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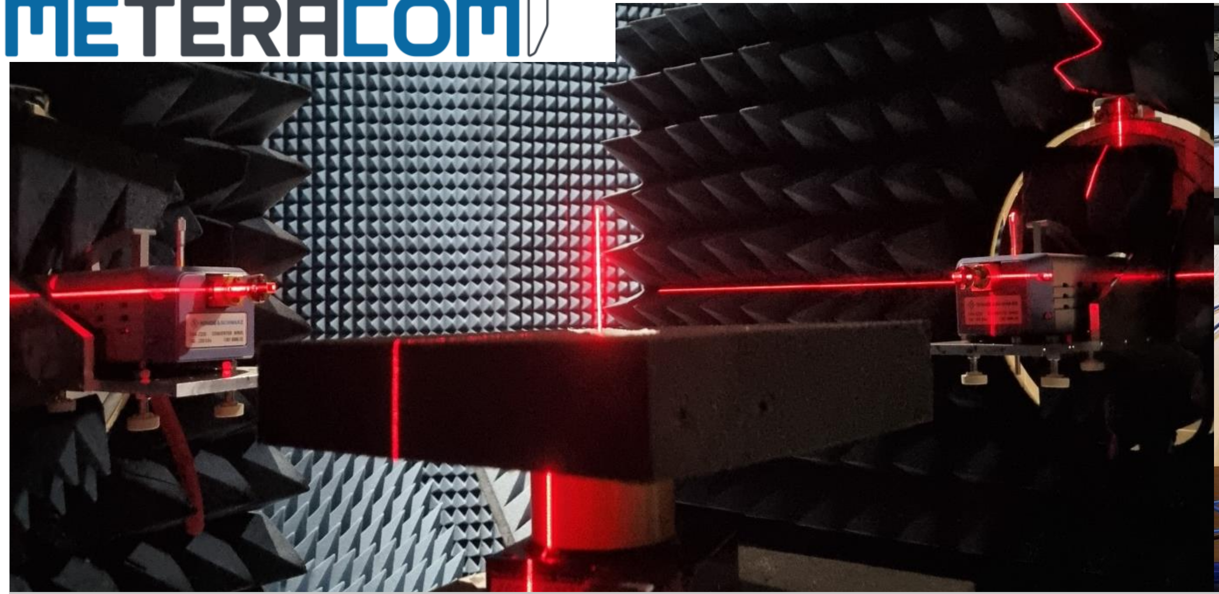
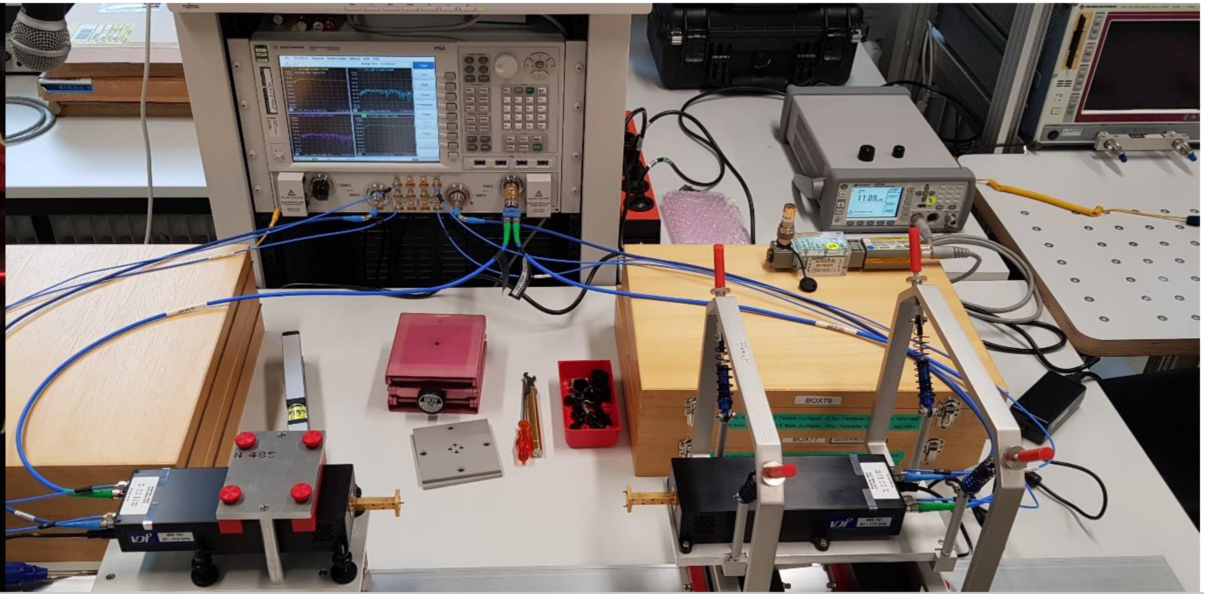
FOR 2863 Meteracom
Metrology for THz Communications





Metrology in wireless communication: Channel Sounder Measurement Verification Using Over-the-Air Artifact

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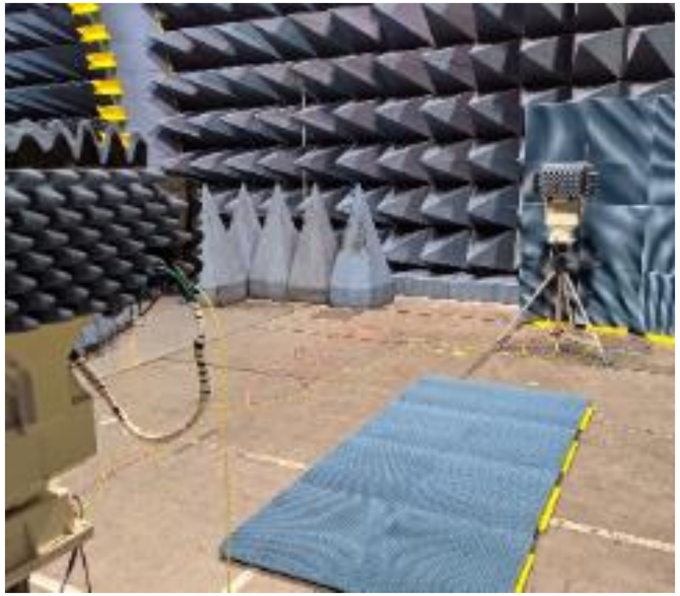
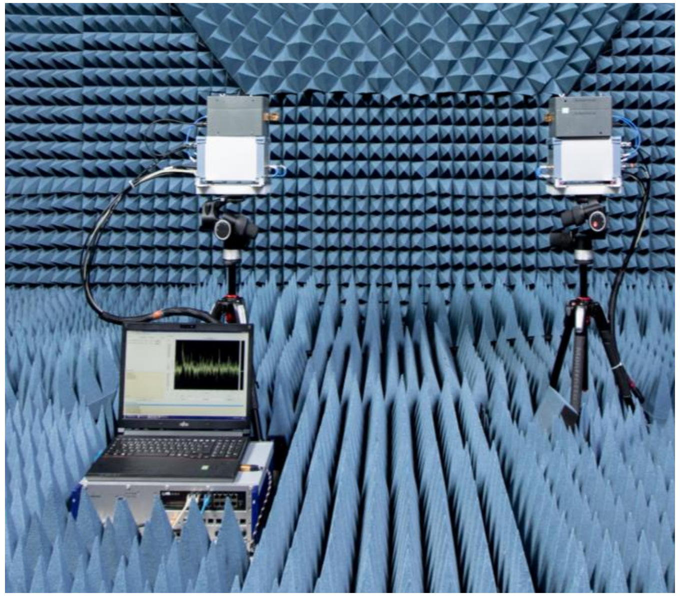
1st International Workshop on Metrology for THz Communications, Braunschweig, 28 June 2022

Metrology for THz Channel Sounding Systems

- In METERACOM, we have the chance to preform measurements, with the help of the available hardware equipment.
- Our aim is to characterize different measurement artifacts represented by waveguide and over-the-air scenarios, and to compare these measurements using different measurement devices.



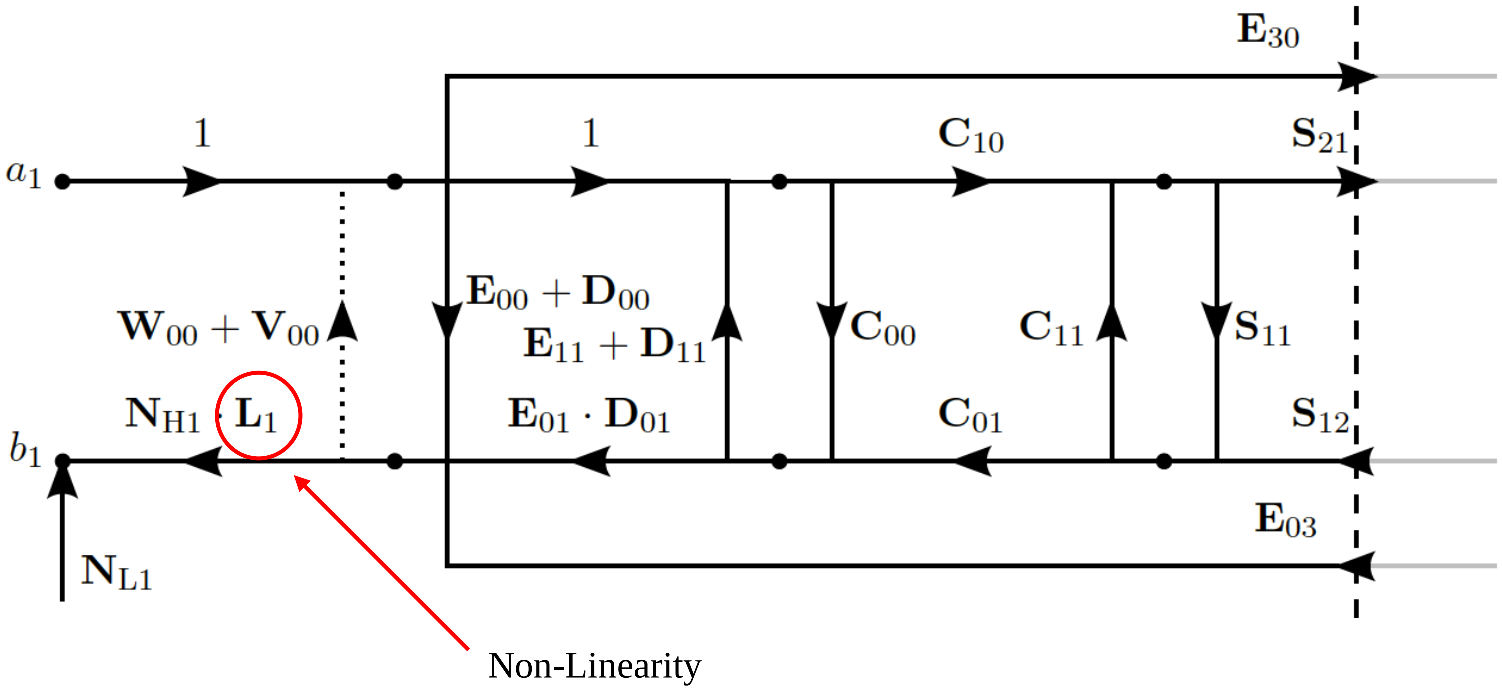
Channel Sounding System at 187.5 GHz, 8 GHz bandwidth at TU-Ilmenau



