

TRACING MILLIMETER WAVES: UNLOCKING THZ COMMUNICATION'S POTENTIAL WITH ACCURACY IN BASIS RF PARAMETERS

Workshop: DFG Meteracom, 15th GeMiC Duisburg, March 2024

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ROHDE & SCHWARZ

Make ideas real



CONTENT

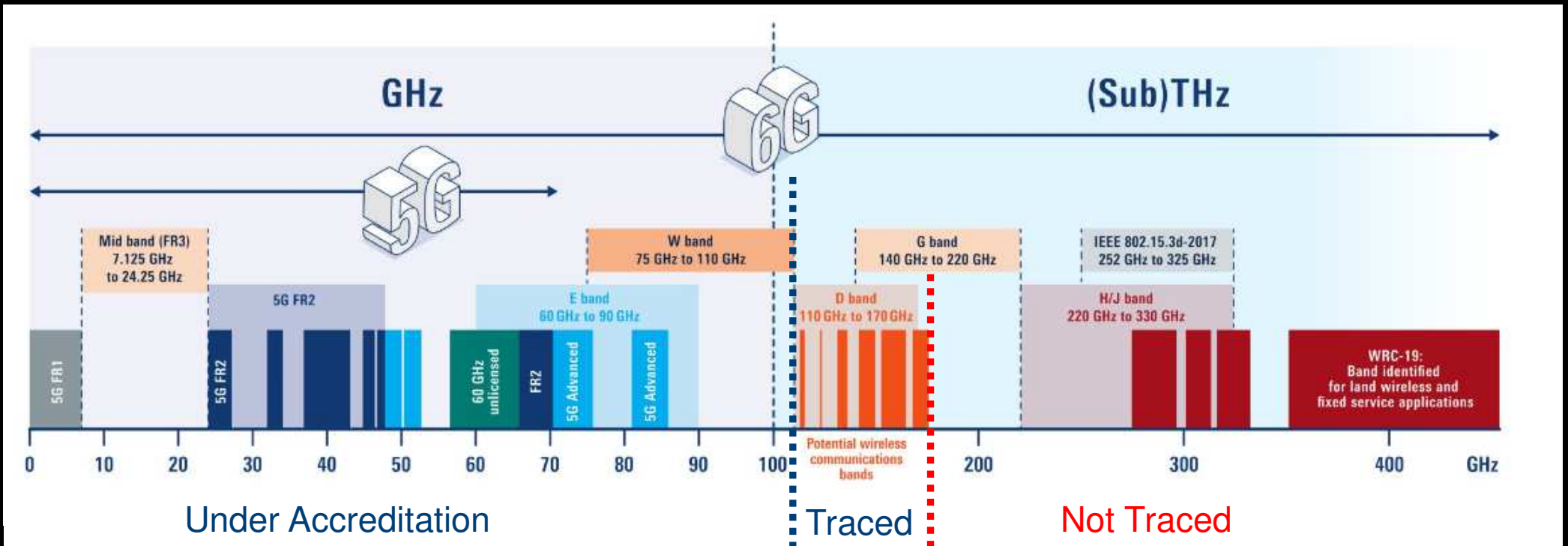
1 Target Setting for THz Communication

2 Challenges

3 Problem Solving Approaches

4 Example Phase Traceability

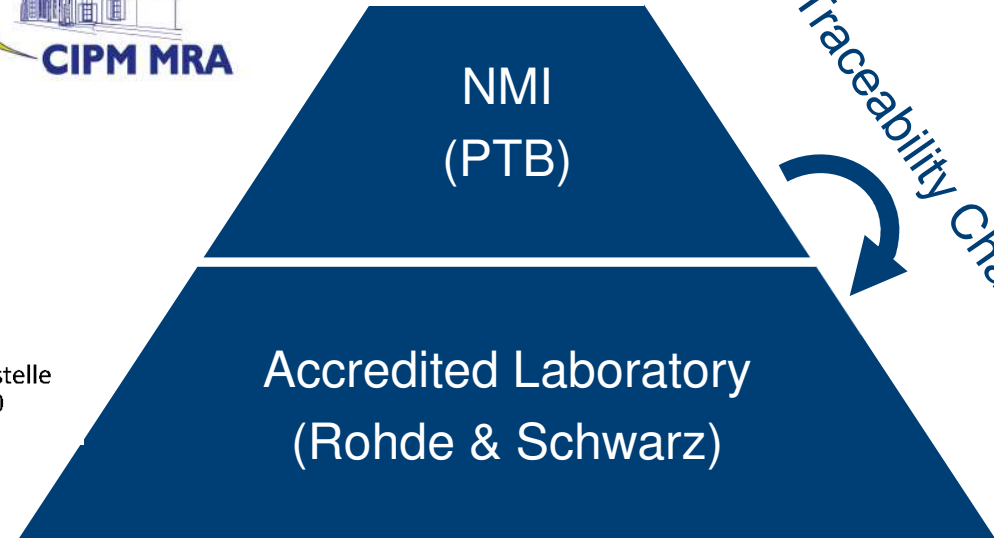
5 Wrap-Up



TARGET SETTING FOR THZ COMMUNICATION

Accreditation creates

- Trust
- Safety
- Market Access
- Freedom of Trade



TARGET SETTING FOR THZ COMMUNICATION

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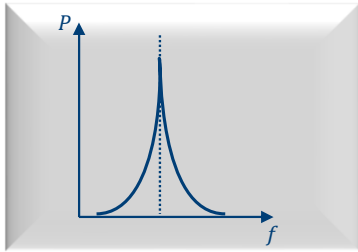
1 Target Setting for THz Communication

