# Development of Pressure Sensor Cell for Fuel Leak Detection

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## 1. Introduction

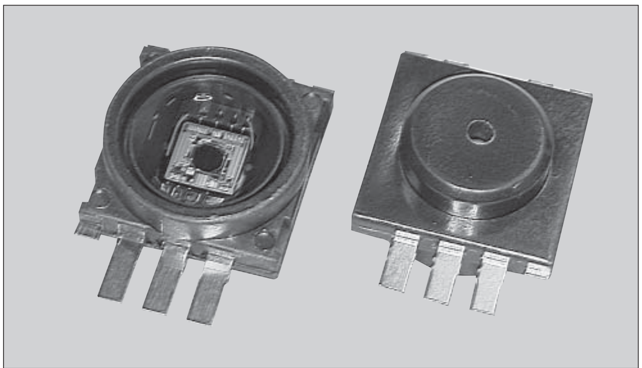
As a result of the OBD (on-board diagnostic system) regulations in the US market, gasoline evaporative leak detection for fuel tank systems is increasingly being required. Highly sensitive pressure sensors that can measure a 10 kPa range of relative pressure are utilized to detect gasoline evaporative leakage.

Fuji Electric has developed a pressure sensor cell for fuel leak detection (FTPS: fuel tank pressure sensor) that uses a CMOS process-based digital trimming scheme. This paper presents a product overview, discusses considerations relating to the high sensitivity and burst pressure design, and reports the results of a product evaluation.

## 2. Features

Figure 1 is an overview of the pressure sensor cell for fuel leak detection (FTPS). A conventional pressure sensor has two chips, one is a sensor gauge and the other is an analog circuit to compensate the sensor characteristics and amplify the output signals from the sensor gauge. Furthermore a conventional pressure sensor also needs EMC (electromagnetic compatibility) protection devices such as chip capacitors, chip resistors or SMD (surface mounted device) filters. Therefore the conventional pressure sensor may have increased susceptibility to failure due to many soldered and wired electric connections between the terminals of chips and other components.

Fig.1 FTPS cell



Fuji Electric has developed the FTPS using integrated single-chip technology to achieve a downsized and highly reliable pressure sensor.

Concepts of the FTPS development are listed below.

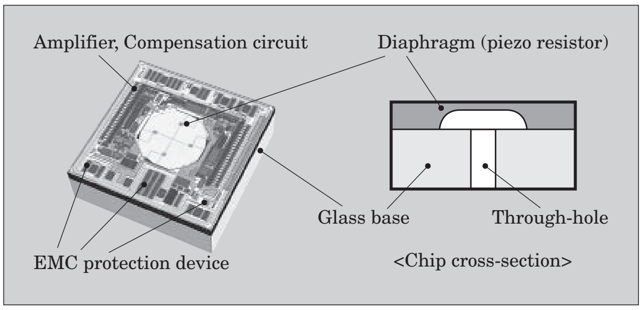
(1) "All in one chip" configuration including a sensor gauge, amplifier, compensation circuit, noise and surge protection devices, and diagnostic circuit all integrated into a single chip
(2) Downsizing by using Fuji Electric's standard small pressure sensor cell package
(3) World's smallest one-chip pressure sensor with installed EMC compliant
(4) Reduced cost through production with Fuji Electric's common facilities for producing standard pressure sensor cell packages
(5) High sensitivity and high burst pressure by using Fuji Electric's proprietary diaphragm etching process

## 3. Structure of the FTPS

Figure 2 shows an overview and cross section of the sensor unit for the FTPS. A Wheatstone bridge configured from four diffused piezo resistors is on the diaphragm. To achieve high sensitivity and high burst pressure, the diaphragm is etched by Fuji's proprietary isotropic etching process to form a round shape.

