.240	5.59	6.10
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 867E–03
ISSUE D

PRESSURE SIDE PORTED (AS, GS)



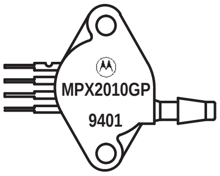
NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	1.080	1.120	27.43	28.45
B	0.740	0.760	18.80	19.30
C	0.630	0.650	16.00	16.51
D	0.027	0.033	0.68	0.84
E	0.160	0.180	4.06	4.57
F	0.048	0.064	1.22	1.63
G	0.100 BSC		2.54 BSC	
J	0.014	0.016	0.36	0.41
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	0.440	0.460	11.18	11.68
S	0.695	0.725	17.65	18.42
U	0.840	0.860	21.34	21.84
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 867F–03
ISSUE D

PRESSURE SIDE PORTED (ASX, GSX)



Marking Information for Pressure Sensor Products

Device No.	Marking
MPX10D	MPX10D
MPX10DP	MPX10DP
MPX10GP	MPX10GP
MPX10GS	MPX10D
MPX12D	MPX12D
MPX12DP	MPX12DP
MPX12GP	MPX12GP
MPX50D	MPX50D
MPX50GP	MPX50GP
MPX100A	MPX100A
MPX100AP	MPX100AP
MPX100AS	MPX100AS
MPX100ASX	MPX100ASX
MPX100D	MPX100D
MPX100DP	MPX100DP
MPX100GP	MPX100GP
MPX2010D	MPX2010D
MPX2010DP	MPX2010DP
MPX2010GP	MPX2010GP
MPX2010GS	MPX2010GS
MPX2050D	MPX2050D
MPX2050DP	MPX2050DP
MPX2050GP	MPX2050GP
MPX2100D	MPX2100D
MPX2100DP	MPX2100DP
MPX2100GP	MPX2100GP
MPX2100A	MPX2100A
MPX2100AP	MPX2100AP
MPX2100ASX	MPX2100ASX
MPX2200AS	MPX2200AS
MPX2200GSX	MPX2200D
MPX4100A	MPX4100A
MPX4100AP	MPX4100AP
MPX4100AS	MPX4100AS
MPX4101A	MPX4101A
MPX4105A	MPX4105A
MPX4115A	MPX4115A
MPX4115AP	MPX4115AP
MPX4115AS	MPX4115AS
MPX4250A	MPX4250A
MPX4250AP	MPX4250AP
MPX4250D	MPX4250D
MPX4250DP	MPX4250DP
MPX4250GP	MPX4250GP

Device No.	Marking
MPX5010D	MPX5010D
MPX5010DP	MPX5010DP
MPX5010GP	MPX5010GP
MPX5010GS	MPX5010D
MPX5010GSX	MPX5010D
MPX5050D	MPX5050D
MPX5050DP	MPX5050DP
MPX5050GP	MPX5050GP
MPX5100D	MPX5100D
MPX5100DP	MPX5100DP
MPX5100GP	MPX5100GP
MPX5700D	MPX5700D
MPX5700DP	MPX5700DP
MPX5700GP	MPX5700GP

Pinout Diagrams for Pressure Sensors

PRESSURE SENSORS

Case Type		Package Style (# Pins)	PIN 1	PIN 2	PIN 3	PIN 4	PIN 5	PIN 6	PIN 7	PIN 8
423A–03		4	V_S	S+	S–	Ground	—	—	—	—
344–15		4	Ground	$+V_{out}$	V_S	$-V_{out}$	—	—	—	—
344B–01		4	Ground	$+V_{out}$	V_S	$-V_{out}$	—	—	—	—
344C–01		4	Ground	$+V_{out}$	V_S	$-V_{out}$	—	—	—	—
344F–01		4	Ground	$+V_{out}$	V_S	$-V_{out}$	—	—	—	—
344E–01		4	Ground	$+V_{out}$	V_S	$-V_{out}$	—	—	—	—
471–01		8	*N/C	V_S	Ground	$-V_{out}$	*N/C	*N/C	*N/C	*N/C
471B–01		8	*N/C	V_S	Ground	V_{out}	*N/C	*N/C	*N/C	*N/C
472–01		8	*N/C	V_S	Ground	V_{out}	*N/C	*N/C	*N/C	*N/C
472B–01	Uncomp/Comp	8	Ground	$+V_{out}$	V_S	$-V_{out}$	*N/C	*N/C	*N/C	*N/C
472B–01	Integrated	8	*N/C	V_S	Ground	V_{out}	*N/C	*N/C	*N/C	*N/C
473A–01	Uncomp/Comp	8	Ground	$+V_{out}$	V_S	$-V_{out}$	*N/C	*N/C	*N/C	*N/C
473A–01	Integrated	8	*N/C	V_S	Ground	V_{out}	—	—	—	—
473B–01		4	*N/C	V_S	Ground	V_{out}	—	—	—	—
482–01		8	*N/C	V_S	Ground	V_{out}	*N/C	*N/C	*N/C	*N/C
482A–01	Integrated	8	*N/C	V_S	Ground	V_{out}	*N/C	*N/C	*N/C	*N/C
482A–01	Comp/Uncomp	8	Ground	$+V_{out}$	V_S	$-V_{out}$	*N/C	*N/C	*N/C	*N/C
482B–03	Comp/Uncomp	8	Ground	$+V_{out}$	V_S	$-V_{out}$	*N/C	*N/C	*N/C	*N/C
482C–03		8	Ground	$+V_{out}$	V_S	$-V_{out}$	*N/C	*N/C	*N/C	*N/C
867–08		6	V_{out}	Ground	V_S	*N/C	*N/C	*N/C	—	—
867B–04		6	V_{out}	Ground	V_S	*N/C	*N/C	*N/C	—	—
867C–05		6	V_{out}	Ground	V_S	*N/C	*N/C	*N/C	—	—
867E–03		6	V_{out}	Ground	V_S	*N/C	*N/C	*N/C	—	—
867F–03		6	V_{out}	Ground	V_S	*N/C	*N/C	*N/C	—	—

* Note: Pins are used for internal device connections. Do not connect to external circuitry or ground.

Reference Tables

FLOW EQUIVALENTS

1 Cu. Ft./Hr.		1 Cu. Ft./Min.		1 CC/Min.		1 CC/Hr.	
0.0166	Cu. Ft./Min	60	Cu. Ft./Min	60	CC/Hr.	0.0167	CC/Min.
0.4719	LPM	28.316	LPM	0.000035	Cu. Ft./Min	0.0000005	Cu. Ft./Min.
28.316	LPH	1699	LPH	0.0021	Cu. Ft./Hr.	0.00003	Cu. Ft./Hr.
471.947	CC/Min.	28317	CC/Min.	0.001	LPM	0.000017	LPM
28317	CC/Hr.	1,699,011	CC/Hr.	0.06	LPH	0.001	LPH
0.1247	Gal/Min.	7.481	Gal/Min.	0.00026	Gal/Min.	0.000004	Gal/Min.
7.481	Gal/Hr.	448.831	Gal/Hr.	0.0159	Gal/Hr.	0.00026	Gal/Hr.

1 LPM		1 LPH		1 Gal/Min.		1 Gal/Hr.	
60	LPH	0.0166	LPM	60	Gal/Hr.	0.0167	Gal/Min.
0.035	Cu. Ft./Min.	0.00059	Cu. Ft./Min.	0.1337	Cu. Ft./Min.	0.002	Cu. Ft./Min.
2.1189	Cu. Ft./Hr.	0.035	Cu. Ft./Hr.	8.021	Cu. Ft./Hr.	0.1337	Cu. Ft./Hr.
1000	CC/Min.	16.667	CC/Min.	3.785	LPM	0.063	LPM
60,002	CC/Hr.	1000	CC/Hr.	227.118	LPH	3.785	LPH
0.264	Gal/Min.	0.004	Gal/Min.	3,785.412	CC/Min.	63.069	CC/Min.
15.851	Gal/Hr.	0.264	Gal/Hr.	227,125	CC/Hr.	3785	CC/Hr.

Airspeed

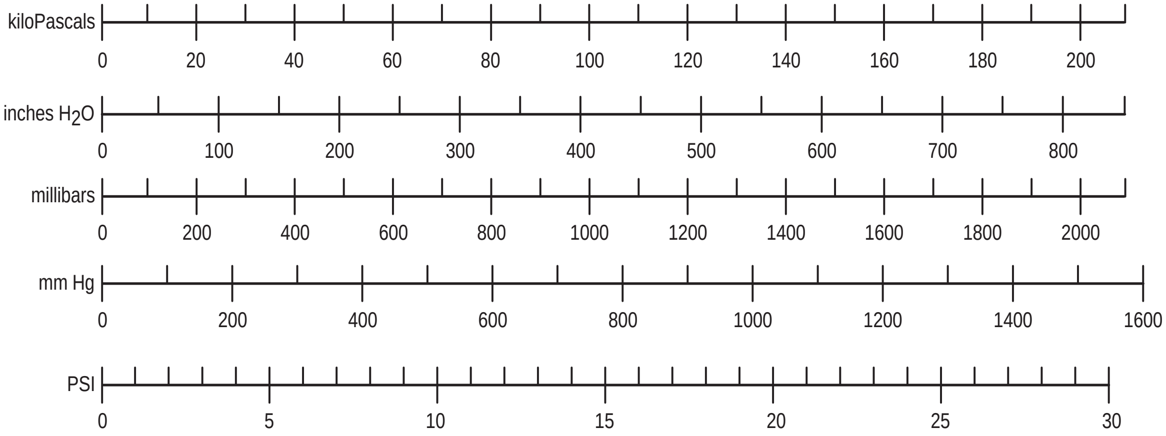
Knots	Inches of Mercury	Knots	Inches of Mercury
60	0.1727	400	8.3850
80	0.3075	425	9.5758
100	0.4814	450	10.8675
110	0.5832	475	12.2654
120	0.6950	500	13.7756
130	0.8168	525	15.4045
140	0.9488	550	17.1590
150	1.0910	575	19.0465
175	1.4918	600	21.0749
200	1.9589	650	25.5893
225	2.4943	700	30.7642
250	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		

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 x 10^{-7}	0.3937	0.014223

Quick Conversion Chart for Common Units of Pressure



Mounting and Handling Suggestions

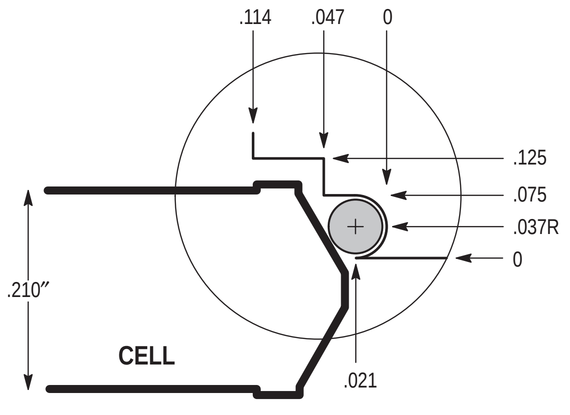
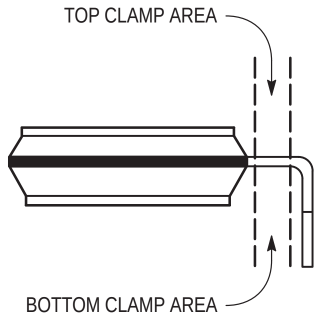


Figure 1.



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.

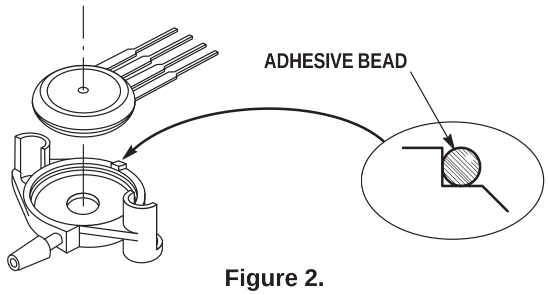


Figure 2.

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.

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

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.

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.

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.

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.

Symbols, Terms and 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 = 0.145038 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 = 0.0193368 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.

Section Four

Pressure Range and Device Index

Pressure Range Index

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MPX2700DP	700 / 100	Temperature Compensated/Calibrated	4–67
MPX2700GVS	700 / 100	Temperature Compensated/Calibrated	4–67
MPX4100A	105 / 15.5	Manifold Absolute Pressure Sensor	4–71
MPX4100AP	105 / 15.5	Manifold Absolute Pressure Sensor	4–71
MPX4100AS	105 / 15.5	Manifold Absolute Pressure Sensor	4–71
MPXS4100A	105 / 15.2	Signal–Conditioned (BAP)	4–76
MPX4101A	102 / 15.3	Manifold Absolute Pressure Sensor	4–81
MPX4115A	115 / 17	Barometeric Absolute Pressure Sensor	4–90
MPX4115AP	115 / 17	Barometeric Absolute Pressure Sensor	4–90
MPX4115AS	115 / 17	Barometeric Absolute Pressure Sensor	4–90
MPXS4115A	115 / 17	Signal Conditioned (BAP)	4–94
MPX4250A	250 / 35	Signal Conditioned	4–103
MPX4250AP	250 / 35	Signal Conditioned	4–103
MPX4250ASX	250 / 35	Signal Conditioned	4–103
MPX5010D	10 / 1.45	Signal Conditioned	4–111
MPX5010DP	10 / 1.45	Signal Conditioned	4–111
MPX5010GP	10 / 1.45	Signal Conditioned	4–111
MPX5010GS	10 / 1.45	Signal Conditioned	4–111
MPX5010GSX	10 / 1.45	Signal Conditioned	4–111
MPXL5010	10 / 1.45	Signal Conditioned	4–116
MPX5050D	50 / 7.25	Signal–Conditioned	4–121
MPX5050DP	50 / 7.25	Signal–Conditioned	4–121
MPX5050GP	50 / 7.25	Signal–Conditioned	4–121
MPX5050GSX	50 / 7.25	Signal–Conditioned	4–121
MPX5050GVP	50 / 7.25	Signal–Conditioned	4–121
MPX5050GVS	50 / 7.25	Signal–Conditioned	4–121
MPX5050GVSX	50 / 7.25	Signal–Conditioned	4–121
MPX50D	50 / 7.25	Uncompensated	4–26
MPX50DP	50 / 7.25	Uncompensated	4–26
MPX50GP	50 / 7.25	Uncompensated	4–26
MPX50GSX	50 / 7.25	Uncompensated	4–26
MPX50GVP	50 / 7.25	Uncompensated	4–26
MPX5100A	100 / 14.5	Signal–Conditioned	4–126
MPX5100AP	100 / 14.5	Signal–Conditioned	4–126
MPX5100D	100 / 14.5	Signal–Conditioned	4–126
MPX5100DP	100 / 14.5	Signal–Conditioned	4–126
MPX5100GP	100 / 14.5	Signal–Conditioned	4–126
MPX5100GSX	100 / 14.5	Signal–Conditioned	4–126
MPX5100GVP	100 / 14.5	Signal–Conditioned	4–126
MPX5500D	500 / 75	Signal Conditioned	4–132
MPX5500DP	500 / 75	Signal Conditioned	4–132
MPX5500GP	500 / 75	Signal Conditioned	4–132
MPX5500GS	500 / 75	Signal Conditioned	4–132
MPX5500GSX	500 / 75	Signal Conditioned	4–132
MPX5700D	700 / 100	Signal Conditioned	4–136
MPX5700DP	700 / 100	Signal Conditioned	4–136
MPX5700GP	700 / 100	Signal Conditioned	4–136
MPX5700GS	700 / 100	Signal Conditioned	4–136
MPX5700GSX	700 / 100	Signal Conditioned	4–136
MPX5999D	1000 / 150	Signal Conditioned	4–140
MPX700A	700 / 100	Uncompensated	4–38
MPX700AP	700 / 100	Uncompensated	4–38
MPX700D	700 / 100	Uncompensated	4–38
MPX700DP	700 / 100	Uncompensated	4–38
MPX700GP	700 / 100	Uncompensated	4–38
MPX700GSX	700 / 100	Uncompensated	4–38
MPX7050D	50 / 7.25	High Impedance	4–144
MPX7050DP	50 / 7.25	High Impedance	4–144
MPX7050GP	50 / 7.25	High Impedance	4–144
MPX7050GS	50 / 7.25	High Impedance	4–144

Device Index (continued)

PRESSURE SENSORS (continued)

Device	Pressure Range (kPa / psi)	Product Type	Page Number
MPX7050GSX	50 / 7.25	High Impedance	4–144
MPX7100A	100 / 14.5	High Impedance	4–148
MPX7100AP	100 / 14.5	High Impedance	4–148
MPX7100D	100 / 14.5	High Impedance	4–148
MPX7100DP	100 / 14.5	High Impedance	4–148
MPX7100GP	100 / 14.5	High Impedance	4–148
MPX7100GS	100 / 14.5	High Impedance	4–148
MPX7100GSX	100 / 14.5	High Impedance	4–148
MPX7200A	200 / 29	High Impedance	4–152
MPX7200D	200 / 29	High Impedance	4–152
MPX7200GP	200 / 29	High Impedance	4–152

Device	Pressure Range (kPa / psi)	Product Type	Page Number
MPX906D	6 / 0.9	Uncompensated	4–42
MPX906GVW	6 / 0.9	Uncompensated	4–42

ACCELEROMETERS

Device	Acceleration Range (G)	Product Type	Page Number
MMAS40G10D	40 g	Accelerometer	2–4
MMAS40GWB	40 g	Accelerometer	2–7

Section Five

Smoke Integrated Circuits

Motorola's Smoke Integrated Circuits (IC's) are low power, CMOS devices designed to meet a wide range of smoke detector applications at very competitive prices. Motorola has been producing both photoelectric and ionization smoke IC's for more than 15 years. Found in consumer and commercial applications worldwide, these integrated circuits can be operated using a battery or AC power. In addition, these devices are designed to be used in stand alone units or as an interconnected system of up to 40 units. All of Motorola's smoke IC's have component recognition from Underwriter's Laboratories and the newest devices meet the NFPA's new "temporal three'' horn pattern.

Mini Selector Guide

Smoke Integrated Circuits (CMOS Analog)

Type	Operating Voltage	Horn Modulation	Primary Power Source	Package Options	Interconnectable	Description
MC14467P1	6–12 V	4/6	DC	DIP	No	Ion
MC14468P	6–12 V	4/6	AC	DIP	Yes	Ion
MC145010DW	6–12 V	4/6	DC	DIP/SOIC	Yes	Photo
MC145010DWR2	6–12 V	4/6	DC	DIP/SOIC	Yes	Photo
MC145010P	6–12 V	4/6	DC	DIP/SOIC	Yes	Photo
MC145012DW	6–12 V	NFPA *(new tone)*	DC	DIP/SOIC	Yes	Photo
MC145012DWR2	6–12 V	FNPA *(new tone)*	DC	DIP/SOIC	Yes	Photo
MC145012P	6–12 V	FNPA *(new tone)*	DC	DIP/SOIC	Yes	Photo
MC145017P	6–12 V	NFPA *(new tone)*	DC	DIP	No	Ion
MC145018P	6–12 V	NFPA *(new tone)*	AC	DIP	Yes	Ion

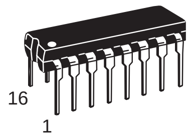
MOTOROLA
SEMICONDUCTOR TECHNICAL DATA

MC14467-1

Low-Power CMOS Ionization Smoke Detector

The MC14467–1, when used with an ionization chamber and a small number of external components, will detect smoke. When smoke is sensed, an alarm is sounded via an external piezoelectric transducer and internal drivers. This circuit is designed to comply with the UL217 and UL268 specifications.

- Ionization Type with On–Chip FET Input Comparator
- Piezoelectric Horn Driver
- Guard Outputs on Both Sides of Detect Input
- Input–Production Diodes on the Detect Input
- Low–Battery Trip Point, Internally Set, can be Altered Via External Resistor
- Detect Threshold, Internally Set, can be Altered Via External Resistor
- Pulse Testing for Low Battery Uses LED for Battery Loading
- Comparator Outputs for Detect and Low Battery
- Internal Reverse Battery Protection

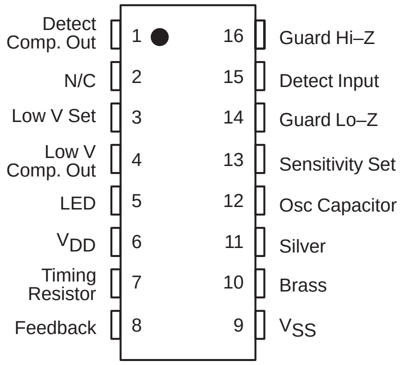


P SUFFIX
PLASTIC DIP
CASE 648–08

ORDERING INFORMATION

MC14467P1 PLASTIC DIP

PIN ASSIGNMENT
(16 PIN DIP)



MAXIMUM RATINGS* (Voltages referenced to V_{SS})

Rating	Symbol	Value	Unit
DC Supply Voltage	V_{DD}	-0.5 to $+15$	V
Input Voltage, All Inputs Except Pin 8	V_{in}	-0.25 to $V_{DD}+0.25$	V
DC Current Drain per Input Pin, Except Pin 15 = 1 mA	I	10	mA
DC Current Drain per Output Pin	I	30	mA
Operating Temperature Range	T_A	-10 to $+60$	°C
Storage Temperature Range	T_{stg}	-55 to $+125$	°C
Reverse Battery Time	t_{RB}	5.0	s

* Maximum Ratings are those values beyond which damage to the device may occur.

This device contains circuitry to protect the inputs against damage due to high static voltages or electric fields; however, it is advised that normal precautions be taken to avoid application of any voltage higher than maximum rated voltages to this high impedance circuit. For proper operation it is recommended that except for pin 8, V_{in} and V_{out} be constrained to the range $V_{SS} \leq (V_{in} \text{ or } V_{out}) \leq V_{DD}$. For pin 8, refer to the Electrical Characteristics.

REV 1

RECOMMENDED OPERATING CONDITIONS (Voltages referenced to V_{SS})

Parameter	Symbol	Value	Unit
Supply Voltage	V_{DD}	9.0	V
Timing Capacitor	—	0.1	µF
Timing Resistor	—	8.2	MΩ
Battery Load (Resistor or LED)	—	10	mA

ELECTRICAL CHARACTERISTICS (Voltages referenced to V_{SS}, T_A = 25°C)

Characteristic	Symbol	V_{DD} Vdc	Min	Typ#	Max	Unit
Operating Voltage	V_{DD}	—	6.0	—	12	V
Output Voltage	V_{OH}					V
Piezoelectric Horn Drivers (I_{OH} = − 16 mA)		7.2	6.3	—	—	
Comparators (I_{OH} = − 30 µA)		9.0	8.5	8.8	—	
Piezoelectric Horn Drivers (I_{OL} = +16 mA)	V_{OL}	7.2	—	—	0.9	V
Comparators (I_{OL} = +30 µA)		9.0	—	0.1	0.5	
Output Voltage — LED Driver, I_{OL} = 10 mA	V_{OL}	7.2	—	—	3.0	V
Output Impedance, Active Guard						kΩ
Pin 14	Lo–Z	9.0	—	—	10	
Pin 16	Hi–Z	9.0	—	—	1000	
Operating Current (R_{bias} = 8.2 MΩ)	I_{DD}	9.0	—	5.0	9.0	µA
		12.0	—	—	12.0	
Input Current — Detect (40% R.H.)	I_{in}	9.0	—	—	± 1.0	pA
Internal Set Voltage						
Low Battery	V_{low}	9.0	7.2	—	7.8	V
Sensitivity	V_{set}	—	47	50	53	%V_{DD}
Hysteresis	v_{hys}	9.0	75	100	150	mV
Offset Voltage (measured at V_{in} = V_{DD}/2)	V_{OS}					mV
Active Guard		9.0	—	—	± 100	
Detect Comparator		9.0	—	—	± 50	
Input Voltage Range, Pin 8	V_{in}	—	− 10	—	V_{DD}+10	V
Input Capacitance	C_{in}	—	—	5.0	—	pF
Common Mode Voltage Range, Pin 15	V_{cm}	—	0.6	—	V_{DD} − 2	V

Data labelled "Typ" is not to be used for design purposes but is intended as an indication of the IC's potential performance.

TIMING PARAMETERS (C = 0.1 µF, R_{bias} = 8.2 MΩ, V_{DD} = 9.0 V, T_A = 25°C, See Figure 6)

Characteristics		Symbol	Min	Typ#	Max	Units
Oscillator Period	No Smoke Smoke	t_{CI}	1.34 32	1.67 40	2.0 48	s ms
Oscillator Rise Time		t_r	8.0	10	12	ms
Horn Output (During Smoke)	On Time Off Time	PW_{on} PW_{off}	120 60	160 80	208 104	ms ms
LED Output	Between Pulses On Time	t_{LED} PW_{on}	32 8.0	40 10	48 12	s ms
Horn Output (During Low Battery)	On Time Between Pulses	t_{on} t_{off}	8.0 32	10 40	12 48	ms s

Data labelled “Typ’’ is not to be used for design purposes but is intended as an indication of the IC’s potential performance.

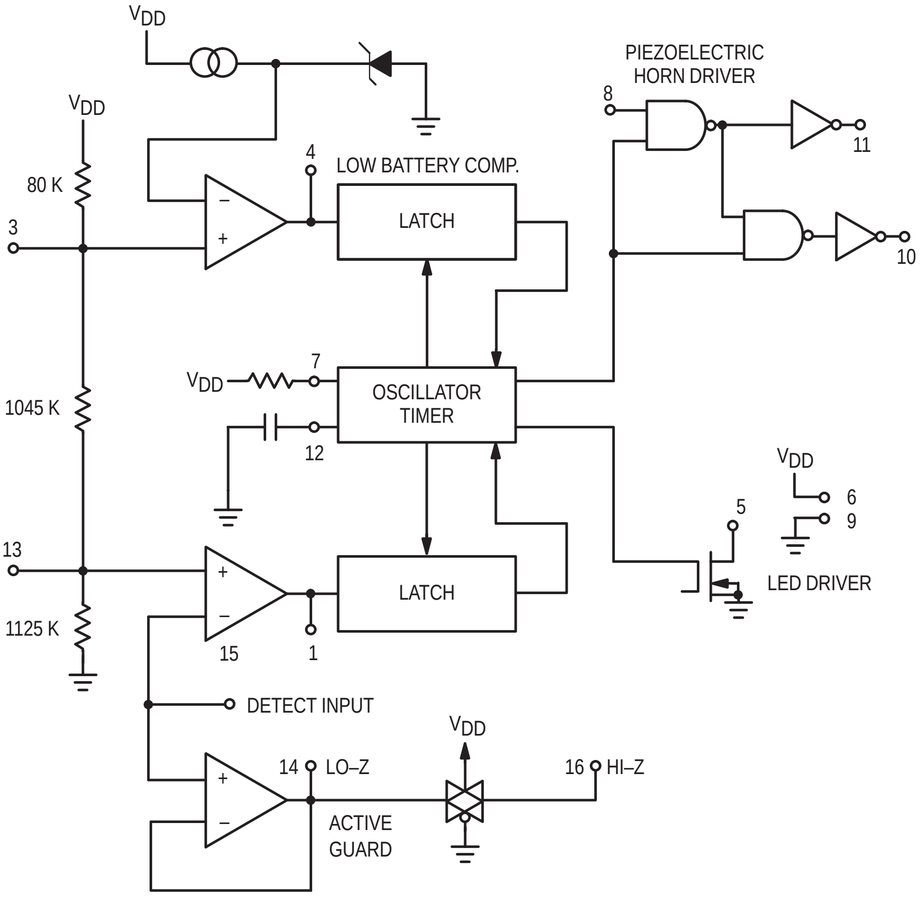


Figure 1. Block Diagram

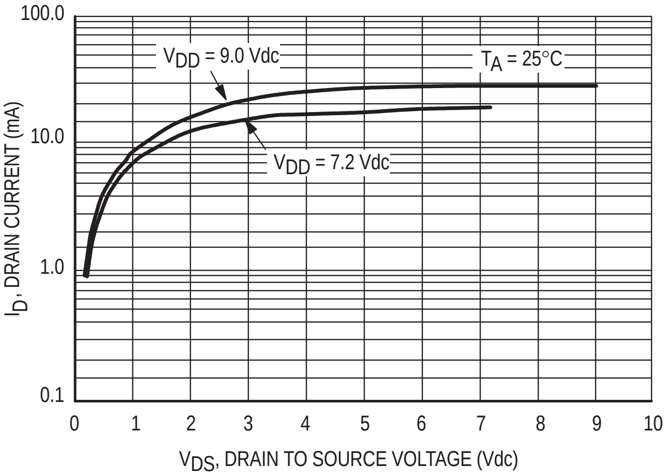


Figure 2. Typical LED Output I–V Characteristic

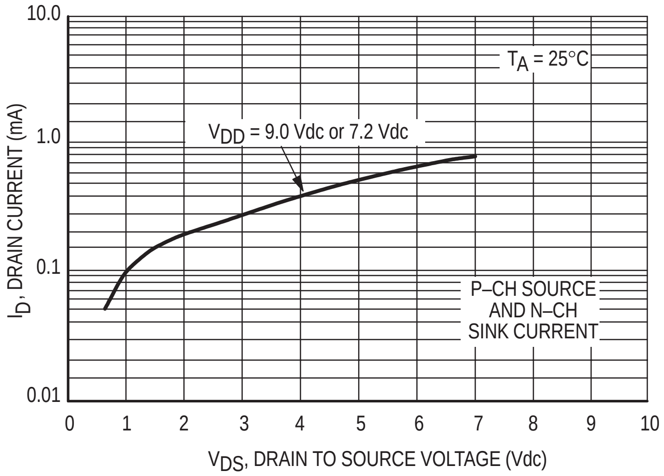


Figure 3. Typical Comparator Output I–V Characteristic

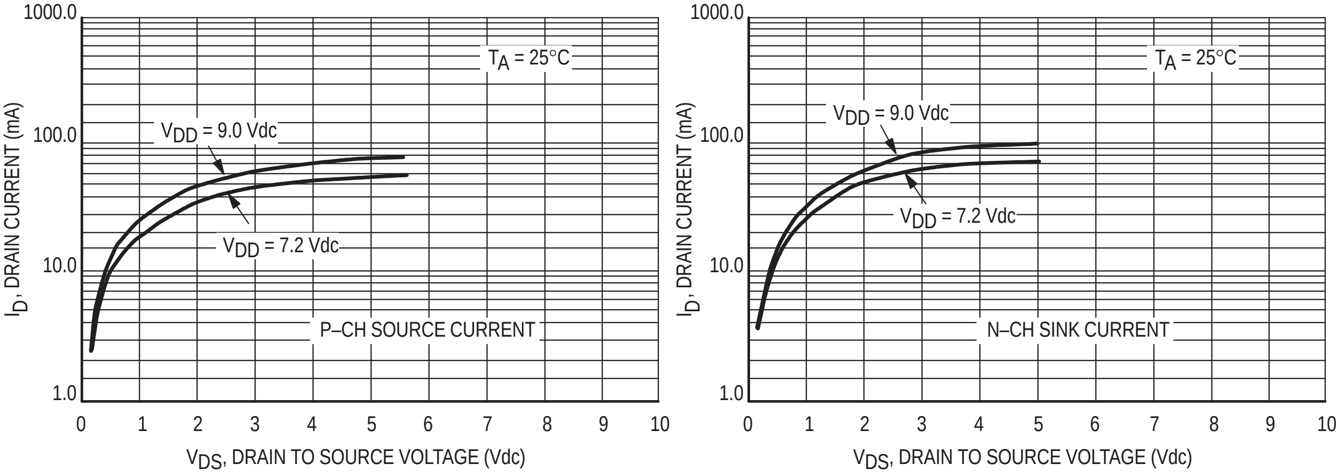


Figure 4. Typical P Horn Driver Output I–V Characteristic

DEVICE OPERATION

TIMING

The internal oscillator of the MC14467–1 operates with a period of 1.67 seconds during no–smoke conditions. Each 1.67 seconds, internal power is applied to the entire IC and a check is made for smoke, except during LED pulse, Low Battery Alarm Chirp, or Horn Modulation (in smoke). Every 24 clock cycles a check is made for low battery by comparing V_{DD} to an internal zener voltage. Since very small currents are used in the oscillator, the oscillator capacitor should be of a low leakage type.

DETECT CIRCUITRY

If smoke is detected, the oscillator period becomes 40 ms and the piezoelectric horn oscillator circuit is enabled. The horn output is modulated 160 ms on, 80 ms off. During the off time, smoke is again checked and will inhibit further horn output if no smoke is sensed. During smoke conditions the low battery alarm is inhibited, but the LED pulses at a 1.0 Hz rate.

An active guard is provided on both pins adjacent to the detect input. The voltage at these pins will be within 100 mV of the input signal. This will keep surface leakage currents to a minimum and provide a method of measuring the input voltage without loading the ionization chamber. The active guard op amp is not power strobed and thus gives constant protection from surface leakage currents. Pin 15 (the Detect input) has internal diode protection against static damage.

SENSITIVITY/LOW BATTERY THRESHOLDS

Both the sensitivity threshold and the low battery voltage levels are set internally by a common voltage divider connected between V_{DD} and V_{SS}. These voltages can be altered by external resistors connected from pins 3 or 13 to either V_{DD} or V_{SS}. There will be a slight interaction here due to the common voltage divider network. The sensitivity threshold can also be set by adjusting the smoke chamber ionization source.

