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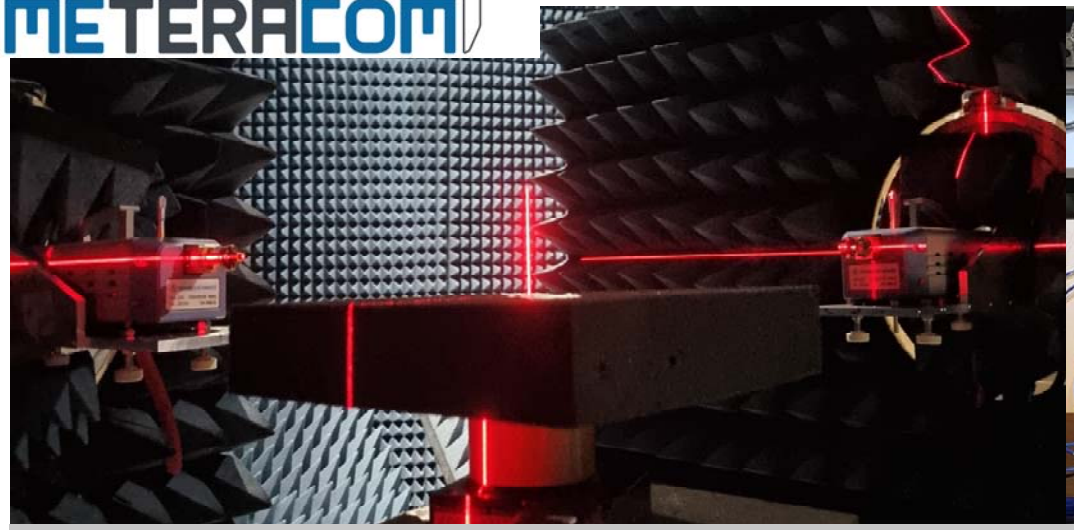
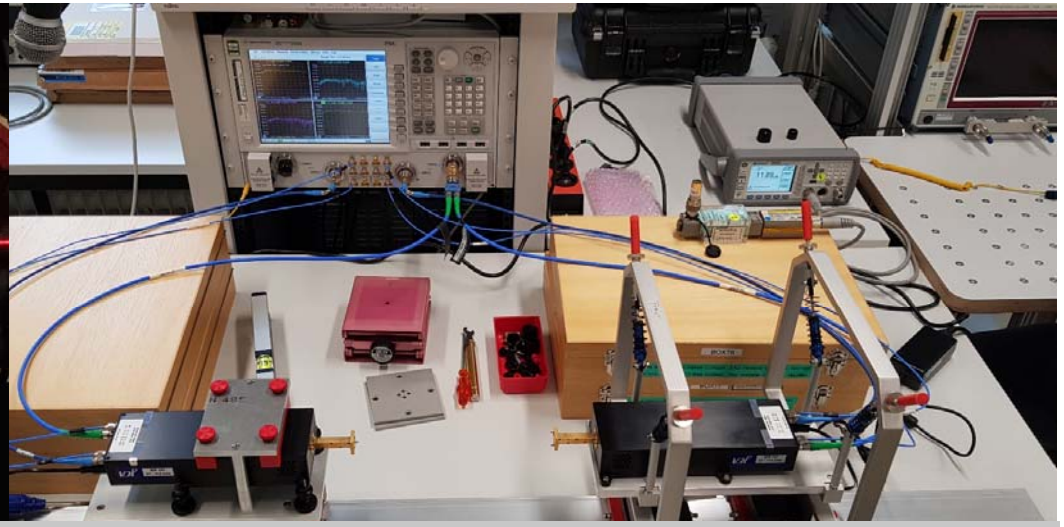
Metrology for THz Communications

2024 DUISBURG
GeMiC
German Microwave Conference

METERACOM





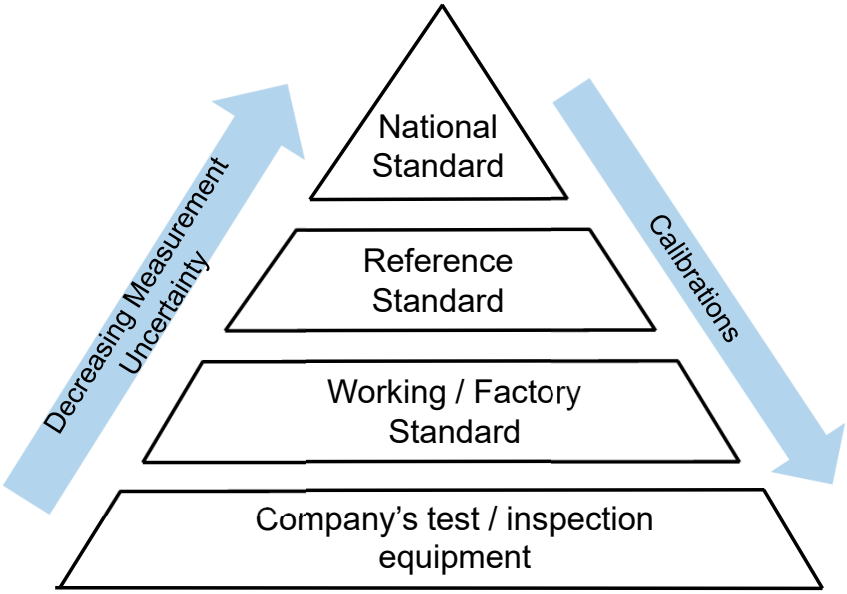
Traceability Challenges for Sub-THz Channel Sounding

Mohanad Dawood Al-Dabbagh, Diego Dupleich, Tobias Doeker, Thomas Kleine-Ostmann, David Humphreys, Reiner S. Thomä, Thomas Kürner

2nd International Workshop on Metrology for THz Communications, Duisburg, 12 March 2024

Introduction

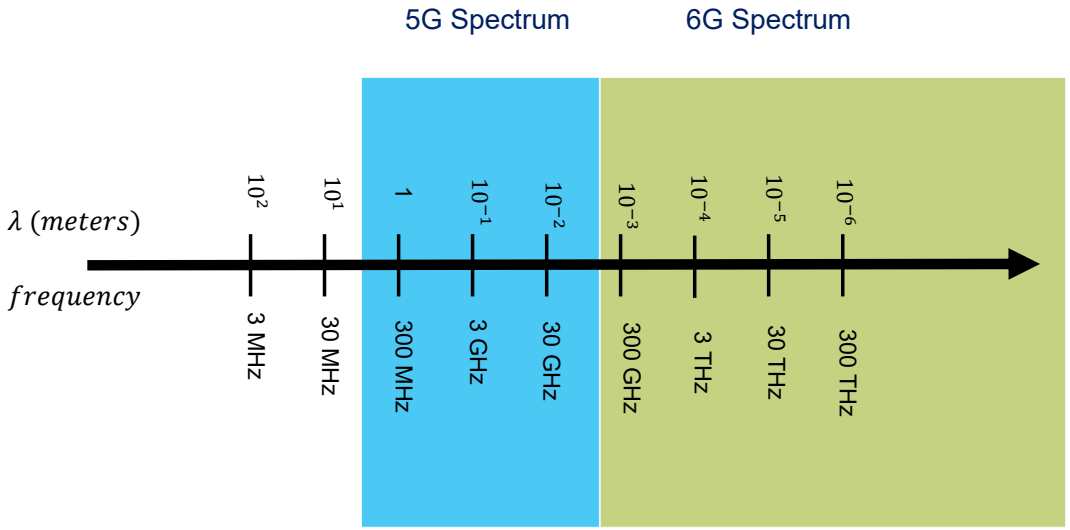
- Measurement traceability is defined as “the property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties” [1].
- The VNA can be used as a reference measurement device to reach traceability via the calibration standards.
- Comparison into a reference device can rule out the environmental influences related to multi-path, and absorptions.
- Theoretical Calculations can also be used as a reference to verify the measured values.



