UC San Diego
JACOBS SCHOOL OF ENGINEERING
Electrical and Computer Engineering

WCSNG
Wireless Communications Sensing and Networking

ZenseTag: RFID assisted Twin-Tag Single Antenna COTS Sensor Interface


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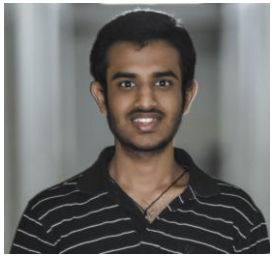
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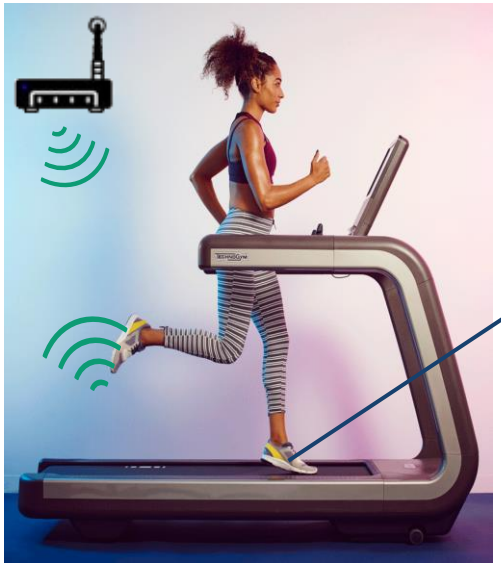
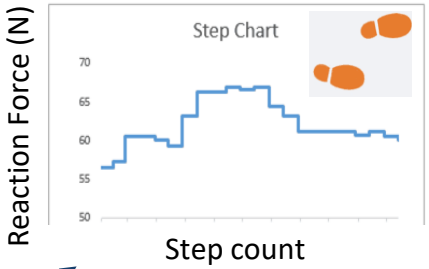
Prof. Dinesh Bharadia

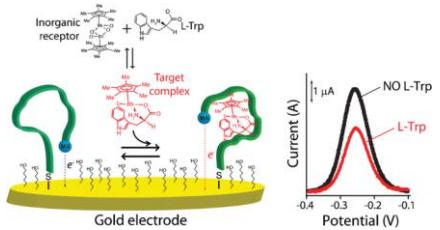
Ubiquitous sensing - Next wave of IoT





Ground Reaction Force

Sensing soil-moisture to automate irrigation



Sensing soil chemical with Biochemical sensors [1]

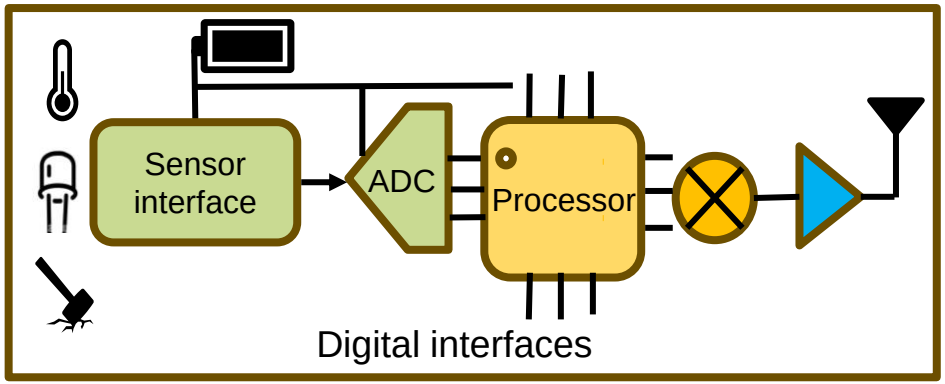
Sensors enable ubiquitous sensing and automation.

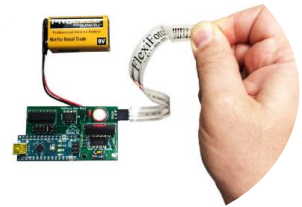
[1]https://doi.org/10.1007/s00216-019-01645-0

Why has ubiquitous sensing not materialized?

- Sensor interfaces are bulky and power hungry.
- Passive sensing solutions are not robust.
- There is no universal sensor interface.

