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An Integrated Silicon Bulk Micromachined Barometric Pressure Sensor for Engine Control Unit and External Mount

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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.

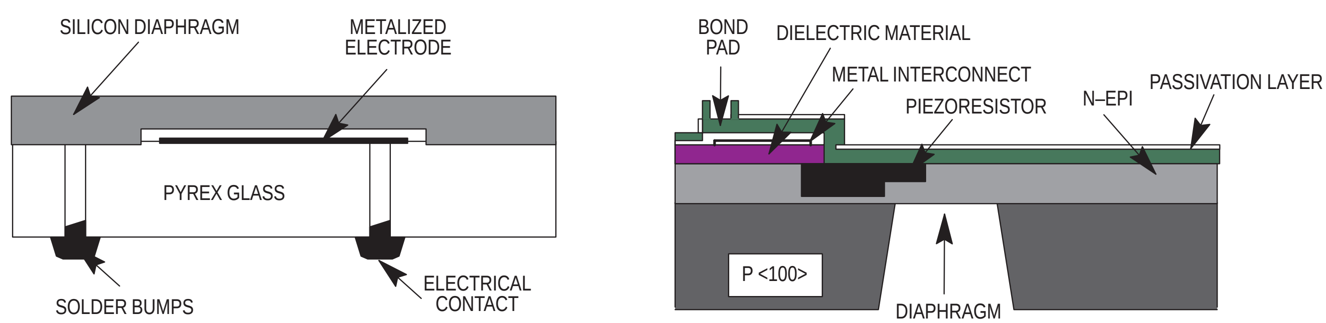


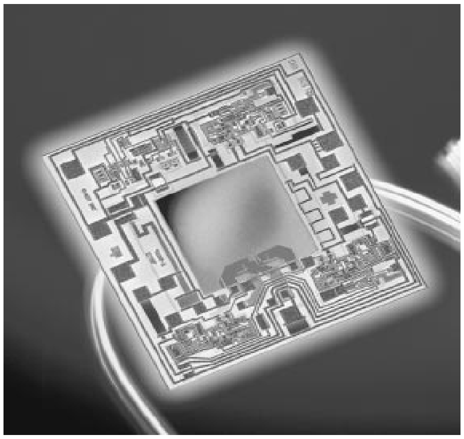
Figure 1. Cross section of a SCAP sensor on the left and a PRT element on the right.

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

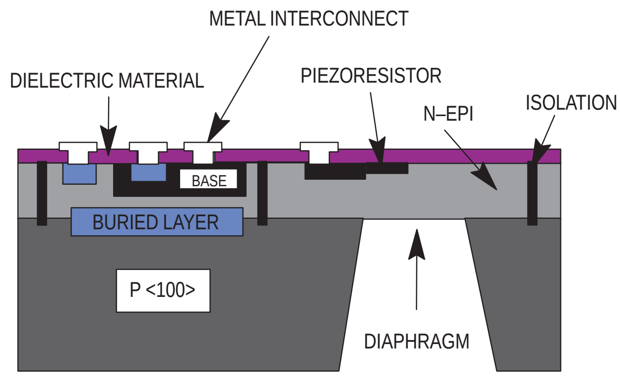


Figure 2. Photograph of a top view and cross–section of an integrated pressure sensor.

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].

