

# BASIS-HF-PARAMETER IM SUB-THZ-BEREICH: WEGBEREITER FÜR DIE ZUKÜNFTIGEN KOMMUNIKATIONSTECHNOLOGIEN IN DER 6G-ÄRA

326. PTB-Seminar: Aktuelle Fortschritte von Kalibrierverfahren  
im Nieder- und Hochfrequenzbereich 2024

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Laborleitung R&S Kalibrierlabor D-K-15195-01-00

**ROHDE & SCHWARZ**

Make ideas real



**1 Target Setting for THz Communication**

**2 Challenges**

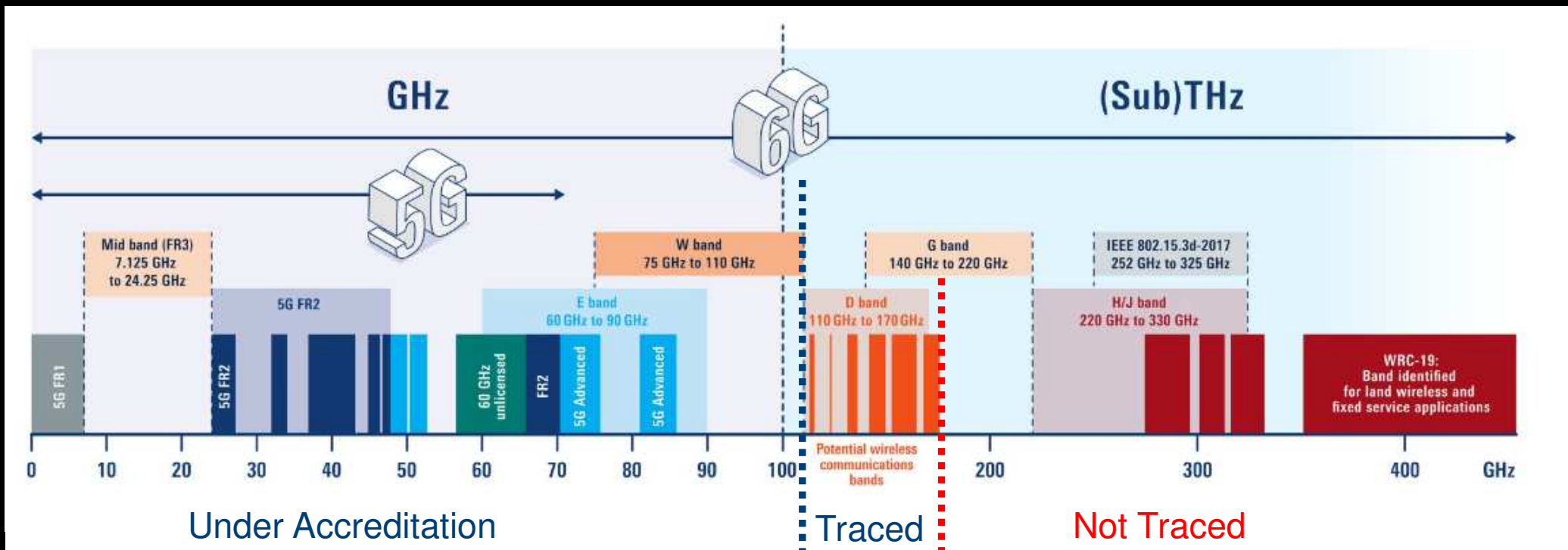
**3 Problem Solving Approaches**

**4 Example Phase Traceability**

**5 Wrap-Up**

# CONTENT

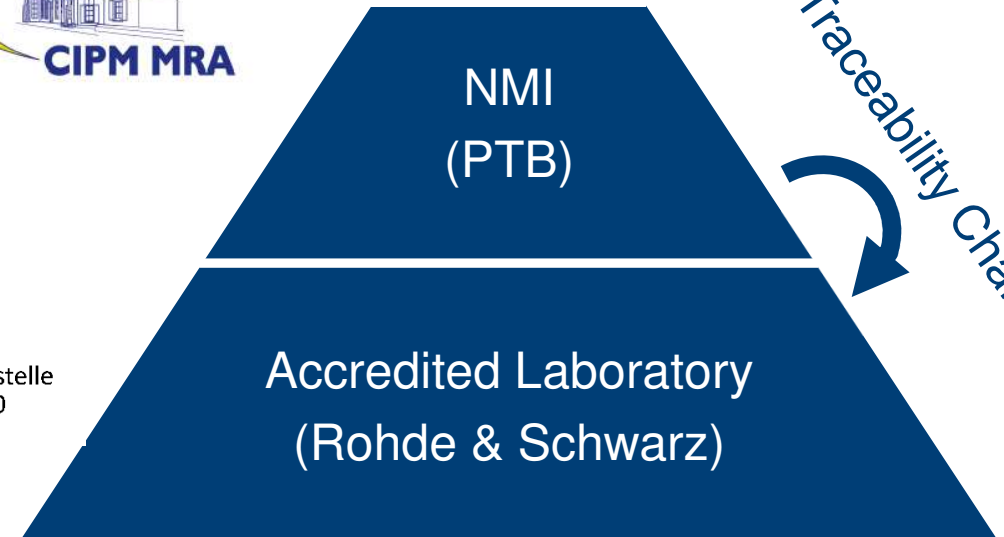




# TARGET SETTING FOR THZ COMMUNICATION

## Accreditation creates

- Trust
- Safety
- Market Access
- Freedom of Trade



# TARGET SETTING FOR THZ COMMUNICATION

1 Target Setting for THz Communication

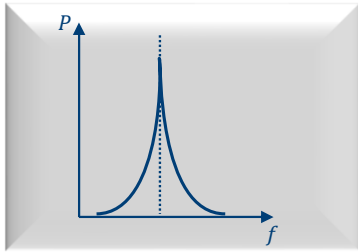
2 **Challenges**

3 Problem Solving Approaches

4 Example Phase Traceability

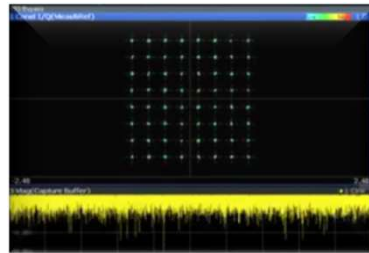
5 Wrap-Up

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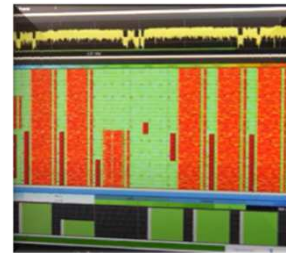
## Basic RF Parameters

