

A Global Solution for Tire Pressure Monitoring Systems

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Abstract

Tires provide the foundation for comfortable, safe and fuel-efficient driving – if they are inflated properly. It seems simple but without a tire pressure monitoring system (TPMS), drivers took tires for granted and proper inflation was not the norm. With demonstrated technology to effectively monitor tire pressure and warn drivers of problems, regulations have emerged in essentially every region to require carmakers to have a TPMS in many classes of vehicles.

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Introduction

NXP has been actively involved in tire pressure monitoring for over 20 years and has a complete solution that includes the pressure sensor, microcontroller (MCU), radio frequency (RF) and interface technologies required. Rather than continue to only offer separate components, our technologies were combined into a single package solution in 2007. Most recently, improvements have provided a smaller single-package solution that takes advantage of advancements in microelectromechanical systems (MEMS) and MCU technology and expands the performance of the integrated solution. This whitepaper addresses the requirements and variations for implementing TPMS, the latest technology for a system-in-package solution and a discussion about future development.

Riding on Air

There is more to inflating tires than just applying the recommended air pressure from the manufacturer. A few situations can cause problems for drivers.

To start with, the manufacturer's recommended air pressure is a "cold" pressure. Determined by measuring tire pressure after the vehicle has been stationary for more than one hour, this pressure defines the load carrying capability of the tire. When tires are hot from driving, tire pressure measurements should not be adjusted downward to imitate the cold inflation pressure. Most tires will normally increase by about 3-5 pounds-per-square-inch (psi) 20-35 kilo-Pascals (kPa) from driving.

Tire pressure gauges commonly measure the difference between the outside ambient pressure and the internal pressure of the tire (known as gauge pressure). However, tire pressure is affected by changes in altitude. For example, a car with proper cold inflation in the typical populous areas a few hundred meters above sea level will gain pressure when driven to a high altitude area, above 2000 meters. Conversely, setting tires to the recommended cold inflation pressure while at a high elevation, above 2000 meters, will result in under-inflation after being driven back to the lower altitude populous areas. Tire pressures in these examples could change by 3 psi / 21 kPa.

Seasonal temperature changes are also a factor for proper tire pressure. Even if a tire does not lose air pressure during an extended non-operating period (see Safety Considerations), a cold inflation pressure set in the summer, say when it is 90°F (32°C), will be about 16% lower on a 0°F (-18°C) winter morning.

Without TPMS, drivers that don't check their tires often, or for specific situations, risk driving with improperly inflated tires.

Historical Perspective

Without TPMS, the National Highway Traffic Safety Administration (NHTSA) estimated that 23,000 accidents and 535 fatalities per year involved flat tires or blowouts. Both of these problems can be the result of improperly inflated tires. For safety reasons, the US Government enacted the Transportation Recall, Enhancement, Accountability and Documentation (TREAD) Act. As part of the TREAD Act, a federal motor vehicle safety standard (FMVSS 138) requires all vehicles, trucks and buses with a gross vehicle weight rating of 10,000 pounds, or less, manufactured since model year 2000 - to have TPMS.

Other regions of the world have also determined that improper tire pressure poses safety problems. In France, the Sécurité Routière estimated that nine percent of all fatal road accidents were the result of under-inflated tires. The German DEKRA linked tire problems to an estimated 41 percent of all injury accidents and identified that without TPMS, 75 percent of vehicles on the road had at least one tire under-inflated by 3 psi (21 kPa) or more.

In addition to safety, properly inflated tires also improve a vehicle's fuel economy. As a result, many regions have required, or will require, TPMS. Table 1 provides a summary of the requirements for different regions and the timing of the implementation.

