Surface Acoustic Wave (SAW) Wireless Passive Temperature Sensors

VECTRON International - SenGenuity

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History of Surface Acoustic Wave (SAW)

1880 Piezoelectricity, discovered by Jacques and Pierre Curie in quartz crystals`

1885 Lord Rayleigh characterizes Surface Acoustic Waves (earth quake)

1889 First interdigital electrode design, “Electric condenser” U.S. patent Nikole Tesla

1965 First Interdigital Transducer (IDT’s) on a polished piezoelectric plate (White / Voltmer)

1970 First applications: pulse expansion and compression in radar systems

1985 SAW filters replace LC filter in TVs and VCRs

1990 SAW filters allow for miniaturization of mobile phones

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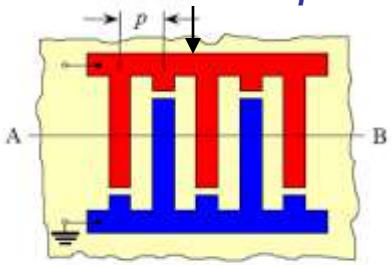
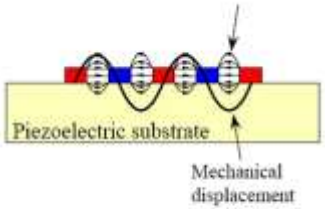
Electrical power



Top view

Electric fields lines

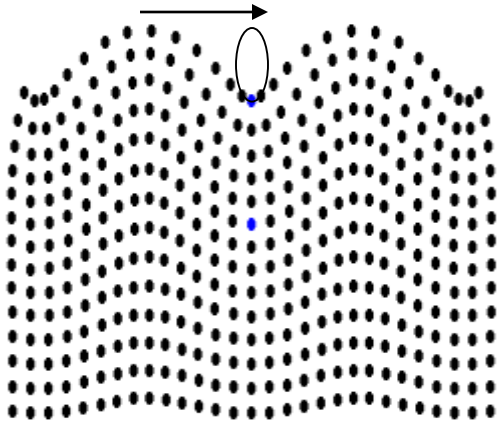


Cross sectional view A-B

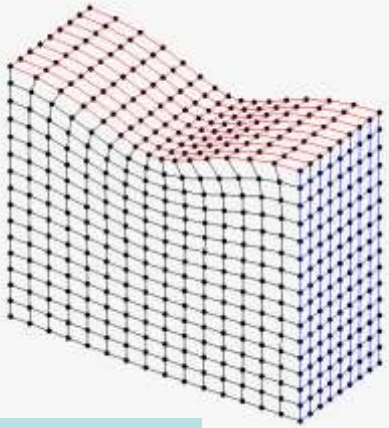
Interdigital Transducer (IDT) as
- transmitter: converse piezoelectric effect ⇒ electric RF field generates SAW
- receiver: piezoelectric effect ⇒ SAW generates electric RF field

In both cases maximum coupling strength for $\lambda_{SAW} = v_{SAW} / f = 2 \cdot p$ (~ 1…10 µm)

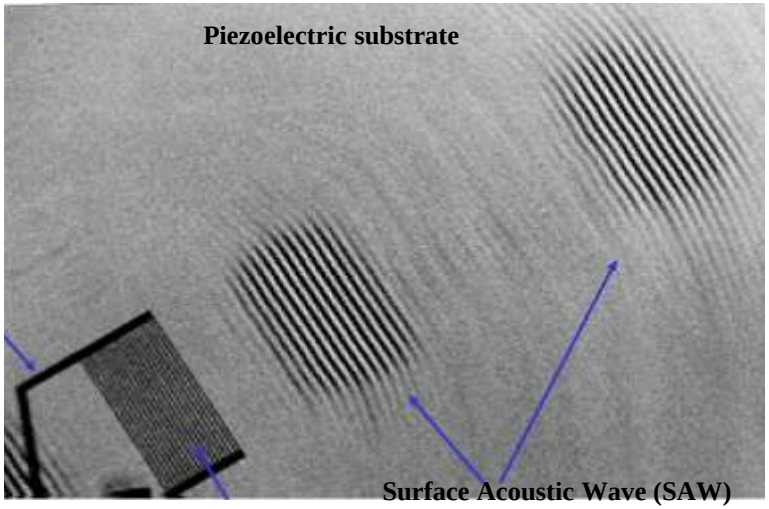
Wave propagation ≈ 3000 [m/s]



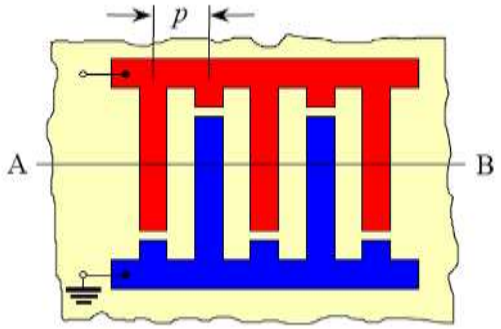
Rayleigh wave

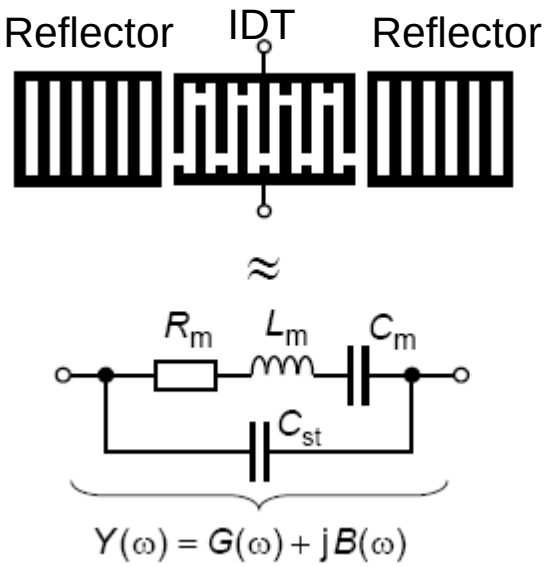


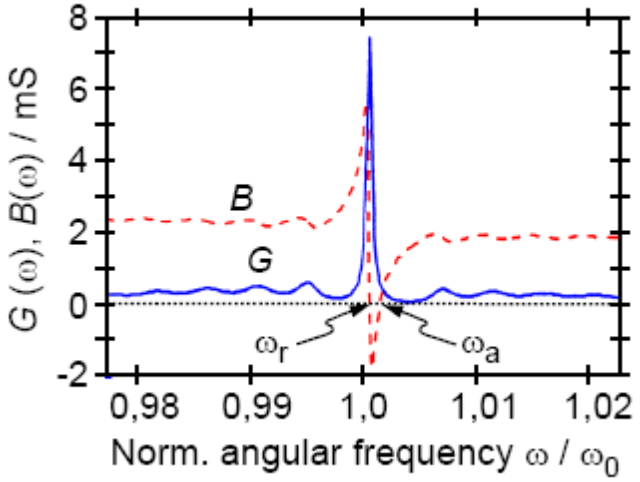
SAW - Rayleigh Wave propagation



SAW Resonator as Temperature Sensor







First Fact:

Surface wave velocities are temperature dependent and are determined by the orientation and type of crystalline material used to fabricate the sensor

