FULL-SPHERE $\sqrt{\Delta \mathrm{RCS}}$ CHARACTERIZATION OF PASSIVE UHF RFID TAGS

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Introduction 1/2

- **Recently:** Phase-based localization with passive UHF RFID tags [1,2]

- **Problem:** Tag phase modeled as a constant neglecting any dependence on the spherical direction (Θ, ϕ)

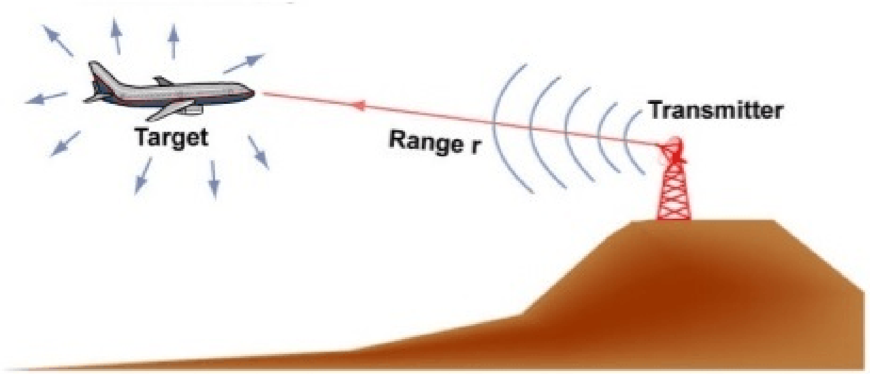
- **In literature:** Many articles about the tag's $\Delta\mathrm{RCS}$, the $\sqrt{\Delta\mathrm{RCS}}$ received almost no attenation

- **Goal:** Full-sphere $\sqrt{\Delta\mathrm{RCS}}$ measurement system to study the tag's phase

- **Contribution:** Measurement system to refine phase-based localization models increasing their accuracy

[1] Jingren Xu et al. "The Principle, Methods and Recent Progress in RFID Positioning Techniques: A Review". In: IEEE Journal of Radio Frequency Identification 7 (2023), pp. 50–63. doi: 10.1109/JRFID.2022.3233855
[2] Pavel V. Nikitin et al. "Phase based spatial identification of UHF RFID tags". In: 2010 IEEE International Conference on RFID (IEEE RFID 2010). 2010 IEEE International Conference on RFID (IEEE RFID 2010). Orlando, FL: IEEE, Apr.2010, pp. 102–109. doi: 10.1109/RFID.2010.5467253

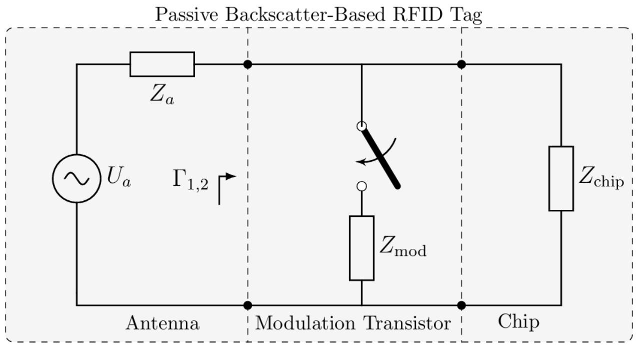
- **Radar Cross-Section** (RCS)
  - Measure how detectable an object is by a radar



Source: https://www.everythingrf.com/community/what-is-radar-cross-section

- **Delta Radar Cross-Section** (ΔRCS)
  - Difference of the tag's two radar cross-sections used for backscatter communication
  - Power quantity without phase ☹

- **Square Root Delta Radar Cross-Section** ($\sqrt{\Delta \mathrm{RCS}}$)
  - Complex-valued extension to the ΔRCS
  - Field quantity including the phase ☺



