COMPUTATIONAL RFID

RFID Computațional

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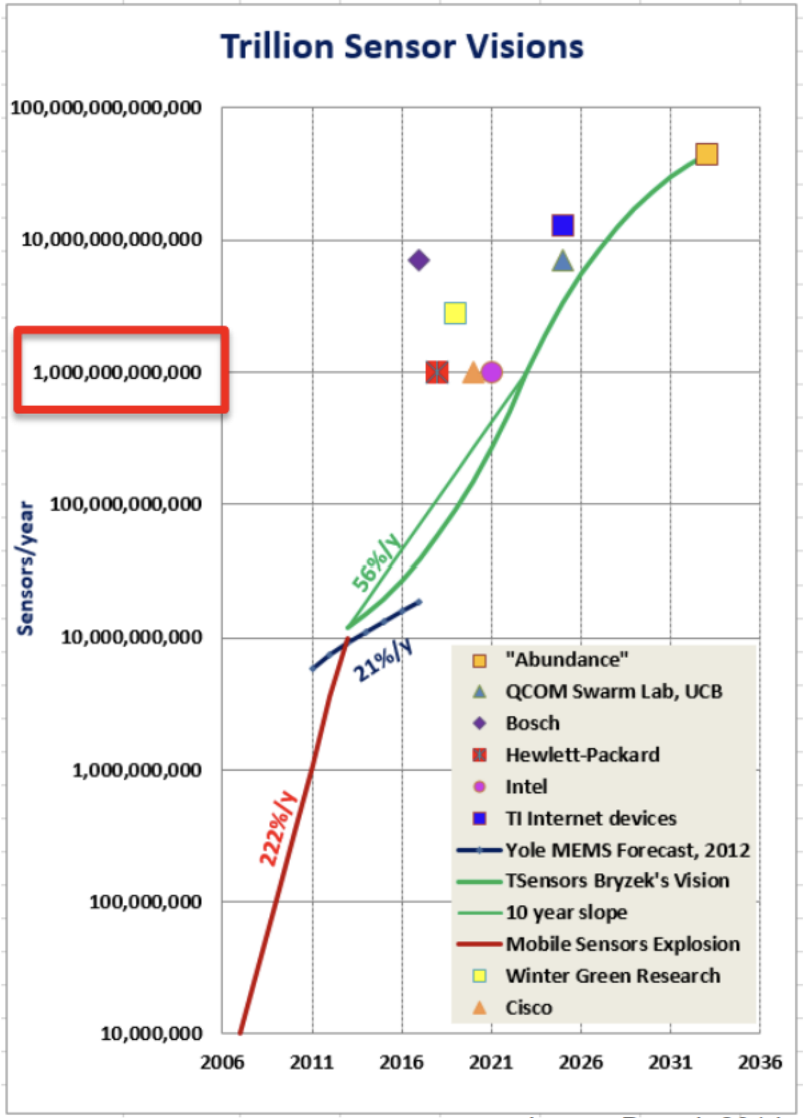
Cyber Physical Systems (CPS) vs Internet of Things (IoT)

CPS: systems that integrate computational elements (cyber) with physical entities (physical) such as sensors, **actuators, and control systems**, to monitor and control physical processes in real-time

IoT: network of interconnected devices that are embedded with sensors, software, and connectivity to collect and exchange data over the internet

Internet of a Trillion Things (IoTT) – not yet there but will eventually (~20 billion now)

Typical “motes”



Janusz Bryzek 2014

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IoTT (trillion things): need **zero** batteries at the sensor – energy harvesting!

Taxonomy of energy harvesting options:

- ***Intermittent:*** Solar power, wind energy, body movement
- ***Opportunistic:*** hydroelectric, steam pipe, body heat
- ***On-demand deterministic:*** wireless power ***transmission***

- **Technology:** Photovoltaic, Piezoelectric, Pyroelectric, Thermoelectric, Electrostatic (capacitive), Magnetic induction, Electromagnetic, RF, etc.

