PROPEL 5G
PROcedures and techniques for Proving compliance to Exposure Limits of 5G wireless devices

A Mobile Manufacturers Forum sponsored project

Benoît Derat, Lyazid Aberbour, Sergio Arianos, **ART-Fi SAS**

Winfried Simon, **IMST GmbH**

Cyril Luxey, EpOC, **University of Nice**

Frédéric Gianesello, **STMicroelectronics**

> Project Scope

→ Response to the MMF RfP on EMF exposure limits and compliance assessment for wireless devices operating at frequencies above 6 GHz – **WP2: Compliance testing at frequencies above 6 GHz**

→ Focus on accurate evaluation of free-space near-field power density (PD)

- No discussion on phantoms
- No discussion on the relevance of basic restrictions on PD

→ Development of concepts generally relevant to frequencies above 6 GHz but mainly validated and applied in the WiGig frequency range (57 – 66 GHz)

> Project Objectives

- → Core objective: evaluate concepts, techniques and procedures for assessing the near-field power density in air in the very near-field of wireless devices
- → Create accurate numerical models of existing 60 GHz antennas to be used as near-field references (SO2.1)
- → Assess the accuracy of near-field reconstruction algorithms and determine optimal algorithm parameters (SO2.2)
- → Build up a planar scanner and apply the most relevant identified techniques to the evaluation of near-field PD for reference devices (SO2.3)

> Critical Aspects under Investigation

→ Probing distance
- A large distance may not allow efficient reconstruction of the very near-field: system sensitivity, loss of reactive field information
- A short probing distance would induce unacceptable perturbations of the DUT

→ Measurement sampling rate

→ Truncation

→ PD averaging area

→ Probe correction

→ Usability of phased methods and sensitivity to phase measurement error

→ Comparison between phased and phaseless approaches

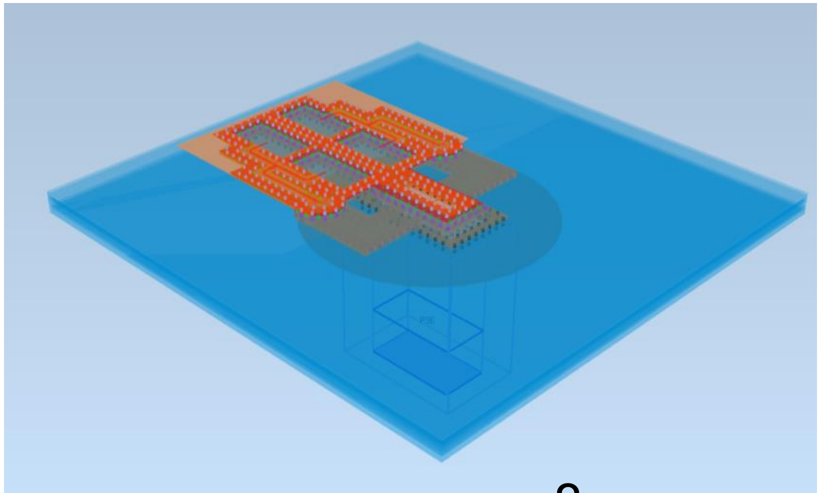
> Reference Antennas

→ Two reference antennas available for both simulations and measurements used for testing near-field algorithms and measurement methods

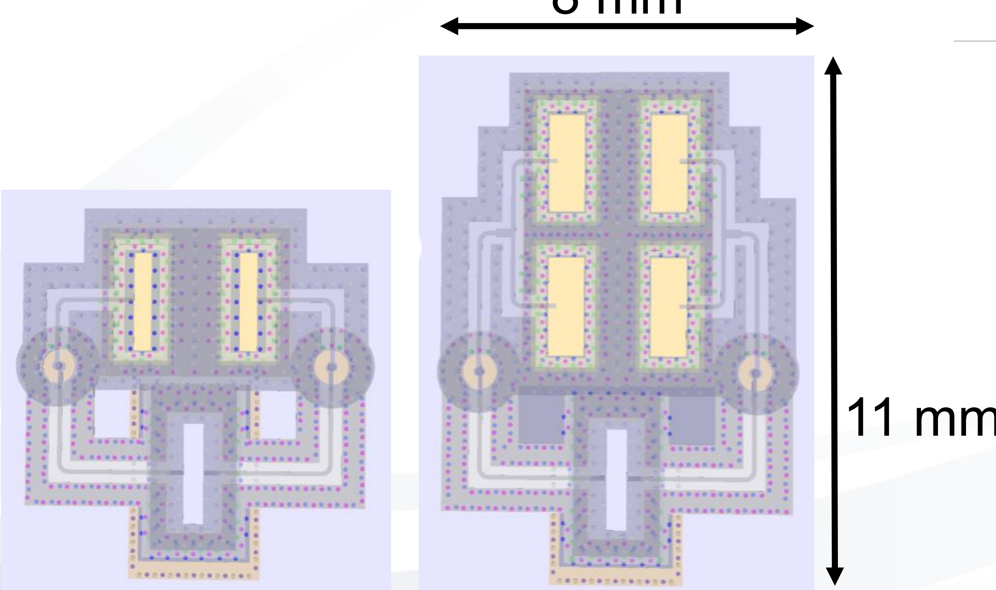
- 60 GHz 2x2 LTCC open-ended waveguide antenna array
- 60 GHz Tx / Rx double-patch antenna

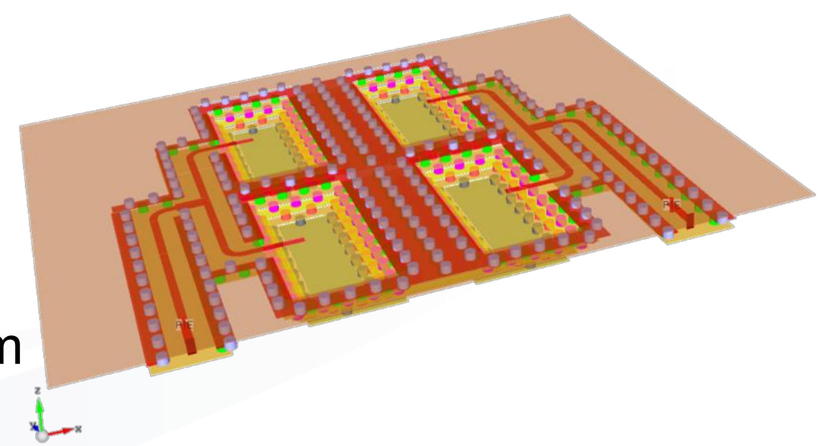
→ Simulations carried out with IEC 62704 compliant Finite Difference Time Domain (FDTD) software EMPIRE by IMST GmbH

LTCC Array Antenna Structure Overview

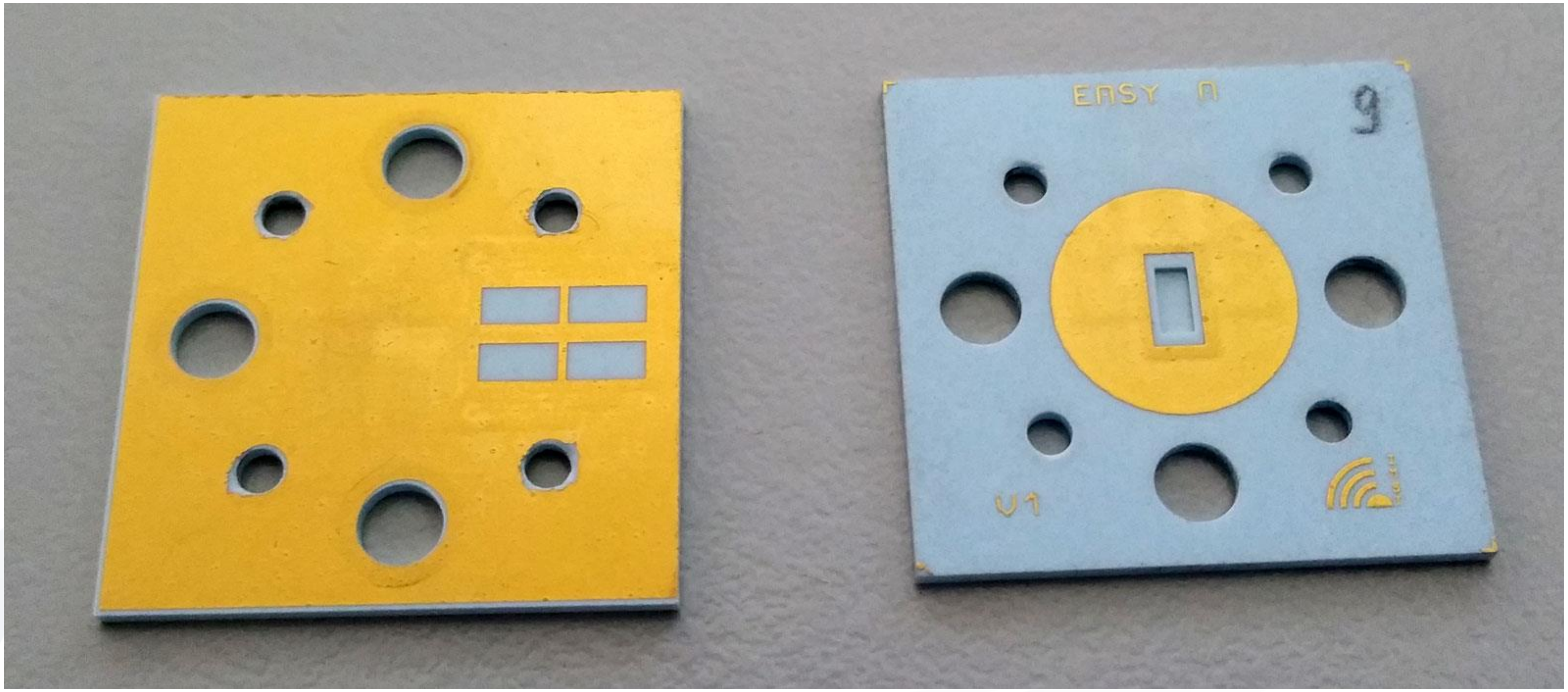


- → Transition to WR-15 WG on the backside (opposite to the antenna aperture)
- → Signal coupled to two striplines with 180° phase difference for symmetrical feeding



