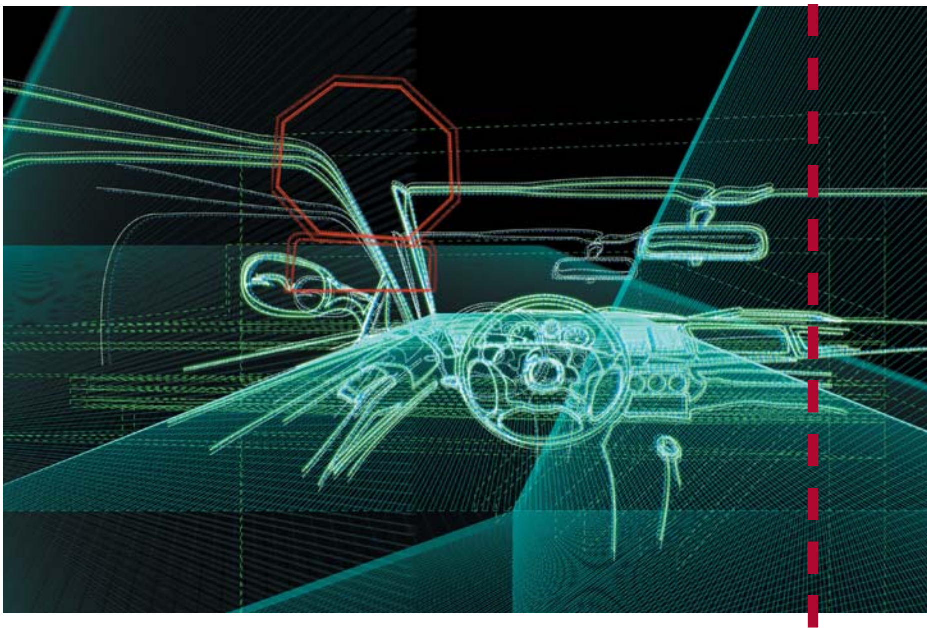
By Bill Schweber, Executive Editor



SENSORS ARE TAKING FULL MEASURE OF THE AUTO-PASSENGER COMPARTMENT.

Extra sensor(y) perception

TODAY'S CARS ARE RIDDLED WITH SENSORS providing critical data for performance and safety. Initially, sensors were the first link in the signal path that monitors engine and drive-train parameters, such as oxygen, fluids, temperatures, voltages, and currents, but their usage soon expanded to the feedback loop from various actuators and motors, including antilock-brake systems and power-window motors. Of course, they are vital to the crash-sensing of air-bag-deployment systems.

The application of sensors is not limited solely to critical auto operation and safety factors or to reporting to the OBD (onboard-diagnostics) system mandated for cars (**Reference 1**). As OEM confidence in sensors has increased along with sensor capabilities and reliability and sensor costs have decreased, sensors are now taking on more varied roles in the passenger compartment—for safety, comfort, convenience, and overall cocooning. Cars and trucks increasingly provide the amenities of home—but on four or more wheels, where every aspect of the passenger compartment and its occupants is subject to assessment.

I KNOW YOU'RE IN THERE

Sensors have always suffered from the contradiction between their simple-to-describe target physical variable and the realities of the specific installation. Most sensors measure well-known and easily understood factors, such as temperature, pressure, illumination, flow, or speed. But when you look at the details and con-

AT A GLANCE

- ▷ Sensor use in cars goes well beyond power-train and safety areas.
- ▷ The passenger compartment is the growth area for sensor use, especially for occupancy detection.
- ▷ Ironically, sensors must use a variety of techniques to ascertain details that are obvious to people.

straints of the situation, you soon see why there are so many sensors in our fragmented, highly application-specific world (see **sidebar** "To package, serve, and protect"). Sensor selection can be especially frustrating when the sensor must measure details obvious to any human observer but infer its assessment using an indirect method.