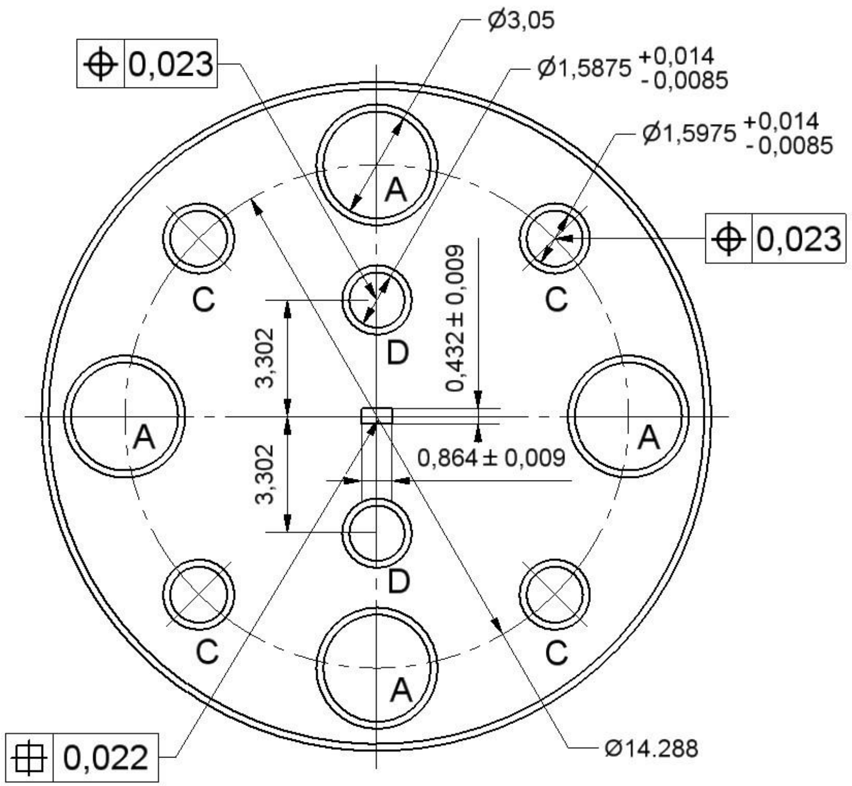
Channel Sounding System at 304 GHz, 8 GHz bandwidth at TU-Braunschweig

Verctor Network Analyzer at WR05, and WR03 frequency bands at PTB

VNA error corrections challenges at high frequency

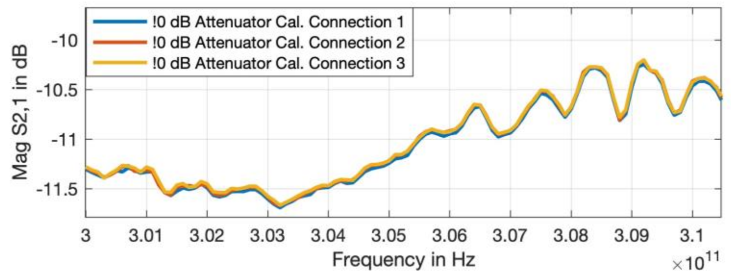


Extension of the seven-term VNA error model with additional terms

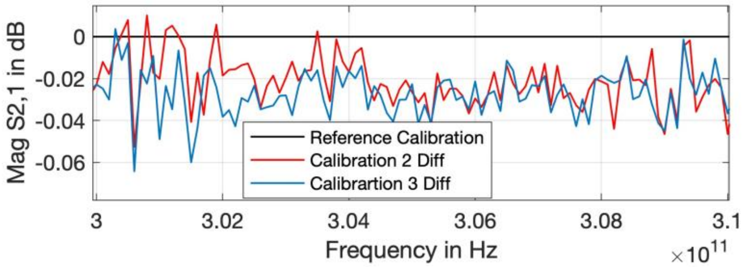


Drawing of shim of the R&S®ZV-WR03 with mechanical tolerances

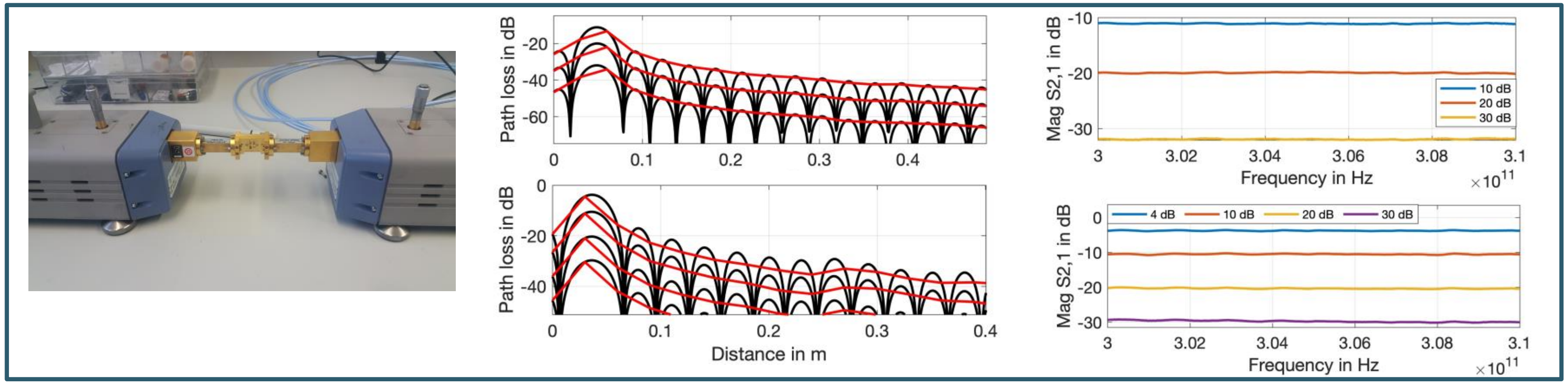
VNA error corrections challenges at high frequency



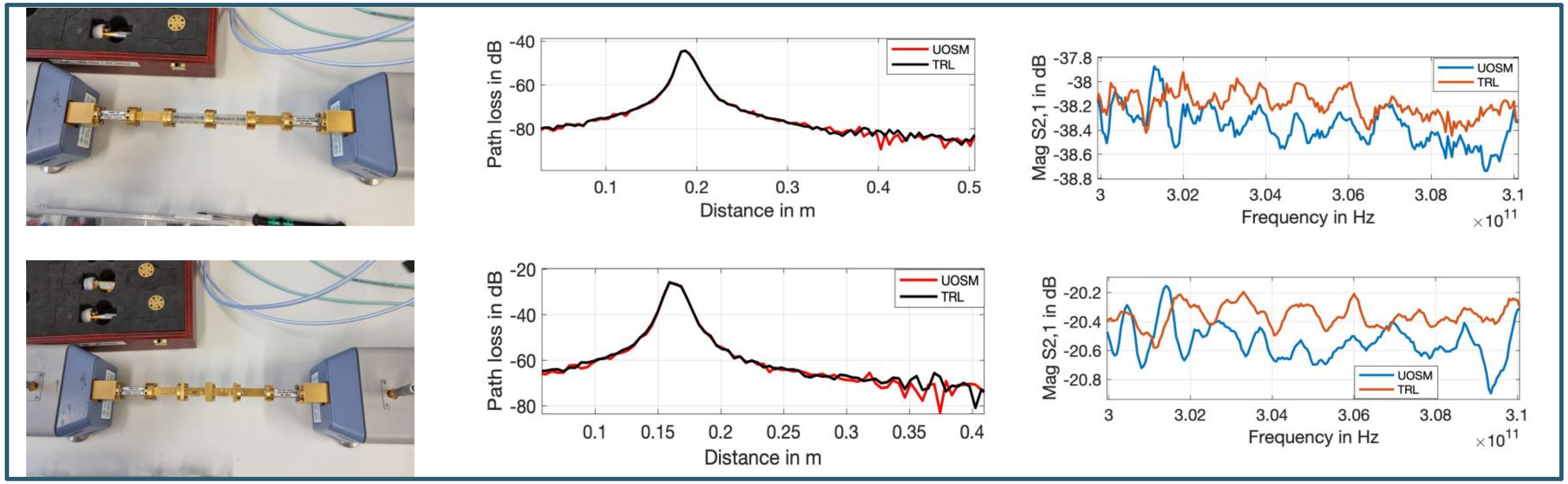
VNA TRL calibration and connection repeatability