RF Power  
Phase Relation  
Phase Noise



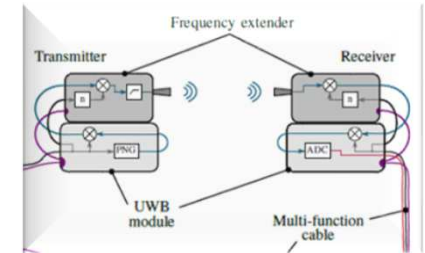
## Non Signaling Test

Physical  
Layer



## Signaling Test

Standards  
Protocols



## Channel Sounding

Time delay  
Multi path  
CIR

Uncertainty knowledge

# CHALLENGES - OVERVIEW

Metrology is most traceable for basis RF parameters



R&S®NTS170TWG: Transfer Standard for Traceability based on Microcalorimeter

Dissemination  
of the unit RF  
power

**NEW:**  
**RF 4 6G**



R&S®NRP170TWG:  
Thermal Waveguide Power Sensor

X. Shang et al., "Some Recent Advances in Measurements at Millimeter-Wave and Terahertz Frequencies: Advances in High Frequency Measurements," in IEEE Microwave Magazine, vol. 25, no. 1, pp. 58-71, Jan. 2024

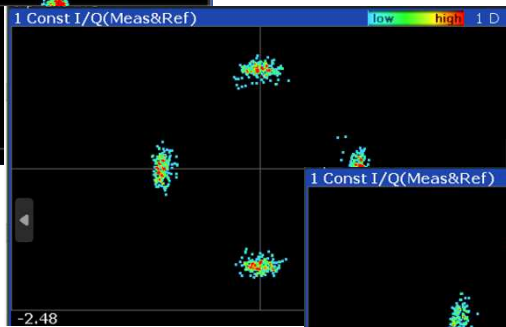
## CHALLENGES – AMPLITUDE

Traceability of RF power up to 170 GHz (D-Band)