2 **Challenges**

3 Problem Solving Approaches

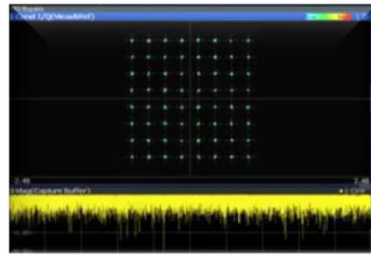
4 Example Phase Traceability

5 Wrap-Up



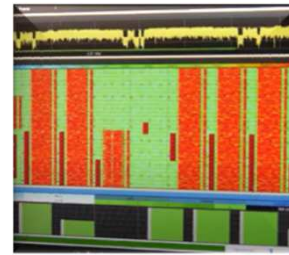
Basic RF Parameters

RF Power
Phase Relation
Phase Noise



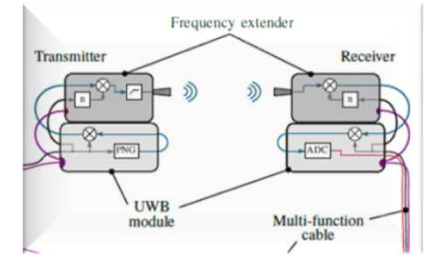
Non Signaling Test

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

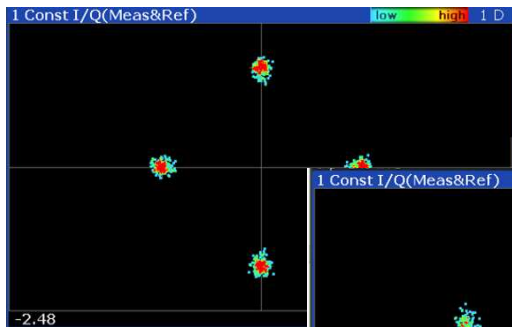


R&S®NRP170TWG:
Thermal Waveguide Power Sensor

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

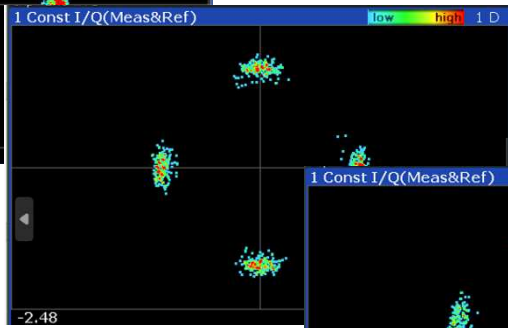
CHALLENGES – AMPLITUDE