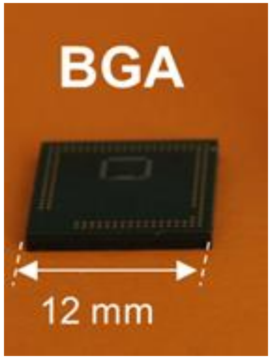


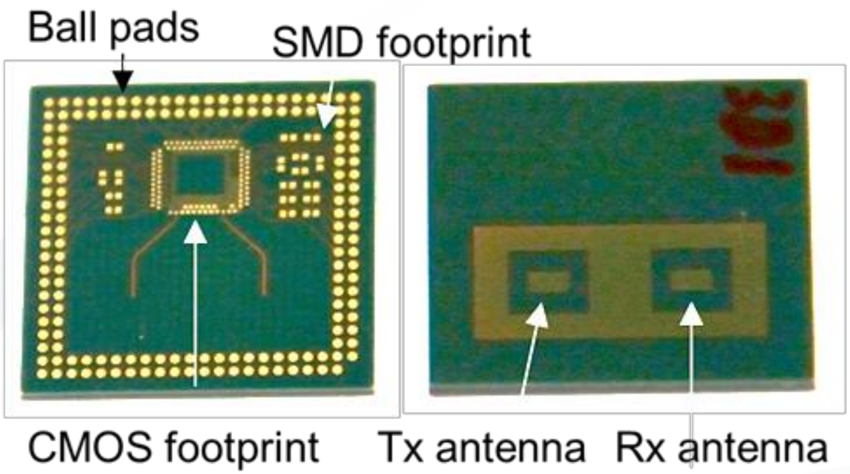
> LTCC Array Antenna Sample

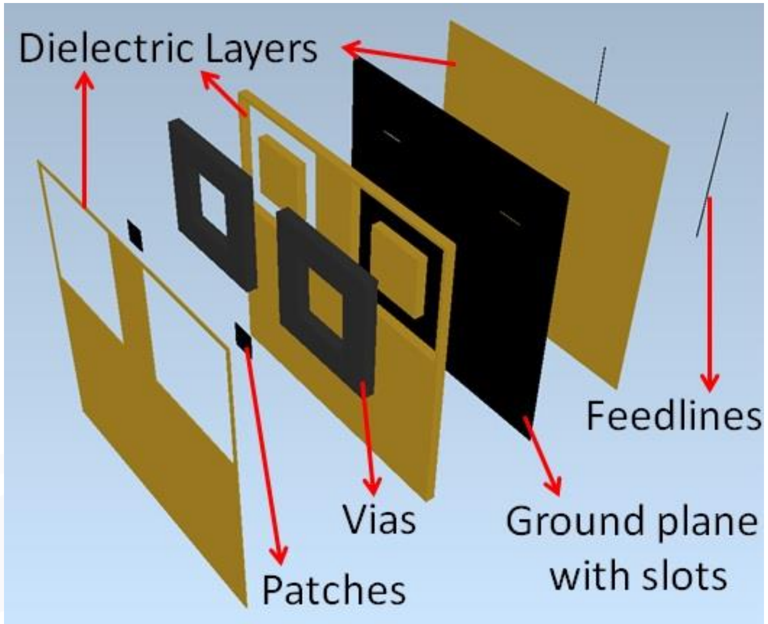


> Tx/Rx Patch Antenna Array

- → Total Size: 22 mm x 26 mm x 16 mm
- → Chip Size: 12 mm x 12 mm
- → Operating frequency: 57-66 GHz



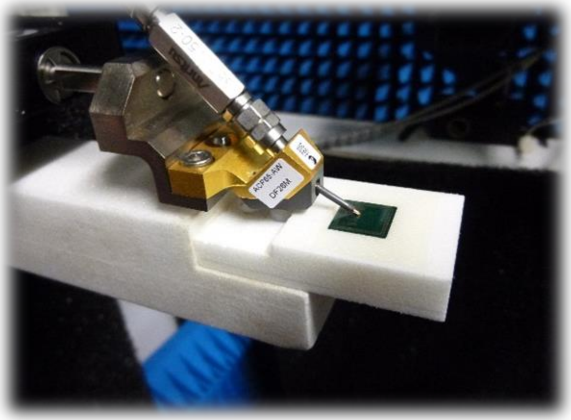




R. PILARD et al., “HDI Organic Technology Integrating Built-In Antennas Dedicated to 60 GHz SiP Solution”, IEEE International Symp. AP, July 2012.

> Tx/Rx Patch Antenna Array Measurement Setup

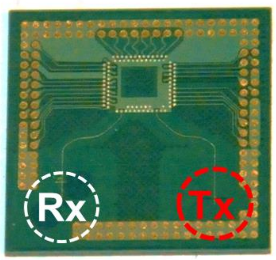
→ Dedicated probe-fed antenna setup for S11 and 3D radiation pattern up to 140 GHz.

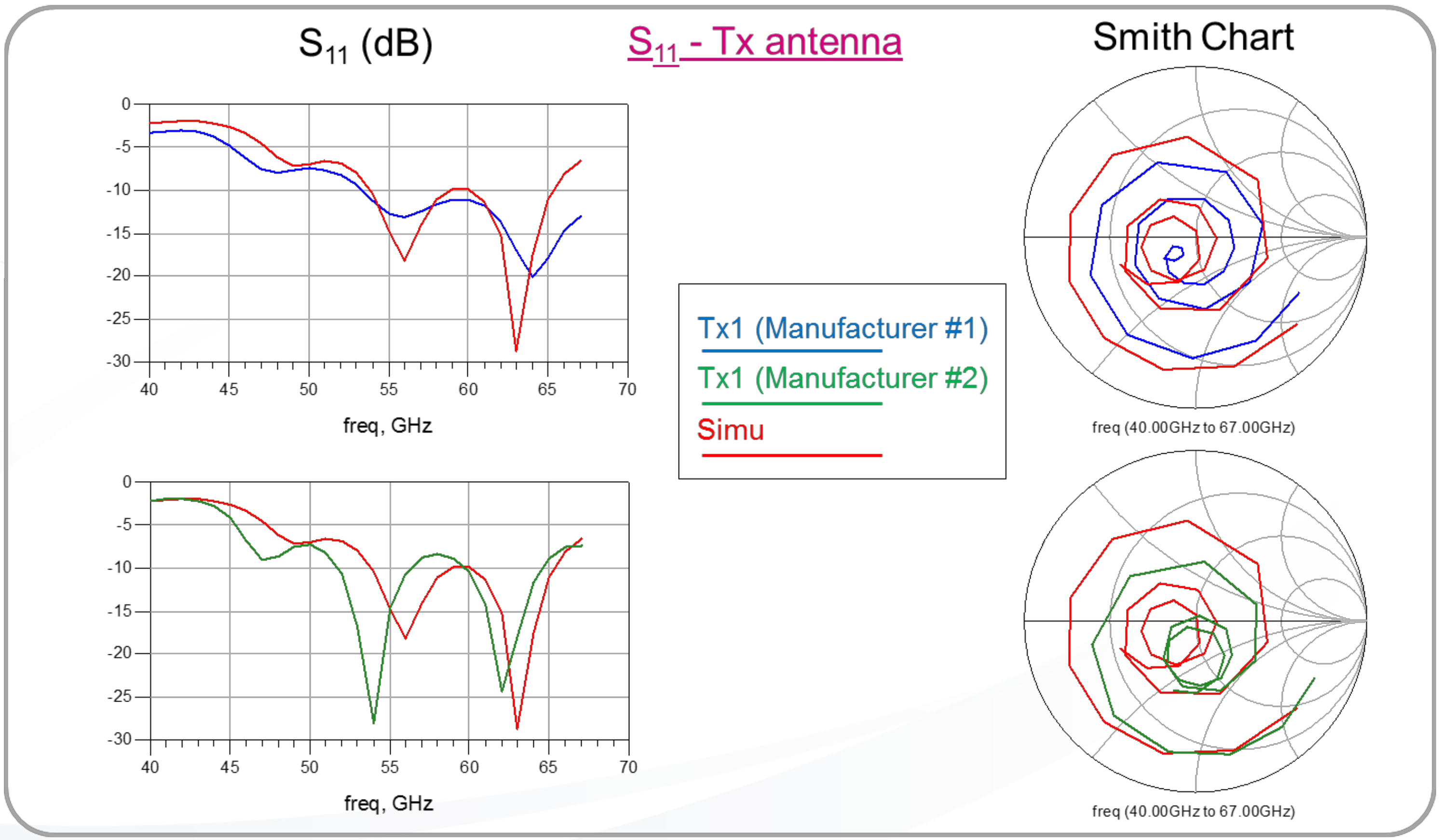


D. Titz et al, "Development of a Millimeter-Wave Measurement Setup and Dedicated Techniques to Characterize the Matching and Radiation Performance of Probe-Fed Antennas", *IEEE Antennas and Propagation Magazine*, vol. 54, pp. 188-203, 2012.