This situation describes passenger-occupancy-detection sensors. Automobile air bags have expanded in complexity far beyond their initial single, head-on-collision units for the driver and front-seat passenger. Cars now have side-impact air bags, air bag curtains, and multiple air bags in complex arrangements, along with staged air-bag deployment matched to the angle and speed of the impact. However, air bags can also injure or even kill cabin occupants if they deploy too aggressively or if the passenger is a small child hit with a full-force deployment.

For these reasons, automakers want air-bag-deployment systems to know information that is obvious to any human observer: the number of passengers, where and how are they sitting, their sizes, and whether any of them are sitting in a child seat. These questions are easy to ask but hard to answer using cost-effective and reliable technology. Auto vendors are using different approaches, including pressure (weight) measurements, imaging (both visible and infrared), and even electric-field sensing.

One obvious way to determine who is sitting in the car is by measuring the seat pressure that each passenger produces, making each seat into a basic scale. In practice, one pressure sensor, such as the ubiquitous silicon-strain or Hall-effect sensor, would be insufficient, because the seating posture, infant car seats, or even a bag of groceries would affect the reading (**Figure 1**). Therefore, vendors use an array of basic pressure or Hall-effect sensors to create a profile of the weight distribution on each seat. According to Allegro Semiconductor, a typical seat combines the outputs of 14 to 16 Hall sensors, so the occupancy-detector system can assess the size of the person or, if it is assessing a car seat, whether the car seat is occupied. The system also combines readings with other data, such as information from the seat-belt system indicating whether the belt is buckled and the tension on the belt.

Engineers must design and build these sensors into the seating structure; they cannot be add-ins that you design in after the car's interior design is complete. Sensor OEMs really do have to execute on the often-repeated cliché of providing complete solutions, not just ICs, by working early with auto vendors or, increasingly, with subsystem suppliers that provide complete, high-level assemblies to auto manufacturers as drop-in components.

A different approach to the occupancy problem is to use several infrared-imaging sensors. The technique electronically steers this thermopile array—which comprises as many as 100 elements, according to vendors such as Melexis—so it scans individual seat locations in the vehicle. The MLX90247 array—which is usually mounted in the headliner of the roof of the car as part of, or near, the dome-light assembly—uses a focused field of view to avoid confusing the driver with a passenger. It addition to a lens, it needs a temperature-measurement device, such as a thermistor, to perform cold-junction compensation for the array's reading across the ambient temperature range.

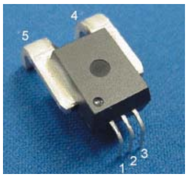


Figure 1

Designers use IC Hall-effect sensors, such as this one from Allegro Microsystems, individually in cars for motion-control feedback and in clusters for passenger-occupancy sensing.

Some vendors offer visible-light imaging instead of IR sensing. Micron Technology has a 1050- to 450-nm CMOS image sensor, with sensitivity spanning visible light as well as the

TO PACKAGE, SERVE, AND PROTECT

The electronics industry has for many years used surface-mount device packages almost exclusively. Sensors have lagged somewhat behind this trend, for several reasons. First, the nature of having to reach out and feel the sensed variable sometimes precludes or challenges an SMT (surface-mount-technology) package, such as in the case of a pressure sensor with an exposed but sealed surface. Second, the auto industry has longer design-in leadtimes than low-end consumer products. Finally, the industry wants to see a demonstrated track record for any technology.

Despite the hurdles, nearly all sensors in a car, especially in the relatively less difficult passenger compartment, are surface-mount devices; photosensors and sources are the primary exception. Besides the size benefits, this packaging means that these sensors are viable for nonautomotive application designs, and all design engineers get the benefits of the development efforts and high-volume production.

It's a two-way street, of course. Many of the automotive sensors are specialized variations on technologies that have been developed for nonautomotive uses and are working their way into cars, once designers can tailor their specifications to the needs of the auto market and they prove their performance.