1. Power-hungry, complex and bulky interfaces

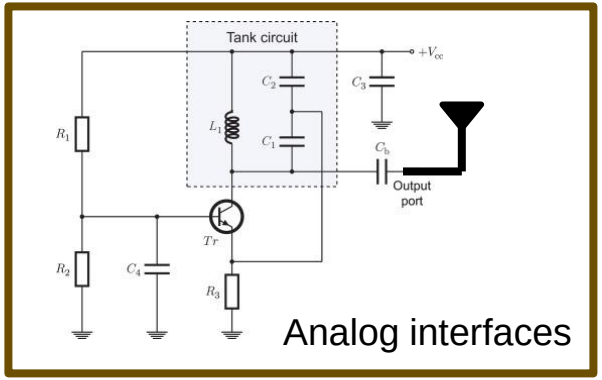


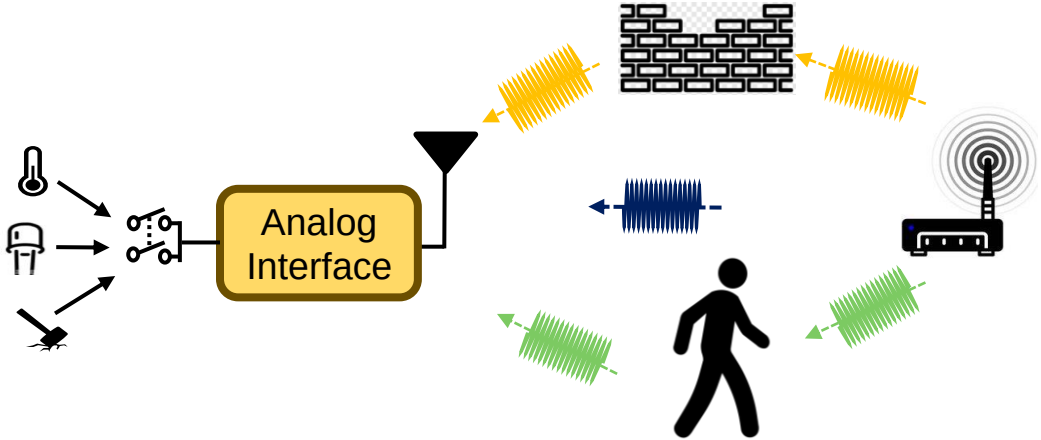


- Bulky Sensor interfaces!
  - Need batteries / energy harvesters.
  - Complex circuits to read sensors.

Current sensor interfaces are bulky, rigid or need batteries!

2. Robustness to multipath

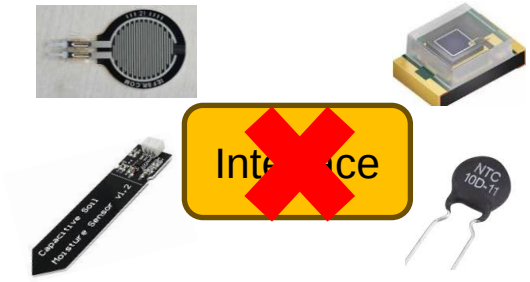




- Passive analog interfaces skip digitization.
- Signals corrupted by multipath.

Analog Sensor interfaces struggle with multipath.

3. No Universal Interface



- A zoo of sensors to choose from! But. . .
  - Every sensor outputs different voltage / current!!
  - Each sensor needs a unique interface!

No universal interface for COTS sensors.

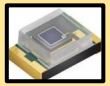
Current sensor interfaces face steep challenges:

