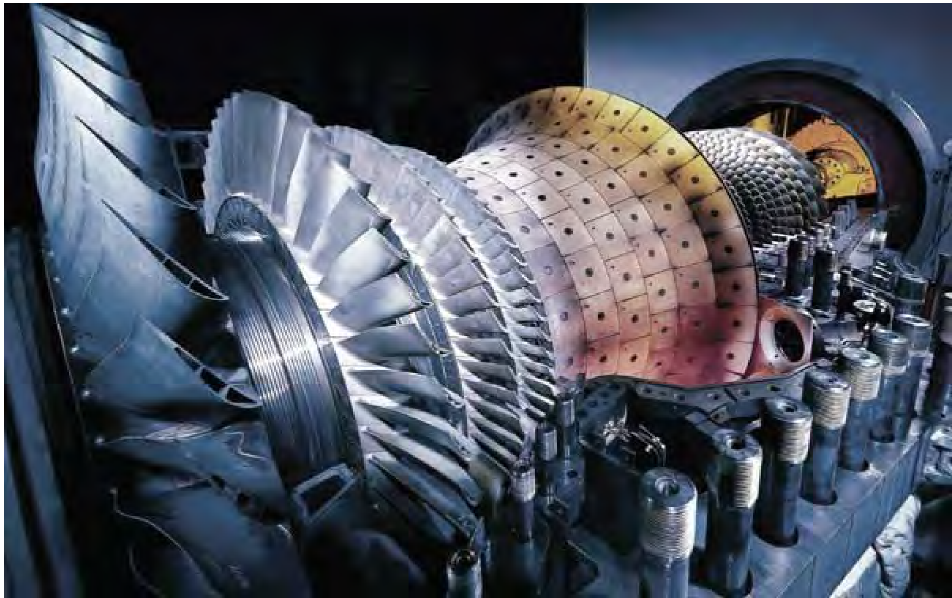
# Passive Wireless Sensing at Microwave Frequencies: Challenges and Approaches

Chair for Electrical Instrumentation
Taimur Aftab, Prof. Dr. Leonhard Reindl

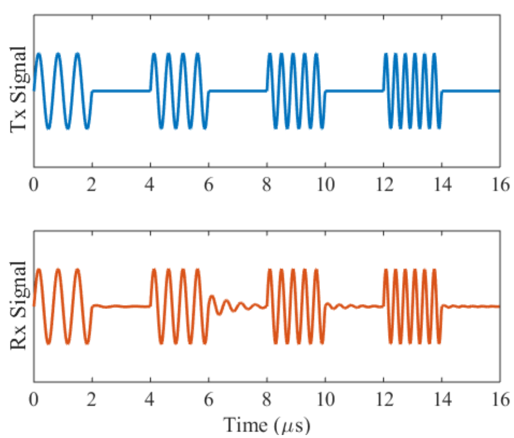
- Zero Power RF chipless sensors

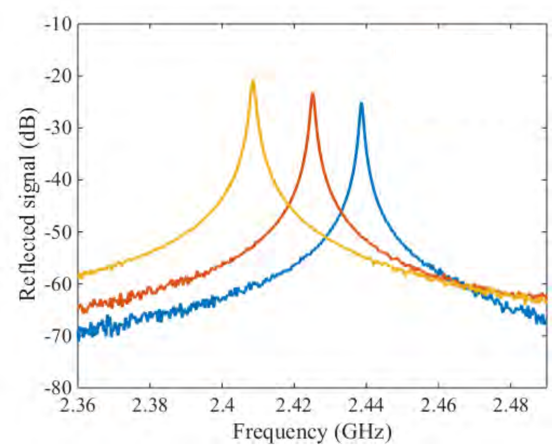
“We enable autonomous devices to perceive the environment.”



# Wireless sensing principle

- Interrogation of high-Q resonators.

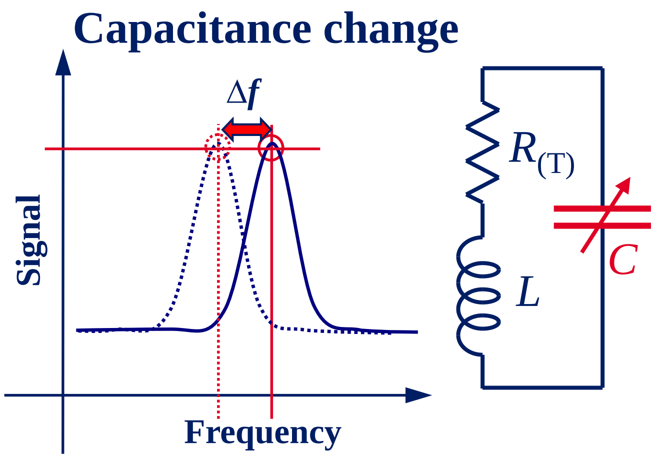



# LC Based Wireless Passive Sensor Systems

- Resonance circuit: capacitive sensor and planar coil;
  f ~ quantity to be measured
- Wireless resonance detection
- Sensor Q factor allows for compensation of temperature cross-sensitivity

