Application Note

NOVOSENSE

Pressure Sensor Basic Concept Introduction

AN-12-0038

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ABSTRACT

For MEMS (Micro-electromechanical Systems) pressure sensors, there are some background information and basic concept which need to be understood before the dedicated datasheets could be fully comprehended. This application note mainly focuses on the basic concept introduction of MEMS pressure sensors in order to simply the pressure sensor related technical documents usage & understanding.

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1.Theory of MEMS Pressure Sensor

In essence, MEMS pressure sensor is a flexible silicon membrane which could convert the applied pressure to an output voltage and the output voltage is proportional to the applied pressure. One MEMS pressure sensor die is shown in Figure 1.1.

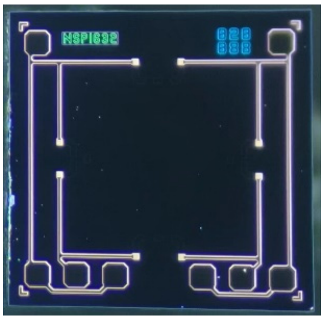


Figure 1.1 Top view of a MEMS pressure sensor die

All MEMS pressure sensors of NOVOSENSE are based on so-called "piezo-resistive effect", i.e. stress change leading to resistor change. There are four resistors in the middle of four edges of the thin membrane. When a fixed pressure is applied on the MEMS membrane, the membrane will bend upward or downward based on the pressure direction. Due to the deformation, stress concentration will occur at the middle points of membrane four edges leading to the resistor change of the four resistors. The four resistors could be grouped as two types. As shown in Figure 1.2, R1 & R3 increases with pressure applied while R2 & R4 behave in the opposite way. With a given supply voltage & pressure, the MEMS output voltage is proportional to the resistor change rate. In general, the resistor change rate is proportional to the applied pressure.

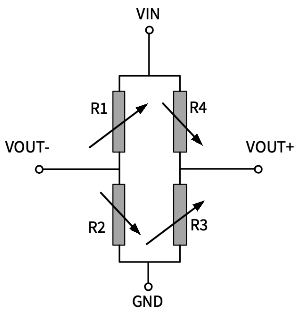


Figure 1.2 Wheatstone bridge of MEMS sensor

$$VOUT_{+}=\frac{R3+\Delta R}{(R3+\Delta R)+(R4-\Delta R)}\times VIN=\frac{R3+\Delta R}{R3+R4}\times VIN$$

$$VOUT_{-}=\frac{R2-\Delta R}{(R1+\Delta R)+(R2-\Delta R)}\times VIN=\frac{R2-\Delta R}{R1+R2}\times VIN$$

$$VOUT=VOUT_{+}-VOUT_{-}$$

$$R1=R2=R3=R4=R$$

$$VOUT=\frac{\Delta R}{R}\times VIN$$

Based on the theoretical analysis, it seems that MEMS die could be used to measure the pressure directly. However, it's not true in real application. There are several non-ideal factors which restrict the MEMS application e.g.

1.small output signal typically < 100mV at 5.0V power supply

2.offset & sensitivity temperature coefficient as shown in Figure 1.3

3.poor uniformity as shown in Figure 1.4

In order to solve the above-mentioned problems, one signal conditioning ASIC (Application Specific Integrated Circuit) is needed to amplify the original small signal, compensate the temperature induced non-ideal effects and transfer the output into an analog signal with range of 0~5V or a digital signal with serial interface i.e. I2C or SPI. After calibration, the sensor output always follows one fixed linear transfer function in full temperature & pressure range as shown in Figure 1.3.