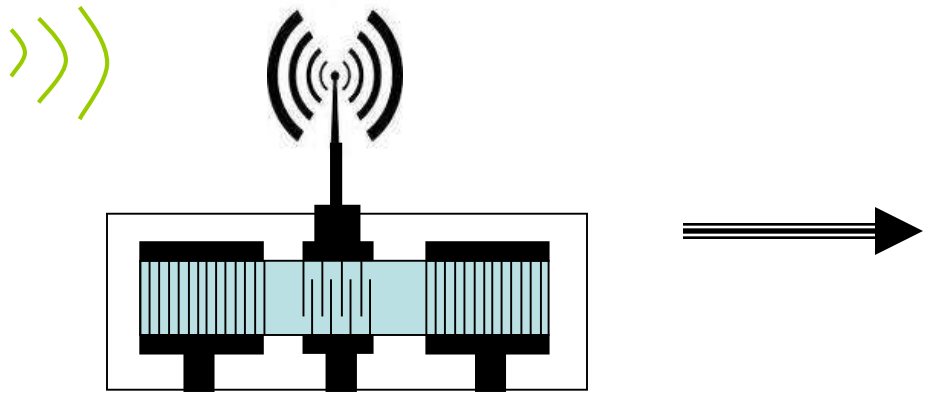
$$v_{SAW} = f_{SAW} \times \lambda \quad \longrightarrow \quad f_{SAW}(T, Cut, \ldots)$$

Second Fact:

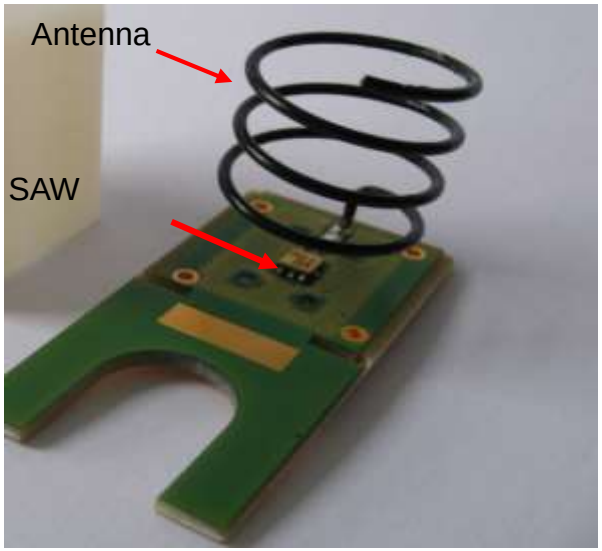
Very low power is required to excite the acoustic wave – Energy Harvesting (EM-Wave)

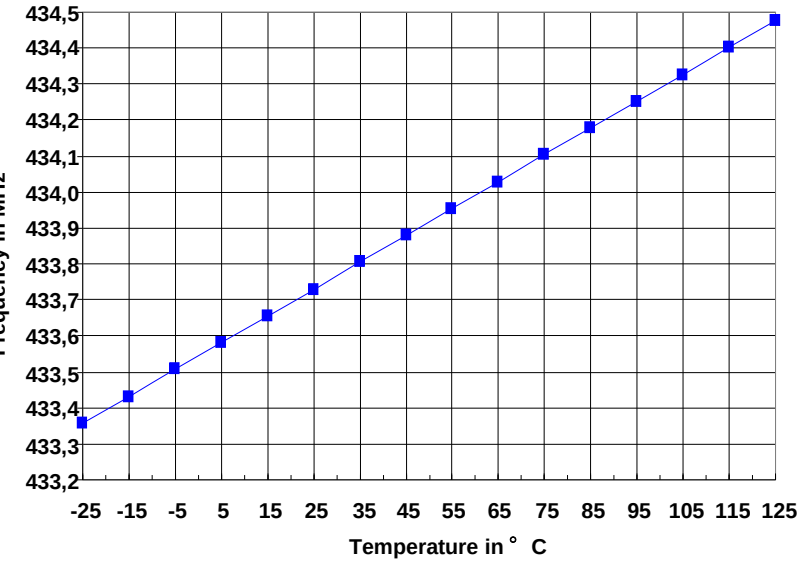
Single SAW Resonator: Absolute measurement

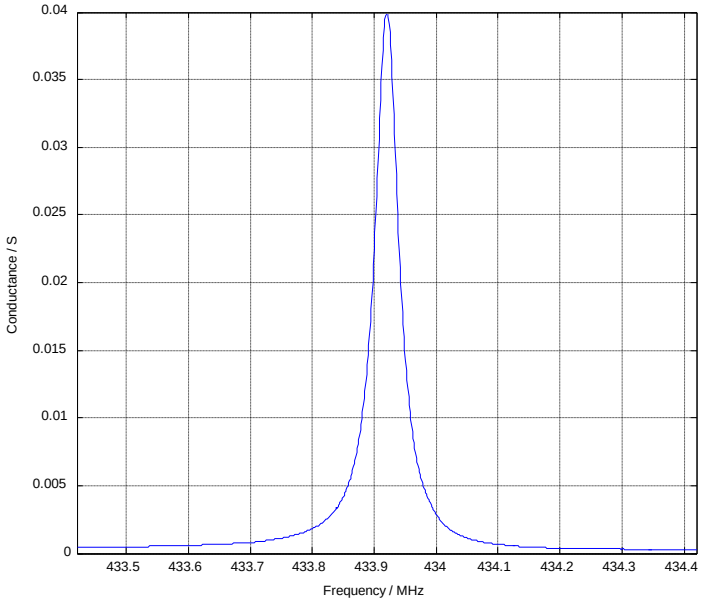
EM –Wave (power)



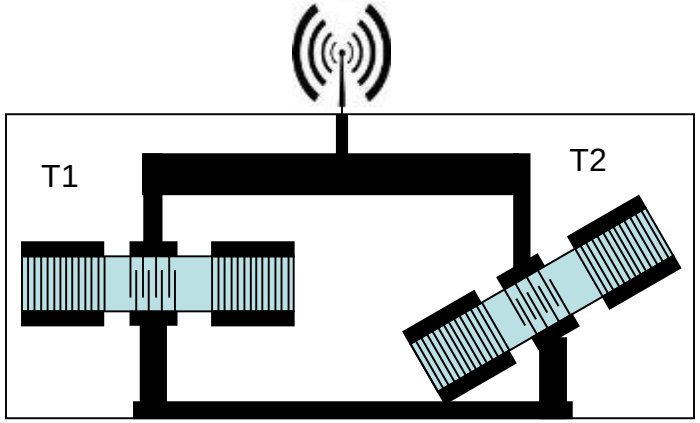
SAW Resonator on Piezoelectric substrate

