

Steering safer wheels for America's motorists

Driven by vehicle safety regulations and customer demand, tire pressure monitoring systems continue to evolve. With this need, innovative solutions are being developed to overcome RF and battery design challenges to cost-effectively provide the best tire safety system functions.

By Tejas Desai, Ken Chance and Takashi (Ted) Ozawa

Major accidents caused by improperly inflated tires and the resulting recall of nearly 6.5 million Firestone tires in 2000 prompted the U.S. Congress to take urgent legislative action to protect America's motorists. The result of these concerns was enactment of the Transportation Recall Enhancement, Accountability and Documentation (TREAD) Act in the fall of 2000. The TREAD act requires the mandatory installation of tire pressure monitoring systems (TPMS) in all U.S. automobiles and light trucks as one of its five major points. Though there has been some industry wrangling through the courts, it's generally agreed that such systems are expected to be in place within the next two to three years, certainly by 2006.

The two major categories of TPMS approaches are direct measurement systems that include a tire pressure sensor for each tire and indirect measurement systems that determine tire inflation pressure from wheel speeds, or something other than actual tire pressure. Direct methods are more accurate than indirect indicators, and direct systems are expected to prevail over time. TPMS will contribute to the rising safety standard of U.S. vehicles.

Direct TPMS methods use pressure sensors to measure pressure in each of the four tires. Then these sensors transmit the pressure data via a wireless RF transmitter to a central receiver. The receiver communicates to a display that informs the driver which tire is underinflated. The tag in each wheel is designed to send a warning signal when a tire's pressure drops below its specified safety level. Tire-mounted pressure sensor is shown in Figure 1. Underinflation has been cited as a cause of tire failures such as tread separation or tire blowouts. It is also responsible for shortening tire life and reducing fuel economy.

Indirect systems employ wheel speed sensors on a vehicle's antilock brake (ABS) system to track each tire's rotation. The premise is that underinflated tires have a smaller radius, resulting in a higher rotational speed compared with a fully inflated tire. The sensor is supposed to detect the faster

rotation, and the system alerts the driver. In practice, this change in radius is small, making indirect measurement less reliable than direct pressure measurement.

When the new regulations take hold, the law's intent is for every light vehicle sold in the United States to include a tire pressure monitoring system as standard original

