 By Dan Strassberg, Senior Technical Editor

AUTOMOTIVE-SENSOR TECHNOLOGY drives nonautomotive embedded designs

EVER-SMARTER MOTOR VEHICLES DEMAND A VARIETY OF RUGGED, LOW-COST SENSORS, MANY OF WHICH ALSO PROVE NEARLY IDEAL IN OTHER SORTS OF EMBEDDED SYSTEMS. NOW, DIGITAL PROGRAMMABILITY IS STARTING TO SIMPLIFY ADAPTING THE AUTOMOTIVE DEVICES TO THEIR NEW USES.

CARS, TRUCKS, AND BUSES are now almost as electronic as they are mechanical. Electronic content will only increase as more and more vehicles incorporate advanced functions, such as stability control and drive by wire. Because electronic systems operate on electrical signals, motor vehicles require sensors to convert myriad optical, chemical, and mechanical stimuli into electrical form. Although sensors have historically been expensive, automotive sensors can't be; manufacturing motor vehicles—even high-priced luxury cars—is extremely cost-sensitive. Nevertheless, despite stringent cost constraints, designers of automotive sensors can't cut corners. The sensors must operate reliably over many years under extremes of temperature, humidity, shock, vibration, and EMI that can severely shorten the lives of the sensors' conventional counterparts.

This challenging situation provides nearly unalloyed good news for designers of nonautomotive sensor-based embedded systems. These engineers often find that they can adapt sensors that were created for automotive applications to uses much different from those the device designers originally contemplated. Because of their automotive uses, these sensors offer excellent reliability at low cost. Moreover, programmability facilitates tailoring the characteristics of a growing number of such devices to new uses.

Today, many automotive sensors are fabricated using IC-manufacturing processes, several of which produce chips that incorporate both analog functions and nonvolatile memory. This approach permits calibration and programming of each device to compensate for manufacturing imperfections. Programmability can thus enable device manufacturers to relax tolerances, thereby increasing device yields while reducing costs.

However, IC designers must carefully

contemplate, case by case, whether adding programmability will actually reduce a sensor chip's costs. The trade-offs can be extraordinarily tricky. If done incorrectly, the addition of nonvolatile memory to what is primarily an analog chip can drive costs up instead of down. The combination of nonvolatile-RAM and analog functions necessitates more complex wafer processing, the memory increases the chip area and thus can reduce yields, and programming can increase the test time.

Although good reasons exist for IC technology's increasing dominance of automotive sensing, not all automotive sensors are ICs. Far from it. Nevertheless, no other manufacturing technology seems so well suited to producing these sensors. IC manufacturing's batch processes produce large numbers of devices having closely controlled characteristics. The result is fundamentally low device cost. In fact, the cost of packaging many automotive-sensor ICs is greater than the cost of the silicon. Even so, the packaged devices generally cost less than devices produced by other means. Moreover, in many cases, those other means simply can't produce suitable devices, nor could they even if auto manufacturers were willing (which they aren't) to accept significantly higher costs.

PACKAGING—A SIGNIFICANT COST

Nobody should be surprised that packaging costs represent a major part of automotive-sensor costs. The packages must protect inherently frail chips from an environment that is hostile in the extreme. Moreover, certain IC sensors impose previously unheard-of requirements on the packaging. For example, some position sensors require close control of the IC-die location with respect to the package's external features. Meeting this requirement requires special assembly processes and fixtures.

Even when no such special requirements exist, automotive-sensor packages must safeguard chips from conditions that most commercial devices never encounter.

AT A GLANCE

- ▷ Sensors already occupy a central role in automotive design. That role is growing with the addition of features such as stability control and drive by wire.
- ▷ For many types of sensors, only IC technology can produce devices that meet the automotive industry's requirements for low-cost devices that perform reliably for years in extreme environments.
- ▷ ICs that combine sensing with nonvolatile RAM enable device manufacturers to program chips to compensate for manufacturing imperfections. However, designers must use great care to prevent the mixed technology from driving up costs.
- ▷ Programmability enables designers of nonautomotive embedded systems to tailor automotive sensors to their needs and thus obtain ruggedness and high reliability at low cost.