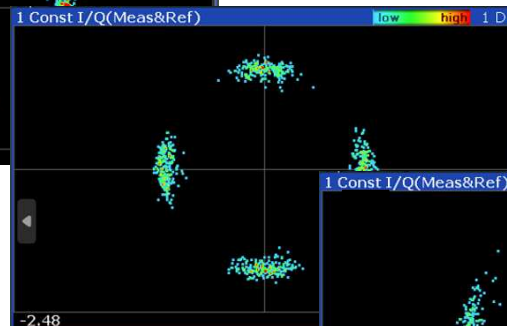


-95 dBc/Hz at 100 kHz Offset

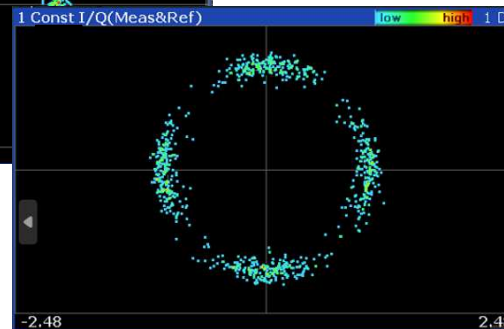
$F_{\text{RF}}$ : 140 GHz



-90 dBc/Hz at 100 kHz Offset



-85 dBc/Hz at 100 kHz Offset

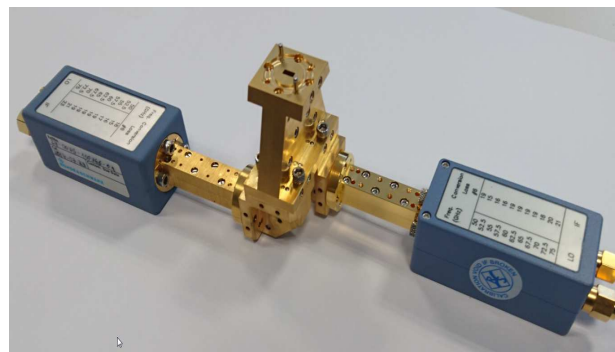


-80 dBc/Hz at 100 kHz Offset

# CHALLENGES – PHASE NOISE

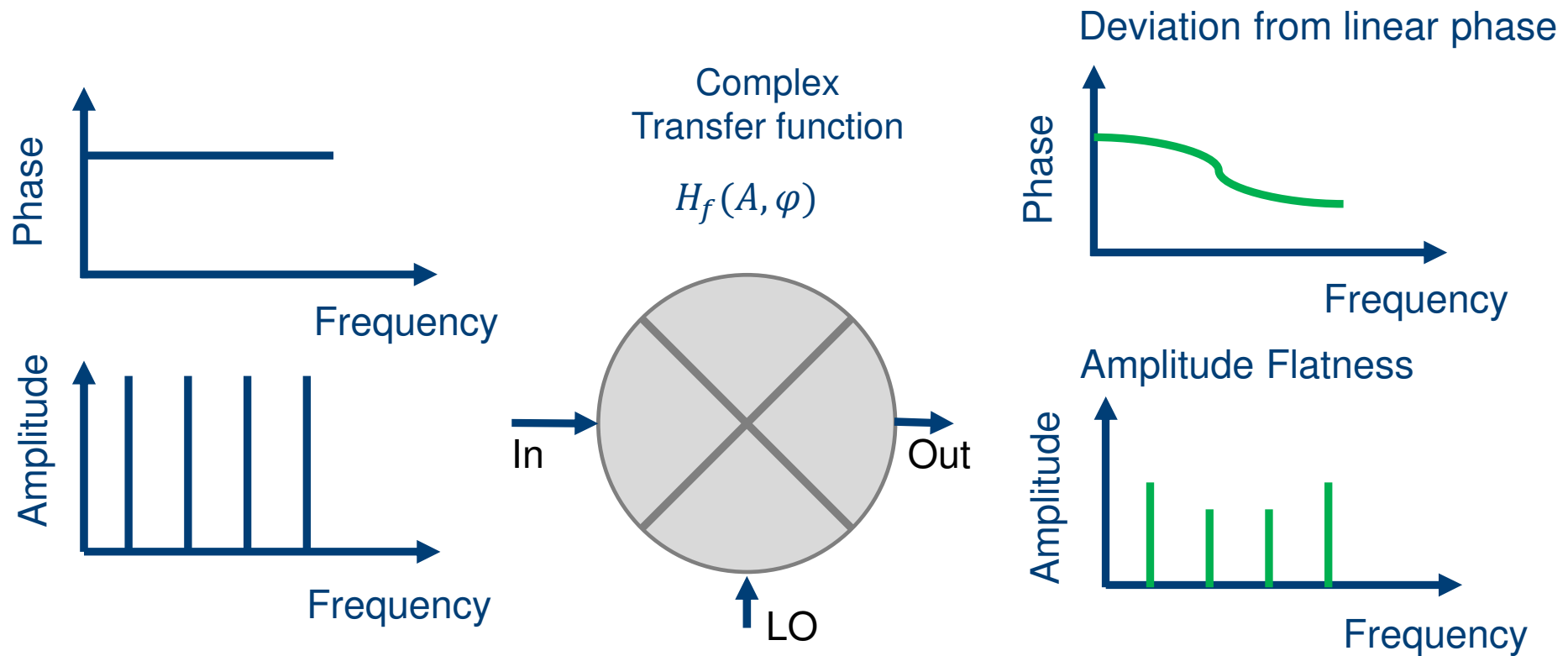
Deterioration with Increasing Frequency





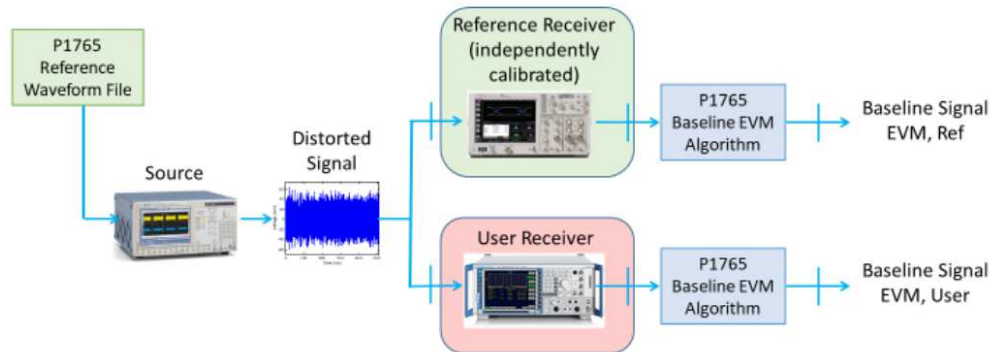
# CHALLENGES – PHASE NOISE (R&S®FSWP)

Traceability of Phase Noise (R&S Application Note: Measurement Setup for Phase Noise Test at Frequencies above 50 GHz)



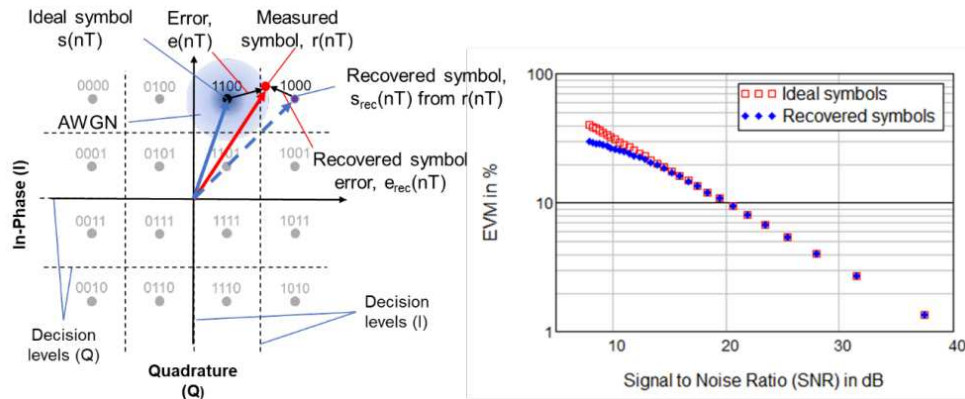
## CHALLENGES – PHASE RELATION

Traceability of Phase Relation (Multisine Signal)



IEEE Recommended Practice for Estimating the Uncertainty in Error Vector Magnitude of Measured Digitally Modulated Signals for Wireless Communications," in *IEEE Std 1765-2022*, vol., no., pp.1-105, 11 Nov. 2022

Reference Receiver:  
Independently calibrated?



# CHALLENGES – DIGITAL MODULATION

Traceability of Error Vector Magnitude

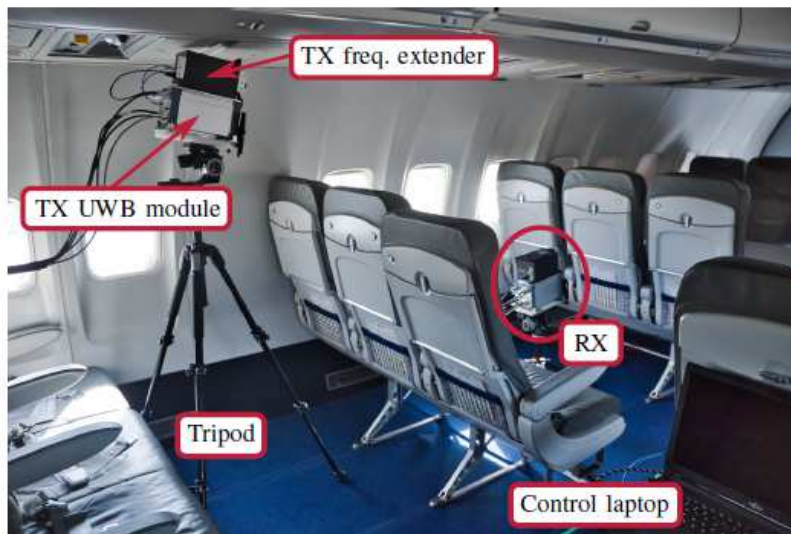


Fig. 2: Partial illustration of the general measurement setup.