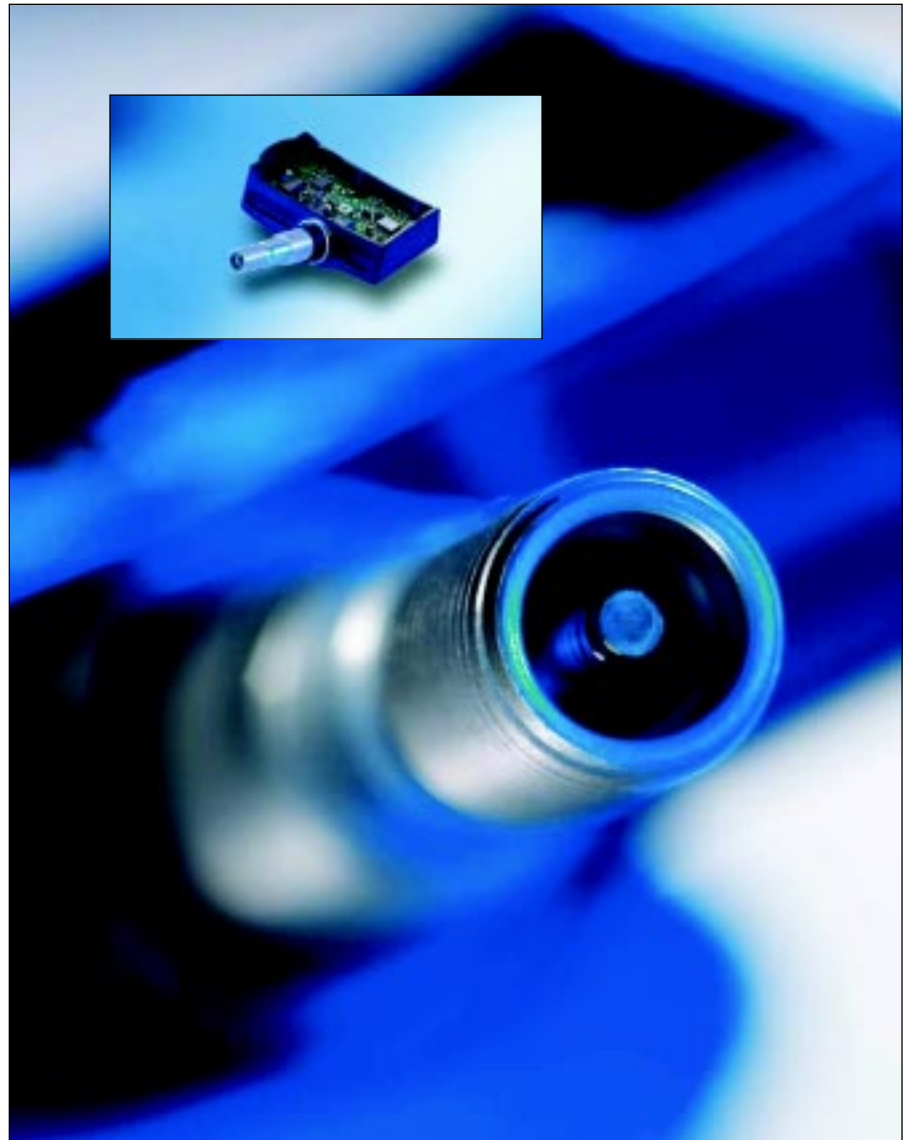


Figure 1. Tire-mounted micro-machined pressure sensor. (Inset) Figure 2. Tire guard system housing is designed to withstand 1,000 times the force of gravity, and the shock and vibrations of uneven roads.



Figure 3. High-temperature-resistant Lithium Manganese Dioxide (Li/MnO₂) coin cells.

equipment. The estimated average cost per new vehicle to consumers would amount to only \$66.33 to implement direct measurement systems. Direct pressure measuring systems will warn a driver when tire pressure is 25% or more below the required pressure for one to four tires. The National Highway Traffic Safety Administration (NHTSA) estimates that tire-monitoring technology will prevent more than 100,000 injuries and 70 deaths per year in the United States alone. NHTSA reports that 23,000 crashes and 535 fatal crashes annually involve blowouts or flat tires.

Europe's earlier concerns

Though accelerated by the recent U.S. TREAD act, tire pressure monitoring systems are not a new development in vehicle safety systems. Siemens VDO Automotive had been researching and developing tire pressure monitoring methods since Renault approached the company as an innovation partner in 1997, nearly two years before tire pressure began to make headlines in North America. Siemens VDO Automotive's expertise in RF transmission-based remote keyless entry and RF/LF passive start and entry systems made it a clear choice for the French auto maker.

The high demand from Renault's customers for this vehicle safety feature, partly due to higher-speed travel on European roads, led to Siemens VDO's development of key enabling technologies that provide a cost-effective, robust solution that takes advantage of existing vehicle components—namely, the remote keyless entry (RKE) receiver.

In the United States, a NHTSA ruling allowed for the indirect method of monitoring tire pressure until 2005. However, both European and U.S. Original Equipment Manufacturers (OEMs) stated their intentions to remain committed to the direct monitoring technology currently offered by Siemens.

Siemens' initial TPMS technology was created in response to European consumers' demand for safer vehicles and in response to incidents of dangerous vehicle rollovers caused by low tire pressure. The innovation

made possible the detection of gradual drops in tire pressure and warned drivers of impending low pressure conditions in their tires.