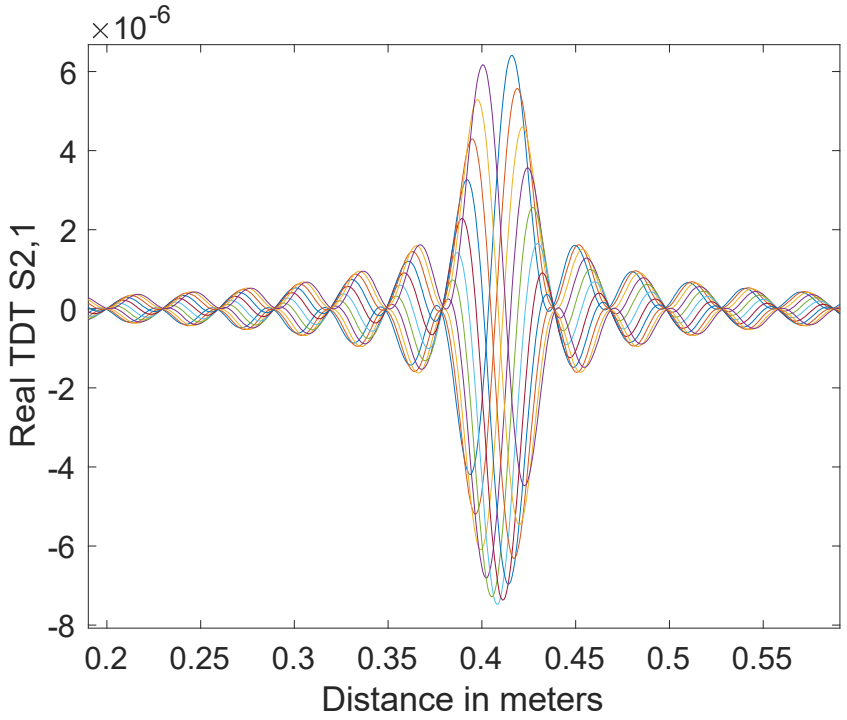
Measurement Traceability Steps

[1] International Organization for Standardization. International Vocabulary of Basic and General Terms in Metrology. 2. Geneva, Switzerland: ISO; 1993.

Introduction

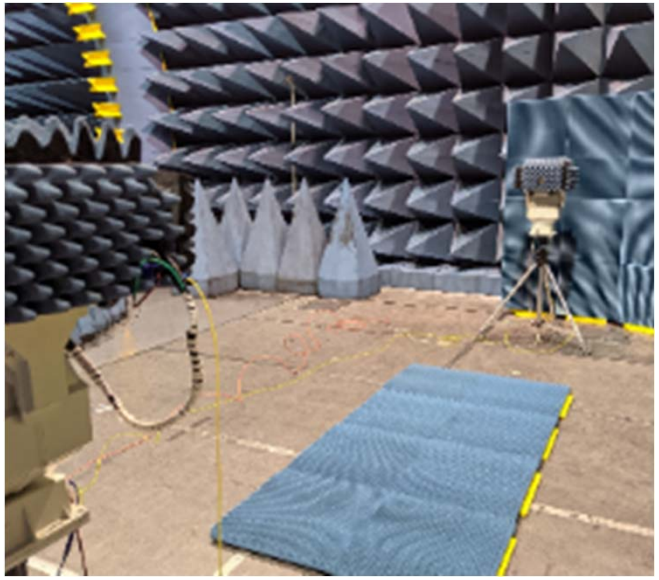


5G, and 6G spectrum bands and wavelength

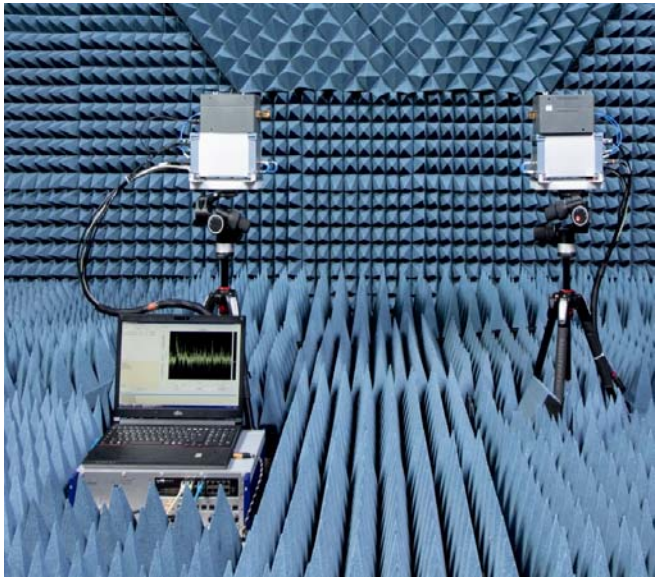


1 mm shift influence on the real time domain impulse response transmission with 0.1 mm step, 10 GHz BW, at 305 GHz

Sub-THz Channel Measuring Systems



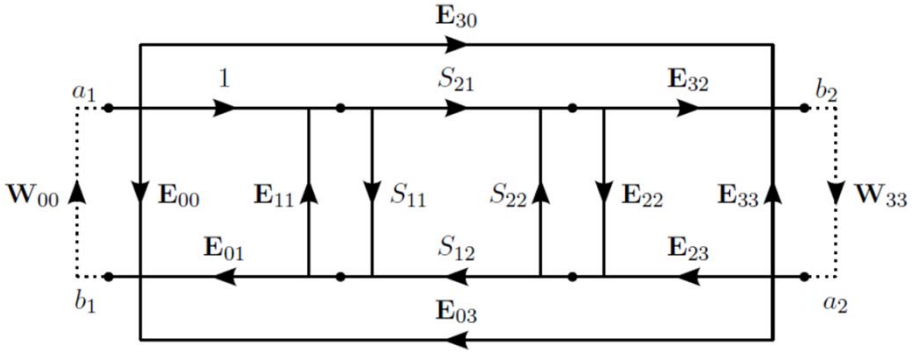
Channel Sounding System at 187.5 GHz, 7.5 GHz bandwidth at TU-Ilmenau



Channel Sounding System at 304 GHz, 9.2 GHz bandwidth at TU-Braunschweig

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

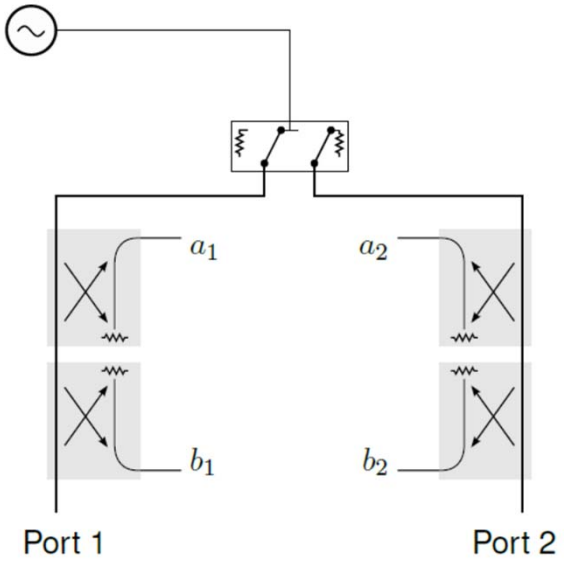
VNA Error Model



The seven-term VNA error model

List of error coefficients of seven-term error model.

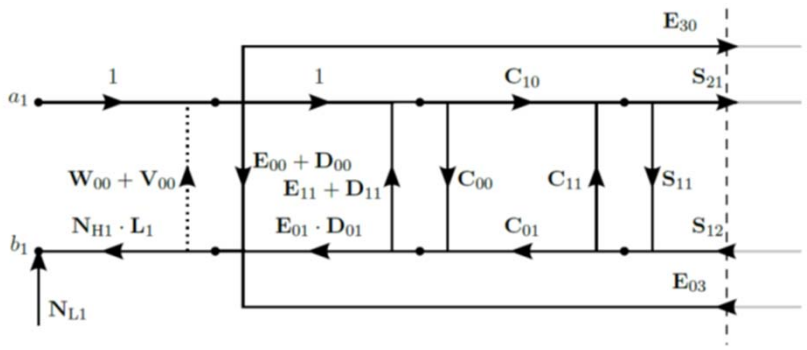
Symbol		Error Coefficient
Forward	Reverse	
E_{00}	E_{33}	Directivity
E_{01}	$E_{32}E_{23}$	Reflection tracking
E_{11}	E_{22}	Source match
E_{30}	E_{03}	Isolation
W_{00}	W_{33}	Switch terms



Four-receiver VNA architecture.

[2] Zeier, M., D. Allal, and R. Judaschke. "EURAMET Calibration Guide No. 12: Guidelines on the Evaluation of Vector Network Analysers (VNA)." European Association of National Metrology Institutes, Braunschweig 3.

