MODERN SENSORS GREATLY ENHANCE CONSUMER-ELECTRONIC-SYSTEM PERFORMANCE

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You can expect a large evolutionary trend in sensors over the next few years. Demand is strong for more precise navigation technology, especially for indoor asset and global tracking. This technology will significantly affect the inertial- and motion-sensor consumer markets, which include accelerometers, gyroscopes, and magnetometers in mobile phones, tablets, game stations, laptops, and other devices. Addressing this trend, this article is the first of a two-part series on sensors in consumer systems (see **sidebar** "Perspectives on modern sensors"). It explores the various sensor options and how to properly link the analog world of sensors and their conditioning circuits to the digital world of processing data and adding intelligence. It also examines the inherent trade-offs for some popular options and discusses discrete approaches versus highly integrated approaches. A one-size-fits-all approach may sometimes fail to attain the performance parameters that some systems need. Although designers may in many cases gravitate to more highly integrated approaches due to time-to-market constraints, these approaches may not lead to a design that consumers will flock to the stores to purchase. Designers should balance performance and features with size and cost to make a successful product for the consumer market.

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WITH THE ADOPTION OF SENSORS AND CONNECTIVITY, CONSUMER DEVICES HAVE UNDERGONE A REVOLUTION: THEY ARE NO LONGER ONE-WAY, ISOLATED ISLANDS. THEY NOW INCLUDE USER AND ENVIRONMENTAL AWARENESS AND INTERACTIVITY, AS WELL AS CONNECTIVITY WITH SURROUNDING SYSTEMS AND THE INTERNET.

Sensors live in the analog world of touch, temperature, image, light, position, motion, and pressure, in which mobile phones, smartphones, notebooks, MP3 players, and game consoles are ubiquitous. The most popular types of sensors help to enliven your world of entertainment, information technology, communication, home appliances, and other product markets. Most touch sensor technologies in today's designs are either capacitive or resistive. Capacitive sensors are suitable for a range of sensing applications, such as keypads, rotators, or buttons, whereas resistive-touchscreen sensors use a four-wire resistive technology, usually with built-in ADCs, to offer both ease of design and greater flexibility to touchscreen applications.

AT A GLANCE

- A one-size-fits-all approach may sometimes fail to attain the performance parameters that some systems need.
- The most popular types of sensors help to enliven your world of entertainment, information technology, communication, home appliances, and other product markets.
- Capacitive sensors are suitable for a range of sensing applications, such as keypads, rotators, or buttons.
- Resistive-touchscreen sensors use a four-wire resistive technology, usually with built-in ADCs, to offer both ease of design and greater flexibility to touchscreen applications.

CAPACITIVE TOUCHSCREENS

A capacitive-touchscreen panel comprises an insulator, such as glass, coated with a transparent conductor, such as ITO (indium tin oxide). Because the human body is also an electrical conductor, touching the surface of the screen results in a distortion of the screen's electrostatic field, which is measurable as a change in capacitance.

When choosing a touchscreen controller, you should consider several aspects, including the accuracy of the CDC (capacitance-to-digital converter); the unit's noise-handling ability, which the digital filter of the ADC usually handles; its environmental compensation; and the advanced algorithms in its host processor or CDC chip, which provide WinCE (Windows Compact Edition) or Linux driver and software capabilities. These features allow you to develop a system that accurately detects finger presence, motion, and intended activity on the touchscreen.

STMicroelectronics offers highly integrated capacitive and resistive, multiple-channel touchscreen solutions with controllers that interface seamlessly to a host processor using the S-Touch series of controllers for touch-key and touchscreen applications. The company's portfolio of sensors also includes MEMS (microelectromechanical-system) motion sensors for measuring motion, acceleration, inclination, and vibration; proximity detectors for metal-body-proximity sensing; and analog and digital temperature sensors.

Touchscreen controllers typically use a 24-bit converter because they need to digitize only small levels of capacitance. One such converter is Analog Devices' 24-bit, two-channel AD7746 CDC. The device measures capacitance that connects between the on-chip excitation source and the on-chip sigma-delta modulator's input. An on-chip square-wave excitation signal is applied on the capacitance of the touchscreen during the conversion, and the modulator continuously samples the charge through the capacitor. The digital filter processes the modulator's output, which is a stream of zeros and ones containing the information in zero and one density. The CDC then scales the data from the digital filter, applying the calibration coefficients. You can read the final result through the serial interface, which sends it to an external host processor through a serial bus (**Figure 1**).