A. Bisognin et al.," Probe-fed measurement system for F-band antennas", *EuCAP* 2014.

> Tx/Rx Patch Antenna Array Measurements vs Simulations 1/2

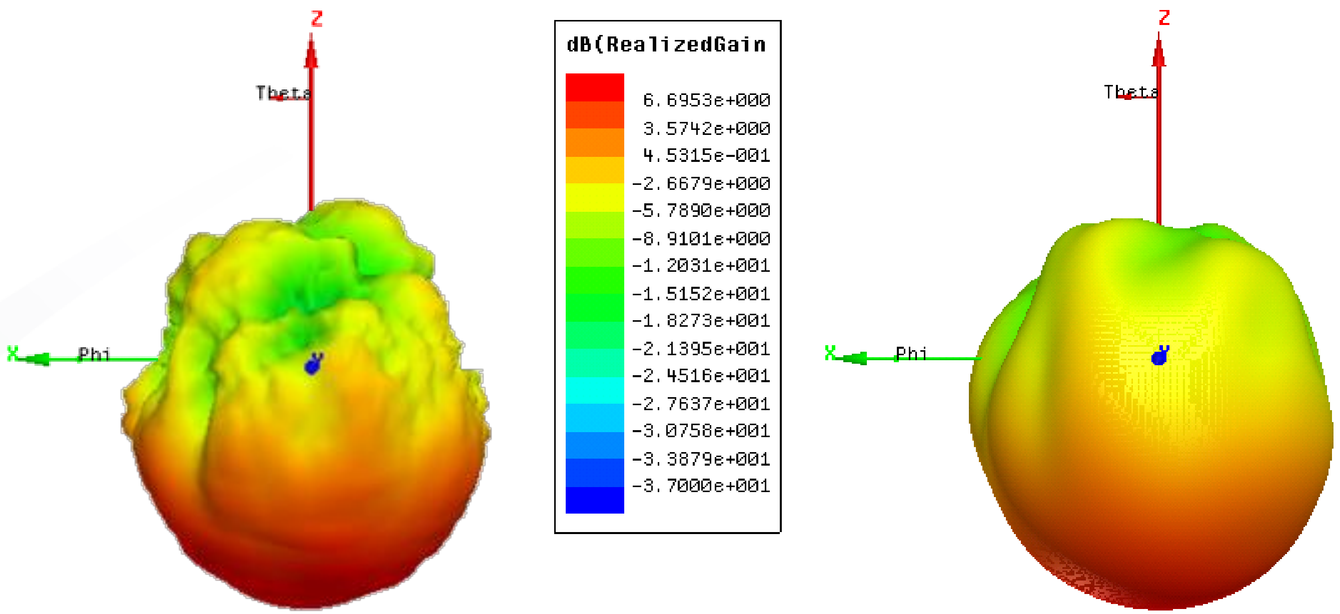




Tx/Rx Patch Antenna Array Measurements vs Simulations 2/2

3D plots – Total Realized Gain (dBi) at 60GHz

Meas. Simu.



> Poynting Vector and Near-Field Power Density

→ The time-integrated value of Poynting vector ***S(t)*** represents the energy flow of the electromagnetic field during the considered period of time at the considered location

→ Near-field PD in harmonic regime can be expressed as the real part of the complex Poynting vector

$$\underline{S}(t) = \underline{E}(t) \times \underline{H}(t)$$

$$\underline{E}(t) = \underline{E_m e^{j\omega t}} \quad ; \quad \underline{H}(t) = \underline{H_m e^{j\omega t}}$$

$$\langle \underline{S}(t) \rangle = \frac{1}{T}\int_0^T \underline{S}(t)dt = \mathrm{Re}\left(\frac{1}{2} E_m \times H_m^*\right)$$

→ The near-field PD can be looked at locally or averaged over a surface through which the power is flowing (ICNIRP – 1 cm²)

> Fundamental Principles Applied in Near-Field Reconstruction

- → Two components of the vector E or H field (magnitude and phase) over a surface are enough to reconstruct the 6 components of the E and H field over the volume enclosed within the surface

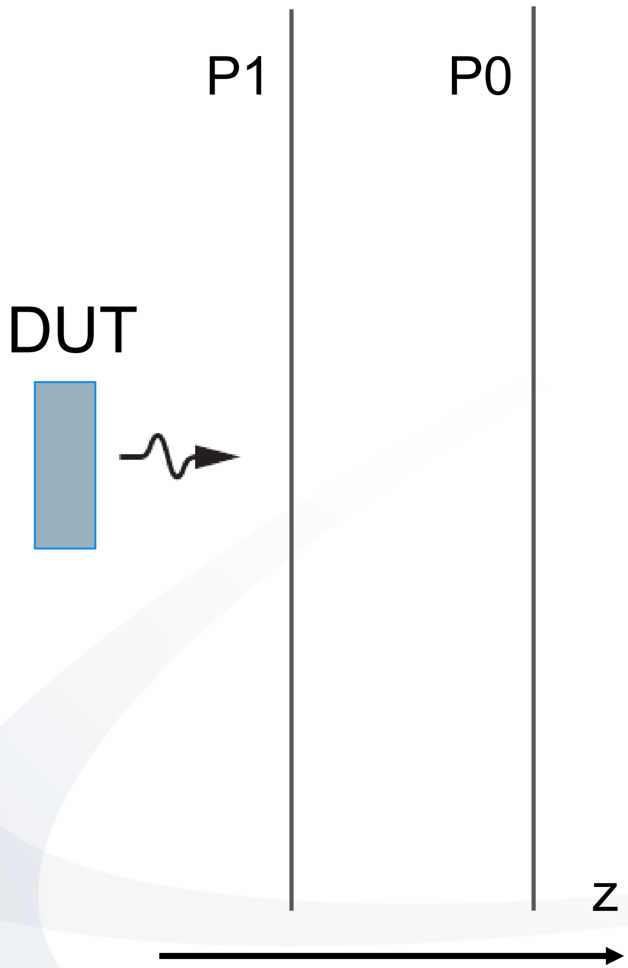
- → The third component of E or H can be calculated from the two other components using Gauss law ($\nabla . \underline{E}$ =0 in a source-free volume)

- → H can be calculated from E using Maxwell-Faraday equation:

$$\nabla \times \underline{E} = \mu \frac{d}{dt} \underline{H}$$

- → The field over the volume is determined from the field over a surface by Huygens principle / surface equivalence theorem

Near-Field PD Reconstruction Based on E-field Measurement and Plane-Wave Expansion



- → E-field measurement taken at plane P0, two components tangential to plane
- → Tangential E-field back-propagated to P1 using plane-wave expansion
- → Normal E-field component reconstructed using Gauss law
- → H-field reconstructed from E using Maxwell-Faraday
- → PD obtained from E and H vector fields

> Accuracy of PWS NF Reconstruction of Power Density

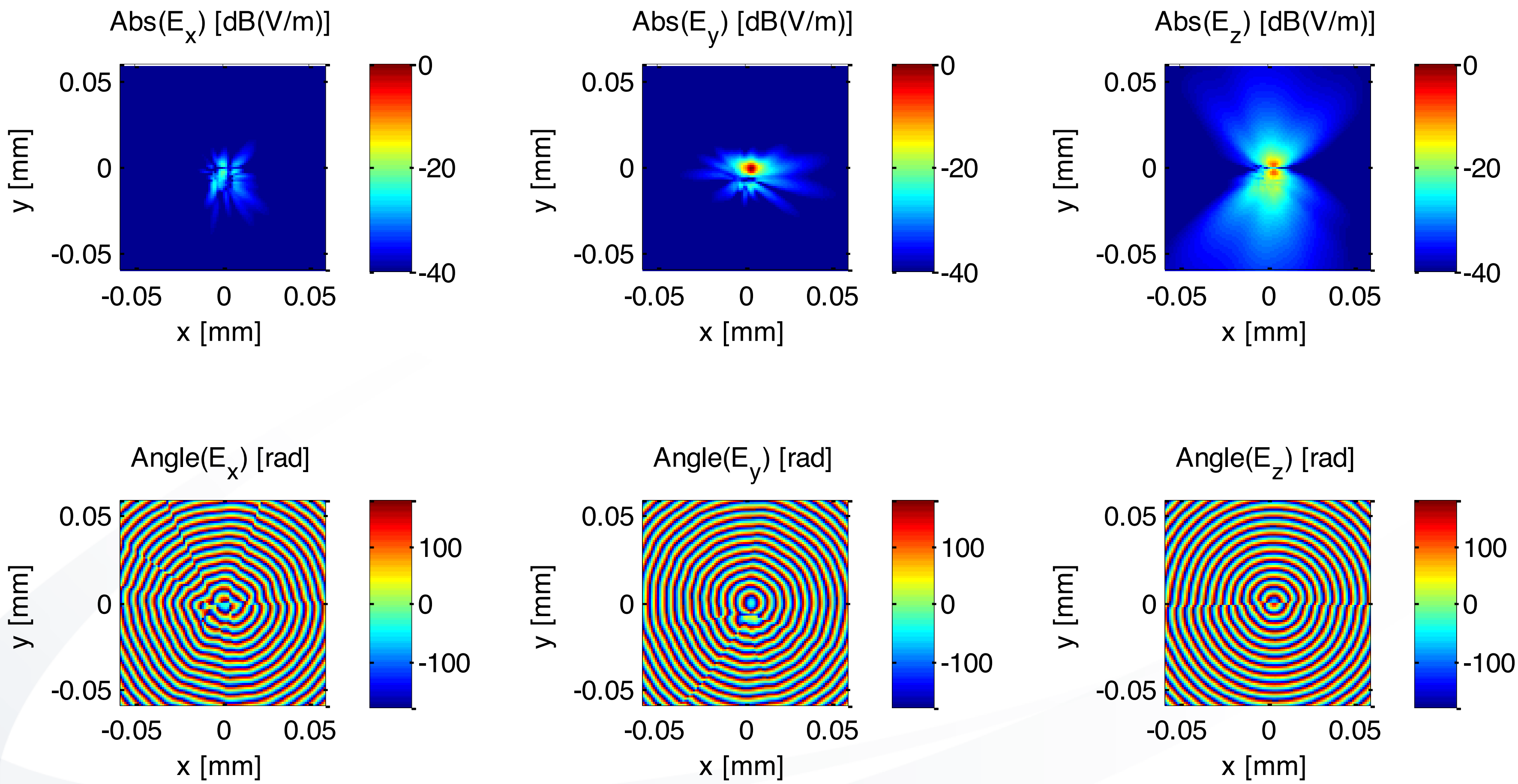
→ Tests on Tx / Rx patch antenna array

- **Frequency:** 60 GHz
- **Exploited quantities:** complex 3D distributions of the DUT radiated E-field and H-field computed with EMPIRE FDTD code
- **Spatial range of the 3D field distributions:** $118 \times 118 \times 30 mm^3$