VNA TRL calibration repeatability Difference



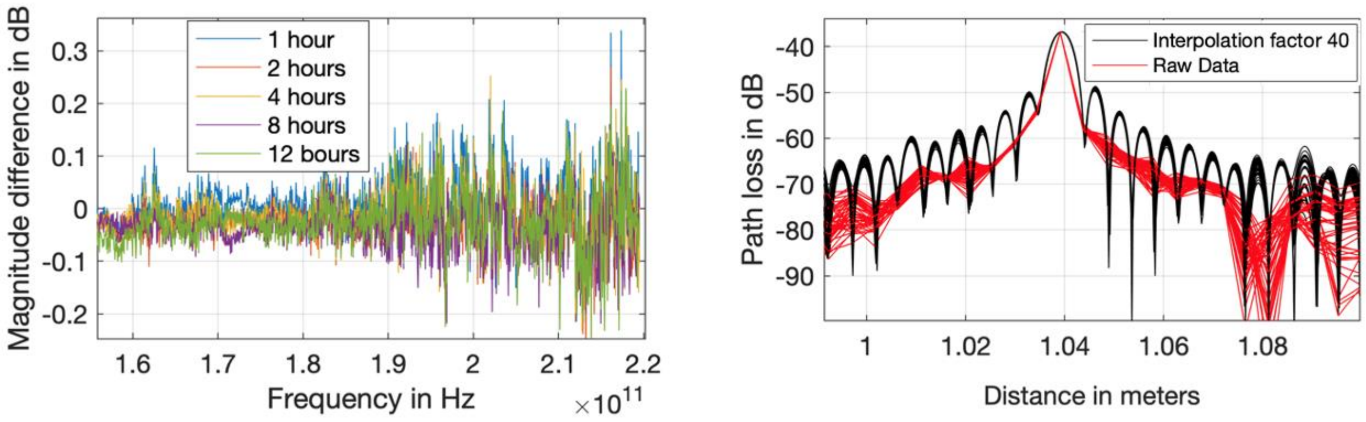
Characterization of different waveguide components and their PDP compared to their electrical length



Characterization of waveguide cascade components used in B2B calibration using TRL and UOSM standards

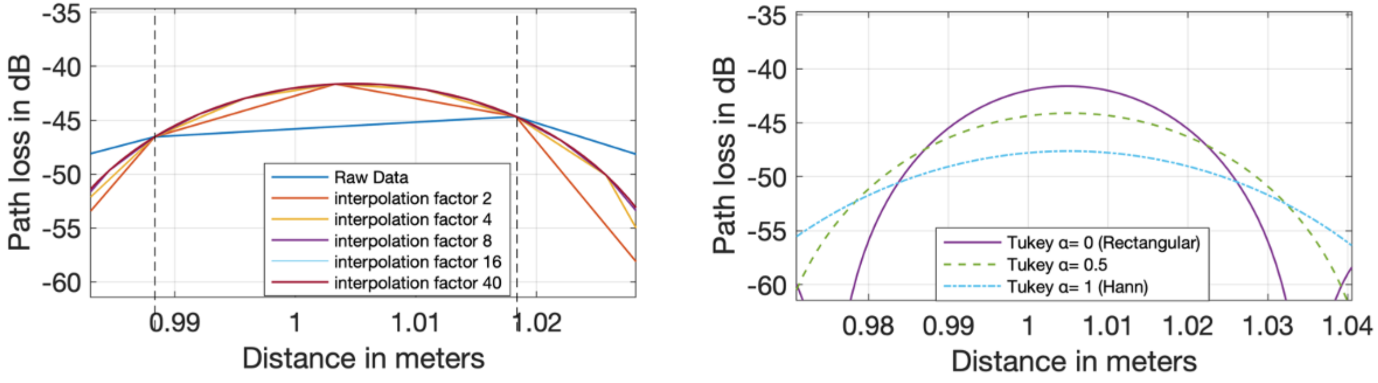
Narrowband Channel behaviour

- There are insufficient spatial points to correctly determine the peak location at the carrier frequency
- Bandwidth can be extended by adding zero values outside the operational range of the VNA
- Windowing increases the dynamic range and reduces in cross-coupling between points



(a) (b)

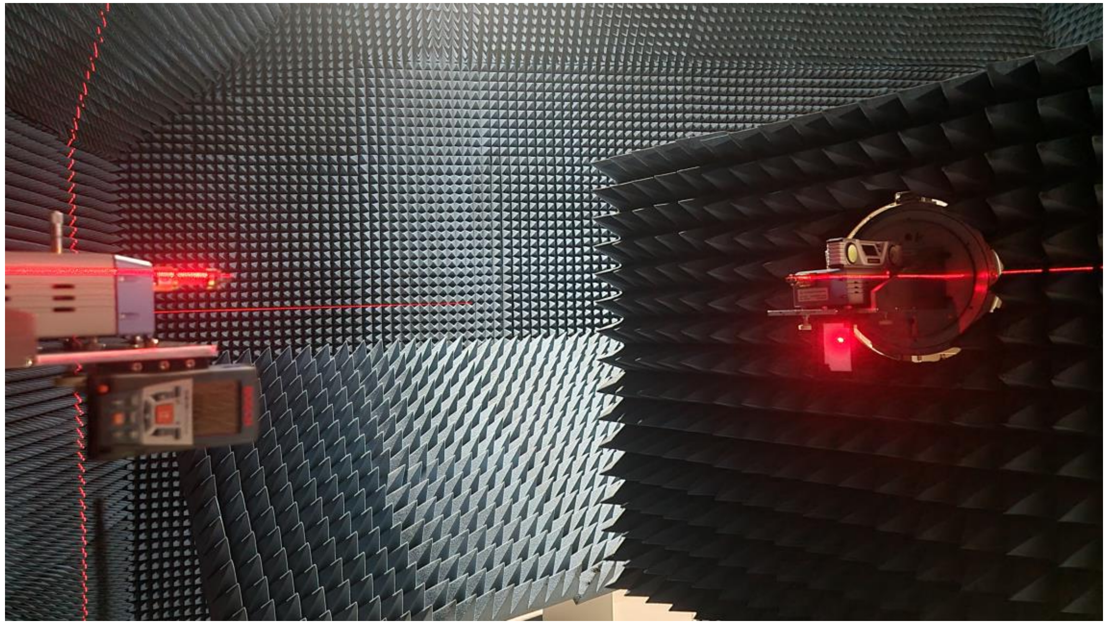
VNA drift measurement, at WR-05, 1 m spacing between antennas. (a) $|S_{21}|$ drift difference. (b) S_{21} PDP for 12 hours, with measurement sweep sequence at every 15 minutes.

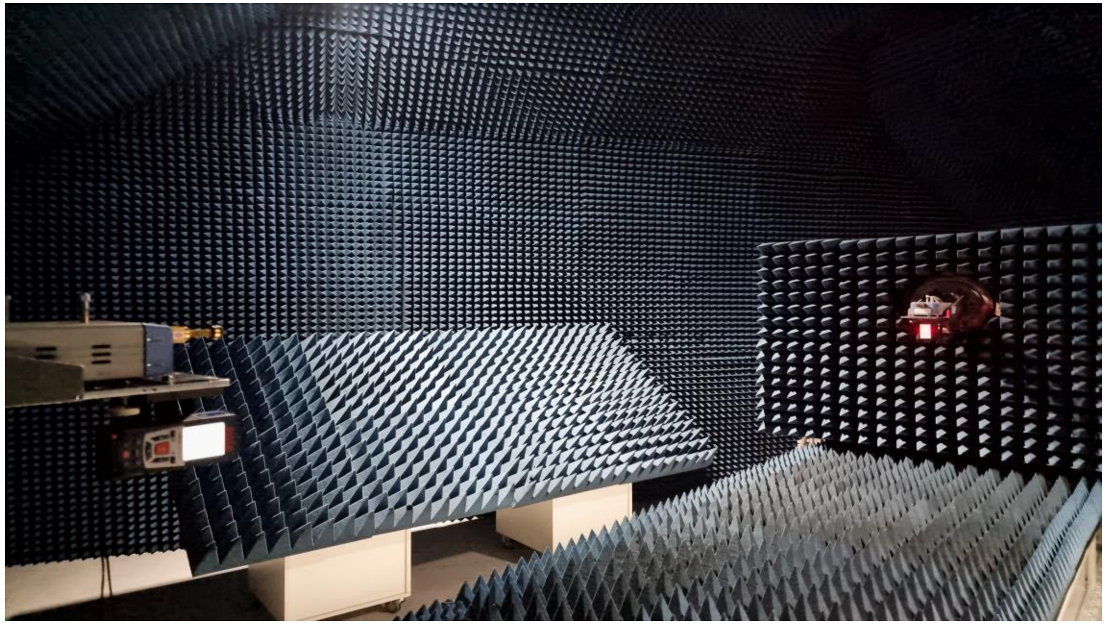


(a) (b)

The influence of windowing and interpolation on PDP peak at 1 m distance (a) S_{21} PDP measurement with zero-padding interpolation (b) different windows influence on PDP peak with factor 40 interpolation.