T. Doeker, J. M. Eckhardt and T. Kürner, "Channel measurements and modeling for low terahertz communications in an aircraft cabin", *IEEE Trans. Antennas Propag.*, vol. 70, no. 11, pp. 10903-10916, Nov. 2022.

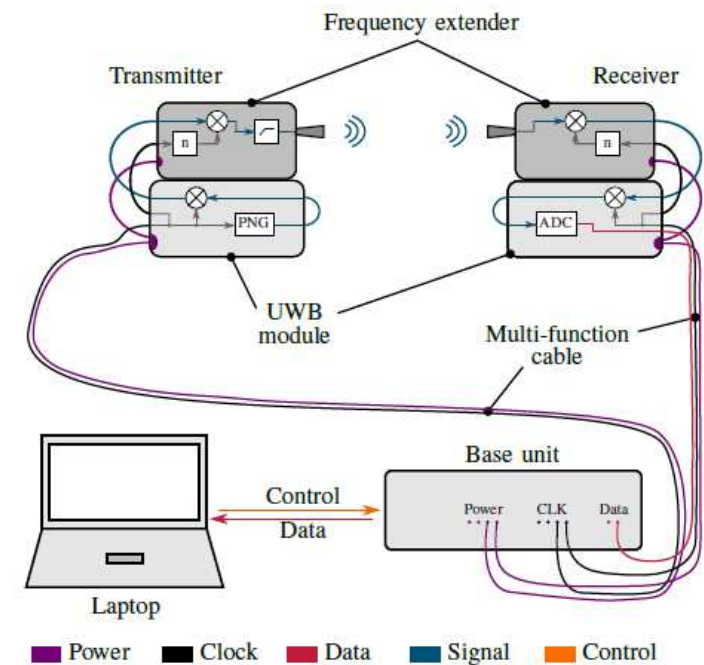


Fig. 3: Schematic block diagram of the channel sounder.

