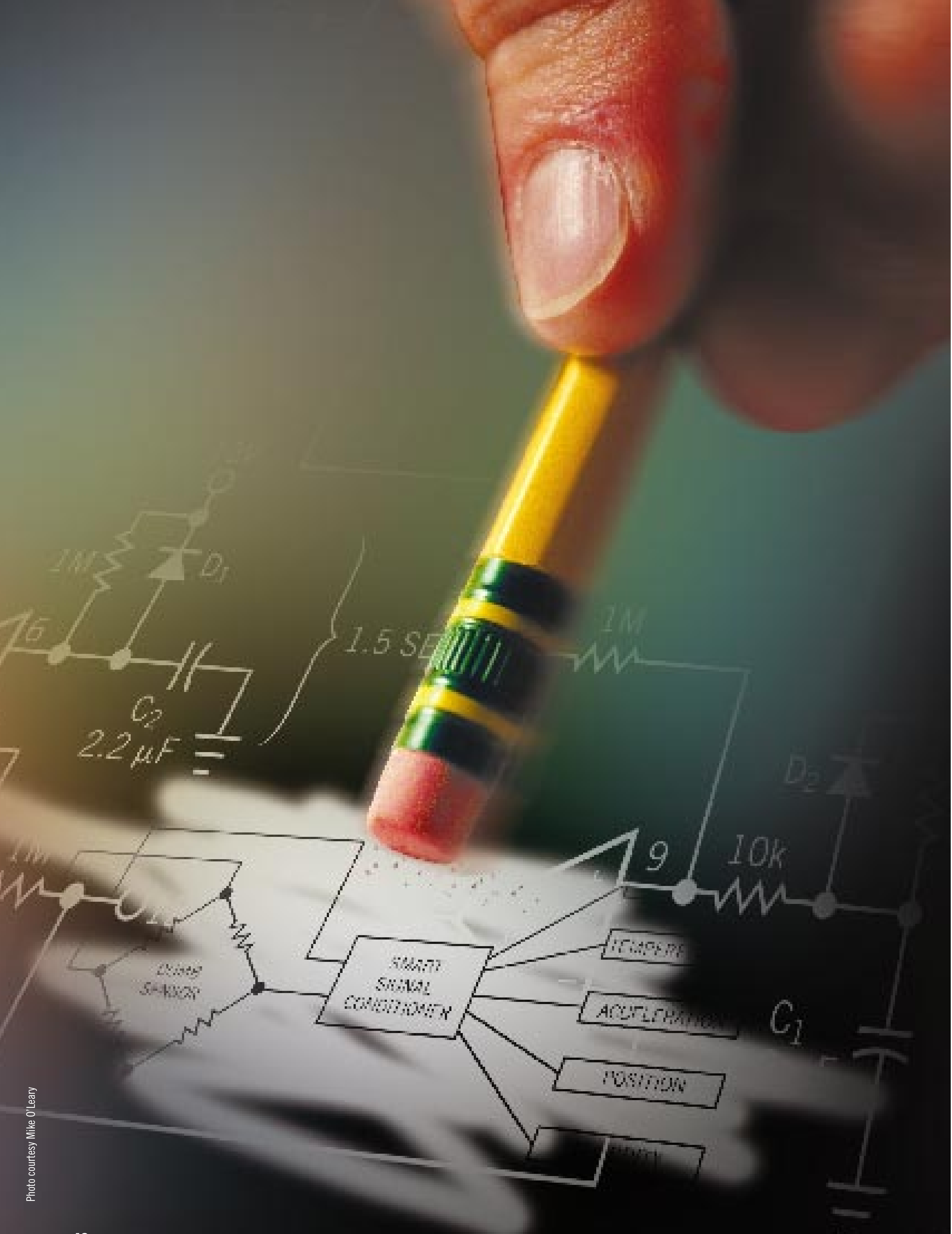


Photo courtesy Mike O'Leary

By Bill Travis, Senior Technical Editor

Smart conditioners rub out sensor errors

BRIDGE-TYPE, PIEZOELECTRIC, AND OTHER SENSORS ARE SUBJECT TO NONLINEARITIES, AS WELL AS GAIN AND OFFSET ERRORS. SMART SIGNAL CONDITIONERS COMPENSATE FOR THE ERRORS AND EXTRACT THE TRUE SIGNALS FROM THE DROSS.