The output voltage of the Wheatstone bridge is am-

Fig.2 Sensor unit for FTPS



plified. The offset voltage, temperature characteristics are trimmed by the compensation circuits to achieve high output characteristics. The compensation circuit is configured from Digital-to-Analog converters, a shift resistor and an EPROM (electrical programmable read only memory) to store the trimming data. Also, protection devices to protect the circuits from surge voltage and electromagnetic noise from automotive systems such as the igniter or from external sources are also installed in the chip. The above circuits are based on manifold absolute pressure (MAP) sensor technology which has been used since 2002. The glass of the sensor unit and the resin package have a through hole for introducing the reference pressure in order to measure relative pressure. The sensor chip and glass are sealed by an anodic bonding process to prevent leakage with an airtight seal and to relieve stress from the resin package and die bond area.

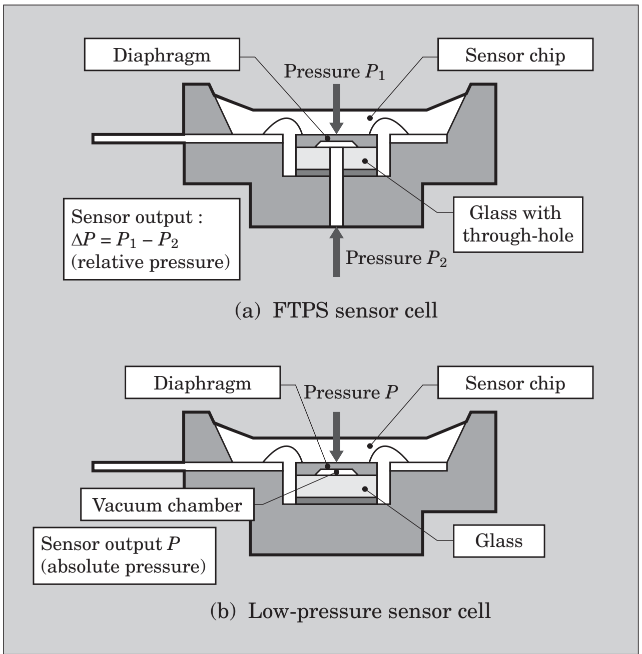
The sensitivity of the FTPS is approximately 200 to 300 mV/kPa, which is about ten times higher than the sensitivity of a MAP sensor.

The chip design for the newly developed FTPS targeted the following improvements.

(1) Improvement of amplifier linearity and gain in order to obtain higher accuracy and sensitivity
(2) Design of the diaphragm for high sensitivity and high burst pressure

Figure 3 compares the cross-sections of the FTPS and MAP sensor. The external dimensions of each resin package are the same so that the same production lines can be used in order to reduce machinery cost and production cost.

Fig.3 Cross sections of FTPS sensor cell and low pressure sensor cell structures




## 4. Design Verification of the FTPS

### 4.1 Design of the amplifier for high sensitivity and high accuracy

Figure 4 shows a block diagram of the pressure sensor circuit.

The components are based on the MAP sensor's circuit. High sensitivity of the FTPS is achieved by increasing the gain of the amplifier that amplifies the output voltage of the Wheatstone bridge. High accuracy is achieved by improved linearity of the amplifier for the MAP sensor. Figure 5 shows the results of the improved linearity and compares the accuracy of the FTPS with that of a conventional amplifier for a MAP sensor.