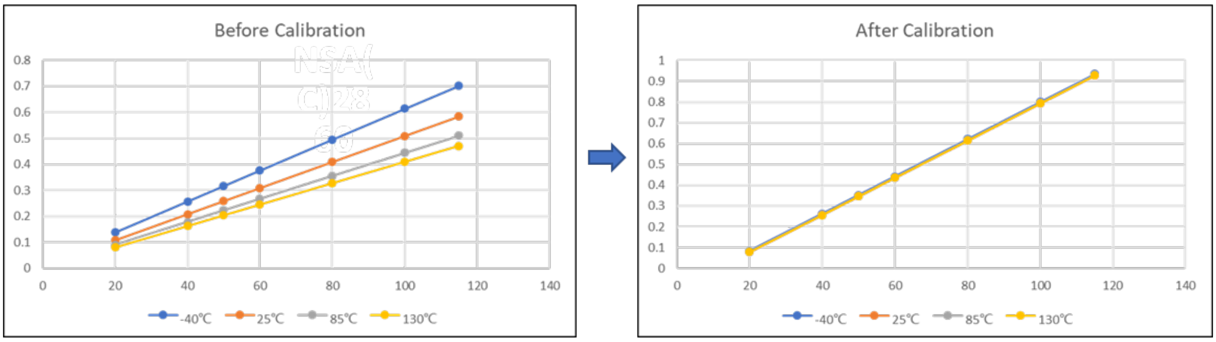


Figure 1.3 MEMS pressure sensor calibration

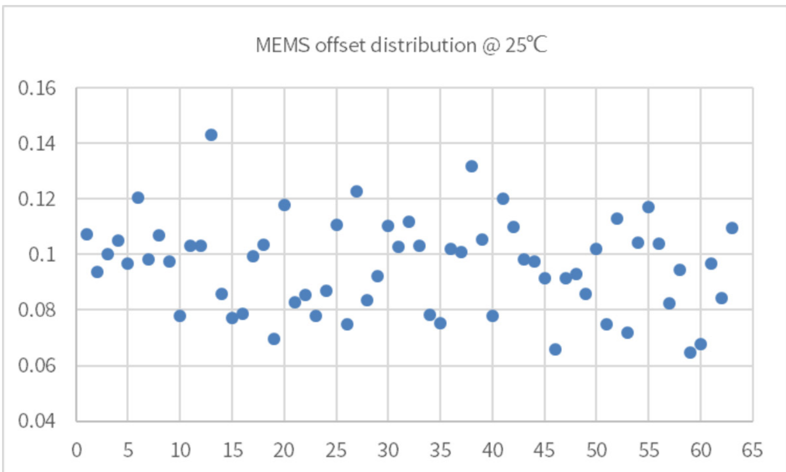


Figure 1.4 MEMS offset distribution of 63pc samples

2.Pressure Sensor Types

Each pressure sensor of NOVOSENSE integrates one MEMS and one ASIC into a single package which is pre-calibrated before delivery. There are three types of pressure sensors based on their different working conditions i.e. absolute pressure sensor, gauge pressure sensor and differential pressure sensor.

2.1.Absolute Pressure Sensor

MEMS pressure sensor could detect the pressure difference between the top & bottom side of the membrane. As shown in Figure 2.1, when the applied pressure is on the top side, and vacuum is on the bottom side, then this kind of pressure sensor is named as absolute pressure sensor.
There are mainly three different series of absolute pressure sensors by NOVOSENSE with different package outlines i.e. NSPAS1N, NSPAS3N & NSPAS3M. These absolute pressure sensors are suitable for the following typical applications:
1.Motorcycle TMAP application
2.Temperature manifold pressure sensor (TMAP)
3.ECU barometric absolute pressure sensor (BAP)
4.Canister desorption pressure detection
5.Battery pressure sensor
6.Seat airbag pressure detection
7.Industrial control

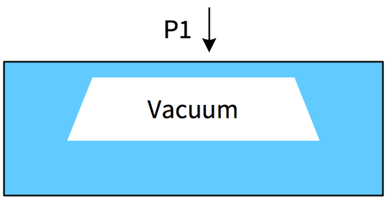
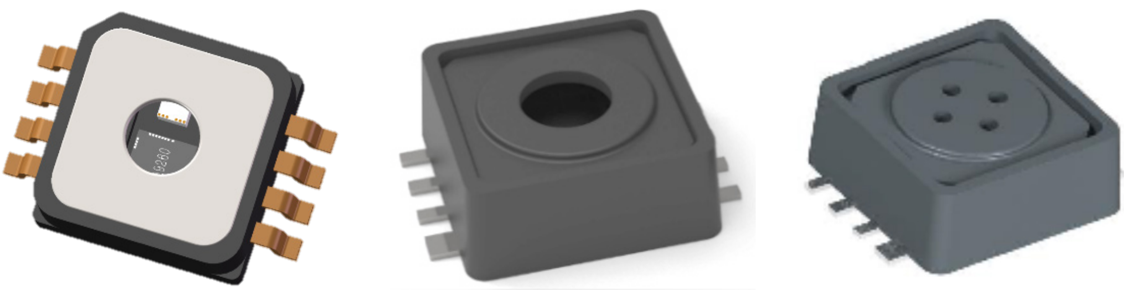


