History, Applications, and Market Overview of Passive Wireless Sensors

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Outline

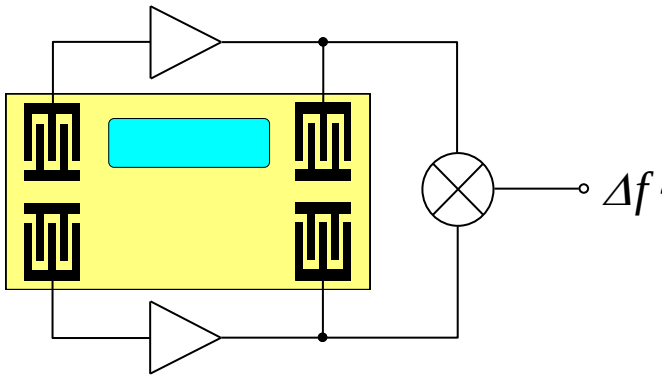
History of passive wireless sensors

Application examples

Market overview

Conclusion

The first Idea: Wolf-Eckhard Bulst



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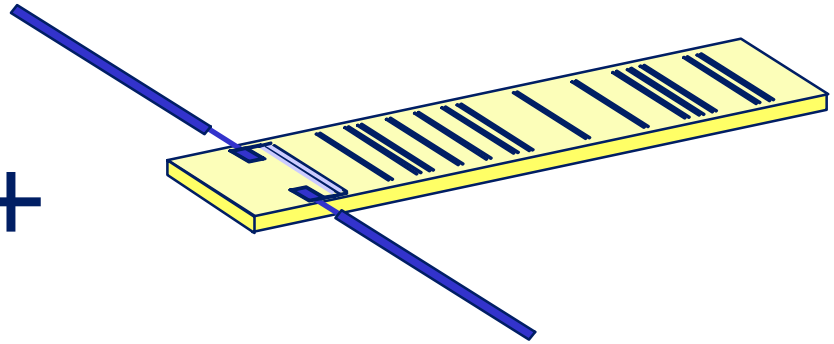
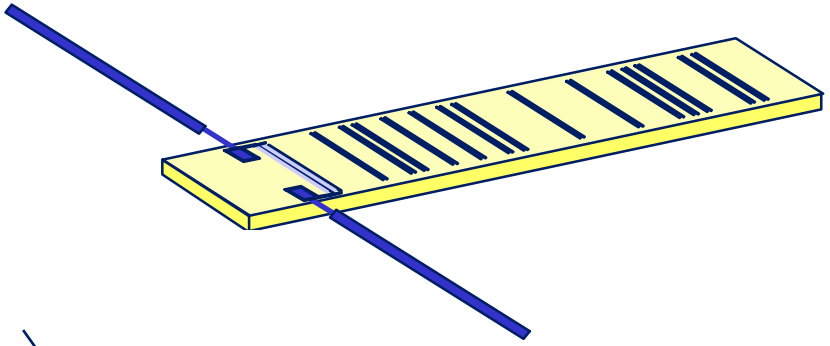
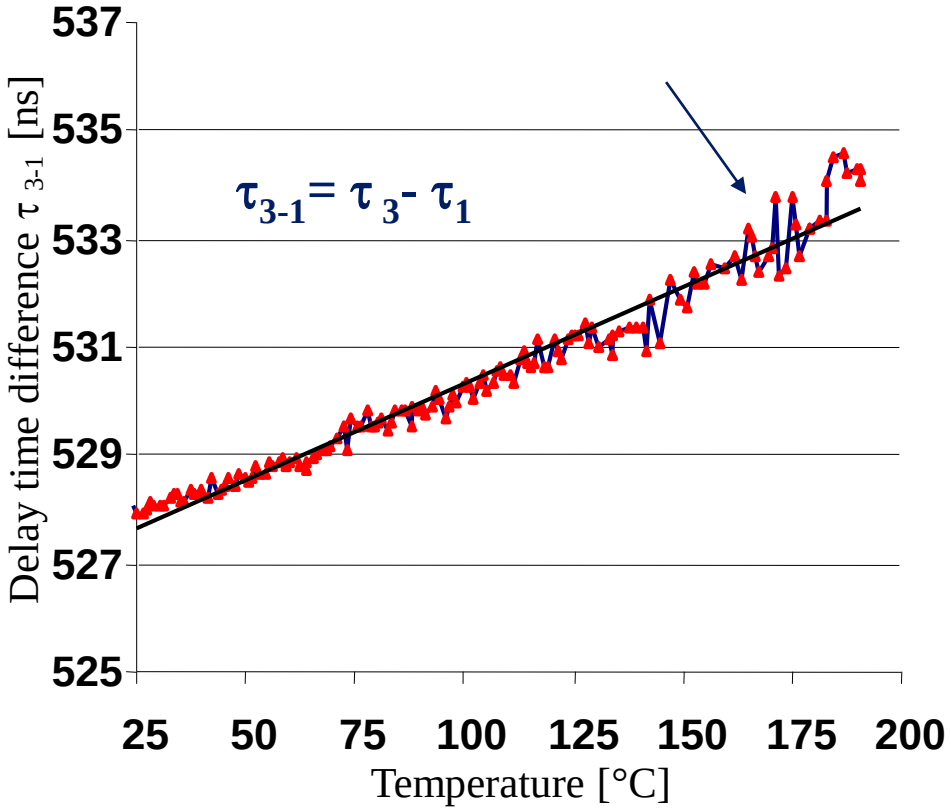


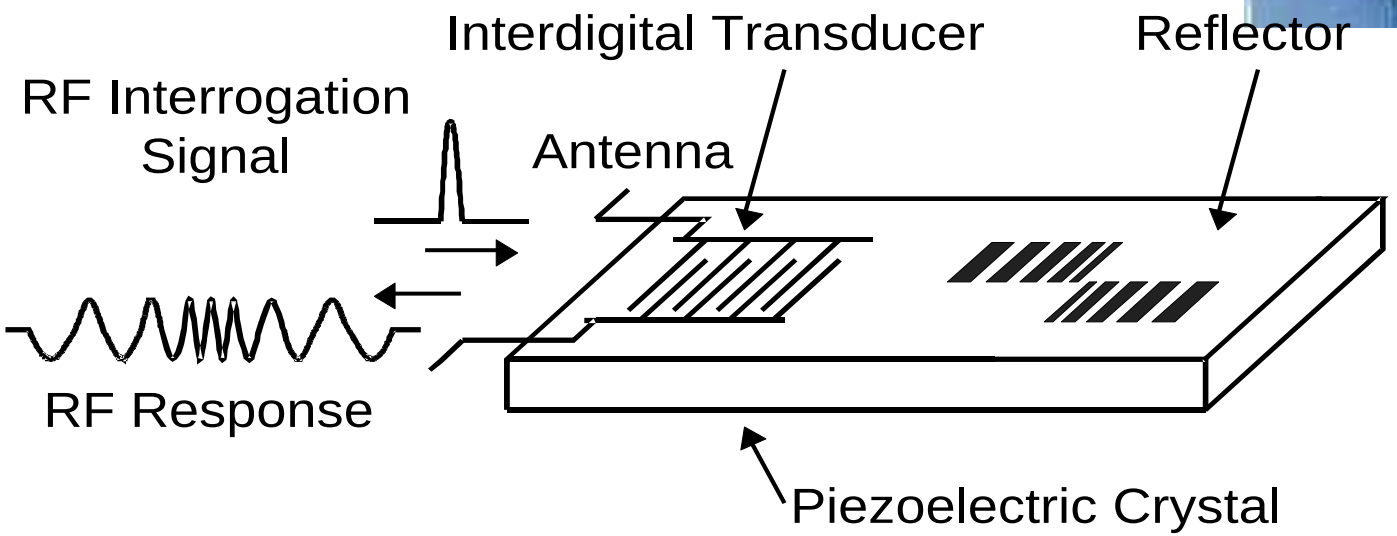
= passive wireless sensors!

But the time shift is very small!



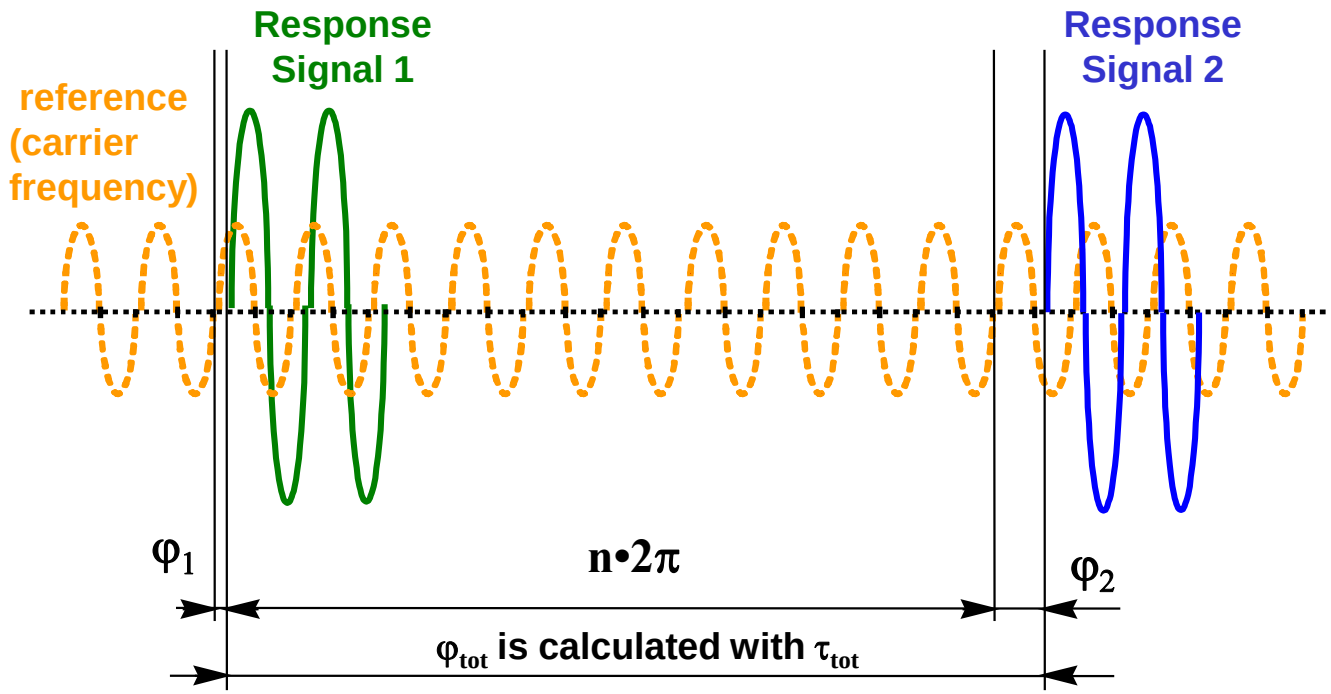


The first Ideas: Franz Seifert



Chirped wireless sensors show large effects!

The first Ideas: Valentin Magori



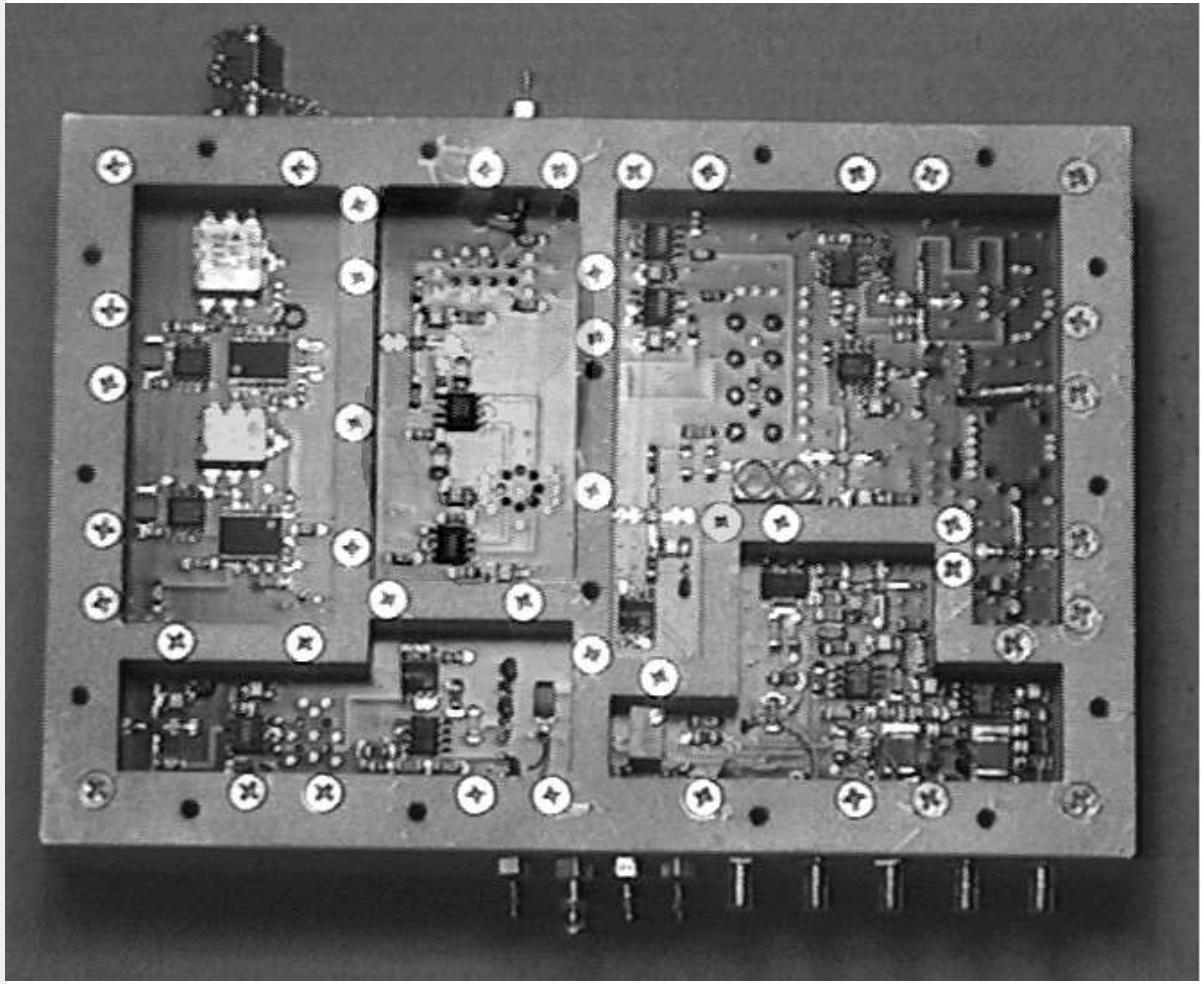
... enhances the time resolution by a factor of 50 and yields to a relative resolution of 10^{-6}.

Use the phase information!

We made some first experiments…

and built 1st reader versions

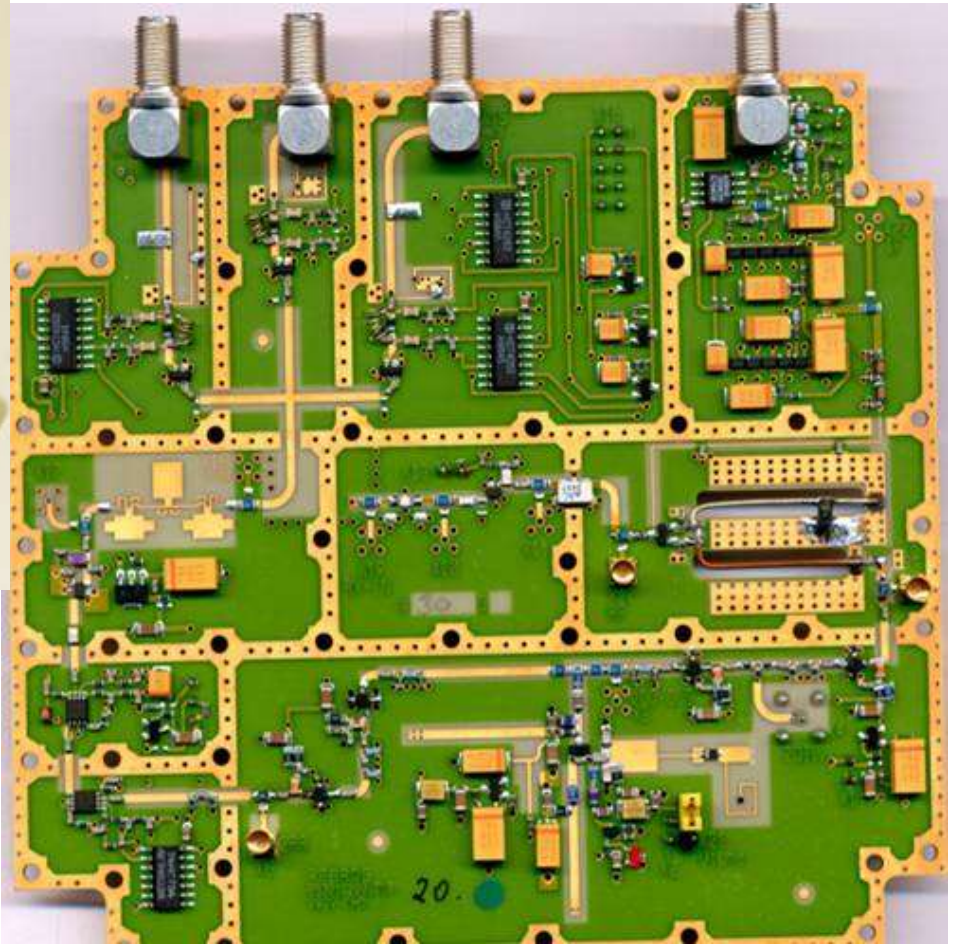
Patric Heide



early 90s by Siemens

In the beginning the price for the reader devices was dominating the system price

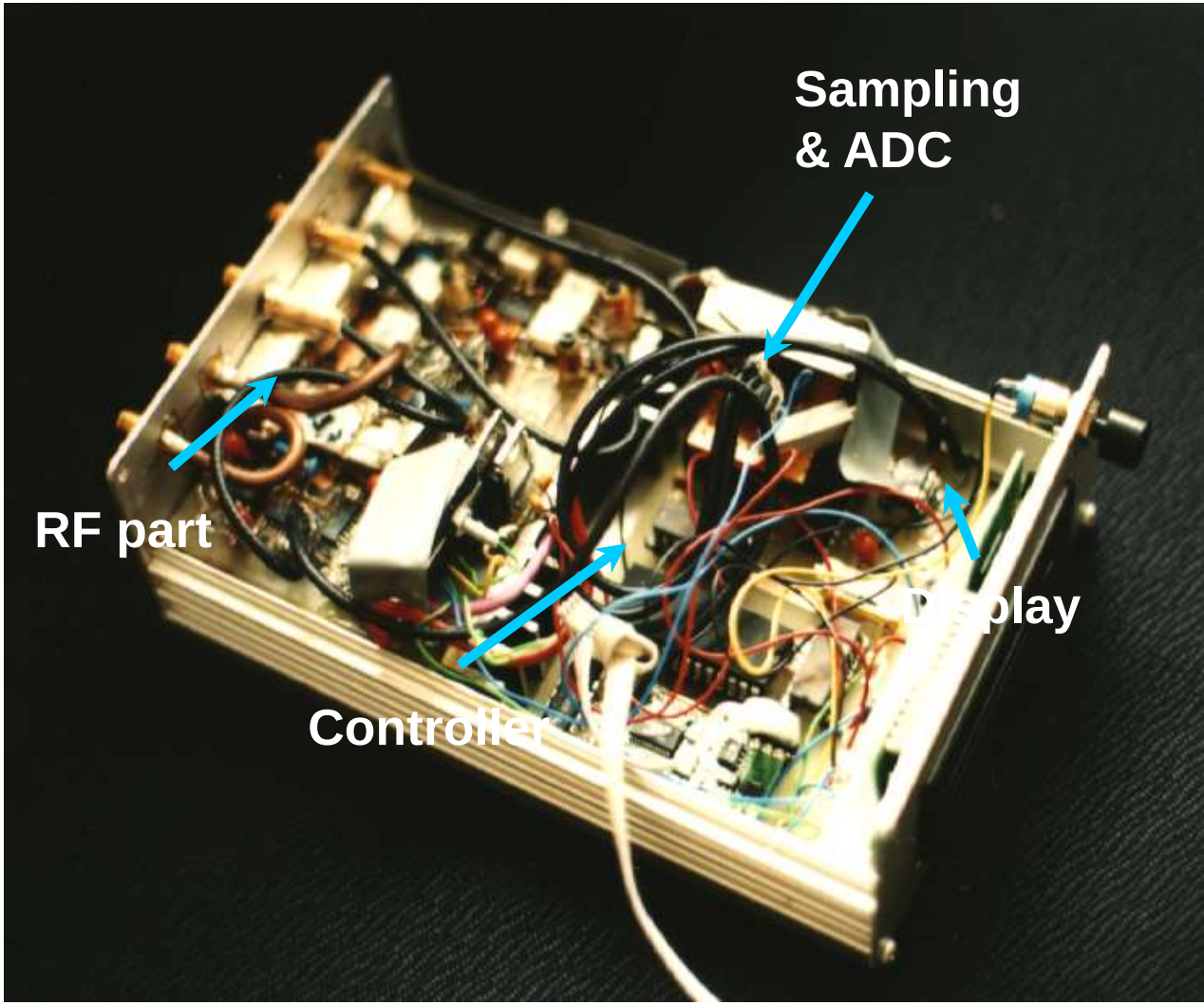
and built 2nd reader versions Frank Schmid



Open card chassis

RF printed circuit board, mid 90s. Still the reader price was dominating

Experimental Reader Unit Working at 433 MHz by Univ. Vienna



We were not amused!

Request Unit 434 MHz, 2nd Version

and we got the first big order: The Norway high way toll ring of Oslo

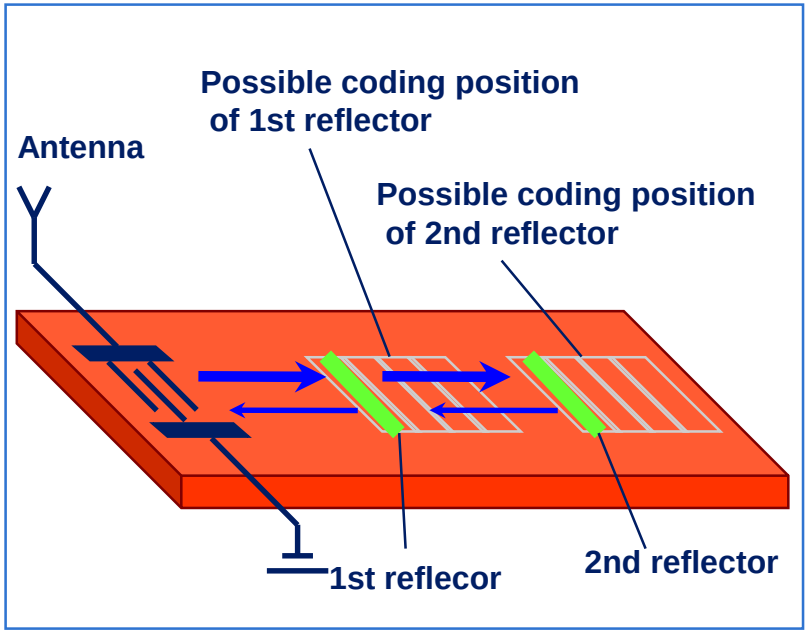
> 500 000 tags were shipped!