VNA Additional Error Terms



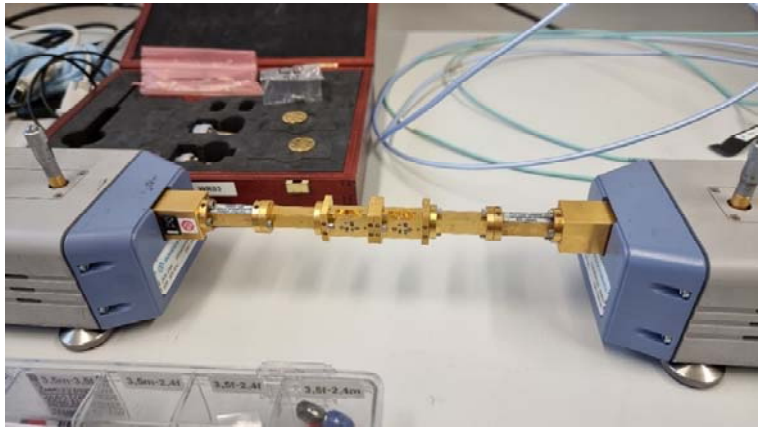
The two-port VNA measurement model of Port 1

List of additional influence quantities in the measurement model

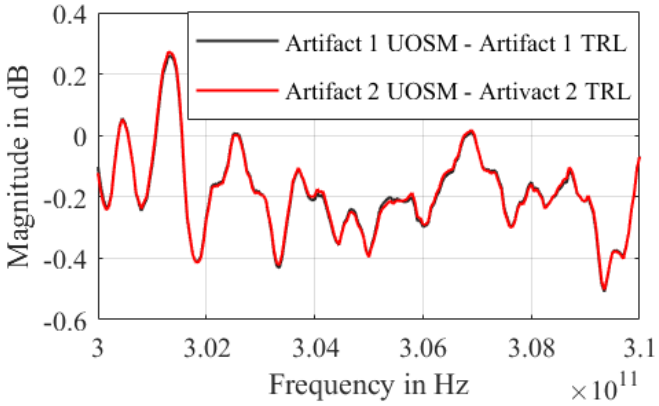
Symbol	Description
N_L	Noise Floor
N_H	Trace Noise
L	Non-Linearity
D_{00}	Drift of Directivity
D_{01}	Drift of reflection Tracking
D_{11}	Drift of Source Match
$C_{00}C_{11}$	Reflection of Cable and connector
$C_{01}C_{10}$	Transmission of cable and connector

[2] Zeier, M., D. Allal, and R. Judaschke. "EURAMET Calibration Guide No. 12: Guidelines on the Evaluation of Vector Network Analysers (VNA)." European Association of National Metrology Institutes, Braunschweig 3.