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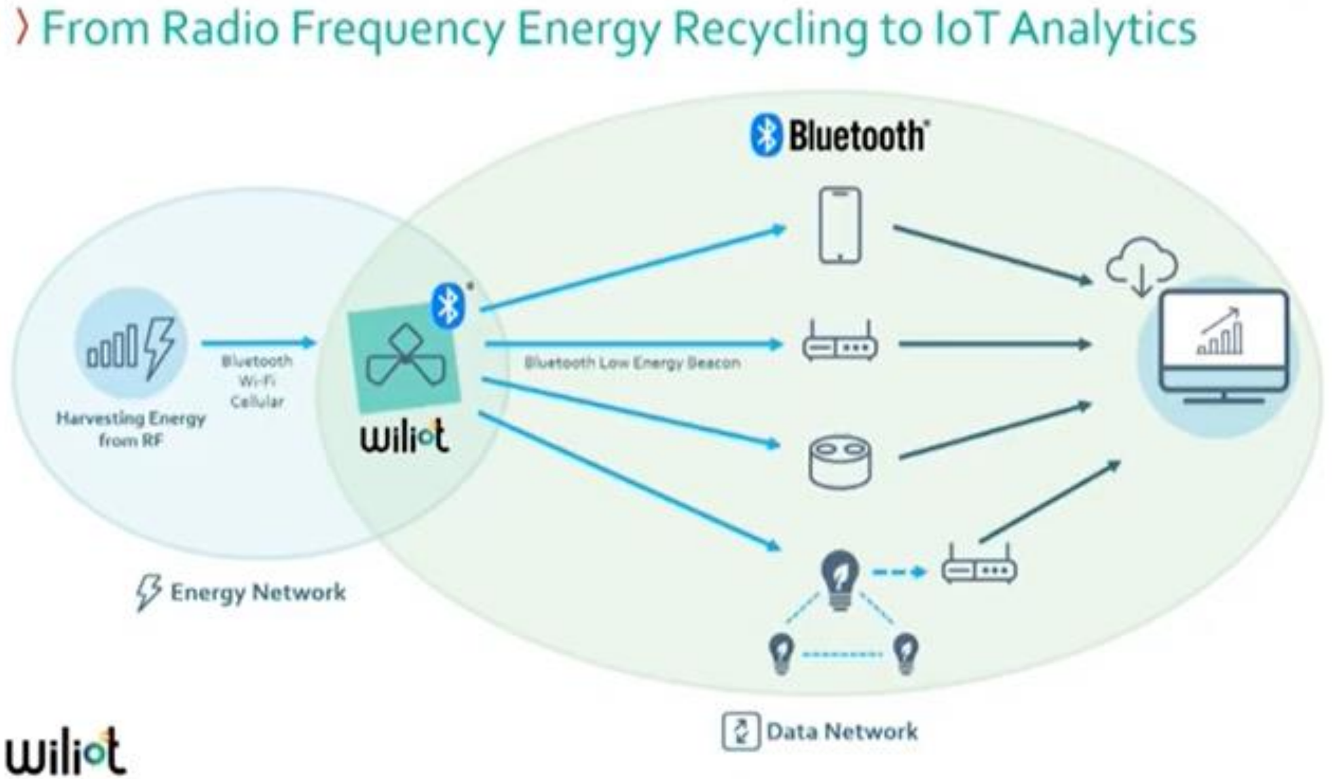
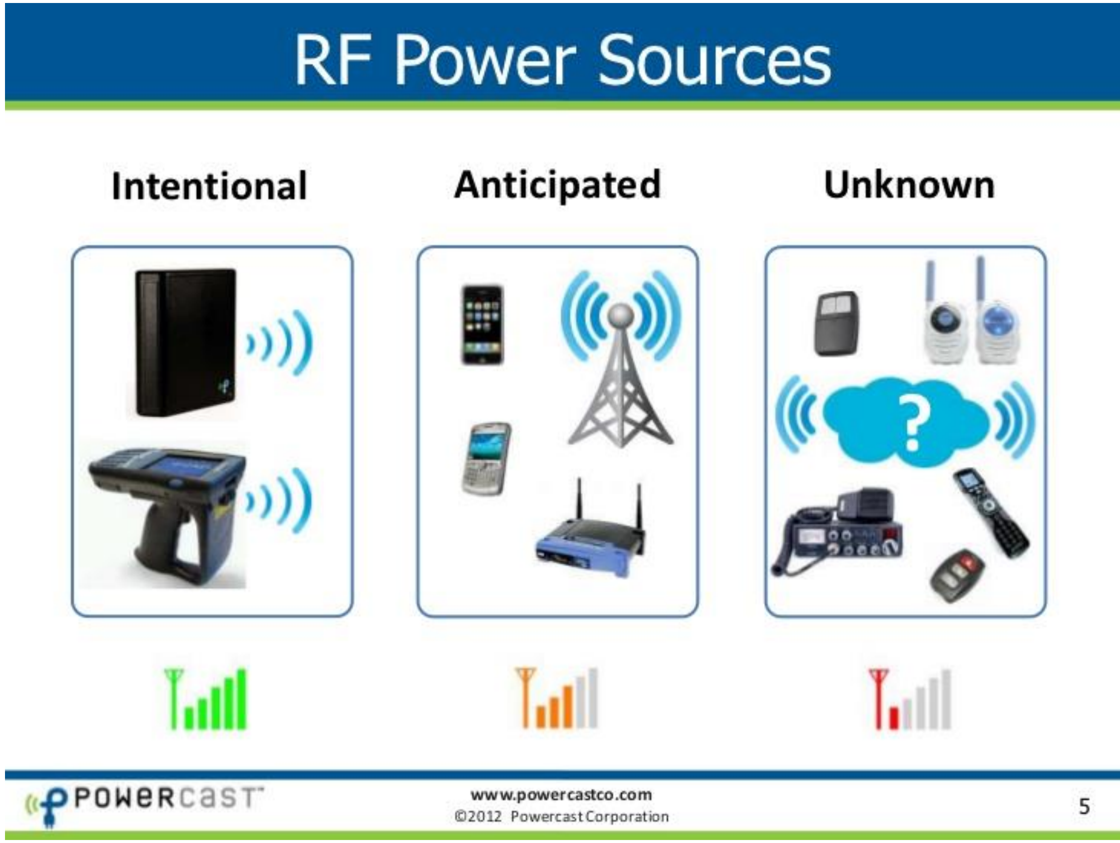
RF power harvesting taxonomy

Powercast, Wiliot, ARM project TRIFFID





wiliot

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RFID

- Replacement for ubiquitous UPC code for inventory
- uses EM fields (NFC, UHF, microwave) to track tags attached to objects
- can be attached to physical money, clothing, possessions, or implanted in animals and people
- market value is expected to rise to >US$16 billion by 2029

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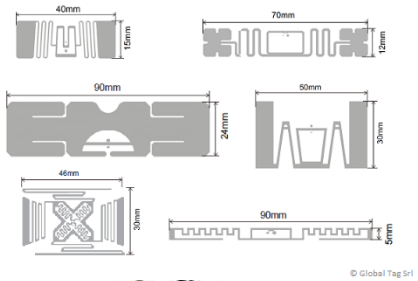
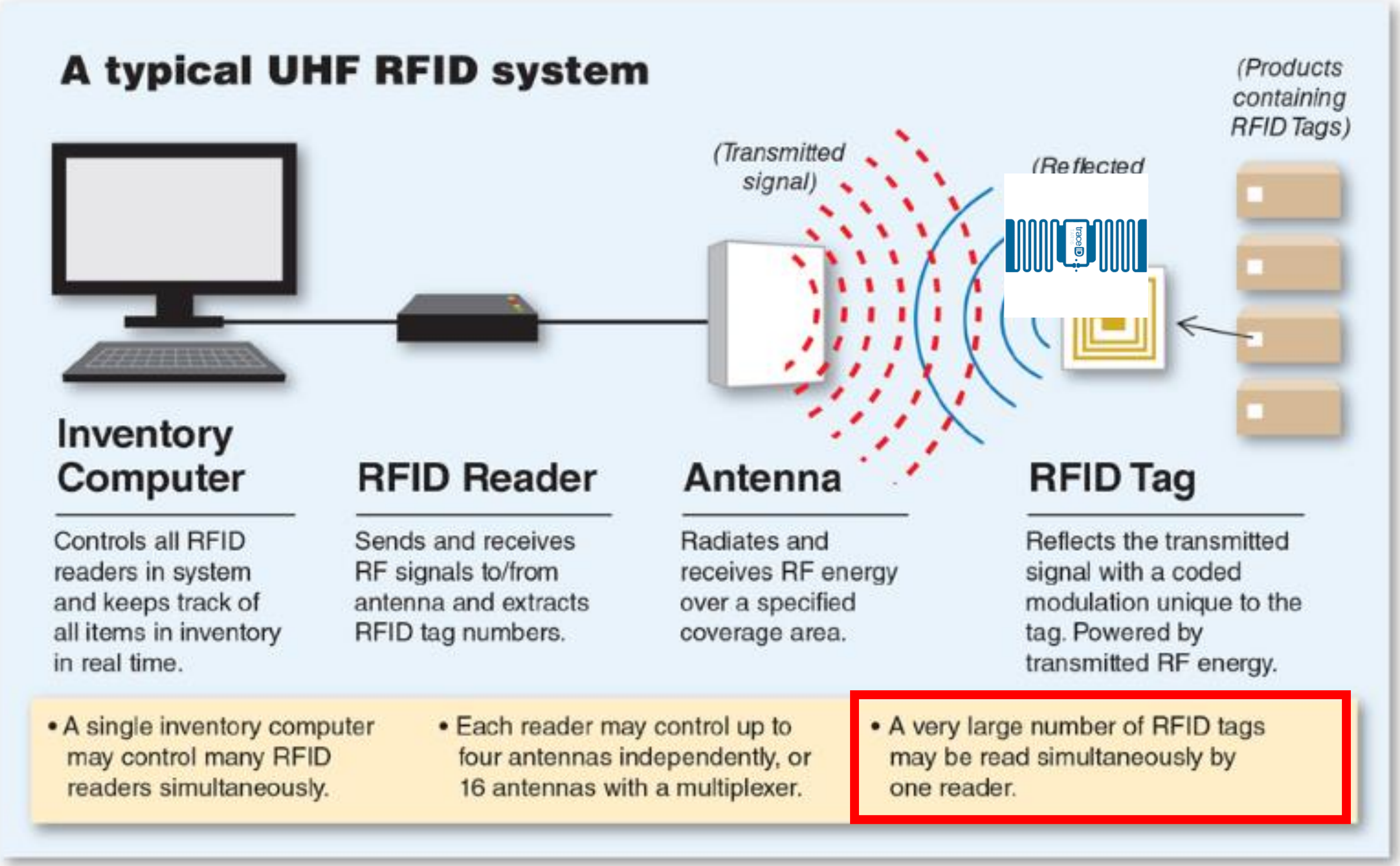
RFID