Requirements
Universal Interface
Compact form factor
Robust to multipath

ZenseTag: Core Contributions

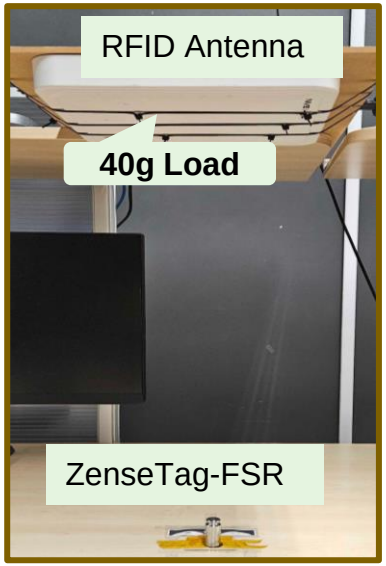
Soil Moisture Sensor

Force Sensitive Resistor

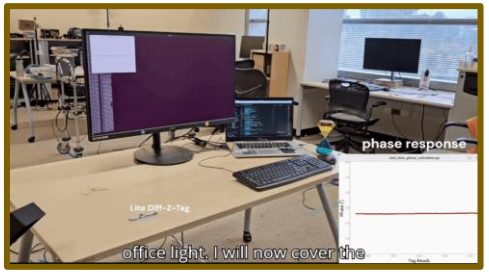


Photodiode

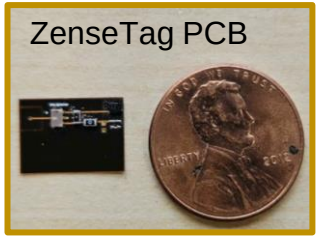
COTS Sensor Interface



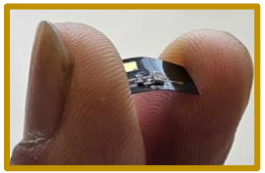
Battery-free/ RFID Compatible



Robust and real-time



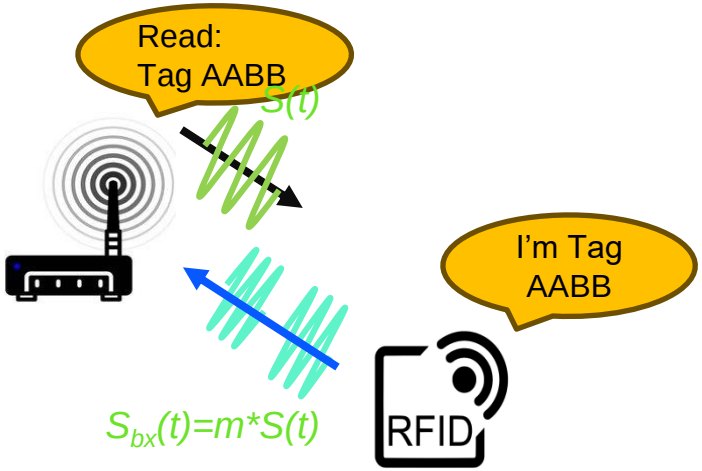
15 X10mm



Compact/ flexible form factor

ZenseTag: Compact and Passive, RFID based tags to provide robust, commercial sensor interface

Can RFID tags enable battery-free sensing?

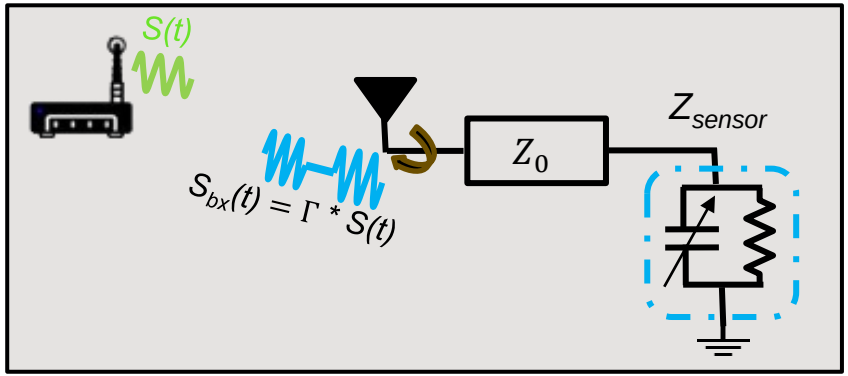


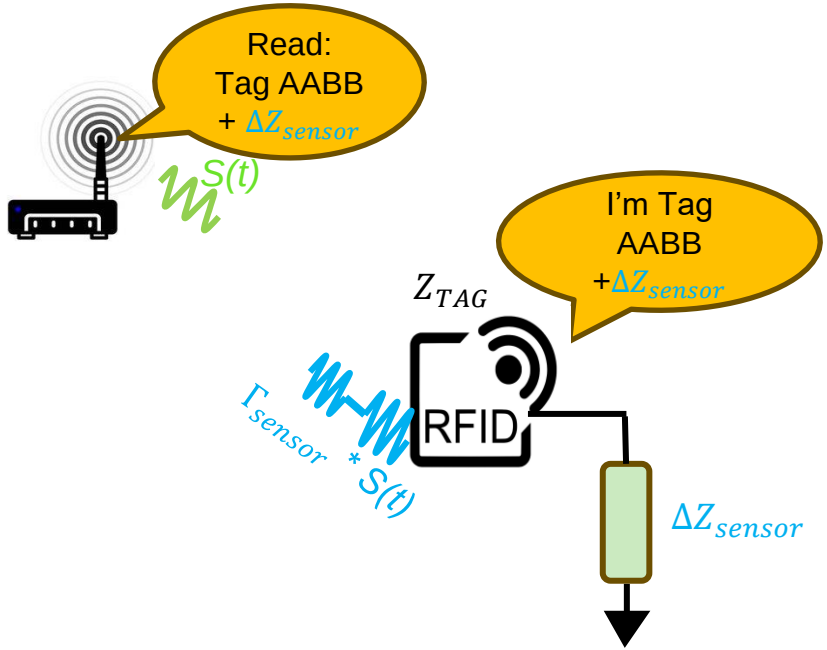
- RFID is a ubiquitous radio platform.
- RFID tags are passive/flexible and inexpensive.
- Tags simply backscatter their digital ID.
- No inherent sensing capability.

