Design and development of signal conditioning circuit for MEMS based piezo-resistive pressure sensor for aerospace and defense applications

N. Kusuma*, S. Mahalakshmi

Central Manufacturing Technology Institute, Bengaluru, Karnataka, India

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MAX1452,
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ABSTRACT

MEMS (Micro Electro Mechanical System) technology is the latest ongoing technology in the current world. Various sensors are being developed using this technology for aerospace and defense applications. The MEMS based piezo-resistive pressure sensors that are fabricated are initially in the die form, integrated with signal conditioning circuit and are packaged suiting to aerospace and defense applications. In this research MAX1452, a highly integrated analog-sensor signal processor optimized for industrial and process control applications is used for signal conditioning which involves amplification, calibration, and temperature compensation. Here an experiment was conducted to interface the wheat-stone bridge sensing circuit to MAX1452, calibrated for set of temperatures, temperature compensated and further tested the signal conditioning circuit with off the shelf available MEMS pressure sensor.

1. Introduction

In current world the Pressure sensors are fabricated using MEMS (Micro Electro Mechanical System) technology, which is being used extensively in various fields because of its smaller size, high sensitivity, high precision, low cost, low power consumption (Yao et al., 2016) etc. In MEMS Technology during the development of MEMS devices such as Sensor and Actuators, Singal conditioning plays a vital role as the output voltage from the MEMS devices after fabrication will be in micro volts, these output voltage signals need signal amplification and noise filteration. In such case Instrumentation amplifiers also can be used for amplification, however signal conditioning circuit with filtering circuit need to be integrated into the MEMS device before packaging.

Off the shelf MEMS devices are also available globally with integrated Signal conditioning using an ASIC (Application Specific Integrated Circuit). Here in this research, MEMS based Piezo-resistive pressure sensor is integrated with signal conditioning circuit comprising MAX1452 and other electronics circuit which acts as signal conditioner and packaged.

1.1. MEMS piezo-resistive pressure sensor

MEMS based pressure sensors are designed with various transduction principles such as piezo-resistive, capacitive and piezo-electric techniques using different materials suiting to various applications. Typically, MEMS pressure sensor is based on n-doped silicon as a substrate and with four p-doped piezoresistive resistor elements implanted on it (Matzen et al., n.d.). MEMS based Piezoresistive pressure sensors are designed with Wheatstone bridge configuration that is initially balanced with equal resistance at all the arms of the bridge and gives out Zero output. Whenever there is a change in resistance value in any one of its arms, there will be correspondingly change in output voltage. This change in resistance happens when the sensor is exposed to mechanical input like pressure and resistor undergoes mechanical movement causing it to change its resistance value. The typical wheat stone bridge configuration of MEMS type Piezoresistive pressure sensor is as shown in Figure 1.

*Corresponding author E-mail: kusuma@cmti.res.in

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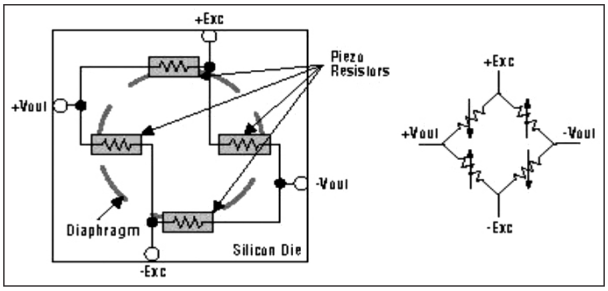

Fig. 1. MEMS based piezoresistive pressure sensor in wheatstone bridge configuration.

The output usually in the order of milli volts assuming bridge configuration of MEMS type Piezoresistive pressure sensor is excited with voltage of choice, 5V DC or 10V DC.

Piezoresistive pressure sensor's resistance value changes with the change in temperature and a linear relation between temperature coefficient of resistance is given by equation 1.

$$R(T) = R(T_0)[1 + \alpha(\Delta T)] \qquad \text{.............(1)}$$

Where,

R(T) = Resistor value at temperature 'T',

R(T_0) = Resistor value at temperature and

'T_0' = Temperature at room temperature

α = Temperature coefficient of resistance for conductor material. $\Delta T = T - T_0$.

