Sensor Conditioner ICs Utilizing Analog Technology to Adjust the Minute Signals of Sensor Elements

MB42M000 Series

FUJITSU is now mass-producing MB42M000 Series, the sensor conditioner ICs used to adjust the minute signals of sensor elements. This article introduces the analog element technology utilized in these sensor conditioner ICs.

Introduction

The market for sensors utilized to measure acceleration, pressure and other variables in various fields including automotive devices, mobile devices, robots, game machines, and industrial devices is currently expanding rapidly at an annual rate of more than 10%. Since the miniaturization of sensors is currently advancing through the adoption of MEMS*1 technology, etc., there is now special demand for analog technology to convert sensor element signals of minute physical quantity into linear electric signals and to amplify them. Furthermore, the compensation of offset and sensitivity characteristics fluctuation generated due to fluctuation in production and temperature changes is also demanded. While the adoption of an operational amplifier is a well-known technique utilized to convert and amplify sensor element signals, the adjustment of external parts is required to match the sensor element sensitivity and offset fluctuations, leading to numerous adjustment processes. It is also essential for the quantity of external parts to be increased to compensate the fluctuation by temperature.

In light of this background, FUJITSU has developed and now provides sensor conditioner ICs that convert, amplify, and compensate the minute sensor element signals simply and with high precision, using a minimum of external parts.

Basic structure of a sensor

Fig.1 shows the basic structure of a sensor. Sensor elements detect changes in various analog signals in the surroundings such as displacement in pressure, speed, acceleration, and angular velocity as well as changes in odor, light, and magnetic waves. It is the sensor conditioner IC that converts and amplifies the minute signals from the sensor element into electric signals that can be processed by a CPU, etc. Once these signals are converted into electric signals to be processed by the CPU, various system controls such as feedback

![Figure 1 Basic Structure of a Sensor](image)
control are executed based on the information so that the optimal process is implemented in order to address the change.

As shown in Fig.1, sensor conditioner ICs have built-in analog circuits including a detector circuit, driving circuit, regulator (compensation) circuit, and temperature sensor. The more recent models may require in many cases nonvolatile memories to record the coefficients for compensating the sensor element signals so as to realize improvement in module production yield and achieve the necessary high precision.

### Conversion of analog signals required in sensor conditioner ICs

The signal to express the changes in the analog physical quantity in the surroundings varies depending on the type of sensor element. Table 1 shows an example of output signals by sensor elements. Sensor elements output changes in physical quantities as changes in capacitance, resistance (changes in voltage), or electric charge, for example. Therefore, the sensor conditioner ICs that receive the output require the appropriate conversion technology for each sensor element.

FUJITSU has developed and now provides sensor conditioner ICs that detect changes in physical quantities such as acceleration and pressure as changes in capacitance (changes in resistance) or capacitance and output the signals as voltage.

Since fluctuation in production and temperature causes characteristics fluctuation in sensor elements, compensative functions to compensate the fluctuation are required. A summary of elemental technology including these corrective functions is provided below.

#### Detection of changes in capacitance

The sensor element outputs the changes in acceleration or pressure as changes in capacitance, and the sensor conditioner IC converts them into electric signals (voltage) that can be processed by the CPU.

An image of a capacitance-type sensor is shown in Fig.2 on the left. The sensor conditioner IC for this type of sensor requires analog technology for a capacitance-voltage converter circuit.

Our representative model for this type is MB42M001. Fig.3 shows a block diagram for this product.

MB42M001 not only converts capacitance into voltage but also delivers programmable conversion gain. In addition, it is capable of canceling the fluctuations in capacitance value by the sensor element (offset capacitance). The C-V conversion gain for MB42M001 (=gain for C-V converter circuit×gain by voltage amplifier) can be changed in the following range:

### C-V conversion gain

\[
\Delta V_{OUT} = \pm \Delta C \times (ACVA \times AVGA) = \pm \Delta C \times (1.81 \text{ to } 145.6) \\
\Delta V_{OUT}: \text{IC output voltage range [V]} \\
\Delta C: \text{Capacitance fluctuation in sensor element [pF]} \\
ACVA: \text{Conversion gain for C-V converter circuit: 0.086 to 1.3 [V/pF]} \\
AVGA: \text{Gain for voltage amplifier: 21V/V to 112V/V}
\]

