April 1997

Understanding and Specifying Texas Instruments' Capacitive Pressure Transducers

Mitch Berkson

This application note is an introduction to TI's capacitive pressure sensors and an aid in understanding their performance specifications.

Capacitive Sensing Element

A pressure transducer is comprised of two major parts - 1) an element which is affected by pressure changes and 2) associated electronics.

The pressure sensing element is a pair of parallel plates which form a capacitor. One plate is fixed to a ceramic diaphragm which flexes in response to pressure changes. The other plate is attached, with a rigid glass seal, to a ceramic substrate which is insensitive to pressure changes (Figure 1). As the pressure varies, the diaphragm flexes and the distance between the capacitor plates changes. This ceramic sensing element design produces a variable capacitor that is highly stable and reliable. Thicker diaphragms are used in higher pressure devices for mechanical strength. Sensors with full scale pressure ranges from 7.5 psi to 10,000 psi are constructed simply by changing the diaphragm thickness during manufacture.

A custom, patented integrated circuit in the transducer measures the capacitance and converts it to a voltage linearly proportional to the pressure. Since this IC can detect very small changes in capacitance due to small diaphragm deflections, excellent hysteresis and repeatability are achieved.

In many cases lowest cost with high accuracy is achieved by using a ratiometric output. This means that, instead of the sensor output voltage itself, it is actually the ratio of the sensor output to the sensor supply voltage which is proportional to pressure. Ratiometric operation is illustrated in Figure 2 where it can be seen that the sensor output voltage varies with supply voltage. For example, a pressure of 50% of span will produce an output of 2.25V with a supply of 4.5V and an output of 2.75V with a supply of 5.5V How can this be useful?

In a typical application the user converts the sensor output to a digital value with an analog to digital converter (ADC). Many ADC's are designed to calculate the ratio of an input voltage to another voltage. Since both the sensor and the ADC communicate using ratios, the power supply accuracy requirement is relaxed (i.e., this system configuration has a high power-supply rejection

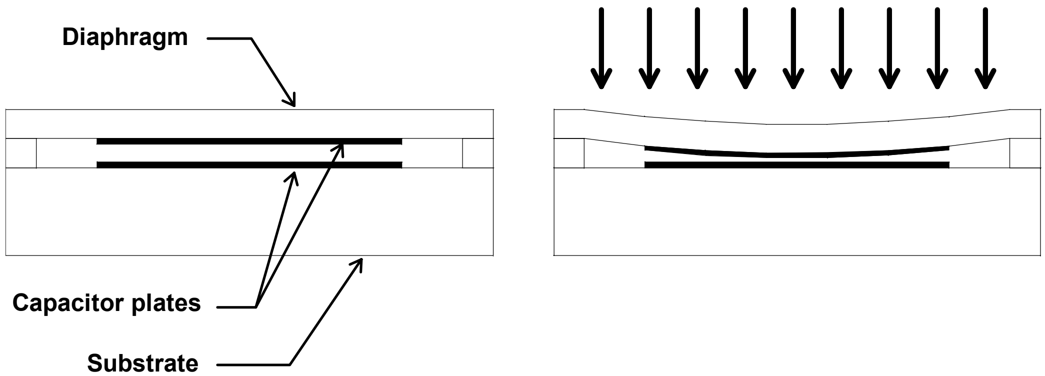

Figure 1. Capacitive sensing element

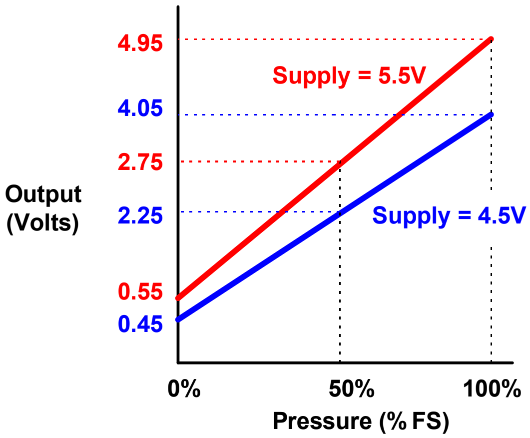

Figure 2. Effect of supply voltage change on ratiometric output

ratio). Figure 3 shows a typical connection schematic for a ratiometric pressure sensor and ADC.