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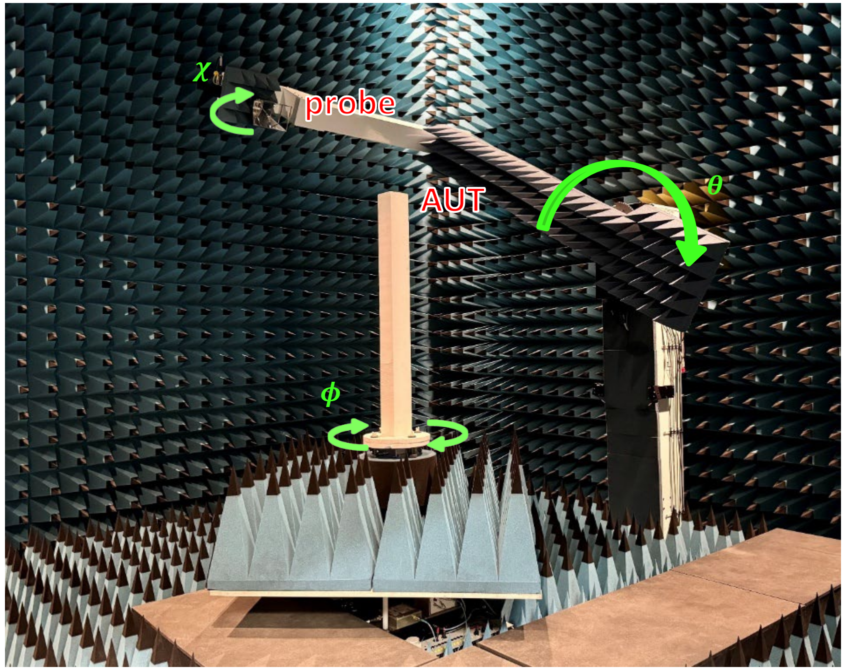
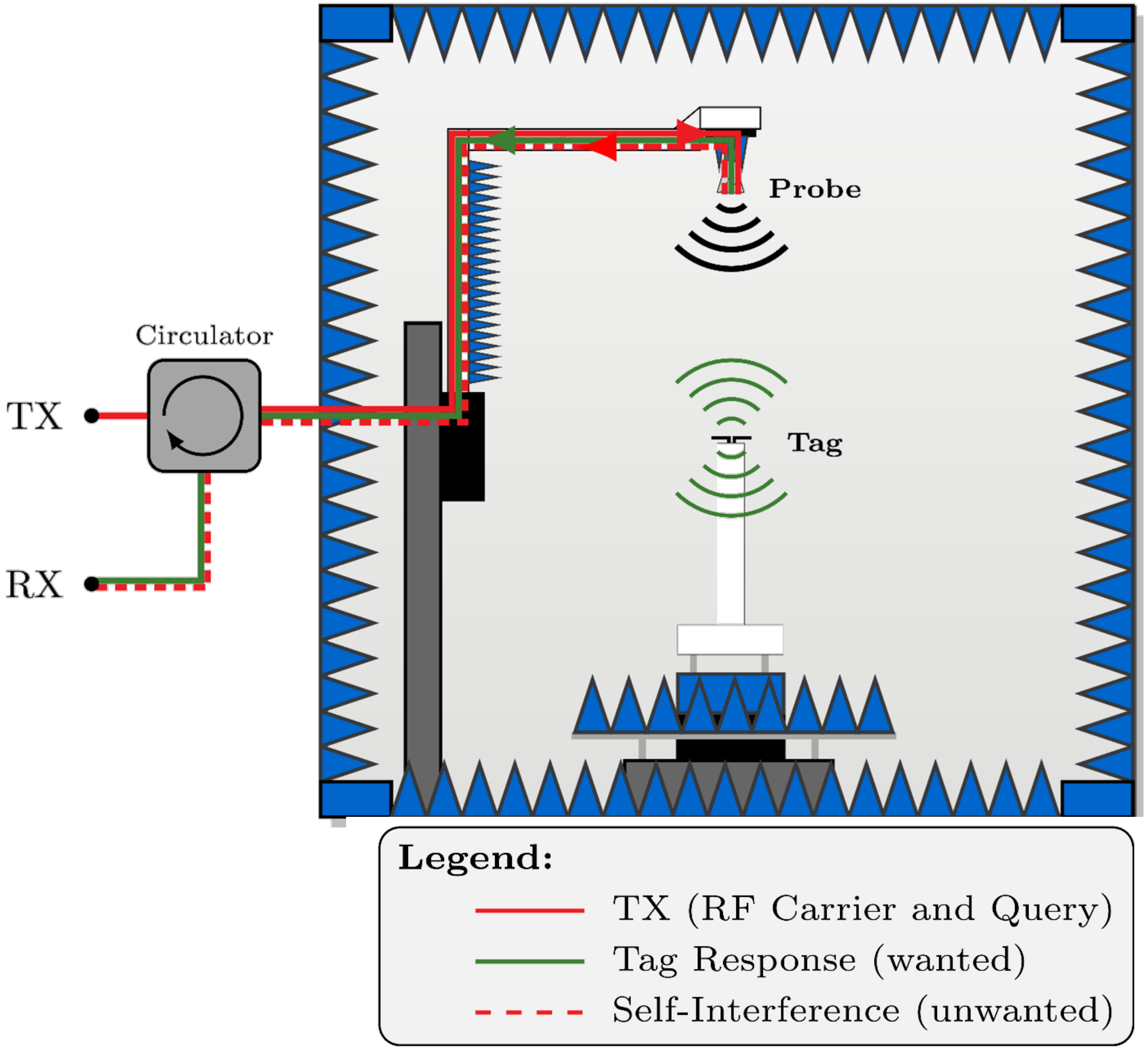
- **Problem:** Passive tag necessitates RF carrier during backscattering

