MEMS Performs Under Pressure

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Tire pressure monitoring systems (TPMS) are electronic systems that monitor air pressure inside pneumatic tires. TPMS senses and then transmits tire-pressure information via wireless communication.

TPMS provides several benefits. It increases safety by reporting under-inflated tires that could compromise vehicle handling or cause the tire to fail unexpectedly. Consequently, TPMS is now part of the mandatory equipment for passenger cars in most developed countries.

TPMS also increases fuel efficiency by reducing rolling resistance, and thus reduces vehicle emissions. Proper tire inflation also save money by reducing tire wear and fuel consumption. These additional benefits are spurring installation of many TPMS in commercial vehicles, e.g. heavy trucks and school buses, even in the absence of regulatory mandates.

TPMS in commercial vehicle has to withstand much higher tire pressure than in passenger cars. Indeed, to accommodate the commonly overloaded trucks in developing countries, commercial TPMS should withstand 1500 kPa; making it the highest pressure application in which MEMS sensor is serving today.

In this article we will describe challenges designing, testing, and verifying TPMS systems designed to measure the higher pressure found in truck tires.

How does it work?

TPMS contain tiny sensors called Micro Electro Mechanical Systems (MEMS). These MEMS combine mechanical and electrical functions on a silicon chip about one square millimeter. This system described here uses capacitive sensing: thin diaphragm that deflects under pressure and this in turn causes changes in capacitance.

Figure 1 shows an overview of capacitive pressure operation. A few microns thick polysilicon diaphragm covers cavity containing vacuum. Under the diaphragm is a bottom plate also made of polysilicon. Changes in pressure deflect the diaphragm and affect the gap between the diaphragm and bottom sense plate. This gap change causes the capacitance between these plates to change, and separate IC converts this capacitance to a pressure reading. The MEMS die contain several of these diaphragms, each less than the width of a human hair (75 micron).

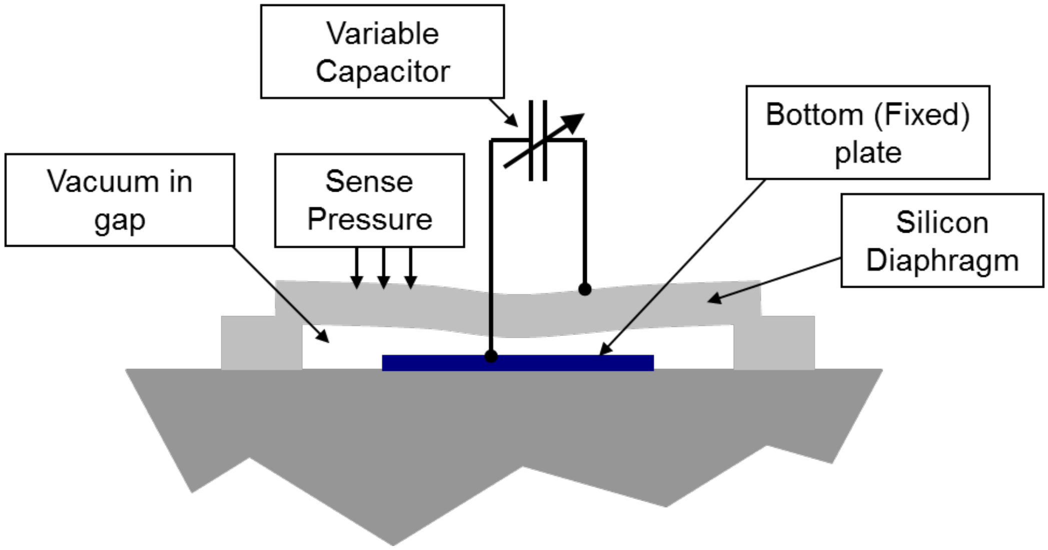

Figure 1: Simplified cross section of capacitive pressure sensor P-Cell.

