MEMS sensor interface using MLX90308 microcontroller and SP82A pressure sensor

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MN-ELN4000 Electronic System Design

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Abstract — The project was aimed at making the MEMSCAP SP82 absolute pressure sensor's perfectly linear pressure response into a non-linear one. This was done by using Melexis MLX90308 programmable sensor interface chip, the software LabVIEW (National Instruments) and DAQ (National Instruments).

Index Terms — Characterization, compensation, MEMSCAP SP82 pressure sensor, Melexis MLX90308, linearity, non-linearity, analog-test, digital-test

I. Introduction

The primary concerns in this report is to study the MEMSCAP SP82A pressure sensor and the evaluation board for Melexis MLX90308 compensation chip. The pressure sensor had to be characterized first and then an interface between the sensor and the Melexis board was obtained. The pressure sensor (placed in the pressure chamber) generates a voltage signal output through a Wheatstone bridge, which changes proportionally to the increase/decrease of the pressure. To make adjustments to the gain and the offset, a signal block conditioning or Melexis microcontroller (MLX90308) is used. Now an acquisition feature is required to link the signals to a program in the computer used for this project. DAQ (Data Acquisition system by National Instruments) was used for the purpose of converting the analog signal into digital form to further process the data using the appropriate tools. The software LabVIEW in the computer presents the data to the user.

II. Equipment

- *MEMSCAP SP82A Pressure sensor:*
  The pressure sensor consists of A silicon membrane with piezoresistors connected as a wheatstone bridge. Piezoresistive materials change their resistivity when they are subjected to stain, in this case the flexing of the membrane. Wheatstone bridge are often used due to their ability to make signals more linear. This has an effect on the values of each resistor when they are subjected to a strain and in turn changes the resistivity. This sensor has been used in several industries and is very reliable. This sensor uses the equation

$$E_{th} = V_s \left(\frac{R_1}{R_1 + R_2} - \frac{R_4}{R_3 + R_4} \right) \quad (1)$$

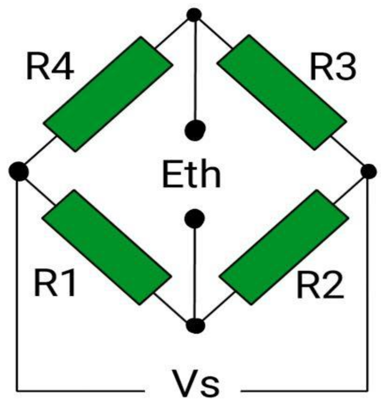


Figure 1: The wheatstone bridge model used in the sensor

- *MLX90308 Programmable Sensor Interface:*
  MLX90308 Programmable Sensor Interface is a microcontroller dedicated towards performing signal conditioning for wired bridge or differential configurations. MLX90308 can regulate gain, offset, linearity and temperature compensation. On its analog mode, it shows best accuracy due to containing all the information, hence when the signal is digitalized, it is converted into bits, which are discrete numbers, and some information is lost. On its digital mode, the signal is converted to a digital data to be further modified using a special software for this purpose. The changes made in the data using this software is sent to EEPROM of the microcontroller. EEPROM stands for Electrically Erasable Programmable Read-Only Memory. The gain and offset are changed. The signal is converted back to analog

- *National Instruments USB-6009 DAQ:*
  This is an USB (Universal Serial Bus) based device that has both analog and digital input and output. It is the medium between the microcontroller and the computer, as discussed earlier. The features pertaining to the DAQ is given in table 1.

Table I: Key features of the DAQ

Property	***Value***
Input resolution	14 bits
Input range	$\pm$ 10V
Maximum sampling rate	48 kS/s
Input impedance	144 kΩ

- LabVIEW simulation software:
  Laboratory Virtual Engineering Workbench is a data acquisition software package. User can set up a desired program to store and manipulate data from a hardware acquisition board.