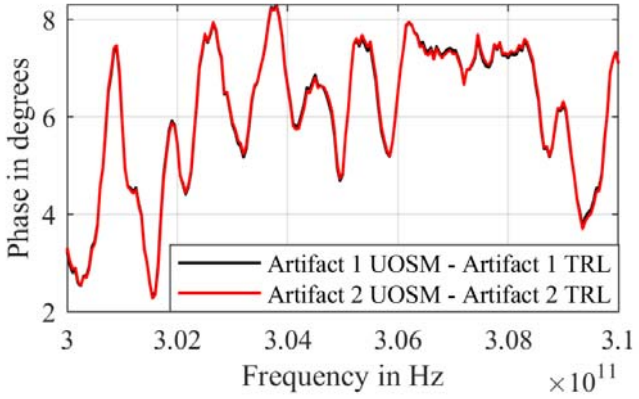
VNA Calibration Standards



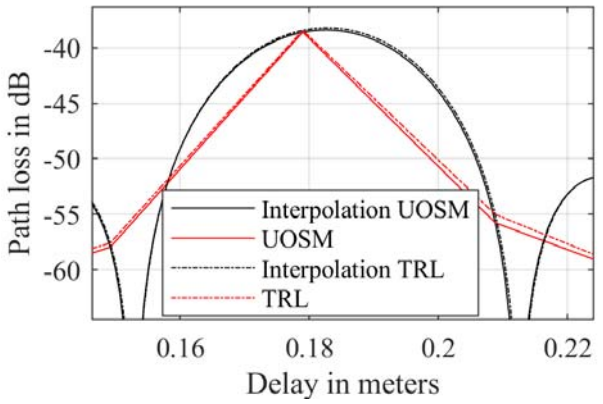
VNA WR03 Waveguide Artifact



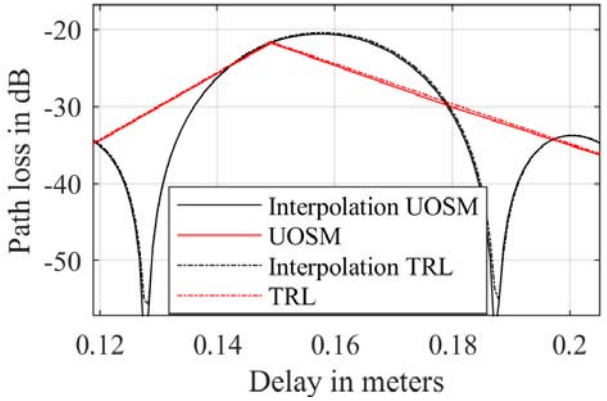
Change of different Calibrations



Phase Change of different Calibrations

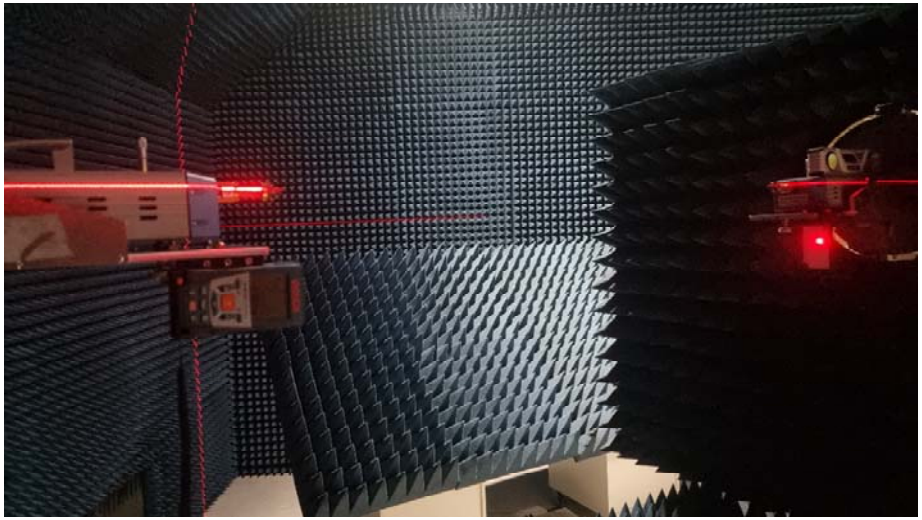


PDP of Artifact 1using Different Calibrations

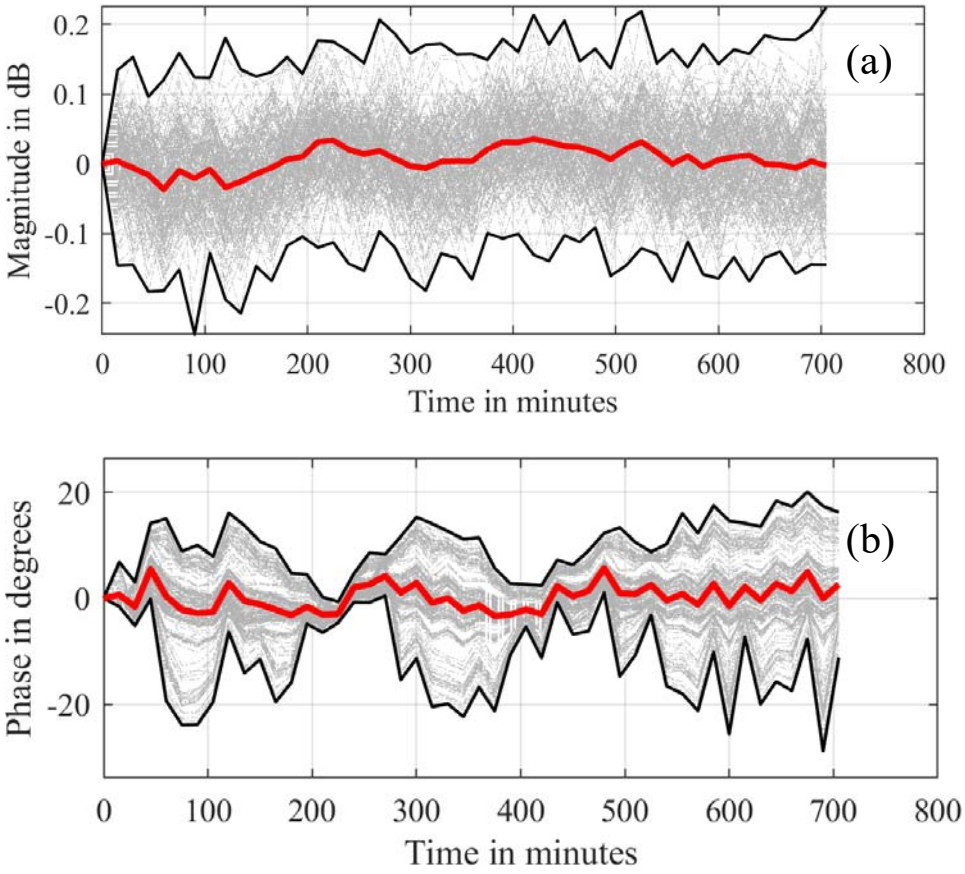


PDP of Artifact 2using Different Calibrations

VNA Magnitude and Phase Drift

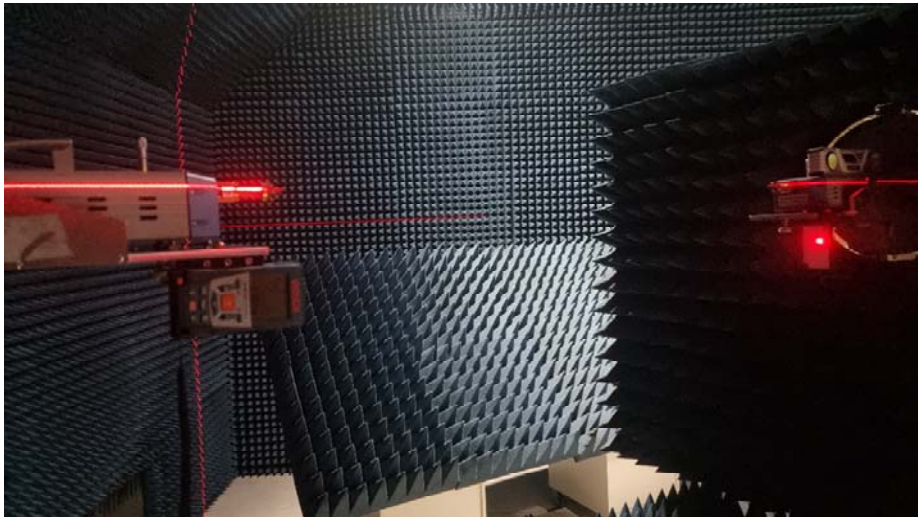


Far-field Antenna Measurement setup at PTB

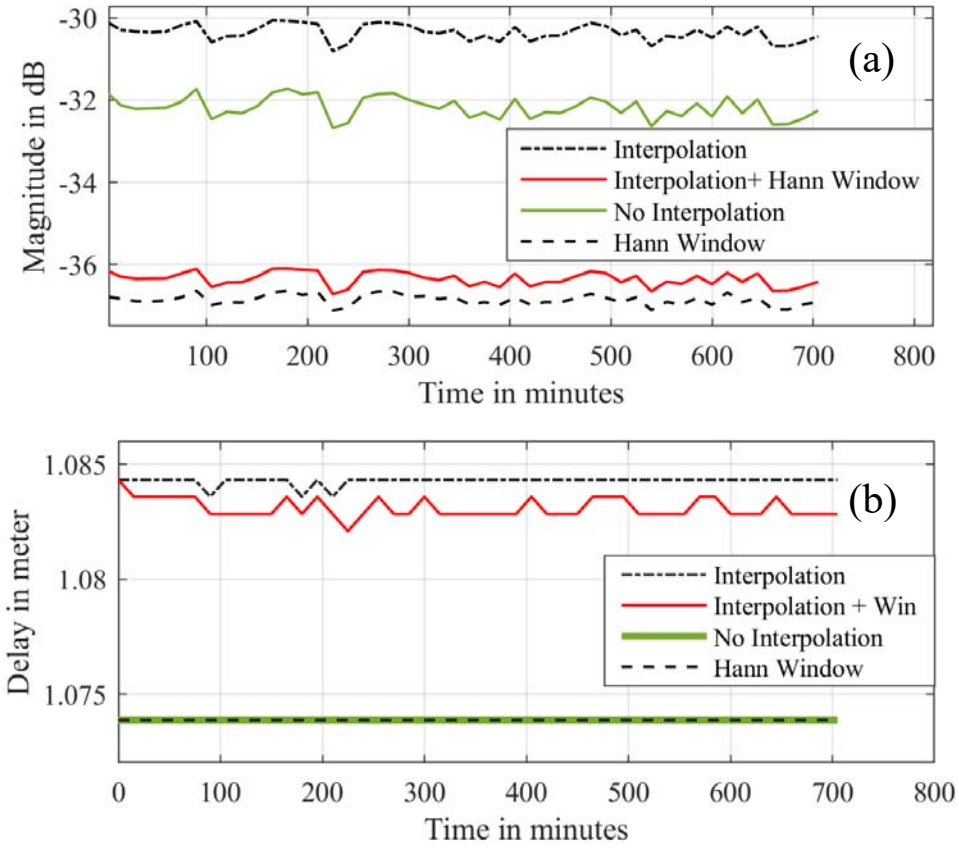


12 hours drift measurement at WR05 (a) Magnitude (b) Phase

VNA PDP Drift

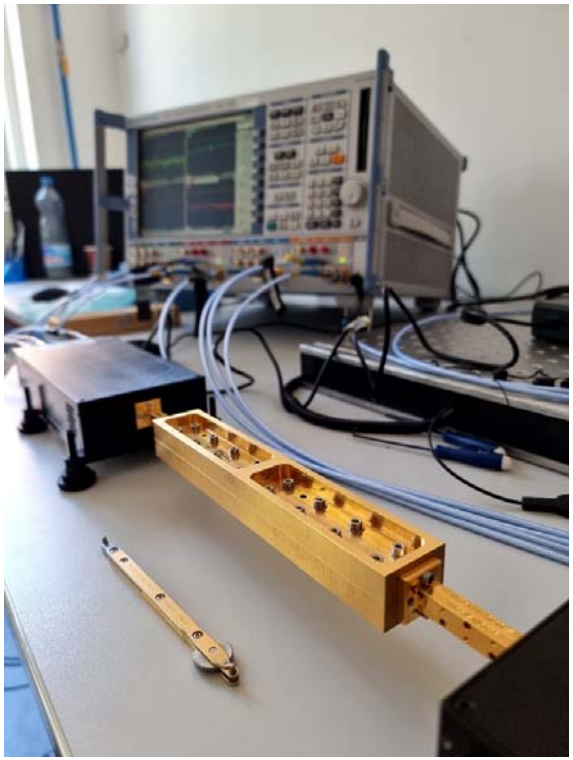


Far-field Antenna Measurement setup at PTB

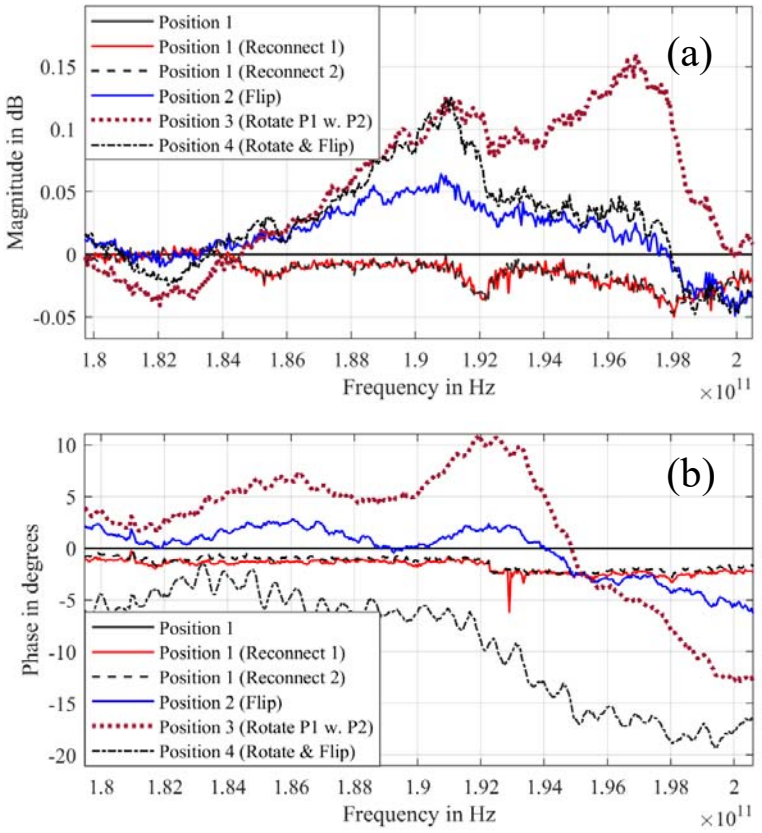


12 hours PDP Drift at WR03 (a) Magnitude (b) Delay