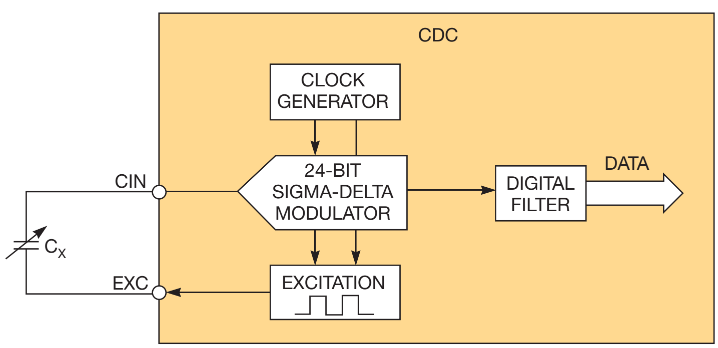

Figure 1 Analog Devices' 24-bit, two-channel AD7746 CDC measures touchscreen capacitance that connects between the on-chip excitation source and the on-chip sigma-delta modulator's input. An on-chip square-wave excitation signal is applied on the capacitance of the touchscreen during the conversion, and the modulator continuously samples the charge through the capacitor.

When considering a device's environmental compensation, keep in mind that ambient-temperature changes can cause fluctuations in stray capacitance. You can use an external temperature sensor for compensation, such as the

TABLE 1 PASSIVE AND ACTIVE TEMPERATURE SENSORS

	Thermocouple	RTD	Thermistor	Semiconductor
Temperature range (°C)	–184 to +2300	–200 to +850	0 to 100	–55 to +150
Accuracy/linearity	High accuracy and repeatability	Fair linearity	Poor linearity	1°C linearity, 1°C accuracy
Comments	Needs cold-junction compensation; has low-voltage output	Requires excitation; is low cost	Requires excitation; has high sensitivity	Requires excitation; 10-mV/K, 20-mV/K, or 1-μA/K typical output

base-to-emitter voltage junction of a transistor; however, you must be careful to compensate for the PCB's (printed-circuit board's) resistance from the transistor to the chip input.

RESISTIVE TOUCHSCREENS

A resistive-touchscreen panel includes several layers, the most important of which are two thin, electrically conductive layers separated by a narrow gap. When an object, such as a finger, presses on a point on the panel's outer surface, the two metallic layers connect at that point. The panel then behaves as a pair of voltage dividers with connected outputs, causing a change in the electrical current, which the panel registers as a touch event and sends to the controller for processing.

When choosing a resistive-touchscreen controller, use many of the same criteria you would use in selecting the capacitive-touchscreen controller. These criteria include the accuracy of the ADC; the noise-handling ability—for which digital filtering can occur on the controller chip, the host processor, or both; environmental compensation; and the ability to use advanced algorithms, which, in resistive units' case, usually reside in the host processor and enable WinCE or Linux driver and software features. A 12-bit ADC is typically accurate enough, and some devices provide ratiometric-conversion tech-

PERSPECTIVES ON MODERN SENSORS

Sensor manufacturers are adding features to consumer devices through a combination of appropriate hardware integration, efficient foundry processes, larger wafers, and clever software innovations. These features will revolutionize the consumer-electronics industry. The perspectives of some key participants in the market follow.

JALINOUS ESFANDYARI, PhD, ***MEMS (microelectromechanical-system)-product marketing manager, STMicroelectronics***
Perspective: "Sensor-fusion solutions are the trend. Sensors now integrate at least six degrees of freedom [an accelerometer with three axes and a gyro with three axes], which makes up an IMU [inertial-measurement unit]. By adding a magnetic sensor and a compass with three axes, you can minimize drift over time and temperature. So, nine degrees of freedom in one package is achievable for location-based and dead-reckoning applications. Even though [you can also integrate] a microcontroller into the package for digital filtering to take care of drift, noise, and distortion, [you need to weigh] trade-offs looking at size versus performance. Sometimes, separating some of the integrated parts might make it easier to arrange on a PCB [printed-circuit board]—for example, keeping the magnetic sensor away from a speaker magnet or an image sensor to avoid problems."

TIM KALTHOFF, ***fellow and chief technologist in the high-performance-analog division, Texas Instruments***
Perspective: "In general, microminiaturization of sensors, through MEMS-technology advances, now allows designers to use sensors in applications they never would have considered in the past due to size and cost."