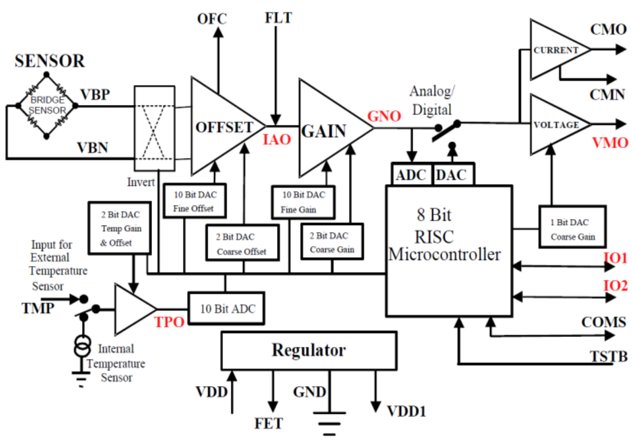


Figure 2: MLX90308 block diagram

III. Methodology

A. First step

The LabVIEW design software was used to manipulate the data from the DAQ. This was done by building a program in LabVIEW to represent the data from the DAQ and make sure the voltage was as readable as possible. The first part was the DAQ assistant set up to receive signals from the right DAQ channels, adjust the min/max voltage and set the sampling rate to 100Hz. To block the noise from power sources nearby a Low-Pass-Filter (20Hz cut-off frequency) was added. To make the data collected more compact an average was added with a factor of 10. At last it was a data collector configured to hold 6000 samples (600s), which was enough to go down to minimum pressure and up again. Two graphs and two numerical readouts was added, one of each before and after signal modification. This gave two different ways to get the data, either manually or by copying the data straight from the graph to excel.

B. Second step

Characterization of the sensor which is determining the sensitivity, errors in non-linearity, hysteresis and loading effect of the Melexis board. Now at first the DAQ device was used to find the pressure to voltage relationship of the sensor without the Melexis board attached to the circuit. Then there will be some quantization errors occurring during the conversion of analog (Voltage) mode to digital (Pressure) mode, given by the equation (2).

$$e_q^{max} = \pm \frac{100}{2(Q-1)} \% \tag{2}$$

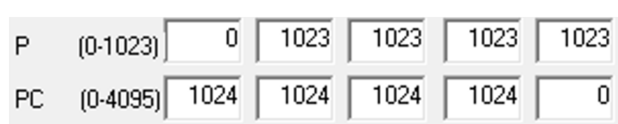
The sensor is enclosed within a tight chamber and connected to the DAQ using jumpers. The software reads the output voltage. As the pressure is decreased using the pump, the voltage (as an output value) is displayed on the screen. This recorded data is the I/O characteristic of the sensor. The procedure is also repeated for pressure increasing from a near vacuum status to atmospheric pressure of 1 bar. If this data is plotted in MS excel sheet, it gives out a very distinct linear representation. Now this data can be used to form a non-linear representation because for a single value of pressure (the input), the voltage displayed (output) will differ based on increasing pressure data or decreasing pressure data. This is called hysteresis, which is quantified as a percentage of f.s.d using:

$$H_{\%} = \frac{V\uparrow - V\downarrow}{V_{max} - V_{min}} * 100\ \% \tag{3}$$

C. Third step

Signal conditioning is done using the Melexis board and software. It means to manipulate the analog signal is such a manner that it is set to meet the requirements for the next step. Now manipulating the analog mode will also reduce the quantization error while the signal is passed from analog to digital mode.

- Melexis board is connected to the DAQ and the LabVIEW program will read the values.
- The Melexis software was set to digital mode where all the coefficient parameters were changed as shown in figure
- The output was recorded and was found to be exactly linear.
- The gain and offset was changed to match the desired output. First the offset was set for the linear relation to cross in the origin. Then the gain was adjusted to give the wanted sensitivity.
- Now this linearity has to be distorted to showcase the Melexis compensation range. The first step towards this is to use a model equation for non-linearity of the I/O relationship of the sensor.



P	(0-1023)	0	1023	1023	1023	1023
PC	(0-4095)	1024	1024	1024	1024	0

Figure 3: Linear configuration for digital mode

Compensation of the Melexis's non-linearity:

- Five points were chosen from the linear graph data to create five segments to be modified, and the values of three of the points where decided to be increased by 0.5V or 1.0V according to table II.

Table II: Table of the five point where compensation of non-linearity is done.

#	Pressure	Linear voltage	Desired non-linear voltage
1	0,2	1,0	1,0
2	0,4	2,0	2,5
3	0,6	3,0	4,0
4	0,8	4,0	4,5
5	1,0	5,0	5,0

- First the pressure was pumped down to 0.2, P1 and PC1 was left at 0 and 1024, as this gave the same slope from 0 to 0.2 as the original linear signal. The "Update" button was pressed and the value from the "Signal In Value" was copied to P2.
- Then the pressure was pumped up to 0.4, and the PC2 was set to an approximate value according to the user manual. "Upload EEPROM" and "Reset Controller" was pressed (often multiple times) to check if the desired voltage was reached, and corrections were made if necessary. The "Update" button was pressed and the value from the "Signal In Value" was copied to P3.
- Pump to 0.6, and repeat the point above to set PC3 and P4. Pump to 0.8 to set PC4 and P5, and pump to 1.0 to set PC5.