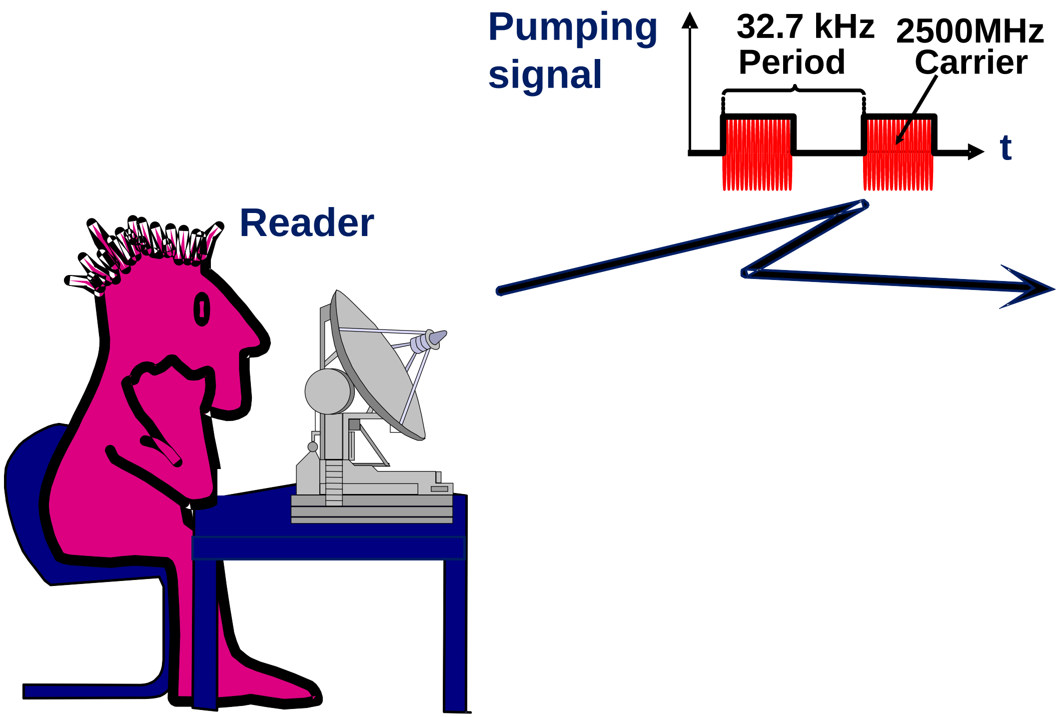

*Silicon micromachined wireless pressure sensor prototype by Bosch*

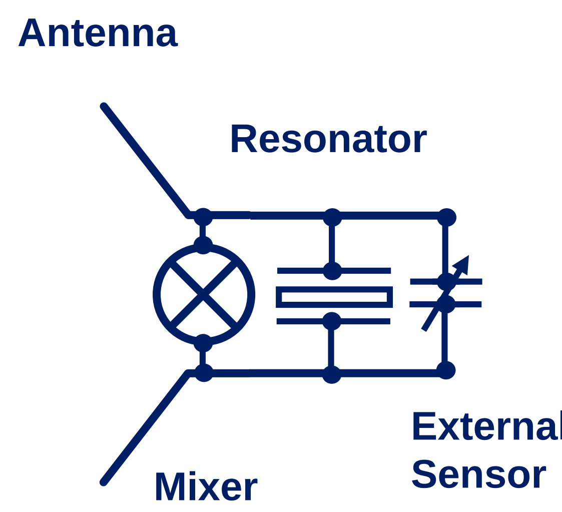



R. Nopper, R.Niekrawietz, L. Reindl, “Wireless Readout of Passive LC Sensors”, IEEE Trans. on Instrumentation and Measurement, Vol 59 (9), pp. 2450-2457, Sep 10, 2010

“Inductively Coupled Passive Sensors for Measurements in Difficultly Accessible Environments”, Reinhard Nopper[1], Dr. Remigius Has[1], Prof. Dr. Leonhard Reindl[2], VDI/VDE congress “Sensoren und Messsysteme“, Nurenburg, 19. Mai 2010,
[1]: Robert Bosch GmbH, Gerlingen-Schillerhöhe, Germany, 2: Laboratory for Electrical Instrumentation, IMTEK, Albert-Ludwigs-Universität Freiburg, Germany