→ Test description

- A 2D-scan is extracted from the simulated E-field and the H-field, with a fixed sampling rate in the x and y directions (tangential)
- The PWS of E-/H-field is computed for back-propagation till a target plane at a distance *h* close to the DUT
- The reconstructed and FDTD simulated E, H fields and power density at the distance *h* are compared

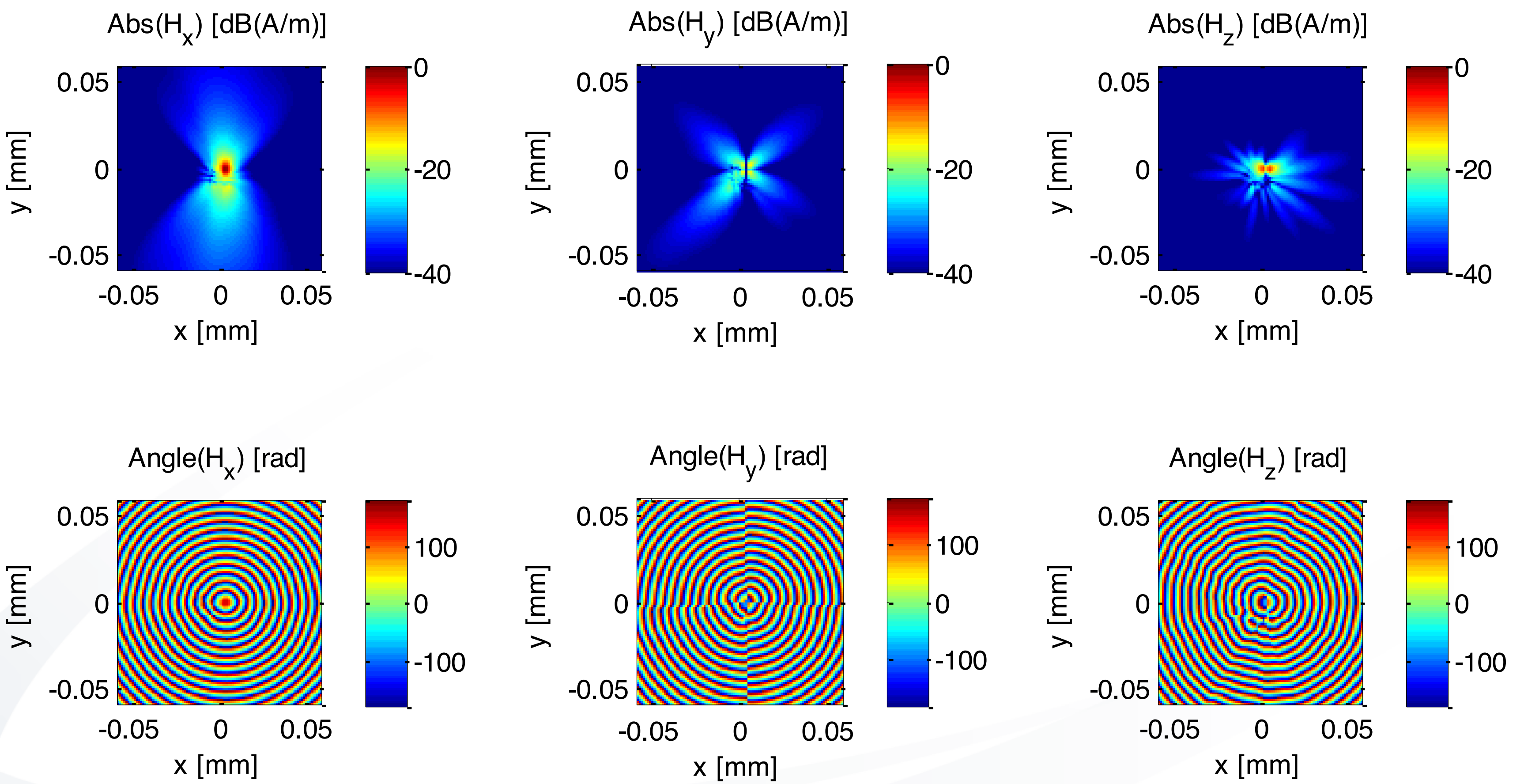
FDTD Simulated E-Field Data at 0 mm from DUT



Sampling step: λ/20 (0.25 mm)

Magnitude normalized to max E-field

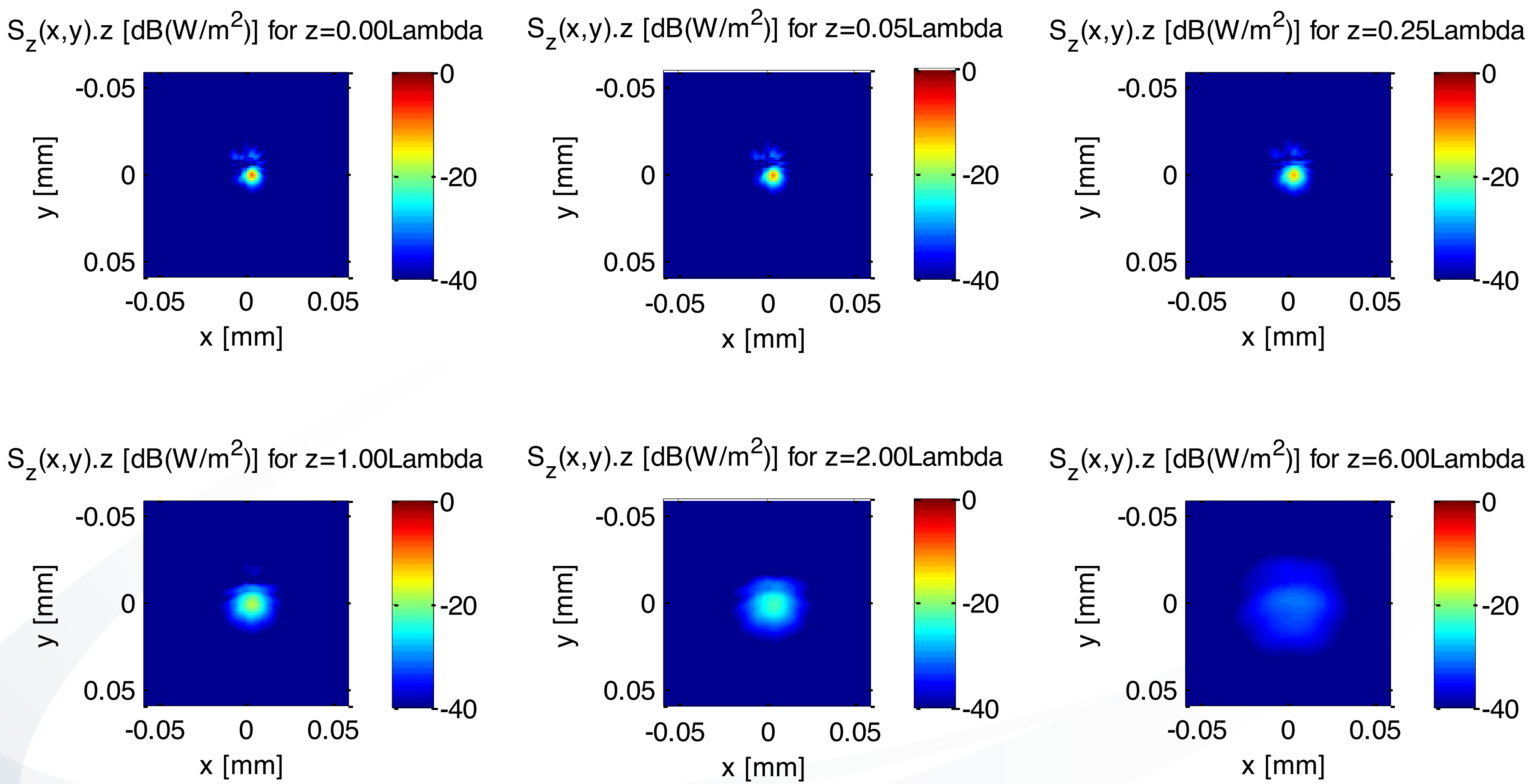
FDTD Simulated H-Field Data at 0 mm from DUT



Sampling step: λ/20 (0.25 mm)