L. Reindl, G. Scholl, T. Ostertag, H. Scherr, U. Wolff, F. Schmidt, „Theory and application of passive SAW radio transponder as sensors“, IEEE Trans. Ultrason. Ferroel. Freq. Control, Vol. 45, No. 5, Sep. 1998, ISSN: 0885-3010, pp. 1281-1292

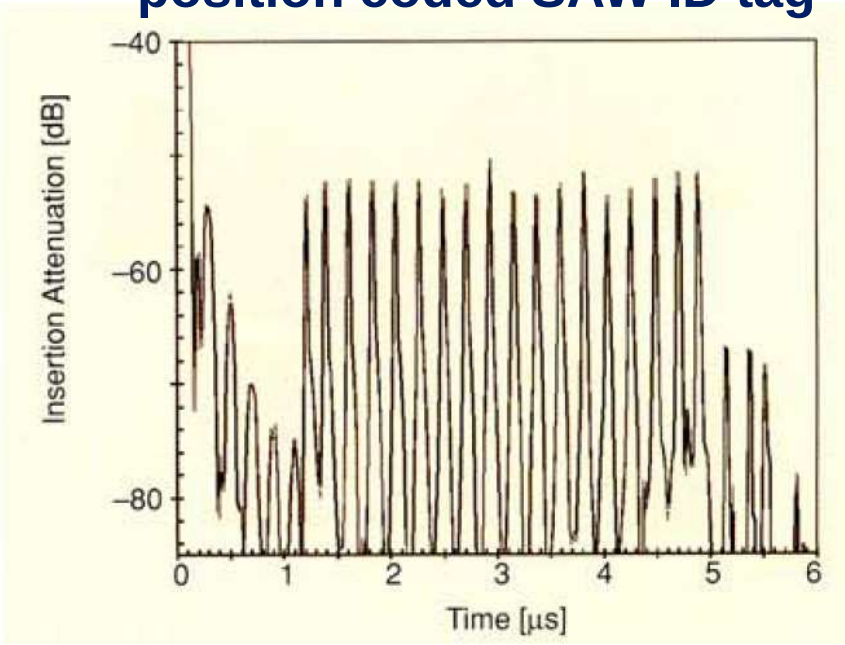
the first big order: The Norway toll ring

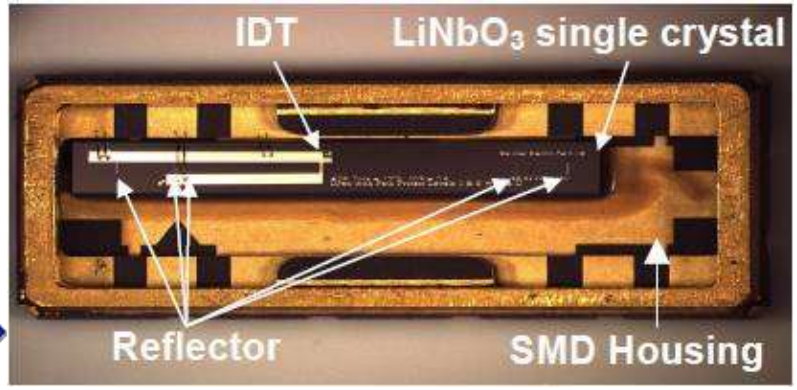
- 500 000 tags sold
- Only 1 malfunction over 5 years
- But, in the first years we had only approx. 60% yield due to code depending losses
- EPCOS management was **not** happy
- EPCOS stopped to support tags

Later on, Victor Plessky, Come up with a Puls Position Coding schema



Measurement of a pulse position coded SAW ID tag





G. Scholl, C. Korden, E. Riha, C.C.W. Ruppel, U. Wolff, G. Riha, L. Reindl, R. Weigel, „SAW-Based Radio Sensor Systems for Short-Range Applications", *IEEE microwave magazine*, pp. 68-76 , December 2003

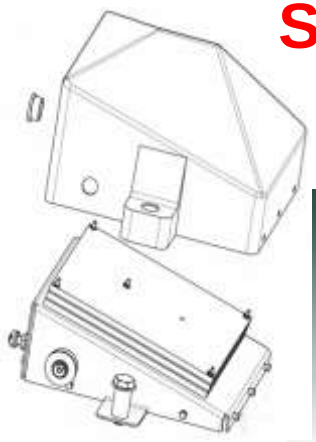
OFW ID System SOFIS installed on the SIEMENS Munich Subway System

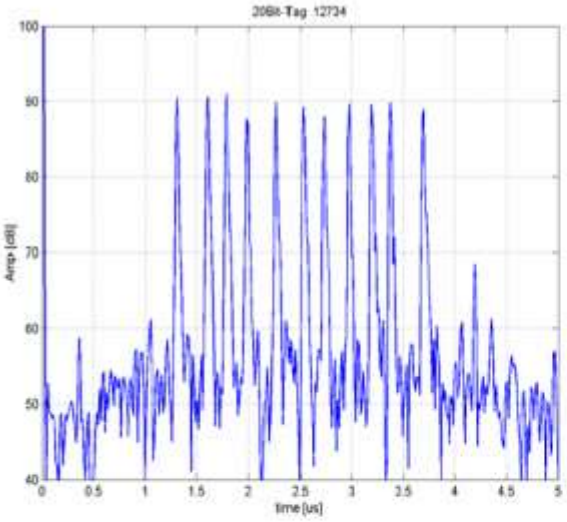
antenna of the 2.45 GHz interrogation unit

Tag housing

High Speed SAW RF-ID System

SOFIS Train Identification System (Siemens TS)





Features:

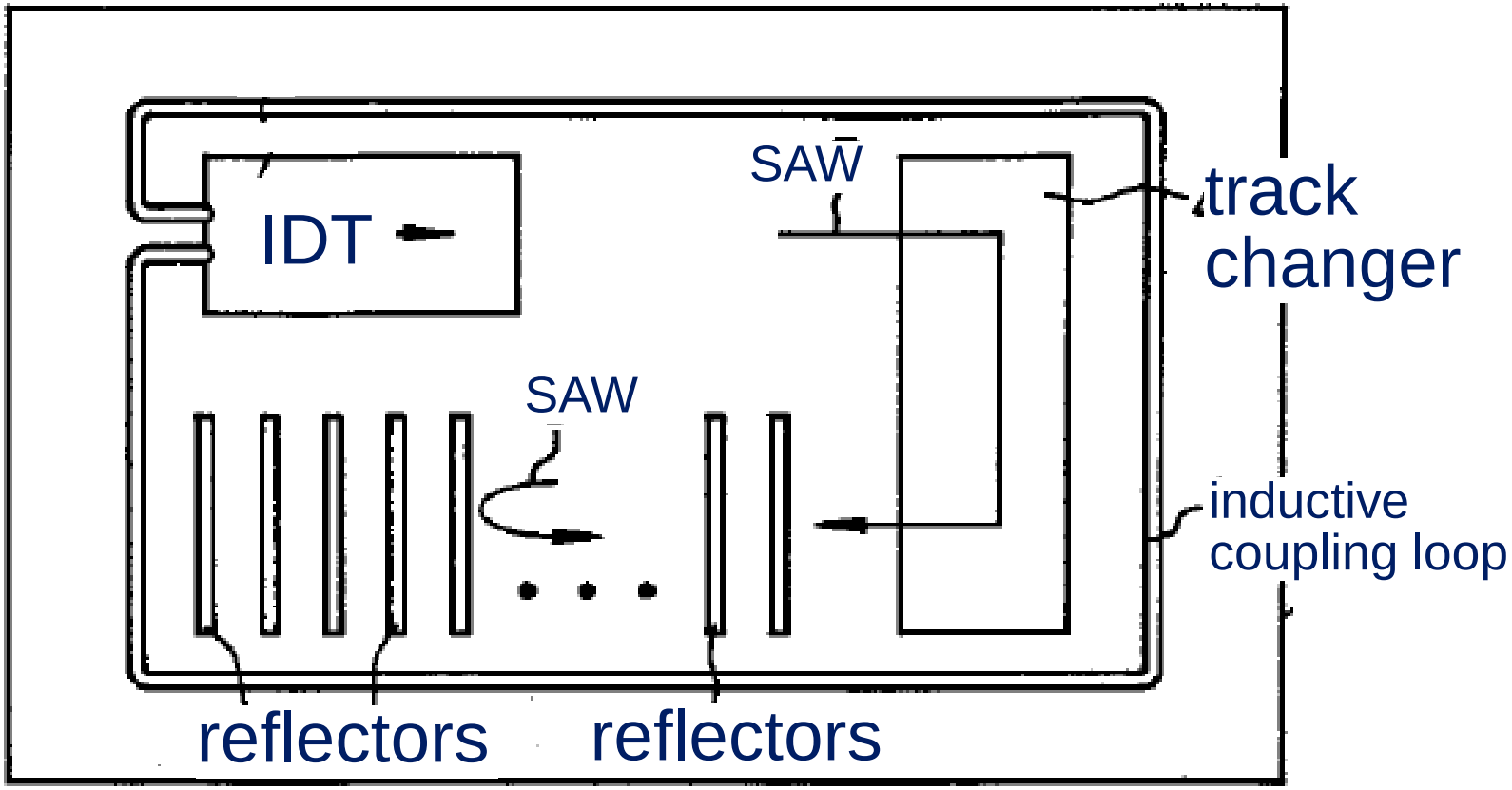
- operates in the 2.4 GHz ISM-band
- object speed up to 350 km/h possible
- detection range of several meters
- high ambient temperature (< 400 °C)
- 20 Bit ID code space

Applications:

- vehicle identification
- object identification for logistics
- landmark identification for localization

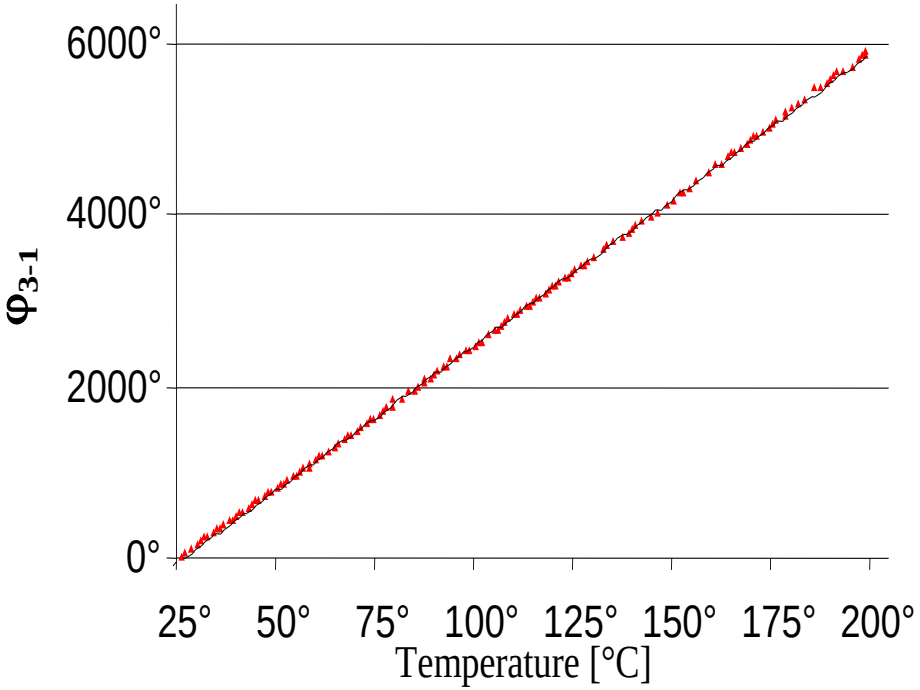
L. Reindl, G. Scholl, T. Ostertag, H. Scherr, U. Wolff, F. Schmidt, „Theory and application of passive SAW radio transponder as sensors“, *IEEE Trans. UFFC*, 45 (5), pp. 1281-1292, 1998.

And we planed SAW tags which can be embedded into a card

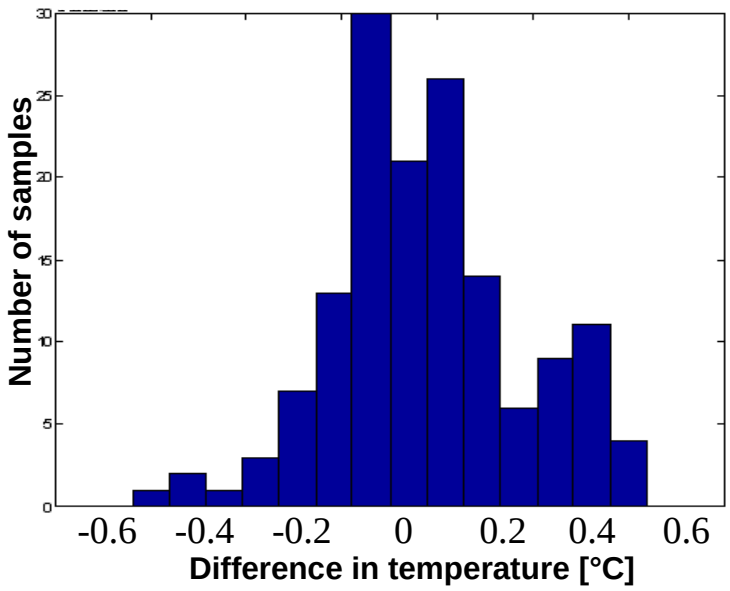


L. Reindl, T. Ostertag, W. Ruile, „Mit akustischen Oberflächenwellen arbeitende Identifizierungs- oder Sensoranordnung“, European Patent application EP0827105, 25.07.1997

Temperature sensors are easy! Temperature characteristics of the continuous phase difference φ_{3-1}



σ=0.2°C



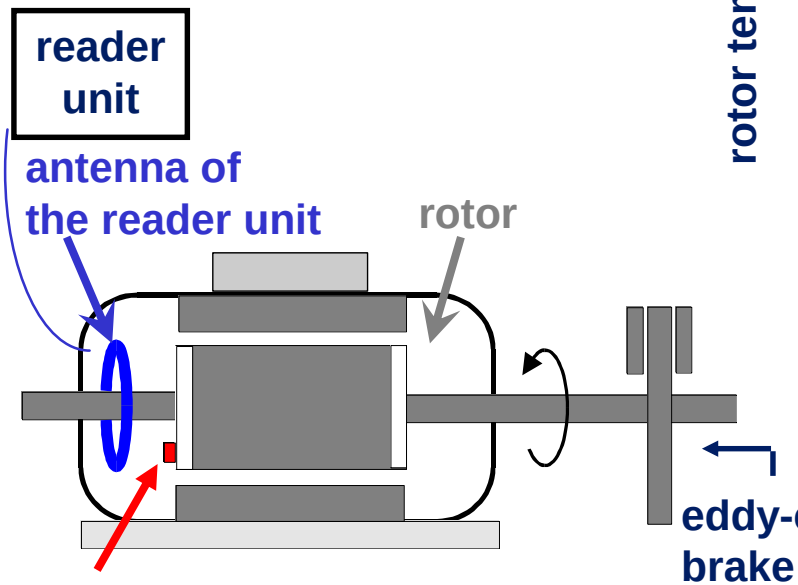
error distribution

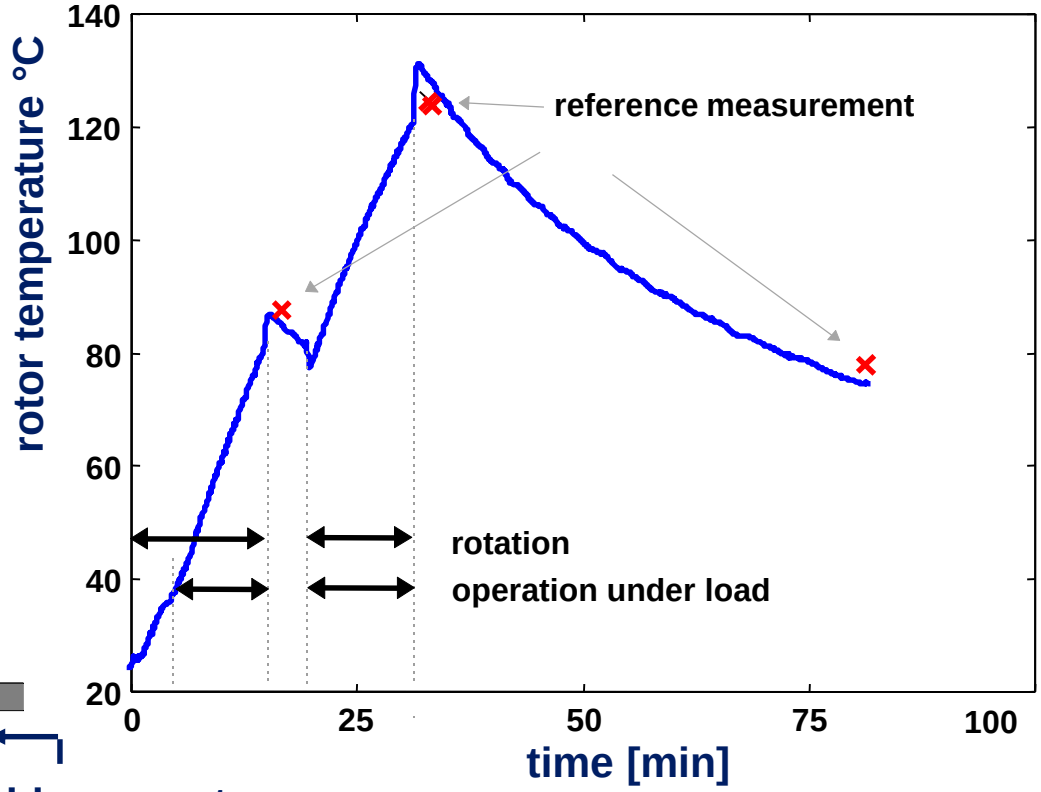
L. Reindl, I. Shrena, „Wireless Measurement of Temperature Using Surface Acoustic Waves Sensors", *IEEE Trans. UFFC*-51 (11), pp. 1457-1463, 2004

S. Schuster, S. Scheiblhofer, L. Reindl, A. Stelzer, „Performance Evaluation of Algorithms for SAW Based Temperature Measurement," *IEEE Trans. UFFC*-53 (6), pp. 1177-1185, 2006.

Measurement of the Rotor Temperature in a 11 kW Asynchronous Motor

Sketch of the set-up

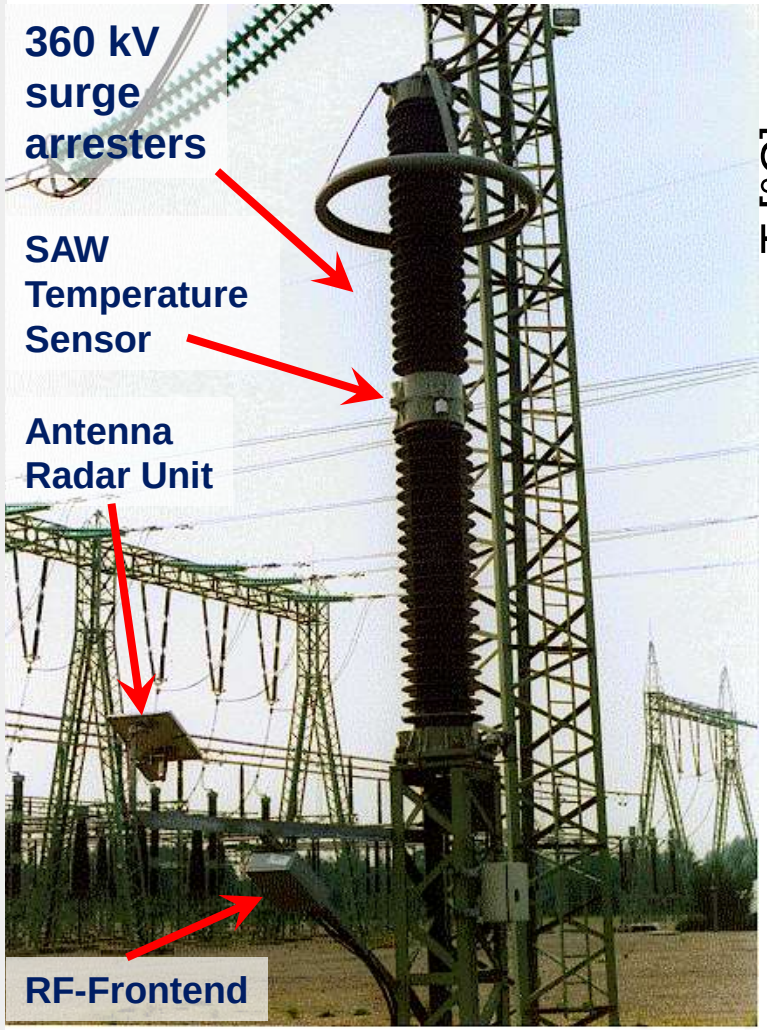


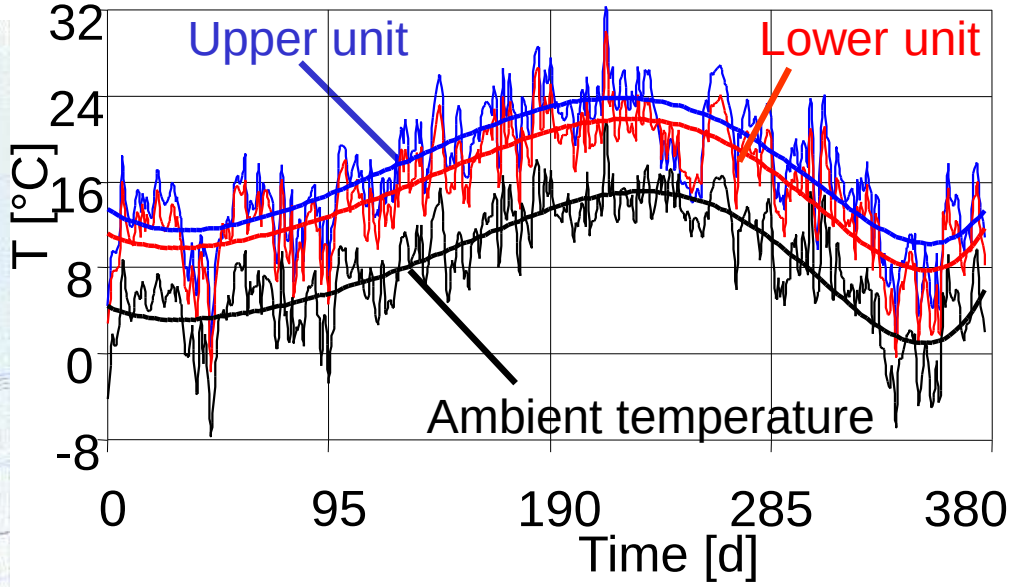


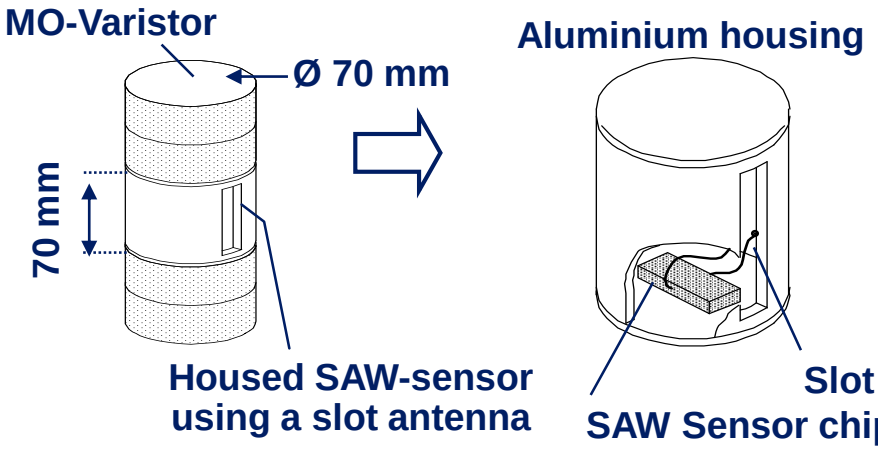
measurement curve

L. Reindl, A. Pohl, G. Scholl, R. Weigel, „SAW-Based Radio Sensor Systems“, IEEE Sensors Journal, 1 (1), pp. 69 –78, invited paper for the inaugural edition, 2001