TPMS Regulations

Region	Requirements
China	Regulation from 2017 mandates TPMS for new vehicles starting in 2019
European Union	Regulation from 2012: EC661-2009 mandates TPMS starting November 2012 for new type approved vehicles and for all new vehicles starting November 2014
Indonesia, Israel, Malaysia, Philippines, Turkey	Require European whole vehicle type approval for vehicles imported from Europe. As a consequence TPMS will be required for all new vehicles in November 2014
Russia, Kazakhstan, Belarus (Eurasia)	Valid from 2015 onwards and replaces nation legislation
South Korea/Japan	Regulation from 2013: TPMS vehicles to be installed on passenger cars from January 2013 for new models and January 2015 for existing models
Taiwan	Regulation from 2012 mandates TPMS for new vehicles starting in 2013
USA	Regulation from 2005: FMVSS138 mandates TPMS for new vehicles starting October 1, 2005

Table 1: Region vs. Requirements for TPMS Regulations.

The requirement for TPMS implementation has elevated tire pressure to a significant portion of the total of the pressure sensors. TPMS will represent more than 29% of the total pressure sensor market by 2023.¹ Source: Strategy Analytics, Jan 2018.

TPMS Vs. Total Automotive Pressure Sensor Growth

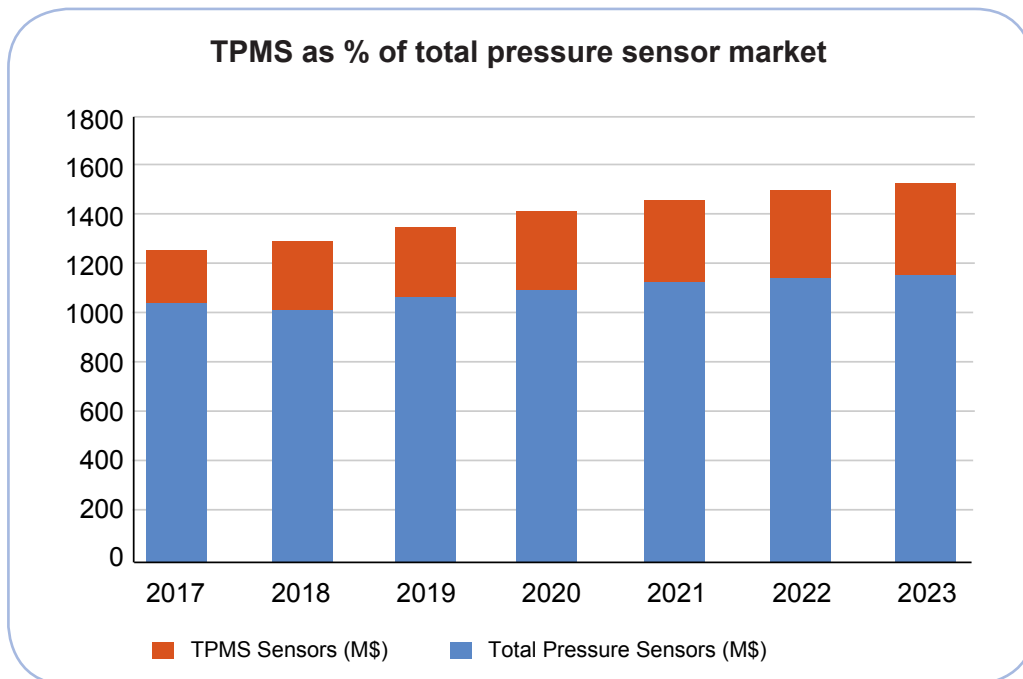


Figure 1: TPMS will represent more than 29% of the total pressure sensor market by 2023.¹ Source: Strategy Analytics, Jan 2018.

Safety Considerations

Properly inflated tires reduce blowouts and braking distances, reduce hydroplaning on wet surfaces and improve overall vehicle handling. For TPMS, tire blowouts are the primary safety use case. Under-inflated tires build up heat faster and cannot carry their required load. This causes excessive flexing in the tire, resulting in tread separation and blowout. Without suffering any road damage at all, tires can leak as much as one psi per month through natural leakage; as much as 85 percent of all tire pressure losses are through slow leaks.

Combining under-inflation with high-speed and/or overloaded conditions increases the risk of tire blowouts. This dangerous event can cause the vehicle to veer into oncoming traffic or spin out of control. Even if control of the vehicle is maintained, an emergency tire change will be required. Changing a tire on the roadway often exposes the motorist to the dangers of oncoming traffic, particularly at night or in adverse weather conditions.