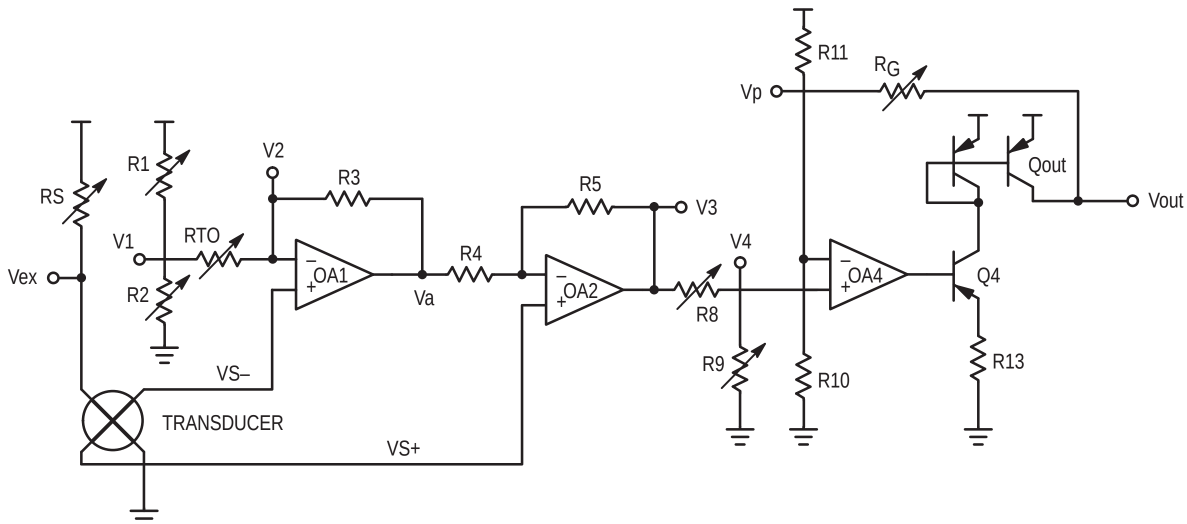


Figure 3. Signal Conditioning Circuit for Transducer

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.