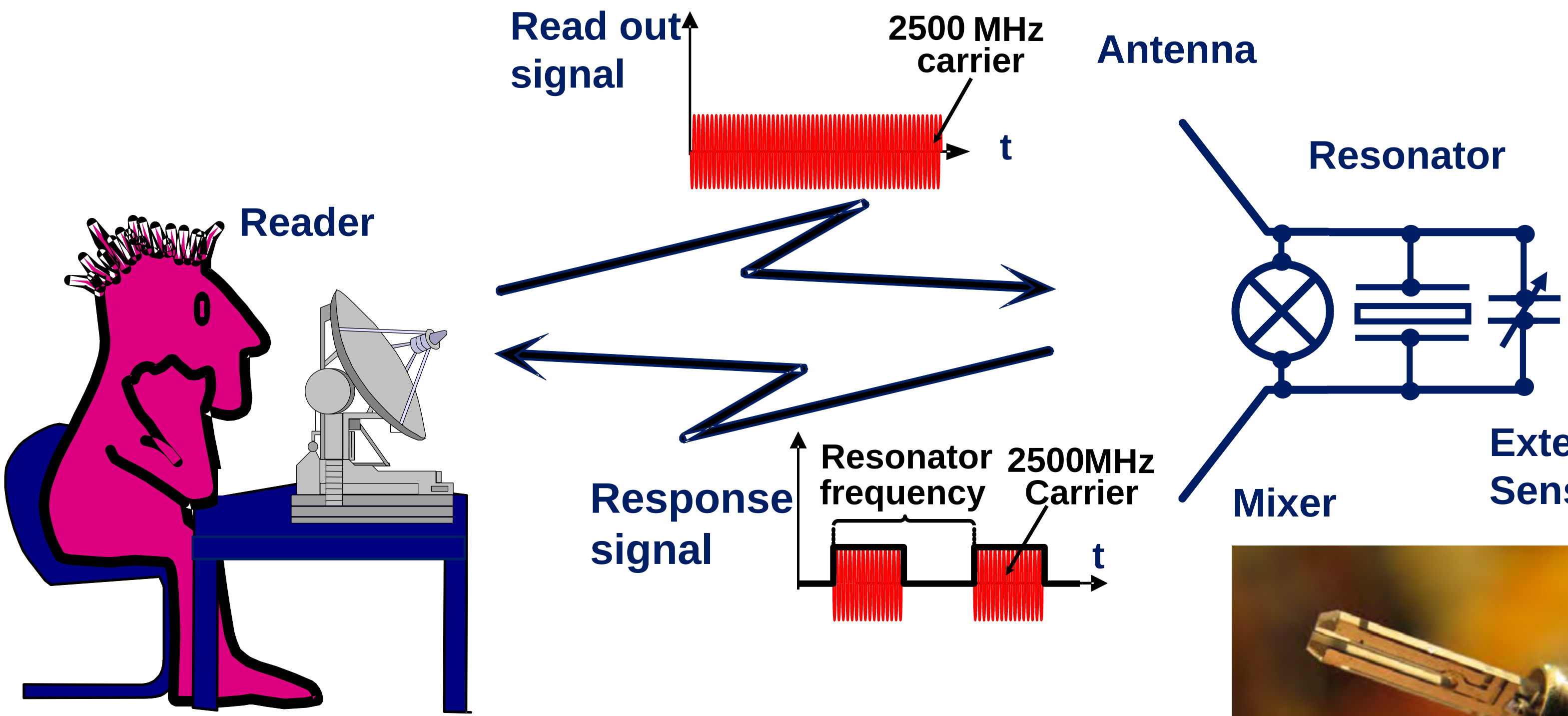
# Wireless Passive Sensor Systems Based on Quartz Crystal Resonators




- An external sensor pulls the Quartz resonant frequency
- Might be combined with the mixing sensor

# Wireless Passive Sensor Systems Based on Quartz Crystal Resonators




- An external sensor pulls the Quartz resonant frequency
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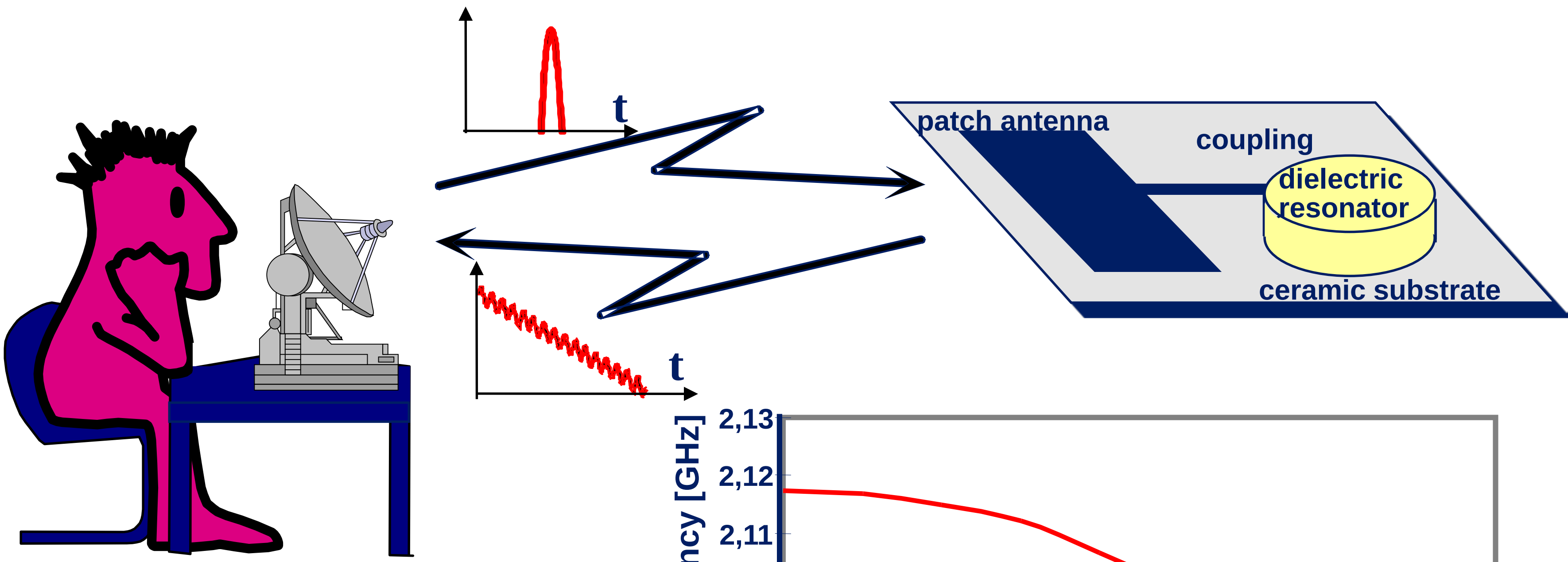
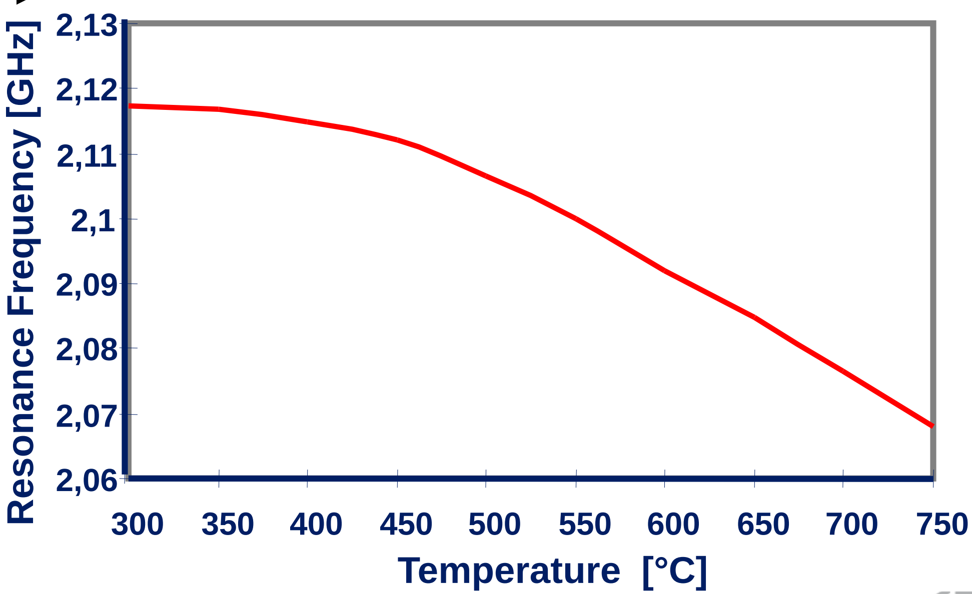
# Wireless Passive Sensor Systems Based on High-Q Dielectric Resonators