Temperature sensors: Online Monitoring for High-Voltage Surge Arresters



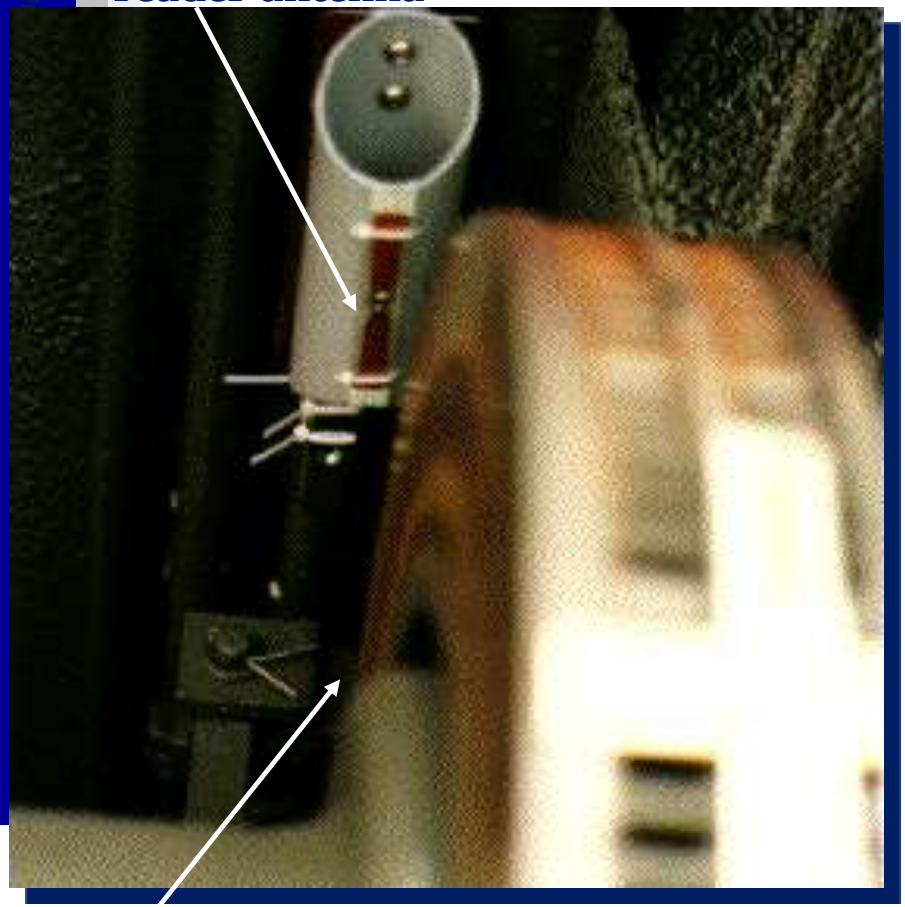


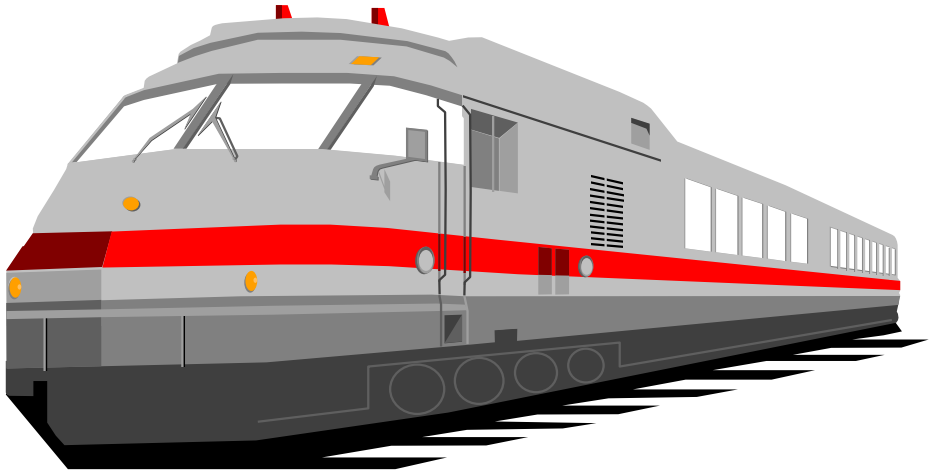


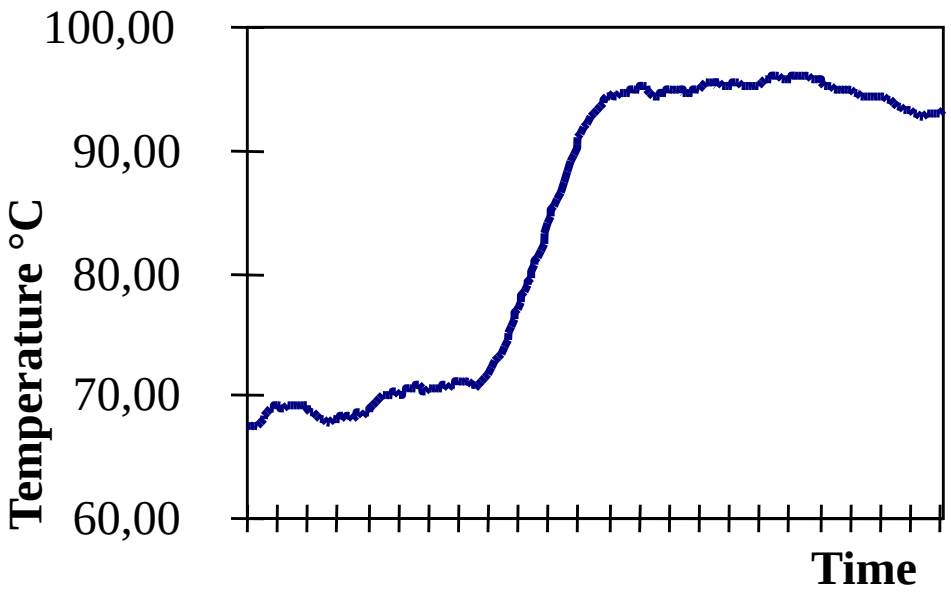
G. Scholl, C. Korden, E. Riha, C.C.W. Ruppel, U. Wolff, G. Riha, L. Reindl, R. Weigel, „SAW-Based Radio Sensor Systems for Short-Range Applications", *IEEE microwave magazine*, pp. 68-76 , December 2003

Brake temperature of a train entering a station

reader antenna

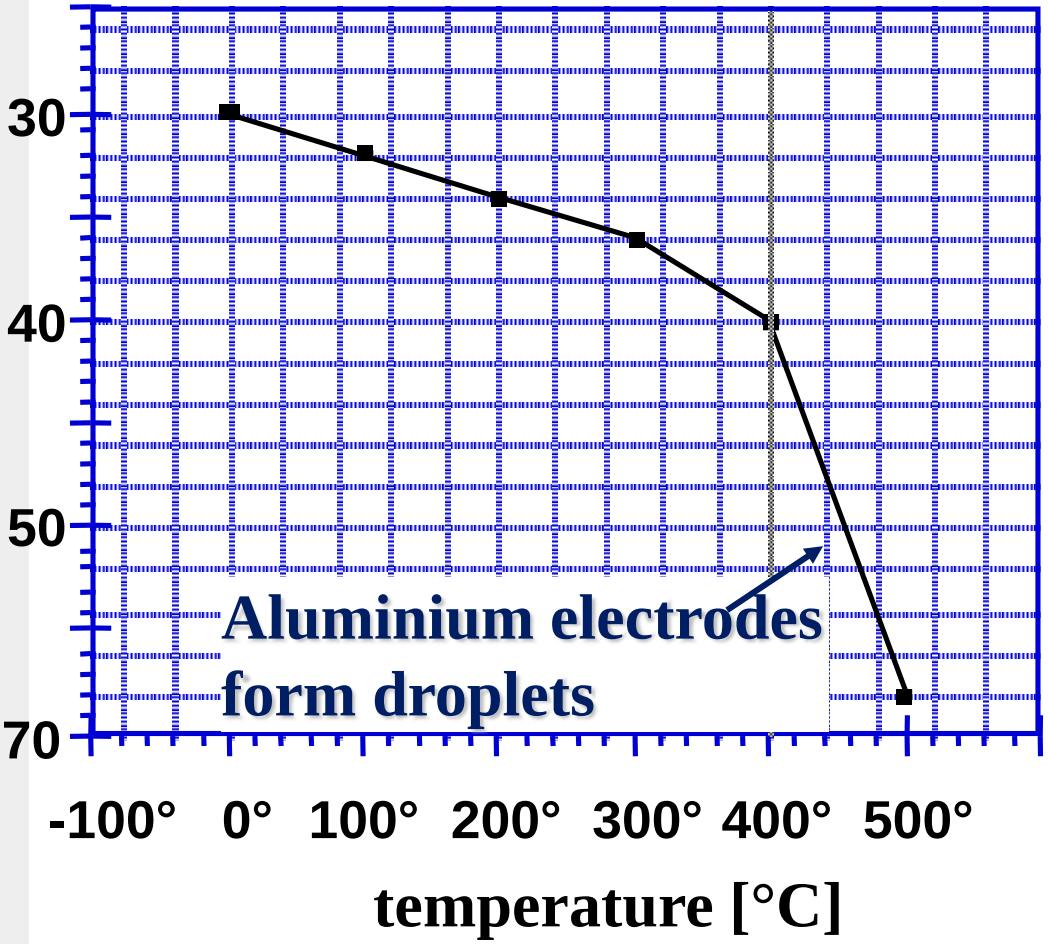






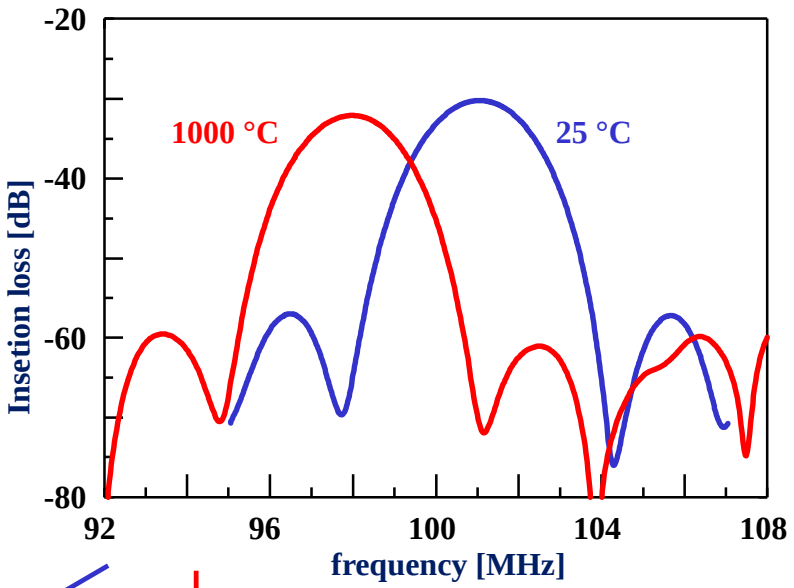
Brake (with attached SAW temperature transponder, not seen)

Signal attenuation versus temperature on LiNbO3-YZ

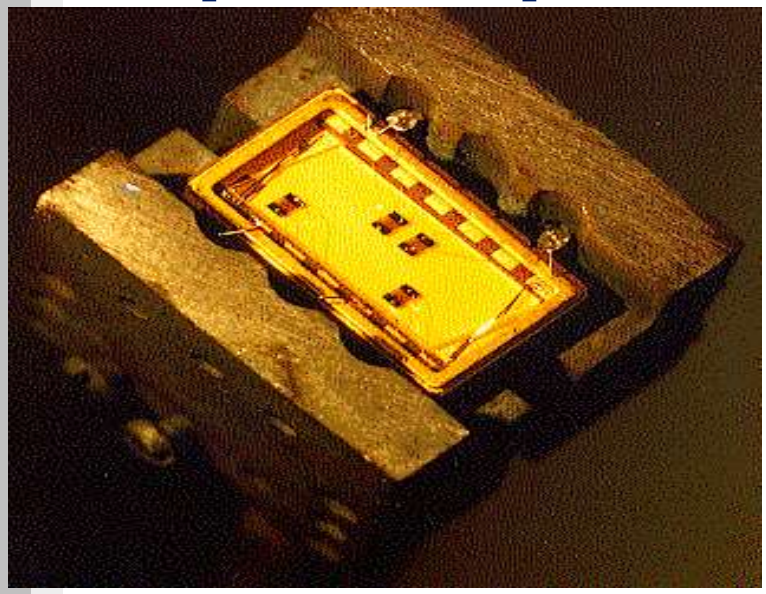


- Up to 200°C standard assembly, interconnect and package techniques can be used.
- Up to 350°C aluminium can be used for electrodes material
- $LINBO_3$ can not be used for temperatures higher than 400°C for short time and 300°C for long time operation.

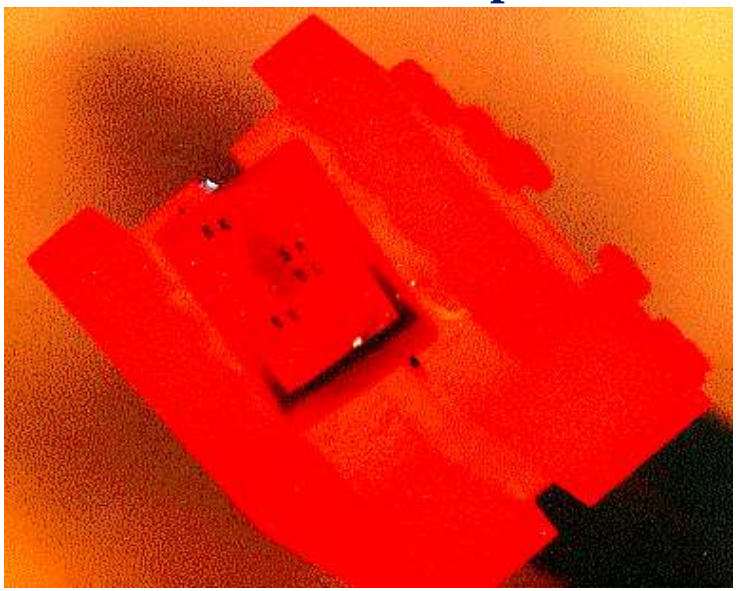
High Temperature SAW Sensors with Platinum Electrodes on Langasit ($La_3Ga_5SiO_{14}$)

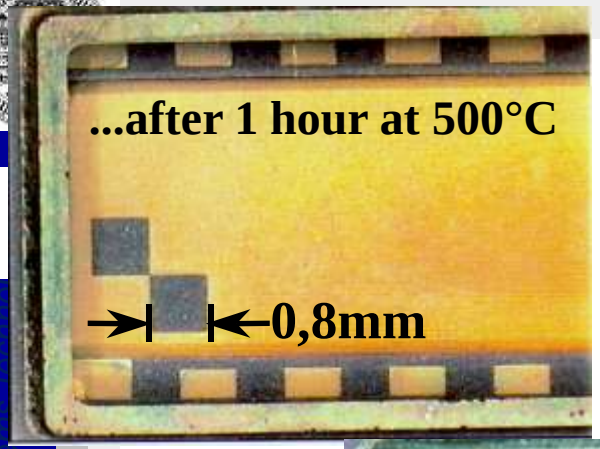


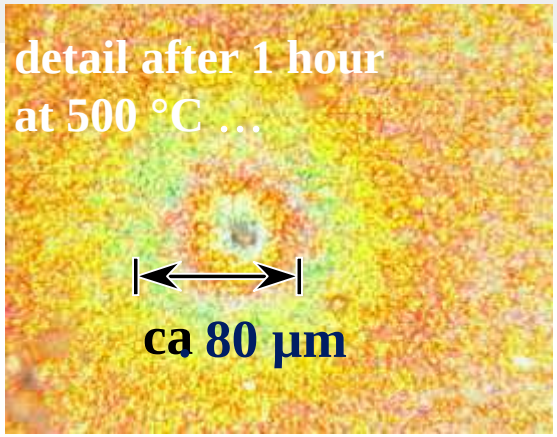
Test chip at room temperature



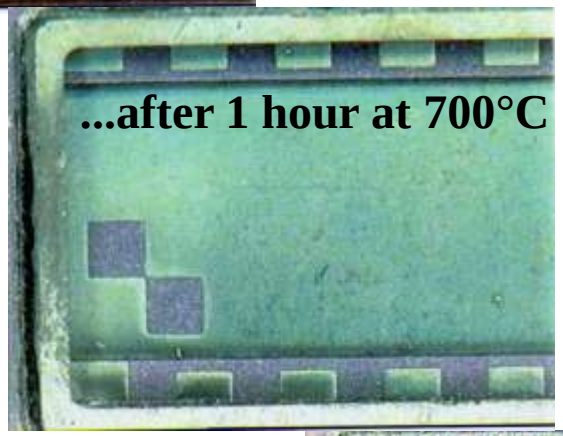
Test chip at 1000°C

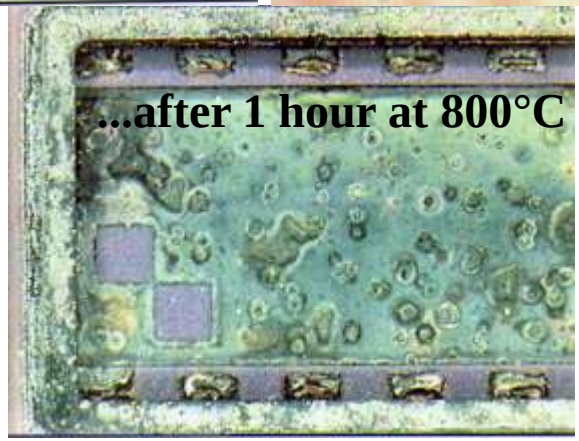




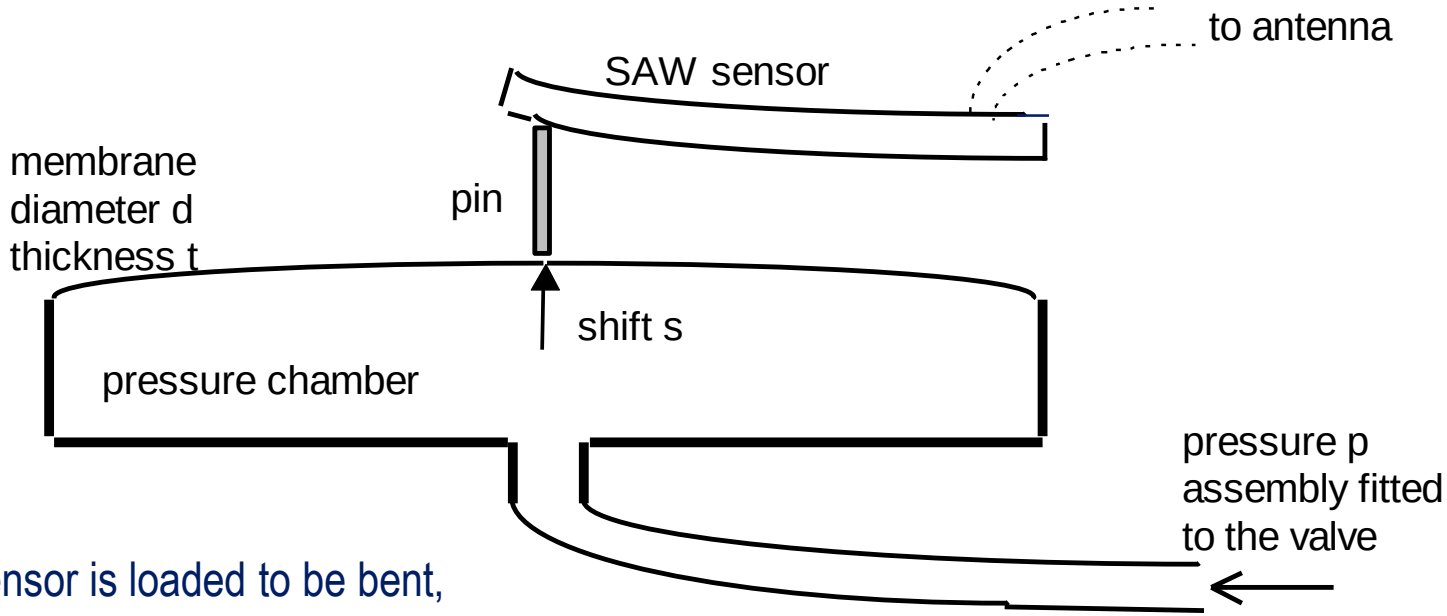


but we got problems with the housing





Mechanical sensors are more tricky: They need a special housing! SAW Pressure Sensor (0th generation, University Vienna)