# CHALLENGES – CHANNEL SOUNDING

Traceability of Channel Impulse Response

1 Target Setting for THz Communication

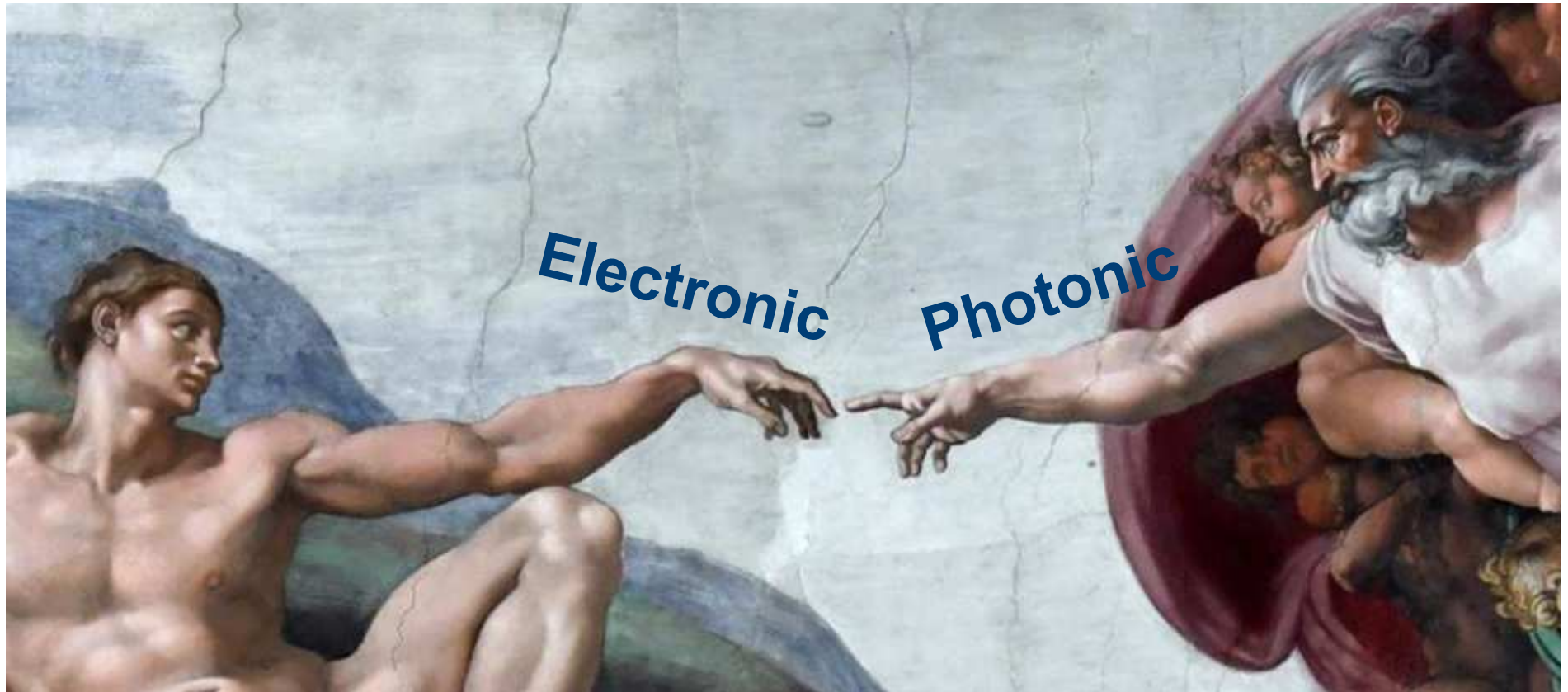
2 Challenges

**3 Problem Solving Approaches**

4 Example Phase Traceability

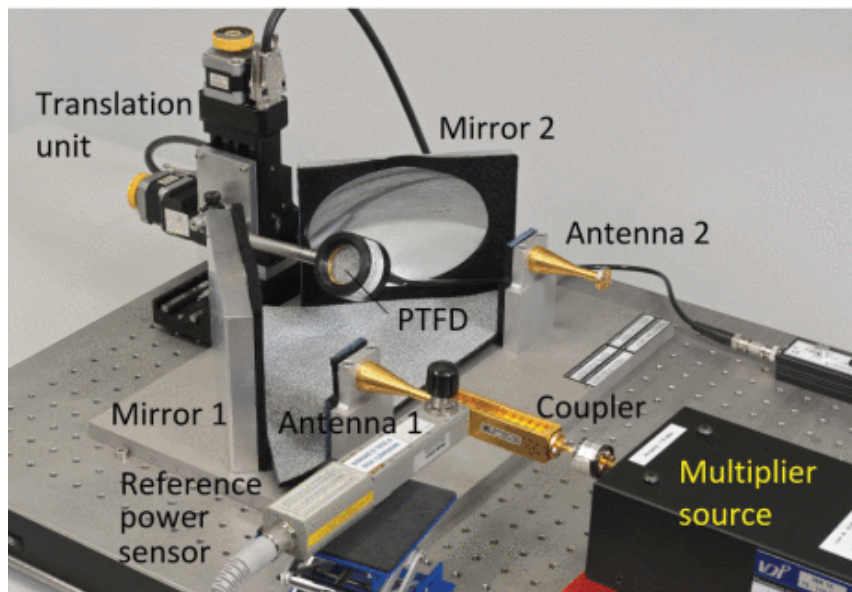
5 Wrap-Up

# CONTENT



## PROBLEM – SOLVING APPROACHES





R. H. Judaschke, M. Kehrt, K. Kuhlmann and A. Steiger, "Linking the Power Scales of Free-Space and Waveguide-Based Electromagnetic Waves," in IEEE Transactions on Instrumentation and Measurement, vol. 69, no. 11, pp. 9056-9061, Nov. 2020

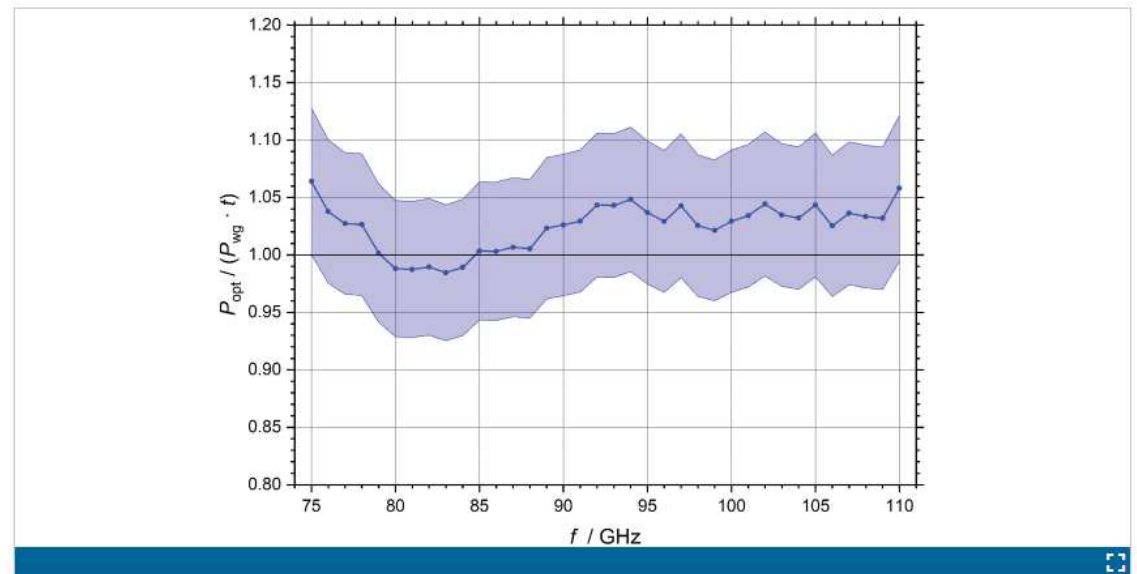
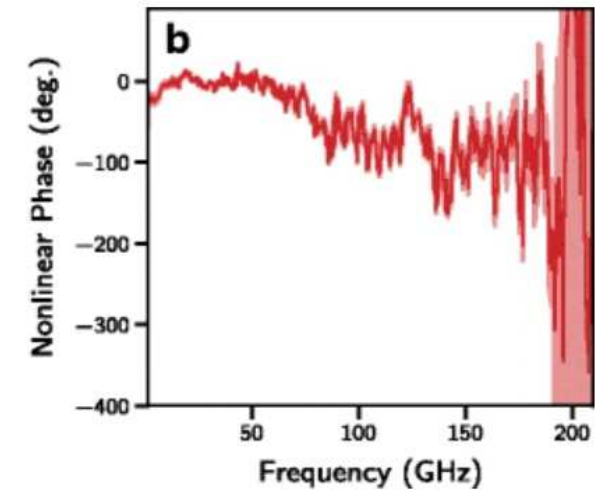
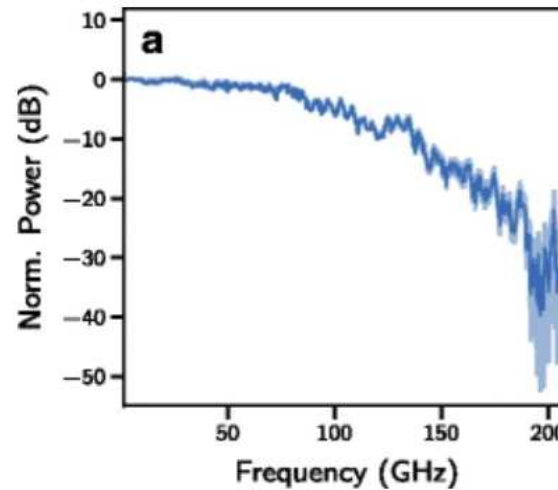
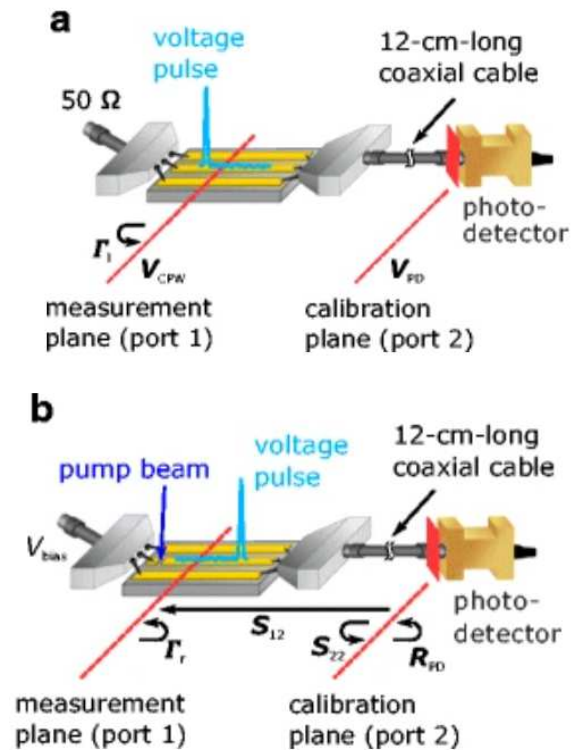