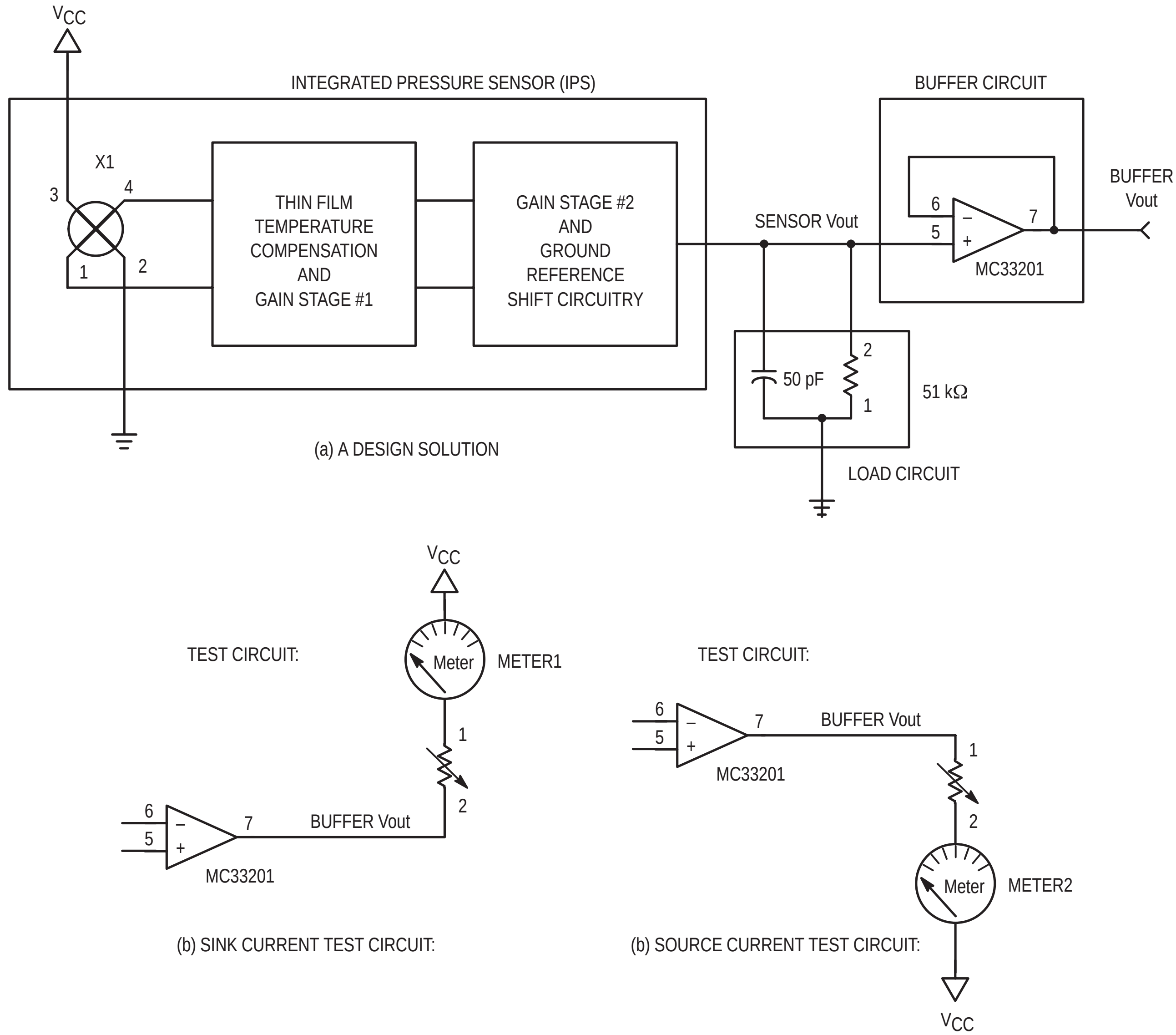


Figure 4. Configuration of Source/Sink design solution and test circuits.

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.

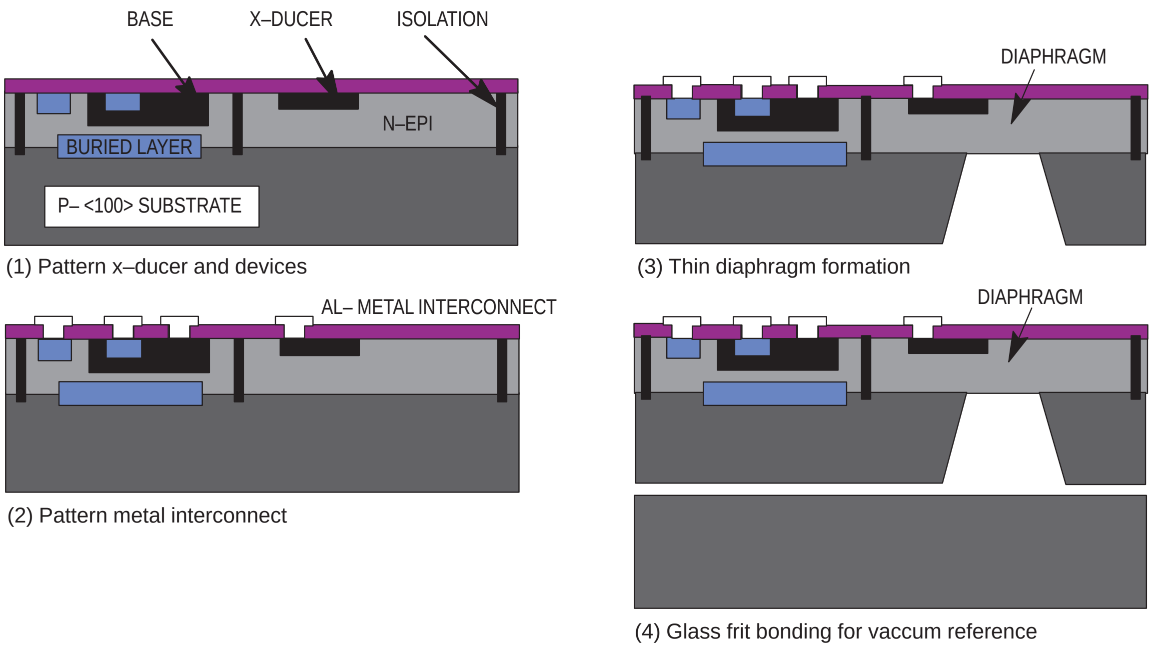


Figure 5. Process sequence for generic integrated absolute pressure sensor.

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].