SAW sensor is loaded to be bent,
yields a scaling of response,
shift (pressure) can be evaluated

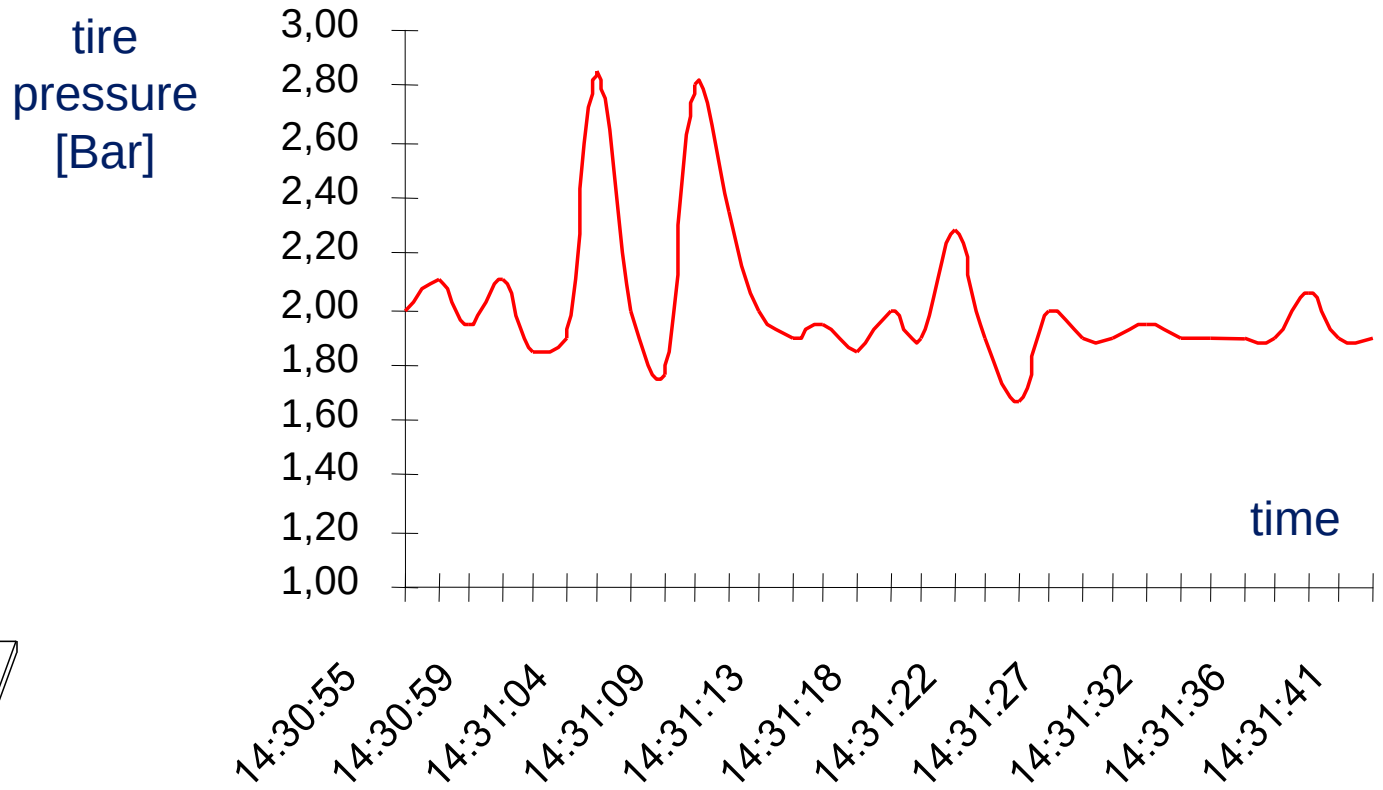
We were not happy!

Mounting of Reader Antenna

Signal Storage and Processing

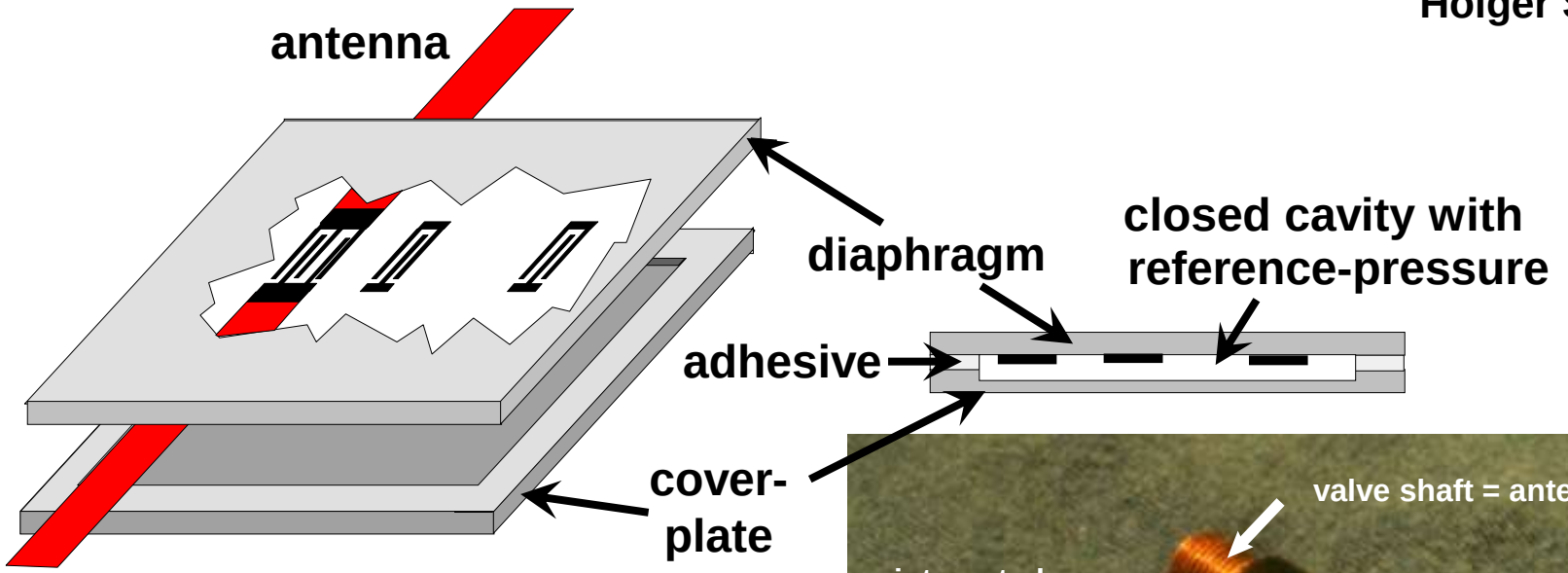
Measurement Results

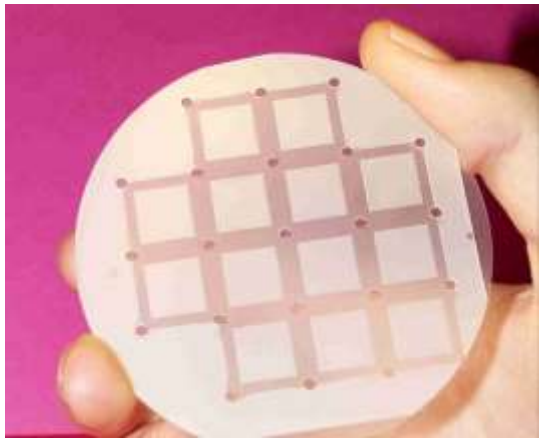
Pressure in a front wheel crossing a two-track railway lane, followed by a gully

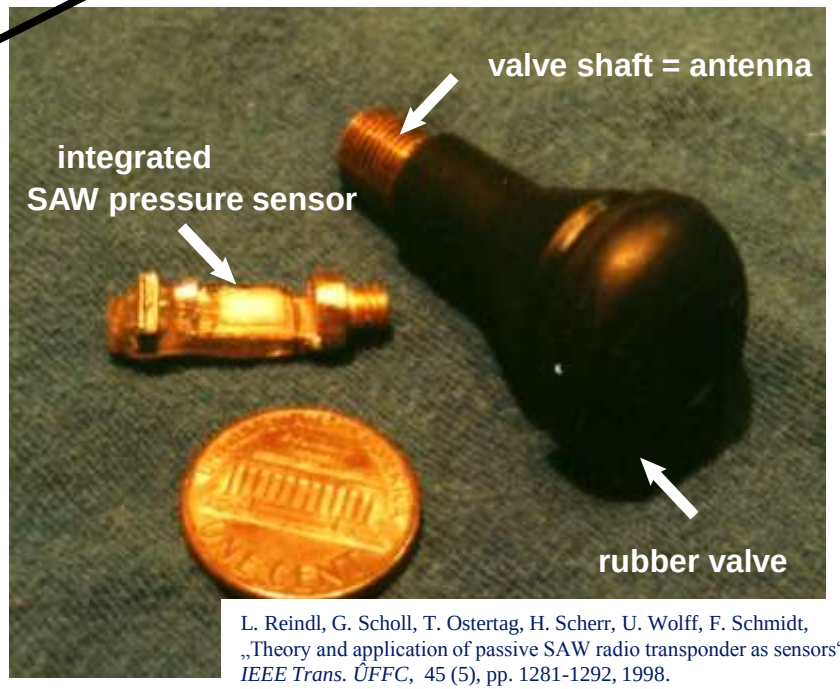


SAW Pressure Sensor (1st Generation, Siemens)

Holger Scherr







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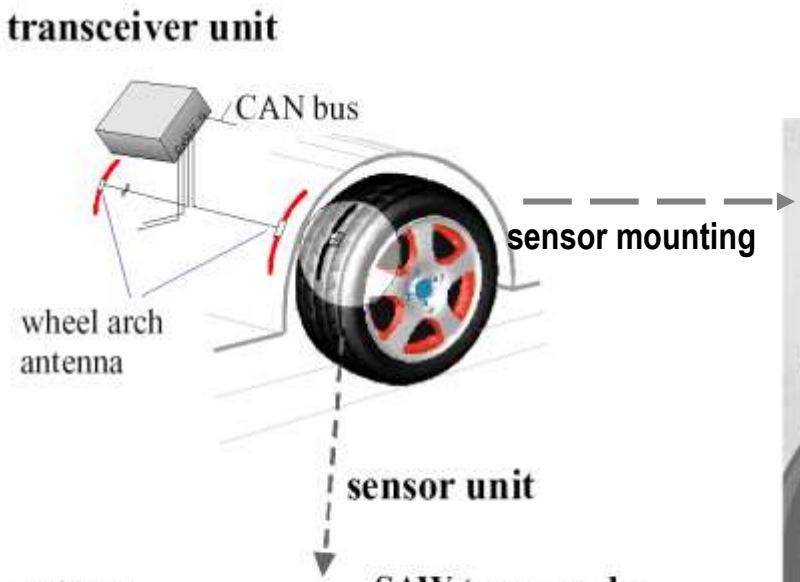
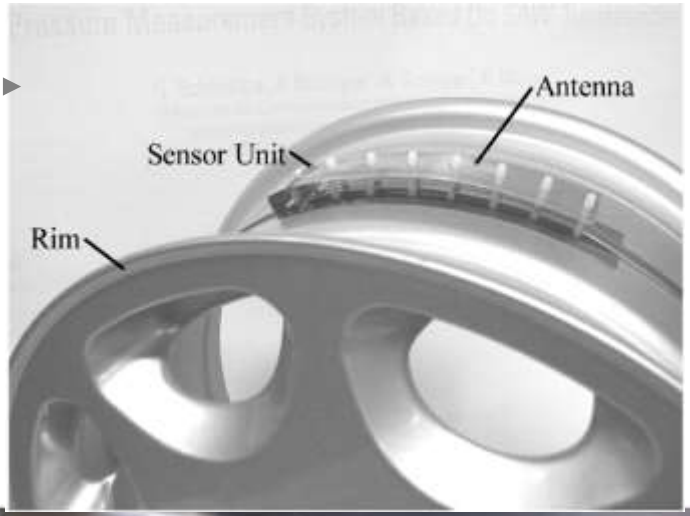
SIEMENS

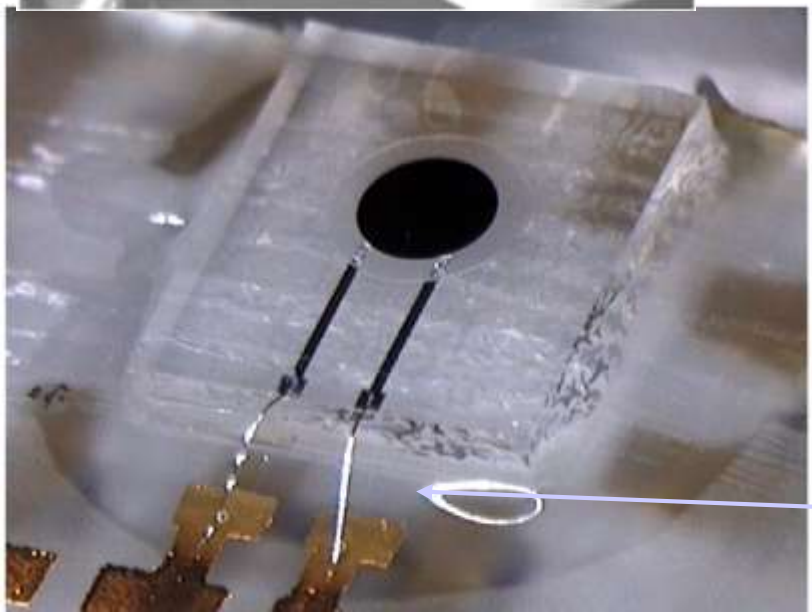
tire pressure sensor, presented by G. Schimetta



capacitive micro-machined pressure sensor

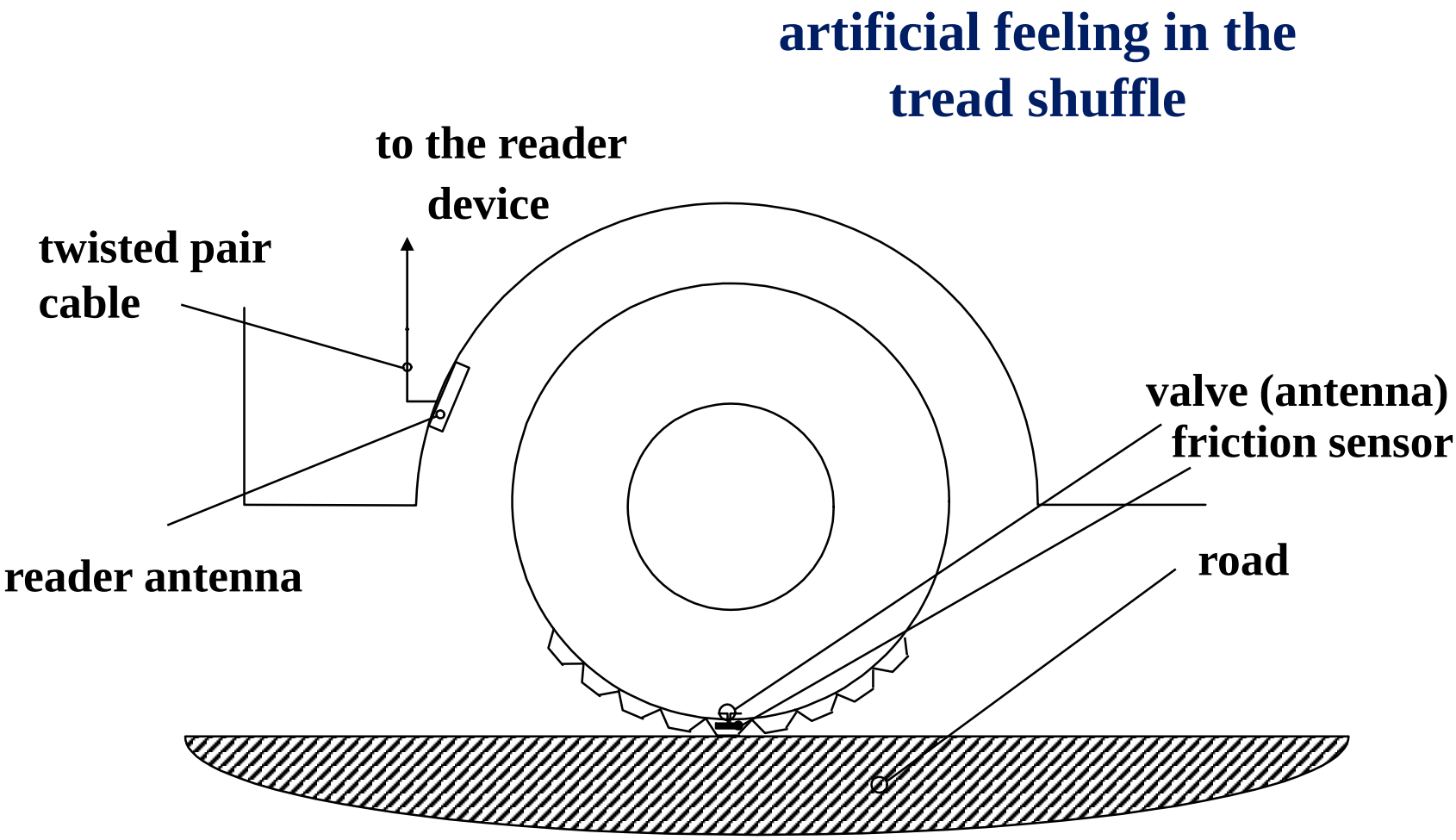


The patch antenna with the integrated sensor board is mounted on the rim with a stress ribbon.

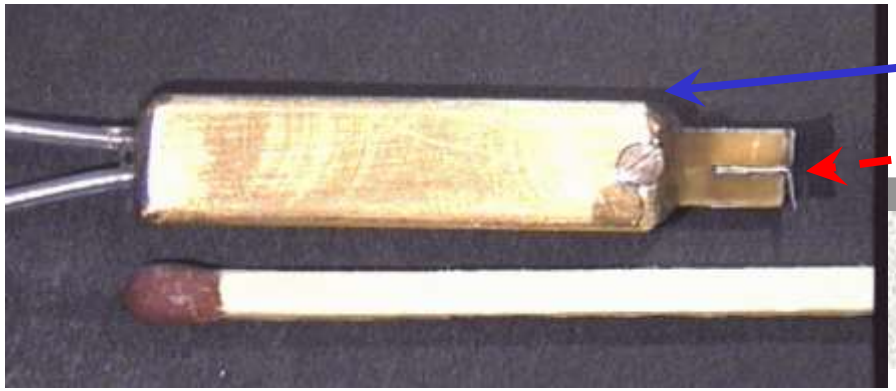


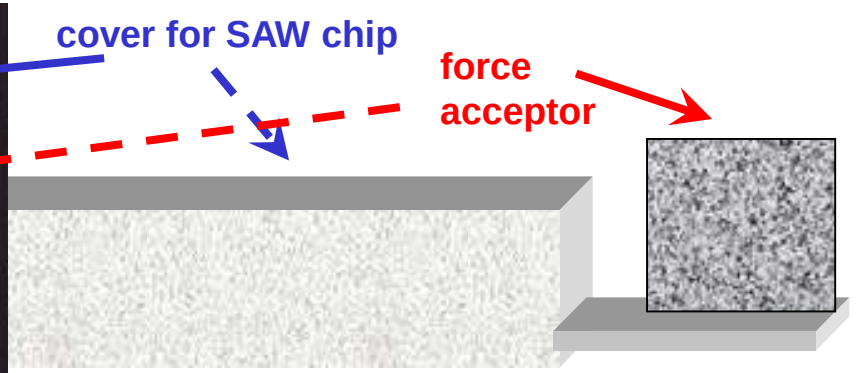
bond wires

SAW Sensor for Tire Friction Control



SAW Sensor for Tire Friction Control





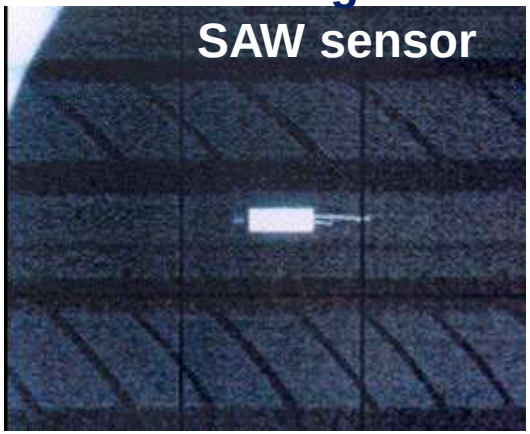
Schematic drawing of an experimental SAW bending beam

EPCOS

Continental

SIEMENS

Radiography of a tire with integrated SAW sensor

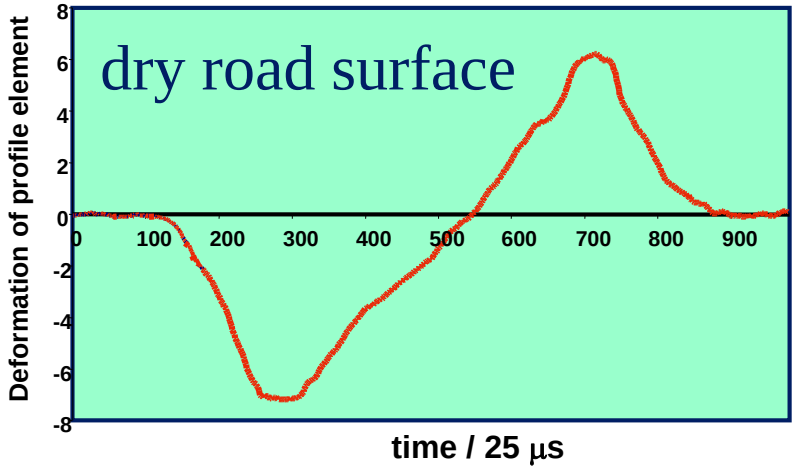


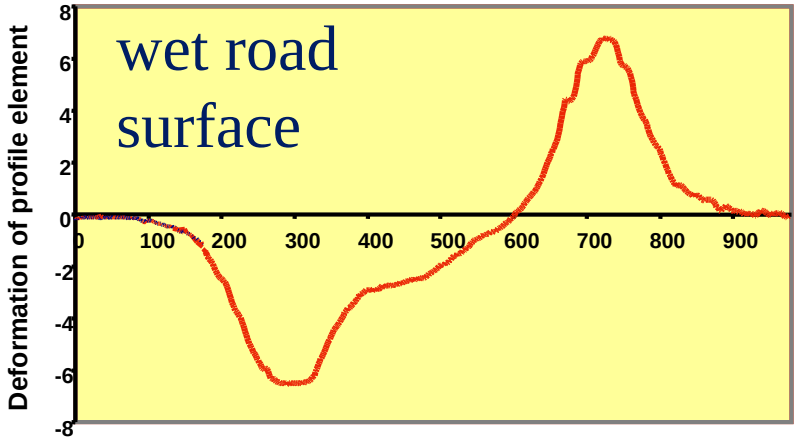
L. Reindl, A. Pohl, G. Scholl, R. Weigel, „SAW-Based Radio Sensor Systems“, IEEE Sensors Journal, 1 (1), pp. 69 –78, invited paper for the inaugural edition, 2001