How the sensor works

Tire pressure measurement is performed by a micro-machined sensor on a silicon-based vacuum-measuring cell. Under varying air pressure, a diaphragm flexes, allowing piezo-resistive sensors to measure the change in pressure and to provide electronically processed data that expresses this change. To withstand the harsh environment of the vehicle tire, the sensor is embedded in a vibration-absorbing compound in a plastic housing. The housing is attached to the rim of the wheel with the valve stem nut, where it is designed to withstand 1,000 times the force of gravity and the shock and vibrations of uneven roads (Figure 2).

The sensor measurement values are transmitted by standard radio frequencies of 434 MHz (Europe) or 315 MHz (United States) to the receiver. The design of the RF transmission function has a major influence on the overall system reliability. Under all possible environmental and driving conditions, tire information must be reliably transmitted from the wheel units to the receiver. The majority of the systems on the market operate in the 315 MHz, 434 MHz or 868 MHz standard automotive frequency bands.

In the United States, 315 MHz and 434 MHz systems were initially offered and both frequencies are suitable when a tire pressure monitoring system is operated as a stand-alone system. However, in an integrated system in which the control unit and the receiver of a remote keyless entry system hosts the tire pressure functionality, the 315 MHz frequency is required. At 434 MHz, in some areas, strong private radio communications repeater stations can completely block the significantly lower-powered key fob output transmissions. Therefore, the 315 MHz frequency was established as the standard for RF-based systems.

When specifying the transmitter output power of the pressure sensor, a compromise

Lower output power from tire pressure sensors is also advantageous because unnecessarily high power output would cause RF channel congestion in the nearby environment, degrading the performance of all RF systems on the same frequency.

was made between output power and energy consumption to balance acceptable battery life for the sensor with acceptable reliability of signal reception. Lower output power from tire pressure sensors is also advantageous because unnecessarily high power output would cause RF channel congestion in the nearby environment, degrading the performance of all RF systems on the same frequency.

Techniques employed to reduce interference include:

1. The transmission of short messages as opposed to long ones. This is accomplished by using a higher baud rate to shorten the transmission.

2. To send transmissions at non-periodic intervals. If the transmis-

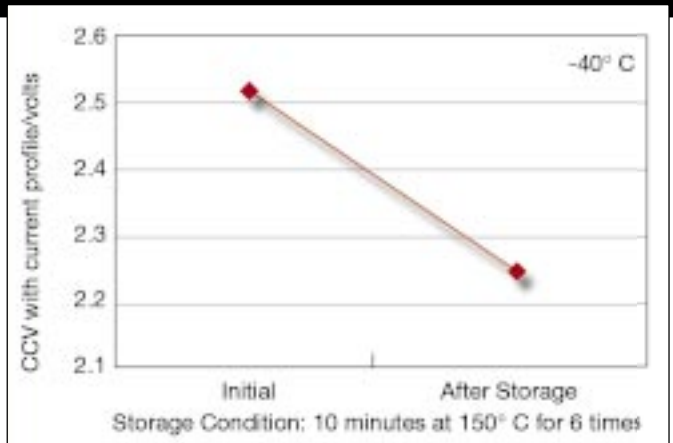


Figure 4. Relationship between depth of discharge (DOD) and temperature performance of CR2450HR-EX.

sion intervals were fixed or periodic, then transmissions could get into phase and suffer from interference.

3. Designed to send transmissions multiple times.

New battery meets system rigors

To provide power to such systems and to meet the more immediate new U.S. federal tire safety rules, Hitachi Maxell has designed two new high-temperature resistant Lithium Manganese Dioxide (Li/MnO₂) coin cells that power the pressure-sensing tags, mounted on the rims of each vehicle's wheels. The improved cells, new industry-standard types CR2450-HR and CR2450HR-EX, include a change in gasket material, a completely new crimping structure and improved content to operate in the high-temperature environment encountered on rotating auto and light truck wheels (Figure 3).

