Dielectric Resonator Based Wireless Passive Sensors

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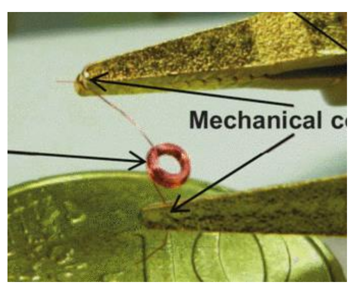
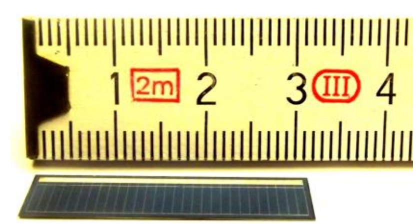
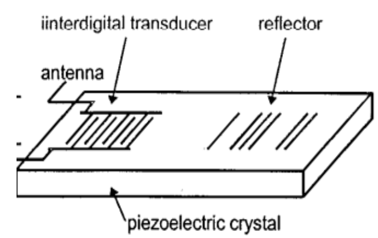
IMTEK

Wireless sensing

- **Wireless networking**
  - Low Power Commu-nication
  - Moni-toring
  - Locali-zation
- **Near field coupling**
  - Inductive coupled
  - RFID
- **Energy harvesting**
  - RF
  - Photo-voltaic
  - Thermo-electric
- **Chipless sensing**
  - Acoustic
  - Electro-magnetic

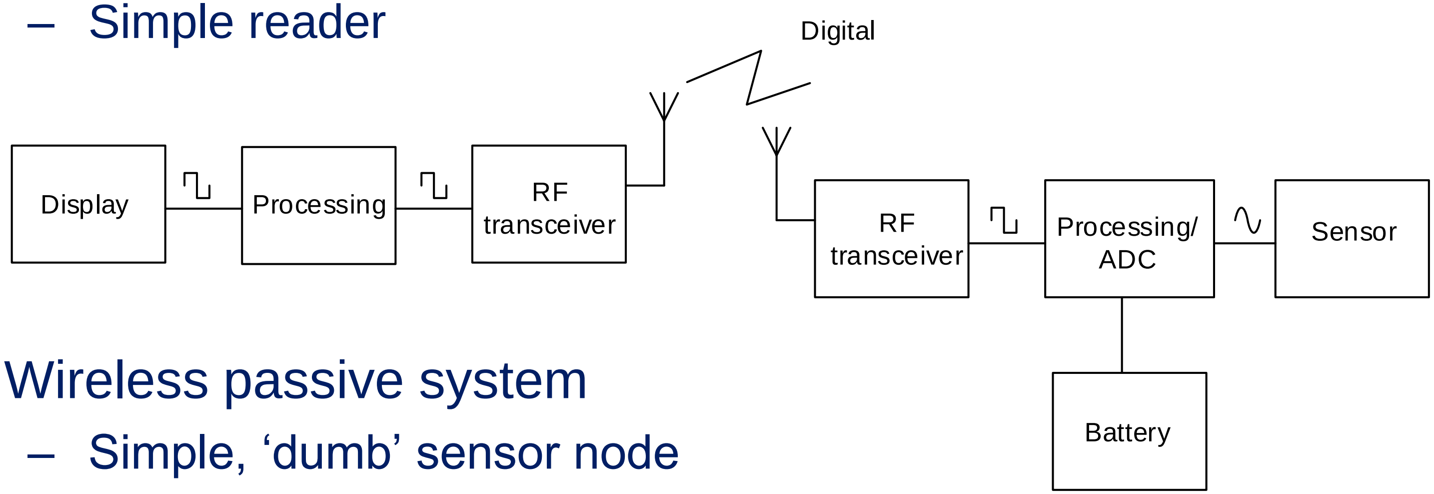




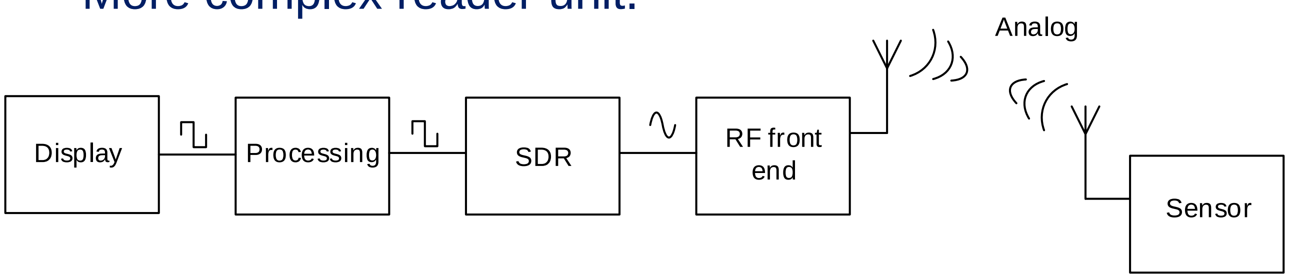


Sensor Motes vs Passive Sensors

- Battery powered system
  - Complex, ‘smart’ sensor node
  - Simple reader



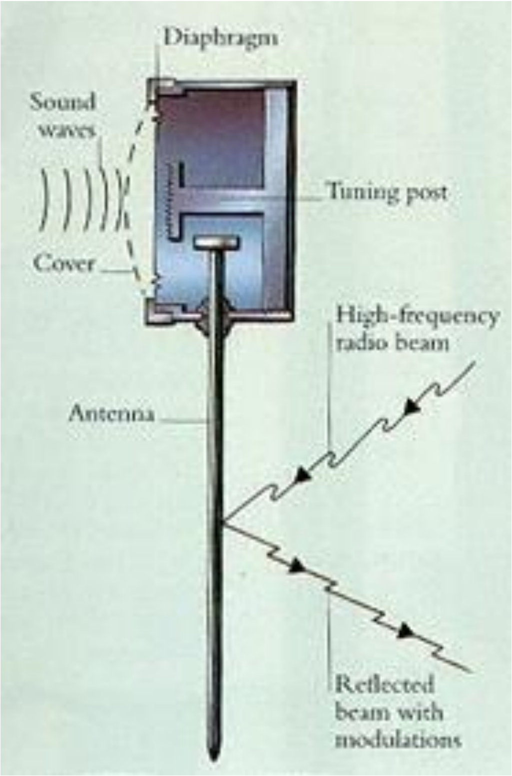
- Wireless passive system
  - Simple, ‘dumb’ sensor node
  - More complex reader unit.