PRESSURE TRANSDUCERS, ACCELEROMETERS, temperature sensors, and linear-position sensors are often imperfect devices, prone to nonlinearities and gain and offset errors. You could spend a lot of time correcting or compensating for the errors. The correction process would normally entail making a slew of measurements at various temperatures and then entering correction coefficients in a look-up-table memory IC, such as an EEPROM. An alternative solution is to use a "smart" sensor-interface circuit. These programmable ICs save time and money by simplifying the multiple-point measurement process and minimizing the number of system components. Two programmable sensor-interface circuits from Melexis Inc illustrate the convenience and utility of using "smart" signal conditioning.

Figure 1 shows a block diagram of the MLX90308 and MLX90314 from Melexis. The circuits contain a dedicated core μC that hosts 64 bytes of RAM and 4 kbytes of ROM. Of the ROM, 3 kbytes are available for customer-application firmware, and 1 kbyte serves for test purposes. The main difference between the MLX90308 and MLX90314 is in the gain figures of the analog-signal chains: 20 and 80, respectively. Both devices are robust and accommodate the automotive temperature range of −40 to +140°C. The ICs provide conditioning for bridge-type or other differential-output sensors, including thermistors, strain gauges, load cells, pressure sensors, accelerometers, and others. The signal conditioning includes gain adjustment, offset compensation, and temperature and linearity corrections. The 48-byte reprogrammable EEPROM stores the compensation values. You use a PC to program the conditioners, with the aid of provided software.

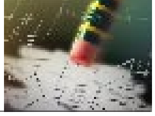


Figure 2a depicts a typical bridge-type sensor. **Figure 2b** shows some of the possible sources of error in the bridge. Assume that a pressure sensor constitutes one arm of the bridge. Further assume that, at a pressure of one atmosphere, the bridge should be in complete balance with an output of 0V. In **Figure 2b**, the finite output with zero stimulus (one atmosphere) represents the offset error. You can see that the output of the actual sensor follows a curved line; hence, its transfer function is nonlinear. It is even nonmonotonic, decreasing at one point with an increase in the stimulus. Now suppose your design goal is to obtain a 5V output with a pressure differential of 10 atmospheres. The difference between the ideal 5V output and the output of the actual bridge-type sensor represents the gain error. In addition to the errors that **Figure 2** shows, you must deal with the temperature coefficient of the sensor, which may also be nonlinear.

AT A GLANCE

▷ Imperfect sensors benefit from smart conditioning.

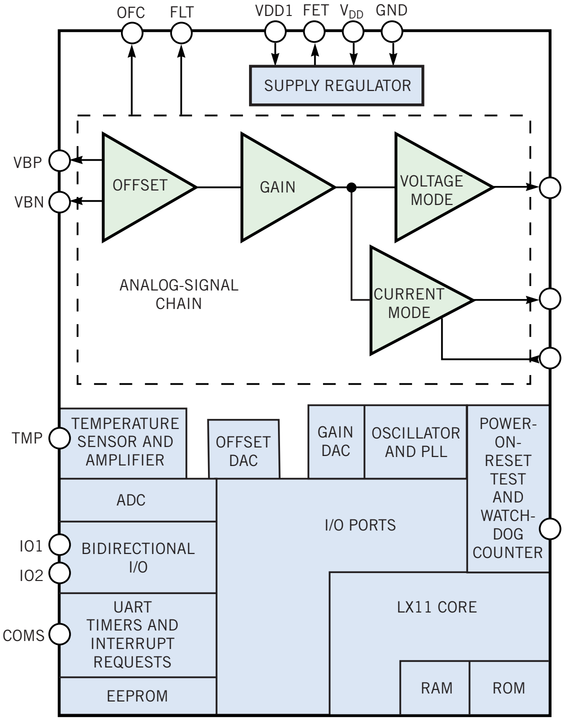
▷ Smart signal conditioners eliminate manual tweaking.