VNA Connection Repeatability



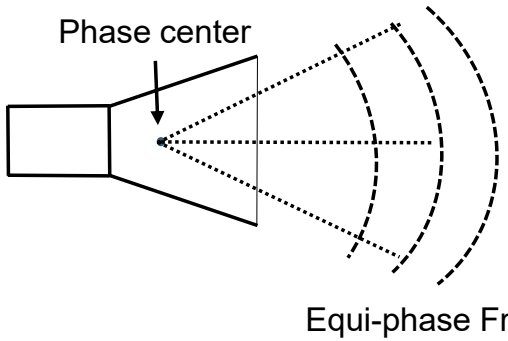
Waveguide artifact at WR05



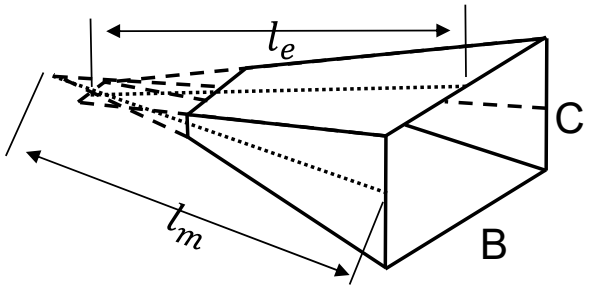
Waveguide artifact repeatability (a) Magnitude (b) Phase

Antenna Phase Center

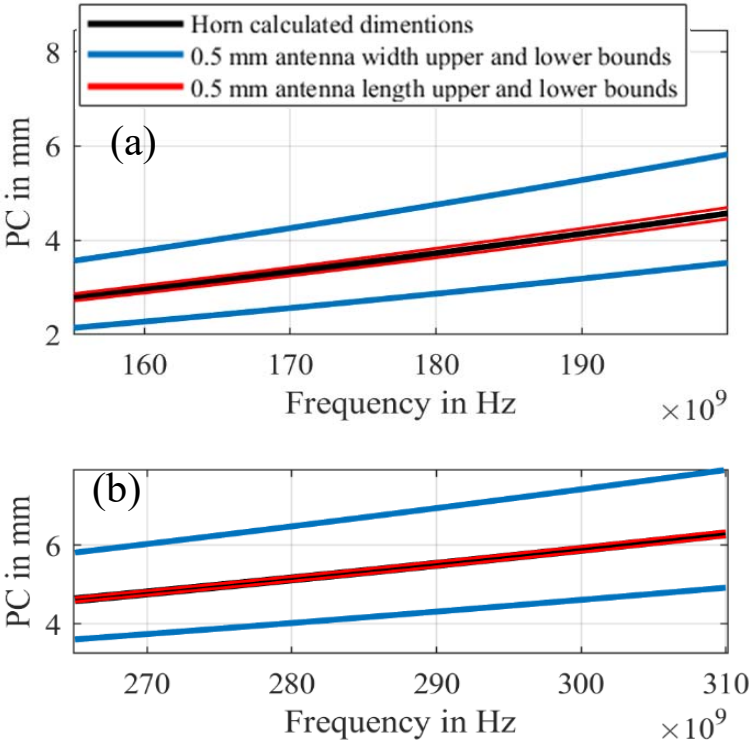
Method 1: Horn Antenna Phase Center Theoretical Calculation



Horn antenna phase center illustration



Horn antenna parameters for phase center calculation

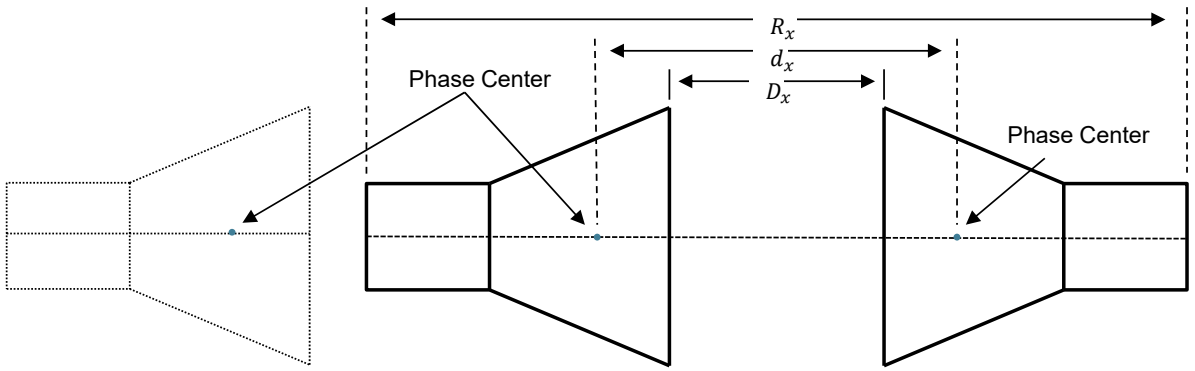


Horn antenna phase center calculation at (a) WR05 and (b) WR03 bands

[3] E. Muehldorf, "The phase center of horn antennas," IEEE transactions on antennas and propagation, vol. 18, no. 6, pp. 753-760, 1970.

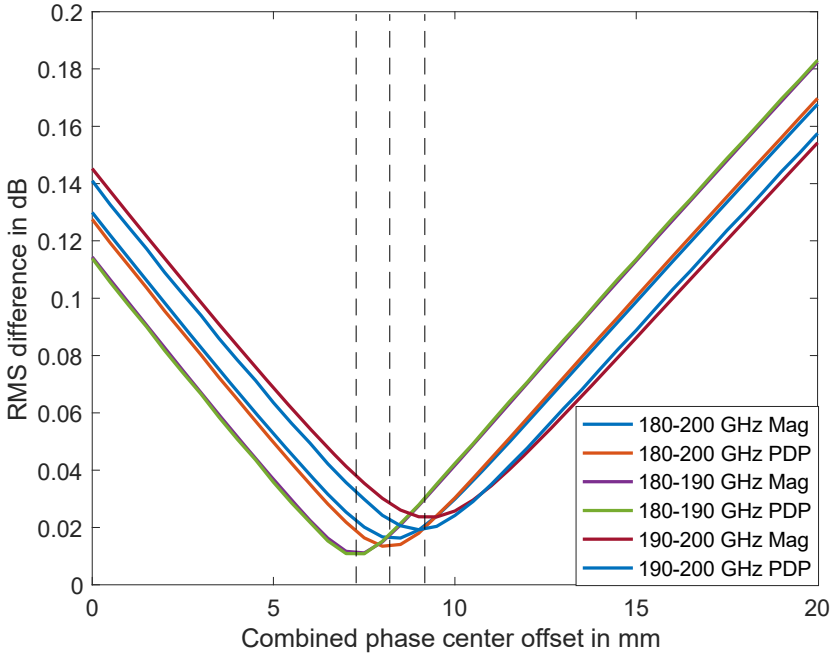
Antenna Phase Center

Method 2: Distance Measurement and Gain Matching Using Transmission Magnitude and PDP