Understanding Performance Specifications

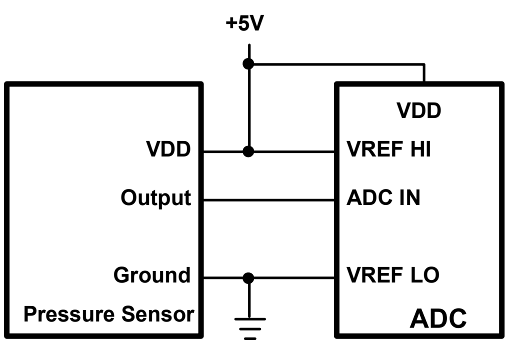

Figure 3. Wiring for Ratiometric ADC

Sensor accuracy is specified in a variety of ways as an aid in finding the best device for a particular application. Specifications include accuracy (static and total error band), linearity, hysteresis, repeatability, calibration and temperature.

Accuracy - Introduction

The term accuracy has many different definitions. The most commonly accepted one is that it is the sum of linearity, hysteresis and repeatability at room temperature. Some manufacturers use the root sum square of these three error sources. Notice that using these definitions of accuracy, a device may be very linear, have low hysteresis and high repeatability, but still produce an output unrelated to the input pressure because it is not calibrated well. As an extreme example, consider that a device with a fixed (or grounded) output will have excellent linearity, hysteresis and repeatability, but still be completely useless as a pressure sensor (see Figure 4). This occurs because none of the above parameters reference the theoretical output curve.
In order to avoid this problem, TI follows NIST recommendations and specifies static error band and total error band. Before looking at error bands, it is important to look at the individual error sources that will make up the error band.

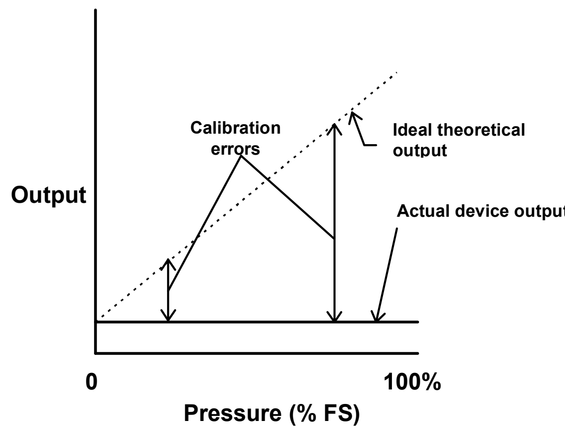

Figure 4. A useless pressure sensor with excellent "accuracy" (linearity, hysteresis and repeatability)

Specifications in TI data sheets are presented as a percentage of span (written % span and also as % FS where FS is an abbreviation for full span). The span on the pressure axis is the full scale pressure range of a device (e.g., for a 0 to 100 psi device, the span is 100 psi; for a 200 to 500 psi device, the span is 300 psi). The span on the device output axis is the full scale output range (e.g., for a 0.5V to 4.5V device, the span is 4.0V).

Linearity (or non-linearity)

Linearity is the maximum deviation of the sensor output from a best-fit straight line (BFSL) measured with increasing pressure only. It is expressed as ±x% FS. Linearity error is illustrated in Figure 5.