Various Finite Element Analysis (FEA) tools are typically used to simulate the performance of MEMS devices. For example pressure sensing for TPMS is usually achieved with a deflecting membrane. Figure 2 is a top view of membrane under pressure. The edge area shown in red is fixed and therefore stationary while middle portion is suspended and deflects under pressure. MEMS simulations are used to determine pressure sensor operation over operating pressure range and to ensure reliable pressure sensor function after extreme conditions exposure such as over-pressure, over-temperature and mechanical shock.

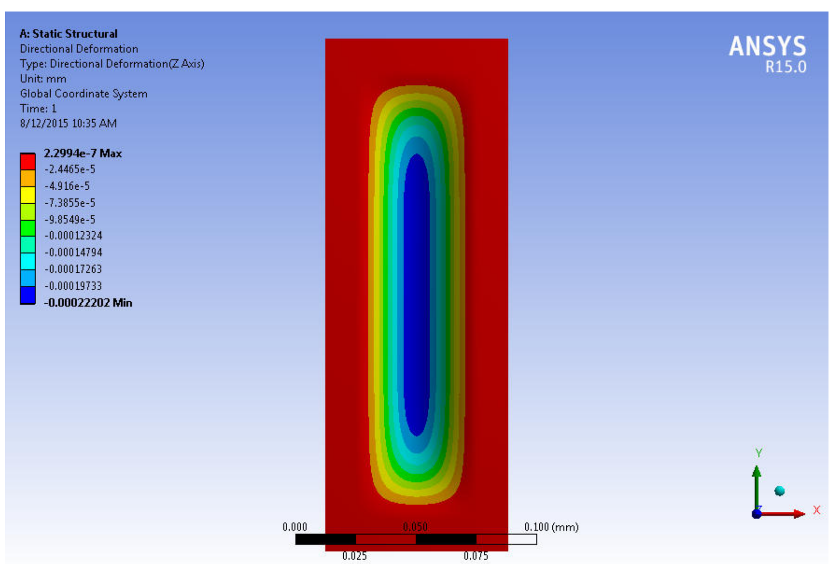

Figure 2: Top view of pressure sensor deflected under pressure. Contours indicate diaphragm deflection in microns.

All of this requires low power operation since the TPMS device needs to operate five or more years on a small battery. Capacitive sensing is well suited for low power operation as these sensors use very low current during operation. Capacitive transducers are also not significantly affected by temperature.

A typical TPMS sensor must operate under very harsh conditions. These include:

- Truck Tire Pressure: The ability to measure typical truck pressure tire pressure 1500 kPa (about 200 PSI), but must survive over-pressures of up to 1500 kPa (about 363 PSI).
- Extreme operating temperature ranging from harsh winter temperatures of -40°C to the higher operating temperatures of +125°C.
- Road conditions such as potholes, speed bumps, and road vibrations where mechanical stresses can approach 6000 g
- Inside tire media that potentially can contain water, dirt, and a wide variety of chemicals

TPMS devices measure pressure but provide other capabilities. Figure 3 shows a typical implementation. A MEMS sensor to measure acceleration is provided to determine whether the vehicle is moving, and to facilitate detection regarding which tire is low in pressure. A temperature sensor is also included. This system is controlled by a programmable 8-bit MCU.