TEST MODE

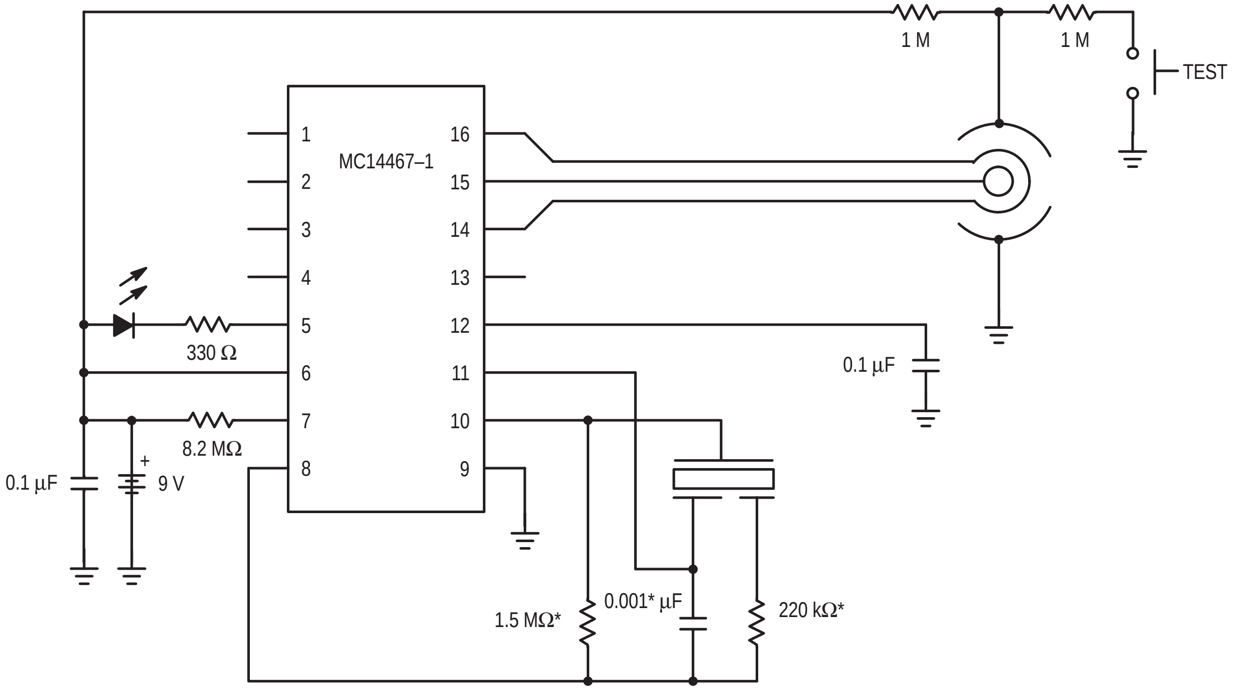
Since the internal op amps and comparators are power strobed, adjustments for sensitivity or low battery level could be difficult and/or time–consuming. By forcing Pin 12 to V_{SS}, the power strobing is bypassed and the outputs, Pins 1 and 4, constantly show smoke/no smoke and good battery/low battery, respectively. Pin 1 = V_{DD} for smoke and Pin 4 = V_{DD} for low battery. In this mode and during the 10 ms power strobe, chip current rises to approximately 50 µA.

LED PULSE

The 9–volt battery level is checked every 40 seconds during the LED pulse. The battery is loaded via a 10 mA pulse for 10 ms. If the LED is not used, it should be replaced with an equivalent resistor such that the battery loading remains at 10 mA.

HYSTERESIS

When smoke is detected, the resistor/divider network that sets sensitivity is altered to increase sensitivity. This yields approximately 100 mV of hysteresis and reduces false triggering.



*NOTE: Component values may change depending on type of piezoelectric horn used.

Figure 5. Typical Application as Ionization Smoke Detector

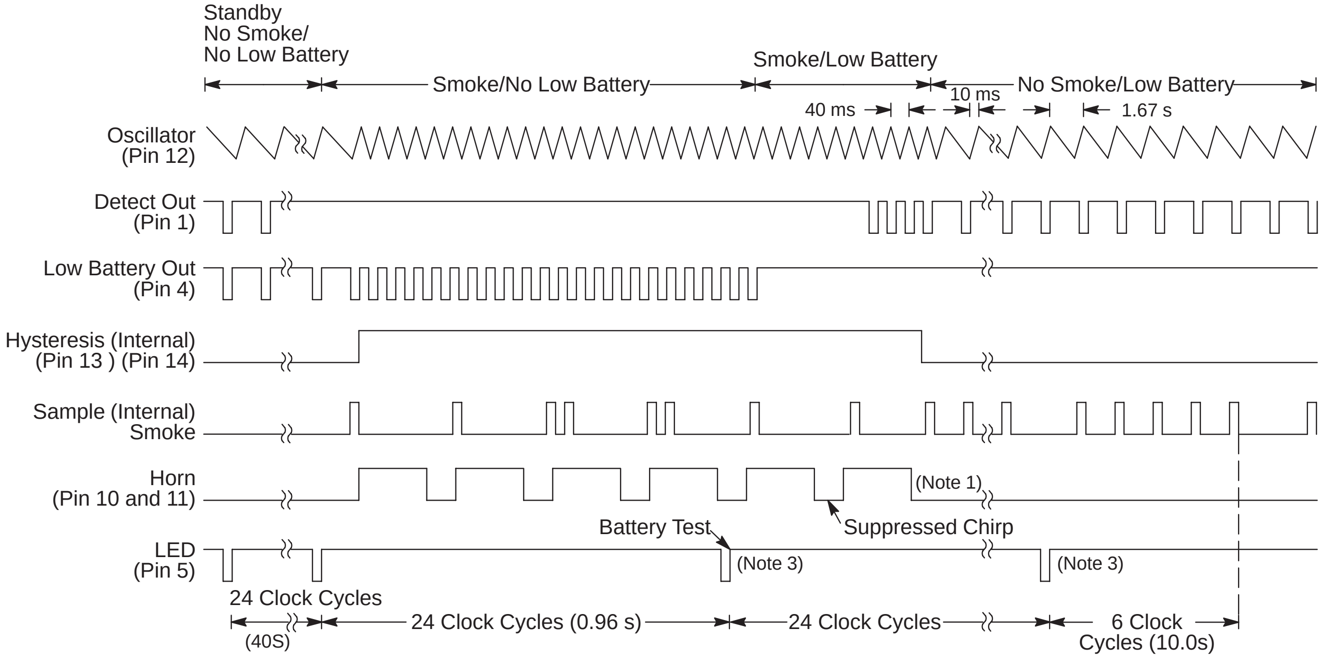


Figure 6. Timing Diagram

NOTES:
1. Horn modulation is self–completing. When going from smoke to no smoke, the alarm condition will terminate only when horn is off.
2. Comparators are strobed on once per clock cycle (1.67 s for no smoke, 40 ms for smoke).
3. Low battery comparator information is latched only during LED pulse.
4. ∼ 100 mV p–p swing.

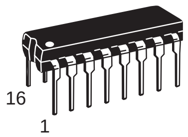
MOTOROLA
SEMICONDUCTOR TECHNICAL DATA

MC14468

Low-Power CMOS Ionization Smoke Detector with Interconnect

The MC14468, when used with an ionization chamber and a small number of external components, will detect smoke. When smoke is sensed, an alarm is sounded via an external piezoelectric transducer and internal drivers. This circuit is designed to comply with the UL217 and UL268 specifications.

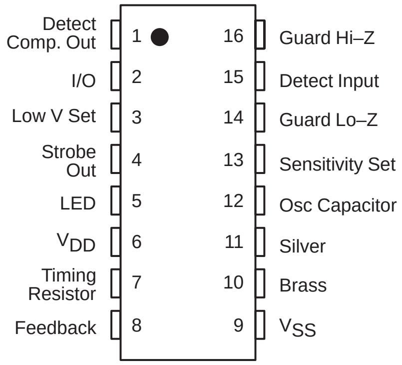
- Ionization Type with On–Chip FET Input Comparator
- Piezoelectric Horn Driver
- Guard Outputs on Both Sides of Detect Input
- Input–Production Diodes on the Detect Input
- Low–Battery Trip Point, Internally Set, can be Altered Via External Resistor
- Detect Threshold, Internally Set, can be Altered Via External Resistor
- Pulse Testing for Low Battery Uses LED for Battery Loading
- Comparator Output for Detect
- Internal Reverse Battery Protection
- Strobe Output for External Trim Resistors
- I/O Pin Allows Up to 40 Units to be Connected for Common Signaling
- Power–On Reset Prevents False Alarms on Battery Change



P SUFFIX
PLASTIC DIP
CASE 648–08

ORDERING INFORMATION
MC14468P PLASTIC DIP

PIN ASSIGNMENT
(16 PIN DIP)



MAXIMUM RATINGS* (Voltages referenced to V_{SS})

Rating	Symbol	Value	Unit
DC Supply Voltage	V_{DD}	– 0.5 to +15	V
Input Voltage, All Inputs Except Pin 8	V_{in}	– 0.25 to V_{DD} +0.25	V
DC Current Drain per Input Pin, Except Pin 15 = 1 mA	I	10	mA
DC Current Drain per Output Pin	I	30	mA
Operating Temperature Range	T_A	– 10 to +60	°C
Storage Temperature Range	T_{stg}	– 55 to +125	°C
Reverse Battery Time	t_{RB}	5.0	s

* Maximum Ratings are those values beyond which damage to the device may occur.

This device contains circuitry to protect the inputs against damage due to high static voltages or electric fields; however, it is advised that normal precautions be taken to avoid application of any voltage higher than maximum rated voltages to this high impedance circuit. For proper operation it is recommended that V_{in} and V_{out} be constrained to the range $V_{SS} \leq (V_{in} \text{ or } V_{out}) \leq V_{DD}$.

REV 1

RECOMMENDED OPERATING CONDITIONS (Voltages referenced to V_{SS})

Parameter	Symbol	Value	Unit
Supply Voltage	V_{DD}	9.0	V
Timing Capacitor	—	0.1	µF
Timing Resistor	—	8.2	MΩ
Battery Load (Resistor or LED)	—	10	mA

ELECTRICAL CHARACTERISTICS (T_A = 25°C)

Characteristic	Symbol	V_{DD} V_{dc}	Min	Typ#	Max	Unit
Operating Voltage	V_{DD}	—	6.0	—	12	V
Output Voltage	V_{OH}					V
Piezoelectric Horn Drivers (I_{OH} = −16 mA)		7.2	6.3	—	—	
Comparators (I_{OH} = −30 µA)		9.0	8.5	8.8	—	
Piezoelectric Horn Drivers (I_{OL} = +16 mA)	V_{OL}	7.2	—	—	0.9	V
Comparators (I_{OL} = +30 µA)		9.0	—	0.1	0.5	
Output Voltage — LED Driver, I_{OL} = 10 mA	V_{OL}	7.2	—	—	3.0	V
Output Impedance, Active Guard						kΩ
Pin 14	Lo–Z	9.0	—	—	10	
Pin 16	Hi–Z	9.0	—	—	1000	
Operating Current (R_{bias} = 8.2 MΩ)	I_{DD}	9.0	—	5.0	9.0	µA
		12.0	—	—	12.0	
Input Current — Detect (40% R.H.)	I_{in}	9.0	—	—	± 1.0	pA
Input Current, Pin 8	I_{in}	9.0	—	—	± 0.1	µA
Input Current @ 50°C, Pin 15	I_{in}	—	—	—	± 6.0	pA
Internal Set Voltage						
Low Battery	V_{low}	9.0	7.2	—	7.8	V
Sensitivity	V_{set}	—	47	50	53	%V_{DD}
Hysteresis	v_{hys}	9.0	75	100	150	mV
Offset Voltage (measured at V_{in} = V_{DD}/2)	V_{OS}					mV
Active Guard		9.0	—	—	± 100	
Detect Comparator		9.0	—	—	± 50	
Input Voltage Range, Pin 8	V_{in}	—	− 10	—	V_{DD}+10	V
Input Capacitance	C_{in}	—	—	5.0	—	pF
Common Mode Voltage Range, Pin 15	V_{cm}	—	0.6	—	V_{DD} − 2	V
I/O Current, Pin 2						
Input, V_{IH} = V_{DD} − 2	I_{IH}	—	25	—	100	µA
Output, V_{OH} = V_{DD} − 2	I_{OH}	—	− 4.0	—	− 16	mA

Data labelled “Typ” is not to be used for design purposes but is intended as an indication of the IC’s potential performance.

TIMING PARAMETERS (C = 0.1 µF, R_{bias} = 8.2 MΩ, V_{DD} = 9.0 V, T_A = 25°C, See Figure 6)

Characteristics		Symbol	Min	Typ#	Max	Units
Oscillator Period	No Smoke Smoke	t_{CI}	1.34 32	1.67 40	2.0 48	s ms
Oscillator Rise Time		t_r	8.0	10	12	ms
Horn Output (During Smoke)	On Time Off Time	PW_{on} PW_{off}	120 60	160 80	208 104	ms ms
LED Output	Between Pulses On Time	t_{LED} PW_{on}	32 8.0	40 10	48 12	s ms
Horn Output (During Low Battery)	On Time Between Pulses	t_{on} t_{off}	8.0 32	10 40	12 48	ms s

Data labelled “Typ’’ is not to be used for design purposes but is intended as an indication of the IC’s potential performance.

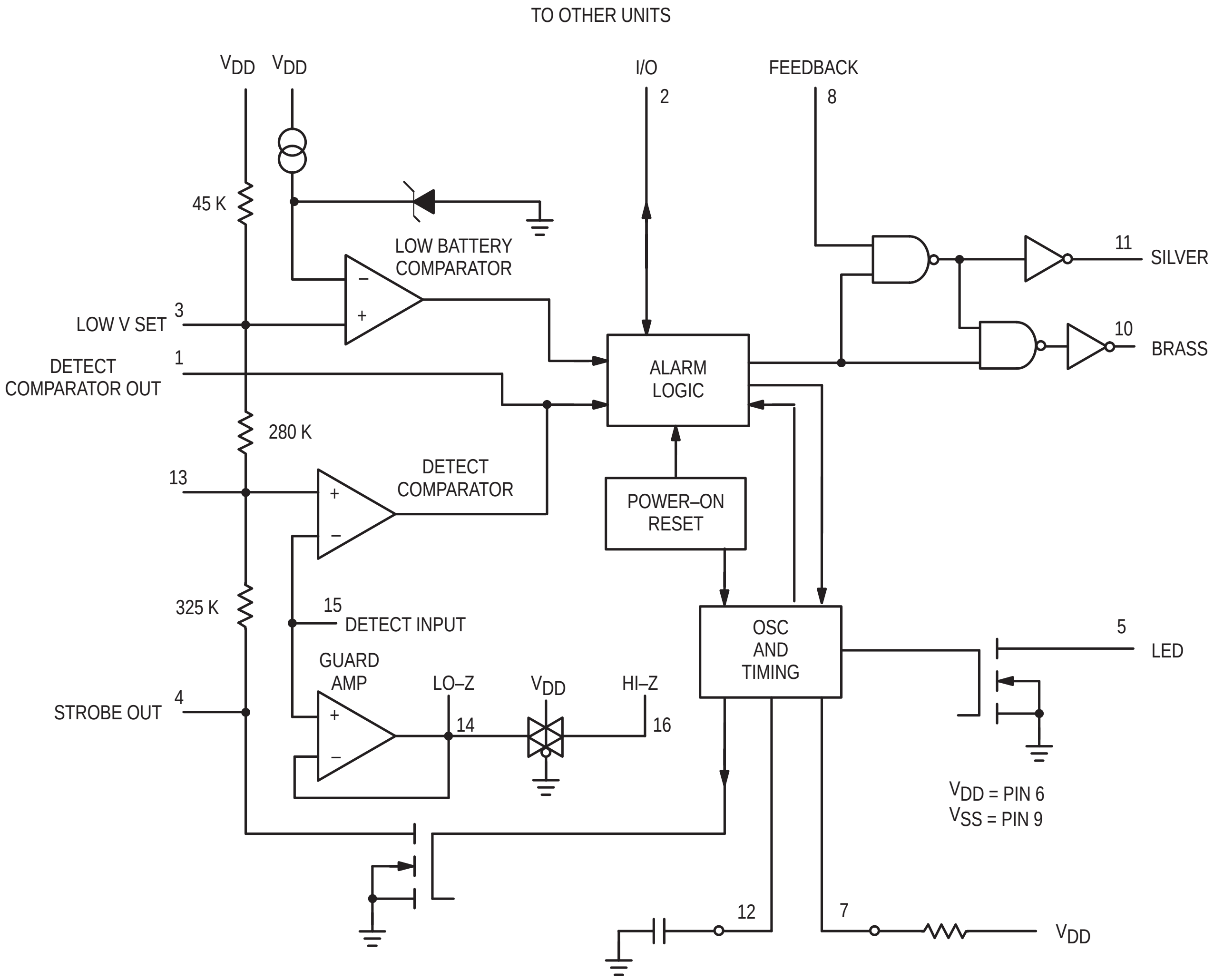


Figure 1. Block Diagram

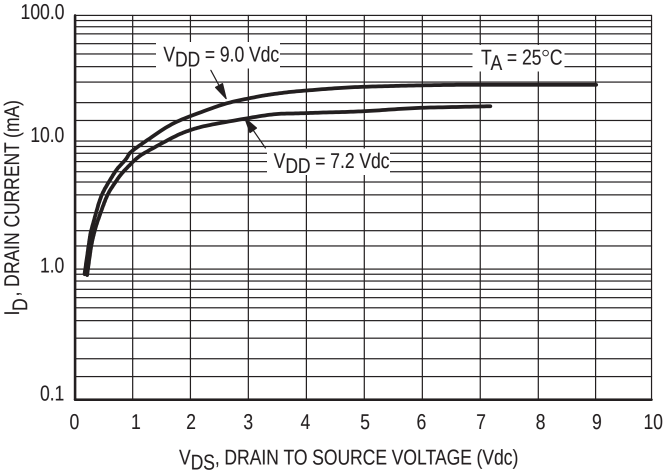


Figure 2. Typical LED Output I–V Characteristic

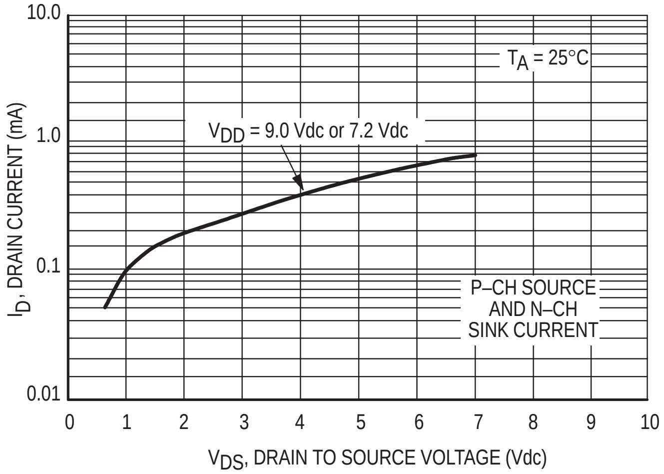


Figure 3. Typical Comparator Output I–V Characteristic

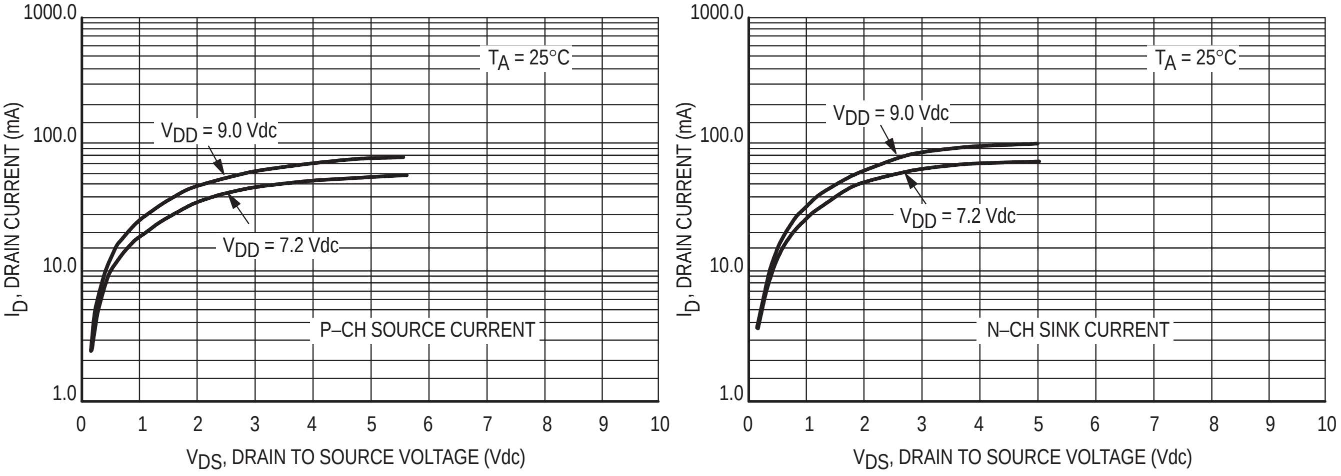


Figure 4. Typical P Horn Driver Output I–V Characteristic

DEVICE OPERATION

TIMING

The internal oscillator of the MC14468 operates with a period of 1.67 seconds during no–smoke conditions. Each 1.67 seconds, internal power is applied to the entire IC and a check is made for smoke, except during LED pulse, Low Battery Alarm Chirp, or Horn Modulation (in smoke). Every 24 clock cycles a check is made for low battery by comparing V_{DD} to an internal zener voltage. Since very small currents are used in the oscillator, the oscillator capacitor should be of a low leakage type.

DETECT CIRCUITRY

If smoke is detected, the oscillator period becomes 40 ms and the piezoelectric horn oscillator circuit is enabled. The horn output is modulated 160 ms on, 80 ms off. During the off time, smoke is again checked and will inhibit further horn output if no smoke is sensed. During local smoke conditions the low battery alarm is inhibited, but the LED pulses at a 1.0 Hz rate. In remote smoke, the LED is inhibited as well.

An active guard is provided on both pins adjacent to the detect input. The voltage at these pins will be within 100 mV of the input signal. This will keep surface leakage currents to a minimum and provide a method of measuring the input voltage without loading the ionization chamber. The active guard op amp is not power strobed and thus gives constant protection from surface leakage currents. Pin 15 (the Detect input) has internal diode protection against static damage.

INTERCONNECT

The I/O (Pin 2), in combination with V_{SS}, is used to interconnect up to 40 remote units for common signaling. A Local Smoke condition activates a current limited output driver, thereby signaling Remote Smoke to interconnected units. A small current sink improves noise immunity during non–smoke conditions. Remote units at lower voltages do not draw excessive current from a sending unit at a higher voltage. The I/O is disabled for three oscillator cycles after power up, to eliminate false alarming of remote units when the battery is changed.

SENSITIVITY/LOW BATTERY THRESHOLDS

Both the sensitivity threshold and the low battery voltage levels are set internally by a common voltage divider connected between V_{DD} and V_{SS}. These voltages can be altered by external resistors connected from pins 3 or 13 to either V_{DD} or V_{SS}. There will be a slight interaction here due to the common voltage divider network. The sensitivity threshold can also be set by adjusting the smoke chamber ionization source.

TEST MODE

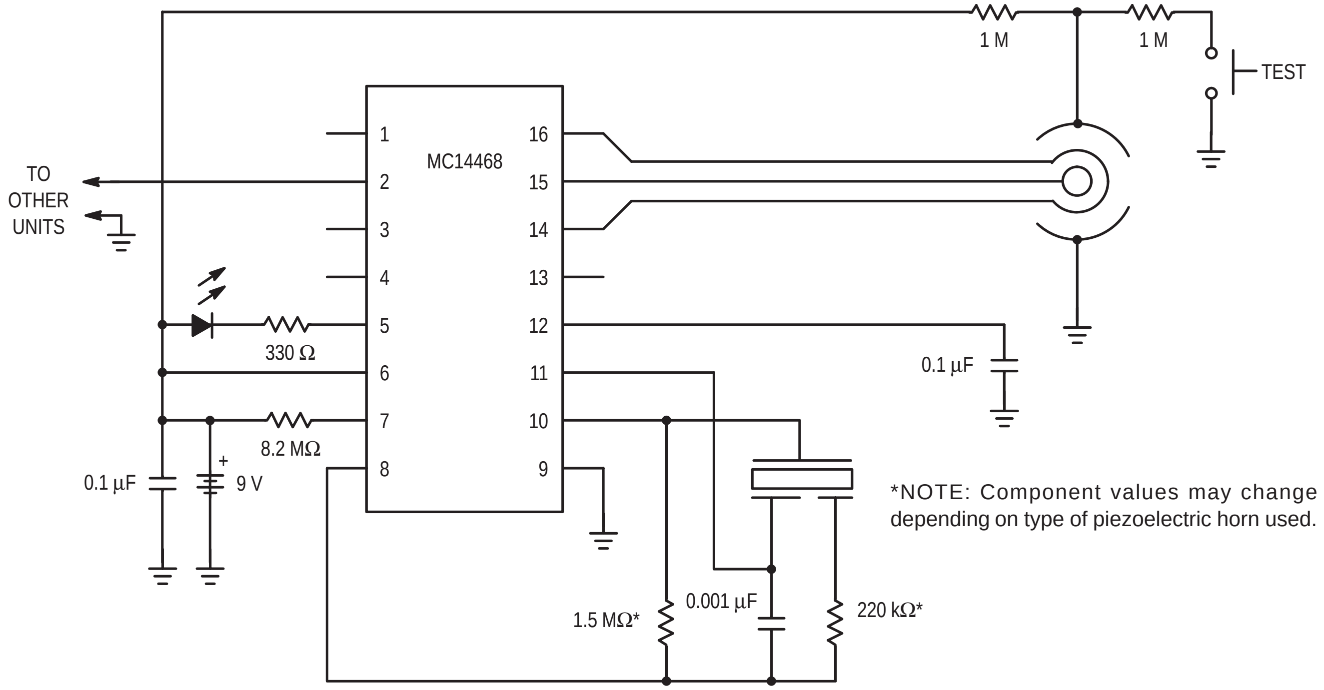
Since the internal op amps and comparators are power strobed, adjustments for sensitivity or low battery level could be difficult and/or time–consuming. By forcing Pin 12 to V_{SS}, the power strobing is bypassed and the output, Pin 1, constantly shows smoke/no smoke. Pin 1 = V_{DD} for smoke. In this mode and during the 10 ms power strobe, chip current rises to approximately 50 µA.

LED PULSE

The 9–volt battery level is checked every 40 seconds during the LED pulse. The battery is loaded via a 10 mA pulse for 10 ms. If the LED is not used, it should be replaced with an equivalent resistor such that the battery loading remains at 10 mA.

HYSTERESIS

When smoke is detected, the resistor/divider network that sets sensitivity is altered to increase sensitivity. This yields approximately 100 mV of hysteresis and reduces false triggering.



*NOTE: Component values may change depending on type of piezoelectric horn used.

Figure 5. Typical Application as Ionization Smoke Detector

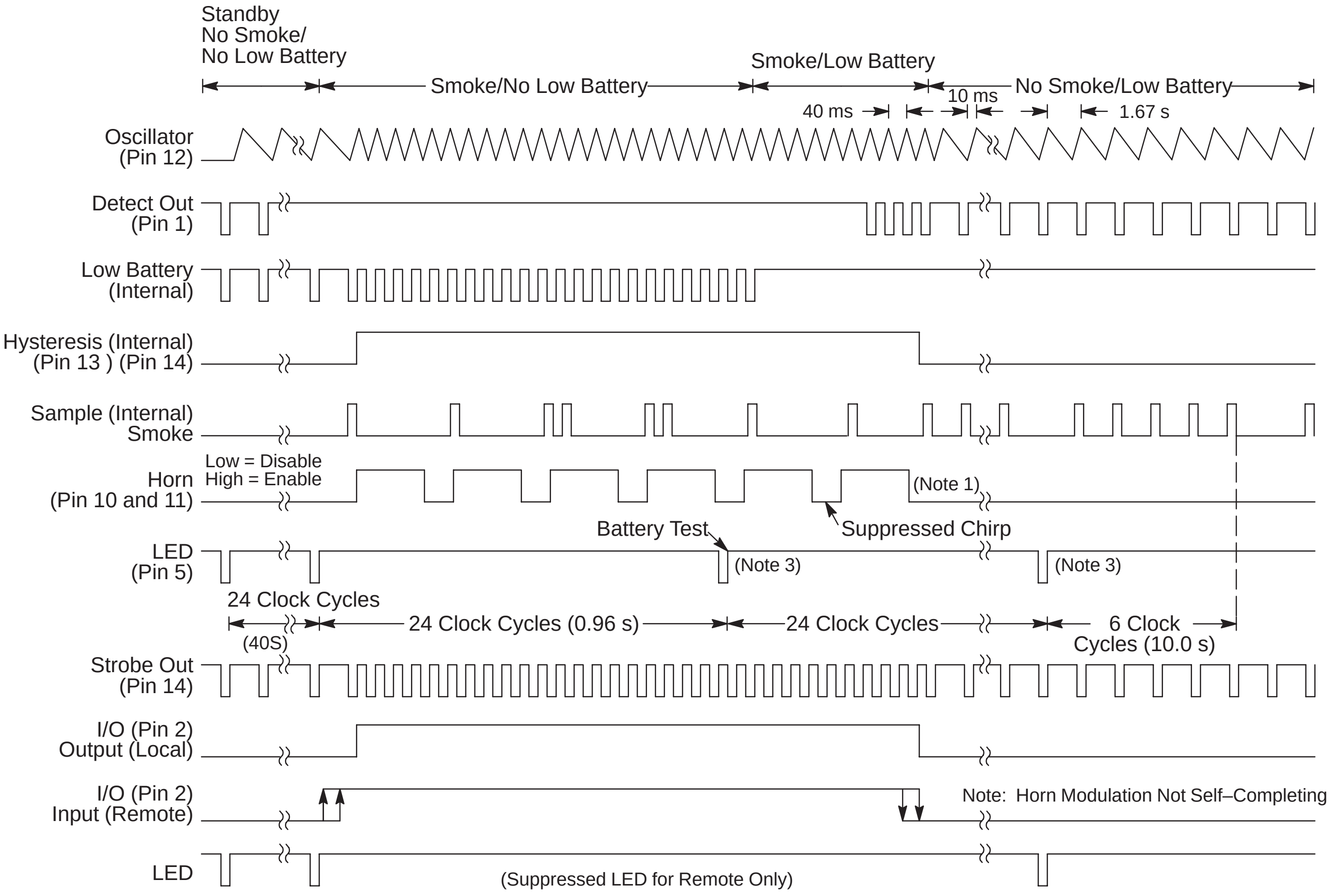


Figure 6. Timing Diagram

NOTES:
1. Horn modulation is self–completing. When going from smoke to no smoke, the alarm condition will terminate only when horn is off.
2. Comparators are strobed on once per clock cycle (1.67 s for no smoke, 40 ms for smoke).
3. Low battery comparator information is latched only during LED pulse.
4. ~ 100 mV p–p swing.

Photoelectric Smoke Detector with I/O

For Battery–Powered Applications

MC145010

The CMOS MC145010 is an advanced smoke detector component containing sophisticated very–low–power analog and digital circuitry. The IC is used with an infrared photoelectric chamber. Detection is accomplished by sensing scattered light from minute smoke particles or other aerosols. When detection occurs, a pulsating alarm is sounded via on–chip push–pull drivers and an external piezoelectric transducer.

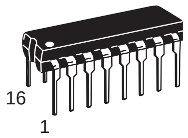
The variable–gain photo amplifier allows direct interface to IR detectors (photodiodes). Two external capacitors, C1 and C2, C1 being the larger, determine the gain settings. Low gain is selected by the IC during most of the standby state. Medium gain is selected during a local–smoke condition. High gain is used during pushbutton test. During standby, the special monitor circuit which periodically checks for degraded chamber sensitivity uses high gain, also.

The I/O pin, in combination with V_{SS}, can be used to interconnect up to 40 units for common signaling. An on–chip current sink provides noise immunity when the I/O is an input. A local–smoke condition activates the short–circuit–protected I/O driver, thereby signaling remote smoke to the interconnected units. Additionally, the I/O pin can be used to activate escape lights, enable auxiliary or remote alarms, and/or initiate auto–dialers.

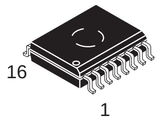
While in standby, the low–supply detection circuitry conducts periodic checks using a pulsed load current from the LED pin. The trip point is set using two external resistors. The supply for the MC145010 can be a 9 V battery.

A visible LED flash accompanying a pulsating audible alarm indicates a local–smoke condition. A pulsating audible alarm with no LED flash indicates a remote–smoke condition. A beep or chirp occurring virtually simultaneously with an LED flash indicates a low–supply condition. A beep occurring half–way between LED flashes indicates degraded chamber sensitivity. A low–supply condition does not affect the smoke detection capability if $V_{DD} \ge 6$ V. Therefore, the low–supply condition and degraded chamber sensitivity can be further distinguished by performing a pushbutton (chamber) test.

