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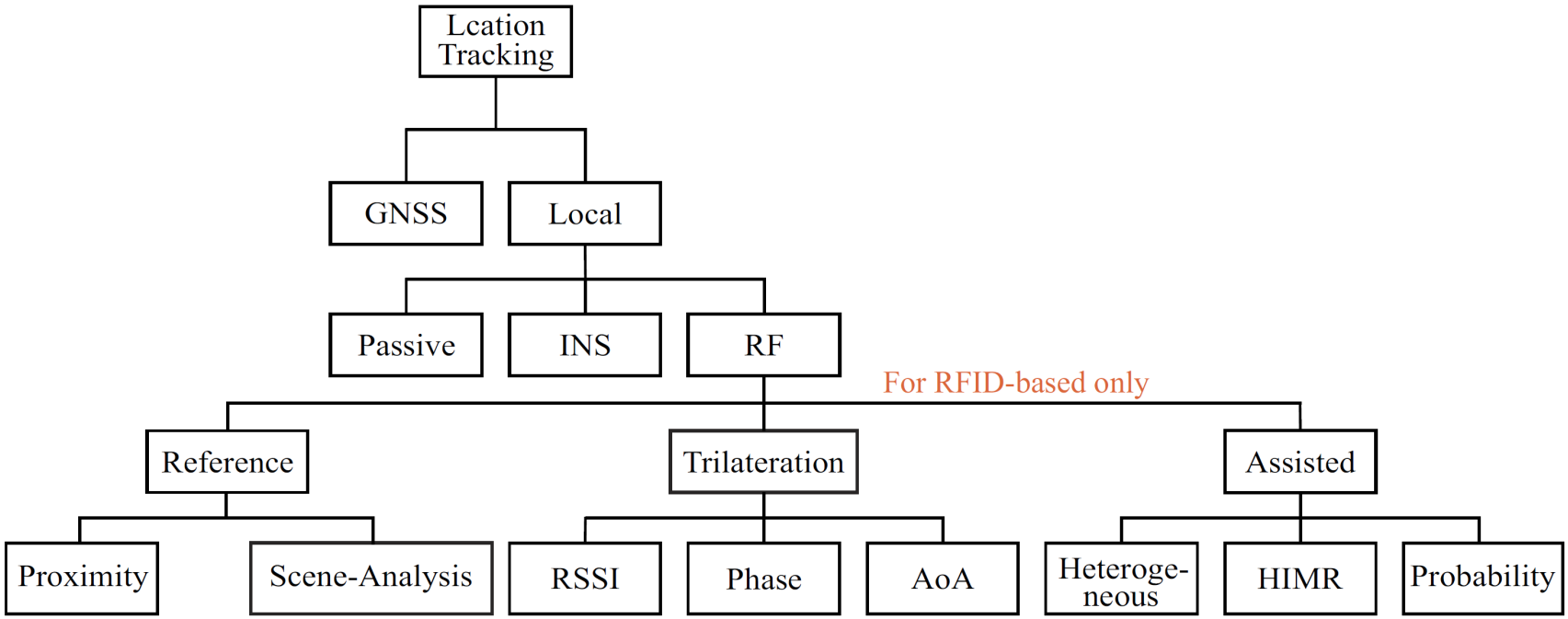
Breaking the Range Limit of RFID Localization: Phase-based Positioning with Tunneling Tags

Cheng Qi, Francesco Amato, Mohammad Alhassoun, and Gregory D. Durgin

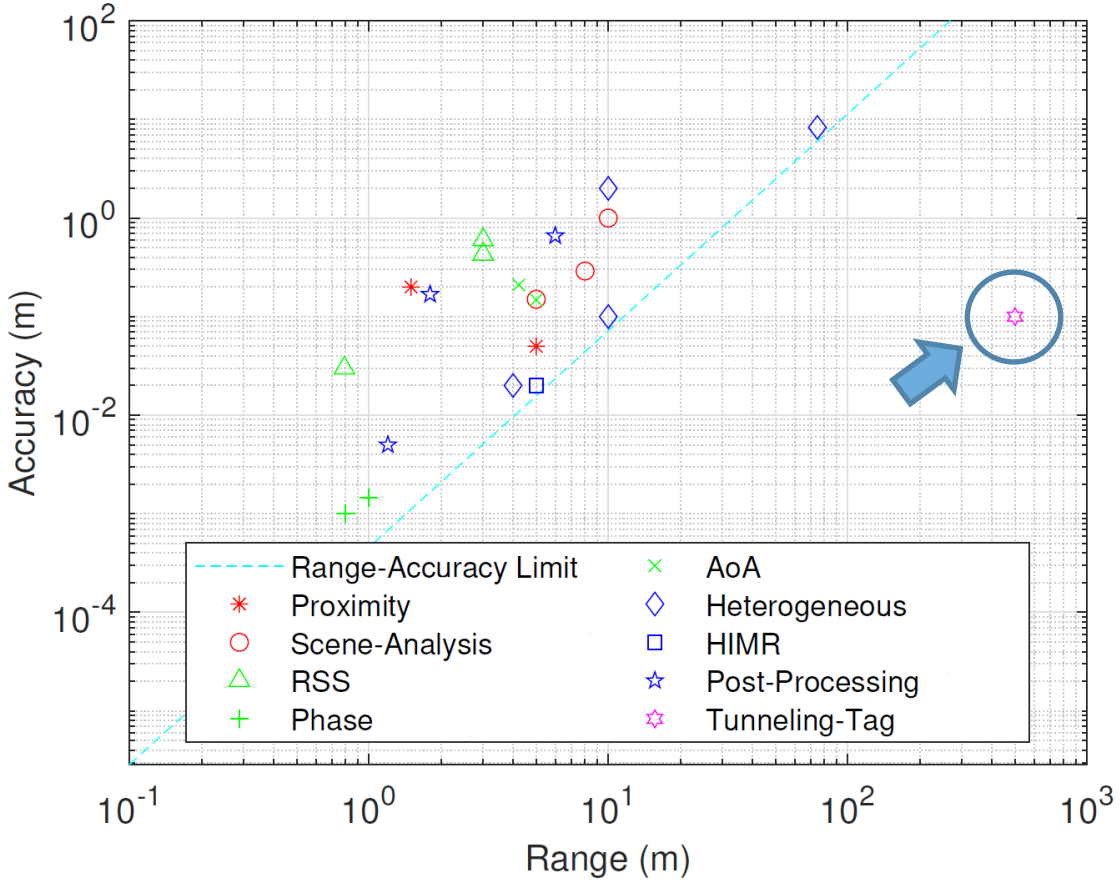
IEEE

Location tracking systems (LTS)



- Taxonomy of location tracking systems and techniques used by RFID location tracking systems.

Accuracy and range of state-of-art LTS



Most techniques are bounded by the range-accuracy limitation with poor accuracy at longer distance

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What limit the accuracy and range?