Can we use the digital ID of Tags for sensing?

How to modulate RFID signal with sensor output?

$$Z_{sensor} = \frac{V_{sensor}(f)}{I_{sensor}(f)}$$



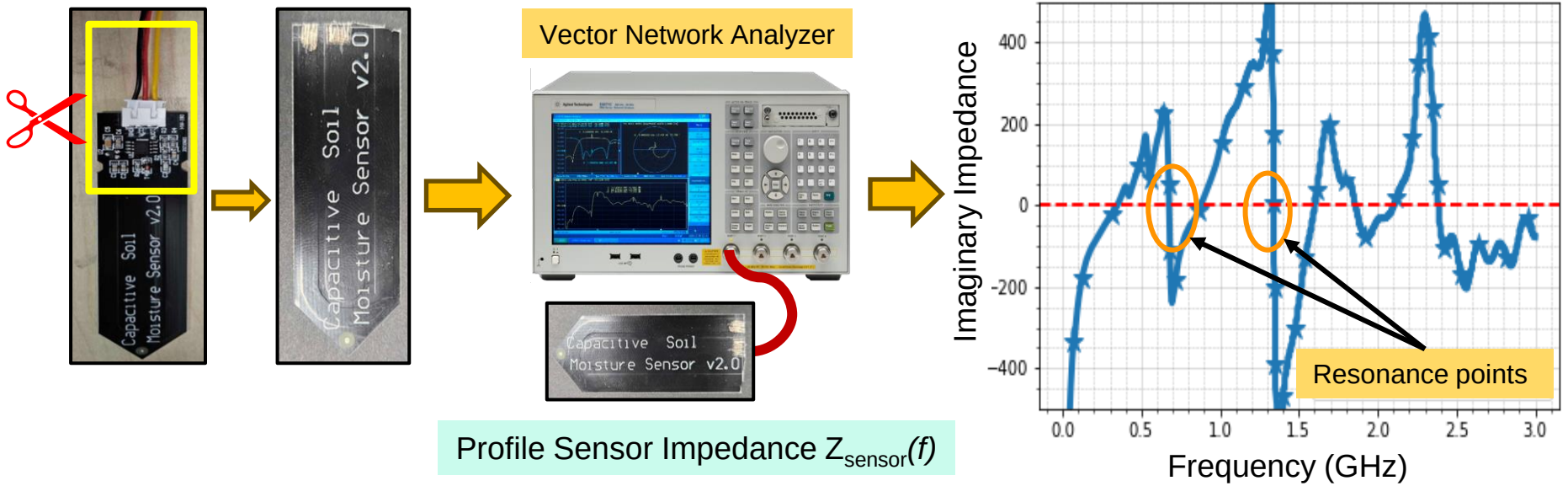


$$\Gamma = \frac{Z_{sensor} - Z_0}{Z_{sensor} + Z_0}$$

$Z_0 \rightarrow Z_{TAG}$

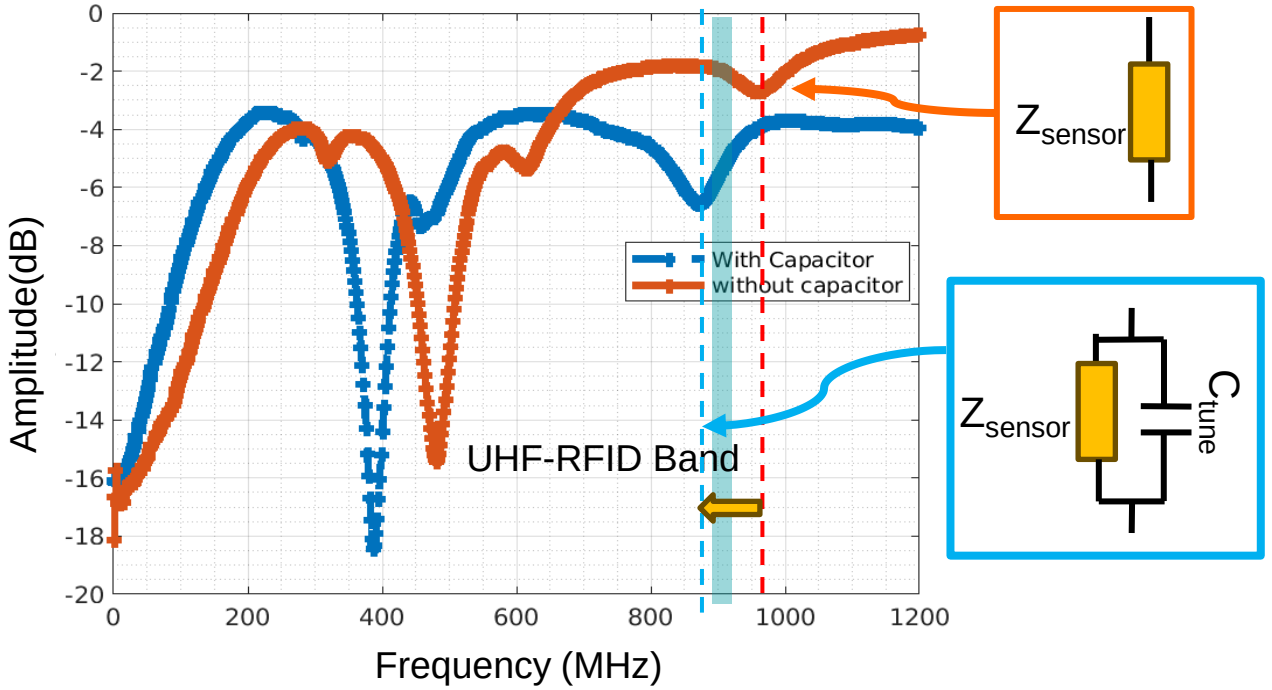