Here the signal conditioning is done by using MAX1452, in a similar way as indicated by John et al. (2010) which involves calibration at room temperature and two other temperatures to test MEMS pressure sensor output at without temperature compensation and with temperature compensation.

1.2. MAX1452

MAX1452 Maxim Integrated (2015) is chosen for signal conditioning of the piezo-resistive type MEMS pressure sensor.

The MAX1452 is a highly integrated analog-sensor signal processor optimized for industrial and process control pressure sensors that utilize piezo-resistive bridge sensors. It provides amplification, calibration and temperature compensation that enables an overall performance approaching the inherent linearity of the sensor.

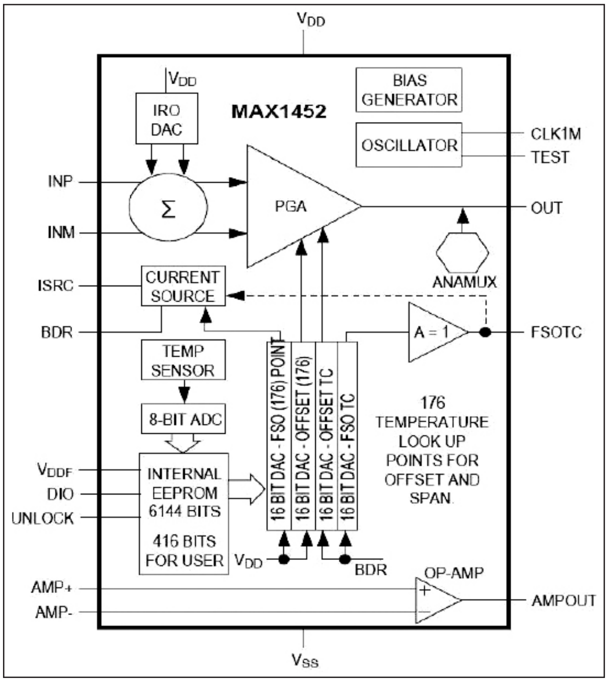

Fig. 2. Block diagram of Max1452.

The MAX1452 architecture includes a programmable sensor excitation, a 4-bit programmable-gain amplifier (PGA), output signal clip-level diagnostics, a 768-byte (6144 bits) internal EEPROM, four 16-bit DACs, and an on-chip temperature sensor. In addition to Offset and Span compensation, MAX1452 provides a unique temperature compensation strategy for Offset TC and FSO TC that was developed to provide a remarkable degree of flexibility while minimizing testing costs. Block diagram of MAX1452 is shown in Figure 2.

The single pin, serial Digital Input-Output (DIO), communication architecture enables calibration programming through the sensor's Vout pin by parallel connecting Vout to DIO. The MAX1452 provides a Secure-Lock feature that allows the customer to prevent modification of sensor co-efficients and secures the 52-byte user definable EEPROM data after the sensor has been calibrated. The Secure-Lock feature also provides a hardware override to enable factory rework.

2. Design and Fabrication of Signal Conditioning Circuit

Initially a Wheatstone bridge was designed with equal resistors (2.2kΩ) in three arms and a RTD sensor (temperature sensor) in fourth arm, further the resistance value of RTD sensor is changed when temperature is raised by using

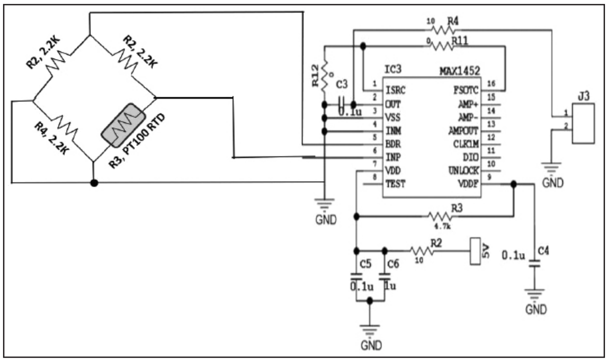

Fig. 3. Singal conditoning cuircuit using MAX1452.

hotplate. RTD sensor will have a resistance of 100 ohms at 0°C and at room temperature resistance value will increase linearly approximately around 125ohms. The Wheatstone bridge circuit is designed only for experimental purpose as shown in Figure 3.