Distance Measurement Artifact



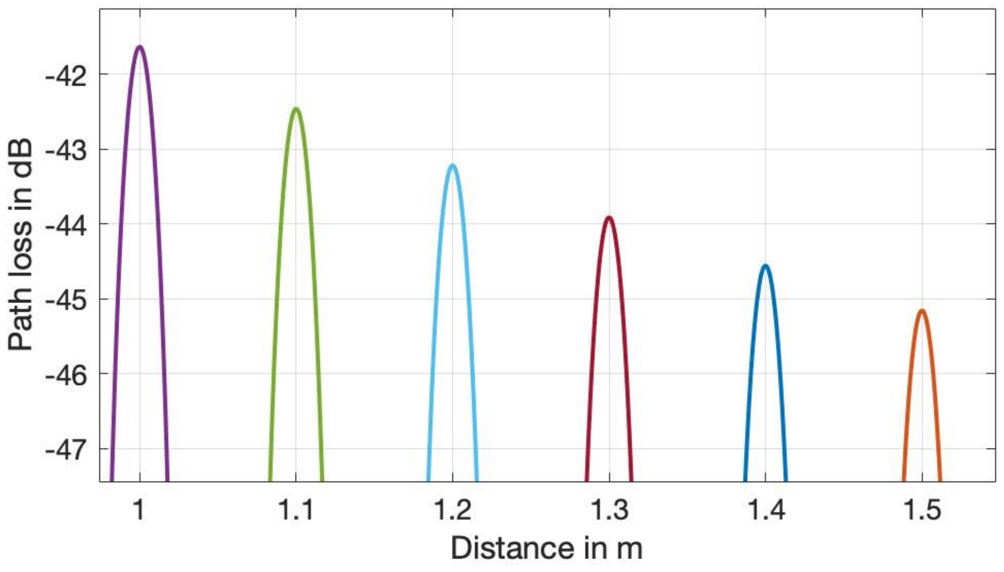


Distance measurement Performed at the antenna scanner room in PTB

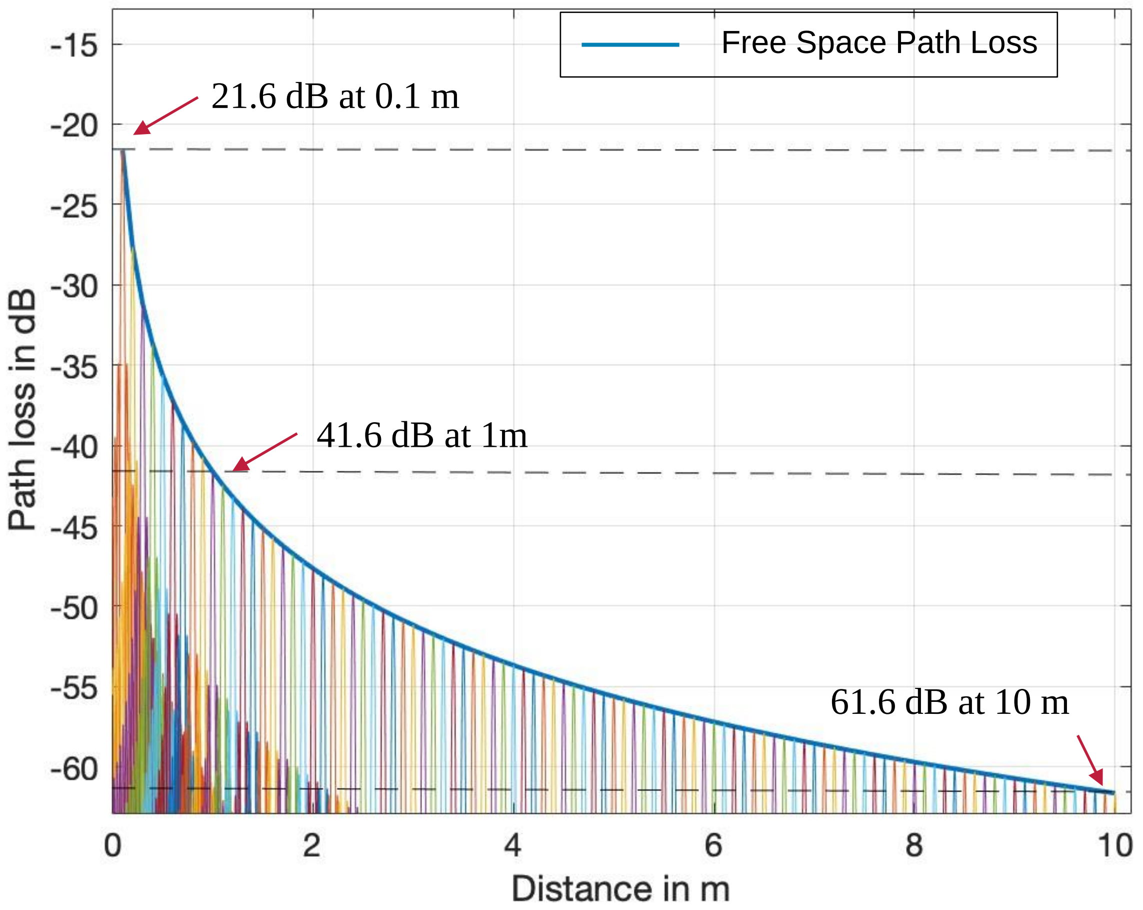
The measurements were recorded in a temperature controlled anechoic chamber at PTB. An automated control system varied the separation distance between the transmitter and receiver over the range (10 – 340) cm at 10 cm intervals. The initial separation measurement was made manually, and the subsequent results were reported by the instrumentation.

Distance Measurement Artifact

- Zero-padding allows manipulation of the Fourier-Transform Radix to improve computational efficiency.



Interpolated PDP simulation at factor of 40 for separation distances of 1 m – 1.5 m

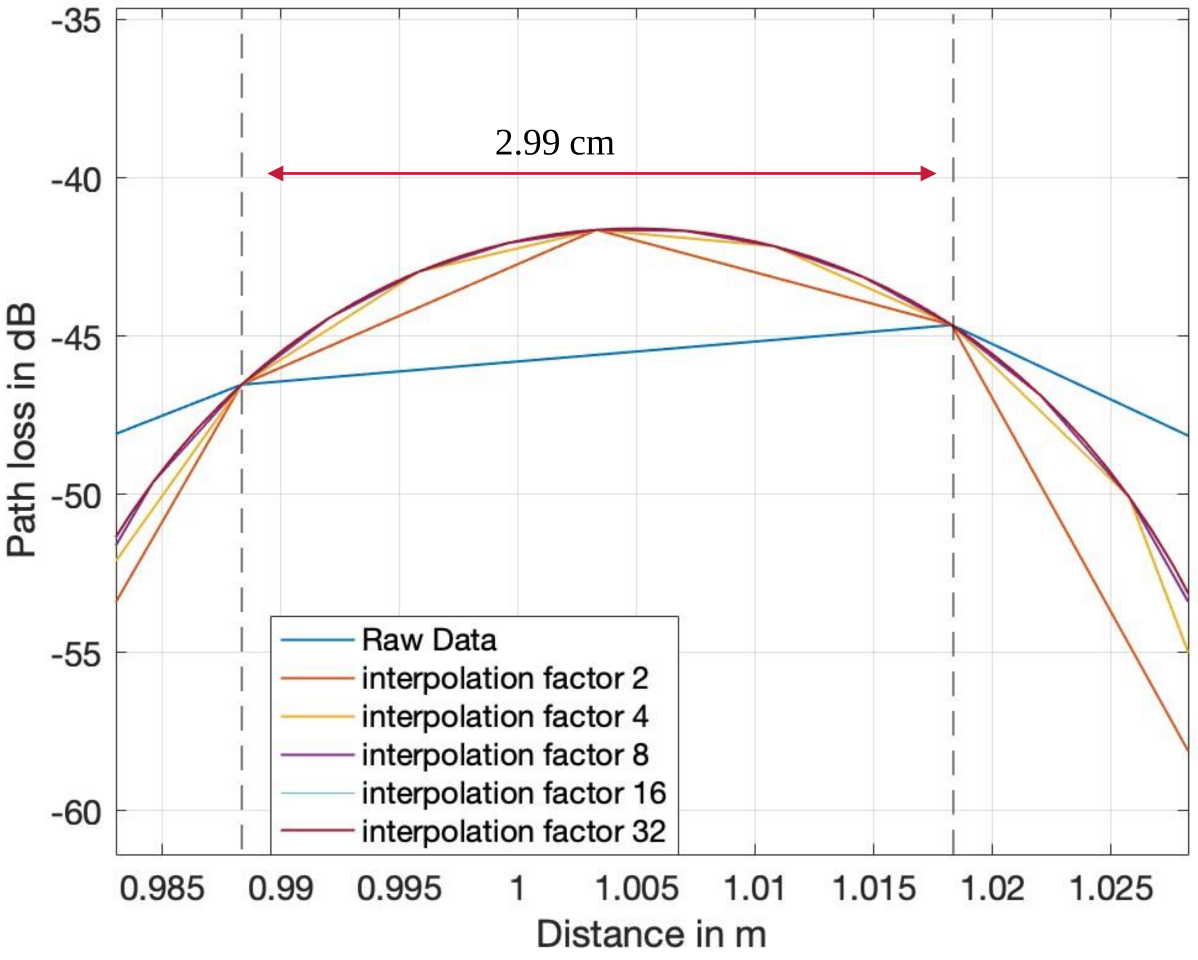


Interpolated PDP simulation at factor of 40 for separation distances of 0.1 m - 10 m

Distance Measurement Artifact

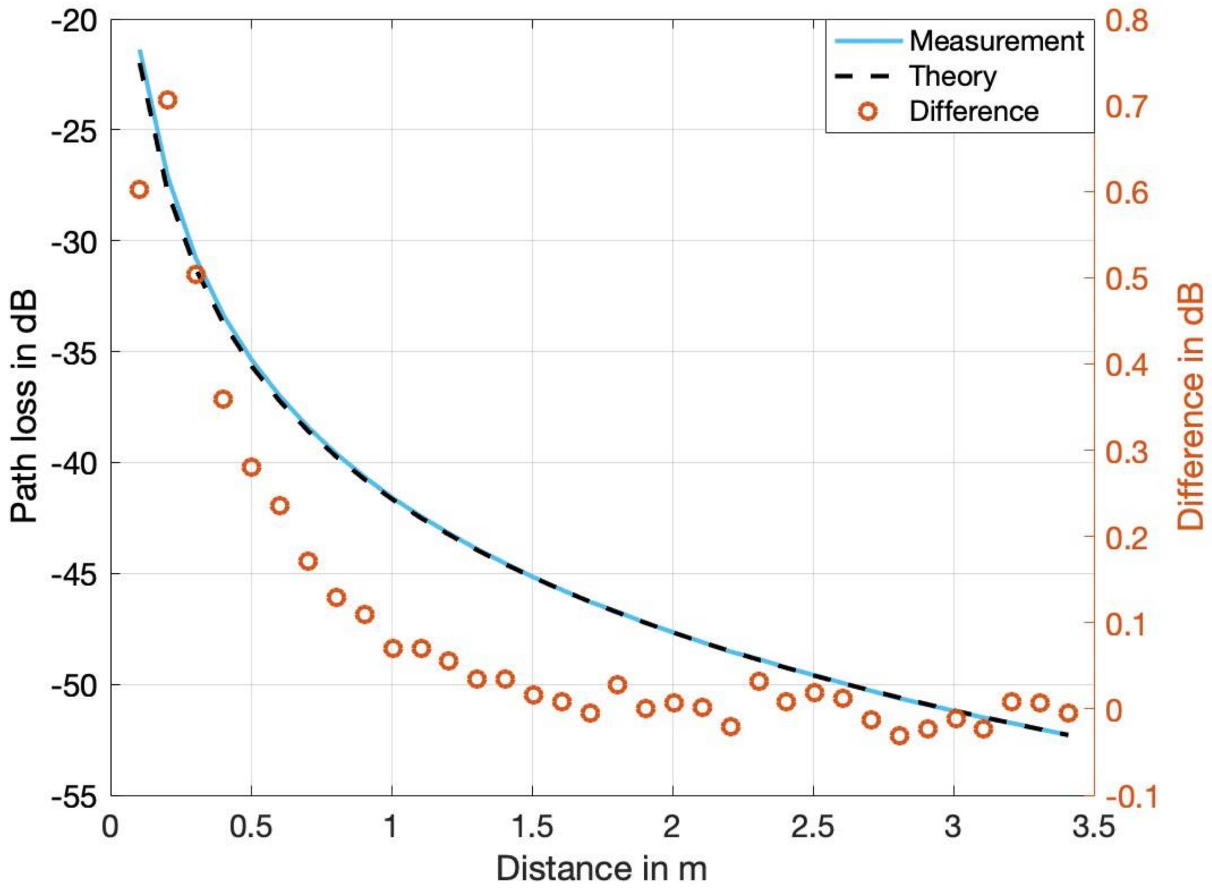
- The 10 GHz measurement bandwidth gives a time resolution of 100 ps, corresponding to a spatial resolution of 2.99 cm.
- The PDP peaks may not correspond to the spatial grid-points set by the measurement bandwidth.
- Zero-padding to extend the maximum frequency is a computationally efficient way to reduce the grid-spacing location of the PDP peak.