The auto environment always poses difficult challenges in addition to ever-present cost issues, including fundamental component reliability and parametric stability over operating and storage temperatures of −40 to +140°C or higher, the need to fit the sensor into the auto structure, the requirement to withstand deliberate and inadvertent wear and abuse, and the objective of providing overall system consistency in performance, so that readings do not mislead.

Some auto vendors mandate integral ESD (electrostatic-discharge) protection to reduce the number of external protection components, as well as sensors that can survive reverse- and double-battery potentials (−16 to +32V), which result from improper hookup when replacing or jump-connecting batteries.

near-IR band. In the day, this 750×480-pixel sensor uses natural light; at night, it uses IR-emitting LEDs for illumination. It is designed for use with a moderate-speed DSP to capture and assess frames with 10-bit/pixel resolution and imaging rates to 100 frames/sec, to determine the exact position and orientation of the occupants (even leaning forward or sideways) as the crash occurs and the air bags fire. To reduce the processing load on the DSP, the algorithm assesses the overall image scene and then restricts its next analysis to only the occupant portion of scene.

Whether the automaker prefers visible or IR sensors, they must make other decisions, including whether to use a single imaging array or a stereo pair, color or monochrome, and even sensor arrays situated in different parts of

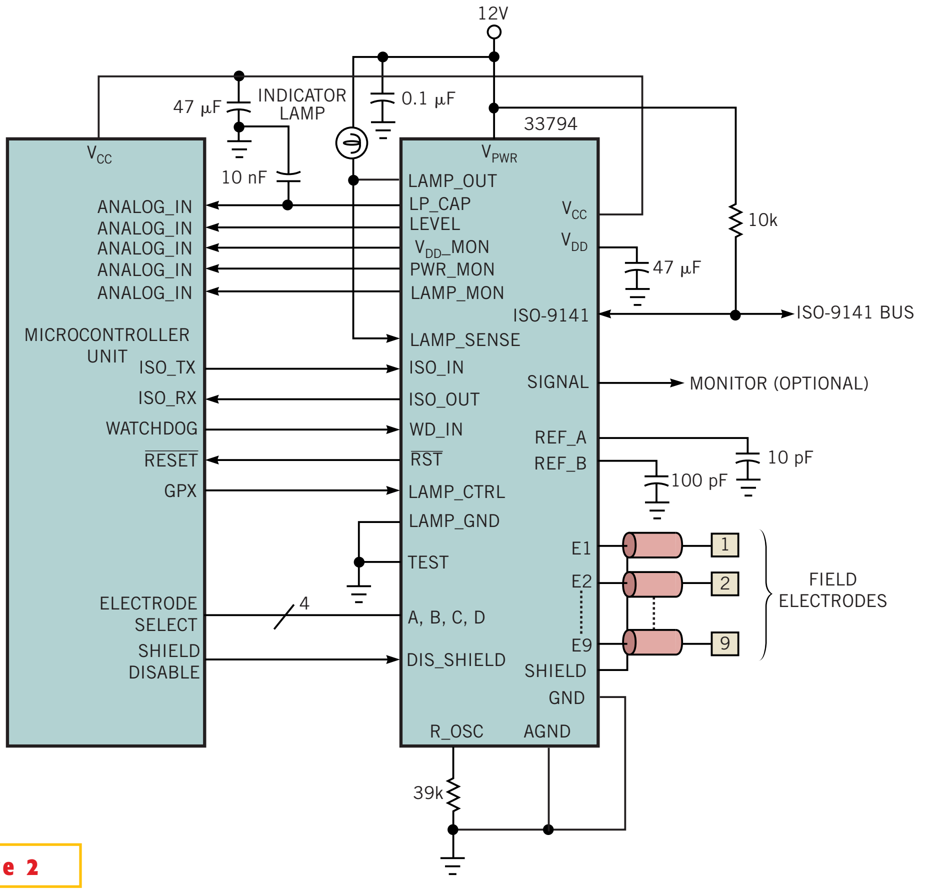


Figure 2

The Freescale device uses a 120-kHz oscillator to sense via multiple points the electric field and, thus, passengers; it can also detect moisture and other phenomena.