Magnitude normalized to max E-field

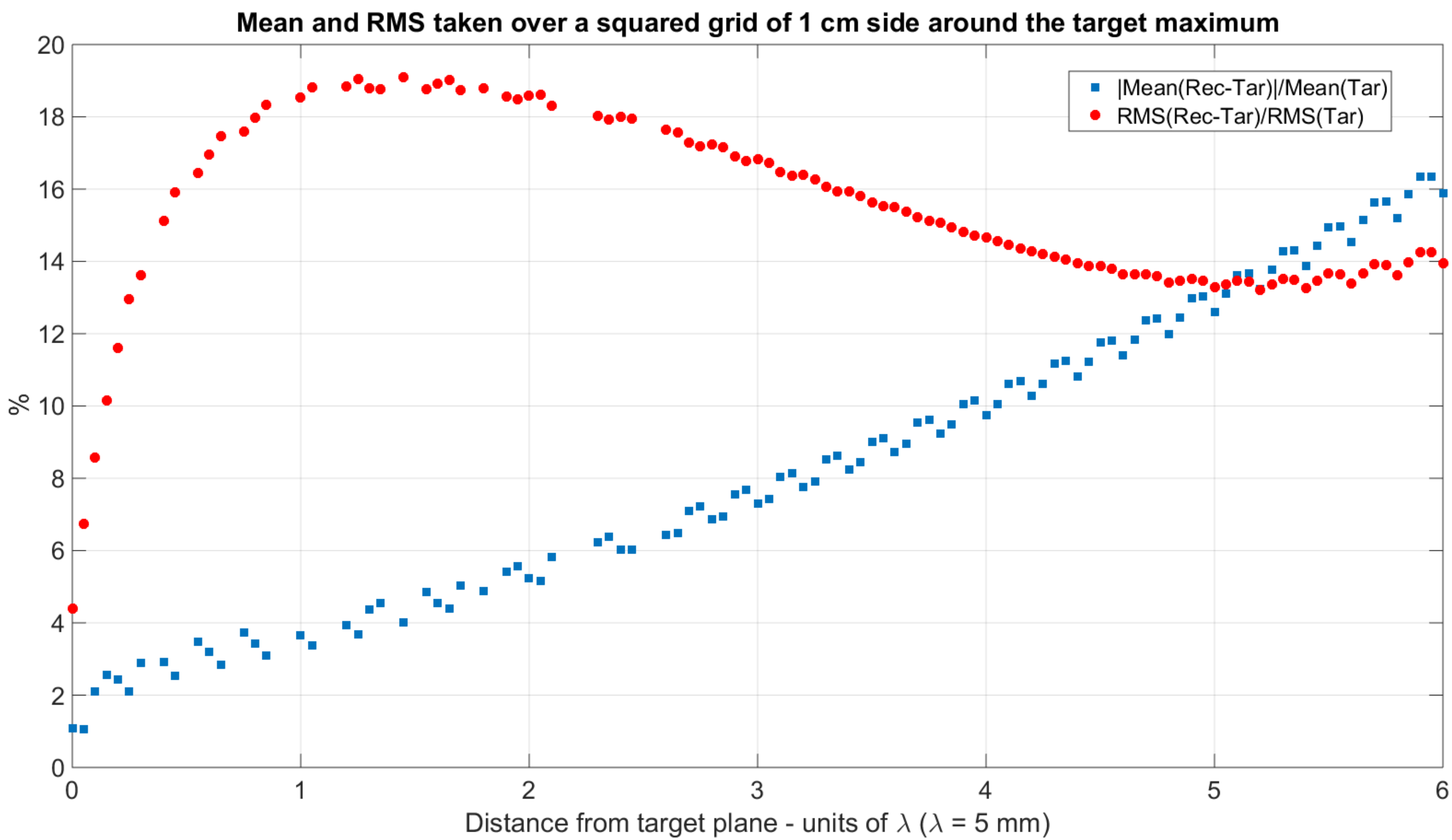
> FDTD Simulated PD Through xy Plane



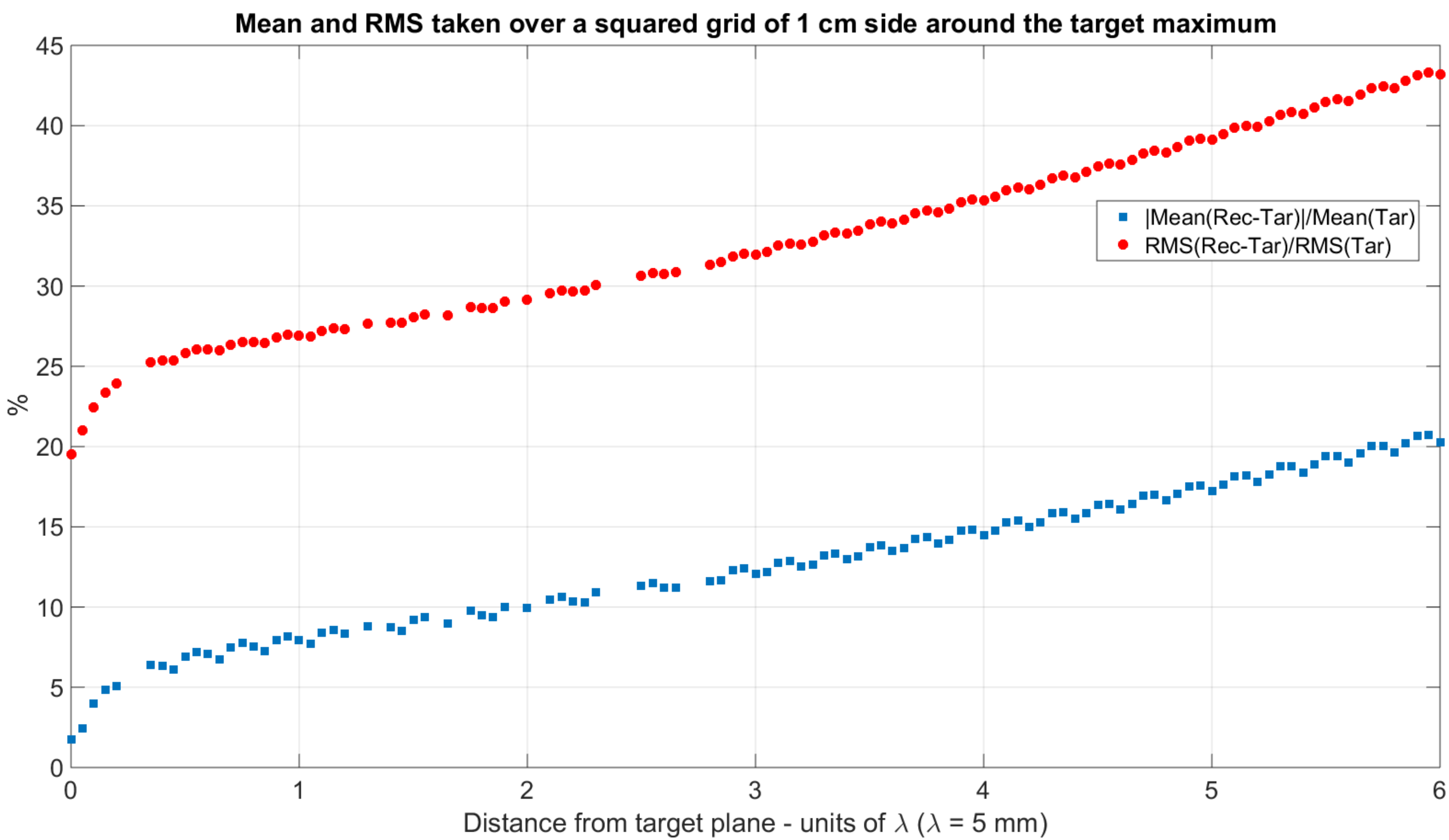
Sampling step: λ/20 (0.25 mm)

Normalized to max S magnitude

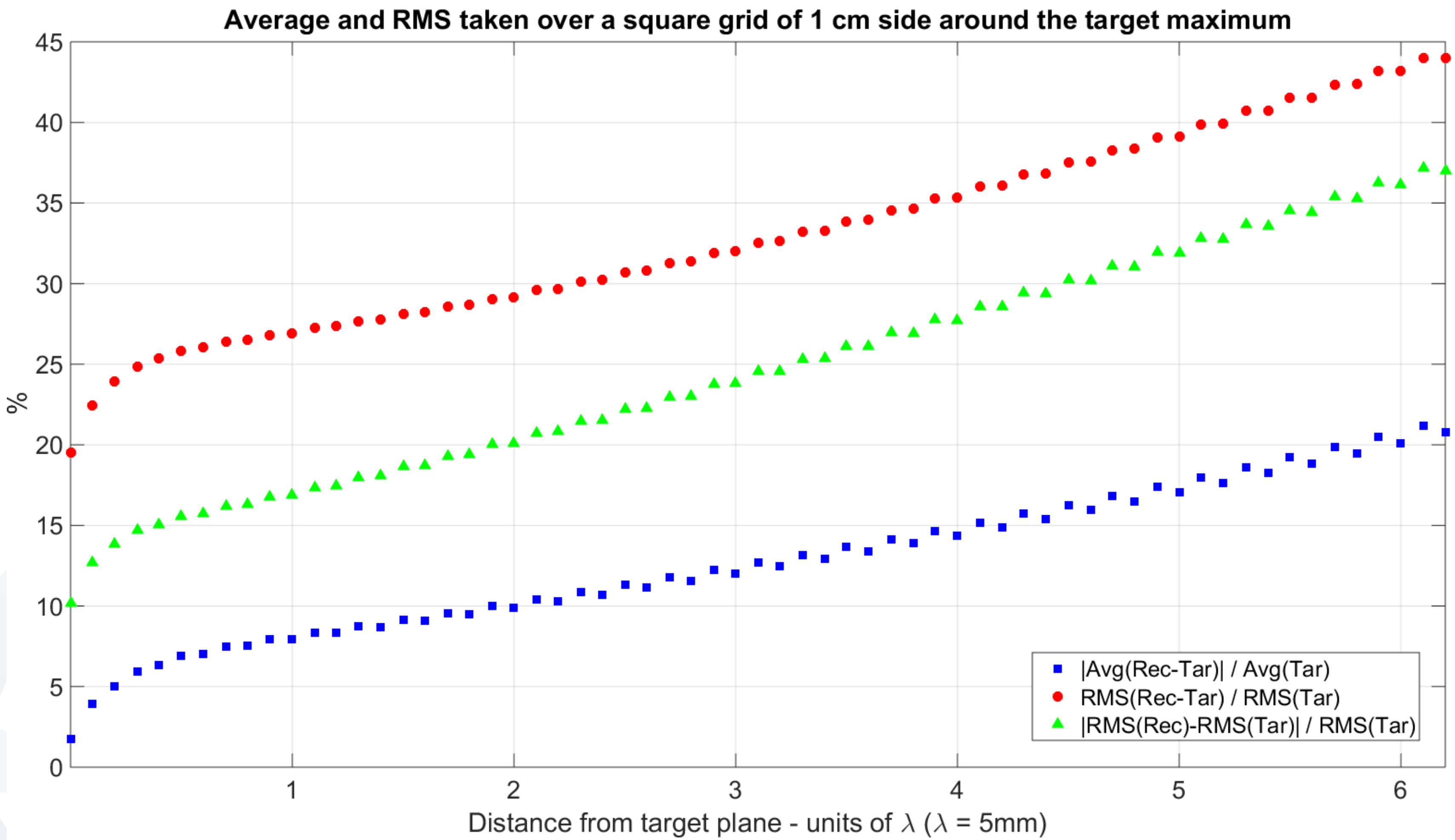
> # Deviation of PD Reconstruction at 2 mm from the DUT - λ/20 Sampling Rate