$$PDP = \left| IFFT\left(S_{21}(f)\, w(f)\right) \right|^2$$



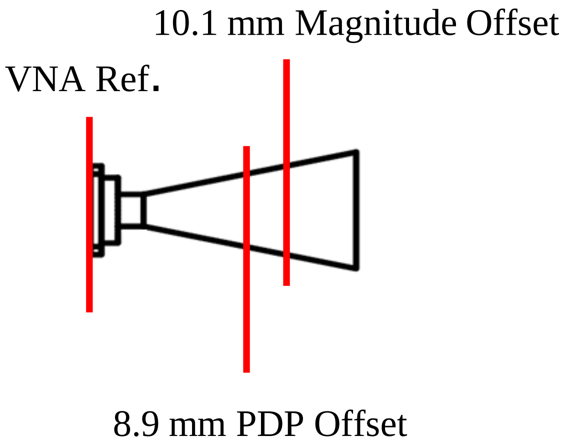
Raw data measurement and zero-padding grid-spacing for 1 m PDP

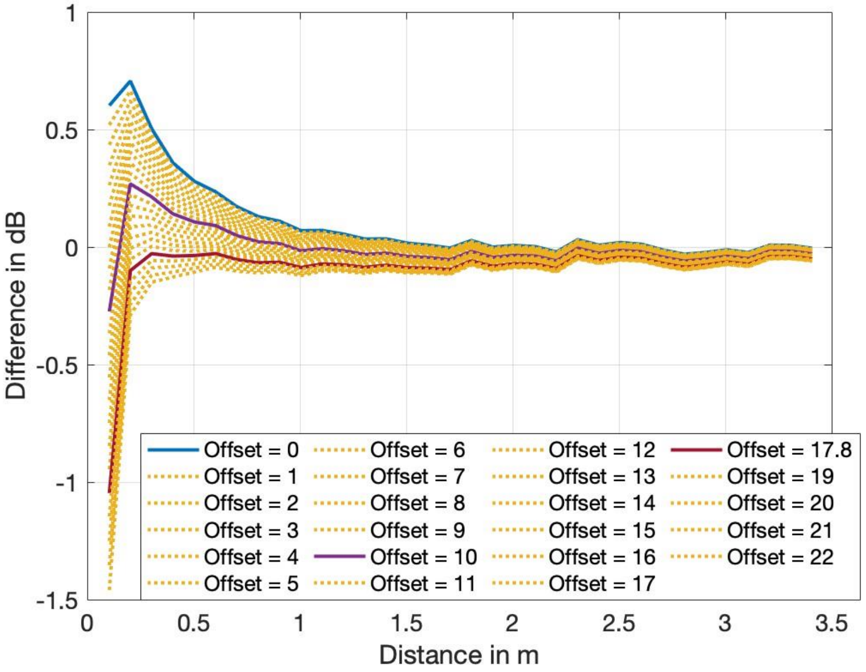
Distance Measurement Artifact



Theoretical and measured PDP path loss difference at 0.1 m – 3.4 m with interpolation factor of 40

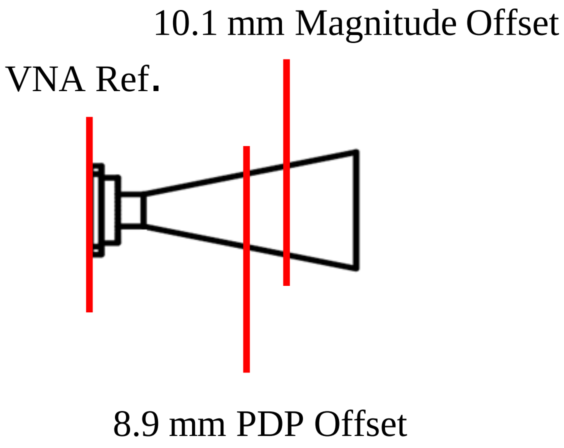
Distance Measurement Artifact

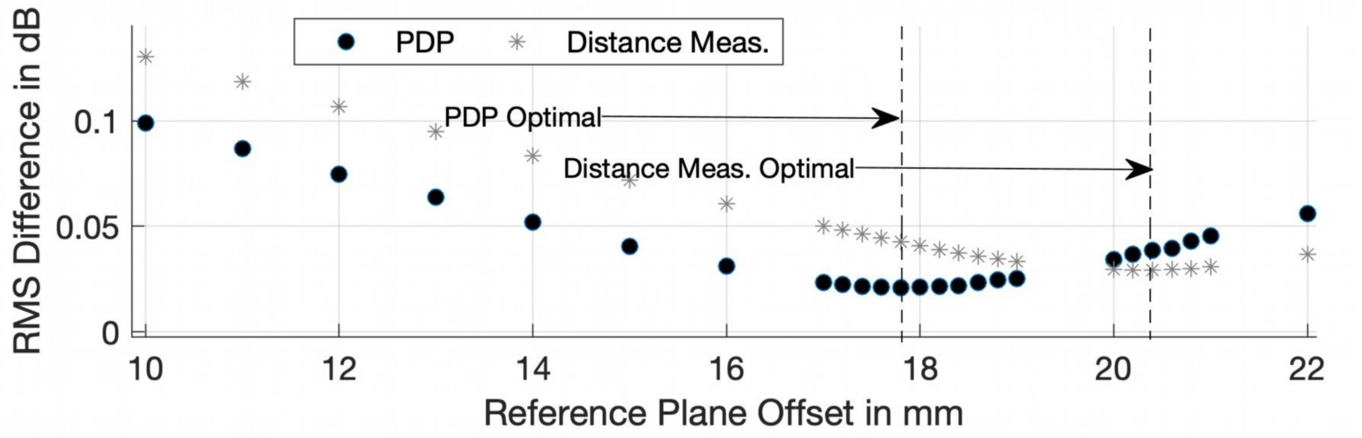




The optimized reference provided a rms fit improvement from 0.17 dB to 0.029 dB (measurement distance) and 0.021 dB (PDP).

Distance Measurement Artifact





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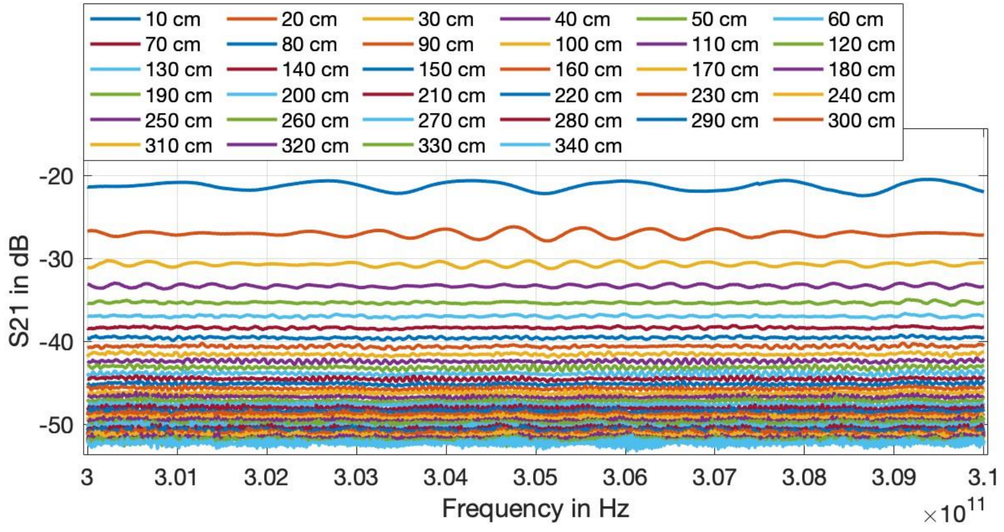
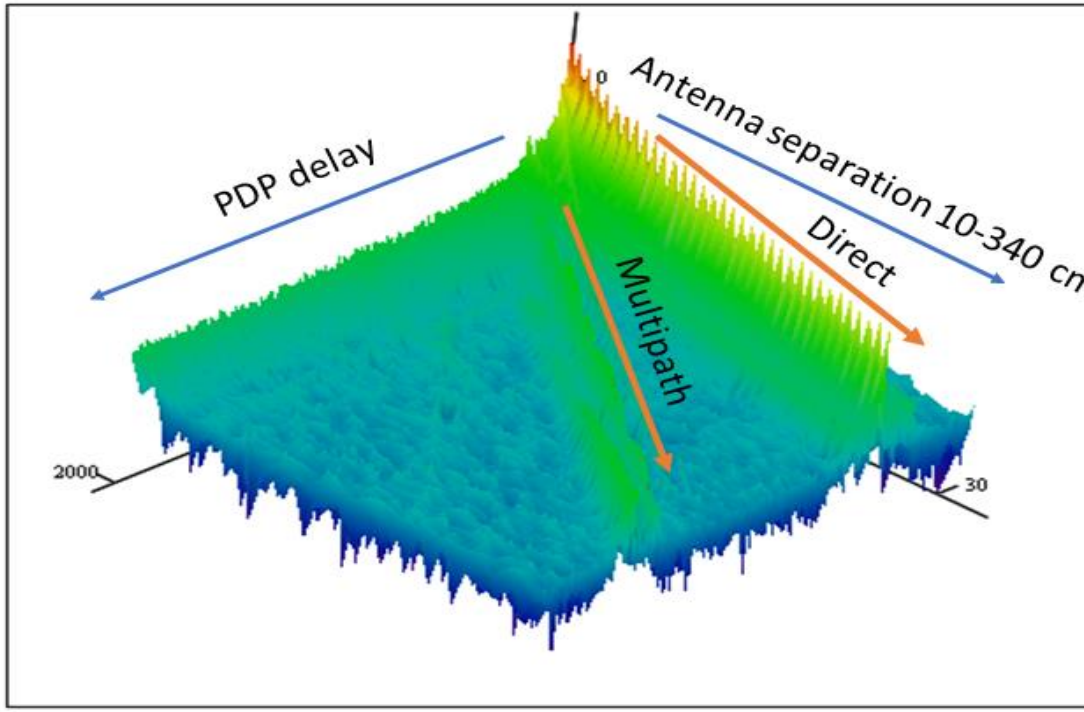
Distance Measurement Artifact