Over-inflation is only a concern for extreme situations where the pressure is above the tire's maximum pressure rating. The overpressure can result from a combination of a highly over-inflated tires and subsequent heating due to driving and sun exposure. Since these cases are rare, most TPMS do not warn of over-inflation. However, some systems will warn of excessive tire temperature.

Fuel Economy Considerations

In addition to the safety aspects of properly inflated tires, there are definite economic considerations as well. European standards evolved from improved fuel economy provided by properly inflated tires. However, increased tire wear and improper tire wear from improperly inflated tires also increase the driver's cost of ownership.

The commercial trucking industry relies on achieving high fuel economies to reduce costs and demonstrate the economic impact of proper tire inflation. Tests conducted by Goodyear Tire and Rubber Company have shown that just a 15 percent under-inflation of the steer, drive and trailer tires can result in an 8 percent drop in expected tire life and up to a 2.5 percent improvement in fuel efficiency.

Since heavy-duty tractor/trailer trucks can have 18 or more tires, maintaining properly inflated tires can save thousands of dollars in fuel and tire servicing costs per vehicle over the course of its several hundred thousand mile lifetime. Passenger cars also benefit in both of these economic areas from properly inflated tires.

Direct and Indirect Tire Pressure Monitoring Systems

Two kinds of tire pressure monitoring techniques are employed in motor vehicles—indirect and direct sensing. An indirect TPMS uses the speed sensors in the anti-lock braking system (ABS) to compare wheel rotating speeds and determine under-inflated conditions. Since an under-inflated tire has a slightly smaller diameter than correctly inflated tires, it rolls at a different rate from properly inflated tires when the vehicle is in motion. The system alerts the driver when it detects an under-inflation condition.

The main drawback of an indirect system, is that it cannot detect the slow loss of pressure that occurs in all tires. This is because air permeates through the rubber and tiny leaks in the side wall bead contact or valve system. If all the tires leak at about the same rate, there is no noticeable change between tire rotational speeds. As a result, an indirect system is not useful for the "maintenance" of tire pressure. However, it works quite well for unexpected tire pressure losses such as punctures and blowouts.

In addition to requiring the vehicle to be in motion, an indirect system generally cannot provide the resolution of a direct system. Also, the user has to reset the system every time the tires are changed, rotated or re-inflated.

In contrast to indirect systems, direct TPMS employs pressure sensors installed in valve stems or elsewhere on the wheel rims or in the tire, to provide independent, frequent air pressure measurements for each tire. These measurements are transmitted to the vehicle instrument cluster to inform the driver.

Since, FMVSS 138 allows up to a 20-minute delay for indicating 25% under-inflation, some systems may delay the reporting of an under-inflation event for several minutes. TPMS system designers use this rule to reduce data transmissions as much as possible and save battery life.

Indirect TPMS has trouble passing European and other standards and that difficulty is reflected in a revised outlook from market research firm Strategy Analytics. Tough legislation across the globe has continued to make things challenging for indirect systems, eating into the cost advantage says Ian Riches, Director of the Automotive Electronics service at Strategy Analytics. "We currently see the market as maintaining an approximate 70/30 split in favor of direct approaches," he says. "By 2020, we expect just over 80% of globally-produced light vehicles to have TPMS. The global penetration of direct will be around 57%, and indirect 24%."

NXP's Direct Tire Pressure Monitoring System

In 2007, NXP pioneered the MPXY8300 single package solution for direct tire pressure monitoring. This reduced the handling of multiple components the size of the printed circuit board and removed the cost adding external components for TPMS suppliers. The small size gives suppliers the opportunity to use one solution in a wide variety of models that employ different rim sizes.

As part of NXP's highly integrated sensing solutions, the FXTH87E TPMS family takes this design approach to the next level. The newest single-package design contains:

- Pressure sensor
- Temperature sensor
- Accelerometer
- MCU
- Radio Frequency (RF) transmitter
- Low Frequency Receiver (LFR)
- Software

The FXTH87E TPMS sensing capability comes from:

- Capacitive pressure sensor
- Temperature sensor
- Optional X-axis and Z-axis accelerometers

Figure 2 shows the CMOS surface micromachined pressure sensing P-cell and XZ, two-axis accelerometer or g-cell in the FXTH87E TPMS.