Fig. 7.

Ratio of measured optical power  $P_{\text{opt}}$  in plane B and waveguide power  $P_{\text{wg}}$  in plane A divided by transmission coefficient  $t$ .

# PROBLEM – SOLVING APPROACHES

Comparison of different RF power traceability chains

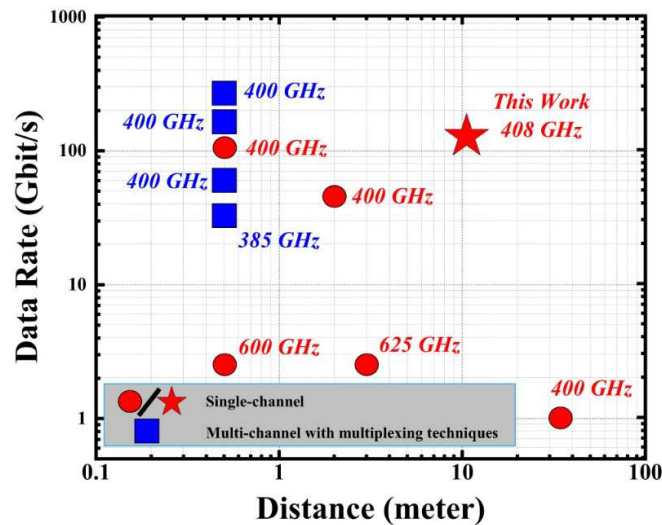


Struszewski, P., Pierz, K. & Bieler, M. Time-Domain Characterization of High-Speed Photodetectors. J Infrared Milli Terahz Waves 38, 1416–1431 (2017).