|S21| measurement results for separation distances of 10 cm -340 cm



300 GHz 3D PDP of all distance measurements showing multipath reflections

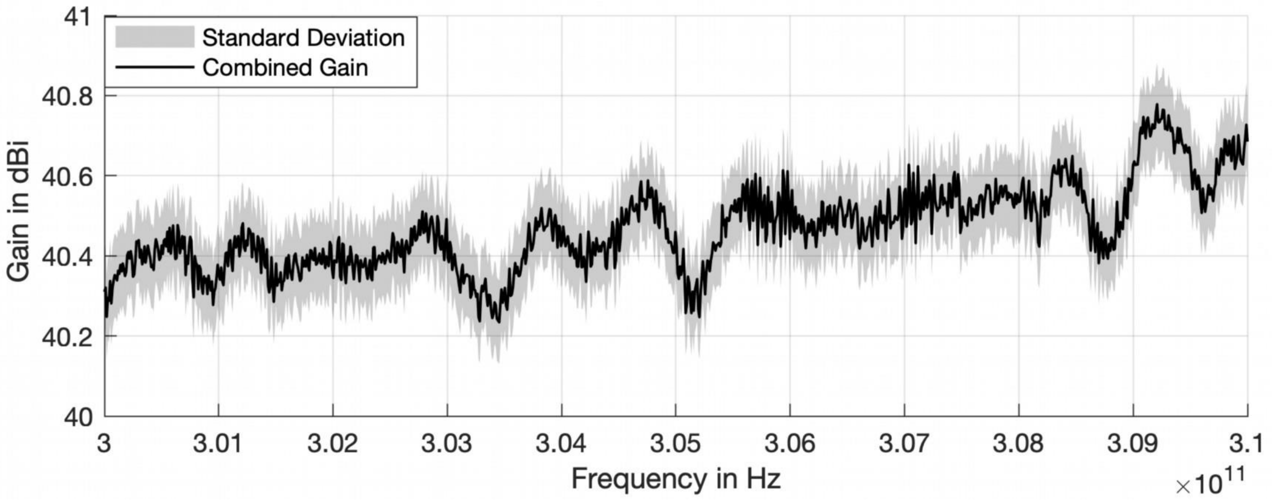
- Multiple reflections are present from the test system will affect channel estimation experiments, which is clearly seen in the difference between PDP and measured distance planes.

Distance Measurement Artifact

The antenna gain is constant regardless of the measured distance. The combined gain of the antennas $G(f)_{dBi}$ is an average value of the Friis calculation leading to:

$$G(f)_{dBi} = \frac{1}{n}\sum_{i=1}^{n} S_{21}(f, d_i)_{dB} - PL_{corr}(f, d_i - \Delta d)_{dB}$$

Where $S_{21}(f, d_i)_{dB}$, and $PL_{corr}(f, d_i - \Delta d)_{dB}$ are the VNA transmission results and the calculated path loss at each of the n antenna separation values, corrected for the reference plane offset Δd.

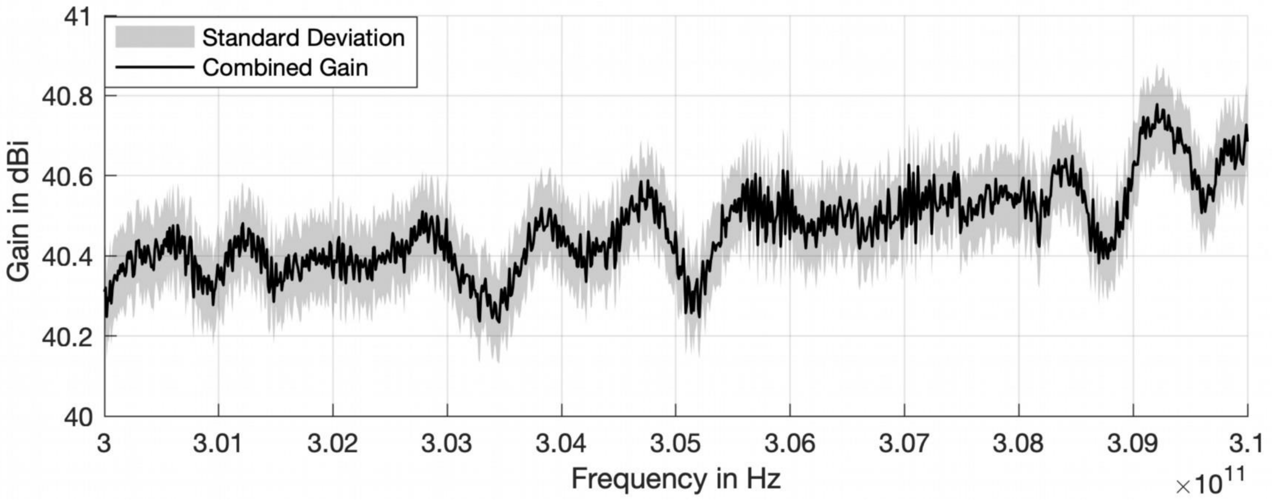


Combined antenna gain calculated using measured transmission (VNA S21) at all antenna separation values

Distance Measurement Artifact

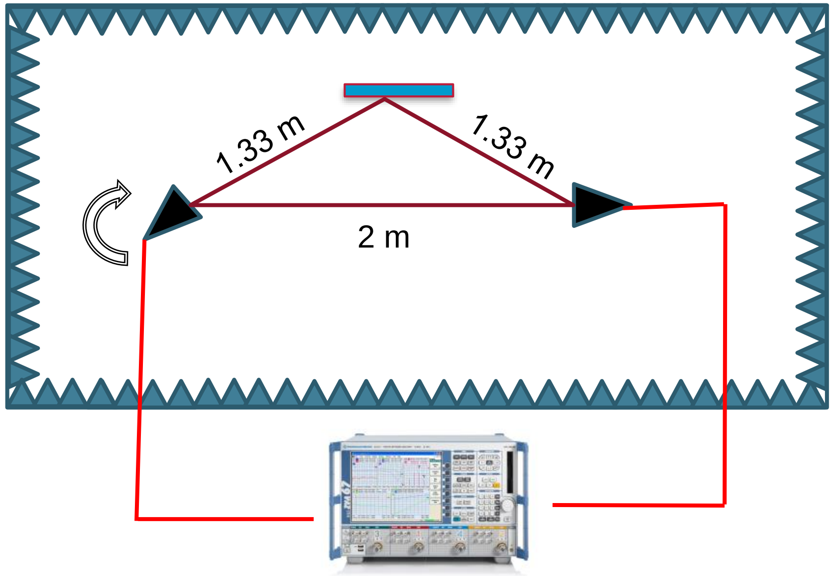
The mid-frequency of combined antenna gain, calculated from this dataset, was (40.44 $\pm$ 0.09 dB at 95% confidence.

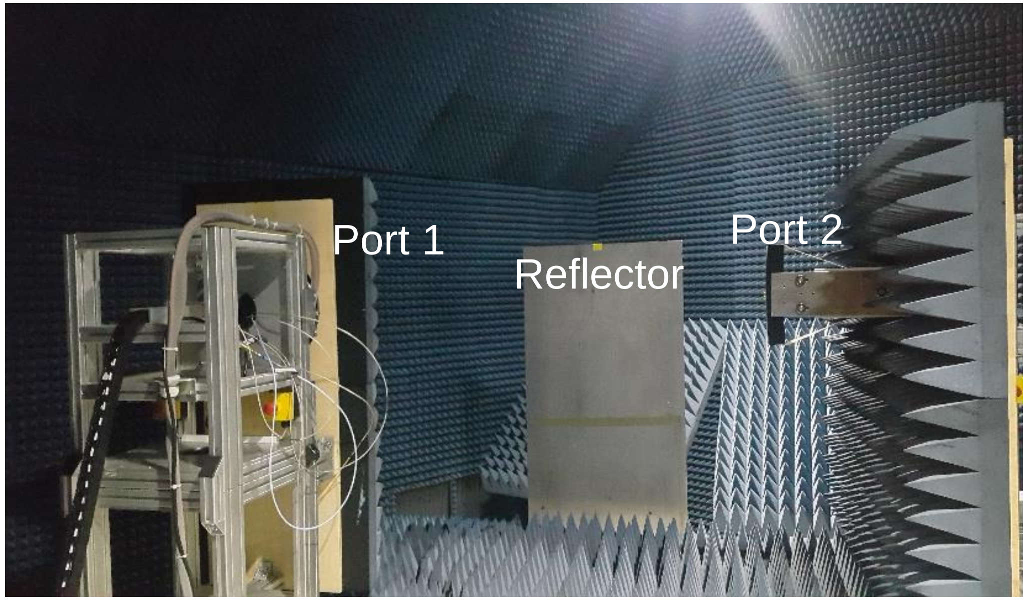
The standard horn has an increasing gain slope towards increasing frequency with a slope of 0.027 dB/GHz



Combined antenna gain calculated using measured transmission (VNA S21) at all antenna separation values