ZenseTag embeds sensor impedance into the tag digital ID.

Cut the bulk-- Measure impedance directly at RF?



ZenseTag profiles sensor impedance directly at RF.

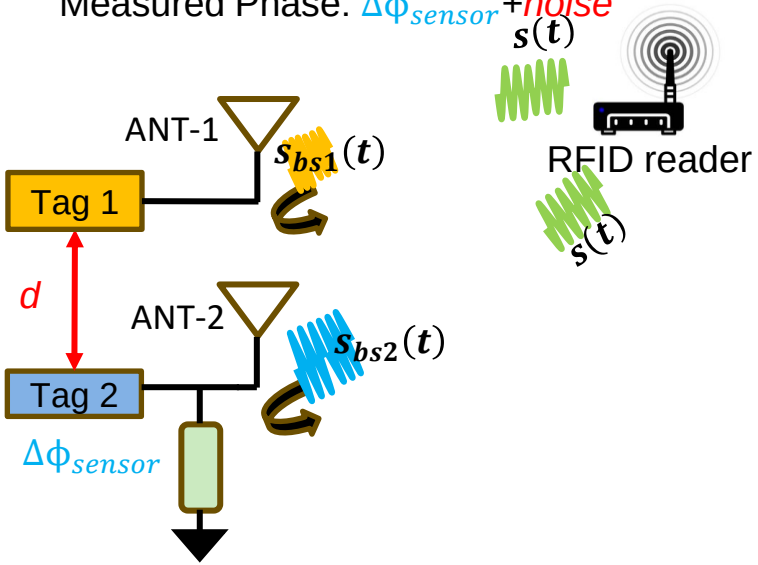
ZenseTag: Tuning the resonance of sensors



ZenseTag tunes Sensor Resonance close to RFID band.