FXTH87E TPMS



Figure 2: CMOS surface micromachined pressure sensor P-cell in the film assisted molding cavity.

Essential Aspects of a Package-Level TPMS Solution

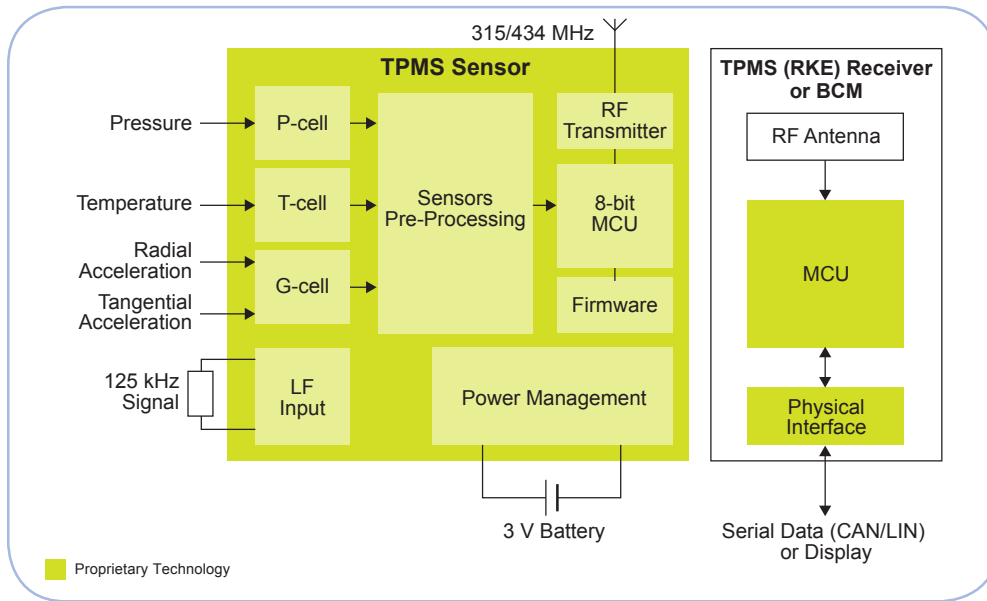


Figure 3: The critical aspects of a TPMS solution include sensing, processing, data transmission and power management technologies.

Typical power consumption of the FXTH87E TPMS is 5 mA at 434 MHz @ 5 dBm (dBmW), and only 180 nA in stop mode. A variety of stop modes allows programmers several options for optimal performance versus current consumption tradeoffs. The MCU integrates both LF and RF communication technologies. The LFR consumes very low power while receiving low-frequency signals for short range communication in TPMS. The internal 315/434 MHz RF transmitter in the FXTH87E TPMS consists of an RF module (RFM) with crystal oscillator, voltage controlled oscillator (VCO), fractal-n phase locked loop (PLL) and RF output amplifier (PA) for an antenna. It also contains a small state machine controller, random time generator and hardware data buffer for automated output or direct control from the MCU. The overall system block diagram shown in Figure 4 identifies other system aspects including analog to digital conversion (ADC), sensor interfaces, RF amplification and a variety of timer and memory blocks.