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<th>Types of Sensor Elements and Output Signals</th>
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<td>Types of Sensor</td>
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<td>Capacitance-type sensor</td>
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![Figure 2](Capacitance-type Sensor and Resistance-type Sensor)

![Capacitance-type sensor](Detection of physical quantity)

- **Capacitance-type sensor**
  - Capacitance changes due to weight stress

- **Resistance-type sensor**
  - Resistance in the beam block changes due to weight stress

- **Advantage**
  - Small current consumption and small temperature characteristic
  - Small size and low cost

- **Disadvantage**
  - Processing precision is required
  - Large current consumption and large temperature characteristic
If the IC output voltage range is $V_o \pm 1.5V$ (e.g., $2.5V \pm 1.5V$ range), this means in the settings that it is capable of tolerating $\pm 0.01pF$ to $\pm 0.83pF$ capacitance change in sensor elements. While these values are for an ideal environment, since it depends on various factors including noise and frequency characteristics for the sensor element, noise in the IC, element fluctuation and external wiring capacity, they indicate that it is capable of addressing sensor elements with various characteristics.

Detection of changes in resistance

An image of a resistance-type sensor is shown in Fig.2 on the right. In the case of resistance-type sensors, the changes in physical quantity are output as voltage by applying current or voltage on the resistance values assigned on the sensor. However, this voltage is a minute signal and a sensor conditioner IC is needed to process it with low noise and high gain. Our resistance-type sensor conditioner ICs incorporate amplifiers that are suited for these requirements.

Fig.4 shows a block diagram for MB42M102. Since the resistance-type sensors amplify sensor element signals with high gain, the offset voltage is also amplified with high gain. Neglecting to compensate this will lead to large fluctuation of output and the CPU will be unable to process it. As such, amplifiers for sensor conditioner ICs must also include functions to compensate the offset voltage. Analog technology is utilized to satisfy such specifications.

Taking our MB42M102 for example, the specifications are as follows:

**Voltage gain**

$V_{OUT}=\Delta V_{in} \times A_{VGA}$

- $V_{OUT}$: IC output voltage range [V]
- $\Delta V_{in}$: Voltage change in sensor element [V]
- $\Delta V_{in}=\pm \Delta G \times S_g$
- $\pm \Delta G$: Detection range [G]
- $S_g$: Sensitivity of sensor element [mV/G]
- $A_{VGA}$: Gain in voltage amplifier: 240V/V to 2,682V/V

Supposing that the sensor element detects acceleration ($\pm 2.0G$ detection) and the IC output voltage range is $V_o \pm 1.5V$ (e.g., $2.5V \pm 1.5V$ range), MB42M102 should be capable of realizing sensor elements with various characteristics with sensitivity of $0.26mV/G$ to $3.1mV/G$ based on calculation using the above formula.

In the case of sensor elements with low sensitivity, the amplifier gain must be increased. Since noise and offset are also amplified in this case, the sensor conditioner IC needs to be designed following sufficient consideration of the filter addition and tolerable offset range that will deliver the desired resolution. The input conversion noise for MB42M102 is $60nVrms/\sqrt{Hz}$, which will deliver $5mG$ resolution with approximately $5mVpp$ output noise by adopting a sensor with $1mV/G$ sensitivity, for example, and setting up the amplifier gain to $1,000V/V$ when the response frequency is $200Hz$.

**Figure 3** Structure of a Capacitance-type Sensor conditioner IC
**Corrective functions required for sensor conditioner ICs**

For sensor conditioner ICs, compensative functions are also important factors in addition to the converter and amplifier circuits that suit different types of sensor elements. Sensor elements have characteristics fluctuation caused by fluctuation in production and changes in the ambient temperature. Since the changes in the signals to be detected are already extremely small, it is essential that these fluctuation factors caused by the surroundings be corrected.