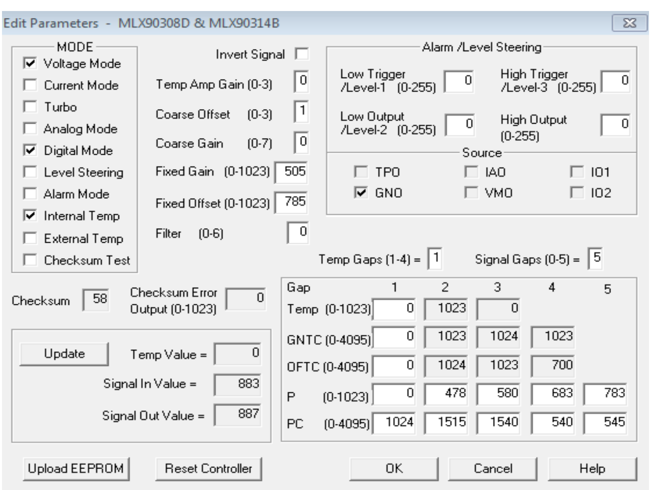


Figure 4: The final Melexis compensation

IV. RESULT

According to the methodology, LabVIEW program is designed to acquire the data from the SP82A pressure sensor. The pressure sensor is first tested without Melexis MLX90308 programmable sensor interface chip for pure sensor data to do the characterization. Then it is tested with the Melexis board with compensation for offset and gain in digital mode.

Pressure is pumped up and down, and the value of voltage is acquired every time for ascending and descending pressure. The range of which the pressure chamber could maintain a steady pressure and the interval used in testing are given in Table.

Table III: Common characteristics of system

Parameters	Value
Input range	0,1 – 1,0 bar
Interval	0,1 bar

1) Analog testing without Melexis MLX90308

In this case the sensor is placed in an airtight chamber where the pressure is controlled by a pump. This is connected directly to a computer to characterize the pure sensor data. The acquired values of voltage with respect to pressure are listed in Table III for descending and ascending pressure.

The values in Table IV are plotted in a graph and Figure 5 shows the result with linear regression. We can see that the sensor without any correction for gain and offset have a linear characteristic as expected with linear equation (4) for the output voltage. This is analog values for voltage, which we can measure directly from the Wheatstone bridge in the pressure sensor.

$$V_{Analog} = 0{,}1081 * P - 0{,}0019 \qquad (4)$$

TABLE IV: Output values of voltage for ascending and descending pressure control

Pressure, P	Voltage (descending P)	Voltage (ascending P)
1,00	0,106	0,106
0,90	0,095	0,095
0,80	0,085	0,084
0,70	0,074	0,073
0,60	0,063	0,063
0,50	0,054	0,052
0,40	0,041	0,041
0,30	0,031	0,031
0,20	0,021	0,020
0,12	0,010	0,010

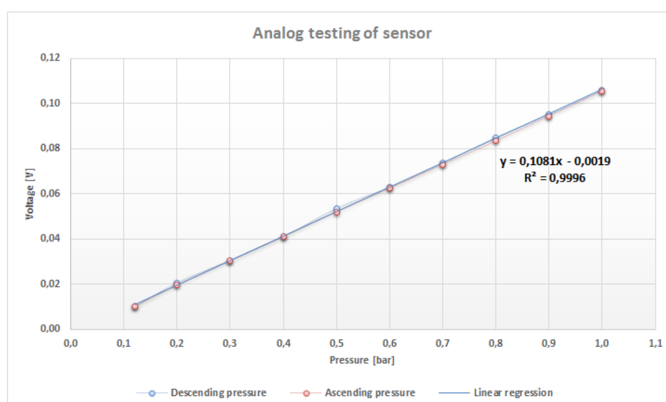


Figure 5: Analog testing of pressure sensor without Melexis MLX90308 programmable sensor interface chip. Test is done for descending and ascending pressure.

2) Digital testing with Melexis MLX90308

To get a better view of pressure sensor MLX90308 programmable sensor interface chip is connected to adjust parameters of the sensor. First of all the gain and offset values are adjusted to get the desired values. The chosen values for gain and offset given by the sensor specifications are given in Table V.

Table V: Desired values for gain and offset.

Parameters	***Desired value***
Gain	5 V
Offset	0 V

In the Melexis MLX90308 software the “fixed gain” and “fixed offset” values are adjusted according to get the desired values stated in Table IV. Different values is tested and output signal is measured on LabVIEW to get the desired gain and offset values. Figure 6 shows the changed values.