▷ Sensors, as well as conditioners, are continually getting smarter.

EEPROM AND RAM CORRECT ERRORS

The MLX90308/90314 firmware performs signal conditioning by analog or digital means. The analog conditioning accommodates separate offset and gain temperature coefficients for as many as four temperature ranges. In both analog and digital modes, the temperature reading controls the temperature compensation. The ICs provide "filtering" of the temperature reading by factoring in a portion of the previous value. EEPROM stores the user-determined filter coefficient. The filtering helps to minimize noise when you use an external temperature sensor. The on-chip RAM stores the filtered temperature values. The next step after measuring temperature is to test for offset and gain values and temperature coefficients. The EEPROM holds the offset and gain values and their respective temperature coefficients for four temperature values. The MLX90308/90314 have 2- and 10-bit DACs for offset and gain coarse and fine correction, respectively. **Figure 3a** shows a typical raw (uncorrected) pressure-sensor output. **Figure 3b** shows the transfer function after the MLX90308 conditions and amplifies the output of the pressure sensor.

Figure 1



A smart signal conditioner from Melexis corrects for gain, offset, and linearity errors and compensates for temperature coefficients.

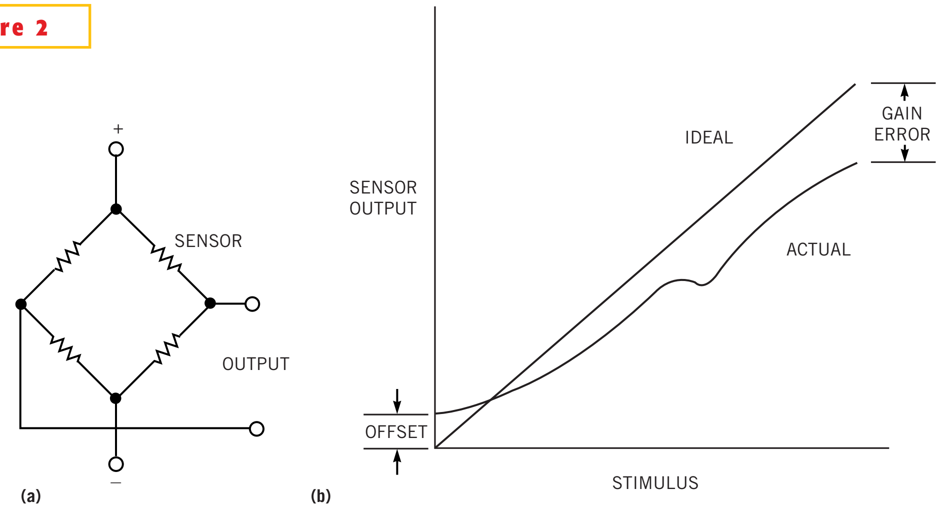
The MAX1478 from Maxim Integrated Products is a 1%-accurate signal conditioner for piezoelectric sensors (**Figure 4**). It includes a programmable current source for sensor excitation, a 3-bit PGA (programmable-gain amplifier), a 128-bit on-chip EEPROM, and four 12-bit DACs. The device compensates for offset, offset temperature coefficient, full-scale span, full-scale-span temperature coefficient, and nonlinearity of silicon piezoelectric sensors. Such sensors are useful for measuring pressure, acceleration, strain, and temperature. The MAX1478 has a fully analog signal path; the PGA accommodates sensor outputs of 10 to 40 mV/V. The PGA in the MAX1478 uses switched-capacitor technology, with an input-referred coarse offset-trimming range of approximately ±63 mV, trimmable in 9-mV steps. The offset DAC provides fine trimming, in 2.8-mV steps. The PGA provides eight gain values of 41 to 230 V/V. The bridge-excitation source is programmable from 0.1 to 2 mA. The on-chip EEPROM contains the a configuration register, an offset-calibration coefficient, an offset-temperature-error coefficient, a full-scale output-calibration coefficient, a full-scale-temperature-error coefficient, and 24 user-defined bits (for example, for dates and serial number). All this information is in the form of 12-bit words.