The new heat-resistant Li/MnO₂ cells are suited for this rugged application. Li/MnO₂ batteries offer a nominal voltage of 3 V. One lithium battery, with a minimum life span of at least five years and as long as 10 years or 150,000 miles, can replace two cells of another chemistry. These coin-type lithium batteries also have a high energy density, making them ideal for use in compact equipment that requires powerful small-sized batteries.

Lithium batteries undergo little change in their internal resistance over time, and deliver stable discharge voltage use after use. Advanced sealing technology creates tough lithium batteries that operate safely over extended periods of time.

The coin-type lithium manganese dioxide battery uses Manganese Dioxide (MnO₂) as its positive active material and Lithium (Li) as its negative material, and an organic electrolyte. At 3 V (nominal voltage), it has about twice the voltage of alkaline button batteries and silver oxide batteries. Because it uses a highly conductive electrolyte, it lowers internal resistance and provides stable operating voltage. This allows for stable power, with little change in operating voltage at high and low temperatures. The leak resistant organic electrolyte also provides better leak resistance than alkaline electrolytes, and the use of a more effective seal structure and improved sealant keep self-discharge to about 1% per year.

Two versions of the new cell with different operating tolerances were developed: the CR2450-HR for standard vehicles and the CR2450HR-EX for high-performance, premium vehicles. The HR version of the cell operates in the temperature range of -40 to 120°C, has a standard capacity of 550 mAh, and weighs 6.8 grams. The HR-EX version of the cell operates between the temperature extremes of -40 to 150°C, has a capacity of 525 mAh and weighs 6.7 grams. Both cells measure 24.5 mm in diameter by 5 mm high. While Figure 4 depicts the relationship between depth of discharge (DOD) and temperature to demonstrate low-temperature capability of battery type CR2450HR-EX, Figure 5 shows voltage over time characteristics of CR2450HR (red curve at 120°C as compared with standard

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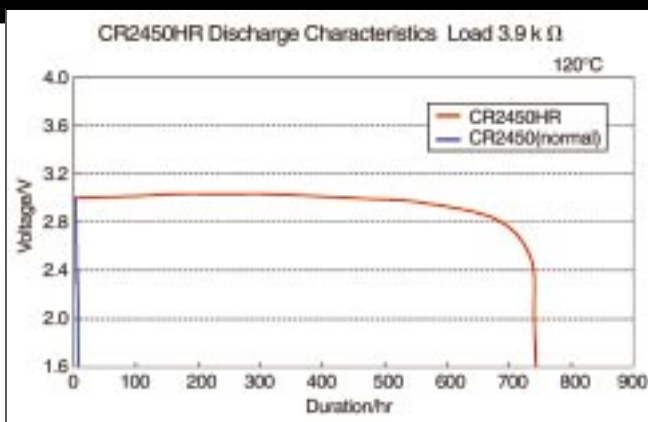


Figure 5. Discharge characteristics, voltage over time of CR2450HR (red curve) at the high temperature of 120°C, compared with standard, unmodified CR2450 cell (blue curve) with 3.9 kΩ load at 120°C.

Table 1. Heat shock test results for CR2450HR series.

Heat shock test 1 Condition: -40/120C for 0.5 hours	
after 2500 cycles	
Leakage	N = 25 No leakage
Deformation	N = 25 No Deformation
Heat shock test 2 Condition: -30/105C for 0.5 hours	
after 3500 cycles	
Leakage	N = 25 No leakage
Deformation	N = 25 No Deformation

Table 2. Vibration and impact test results for CR2450HR series.