System Level Blocks for TPMS

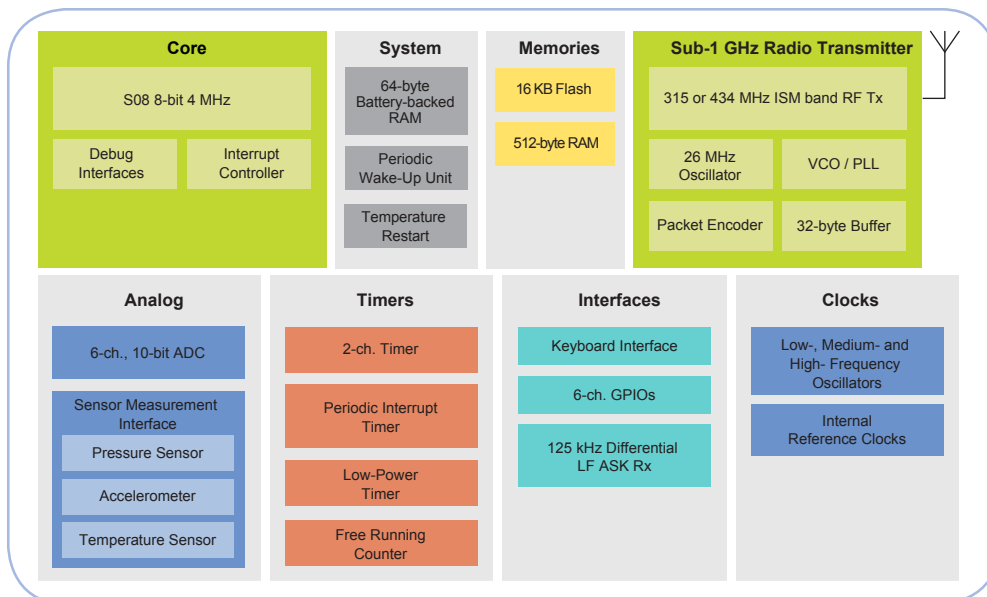


Figure 4: The FXTH87E block diagram shows the variety of system level blocks for TPMS.

FXTH87E Provides TPMS Design Flexibility

Standard Part Number	Pressure Range - kPa	Pressure Tolerance -40°C to 85°C	Axis of Acceleration	Z-axis Range - g's	Z-axis Tolerance @ 0g -40°C to 125°C	X-axis Range - g's	X-axis Tolerance @ 0g -40°C to 125°C
Standard Tolerances							
FXTH87EG02DT1	100 to 500	±5 kPa	Z	-285 to +400	±7 g	NA	NA
FXTH87EH02DT1	100 to 900	±5 kPa	Z	-285 to +400	±7 g	NA	NA
FXTH87EG11DT1	100 to 500	±5 kPa	XZ	-215 to +305	±5 g	-80 to +90	±4 g
FXTH87EH11DT1	100 to 900	±5 kPa	XZ	-215 to +305	±5 g	-80 to +90	±4 g
FXTH87EH12DT1	100 to 900	±5 kPa	XZ	-285 to +400	±7 g	-80 to +90	±4 g
Precision Tolerances							
FXTH87EG026T1	100 to 500	±5 kPa	Z	-285 to +400	±3 g	NA	NA
FXTH87EH026T1	100 to 900	±5 kPa	Z	-285 to +400	±3 g	NA	NA
FXTH87EG116T1	100 to 500	±5 kPa	XZ	-215 to +305	±3 g	-80 to +90	±3 g
FXTH87EH116T1	100 to 900	±5 kPa	XZ	-215 to +305	±3 g	-80 to +90	±3 g
FXTH87EH126T1	100 to 900	±5 kPa	XZ	-285 to +400	±3 g	-80 to +90	±3 g

Table 2: Orderable TPMS parts with accelerometer axes and pressure ranges.

The low-power, surface micromachined capacitive pressure sensor's pressure p-cell, provides precise measurements to cover the requirements from small passenger vehicles, to performance vehicles and large sport utility vehicles (SUVs). The latest FXTH87E TPMS family is offered as described in table 2 above. The legacy FXTH87 TPMS family is offered in pressure ranges up to 1800 kPa (up to 260 psi) for commercial vehicle applications.

The capacitive pressure sensor requires only 0.14 μ A supply current (3 V, 30 KHz) and 0.9 nano-amp-second (nAs) minimum charge per reading. As shown in Table 2, when combined with the accelerometer options, the FXTH87 provides considerable TPMS design flexibility.

As shown in Figure 5, 24 pin, 7 x 7 QFN (quad-flat no-leads) packages are commonly available for FXTH87 TPMS products. This system-in-package solution optimizes board size, potting material and weight savings.

