All Sensors ***Pressure Points*** are application tips to simplify designing with microelectromechanical systems (MEMS) pressure sensors and avoiding common pitfalls.

Pressure Point 12: Making MEMS Pressure Sensors Easier to Use (Part 2)

Pressure is one of the most common measurements. Based on their small size, low cost and high reliability, microelectromechanical systems (MEMS) pressure sensors that use the high-volume manufacturing techniques of the semiconductor industry are found in over 90% of today's applications.

It could be said that there are two types of pressure measurements: those that are made using a MEMS pressure sensor and those that will be. In either case, pressure sensors that are easier to use help designers of products for new or existing applications get their products to market faster. Pressure sensors with a digital output and an evaluation board have two aspects that make design-ins easier. Providing comparative data on two popular MEMS pressure sensors, this two-part white paper will show how pressure sensors with sigma-delta (ΔΣ) analog to digital converters (ADCs) (Part 1) and a sensor evaluation kit (Part 2) simplify design-ins.

Sensors with an Integral ADC

To simplify the use of an analog sensor in digital systems, some sensor manufacturers offer sensors with an integral ADC. A comparison of test results is shown later in this report. Table 1 shows the sensors from All Sensors Corporation (ASC) and another supplier and Table 2 shows their key specifications. This includes the effective number of bits (ENOB) resolution and the total error band (TEB), which typically provides the most important "accuracy" for many applications.

Sensor	TEB
All Sensors DLHR-L10D	±0.75%
All Sensors DLHR-L02D	±0.75%
All Sensors DLHR-L01D	±1.00%
Supplier X Product 1	±2.0%
Supplier X Product 2	±1.0%

Table 1. Pressure sensors with digital front-end selected for test

Parameter	DLHR-L10D	DLHR-L02D	DLHR-L01D	Product 1	Product 2
Pressure range	Diff., ±10 inH^{2}O	Diff., ±2 inH^{2}O	Diff., ±1 inH^{2}O	Diff., ±20 inH^{2}O	Diff., ±2 inH^{2}O
Sensor die configuration	5-resistor bridge, 2×2mm proprietary die			4-resistor bridge, 2.5×2.5mm proprietary	
ADC Type	16/17/18-bit Δ-Σ			24-bit Δ-Σ	
DSP	YES			NO	
TEB	±0.75%	±0.75%	±1.00%	±1.0%	±2.0%
Output rate	15 to 270 SPS			20 SPS to 2000 SPS	
Typical ENOB min. speed	17 bits			18 bits	16 bits
	16 SPS			20 SPS	
INL				±15 ppm of FSR (ADC)	
Power requirements	Single, 1.68 – 3.63 VDC			Single, 2.3 – 5.5 VDC	
Onboard temperature sensor	Yes, 16 bits			Yes, 14 bits	
Temperature range	-25°C to +85°C			-40°C to +85°C	
Digital interface	I^{2}C, SPI			SPI	
One off reference price (DigiKey/Mouser)	$53.04 USD			$57.61 USD	

Table 2. Specification comparison of evaluated pressure sensors

Disregarding the output data resolution, the accuracy (TEB) specifications differ significantly. This confirms earlier theory, that the accuracy of the pressure sensor is a system measurement, not depending on ADC resolution.

The All Sensors Difference

Since it is not easy to compensate silicon die for good accuracy, linearity and stability, All Sensors chose to use two of the same sensor dies, route pressure to them in opposite directions, and measure the differential signal between the two.

Silicon die from the same wafer batch have very good correlation, so errors such as non-linearity, temperature dependence and offsets can be nulled from the output signal. Such an arrangement is similar to making a Wheatstone bridge from two on-die bridge sensors. This patented method \ provides active dual-die compensation for common-mode pressure sensor errors.

To provide better performance, especially for low pressure measurements, the die structure in All Sensors' chip uses a proprietary Collinear Beam^2 or COBEAM^2™ technology. COBEAM^2 technology is designed to provide better pressure sensitivity in a small package, which previously required boss structures and larger die topologies. The smaller die design without the boss structure significantly reduces both unwanted gravity and vibration sensitivity.