- Operating Frequency
- Path Loss/Distance
- Reader Sensitivity
- Reader/Tag Antenna
- Multipath
- Shadowing
- Technique
- Algorithm

Typical frequency bands

Wavelength and range limits

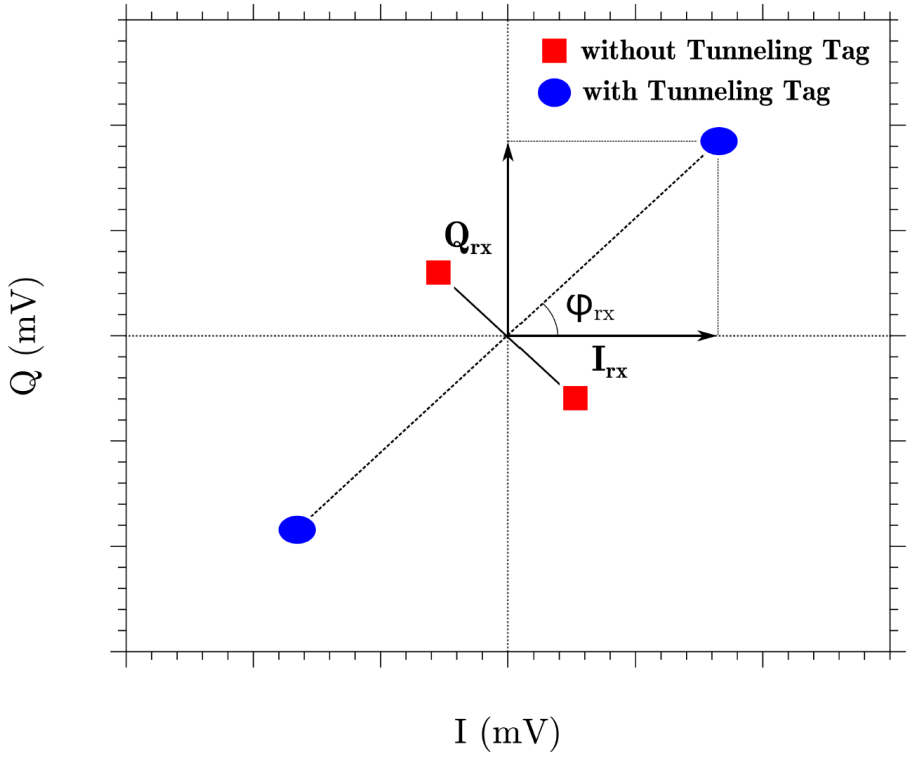
Frequency	Band	Wavelength	Range
125/134 KHz	LF	2.2 km - 2.4 km	<1 m
13.56 MHz	HF	20 m - 22 m	<10 m
433 MHz	UHF	0.68 m - 0.69 m	<30 m
860 - 960 MHz	UHF	0.31 m - 0.34 m	<100 m
2.4 -2.45 GHz	UHF	0.12 m - 0.125 m	<10 m
5.8 GHz	Microwave	5.11 cm - 5.24 cm	<5 m
>24 GHz	mm-Wave	1.23 cm - 1.25 cm	<1 m

What do you get from a backscatter link?

Amplitude and Phase

$$RSSI = \frac{I_{rx}^2 + Q_{rx}^2}{Z_0}$$

$$\varphi_{rx} = \arctan\left(\frac{Q_{rx}}{I_{rx}}\right)$$



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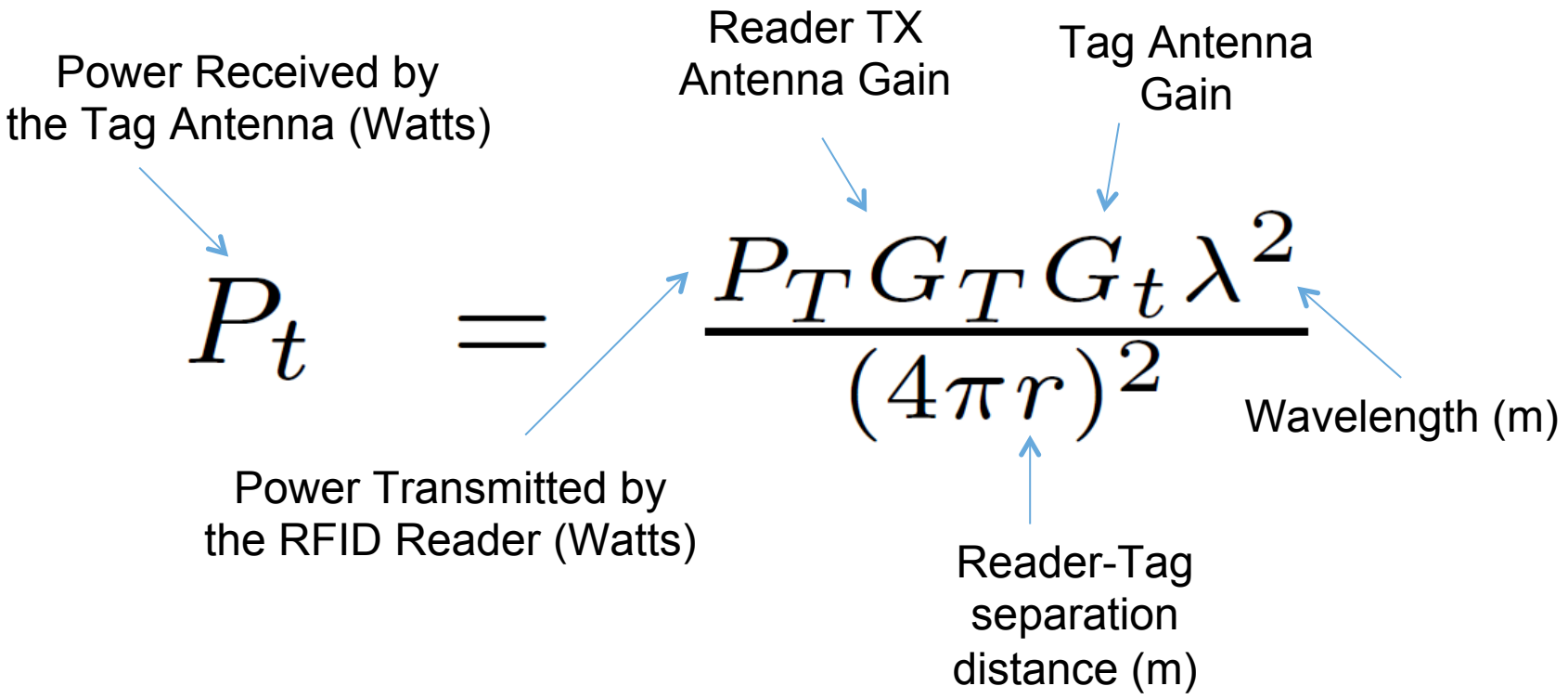
Conventional RF Link Budget