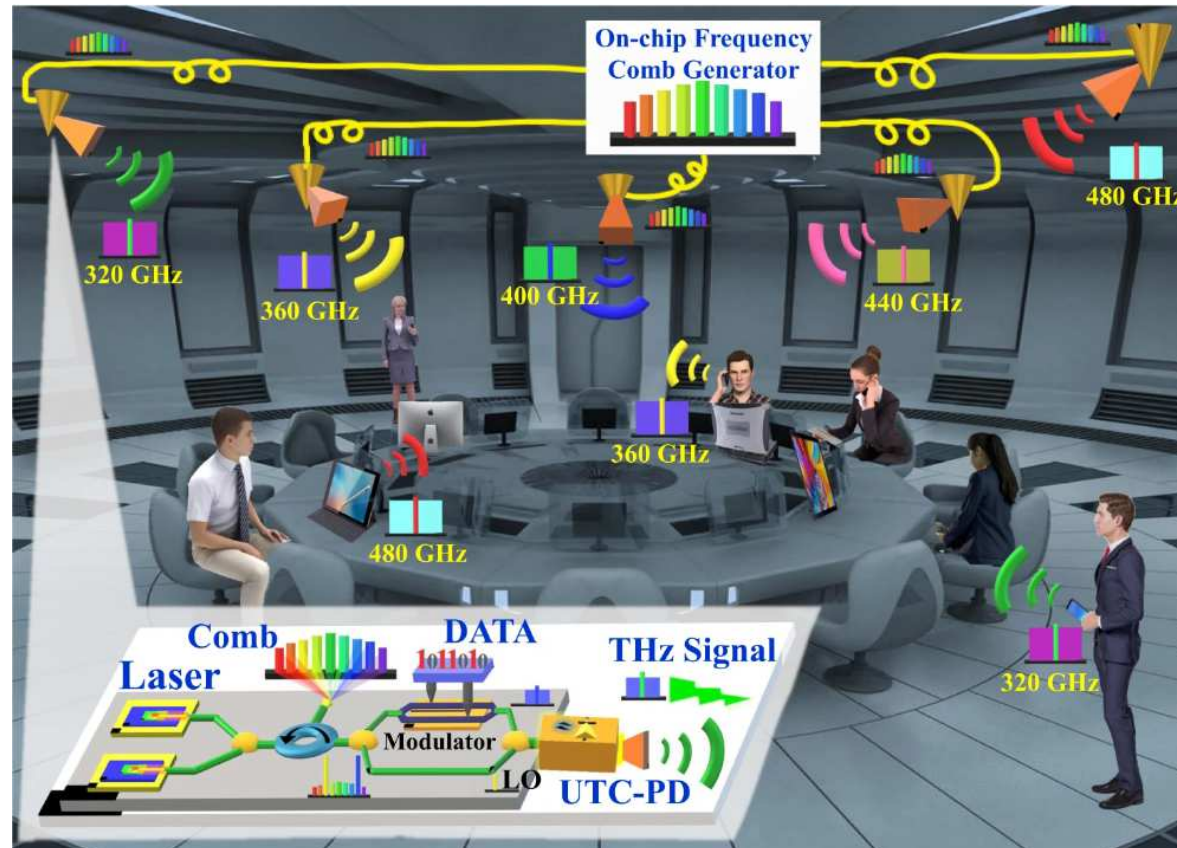
# PROBLEM – SOLVING APPROACHES

Shortest electrical pulses traced to laser based metrology





Jia, S., Lo, MC., Zhang, L. et al. Integrated dual-laser photonic chip for high-purity carrier generation enabling ultrafast terahertz wireless communications. Nat Commun 13, 1388 (2022).  
<https://doi.org/10.1038/s41467-022-29049-2>