- Complies with the UL217 and UL268 Specifications
- Operating Voltage Range: 6 to 12 V
- Operating Temperature Range: – 10 to 60°C
- Average Supply Current: 12 µA
- Power–On Reset Places IC in Standby Mode (Non–Alarm State)
- Electrostatic Discharge (ESD) and Latch Up Protection Circuitry on All Pins
- Chip Complexity: 2000 FETs, 12 NPNs, 16 Resistors, and 10 Capacitors



P SUFFIX
PLASTIC DIP
CASE 648–08

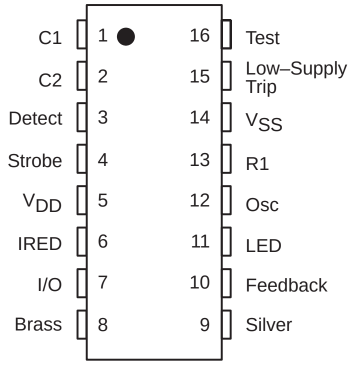


DW SUFFIX
SOG PACKAGE
CASE 751G–03

ORDERING INFORMATION

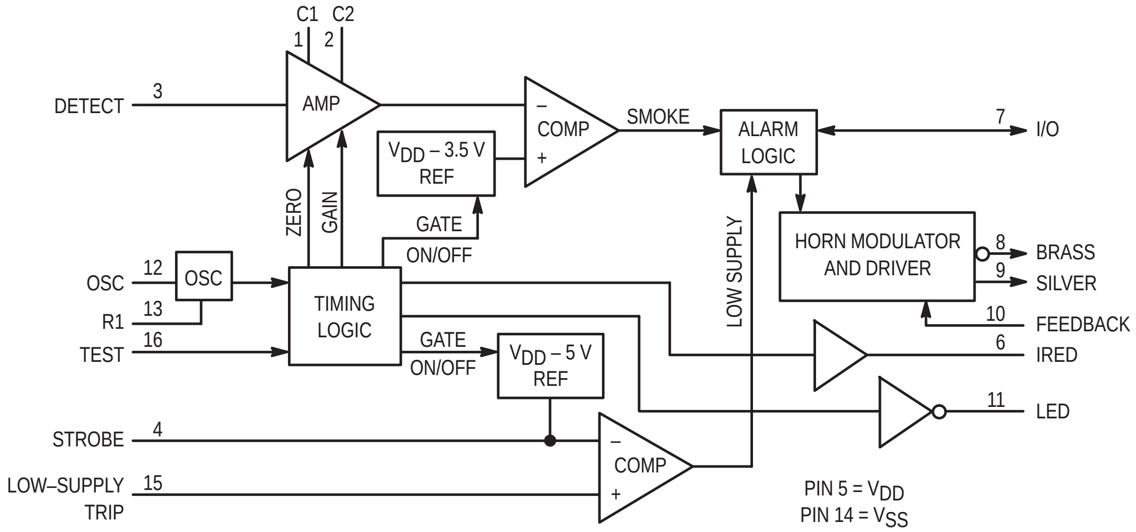
MC145010P	**PLASTIC DIP**
MC145010DW	**SOG PACKAGE**

PIN ASSIGNMENT



REV 1

BLOCK DIAGRAM



MAXIMUM RATINGS* (Voltages Referenced to V_{SS})

Symbol	Parameter		Value	Unit
V_{DD}	DC Supply Voltage		– 0.5 to +12	V
V_{in}	DC Input Voltage	C1, C2, Detect Osc, Low–Supply Trip I/O Feedback Test	– 0.25 to V_{DD} +0.25 – 0.25 to V_{DD} +0.25 – 0.25 to V_{DD} +10 – 15 to +25 – 1.0 to V_{DD} +0.25	V
I_{in}	DC Input Current, per Pin		± 10	mA
I_{out}	DC Output Current, per Pin		± 25	mA
I_{DD}	DC Supply Current, V_{DD} and V_{SS} Pins		+25 / – 150	mA
P_D	Power Dissipation in Still Air,	5 Seconds Continuous	1200** 350***	mW
T_{stg}	Storage Temperature		– 55 to +125	°C
T_L	Lead Temperature, 1 mm from Case for 10 Seconds		260	°C

* Maximum Ratings are those values beyond which damage to the device may occur. Functional operation should be restricted to the limits in the Electrical Characteristics tables.

** Derating: – 12 mW/°C from 25° to 60°C.

*** Derating: – 3.5 mW/°C from 25° to 60°C.

This device contains protection circuitry to guard against damage due to high static voltages or electric fields. However, precautions must be taken to avoid applications of any voltage higher than maximum rated voltages to this high–impedance circuit. For proper operation, V_{in} and V_{out} should be constrained to the range $V_{SS} \leq (V_{in}$ or $V_{out}) \leq V_{DD}$ except for the I/O, which can exceed V_{DD}, and the Test input, which can go below V_{SS}.

Unused inputs must always be tied to an appropriate logic voltage level (e.g., either V_{SS} or V_{DD}). Unused outputs and/or an unused I/O must be left open.

ELECTRICAL CHARACTERISTICS (T_A = – 10 to 60°C Unless Otherwise Indicated, Voltages Referenced to V_{SS})

Symbol	Parameter	Test Condition	V_{DD} V	Min	Max	Unit
V_{DD}	Power Supply Voltage Range		—	6.0	12	V
V_{TH}	Supply Threshold Voltage, Low–Supply Alarm	Low–Supply Trip: $V_{in} = V_{DD}/3$	—	6.5	7.8	V
I_{DD}	Average Operating Supply Current (per Package)	Standby Configured per Figure 5	12.0	—	12	µA
i_{DD}	Peak Supply Current (per Package)	During Strobe On, IRED Off Configured per Figure 5	12.0	—	2.0	mA
		During Strobe On, IRED On Configured per Figure 5	12.0	—	3.0	
V_{IL}	Low–Level Input Voltage I/O		9.0	—	1.5	V
	Feedback		9.0	—	2.7	
	Test		9.0	—	7.0	
V_{IH}	High–Level Input Voltage I/O		9.0	3.2	—	V
	Feedback		9.0	6.3	—	
	Test		9.0	8.5	—	
I_{in}	Input Current OSC, Detect	$V_{in} = V_{SS}$ or V_{DD}	12.0	—	± 100	nA
	Low–Supply Trip	$V_{in} = V_{SS}$ or V_{DD}	12.0	—	± 100	
	Feedback	$V_{in} = V_{SS}$ or V_{DD}	12.0	—	± 100	
I_{IL}	Low–Level Input Current Test	$V_{in} = V_{SS}$	12.0	—	– 1	µA
I_{IH}	Pull–Down Current Test	$V_{in} = V_{DD}$	9.0	0.5	10	µA
	I/O	No Local Smoke, $V_{in} = V_{DD}$	9.0	25	100	
		No Local Smoke, V_{in} = 17 V	12.0	—	140	
V_{OL}	Low–Level Output Voltage LED	I_{out} = 10 mA	6.5	—	0.6	V
	Silver, Brass	I_{out} = 16 mA	6.5	—	1.0	
V_{OH}	High–Level Output Voltage Silver, Brass	I_{out} = – 16 mA	6.5	5.5	—	V
V_{out}	Output Voltage (For Line Regulation, See Pin Descriptions) Strobe	Inactive, I_{out} = –1 µA	—	V_{DD} – 0.1	—	V
		Active, I_{out} = 100 µA to 500 µA (Load Regulation)	9.0	V_{DD} – 4.4	V_{DD} – 5.6	
	IRED	Inactive, I_{out} = 1 µA	—	—	0.1	
		Active, I_{out} = 6 mA (Load Regulation)	9.0	2.25*	3.75*	
I_{OH}	High–Level Output Current I/O	Local Smoke, V_{out} = 4.5 V	6.5	– 4	—	mA
		Local Smoke, $V_{out} = V_{SS}$ (Short Circuit Current)	12.0	—	– 16	
I_{OZ}	Off–State Output Leakage Current LED	$V_{out} = V_{SS}$ or V_{DD}	12.0	—	± 1	µA
V_{IC}	Common Mode Voltage Range C1, C2, Detect	Local Smoke, Pushbutton Test, or Chamber Sensitivity Test	—	V_{DD} – 4	V_{DD} – 2	V
V_{ref}	Smoke Comparator Reference Voltage Internal	Local Smoke, Pushbutton Test, or Chamber Sensitivity Test	—	V_{DD} – 3.08	V_{DD} – 3.92	V

* T_A = 25°C only.

AC ELECTRICAL CHARACTERISTICS (Reference Timing Diagram Figures 3 and 4)

(T_A = 25°C, V_{DD} = 9.0 V, Component Values from Figure 5: R1 = 100.0 KΩ, C3 = 1500.0 pF, R2 = 10.0 MΩ)

No.	Symbol	Parameter	Test Condition	Clocks	Min	Max	Unit
1	$1/f_{osc}$	Oscillator Period*	Free–Running Sawtooth Measured at Pin 12	1	9.5	11.5	ms
2	t_{LED}	LED Pulse Period	No Local Smoke, and No Remote Smoke	4096	38.9	47.1	s
3			Remote Smoke, but No Local Smoke	—	None		
4			Local Smoke or Pushbutton Test	64	0.60	0.74	
5	$t_{w(LED)}$, $t_{w(stb)}$	LED Pulse Width and Strobe Pulse Width		1	9.5	11.5	ms
6	t_{IRED}	IRED Pulse Period	Smoke Test	1024	9.67	11.83	s
7			Chamber Sensitivity Test, without Local Smoke	4096	38.9	47.1	
8			Pushbutton Test	32	0.302	0.370	
9	$t_{w(IRED)}$	IRED Pulse Width		T_f*	94	116	µs
10	t_r	IRED Rise Time		—	—	30	µs
	t_f	IRED Fall Time		—	—	200	
11	t_{mod}	Silver and Brass Modulation Period	Local or Remote Smoke	—	297	363	ms
11,12	t_{on}/t_{mod}	Silver and Brass Duty Cycle	Local or Remote Smoke	—	73	77	%
13	t_{CH}	Silver and Brass Chirp Pulse Period	Low Supply or Degraded Chamber Sensitivity	4096	38.9	47.1	s
14	$t_{w(CH)}$	Silver and Brass Chirp Pulse Width	Low Supply or Degraded Chamber Sensitivity	1	9.5	11.5	ms
15	t_{RR}	Rising Edge on I/O to Smoke Alarm Response Time	Remote Smoke, No Local Smoke	—	—	800	ms
16	t_{stb}	Strobe Out Pulse Period	Smoke Test	1024	9.67	11.83	s
17			Chamber Sensitivity Test, without Local Smoke	4096	38.9	47.1	
18			Low Supply Test, without Local Smoke	4096	38.9	47.1	
19			Pushbutton Test	—	0.302	0.370	

* Oscillator period T (= $T_r + T_f$) is determined by the external components R1, R2, and C3 where $T_r = (0.6931)\ R_2 * C_3$ and $T_f = (0.6931)\ R_1 * C_3$.

The other timing characteristics are some multiple of the oscillator timing as shown in the table.

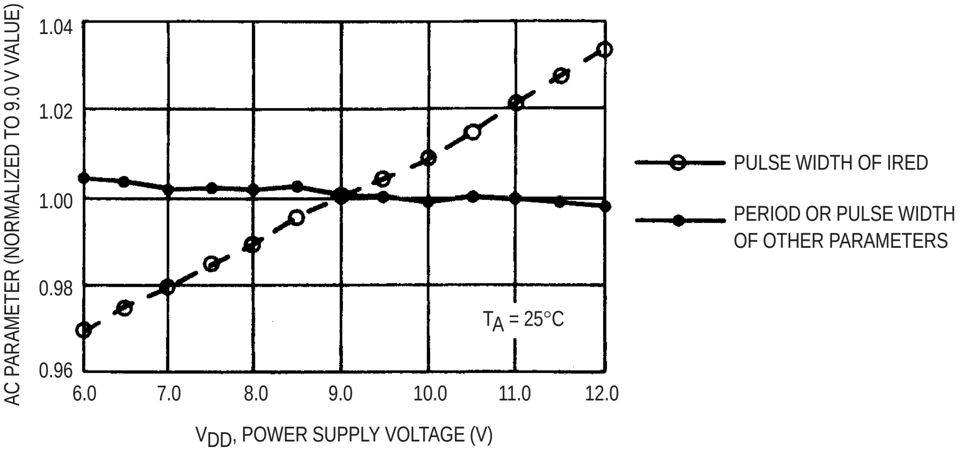
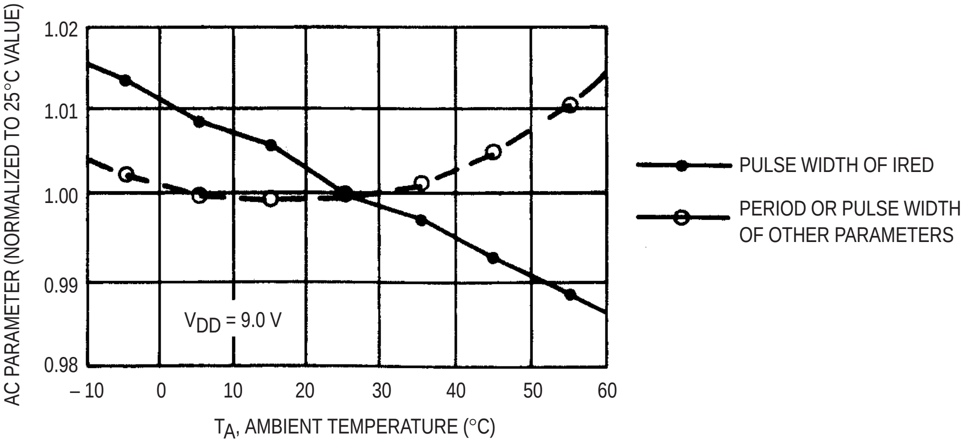
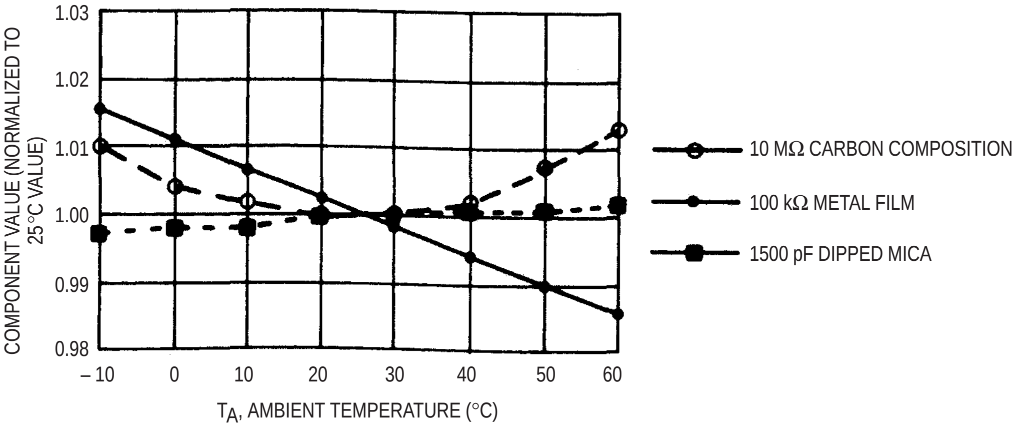


Figure 1. AC Characteristics versus Supply



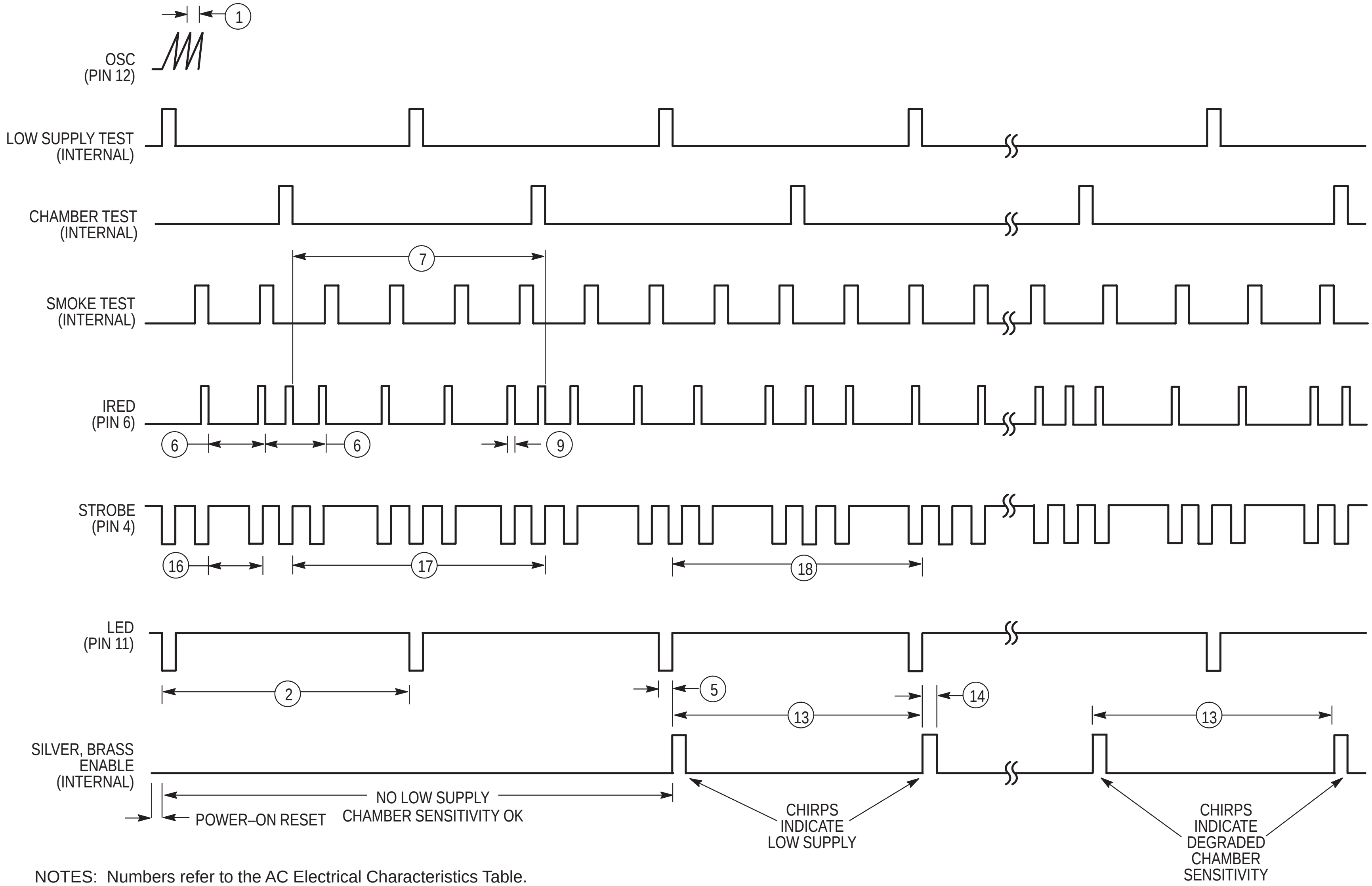
NOTE: Includes external component variations. See Figure 2B.

Figure 2A. AC Characteristics versus Temperature



NOTE: These components were used to generate Figure 2A.

Figure 2B. RC Component Variation Over Temperature



NOTES: Numbers refer to the AC Electrical Characteristics Table.
Illustration is not to scale.

Figure 3. Standby Timing Diagram

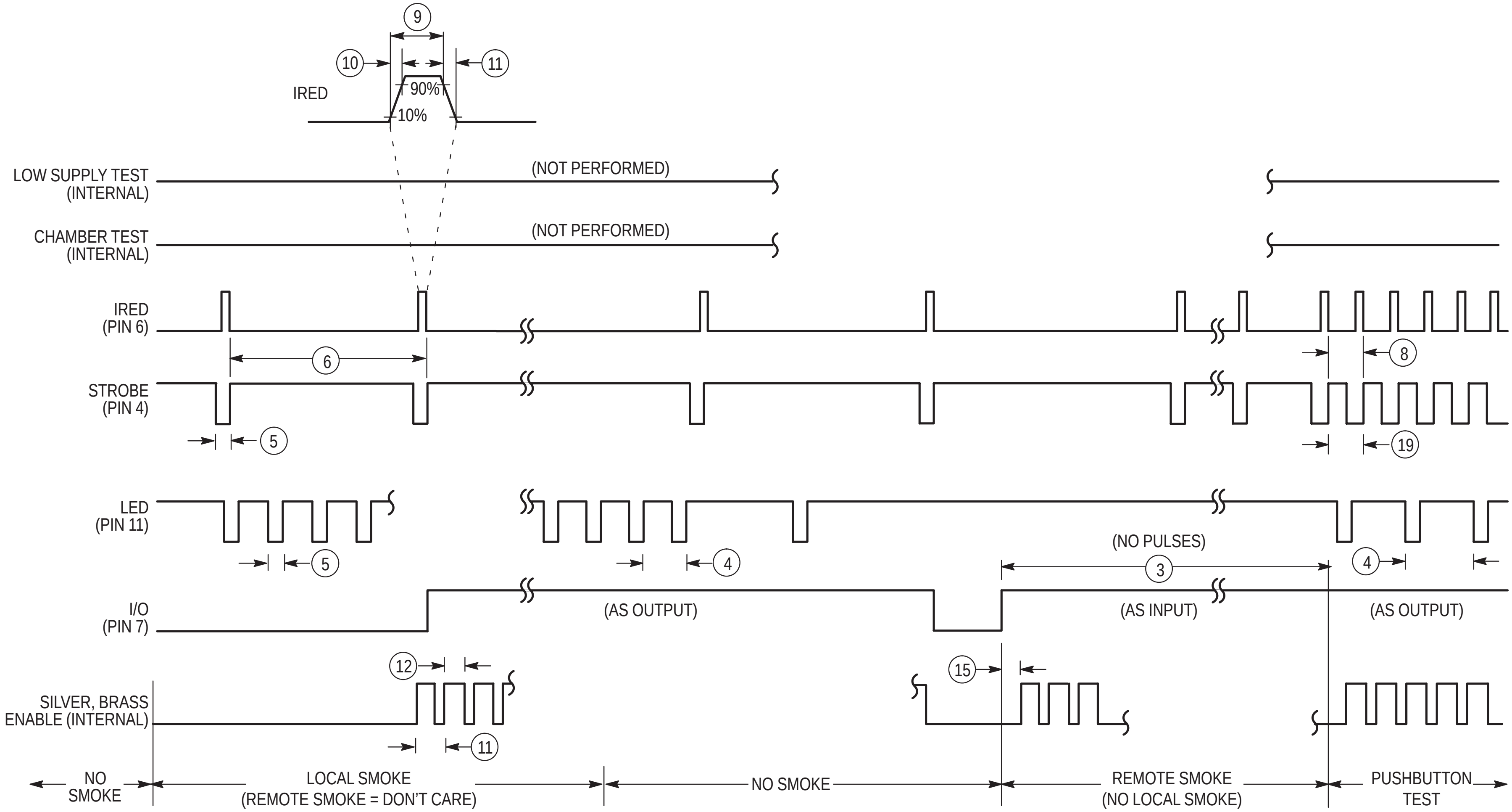
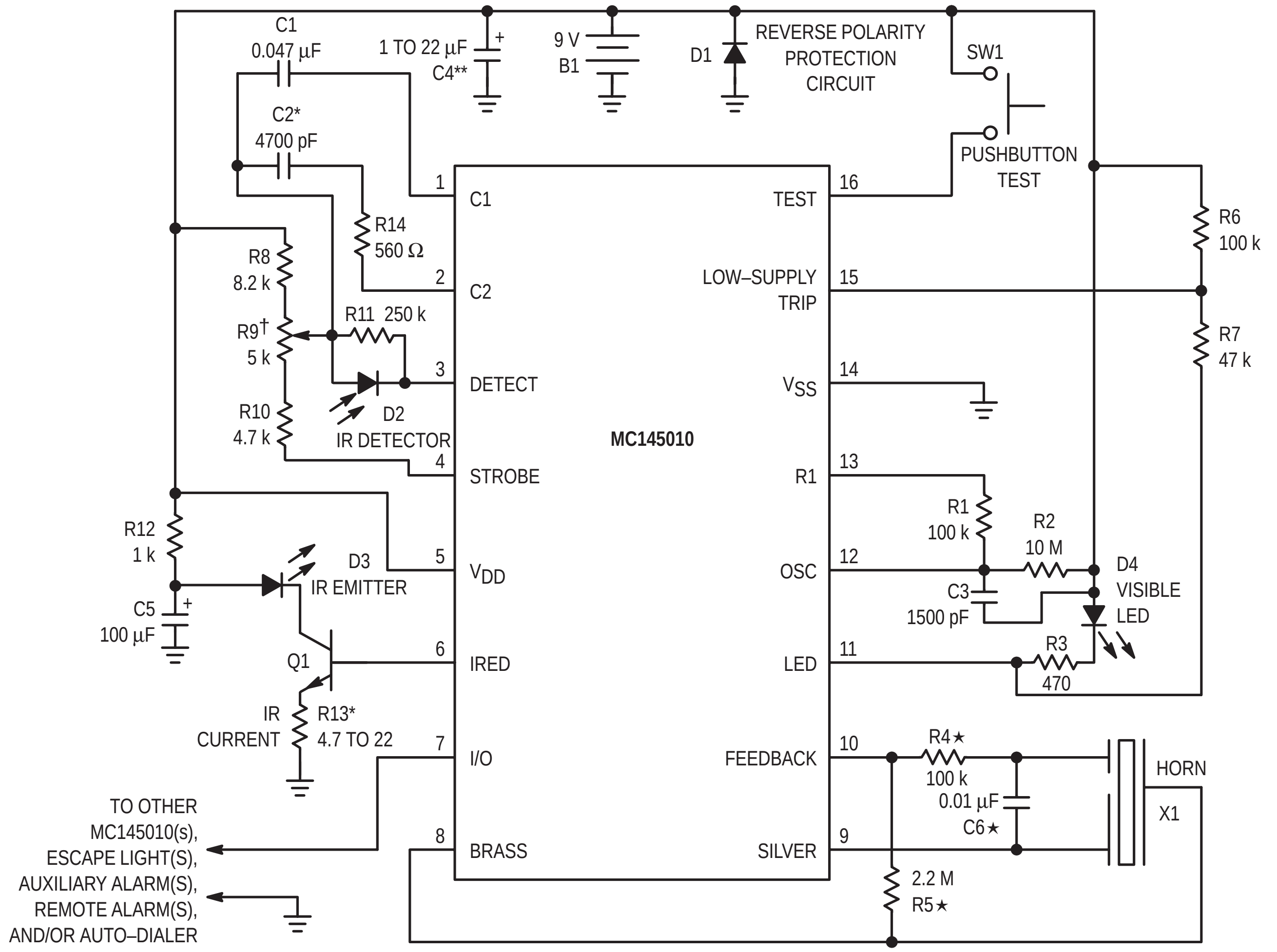


Figure 4. Smoke Timing Diagram

NOTES: Numbers refer to the AC Electrical Characteristics Table.
Illustration is not to scale.



★Values for R4, R5, and C6 may differ depending on type of piezoelectric horn used.
* C2 and R13 are used for coarse sensitivity adjustment. Typical values are shown.
†R9 is for fine sensitivity adjustment (optional). If fixed resistors are used, R8 = 12 k, R10 is 5.6 k to 10 k, and R9 is eliminated. When R9 is used, noise pickup is increased due to antenna effects. Shielding may be required.
**C4 should be 22 µF if B1 is a carbon battery. C4 could be reduced to 1 µF when an alkaline battery is used.

Figure 5. Typical Battery–Powered Application

PIN DESCRIPTIONS

C1 (Pin 1)

A capacitor connected to this pin as shown in Figure 5 determines the gain of the on–chip photo amplifier during pushbutton test and chamber sensitivity test (high gain). The capacitor value is chosen such that the alarm is tripped from background reflections in the chamber during pushbutton test.

$A_V \approx 1 + (C1/10)$ where C1 is in pF. CAUTION: The value of the closed–loop gain should not exceed 10,000.

C2 (Pin 2)

A capacitor connected to this pin as shown in Figure 5 determines the gain of the on–chip photo amplifier except during pushbutton or chamber sensitivity tests.

$A_V \approx 1 + (C2/10)$ where C2 is in pF. This gain increases about 10% during the IRED pulse, after two consecutive local smoke detections.

Resistor R14 must be installed in series with C2. $R14 \approx [1/(12\sqrt{C2})] - 680$ where R14 is in ohms and C2 is in farads.

DETECT (Pin 3)

This input to the high–gain pulse amplifier is tied to the cathode of an external photodiode. The photodiode should have low capacitance and low dark leakage current. The diode must be shunted by a load resistor and is operated at zero bias.

The Detect input must be ac/dc decoupled from all other signals, V_{DD}, and V_{SS}. Lead length and/or foil traces to this pin must be minimized, also. See Figure 6.

STROBE (Pin 4)

This output provides a strobed, regulated voltage referenced to V_{DD}. The temperature coefficient of this voltage is ± 0.2%/°C maximum from – 10° to 60°C. The supply–voltage coefficient (line regulation) is ± 0.2%/V maximum from 6 to 12 V. Strobe is tied to external resistor string R8, R9, and R10.

V_{DD} (Pin 5)

This pin is connected to the positive supply potential and may range from +6 to +12 V with respect to V_{SS}. CAUTION: In battery–powered applications, reverse–polarity protection must be provided externally.

IRED (Pin 6)

This output provides pulsed base current for external NPN transistor Q1 used as the infrared emitter driver. Q1 must have $\beta \geq 100$. At 10 mA, the temperature coefficient of the output voltage is typically + 0.5%/°C from – 10° to 60°C. The supply–voltage coefficient (line regulation) is ± 0.2%/V maximum from 6 to 12 V. The IRED pulse width (active–high) is determined by external components R1 and C3. With a 100 kΩ/1500 pF combination, the nominal width is 105 µs.

To minimize noise impact, IRED is not active when the visible LED and horn outputs are active. IRED is active near the end of Strobe pulses for Smoke Tests, Chamber Sensitivity Test, and Pushbutton Test.

I/O (Pin 7)

This pin can be used to connect up to 40 units together in a wired–OR configuration for common signaling. V_{SS} is used as the return. An on–chip current sink minimizes noise pick up during non–smoke conditions and eliminates the need for an external pull–down resistor to complete the wired–OR. Remote units at lower supply voltages do not draw excessive current from a sending unit at a higher supply voltage.

I/O can also be used to activate escape lights, auxiliary alarms, remote alarms, and/or auto–dialers.

As an input, this pin feeds a positive–edge–triggered flip–flop whose output is sampled nominally every 625 ms during standby (using the recommended component values). A local–smoke condition or the pushbutton–test mode forces this current–limited output to source current. All input signals are ignored when I/O is sourcing current.

I/O is disabled by the on–chip power–on reset to eliminate nuisance signaling during battery changes or system power–up.

If unused, I/O must be left unconnected.

BRASS (Pin 8)

This half of the push–pull driver output is connected to the metal support electrode of a piezoelectric audio transducer and to the horn–starting resistor. A continuous modulated tone from the transducer is a smoke alarm indicating either local or remote smoke. A short beep or chirp is a trouble alarm indicating a low supply or degraded chamber sensitivity.

SILVER (Pin 9)

This half of the push–pull driver output is connected to the ceramic electrode of a piezoelectric transducer and to the horn–starting capacitor.

FEEDBACK (Pin 10)

This input is connected to both the feedback electrode of a self–resonating piezoelectric transducer and the horn–starting resistor and capacitor through current–limiting resistor R4. If unused, this pin must be tied to V_{SS} or V_{DD}.

LED (Pin 11)

This active–low open–drain output directly drives an external visible LED at the pulse rates indicated below. The pulse width is equal to the OSC period.

The load for the low–supply test is applied by this output. This low–supply test is non–coincident with the smoke tests, chamber sensitivity test, pushbutton test, or any alarm signals.

The LED also provides a visual indication of the detector status as follows, assuming the component values shown in Figure 5:

Standby (includes low–supply and chamber sensitivity tests) — Pulses every 43 seconds (nominal)

Local Smoke — Pulses every 0.67 seconds (nominal)

Remote Smoke — No pulses

Pushbutton Test — Pulses every 0.67 seconds (nominal)

OSC (Pin 12)

This pin is used in conjunction with external resistor R2 (10 MΩ) to V_{DD} and external capacitor C3 (1500 pF) to V_{DD} to form an oscillator with a nominal period of 10.5 ms.

R1 (Pin 13)

This pin is used in conjunction with resistor R1 (100 kΩ) to pin 12 and C3 (1500 pF, see pin 12 description) to determine the IRED pulse width. With this RC combination, the nominal pulse width is 105 µs.

V_{SS} (Pin 14)

This pin is the negative supply potential and the return for the I/O pin. Pin 14 is usually tied to ground.

LOW–SUPPLY TRIP (Pin 15)

This pin is connected to an external voltage which determines the low–supply alarm threshold. The trip voltage is obtained through a resistor divider connected between the V_{DD} and LED pins. The low–supply alarm threshold voltage (in volts) ≈ (5R7/R6) + 5 where R6 and R7 are in the same units.

TEST (Pin 16)

This input has an on–chip pull–down device and is used to manually invoke a test mode.

The *Pushbutton Test* mode is initiated by a high level at pin 16 (usually depression of a S.P.S.T. normally–open pushbutton switch to V_{DD}). After one oscillator cycle, IRED pulses approximately every 336 ms, regardless of the presence of smoke. Additionally, the amplifier gain is increased by automatic selection of C1. Therefore, the background reflections in the smoke chamber may be interpreted as smoke, generating a simulated–smoke condition. After the second IRED pulse, a successful test activates the horn–driver and I/O circuits. The active I/O allows remote signaling for system testing. When the Pushbutton Test switch is released, the Test input returns to V_{SS} due to the on–chip pull–down device. After one oscillator cycle, the amplifier gain returns to normal, thereby removing the simulated–smoke condition. After two additional IRED pulses, less than a second, the IC exits the alarm mode and returns to standby timing.

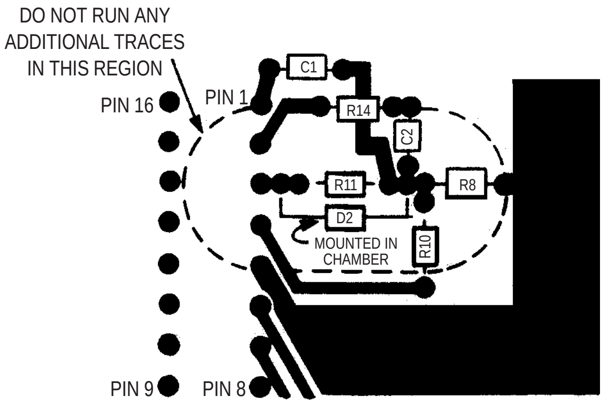
CALIBRATION

To facilitate checking the sensitivity and calibrating smoke detectors, the MC145010 can be placed in a calibration mode. In this mode, certain device pins are controlled/reconfigured as shown in Table 1. To place the part in the calibration mode, pin 16 (Test) must be pulled below the V_{SS} pin with 100 µA continuously drawn out of the pin for at least one cycle on the OSC pin. To exit this mode, the Test pin is floated for at least one OSC cycle.

In the calibration mode, the IRED pulse happens at every clock cycle and strobe is always on (active low). Also, Low Battery and supervisory tests are disabled in this mode.