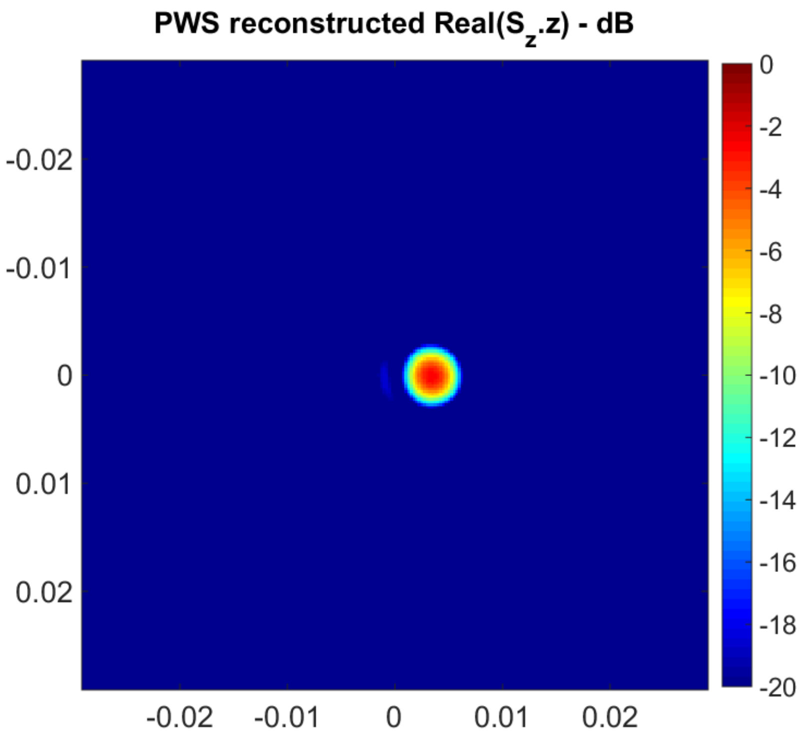
Deviation of PD Reconstruction at 1 mm from the DUT - λ/20 Sampling Rate