The sensor conditioner ICs that FUJITSU has developed currently adopt two types of compensative functions. One is the look-up table compensation method and the other is the analog inclination compensation method. In both compensation methods, the compensation coefficients for the absorption of individual differences due to fluctuation in the production of sensor elements and for the compensation of offset fluctuations and sensitivity fluctuations generated by changes in the ambient temperature are stored in the built-in nonvolatile memory to correct.

**Look-up table compensation**

*Fig.5* shows a functional block for temperature correction using the look-up table compensation method. *Fig.6* shows an image drawing for this compensation method.

In the look-up table compensation method, the temperature ranges are divided into 12 points every 10°C. Appropriate amplifier offset and gain values to compensate the sensor offset and sensitivity fluctuations by temperature are set for each temperature point. The gain and offset values set for the temperature are read and relayed to the amplifier circuit when the ambient temperature changes. This enables the output of voltage that is not greatly affected by temperature fluctuations in sensitivity or offset. Variability of offset and gain is addressed by switching the ladder resistance.

**Analog inclination correction**

*Fig.7* shows a functional block for temperature compensation using the analog inclination compensation method. *Fig.8* shows an image drawing for this compensation method.

Compared to the look-up table method, which corrects for certain specified temperature ranges, the analog inclination compensation method gives reverse characteristic dependency from the sensor element to the IC against the temperature to flatten the output characteristics. For offset voltage, a break point can be set at an optional temperature point in 5°C increments from −20°C to 55°C. An inclination coefficient is given to each of the directions to higher and lower temperatures to make the correction.

Sensitivity can be corrected by giving a linear temperature coefficient to the constant current (or constant voltage) source for driving the sensor.

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**Figure 4  Structure of a Resistance-type Sensor IC**
The world is now being inundated with a variety of analog data and the development of sensor elements to capture these changes is advancing. A good example is the recent miniaturization of sensors by the MEMS device. Other methods also exist that will enable miniaturization and combination. The number of sensors is expected to grow explosively and enable further variation in use environments including high temperature and high humidity conditions. To efficiently convert data into electric signals and allow stable use under such conditions, the development of such a sensor conditioner IC is essential.

Recently introduced sensor conditioner IC functions are not limited to capturing signal output solely from sensor elements—signal output forms are changing from analog to digital and from wired to wireless, with the demand for the

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**Figure 5** Functional Block for Look-up Table Compensation

![Sensor conditioner IC](image1)

- **Sensor element**
- **Temperature sensor**
- **Output**
- **Gain coefficient**
- **Offset coefficient**
- **Data latch block**
- **Nonvolatile memory**
  - Gain/offset coefficient for $-35^\circ C$
  - Gain/offset coefficient for $-25^\circ C$
  - Gain/offset coefficient for $+25^\circ C$
  - Gain/offset coefficient for $+35^\circ C$
  - Gain/offset coefficient for $+65^\circ C$
  - Gain/offset coefficient for $+75^\circ C$

**Figure 6** Image for Temperature Correction by Look-up Table Compensation

![Example of sensor element characteristic](image2)

- **Sensitivity** vs. $T_a[^\circ C]$
  - Sensitivity and temperature characteristics without compensation
  - Amplifier gain correction for each $\Delta 10^\circ C$
  - Compensation of sensor fluctuation

![Example of sensor element plus MB42M101 characteristic](image3)

- **Sensitivity** vs. $T_a[^\circ C]$
  - Sensitivity and temperature characteristics without compensation
  - Amplifier gain correction for each $\Delta 10^\circ C$
  - Temperature characteristic for offset without compensation
  - Amplifier offset correction for each $\Delta 10^\circ C$
latter growing rapidly. FUJITSU will develop a varied group of products so as to realize lower power consumption, further miniaturization, and high function development based on the analog technology introduced in this article. In this manner, FUJITSU will offer a rich lineup that can address various different sensor elements.

NOTES
* Other company names and brand names are the trademarks or registered trademarks of their respective owners.

Figure 7 Functional Block for Analog Inclination Compensation

Figure 8 Image for Temperature Correction by Analog Inclination Compensation