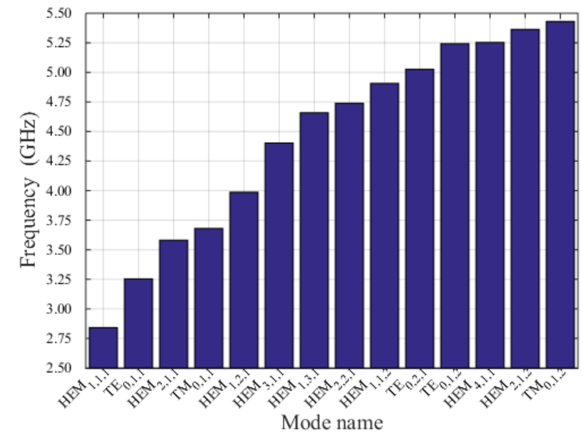


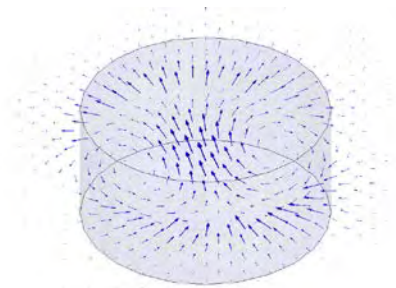

- Wireless read-out of passive resonators works also for high Q dielectric microwave resonator
- Temperature of operation > 750°C



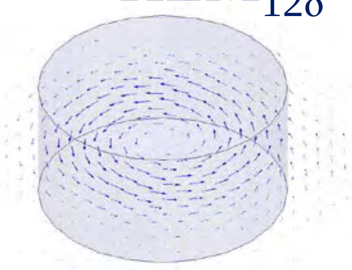
# Parallel plate dielectric resonators

- Very high Q resonator
- Used traditionally to characterize DR
- Adjustable resonance frequency
- Operating in the fundamental $TE_{01\delta}$ mode

