Silicon Friendly Materials and Device Solutions for Microenergy Applications

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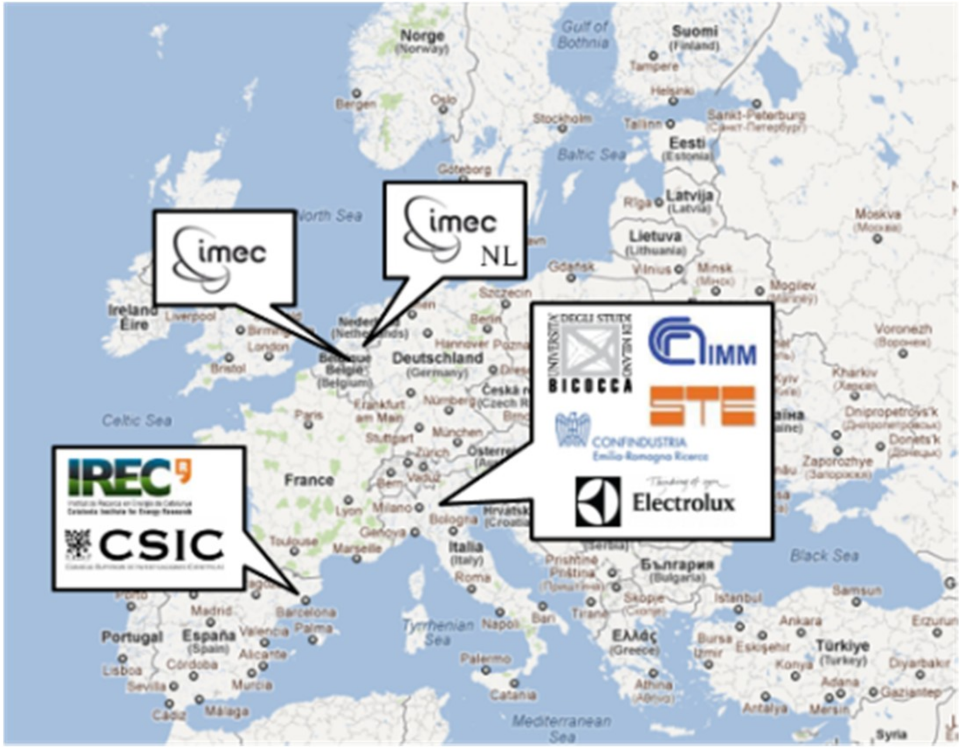
SEVENTH FRAMEWORK PROGRAMME

- **Goal:** Silicon materials and Silicon technologies & architectures for long term autonomy microenergy solutions
- **Focus:** (**1**) Technology development at device level (2) Systems integration feasibility
- **Devices**: (1) Harvesters based on thermoelectrics (2) Harvesters based on mechanical vibrations (3) thin film / 3D batteries
- Application scenarios: (1) Tire Pressure Monitoring (2) Appliances Monitoring

- **Why microenergy solutions:** Replace primary batteries (cost, environmental, deployment flexibility issues) by harvesters + secondary batteries
- **Why Silicon materials and architectures:** tap into the micro-nanoelectronics field which is an enabling technology, dealing with miniaturized and high density features (3D) implementations, offering economy of scale (serve mass markets) and the possibility of integration and addition of control and smartness
- **Why such applications:** complementary micro-energy test-beds from the perspective of silicon benefits ('smaller is better', 'cheaper is better') and availability of energy harvesting sources

Appliance Monitoring

Tire Pressure Monitoring



N.9 Partners (E, I, B, NL)
Coordinator: CSIC (IMB-CNM)

- **Tire pressure monitoring system (TPMS)**
  - *STE, Imec-NL*
  - Clear case for vibration energy harvester (electrostatic)
  - Large market driven by legislation
  - Sensors: pressure and temperature
  - Low power consumption
- **Professional appliances: gas powered fryer**
  - *Electrolux, CSIC, UNIMIB, CNR, IREC, STE*
  - High temperature gradient → thermal harvester
  - Sensor: temperature
  - No electrical connection
  - Temperature monitoring (food safety)

EU approach to research and market

EU demand to industrial and scientific frameworks:

Contribution to economic growth.

Enabling technologies addressing societal changes.

Economical downturn requires:

1. New approach to scientific research.
2. Product-oriented research for usability in real world.
3. Joint action between research and industry.
4. **SiNERGY**

system's integration.

Fusion of EE MicroDevices and EE Telemetry.

Domains: (i) Tires, (ii) Industrial Appliances.

Scientific approach: Energy Efficiency and System Authonomy.

Market approach: Smart deployment and easy maintenance.

Economic sustainability: business-oriented approach to product.

Quality approach: Qualification and Product's certification.

1. From greek **Tele** = "remote" and **metron** = "measure".
2. **Telemetry**: process to measure data in inaccessible points.
3. And transmit them to receiving devices for monitoring.

A tire is a remote and inaccessible point.

Concept of Autonomous WS

- **World of sensors**: driven by constant breakthroughs.
- **Areas: Autonomous sensors deployed in the ambient.**
- The concept of AWS originated at the NASA Jet Propulsion Laboratory (JPL) in the late 1990s (K.A. Delin et al.2005).