All Sensors Eval Board Review

In addition to simplifying the use of a pressure sensor in a digital system by providing an integral ADC, All Sensors offers its All Sensors evaluation kit to test pressure sensors before the prototype design process. This evaluation kit (see Figure 1) is capable of providing data on digital, millivolt, and amplified pressure sensors and has the following features:

- Has a ZIF socket that allows instant electrical connection, without need of soldering or pin forming.
- Displays data from digital sensors in one of 12 convenient units
- Captures data from digital sensors to comma-separated values (CSV) text file, with sample index and timestamp on each readout
- Uses standard Windows USB HID drivers. Eval board using micro-USB connector for data/power.
- Has standard 4-mm banana-type terminals for lab test equipment and external power

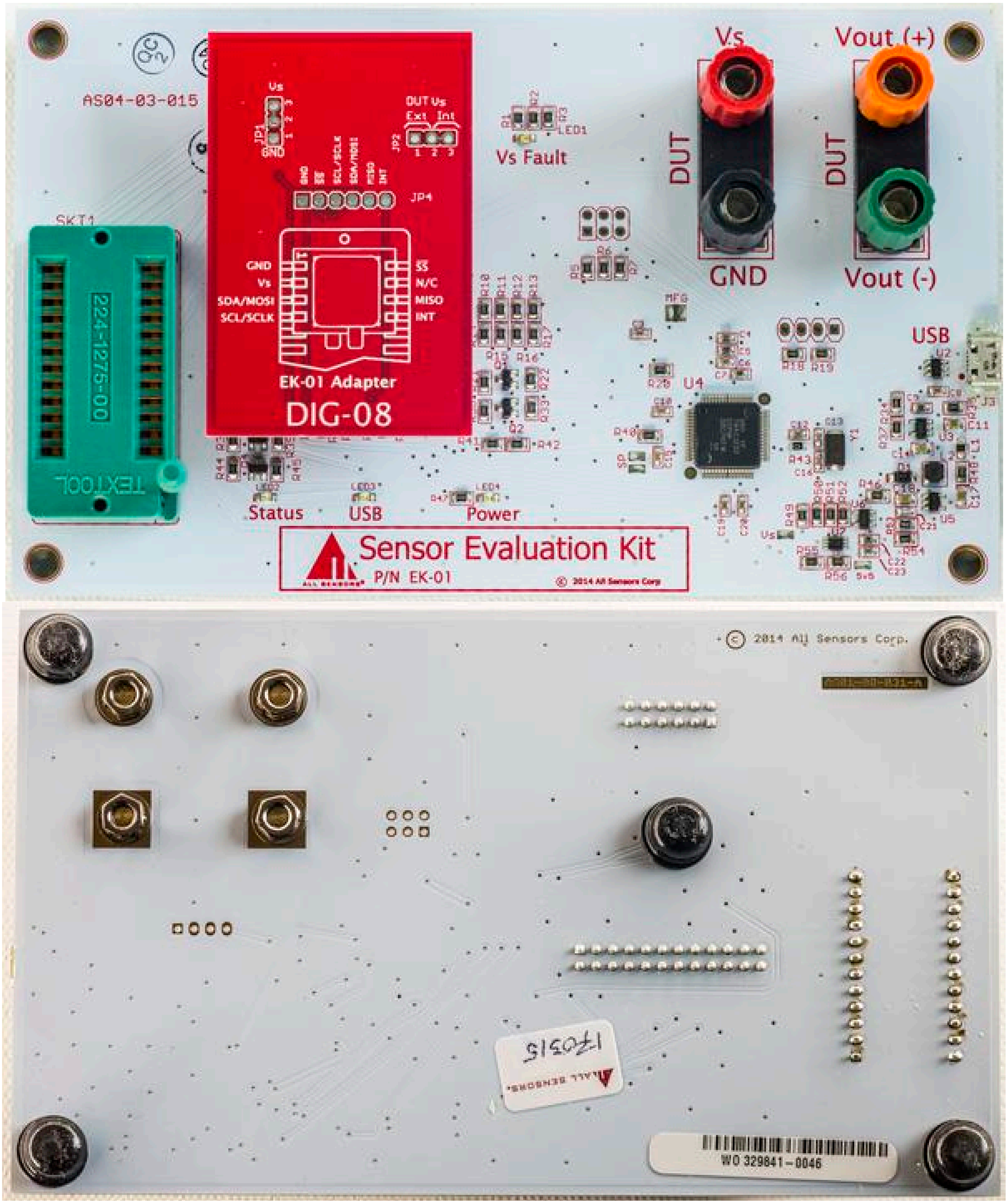

Figure 1. Evaluation board for All Sensors devices

The Evalkit is based around Texas Instruments TM4C1233D5PM Cortex-M4F ARM® microcontroller. It has a native USB 2.0 interface, as well as I^{2}C and SPI interfaces to communicate with sensors and is specified to operate in the industrial range.