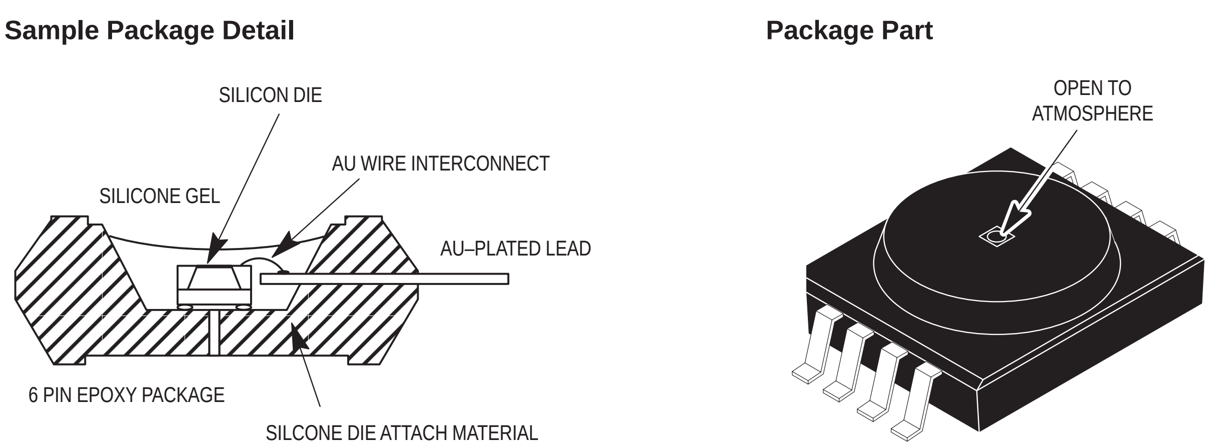


Figure 6. General description of absolute pressure sensor for BAP application.

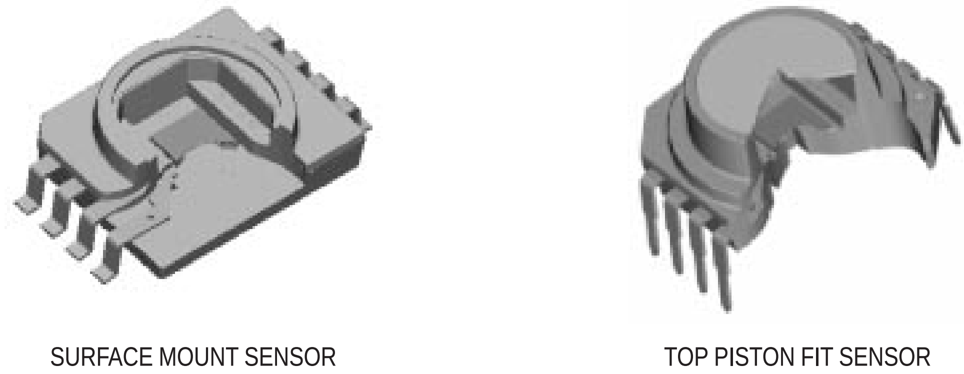


Figure 7. Surface Mount and Top Piston Fit Packages

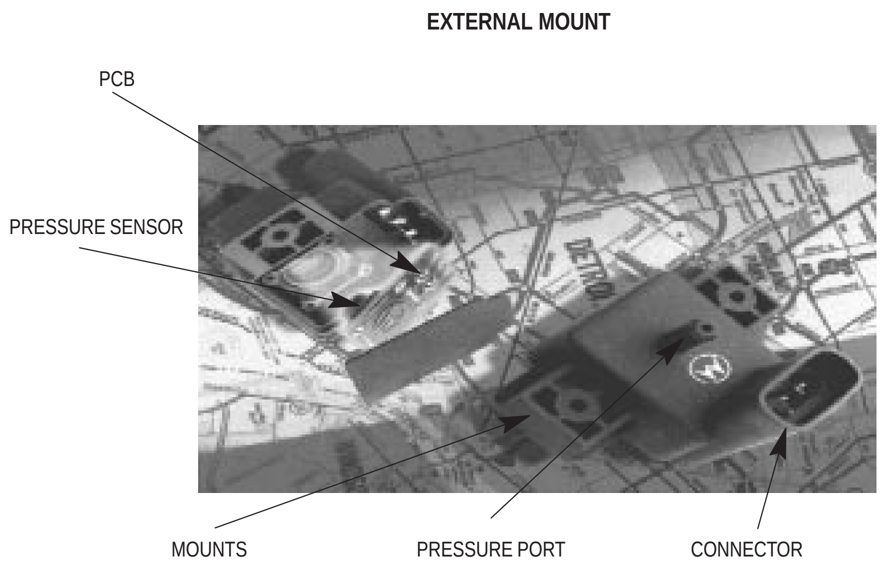


Figure 8. Conceptual housing options for user implementation. The direct ECU mount photograph only shows the IPS sensor, the remaining circuitry is removed.

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.

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