3 domains of research:

- Atmospheric Studies (Carbon Cycle).
- Ocean Studies (Run-Off).
- Land Management (Agricultural).

Dr. Kevin *Delin*, leader of the Sensor Webs Project at *JPLab*

Theory of the pervasiveness of AWS:

- First example of Internet of Things.

AWS must have at the least:

1. Processing autonomy – (Microcontroller).
2. Communication autonomy – (Radio function).
3. Energy autonomy – (Battery or whatever else).

Paradigm work out:

1. Low power, Autonomous and «Maitenance free».
2. Small in mech form factor.
3. Low cost and full disposability feature.

Concepts: AWS and EEWS.

Objectives of SiNERGY

Fusion:

EE and A feature to generate eeAWS devices.

Domains:

Tire Pressure Monitoring (TPMS in tire carcass).
Predictive maintenance in professional appliances.

Why:

1. **Legislation driven tech.**
2. **Environment driven app: the societal stream.**

Less chemical disposal (landfills/RoHS directive).
Check pressure = less fuel consumption (5 gallons wasted/day).
Reduction of CO2 emissions.
Environmental diversity preservation (less chemical disposal).

TPMS: Legislation Driven Tech

- **TREAD Act**
- Passed by Congress in 2000 in response to fatal accidents caused by defective Firestone tires
- Primary purpose: **Safety**
- Phase-in 20/70/100% (100% since September 2007)
- Notification whenever pressure drops **25%** below the recommended **cold** inflation pressure
- Detection time: **20 minutes**

- **UNECE 64**
- Implementation will start Nov 1, 2012 for vehicles "Type approved" after this date, and Nov. 1, 2014 for all new vehicles
- Primary purpose: **Environmental**
- Notification whenever pressure drops **20%** below the recommended **warm** inflation pressure
- Detection time: **10 minutes** (one wheel) / 60 minutes (more than one wheel)
- Winter wheel legislation also passed in several European countries

- In March 2011, the South Korean Ministry of Land, Transport and Maritime Affairs revised the South Korea Motor Vehicle Safety Standards to mandate TPMS on all vehicles with a gross vehicle weight of 4.5 metric tons (9,921 lbs) or less
- Timing two months behind that of Europe, with the phase-in beginning in January 2013 and completed by January 2015
- Expected to mirror UNECE 64

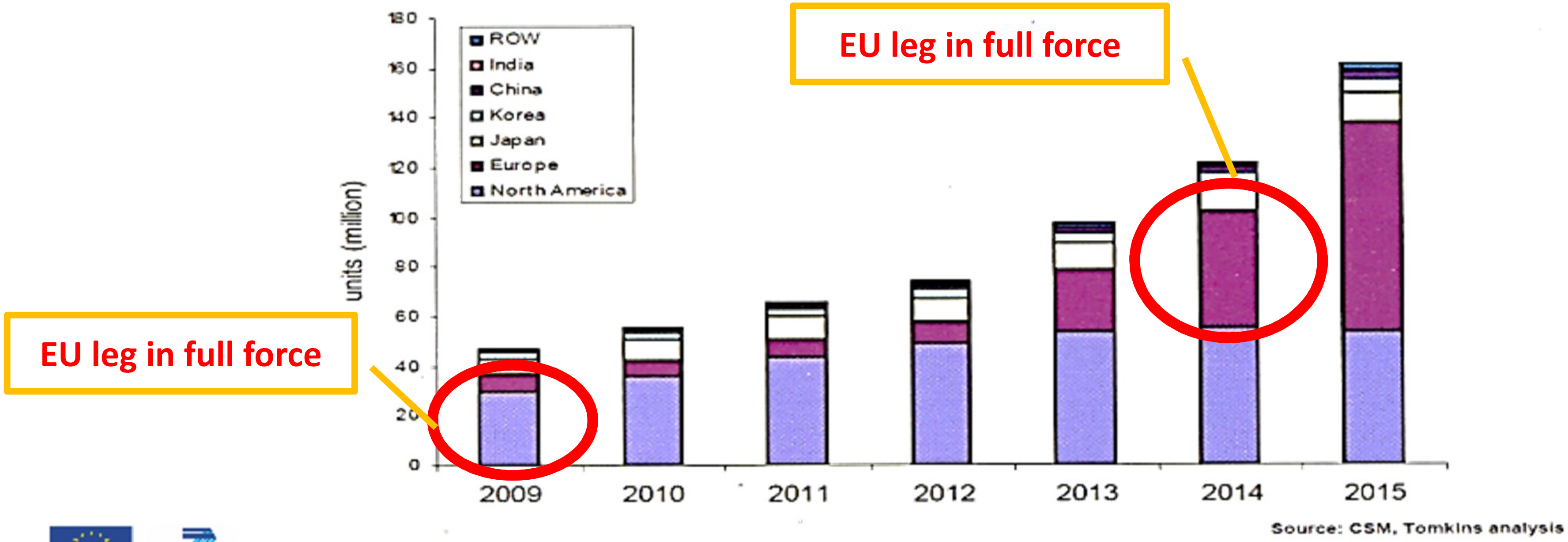
- Safety & Emissions have benefit of TPMS in vehicles (US legislation mandating their use in all vehicles- FMVSS138)
- Japan China and perhaps India to follow soon.
- European UNECE 64 already in force: more stringent than Federal Motor Vehicle Safety Standards 138 (FMVSS13).