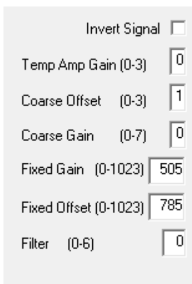


Figure 6: A section of Melexis MLX90308 software were the fixed gain and fixed offset values are changed to get the desired values of Table IV.

After the correction for gain and offset. The same test of pumping pressure down and up as in analog mode is performed to see the characteristic of the sensor. Table VI shows the measured voltage for descending and ascending pressure. The values are plotted in Figure 4, and we can see that the gain is changed to approximately 5 V. Offset value is also approximately 0 V, because we do not want any change in the offset according to change in gain. Linear regression of the graph shows the linear equation (5) for the output voltage in digital mode with correction.

$$V_{Digital} = 4{,}9607 * P + 0{,}0352 \qquad (5)$$

Table VI: Output values of voltage for ascending and descending pressure control.

Pressure, P	***Voltage (descending P)***	***Voltage (ascending P)***
1,00	4,989	4,990
0,90	4,502	4,491
0,80	4,010	4,009
0,70	3,510	3,512
0,60	3,008	3,007
0,50	2,517	2,516
0,40	2,022	2,022
0,30	1,519	1,519
0,20	1,028	1,029
0,12	0,630	0,631

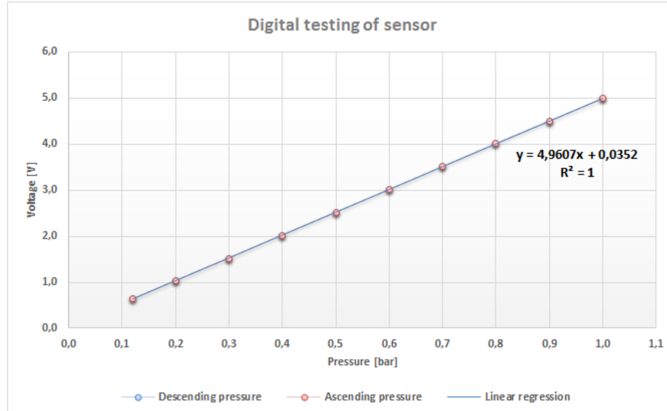


Figure 7: Digital testing of pressure sensor with Melexis MLX90308 programmable sensor interface chip. Test is done for descending and ascending pressure.

3) Non-linearity testing

In this test the purpose is to convert the digital linear signal from sensor into a non-linear signal. Table VIII shows three pressure points were the linear voltage is changes at 0.4V, 0.6V and 0.8V, and for the start and end pressure points at 0.2V and 5.0V the voltage is the same.

Table VII: The table shows the five points on the linear signal “# Gap” that are chosen. The desired voltage on these points is selected to make the linear signal to a non-linear signal.

# Gap	***Pressure***	***Linear voltage***	***Desired non-linear voltage***
5	1,00	5,0	5,0
4	0,80	4,0	4,5
3	0,60	3,0	4,0
2	0,40	2,0	2,5
1	0,20	1,0	1,0

These pressure points are edited in the Melexis MLX90308 software to make the linear signal non-linear as described in methodology. By following the procedure for non-linearity compensation the value of P and PC is changes to get the desired voltage. Figure 5 shows the compensated values in the Melexis MLX90308 software to make the sensor non-linear.

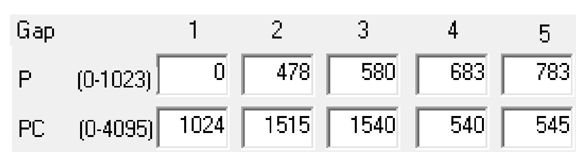


Figure 8: Corrected values for P and PC in the Melexis MLX90308 software to make the linear signal non-linear and get the desired voltage at pressure five points.

After the non-linearity correction, the same test with descending and ascending pressure is done to see if the sensor is made non-linear. With same intervals as previous test we can see from Table VII that for the five given point we have achieved the desired voltage from table VIII by adjusting the five values in Melexis MLX90308 software. By plotting the values in a graph Figure 9 shows the digital linear signal and the compensated non-linear signal.

Table VIII: Non-linear voltage that are measured with correction for five pressure points.