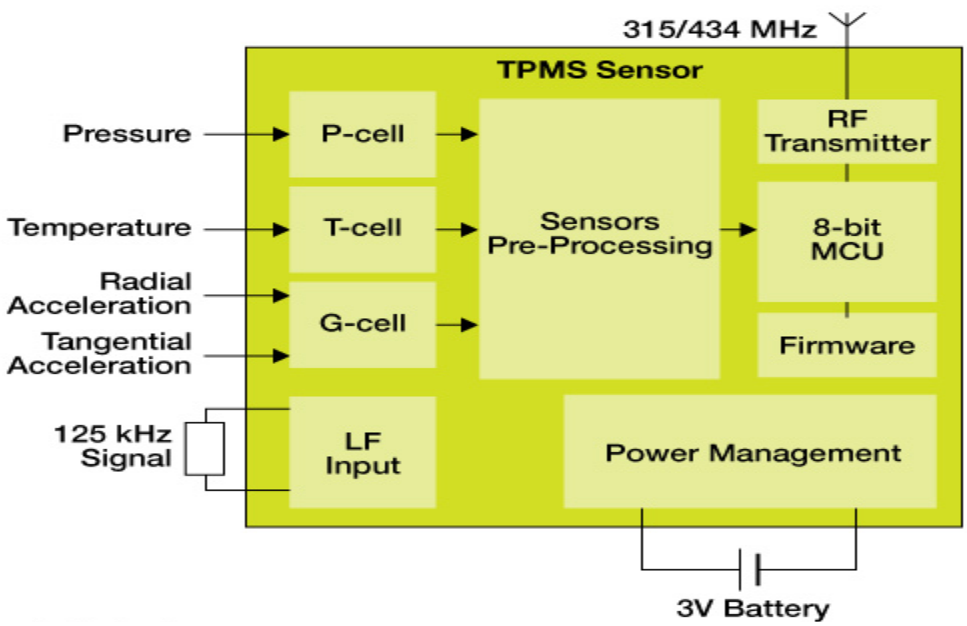

Figure 3: Tire implementation

Making sure it works

The TPMS Qualification Standards require passing a large number of tests that are designed to accelerate environmental and lifetime stresses, validate package assembly integrity, verify electrical integrity, verify robustness to various media exposure and cavity package integrity. Tests associated with each of these groupings are shown in Table 1 below.

Some of the more rigorous tests are Preconditioning, High Temperature Operating Life Pressure (HTOLP), Temperature, Humidity, Bias (THB), Temperature Cycling (TC), Thermal Shock, Rapid Decompression (RDE) and Centrifuge. Each of these tests is performed to simulate a lifetime of stress in few weeks.

Accelerated Environmental	Acronym
Pre Conditioning	PC
Temperature Cycling	TC
Temperature Humidity Bias	THB
Highly Accelerated Stress Test	HAST
Low Temperature Storage	LTS
Cycled Temperature Humidity Bias	CTHB
Low Temperature Storage	LTS
Low Air Pressure Storage	LAPS

Accelerated Lifetime	Acronym
Early Life Failure Rate	ELFR
High Temperature Operating Life with Pressure	HTOLP

Media Tests (Examples)	
Engine Oil	
Automatic Transmission Oil	
Diesel Fuel	
Brake Fluid	

Package Assembly Integrity	Acronym
Wire Bond Shear	WBS
Wire Bond Pull	WBP
Solderability	SD
Physical Dimensions	PD

Electrical Verification	Acronym
Parametrics	P
ElectroStatic Discharge	ESD
Latch Up	LU
Elecrical Distribution	ED
Gate Leakage	GL

Cavity Package Integrity	Acronym
Mechanical Shock	MSUP
Centrifuge	Centrifuge
Variable Frequency Vibration	VFV
Drop	Drop
Rapid Decompression	RDE
Pressure Cycling	PC
Over Pressure	OP

Table 1: Listing of some tests associated with the TPMS system.

- The Preconditioning test is used to measure the ability of the device to resist the worst case moisture absorption followed by one solder cycle and two rework cycles. Before devices are subjected to THB, TC, Thermal Shock or any other Highly Accelerated Stress Test (HAST), the devices must be subjected to preconditioning and pass a post stress electrical test.
- The HTOLP test is used to determine the reliability of the TPMS system by accelerating failure mechanisms that are activated by heat and pressure. The parts are are subjected to elevated temperatures under bias.

- The THB test is an environmental test designed to accelerate corrosion and dendritic growth. The duration of the test is 1008 hours with readouts at 168 and 504 hours during testing. The stress temperature is 85°C and relative humidity is 85%. Typically the bias voltage is the maximum operating voltage of the device.
- The TC test is used to accelerate fatigue failures within the device packaging system. Typical failures include wire bond failures, package cracking and die cracking. The specific characteristics of the temperature ranges, ramp rates and soak times are defined by industry standards.
- Thermal shock testing is similar to temperature cycling except that in thermal shock testing, the parts are subjected to sudden changes in temperature with aggressive ramp rates. This test creates failures due to temperature transients and temperature gradients.
- RDE testing models the device exposure to a rapid change in pressure from tire pressure to ambient air pressure.