➔ **Self-interference limiting the SNR**

Carrier cancellation ☹

Bistatic arrangement



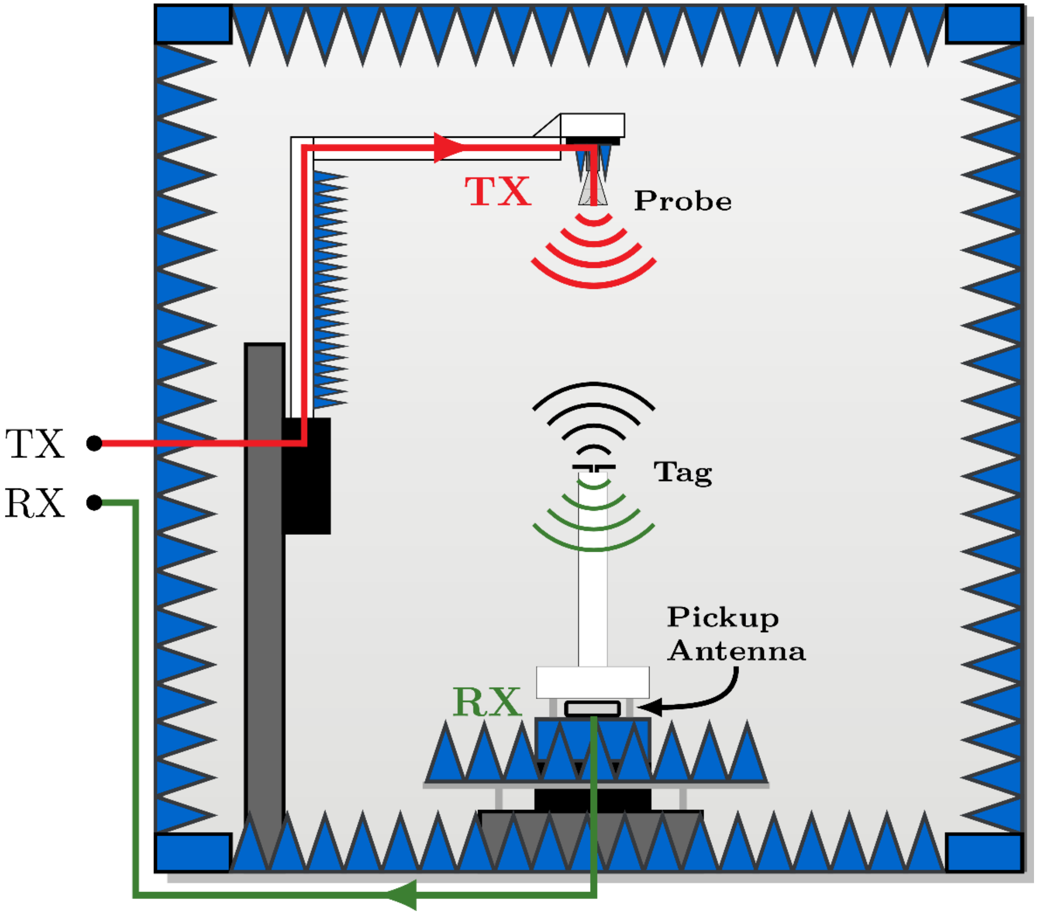


Bistatic Arrangement: Configuration Probe-TX

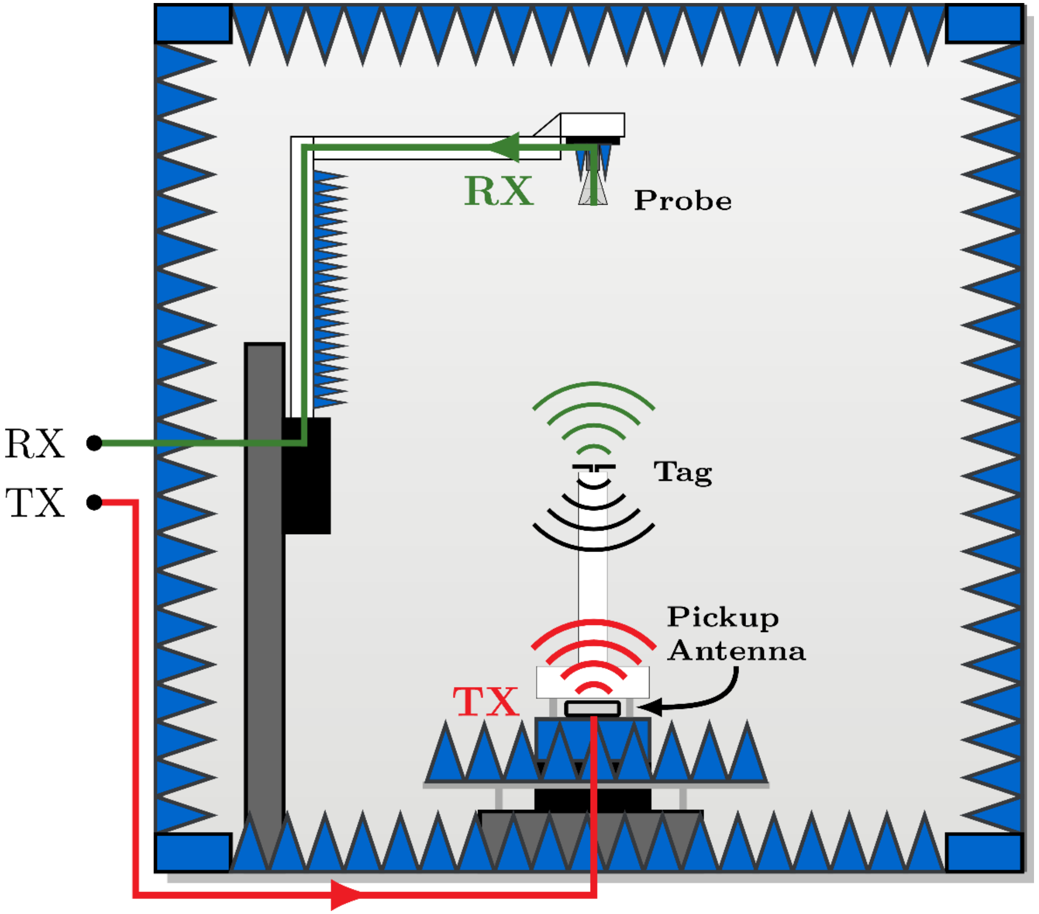
- **Approach:** Pickup antenna placed at the ϕ-stage
  - Low-loss link, "extended port" of the tag