This circuit is interfaced to MAX1452, 5V is connected to the sensing circuit via BDR output.

The Wheatstone bridge circuit designed provides the Balanced (0V) and Un-Balanced (4.5V) output.

The Temp sensor will be able to sense the temperature up to 100°C. The Wheatstone bridge (which is the sensing circuit) is triggered by BDR output terminal of MAX1452 and provides the output from bridge to INP & INM pins of MAX1452. Here circuit is initially calibrated using MAX1452 Calibration software provided by manufacturers.

2.1. Calibration of MAX1452

MAX1452 is programmed without temperature compensation in digital mode using the Calibration software MAX1542.exe, initial calibration *(Step-by-Step Procedure for Performing Temperature Compensation Using MAX1452 and MAX1455 Evaluation Kit Software,* 2025b) is done at room temperature (25°C) with wheatstone bridge at PGA index =1, OFF DAC = 4000hex, FSO DAC=8000hex, Bridge Voltage Vb=2.516V and Output Offset=0.5V and Output is enabled in MAX4152. Further all the above co-effiecents are written into the EEPROM of MAX1452 by Write Flash command. The Full Scale Output is measured in Analog mode which is displayed in DMM.

Calibration was also done at two temperatures 40°C and at 60°C. This is discussed in the Results and discussions section.

2.2. Temperature compensation

Temperature compensation is done as the resistance value of the sensing circuit changes with change in temperature irrespective of whether a pressure/force is applied on the sensing element or not. Even at zero applied pressure, due to change in temperature there is going to be change in resistance value. This change in resistance have to be compensated. In MAX1452, there is an option to perform temperature compensation.

Comp52.exe application software is used to perform the temperature compensation. This software executes a series of steps designed to calculate the correction coefficients needed for compensation. Once the coefficients are calculated, the flash tables are programmed and compensated sensor can be obtained.

The temperature compensation process was started with few parameters set as follows:

Absolute Error: required Accuracy

Target Span output voltage: 4.000V

Target Offset voltage: 0.5V

Temperature compensation was done at three temperatures such as room temperature (25°C), 40°C and 50°C.

Initially at room temperature in digital mode, the full-scale bridge output voltage up to 4.5V was set as Target voltage and output voltage V_0 was measured from DMM (Digital Multi Meter). This is for maximum pressure, in the same manner, minimum bridge output voltages were set for minimum pressure. Further bridge voltage was set for three FSOSAC settings, by this Ideal bridge voltage Vb was calculated by the computer for desired span. This should be well within the Target Output voltage. Subsequently output bridge voltages were set for OFFDAC. This was repeated for two temperatures 40°C and 50°C. All these settings were recorded and written into the FLASH memory.

Later temperature compensation was verified in Analog mode. The results obtained are discussed in the section Results and discussions.

2.3 Testing signal conditioning circuit with actual MEMS pressure sensor

The signal conditioner designed was tested with

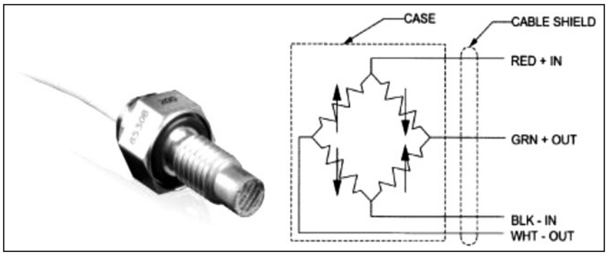

Fig. 4. MEMS pressure transducer.