Market impact of TPMS legislation

Communication autonomy in vehicles is at an early stage.

Number of WS in a vehicles is relatively low.

The newly introduced TPMS is the only WS in a vehicle.



Target Application Scenario

1. TPMS Between '90 and 2013

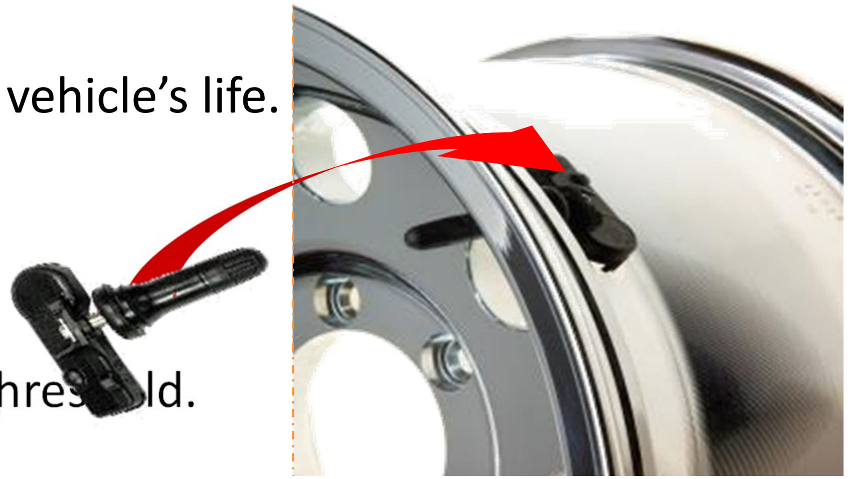
– Lithium Battery operated (CR or HR)
– Temp range: -20 + 80 C°
– Attached to Rim.
– Difficult to fit at OE and tire-workshop level.

2. Overall authonomy:

– OE requirement: 7 – 10 years to meet vehicle's life.
– Exceedings tire life.

3. Not suitable for EH use.

– RIM vibration profile before suitable thres[illegible]ld.



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Technological swap

1. eeAWS in Tires >2018

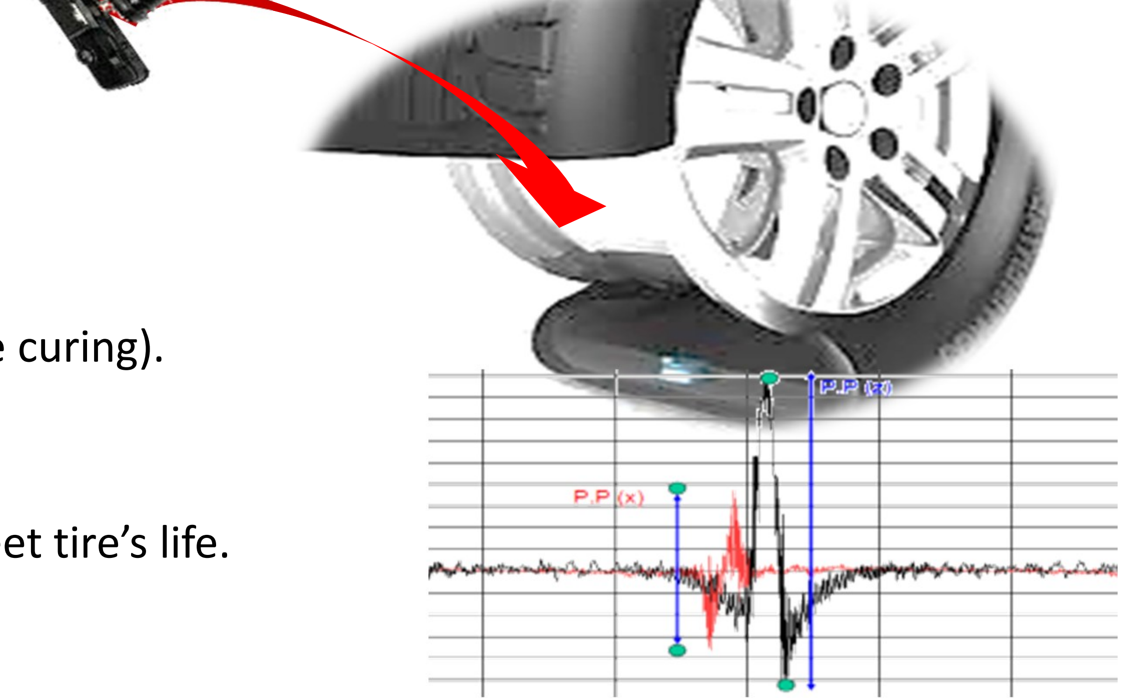
- EH powered
- Temp range: -40 + 125 C°
- Patch attached to innerliner.
- Improved installation (easy tire curing).