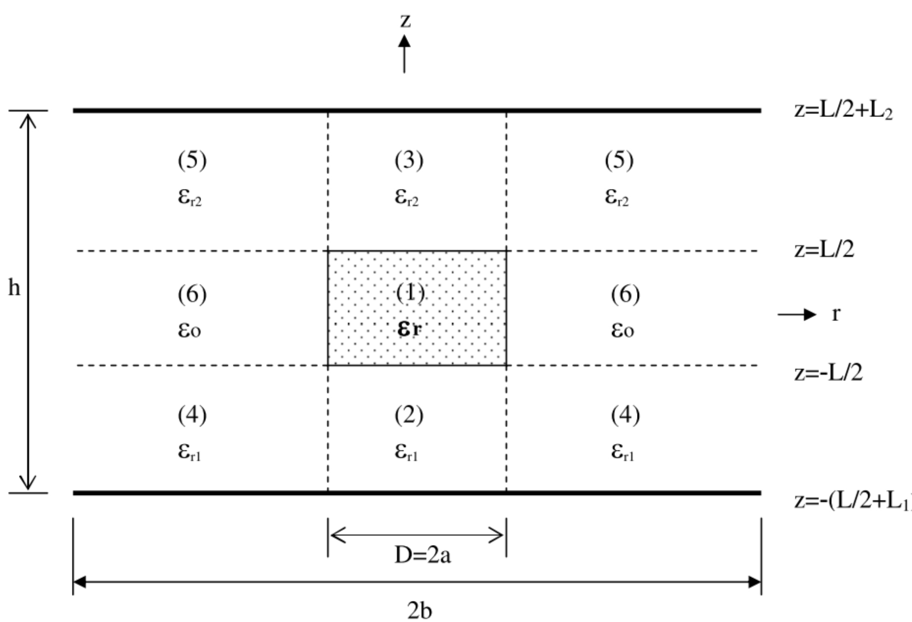


$HEM_{12\delta}$

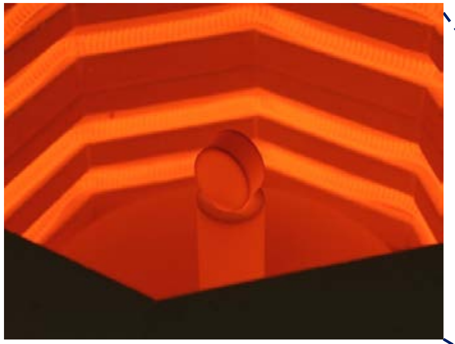


$TE_{01\delta}$

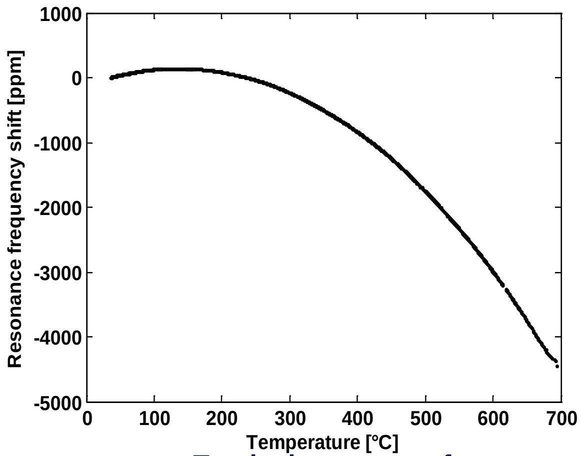


# Wireless Dielectric Temperature Sensor

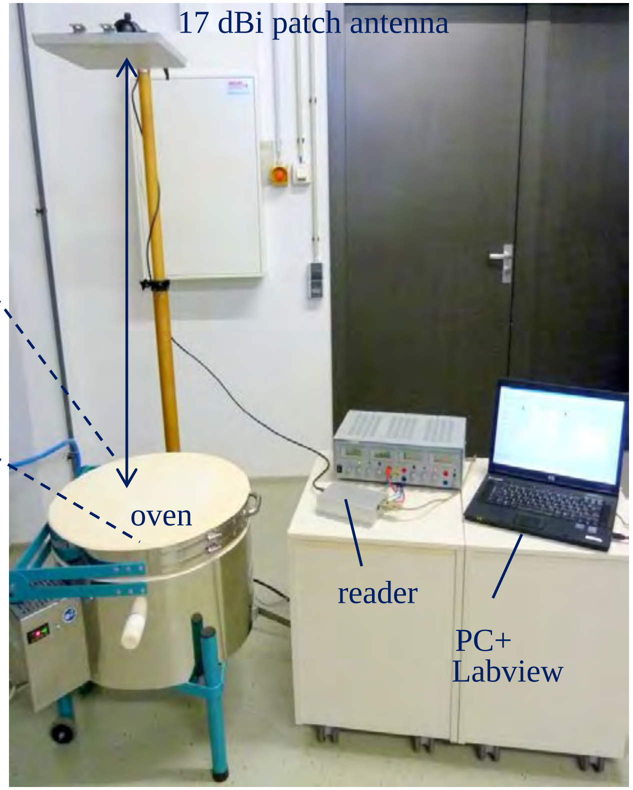
- **Metallization free dielectric resonator based high temperature sensing**