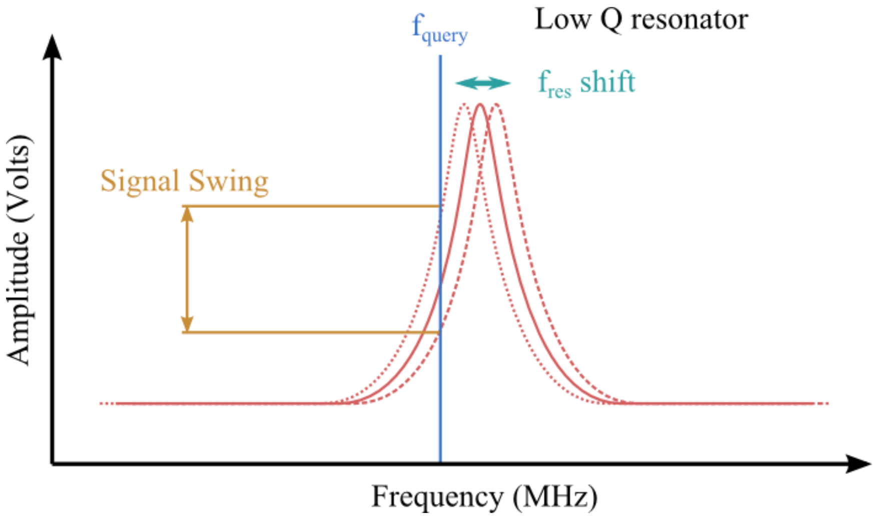


History – Theremin's cavity

- Surveillance device ~ 1945
- First wireless passive sensor

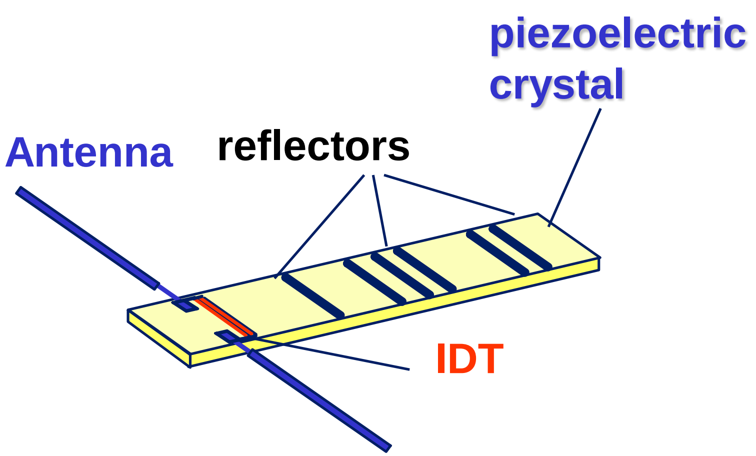
http://counterespionage.worldsecuresystems.com/the-great-seal-bug-part-1.html

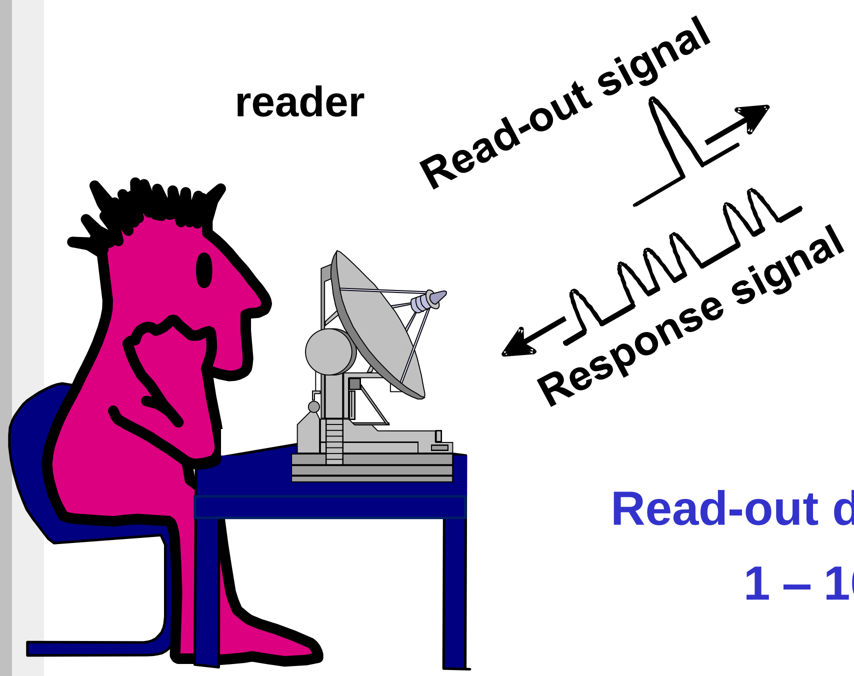




History - Wireless SAW Sensors

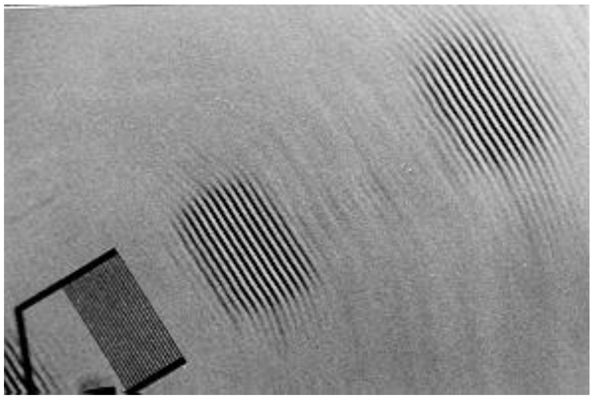
- Discovered in mid 1990's
- Surface acoustic delay lines
- Harsh Environment compatible





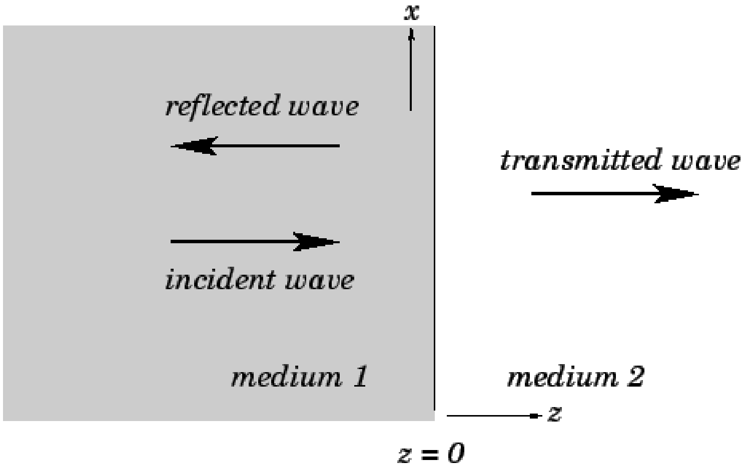
Read-out distance:

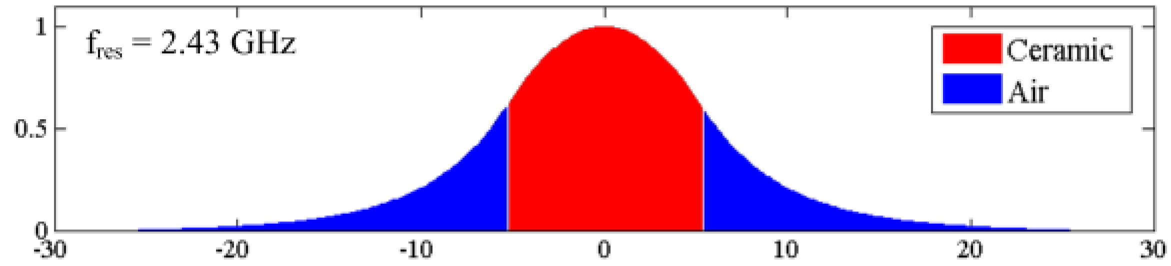
1 – 10 m



EM Resonators – Basic distinctions

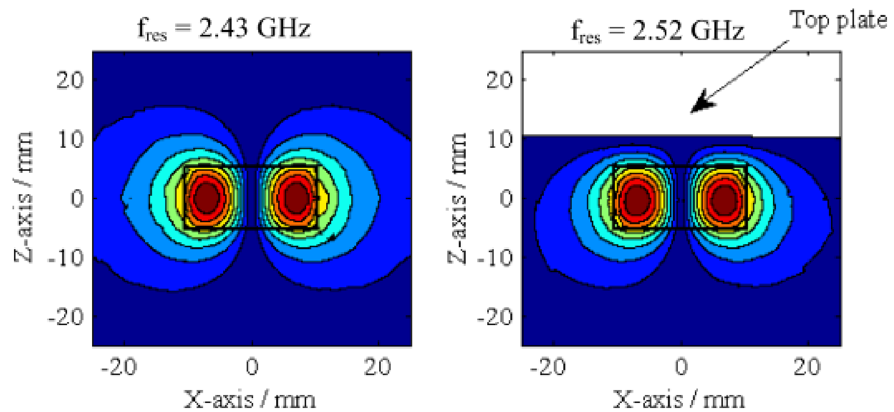
- Confined
  - Cavity
  - Coaxial
- Evanescent
  - Microstrip/stripline
  - Dielectric