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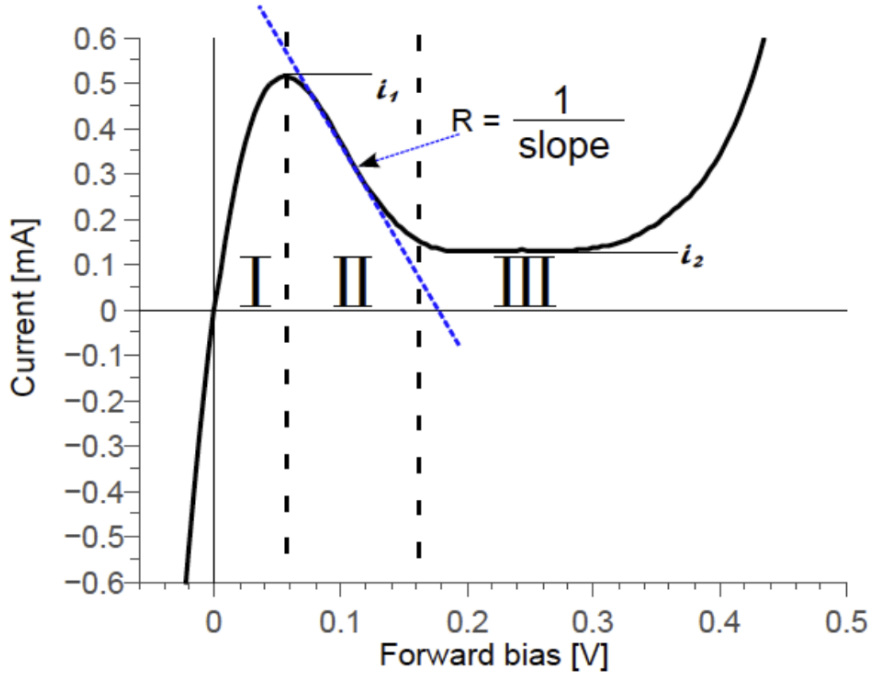
Quantum Tunnel Tags

Break the Range Limitation



- Tunnel diode at end of antenna
- Bias in neg-resistance region makes amplifier
- Very low power consumption (10s of microWatts)

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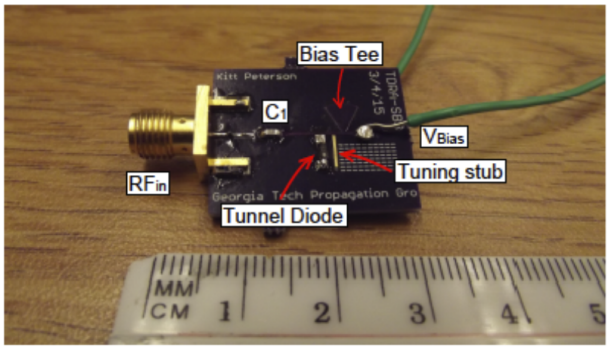
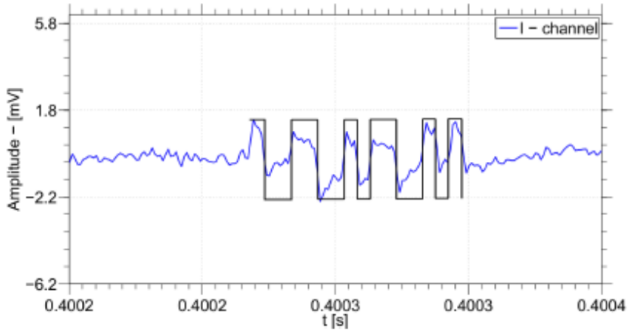
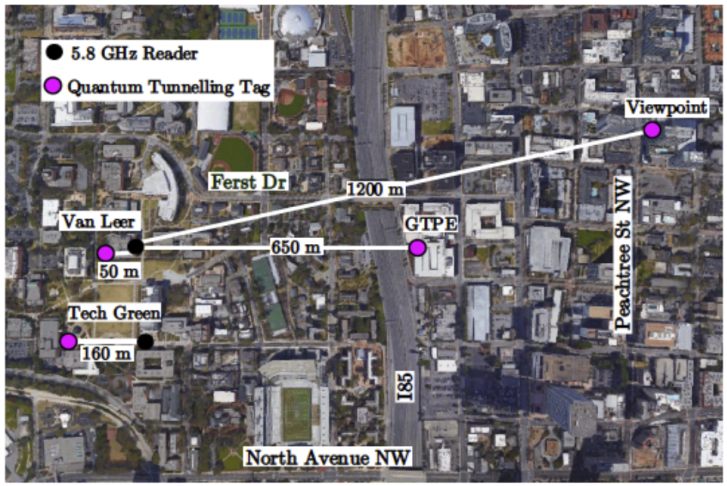
Quantum Tunnel Tags

Break the Range Limitation



(a) Reflection Amplifier prototype





1200m Range Through Midtown Atlanta at 5.8 GHz

F. Amato, C.W. Peterson, B.P. Degnan, M.B. Akbar, G.D. Durgin. "Long Range and Low-Powered RFID tags with Tunnel Diode". *IEEE RFID-TA 2015*. Tokyo, Japan. 16-18 September 2015.

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Why use phase-based ranging?

Limitation brought by quantum tunneling tags

$$P_t = \frac{P_T G_T G_t \lambda^2}{(4\pi r)^2} \cdot G_{TT}$$

Backscatter Gain (Not Uniform)