**Inner view of the oven at 700 °C with a dielectric resonator placed inside**




**Tracked resonance frequency shift**
**Maximum frequency shift of -4500 ppm**

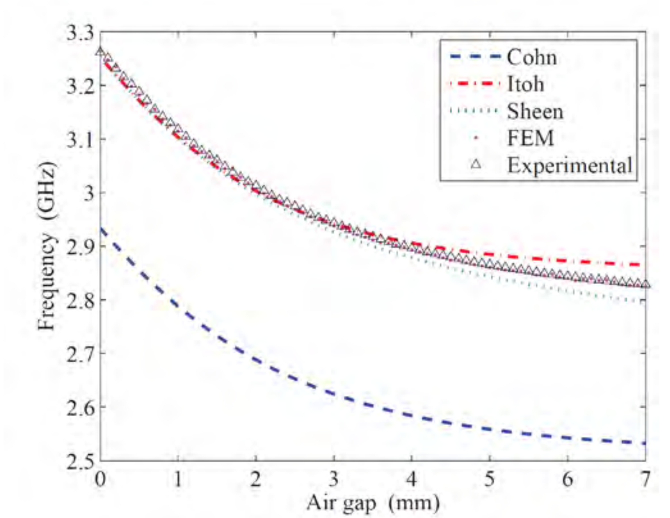


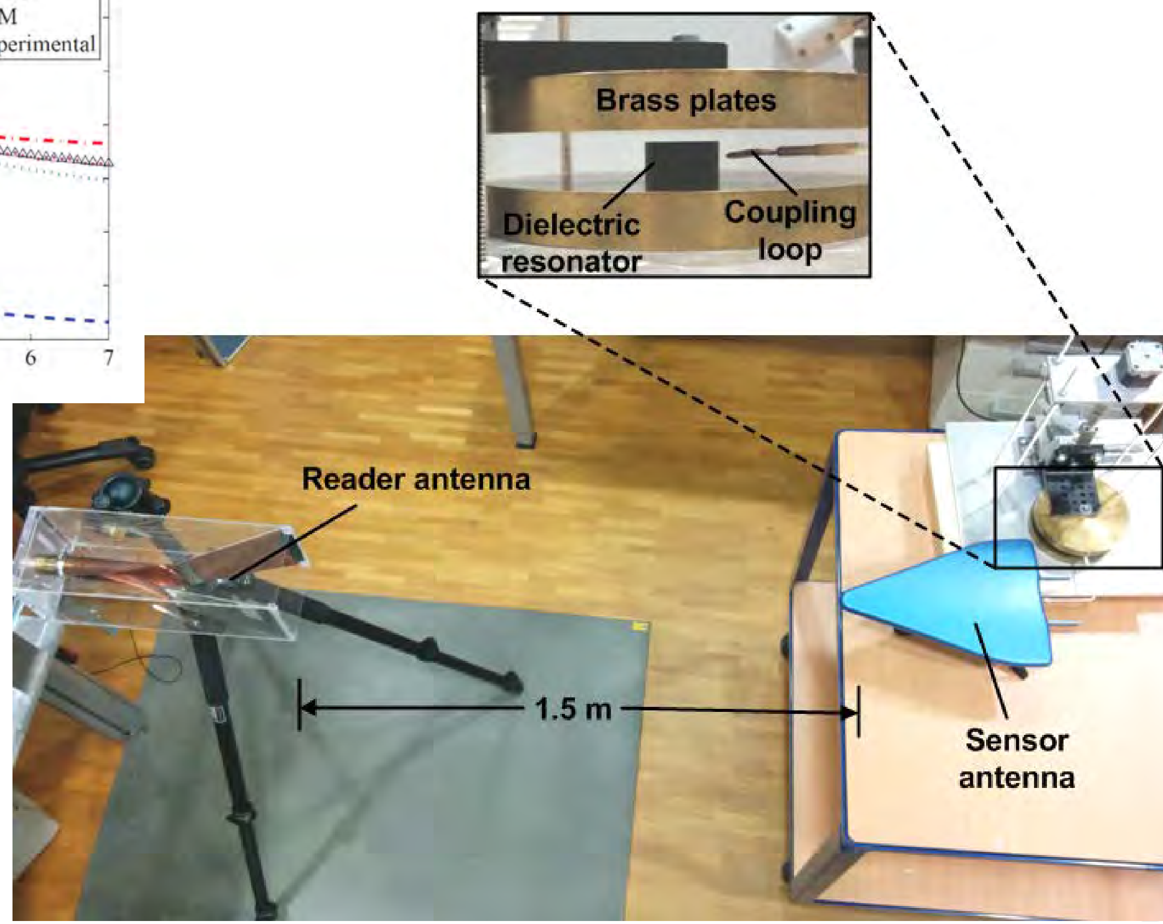

**Complete measurement setup**
**Reading distance: 1.20 m**


J.-M. Boccard, T. Aftab, J. Hoppe, A. Yousaf, R. Hütter, L. M. Reindl,Far- Field passive temperature sensing up to 700 °C using a dielectric resonator 2014 IEEE International Conference on Wireless for Space and Extreme Environments, Wisee, European Space Agency, ESTEC,

# Wireless experimental setup

- Wireless measurement of displacement.