= distance measured from antenna apertures for separation distance
= distance between phase centers at separation distance
= combined electrical and mechanical lengths from the VNA reference plane at separation distance

Sketch of the measurement setup

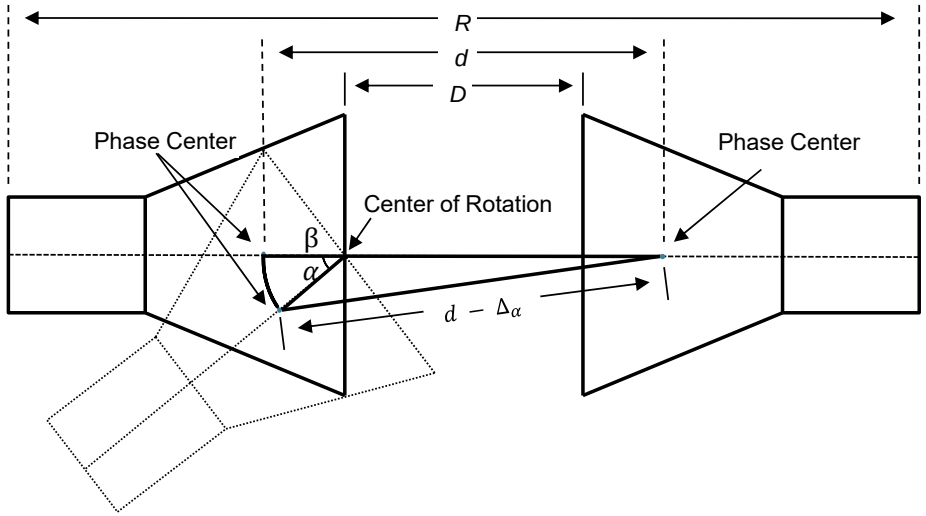


RMS difference in dB vs. successive combined phase center offset comparison at WR05 band

[4] M. D. Al-Dabbagh, D. Ulm, T. Kleine-Ostmann and D. Humphreys“, 18th European Conference on Antennas and Propagation (EuCAP), Glasgow, UK, 2024 (Accepted)

Antenna Phase Center

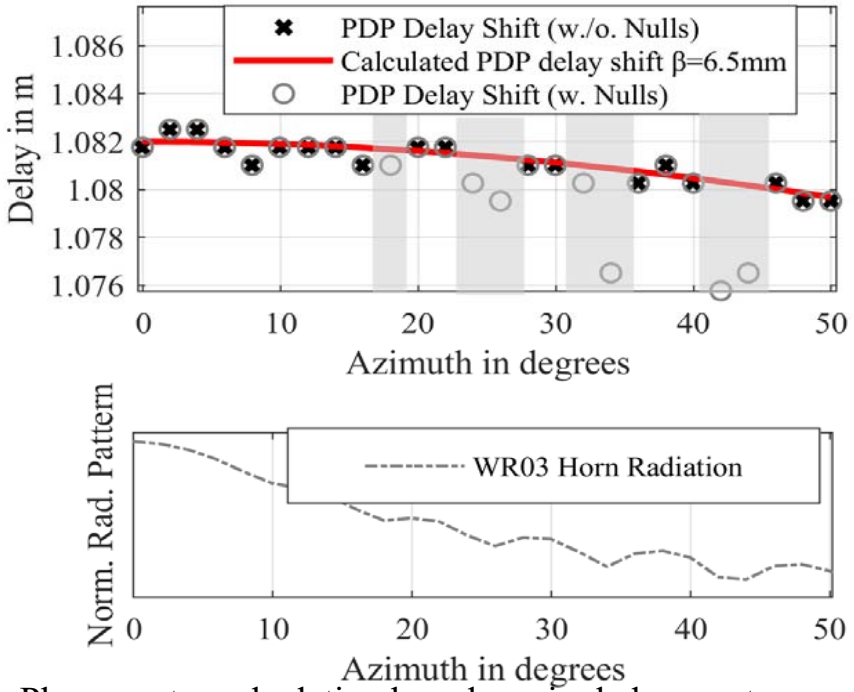
Method 3: Phase Center Rotation and PDP Delay Calculation



D= 1 meter distance measured from antenna apertures
d= distance between phase centers at rotation
= arm rotational angels at Port 1
= Phase center distance from the antenna aperture

R= combined electrical and mechanical lengths from the VNA reference plane

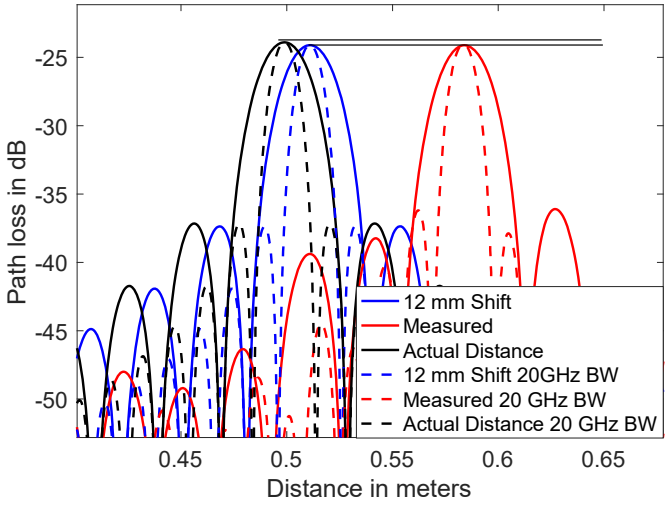
Sketch of the measurement setup



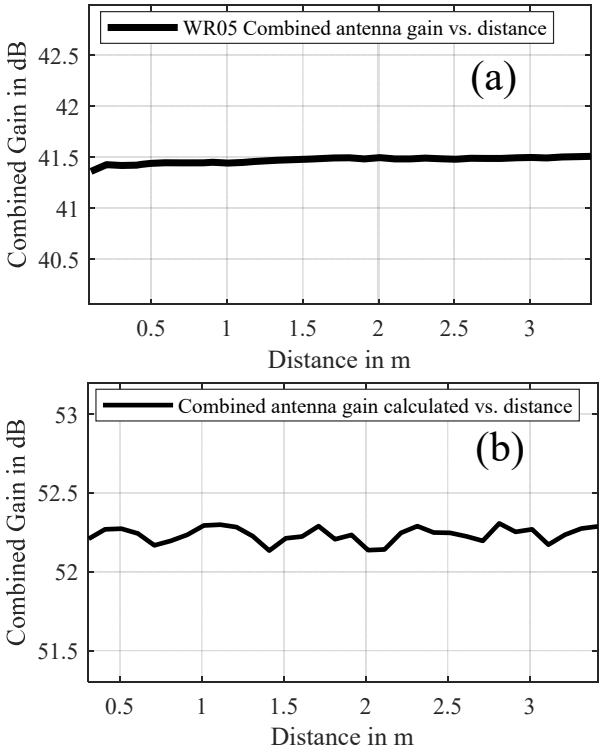
Phase center calculation based on single horn antenna rotation at WR03 band

[4] M. D. Al-Dabbagh, D. Ulm, T. Kleine-Ostmann and D. Humphreys", 18th European Conference on Antennas and Propagation (EuCAP), Glasgow, UK, 2024 (Accepted)