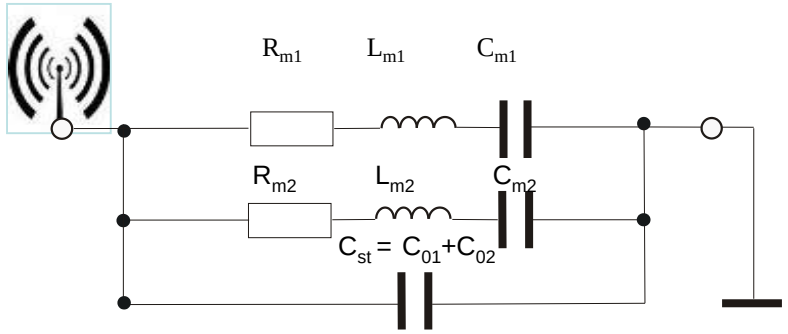


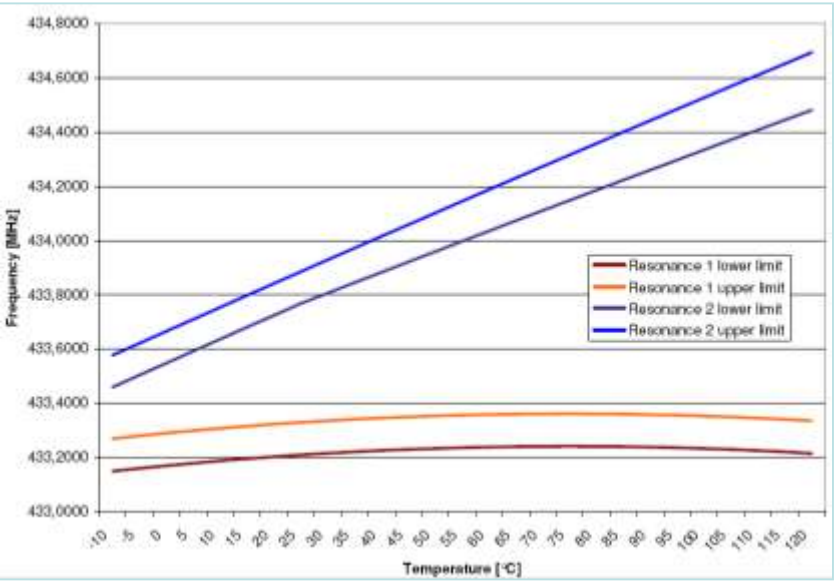


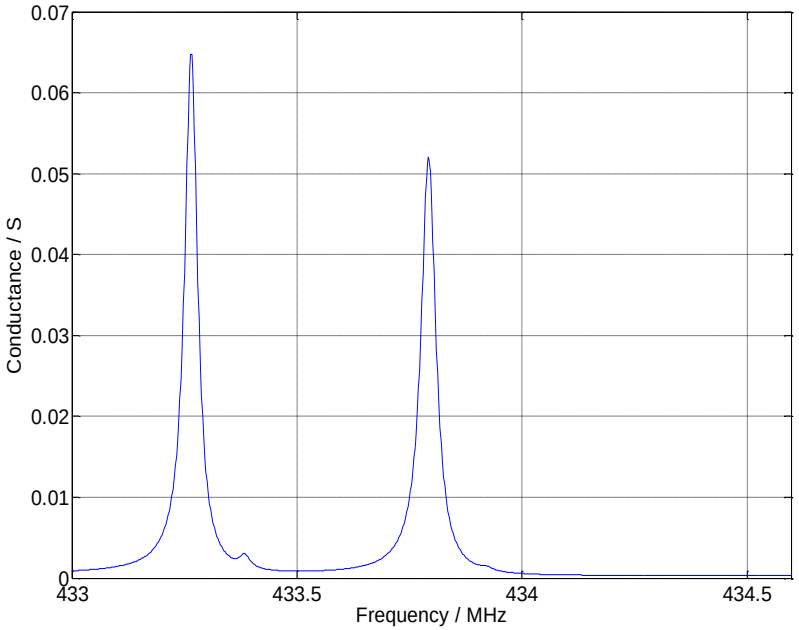


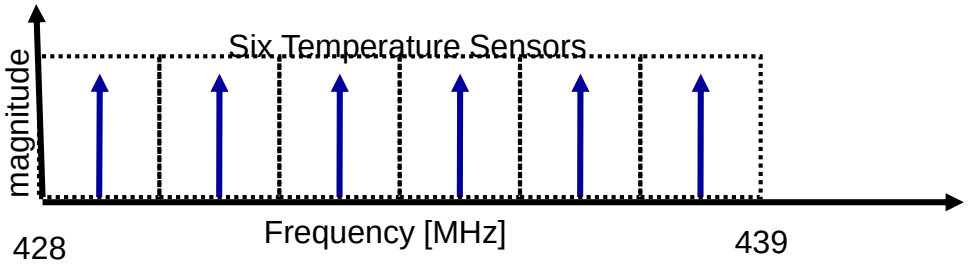
Double SAW Resonator: Differential measurement