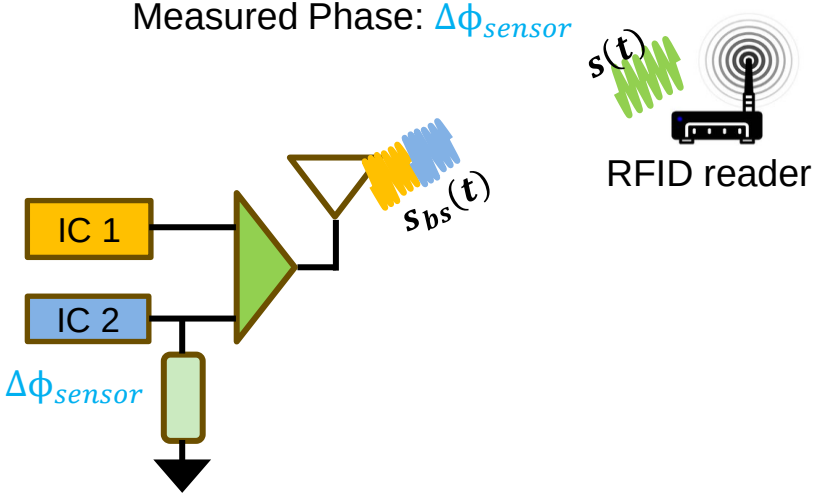
ZenseTag: Core Contributions

Measured Phase: $\Delta\phi_{sensor}$ +*noise*



Current Analog Sensing

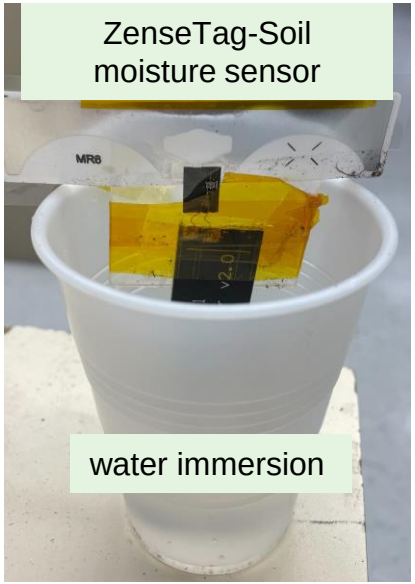
Measured Phase: $\Delta\phi_{sensor}$

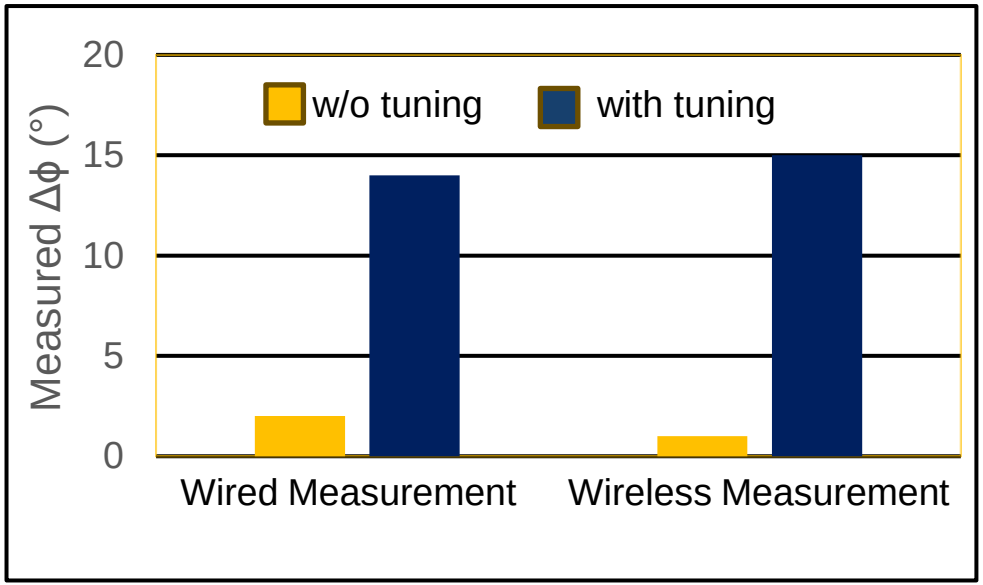


ZenseTag Differential Sensing

ZenseTag uses a single antenna to interface 2 ICs, for robust sensing

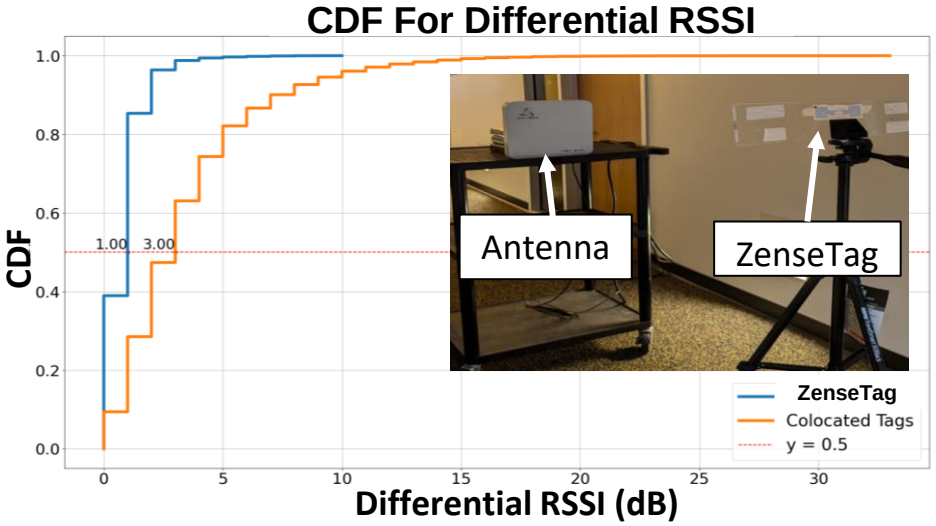
Benchmarks: Resonance-enhanced sensitivity