The MAX1478 compensates for offset errors by first using the 3-bit DAC, IRODAC in **Figure 4**. At the summing junction of the PGA, the DAC adds a coarse-correction voltage, in 9-mV steps from −63 to +63 mV. The 12-bit offset DAC then makes a fine correction with a resolution of 2.8 mV. The device sets the full-scale output with a coarse adjustment using the PGA. The PGA has selectable gain levels of 41 to 230 in increments of 27. The 12-bit FSO DAC then effects a fine adjustment. The output of the DAC, in conjunction with R_{ISRC}, sets the baseline excitation current to the bridge. The configuration register in the EEPROM holds the PGA gain, the polarity of the offset and its temperature coefficient, and the coarse-offset correction. It also enables (switches in) the internal resistors, R_{FTC} and R_{ISRC}. Registers in all the 12-bit DACs store the coefficients the DACs use to correct errors.

UNIVERSAL CONDITIONER

The MAX1462 from Maxim Integrated Products provides virtually universal conditioning for bridge-type sensors (**Figure 5**). The device combines a PGA with a 16-bit ADC with provisions for digital correction over the specified temperature

Figure 2

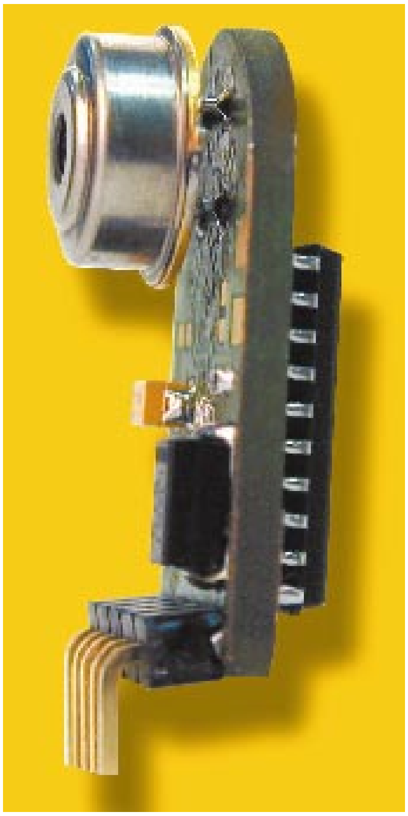


A typical bridge-type sensor (a) can exhibit offset, gain (slope), and linearity errors (b).

range. It stores calibration and compensation coefficients in an on-chip, 128-bit EEPROM. A 12-bit DAC provides the conditioned output in ratiometric (proportional to the supply voltage) form. The main functions of the MAX1462 include the analog front end with its PGA and coarse-offset correction and the test-system interface. This interface lets you write calibration coefficients to the DSP registers and the EEPROM. The sensor signal enters the MAX1462 and then undergoes coarse gain and offset adjustment. For optimum dynamic range of the ADC, 5 bits in the configuration register set the gain and offset of the PGA.