Table 1. Configuration of Pins in the Calibration Mode

Description	Pin	Comment
I/O	7	Disabled as an output. Forcing this pin high places the photo amp output on pin 1 or 2, as determined by Low–Supply Trip. The amp's output appears as pulses and is referenced to V_{DD}.
Low–Supply Trip	15	If the I/O pin is high, pin 15 controls which gain capacitor is used. Low: normal gain, amp output on pin 1. High: supervisory gain, amp output on pin 2.
Feedback	10	Driving this input high enables hysteresis (10% gain increase) in the photo amp; pin 15 must be low.
OSC	12	Driving this input high brings the internal clock high. Driving the input low brings the internal clock low. If desired, the RC network for the oscillator may be left intact; this allows the oscillator to run similar to the normal mode of operation.
Silver	9	This pin becomes the smoke comparator output. When the OSC pin is toggling, positive pulses indicate that smoke has been detected. A static low level indicates no smoke.
Brass	8	This pin becomes the smoke integrator output. That is, 2 consecutive smoke detections are required for "on" (static high level) and 2 consecutive no–detections for "off" (static low level).



NOTES: Illustration is bottom view of layout using a DIP. Top view for SOIC layout is mirror image.
Optional potentiometer R9 is not included.
Drawing is not to scale.
Leads on D2, R11, R8, and R10 and their associated traces must be kept as short as possible. This practice minimizes noise pick up.
Pin 3 must be decoupled from all other traces.

Figure 6. Recommended PCB Layout

MOTOROLA
SEMICONDUCTOR TECHNICAL DATA

Photoelectric Smoke Detector with I/O

For Line–Powered Applications

MC145011

The CMOS MC145011 is an advanced smoke detector component containing sophisticated very–low–power analog and digital circuitry. The IC is used with an infrared photoelectric chamber. Detection is accomplished by sensing scattered light from minute smoke particles or other aerosols. When detection occurs, a pulsating alarm is sounded via on–chip push–pull drivers and an external piezoelectric transducer.

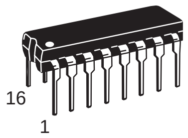
The variable–gain photo amplifier allows direct interface to IR detectors (photo–diodes). Two external capacitors C1 and C2, C1 being the larger, determine the gain settings. Low gain is selected by the IC during most of the standby state. Medium gain is selected during a local–smoke condition. High gain is used during pushbutton test. During standby, the special monitor circuit which periodically checks for degraded chamber sensitivity uses high gain, also.

The I/O pin, in combination with V_{SS}, can be used to interconnect up to 40 units for common signaling. An on–chip current sink provides noise immunity when the I/O is an input. A local–smoke condition activates the short–circuit–protected I/O driver, thereby signaling remote smoke to the interconnected units. Additionally, the I/O pin can be used to activate escape lights, enable auxiliary or remote alarms, and/or initiate auto–dialers.

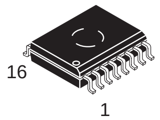
While in standby, the low–supply detection circuitry conducts periodic checks using a load current from the LED pin. The trip point is set using two external resistors. The supply for the MC145011 must be a dc power source capable of supplying 35 mA continuously and 45 mA peak. When the MC145011 is in standby, an external LED is continuously illuminated to indicate that the device is receiving power.

An extinguished LED accompanied by a pulsating audible alarm indicates a local–smoke condition. A pulsating audible alarm with the LED illuminated indicates a remote–smoke condition. A beep or chirp indicates a low–supply condition or degraded chamber sensitivity. A low–supply condition does not affect the smoke detection capability if $V_{DD} \geq 6$ V. Therefore, the low–supply condition and degraded chamber sensitivity can be distinguished by performing a pushbutton (chamber) test.

- Complies with the UL217 and UL268 Specifications
- Operating Voltage Range: 6 to 12 V
- Operating Temperature Range: –10 to 60°C
- Average Standby Supply Current (Visible LED Illuminated): 20 mA
- Power–On Reset Places IC in Standby Mode (Non–Alarm State)
- Electrostatic Discharge (ESD) and Latch Up Protection Circuitry on All Pins
- Chip Complexity: 2000 FETs, 12 NPNs, 16 Resistors, and 10 Capacitors



P SUFFIX
PLASTIC DIP
CASE 648–08

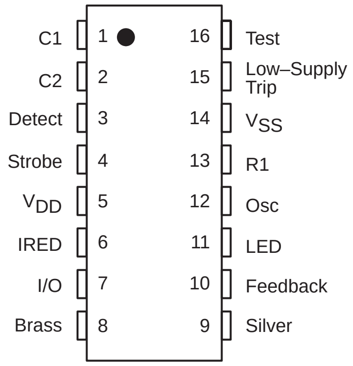


DW SUFFIX
PLASTIC SOG
CASE 751G–03

ORDERING INFORMATION

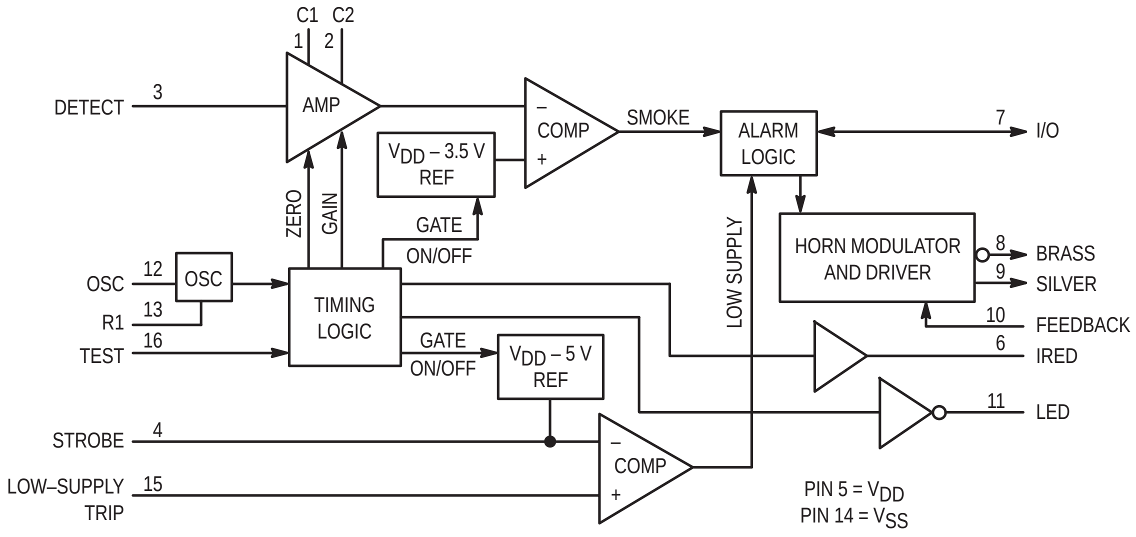
MC145011P	**PLASTIC DIP**
MC145011DW	**SOG PACKAGE**

PIN ASSIGNMENT



REV 1

Block Diagram



MAXIMUM RATINGS* (Voltages referenced to V_{SS})

Symbol	Parameter	Value	Unit
V_{DD}	DC Supply Voltage	– 0.5 to +12	V
V_{in}	DC Input Voltage C1, C2, Detect Osc, Low–Supply Trip I/O Feedback Test	– 0.25 to V_{DD} +0.25 – 0.25 to V_{DD} +0.25 – 0.25 to V_{DD} +10 – 15 to +25 – 1.0 to V_{DD} +0.25	V
I_{in}	DC Input Current, per Pin	± 10	mA
I_{out}	DC Output Current, per Pin	± 25	mA
I_{DD}	DC Supply Current, V_{DD} and V_{SS} Pins	+25 / – 150	mA
P_D	Power Dissipation in Still Air, 5 Seconds Continuous	1200** 350***	mW
T_{stg}	Storage Temperature	– 55 to +125	°C
T_L	Lead Temperature, 1 mm from Case for 10 Seconds	260	°C

* Maximum Ratings are those values beyond which damage to the device may occur. Functional operation should be restricted to the limits in the Electrical Characteristics tables.

** Derating: – 12 mW/°C from 25° to 60°C.

*** Derating: – 3.5 mW/°C from 25° to 60°C.

This device contains protection circuitry to guard against damage due to high static voltages or electric fields. However, precautions must be taken to avoid applications of any voltage higher than maximum rated voltages to this high–impedance circuit. For proper operation, V_{in} and V_{out} should be constrained to the range $V_{SS} \leq (V_{in}$ or $V_{out}) \leq V_{DD}$ except for the I/O, which can exceed V_{DD}, and the Test input, which can go below V_{SS}.

Unused inputs must always be tied to an appropriate logic voltage level (e.g., either V_{SS} or V_{DD}). Unused outputs and/or an unused I/O must be left open.

ELECTRICAL CHARACTERISTICS (T_A = – 10 to 60°C Unless Otherwise Indicated, Voltages Referenced to V_{SS})

Symbol	Parameter	Test Condition	V_{DD} V	Min	Max	Unit
V_{DD}	Power Supply Voltage Range		—	6.0	12	V
V_{TH}	Supply Threshold Voltage, Low–Supply Alarm	Low–Supply Trip: $V_{in} = V_{DD}/3$	—	6.5	7.8	V
I_{DD}	Average Operating Supply Current, Excluding the Visible LED Current (per Package)	Standby Configured per Figure 5	12.0	—	12	µA
i_{DD}	Peak Supply Current , Excluding the Visible LED Current (per Package)	During Strobe On, IRED Off Configured per Figure 5	12.0	—	2.0	mA
		During Strobe On, IRED On Configured per Figure 5	12.0	—	3.0	
V_{IL}	Low–Level Input Voltage I/O		9.0	—	1.5	V
	Feedback		9.0	—	2.7	
	Test		9.0	—	7.0	
V_{IH}	High–Level Input Voltage I/O		9.0	3.2	—	V
	Feedback		9.0	6.3	—	
	Test		9.0	8.5	—	
I_{in}	Input Current Osc, Detect	$V_{in} = V_{SS}$ or V_{DD}	12.0	—	± 100	nA
	Low–Supply Trip	$V_{in} = V_{SS}$ or V_{DD}	12.0	—	± 100	
	Feedback	$V_{in} = V_{SS}$ or V_{DD}	12.0	—	± 100	
I_{IL}	Low–Level Input Current Test	$V_{in} = V_{SS}$	12.0	—	– 1	µA
I_{IH}	Pull–Down Current Test	$V_{in} = V_{DD}$	9.0	0.5	10	µA
	I/O	No Local Smoke, $V_{in} = V_{DD}$	9.0	25	100	
		No Local Smoke, V_{in} = 17 V	12.0	—	140	
V_{OL}	Low–Level Output Voltage LED	I_{out} = 10 mA	6.5	—	0.6	V
	Silver, Brass	I_{out} = 16 mA	6.5	—	1.0	
V_{OH}	High–Level Output Voltage Silver, Brass	I_{out} = – 16 mA	6.5	5.5	—	V
V_{out}	Output Voltage (For Line Regulation, see Pin Descriptions) Strobe	Inactive, I_{out} = –1 µA	—	V_{DD} – 0.1	—	V
		Active, I_{out} = 100 µA to 500 µA (Load Regulation)	9.0	V_{DD} – 4.4	V_{DD} – 5.6	
	IRED	Inactive, I_{out} = 1 µA	—	—	0.1	
		Active, I_{out} = 6 mA (Load Regulation)	9.0	2.25*	3.75*	
I_{OH}	High–Level Output Current I/O	Local Smoke, V_{out} = 4.5 V	6.5	– 4	—	mA
		Local Smoke, $V_{out} = V_{SS}$ (Short Circuit Current)	12.0	—	– 16	
I_{OZ}	Off–State Output Leakage Current LED	$V_{out} = V_{SS}$ or V_{DD}	12.0	—	± 1	µA
V_{IC}	Common Mode Voltage Range C1, C2, Detect	Local Smoke, Pushbutton Test, or Chamber Sensitivity Test	—	V_{DD} – 4	V_{DD} – 2	V
V_{ref}	Smoke Comparator Reference Voltage Internal	Local Smoke, Pushbutton Test, or Chamber Sensitivity Test	—	V_{DD} – 3.08	V_{DD} – 3.92	V

* T_A = 25°C only.

AC ELECTRICAL CHARACTERISTICS (Reference Timing Diagram Figures 3 and 4)

(T_A = 25°C, V_{DD} = 9.0 V, Component Values from Figure 5: R1 = 100.0 KΩ, C3 = 1500.0 pF, R2 = 10.0 MΩ)

No.	Symbol	Parameter	Test Condition	Min	Max	Unit
1	$1/f_{osc}$	Oscillator Period*	Free–Running Sawtooth Measured at Pin 12	9.5	11.5	ms
2	t_{LED}	LED Status	No Local Smoke, and No Remote Smoke	Illuminated		
3			Remote Smoke, but No Local Smoke	Illuminated		
4			Local Smoke or Pushbutton Test	Extinguished		
5	$t_{w(stb)}$	Strobe Pulse Width		9.5	11.5	ms
6	t_{IRED}	IRED Pulse Period	Smoke Test	9.67	11.83	s
7			Chamber Sensitivity Test, without Local Smoke	38.9	47.1	
8			Pushbutton Test	0.302	0.370	
9	$t_{w(IRED)}$	IRED Pulse Width		94	116	µs
10	t_r	IRED Rise Time		—	30	µs
	t_f	IRED Fall Time		—	200	
11	t_{mod}	Silver and Brass Modulation Period	Local or Remote Smoke	297	363	ms
11, 12	t_{on}/t_{mod}	Silver and Brass Duty Cycle	Local or Remote Smoke	73	77	%
13	t_{CH}	Silver and Brass Chirp Pulse Period	Low Supply or Degraded Chamber Sensitivity	38.9	47.1	s
14	$t_{w(CH)}$	Silver and Brass Chirp Pulse Width	Low Supply or Degraded Chamber Sensitivity	9.5	11.5	ms
15	t_{RR}	Rising Edge on I/O to Smoke Alarm Response Time	Remote Smoke, No Local Smoke	—	800	ms
16	t_{stb}	Strobe Pulse Period	Smoke Test	9.67	11.83	s
17			Chamber Sensitivity Test, without Local Smoke	38.9	47.1	
18			Low Supply Test, without Local Smoke	38.9	47.1	
19			Pushbutton Test	0.302	0.370	

* Oscillator period T (= $T_r + T_f$) is determined by the external components R1, R2, and C3 where T_r = (0.6931) R2 C3 and T_f = (0.6931) R1 C3. The other timing characteristics are some multiple of the oscillator timing as shown in the table.

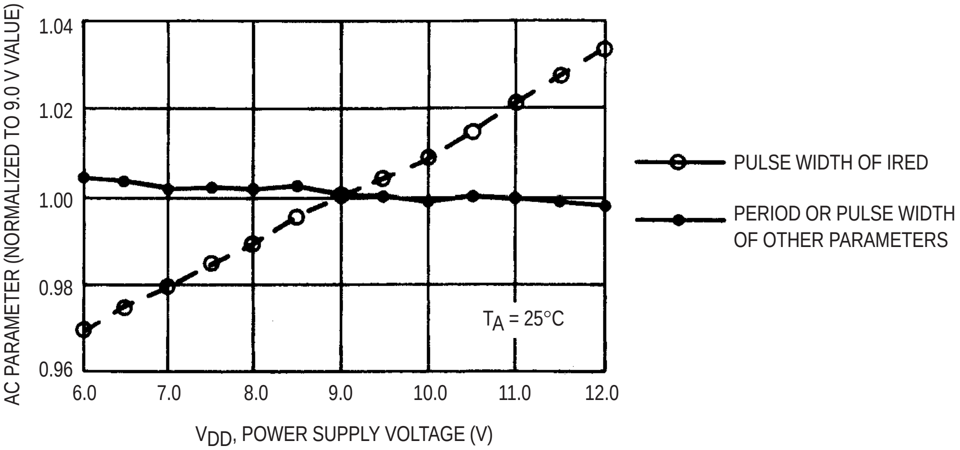
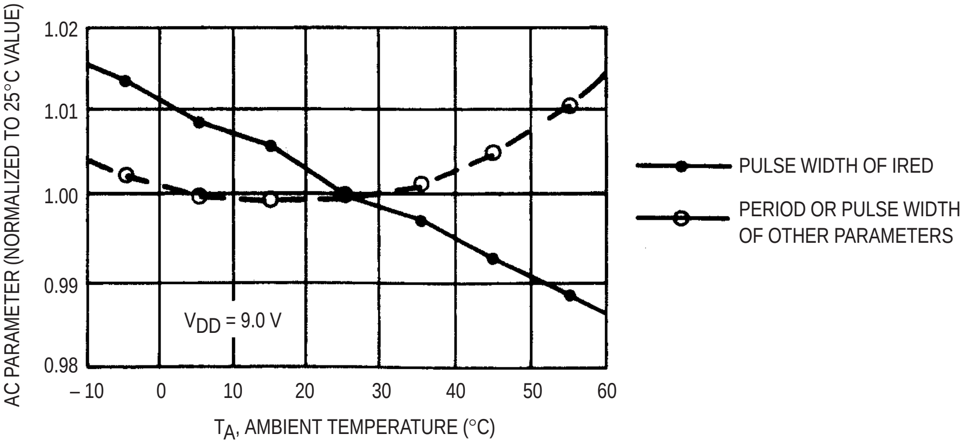
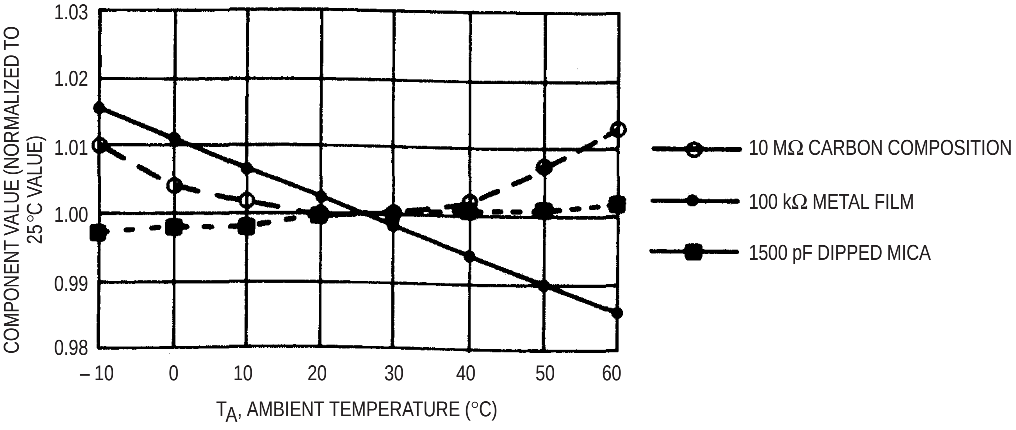


Figure 1. AC Characteristics versus Supply



NOTE: Includes external component variations. See Figure 2B.

Figure 2A. AC Characteristics versus Temperature



NOTE: These components were used to generate Figure 2A.

Figure 2B. RC Component Variation Over Temperature

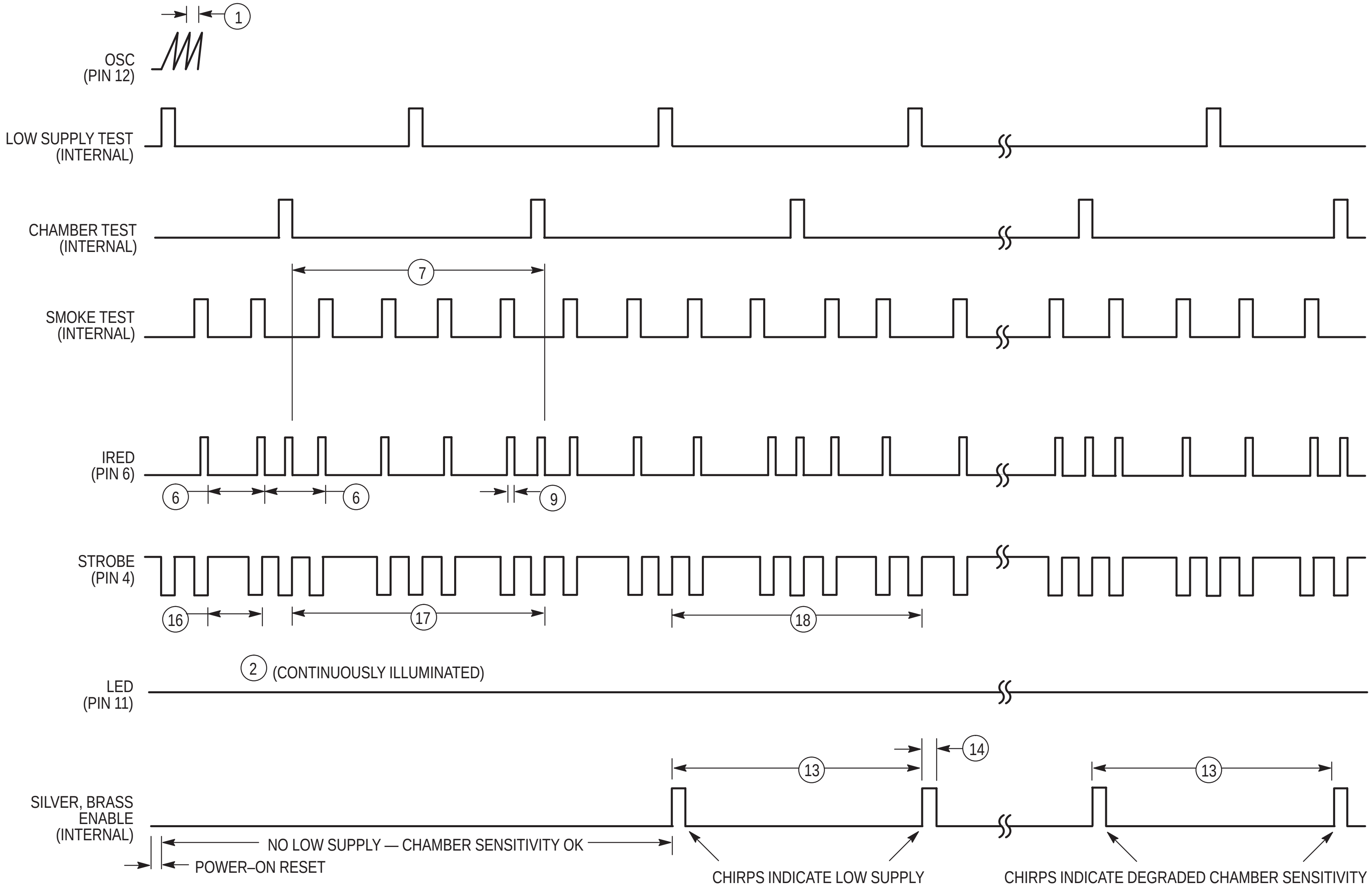


Figure 3. Standby Timing Diagram

NOTES: Numbers refer to the AC Electrical Characteristics Table.
Illustration is not to scale.

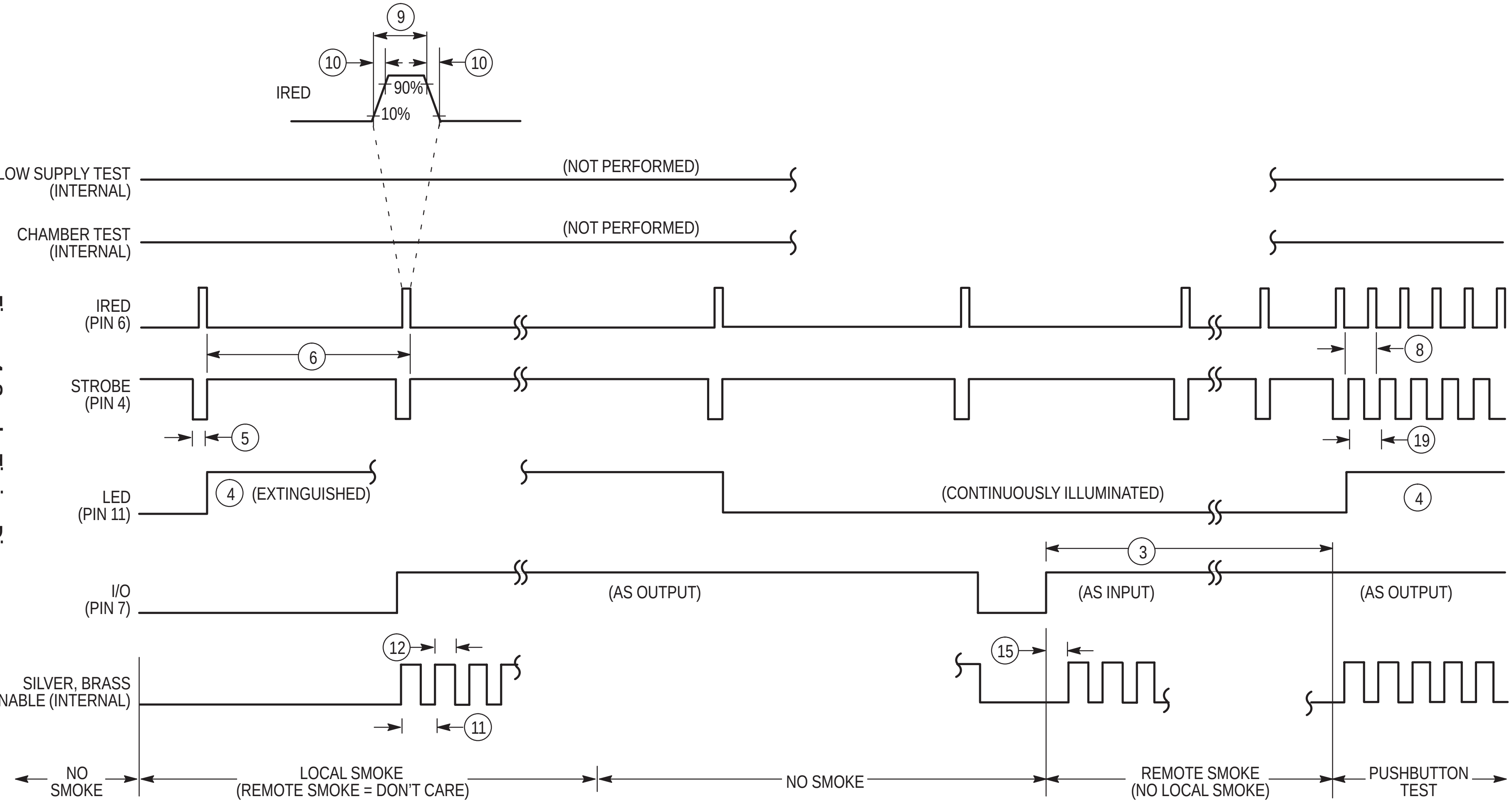
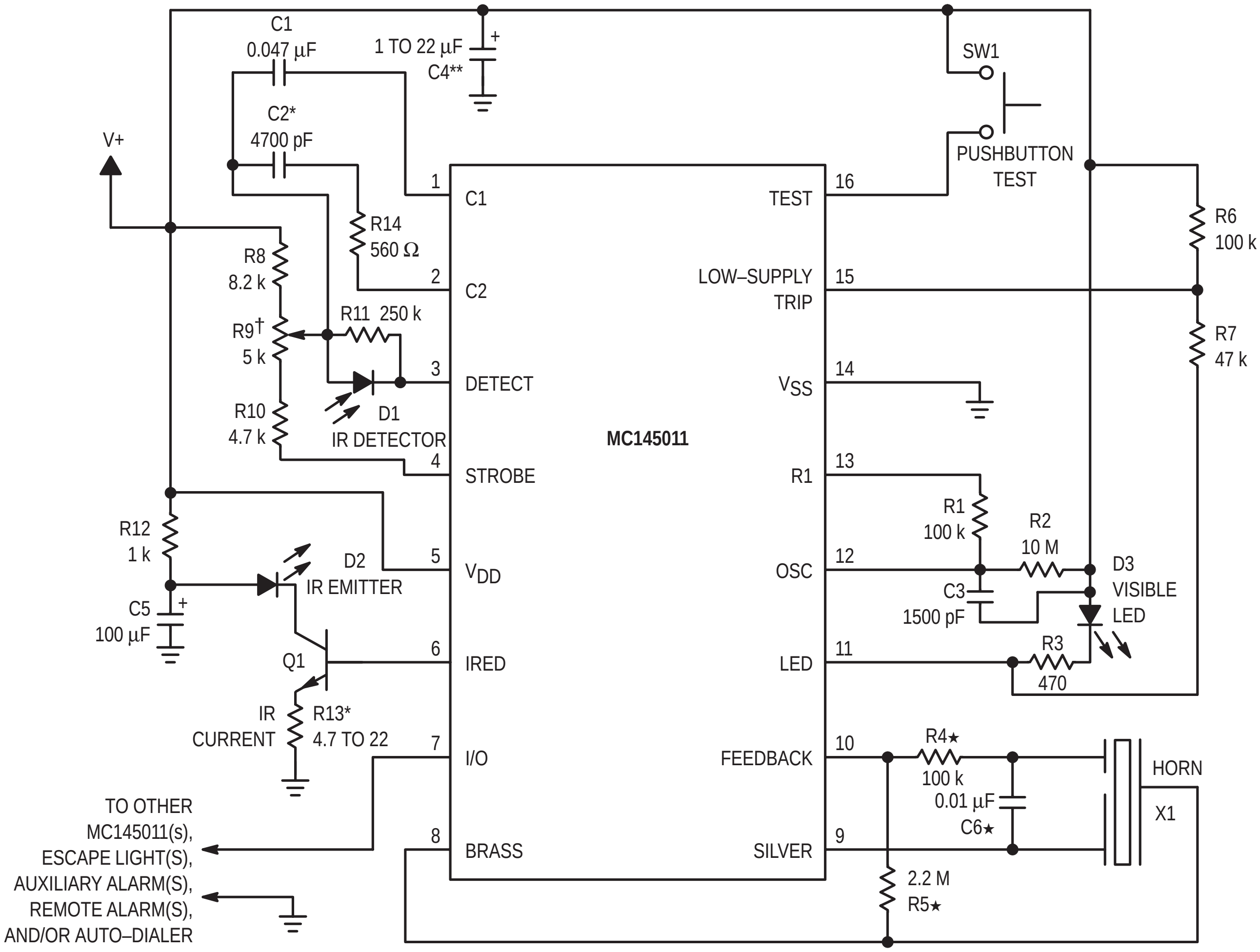


Figure 4. Smoke Timing Diagram

NOTES: Numbers refer to the AC Electrical Characteristics Table.
Illustration is not to scale.



★ Values for R4, R5, and C6 may differ depending on type of piezoelectric horn used.
* C2 and R13 are used for coarse sensitivity adjustment. Typical values are shown.
† R9 is for fine sensitivity adjustment (optional). If fixed resistors are used, R8 = 12 k, R10 is 5.6 k to 10 k, and R9 is eliminated. When R9 is used, noise pickup is increased due to antenna effects. Shielding may be required.
** C4 should be 22 µF if supply line resistance is high (up to 50 Ω). C4 could be reduced to 1 µF when supply line resistance is < 30 Ω.

Figure 5. Typical Application

PIN DESCRIPTIONS

C1 (Pin 1)

A capacitor connected to this pin as shown in Figure 5 determines the gain of the on–chip photo amplifier during pushbutton test and chamber sensitivity test (high gain). The capacitor value is chosen such that the alarm is tripped from background reflections in the chamber during pushbutton test.

$A_V \approx 1 + (C1/10)$ where C1 is in pF. CAUTION: The value of the closed–loop gain should not exceed 10,000.

C2 (Pin 2)

A capacitor connected to this pin as shown in Figure 5 determines the gain of the on–chip photo amplifier except during pushbutton or chamber sensitivity tests.

$A_V \approx 1 + (C2/10)$ where C2 is in pF. This gain increases about 10% during the IRED pulse, after two consecutive local smoke detections.

Resistor R14 must be installed in series with C2. $R14 \approx [1/(12\sqrt{C2})] - 680$ where R14 is in ohms and C2 is in farads.

DETECT (Pin 3)

This input to the high–gain pulse amplifier is tied to the cathode of an external photodiode. The photodiode should have low capacitance and low dark leakage current. The diode must be shunted by a load resistor and is operated at zero bias.

The Detect input must be ac/dc decoupled from all other signals, V_{DD}, and V_{SS}. Lead length and/or foil traces to this pin must be minimized, also. See Figure 6.

STROBE (Pin 4)

This output provides a strobed, regulated voltage referenced to V_{DD}. The temperature coefficient of this voltage is ± 0.2%/°C maximum from – 10° to 60°C. The supply–voltage coefficient (line regulation) is ± 0.2%/V maximum from 6 to 12 V. Strobe is tied to external resistor string R8, R9, and R10.

V_{DD} (Pin 5)

This pin is connected to the positive supply potential and may range from + 6 to + 12 V with respect to V_{SS}.

IRED (Pin 6)

This output provides pulsed base current for external NPN transistor Q1 used as the infrared emitter driver. Q1 must have $\beta \geq 100$. At 10 mA, the temperature coefficient of the output voltage is typically + 0.5%/°C from – 10° to 60°C. The supply–voltage coefficient (line regulation) is ± 0.2%/V maximum from 6 to 12 V. The IRED pulse width (active–high) is determined by external components R1 and C3. With a 100 kΩ/1500 pF combination, the nominal width is 105 µs.

To minimize noise impact, IRED is not active when the visible LED and horn outputs are active. IRED is active near the end of Strobe pulses for Smoke Tests, Chamber Sensitivity Test, and Pushbutton Test.

I/O (Pin 7)

This pin can be used to connect up to 40 units together in a wired–OR configuration for common signaling. V_{SS} is used as the return. An on–chip current sink minimizes noise pick up during non–smoke conditions and eliminates the need for an external pull–down resistor to complete the wired–OR. Remote units at lower supply voltages do not draw excessive current from a sending unit at a higher supply voltage.

I/O can also be used to activate escape lights, auxiliary alarms, remote alarms, and/or auto–dialers.

As an input, this pin feeds a positive–edge–triggered flip–flop whose output is sampled nominally every 625 ms during standby (using the recommended component values). A local–smoke condition or the pushbutton–test mode forces this current–limited output to source current. All input signals are ignored when I/O is sourcing current.