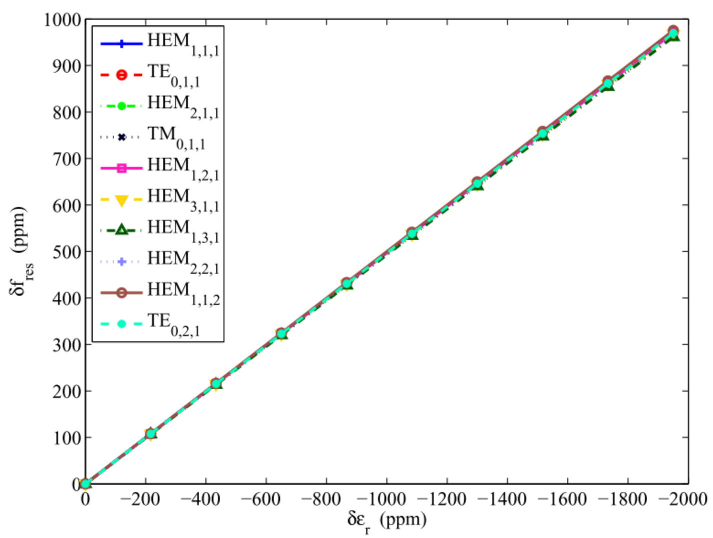
EM Resonators – Evanescent field effect

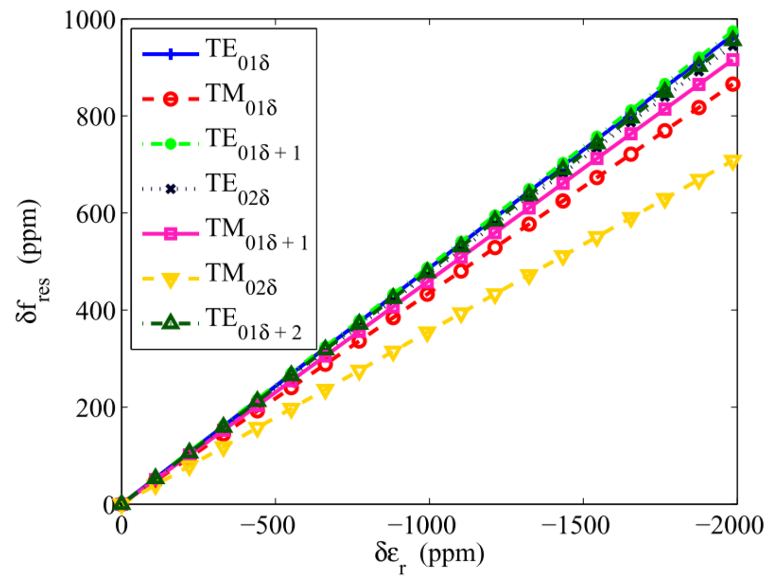
- Confined
  - Cavity
  - Coaxial
- Evanescent
  - Microstrip/stripline
  - Dielectric



$$k_0 a \propto \frac{1}{\sqrt{\epsilon_r}}$$

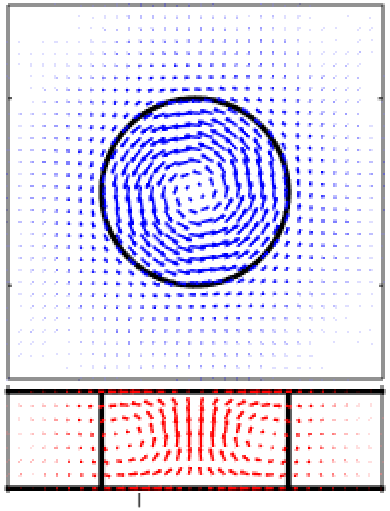
$$k_0 a \propto \frac{1}{\sqrt{\epsilon_r + X}}$$





Parallel plate dielectric resonators

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



$$k_{ci} = \frac{2.4048}{a} \qquad a$$

$$k_{co}^2 = \beta_I^2 - k_o^2 \qquad b$$

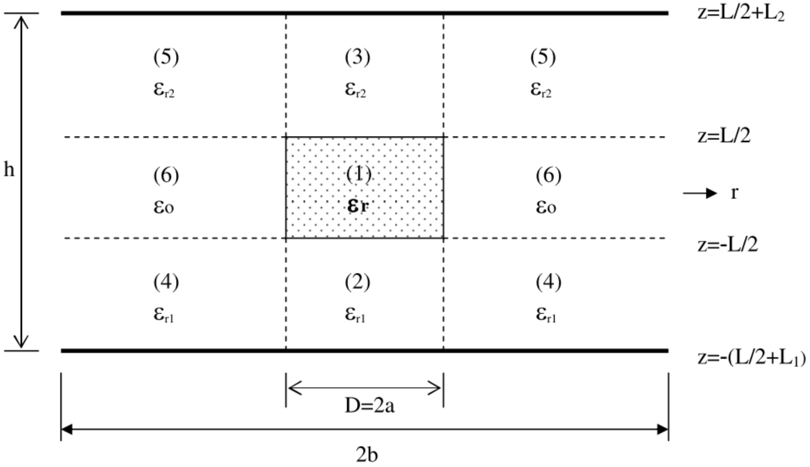
$$\beta_I^2 = k_o^2 \varepsilon_r - k_{ci}^2 \qquad c$$

$$k_o = \omega\sqrt{\mu_o \varepsilon_o} \qquad d$$

$$\phi_1 + \phi_2 = 0 \qquad e$$

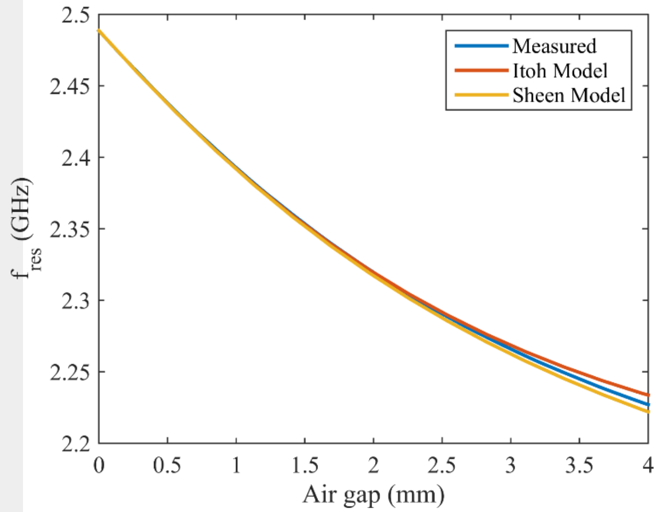
$$\phi_{1,2} = \tan^{-1}\left(\frac{\alpha_{1,2}}{\beta_I}\coth \alpha_{1,2} L_{1,2}\right) - \beta_I \frac{L}{2} \qquad f$$