$$\varphi_{ps} = -\frac{2\pi f_c d}{c}$$

Propagation phase shift

$$\varphi_{rx} = \varphi_{ps} + \varphi_{multipath} + \varphi_0$$

Phase shift caused by Tunnel diode

Phase shift caused by multipath

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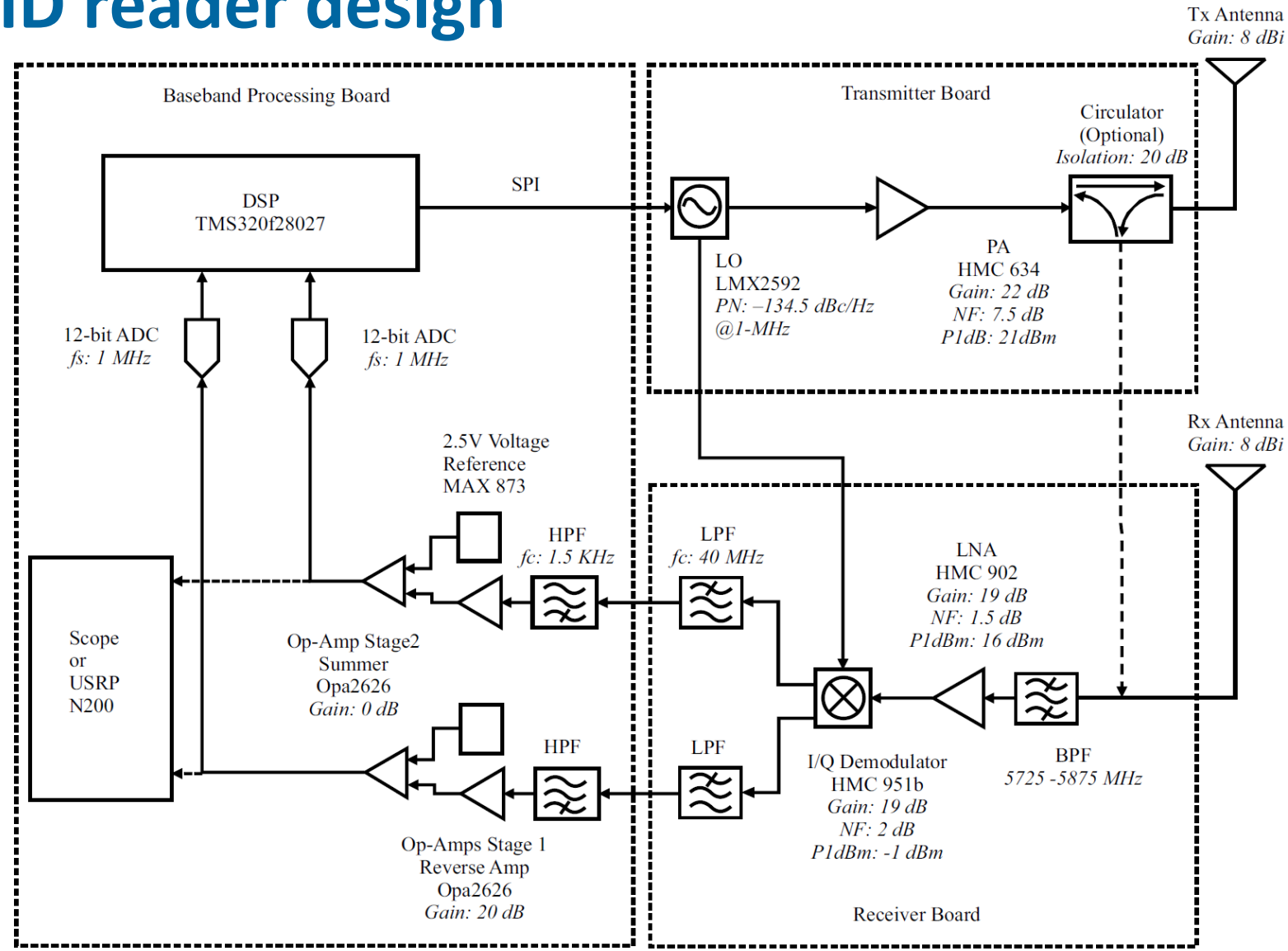
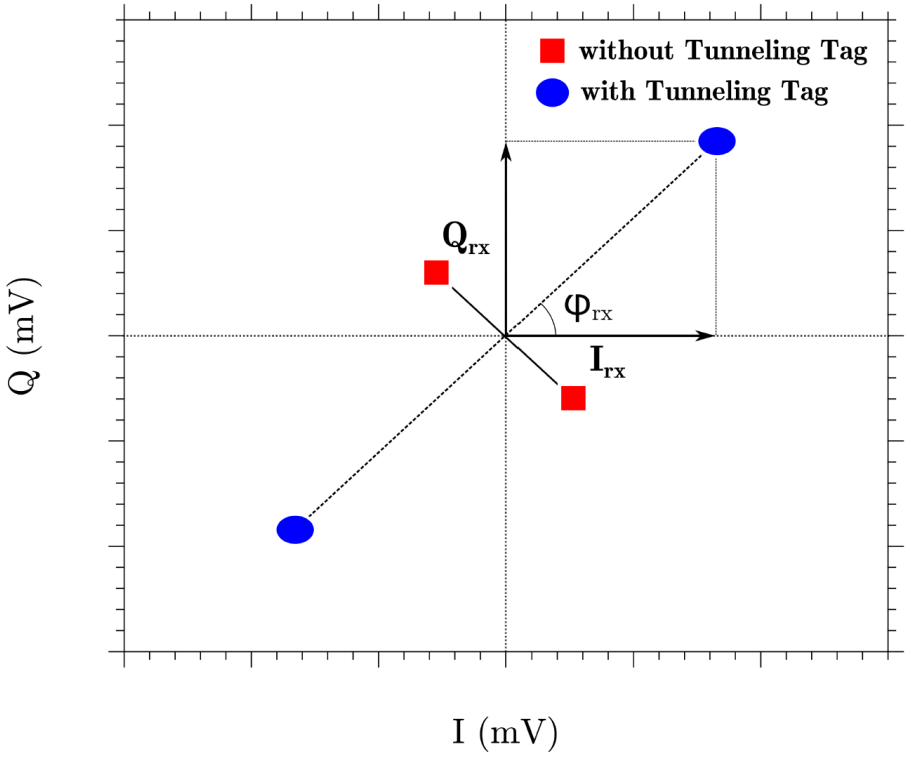
RFID reader design



What do you get from a backscatter link?

Amplitude and Phase

$$\varphi_{ps} = -\frac{2\pi f_c d}{c}$$



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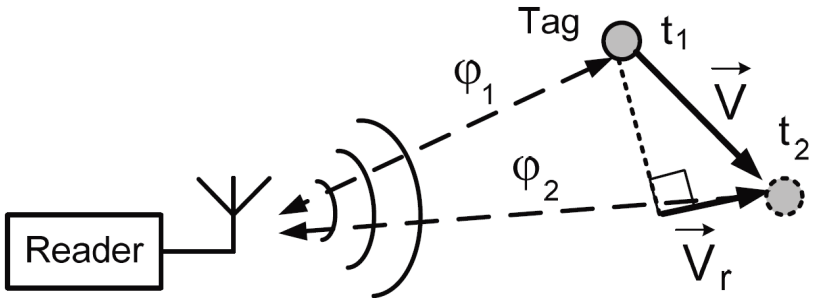
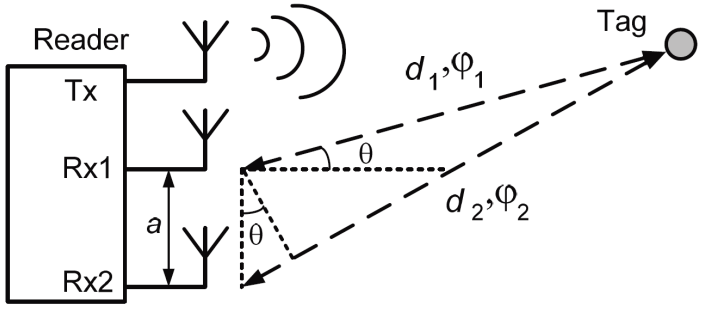
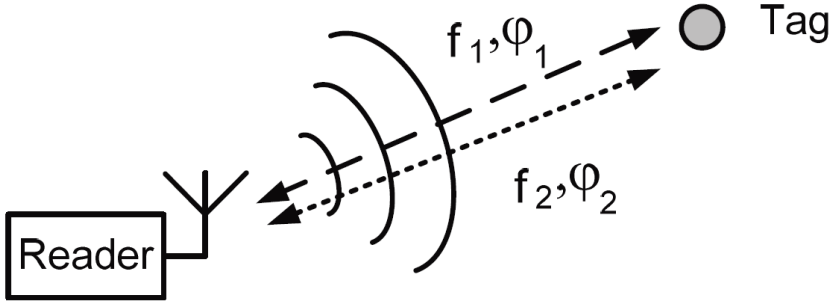
Three ranging techniques that utilize phase

And their drawbacks





- Reader/tag has to move
- Expensive Implementation



- Need a broader bandwidth

Pavel V. Nikitin, Rene Martinez, Shashi Ramamurthy, Hunter Leland, Gary Spiess, and K. V. S. Rao. "Phase Based Spatial Identification of UHF RFID Tags", IEEE RFID 2010