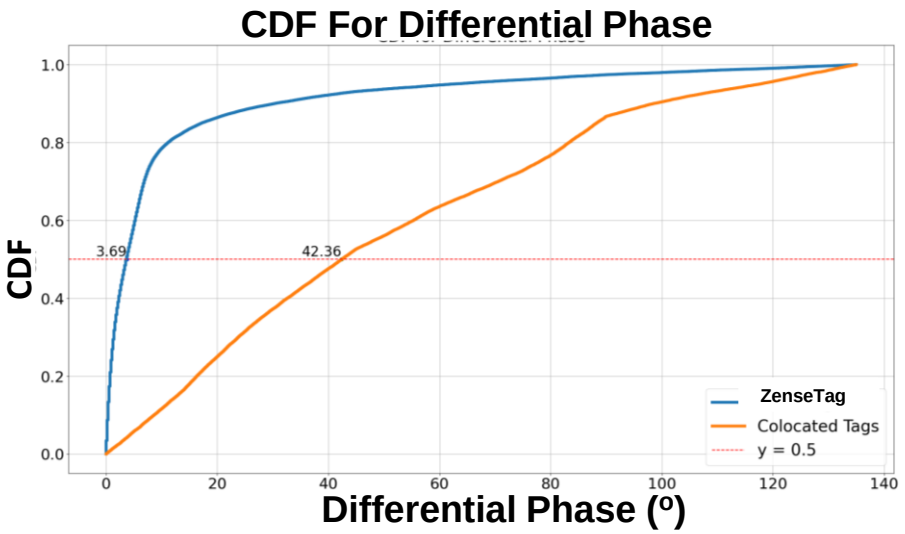




Tuning resonance achieves **7x** improvement in sensor phase response at RF

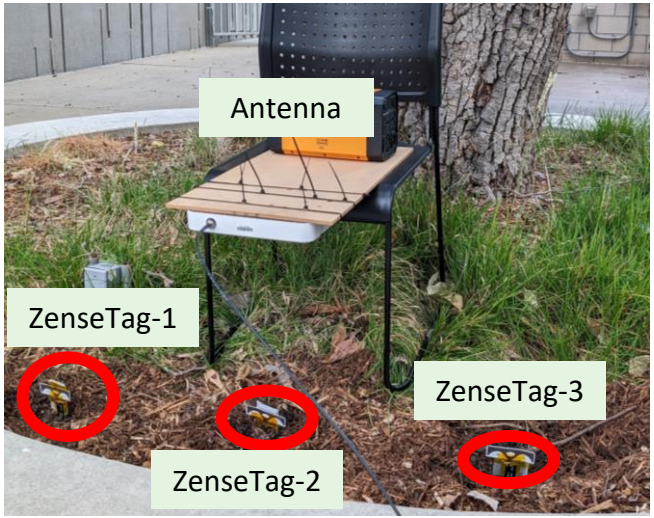
Benchmarks: Multipath resilience



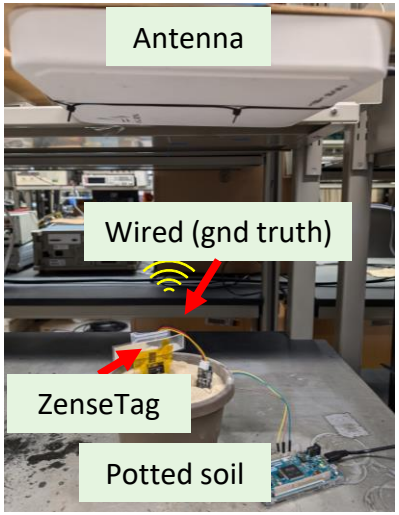


ZenseTag: **>10x accurate** phase estimate, +**2dB accurate** amplitude estimate

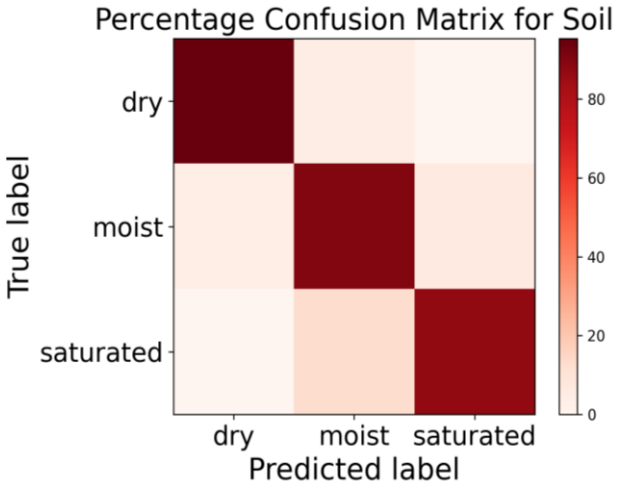
Evaluations: Sensing soil moisture



Outdoor evaluation setup



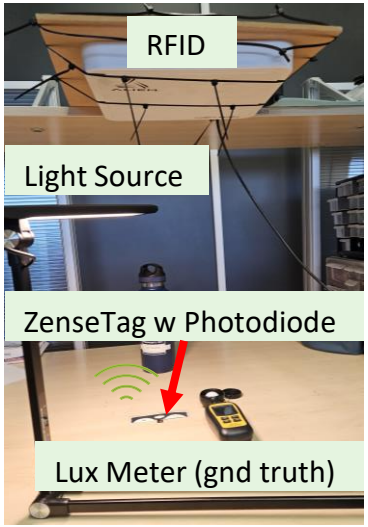
Indoor evaluation setup