I/O is disabled by the on–chip power–on reset to eliminate nuisance signaling during battery changes or system power–up.

If unused, I/O must be left unconnected.

BRASS (Pin 8)

This half of the push–pull driver output is connected to the metal support electrode of a piezoelectric audio transducer and to the horn–starting resistor. A continuous modulated tone from the transducer is a smoke alarm indicating either local or remote smoke. A short beep or chirp is a trouble alarm indicating a low supply or degraded chamber sensitivity.

SILVER (Pin 9)

This half of the push–pull driver output is connected to the ceramic electrode of a piezoelectric transducer and to the horn–starting capacitor.

FEEDBACK (Pin 10)

This input is connected to both the feedback electrode of a self–resonating piezoelectric transducer and the horn–starting resistor and capacitor through current–limiting resistor R4. If unused, this pin must be tied to V_{SS} or V_{DD}.

LED (Pin 11)

This active–low open–drain output directly drives an external visible LED.

The load for the low–supply test is applied by this output. This low–supply test is non–coincident with the smoke tests, chamber sensitivity test, pushbutton test, or any alarm signals.

The LED also provides a visual indication of the detector status as follows, assuming the component values shown in Figure 5:

Standby (includes low–supply and chamber sensitivity tests) — constantly illuminated

Local Smoke — constantly extinguished

Remote Smoke — constantly illuminated

Pushbutton Test — constantly extinguished (system OK); constantly illuminated (system problem)

OSC (Pin 12)

This pin is used in conjunction with external resistor R2 (10 MΩ) to V_{DD} and external capacitor C3 (1500 pF) to V_{DD} to form an oscillator with a nominal period of 10.5 ms.

R1 (Pin 13)

This pin is used in conjunction with resistor R1 (100 kΩ) to pin 12 and C3 (1500 pF, see pin 12 description) to determine the IRED pulse width. With this RC combination, the nominal pulse width is 105 µs.

V_{SS} (Pin 14)

This pin is the negative supply potential and the return for the I/O pin. Pin 14 is usually tied to ground.

LOW–SUPPLY TRIP (Pin 15)

This pin is connected to an external voltage which determines the low–supply alarm threshold. The trip voltage is obtained through a resistor divider connected between the V_{DD} and LED pins. The low–supply alarm threshold voltage (in volts) ≈ (5R7/R6) + 5 where R6 and R7 are in the same units.

TEST (Pin 16)

This input has an on–chip pull–down device and is used to manually invoke a test mode.

The *Pushbutton Test* mode is initiated by a high level at pin 16 (usually depression of a S.P.S.T. normally–open pushbutton switch to V_{DD}). After one oscillator cycle, IRED pulses approximately every 336 ms, regardless of the presence of smoke. Additionally, the amplifier gain is increased by automatic selection of C1. Therefore, the background reflections in the smoke chamber may be interpreted as smoke, generating a simulated–smoke condition. After the second IRED pulse, a successful test activates the horn–driver and I/O circuits. The active I/O allows remote signaling for system testing. When the Pushbutton Test switch is released, the Test input returns to V_{SS} due to the on–chip pull–down device. After one oscillator cycle, the amplifier gain returns to normal, thereby removing the simulated–smoke condition. After two additional IRED pulses, less than a second, the IC exits the alarm mode and returns to standby timing.

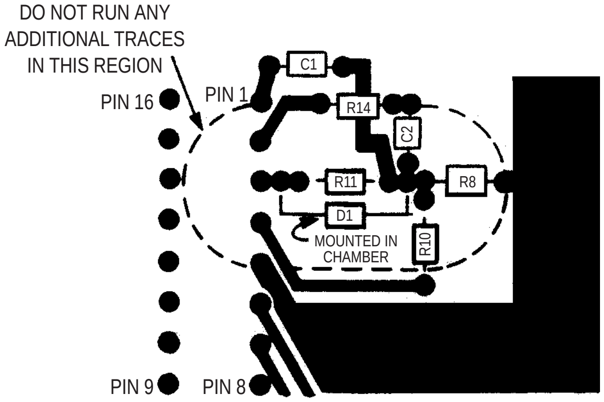
CALIBRATION

To facilitate checking the sensitivity and calibrating smoke detectors, the MC145011 can be placed in a calibration mode. In this mode, certain device pins are controlled/reconfigured as shown in Table 1. To place the part in the calibration mode, Pin 16 (Test) must be pulled below the V_{SS} pin with 100 µA continuously drawn out of the pin for at least one cycle on the OSC pin. To exit this mode, the Test pin is floated for at least one OSC cycle.

In the calibration mode, the IRED pulse rate is increased to one for every OSC cycle. Also, Strobe is always active low.

Table 1. Configuration of Pins in the Calibration Mode

Description	Pin	Comment
I/O	7	Disabled as an output. Forcing this pin high places the photo amp output on pin 1 or 2, as determined by Low–Supply Trip. The amp's output appears as pulses and is referenced to V_{DD}.
Low–Supply Trip	15	If the I/O pin is high, pin 15 controls which gain capacitor is used. Low: normal gain, amp output on pin 1. High: supervisory gain, amp output on pin 2.
Feedback	10	Driving this input high enables hysteresis (10% gain increase) in the photo amp; pin 15 must be low.
Osc	12	Driving this input high brings the internal clock high. Driving the input low brings the internal clock low. If desired, the RC network for the oscillator may be left intact; this allows the oscillator to run similar to the normal mode of operation.
Silver	9	This pin becomes the smoke comparator output. When the OSC pin is toggling, positive pulses indicate that smoke has been detected. A static low level indicates no smoke.
Brass	8	This pin becomes the smoke integrator output. That is, 2 consecutive smoke detections are required for "on" (static high level) and 2 consecutive no–detections for "off" (static low level).



NOTES: Illustration is bottom view of layout using a DIP. Top view for SOIC layout is mirror image.
Optional potentiometer R9 is not included.
Drawing is not to scale.
Leads on D1, R11, R8, and R10 and their associated traces must be kept as short as possible. This practice minimizes noise pick up.
Pin 3 must be decoupled from all other traces.

Figure 6. Recommended PCB Layout

MOTOROLA
SEMICONDUCTOR TECHNICAL DATA

Photoelectric Smoke Detector with I/O and Temporal Pattern Horn Driver

For Battery–Powered Applications

The CMOS MC145012 is an advanced smoke detector component containing sophisticated very–low–power analog and digital circuitry. The IC is used with an infrared photoelectric chamber. Detection is accomplished by sensing scattered light from minute smoke particles or other aerosols. When detection occurs, a pulsating alarm is sounded via on–chip push–pull drivers and an external piezoelectric transducer.

The variable–gain photo amplifier allows direct interface to IR detectors (photodiodes). Two external capacitors, C1 and C2, C1 being the larger, determine the gain settings. Low gain is selected by the IC during most of the standby state. Medium gain is selected during a local–smoke condition. High gain is used during pushbutton test. During standby, the special monitor circuit which periodically checks for degraded chamber sensitivity uses high gain also.

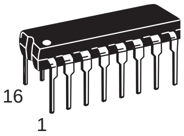
The I/O pin, in combination with V_{SS}, can be used to interconnect up to 40 units for common signaling. An on–chip current sink provides noise immunity when the I/O is an input. A local–smoke condition activates the short–circuit–protected I/O driver, thereby signaling remote smoke to the interconnected units. Additionally, the I/O pin can be used to activate escape lights, enable auxiliary or remote alarms, and/or initiate auto–dialers.

While in standby, the low–supply detection circuitry conducts periodic checks using a pulsed load current from the LED pin. The trip point is set using two external resistors. The supply for the MC145012 can be a 9 V battery.

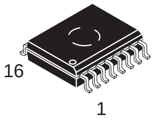
A visible LED flash accompanying a pulsating audible alarm indicates a local–smoke condition. A pulsating audible alarm with no LED flash indicates a remote–smoke condition. A beep or chirp occurring virtually simultaneously with an LED flash indicates a low–supply condition. A beep or chirp occurring halfway between LED flashes indicates degraded chamber sensitivity. A low–supply condition does not affect the smoke detection capability if $V_{DD} \geq 6$ V. Therefore, the low–supply condition and degraded chamber sensitivity can be further distinguished by performing a pushbutton (chamber) test.

- Complies with the UL217 and UL268 Specifications
- Operating Voltage Range: 6 to 12 V
- Operating Temperature Range: – 10 to 60°C
- Average Supply Current: 8 µA
- I/O Pin Allows Units to be Interconnected for Common Signalling
- Power–On Reset Places IC in Standby Mode (Non–Alarm State)
- Electrostatic Discharge (ESD) and Latch Up Protection Circuitry on All Pins
- Chip Complexity: 2000 FETs, 12 NPNs, 16 Resistors, and 10 Capacitors
- Supports NFPA 72, ANSI S3.41, and ISO 8201 Audible Emergency Evacuation Signals

MC145012



P SUFFIX
PLASTIC DIP
CASE 648–08

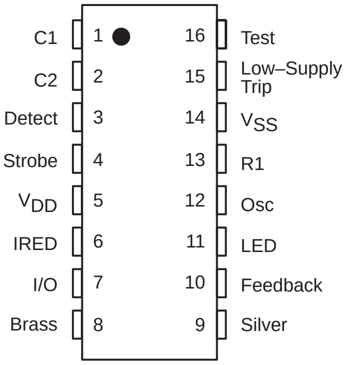


DW SUFFIX
SOG PACKAGE
CASE 751G–03

ORDERING INFORMATION

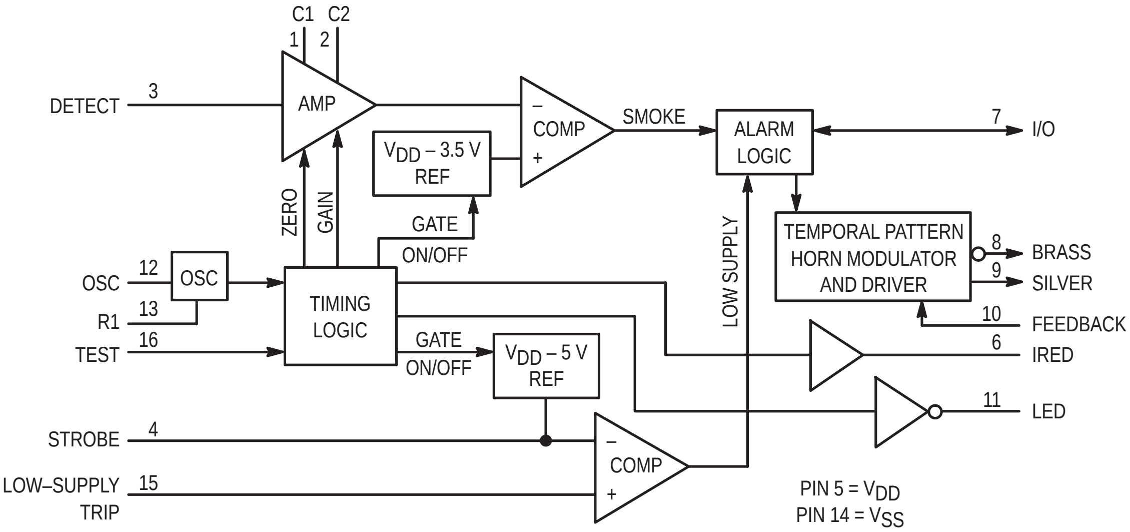
MC145012P	**PLASTIC DIP**
MC145012DW	**SOG PACKAGE**

PIN ASSIGNMENT



REV 1

BLOCK DIAGRAM



MAXIMUM RATINGS* (Voltages referenced to V_{SS})

Symbol	Parameter	Value	Unit
V_{DD}	DC Supply Voltage	-0.5 to +12	V
V_{in}	DC Input Voltage C1, C2, Detect Osc, Low–Supply Trip I/O Feedback Test	-0.25 to V_{DD} +0.25 -0.25 to V_{DD} +0.25 -0.25 to V_{DD} +10 -15 to +25 -1.0 to V_{DD} +0.25	V
I_{in}	DC Input Current, per Pin	± 10	mA
I_{out}	DC Output Current, per Pin	± 25	mA
I_{DD}	DC Supply Current, V_{DD} and V_{SS} Pins	+25 / -150	mA
P_D	Power Dissipation in Still Air, 5 Seconds Continuous	1200** 350***	mW
T_{stg}	Storage Temperature	-55 to +125	°C
T_L	Lead Temperature, 1 mm from Case for 10 Seconds	260	°C

* Maximum Ratings are those values beyond which damage to the device may occur. Functional operation should be restricted to the limits in the Electrical Characteristics tables.

** Derating: – 12 mW/°C from 25° to 60°C.

*** Derating: – 3.5 mW/°C from 25° to 60°C.

This device contains protection circuitry to guard against damage due to high static voltages or electric fields. However, precautions must be taken to avoid applications of any voltage higher than maximum rated voltages to this high–impedance circuit. For proper operation, V_{in} and V_{out} should be constrained to the range $V_{SS} \leq (V_{in}$ or $V_{out}) \leq V_{DD}$ except for the I/O, which can exceed V_{DD}, and the Test input, which can go below V_{SS}.

Unused inputs must always be tied to an appropriate logic voltage level (e.g., either V_{SS} or V_{DD}). Unused outputs and/or an unused I/O must be left open.

ELECTRICAL CHARACTERISTICS (Voltages Referenced to V_{SS}, T_A = – 10 to 60°C Unless Otherwise Indicated)

Symbol	Parameter	Test Condition	V_{DD} V	Min	Max	Unit
V_{DD}	Power Supply Voltage Range		—	6	12	V
V_{TH}	Supply Threshold Voltage, Low–Supply Alarm	Low–Supply Trip: $V_{in} = V_{DD}/3$	—	6.5	7.8	V
I_{DD}	Average Operating Supply Current (per Package) (Does Not Include Current through D3–IR Emitter)	Standby Configured per Figure 5	12.0	—	8.0	µA
i_{DD}	Peak Supply Current (per Package) (Does Not Include IRED Current into Base of Q1)	During Strobe On, IRED Off Configured per Figure 5	12.0	—	2.0	mA
		During Strobe On, IRED On Configured per Figure 5	12.0	—	3.0	
V_{IL}	Low–Level Input Voltage I/O Feedback Test		9.0 9.0 9.0	— — —	1.5 2.7 7.0	V
V_{IH}	High–Level Input Voltage I/O Feedback Test		9.0 9.0 9.0	3.2 6.3 8.5	— — —	V
I_{in}	Input Current OSC, Detect Low–Supply Trip Feedback	$V_{in} = V_{SS}$ or V_{DD} $V_{in} = V_{SS}$ or V_{DD} $V_{in} = V_{SS}$ or V_{DD}	12.0 12.0 12.0	— — —	± 100 ± 100 ± 100	nA
I_{IL}	Low–Level Input Current Test	$V_{in} = V_{SS}$	12.0	– 100	– 1	µA
I_{IH}	Pull–Down Current Test I/O	$V_{in} = V_{DD}$ No Local Smoke, $V_{in} = V_{DD}$ No Local Smoke, V_{in} = 17 V	9.0 9.0 12.0	0.5 25 —	10 100 140	µA
V_{OL}	Low–Level Output Voltage LED Silver, Brass	I_{out} = 10 mA I_{out} = 16 mA	6.5 6.5	— —	0.6 1.0	V
V_{OH}	High–Level Output Voltage Silver, Brass	I_{out} = – 16 mA	6.5	5.5	—	V
V_{out}	Output Voltage Strobe (For Line Regulation, See Pin Descriptions)	Inactive, I_{out} = 1 µA Active, I_{out} = 100 µA to 500 µA (Load Regulation)	— 9.0	V_{DD} – 0.1 V_{DD} – 4.4	— V_{DD} – 5.6	V
	IRED	Inactive, I_{out} = 1 µA Active, I_{out} = 6 mA (Load Regulation)	— 9.0	— 2.25*	0.1 3.75*	
I_{OH}	High–Level Output Current I/O	Local Smoke, V_{out} = 4.5 V	6.5	– 4	—	mA
		Local Smoke, $V_{out} = V_{SS}$ (Short Circuit Current)	12.0	—	– 16	
I_{OZ}	Off–State Output Leakage Current LED	$V_{out} = V_{SS}$ or V_{DD}	12.0	—	± 1	µA
V_{IC}	Common Mode Voltage Range C1, C2, Detect	Local Smoke, Pushbutton Test, or Chamber Sensitivity Test	—	V_{DD} – 4	V_{DD} – 2	V
V_{ref}	Smoke Comparator Reference Voltage Internal	Local Smoke, Pushbutton Test, or Chamber Sensitivity Test	—	V_{DD} – 3.08	V_{DD} – 3.92	V

* T_A = 25°C only.

AC ELECTRICAL CHARACTERISTICS (Reference Timing Diagram Figures 3 and 4)
(T_A = 25°C, V_{DD} = 9.0 V, Component Values from Figure 5: R1 = 100.0 KΩ, C3 = 1500.0 pF, R2 = 7.5 MΩ)

No.	Symbol	Parameter	Test Condition	Clocks	Min*	Typ**	Max*	Unit
1	$1/f_{osc}$	Oscillator Period	Free–Running Sawtooth Measured at Pin 12	1	7.0	7.9	8.6	ms
2	t_{LED}	LED Pulse Period	No Local Smoke, and No Remote Smoke	4096	28.8	32.4	35.2	s
3			Remote Smoke, but No Local Smoke	—	Extinguished			
4			Local Smoke	64	0.45	0.5	0.55	
5			Pushbutton Test	64	0.45	0.5	0.55	
6	$t_{w(LED)}$, $t_{w(stb)}$	LED Pulse Width and Strobe Pulse Width		1	7.0	—	8.6	ms
7	t_{IRED}	IRED Pulse Period	Smoke Test	1024	7.2	8.1	8.8	s
8	t_{IRED}	IRED Pulse Period	Chamber Sensitivity Test, without Local Smoke	4096	28.8	32.4	35.2	s
9			Pushbutton Test	128	0.9	1	1.1	
10	$t_{w(IRED)}$	IRED Pulse Width		T_f*	94		116	µs
11	t_r	IRED Rise Time		—	—		30	µs
12	t_f	IRED Fall Time		—	—		200	
13	t_{on}	Silver and Brass Temporal Modulation Pulse Width		64	0.45	0.5	0.55	s
14	t_{off}				0.45	0.5	0.55	
15	t_{offd}			192	1.35	1.52	1.65	
16	t_{CH}	Silver and Brass Chirp Pulse Period	Low Supply or Degraded Chamber Sensitivity	4096	28.8	32.4	35.2	s
17	t_{wCH}	Silver and Brass Chirp Pulse Width		1	7.0	7.9	8.6	ms
18	t_{RR}	Rising Edge on I/O to Smoke Alarm Response Time	Remote Smoke, No Local Smoke	—	—	2 **!**	—	s
19	t_{stb}	Strobe Out Pulse Period	Smoke Test	1024	7.2	8.1	8.8	s
20			Chamber Sensitivity Test, without Local Smoke	4096	28.8	32.4	35.2	
21			Low Supply Test, without Local Smoke	4096	28.8	32.4	35.2	
22			Pushbutton Test	—	—	1	—	

* Oscillator period T (= $T_r + T_f$) is determined by the external components R1, R2, and C3 where $T_r = (0.6931)\ R_2 * C_3$ and $T_f = (0.6931)\ R_1 * C_3$. The other timing characteristics are some multiple of the oscillator timing as shown in the table. The timing shown should accomodate the NFPA 72, ANSI S3.41, and ISO 8201 audible emergency evacuation signals.

** Typicals are not guaranteed.

! Time is typical — depends on what point in cycle signal is applied.

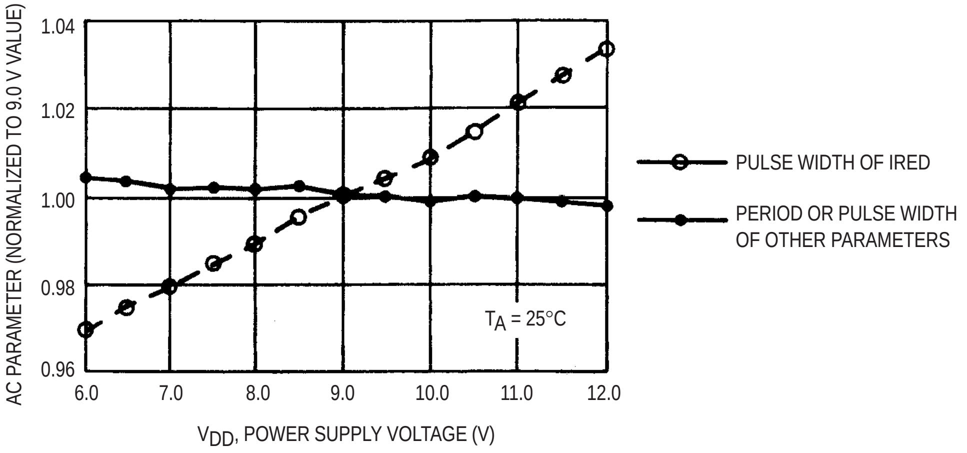
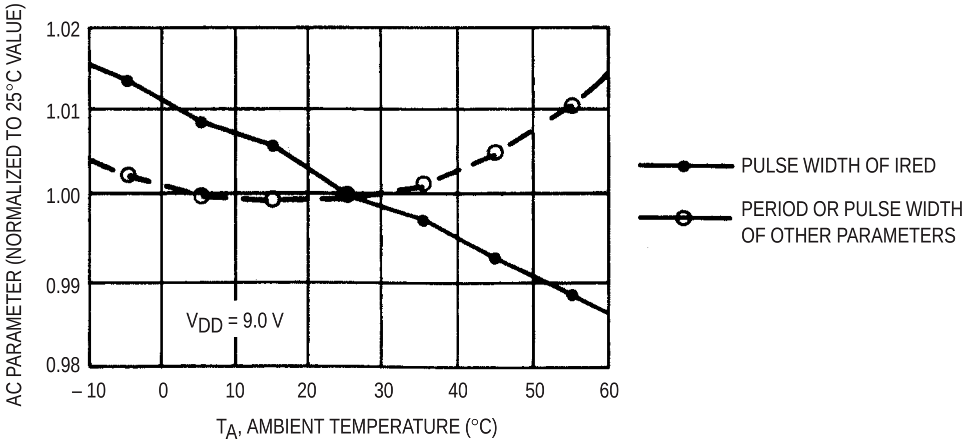
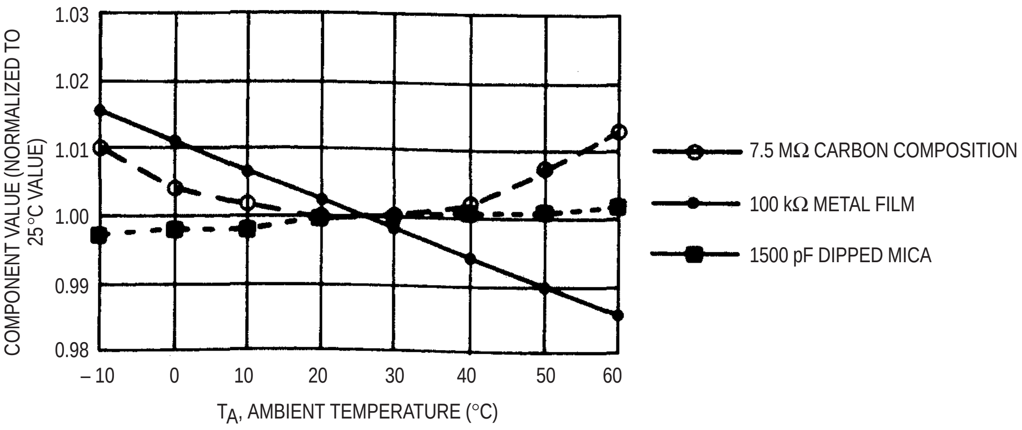


Figure 1. AC Characteristics versus Supply



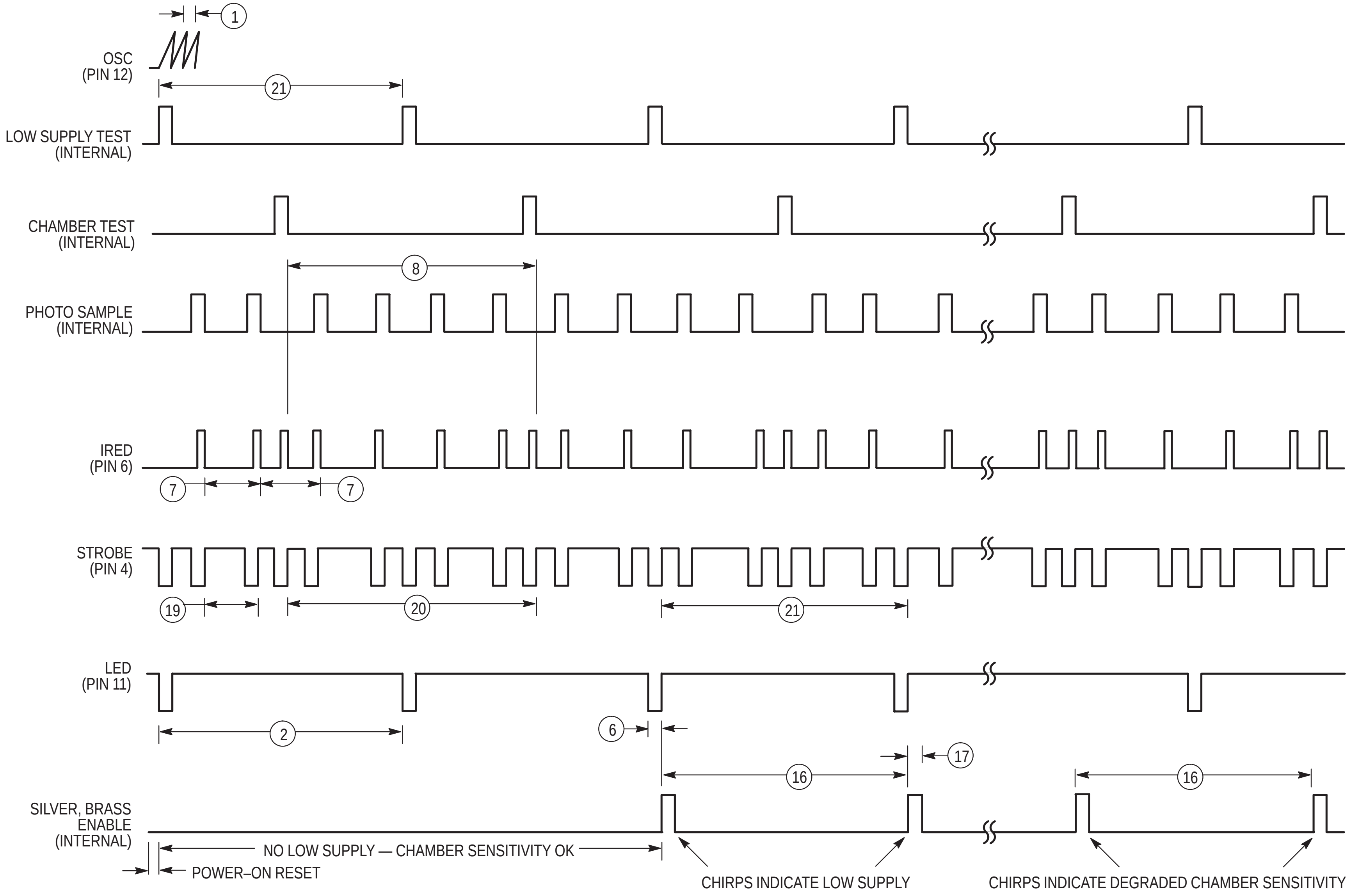
NOTE: Includes external component variations. See Figure 2B.

Figure 2A. AC Characteristics versus Temperature



NOTE: These components were used to generate Figure 2A.

Figure 2B. RC Component Variation Over Temperature



NOTES: Numbers refer to the AC Electrical Characteristics Table.
Illustration is not to scale.

Figure 3. Typical Standby Timing

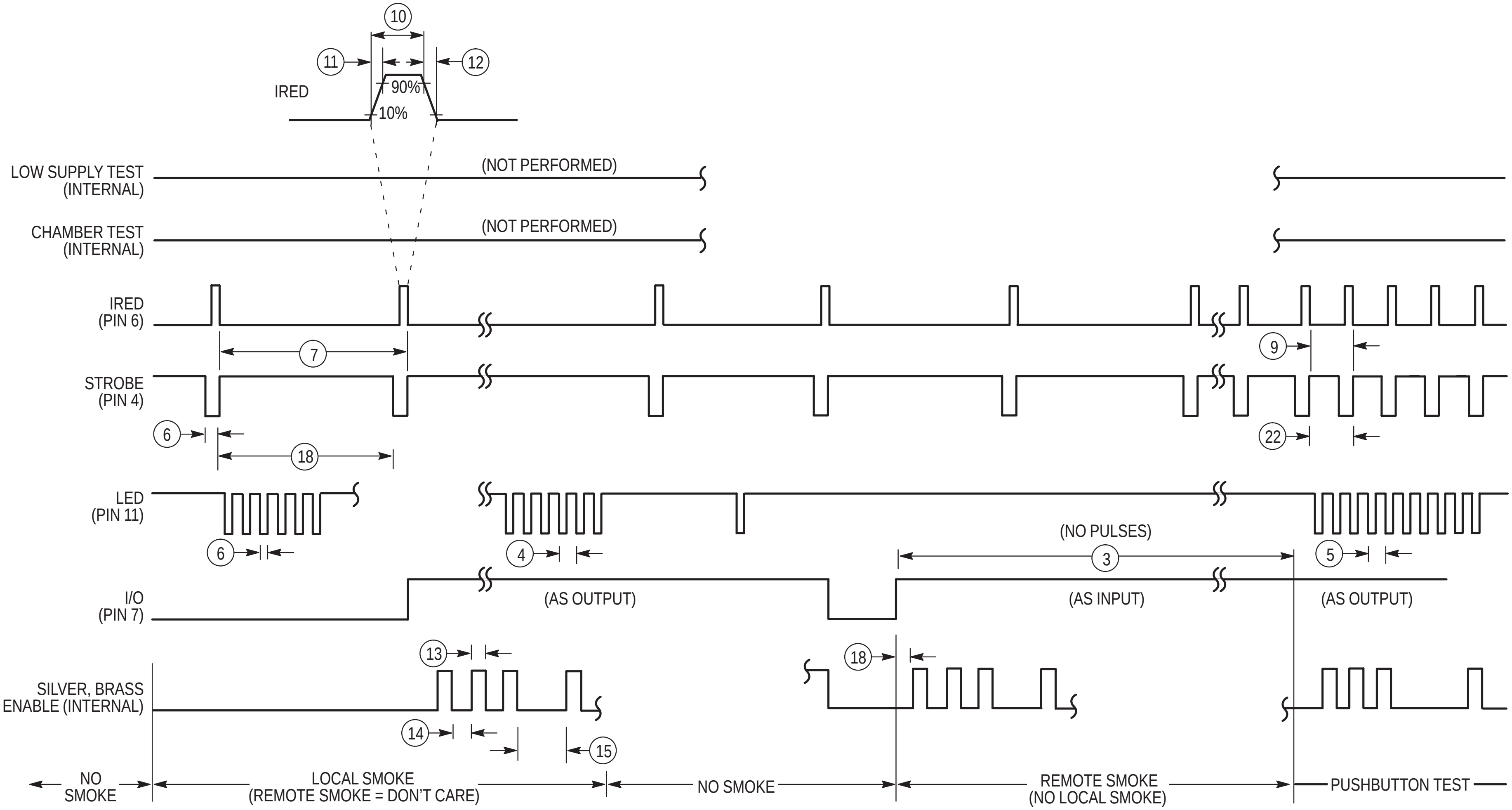
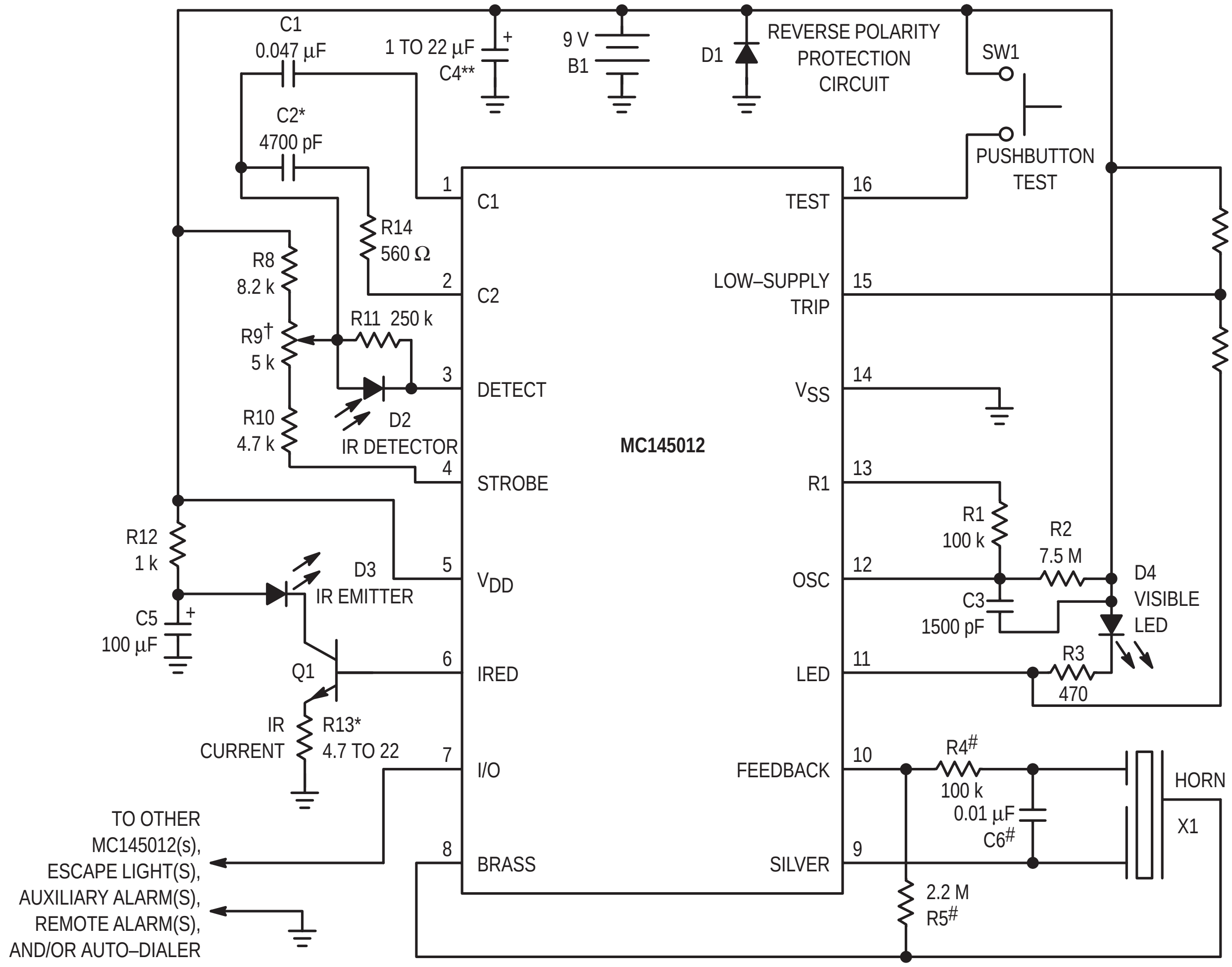


Figure 4. Typical Local Smoke Timing

NOTES: Numbers refer to the AC Electrical Characteristics Table.
Illustration is not to scale.