- **Suppresses:** Self-Interference ✓

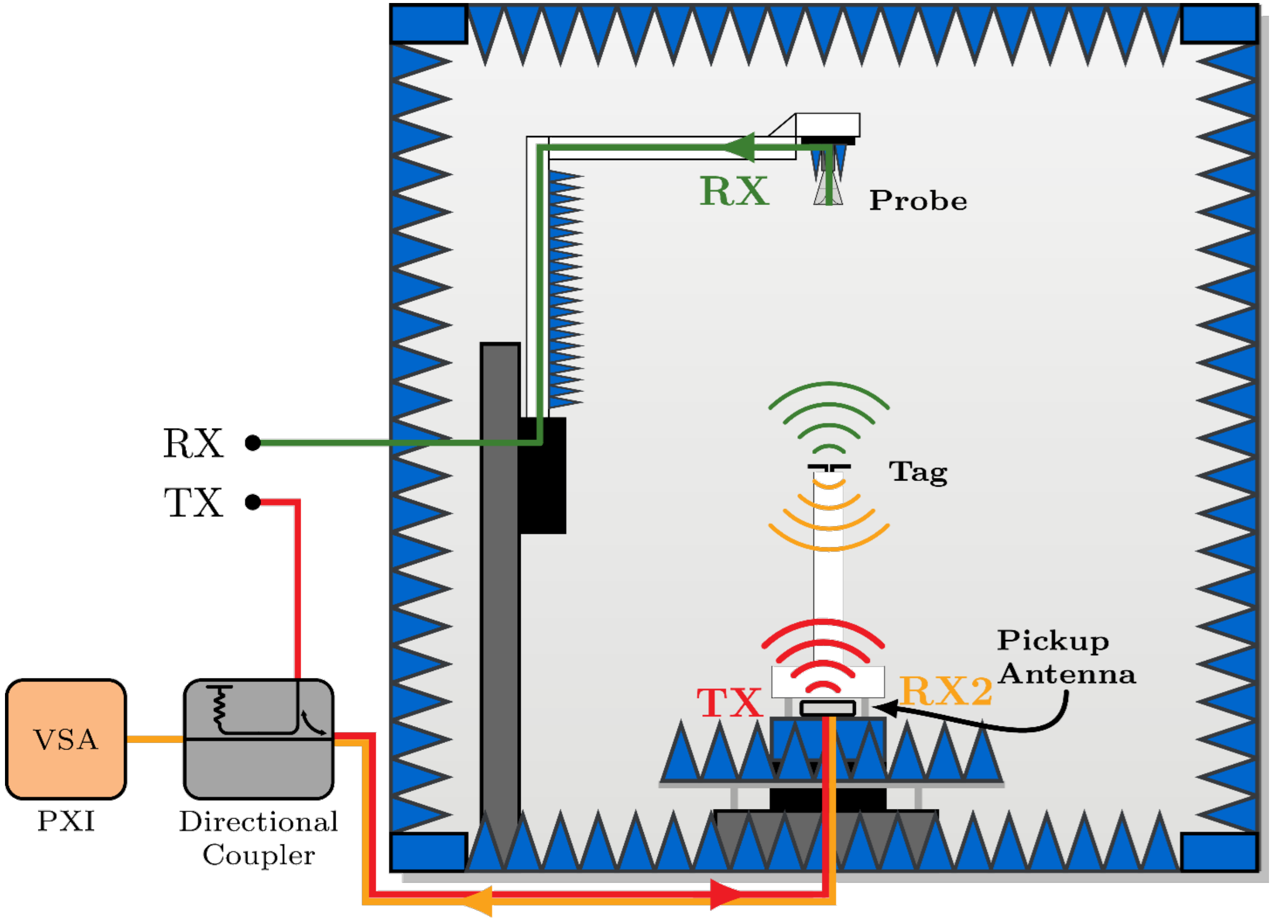
- **Challenge:** Activate tag near radiation nulls ×



- **Approach:** Reverse TX/RX
- **Effect:** Tag can be easily activated ✓
- **Challenge:** Position-dependent SNR at the receiver ×



- **Approach:** Additional RX
- **Effect:** Circumvents the hard decoder by a correlation of both RX signals ✓
- **Challenge:** Situation at the pickup antenna again monostatic → **Self-interference** ×



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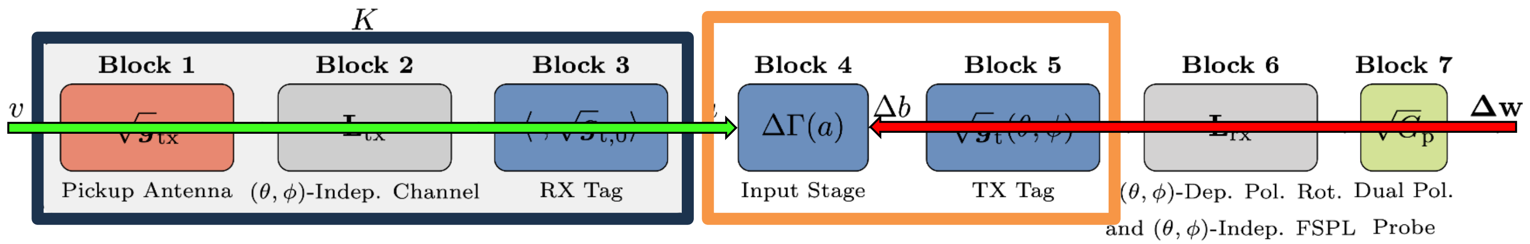
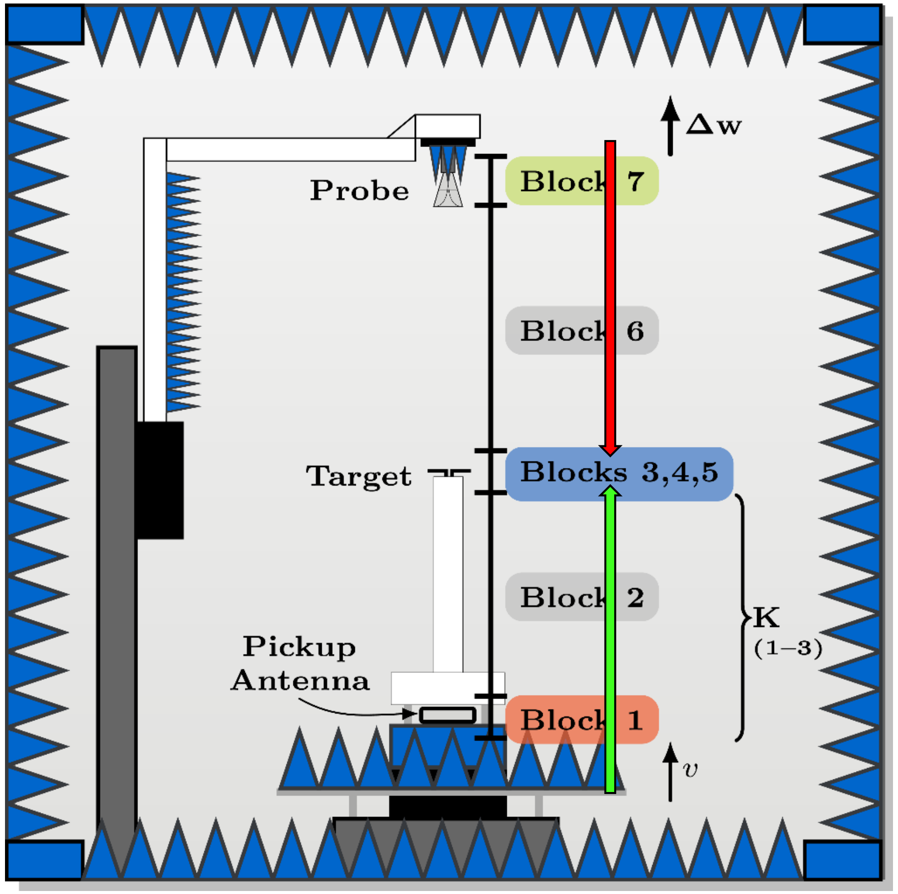