https://newaverfid.com/experts-corner/rfid-reader-antenna-basics-optimizing-tag-selection-deployment

Backscatter radio – asymmetric passive

1W (30dBm) transmitter (RFID "reader") – passive receiver (RFID "tag")

Backscatter – clever way to communicate

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Backscatter radio

"Active" symmetric communication

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Backscatter radio

Backscatter – asymmetric, think reflection

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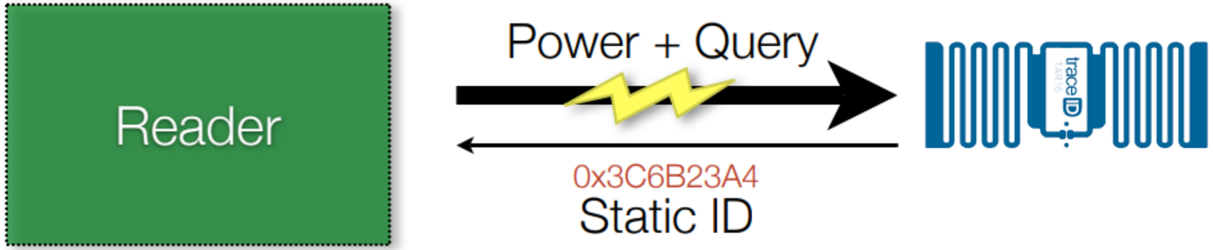
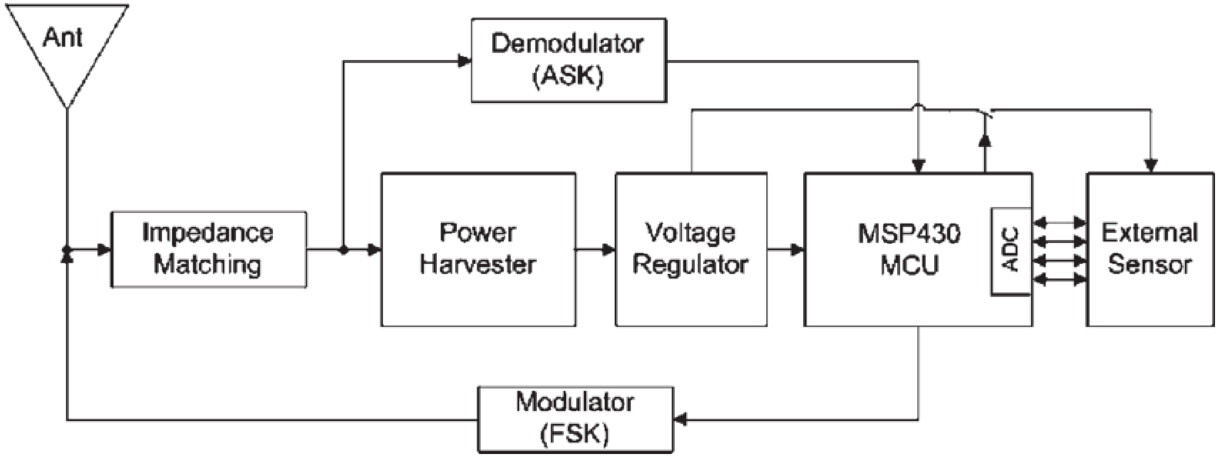
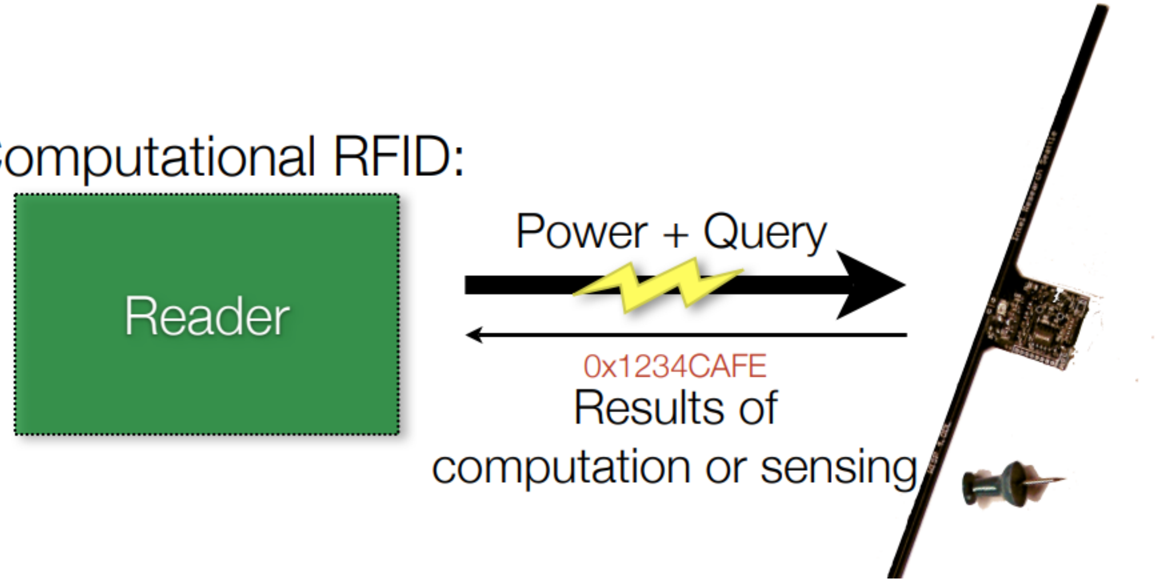
RFID vs. Ccomputational RFID – WISP project

RFID:





Computational RFID:



"Heavy" (MSP430) implementation – proof of concept

"Getting Things Done on Computational RFIDs with Energy-Aware Checkpointing and Voltage-Aware Scheduling" Ben Ransford et al., HotPower'08

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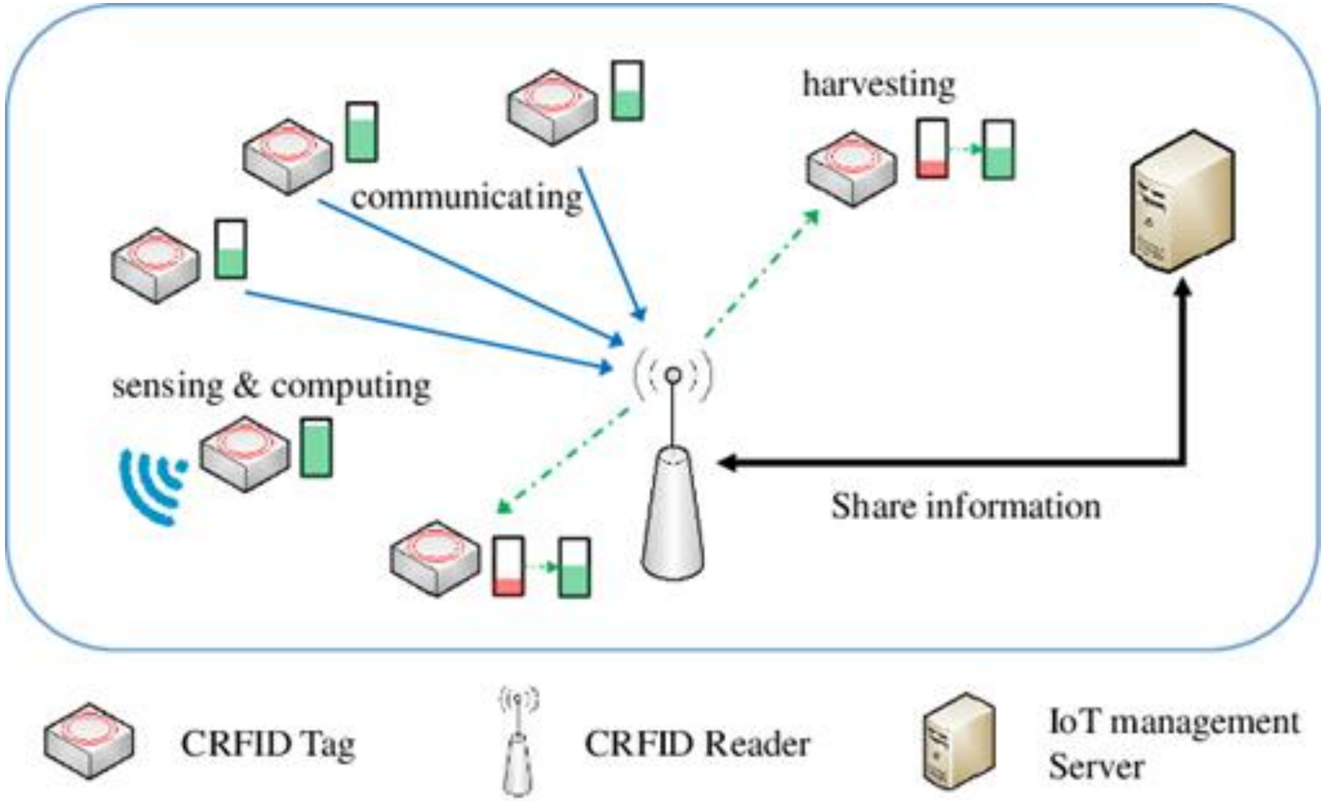
One application: Smart Buildings

Computational RFID (CRFID): Wireless UHF RF power transfer

Passive communication: backscatter radio

Asymmetric split functionality: tag and reader (“extreme edge” and “mist”)