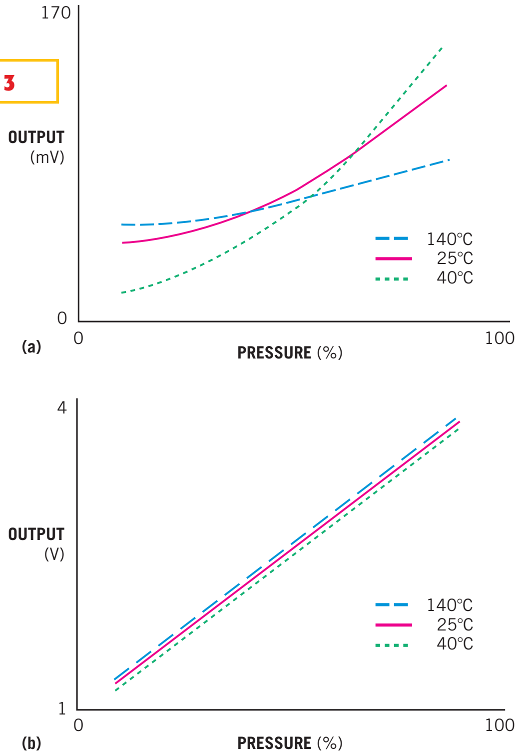
The on-chip temperature sensor also has a 3-bit DAC that places the temperature in the ADC's operating range. A read-only DSP register stores the digitized temperature. The DSP block uses the digitized sensor signal, the temperature information, and the correction coefficients to calculate the corrected and compensated output. You begin calibration of the MAX1462 by soaking the IC and the sensor at the first temperature A and applying a known, large excitation signal, L to the sensor. Start a conversion and record the digitized temperature, T_A, and the digitized signal, A_L. Then apply a small signal, S, to the sensor and take the reading, A_S. Repeat this procedure for temperatures B and C, and record signals B_L, B_S, C_L, and C_S. Using several sets of simultaneous equations, you can now derive the optimum gain and offset calibration coefficients to write to the MAX1462's EEPROM. The algorithm minimizes the error directly at the six test conditions: temperatures A, B, and C and signals L and S.

After you calibrate the MAX1462 and the sensor and remove them from the test system, they form a mated pair. In typical operation, the device can reduce gain and offset errors from, say, ±8% of full-scale to within ±0.03% of full-scale span. The MAX1462 requires minimal external components: one bypass capacitor from V_{DD} to ground, a 2-MHz ceramic resonator, and two 10-kΩ resistors. If you need an analog output from the on-chip op amp, you need two 500-kΩ resistors and a 1-µF capacitor for filtering. An evaluation kit is available to assist you in developing prototypes and test systems. The kit comprises an evaluation board contain-

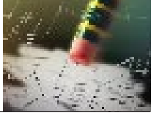


A thermopile and a signal conditioner from Melexis make a complete IR thermometer.

Figure 3



The MLX90308 from Melexis makes raw, nonlinear, temperature-sensitive lines from a pressure sensor (a) into straight lines (b).