### 4.2 Design of the diaphragm for high sensitivity and high burst pressure

The thickness and diameter of the diaphragm are

Fig.4 Block diagram of output sensor circuit

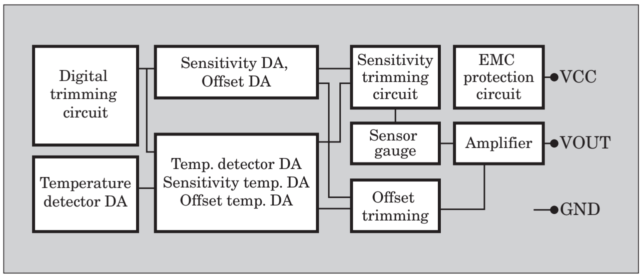
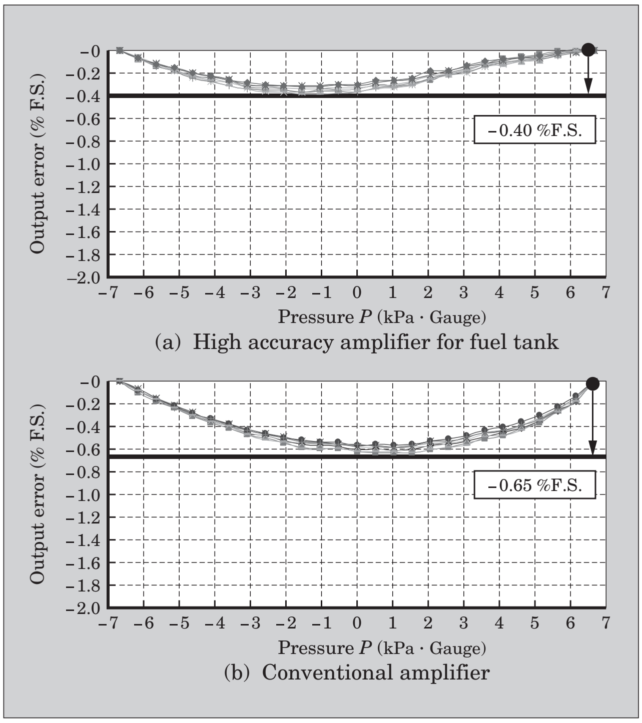



Fig.5 Higher accuracy due to improved linearity of the amplifier



also factors that determine the sensor sensitivity.

Using the finite element method (FEM), we investigated the optimum thickness and diameter of the diaphragm for FTPS. Figure 6 shows the model for FEM analysis of the diaphragm and Fig. 7 shows the FEM analysis results.

### 4.3 Results of burst pressure test

Burst pressure depends on the thickness of the diaphragm and decreases as the diaphragm becomes thinner. Therefore we evaluated the FTPS diaphragm burst pressure using the thinnest diaphragm within the tolerance for high sensitivity. We found that the diaphragm and the adhesion between the sensor unit and resin cases do not broke at pressure of 500 kPa which corresponds to approximately seventy-five times the 6.6 kPa operating pressure on each surface of the circuit and on the back of the diaphragm.

Fig.6 Diaphragm optimization (FEM analysis model)

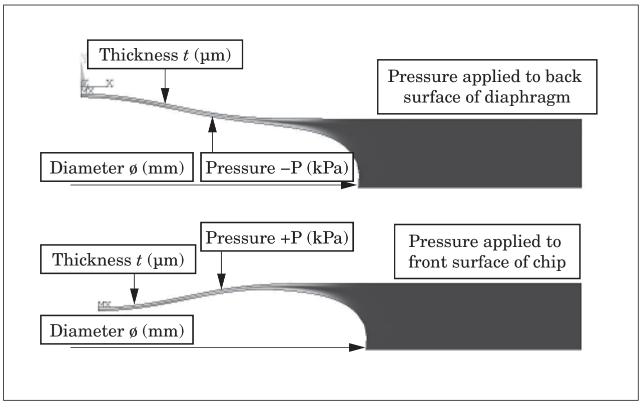
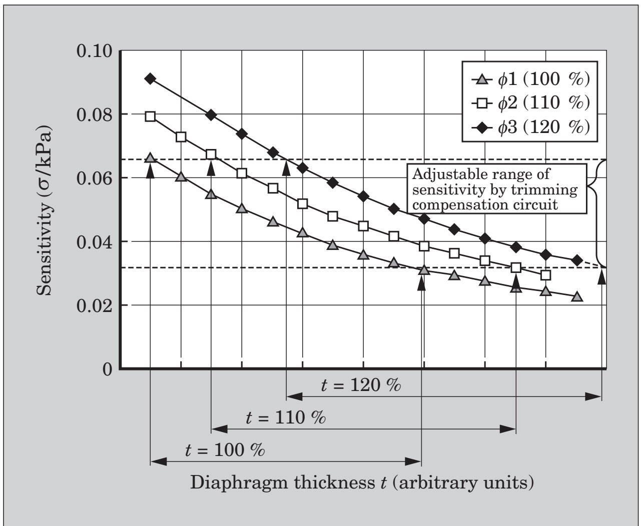