#Values for R4, R5, and C6 may differ depending on type of piezoelectric horn used.

* C2 and R13 are used for coarse sensitivity adjustment. Typical values are shown.

†R9 is for fine sensitivity adjustment (optional). If fixed resistors are used, R8 = 12 k, R10 is 5.6 k to 10 k, and R9 is eliminated. When R9 is used, noise pickup is increased due to antenna effects. Shielding may be required.

**C4 should be 22 µF if B1 is a carbon battery. C4 could be reduced to 1 µF when an alkaline battery is used.

Figure 5. Typical Battery–Powered Application

PIN DESCRIPTIONS

C1 (Pin 1)

A capacitor connected to this pin as shown in Figure 5 determines the gain of the on–chip photo amplifier during pushbutton test and chamber sensitivity test (high gain). The capacitor value is chosen such that the alarm is tripped from background reflections in the chamber during pushbutton test.

$A_V \approx 1 + (C1/10)$ where C1 is in pF. CAUTION: The value of the closed–loop gain should not exceed 10,000.

C2 (Pin 2)

A capacitor connected to this pin as shown in Figure 5 determines the gain of the on–chip photo amplifier except during pushbutton or chamber sensitivity tests.

$A_V \approx 1 + (C2/10)$ where C2 is in pF. This gain increases about 10% during the IRED pulse, after two consecutive local smoke detections.

Resistor R14 must be installed in series with C2. $R14 \approx [1/(12\sqrt{C2})] - 680$ where R14 is in ohms and C2 is in farads.

DETECT (Pin 3)

This input to the high–gain pulse amplifier is tied to the cathode of an external photodiode. The photodiode should have low capacitance and low dark leakage current. The diode must be shunted by a load resistor and is operated at zero bias.

The Detect input must be ac/dc decoupled from all other signals, V_{DD}, and V_{SS}. Lead length and/or foil traces to this pin must be minimized, also. See Figure 6.

STROBE (Pin 4)

This output provides a strobed, regulated voltage referenced to V_{DD}. The temperature coefficient of this voltage is ± 0.2%/°C maximum from – 10° to 60°C. The supply–voltage coefficient (line regulation) is ± 0.2%/V maximum from 6 to 12 V. Strobe is tied to external resistor string R8, R9, and R10.

V_{DD} (Pin 5)

This pin is connected to the positive supply potential and may range from + 6 to + 12 V with respect to V_{SS} CAUTION: In battery–powered applications, reverse–polarity protection must be provided externally.

IRED (Pin 6)

This output provides pulsed base current for external NPN transistor Q1 used as the infrared emitter driver. Q1 must have $\beta \geq 100$. At 10 mA, the temperature coefficient of the output voltage is typically + 0.5%/°C from – 10° to 60°C. The supply–voltage coefficient (line regulation) is ± 0.2%/V maximum from 6 to 12 V. The IRED pulse width (active–high) is determined by external components R1 and C3. With a 100 kΩ/1500 pF combination, the nominal width is 105 µs.

To minimize noise impact, IRED is not active when the visible LED and horn outputs are active. IRED is active near the end of strobe pulses for smoke tests, chamber sensitivity test, and pushbutton test.

I/O (Pin 7)

This pin can be used to connect up to 40 units together in a wired–OR configuration for common signaling. V_{SS} is used as the return. An on–chip current sink minimizes noise pick up during non–smoke conditions and eliminates the need for an external pull–down resistor to complete the wired–OR. Remote units at lower supply voltages do not draw excessive current from a sending unit at a higher supply voltage.

I/O can also be used to activate escape lights, auxiliary alarms, remote alarms, and/or auto–dialers.

As an input, this pin feeds a positive–edge–triggered flip–flop whose output is sampled nominally every 1 second during standby (using the recommended component values). A local–smoke condition or the pushbutton–test mode forces this current–limited output to source current. All input signals are ignored when I/O is sourcing current.

I/O is disabled by the on–chip power–on reset to eliminate nuisance signaling during battery changes or system power–up.

If unused, I/O must be left unconnected.

BRASS (Pin 8)

This half of the push–pull driver output is connected to the metal support electrode of a piezoelectric audio transducer and to the horn–starting resistor. A continuous modulated tone from the transducer is a smoke alarm indicating either local or remote smoke. A short beep or chirp is a trouble alarm indicating a low supply or degraded chamber sensitivity.

SILVER (Pin 9)

This half of the push–pull driver output is connected to the ceramic electrode of a piezoelectric transducer and to the horn–starting capacitor.

FEEDBACK (Pin 10)

This input is connected to both the feedback electrode of a self–resonating piezoelectric transducer and the horn–starting resistor and capacitor through current–limiting resistor R4. If unused, this pin must be tied to V_{SS} or V_{DD}.

LED (Pin 11)

This active–low open–drain output directly drives an external visible LED at the pulse rates indicated below. The pulse width is equal to the OSC period.

The load for the low–supply test is applied by this output. This low–supply test is non–coincident with the smoke tests, chamber sensitivity test, pushbutton test, or any alarm signals.

The LED also provides a visual indication of the detector status as follows, assuming the component values shown in Figure 5:

Standby (includes low–supply and chamber sensitivity tests) — Pulses every 32.4 seconds (typical)

Local Smoke — Pulses every 0.51 seconds (typical)

Remote Smoke — No pulses

Pushbutton Test — Pulses every 0.51 seconds (typical)

OSC (Pin 12)

This pin is used in conjunction with external resistor R2 (7.5 MΩ) to V_{DD} and external capacitor C3 (1500 pF) to V_{DD} to form an oscillator with a nominal period of 7.9 ms (typical).

R1 (Pin 13)

This pin is used in conjunction with resistor R1 (100 kΩ) to Pin 12 and C3 (1500 pF, see Pin 12 description) to determine the IRED pulse width. With this RC combination, the nominal pulse width is 105 µs.

V_{SS} (Pin 14)

This pin is the negative supply potential and the return for the I/O pin. Pin 14 is usually tied to ground.

LOW–SUPPLY TRIP (Pin 15)

This pin is connected to an external voltage which determines the low–supply alarm threshold. The trip voltage is obtained through a resistor divider connected between the V_{DD} and LED pins. The low–supply alarm threshold voltage (in volts) ≈ (5R7/R6) + 5 where R6 and R7 are in the same units.

TEST (Pin 16)

This input has an on–chip pull–down device and is used to manually invoke a test mode.

The *Pushbutton Test* mode is initiated by a high level at Pin 16 (usually depression of a S.P.S.T. normally–open pushbutton switch to V_{DD}). After one oscillator cycle, IRED pulses approximately every 1.0 second, regardless of the presence of smoke. Additionally, the amplifier gain is increased by automatic selection of C1. Therefore, the background reflections in the smoke chamber may be interpreted as smoke, generating a simulated–smoke condition. After the second IRED pulse, a successful test activates the horn–driver and I/O circuits. The active I/O allows remote signaling for system testing. When the Pushbutton Test switch is released, the Test input returns to V_{SS} due to the on–chip pull–down device. After one oscillator cycle, the amplifier gain returns to normal, thereby removing the simulated–smoke condition. After two additional IRED pulses, less than three seconds, the IC exits the alarm mode and returns to standby timing.

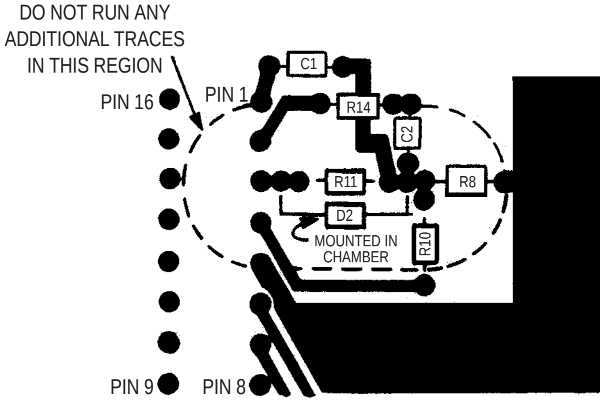
CALIBRATION

To facilitate checking the sensitivity and calibrating smoke detectors, the MC145012 can be placed in a calibration mode. In this mode, certain device pins are controlled/reconfigured as shown in Table 1. To place the part in the calibration mode, Pin 16 (Test) must be pulled below the V_{SS} pin with 100 µA continuously drawn out of the pin for at least one cycle on the OSC pin. To exit this mode, the Test pin is floated for at least one OSC cycle.

In the calibration mode, the IRED pulse rate is increased to one for every OSC cycle. Also, Strobe is always active low.

Table 1. Configuration of Pins in the Calibration Mode

Description	Pin	Comment
I/O	7	Disabled as an output. Forcing this pin high places the photo amp output on Pin 1 or 2, as determined by Low–Supply Trip. The amp's output appears as pulses and is referenced to V_{DD} etc.
Low–Supply Trip	15	If the I/O pin is high, Pin 15 controls which gain capacitor is used. Low: normal gain, amp output on Pin 1. High: supervisory gain, amp output on Pin 2.
Feedback	10	Driving this input high enables hysteresis (10% gain increase) in the photo amp; Pin 15 must be low.
OSC	12	Driving this input high brings the internal clock high. Driving the input low brings the internal clock low. If desired, the RC network for the oscillator may be left intact; this allows the oscillator to run similar to the normal mode of operation.
Silver	9	This pin becomes the smoke comparator output. When the OSC pin is toggling, positive pulses indicate that smoke has been detected. A static low level indicates no smoke.
Brass	8	This pin becomes the smoke integrator output. That is, 2 consecutive smoke detections are required for "on" (static high level) and 2 consecutive no–detections for "off" (static low level).



NOTES: Illustration is bottom view of layout using a DIP. Top view for SOIC layout is mirror image.
Optional potentiometer R9 is not included.
Drawing is not to scale.
Leads on D2, R11, R8, and R10 and their associated traces must be kept as short as possible. This practice minimizes noise pick up.
Pin 3 must be decoupled from all other traces.

Figure 6. Recommended PCB Layout

Photoelectric Smoke Detector with I/O and Temporal Pattern Horn Driver

For Line–Powered Applications

The CMOS MC145013 is an advanced smoke detector component containing sophisticated very–low–power analog and digital circuitry. The IC is used with an infrared photoelectric chamber. Detection is accomplished by sensing scattered light from minute smoke particles or other aerosols. When detection occurs, a pulsating alarm is sounded via on–chip push–pull drivers and an external piezoelectric transducer.

The variable–gain photo amplifier allows direct interface to IR detectors (photodiodes). Two external capacitors, C1 and C2, C1 being the larger, determine the gain settings. Low gain is selected by the IC during most of the standby state. Medium gain is selected during a local–smoke condition. High gain is used during pushbutton test. During standby, the special monitor circuit which periodically checks for degraded chamber sensitivity uses high gain also.

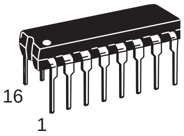
The I/O pin, in combination with V_{SS}, can be used to interconnect up to 40 units for common signaling. An on–chip current sink provides noise immunity when the I/O is an input. A local–smoke condition activates the short–circuit–protected I/O driver, thereby signaling remote smoke to the interconnected units. Additionally, the I/O pin can be used to activate escape lights, enable auxiliary or remote alarms, and/or initiate auto–dialers.

While in standby, the low–supply detection circuitry conducts periodic checks using a pulsed load current from the LED pin. The trip point is set using two external resistors. The supply for the MC145013 must be a dc power source capable of supplying 35 mA continuously and 45 mA peak. When the MC145013 is in standby, an external LED is continuously illuminated to indicate that the device is receiving power.

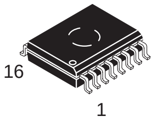
An extinguished LED accompanied by a pulsating audible alarm indicates a local–smoke condition. A pulsating audible alarm with the LED illuminated indicates a remote–smoke condition. A beep or chirp indicates a low–supply condition or degraded chamber sensitivity. A low–supply condition does not affect the smoke detection capability if $V_{DD} \geq 6$ V. Therefore, the low–supply condition and degraded chamber sensitivity can be distinguished by performing a pushbutton (chamber) test.

- Complies with the UL217 and UL268 Specifications
- Operating Voltage Range: 6 to 12 V
- Operating Temperature Range: – 10 to 60°C
- Average Supply Current (Visible LED Illuminated): 20 mA
- I/O Pin Allows Units to be Interconnected for Common Signalling
- Power–On Reset Places IC in Standby Mode (Non–Alarm State)
- Electrostatic Discharge (ESD) and Latch Up Protection Circuitry on All Pins
- Chip Complexity: 2000 FETs, 12 NPNs, 16 Resistors, and 10 Capacitors
- Supports NFPA 72, ANSI S3.41, and ISO 8201 Audible Emergency Evacuation Signals

MC145013



P SUFFIX
PLASTIC DIP
CASE 648–08

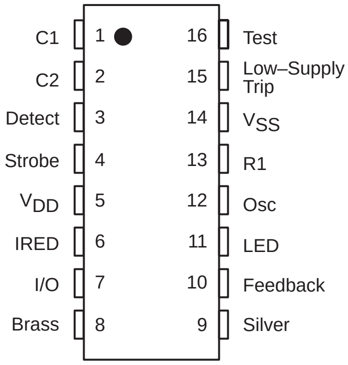


DW SUFFIX
SOG PACKAGE
CASE 751G–03

ORDERING INFORMATION

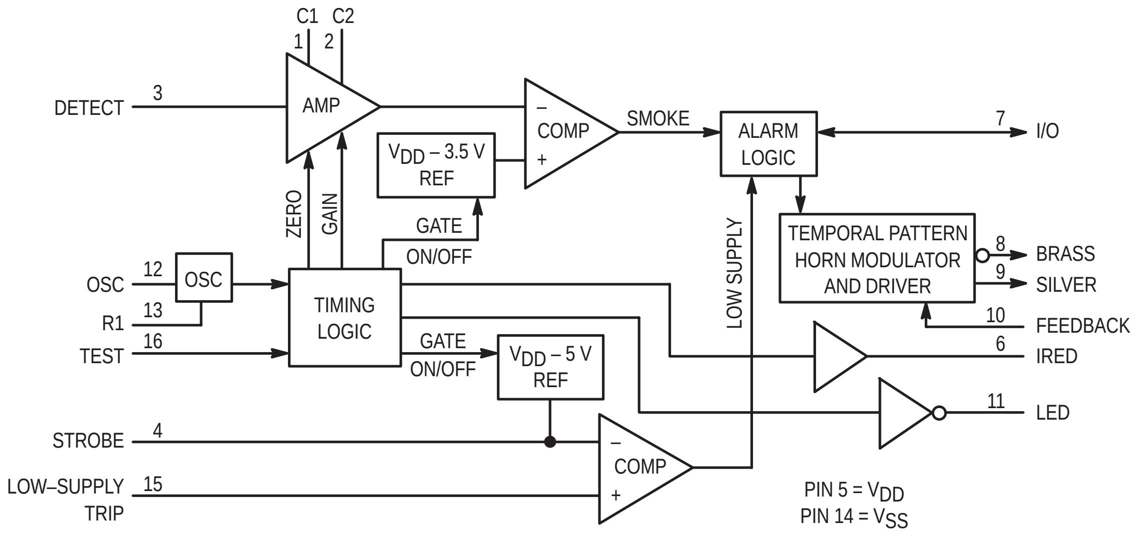
MC145013P	**PLASTIC DIP**
MC145013DW	**SOG PACKAGE**

PIN ASSIGNMENT



REV 1

BLOCK DIAGRAM



MAXIMUM RATINGS* (Voltages referenced to V_{SS})

Symbol	Parameter	Value	Unit
V_{DD}	DC Supply Voltage	– 0.5 to +12	V
V_{in}	DC Input Voltage C1, C2, Detect	– 0.25 to V_{DD} +0.25	V
	Osc, Low–Supply Trip	– 0.25 to V_{DD} +0.25	
	I/O	– 0.25 to V_{DD} +10	
	Feedback	– 15 to +25	
	Test	– 1.0 to V_{DD} +0.25	
I_{in}	DC Input Current, per Pin	± 10	mA
I_{out}	DC Output Current, per Pin	± 25	mA
I_{DD}	DC Supply Current, V_{DD} and V_{SS} Pins	+25 / – 150	mA
P_D	Power Dissipation in Still Air, 5 Seconds	1200**	mW
	Continuous	350***	
T_{stg}	Storage Temperature	– 55 to +125	°C
T_L	Lead Temperature, 1 mm from Case for 10 Seconds	260	°C

* Maximum Ratings are those values beyond which damage to the device may occur. Functional operation should be restricted to the limits in the Electrical Characteristics tables.

** Derating: – 12 mW/°C from 25° to 60°C.

*** Derating: – 3.5 mW/°C from 25° to 60°C.

This device contains protection circuitry to guard against damage due to high static voltages or electric fields. However, precautions must be taken to avoid applications of any voltage higher than maximum rated voltages to this high–impedance circuit. For proper operation, V_{in} and V_{out} should be constrained to the range $V_{SS} \leq (V_{in}$ or $V_{out}) \leq V_{DD}$ except for the I/O, which can exceed V_{DD}, and the Test input, which can go below V_{SS}.

Unused inputs must always be tied to an appropriate logic voltage level (e.g., either V_{SS} or V_{DD}). Unused outputs and/or an unused I/O must be left open.

ELECTRICAL CHARACTERISTICS (Voltages Referenced to V_{SS}, T_A = – 10 to 60°C Unless Otherwise Indicated)

Symbol	Parameter		Test Condition	V_{DD} V	Min	Max	Unit
V_{DD}	Power Supply Voltage Range			—	6	12	V
V_{TH}	Supply Threshold Voltage, Low–Supply Alarm		Low–Supply Trip: $V_{in} = V_{DD}/3$	—	6.5	7.8	V
I_{DD}	Average Operating Supply Current (per Package) (Does Not Include Current through D3–IR Emitter)		Standby Configured per Figure 5	12.0	—	8.0	µA
i_{DD}	Peak Supply Current (per Package) (Does Not Include IRED Current into Base of Q1)		During Strobe On, IRED Off Configured per Figure 5	12.0	—	2.0	mA
			During Strobe On, IRED On Configured per Figure 5	12.0	—	3.0	
V_{IL}	Low–Level Input Voltage	I/O		9.0	—	1.5	V
		Feedback		9.0	—	2.7	
		Test		9.0	—	7.0	
V_{IH}	High–Level Input Voltage	I/O		9.0	3.2	—	V
		Feedback		9.0	6.3	—	
		Test		9.0	8.5	—	
I_{in}	Input Current	OSC, Detect	$V_{in} = V_{SS}$ or V_{DD}	12.0	—	± 100	nA
		Low–Supply Trip	$V_{in} = V_{SS}$ or V_{DD}	12.0	—	± 100	
		Feedback	$V_{in} = V_{SS}$ or V_{DD}	12.0	—	± 100	
I_{IL}	Low–Level Input Current	Test	$V_{in} = V_{SS}$	12.0	– 100	– 1	µA
I_{IH}	Pull–Down Current	Test	$V_{in} = V_{DD}$	9.0	0.5	10	µA
		I/O	No Local Smoke, $V_{in} = V_{DD}$	9.0	25	100	
			No Local Smoke, V_{in} = 17 V	12.0	—	140	
V_{OL}	Low–Level Output Voltage	LED	I_{out} = 10 mA	6.5	—	0.6	V
		Silver, Brass	I_{out} = 16 mA	6.5	—	1.0	
V_{OH}	High–Level Output Voltage	Silver, Brass	I_{out} = – 16 mA	6.5	5.5	—	V
V_{out}	Output Voltage (For Line Regulation, See Pin Descriptions)	Strobe	Inactive, I_{out} = 1 µA	—	V_{DD} – 0.1	—	V
			Active, I_{out} = 100 µA to 500 µA (Load Regulation)	9.0	V_{DD} – 4.4	V_{DD} – 5.6	
		IRED	Inactive, I_{out} = 1 µA	—	—	0.1	
			Active, I_{out} = 6 mA (Load Regulation)	9.0	2.25*	3.75*	
I_{OH}	High–Level Output Current	I/O	Local Smoke, V_{out} = 4.5 V	6.5	– 4	—	mA
			Local Smoke, $V_{out} = V_{SS}$ (Short Circuit Current)	12.0	—	– 16	
I_{OZ}	Off–State Output Leakage Current	LED	$V_{out} = V_{SS}$ or V_{DD}	12.0	—	± 1	µA
V_{IC}	Common Mode Voltage Range	C1, C2, Detect	Local Smoke, Pushbutton Test, or Chamber Sensitivity Test	—	V_{DD} – 4	V_{DD} – 2	V
V_{ref}	Smoke Comparator Reference Voltage	Internal	Local Smoke, Pushbutton Test, or Chamber Sensitivity Test	—	V_{DD} – 3.08	V_{DD} – 3.92	V

* T_A = 25°C only.

AC ELECTRICAL CHARACTERISTICS (Reference Timing Diagram Figures 3 and 4)

(T_A = 25°C, V_{DD} = 9.0 V, Component Values from Figure 5: R1 = 100.0 KΩ, C3 = 1500.0 pF, R2 = 7.5 MΩ)

No.	Symbol	Parameter	Test Condition	Clocks	Min*	Typ**	Max*	Unit
1	$1/f_{osc}$	Oscillator Period	Free–Running Sawtooth Measured at Pin 12	1	7.0	7.9	8.6	ms
2	t_{LED}	LED Pulse Period	No Local Smoke, and No Remote Smoke	—	Illuminated			—
3			Remote Smoke, but No Local Smoke	—	Illuminated			
4			Local Smoke	—	Extinguished			
5			Pushbutton Test	—	Extinguished			
6	$t_{w(LED)}$, $t_{w(stb)}$	LED Pulse Width and Strobe Pulse Width		1	7.0	—	8.6	ms
7	t_{IRED}	IRED Pulse Period	Smoke Test	1024	7.2	8.1	8.8	s
8	t_{IRED}	IRED Pulse Period	Chamber Sensitivity Test, without Local Smoke	4096	28.8	32.4	35.2	s
9			Pushbutton Test	128	0.9	1	1.1	
10	$t_{w(IRED)}$	IRED Pulse Width		T_f*	94		116	µs
11	t_r	IRED Rise Time		—	—		30	µs
12	t_f	IRED Fall Time		—	—		200	
13	t_{on}	Silver and Brass Temporal Modulation Pulse Width		64	0.45	0.5	0.55	s
14	t_{off}				0.45	0.5	0.55	
15	t_{offd}			192	1.35	1.52	1.65	
16	t_{CH}	Silver and Brass Chirp Pulse Period	Low Supply or Degraded Chamber Sensitivity	4096	28.8	32.4	35.2	s
17	t_{wCH}	Silver and Brass Chirp Pulse Width		1	7.0	7.9	8.6	ms
18	t_{RR}	Rising Edge on I/O to Smoke Alarm Response Time	Remote Smoke, No Local Smoke	—	—	2 !	—	s
19	t_{stb}	Strobe Out Pulse Period	Smoke Test	1024	7.2	8.1	8.8	s
20			Chamber Sensitivity Test, without Local Smoke	4096	28.8	32.4	35.2	
21			Low Supply Test, without Local Smoke	4096	28.8	32.4	35.2	
22			Pushbutton Test	—	—	1	—	

* Oscillator period T (= $T_r + T_f$) is determined by the external components R1, R2, and C3 where T_r = 0.6931 R2 C3 and T_f = 0.6931 R1 C3. The other timing characteristics are some multiple of the oscillator timing as shown in the table. The timing shown should accomodate the NFPA 72, ANSI S3.41, and ISO 8201 audible emergency evacuation signals.

** Typicals are not guaranteed.

! Time is typical — depends on what point in cycle signal is applied.

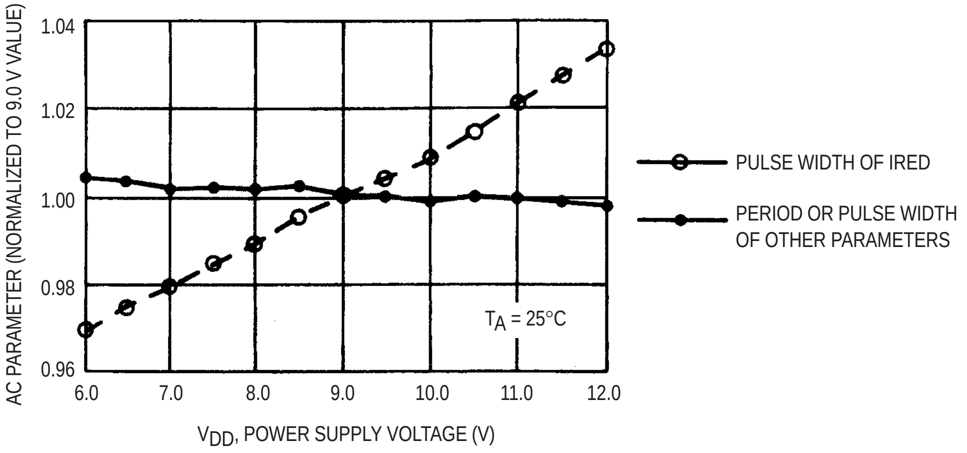
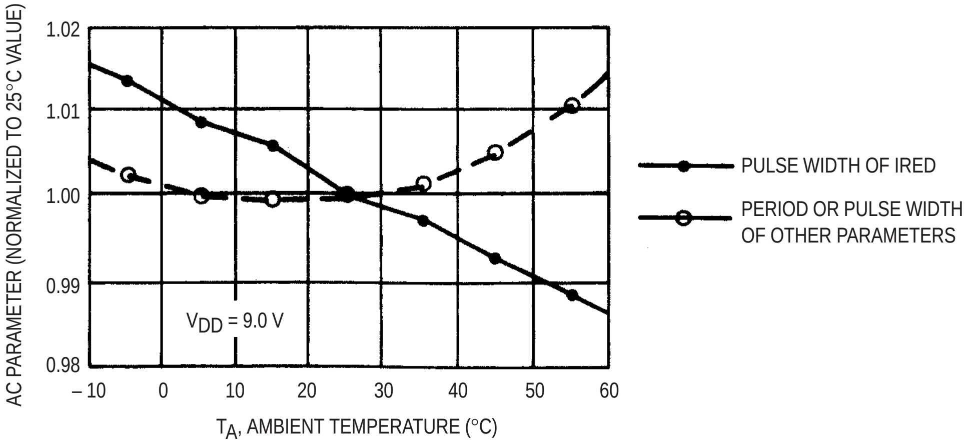
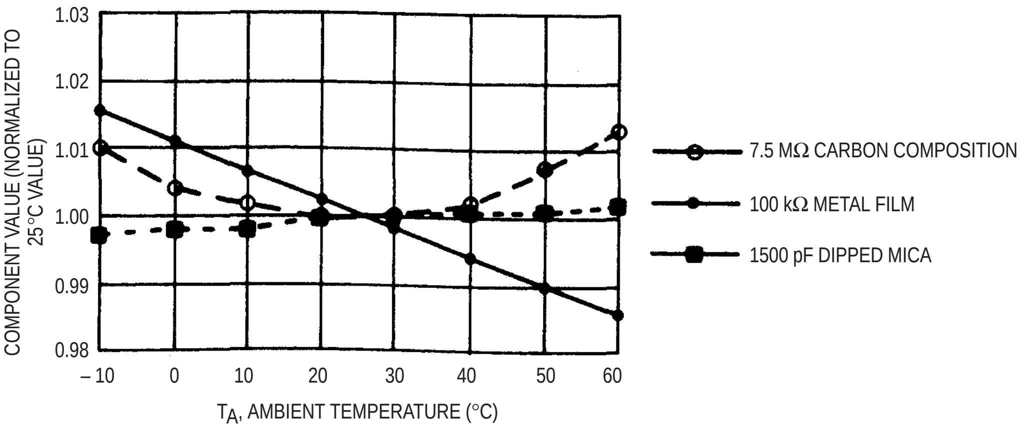


Figure 1. AC Characteristics versus Supply



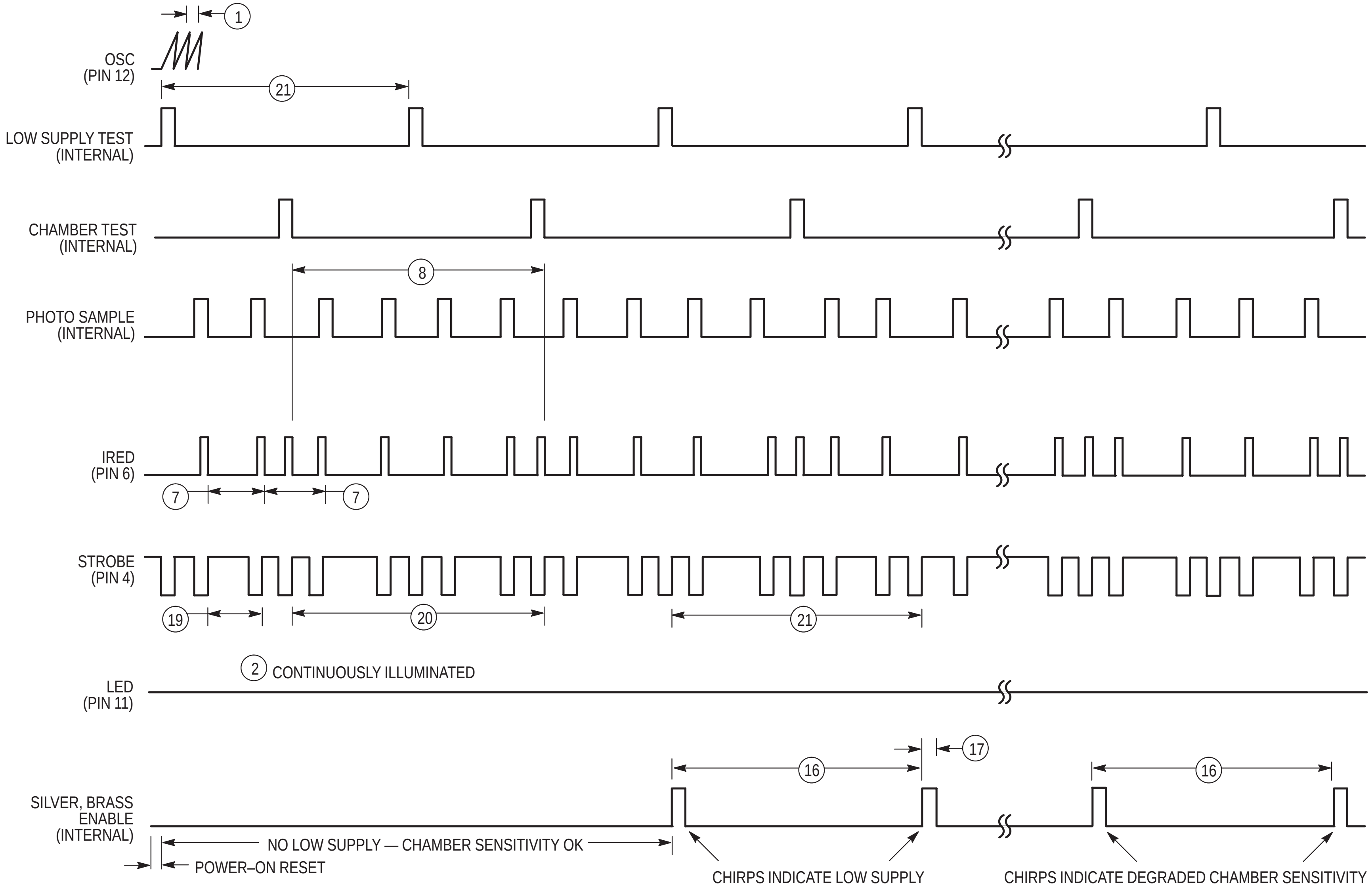
NOTE: Includes external component variations. See Figure 2B.

Figure 2A. AC Characteristics versus Temperature



NOTE: These components were used to generate Figure 2A.

Figure 2B. RC Component Variation Over Temperature



NOTES: Numbers refer to the AC Electrical Characteristics Table.
Illustration is not to scale.