Asymmetric duty cycles



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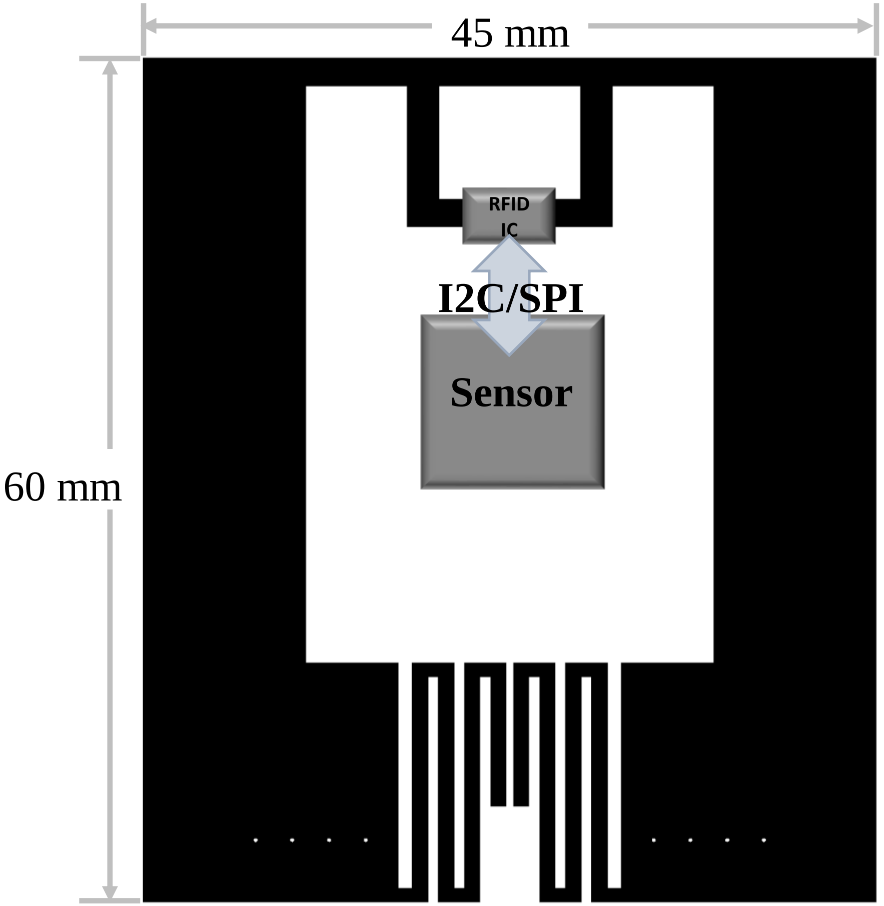
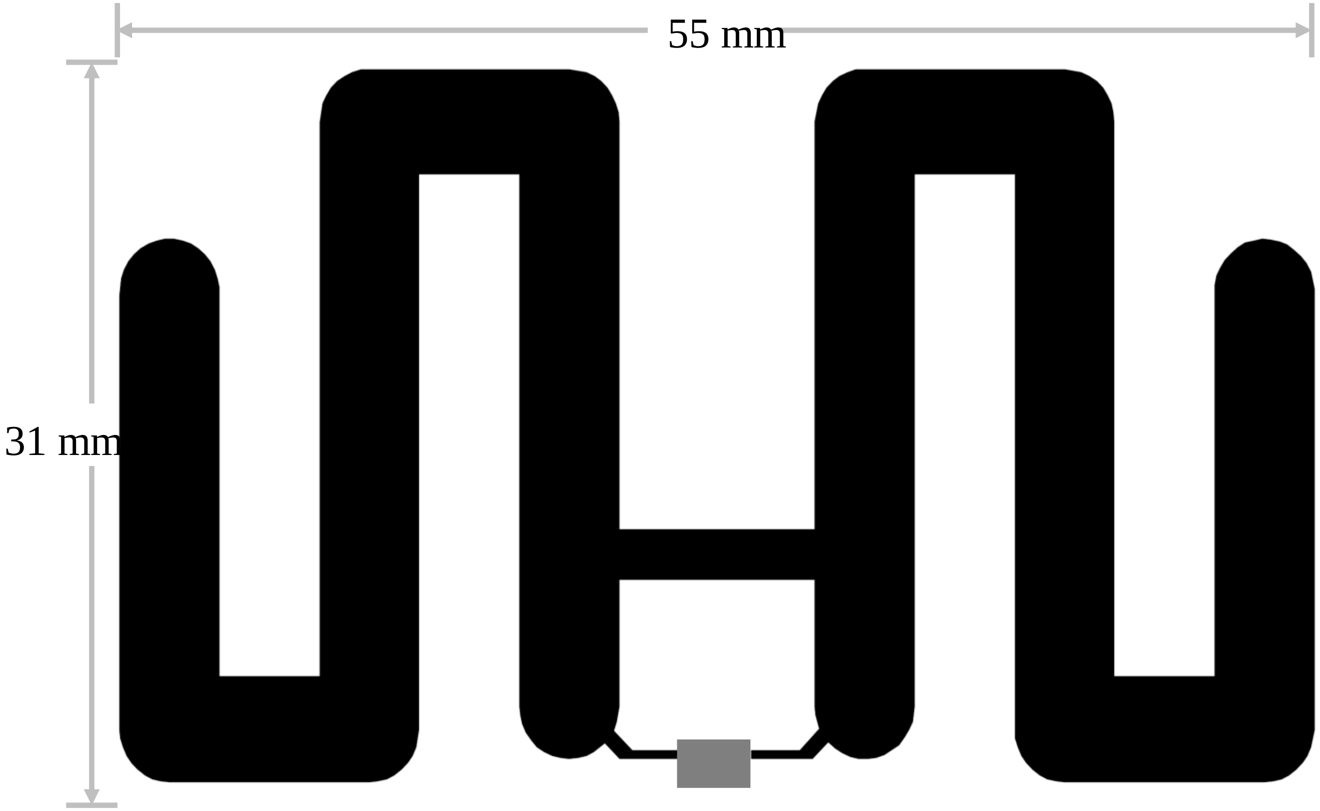
Simplest possible CRFID – I2C/SPI sensor



MetalFAntenna_b_v2_DrawBW.pdf



EM4325-Dipole-Draw.pdf

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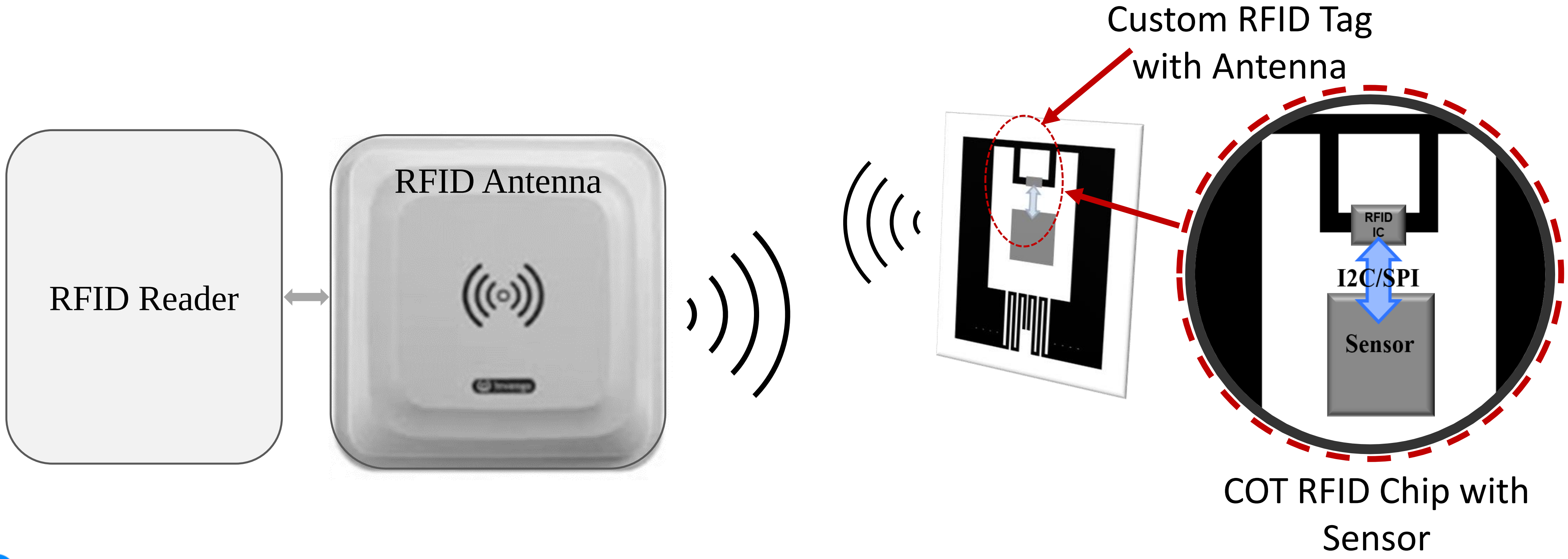
CRFID SYSTEM

System that includes a custom reader + antenna and a custom tag with antenna, COT RFID chip, COT sensor, connected over I2C/SPI to a custom chip