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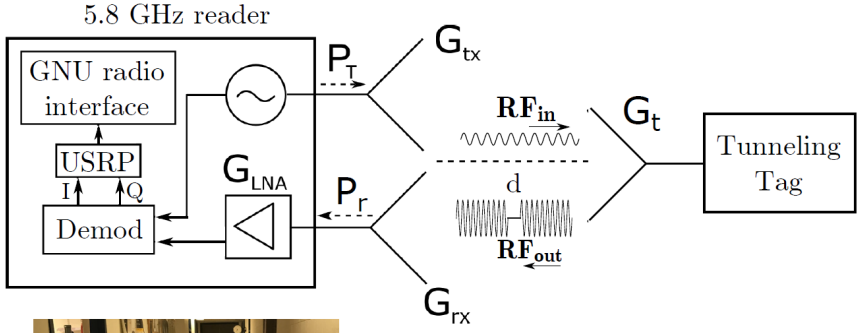
Measurement setup

0 dBm Output Power

	Indoor		Outdoor	
	TT	ST	TT	ST
G_t (dBi)	1	9	1	9
d (m)	3, 15		15	
P_T (dBm)	3			
G_{tx} (dBi)	7.5			
G_{rx} (dBi)	7.5			

TT: Tunneling Tag; ST: Semi-passive Tag.



b)

a)

c)

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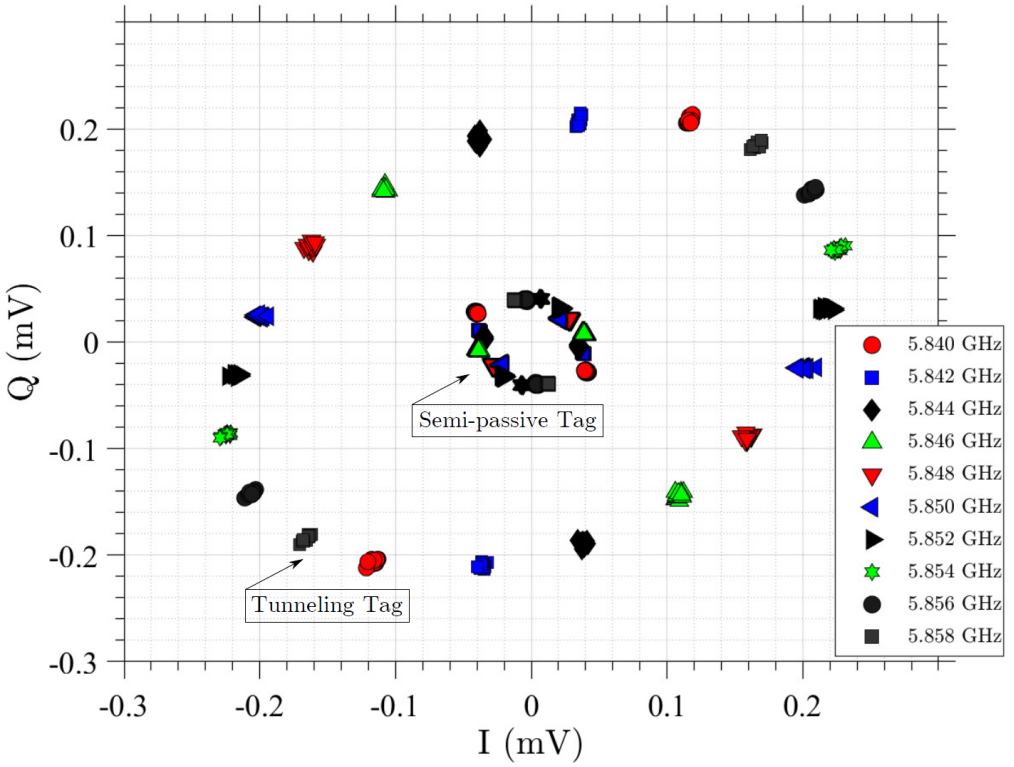
IQ constellation

for both the semi-passive and the Tunneling tags measured indoor at a distance of 3 m

The IQ constellation points in the 5.8 GHz band (5.840 to 5.858 GHz) for both the semi-passive and the Tunneling tags measured indoor at a distance of 3 m from the reader.

As expected, the Tunneling Tag provides a higher level of backscattered power.



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How to get range estimation from phase?

$$\hat{D} = \frac{c}{4\pi N} \sum_{n=1}^{N-1} \left| \frac{\varphi_{rx_n} - \varphi_{rx_{n+1}}}{f_n - f_{n+1}} \right|,$$

$$\Delta f = f_{n+1} - f_n \qquad \lambda_e = c/\Delta f$$

$$\hat{D} = \frac{\lambda_e}{4\pi N} \sum_{n=1}^{N-1} \left| \varphi_{rx_n} - \varphi_{rx_{n+1}} \right| = \frac{\lambda_e}{4\pi} \Delta\bar{\varphi},$$

- Maximum Range : $\hat{D}_m = \frac{\lambda_e}{2}$, 150m for 1MHz Frequency Step.