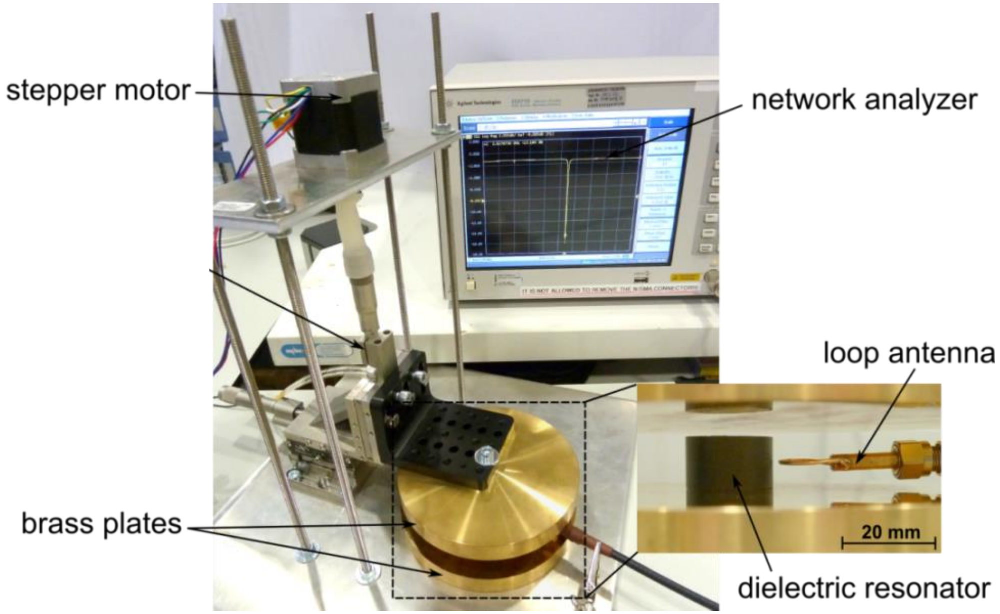
$$\alpha_{1,2}^2 = k_{ci}^2 - k_o^2 \varepsilon_{r1,r2} \qquad g$$



Parallel plate dielectric resonators

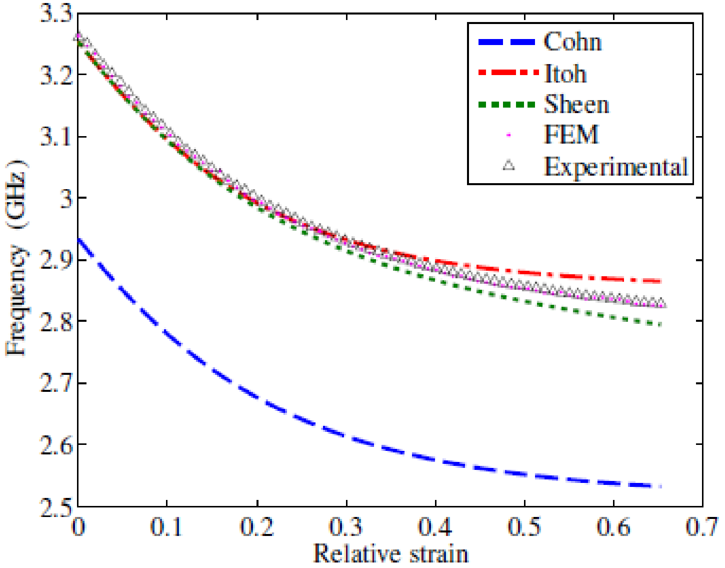
- Measurement: return-loss S11 in a parallel plate configuration
- Resonant frequency shift (TE01δ Mode) with respect to the displacement of the parallel plates