MICHAEL STEFFES, ***application manager, Intersil***
Perspective: "The online-design tools are getting better at getting you close to the end solution." National Semiconductor's Webench is a great example of such a tool (Reference A).

SAJOL GHOSHAL, ***business-unit manager for advanced platform products, TAOS (Texas Advanced Optoelectronic Solutions)***
Perspective: "Energy management is the key in products such as smartphones. Light sensors can turn an LED off or lower its intensity, which results in a big savings in power and, thus, longer battery life. Batteries needed recharging in two hours in the past, and now we can give users eight to nine hours. Using CMOS technology and simple algorithms achieves this goal."

KERRY GLOVER, ***application manager, TAOS***
Perspective: "Higher integration is coming, with LED drivers having the light sensors on the same chip. [This approach will give designers a faster time to market.]"

OLEG STECIW, ***senior marketing manager for optical-sensing products, Intersil***
Perspective: "We are not seeing many discrete implementations. Light sensors with integrated transimpedance amplifiers, ADCs, and series digital buses, such as I^2C [inter-integrated circuit] and SMBus [system-management bus], improve not only performance but also critical time to market. Older-generation light-sensor algorithms did not work well, and users would tend to disable the function, but software has greatly improved, and studies show 30 to 40% power savings in backlighting."

Software will affect designers' choices. They can achieve intelligence and enhanced performance in software—sometimes at the expense of hardware. Examples include filtering, comparing, timing, and virtual touchscreen switches and knobs. Designers will have tough choices to make, depending on the market they are focusing on, but these choices will be available to them as sensor trends continue to evolve over the next few years.

REFERENCE

A Rako, Paul, "Single-op-amp Sallen-Key filters, filter fanatics," *EDN*, April 20, 2011, http://bit.ly/nCEa3n.

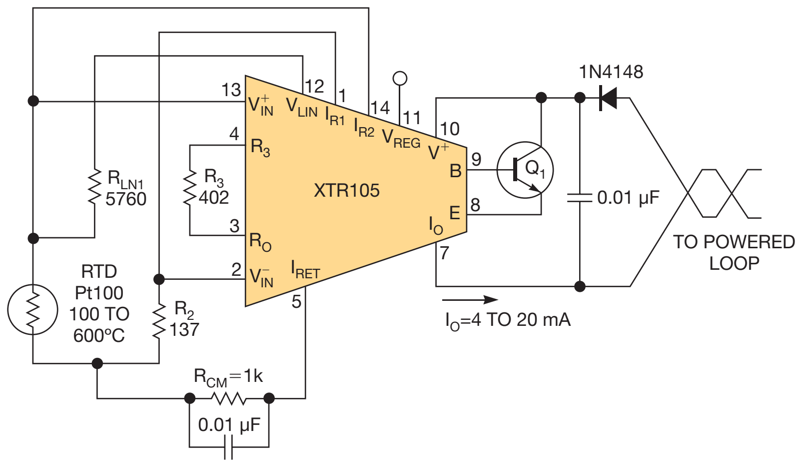

Figure 2 Texas Instruments' monolithic, 4- to 20-mA, two-wire XTR105 current transmitter has two precision current sources. Possible choices for Q_2 include 2N4922, TIP29C, and TIP31C, which come in TO-225, TO-220, and TO-220 packages, respectively.

niques, which provide noise immunity and tolerance of long leads. The binary result is free of reference drift errors because the excitation source is driven by the ADC reference. To implement environmental compensation for resistive touchscreens, you can use either on-chip measurement to sense fluctuations in temperature that can affect the data converter or off-chip temperature monitoring to compensate for resistive changes with ambient temperature.

One example of a resistive-touchscreen controller, Maxim's low-power MAX11811, works with power-sensitive, handheld systems employing advanced low-voltage processors. The device contains a 12-bit SAR (successive-approximation-register) ADC and a multiplexer to interface with a resistive-touchscreen panel. A digital serial interface provides communications. The MAX11811 includes digital preprocessing of the touchscreen's measurements, reducing bus-loading and application-processor requirements.

TEMPERATURE SENSORS

Passive temperature sensors include RTDs (resistance-temperature detectors), thermocouples, and thermistors. You can usually interface RTDs and thermistors to an amplifier circuit to provide a voltage that is proportional to temperature. **Table 1** compares passive and active temperature sensors.