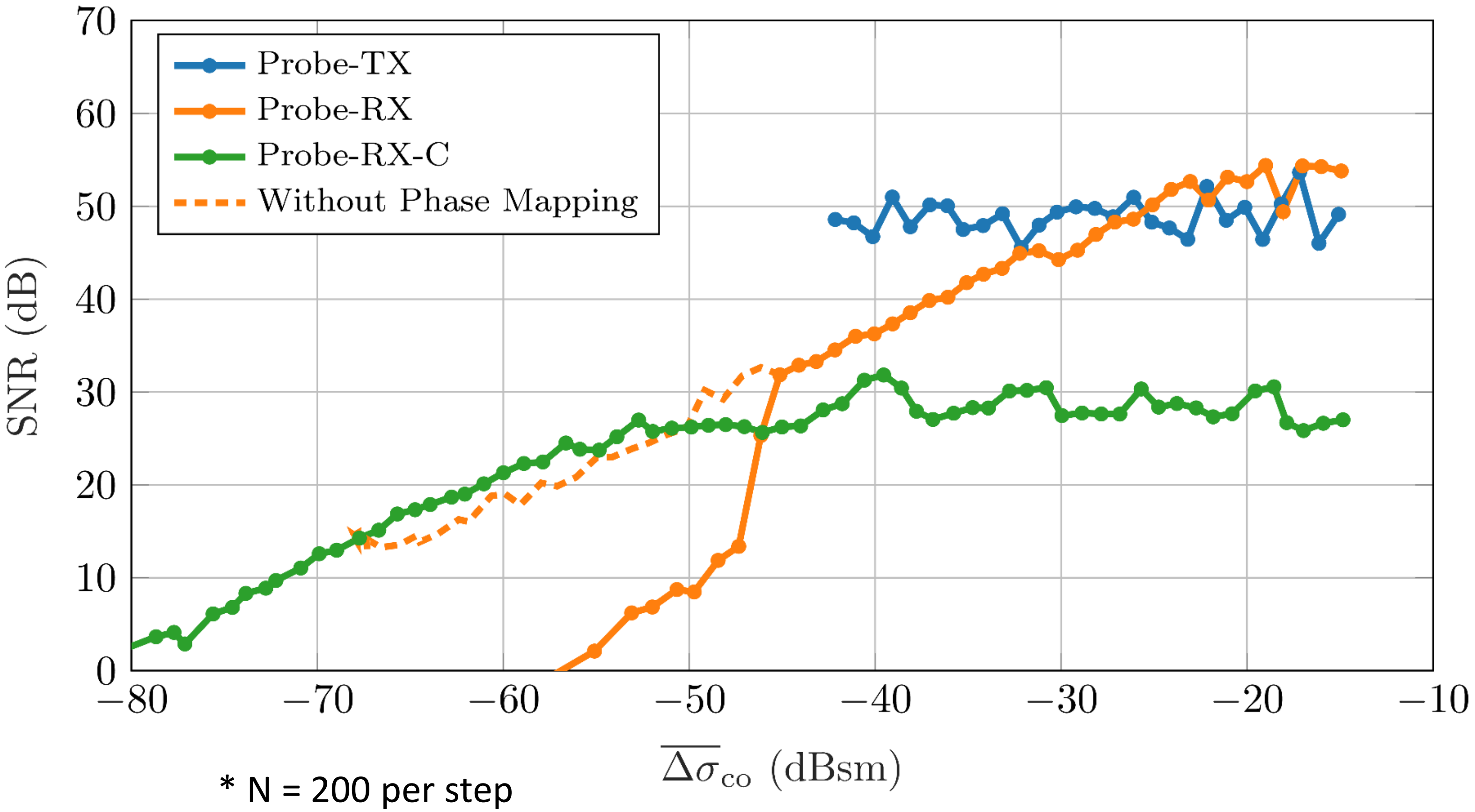
- **Goal:** Determine a monostatic $\sqrt{\Delta\mathrm{RCS}}(\chi, \Theta, \phi)$
- **Problem:** Bistatic measurements with unknown path K
- **Approach:**
  - Activate tag from both directions (⇄)
  - Operate tag at fixed power level (by utilizing its sensitivity level)
  - Ratio of required TX power levels eliminates unknown K
- **Result:** Monostatic $\sqrt{\Delta\mathrm{RCS}}$ from bistatic measurement: $\sqrt{g_\mathrm{t}^\chi}(\theta,\phi)\Delta\Gamma(a_\mathrm{min})\sqrt{g_\mathrm{t}^\chi}(\theta_0,\phi_0) = \frac{\sqrt{4\pi}}{\lambda}\sqrt{\Delta\sigma_\chi}(\theta,\phi)$