GETTING ON THE BUS, MAYBE

Most sensor elements or ICs inherently provide a low-level analog signal as their output. Some IC sensors also include integral signal conditioning to bring this signal up to a more practical 0 to 5V range (usually a single-ended signal but differential in some designs) or a 0- to 10-mA signal.

In addition, most sensor situations need a microcontroller to interpret the signal. Because the analog signals generally have fairly low bandwidth and modest accuracy, an 8- to 12-bit, 10k- to100k-sample/sec ADC built into the microcontroller is generally sufficient. Some sensors include a built-in converter in their package assembly, thus providing an opportunity for linearizing and calibrating the sensor. Designers commonly use two-die assemblies on a single lead frame for cost and space savings.

This two-die assembly is especially interesting to automakers, because it lets them reduce the required precision of the sensor assembly's installation. The automaker can install the sensor assembly, run a calibration sequence, and store any calibration factors needed to compensate for mechanical tolerances and slack in position or angle of mounting, as well as any changes in sensor performance due to installation stress.

Most sensor-processor outputs, in turn, feed into the car's larger functional subsystems. Given the large number of sensors in today's cars, the number of sensor wires quickly adds up, adding to the cost, the need for more connectors, and overall cable placement and routing difficulties. Auto-system designers must decide how many sensor runs to aggregate at a local node, where to aggregate them, and what type of formal bus, if any, to use between the node and the rest of the vehicle's networks.

This link between the digitized sensor output and the car's electronic intelligence occurs in several ways. Vendors are using CAN (controller-area-network) buses for higher speed links, single-wire CAN for lower speed links, and LIN (local-interconnect) buses for low-speed links (or J2602, the Society of Automotive Engineers' version of LIN). The choice of bus, although not directly relevant to the sensor performance, affects the configuration and wiring of the many sensors, as well as the placement of local processor-centered support and connectivity functions.

For example, the KMA200 programmable angular-measurement sensor from Philips Semiconductors uses the magnetorestrictive properties of thin-film permalloy to sense the angle between an external magnetic field in the plane of the sensor and the sensor itself. The vendor claims that this technique provides greater accuracy over far greater distances than the well-known Hall-effect device. Each sensor comes with EEPROM-stored calibration factors, has a unique 32-bit identifier, and reports results via an SPI interface.

the car interior to give different viewing angles.

REMEMBER YOUR FIELD THEORY

Although seat pressure and image sensing are effective techniques, a subtler approach is the basis of a system from Freescale Semiconductor (formerly, a part of Motorola) and Elesys. The technique, e-field sensing, uses the electric field that objects develop due to charged atoms. E-field sensing is a form of 3-D image sensing, using signals collected by multiple electrodes to "paint" the occupancy picture.

Freescale's MC33794 is the core of many such e-field designs (**Figure 2**). It contains a 120-kHz oscillator that sends a signal to the sensor electrodes through an internal resistor. The voltage drop across an internal resistor is a function of the electrode capacitance to ground. This capacitive loading on each of the IC's nine electrodes makes up the sensed field.

Key to the e-field technique is the antenna. A typical antenna is located 1 to 2m from the IC and its related electronics and is roughly the size of a mousepad. Automakers can build it using conductive foam that becomes part of the car seat. To minimize any stray pickup in the transmission line to the antenna that could obscure the desired antenna-only area signals, the IC can actively drive the shield to reduce loading, similar to a guard input on a sensitive analog input of a voltmeter.

The Hall effect and e-field sensing handle more than just bulk-occupancy detection in the passenger compartment. They can be the core of contactless switches and buttons that the car occupants use to activate dashboard controls, windows, and other functions. This approach can, in theory, provide enhanced reliability and long-life operation and avoid problems due to contact corrosion, dirt buildup, and mechanical stress. The e-field sensing can also sense water on, or fogging of, the windshield.