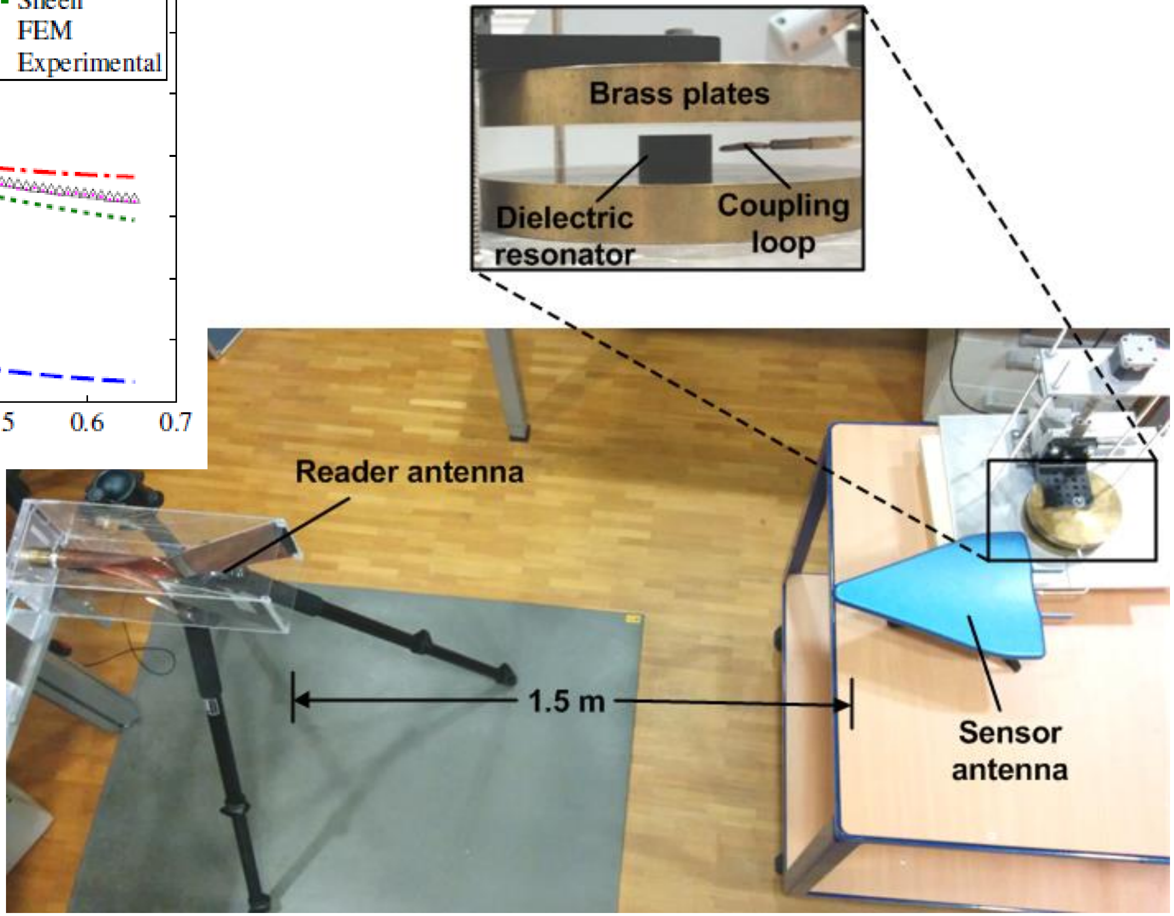




Parallel plate Wireless Strain Sensor

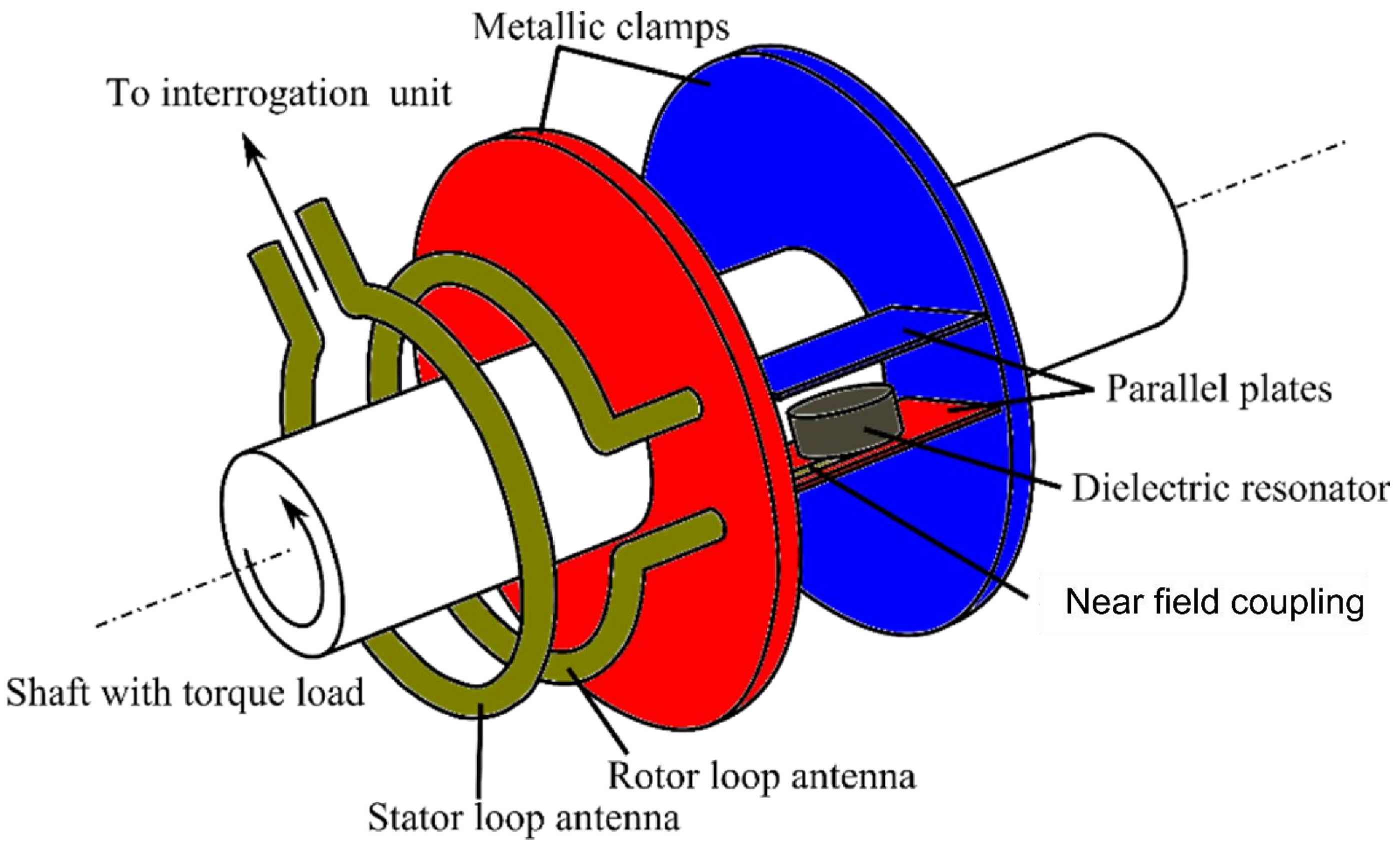
- Wireless measurement of displacement.





Sensor concept

- Dielectric resonator as a transducer.



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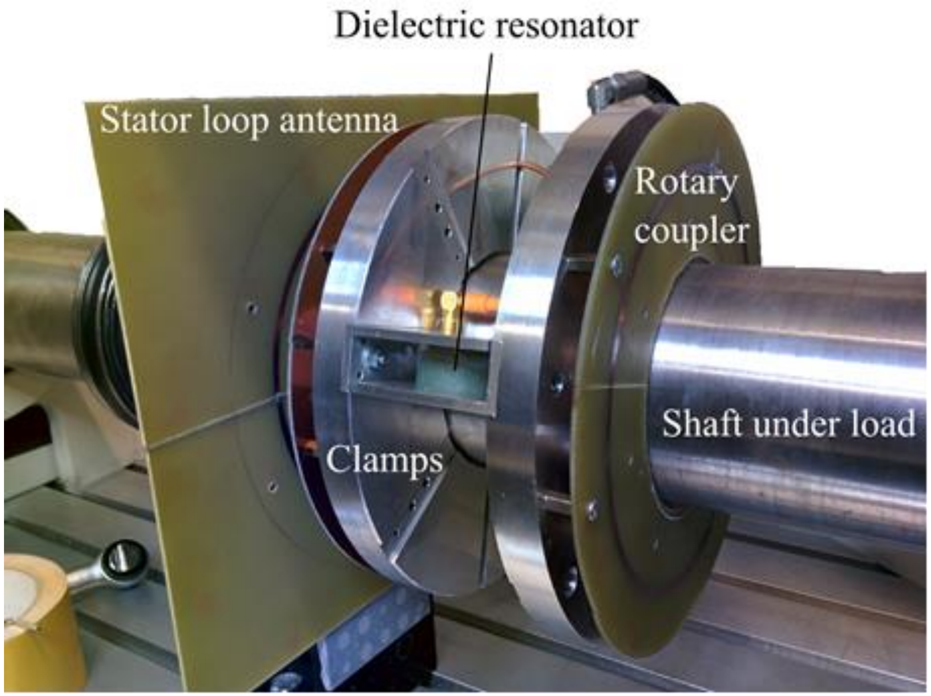
Torque sensor prototype

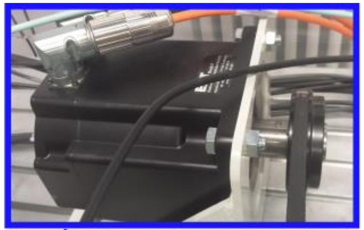
- Clamp on device.
- Low installation time.
- 2.4 GHz ISM band compatible
- Dual sensors on each side for offset compensation
- Offset due to
  - Temperature
  - Sideways force
  - Coupler imperfections