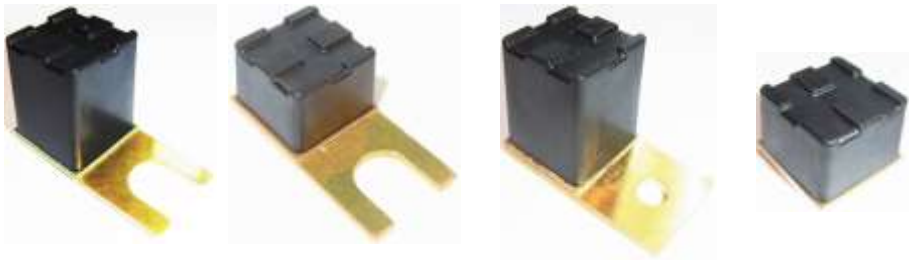




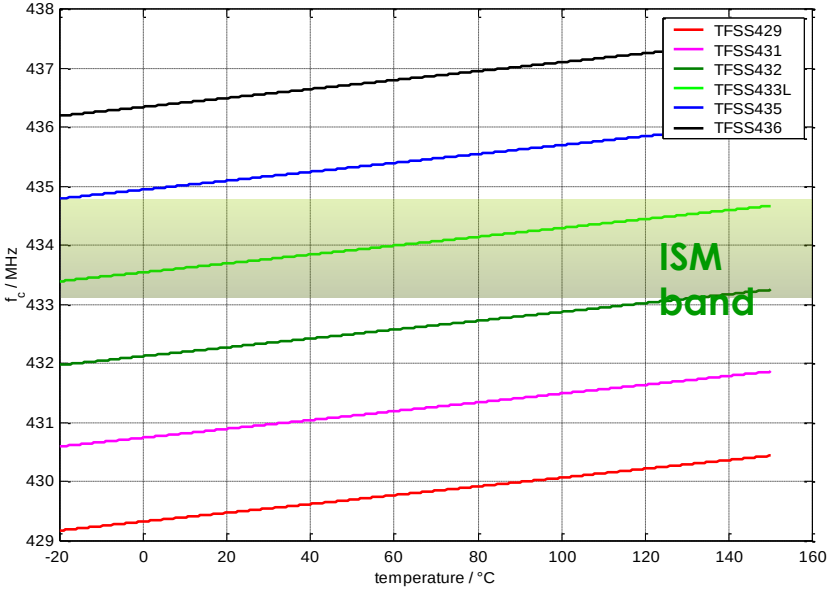


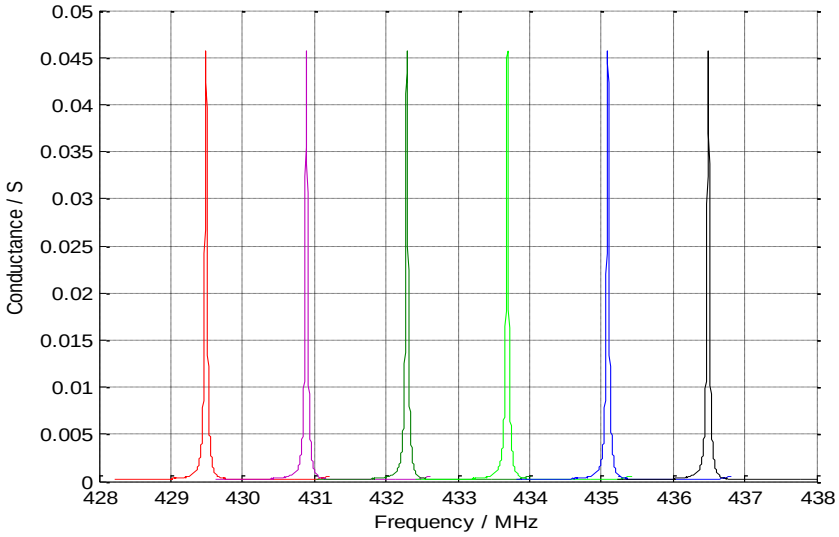


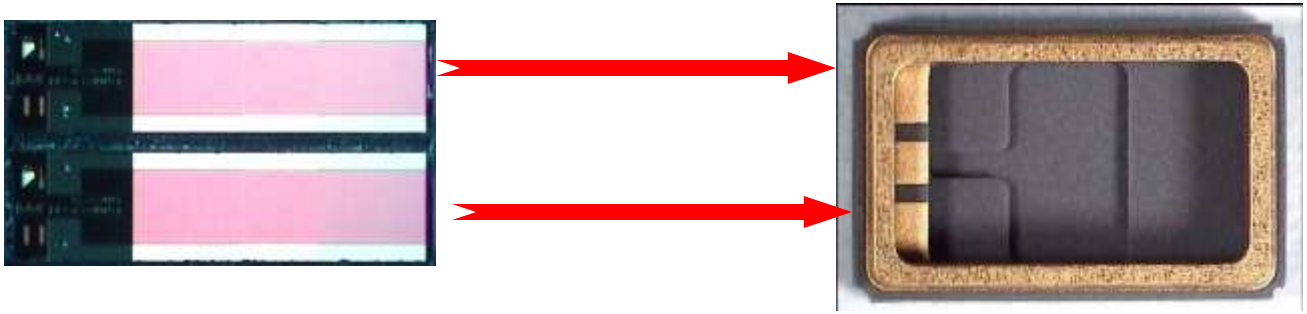
Temperature measurement system with 6 / 12 / 36 sensors

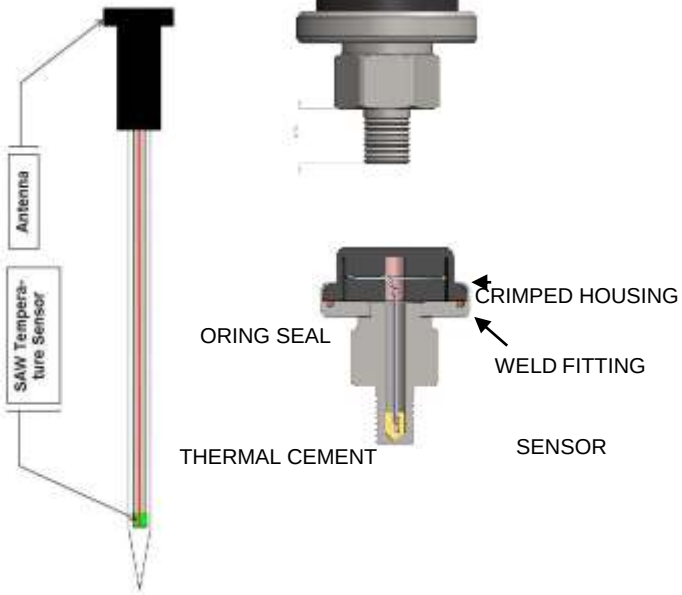


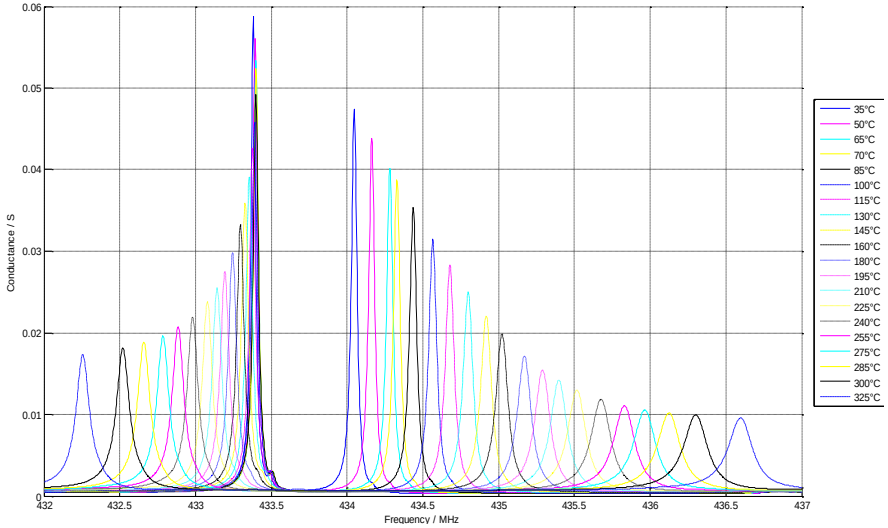
Types of sensor modules



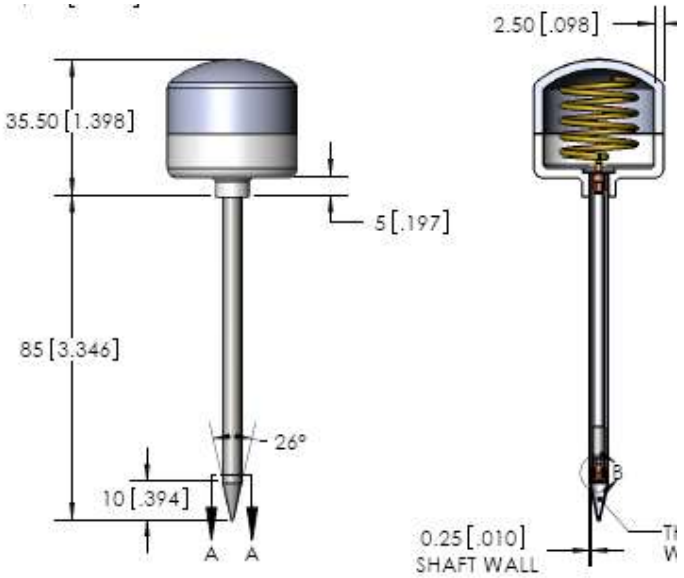


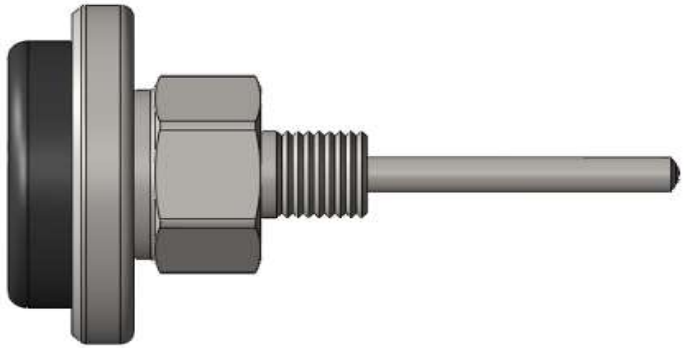






Types of sensor modules


35.50 [1.398]
5 [.197]
85 [3.346]
26°
10 [.394]
A A
2.50 [.098]
0.25 [.010]
SHAFT WALL



Support of Absolute and Differential Measurement

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Absolute Measurement

- Measurement of absolute frequency of one resonator

- **Advantages:**
- Less consumption of bandwidth
- Easier frequency trimming of sensors in manufacturing
- Faster interrogation
- Slightly higher reading range

- **Disadvantages:**
- Higher pulling effects
- Higher ageing of frequency
- More expensive frequency source for interrogation unit