2. Overall authonomy:

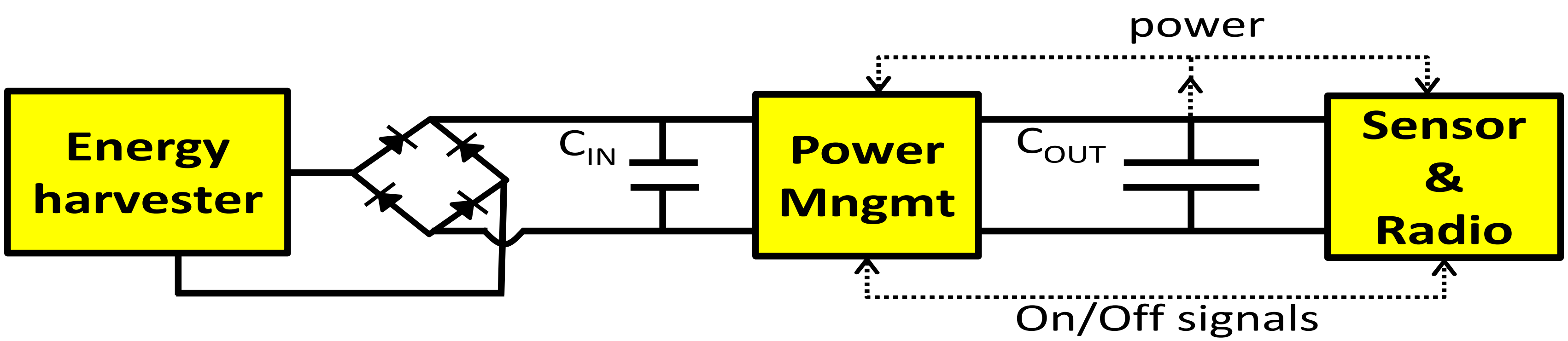
- OE specs. req.: 3-4 years to meet tire's life.

3. Suitable for EH use.

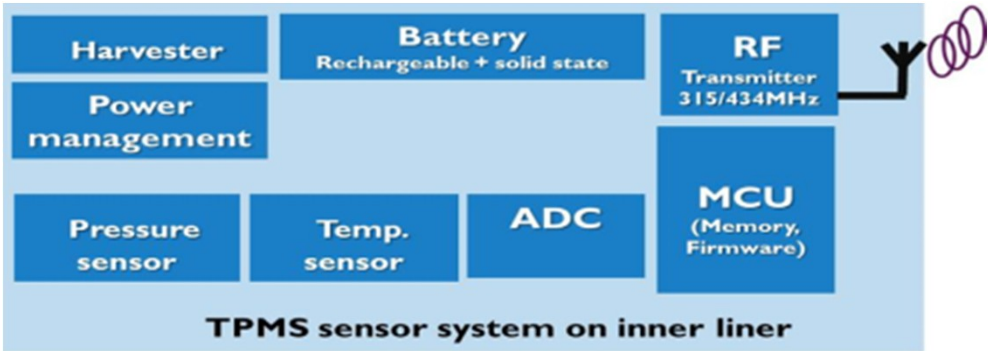
- Tire shock profile threshold to meet energy requirements.
- Peak to peak acceleration enough to trigger cold start.



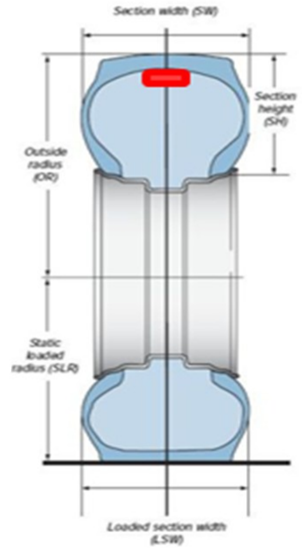
Shock profile in tire thread


power
Energy harvester
C_{IN}
Power Mngmt
C_{OUT}
Sensor & Radio
On/Off signals

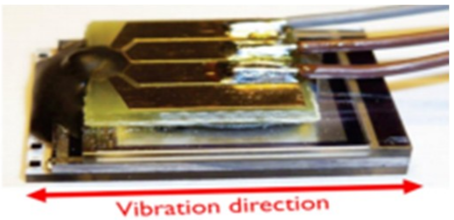
- System architecture TPMS
  - Tire as vibration source: electrostatic energy harvester
  - RF module
    - Low power operation
  - System with capacitors