Figure 2.1 Absolute pressure sensor



(a) NSPAS1N (b) NSPAS3N (c) NSPAS3M

Figure 2.2 Absolute pressure sensors of NOVOSENSE

2.2.Gauge Pressure Sensor

As shown in Figure 2.3, when the applied pressure is on the top side, and the bottom is directly connected to the atmosphere or vise versa, then this kind of pressure sensor is gauge pressure sensor.

NOVOSENSE could offer four types of gauge pressure sensors with different packages as shown in Figure 2.4.

Typical applications of NSPGD1:

1.Washing machine

2.Dishwasher

3.Air bed, massage chair

4.Smart sphygmomanometer, oxygen generator

Typical applications of NSPGS2F:

1.Vacuum cleaner, vacuum juicer

2.Air bed, massage chair

3.Smart sphygmomanometer, oxygen generator

Typical applications of NSPGS5F:

1.Fire pressure monitoring

2.Ventilators

3.HVAC/VAV

4.Safety cabinets

5.Pressure switches

Typical applications of NSPGL1:

1.FTPS fuel vapor pressure detection

2.Pressure senor for filter monitoring

3.Vacuum boost applications

4.Crankcase ventilation system

5.Industrial vacuum detection

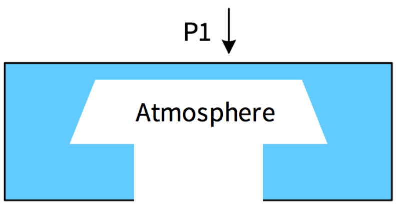


Figure 2.3 Gauge pressure sensor

(a) NSPGD1 (b) NSPGS2F (c) NSPGS5F (d) NSPGL1

Figure 2.4 Gauge pressure sensors of NOVOSENSE

2.3.Differential Pressure Sensor

As shown in Figure 2.5, when there are two different applied pressures at both sides of the membrane, then this kind of pressure sensor is differential pressure sensor.

There is one type of differential pressure senor from NOVOSENSE i.e. NSPDSx series including NSPDS5F, NSPDS7F and NSPDS9F with different pressure range & output types.

Typical applications of NSPDSx:

1.Residual pressure for fire protection

2.Ventilators

3.HVAC/VAV

4.Safety cabinets

5.Pressure switches

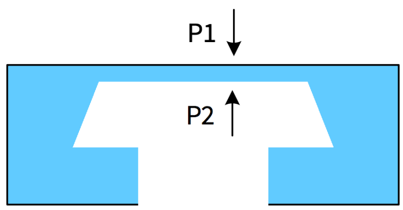


Figure 2.5 Differential pressure sensor

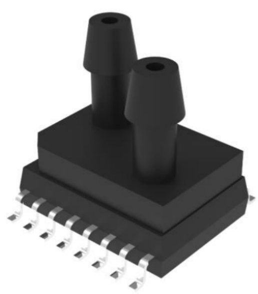


Figure 2.6 Differential pressure sensors of NOVOSENSE

3.Output Types

Generally speaking, NOVOSENSE pressure sensors could generate two types of output signal i.e. analog output & digital output.

3.1.Analog Output

Analog output pressure sensor generates an analog voltage which is proportional to the applied pressure with a fixed transfer function. Figure 3.1 shows one example of transfer function of an analog output pressure sensor.