Differential Measurement

- Measurement of absolute frequency of two resonances
- Difference frequency calculated from measured resonances

- **Advantages:**
- Higher stability caused by lower pulling effects during sensor module manufacturing and caused by environment
- Reduced ageing of difference frequency
- Slightly cheaper reader architecture

- **Disadvantages:**
- Higher bandwidth consumption
- Questionable frequency trimming of difference frequency
- Slightly slower interrogation
- Slightly lower reading range

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Specification:

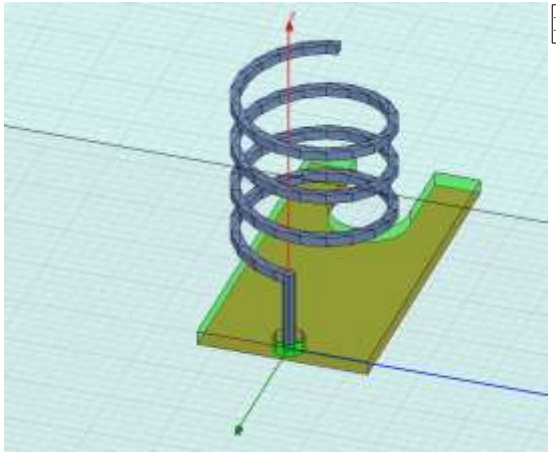
- Maximum possible temperature resolution Storage
- Maximum Echo or receive signal (Rx) level

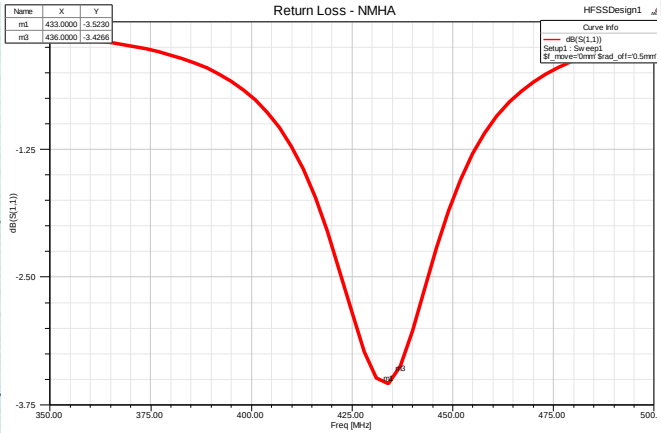
Friis Formula:

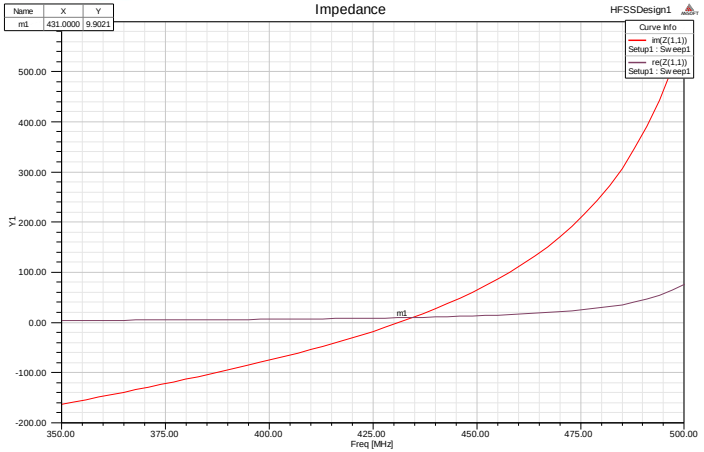
$$P_r = P_e \cdot \frac{G_i^2 \cdot G_{SAW}^2 \cdot \lambda^4}{(4 \cdot \pi \cdot r)^4} \cdot \alpha \cdot \underbrace{\left(1 - e^{\frac{-T}{\tau}}\right) \cdot \left(e^{-\frac{t_{com}}{\tau}}\right)}_{Q-factor}$$

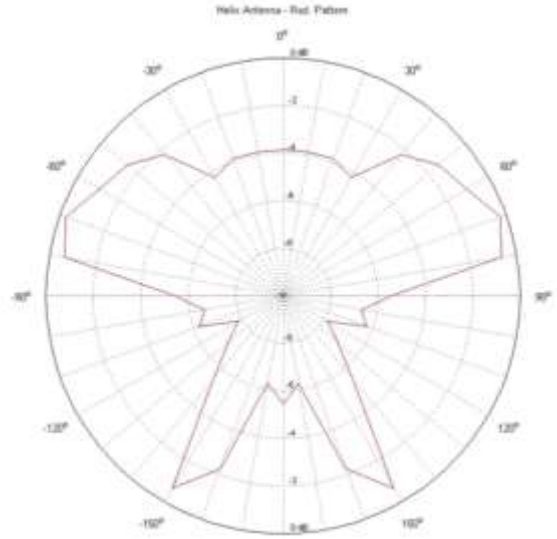
Pr : ***Receive power***
Pe : ***Reader output power***
Gi : ***Reader antenna gain***
Gsaw: ***SAW sensor antenna gain***
r : ***Distance between Interrogator and sensor antennas***
α : ***matching/loss between antenna an sensor***
T/ t_{co}: ***The interval of the transmission / commutation between Tx and RX***