Not only the chips but also the packages must operate over a temperature range of −40 to +125°C (−40 to +150°C for ICs mounted on the engine block). Moreover, the packages must protect the chips from high humidity and in some cases from salt spray. Packages must also safeguard chips from extreme shock and vibration, and the chips themselves must usually withstand severe electrostatic and RF fields. The requirements are generally similar to those for ICs used in military and aerospace applications—except that the unit volumes are higher, and automotive companies won't pay MIL prices; in some cases, they won't even pay commercial prices.

You might think that the large quantities of identical sensors used in automotive applications would make custom packaging palatable to automotive customers. However, automotive-sensor purchasers prefer, when possible, to buy devices in IC packages that are standard, at least from a dimensional standpoint. The infrastructure for such packages (test sockets, for example) already exists, and finding multiple sources is easier for ICs in such packages than for chips in more specialized packages. IC-sensor manufacturers estimate that they encase at least half of the automotive units they produce in packages that conform to industry-standard outlines.

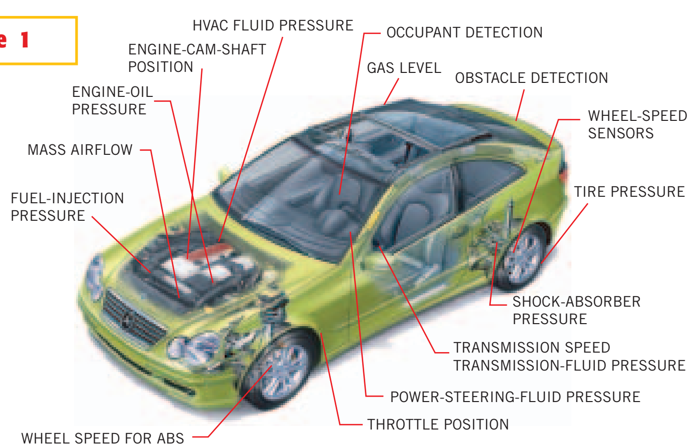
Though dimensionally standard, nearly all of these packages are versions that the IC or package manufacturers have qualified for automotive service. The ISO (International Standards Organization) has created standards that govern various aspects of IC and IC-package performance in automotive applications. One such standard, ISO/TR 7637/1, covers devices' ability to withstand ESD (electrostatic discharge).

Sometimes, adapting a commercial-grade device to automotive service involves considerably more than special care in packaging. Modifications can require significant changes in wafer processing. This was the case with optical sensors for under-the-hood deployment. Generally, photodiode detectors operate only to 85°C. Above that temperature (or in a few cases, above 100°C), the back-biased photodiodes' leakage current becomes excessive. Altering the device doping enabled operation to 125°C, however.

SERPENTINE SUPPLY CHAIN

More often than not, the sensor purchasers are not auto manufacturers themselves but are suppliers to auto manufacturers or suppliers to companies that supply assemblies to auto manufacturers. For example, company A might sell power-window actuators (specialized electric mo-

Figure 1



The labels show the nature and location of only a few of the sensors in late-model luxury cars (adapted from material provided by ON Semiconductor).

tors) to company B, which sells complete door assemblies to company C, which makes cars. In this scenario, the company most likely to require a second source is B. However, B may well be deceiving itself about the advantages of having multiple sources.

Suppose that the window actuator is one of the new "one-push-up" devices built around electric motors that incorporate pinch (or obstruction) sensors. To guard against the possibility of injury to someone whose hand or neck got in the way of a window's upward motion, older actuators required the driver or passenger to hold down the control button during the window's entire upward travel. One-push-up actuators require only a single brief push; if an on-chip sensor determines that the motor is developing excessive torque, the control IC within the motor causes the window travel to reverse. Even if B qualifies a second company, D, to supply actuators, both A and D may obtain the pinch-sensing motor-control IC from company E. Therefore, a problem at E can halt the supply of actuators from both A and D.

Figure 2

These simple sensors from Teledyne detect oxygen in automotive emission-control applications.