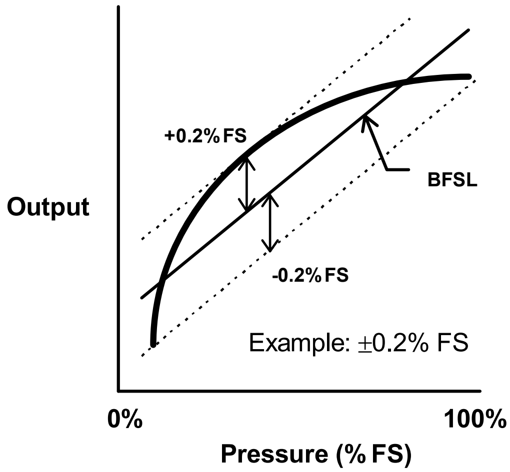

Figure 5. Linearity

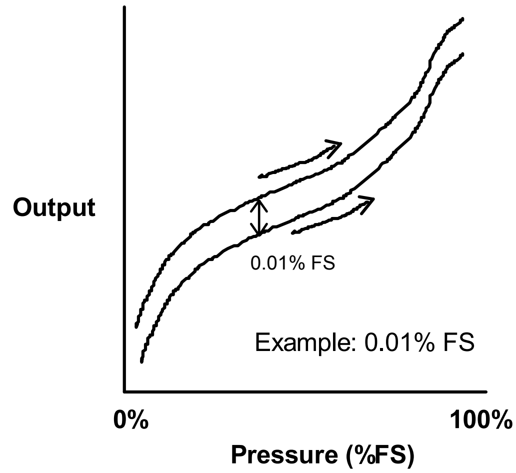

Figure 7. Repeatability

Hysteresis

Hysteresis is the maximum difference in sensor output at a pressure when that pressure is first approached with pressure increasing and then approached with pressure decreasing during a full span pressure cycle. It is stated as less than x% FS. Hysteresis error is shown in Figure 6.

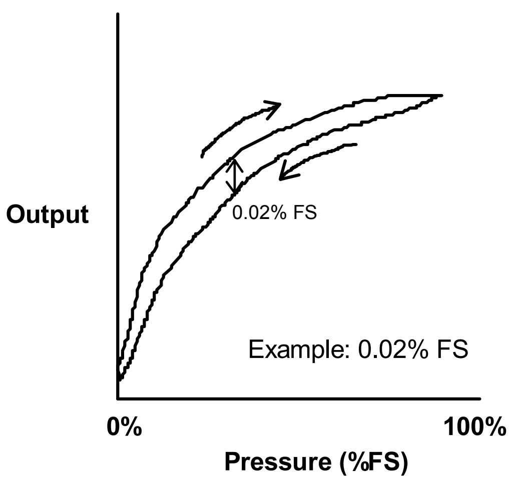

Figure 6. Hysteresis

Repeatability

Repeatability is the maximum difference in output when the same pressure is applied, consecutively, under the same conditions and approaching from the same direction. Repeatability is determined by two pressure cycles and is stated as within x% FS. Repeatability error is illustrated in Figure 7.

Accuracy - Reprise

Now that the contributors to the static and total error bands have been defined, we can proceed to how they are specified in the data sheet.

The envelope bounding all room temperature errors, including linearity, hysteresis, repeatability and calibration error defines the static error band. This error band represents the uncertainty in knowing the true pressure. The smaller the band, the better the device. Figure 8 shows a typical static error band and how it envelopes the actual output curve.

Devices with equal error bands are interchangeable without affecting system accuracy. TI's manufacturing methods are designed to produce sensors with matching error bands over millions of sensors produced each year.

A similar concept can be applied over environmental conditions like temperature, vibration, etc. In this case it's called the total error band at the specified conditions. The test conditions must be specified so error bands can be compared. TI specifies two total error bands - one for the industrial temperature range -20°C to 85°C and one for a wider temperature range from -40°C to 135°C (sometimes referred to as the automotive temperature range). These error bands are shown in Figure 8.

Total error bands are usually wider than static error bands because they must comprehend the effects of temperature on the offset voltage and gain. Use of the total error band means that, at a glance, you can understand the combined error effects. Other manufacturers may make you add up temperature coefficients of offset and temperature coefficients of gain, and sometimes