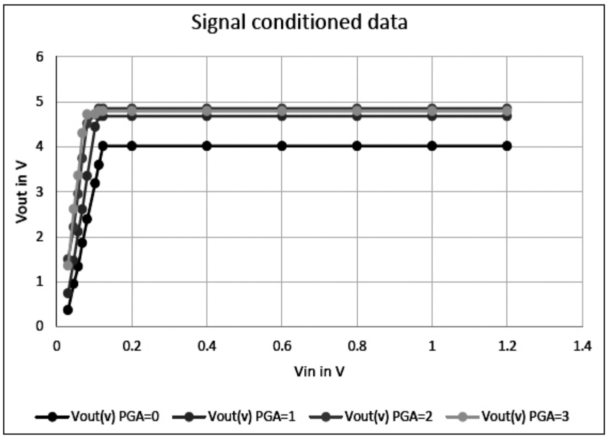

Fig. 5. Signal conditoned data at different PGA index value.

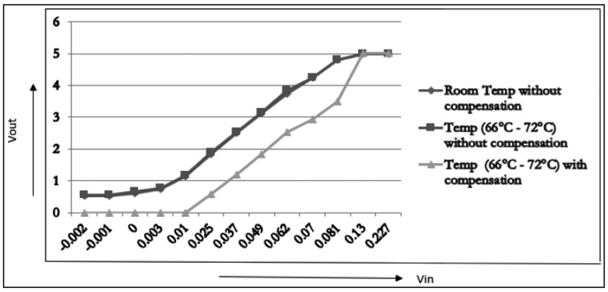

Fig. 6. Vo Vs Vin without and with temperature compensation.

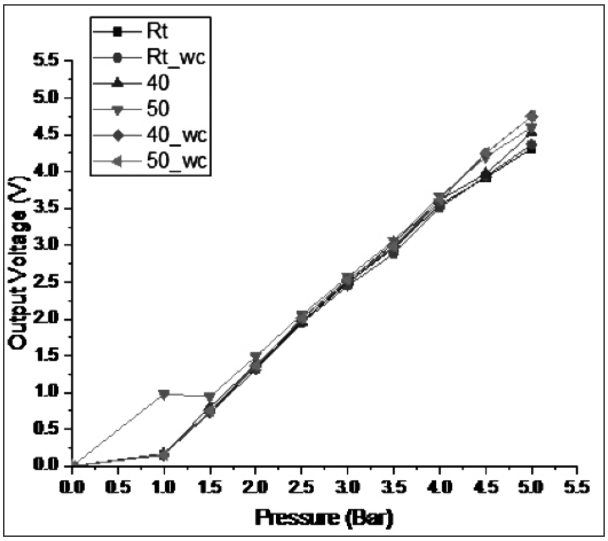

Fig. 7. All plots in a single graph sheet.

actual MEMS pressure transducer model 8530B from (ENDEVCO, n.d.), it is a piezoresistive based sensor with wheat stone bridge configuration as shown in the below Figure 4. Connections are done as mentioned in Section 1.1

The important technical specifications are as follows: Range = 0 -500psi (35bar), Sensitivity = 0.6±0.2, Zero-measurand output = ±10mV max, Burst Pressure= 2000psi (138bar), Full scale output = 300 ± 100mV, Supply voltage = 10VDC.

The above MEMS Pressure sensor was interfaced with the designed Signal conditioning circuit, here MAX1452 was recalibrated at room temperature, 40°C and 50°C, later temperature compensated to measure the output voltage for corresponding applied pressure on the MEMS pressure sensor. All the procedures were followed as mentioned in Section 2.1 and 2.2, during Calibration and temperature compensation. And results are discussed in Section 3.

3. Results and Discussions

Initially the signal conditioner designed was calibrated at PGA index=0 and steps were repeated for PGA index = 1, 2, 3 and also temperature was raised at the sensor curcuit (at 4^{th} arm PT100 RTD) by using hotplate model IKA C MAG HP-7. Experimental input voltage and output volatge for different PGA index is shown in Figure-5.