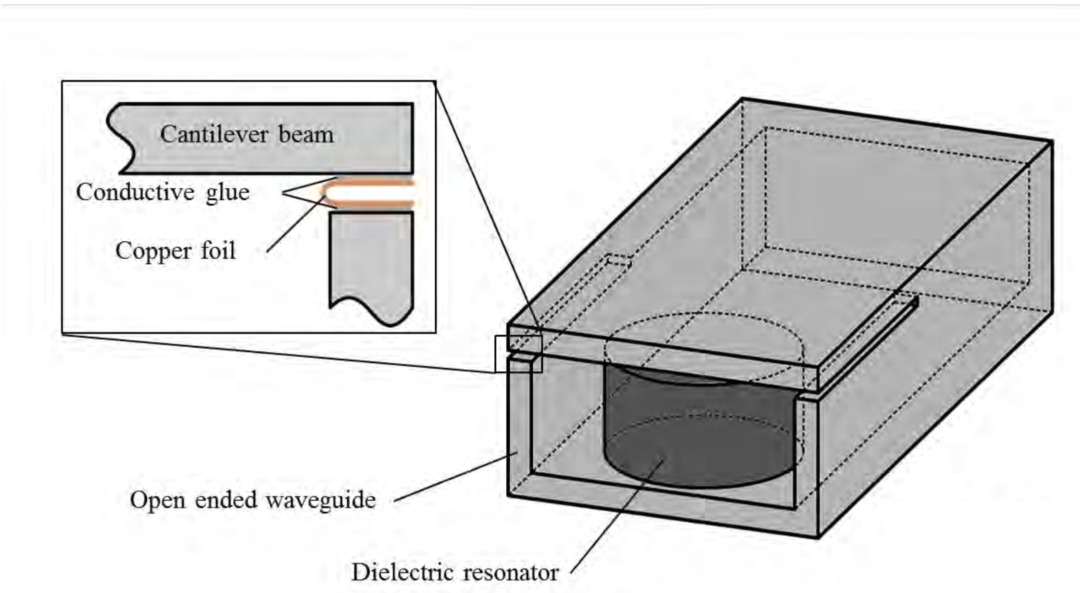


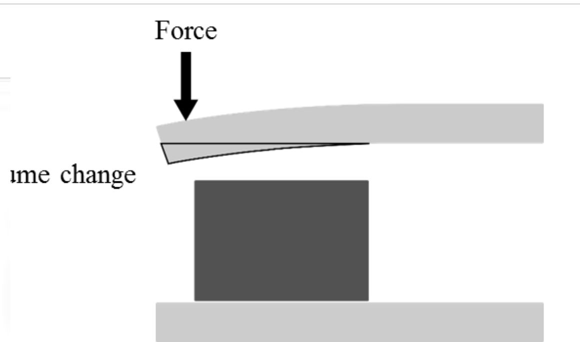




- Range: 1.5 m
- Resolution: 50 σ/µm
- Rate: 10 Hz
- Sensitivity: 1ppm/ppm

# Force Sensor

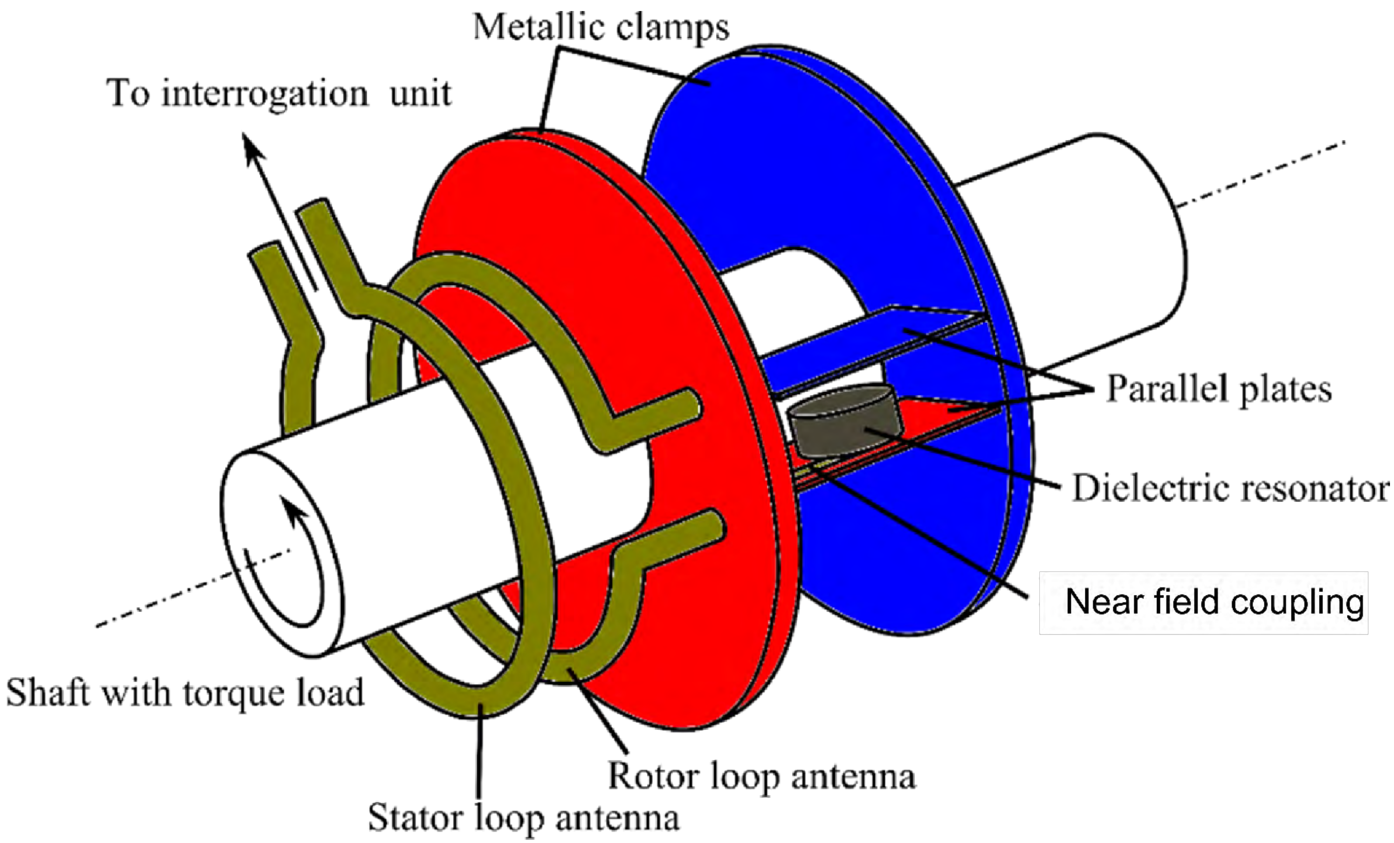
- Evanescent open ended waveguide antenna.
- Loaded with a dielectric resonator
- Cantilever beam spring.
- Force → Displacement → Frequency shift