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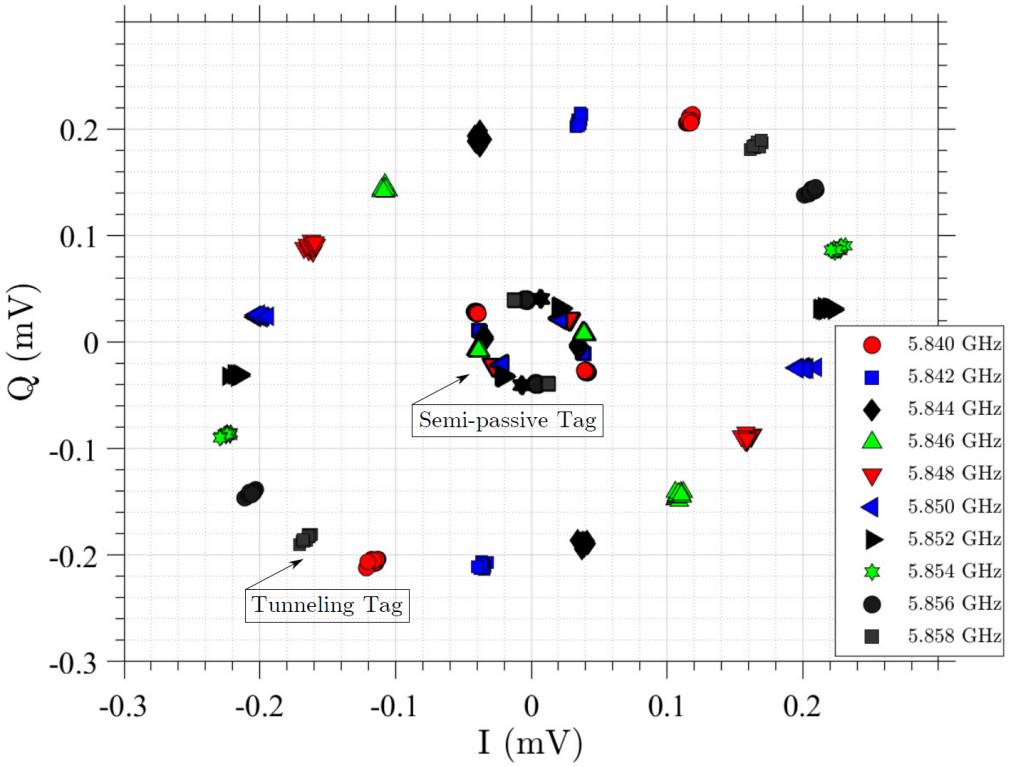
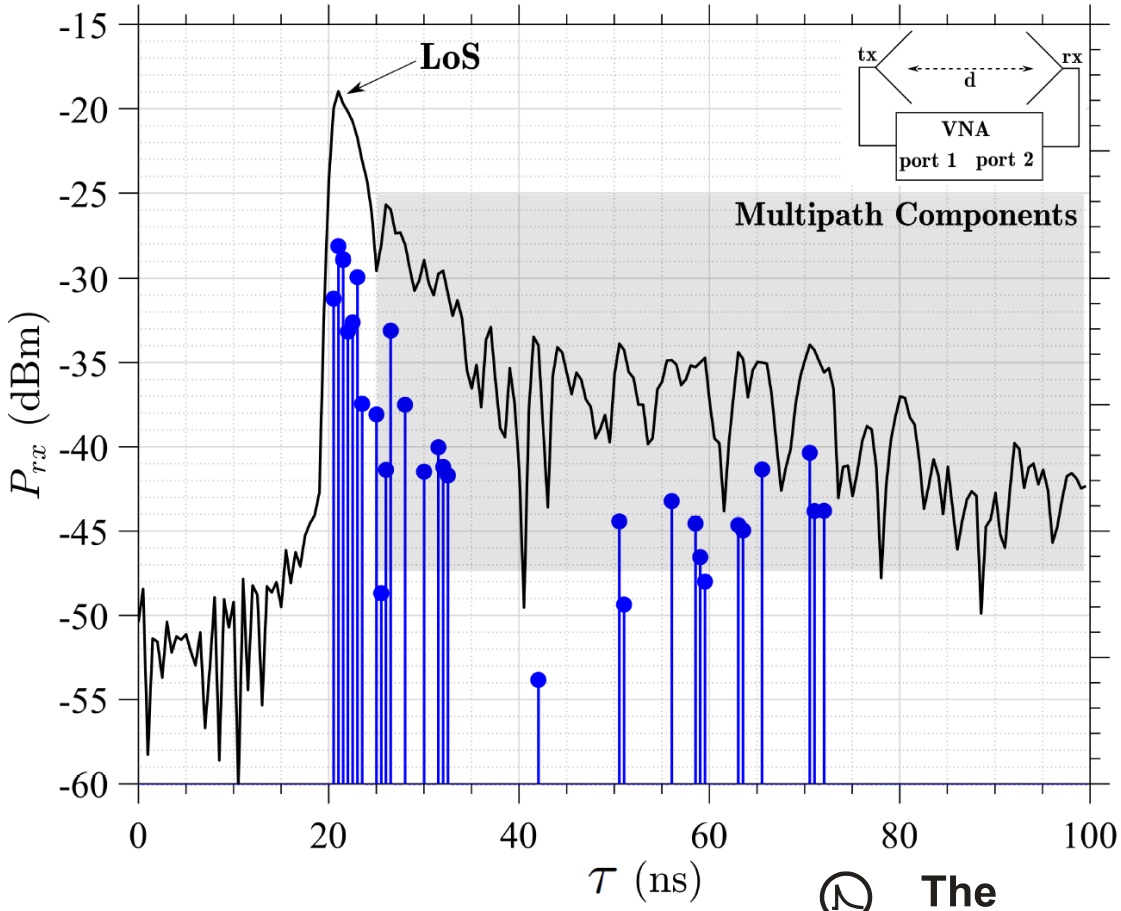


When multipath comes to play

Multipath measurements

- IFFT of S21 response
- CLEAN Algorithm to reduce the noise level



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When multipath comes to play

Calibration

$$\varphi_{rx} = \varphi_{ps} + \varphi_{multipath} + \varphi_0$$

$$\tilde{R}(\tau) = \sum_n A_n(\tau)$$

$$\approx R_o \exp\left(-j\Delta\bar{\varphi}\right) \exp\left(-j2\pi f\tau\right)$$

$$\Delta\bar{\varphi} = \frac{2\pi c\bar{\tau}}{\lambda} \quad \Rightarrow \quad \bar{\tau} = \frac{\int_0^\infty \tau A(\tau)}{\int_0^\infty A(\tau)}$$

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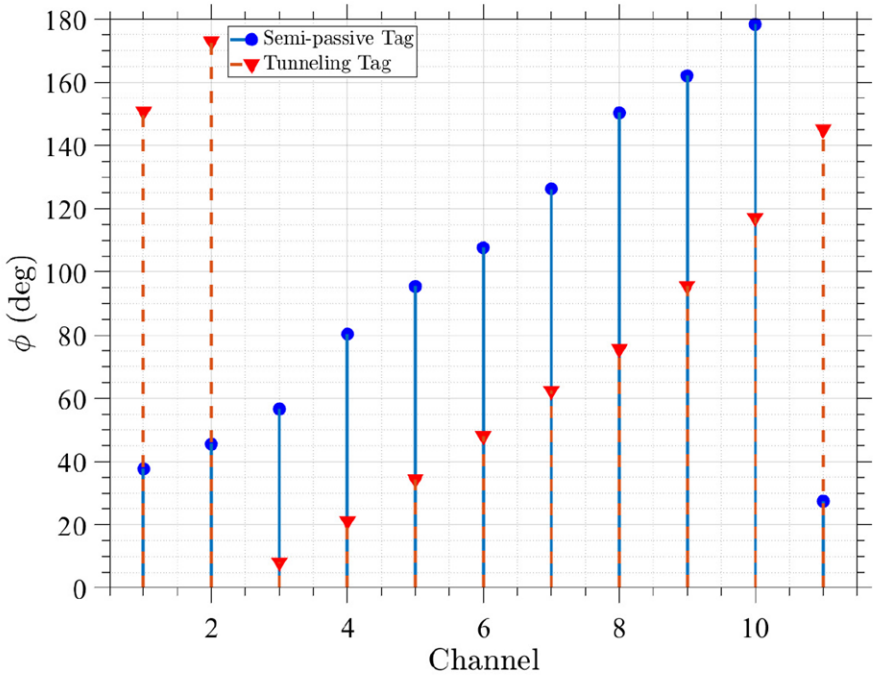
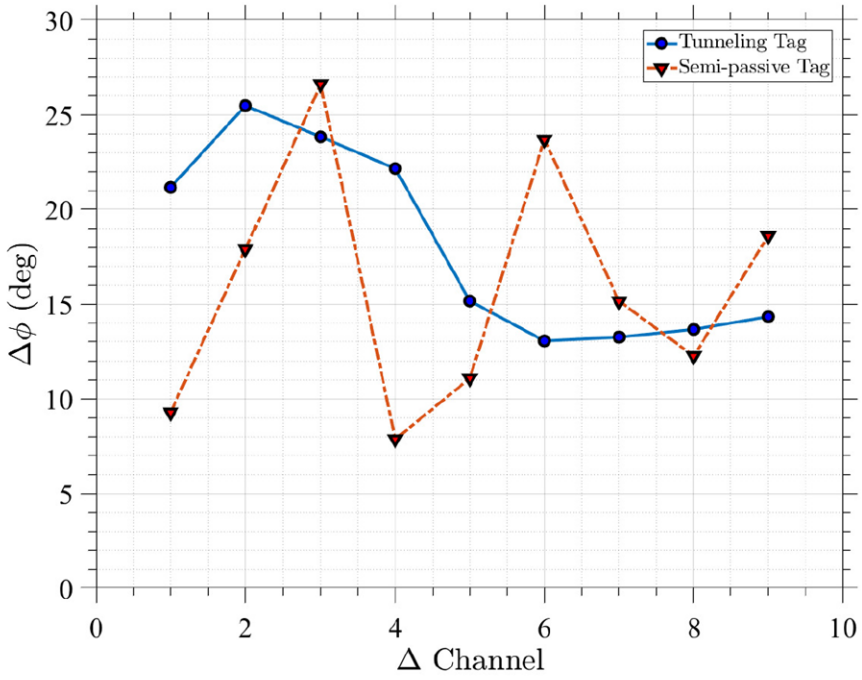
Phase measurements