SAW Sensor for Tire Friction Control

The deformation of a profile element gives information of the friction coefficient between tire and road

SAW sensor integrated into a standard tire

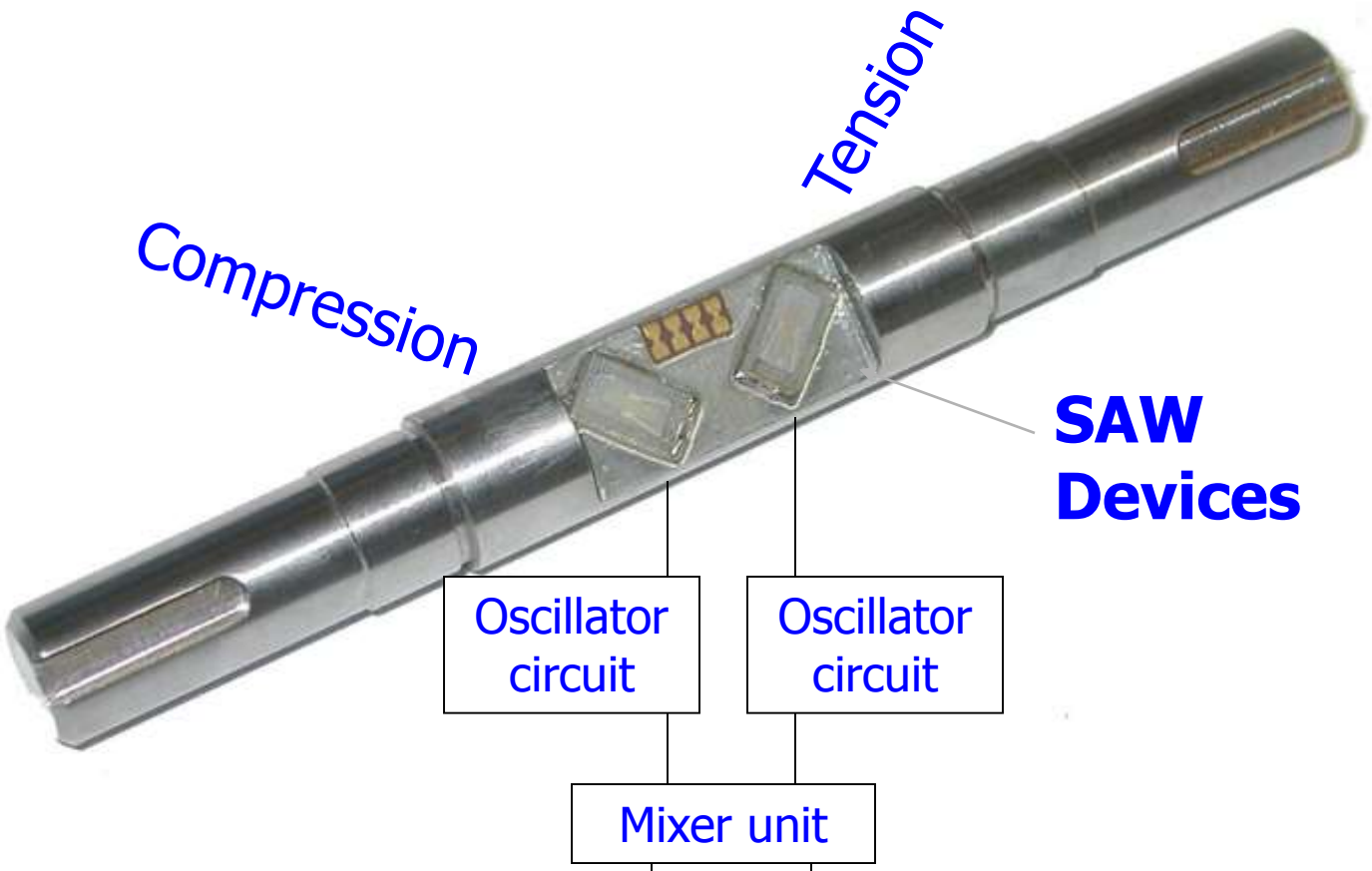




A. Pohl, R. Steindl, L. Reindl, „The 'intelligent tire' utilizing passive SAW sensors - measurement of tire friction“, *IEEE Trans.Instrumentation and Measurement*, 48 (6), pp. 1041-1046, 1999

We also build torque sensors, but Sensor Technology was better

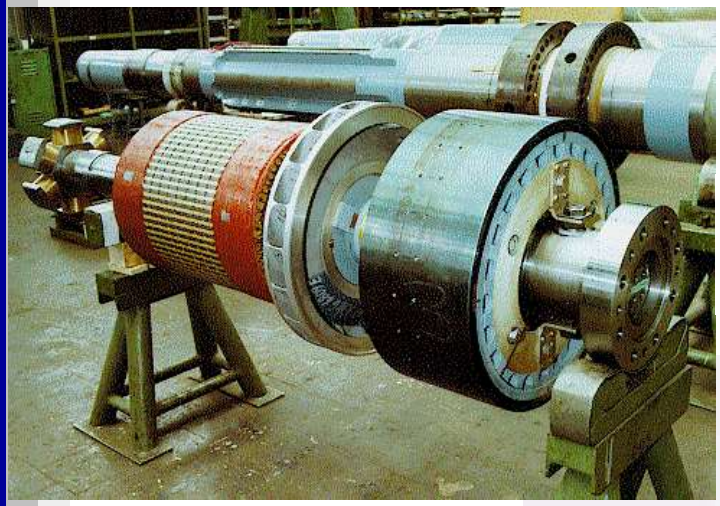
TORSEM E300 RWT 1 System



TORSEM E300 RWT 1 System

TORQSENSE E300 RWT 1 System

Industrial Applications of SAW Sensors



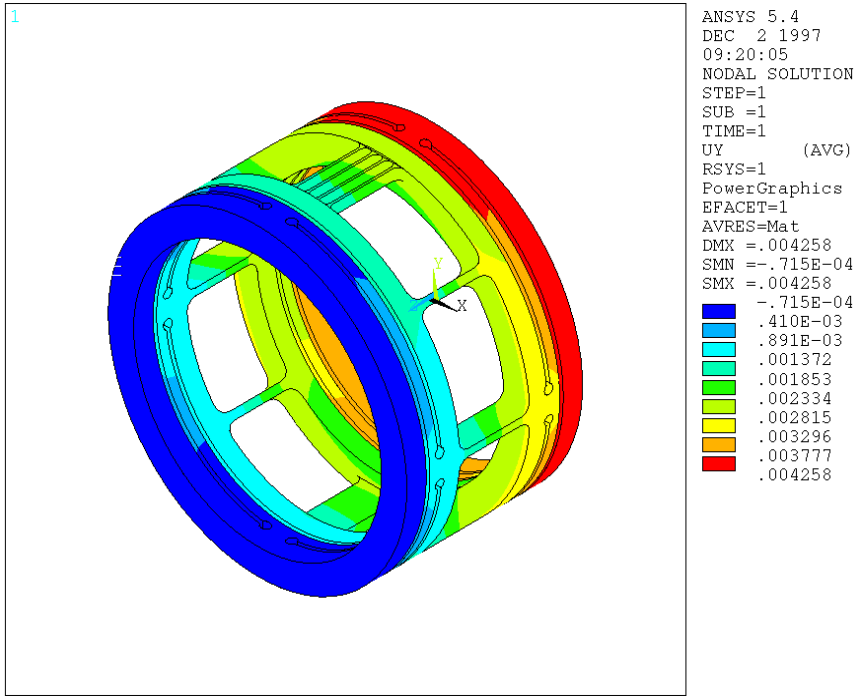
SAW Radio Sensing for wireless measurement of torque, speed, temperature, and vibrations in high voltage motors

SAW Radio Sensing for wireless measurement of the exciting current in turbo generators with rotating rectifiers

SAW Radio Sensing for monitoring, diagnosis and control of high voltage gas-insulated switchgears

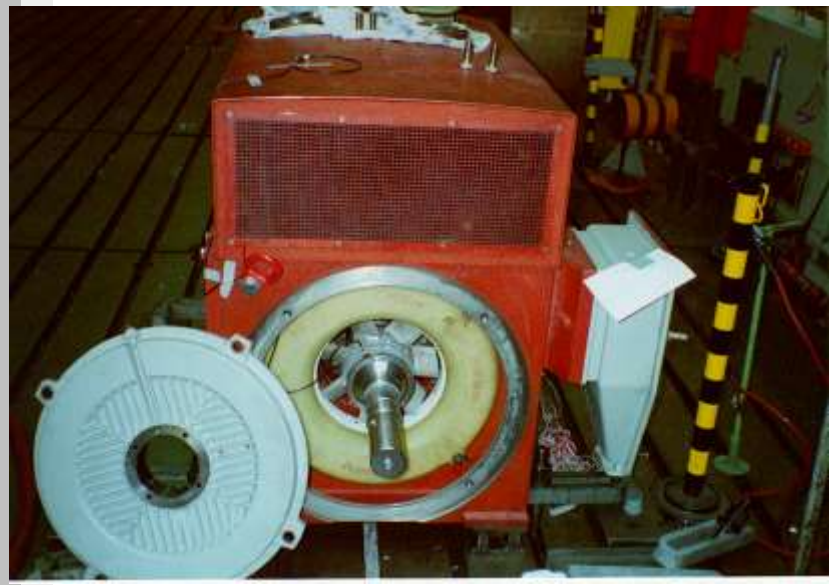
SAW torque sensor: application on the shaft

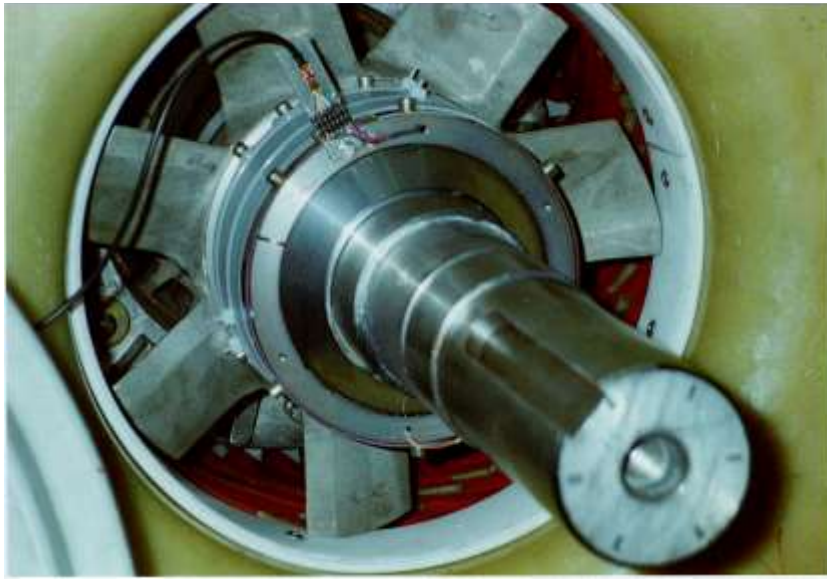
Torque trnsmitter with an isolation between bending and traction

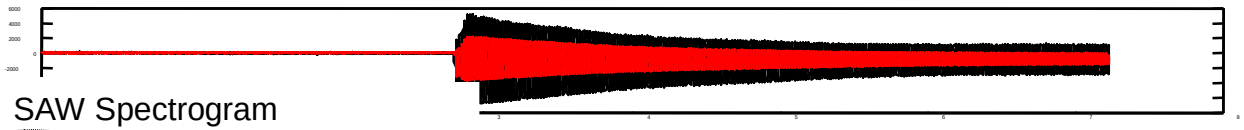


FEM simulation of the torque transmitter

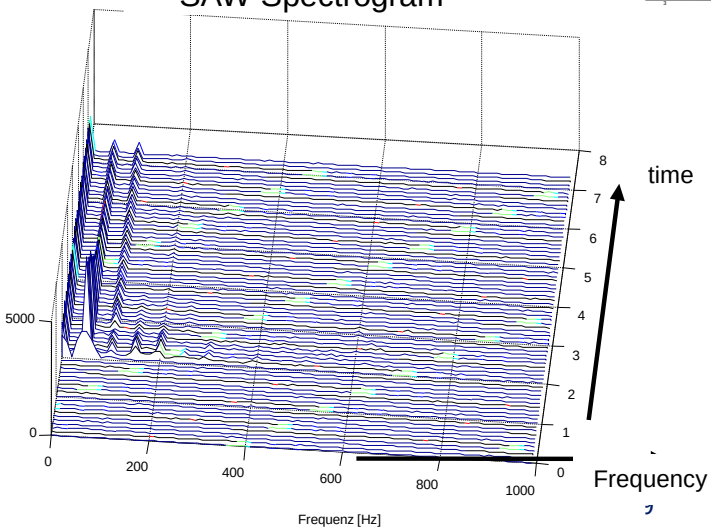
SAW torque sensor applied on a 750-kW/ 2,4-kNm Engin



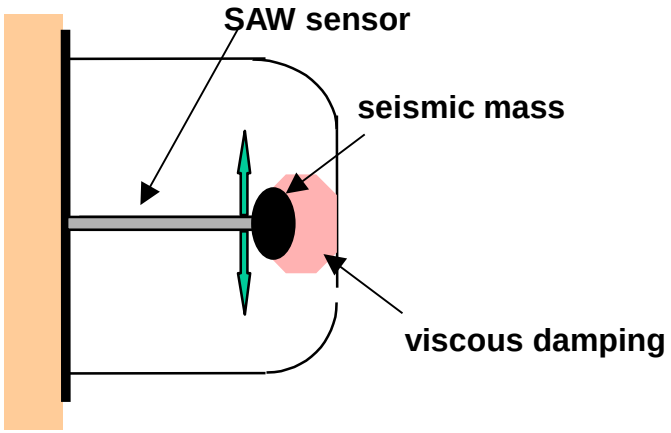




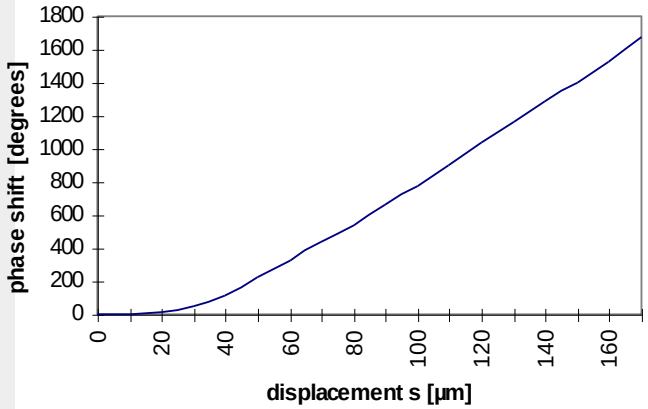
SAW Spectrogram



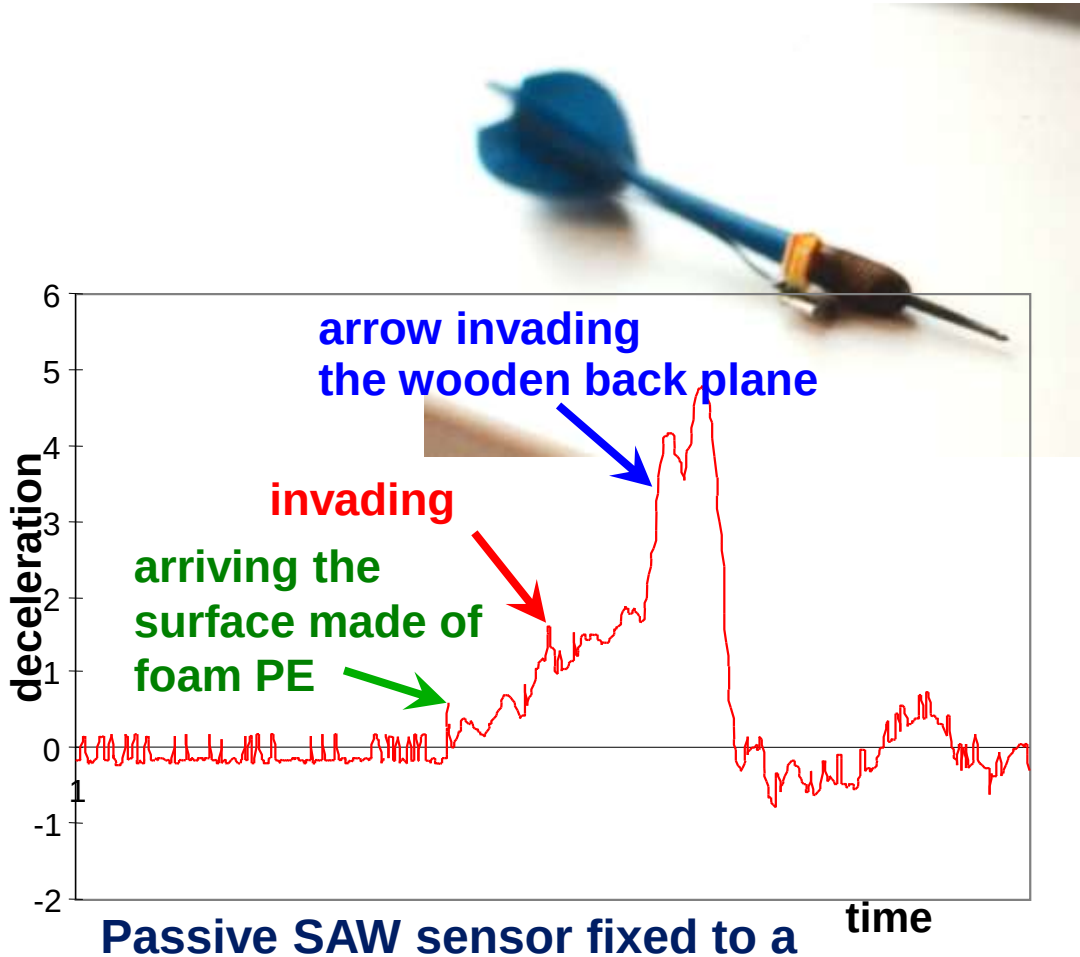
SAW accelerometer



SAW accelerometer using a seismic mass and a flexured SAW cantilever beam



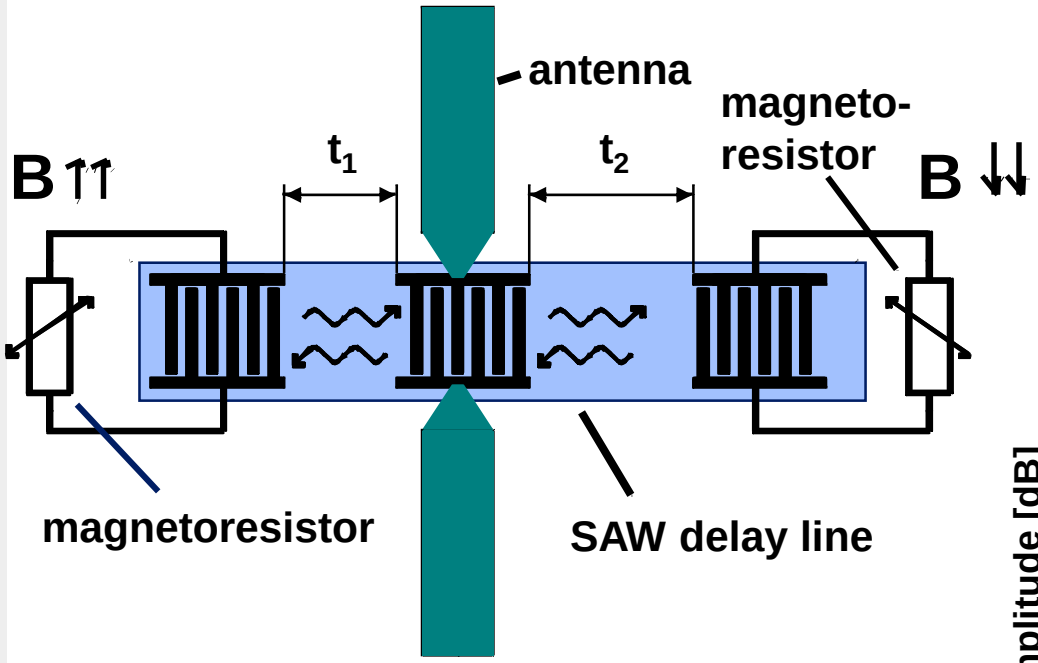
Phase variation of a 5 µs SAW delay line on a Quartz substrate relative to the displacement of one edge of the substrate, the opposite edge remaining fixed

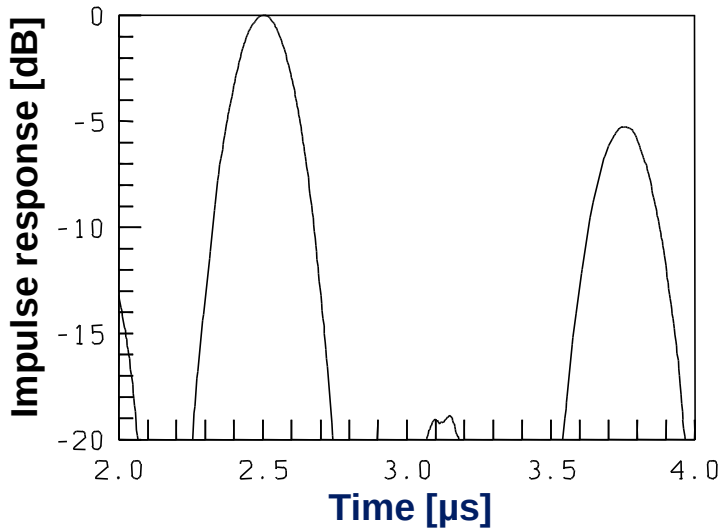


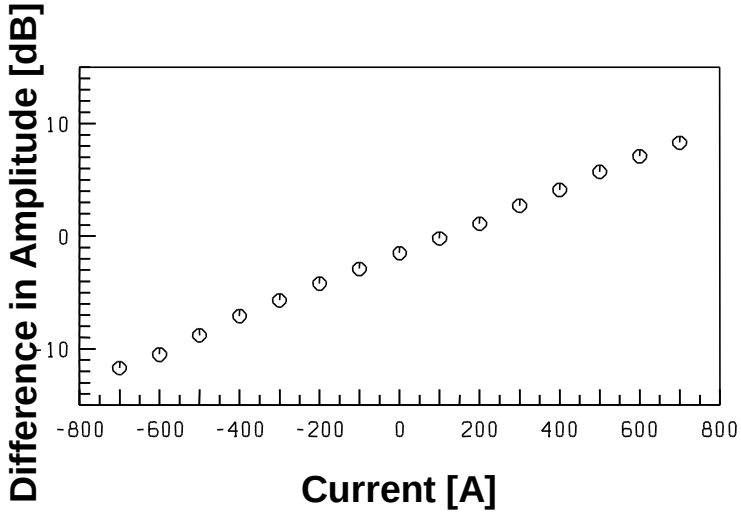
Passive SAW sensor fixed to a dart arrow, invading the target