Figure 3. Typical Standby Timing

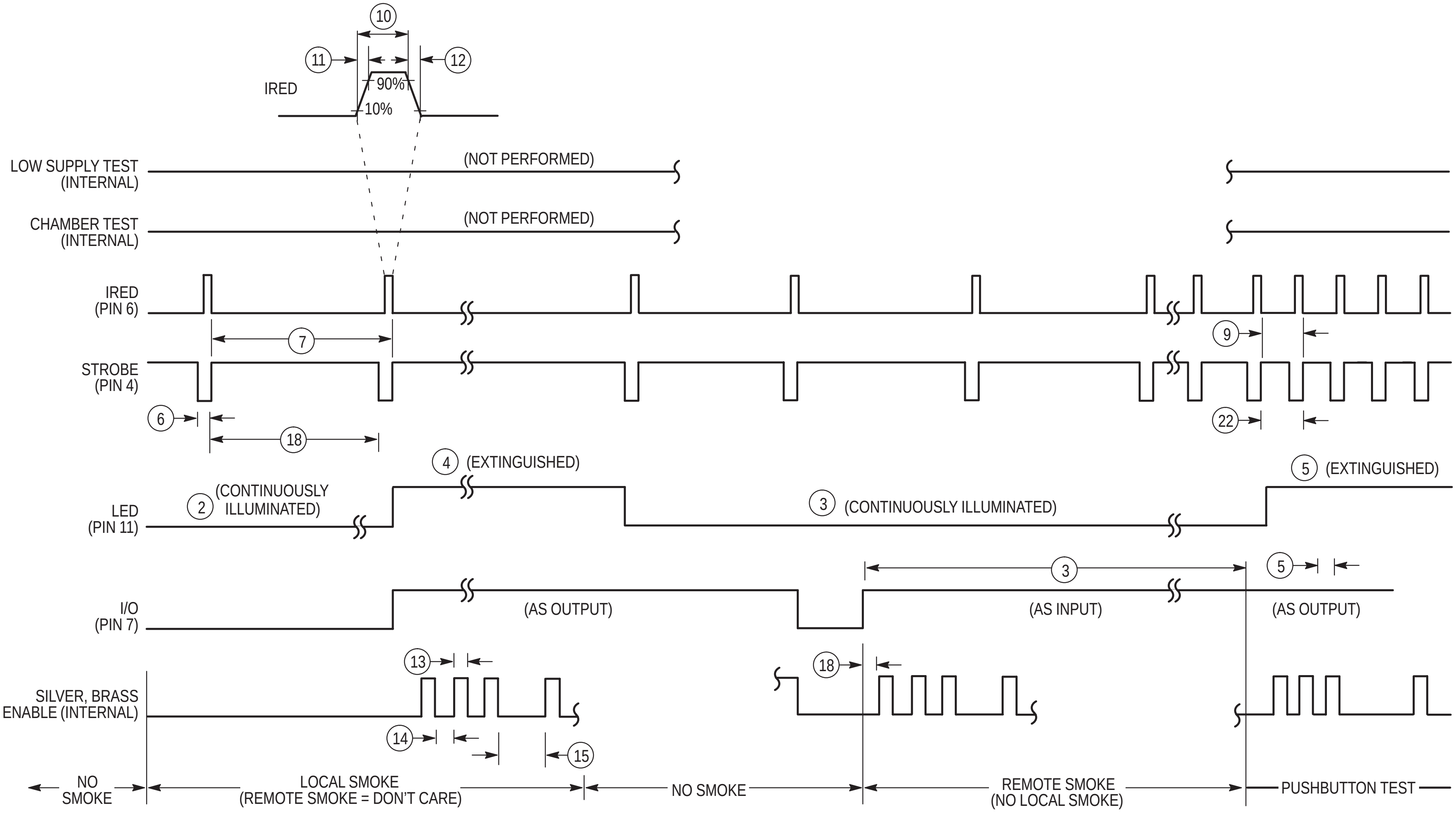
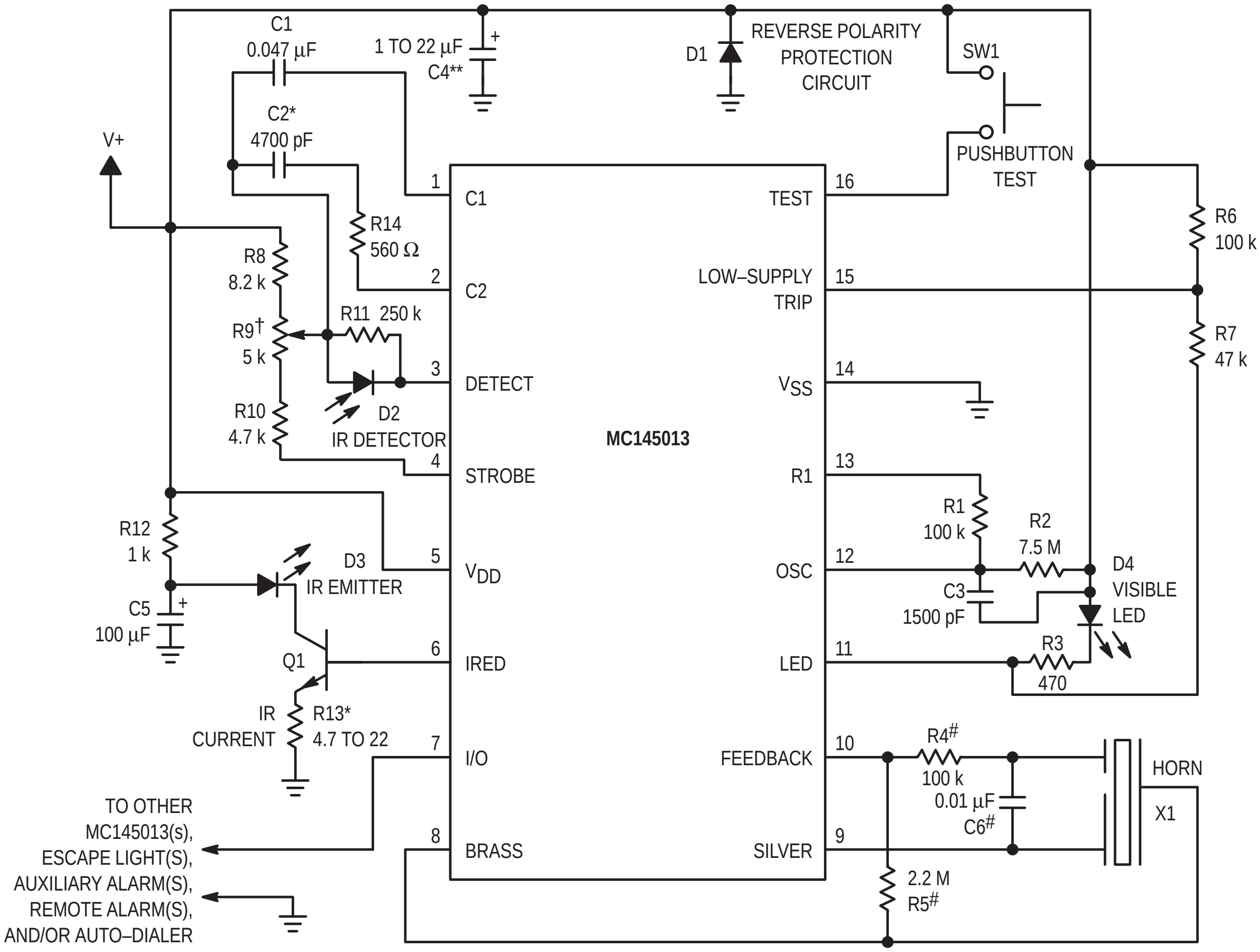


Figure 4. Typical Local Smoke Timing

NOTES: Numbers refer to the AC Electrical Characteristics Table.
Illustration is not to scale.



#Values for R4, R5, and C6 may differ depending on type of piezoelectric horn used.
* C2 and R13 are used for coarse sensitivity adjustment. Typical values are shown.
†R9 is for fine sensitivity adjustment (optional). If fixed resistors are used, R8 = 12 k, R10 is 5.6 k to 10 k, and R9 is eliminated. When R9 is used, noise pickup is increased due to antenna effects. Shielding may be required.
**C4 should be 22 µF if supply line resistance is high (up to 50 Ω). C4 could be reduced to 1 µF when supply line resistance is < 30 Ω.

Figure 5. Battery–Powered Application

PIN DESCRIPTIONS

C1 (Pin 1)

A capacitor connected to this pin as shown in Figure 5 determines the gain of the on–chip photo amplifier during pushbutton test and chamber sensitivity test (high gain). The capacitor value is chosen such that the alarm is tripped from background reflections in the chamber during pushbutton test.

$A_V \approx 1 + (C1/10)$ where C1 is in pF. CAUTION: The value of the closed–loop gain should not exceed 10,000.

C2 (Pin 2)

A capacitor connected to this pin as shown in Figure 5 determines the gain of the on–chip photo amplifier except during pushbutton or chamber sensitivity tests.

$A_V \approx 1 + (C2/10)$ where C2 is in pF. This gain increases about 10% during the IRED pulse, after two consecutive local smoke detections.

Resistor R14 must be installed in series with C2. $R14 \approx [1/(12\sqrt{C2})] - 680$ where R14 is in ohms and C2 is in farads.

DETECT (Pin 3)

This input to the high–gain pulse amplifier is tied to the cathode of an external photodiode. The photodiode should have low capacitance and low dark leakage current. The diode must be shunted by a load resistor and is operated at zero bias.

The Detect input must be ac/dc decoupled from all other signals, V_{DD}, and V_{SS}. Lead length and/or foil traces to this pin must be minimized, also. See Figure 6.

STROBE (Pin 4)

This output provides a strobed, regulated voltage referenced to V_{DD}. The temperature coefficient of this voltage is ± 0.2%/°C maximum from – 10° to 60°C. The supply–voltage coefficient (line regulation) is ± 0.2%/V maximum from 6 to 12 V. Strobe is tied to external resistor string R8, R9, and R10.

V_{DD} (Pin 5)

This pin is connected to the positive supply potential and may range from + 6 to + 12 V with respect to V_{SS}.

IRED (Pin 6)

This output provides pulsed base current for external NPN transistor Q1 used as the infrared emitter driver. Q1 must have $\beta \geq 100$. At 10 mA, the temperature coefficient of the output voltage is typically + 0.5%/°C from – 10° to 60°C. The supply–voltage coefficient (line regulation) is ± 0.2%/V maximum from 6 to 12 V. The IRED pulse width (active–high) is determined by external components R1 and C3. With a 100 kΩ/1500 pF combination, the nominal width is 105 µs.

To minimize noise impact, IRED is not active when the visible LED and horn outputs are active. IRED is active near the end of strobe pulses for smoke tests, chamber sensitivity test, and pushbutton test.

I/O (Pin 7)

This pin can be used to connect up to 40 units together in a wired–OR configuration for common signaling. V_{SS} is used as the return. An on–chip current sink minimizes noise pick up during non–smoke conditions and eliminates the need for an external pull–down resistor to complete the wired–OR. Remote units at lower supply voltages do not draw excessive current from a sending unit at a higher supply voltage.

I/O can also be used to activate escape lights, auxiliary alarms, remote alarms, and/or auto–dialers.

As an input, this pin feeds a positive–edge–triggered flip–flop whose output is sampled nominally every 1 second during standby (using the recommended component values). A local–smoke condition or the pushbutton–test mode forces this current–limited output to source current. All input signals are ignored when I/O is sourcing current.

I/O is disabled by the on–chip power–on reset to eliminate nuisance signaling during battery changes or system power–up.

If unused, I/O must be left unconnected.

BRASS (Pin 8)

This half of the push–pull driver output is connected to the metal support electrode of a piezoelectric audio transducer and to the horn–starting resistor. A continuous modulated tone from the transducer is a smoke alarm indicating either local or remote smoke. A short beep or chirp is a trouble alarm indicating a low supply or degraded chamber sensitivity.

SILVER (Pin 9)

This half of the push–pull driver output is connected to the ceramic electrode of a piezoelectric transducer and to the horn–starting capacitor.

FEEDBACK (Pin 10)

This input is connected to both the feedback electrode of a self–resonating piezoelectric transducer and the horn–starting resistor and capacitor through current–limiting resistor R4. If unused, this pin must be tied to V_{SS} or V_{DD}.

LED (Pin 11)

This active–low open–drain output directly drives an external visible LED.

The load for the low–supply test is applied by this output. This low–supply test is non–coincident with the smoke tests, chamber sensitivity test, pushbutton test, or any alarm signals.

The LED also provides a visual indication of the detector status as follows, assuming the component values shown in Figure 5:

Standby (includes low–supply and chamber sensitivity tests) — Constantly illuminated

Local Smoke — Constantly extinguished

Remote Smoke — Constantly illuminated

Pushbutton Test — Constantly extinguished (system OK); constantly illuminated (system problem)

OSC (Pin 12)

This pin is used in conjunction with external resistor R2 (7.5 MΩ) to V_{DD} and external capacitor C3 (1500 pF) to V_{DD} to form an oscillator with a nominal period of 7.9 ms (typical).

R1 (Pin 13)

This pin is used in conjunction with resistor R1 (100 kΩ) to Pin 12 and C3 (1500 pF, see Pin 12 description) to determine the IRED pulse width. With this RC combination, the nominal pulse width is 105 µs.

V_{SS} (Pin 14)

This pin is the negative supply potential and the return for the I/O pin. Pin 14 is usually tied to ground.

LOW–SUPPLY TRIP (Pin 15)

This pin is connected to an external voltage which determines the low–supply alarm threshold. The trip voltage is obtained through a resistor divider connected between the V_{DD} and LED pins. The low–supply alarm threshold voltage (in volts) $\approx (5R7/R6) + 5$ where R6 and R7 are in the same units.

TEST (Pin 16)

This input has an on–chip pull–down device and is used to manually invoke a test mode.

The *Pushbutton Test* mode is initiated by a high level at Pin 16 (usually depression of a S.P.S.T. normally–open pushbutton switch to V_{DD}). After one oscillator cycle, IRED pulses approximately every 1.0 second, regardless of the presence of smoke. Additionally, the amplifier gain is increased by automatic selection of C1. Therefore, the background reflections in the smoke chamber may be interpreted as smoke, generating a simulated–smoke condition. After the second IRED pulse, a successful test activates the horn–driver and I/O circuits. The active I/O allows remote signaling for system testing. When the Pushbutton Test switch is released, the Test input returns to V_{SS} due to the on–chip pull–down device. After one oscillator cycle, the amplifier gain returns to normal, thereby removing the simulated–smoke condition. After two additional IRED pulses, less than three seconds, the IC exits the alarm mode and returns to standby timing.

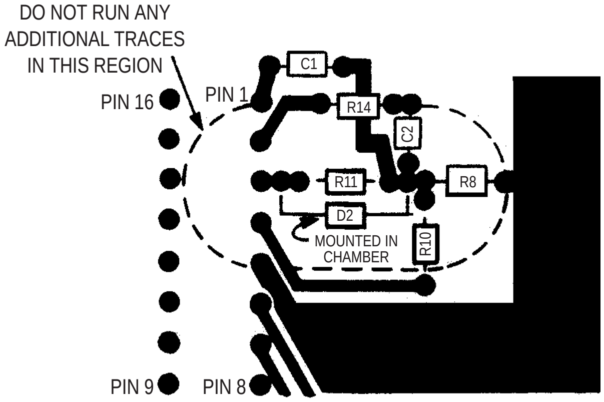
CALIBRATION

To facilitate checking the sensitivity and calibrating smoke detectors, the MC145013 can be placed in a calibration mode. In this mode, certain device pins are controlled/reconfigured as shown in Table 1. To place the part in the calibration mode, Pin 16 (Test) must be pulled below the V_{SS} pin with 100 µA continuously drawn out of the pin for at least one cycle on the OSC pin. To exit this mode, the Test pin is floated for at least one OSC cycle.

In the calibration mode, the IRED pulse rate is increased to one for every OSC cycle. Also, Strobe is always active low.

Table 1. Configuration of Pins in the Calibration Mode

Description	Pin	Comment
I/O	7	Disabled as an output. Forcing this pin high places the photo amp output on Pin 1 or 2, as determined by Low–Supply Trip. The amp's output appears as pulses and is referenced to V_{DD} etc.
Low–Supply Trip	15	If the I/O pin is high, Pin 15 controls which gain capacitor is used. Low: normal gain, amp output on Pin 1. High: supervisory gain, amp output on Pin 2.
Feedback	10	Driving this input high enables hysteresis (10% gain increase) in the photo amp; Pin 15 must be low.
OSC	12	Driving this input high brings the internal clock high. Driving the input low brings the internal clock low. If desired, the RC network for the oscillator may be left intact; this allows the oscillator to run similar to the normal mode of operation.
Silver	9	This pin becomes the smoke comparator output. When the OSC pin is toggling, positive pulses indicate that smoke has been detected. A static low level indicates no smoke.
Brass	8	This pin becomes the smoke integrator output. That is, 2 consecutive smoke detections are required for "on" (static high level) and 2 consecutive no–detections for "off" (static low level).



NOTES: Illustration is bottom view of layout using a DIP. Top view for SOIC layout is mirror image.
Optional potentiometer R9 is not included.
Drawing is not to scale.
Leads on D2, R11, R8, and R10 and their associated traces must be kept as short as possible. This practice minimizes noise pick up.
Pin 3 must be decoupled from all other traces.

Figure 6. Recommended PCB Layout

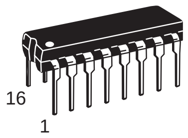
MOTOROLA
SEMICONDUCTOR TECHNICAL DATA

MC145017

Low-Power Complementary MOS Ionization Smoke Detector

The MC145017, when used with an ionization chamber and a small number of external components, will detect smoke. When smoke is sensed, an alarm is sounded via an external piezoelectric transducer and internal drivers. This circuit is designed to comply with the UL217 and UL268 specifications.

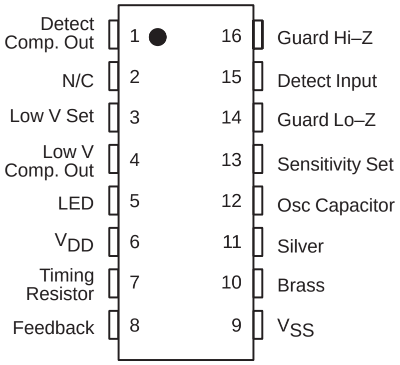
- Ionization Type with On–Chip FET Input Comparator
- Piezoelectric Horn Driver
- Guard Outputs on Both Sides of Detect Input
- Input–Production Diodes on the Detect Input
- Low–Battery Trip Point, Internally Set, can be Altered Via External Resistor
- Detect Threshold, Internally Set, can be Altered Via External Resistor
- Pulse Testing for Low Battery Uses LED for Battery Loading
- Comparator Outputs for Detect and Low Battery
- Internal Reverse Battery Protection
- Supports NFPA 72, ANSi 53.41, and ISO 8201 Audible Emergency Evacuation Signals



P SUFFIX
PLASTIC DIP
CASE 648–08

ORDERING INFORMATION
MC145017P PLASTIC DIP

PIN ASSIGNMENT
(16 PIN DIP)



MAXIMUM RATINGS* (Voltages referenced to V_{SS})

Rating	Symbol	Value	Unit
DC Supply Voltage	V_{DD}	– 0.5 to +15	V
Input Voltage, All Inputs Except Pin 8	V_{in}	– 0.25 to V_{DD} +0.25	V
DC Current Drain per Input Pin, Except Pin 15 = 1 mA	I	10	mA
DC Current Drain per Output Pin	I	30	mA
Operating Temperature Range	T_A	– 10 to +60	°C
Storage Temperature Range	T_{stg}	– 55 to +125	°C
Reverse Battery Time	t_{RB}	5.0	s

* Maximum Ratings are those values beyond which damage to the device may occur.

This device contains circuitry to protect the inputs against damage due to high static voltages or electric fields; however, it is advised that normal precautions be taken to avoid application of any voltage higher than maximum rated voltages to this high impedance circuit. For proper operation it is recommended that V_{in} and V_{out} be constrained to the range $V_{SS} \leq (V_{in} \text{ or } V_{out}) \leq V_{DD}$.

REV 1

RECOMMENDED OPERATING CONDITIONS (Voltages referenced to V_{SS})

Parameter	Symbol	Value	Unit
Supply Voltage	V_{DD}	9.0	V
Timing Capacitor	—	0.1	µF
Timing Resistor	—	8.2	MΩ
Battery Load (Resistor or LED)	—	10	mA

ELECTRICAL CHARACTERISTICS (Voltages referenced to V_{SS}, TA = 25°C)

Characteristic	Symbol	V_{DD} V_{dc}	Min	Typ	Max	Unit
Operating Voltage	V_{DD}	—	6.0	—	12	V
Output Voltage	V_{OH}					V
Piezoelectric Horn Drivers (I_{OH} = −16 mA)		7.2	6.3	—	—	
Comparators (I_{OH} = −30 µA)		9.0	8.5	8.8	—	
Piezoelectric Horn Drivers (I_{OL} = +16 mA)	V_{OL}	7.2	—	—	0.9	V
Comparators (I_{OL} = +30 µA)		9.0	—	0.1	0.5	
Output Voltage — LED Driver, I_{OL} = 10 mA	V_{OL}	7.2	—	—	3.0	V
Output Impedance, Active Guard						kΩ
Pin 14	Lo–Z	9.0	—	—	10	
Pin 16	Hi–Z	9.0	—	—	1000	
Operating Current (R_{bias} = 8.2 MΩ)	I_{DD}	9.0	—	5.0	9.0	µA
		12.0	—	—	12.0	
Input Current — Detect (40% R.H.)	I_{in}	9.0	—	—	± 1.0	pA
Input Current, Pin 8	I_{in}	9.0	—	—	± 0.1	µA
Input Current @ 50°C, Pin 15	I_{in}	—	—	—	± 6.0	pA
Internal Set Voltage						
Low Battery	V_{low}	9.0	7.2	—	7.8	V
Sensitivity	V_{set}	—	47	50	53	%V_{DD}
Hysteresis	v_{hys}	9.0	75	100	150	mV
Offset Voltage (measured at V_{in} = V_{DD}/2)	V_{OS}					mV
Active Guard		9.0	—	—	± 100	
Detect Comparator		9.0	—	—	± 50	
Input Voltage Range, Pin 8	V_{in}	—	− 10	—	$V_{DD}{+10}$	V
Input Capacitance	C_{in}	—	—	5.0	—	pF
Common Mode Voltage Range, Pin 15	V_{cm}	—	0.6	—	$V_{DD} - 2$	V

Data labelled “Typ” is not to be used for design purposes but is intended as an indication of the IC’s potential performance.

TIMING PARAMETERS (C = 0.1 µF, R_{bias} = 8.2 MΩ, V_{DD} = 9.0 V, T_A = 25°C, See Figure 6)

Characteristics		Symbol	Min	Max	Units
Oscillator Period	No Smoke Smoke	t_{CI}	1.46 37.5	1.85 45.8	s ms
Oscillator Rise Time		t_r	10.1	12.3	ms
Horn Output (During Smoke)	On Time Off Time	PW_{on} PW_{off}	450 450	550 550	ms ms
LED Output Pulses	Between On Time	t_{LED} PW_{on}	35.0 10.1	44.5 12.3	s ms
Horn Output (During Low Battery) Pulses	On Time Between	t_{on} t_{off}	10.1 35.0	12.3 44.5	ms s

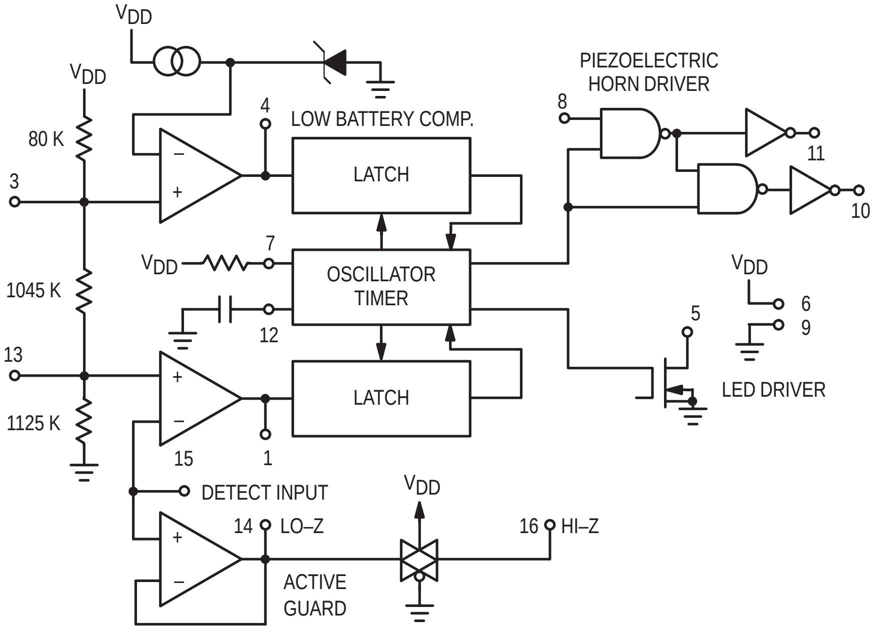


Figure 1. Block Diagram

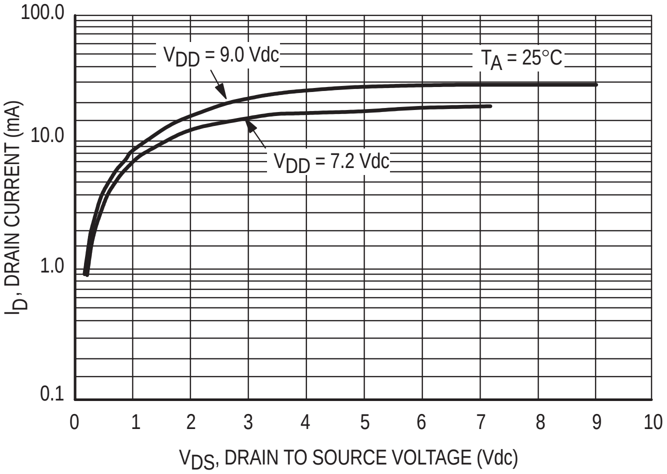


Figure 2. Typical LED Output I–V Characteristic

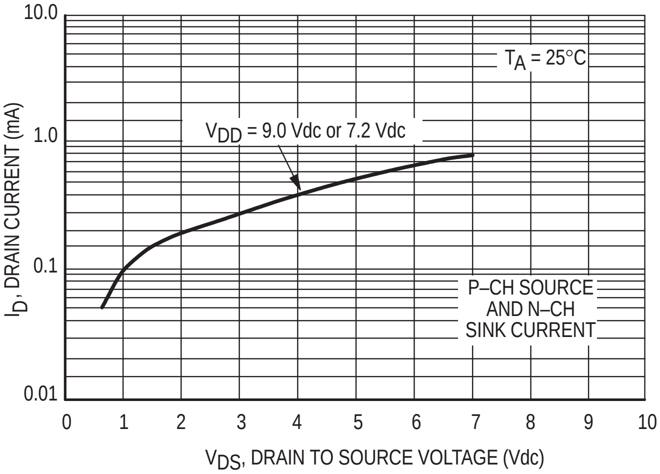


Figure 3. Typical Comparator Output I–V Characteristic

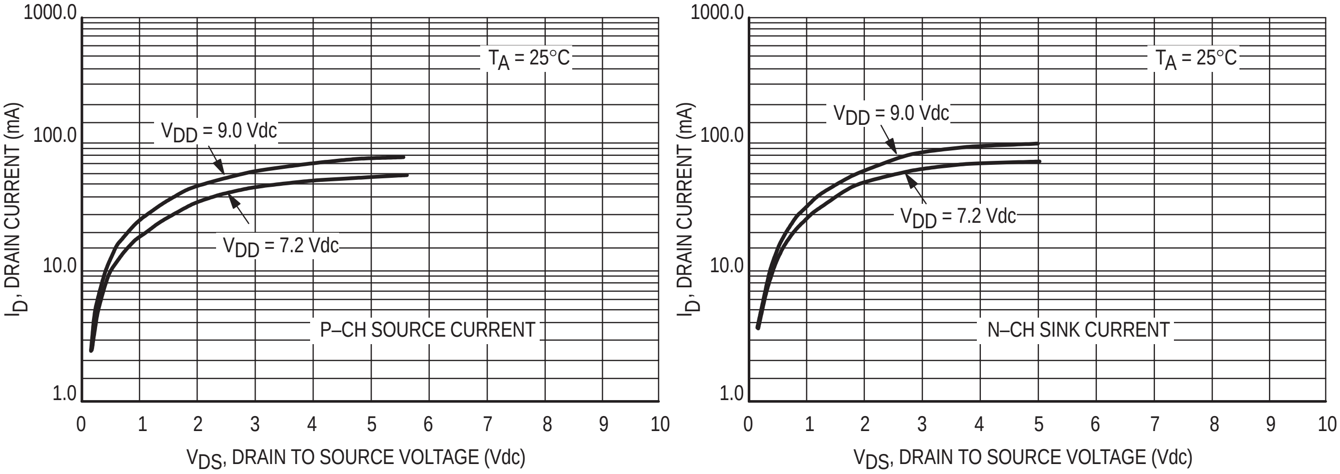


Figure 4. Typical P Horn Driver Output I–V Characteristic

DEVICE OPERATION

TIMING

The internal oscillator of the MC145017 operates with a period of 1.65 seconds during no–smoke conditions. Each 1.65 seconds, internal power is applied to the entire IC and a check is made for smoke, except during LED pulse, Low Battery Alarm Chirp, or Horn Modulation (in smoke). Every 24 clock cycles a check is made for low battery by comparing V_{DD} to an internal zener voltage. Since very small currents are used in the oscillator, the oscillator capacitor should be of a low leakage type.

DETECT CIRCUITRY

If smoke is detected, the oscillator period becomes 41.67 ms and the piezoelectric horn oscillator circuit is enabled. The horn output is modulated 500 ms on, 500 ms off. During the off time, smoke is again checked and will inhibit further horn output if no smoke is sensed. During smoke conditions the low battery alarm is inhibited, but the LED pulses at a 1.0 Hz rate.

An active guard is provided on both pins adjacent to the detect input. The voltage at these pins will be within 100 mV of the input signal. This will keep surface leakage currents to a minimum and provide a method of measuring the input voltage without loading the ionization chamber. The active guard op amp is not power strobed and thus gives constant protection from surface leakage currents. Pin 15 (the Detect input) has internal diode protection against static damage.

SENSITIVITY/LOW BATTERY THRESHOLDS

Both the sensitivity threshold and the low battery voltage levels are set internally by a common voltage divider connected between V_{DD} and V_{SS}. These voltages can be altered by external resistors connected from pins 3 or 13 to either V_{DD} or V_{SS}. There will be a slight interaction here due to the common voltage divider network. The sensitivity threshold can also be set by adjusting the smoke chamber ionization source.

TEST MODE

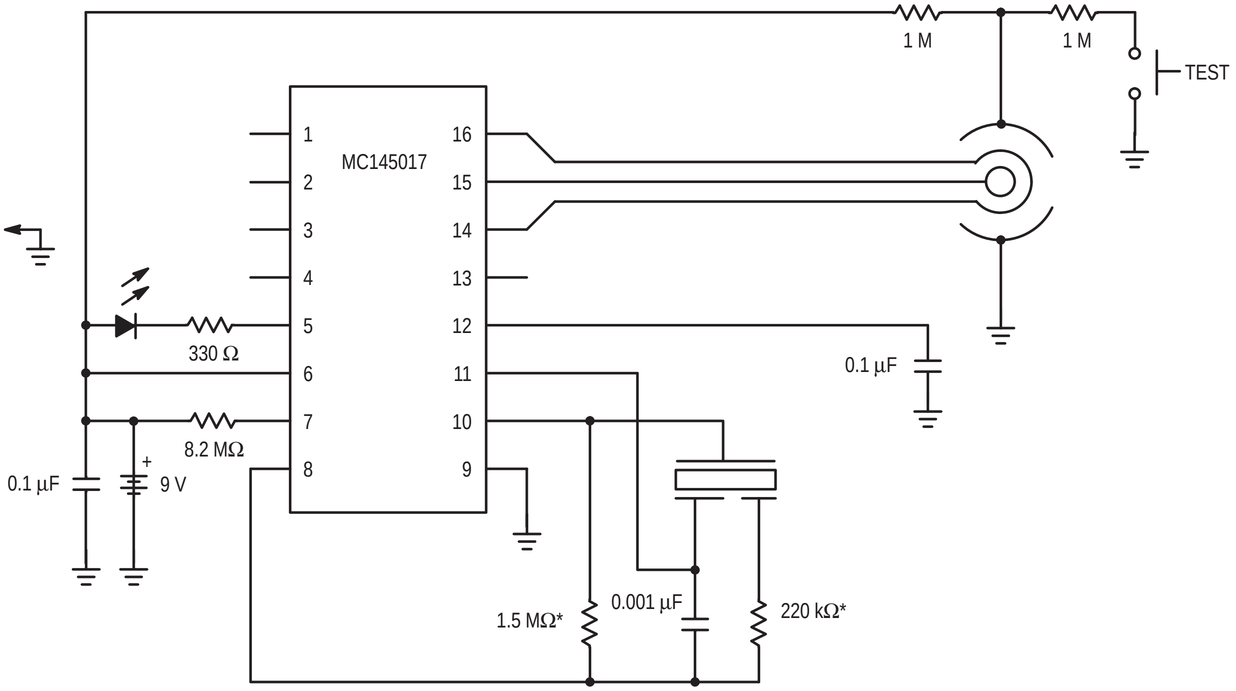
Since the internal op amps and comparators are power strobed, adjustments for sensitivity or low battery level could be difficult and/or time–consuming. By forcing Pin 12 to V_{SS}, the power strobing is bypassed and the outputs, Pins 1 and 4, constantly show smoke/no smoke and good battery/low battery, respectively. Pin 1 = V_{DD} for smoke and Pin 4 = V_{DD} for low battery. In this mode and during the 10 ms power strobe, chip current rises to approximately 50 µA.

LED PULSE

The 9–volt battery level is checked every 40 seconds during the LED pulse. The battery is loaded via a 10 mA pulse for 11.6 ms. If the LED is not used, it should be replaced with an equivalent resistor such that the battery loading remains at 10 mA.