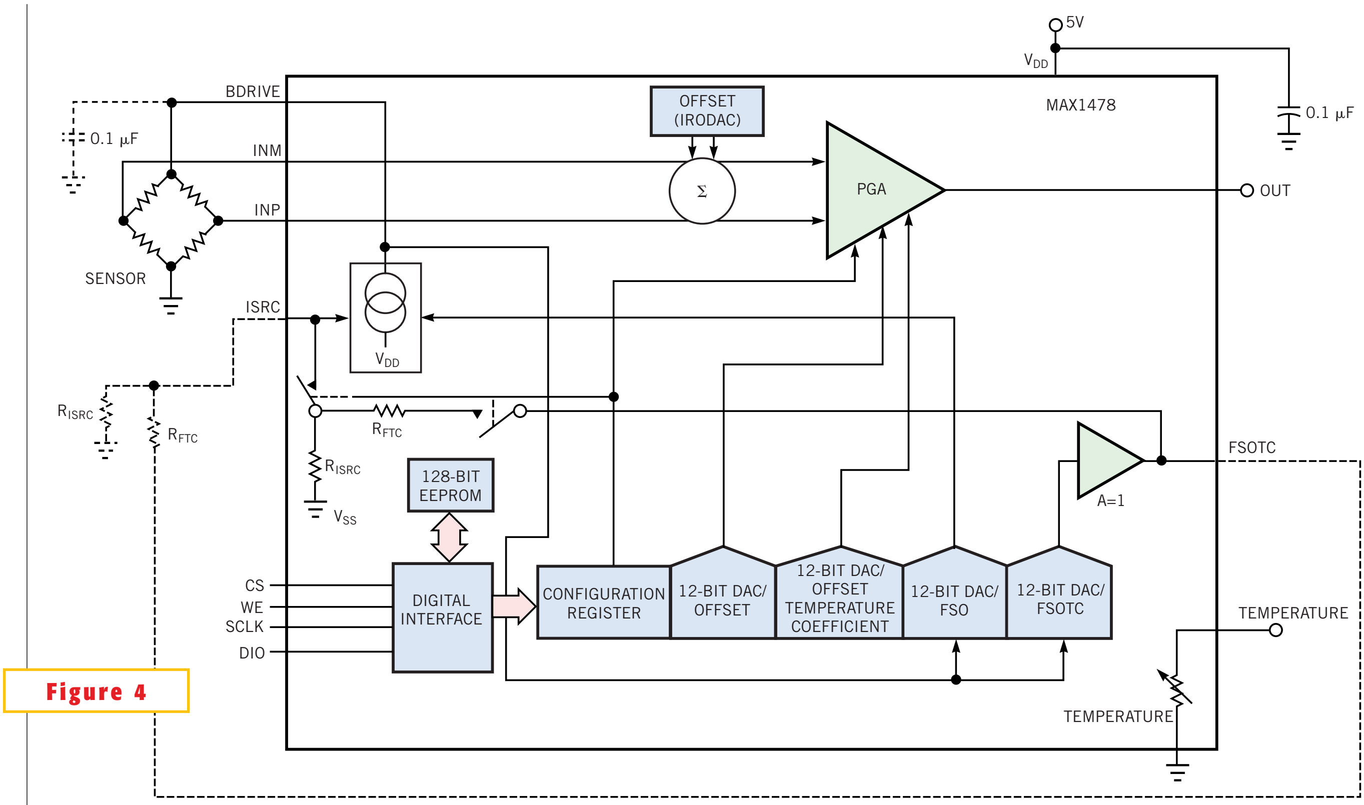


Figure 4

The MAX1478 from Maxim provides offset, gain, and nonlinearity correction for piezoelectric sensors.

ing a MAX1462 and silicon pressure sensor, an interface board to a PC, a Windows-compatible communication/compensation software program, and an application manual.

READOUT IC RESOLVES 4 aF/$\sqrt{\text{Hz}}$

An IC from MicroSensors Inc provides low-noise capacitive readout and control functions. The MS3110 (**Figure 6**) provides capacitance resolution of 4 aF/$\sqrt{\text{Hz}}$(aF=10^{-18}F). The smart IC contains an EEPROM for gain, offset, and bandwidth control. The MS3110 senses the change in capacitance between two capacitors, CS_{1IN} and CS_{2IN}, and provides an output voltage proportional to that change. The output voltage is a function of the change between the total parallel capacitances CS_{1T} and CS_{2T}, according to the transfer function $V_{OUT}=\text{Gain}\cdot V_{2P25}\cdot 1.14\cdot(CS_{2T}-CS_{1T})/C_F+V_{REF}$, where V_{OUT} is the output voltage, gain is 2 or 4V/V, V_{2P25} and V_{REF} are 2.25V dc, and C_F is optimized for the input-capacitance range. The 10×10-bit EEPROM accommodates several functions, including current- and voltage-reference trims, oscillator trim, output-buffer gain and offset trims, lowpass-filter bandwidth, feedback-capacitor selection, and balance-capacitor trim.

In operation, the upper and lower terminals of the capacitive bridge switch between V_{2P25} and V_{NEG} at 100 kHz. The output of the gain block, A, drives a sample/hold amplifier, which in turn drives the two-pole lowpass filter. The data sheet for the MS3110 gives programming truth tables for all parameters. For instance, you can fine-tune the 2.25V reference in 20-mV steps over a ±5.1% range. And you can trim the feedback capacitor in 19-fF steps from 0 to 19.437 pF. The cutoff frequency of the lowpass filter is programmable from 500 Hz to 8 kHz. An evaluation board is available for the MS3110. Note that capacitive sensors