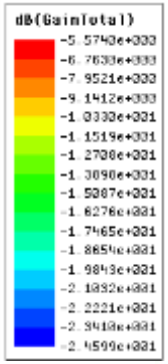
Sensor Antenna

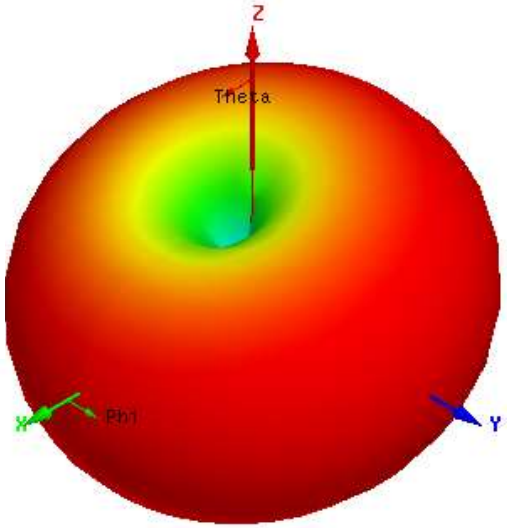




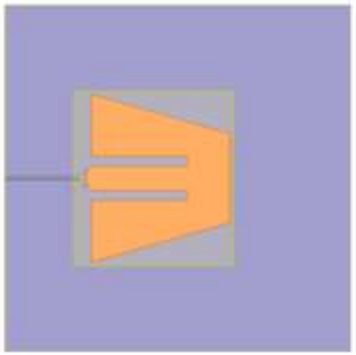


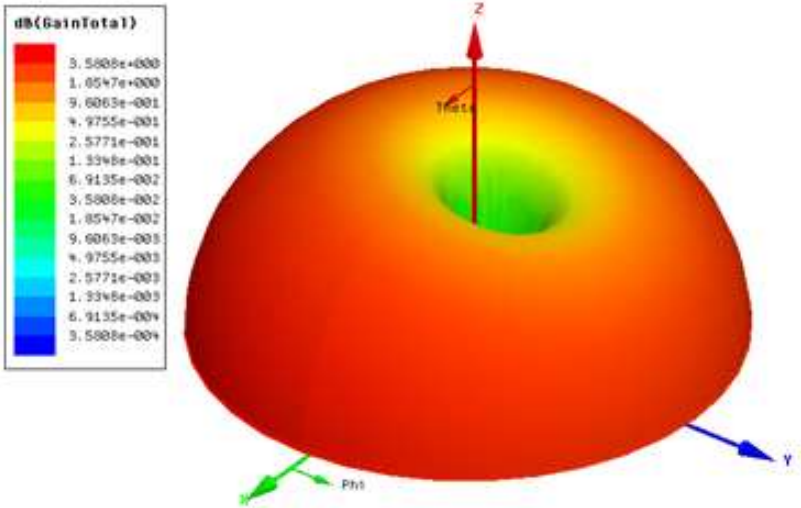


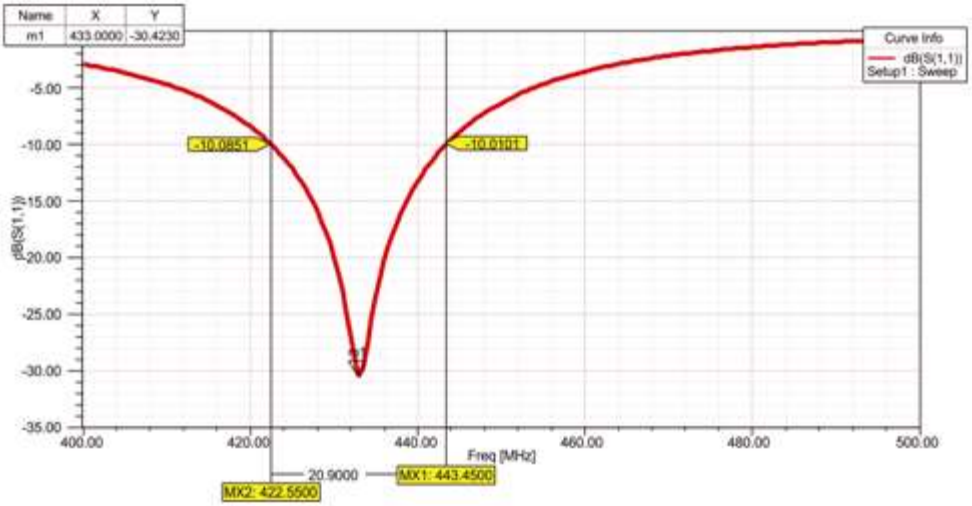


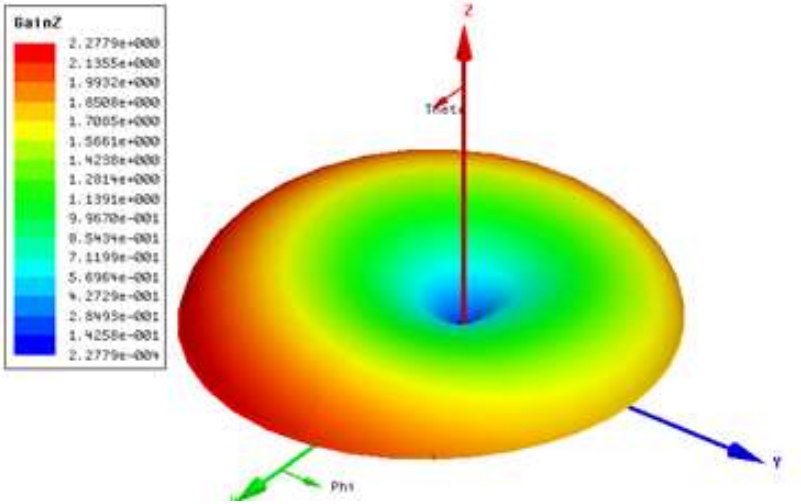


Reader Antenna









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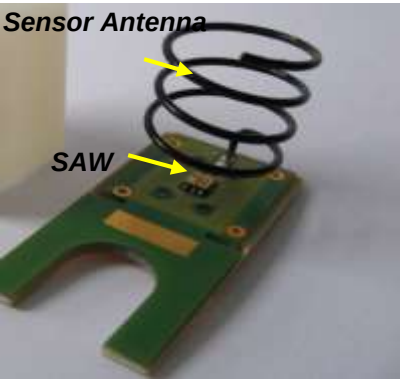
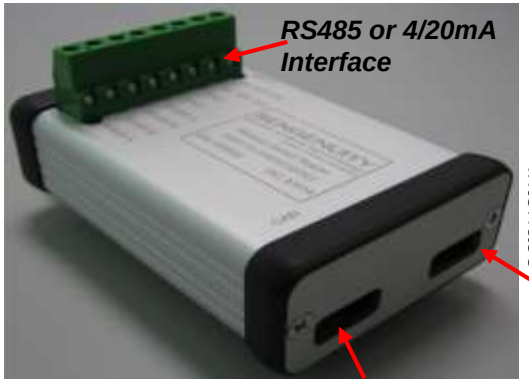
SAW Sensor Modules

Reader Antennas

Reader Units





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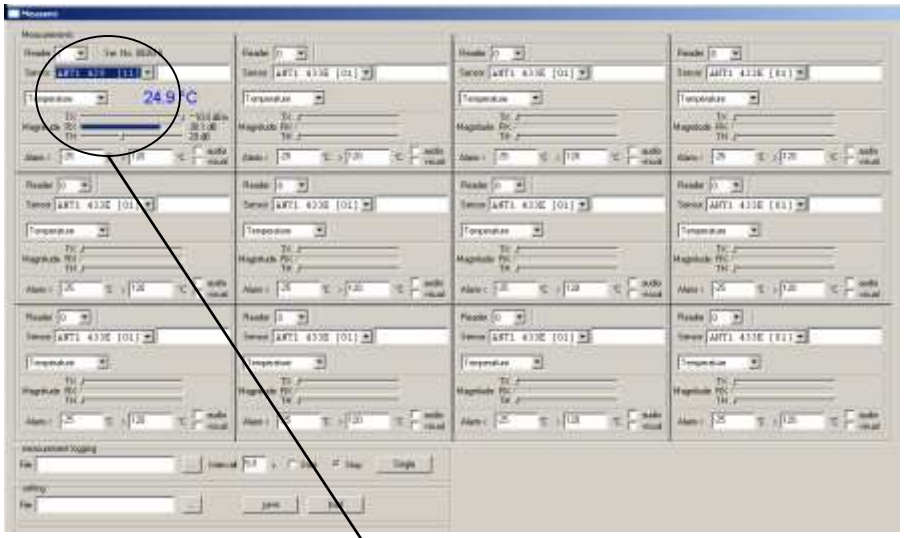

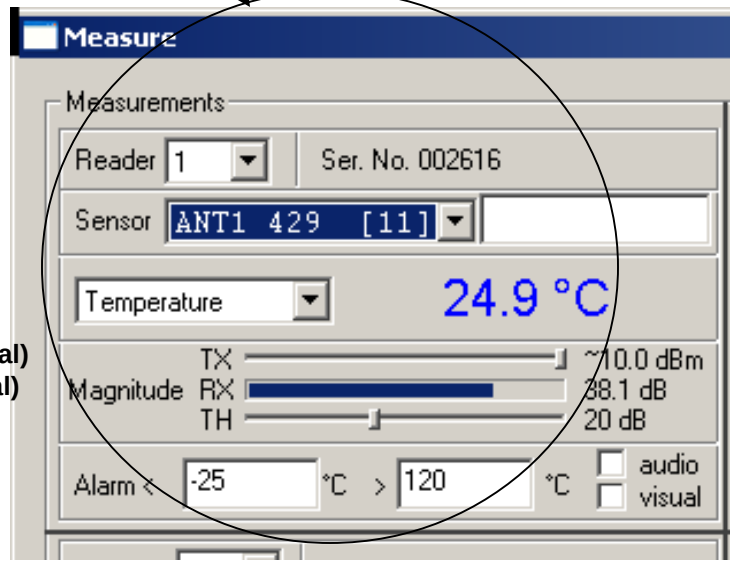

TX (Transmit signal)
RX (Receive signal)
TH (Threshold)