HYSTERESIS

When smoke is detected, the resistor/divider network that sets sensitivity is altered to increase sensitivity. This yields approximately 100 mV of hysteresis and reduces false triggering.



*NOTE: Component values may change depending on type of piezoelectric horn used.

Figure 5. Typical Application as Ionization Smoke Detector

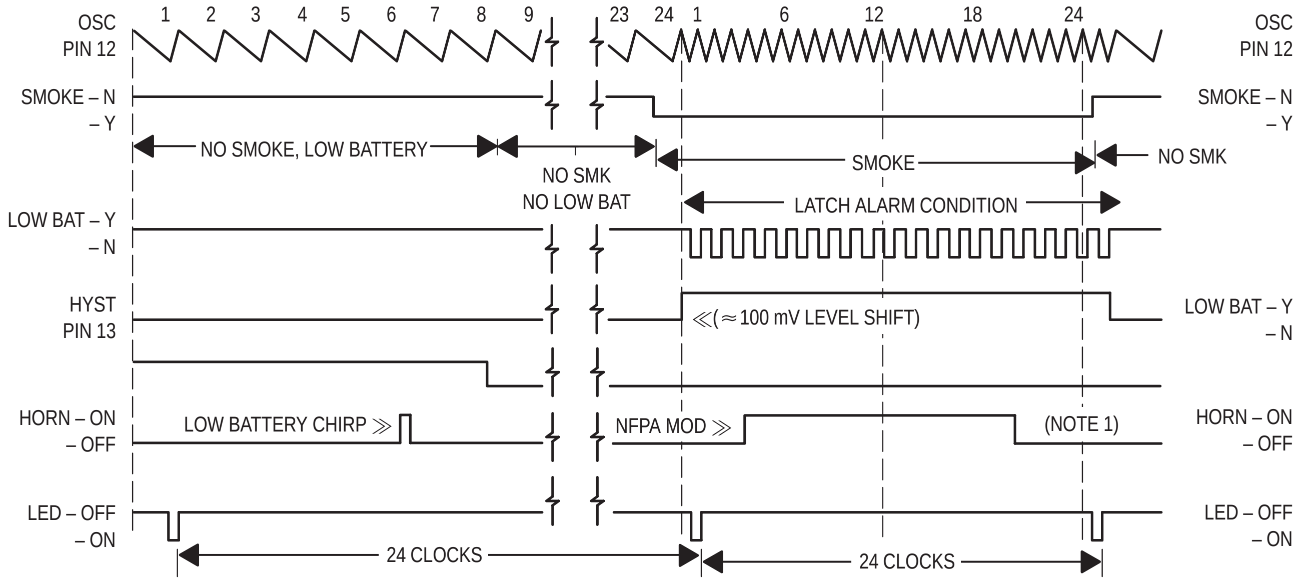


Figure 6. MC145017 Timing Diagram

NOTES:

1. Horn modulation is self–completing. When going from smoke to no smoke, the alarm condition will terminate only when horn is off.
2. Comparators are strobed once per cycle (1.65 sec for no smoke, 40 msec for smoke).

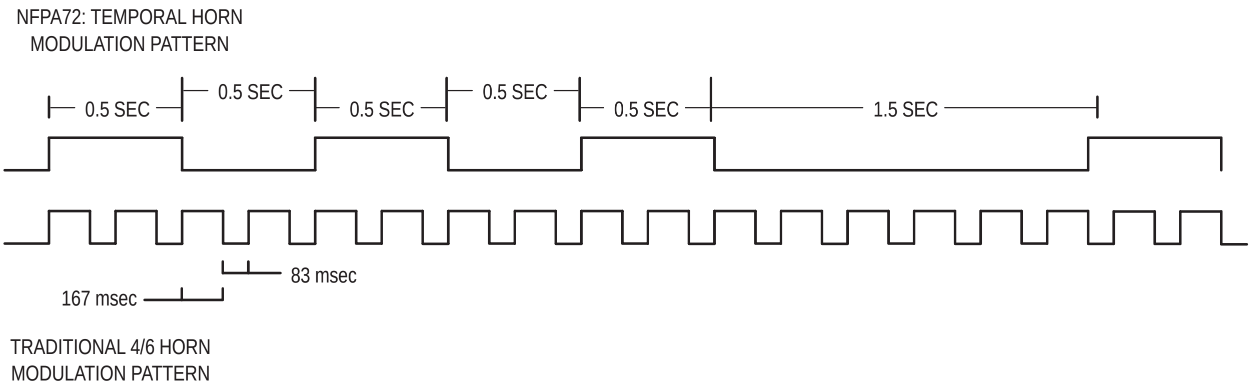


Figure 7. Horn Modulation

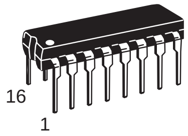
MOTOROLA
SEMICONDUCTOR TECHNICAL DATA

MC145018

Low-Power Complementary MOS Ionization Smoke Detector with Interconnect

The MC145018, when used with an ionization chamber and a small number of external components, will detect smoke. When smoke is sensed, an alarm is sounded via an external piezoelectric transducer and internal drivers. This circuit is designed to comply with the UL217 and UL268 specifications.

- Ionization Type with On–Chip FET Input Comparator
- Piezoelectric Horn Driver
- Guard Outputs on Both Sides of Detect Input
- Input–Protection Diodes on the Detect Input
- Low–Battery Trip Point, Internally Set, can be Altered Via External Resistor
- Detect Threshold, Internally Set, can be Altered Via External Resistor
- Pulse Testing for Low Battery Uses LED for Battery Loading
- Comparator Output for Detect
- Internal Reverse Battery Protection
- Strobe Output for External Trim Resistors
- I/O Pin Allows Up to 40 Units to be Connected for Common Signaling
- Supports NFPA 72, ANSi 53.41, and ISO 8201
  Audible Emergency Evacuation Signals
- Power–On Reset Places IC in Standby Mode

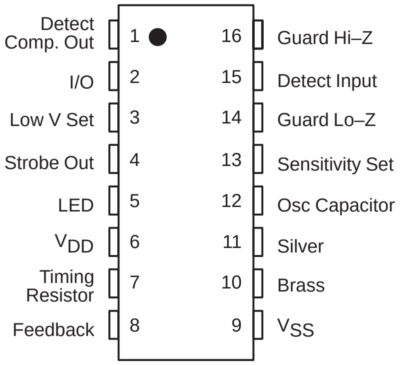


P SUFFIX
PLASTIC DIP
CASE 648–08

ORDERING INFORMATION

MC145018P PLASTIC DIP

PIN ASSIGNMENT
(16 PIN DIP)



MAXIMUM RATINGS* (Voltages referenced to V_{SS})

Rating	Symbol	Value	Unit
DC Supply Voltage	V_{DD}	– 0.5 to +15	V
Input Voltage, All Inputs Except Pin 8	V_{in}	– 0.25 to V_{DD} +0.25	V
DC Current Drain per Input Pin, Except Pin 15 = 1 mA	I	10	mA
DC Current Drain per Output Pin	I	30	mA
Operating Temperature Range	T_A	– 10 to +60	°C
Storage Temperature Range	T_{stg}	– 55 to +125	°C
Reverse Battery Time	t_{RB}	5.0	s

* Maximum Ratings are those values beyond which damage to the device may occur.

This device contains circuitry to protect the inputs against damage due to high static voltages or electric fields; however, it is advised that normal precautions be taken to avoid application of any voltage higher than maximum rated voltages to this high impedance circuit. For proper operation it is recommended that V_{in} and V_{out} be constrained to the range $V_{SS} \leq (V_{in}$ or $V_{out}) \leq V_{DD}$.

REV 1

RECOMMENDED OPERATING CONDITIONS (Voltages referenced to V_{SS})

Parameter	Symbol	Value	Unit
Supply Voltage	V_{DD}	9.0	V
Timing Capacitor	—	0.1	µF
Timing Resistor	—	8.2	MΩ
Battery Load (Resistor or LED)	—	10	mA

ELECTRICAL CHARACTERISTICS (Voltages referenced to V_{SS}, TA = 25°C)

Characteristic	Symbol	V_{DD} V_{dc}	Min	Typ	Max	Unit
Operating Voltage	V_{DD}	—	6.0	—	12	V
Output Voltage	V_{OH}					V
Piezoelectric Horn Drivers (I_{OH} = − 16 mA)		7.2	6.3	—	—	
Comparators (I_{OH} = − 30 µA)		9.0	8.5	8.8	—	
Piezoelectric Horn Drivers (I_{OL} = +16 mA)	V_{OL}	7.2	—	—	0.9	V
Comparators (I_{OL} = +30 µA)		9.0	—	0.1	0.5	
Output Voltage — LED Driver, I_{OL} = 10 mA	V_{OL}	7.2	—	—	3.0	V
Output Impedance, Active Guard	Lo–Z	9.0	—	—	10	kΩ
Pin 14	Hi–Z	9.0	—	—	1000	
Pin 16						
Operating Current (R_{bias} = 8.2 MΩ)	I_{DD}	9.0 12.0	— —	5.0 —	9.0 12.0	µA
Input Current — Detect (40% R.H.)	I_{in}	9.0	—	—	± 1.0	pA
Input Current, Pin 8	I_{in}	9.0	—	—	± 0.1	µA
Input Current @ 50°C, Pin 15	I_{in}	—	—	—	± 6.0	pA
Internal Set Voltage						
Low Battery	V_{low}	9.0	7.2	—	7.8	V
Sensitivity	V_{set}	—	47	50	53	%V_{DD}
Hysteresis	v_{hys}	9.0	75	100	150	mV
Offset Voltage (measured at $V_{in} = V_{DD}/2$)	V_{OS}					mV
Active Guard		9.0	—	—	± 100	
Detect Comparator		9.0	—	—	± 50	
Input Voltage Range, Pin 8	V_{in}	—	− 10	—	V_{DD}+10	V
Input Capacitance	C_{in}	—	—	5.0	—	pF
Common Mode Voltage Range, Pin 15	V_{cm}	—	0.6	—	V_{DD} − 2	V
I/O Current, Pin 2						
Input, $V_{IH} = V_{DD} - 2$	I_{IH}	—	25	—	100	µA
Output, $V_{OH} = V_{DD} - 2$	I_{OH}	—	− 4.0	—	− 16	mA

Data labelled "Typ'' is not to be used for design purposes but is intended as an indication of the IC's potential performance.

TIMING PARAMETERS ($C = 0.1\ \mu F$, $R_{bias} = 8.2\ M\Omega$, $V_{DD} = 9.0\ V$, $T_A = 25°C$, See Figure 6)

Characteristics		Symbol	Min	Max	Units
Oscillator Period	No Smoke Smoke	t_{CI}	1.46 37.5	1.85 45.8	s ms
Oscillator Rise Time		t_r	10.1	12.3	ms
Horn Output (During Smoke)	On Time Off Time	PW_{on} PW_{off}	450 450	550 550	ms ms
LED Output Pulses	Between On Time	t_{LED} PW_{on}	35.0 10.1	44.5 12.3	s ms
Horn Output (During Low Battery) Pulses	On Time Between	t_{on} t_{off}	10.1 35.0	12.3 44.5	ms s

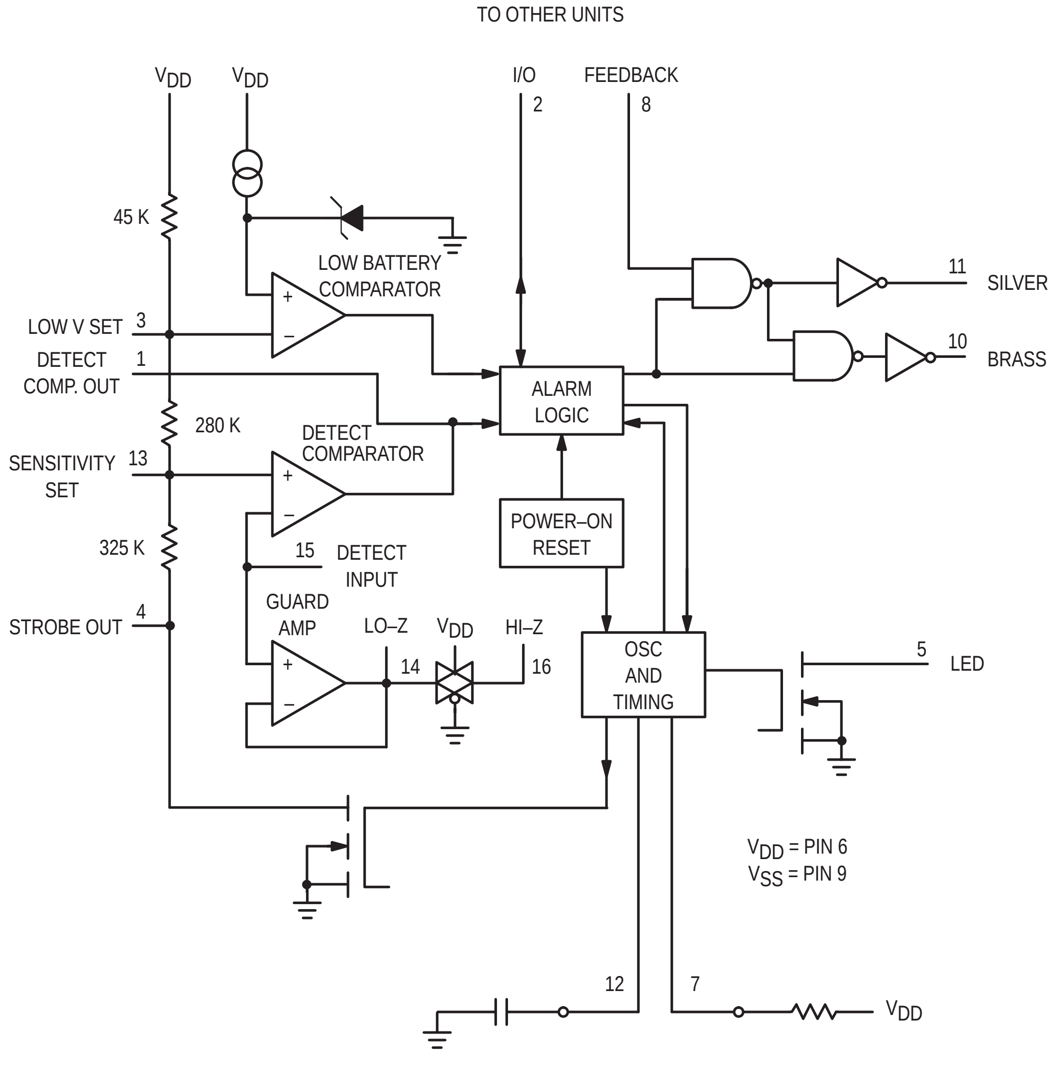


Figure 1. Block Diagram

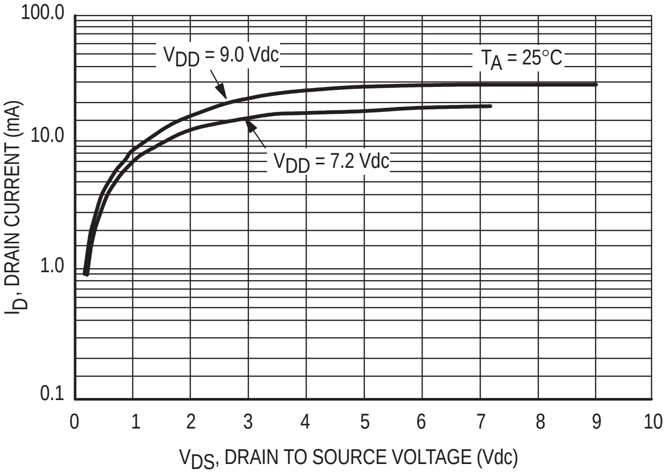


Figure 2. Typical LED Output I–V Characteristic

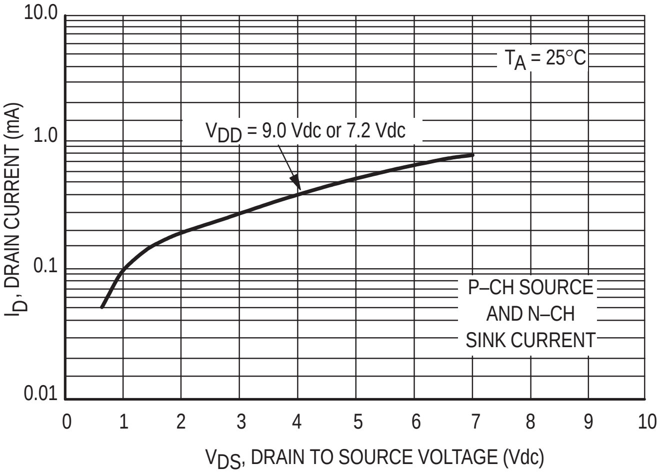


Figure 3. Typical Comparator Output I–V Characteristic

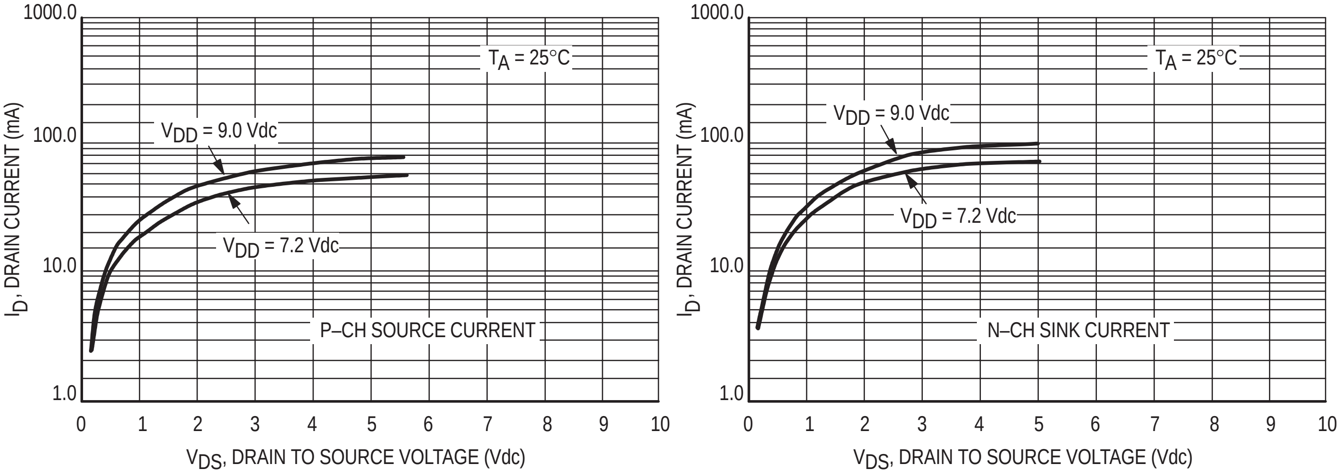


Figure 4. Typical P Horn Driver Output I–V Characteristic

DEVICE OPERATION

TIMING

The internal oscillator of the MC145018 operates with a period of 1.65 seconds during no–smoke conditions. Each 1.65 seconds, internal power is applied to the entire IC and a check is made for smoke, except during LED pulse, Low Battery Alarm Chirp, or Horn Modulation (in smoke). Every 24 clock cycles a check is made for low battery by comparing V_{DD} to an internal zener voltage. Since very small currents are used in the oscillator, the oscillator capacitor should be of a low leakage type.

DETECT CIRCUITRY

If smoke is detected, the oscillator period becomes 41.67 ms and the piezoelectric horn oscillator circuit is enabled. The horn output is modulated 500 ms on, 500 ms off. During the off time, smoke is again checked and will inhibit further horn output if no smoke is sensed. During local smoke conditions the low battery alarm is inhibited, but the LED pulses at a 1.0 Hz rate. In remote smoke, the LED is inhibited as well.

An active guard is provided on both pins adjacent to the detect input. The voltage at these pins will be within 100 mV of the input signal. This will keep surface leakage currents to a minimum and provide a method of measuring the input voltage without loading the ionization chamber. The active guard op amp is not power strobed and thus gives constant protection from surface leakage currents. Pin 15 (the Detect input) has internal diode protection against static damage.

INTERCONNECT

The I/O (Pin 2), in combination with V_{SS}, is used to interconnect up to 40 remote units for common signaling. A Local Smoke condition activates a current limited output driver, thereby signaling Remote Smoke to interconnected units. A small current sink improves noise immunity during non–smoke conditions. Remote units at lower voltages do not draw excessive current from a sending unit at a higher voltage. The I/O is disabled for three oscillator cycles after power up, to eliminate false alarming of remote units when the battery is changed.

SENSITIVITY/LOW BATTERY THRESHOLDS

Both the sensitivity threshold and the low battery voltage levels are set internally by a common voltage divider connected between V_{DD} and V_{SS}. These voltages can be altered by external resistors connected from pins 3 or 13 to either V_{DD} or V_{SS}. There will be a slight interaction here due to the common voltage divider network. The sensitivity threshold can also be set by adjusting the smoke chamber ionization source.

TEST MODE

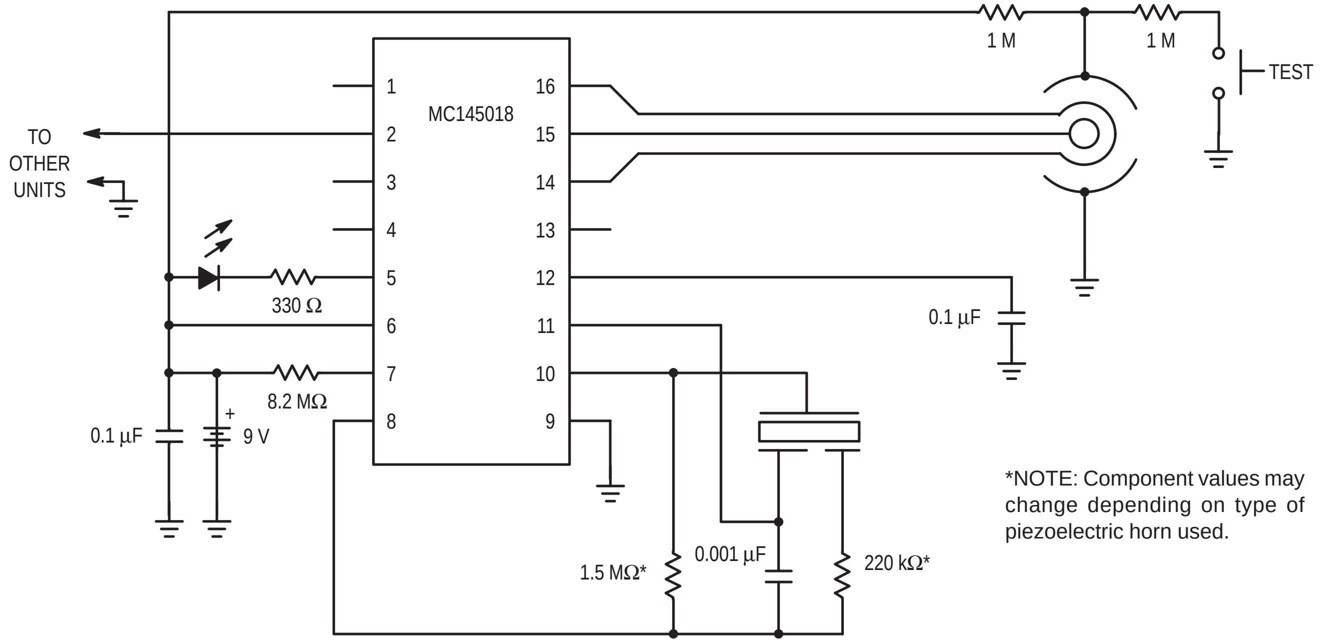
Since the internal op amps and comparators are power strobed, adjustments for sensitivity or low battery level could be difficult and/or time–consuming. By forcing Pin 12 to V_{SS}, the power strobing is bypassed and the output, Pin 1, constantly shows smoke/no smoke. Pin 1 = V_{DD} for smoke. In this mode and during the 10 ms power strobe, chip current rises to approximately 50 µA.

LED PULSE

The 9–volt battery level is checked every 40 seconds during the LED pulse. The battery is loaded via a 10 mA pulse for 11.6 ms. If the LED is not used, it should be replaced with an equivalent resistor such that the battery loading remains at 10 mA.

HYSTERESIS

When smoke is detected, the resistor/divider network that sets sensitivity is altered to increase sensitivity. This yields approximately 100 mV of hysteresis and reduces false triggering.



*NOTE: Component values may change depending on type of piezoelectric horn used.

Figure 5. Typical Application as Ionization Smoke Detector

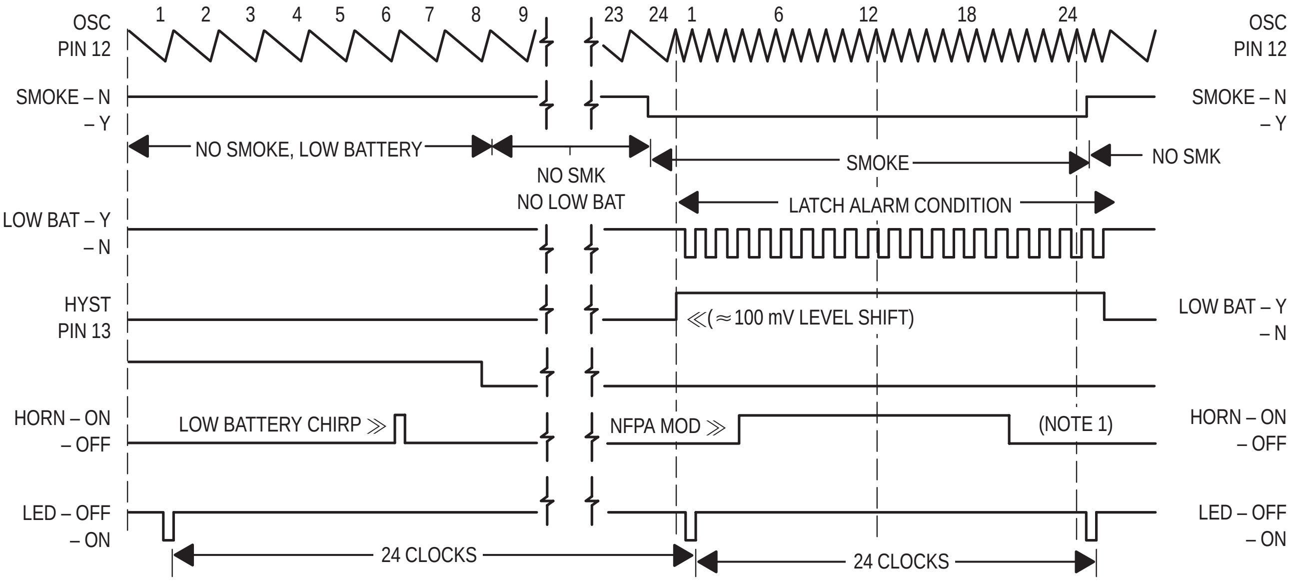


Figure 6. MC145018 Timing Diagram

NOTES:
1. Horn modulation is self–completing. When going from smoke to no smoke, the alarm condition will terminate only when horn is off.
2. Comparators are strobed once per cycle (1.65 sec for no smoke, 40 msec for smoke).
3. For timing under remote conditions, refer to MC14468 data sheet.

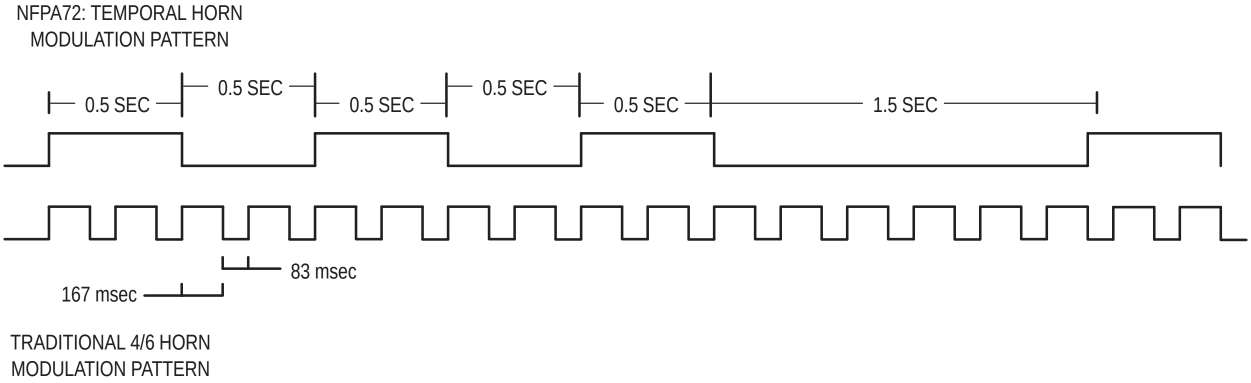
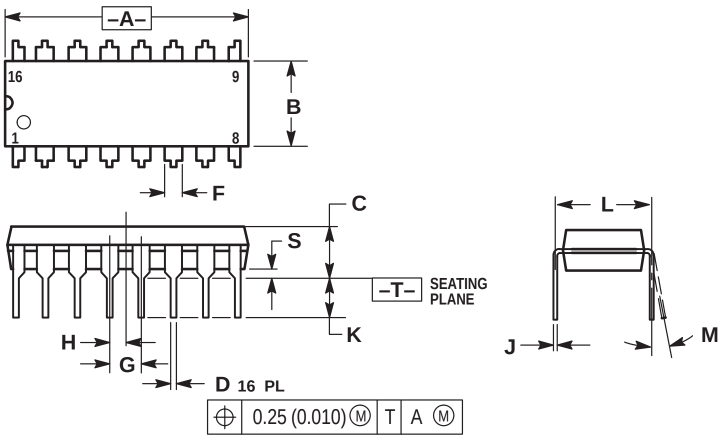


Figure 7. Horn Modulation

Package Outline Dimensions

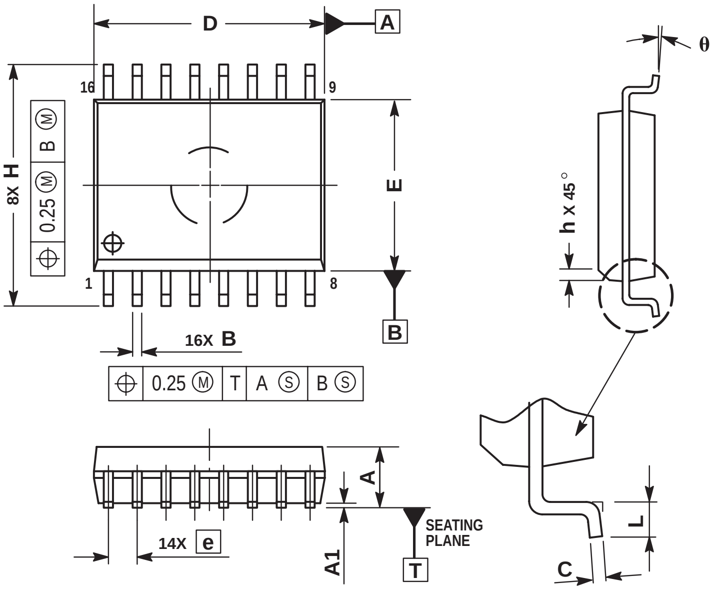


NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION L TO CENTER OF LEADS WHEN FORMED PARALLEL.
4. DIMENSION B DOES NOT INCLUDE MOLD FLASH.
5. ROUNDED CORNERS OPTIONAL.

	INCHES		MILLIMETERS	
DIM	**MIN**	**MAX**	**MIN**	**MAX**
A	0.740	0.770	18.80	19.55
B	0.250	0.270	6.35	6.85
C	0.145	0.175	3.69	4.44
D	0.015	0.021	0.39	0.53
F	0.040	0.70	1.02	1.77
G	0.100 BSC		2.54 BSC	
H	0.050 BSC		1.27 BSC	
J	0.008	0.015	0.21	0.38
K	0.110	0.130	2.80	3.30
L	0.295	0.305	7.50	7.74
M	0 °	10 °	0 °	10 °
S	0.020	0.040	0.51	1.01

STYLE 1:		STYLE 2:	
PIN 1.	CATHODE	PIN 1.	COMMON DRAIN
2.	CATHODE	2.	COMMON DRAIN
3.	CATHODE	3.	COMMON DRAIN
4.	CATHODE	4.	COMMON DRAIN
5.	CATHODE	5.	COMMON DRAIN
6.	CATHODE	6.	COMMON DRAIN
7.	CATHODE	7.	COMMON DRAIN
8.	CATHODE	8.	COMMON DRAIN
9.	ANODE	9.	GATE
10.	ANODE	10.	SOURCE
11.	ANODE	11.	GATE
12.	ANODE	12.	SOURCE
13.	ANODE	13.	GATE
14.	ANODE	14.	SOURCE
15.	ANODE	15.	GATE
16.	ANODE	16.	SOURCE

CASE 648–08
ISSUE R



NOTES:
1. DIMENSIONS ARE IN MILLIMETERS.
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M, 1994.
3. DIMENSIONS D AND E DO NOT INLCUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION 0.15 PER SIDE.
5. DIMENSION B DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.13 TOTAL IN EXCESS OF THE B DIMENSION AT MAXIMUM MATERIAL CONDITION.

	MILLIMETERS	
DIM	**MIN**	**MAX**
A	2.35	2.65
A1	0.10	0.25
B	0.35	0.49
C	0.23	0.32
D	10.15	10.45
E	7.40	7.60
e	1.27 BSC	
H	10.05	10.55
h	0.25	0.75
L	0.50	0.90
θ	0 °	7 °

CASE 751G–03
ISSUE B

Section Six

Evaluation Boards

Sensor Evaluation Boards

Order No.	Sensor	Description	Cost
ASB200	MC68HC705JP7	Controller Board with user manual , microcontroller, software, and PSPICE models	$275
ASB201	MPX10, MPX50	Uncompensated sensor module	$ 75
ASB202	MPX2010, MPX2050	Compensated sensor module	$ 75
ASB205	MPXT5006, MPX5010, MPX5050, MPX5100, MPX5999	Integrated sensor module	$ 75
ASB210	MPX2010	Pulsed, 10″H_2O module	$ 75

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