RTDs are accurate and repeatable, have low drift error, and have a temperature range of −200 to +850°C. Due to nonlinearities, these sensors

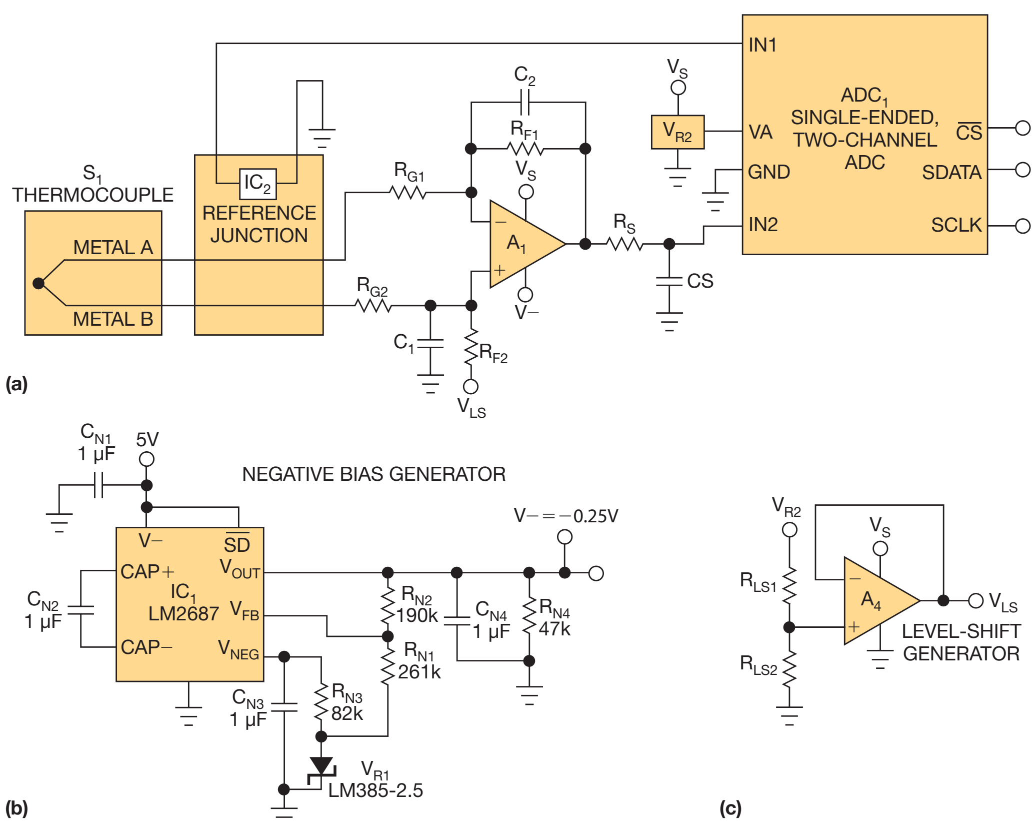

Figure 3 A differential amplifier amplifies the thermocouple voltage, driving a single-ended ADC (a). The negative bias generator (b) and level-shift generator (c) are optional (courtesy National Semiconductor).

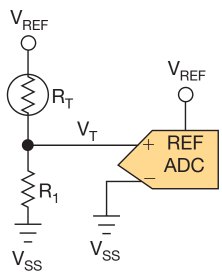

Figure 4 You can use NTC thermistors for temperature measurement as resistance thermometers, but calibration is necessary if the application operates over large changes in temperature (courtesy Maxim Integrated Products).

also need linearization, which you can implement using a look-up table in a microcontroller. These sensors are usually in a bridge configuration with differential outputs to help minimize lead-resistance errors. A difference amplifier or an instrumentation amplifier can be used to amplify and filter these sensors.

Texas Instruments, however, offers an integrated approach in its monolithic, 4- to 20-mA, two-wire XTR105 current transmitter, which has two precision current sources. It provides complete current excitation for platinum-RTD temperature sensors and bridges, instrumentation amplifiers, and current output circuitry on one IC. Engineers usually run the 4- to 20-mA standard differential output, which is popular for noisy environments, across long distances using twisted-pair wires to a 4- to 20-mA differential receiver, such as TI's RCV420. Versatile linearization circuitry provides a second-order correction to the RTD, typically achieving a 40-fold improvement in linearity (**Figure 2**).

Thermocouples are rugged, have a temperature range of –184 to +2300°C, and are inexpensive. On the downside, they are highly nonlinear and typically need significant linearization algorithms. Their voltage output is also relatively low, so they require analog amplifier-gain stages and cold-junction compensation (**Figure 3**).