Torque Sensor - Experimental setup

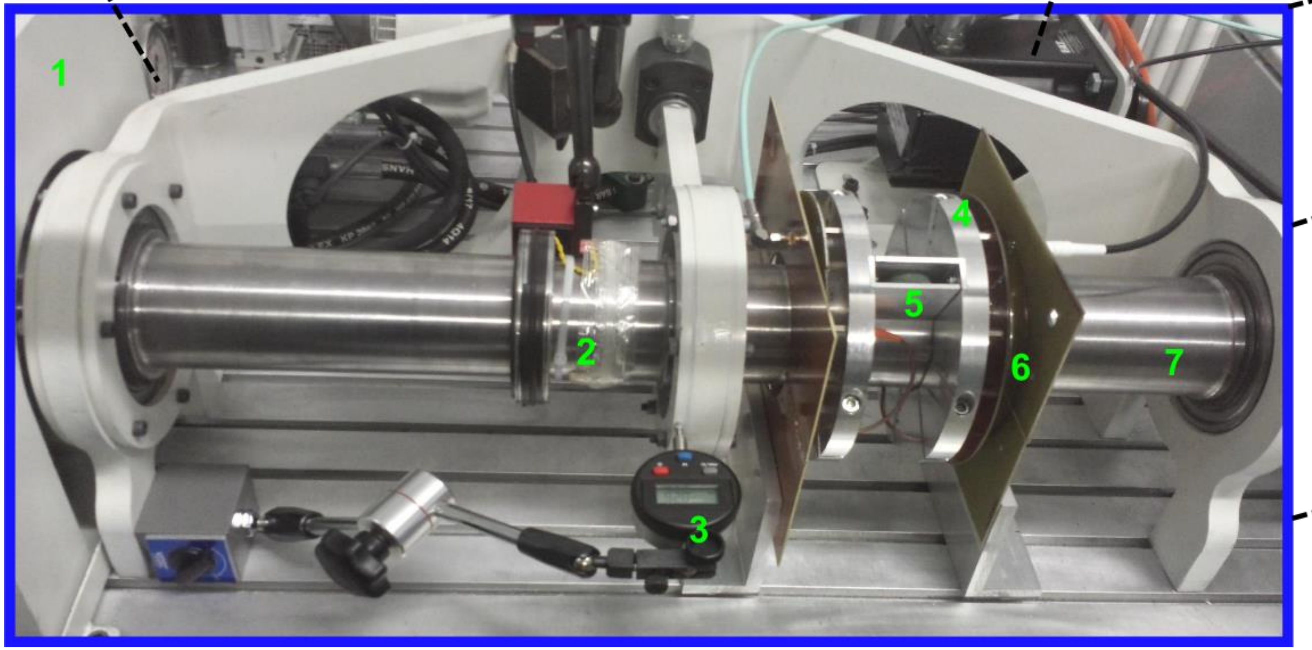
Hydraulic unit

1-Bi.directional torque actuator unit
2-DMS
3-Displacement sensor(bending)
4-Clamps with differential sensors
5-PPDR
6-Rotary coupler and stator
7-Coaxial shaft

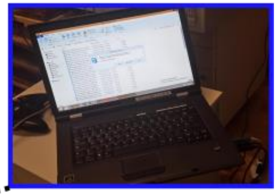


Motor

Industrial Automisation Unit



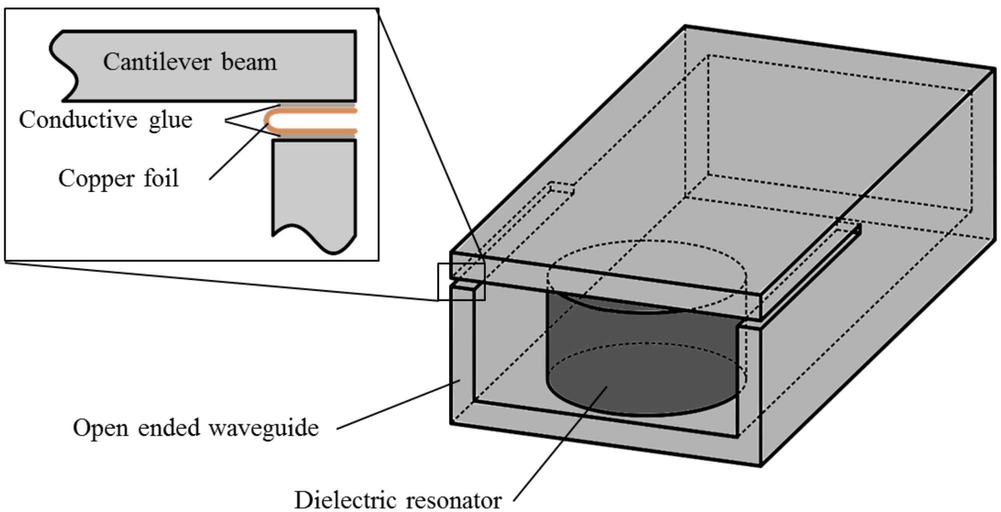
Reader Unit

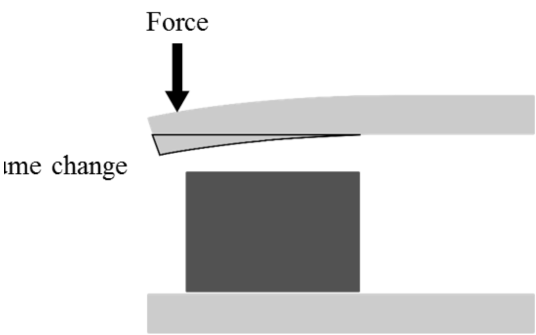


PC with centralized LabView program

OWEG Sensor - Force Sensor/Load cell

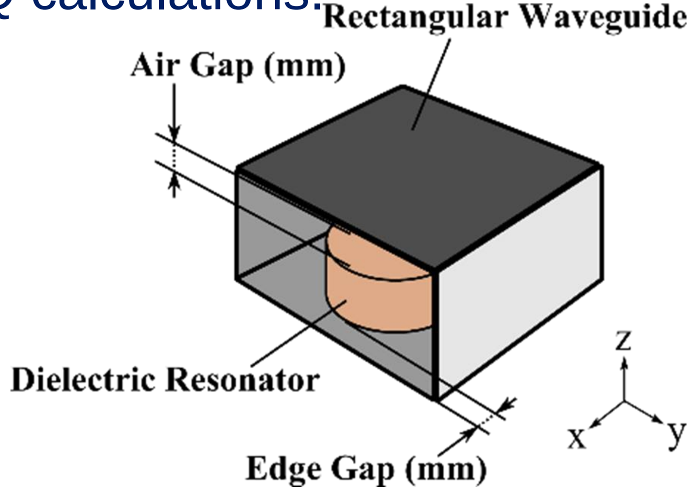
- Evanescent open ended waveguide antenna.
- Loaded with a dielectric resonator
- Cantilever beam spring.
- Force → Displacement → Frequency shift

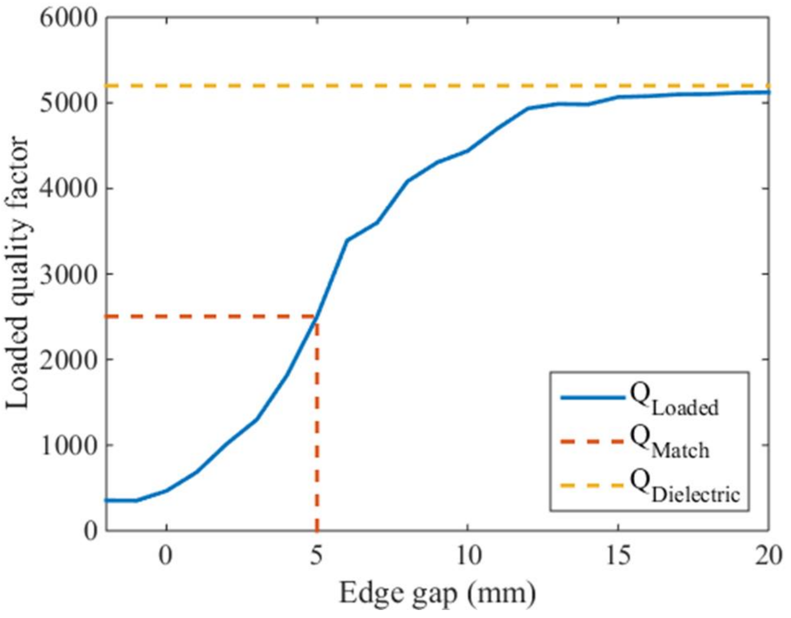


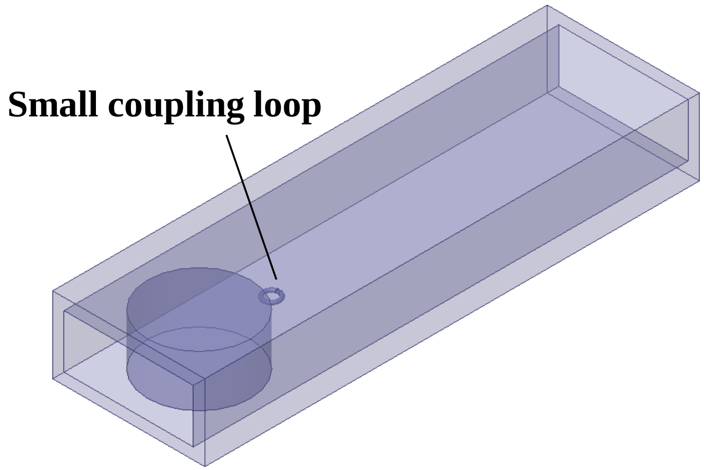


OEWG Sensor - Simulations

- 'Edge gap' – main coupling control variable
- Weak loop coupling simulation for Q calculations.