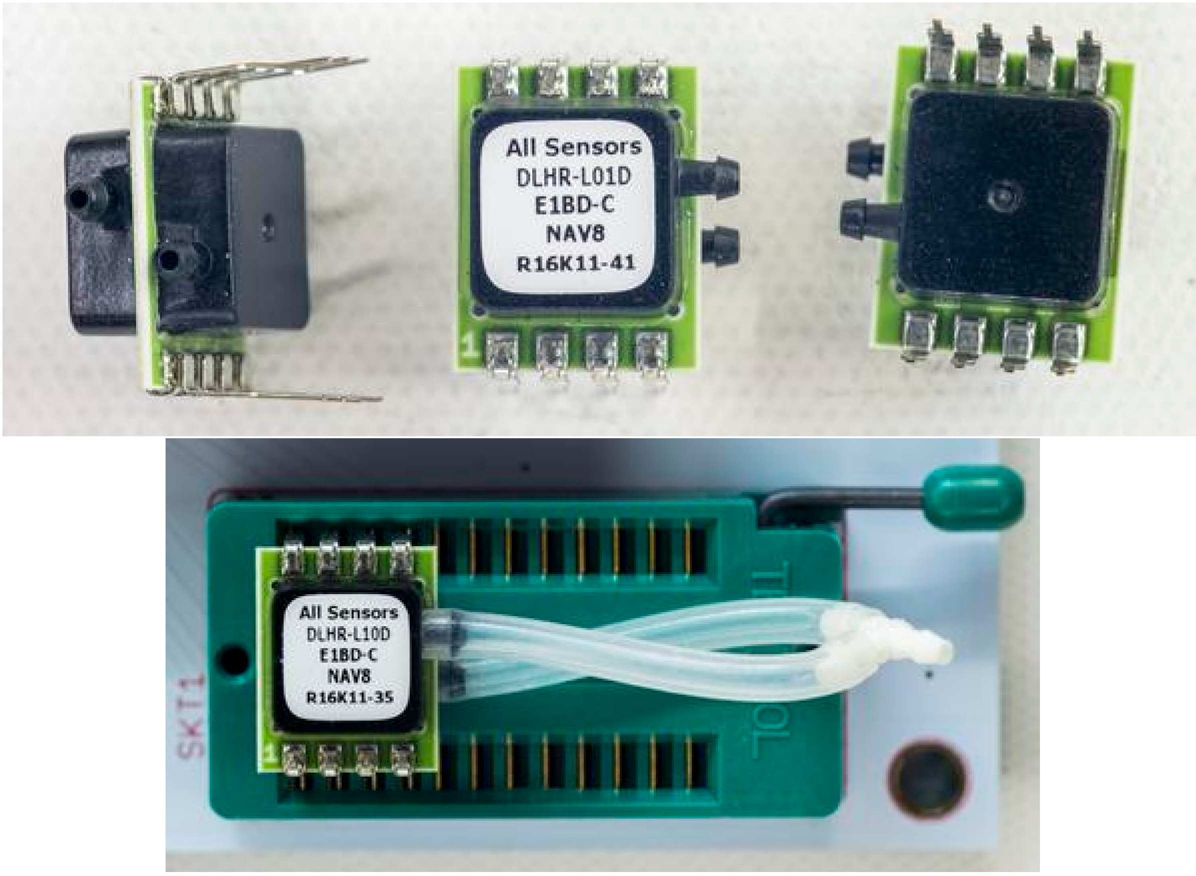

Figure 2. Sensor and connection to Evalboard socket

The evaluation kit comes with a simple to use software tool. It supports various sensors with both SPI and I^2C interface connections, and can be used to set data timings, pressure measurement units and average filtering power. See Figure 3. Once a sensor is properly configured, the software reads both pressure and temperature and displays the results on a graphic user interface (GUI). Data stored into a CSV file can be used for longer data captures and external data analysis.