Temperature

Starter Kit: Wireless SAW Temperature Sensors

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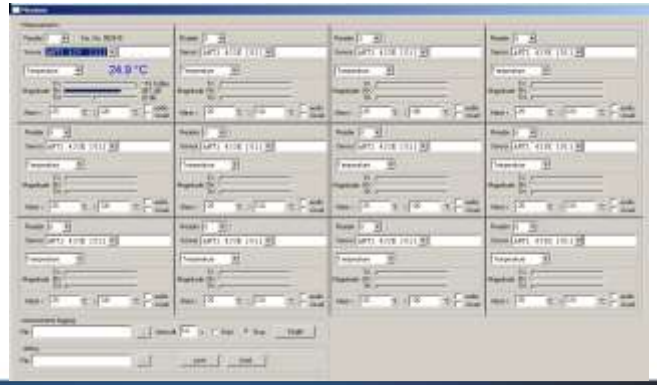
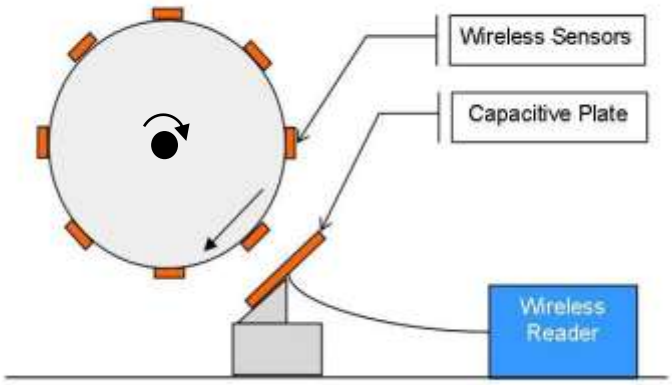
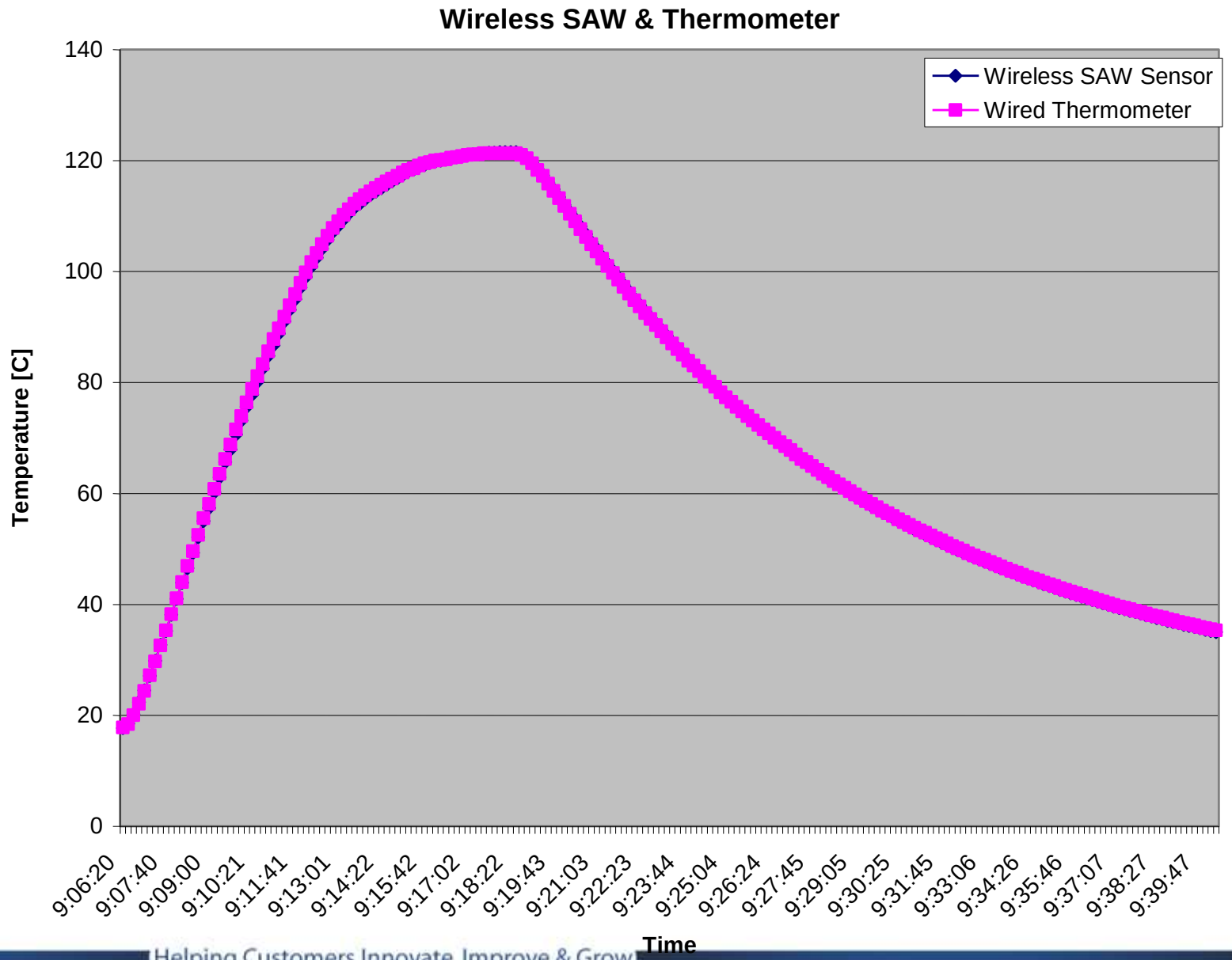