Pressure	***Linear voltage***	***Non-linear voltage***
➢ 1,00	4,989	5,019
0,90	4,502	4,756
➢ 0,80	4,010	4,505
0,70	3,510	4,245
➢ 0,60	3,008	3,963
0,50	2,517	3,235
➢ 0,40	2,022	2,490
0,30	1,519	1,748
➢ 0,20	1,028	1,030
0,12	0,630	0,628

$$V_{Linear} = 4{,}9607 * P + 0{,}0352 \quad (6)$$

$$V_{Non-linear} = -4{,}1774 * P^2 + 9{,}8714 * P - 0{,}6771 \quad (7)$$

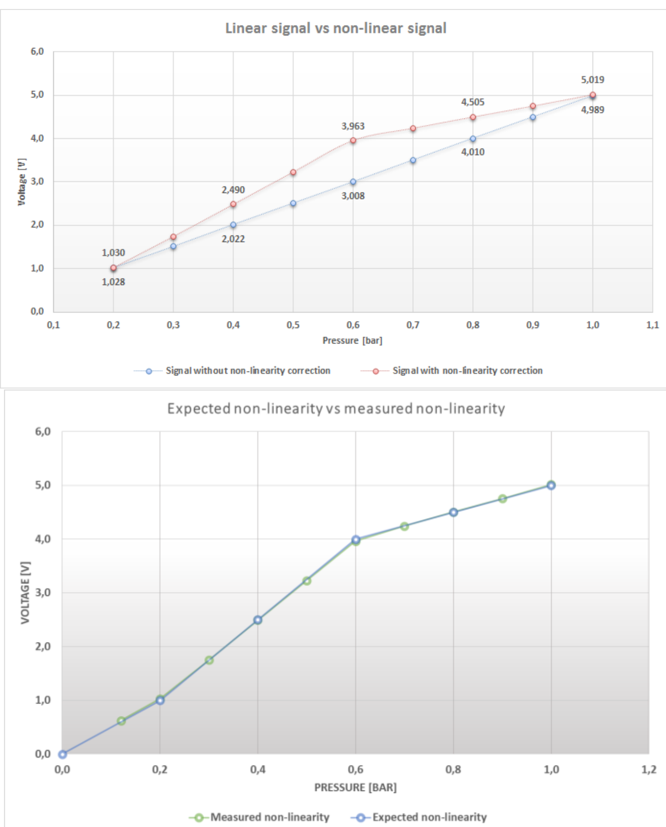


Figure 9 (a) Linear and non-linear signal in digital mode. (b) The linear signal is compensated to make it non-linear and it is compared to the expected non linearity.

V. Discussion

A. The general system

In the testing platform, we have many parameter that can cause inaccurate result of the characterization. The first is the limitation of pressure chamber, which have difficulties to maintain a stable pressure over longer time. This is specially typical for the lower values for pressure in our case or extreme values. Leakage in the chamber can be a reason for this. Second parameter, which can give inaccurate characterization, can be the noise in the system setup because of all the wiring. The National Instruments USB-6009 DAQ can also have limitation in analog to digital conversation can cause less resolution.

B. Comparison of pure signal, digital signal and non-linear

The pure signal is giving an almost perfect linear output. The small offset is due to the Wheatstone bridge. In digital mode offset was removed and the gain was set to 50, giving a 1:5 relation between pressure in [bar] and voltage out [V].

All the measurements had a small variation from the ideal value, and this is probably due to various reasons being difficulties to read out the exact value (human error), some noise possible coming from the equipment and in the digital mode, conversion will also create some error. For the characterization, the σ^2 = 0,9996. That is very close to the desired value of 1. This shows that the sensor is very accurate.

Comparing the expected theoretical values with the measured , it is clear that the Melexis is doing exactly what was expected. This can be seen clearly in Figure 9 (a) and (b).

Also notable is the lack of hysteresis, both in the original signal, and in the modified signal. It is clear that the set parameters for gain and offset was correct for the linear line that was wanted, going both through the origin and 5V and 1 bar pressure.

VI. Conclusion

In this project a MEMSCAP SP82A pressure sensor has been successfully characterized. A typical measurement system has been illustrated, which consists of basic elements: sensor, signal processing and conditioning, and data presentation. Digital signal conditioning has been used to demonstrate non-linear compensation for the linear sensor characteristic. Melexis MLX90308 programmable interface chip is used for signal conditioning, LabVIEW is utilized for signal processing and data presentation is done on Microsoft Excel.

For further research and better characterization, a better pressure chamber could have been used and a testing platform that are more shielded form external noise sources, such as wires and connection points. An analog-to-digital converter (ADC) with better resolution could also give results that are more accurate.

In a bigger perspective through the project work fundamental theories and practical application have given good platform for continued studies.

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