a) Phases and b) phase differences between ten adjacent channels measured indoor at 3 meters away from the reader with both the semi-passive and the Tunneling tags.



a)



b)

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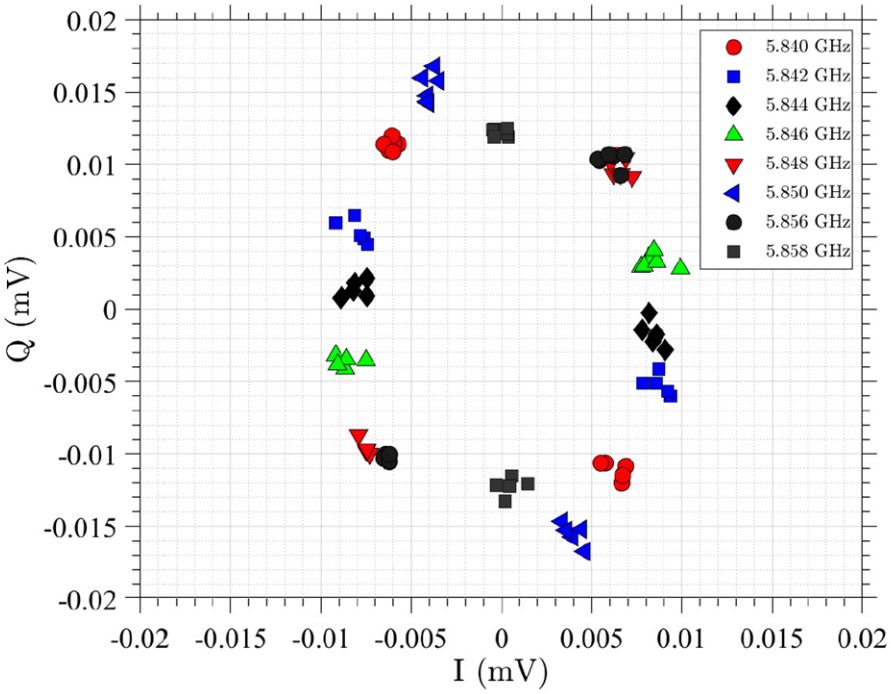
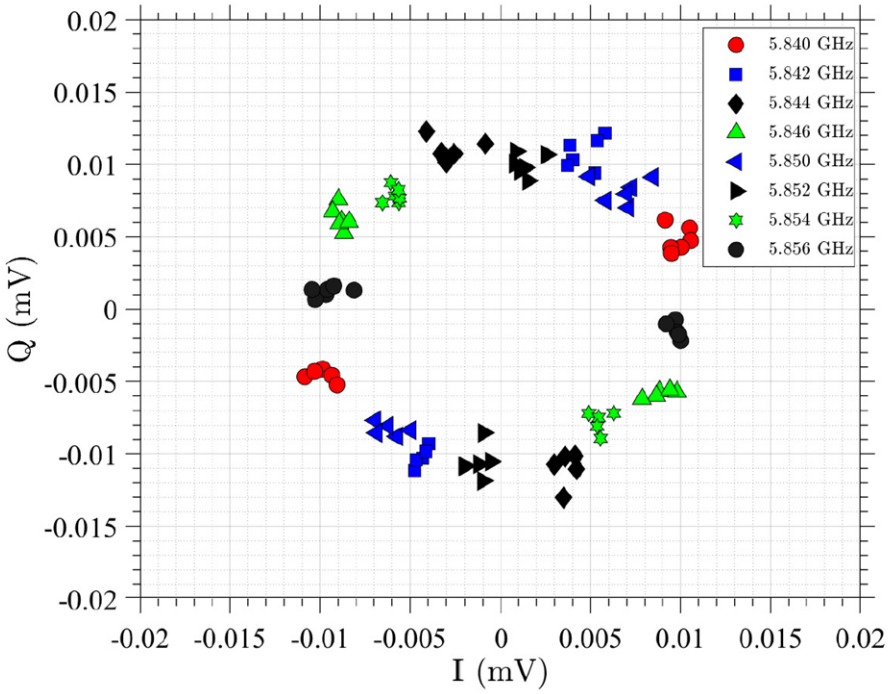
Phase measurements

The c) indoor and d) outdoor IQ constellation points in the 5.8 GHz band measured from the same distance.



c)



d)