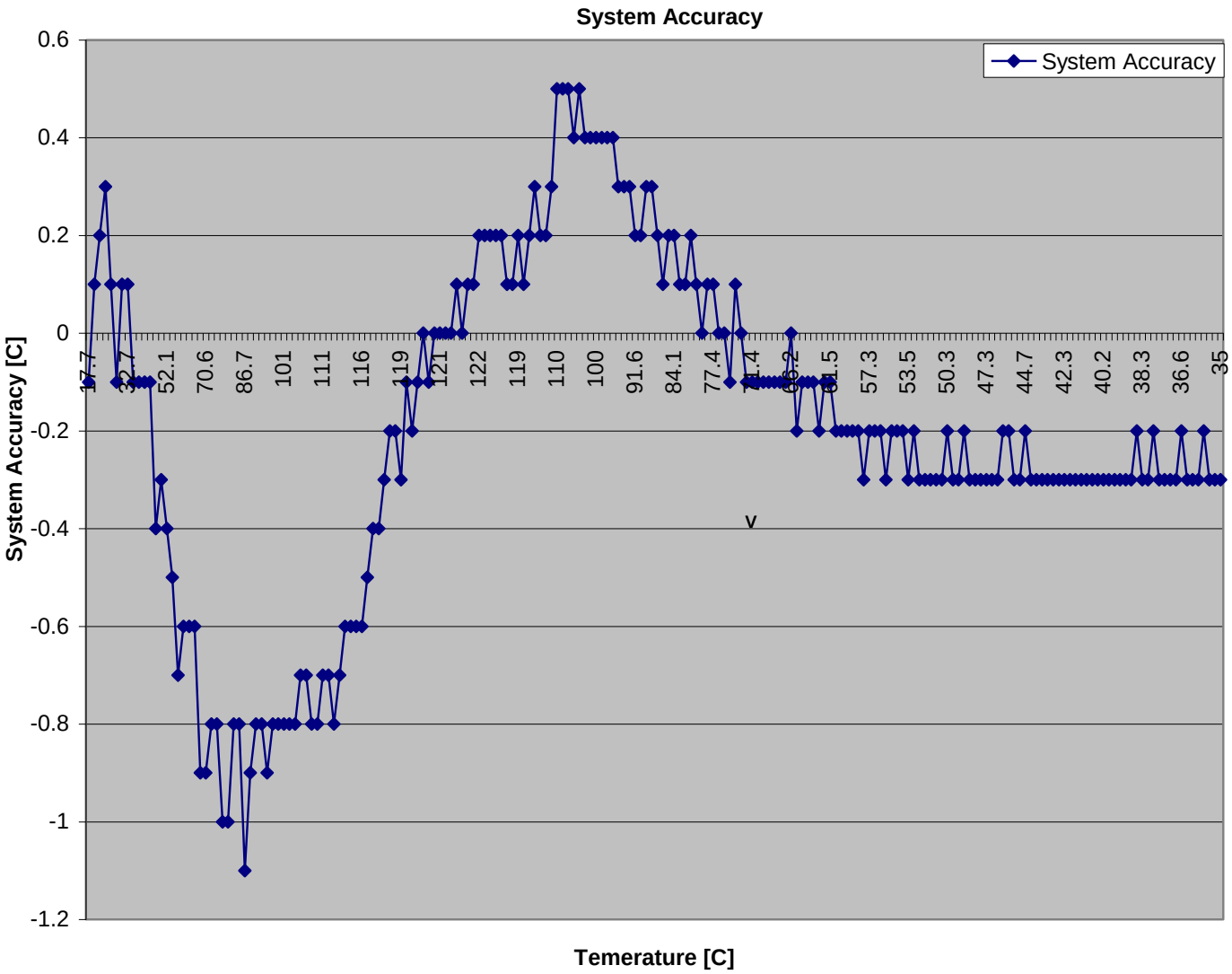
Applications



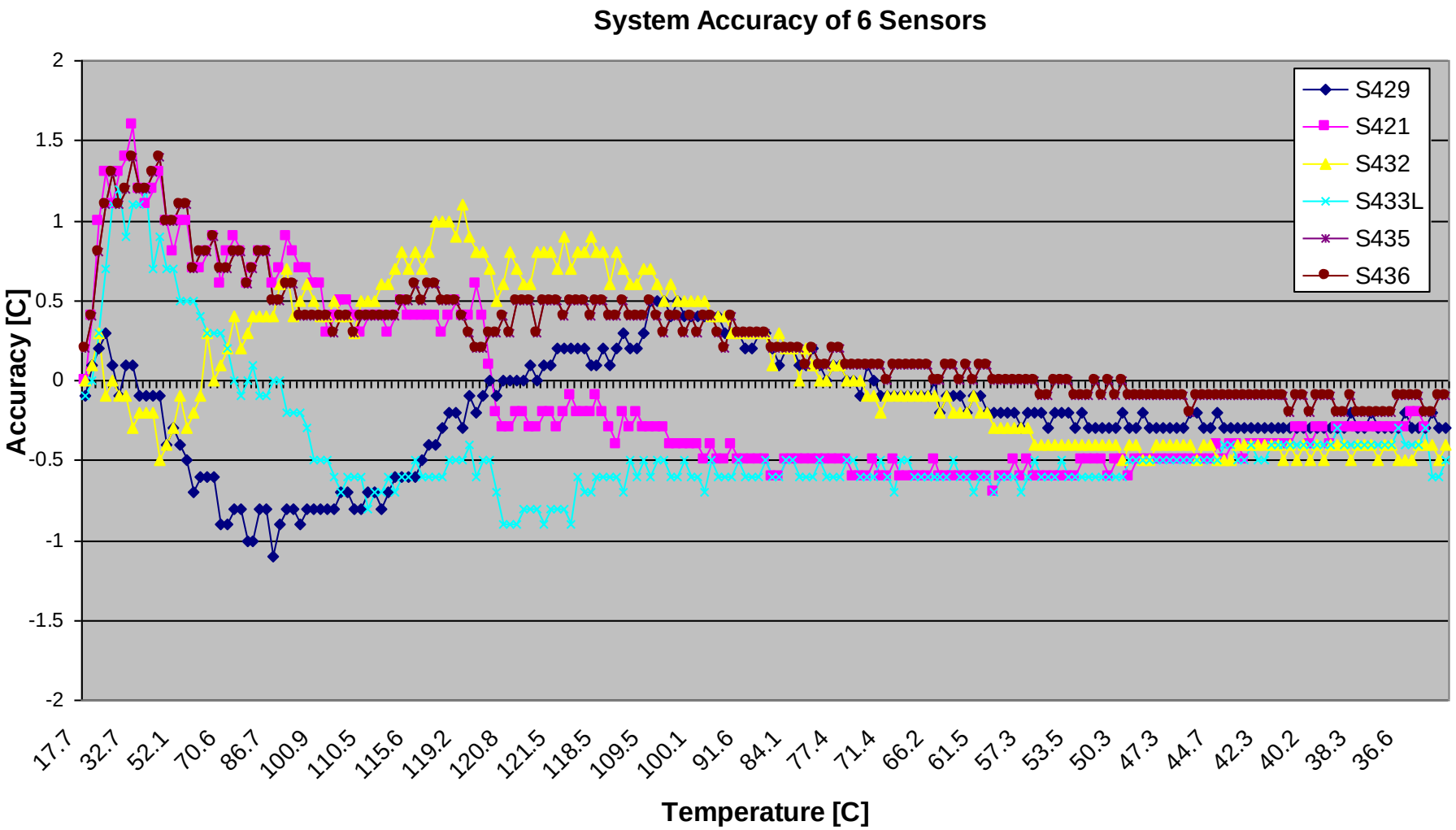
Measurement results



Measured results



System Accuracy of all Six Sensors



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Solution (Advantages)

- ***Passive*** and ***Wireless,*** non-invasive and no active electronic circuits
  - It has been estimated that typical wiring cost in industrial installation is US$ 130 – 650 per meter and adopting wireless technology would eliminate 20% - 80% of this cost
- ***Medium*** & ***High*** temperature operating ranges: -20°C to 120°C & up to +260°C
- ***Reading Distance***: 0.1 to 3 Meters (depend on the antenna and RF environment)
- ***System accuracy***: ± 2°C (temperature operating range -20°C to 120°C)
- ***Robust, reliable , stable and suitable for harsh***, hazard and inaccessible hot-spots
- ***Multi- Communication Protocol***: RS485, RS232, USB, CAN. Analog-Output, MODBU
- ***User Friendly***, ease of installation, simple to use Interfaces and data logging
- ***Real-Time*** and Continuously Thermal Monitoring – 24/7/365
- ***Miniature:*** small and light, low cost
- ***Low Maintenances***
- ***Low ageing degradations*** (± 2°C <12 years)
- ***Environmental*** and green technology – no recycling of battery

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Limitations

- ***FCC/EC/EMC***
- ***Number of Sensors - Interference***

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Questions?

Thank You

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