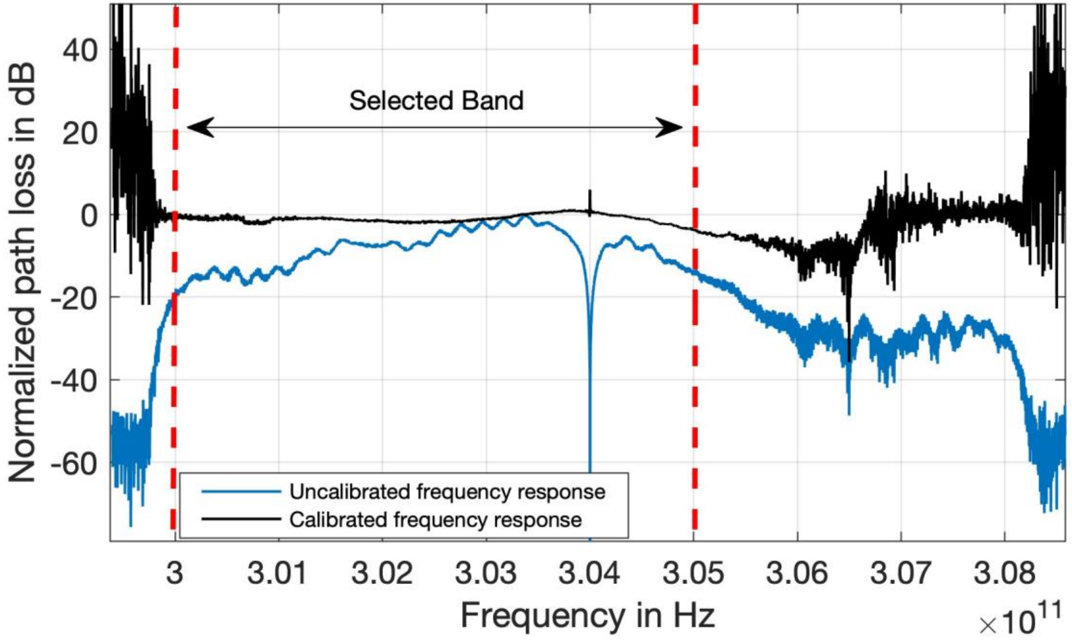
Multi-Path Measurement Artifact



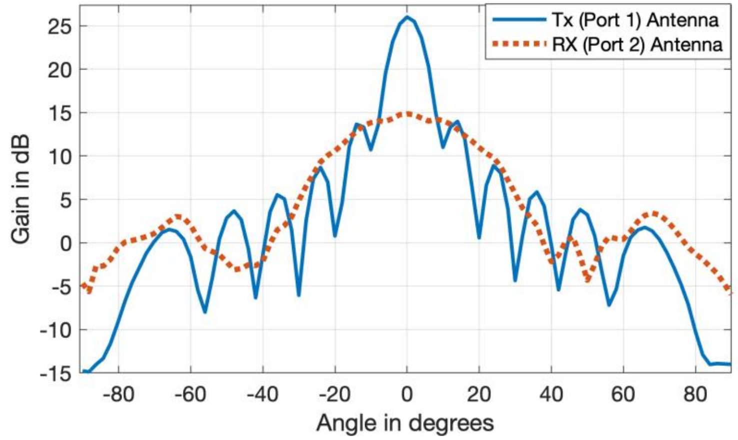


Measurement setup using ZVA-Z325TM frequency converters and the Correlational Based channel sounder placed on controlling motors holders. Port 1 antenna rotates in different angles with 2 m separation distance from Port 2

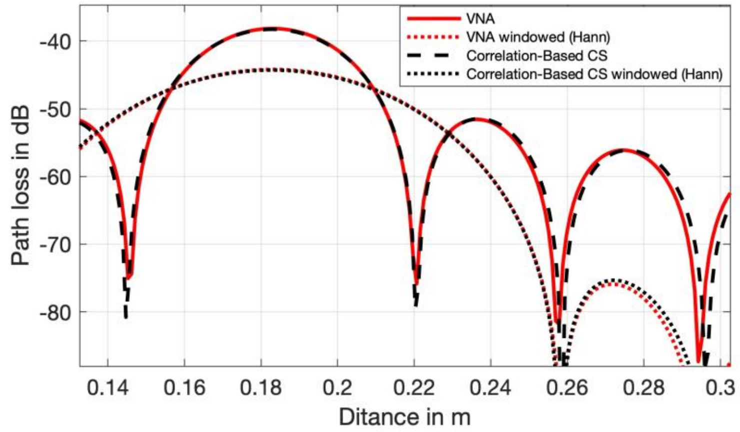
Multi-Path Measurement Artifact



Channel sounder's frequency response at 2 m OTA, 0 degrees without and with back-to-back calibration

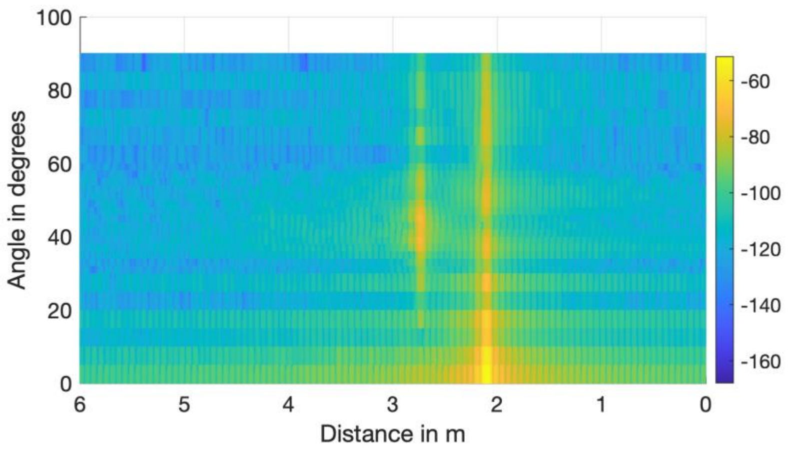


Transmitter and receiver E-plane radiation pattern

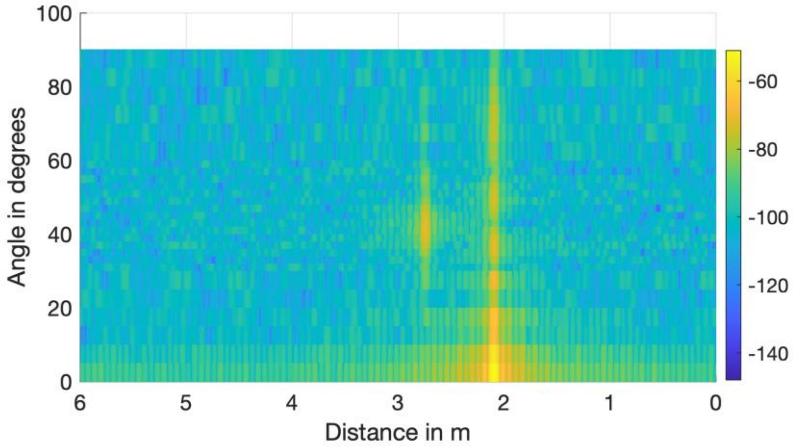


Reference waveguide PDP measurement using VNA and CS

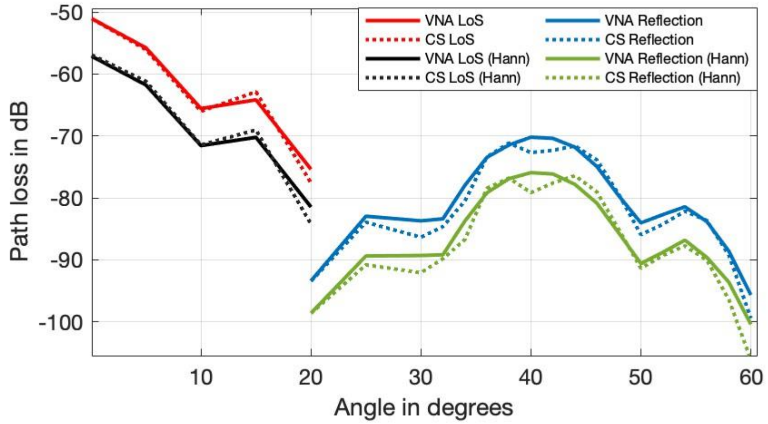
Multi-Path Measurement Artifact



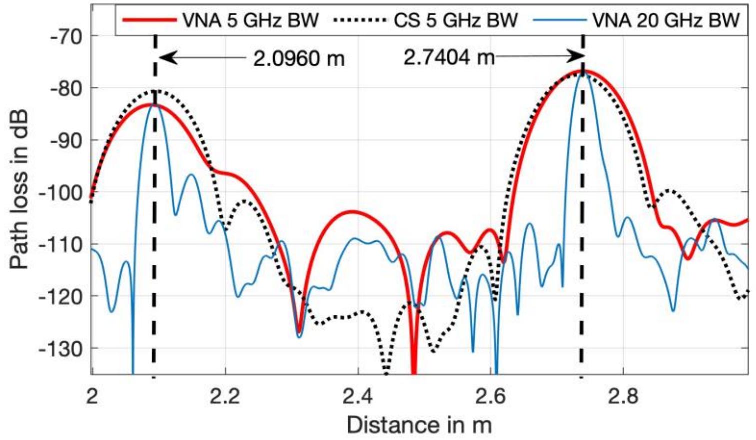
CS LoS and reflection at different angles