Standard TPMS Packages



Figure 5: Standard TPMS packages include 7 x 7-mm QFN.

Ongoing TPMS Enhancements

Active industry research and other technology advances as well as new regulations promise to change the requirements for the capabilities of future TPMS systems. Displaying more information about the health of the vehicle, specifically as it relates to tires, will require carmakers to acquire and transmit data more frequently. Integration with other systems, the use of energy harvesting, dual-axis accelerometers, airless tires and regulation changes such as an expanded frequency range are already being discussed.

Tier one system manufacturers have introduced products that integrate TPMS with other vehicle systems. Stability control systems could take advantage of the additional information that TPMS provides.

Stability control will require sensor fusion to integrate TPMS data with data from other vehicle sensors. NXP's sensor fusion capability can provide raw data in the appropriate format for other vehicle system's usage.

Energy harvesting technology that extracts electrical energy from the vibration of the tires could avoid the replacement or significantly extend the life of batteries that power TPMS nodes in each tire. Energy harvesting could enable other TPMS advances.

Today, TPMS data is transmitted at very slow intervals and is only useful to determine decreasing tire pressure. The integration of tire pressure data into stability control would require more frequent transmission of greater amounts of data which would significantly reduce the battery life of existing designs. Energy harvesting would enable much higher data rates without requiring more frequent battery replacement. NXP is exploring the implementation of emerging energy harvesting techniques to TPMS.

Dual-axis accelerometers as well as 3-axis accelerometers are commonly used in consumer electronics for motion detection. However, most of today's tire pressure monitoring systems use a single g-cell. With dual-axis accelerometers, TPMS manufacturers can identify a specific tire, a process called localization. Some TPMS manufacturers may require 3-axis capability.

For example, China TPMS regulations include an option requiring a display for each tire if it was changed from one location to another because of tire rotation or a problem. Today, specific tire localization requires driving the vehicle, so systems can poll each tire and determine where each one is located.

The use of dual-axis accelerometers covers almost all localization schemes. In contrast, single-axis accelerometers are restricted in their applications.

Airless tires could dramatically disrupt TPMS implementation. Tire manufacturers are trying to develop airless tires and within the next five to ten years these tires could start to appear on production volume vehicles. However, until airless tires become the norm, carmakers will have to rely on TPMS technology to maintain the correct air pressure in inflated tires. Airless tires will require tire monitoring systems that will need to measure the forces and loads applied to the tires.

Regulation changes, such as using a higher frequency in the industrial, scientific and medical (ISM) band than the crowded 434 MHz, are being proposed. Either China or Taiwan may change to 835-875 MHz. As new frequencies are established, NXP has transmitters that operate in the new frequency range, including 2.4 GHz ISM.

In conjunction with leaders in the automotive market, NXP's ongoing developments in TPMS applications continue to explore greater use of the system-in-package technology for cost effective, time-reduced designs at TPMS suppliers.

Driving More Safely and More Efficiently

Tire pressure monitoring systems have demonstrated the capability to improve vehicle safety and provide greater fuel economy, which in turn reduce CO2 emissions. With reduced tire wear for longer tire life and more consistent ride quality as additional benefits, these systems should not need government regulations to provide value to vehicle buyers. However, the regulations exist and continue to grow in all regions of the world. The added stimulus from regulations provides highly predictable market growth and a high degree of competition among TPMS suppliers.

NXP pioneered the initial system-in-package technology for TPMS in 2003. The recent advancements in the FXTH87E TPMS have taken this design approach to the next level. The pressure range, accelerometer axes, packaging and other options make the FXTH87E TPMS an easy design-in solution to meet even the most sophisticated TPMS requirements in every region of the world today.

With the automotive market as a key driver for NXP, TPMS expertise has gone beyond expert discussions at the system level with customers to integrating our technologies into a single package. This not only takes advantage of our silicon level experience in several areas, it adds software expertise acquired through research and development in several other system areas including sensor fusion. The end results are highly-integrated system solutions that are specifically demonstrated in tire pressure monitoring systems.

References

1. Source: Strategy Analytics, Jan. 2018

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