Rather than measure absolute temperature, thermocouples measure the temperature difference between two points. To measure a single temperature, thermocouples maintain one of the junctions—normally the cold junction—at a known reference temperature and the other junction at the temperature they want to sense. Although having a junction of known temperature is useful for laboratory calibration, it is inconvenient for most measurement-and-control applications. Thermocouples instead incorporate artificial cold junctions using thermally sensitive devices, such as thermistors or diodes, to measure the temperature of the input connections at the instrument. Special care must be taken to minimize any temperature gradient between terminals. Hence, you can simulate the voltage from a known cold junction and apply the appropriate correction.

Thermistors, whose temperatures range from 0 to 100°C, are inexpensive and come in small packages; however, they require temperature compensation in the form of a look-up table and also need an excitation current, as do RTDs. Thermistors have either an NTC (negative temperature coefficient) or a PTC (positive temperature coefficient). Most PTC thermistors are switching devices, meaning that their resistance rises suddenly at certain critical temperatures. For this reason, you can use them as current-limiting devices for circuit protection. You can use NTC thermistors for temperature measurement as resistance thermometers, but calibration is necessary if the application operates over large changes in temperature. For applications operating over small changes in temperature, the resistance of the material is linearly proportional to the temperature—if you select the appropriate semiconductor (**Reference 1** and **Figure 4**). You can also use thermistors in a bridge configuration in the same way that you do to solve lead resistance in RTDs and feed the differential output into an amplifier.

The most common active temperature sensors, digital temperature sensors, yield high accuracy from the sensor to the microcontroller. Their data sheets specify both drift and repeatability; they need no calibration, and they are highly integrated. Examples of these devices include On Semiconductor's ADT7484A and Texas Instruments' TMP006, an example of miniaturization, integration, and innovation. This device is the first in a series that measures the temperature of an object without making contact with the object. The high level of integration allows the output to include a digital serial SMBus (system-management bus) and a chip-

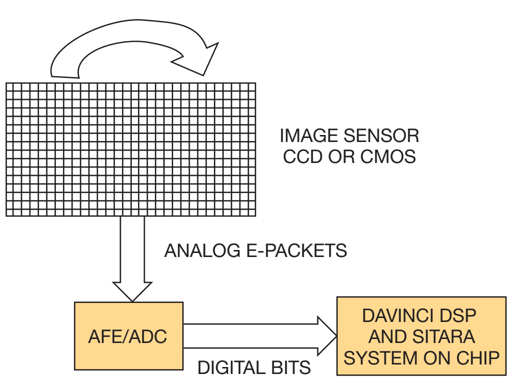

Figure 5 Texas Instruments' VSP2582 analog front end conditions and digitizes the sensor output and sends the data to a DSP.

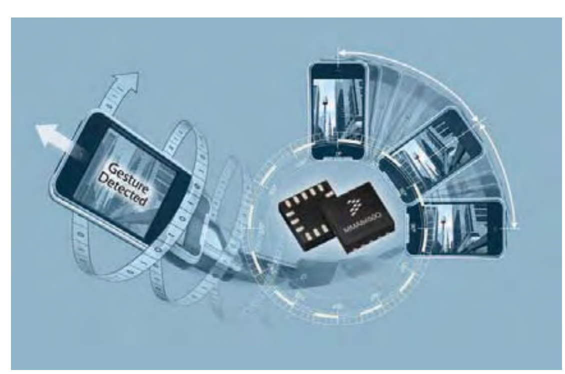

Figure 6 Freescale's tiny, low-power, handheld MMA8450Q motion sensor has an onboard DSP for motion applications.