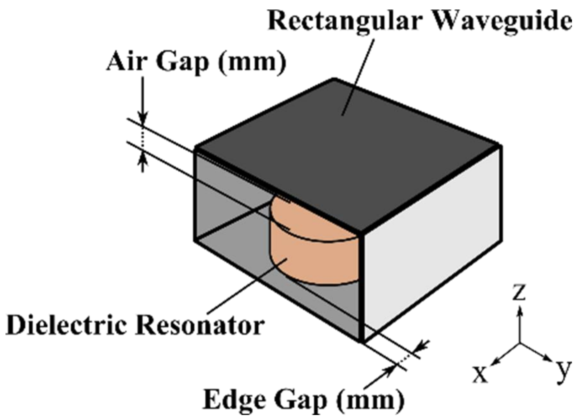


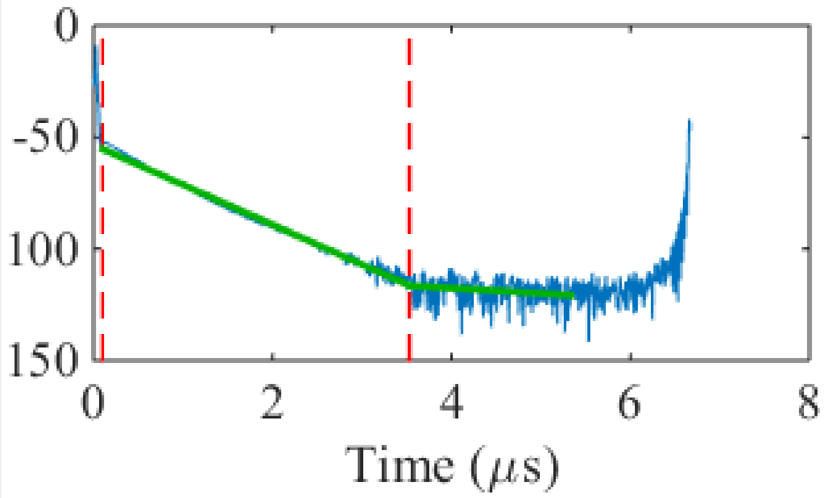


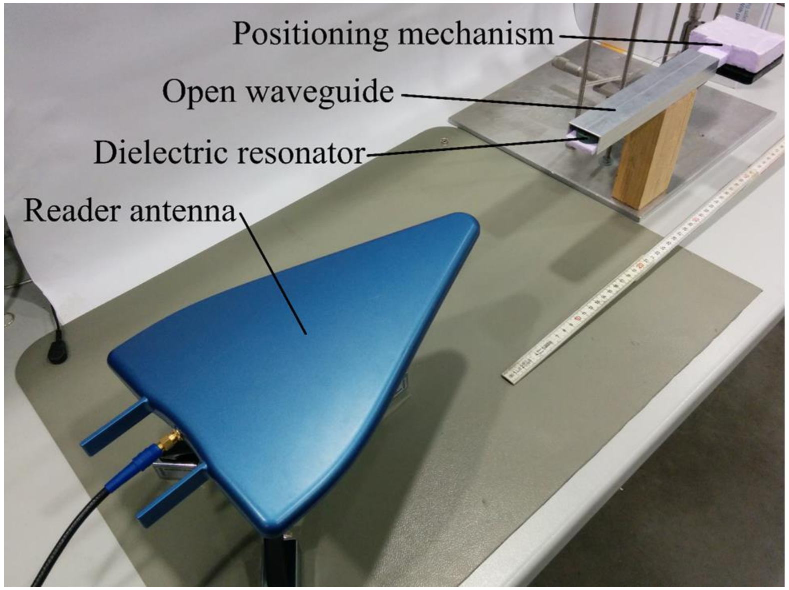


OEWG Sensor - Results

- High Loaded Q (~3000)
- Good Directivity (2 dBi)
- High Sensitivity (5 ppm/με)
- Good Range (1-5 m)







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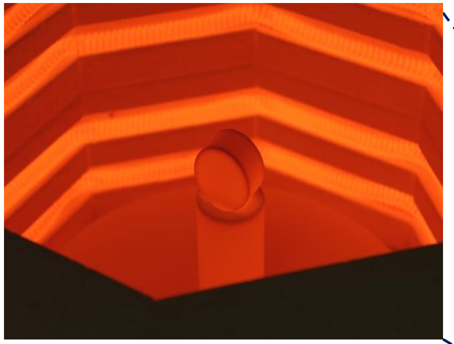
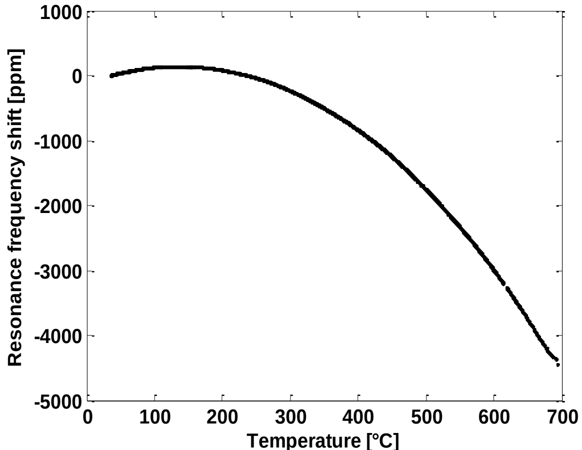
High temperature sensor

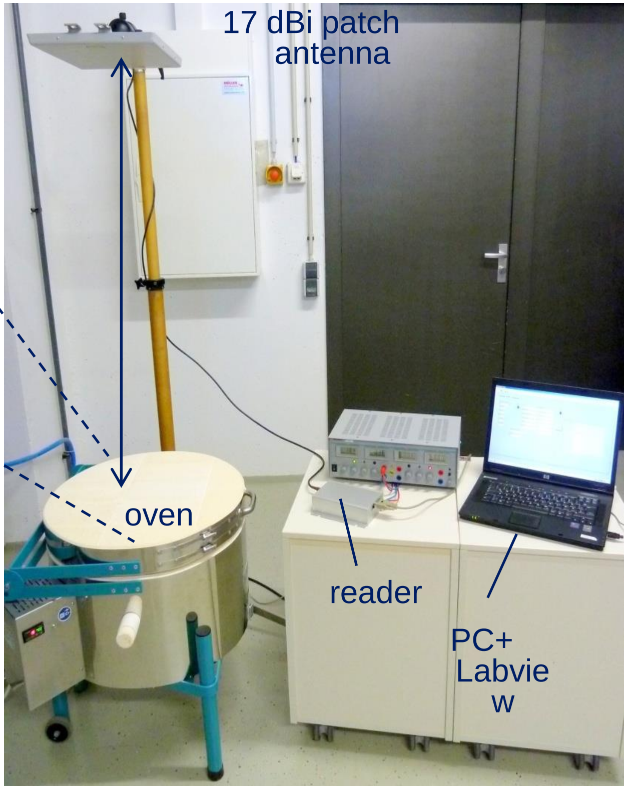
- **Metallization free Dielectric Resonator based high temperature sensing**