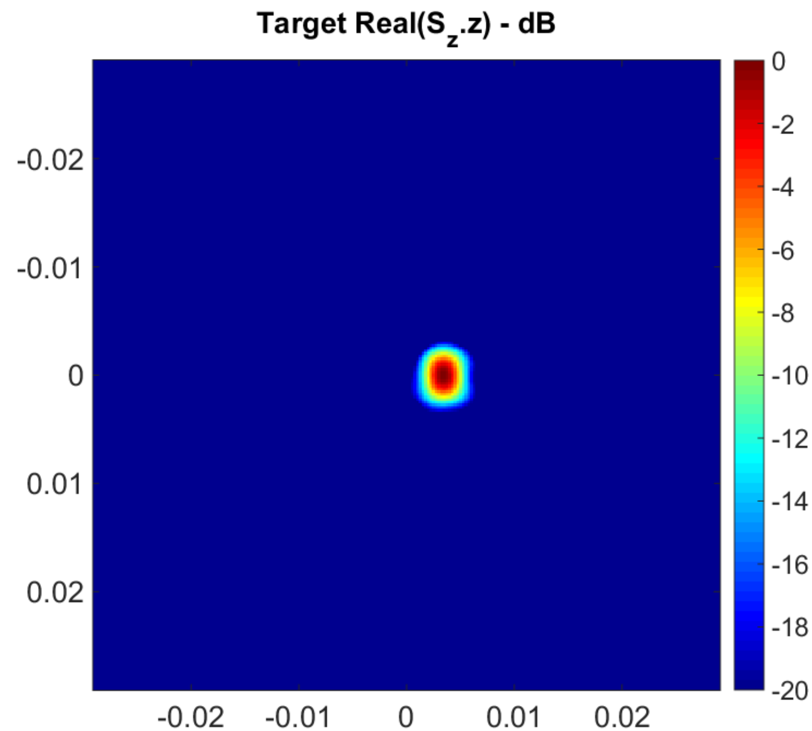


> Deviation of PD Reconstruction at 1 mm from the DUT - λ/10 Sampling Rate



> Reconstructed PD with Measurement Plane Taken at 20 mm from Target Plane

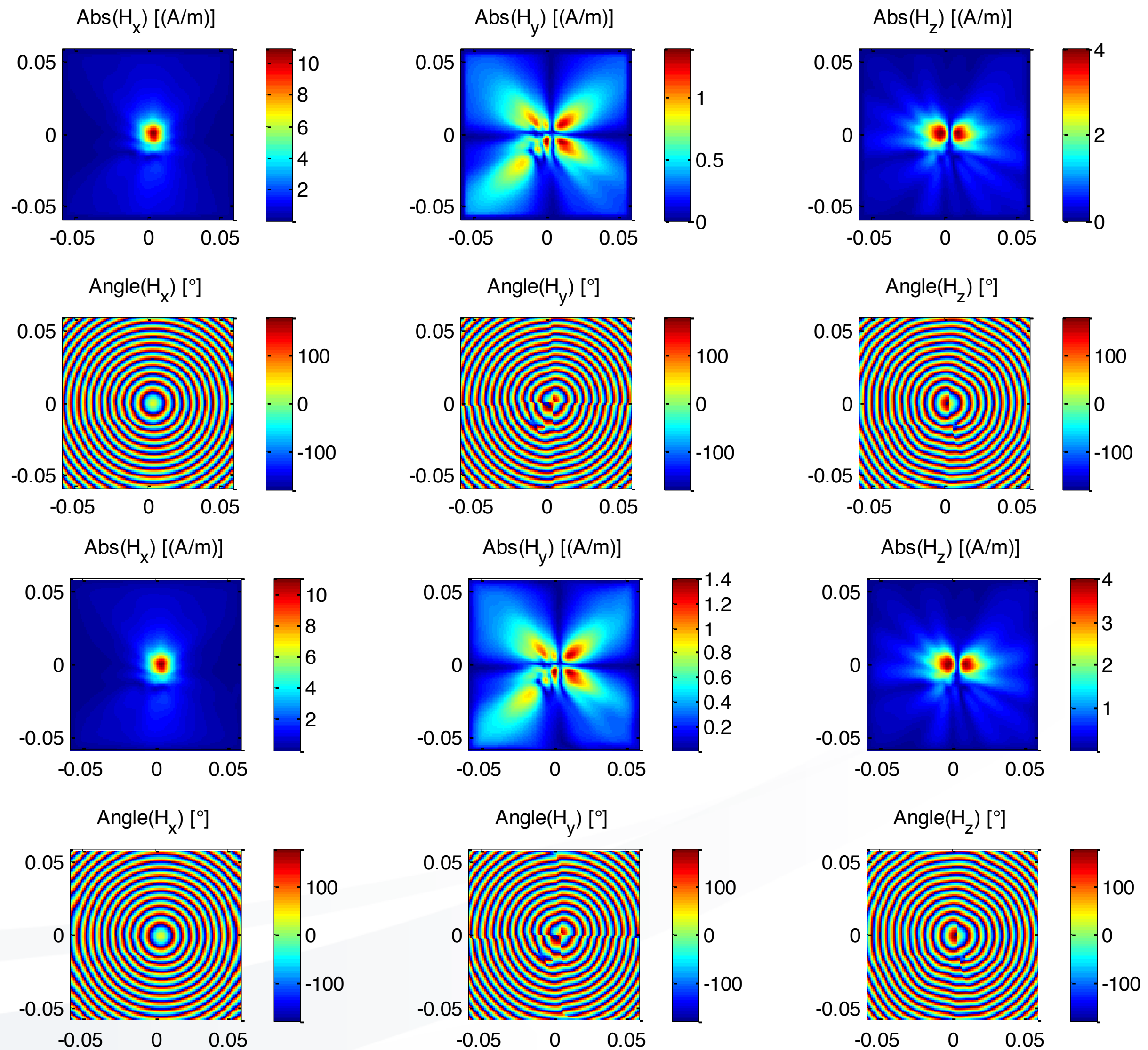




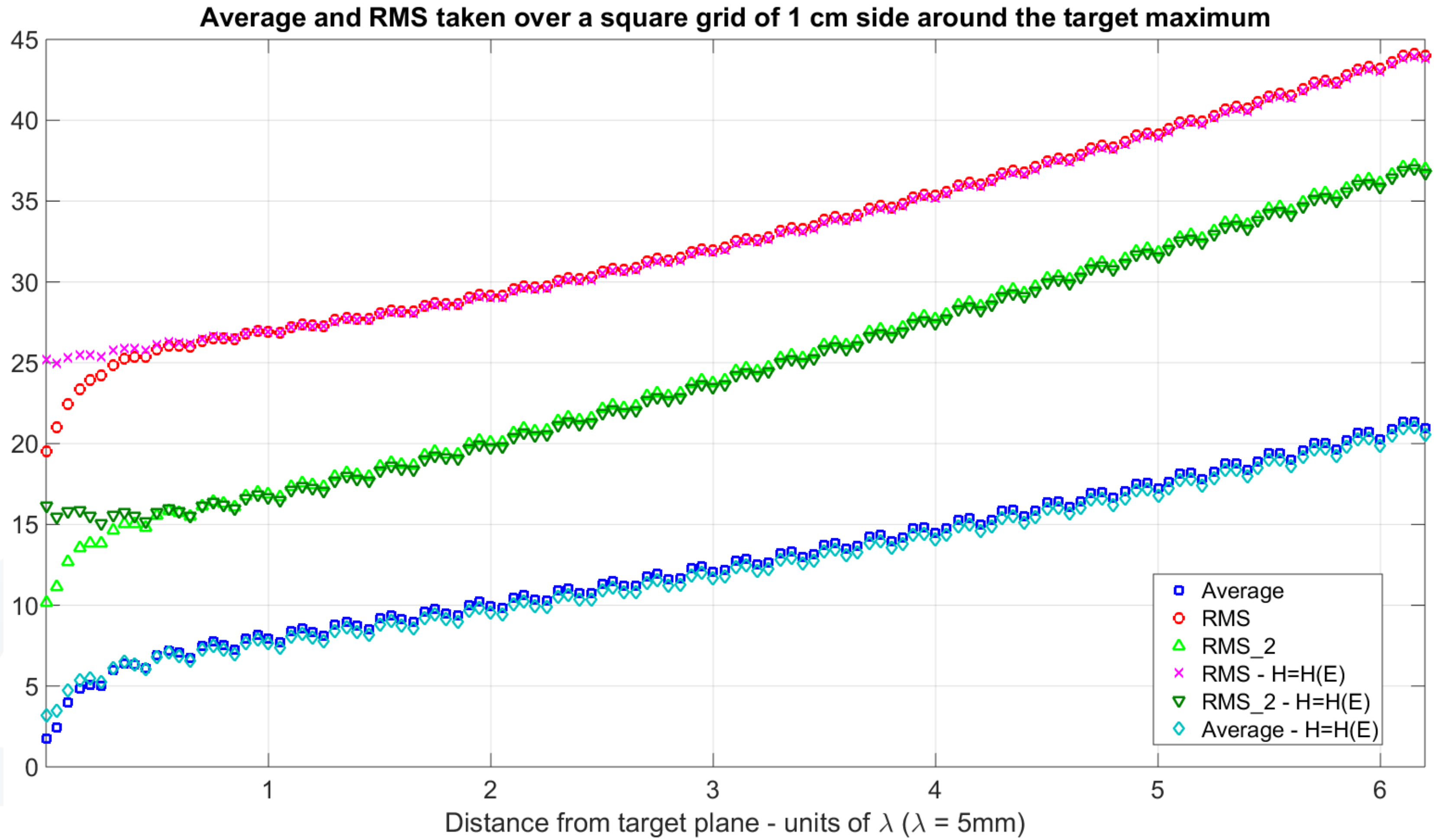
> Comparison between Simulated and Reconstructed H-field at 7mm from DUT