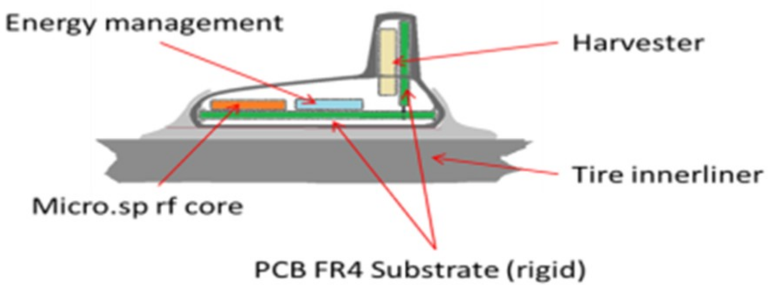


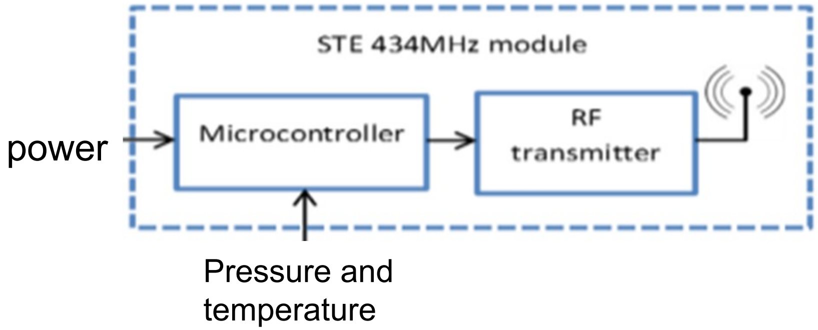
- Integration TPMS module
  - Mounted on inner liner tire
  - Vertical position of harvester
  - Mechanical fixture needs development
    - Robust casing for harvester?
      - 3D printed
      - Molded
    - Solder joints?



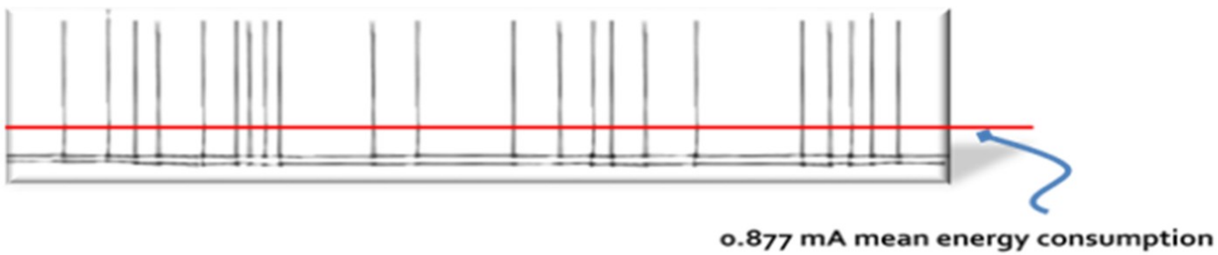
This looks to be future casing and fixing method to be adopted by OEMs.







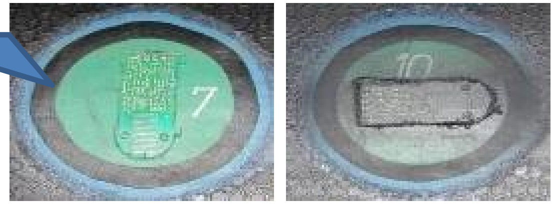
- RF module STE
  - 433MHz radio transmitter
  - Pulse Modulation (4-PPM).
  - 0mA energy consumption of radio block between pulses.
  - 64 bits of transmitted data each message.
  - Micro.sp patented technology from STE will be used
  - Power breakdown
    - Peak power: 75mW
    - Average power during transmission: 2.7mW
    - Average TPMS module power consumption: ~4.0µW (power sensors negligible)



mechanics.

ACTUAL TPMS valve concept

Tire patch TPMS concept



DIFFERENT MECHANICS TO COMPLY TO A DIFFERENT DYNAMIC.

Tire thread attached solutions require system's re-design:

1. > emitted power / > energy efficiency to support > RF radiation.
2. > resistance to stress during tire revolution.
    - New process of fabrication.
3. > resistance to temperature inside tire (>125° C).
    - Component selection to meet higher requirements.

output power vs small mech. Dim.

micro.sp (STE)

Dimensions:

1. 12 X 12 mm (discrete version 0402).
2. Single layer (top layer mount).

TX mode: < 1mA.