$\sqrt{g_\mathrm{t}^\chi}$ ... Tag antenna gain
$\Delta\Gamma$ ... Tag modulation state difference

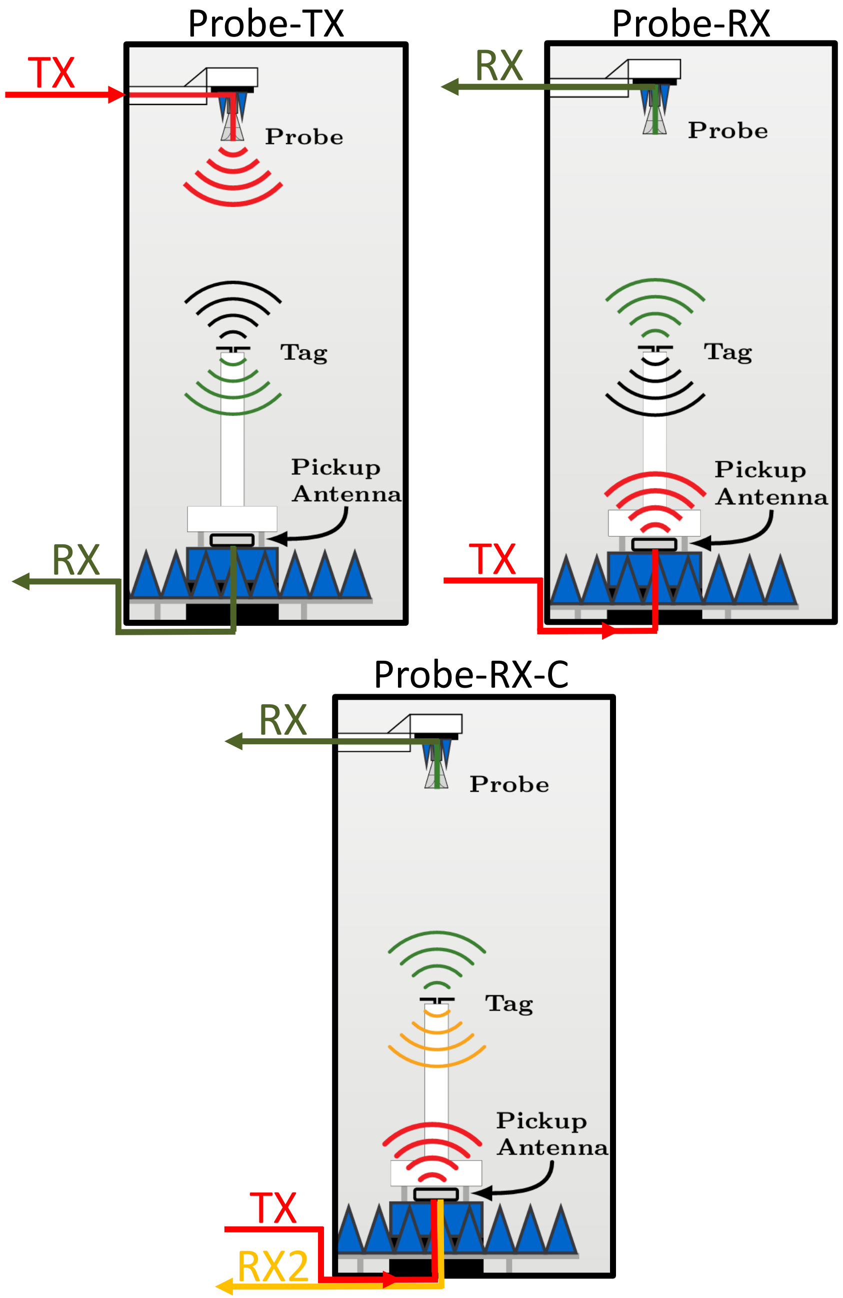
Contents

- Arrangements
- Measurement Model
- **Configurations' Performance Comparison**
- Spherical Wave Expansion & Pattern Stitching
- Measurement Results

Configurations' Performance Comparison: Achieved Dynamic Range



* N = 200 per step



➔ No single configuration without limitations, tradeoffs inevitable

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Shortcomings:

- $\sqrt{\Delta \mathrm{RCS}}$ pattern accuracy limited by dynamic range (missing points)
- Θ-truncation & omnidirectional tag behavior

➔ Utilize Spherical Wave Expansion (SWE) [3]

- SWE prerequisite for pattern stitching [4]:

First Partial Measurement → 180° Rotation of the AUT → Second Partial Measurement → Apply Stitching

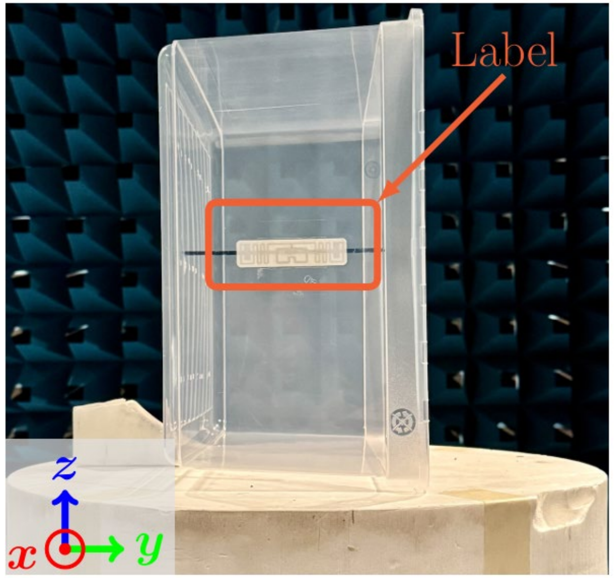
Full-Sphere $\sqrt{\Delta \mathrm{RCS}}$ ☺