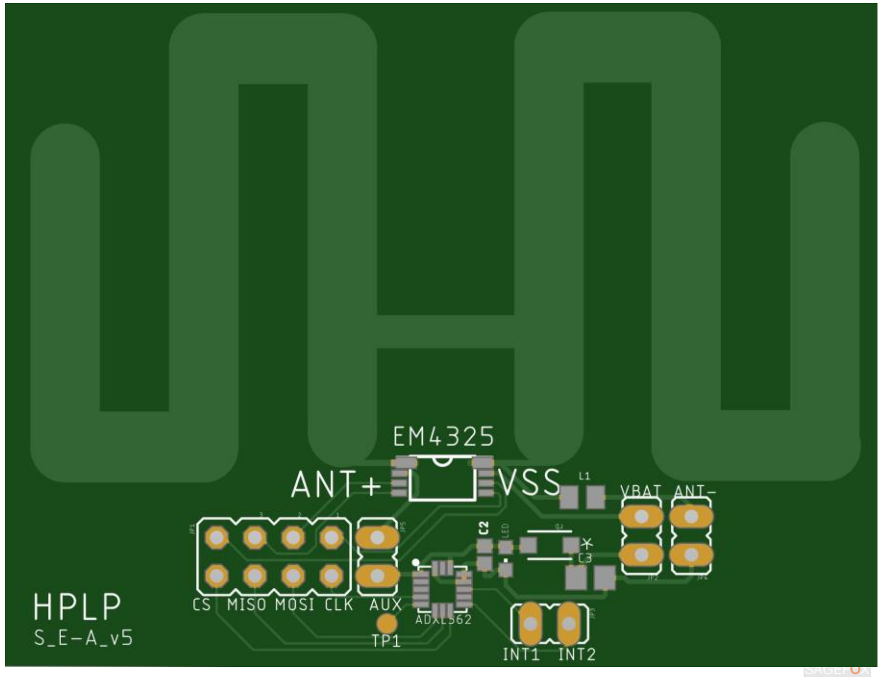
Pseudo-BAP mode

BAP – battery-assisted passive: much better range

THE EM4325 RFID CHIP

	fully-passive	BAP
Read Sensitivity $S_{chip,r}$ [dBm]	-8.3	-31
Write Sensitivity $S_{chip,w}$ [dBm]	-7	-31
Chip input Imped. Z_{chip} [Ω]	23.3-j145	7.4-j122

Asymmetric duty cycling allows a pseudo-BAP mode charging a capacitor for a long time before activating tag – can only be achieved with custom reader



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Asymmetric duty cycling

Duty cycling is the workhorse of low power design: power gating

Average power = m% * Power

RF transmission: extreme duty cycling needed with energy harvesting

RFID: symmetric and fast duty cycling to access as many tags as possible

CRFID: m% * xmit Power = n% * rcv Power

Custom reader: 100% * xmit Power = n% * rcv Power –> larger rcv Power!

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Future work: CRFID 2.0

- ***COTS RFID tag front-end :*** avoids reinventing the wheel, optimized for RFID
- ***COTS sensors:*** see above
- ***Custom ULP NVM FPGA:*** replace "heavy" processor
- ***"Customized" reader based on COTS reader module:*** widen xmit duty cycle
- ***Pseudo-BAP:*** better range
- ***On-metal compatible antenna:*** wider range of applications

Custom FPGA "features":

- Ultra low power – improves range
- Low leakage – improves functional duty cycle
- NVM – instant on
- No checkpointing – avoids endurance limitations

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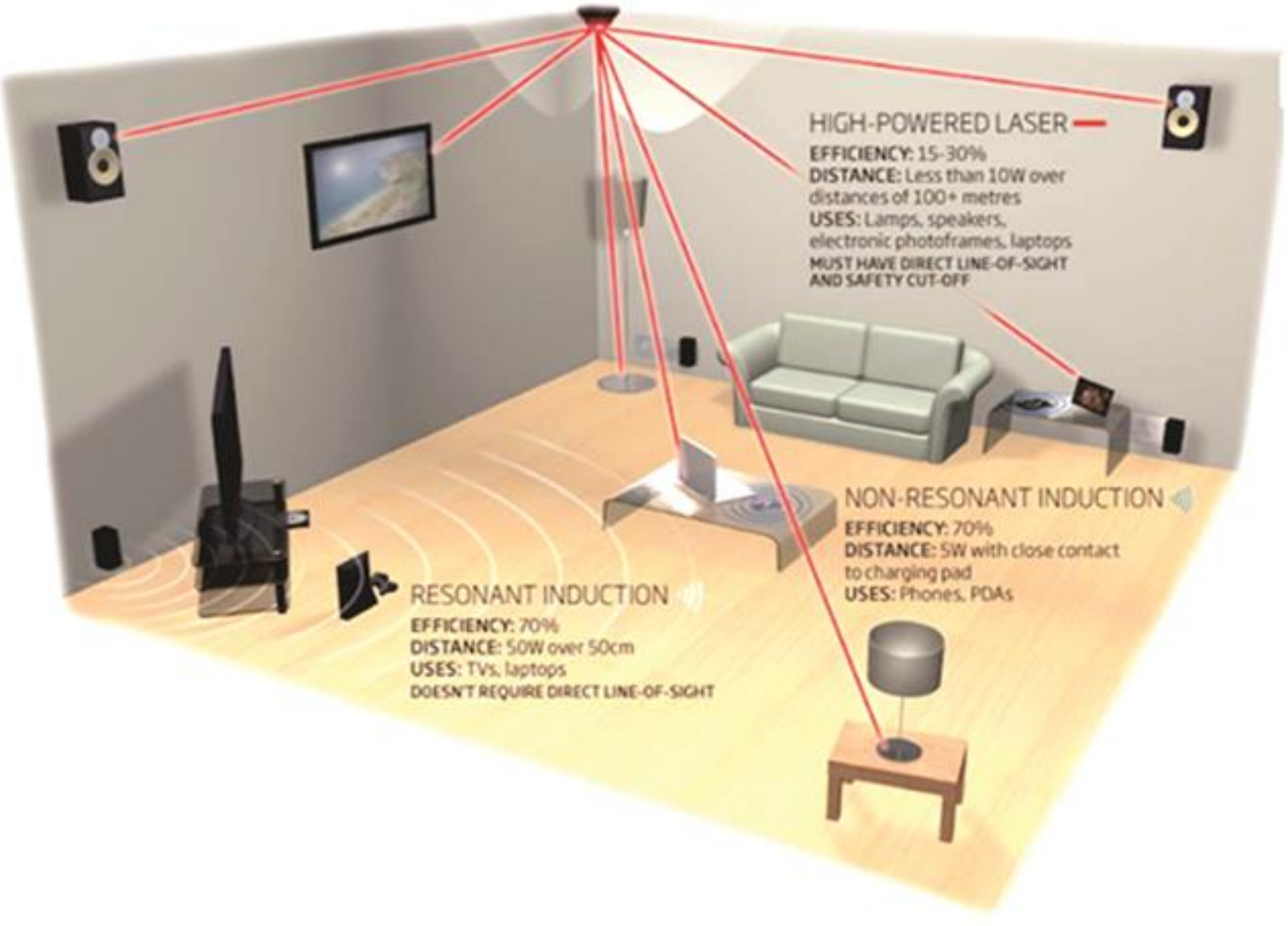
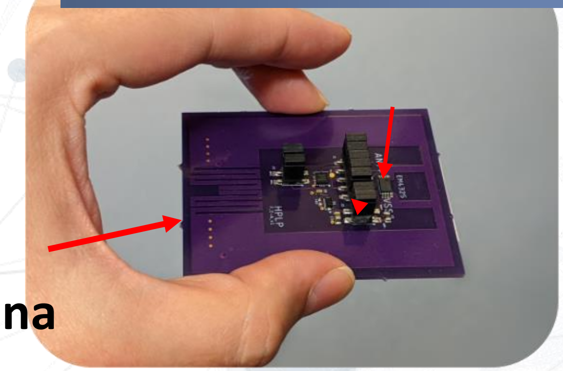
Living room/office of the future