A. Pohl, R. Steindl, L. Reindl, „The 'intelligent tire' utilizing passive SAW sensors - measurement of tire friction“, *IEEE Trans.Instrumentation and Measurement*, 48 (6), pp. 1041-1046, 1999

SAW Current Sensors



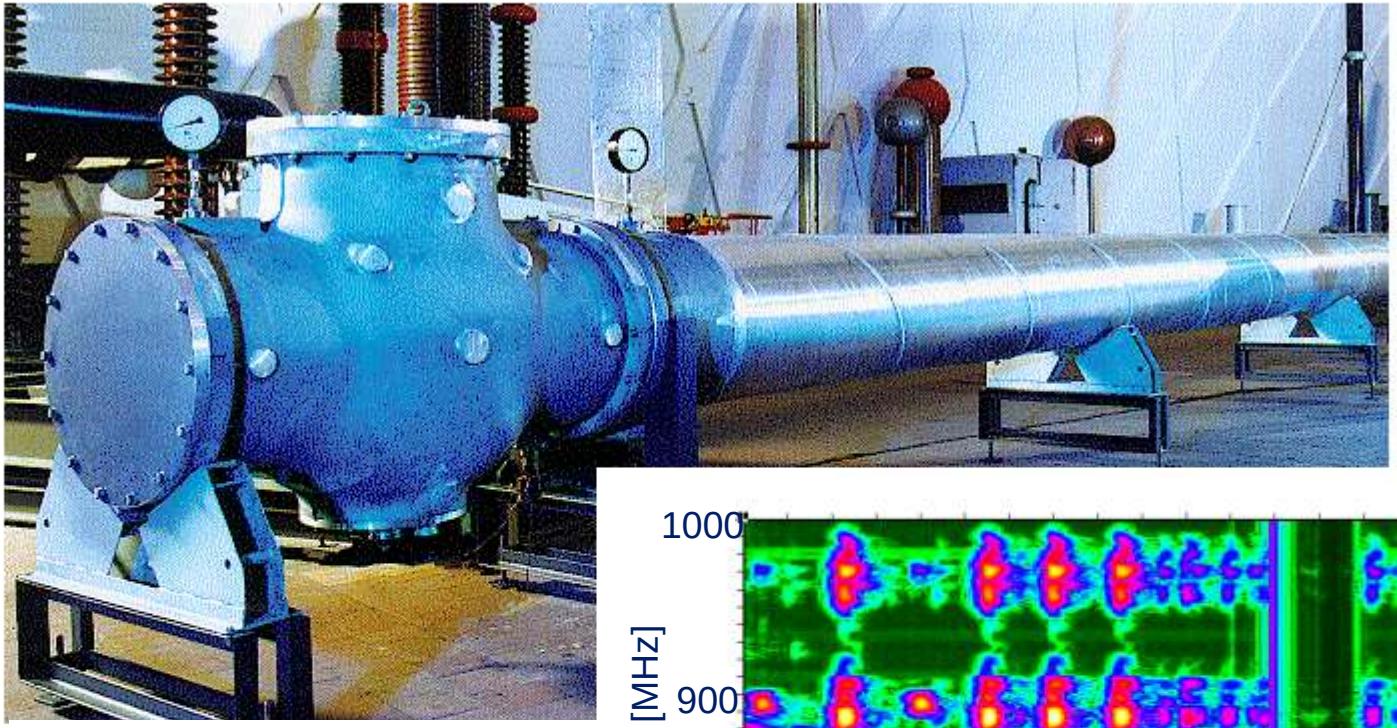


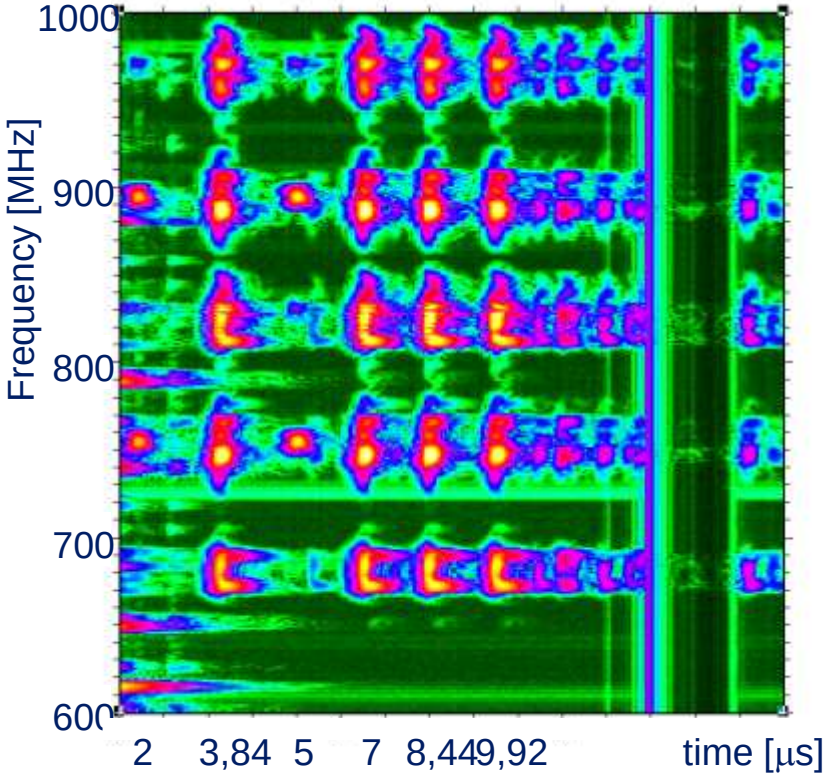


resolution ~ 5% of full scale

L. Reindl, G. Scholl, T. Ostertag, H. Scherr, U. Wolff, F. Schmidt, „Theory and application of passive SAW radio transponder as sensors“, *IEEE Trans. UFFC*, 45 (5), pp. 1281-1292, 1998.

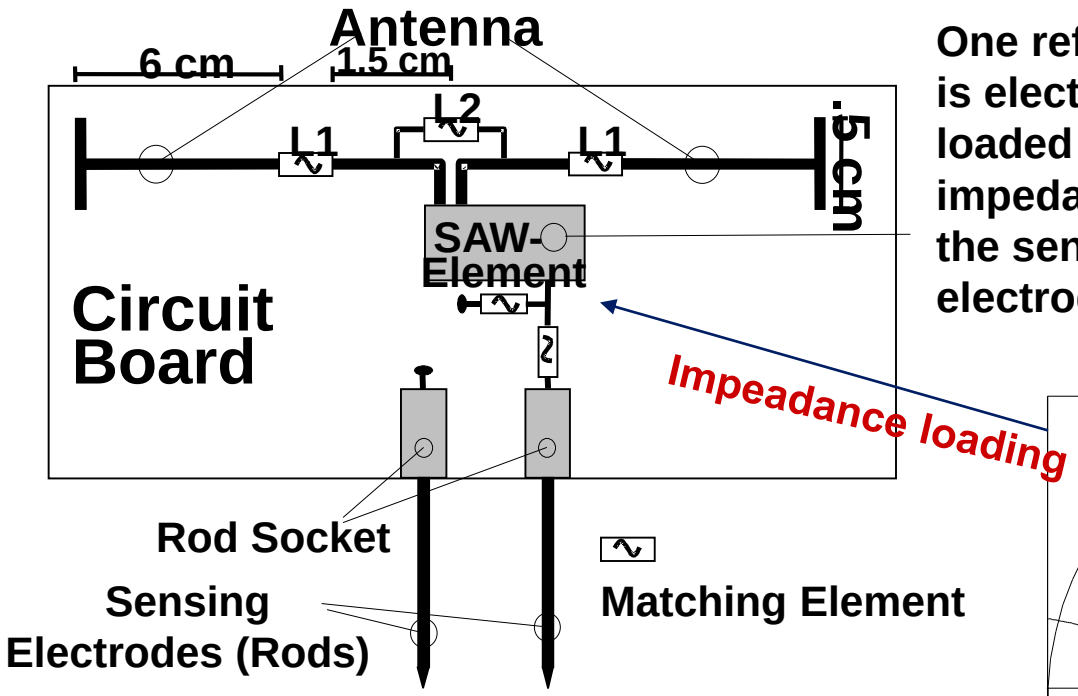
Wireless Current Sensor in an high power switchgear





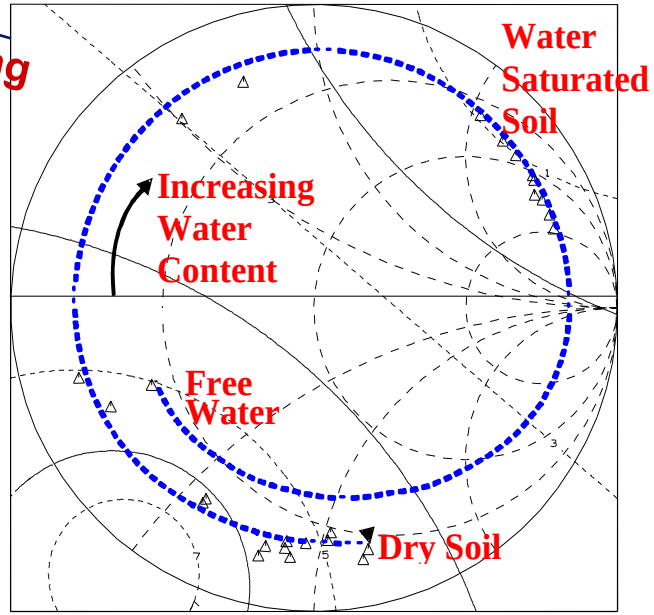
SAW Based Sensor for Measuring the Water Content of Sandy Soil

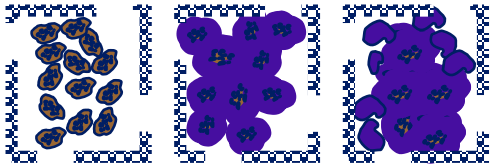
Alexander Kiermayer



One reflector is electrically loaded by the impedance of the sensing electrodes

Impeadance loading





permitivity ε‘ of sandy soil with increasing water content

ε‘~5 5< ε‘< 30 ε‘~30

water content

L. Reindl, C.C.W. Ruppel, A. Kirmayr, N. Stockhausen, M.A. Hilhorst, J. Balendonck, „Radio Requestable Passive SAW Water Content Sensor“, *IEEE Trans. MTT*-49 (4), pp. 803-808, 2000

Why did the technique die out at Siemens?

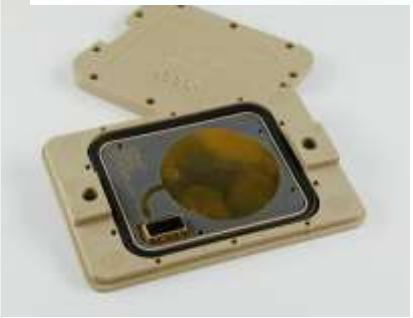
Mr. Pegam

- End of the 90s Siemens lost a lot of money with DRAM chips
- Analysts told the management, that now Siemens is a good candidate for an unfrendly take over and splitting
- Siemens needed fresh money and wanted to eliminate the semiconductor danger
- So the management decided to splitt Epcos and Infineon off the Siemens company
- All the SAW busyness was transfered to Epcos
- But Epcos was a device supplier not a system house
- Epcos was fully busy in producing frontend filters for mobile phones and therefore not interessted to go into a new business
- So, we lost both, our customers at Siemens and our device fabrication facility

The end at Epcos: Epcos did not sign the contract for a SAW Identification Systems for Car Manufacturing

Gerd Scholl

SAW ID-Tags



Reader Unit

long readout distance,
high temperature stability

- highly flexible assembly set-up,
- only one single ID system for entire production process

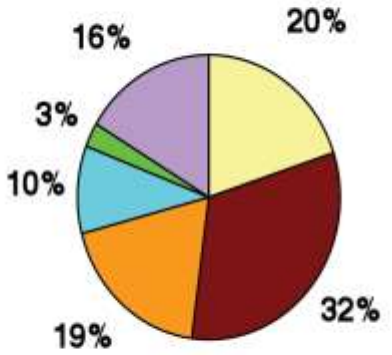
Where are we now?
Wireless Sensor Marked Player

Company	Temp	Pressure	Stress	Torque	Bio/Chem
Applied Sensor R&D (USA)	☻		☻		☻
Avianamolecular (USA)					☻
Bürkert (D)					☻
CTR (A)	☻				
Doble Lemke (D, CH)	☻				
Electronic Sensor Technology					☻
GVR Trade (CH)	☻				
Heinz (D)	☻	☻	☻		
Honeywell (USA)	☻	☻			
Promicron (D)	☻		☻	(☻)	
SAW Instruments (D)					☻
Sengenuity (USA)	☻		(☻)	(☻)	
sensAction (D)					☻
SENSeOR (D,F)	☻	☻	☻	(☻)	☻
Siemens / GE / NG / Honeywell	(☻)	(☻)	(☻)	(☻)	(☻)
Transense (UK)		☻	☻	☻	
	10	4	5	3	8

Marked Potential

Sensors Market Revenues Breakdown by Industry

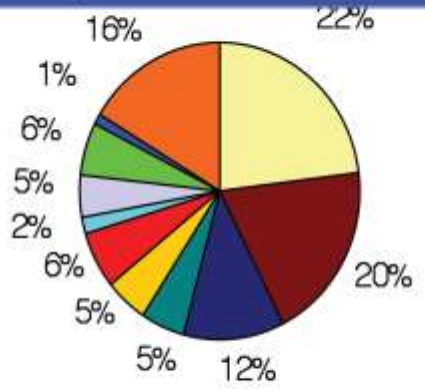
2004 ~$ 40 B 2010 ~$ 56B



Automotive
HVAC & Building Ctrl
Machine Tools
Process & Manuf.
Others
Office Aut & Com.

Sensors Market Revenues by Application

2004 ~$ 40 B 2010 ~$ 56B

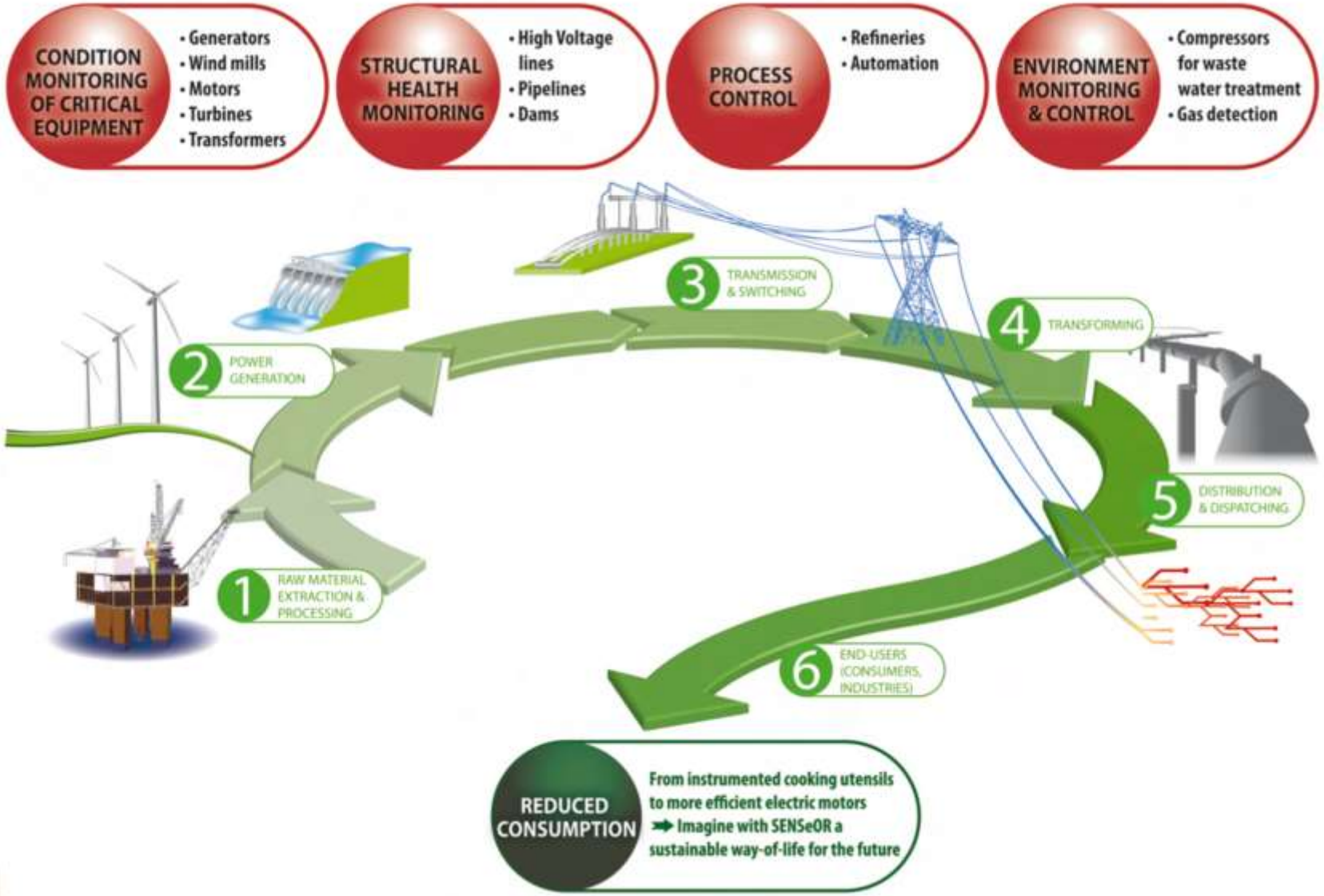


Pressure
Chemical
Fiber Optics
Level
Proximity & Displ.
Position
Flow
Temperature
Force & Load
Image
Others

- The Sensor industry is very big and highly fragmented. Lots of big niche applications exist.
- Key players believe that one-stop shopping is becoming increasingly important. M&A is common.
- SAW-based sensors promise breakthrough performances for fast market ramp

Global Industry Analysis Report – 2004

Upcomming „Green Marked“



Who Can Build Your Reader?

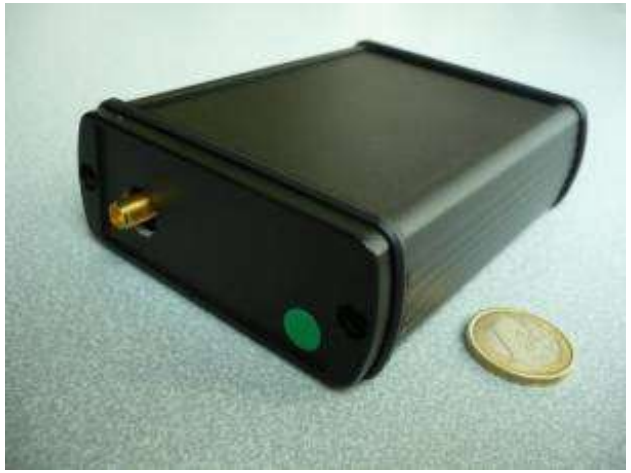
From the shelf:

- SENSeOR
- Transense
- MIELE / Heinz

Design of reader, production, or development

- Johannes-Kepler-Universität Linz, CD-Labor
- RSSI GmbH

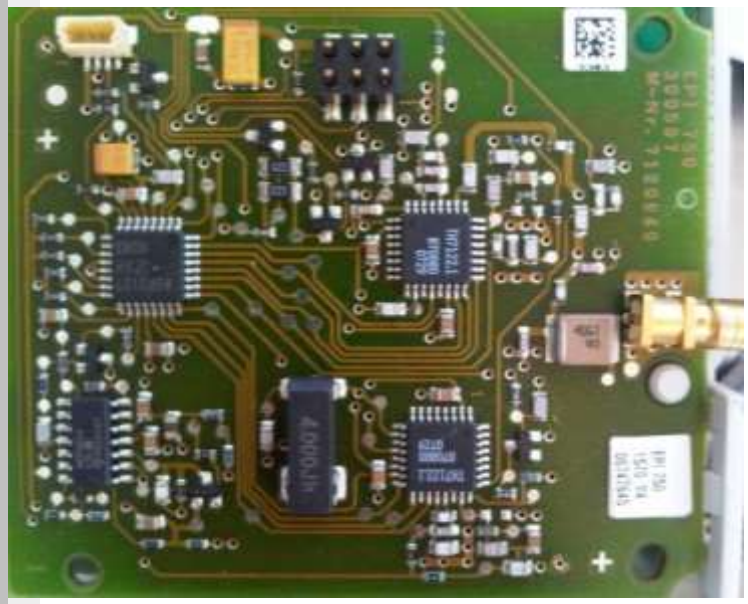
Examples of Readers



Mobile readers

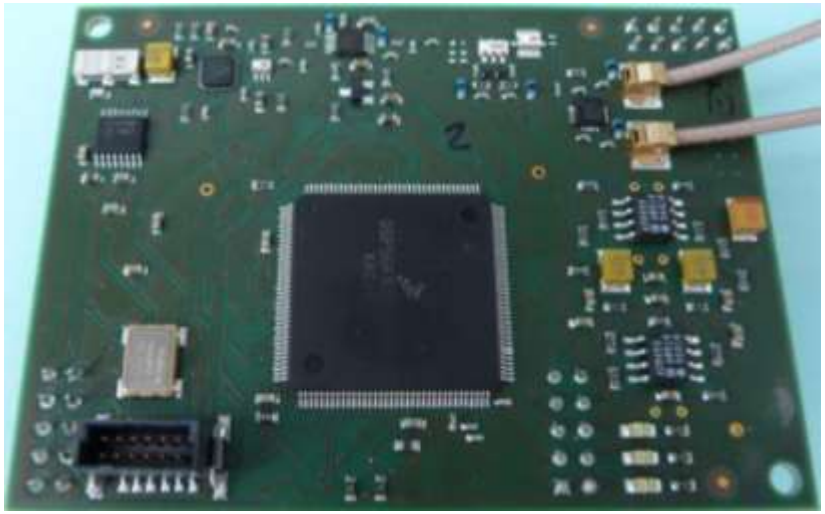
on a intermec

OEM – Low Cost



MIELE / Heinz

High-End vs Low-Cost



Technical Data High End Reader

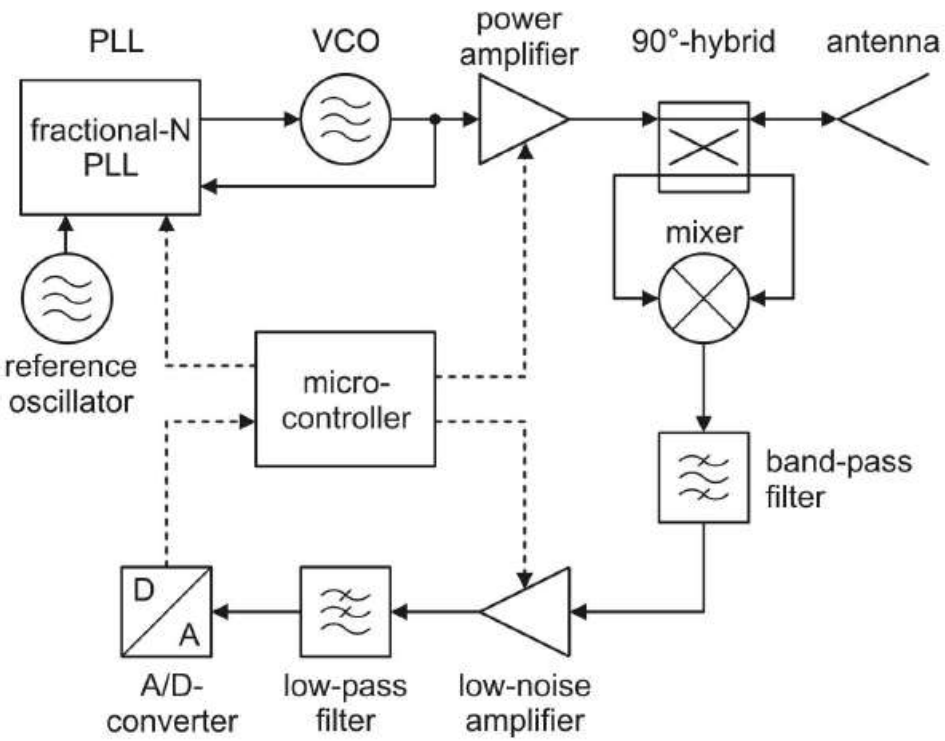
Reading Range	>10m
Maximum Object Speed	>120 km/h
Supply Voltage:	9-36VDC
Power Consumption	10W
Antenna Ports	4 SMA Connectors
Frequency Range:	2.40 – 2.483 GHz
Output Power	<= +20dBm
Interface:	2 * RS232
Temperature Range	-40° C bis +60 ° C

Technical Data Low Cost OEM SAW Ident Reader

Reading Range	>3m
Maximum Object Speed	15m/sec
Supply Voltage:	5VDC +/- 10%
Current Consumption:	0.5A
Antenna Ports	2 UMP Style connectors
Frequency Range:	2.40 – 2.483 GHz
Output Power:	<= 15dBm
Interface:	Asynchron Serial 3.6V - CMOS
Interface Parameter:	115200Baud, 8 n1, no Handshake
Dimensions:	75mm x 55mm

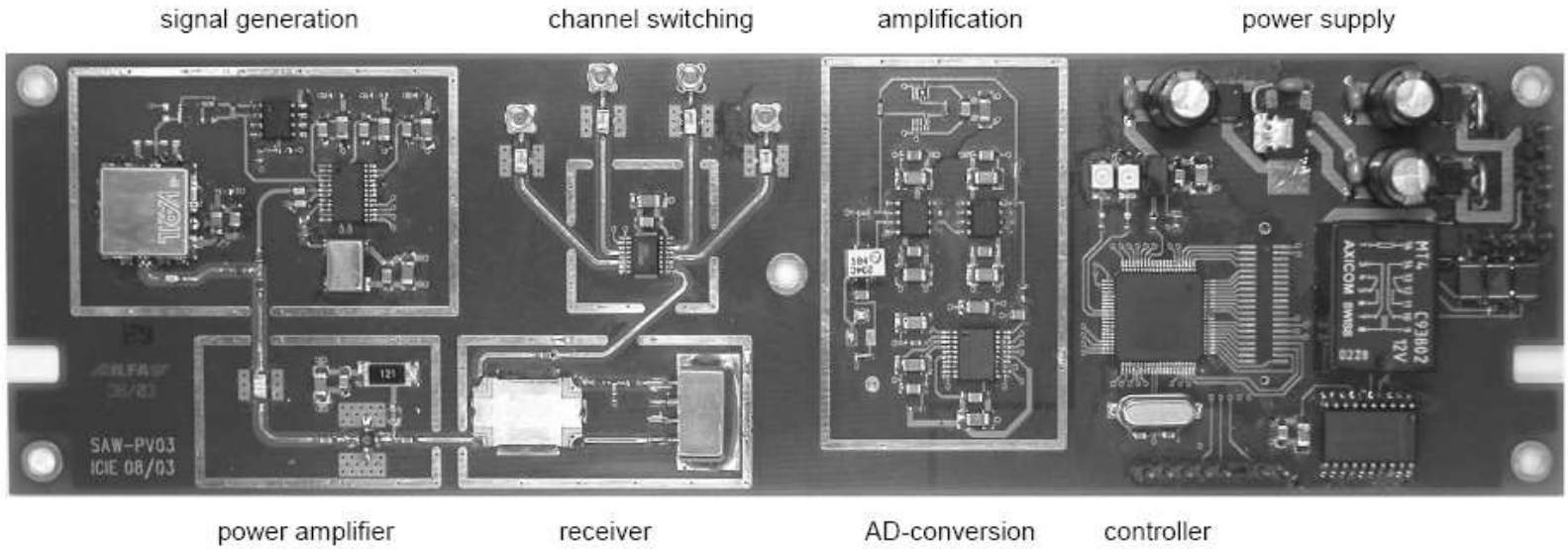
RSSI GmbH
Radio Sensor Solutions

Andreas Stelzer



Block diagram and photo of a ID / temperature readout unit.

A. Stelzer, S. Schuster, and S. Scheiblhofer, "Readout unit forwireless SAW sensors and ID-tags," in Proc. 2nd Int. Symp. Acoust. Wave Dev. for Future Mobile Comm. Syst., Chiba, Japan, Mar. 3–5, 2004, pp. 37–44.



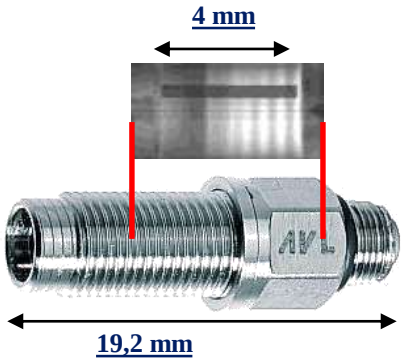
Commercial Reader Unit by CTR

SAW demokit reader unit operating at 2.45 GHz built up using standard ICs;
photo by CTR, Villach, Austria

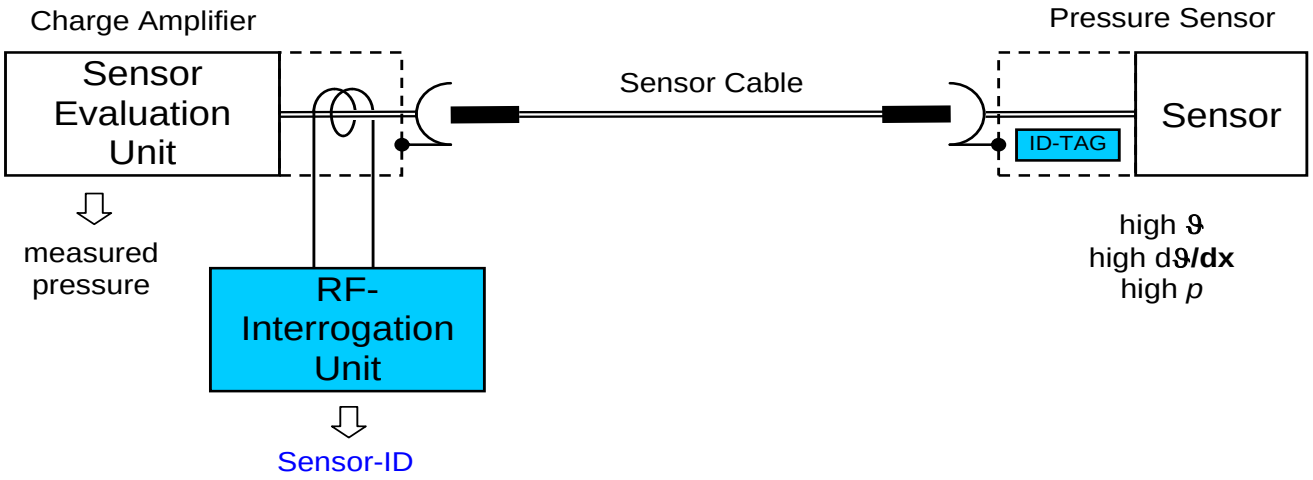
web: http://www.ctr.at/carinthian_tech_research_english/

ID Applications

- **AVL-Pressure Sensor with integrated ID**
  - Integration into the sensor
  - SAW tag less than 5 mm in length
- **Environmental Condition**
  - **Temperatur:** 2000 h @ 300 °C, 10 h @ 400 °C
  - **Schock:** 2000 – 3000 g



AVL: Cylinder Pressure Probe



Id Applications

- **Drilling Equippment with ID**
- **Environmental Conditions**
  - **Temperature:** +250 °C
  - **Preassure:** 1300 bar
  - **Abrasive fluids**

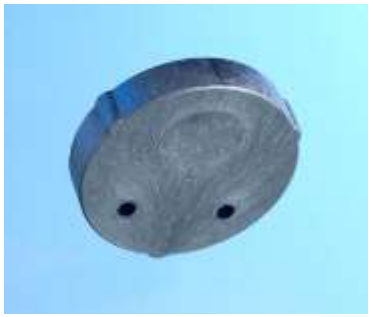
Identifikation and Logistic

- **Schlackebehälter mit ID**
- **Environmental Condition**
  - **Temperature:** >+250 °C
  - **Metallic environment**
  - **Strong mechanical loads**

Identification of autoclave transport

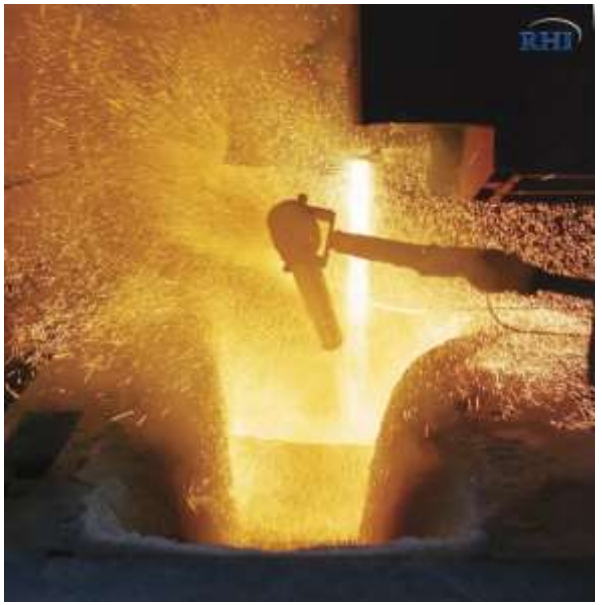
- Automatic identification of transport wagons during autoclaving
- Exact monitoring of process exposure of wagons

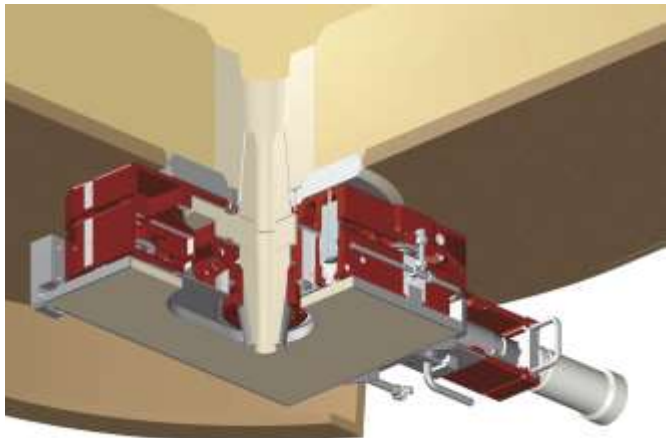
- Harsh environment:
  - +190 °C
  - 10-12 bar
  - Saturated steam
  - Process time 24 h
- Plastic encapsulation dissolves
  - All metal tag withstands the process



RFID and sensing in steel plant

- automatic identification of slide gate plates
- temperature monitoring during casting process
- harsh environment
  - temperatures up to +1400°C
  - dust, rude handling
  - impact loads





SAW transponder

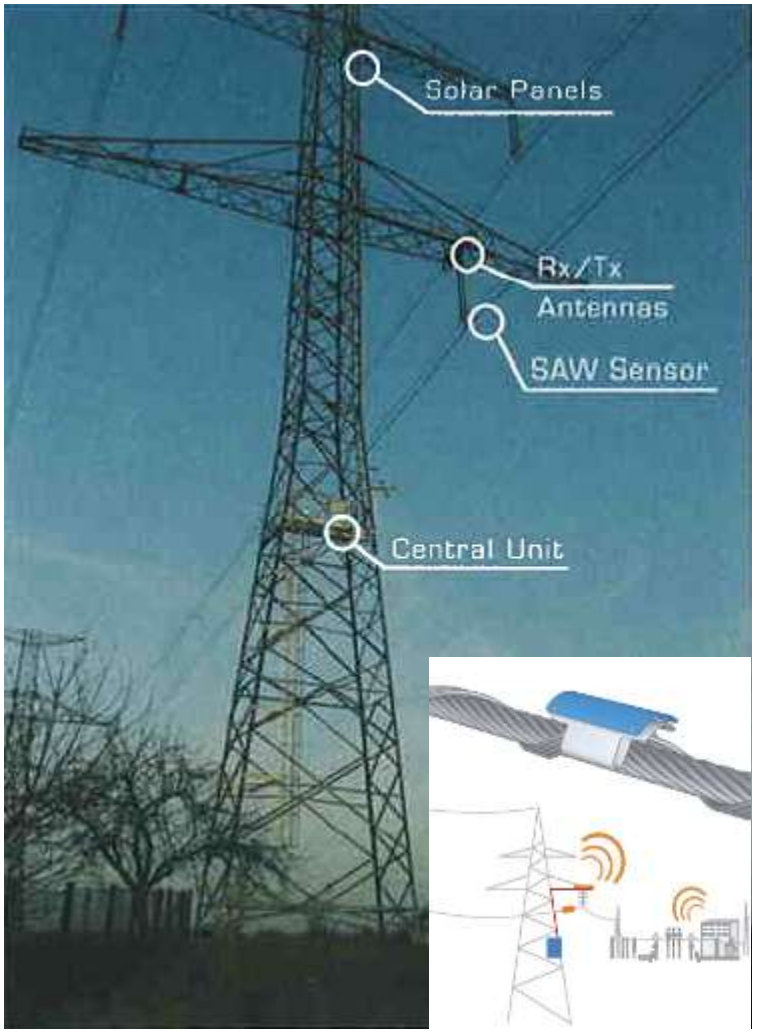
Identification & temperature control of drying process in refractory products

- Prevention of remaining humidity
- Harsh environment
  - high temperature
  - metallic surrounding
- Online monitoring of drying
- Tracking of hot, moving equipment

Temperature monitoring of power transmission lines

- Preventing exceeding of the rated temperature
- Overloading with no exceeding of the rated temperature
- Measuring stations are fully remote configurable from the database server

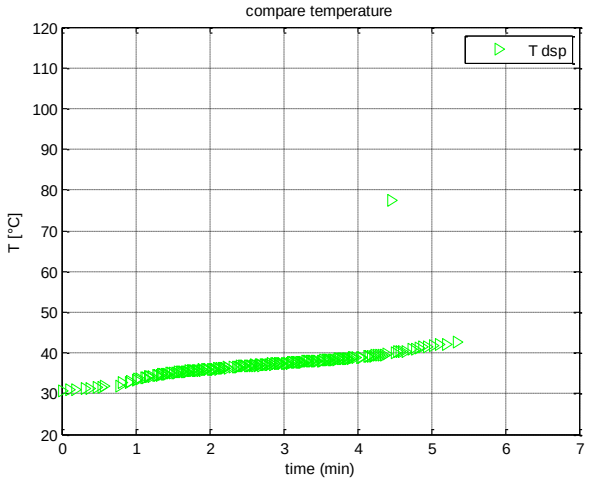
- Measuring range up to 15 m
- Temperature accuracy: 0,5 K
- Temperature resolution: 0,01 K
- Temperature range: -40 °C to +150 °C
- Measuring Interval 60 sec for computing the free span temperature of the OHTL

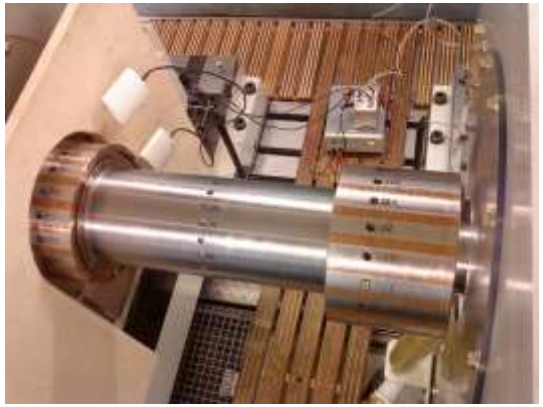


Temperature monitoring of rotating machine elements

- Prevent damage on machine parts
- Condition monitoring

- Measuring range up to 0,5 m
- Temperature accuracy: 1 K
- Temperature resolution: 0,2 K
- Temperature range: -20 °C to +250 °C
- Rotor speed 15000 rpm





SENSeOR's offer
Unique Features for High Value Applications

Revolutionary sensors

- **Wireless**
- **Passive**
- **Robust**

➔ Enabling measurements

- On moving and rotating parts
- In confined or inaccessible spaces
- Where cabling costs too much or is impossible
- In harsh environments – like: strong fields, explosive, corrosive

➔➔ For measurable benefits

- **Improved productivity**
- **Performance optimization**
- **Security enhancements**

Condition Monitoring - Structural Health Monitoring
Process Control - Precision Metrology

SAW Temperature Evaluation Kit EVAL KIT T01

Pressure sensor chip

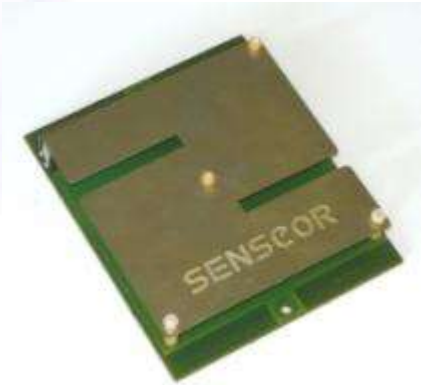
Packaged temperature sensor TSE AS10

Fixture mounted temperature sensor with antenna TSA D031

SENSeOR offers to partner with anyone such as to industrialize such applications and to make the technology known.

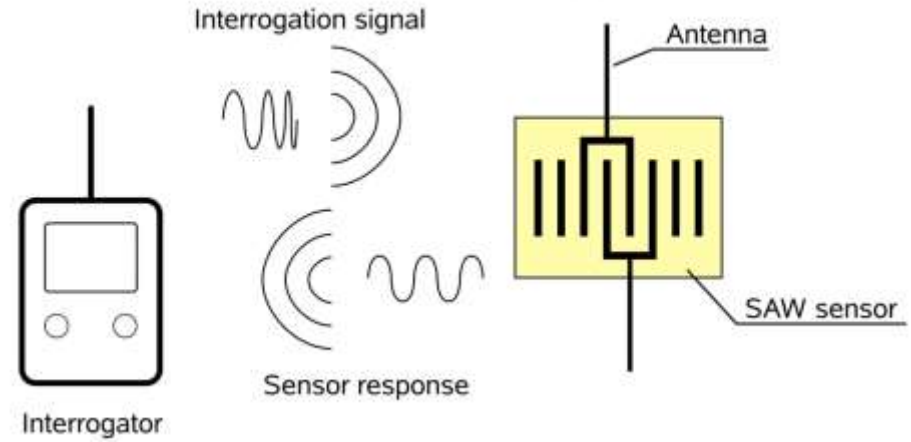
Once we find strong applications and/or partners in the US then SENSeOR will establish an office in the USA.