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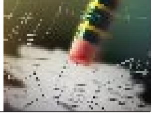
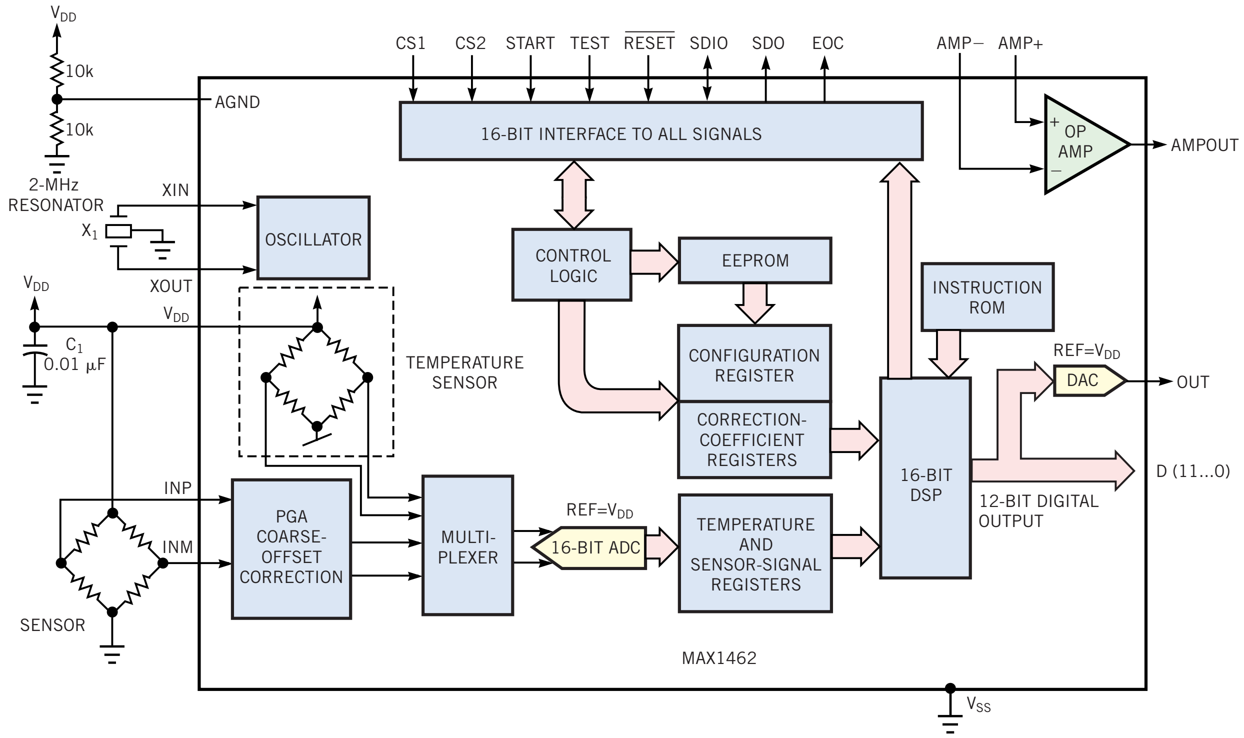


Figure 5



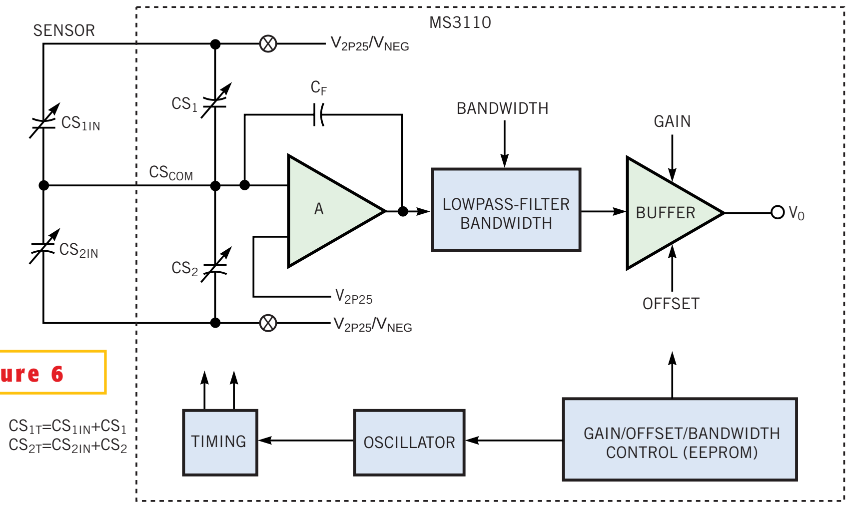
A smart ADC from Maxim provides universal conditioning for bridge-type sensors.