- Augment wifi router with ***UHF reader capability + extra RFID antenna***
- System/software/AI/ML/hybrid



Application: Predictive maintenance for Industry 4.0

Application:
Sensing tags for remote monitoring of rotary machinery



Antenna

RF Communication + RF Energy Harvesting
IC temperature sensor
SPI interface
Flexible Configuration
Expandable sensing - vibration

Remote Measurements

- Temperature and vibration monitoring using passive CRFID tag
- Monitoring with **no wires or battery**

Temp

```
---- tests::em_sensor_test stdout ----
Got temp: 25.75 °C


successes:
    tests::em_sensor_test
```

Vibration

```
Sample 0: X-Axis: -0.144 g
Sample 1: Y-Axis: 1.126 g
Sample 2: Z-Axis: 0.096 g
Sample 3: X-Axis: -0.1 g
Sample 4: Y-Axis: 1.074 g
Sample 5: Z-Axis: 0.006 g
Sample 6: X-Axis: -0.1 g
Sample 7: Y-Axis: 1.07 g
Sample 8: Z-Axis: 0.008 g
```

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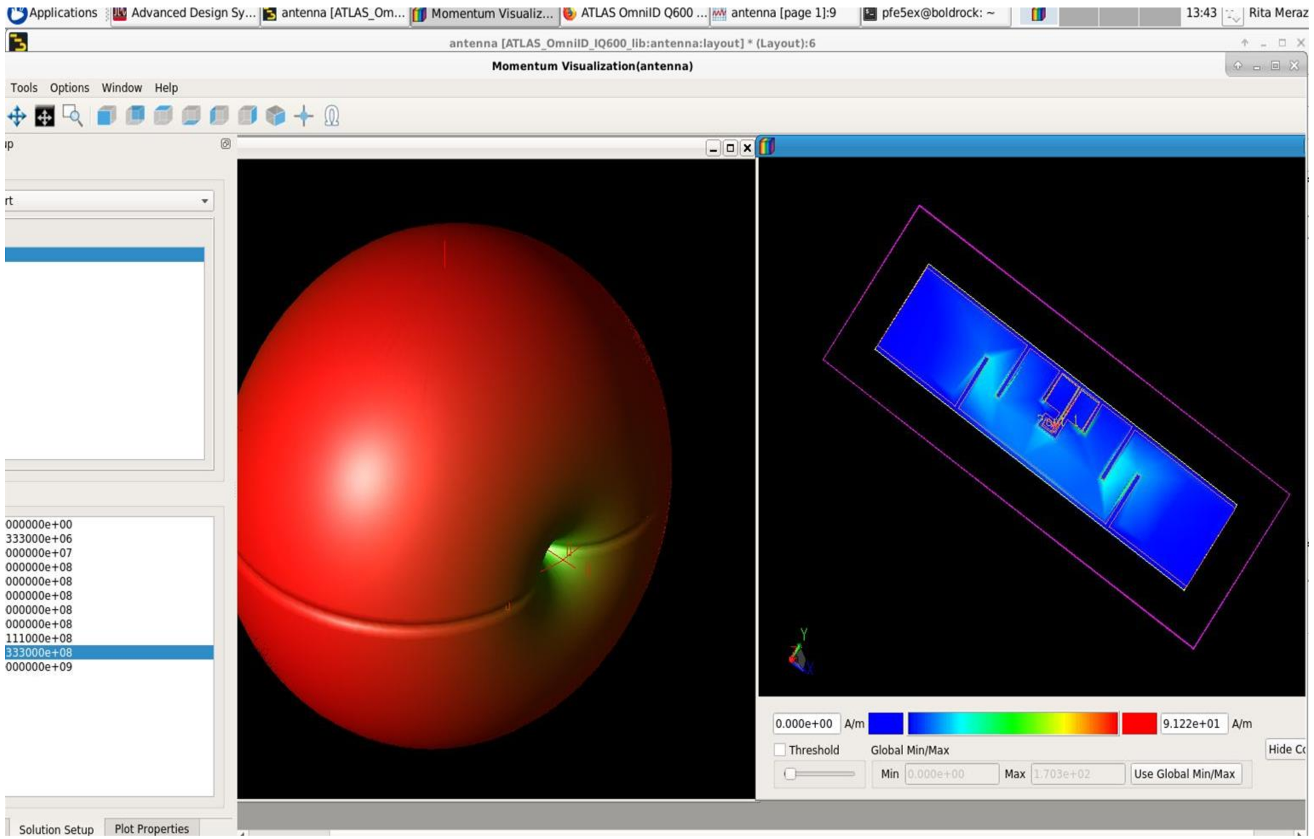
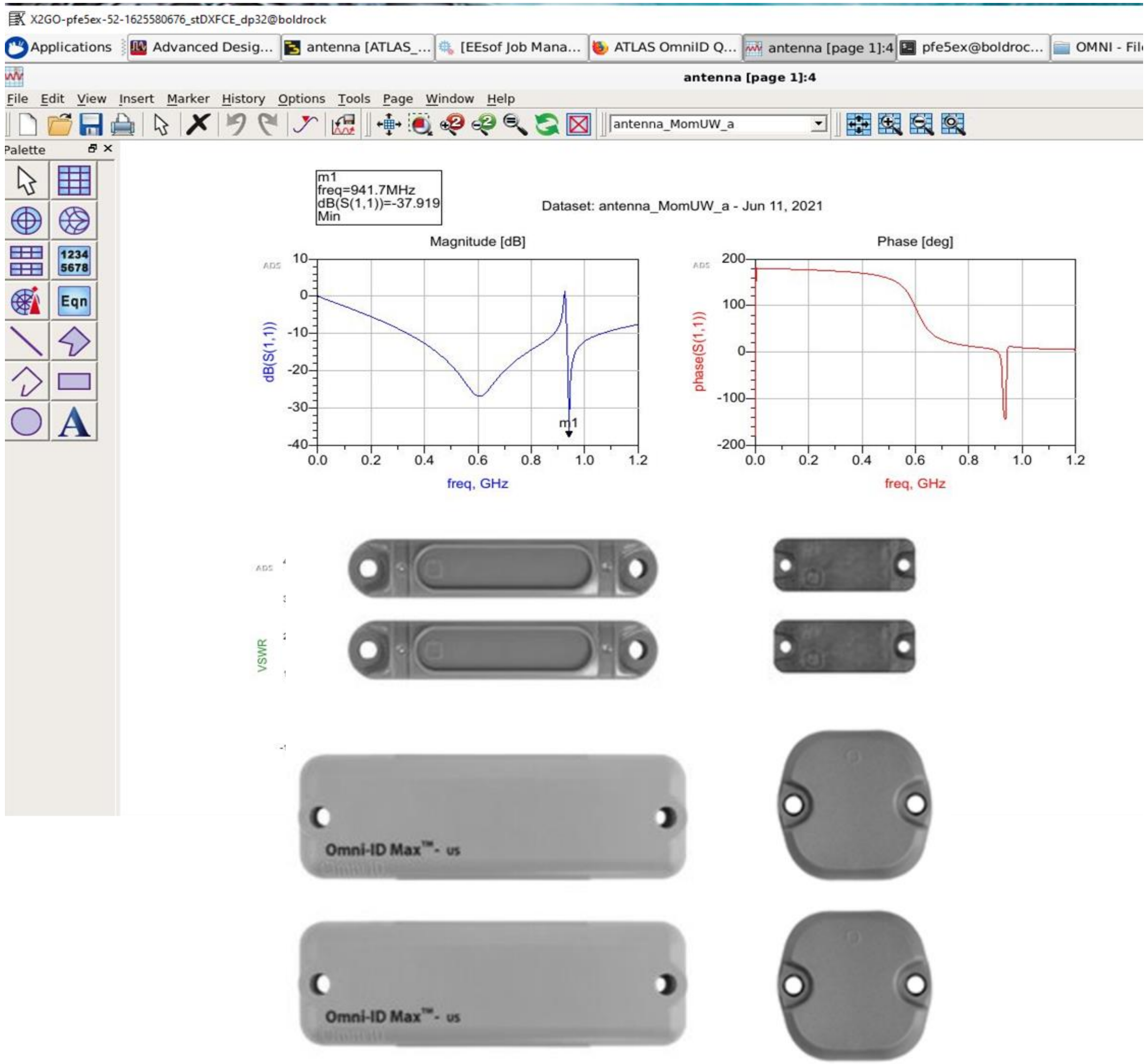
Metal-compatible antenna