A point of concern for developers of nonautomotive embedded systems that employ components developed for automotive applications is whether the necessary support will be available. Many nonautomotive companies want to purchase these components in relatively small quantities of thousands or even hundreds, whereas automotive suppliers often contract for purchases of the parts in quantities of hundreds of thousands or millions.

The semiconductor manufacturers have several answers for such concerns. First, they say, they recognize that the aggregate of all nonautomotive-sensor sales potentially represents a significant and

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profitable business. To provide equipment designers with the information they need, most IC companies that manufacture automotive sensors publish detailed data sheets that provide the kinds of information sought by design engineers who intend to use the components in nonautomotive applications. The IC companies are also working to develop their distributors' capabilities for applications support. Beyond that, several of the IC companies say that their factory applications staffs really are eager to assist customers whose quantity requirements are merely modest.

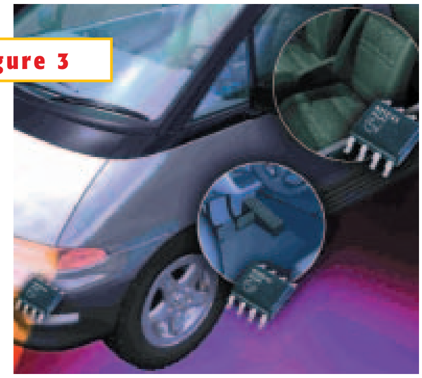
Some companies—Melexis is one—provide not only demonstration boards but also development kits for their sensor products. Melexis has set up its Web site to allow online purchases of these materials. Sensors that incorporate nonvolatile RAM do so because programmability is a key issue with the part specifiers and the designers of equipment who use the devices. The IC companies recognize that they must provide the information and the equipment to enable these designers to program the parts in the lab. Moreover, equipment manufacturers will often need different tools to program the chips in production. The IC companies are committed to supplying or developing sources for this equipment, as well.

DIVERSE NEEDS

Modern motor vehicles use a huge variety of sensor types. **Figure 1** shows where several types of sensors are deployed in a modern luxury car. The matrix of **Table 1** lists a number of the measured parameters and the technologies (sensor types) commonly used to measure them. This matrix is not comprehensive, however. For example, it does not include flow sensors, nor does it list sensors that detect specific chemical compounds and elements, such as O_2 (**Figure 2**). Chemical sensors are key elements of automotive-emission-control systems.

Reference 1 presents a more comprehensive treatment of the available parts and technologies. Remember, though, that because the book originates with a major manufacturer of automotive sensors, it draws examples from that company's product lines.

Figure 3



Philips Semiconductors' magnetoresistive angle sensor semiconductor—the KMZ43T—overcomes a major issue of sensor placement in cars by requiring smaller magnets, enabling easier placement, and reducing design costs.

An area of sensing that is now considered almost synonymous with automotive applications is the accelerometer based on MEMS (microelectromechanical-systems) technology. As **Reference 2** explains, although the manufacture of MEMS devices intimately relates to IC manufacturing, and some MEMS-based sensors are single chips that incorporate both sensing elements and IC signal conditioners, MEMS manufacturers don't like to call their products ICs.

Nevertheless, the idea of low-cost, batch-fabricated, thumbnail-sized (and smaller) devices that sense or create motion is new and different enough to retain the feel of science fiction. Without doubt, MEMS-based automotive-sensor applications will continue to expand beyond today's capacitive accelerometers. Indeed, MEMS may well become the premiere automotive-sensor technology. For example, several MEMS manufacturers are reported to be actively pursuing MEMS-based gyroscopes.

Far less glamorous than MEMS sensors, but still of great importance, are magnetic devices, such as those discussed in **Reference 3**. Although most of the rotary-position and velocity sensors discussed in the **reference** use the Hall effect, some newer devices are based on the GMR (giant-magnetoresistive) effect. GMR technology is receiving a lot of interest because of its importance in increasing the areal density of hard-disk drives. However, Hall devices have the advantage of being able to combine sensing and signal conditioning on a single IC chip. **Figure 3** shows the application of magnetoresistive angle sensors in cars.