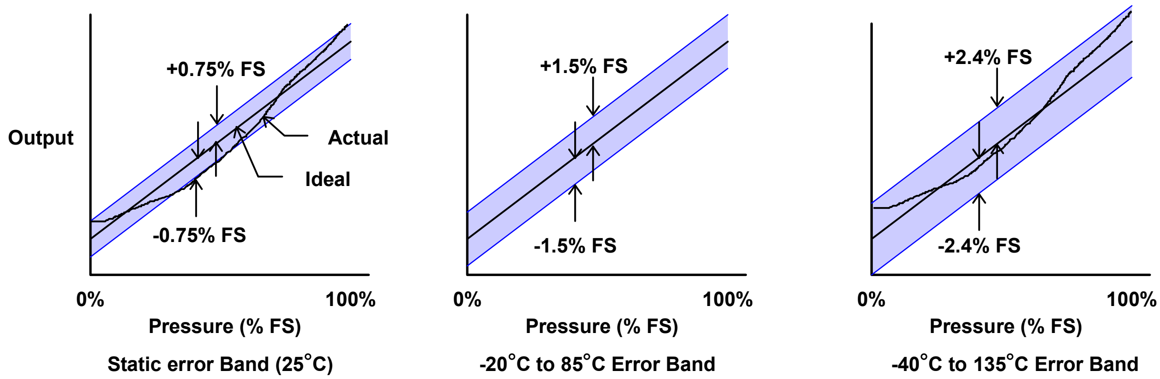

Figure 8. Error Band at Different Temperature Ranges

it's not clear how they should be added - straight addition, root sum of squares or other.

Electrical Specifications

EMC

The EMC specifications refer to testing performed to verify pressure sensor performance in electrically noisy environments. Testing levels of 100 V/m from 512 MHz to 1GHz and 200 V/m from 10 MHz to 512 MHz simulate the effect of 30 to 100 watt transmitters (e.g., CB radios) operated in the vicinity of the pressure sensor. When subjected to these radio frequency power levels, the sensor output will not temporarily vary more than ±2% FS. After the field is removed, any sensor output deviation stops without any effect on device performance.

In order to achieve this level of EMC performance, the case of the pressure sensor is a Faraday cage capacitively coupled to ground and VDD using capacitors rated for 50VDC.

ESD

The pressure sensor is rated to withstand, without damage, an electrostatic discharge (ESD) as shown on the data sheet.

Output Load Range

The output load range is the range of equivalent resistance (either pull-up or pull-down) which may be connected to the pressure sensor output and have the sensor perform within its specified accuracy bands.

Since the output of the pressure sensor has non-zero impedance, a load connected between the device output and power or ground will act as a voltage divider with this impedance. The load resistance should be within the range specified on the data sheet (e.g., "2KΩ - no load" would mean that a 2KΩ or larger pull up or pull down equivalent resistance is acceptable).

Supply Voltage Range

Pressure sensor specifications (e.g., static error band, total error band) are valid when the sensor is powered with the supply voltage shown on the data sheet.

The sensor will operate normally with a supply voltage up to 8.5V. It may be damaged if a voltage greater than the overvoltage protection voltage or less than the reverse voltage protection voltage is applied.

Mechanical Specifications

Proof Pressure

Proof pressure is the maximum pressure to which a device may be exposed after which it will return to its normal operating pressure range and perform within specification. Proof pressure is specified as a multiple of the upper limit of the device's operating range (e.g., 1.5X for a 0-100 psi device would mean a proof pressure of 150 psi).

The testing performed by TI to verify proof pressure is for the pressure transducer to withstand 1000 cycles of exposure to the proof pressure, at room temperature, holding the pressure for 30 seconds each cycle, without degradation of performance.

Burst Pressure

Burst pressure is the maximum pressure to which a device may be exposed for two minutes without rupture of the sensing element or transducer case or seals. It is not guaranteed that the device will function within specification when returned to its normal operating range after being exposed to a pressure above its proof pressure (even if that pressure is below its burst pressure). Like proof pressure, burst pressure is specified as a multiple of the upper limit of the device's operating range.

Drop Test

During the drop test, the port threads, if present, are protected with a thread cap.

Connector

NEMA type 4X and DIN IP65 connectors are intended to withstand exposure to windblown dust and rain, splashing water and hose directed water. This provides protection for both indoor and outdoor use. The NEMA 4X classification also indicates that the connector will not be damaged by the formation of ice on the exterior and will be constructed of specific material that will provide a degree of protection against corrosion.

Doc #510493