Fig.7 Diaphragm optimization (FEM analysis results)




### 4.4 Output characteristics of the FTPS

Figure 8 shows the output characteristics of the FTPS when measured at the relative pressure of ±6.6 kPa. The operating pressure range can be changed from ±6 kPa to ±10 kPa (relative pressure) by trimming the compensation circuits on the chip and by changing the thickness of the diaphragm.

### 4.5 Standard specifications

Table 1 lists the standard specifications of the FTPS.

### 4.6 Package option and mechanical interface

The FTPS cell package options support a wide range of mounting methods such as a housing type for mounting directly in a fuel tank or a pipe cap on cell package for tube installation.

Fig.8 Pressure vs. output characteristics

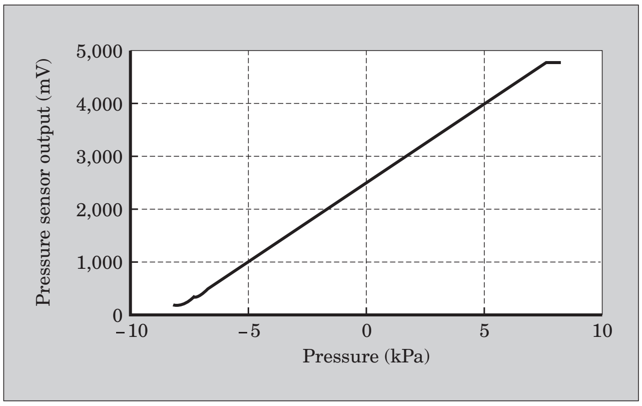



Table 1 FTPS standard specifications

| Item | Unit | Specification | Notes |
|---|---|---|---|
| Overvoltage | V | 16.5 | < 1 min |
| Proof pressure | kPa | 60 | |
| Storage temperature | °C | − 40 to +135 | |
| Operating temperature | °C | − 30 to +125 | |
| Operating pressure | kPa | ±6.66 | *1 *2 |
| Output range | V | 0.5 to 4.5 | |
| Load resistor | kΩ | Pull-up 300<br>Pull-down 100 | |
| Diagnostic output voltage | V | < 0.2 | *3 |
| | V | > 4.8 | *3 |
| Sink current | mA | 1 | |
| Source current | mA | 0.1 | |
| Pressure error | %F.S. | < 3.0 | |
| Temperature error | Scaling factor | < 1.5 | |
| EMC certified standard | JASO D00-87 / CISPR 25<br>ISO 11452-2 / ISO 7637 | | |

*1 Relative pressure
*2 Full-scale pressure range trimming is optionally available.
*3 Output voltage when the Vcc or Vout line is open
The diagnostic output voltage depends on the load resistance.

## 5. Conclusion

Fuji Electric has developed a pressure sensor cell for fuel leak detection that uses a CMOS process-based digital trimming scheme. This paper presented a product overview, discussed considerations relating to the high sensitivity and burst pressure design, and reported the results of a product evaluation. The basic specifications of the newly developed sensor cell are well suited for applications within the pressure range of 6 to 10 kPa (relative pressure), and package options support a wide range of mounting methods. Automotive regulations for safety and environmental protection will become stricter throughout the world. The marketplace needs for pressure sensors will be increase in the future. Fuji Electric intends to develop new pressure sensors with high accuracy and high performance in order to contribute to the automotive market and protect the environment.

### Reference

(1) Ueyanagi, K. et al, FUJI ELECTRIC REVIEW. Vol.50, No.2, 2004, p.68-70