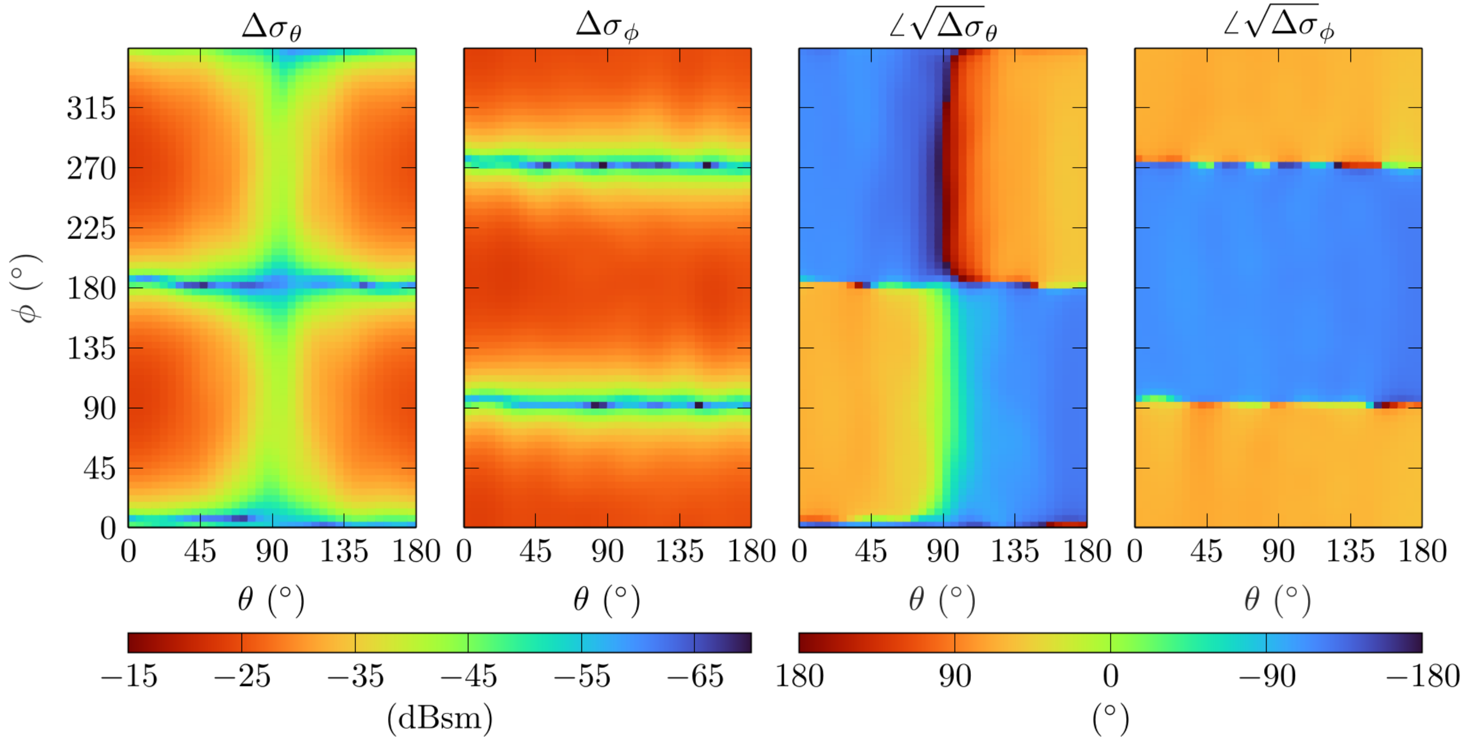
[3] J. E. Hansen, ed. Spherical Near-Field Antenna Measurements. Institution of Engineering and Technology, 2008. 387 pp.
[4] J. Soklic. "Full-Sphere Antenna Measurements via Pattern Stitching". PhD thesis.

Contents

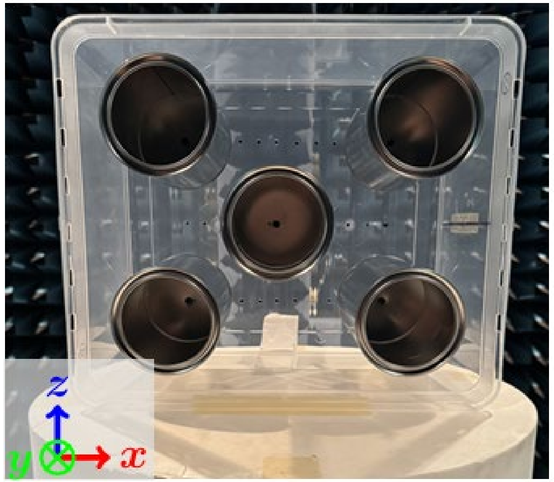
Measurement Results

- RFID Label on the side wall of an empty crate
- Crate centered in the measurement sphere
- $\sqrt{\Delta \mathrm{RCS}}$ Pattern resembles that of a y-oriented dipole