$V_{out}=(A*P+B)*V_{ref}$

V_{out}: output voltage

A: gain of transfer function

B: offset of transfer function

V_{ref}: reference voltage

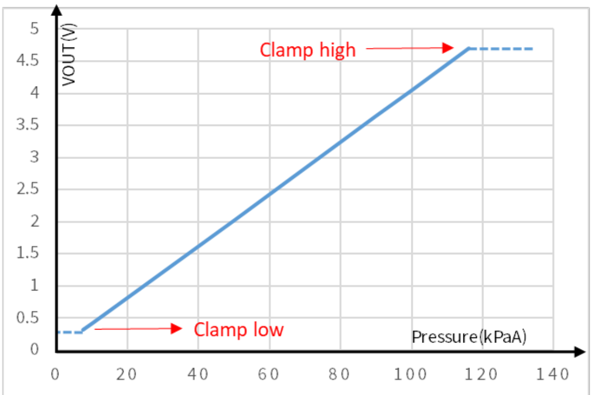


Figure 3.1 Transfer function of analog output pressure sensor

3.1.1.Absolute Analog Output

If the reference voltage V_{ref} in the transfer function formula is a fixed value e.g. 3.3V or 5.0V, this kind of sensor is called absolute analog output sensor. When there is a small disturbance on the supply voltage (within 5% variation), the sensor output could still keep stable since it uses an internal voltage source as reference for the DAC(digital to analog converter) inside the ASIC. However, if there is a large voltage drop on the supply pin e.g. larger than 10%, the output voltage could no longer maintain stable leading to accuracy loss.

3.1.2.Ratiometric Analog Output

If the reference voltage V_{ref} in the transfer function formula is supply voltage VDD, then this type of senor is named as ratiometric analog output sensor. In another word, the senor accuracy is not affected by and independent of the supply voltage. It is the ratio of output voltage and the supply voltage that really matters. This type of sensor is widely used in automotive industry due to its high reliability, but it costs one additional ADC(analog to digital converter) resource of the ECU compared with absolute analog pressure sensor.

3.2.Digital Output

Digital pressure sensor converts pressure signal into a proportional digital code transferred by digital interface e.g. I2C and SPI. One example of transfer function for digital gauge pressure sensor is indicated in Figure 3.2.

$Code_{out}=(A*P+B)*Code_{width}$

$Code_{out}$: digital output code

A: gain of transfer function

B: offset of transfer function

$Code_{width}$: ADC code width

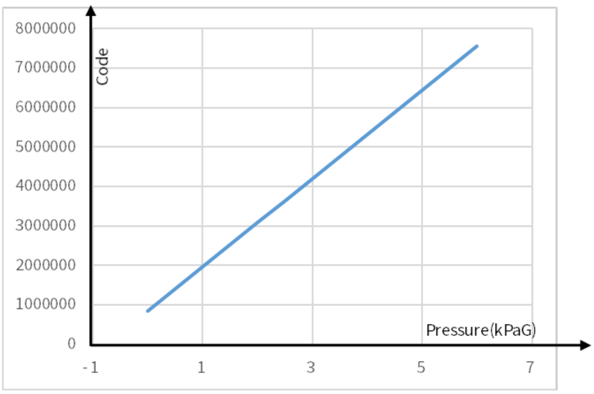


Figure 3.2 Transfer function of digital output pressure sensor

4.Clamp

Analog output pressure senor has a unique feature compared with digital output pressure sensor which is clamp. If the applied pressure is smaller than the minimum pressure or larger than the maximum pressure of the sensor operation range, then the sensor output voltage would be clamped to a fixed value i.e. clamp voltage as shown in Figure 3.1. When the clamp voltage is detected, the host (ECU or MCU) could react accordingly e.g. trigger an alarm signal indicating the pressure is out of range.

5.Accuracy Calculation

Pressure sensor accuracy or error is usually defined as percentage of full-scale output i.e. %F.S.. The calculation formula is listed as follows. Table 5.1 shows the order information of one analog output pressure sensor while Table 5.2 demonstrates the order information of one digital output pressure sensor.

$$\text{Accuracy \%F.S.}=\frac{\text{normalized error}}{\text{normalized output range}}$$