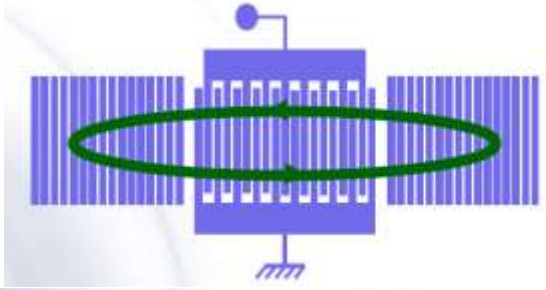
Thermowell packaged temperature sensor TSM D100

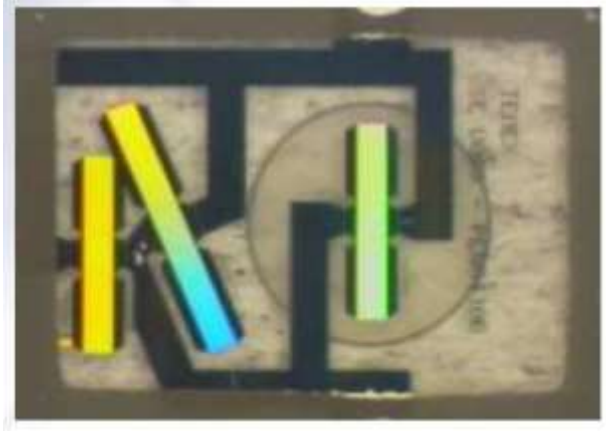


PIFA antenna mounted temperature sensor TSA D003

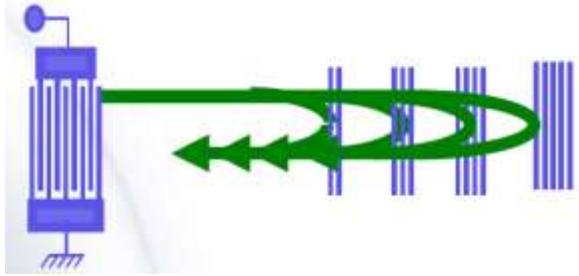
Senseor pressure sensor

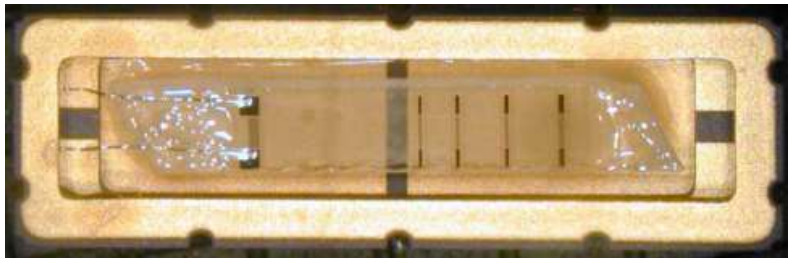






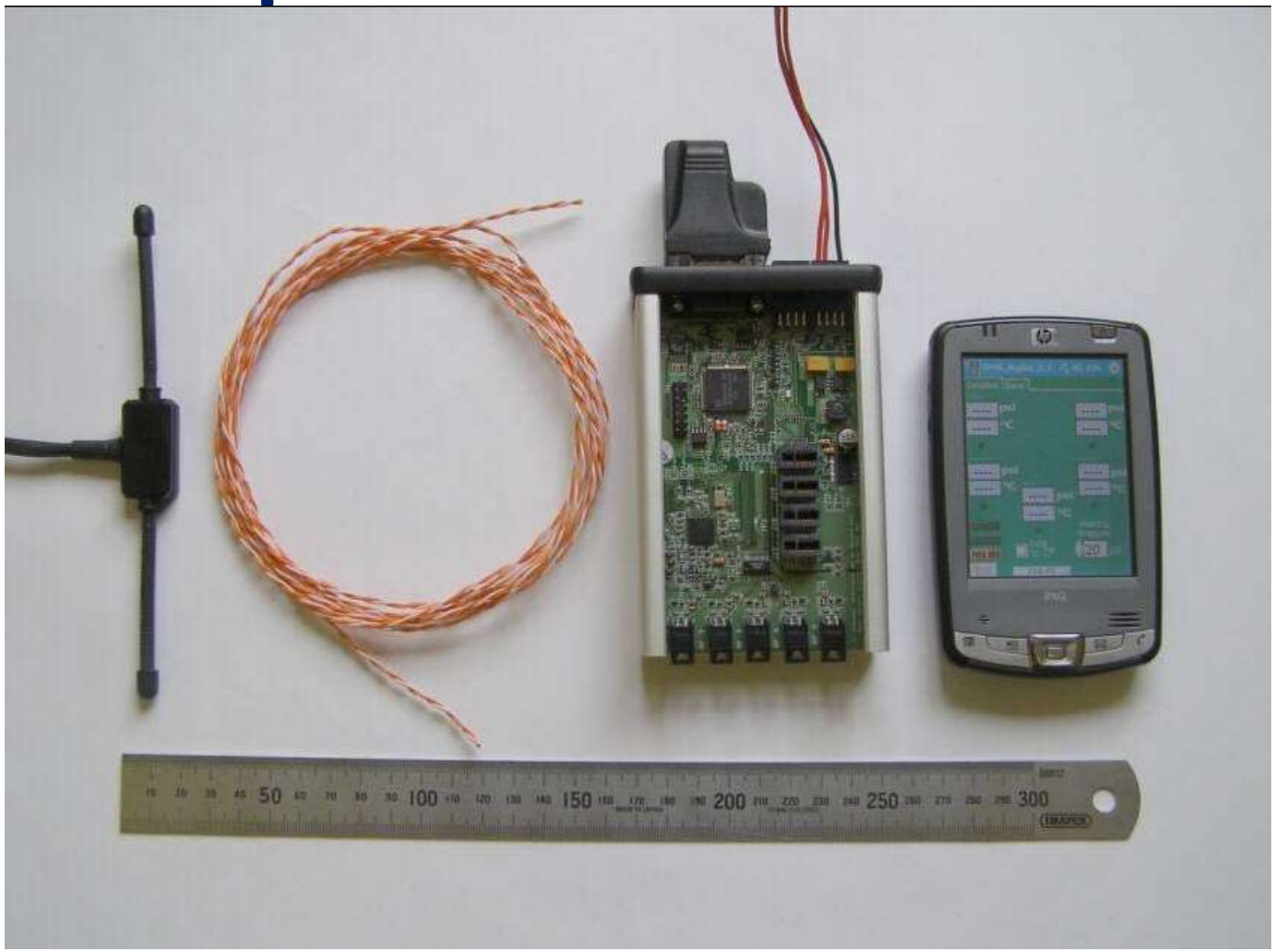
pressure & temperature sensor (8x4mm)





Example of SAW temperature sensor (9x3,8mm)

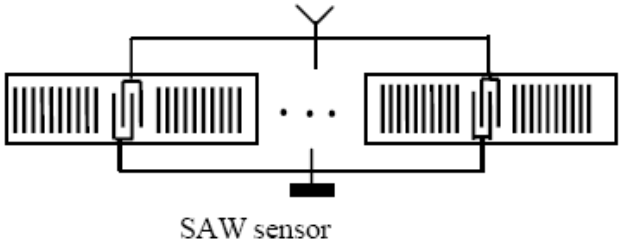
Transens pressure sensor



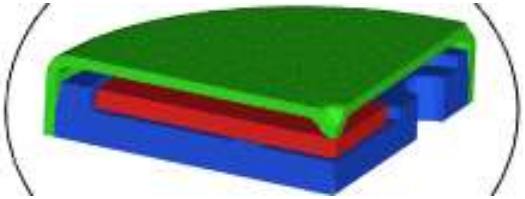
key components of demo system:
Wheel arch antenna (far left), twisted pair (left), electronic interrogation unit (fitted with Bluetooth dongle), PDA display unit (right)

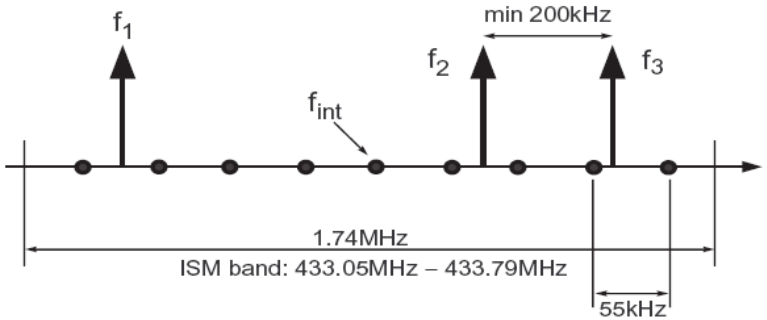
B. Dixon, V. Kalinin, J. Beckley, R. Lohr, „A Second Generation In-Car Tire Pressure Monitoring System Based on Wireless Passive SAW Sensors “, 2006.

Transens pressure sensor



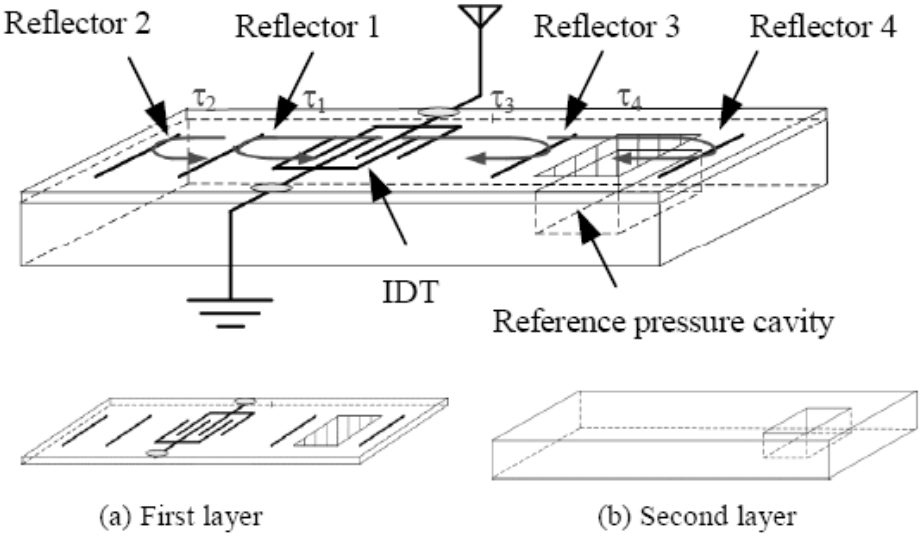
valve assembly incorporating sensor and antenna



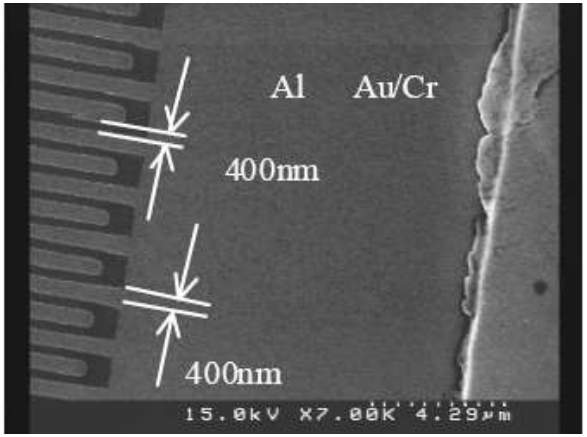


B. Dixon, V. Kalinin, J. Beckley, R. Lohr, „A Second Generation In-Car Tire Pressure Monitoring System Based on Wireless Passive SAW Sensors “, 2006.

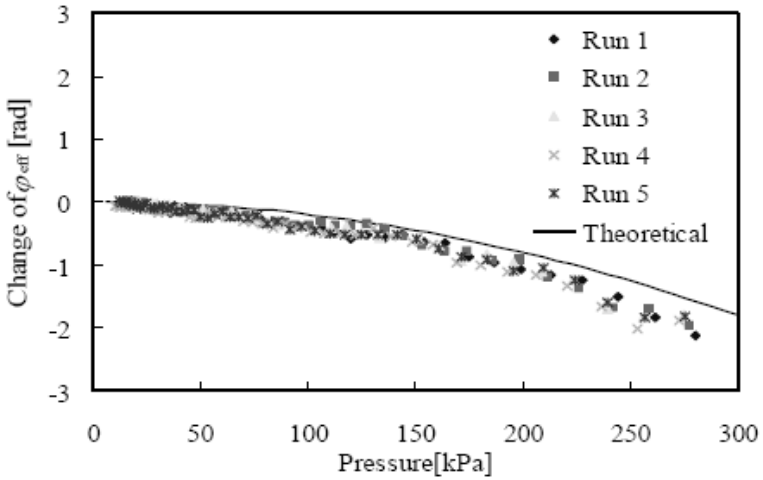
Nissan pressure sensor



Schematic structure of the SAW delay line pressure sensor



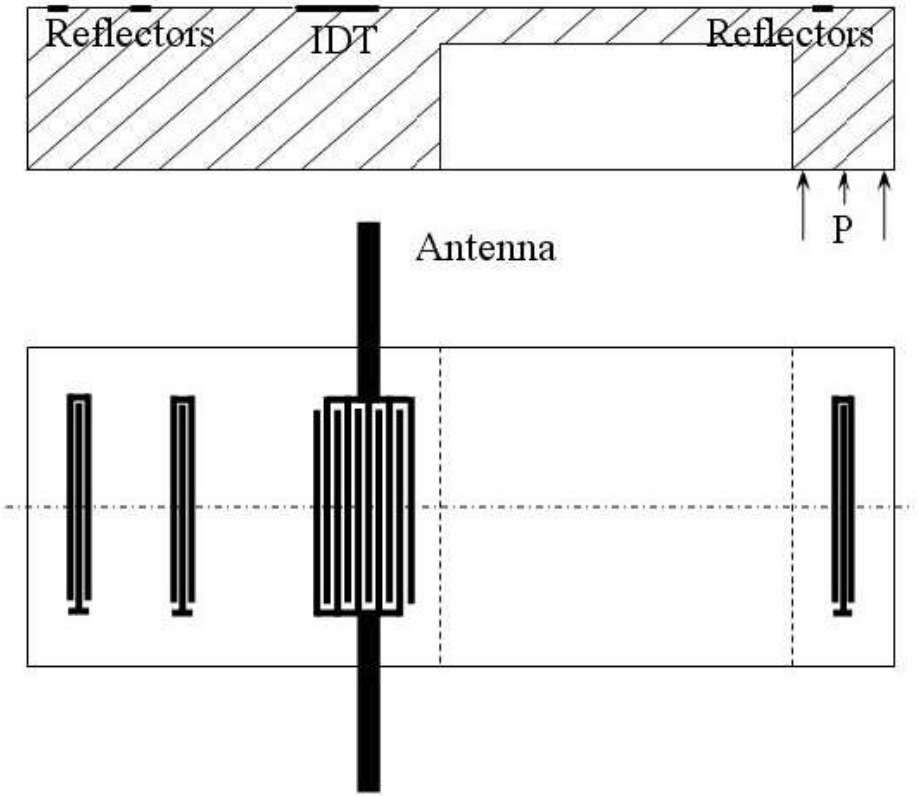
Fabricated interdigital transducer



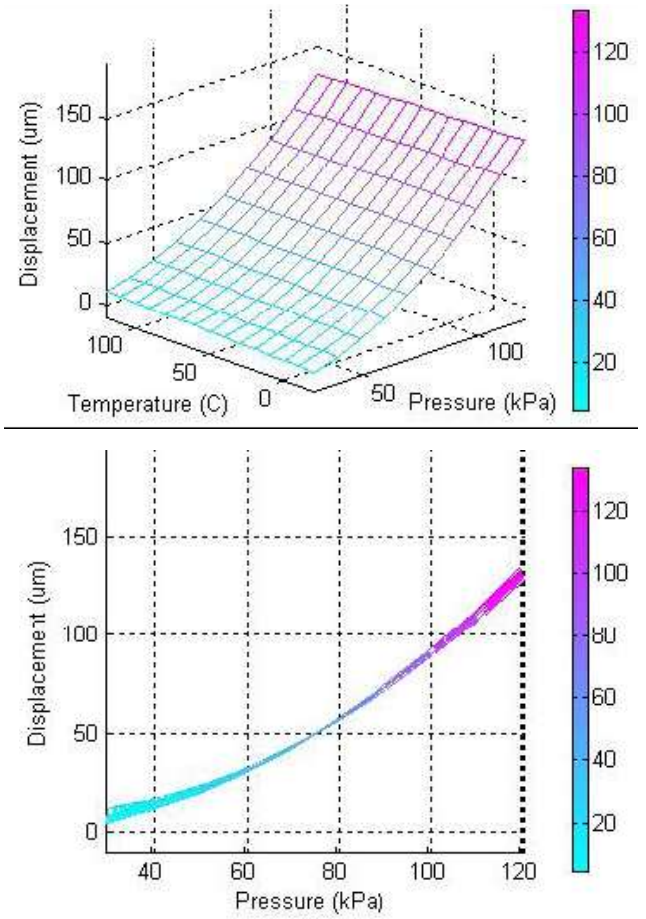
Change of the effective phase ϕ_{eff} by pressure change

S. Hashimoto, J. Kuypers, S. Tanaka, M. Esashi, „Design and Fabrication of Passive Wireless SAW Sensor for Pressure Measurement “, 2008.

Harbin Institute of Technology, China, pressure sensor



The structure of the wireless passive SAW sensor

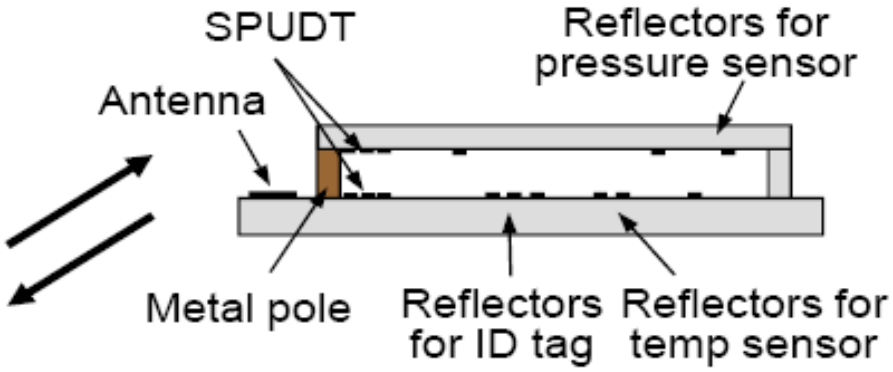


Displacement affected by the temperature and pressure after data processing.

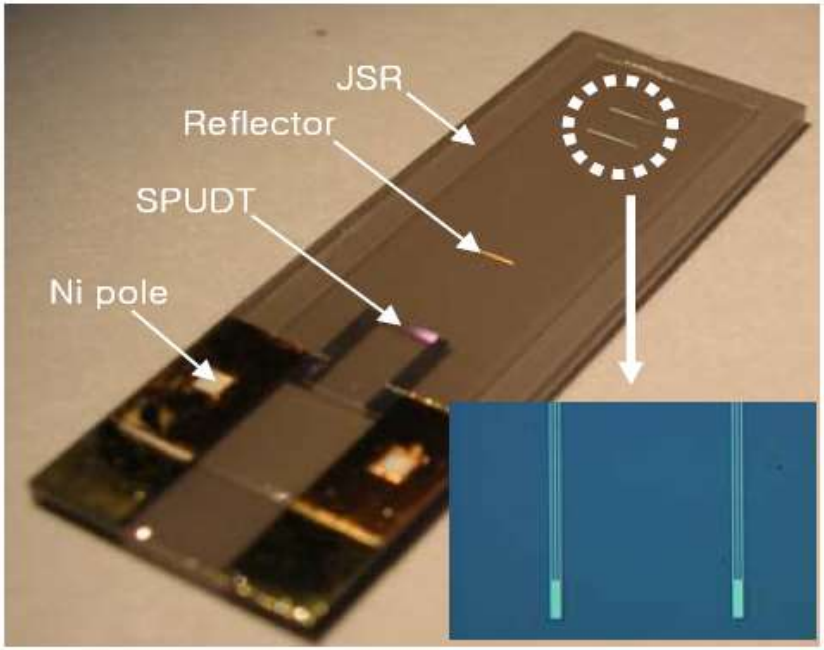
T. Li, L.Zheng, H.Hu, „A Novel Wireless Passive SAW Sensor Based on the Delay Line Theory “, Proc. 3rd IEEE Int. Conf. on Nano/Micro Engineered and Molecular Systems, Sanya, China, 2008.

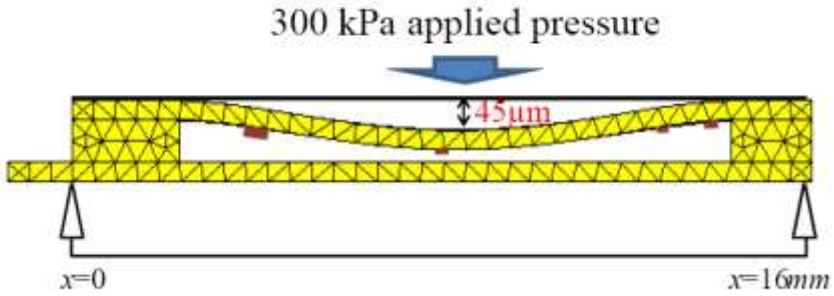
Anyun University, Korea, wireless SAW sensor for simultaneous measurement of pressure, temperature & ID

Cross-sectional view of the fabricated microsensor



top views of the top and bottom devices





Calculated diaphragm bending under applied pressure of 350kPa using FEM analysis

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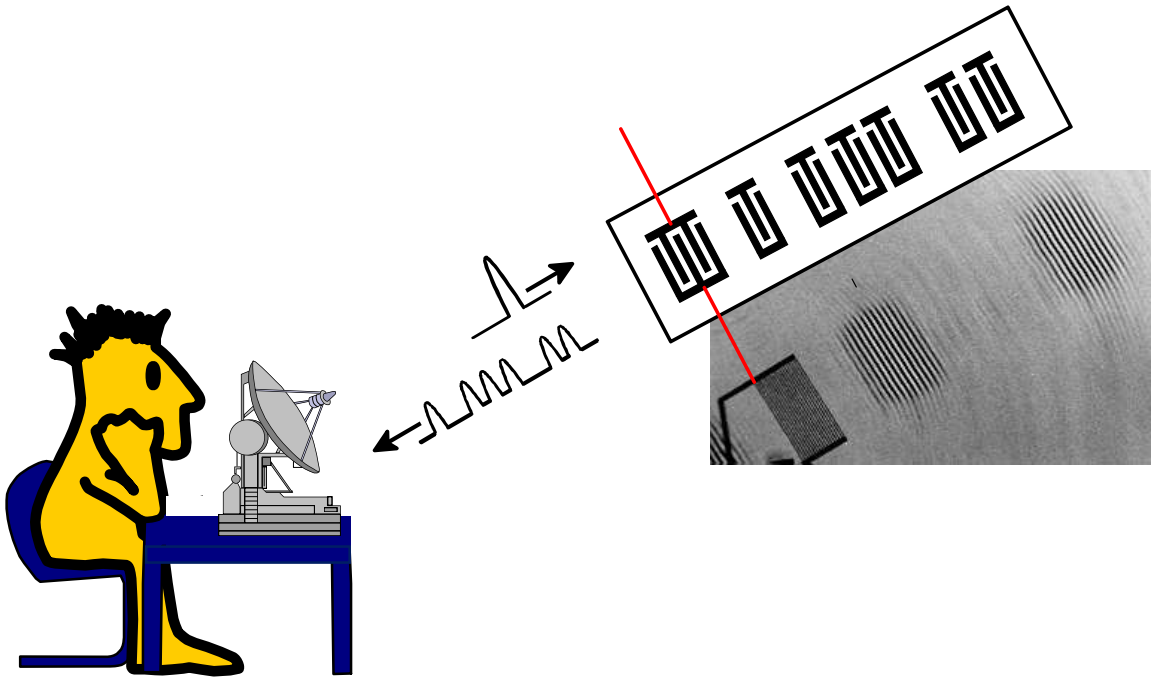
Conclusion

- The history
- Some selected application ort examples
- A short marked overview

has been presented



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Animated SEM-photos of an operating interdigital transducer