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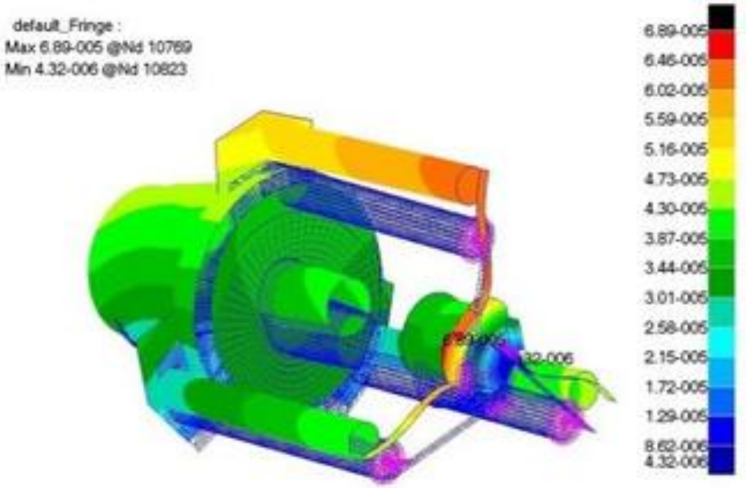
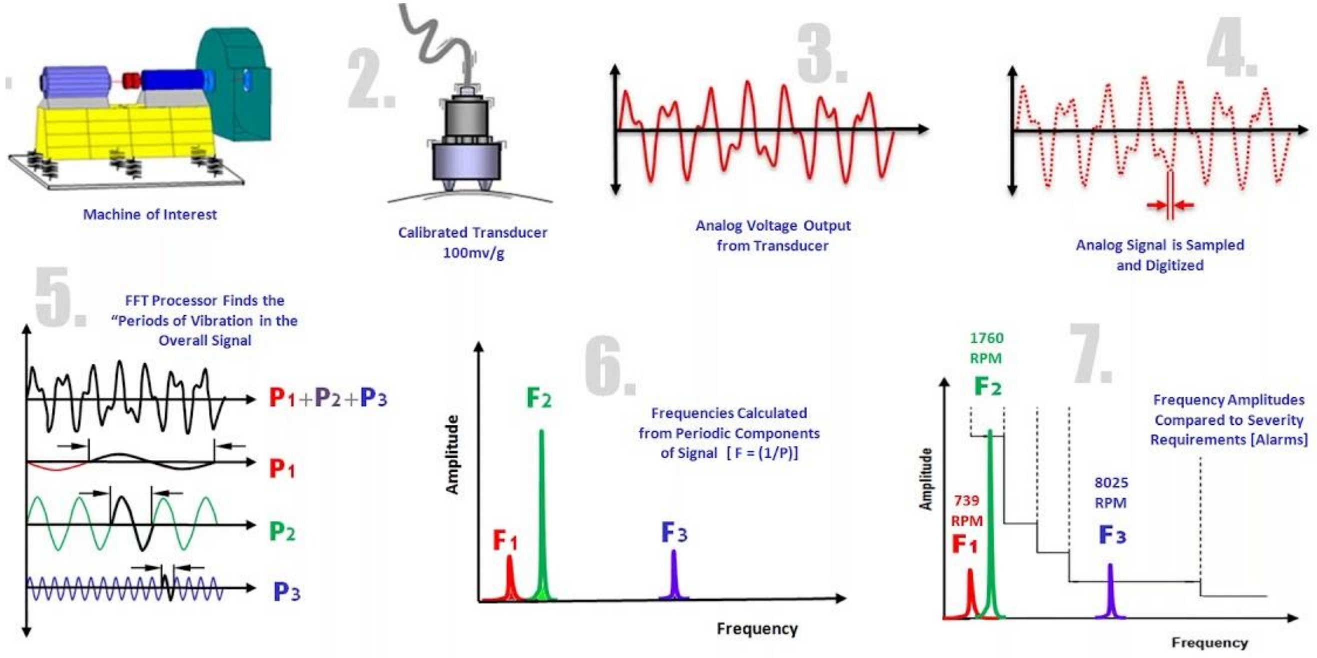
How to predict machine "health"

- Vibration from rotary components
- Surface Temperature





Embed ML into hardware

Detect anomaly "within" data real time

Understand patterns; predict next segment

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Other areas of research:

- AI hardware
- Processing in Memory
- Spintronics
- Nanoelectronics

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University of Virginia (UVA)

- Founded by Thomas Jefferson in 1818
- Charlottesville, Virginia
- University World Heritage Site, UNESCO
- “Public Ivy” (Berkeley, Michigan, UCLA)

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https://engineering.virginia.edu/high-performance-low-power

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