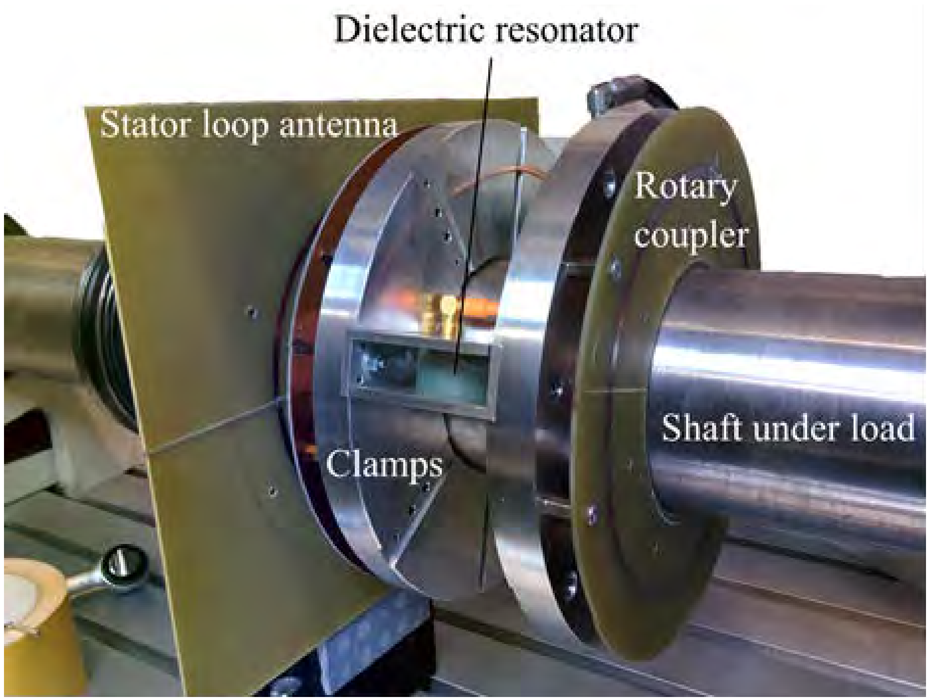
# Idea: Torque sensor

- Dielectric resonator as a transducer.



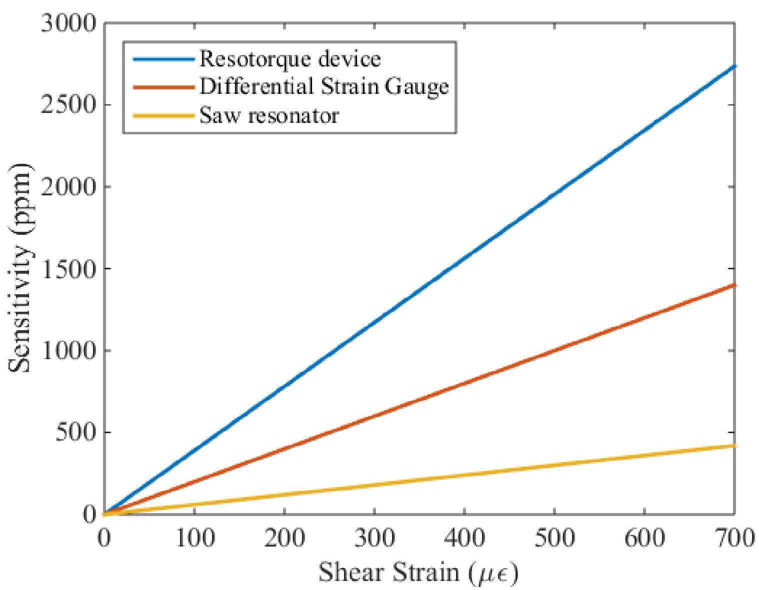
# Implementation: Torque sensor

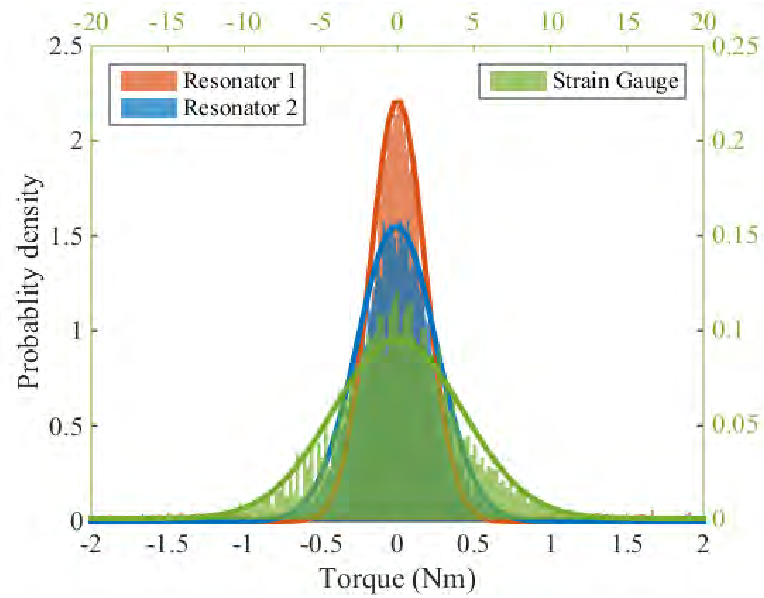
- Clamp on device.
- Low installation time.
- 2.4 GHz ISM band compatible
- Dual sensors on each side for offset compensation
- Offset due to
  - Temperature
  - Sideways force
  - Coupler imperfections



# Results: Torque sensor

- Sensitivity comparison
- Higher sensitivity of indirect displacement based measurement.
- Sensitivity in frequency shift rather than small Wheatstone bridge perturbation.
- Sensor resolution: 25x higher




DUT: 3.9 (kHz/GHz)/με

DMS: 2 (μV/V)/με

SAWR: 0.6 (kHz/GHz)/με

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