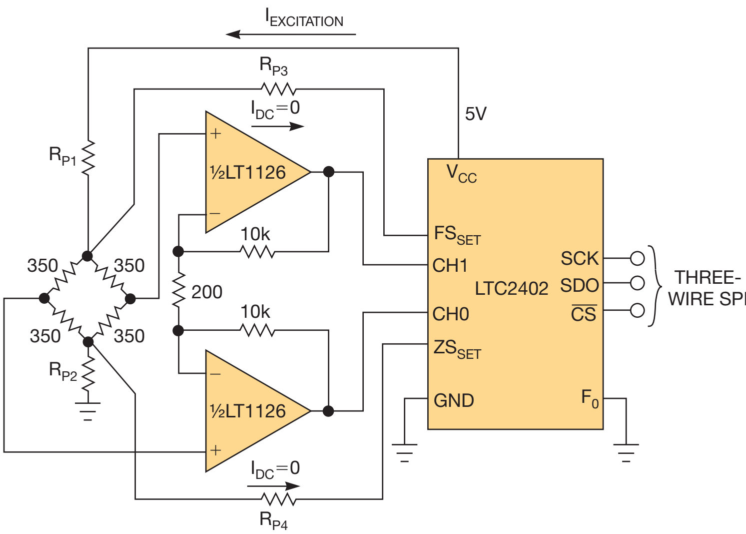

Figure 7 A discrete bridge pressure sensor needs a constant current excitation, which greatly improves the temperature dependence of the bridge over the voltage-source drive, and a differential-amplifier input conditioner for amplification and common-mode noise rejection (courtesy Linear Technology).

scale package. Atmel's temperature-sensor portfolio also includes a variety of options.

Image sensors typically use analog CCD (charge-coupled device) or CMOS technology. A CCD converts light in the form of photons into an electrical signal in the form of electrons and requires CDS (correlated double sampling) to condition the sensor. An active-pixel CMOS imaging chip uses a CMOS-semiconductor process and requires a sample-and-hold device. Extra circuitry next to each photo sensor converts the light energy to a voltage. The chip may include additional circuitry to convert the voltage to digital data.

FOR MORE INFORMATION

Analog Devices
www.analog.com

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On Semiconductor
www.onsemi.com

STMicroelectronics
www.st.com

Texas Advanced Optoelectronic Solutions
www.taosinc.com

Texas Instruments
www.ti.com

Interfacing and signal conditioning can involve processes as simple as an integrated, high-speed ADC, such as NXP's TDA8784, or an AFE (analog front end), such as Texas Instruments' VSP2582 (**Figure 5**). The AFE or the ADC conditions and digitizes the sensor output and sends the data off to a DSP.

Display management is a critical part of any consumer product, especially battery-dependent devices. Intersil offers a great selection of light-to-digital and light-to-analog sensors for backlight control and ambient-light sensing for mobile or fixed devices with a display. Intelligent optoelectronic sensors from TAOS (Texas Advanced Optoelectronic Solutions) simplify the measurement and analog-to-digital conversion of light and reduce the need for signal-conditioning or preprocessing circuitry in light-centric systems.

Many position and motion sensors are available, including Freescale's low-g-force-acceleration sensors, which detect orientation, shake, tap, double tap, fall, tilt, motion, positioning, shock, or vibration. The company's handheld MMA8450Q has an integrated DSP (**Figure 6**). You can configure this intelligent, low-power, low-noise accelerometer to generate inertial wake-up-interrupt signals when a programmable acceleration threshold is crossed on any of three sensed axes. End users can program the acceleration and time thresholds of the interrupt generators. Other tiny, low-power sensors in the industry have easy serial interfaces to DSPs for motion applications.

MEMS piezoresistive bridge sensors are the most common devices for measuring pressure. Bosch-Sensortec features a variety of such sensors in its product portfolio. Designers can also use bridge pressure sensors in discrete designs with analog conditioning circuitry for custom applications. Measurement Specialties, for example, offers the MS7301-D series of bridge piezoresistive devices in die form. A discrete bridge pressure sensor needs a constant current excitation, which greatly improves the temperature dependence of the bridge over the voltage-source drive, and a differential-amplifier input conditioner for amplification and common-mode-noise rejection can be used because bridge sensors typically output 2 mV/V full-scale (**Figure 7**). You can also use an instrumentation amplifier, which has high input impedance, for high-impedance bridges. A 24-bit sigma-delta ADC has a high dynamic range for better resolution (**Reference 2**). Good design architectures to signal-condition these sensors couple with DSPs or microcontrollers to provide improved safety and security in vehicles, smarter performance in ubiquitous home networks, location data from a gamut of possible inputs, and more realistic experiences in gaming electronics. **EDN**

REFERENCES

1 "A Simple Thermistor Interface to an ADC," Maxim Integrated Products, Application Note 1753, Nov 26, 2002, http://bit.ly/qP668l.

2 Mayes, Michael K, and Derek Redmayne, "1- and 2-Channel, No Latency ΔΣ, 24-Bit ADCs Easily Digitize a Variety of Sensors," *Linear Technology Magazine*, Volume 10, No. 1, February 2000, pg 1, http://bit.ly/q2TILV.

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