Going forward

TPMS has always been one of the most advanced sensing systems produced in large volumes. The system includes a two-axis MEMS accelerometer, MEMS pressure sensor, a microcontroller, an RF transmitter and a temperature sensor, all housed in a 7 mm × 7 mm × 2.2 mm package (see Figures 3) and must operate on a single coin cell battery for 7 to 10 years.

With the latest innovation in MEMS pressure sensor design, TPMS is now available not just for passenger cars but also deployed in trucks, busses, and larger vehicles. The same safety, fuel efficiency, and cost savings reasons exist for many cases. The list TPMS of applications is growing, possible future applications include motorcycles, bicycles, and industrial vehicles.

But these TPMS devices can offer much more. Sensor Data Analytics is the science of examining raw data with the purpose of uncovering insights and drawing conclusions. This science can now also be applied to raw sensor data gathered by TPMS devices. Current TPMS devices are mainly used to sense pressure in a tire, but since acceleration and temperature readings are also available, all this information could be used to warn a driver is driving dangerously or to enhance safety and fuel efficiency even further.

Concluding remarks

TPMS technology has advanced and now has pressure range and ruggedness for truck tire pressure sensing. This sensor targets higher pressures used in truck tires, and includes a two-axis MEMS accelerometer, MEMS pressure sensor, a microcontroller, an RF transmitter and a temperature sensor. It is all housed in a 7 mm × 7 mm × 2.2 mm package (see Figure 4).

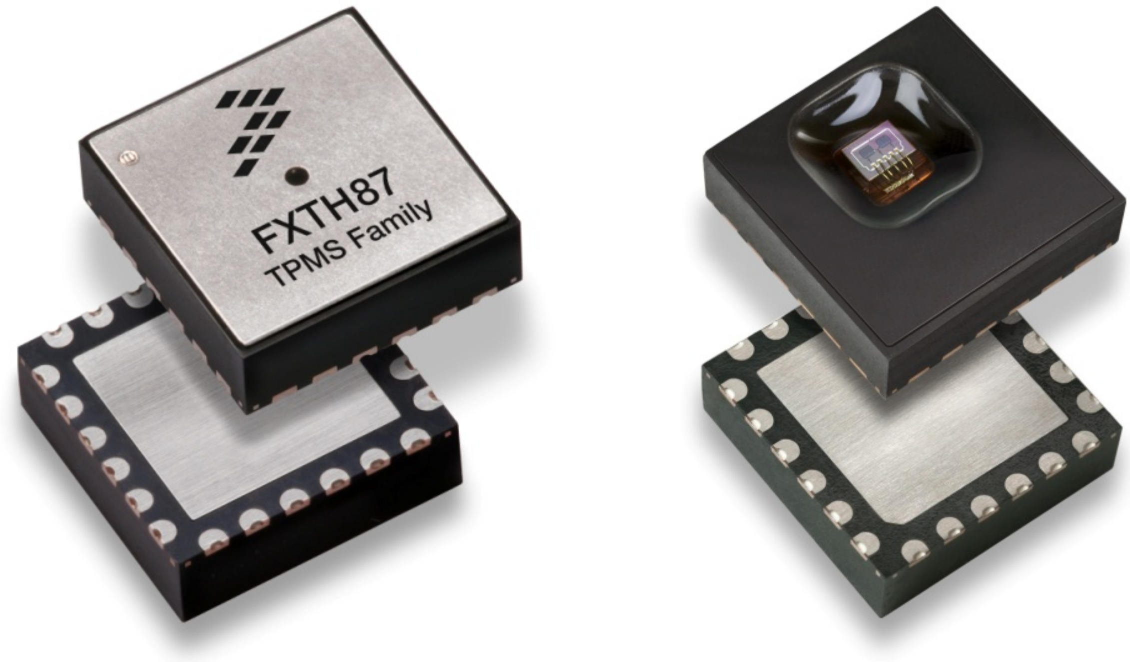

Figure 4: TPMS pressure sensor for truck-tire pressure sensing. Entire sensor package is 7mm × 7 mm × 2.2mm.