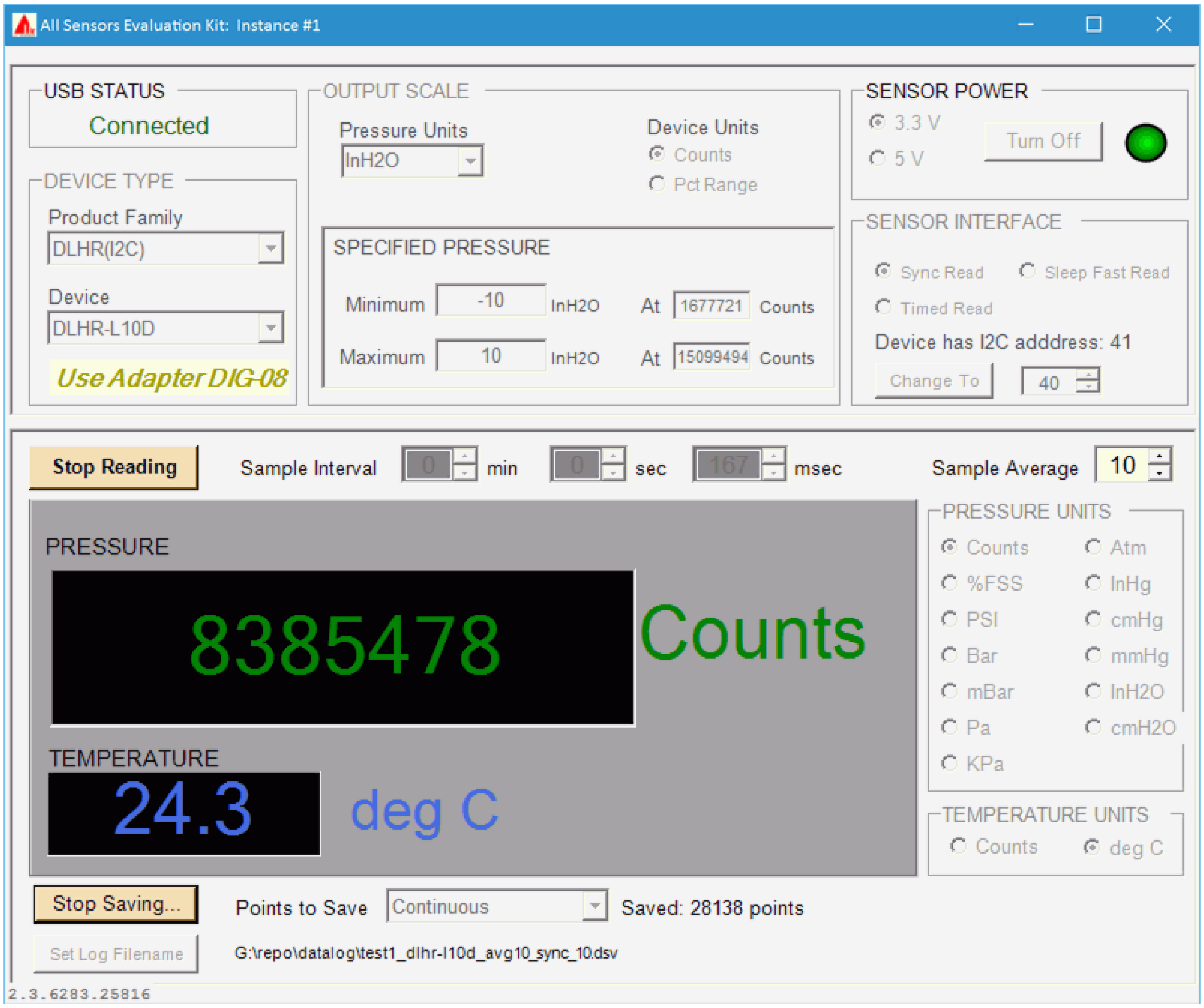

Figure 3. Demo kit software GUI

Comparative Test Results

In this testing, a Fluke 719 calibrator provides a known pressure into the sensors and their output digital values are recorded at the same time to compare calibration results. The second port of both sensors is open to atmosphere, converting the differential sensor into a simplified gauge device.

Reference input	Used sensors	Fluke 719 reading	ASC sensor	X sensor
-1.00 inH2O	DLHR-L01D + X	-1.00 inH2O	-1.008 (0.8%)	-0.938 (-6.2%)
-0.50 inH2O	DLHR-L01D + X	-0.50 inH2O	-0.4994 (-0.12%)	-0.474 (-5.2%)
-0.25 inH2O	DLHR-L01D + X	-0.25 inH2O	-0.2496 (-0.16%)	-0.242 (-3.2%)
0.00 inH2O	DLHR-L01D + X	0.00 inH2O	0.004	0.002
+0.25 inH2O	DLHR-L01D + X	+0.25 inH2O	0.2561 (2.44%)	0.247 (-1.2%)
+0.50 inH2O	DLHR-L01D + X	+0.50 inH2O	0.5077 (1.54%)	0.468 (-6.4%)
+1.00 inH2O	DLHR-L01D + X	+1.00 inH2O	1.009 (0.9%)	0.927 (-7.3%)

Table 3. DHLR-L01D and Supplier X Comparison results with Fluke 719 30G calibrator output