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

Wireless Passive for WAIC

- 4.3 GHz resonators possible
  - Q ~ 2000
  - 1 – 5 m Wireless range
- Possible applications
  - Strain sensing for SHM
  - EGT sensing
- Challenges
  - Interoperability with existing systems
  - Regulatory

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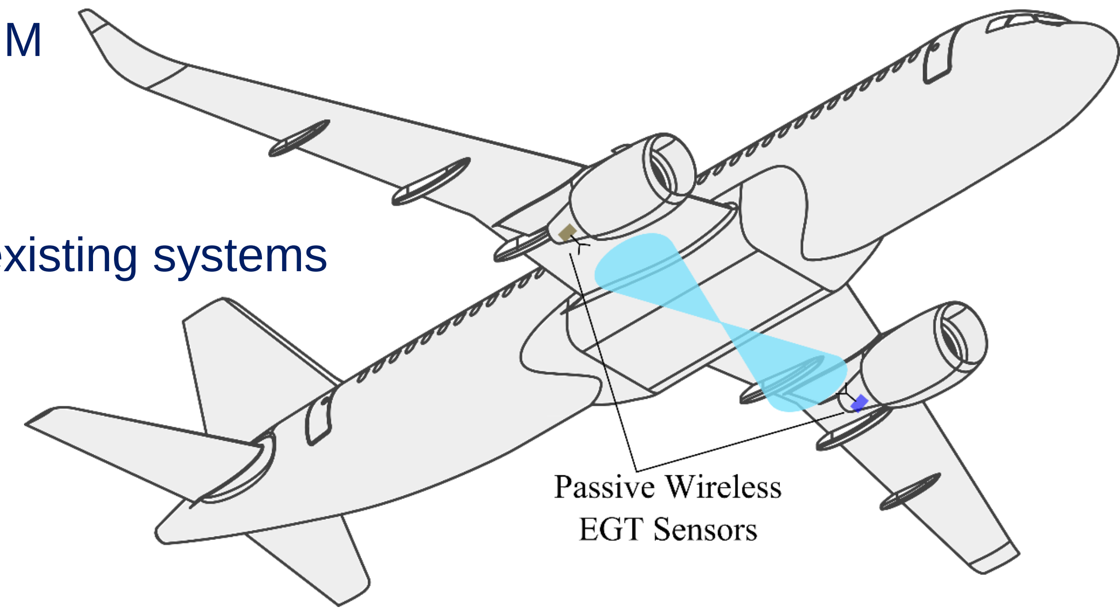
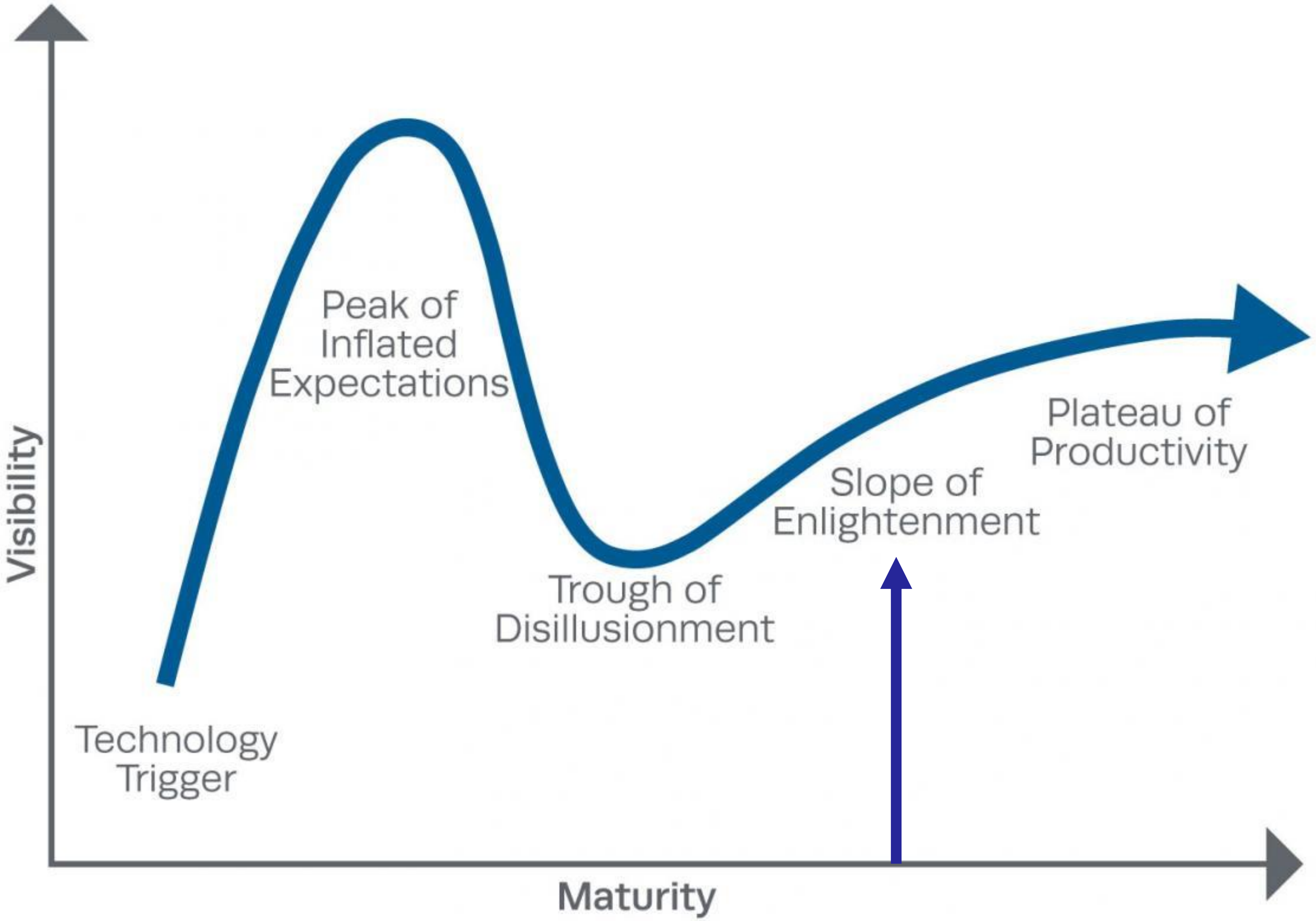
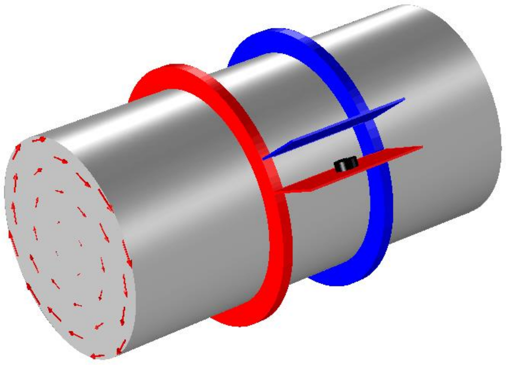


Outlook



https://www.mitre.org/publications/systems-engineering-guide/acquisition-systems-engineering/acquisition-program-planning/assessing-technical-maturity



THANK YOU