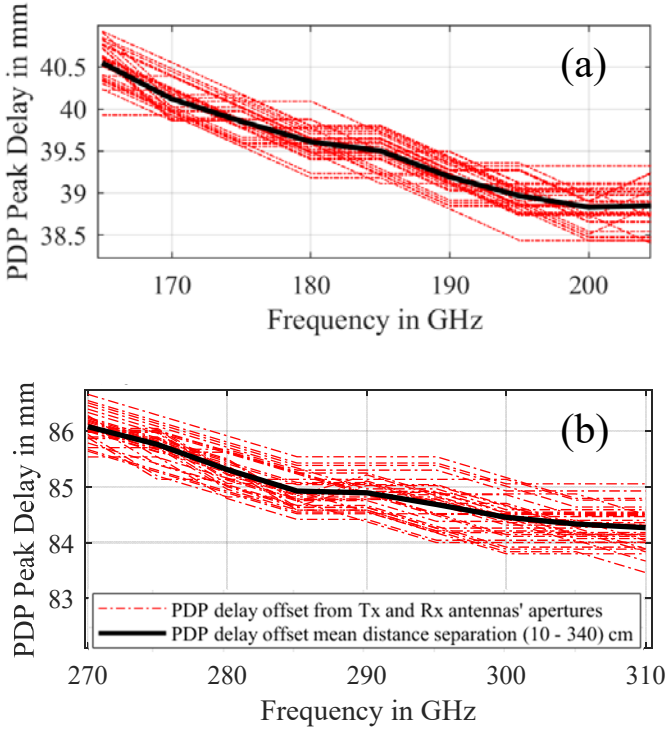
Antenna Reference Plane Shift



PDP Magnitude match using reference plane shift at WR03 band



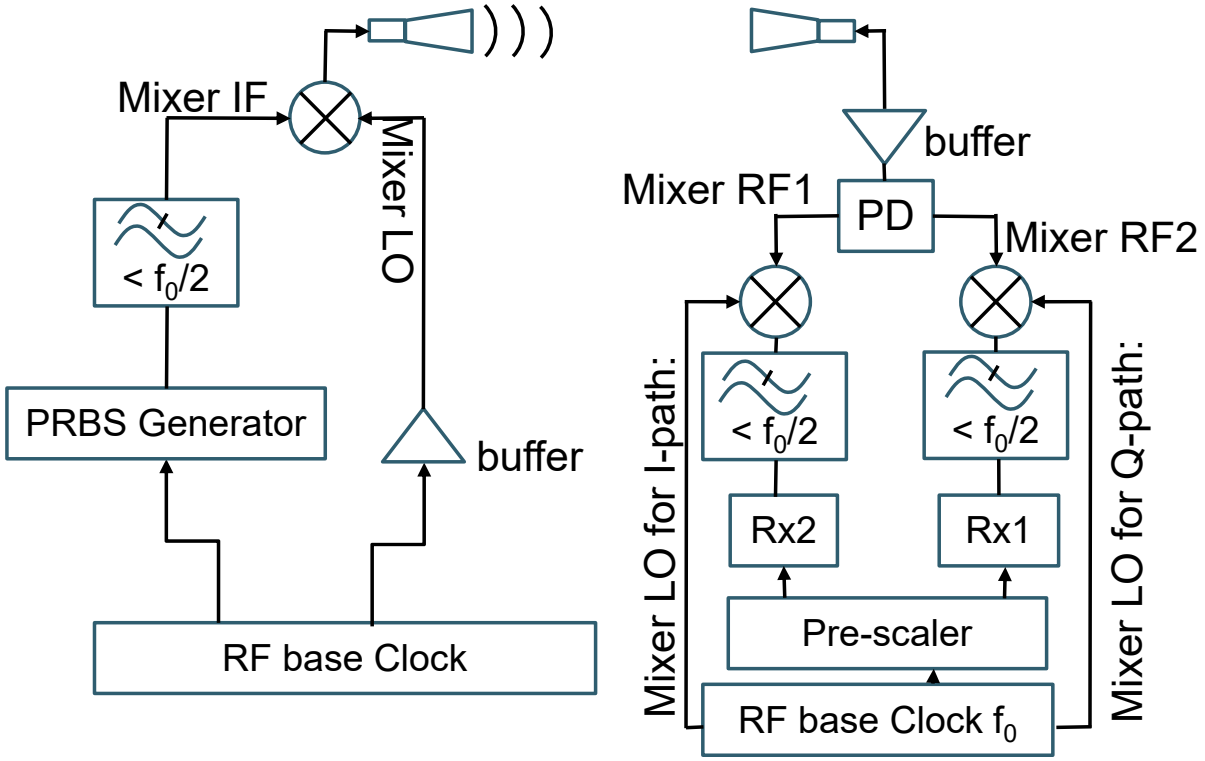
Combined Gain of Horn Antennas (a) WR05 (b) WR03



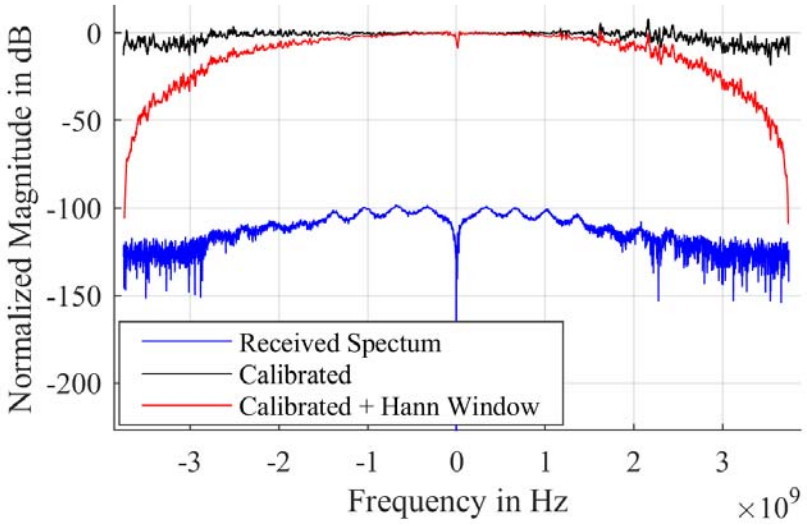
PDP delay offset vs. frequency using 20 GHz measurement (a) WR05 (b) WR03

[4] M. D. Al-Dabbagh, D. Ulm, T. Kleine-Ostmann and D. Humphreys“, 18th European Conference on Antennas and Propagation (EuCAP), Glasgow, UK, 2024 (Accepted)