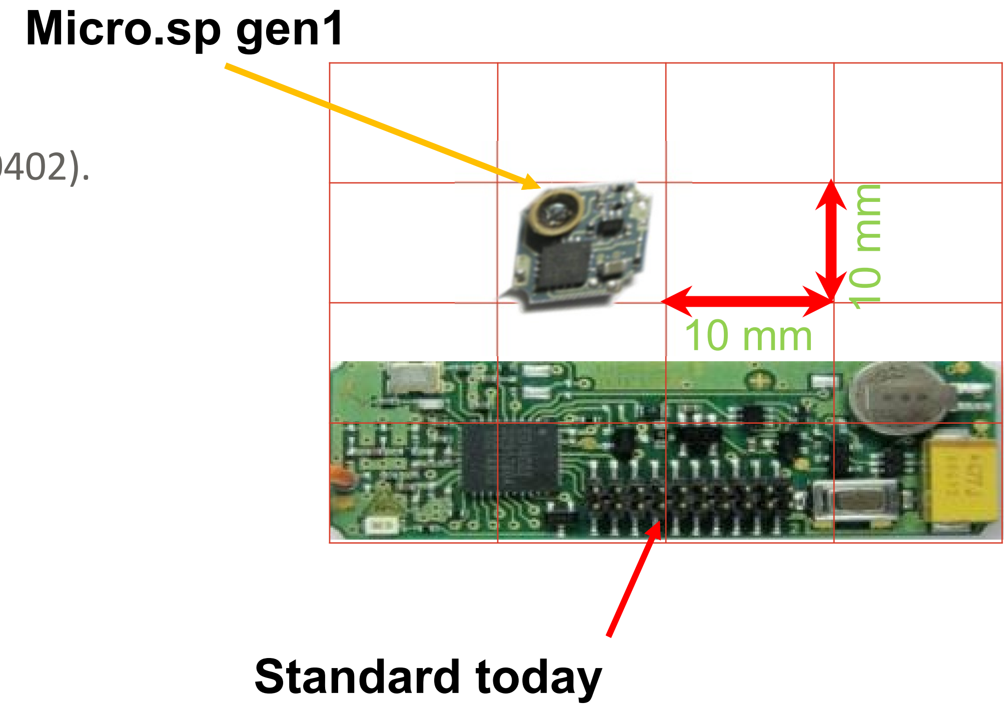
Average current @10s TX rate: <3,5µA

Market TPMS sensor

Dimensions: 43 x 16 x 8 mm

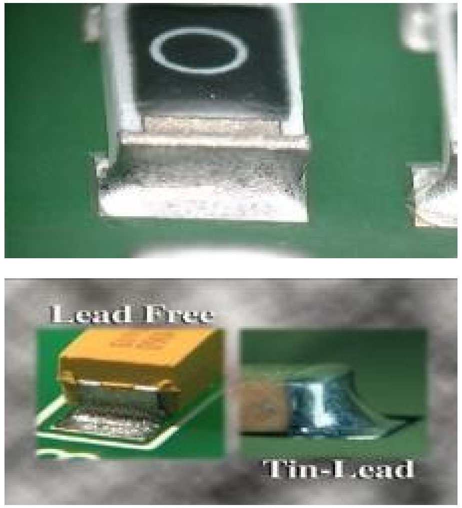
Tx mode: 24 mA

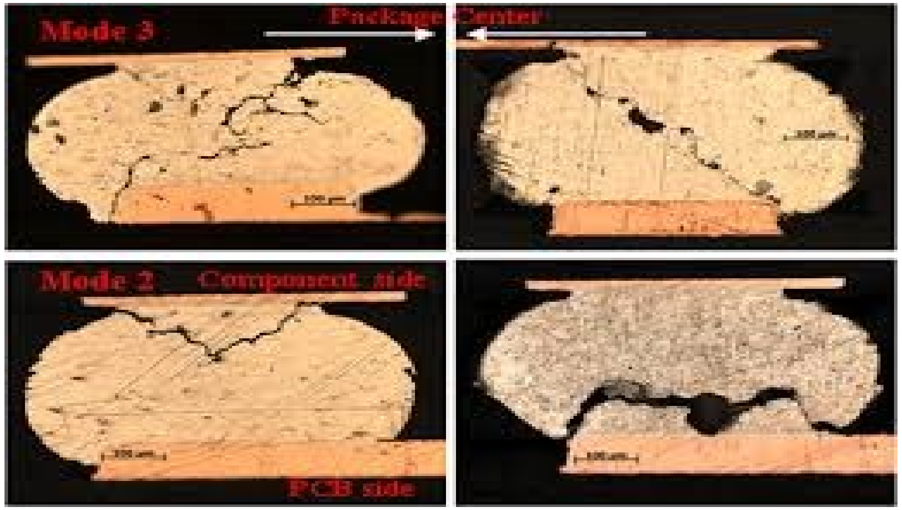
Average current @10s TX rate: ~13,5µA



Automotive compliance to meet robustness in tires

1. Strip lines and interconnections.
2. Solder plate resistance to Temperature profile.
3. Vibration profile andd shock resistance during rolling conditions.





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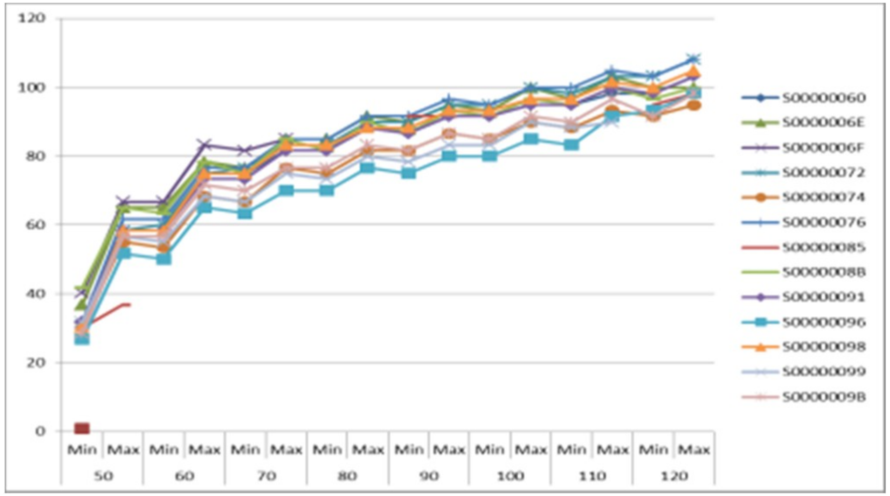
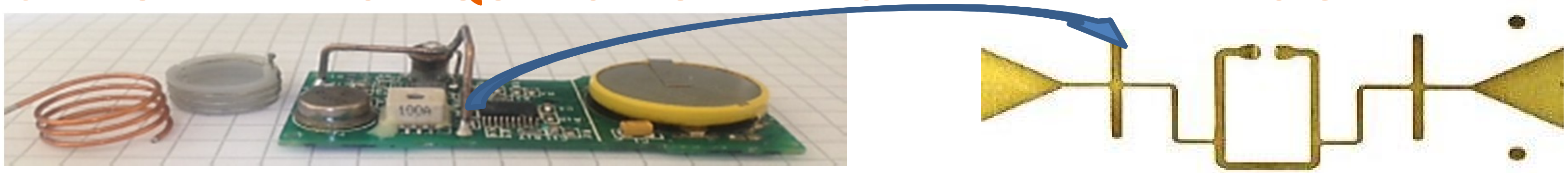
temperature in rolling conditions