PUTTING BUSES IN CARS

The way in which automotive sensors provide their data is the subject of numerous articles, such as **references 4** and **5**. Most sensors are fundamentally analog devices that sense physical phenomena in analog ways. For decades, each type of sensor produced an analog out-

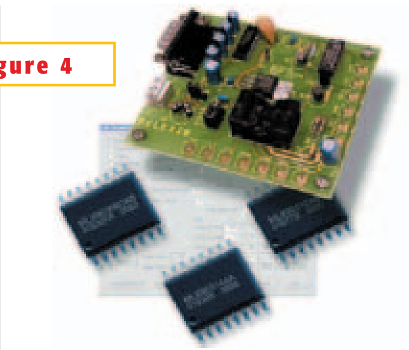
TABLE 1—SENSOR TECHNOLOGIES AND PARAMETERS IN MOTOR VEHICLES

Sensor types	Force	Pressure	Position	Displacement	Velocity	Acceleration	Shock, vibration	Proximity	Temperature
Capacitance	x	x	x	x		x	x	x	
Strain gauge	x	x	x	x	x	x	x		
Piezoelectric	x	x		x	x	x	x		
Potentiometer	x	x	x	x					
Differential transformer	x	x	x	x	x	x			
Eddy current			x	x	x			x	
Inductive			x	x	x		x	x	
Hall effect			x	x				x	
Magnetoresistive			x	x				x	
Thermocouple									x
Thermistor									x
Semiconductor junction									x

Note: Table does not show volume and mass-flow sensors, nor does it show devices that respond to specific chemical compounds and elements, such as oxygen. MEMS accelerometers are capacitive sensors.

put that was unique to the sensor technology and the range of the sensed variable. Converting such output signals to a usable form was the job for a separate signal conditioner, which usually took the form of a circuit module. The sensing-element output was often a low-level analog voltage or current and often a nonlinear function of the sensed variable. The primitive (or nonexistent) computing functions of the day needed linearized high-level outputs, scaled to the measured variable, and often corrected for offset and gain.

Figure 4



Many automotive sensors still require separate interfaces to drive the systems that make real-time decisions based on information from the sensors. This pc-board assembly includes signal-conditioning circuits (courtesy Melexis).

Later, it became commonplace to integrate some types of sensors with the signal-conditioning circuits and to scale the outputs to a standardized range. In industrial applications, and particularly in process control, a range of 4 to 20 mA is still common.

Several long-standing trends have carried this approach far forward. Dramatic reductions in the size and cost of A/D converters have made it possible to produce tiny digital-output signal conditioners that cost little, if any, more than analog-output circuits. The pervasive use of digital communications has motivated the design of signal conditioners that communicate via standard digital protocols. And the advent of sensors based on IC technology has made possible the combination of the sensor, the signal conditioner, and the standardized digital interface into a single low-cost IC. Even so, many modern cars still use modular signal conditioners, such as the one that **Figure 4** depicts.

As wonderful as this result sounds, it's not without its problems. A major problem is the result of the ease of mastering the technology, or of too many EEs either being too creative or thinking they are more creative than they are. It seems as if every living EE has designed at least one new bus and associated communications protocol and that no two of these buses and protocols are compatible. The Tower of Babel created by the plethora of competing bus and protocol "standards" is a colossal waste of time, energy, and money.

The automotive industry has not been immune to these bus wars. The best known of the automotive buses is CAN (controller-area network, **Reference 4**). CAN gained its initial adherents among European car manufacturers. A newer bus that does not aim at supplanting CAN but rather aims to complement it is LIN (local-interconnect network). LIN is a low-cost bus for applications that are not critical to the safety of the vehicle occupants. At the LIN Consortium Web site, you can learn about the large number of automotive and electronic companies that are climbing on board the LIN bus.□

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Author's biography

Senior Technical Editor Dan Strassberg has spent more than 40 years designing test-and-measurement products and covering the field as a journalist. So far, he's retained his enthusiasm for the subject. You can contact him at 1-617-558-4205, fax 1-617-928-4205, or e-mail dstrassberg@edn.com.