Channel Sounding System Principle

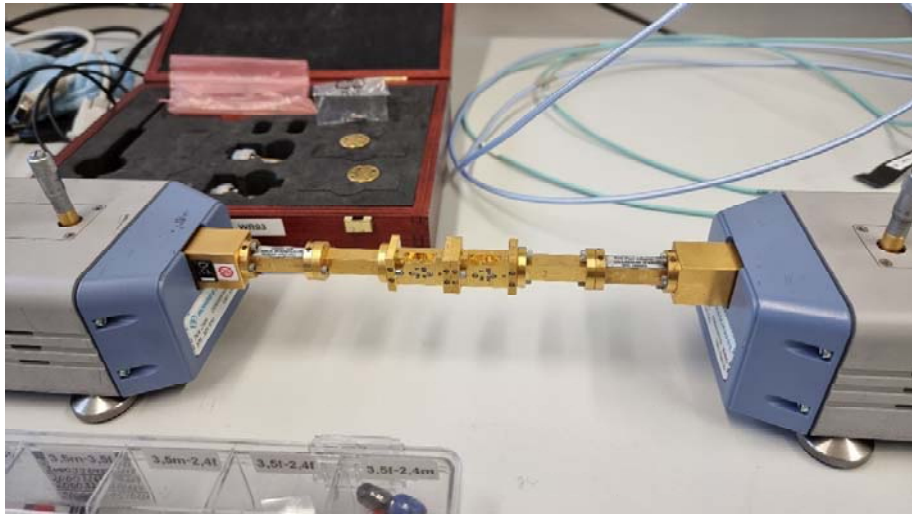


Up- and Down-conversion principle from extended UWB-band

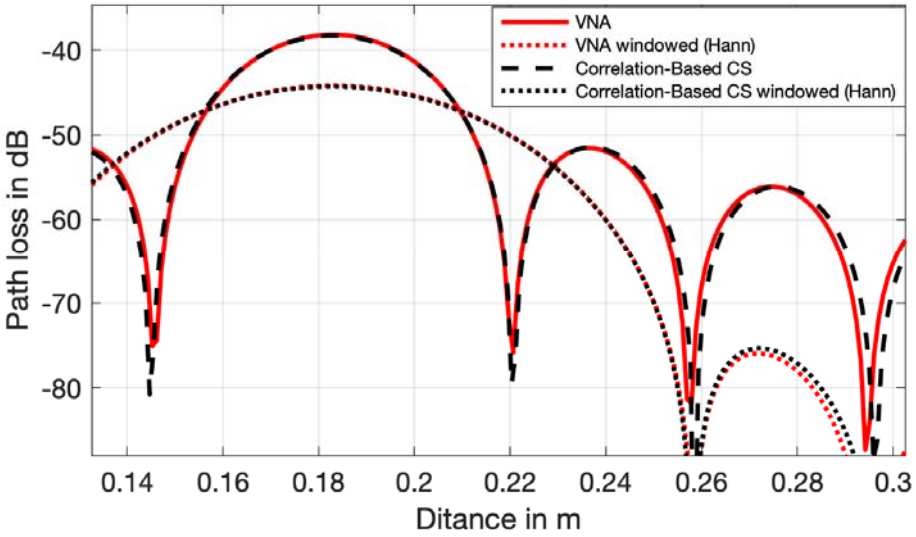


Received Spectrum at 1 m LoS distance, before and after calibration at 187.5 GHz

Channel Sounder and VNA Reference Measurements



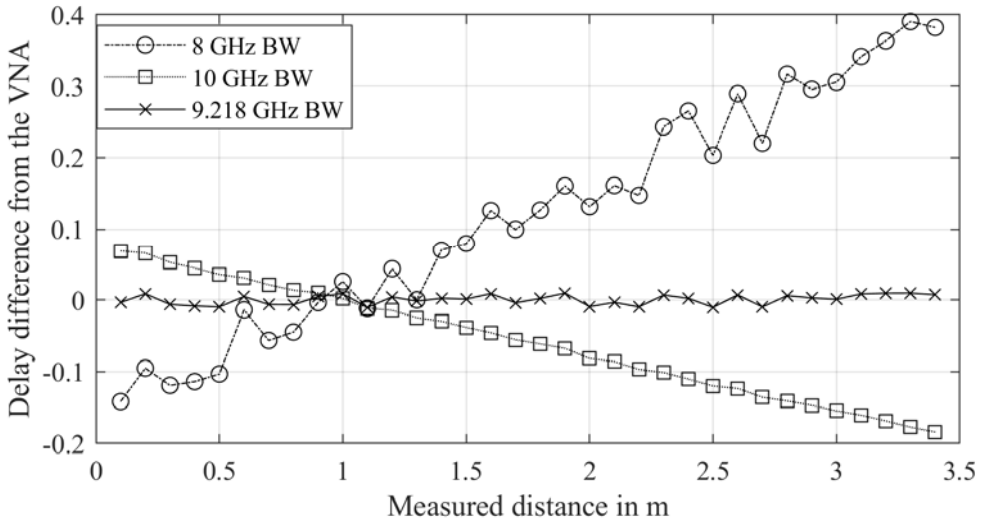
Reference waveguide cascade photograph using VNA



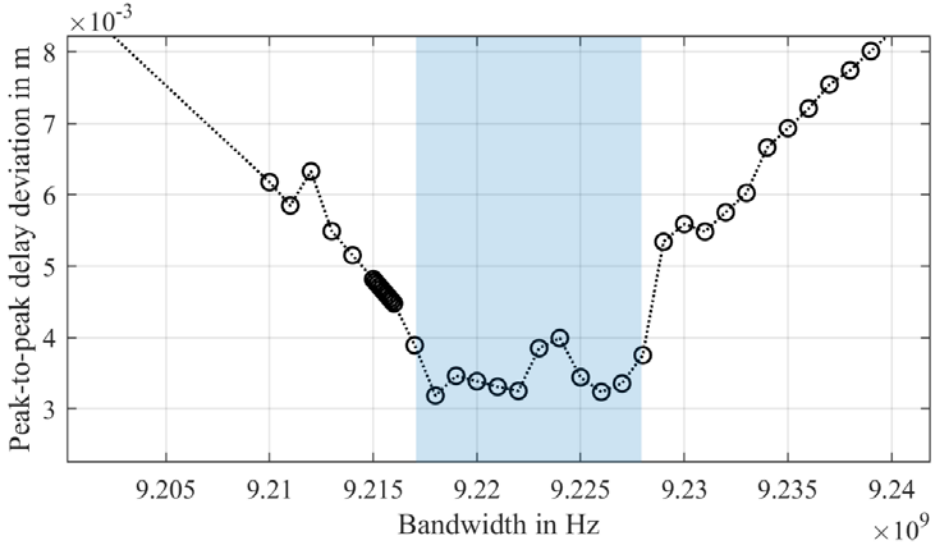
Reference waveguide PDP measurement using VNA and CS

Channel Sounder's Spectrum

Measurement Bandwidth investigation



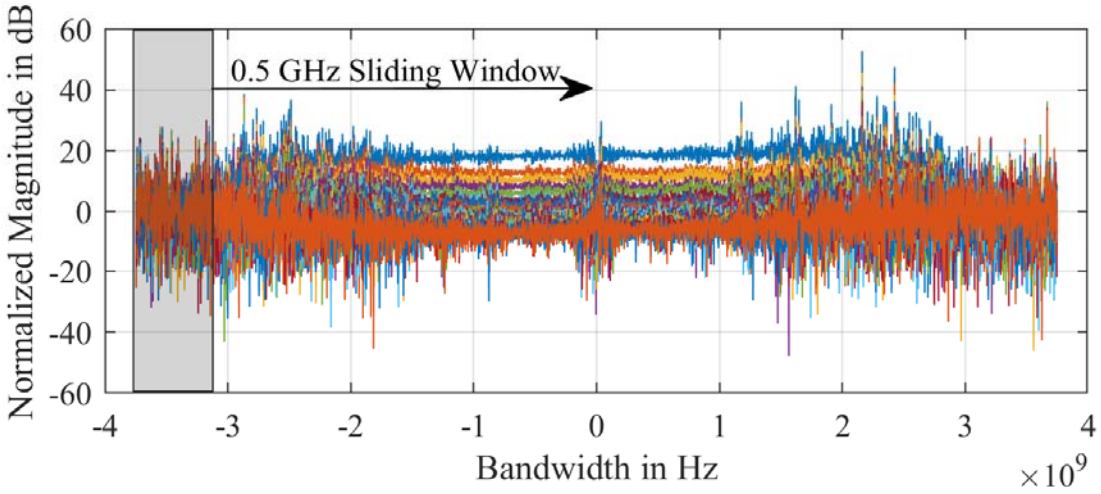
WR03 Channel Sounder Bandwidth influence on PDP delay



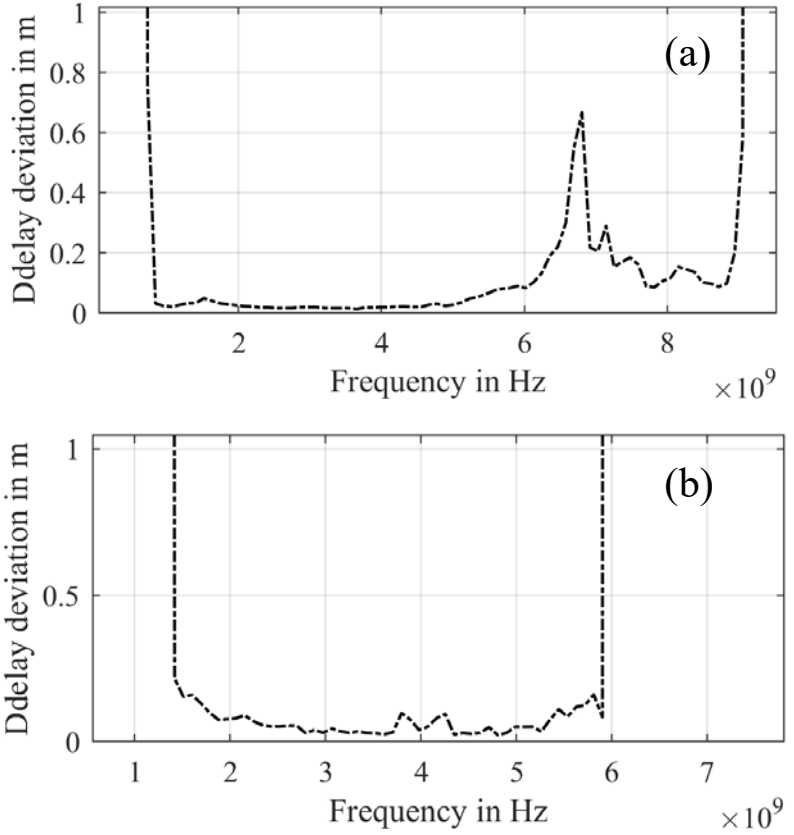
WR03 channel sounder's combined distances difference from VNA measured values in terms of characterized bandwidth

Channel Sounder's Feasible Spectrum

Measurement Bandwidth investigation



WR05 Channel Sounder Spectrum characterization using a sliding window



Channel Sounder's feasible spectrum based on delay (a) WR03 (b) WR05

Thank you very much for your Attention

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