With all these occupancy choices, which is best? As always, the answer is, "It depends." Each technology offers tradeoffs in cost, placement, and consistent performance. For example, you must carefully design the Hall sensor and e-field sensor into the seats, early in the vehicle-design cycle. In contrast, you can add the IR sensor at a later stage. However, ambient temperature and lighting affect the IR sensor, and the designer must compensate for these effects as well as understand what performance limitations and obscuring that full sunlight may bring if the sensor is not properly controlled. The visible-light imager has no problem with daylight but must have the dynamic range for the full-sunlight to shadowy circumstances.

Figure 3

No aspect of the vehicle interior is too small to miss. The S3689 IR sensor from Hamamatsu provides a signal based on the heat load that the interior climate control is struggling to cope with.

IT'S AN ENVIRONMENT OF ITS OWN

There is more to the passenger cabin than occupancy. Issues related to lighting, temperature, and airflow, as well as a plethora of power-assisted accessories, affect passengers' comfort, perception, and sense of well-being. Today's cars are bristled with tiny, power-assist motors for functions such as mirror and seat-position control; the motors are usually brushless types with Hall-effect sensors for feedback. Connecting all these functions to the car's nervous system is another challenge (see **sidebar** "Getting on the bus, maybe").

Although interior heating and air conditioning have long been common in vehicles, today's high-end vehicle passengers expect a more personal touch through heated and cooled seats. (Of course, if you are in desert areas, that cooled seat is more than a convenience.) Several ways exist to provide these seat creature comforts. Built-in electrical coils in or near the seat generate heat, and a small blower moves the heated air to the seat surface. Cooling is more mechanically difficult, because routing chilled air through miniature ductwork in the seats is a challenge. Some vendors are using Peltier coolers under the seats to develop the chilled air, which the system then forces through the perforated seat fabric.

Regardless of the technique you use, there are two sensor considerations. The first is obvious: to measure the seat temperature to control the heating and cooling. In addition, the tiny airflow motors, usually brushless, need sensors such as Hall-effect devices to manage their rotation and provide feedback to the closed-loop control.

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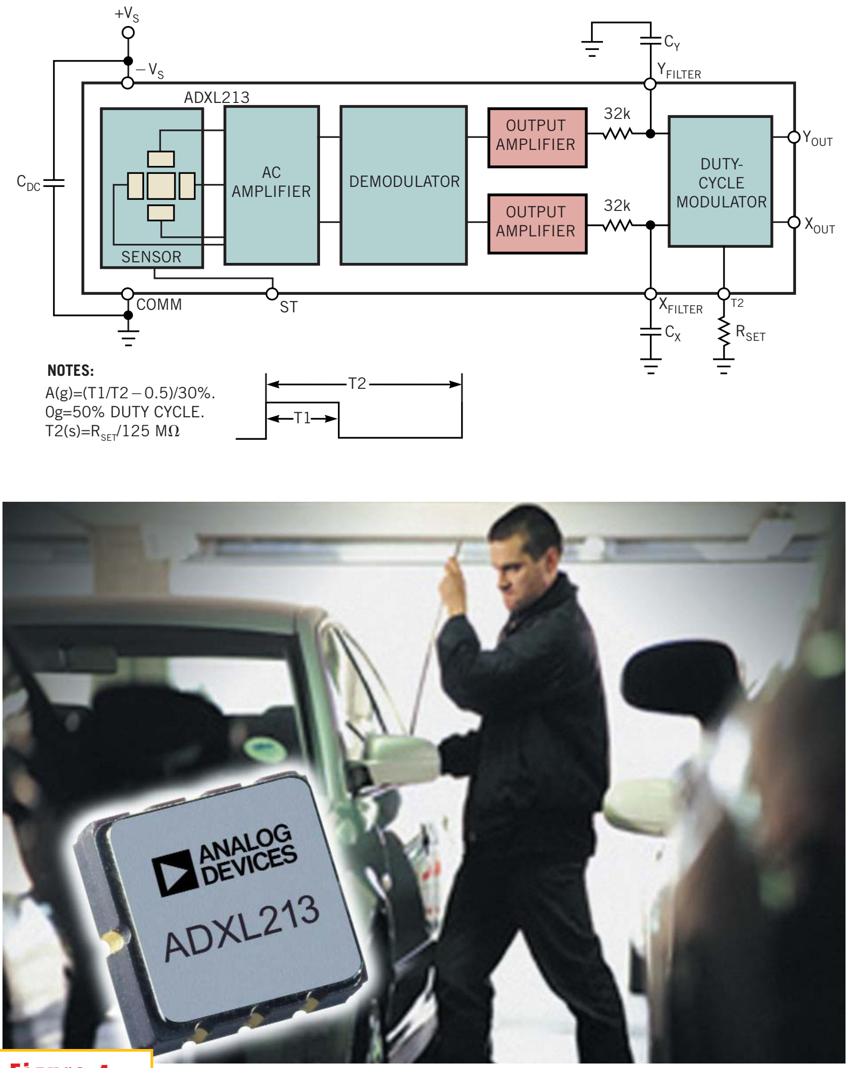