VNA LoS and reflection at different angles



VNA and CS measured path loss based on PDP LoS and Reflection peaks



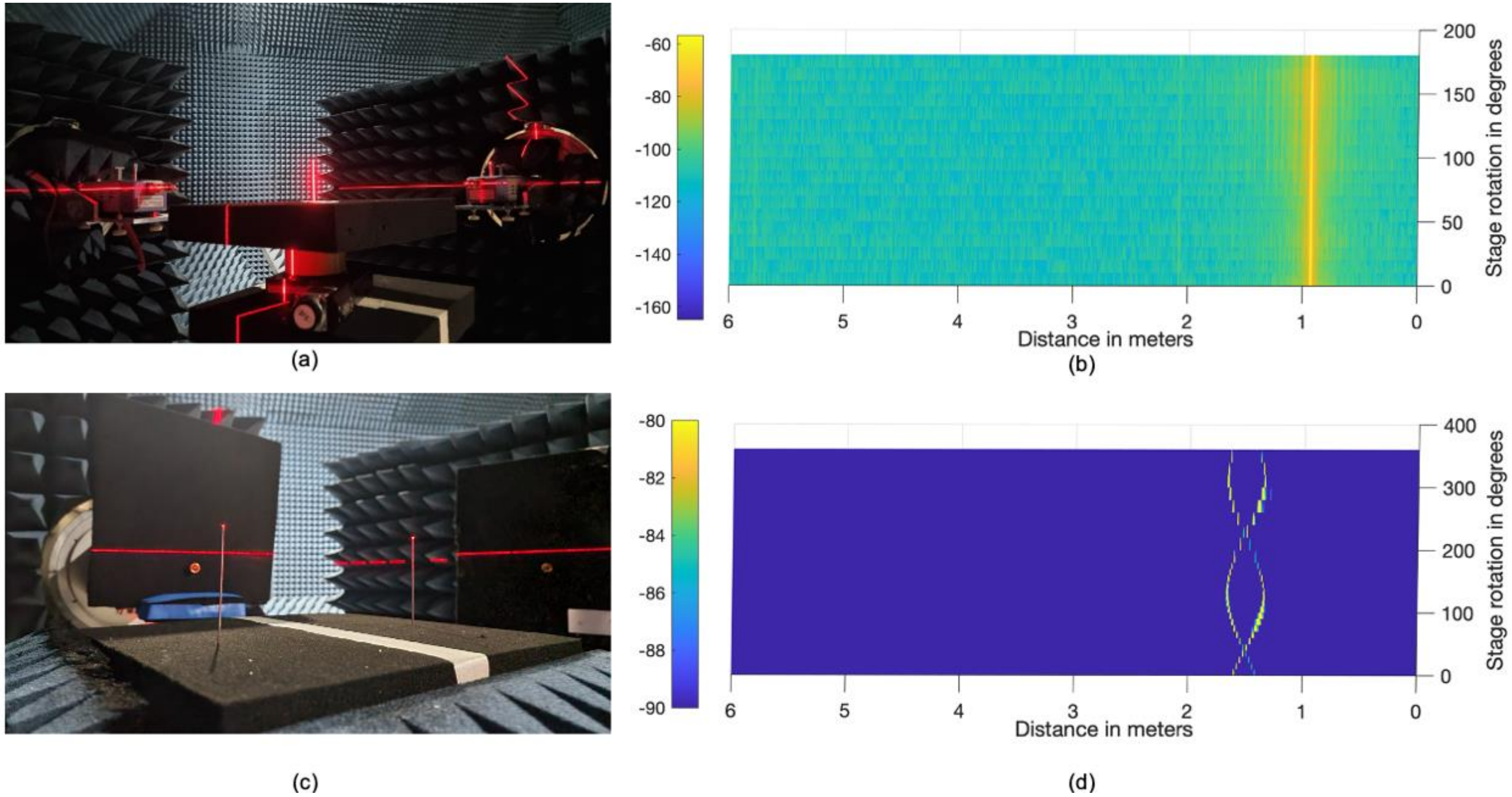
PDP at 40 rotational angle showing LoS and reflection peaks

Multi-Path Measurement Artifact

- Different sphere sizes of 10 mm – 6 mm diameter and a 1.5 mm diameter thin wire of 10 mm length have been tested.

- The measurements were performed using the channel sounder systems and the VNA extension modules at WR05 and WR03 frequency bands.

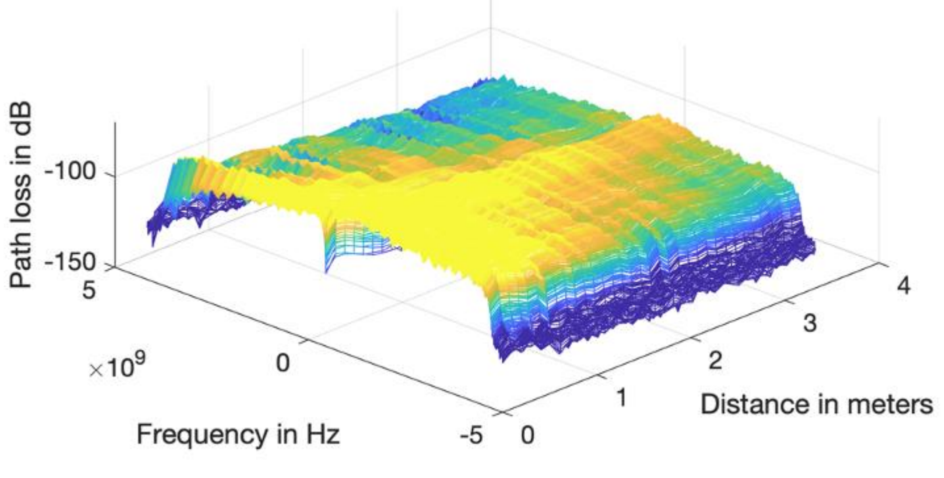
- The Channel sounders produced an acceptable result on the estimation of the expected multi-path components, showing a higher sensitivity to the measurement bandwidth.



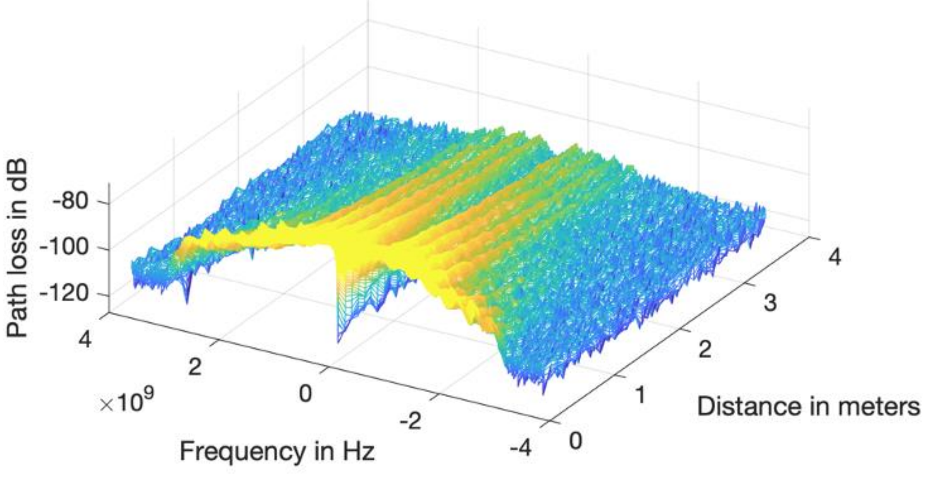
(a) Photograph of single wire measurements, (b) Single wire reflective radiation at different rotations (c) Photograph of two wire measurements (d) Two wires reflective radiation at different rotations.

Channel Sounding Spectrum Investigation

- The channel sounding systems measured bandwidth at different separation distances
- The filtering be applied using a rectangular window to cut the spectrum noisy boundaries
- Hanning window used for the mid-spectrum to smooth the autocorrelated signal



(a)

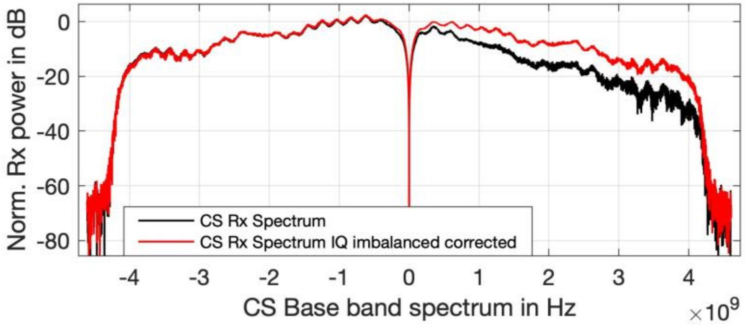


(b)

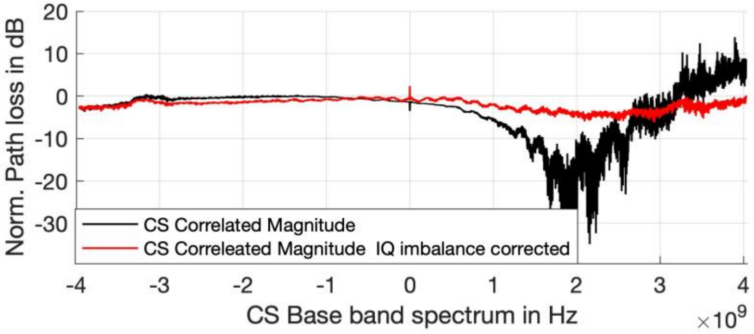
Channel sounder double side bandwidth for distance separations (10 - 350) cm (a) WR-03 (b) WR-05

Channel Sounding Spectrum Investigation

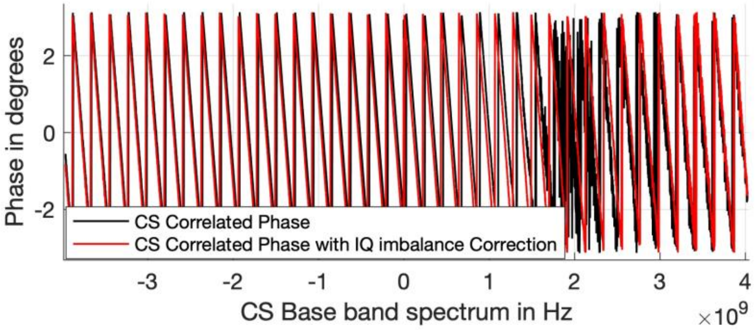
- The channel sounding systems suffered from IQ imbalance which is clearly visible from the double-side spectrum asymmetry
- IQ correction was applied for each measured distance
- The IQ imbalance correction helps to extend the channel sounder spectrum correction after calibration
- Data analysis is on going



WR03 Channel sounder Rx signal at 1,3 m magnitude before Calibration



WR03 Channel sounder Rx signal at 1,3 m magnitude after Calibration



WR03 Channel sounder Rx signal at 1,3 m phase after Calibration

Conclusion

- Measurement verification was performed using theory represented by Friis path loss and using the VNA as a reference measurement device.

- The Sinc (x) interpolation of the measured distances has been applied and showed an improvement in the corrected PDP estimation.

- Multiple reflections are present from the test system will affect channel estimation experiments, which is clearly seen in the difference between PDP and measured distance planes.

- The multi-path measurement showed a good match in PDP comparison between the VNA and the channel sounder.

- The IQ imbalance correction helps to extend the channel sounder spectrum correction after calibration.

Thank you very much for your Attention

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Universität Stuttgart

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