are useful as touch-sensitive devices and in measurements of pressure, velocity, acceleration, and fluid flow.

So far, this article has focused on smart conditioners for sensors. Many sensors, however, are already smart enough to not need any additional assistance. For example, a programmable linear Hall-effect sensor from Micronas contains EEPROM, an ADC and a DAC, DSP functions, and chopper stabilization for the Hall-plate sensor. You program the HAL 800 by modulating the supply voltage. The programming is virtually automatic; you need adjust only the output voltage according to the input signal (mechanical angle, distance, or current). With this calibration procedure, you can compensate for the tolerances of the sensor, the magnet, and the mechanical positioning in the final assembly. Further, you can program temperature coefficients to suit all common magnet materials. The HAL 800/805 suits hostile industrial and automotive applications and operates over −40 to +150°C. Recent additions to the HAL family include the HAL 810, which features a PWM output, and the HAL 815, which offers advanced diagnostic functions. Similar in concept to the HAL devices but different in its programming method, the MLX90215 from Melexis also offers temperature-coefficient compensation and sensitivity adjustment. You program this device by zapping zener diodes in a read-only memory. The MLX90215 also targets harsh environments and operates over −40 to +150°C.

A signal-conditioning sensor-interface from Melexis combines with an infrared thermopile to form a high-accuracy IR thermometer that can measure within 0.1°C. The MLX90313 programmable conditioner and the MLX90247 micro-

Figure 6

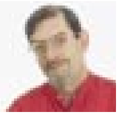


A capacitance discriminator from MicroSensors can discern extremely small changes in capacitance.

machined thermopile fit together to make the MLX90601 digital-thermometer module. The module can serve as an infrared temperature controller or system, a temperature switching system, or a potentiometer-controlled, manually adjustable thermostat. The MLX90601 can measure object and ambient temperature. After digitizing and linearization, both temperature values go into 10-bit registers. Digital comparators have as thresholds low and high calibrated temperatures. The comparators operate with the values from the registers as input.

A temperature-sensor IC from National Semiconductor exhibits considerable intelligence. The LM74 contains a temperature sensor, a 13-bit delta-sigma ADC, and an SPI- and Microwire-compatible interface. The host computer can query the LM74 at any time to read temperature. A shutdown mode reduces current consumption to less than 10 μA. Accuracy over −10 to +65°C is ±1.25°C maximum. The resolution of the temperature reading is 0.0625°C. The LM74 comes in a five-bump surface-mount package. As a final example of smart sensors, the US79 from Melexis uses the Hall effect for fan control. It mounts on the fan, connects in series with the motor coils, and needs no external components. The IC has power-MOSFET drivers that can handle 400 mA without overheating. The US79 is extremely rugged and can withstand more than 15,000V of ESD from the fan.

You can reach Senior Technical Editor Bill Travis at 1-617-558-4471, fax 1-617-558-4470, e-mail b.travis@cahners.com.



Smart conditioners can compensate for imperfections in many sensors. Calibration coefficients stored in EEPROM can correct gain, offset, and linearity errors and can compensate for temperature coefficients. These conditioners save time and money by eliminating the need for arduous manual calibration and trimming procedures. In the meantime, sensor ICs themselves are continually getting smarter, and many of them incorporate the best elements of the smart conditioners.□