Figure 4 Dual-axis accelerometers such as the ADXL213 from Analog Devices (top) can also monitor any undesired car motion, such as from a potential thief (bottom).

However, the car wants to know more than just the seat's temperature. Even if the vehicle lacks seat heating and cooling, a closed-loop climate control needs to know the passenger or interior temperature. One way is to install a small fan to pull compartment air into the dashboard and then past a temperature sensor. But this approach requires a protected hole in the dashboard, as well as a space-consuming fan, and it tells you the temperature of the air, not the passenger. As an alternative, some automakers are now using focused IR sensors mounted flush into the dashboard panel to directly see the skin temperature of the driver and passenger. For further climate-control-system enhancement, components such as the S3689 wide-angle photosensor from Hamamatsu, with peak response at 960 nm, measure the sun-induced heat load in the car's interior (**Figure 3**).

Because the dashboard and its instrument panel are the driver's interface to the vehicle, proper lighting is also a concern. Wide-dynamic-range visible-light sensors, such as an LX1971 from Microsemi Integrated Products (peak response at 520 nm), find use in this situation. These dashboard-mounted photosensors provide a controlling output to maintain the interior illumination at the user-set level, independent of ambient lighting, shadows, tunnel environments, and similar perturbations.

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None of these sensors and creature comforts will help if someone steals your car or you get lost. Auto vendors and after-market alarm-system vendors are looking to use the latest in proven technologies to supplement existing techniques. For example, the sensitive, ±1.2g ADXL213 accelerometer from Analog Devices uses MEMS (microelectrical-mechanical-systems) technology initially developed for high-g air bag crash sensors to sense any jostling, shaking, or even slow tilting of the car that might occur if the car were being lifted, towed, or broken into (**Figure 4**).

Although GPS (global-positioning-system)-based car-navigation systems offer tremendous help in locating autos, they do have limitations. During "dark" signal periods when the satellite signals are blocked, such as in tunnels, or in difficult signal areas, such as urban canyons that block or bounce signals, GPS devices can lose track or become confused. For this reason, higher end GPS units include low-g accelerometers, which supplement the GPS-only readings. These sensors provide a dead-reckoning navigation update based on the vehicle's last known position and the distance the car traveled since that position. (Distance is the integral of velocity; velocity is the integral of acceleration.) Although this method is less accurate than GPS over long distances, it provides a good interim update for the signal-dropout gaps.□

REFERENCE

1. Vrana, Greg, "Analytic technology: Diagnose what ails your auto," *EDN*, Dec 20, 2001.

ACKNOWLEDGMENTS

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