Later the Temperature compensation was done using signal conditioning circuit for set temperatures - room temperature, 66°C and 72°C, and output was measured and results for without and with temperature compensation are shown in Figure 6.

Further the signal conditioning circuit was tested with actual MEMS Pressure sensor and the output obtained for the pressure from 0 to 5.5bar. Output measured for without and with temperature compensation is shown in Figure 7.

Abbreviations

Rt-Under Room temperature

Rt_wc-Room temperature calibration

40- At 40 °C without compensation.

40_wc- At 40 °C with compensation.

50- At 50 °C without compensation.

50_wc-At 50 °C with compensation.

Inference: From the graphs we can conclude that slope is nothing but sensitivity of pressure sensor with some tolerance. Before compensation, sensitivity was (0.96157±0.04904) volts per 1 bar of pressure. After compensation, sensitivity was (0.96466±0.04895) volts per 1 bar of pressure. We can conclude that after compensation, sensitivity is improved and compensated values are almost close to linear fit. Deviation in room temperature and without compensation graphs is due to instability in room temperature. Please note that with increase in pressure error also increases.

With the increase in temperature, pressure sensor bridge voltage increases which leads to increase in PGA output. By using MAX1452 and two temperature coefficient method, compensation has been done and compensated graphs have been plotted in Figure 7 and plots are almost close to linear fit and overlap at some points. The expected outcome is with the increase in pressure, error increases and that's what the result shows.

4. Conclusion

In this research, signal conditioning circuit is designed using MAX1452, calibrated for four PGA index values and as resistance changes due to change in temperature, temperature compensation is done for three temperatures and tested with actual piezoresistive based MEMS Pressure sensor with wheat-stone bridge configuration and graphs are plotted for Output for applied pressure at the input and it can be seen that after temperature compensation, sensitivity is improved and compensated values are almost close to linear fit and overlap at some points. This signal conditioning methods can be adopted for all piezo-resistive type of MEMS devices.

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N. Kusuma M.Tech in Microelectronics from BITS Pilani, Rajasthan and graduated in Electronics and Communication Engineering from National Institute of Engineering, Mysore University, currently pursuing Ph.D at BITS Pilani, having 30 years of Professional experience in various field such as Computerised Numerical Controllers (CNC)/ Design & Development of Electrical Controllers for Special Purpose Machines (SPMs), Programmable Logic Controllers (PLC) programming, designing of MEMS Sensors, MEMS Fabrication process, MEMS Characterization process and Micro System Packaging processes.

She is currently holding the post of Scientist-E, Centre Head – Sensors, Vision Technology and IT, at Central Manufacturing Technology Institute, Bengaluru. She is working on development of MEMS Sensors, Technology development, providing associated Laboratory services and maintenance.

She has been trained in machine tool vibration data acquisition and analysis at Western Michigan University (WMU), Kalamazoo, Michigan, USA, Microlithography operation (MEMS fabrication process) at Lurie Nano fabrication Facility (LNF), University of Michigan, Ann Arbor, Michigan, USA, she has visited MEMS Labs at Integrated Micro Electronics (IME), Singapore, IISc Bengaluru, STARC Bengaluru, CEERI Pilani, SCL Chandigarh, and BEL Bengaluru. This has contributed to establishing International level State-of-the-art facility at "Sensor Technology Development Centre" at CMTI.

She has presented 4 journal papers and 15 conference papers and guided M.Tech and B.Tech students for their industrial projects.

S. Mahalakshmi is presently working as a Technical Assistant at the Centre for Sensors & Vision Technology (C-SVT) at Central Manufacturing Technology Institute, Bangalore. She has completed her Diploma in Electronics and Communication Engineering at GRWPT, Shimoga. She is currently working on MEMS fabrication and micro-system packaging processes such as photolithography, wet chemical processing, wire bonding & bond testing etc. (E-mail: mahalakshmi@cmti.res.in)