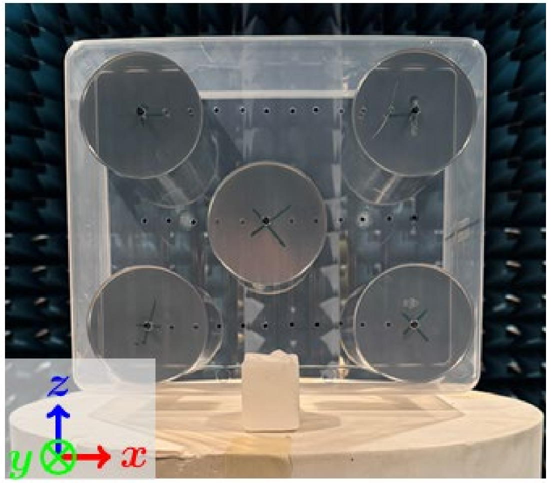




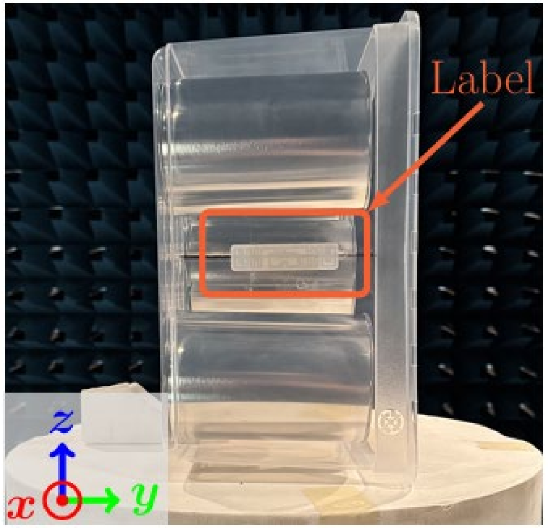
- Crate filled with metal cans
- Tag activation sensitive to placement of the cans
- $\sqrt{\Delta \mathrm{RCS}}$ Pattern severely affected compared to the pattern of the empty crate



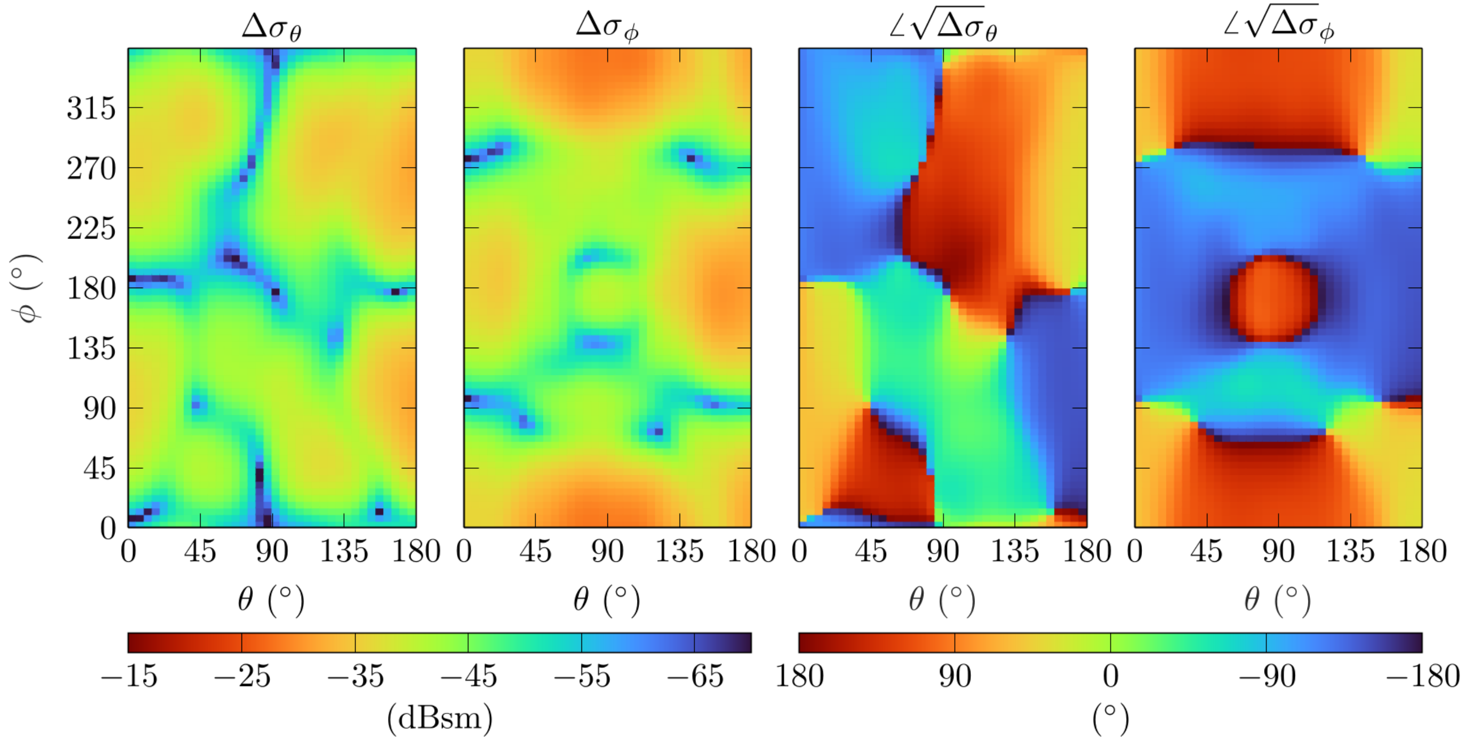
(a) Top orientation



(b) Bottom orientation



(c) Bottom orientation - side view



Conclusion

- **Goal:** Measurement system for $\sqrt{\Delta\mathrm{RCS}}$ of UHF RFID tags

- **Three configurations evaluated:**
  – Configurations Probe-TX, Probe-RX, Probe-RX-C

- **Utilization of SWE:**
  – Handle (Θ, ϕ) −positions that cannot be measured
  – Combining two measurements to full sphere patterns

- **Results:**
  – Measurement system with out-of-the-shelf components
  – Excellent dynamic range
  – Fully calibrated $\sqrt{\Delta\mathrm{RCS}}$ measurements