Vibration test Condition: JASO D467-97 7.13 5 to 200 Hz, period 10 minutes acceleration 250 m/s ² , amplitude 10 mm 3.5 hours for X, Y, Z orientation	
Results	
Leakage	N = 25 No leakage
Deformation	N = 25 No Deformation
Internal short circuit	N = 25 No short circuit
Impact test Condition: 100 G for 1 ms	
Leakage	N = 25 No Leakage
Deformation	N = 25 No Deformation
Internal short circuit	N = 25 No short circuit

CR2450 (blue curve) with 3.9 kΩ load at 120°C. Test results of heat shock and vibration impact are demonstrated in Tables 1 and 2.

Siemens VDO Automotive overcame the frequency and power design challenges and launched the TireGuard tire monitoring

system in 2000. This cost-effective product uses a vehicle's existing remote keyless entry system to receive tire pressure monitoring signals, a cost-savings integration step that also reduces vehicle wiring complexity. Tire Guard is a direct tire pressure monitoring system that constantly updates the driver on the vehicle's tire pressure. It is highly reliable and robust

and can be integrated with existing car body electronics. Its direct measurement of the air pressure in the tire allows for the detection of small changes in air pressure, through a continuously transmitted signal providing real-time updates, even when the vehicle is parked.

Joint effort

TireGuard's innovative software and RF communications solutions attracted Goodyear as a partner for future-generation TPMS systems. Siemens VDO Automotive and Goodyear Tire and Rubber Co. are jointly developing the next-generation tire pressure monitoring solution called Tire IQ. It will be available in the time frame when carmakers will have to satisfy U.S. legislation requiring 100 percent of new vehicles to be equipped with a tire pressure monitoring system.

Embedded in the tire material, the lightweight Tire IQ sensor measures tire pressure and temperature. The device also contains a microchip that can store total mileage and can record the distance driven while a tire is under inflated. The antenna, also integrated into the tire, transmits the data to a transceiver unit housed in the wheel well. This wheel well-mounted transceiver not only receives data—it also energizes the sensor by emitting a burst of RF energy. Using this energy, the sensor takes a pressure and temperature reading and transmits it back to the transceiver. In this way, the sensor can operate battery-free and readings from the sensor can be obtained on command from the vehicle's central controller without regard to depletion of a limited battery.

The captured data then are analyzed and processed by special software located in a separate control unit or integrated in the vehicle's central electronic control unit (ECU). When the system detects loss in tire pressure, a condition known to lead to increased fuel consumption and tire wear, the driver is alerted and is provided with detailed information about the affected tire.

Because each Tire IQ sensor is embedded

in a specific tire, Tire IQ allows information unique to an individual tire, such as type and history, to be shared on the vehicle bus. This information then can be used by various vehicle systems such as antilock braking, traction control and on-board diagnostics, thereby improving their performance.

With the expected market growth of tire pressure monitoring systems, two trends in system technical development stand out. First, existing systems will be produced at less cost and with improved performance. Second, completely new system approaches will offer additional functionalities and will require new technologies for their implementation.

Currently, a variety of direct tire pressure monitoring systems are on the market or being readied for introduction. They differ in their monitoring precision, their RF approach and special system functionality, such as initialization and automatic localization. The growing experience of vehicle manufacturers and system suppliers will promote requirement standardization, eventually leading to highly integrated, optimized electronic circuits.

Once additional technology hurdles are overcome in the future, the programmable microcontroller in today's wheel sensor units will be replaced by a state machine with a limited number of free parameters. The battery will be replaced by a generator, such as a piezoelement, with environmental and cost improvements. In addition, intelligent system functions will evolve to provide maximum feature content, such as automatic localization, with a minimum hardware effort.

The intelligent tire will be the next stage in the further development of tire information systems. Electronics has taken aim at the tire itself, bringing with it a multitude of additional functions for measuring physical properties such as: tire temperature, tire deformation (footprint, side wall), tread deformation and tread wear.

Tire pressure monitoring systems will continue to evolve in the world market, driven by vehicle safety regulations and customer demand. Growing with this need, innovative solutions will continue to change and adapt to overcome RF and energy design challenges to cost-effectively provide the best tire safety system functions. RFD

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