1. During testing the sensor temperature was logged.
2. Bead mounted sensors record a lower temperature than the centre line mounted units by up to 20° C.
3. Maximum temperature can be seen to be 95 -110° C when running at >120KPH.

Highly efficient antenna

CARBON IN TIRES REQUIRES MORE EFFICIENT ANTENNA DESIGN.



Rim-based solution antenna does not comply to inner-liner based solutions:

1. Low RF propagation through carbon without RIM ground plane.
2. Antenna is located too close to carbon and tire belts (shielding effect).
3. Inner-liner fitting requires new approach to antenna design for max extension and max robustness.

Tire patch is closer to tire belts:

1. Need more EFFECTIVE RADIATED POWER (ERP).
2. Higher efficiency to save energy (system's life requirements).
3. Higher communication range.

RF PROPAGATION IN TIRE

1. DEV PLAN AND TESTS AT STE LABs

1. Internal valve sensor: on going tests.
2. Important and relevant results:

   A. Tire rig and test jig.
   B. RF propagation.
   C. Antenna design.
   D. Form factor definition.

Attenuation in tyre compounds

1. An accurate measurement of tyre compounds effect on the RF radiation and relative power attenuation was performed.
2. Comparative tests with ERP of rubber coated TX in free space had been done for reference.

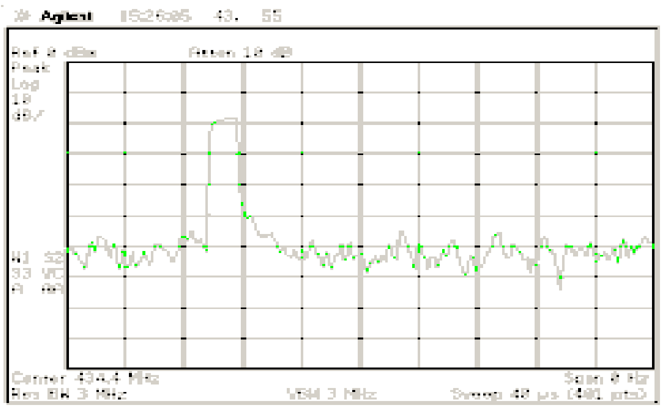


Fig. 1 - ERP from a car tyre: -19 dBm.

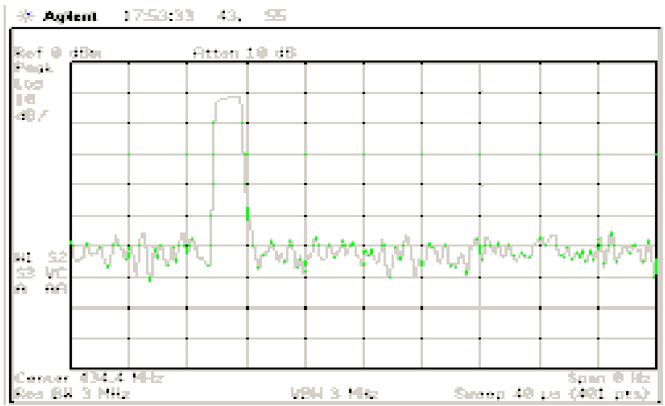


Fig. 2 – ERP Reference level: -11 dBm.

In-tyre RF attenuation: measurements

Fig. 1 – Tyre compound measurement set/up.

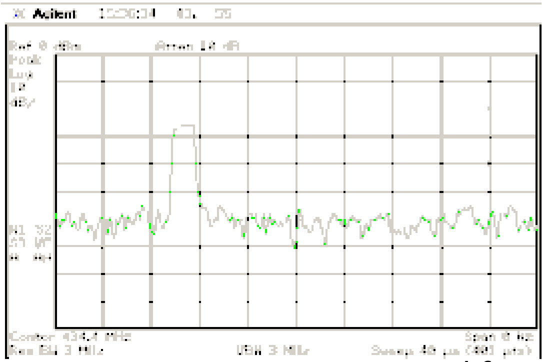


Fig.2 - ERP as measured from a truck tyre: -26 dBm.

1. **Attenuation of passenger tyre = 8 dB.**
2. **Attenuation of truck tyre = 15 dB.**

Tests performed:

1. car tyre attenuation = 9dB.
2. truck tyre attenuation = 19db.