Large offset was read from the Supplier X sensor. Additional calibration and compensation math may be required to provide better calibration results, so these results obviously need further investigation. Repeated tests show the same numbers, so the data is provided here as is. Note: the Fluke 719 30G is not the best tool to source pressure levels below 5 inH2O.

Reference input	Used sensors	Fluke 719 reading	ASC sensor	X sensor
-2.00 inH2O	DLHR-L02D + X	-2.00 inH2O	-1.996 (-0.2%)	-1.869 (-6.5%)
-1.00 inH2O	DLHR-L02D + X	-1.00 inH2O	-1.001 (0.1%)	-0.932 (-6.8%)
-0.50 inH2O	DLHR-L02D + X	-0.50 inH2O	-0.507 (1.4%)	-0.467 (-6.6%)
0.00 inH2O	DLHR-L02D + X	0.00 inH2O	0.001	0.008
+0.50 inH2O	DLHR-L02D + X	+0.50 inH2O	0.503 (0.6%)	0.465 (-7%)
+1.00 inH2O	DLHR-L02D + X	+1.00 inH2O	1.006 (0.6%)	0.927 (-7.3%)
+2.00 inH2O	DLHR-L02D + X	+2.00 inH2O	2.005 (0.25%)	1.861 (-6.95%)

Table 4. DHLR-L02D and Supplier X comparison results with Fluke 719 30G calibrator output

Similar offset around 7% was detected from the Supplier X sensor as well. Code to interface sensor was reused, with correction for different pressure range. ASC sensor data was below 1.5%.