Simulation

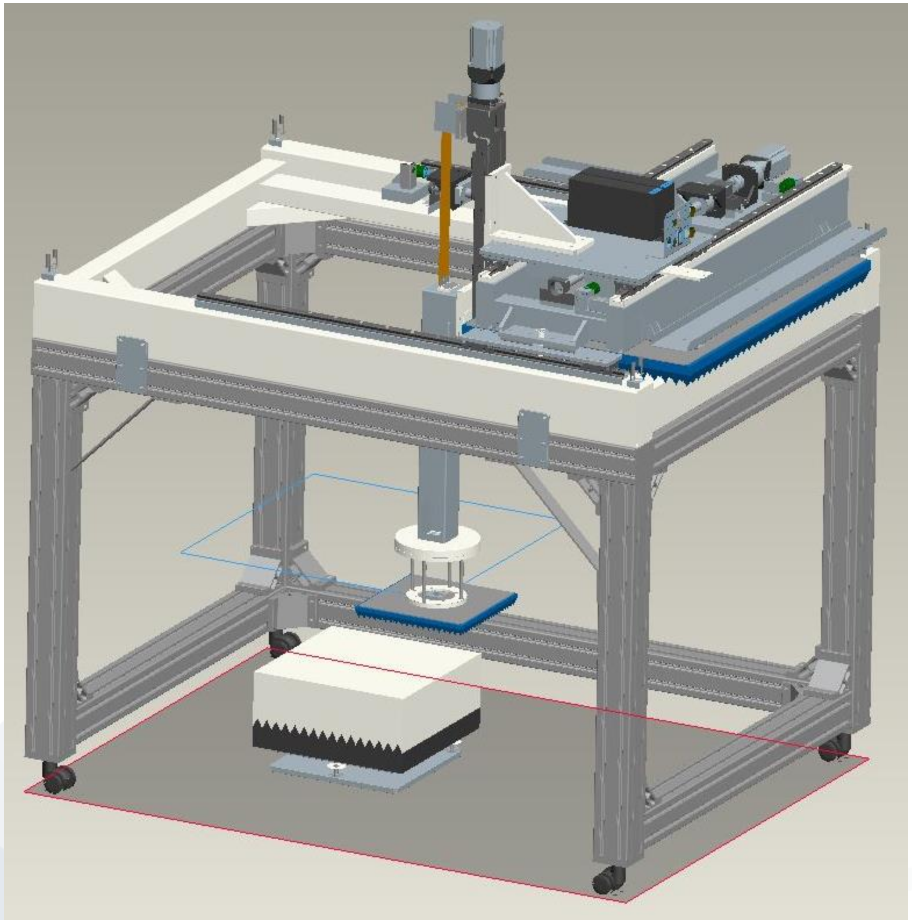
Reconstruction

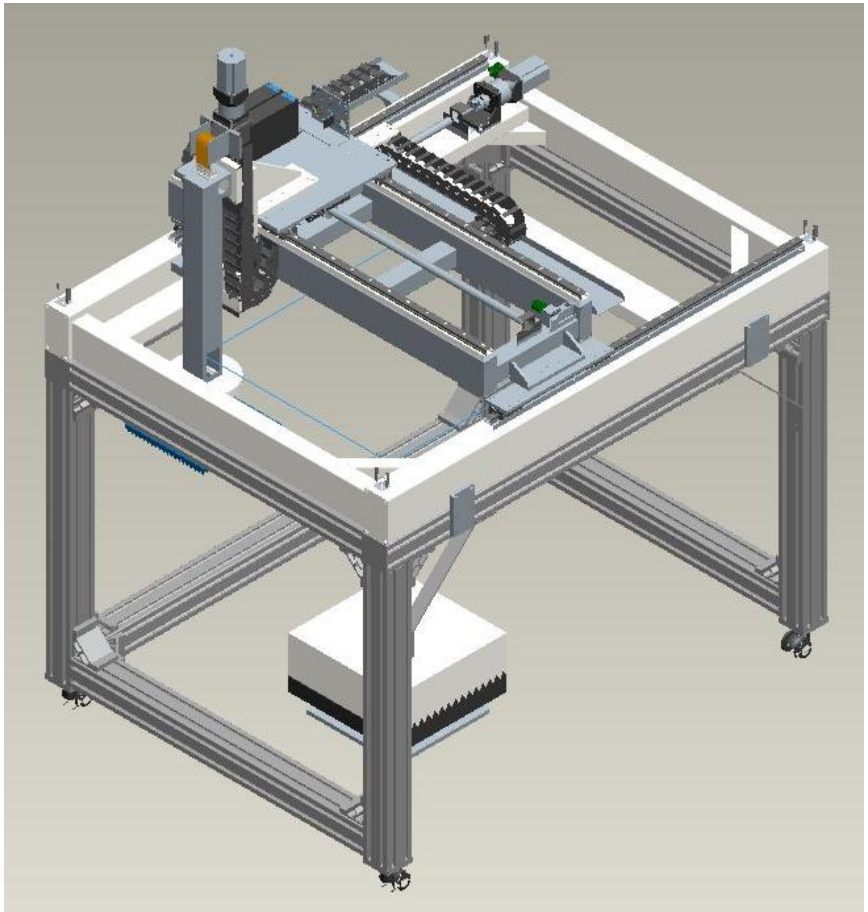


> Impact of H Reconstruction on PD Reconstruction Accuracy



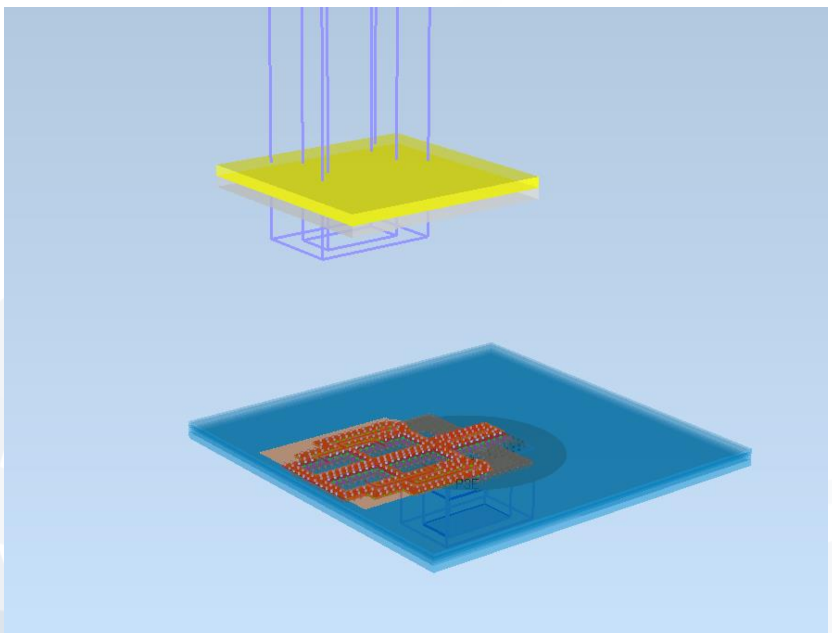
> NF PD Measurement Setup Construction

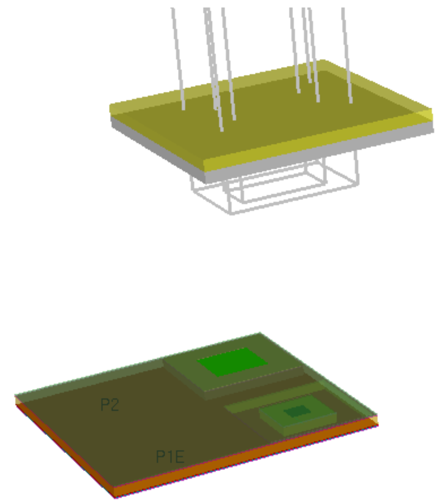




Investigation of Measurement Distance Tested Configurations

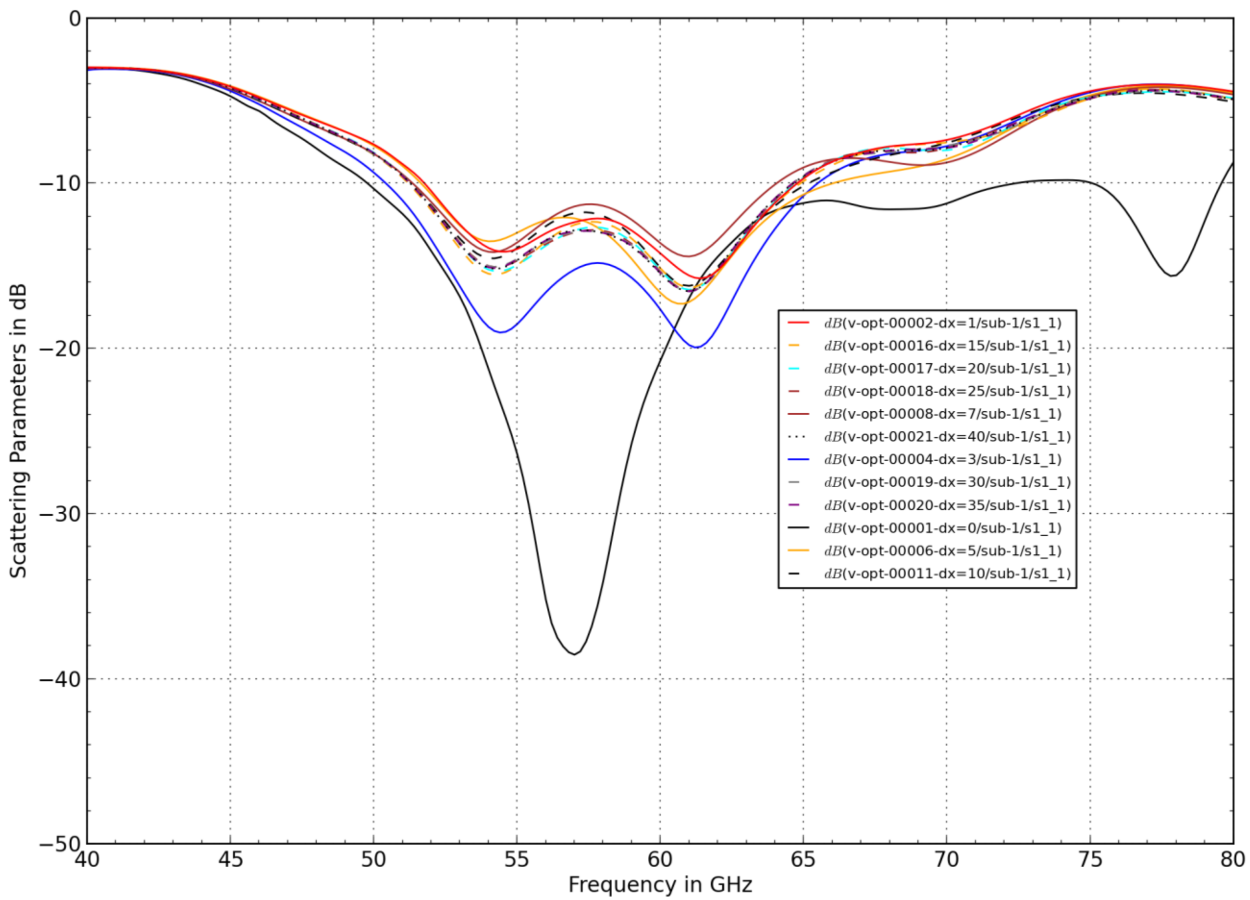
- → Simulated WG probe in the vicinity of the reference antennas
- → The WG probe is placed above the zone of maximum NF PD
- → The WG probe is gradually moved away from the DUT and the impact of the probe on the DUT is evaluated





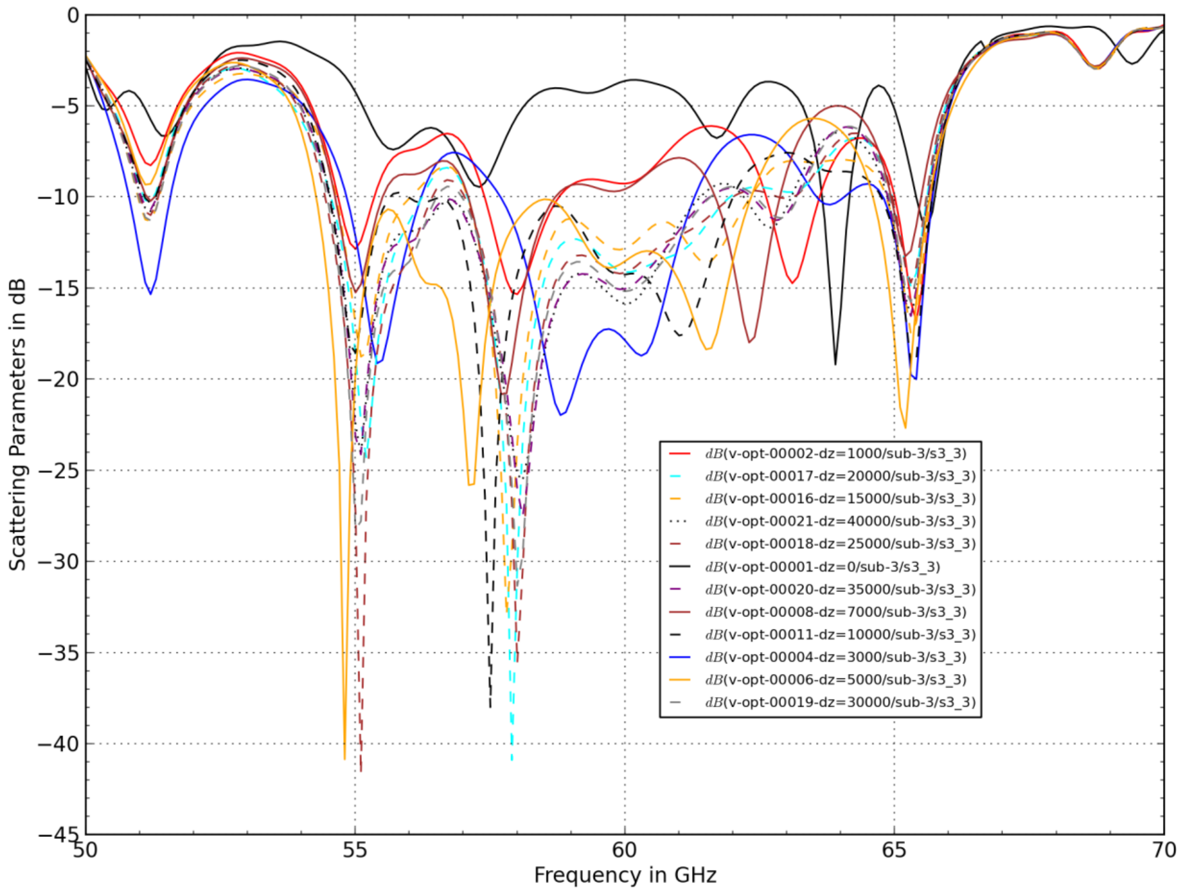
> Investigation of Measurement Distance S11 with WG Probe in 0° Position for Patch Antenna

→ Low impact on S11 with probe at >15 mm distance



Investigation of Measurement Distance S11 with WG Probe in 0° Position for WG Antenna

→ Low impact on S11 with probe at >25 mm distance



> Conclusions

→ Two reference antenna simulation setups were made available as well as physical models

→ Accuracy of active near-field PD reconstruction using two-components of vector E-field has been demonstrated from numerical data

- When measurement plane is at 25 mm from the DUT, deviation between simulated and reconstructed peak $1cm^2$ spatial-averaged PD was found to be 13% at 2 mm from the DUT and 18% at 1 mm
- H field reconstruction proved to be extremely accurate
- Investigation on impact of measurement grid step shows that reconstruction accuracy does not degrade much with a step of up to $\lambda/8$

→ 5λ is a reasonable probing distance to avoid unacceptable perturbations of the DUT

→ A measurement scanner is being implemented to validate and further test near-field reconstruction algorithms: phased vs phaseless in practice?