Differences: tyre belt, rubber compound, thickness…

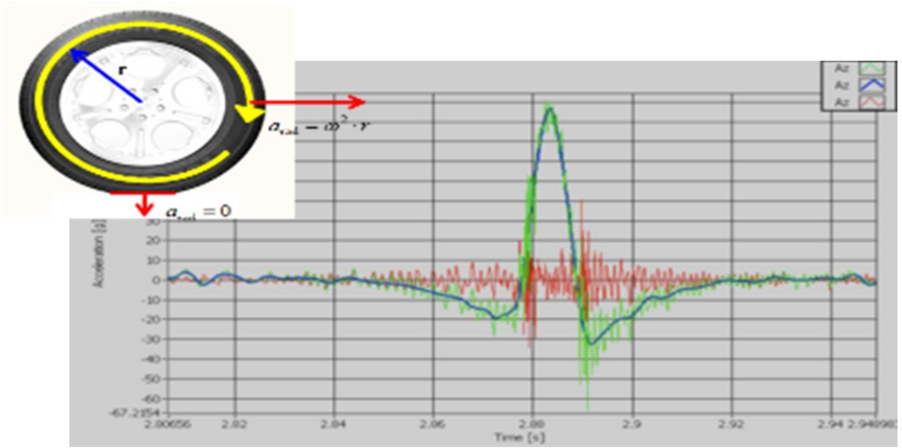
On going investigations:

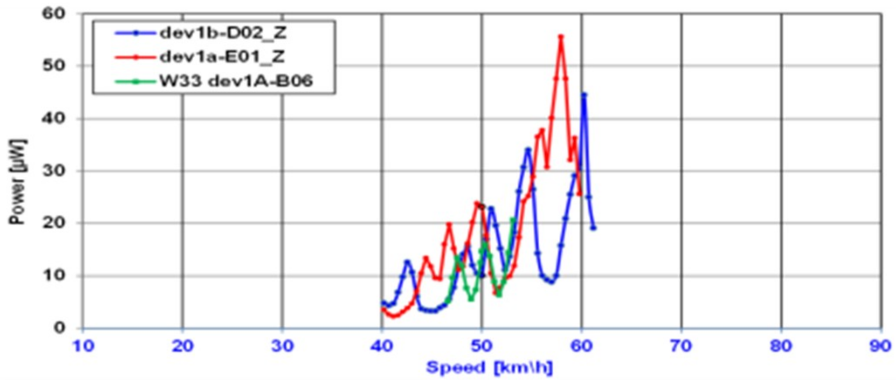
A. Pulse width:
   1. Higher pulse width;
   2. Lower pulse width;

B. Antenna layout:
   1. Magnetic antenna.
   2. Electrical antenna.
   3. Shape optimization against product shape.

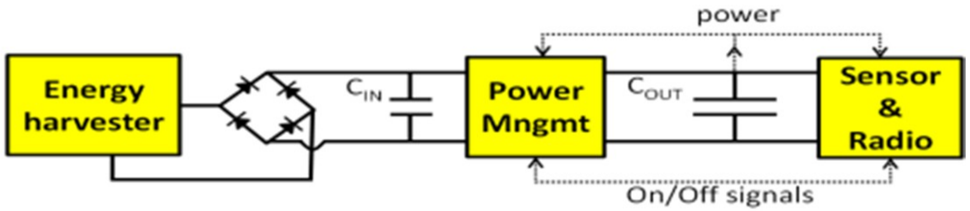
- Tire as vibration energy source
  - Shocks → ring-down signal
  - Test with real measured tire profiles
  - Power output: 10-20µW @ 50km/h

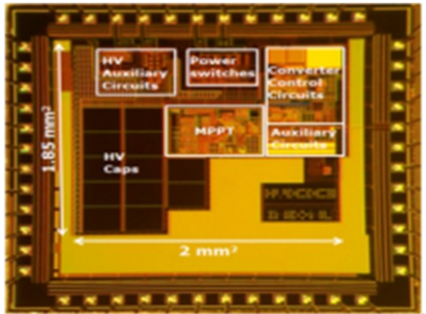
Electrostatic		
Vout/G*	10	V/G
Vout max**	60	V
Acceleration range	5	G
Displacement range	100	µm
P/G²	100	µW/G²
Impedance	~5M	Ω
area	1.2	cm²

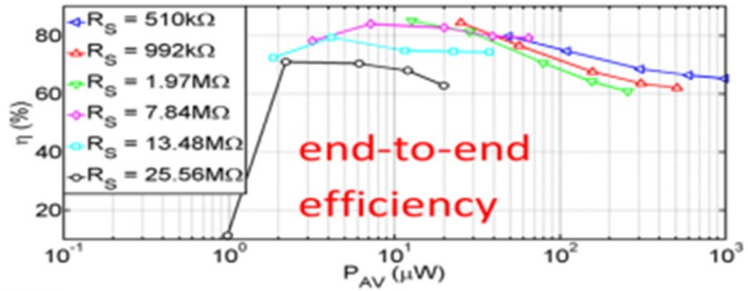




• Power management IC
  – High voltage up to 60V
  – Maximum Power Point Tracking
  – start-up from zero
  – Vout~ 2.5 VDC (settable)







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