Reference input	Used sensors	Fluke 719 reading	ASC sensor	X sensor
-20.00 inH2O	DLHR-L10D + X	-20.00 inH2O	N/A	-18.979 (-5.1%)
-15.00 inH2O	DLHR-L10D + X	-15.00 inH2O	N/A	-14.226 (-5.1%)
-12.00 inH2O	DLHR-L10D + X	-12.00 inH2O	-12.005 (0.04%)	-11.400 (-5%)
-10.00 inH2O	DLHR-L10D + X	-10.00 inH2O	-10.012 (-0.12%)	-9.531 (-4.69%)
-8.00 inH2O	DLHR-L10D + X	-8.00 inH2O	-8.017 (0.21%)	-7.614 (-4.82%)
-6.00 inH2O	DLHR-L10D + X	-6.00 inH2O	-6.018 (0.3%)	-5.688 (-5.2%)
-4.00 inH2O	DLHR-L10D + X	-4.00 inH2O	-4.004 (0.1%)	-3.793 (-5.17%)
-2.00 inH2O	DLHR-L10D + X	-2.00 inH2O	-2.015 (0.75%)	-1.902 (-4.9%)
-1.00 inH2O	DLHR-L10D + X	-1.00 inH2O	-1.007 (0.7%)	-0.944 (-5.6%)
0.00 inH2O	DLHR-L10D + X	0.00 inH2O	-0.02	-0.008 ()
+1.00 inH2O	DLHR-L10D + X	+1.00 inH2O	1.010 (1%)	0.958 (-4.2%)
+2.00 inH2O	DLHR-L10D + X	+2.00 inH2O	2.002 (0.1%)	1.904 (-4.8%)
+4.00 inH2O	DLHR-L10D + X	+4.00 inH2O	3.997 (-0.075%)	3.805 (-4.9%)
+6.00 inH2O	DLHR-L10D + X	+6.00 inH2O	6.003 (0.05%)	5.705 (-4.9%)
+8.00 inH2O	DLHR-L10D + X	+8.00 inH2O	7.997 (-0.037%)	7.586 (-5.2%)
+10.00 inH2O	DLHR-L10D + X	+10.00 inH2O	9.998 (-0.02%)	9.483 (-5.17%)
+12.00 inH2O	DLHR-L10D + X	+12.00 inH2O	11.965 (-0.29%)	11.381 (-5.15%)
+15.00 inH2O	DLHR-L10D + X	+15.00 inH2O	N/A	14.221 (-5.2%)
+20.00 inH2O	DLHR-L10D + X	+20.00 inH2O	N/A	18.964 (-5.18%)

Table 5. DHLR-L10D and Supplier X comparison results with Fluke 719 30G calibrator output

Here, the apparent error of Supplier X's output was visible and very high, requiring addition correction for 5% offset. This is a good example that higher resolution on its own does not guarantee better accuracy of the system.

Given the unknown calibration or use history of Fluke 719 used in this test, the obtained results are good, mostly well under 1% for All Sensors DLHR sensors. Thanks to its onboard DSP, which handled all calibration and internal data correction, using the DLHR-LxxD sensors was very easy and straightforward.

The other supplier's pressure sensor however had extra offset, which need to be manually corrected. Compensation for Supplier X's sensors was performed according to datasheet listed math and stored EEPROM data.

Summary & Conclusions

Years ago, a significant amount of knowledge was needed to implement a pressure measurement into the system, starting from sensor design, low-noise and a stable front end for the sensor, measurement system and compensation methods. Today, even students without any practical electronics design background can get digital output sensors, connect them to popular platform like a Linux-based Raspberry Pi or Arduino and get initial pressure measurements in a matter of hours, not weeks. The obtained value is already a calibrated and compensated value, ready to be used for further processing in an application.

Given the noise levels in the maximum practical application, pressure sensors with an 18-bit ADC provide equally acceptable results as a 24-bit ADC. In fact, 17-bit ENOB is only achievable with a low noise pressure sensor die, such as All Sensors CoBeam^2 Technology, which is superior to other low noise solutions. Furthermore, All Sensors DLH/R series pressure sensors are easy to use and require no external math by the user.

Signal conditioned silicon pressure sensors with a digital output have achieved pricing and packaging that make them acceptable for a wide number of applications. Their accuracy and digital compensation makes them attractive in variety of precision sensing projects including many industrial applications. These applications include flow metering, liquids level measurements, process monitoring, research, optical power detection and many more. With the new high resolution digital sensors, applications can now be addressed which were not possible before with the industry-standard 14-bit ADCs that provided a maximum 13-bit ENOB.

Reference

1. Based on "Evaluation of modern pressure sensors with digital interface," https://xdevs.com/article/pressure/