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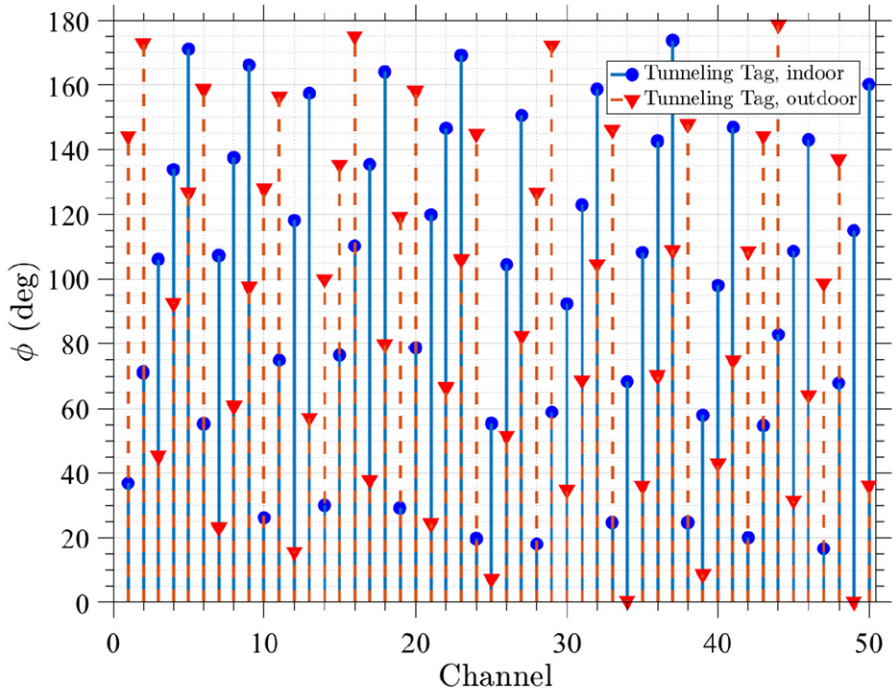
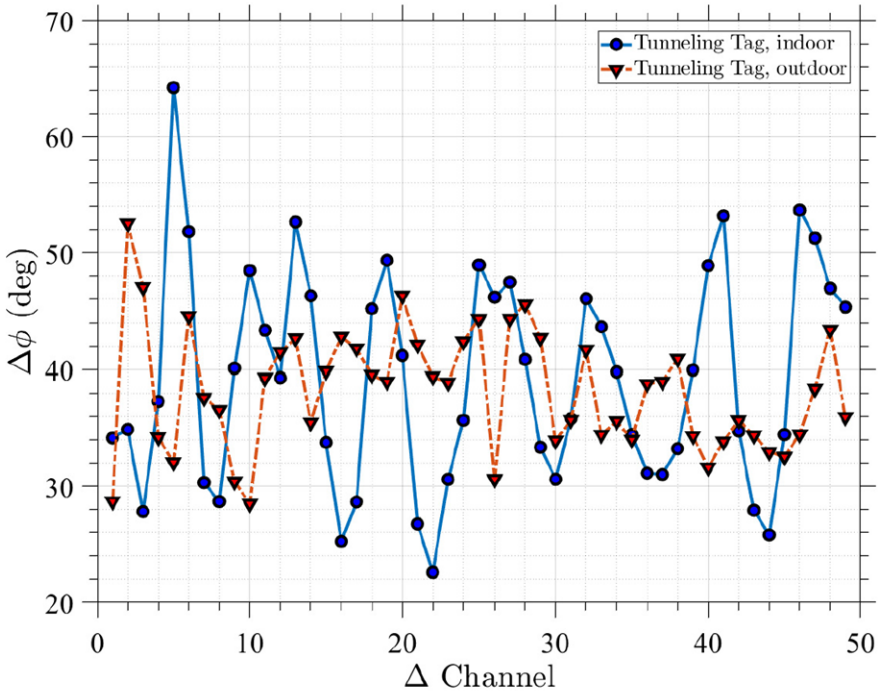
Phase measurements

Tunneling Tag indoor and outdoor a) phases and b) phase differences between fifty adjacent channels measured at 15 meters from the reader.



a)



b)

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Summary

Localization accuracy for different tag in different senarios

	Semi-passive Tag	Tunneling Tag
Indoor 3m Uncalibrated	3.598 m (19.9%)	3.643 m (21.5%)
Indoor 3m Calibrated	3.0129 m (0.43%)	3.0582 m (1.94%)
Indoor 15m Uncalibrated	N/A	16.35 m (9.00%)
Outdoor 15m Uncalibrated	N/A	15.91 m (6.07%)

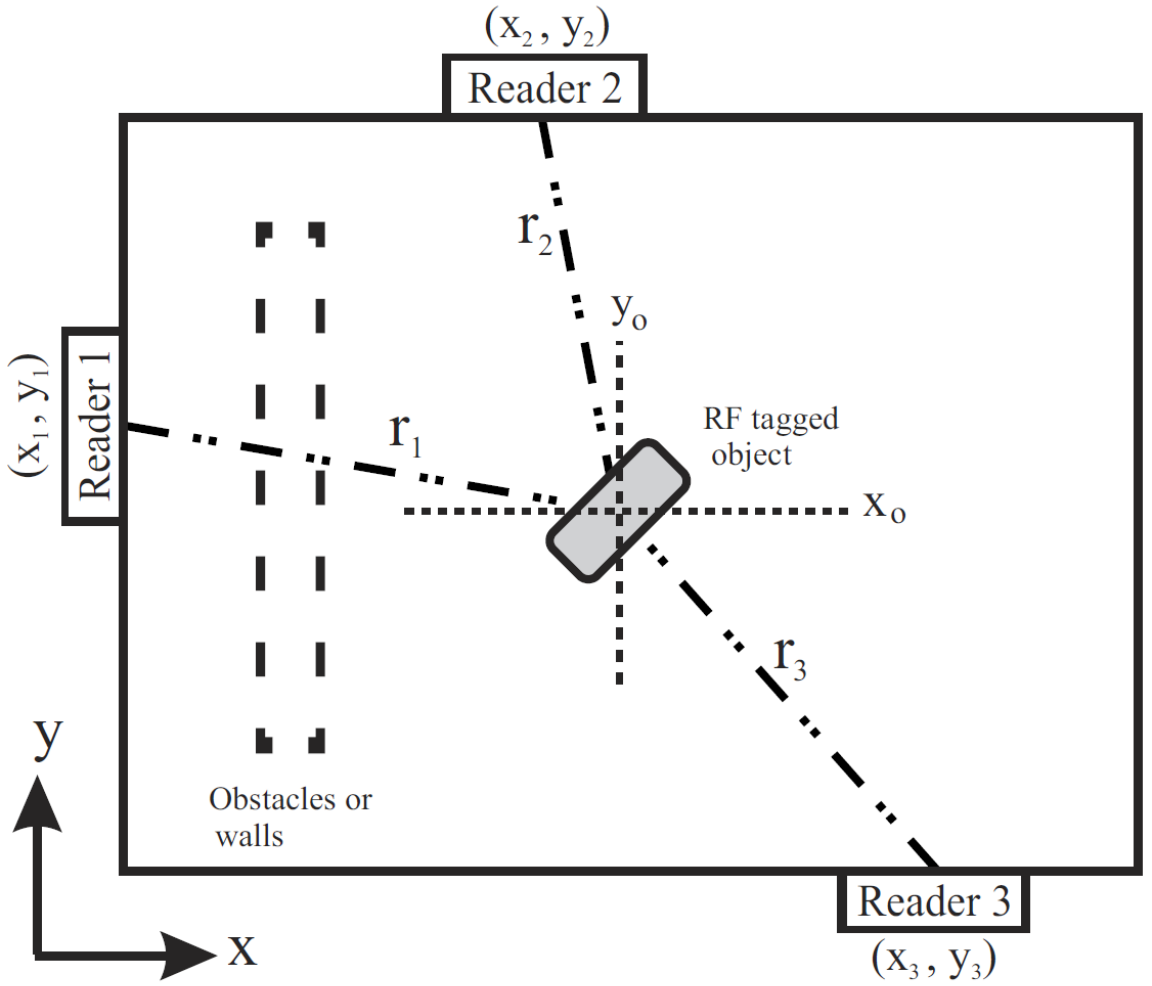
Contribution

- outlined a distance estimation algorithm based on received signal phase using a custom frequency-hopping RFID system operating at the 5.8 GHZ ISM band (from 5.725 GHz to 5.975 GHz);
- used a 5.8 GHz RFID system with a Tunneling Tag extending the communication range of a conventional RFID tag and applied the phase-based positioning algorithm;
- ran indoor preliminary experiments to estimate the delay errors due to multipath;
- demonstrate how a long-range LoS localization is possible with Tunneling Tags.

IEEE

Next step

- Extend Phase-Based Tracking to 2D By Using Trilateration
- Investigate Phase-Based Tracking in NLOS Environments



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Q&A

Thank you

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