Analog output:

$$\text{normalized error}=\frac{V_{out\_measure}}{V_{ref}}-(P_{measure}*A+B)$$

$$\text{normalized output range}=\frac{O_H-O_L}{V_{ref}}$$

Digital output:

$$\text{normalized error}=\frac{Code_{out\_measure}}{Code_{width}}-(P_{measure}*A+B)$$

$$\text{normalized output range}=\frac{O_H-O_L}{Code_{width}}$$

Table 5.1 Order information of ratiometric analog output pressure sensor

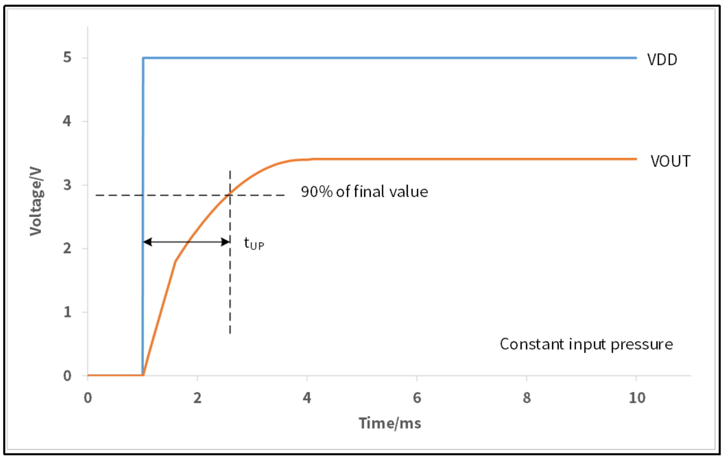
Product Type	Output Type	Pressure Range		Output Range		Clamp Level		Gain and Offset		Supply Voltage	Accuracy	
		P_L	P_H	O_L	O_H	V_{CL}	V_{CH}	A	B		0~85℃	-40~130℃
NSPAS3N115RR03	Ratiometric	20.00kPa	115.00kPa	0.400V	4.650V	0.40V	4.65V	0.008947	-0.098947	5.0V	±1.0%F.S.	±1.5%F.S.

Table 5.2 Order information of I2C digital output pressure sensor

Product Type	Output Type	Pressure Range		Output Range		Clamp Level		Gain and Offset		Supply Voltage	Accuracy	
		P_L	P_H	O_L	O_H	V_{CL}	V_{CH}	A	B		Initial	Full life
NSPDS7F004DT41	I2C	-0.50kPa	4.00kPa	838861	7549746	NA	NA	5.6250	-1.0625	3.3V	±1.0%F.S.	±2.0%F.S.

6.Powerup Time

The power-up time t_{up} is defined as the maximum time between the supply voltage reaching its operating range and the output voltage reaching 90% of its final value based on the assumption that Vout pin left open and input pressure keeps constant.

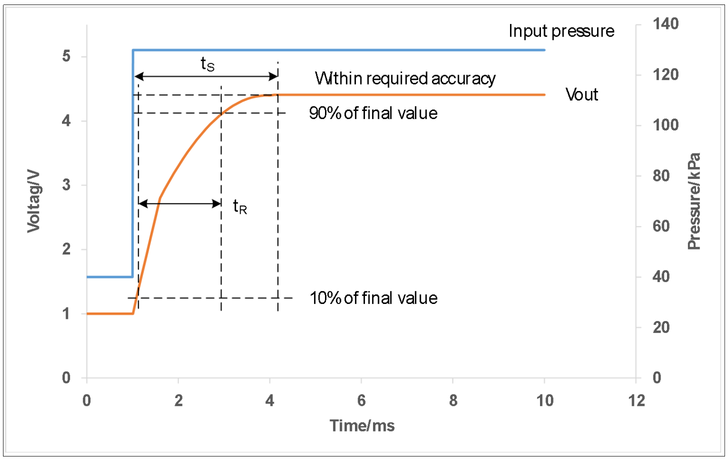


7.Response Time and Stabilization Time

The response time t_R is defined as the time required by the output to change from 10% to 90% of its final value after a specified pressure step i.e. step response time.

The stabilization time ts is defined as the time required by the output to meet the specified accuracy after the pressure has been stabilized.

Please refer to AN-12-0013 for detailed response time test setup & experimental results.



8.Summary

This application note illustrates the theory of MEMS pressure sensors and some widely used basic concepts of pressure sensors in datasheets. This note could be used as a supplement or reference document during reading any formal datasheet of NOVOSNESE MEMS pressure sensors.

9.Revision History

Revision	Description	Author	Date
1.0	Initial Version	Charles Chen	8/7/2024

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