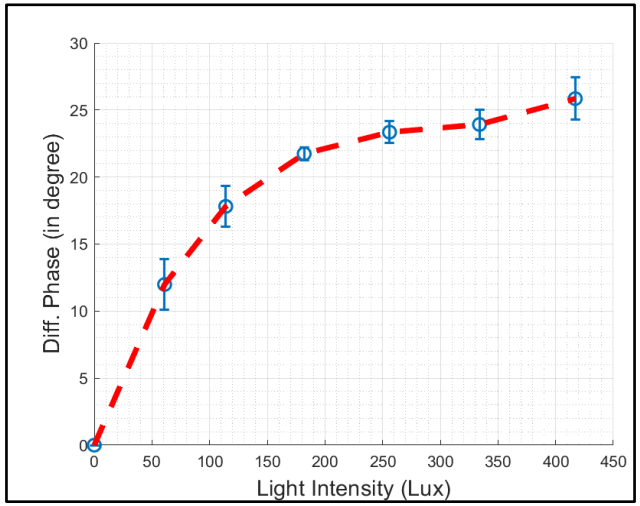
Soil Moisture Classification results

ZenseTag achieves **>93%** classification accuracy for soil moisture

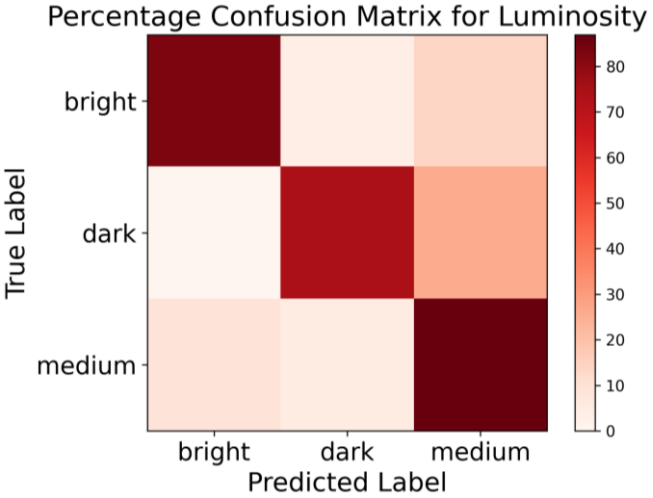
Evaluations: Sensing Luminosity



Evaluation setup



Calibration curve



Luminosity Classification results

ZenseTag achieves **>85%** classification accuracy for light intensity

Evaluations: Demonstrations

ZenseTag-Soil Moisture Sensor

ZenseTag-Luminosity Sensor

ZenseTag-Contact Force Sensor

For more details,
please read our paper :