# PROBLEM – SOLVING APPROACHES

Generation of ultralow THz noise sources by optical frequency combs

1 Target Setting for THz Communication

2 Challenges

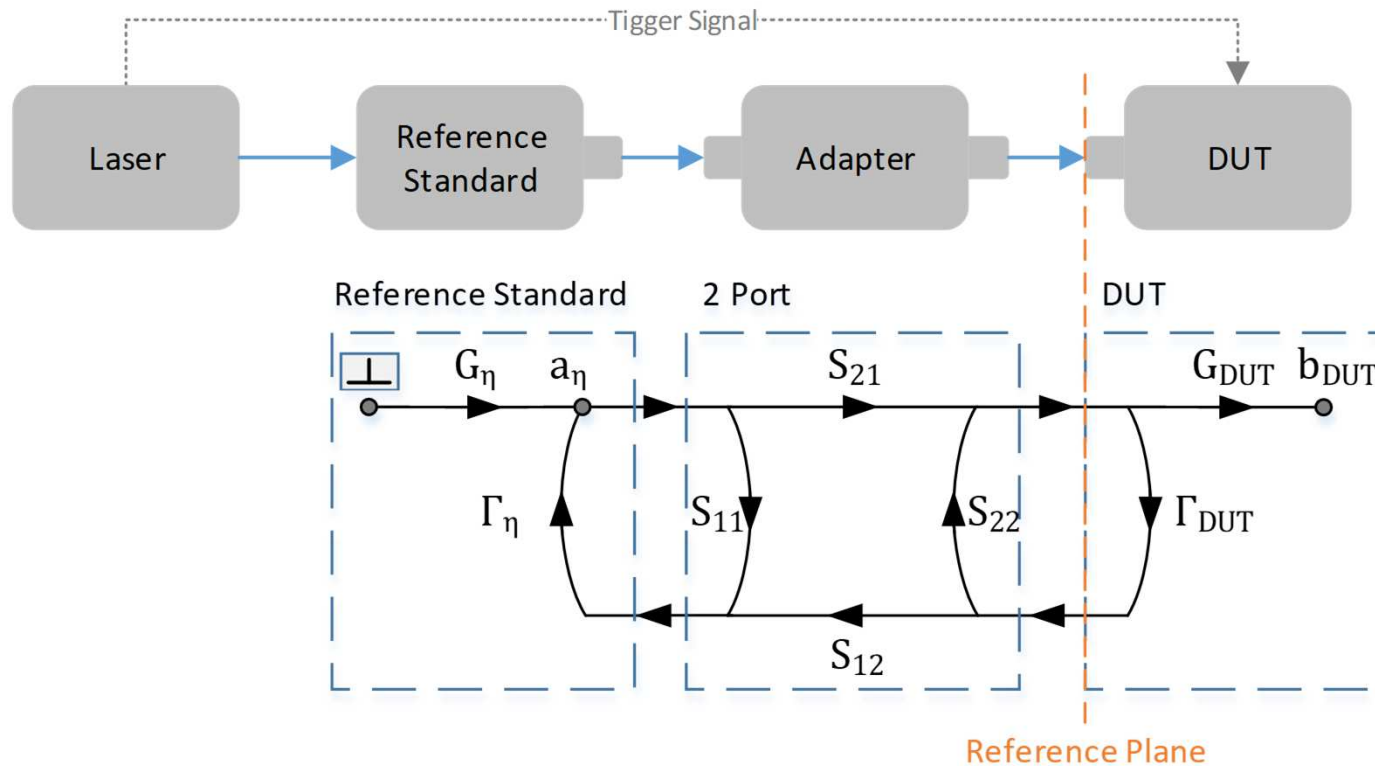
3 Problem Solving Approaches

4 **Example Phase Traceability**

5 Wrap-Up

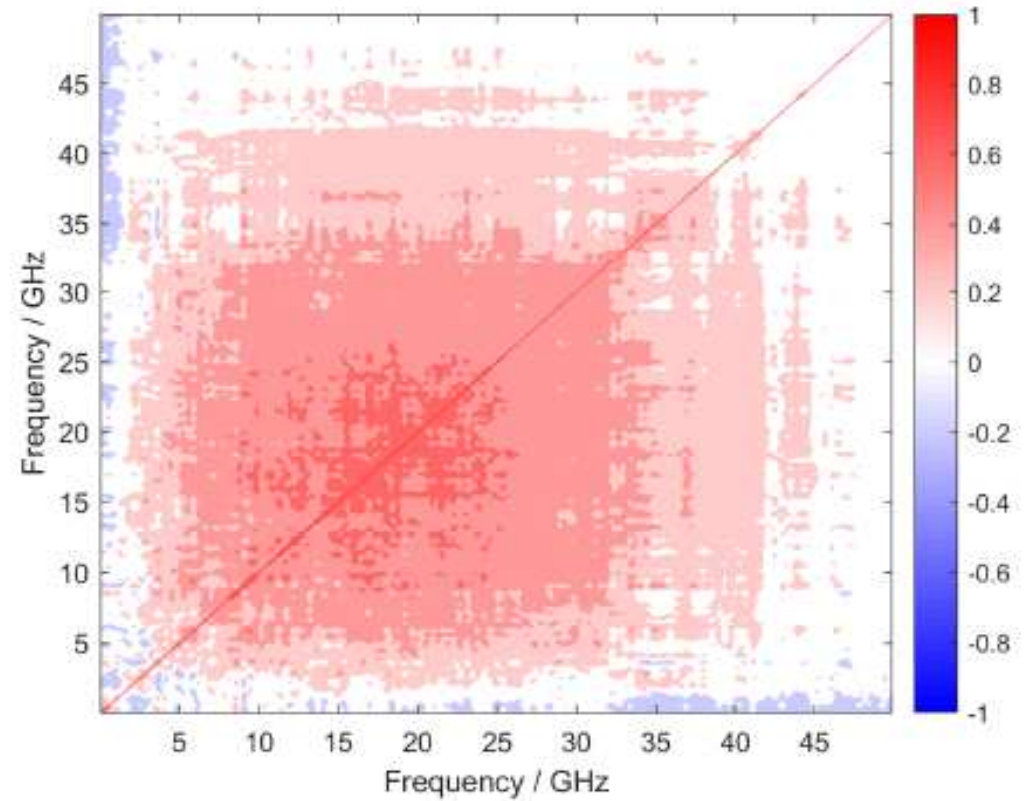
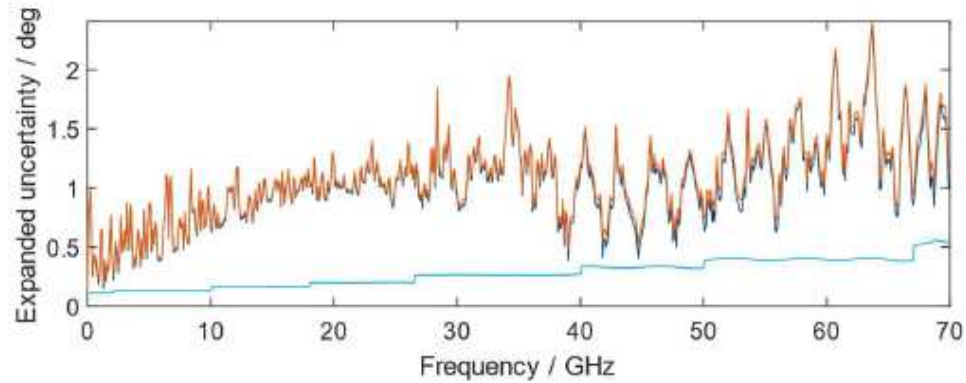
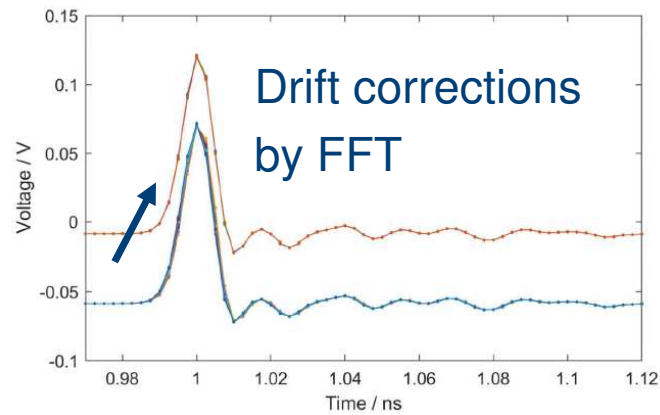
# CONTENT





# EXAMPLE PHASE TRACEABILITY

Well known S-parameter metrology



# EXAMPLE PHASE TRACEABILITY

Uncertainty analysis using fourier transformation and correlation matrices

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2 Challenges

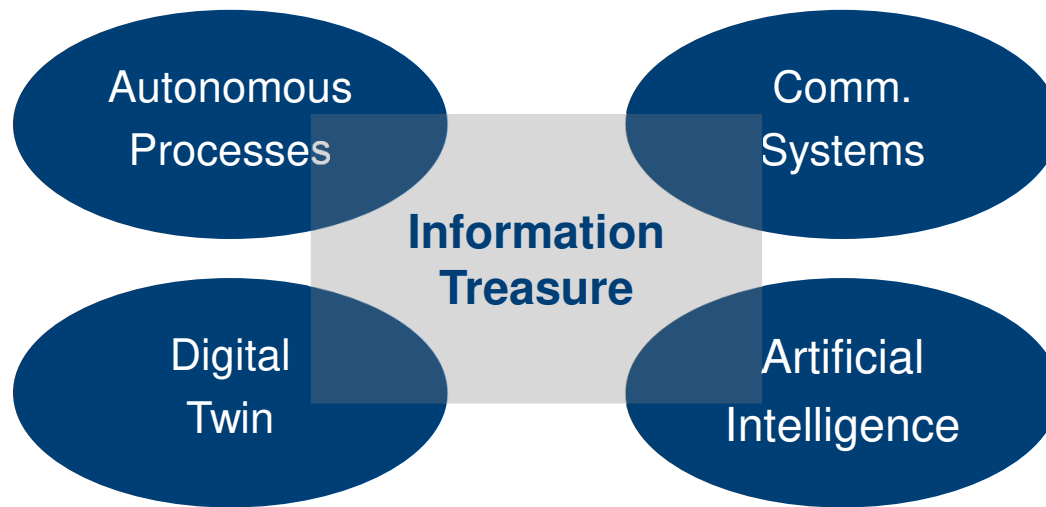
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5 **Wrap-Up**

# CONTENT

THz communication shows a large potential for massive communication and sensing, but it needs also a massive development effort to become an industrial important advantage, as it is only one Lego brick on the way to “Made by European”.



**WRAP-UP**



# METERACOM – METROLOGY FOR TERAHERTZ COMMUNICATION (FUNDED BY DFG)





# THANK YOU

# ROHDE & SCHWARZ