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

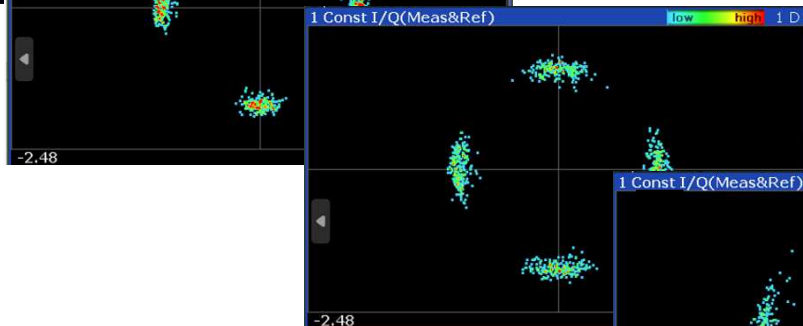


-95 dBc/Hz at 100 kHz Offset

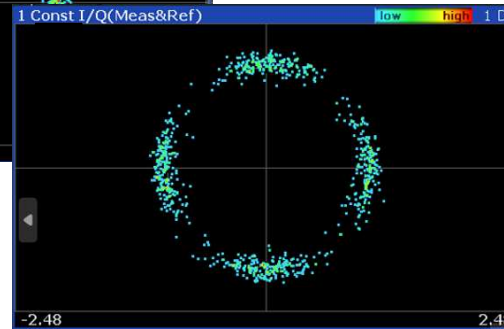
F_{RF} : 140 GHz



-90 dBc/Hz at 100 kHz Offset



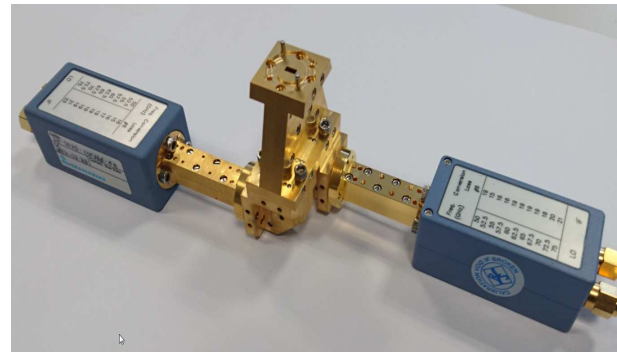
-85 dBc/Hz at 100 kHz Offset



-80 dBc/Hz at 100 kHz Offset

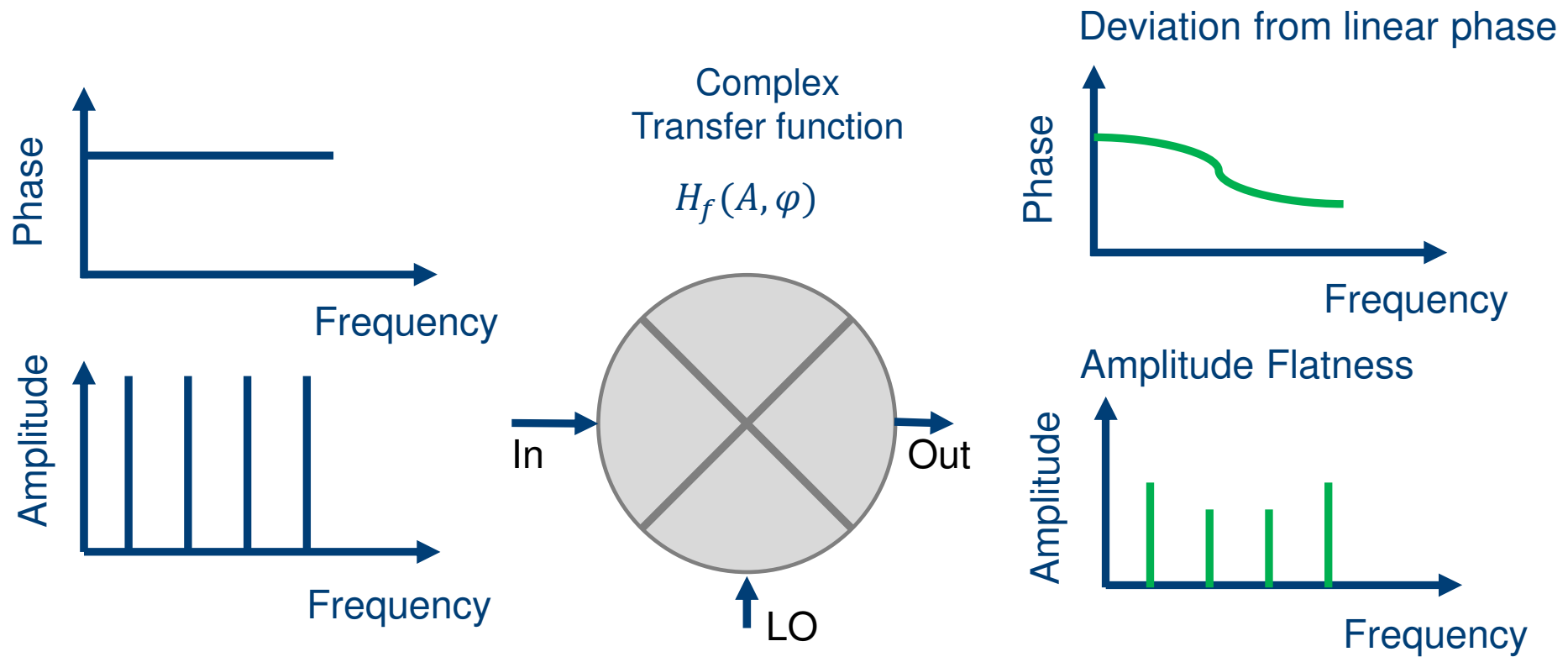
CHALLENGES – PHASE NOISE

Deterioration with Increasing Frequency



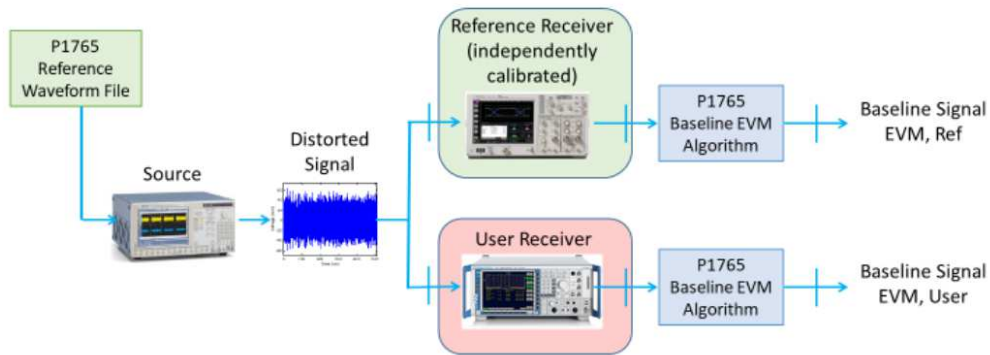
CHALLENGES – PHASE NOISE (R&S®FSWP)

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

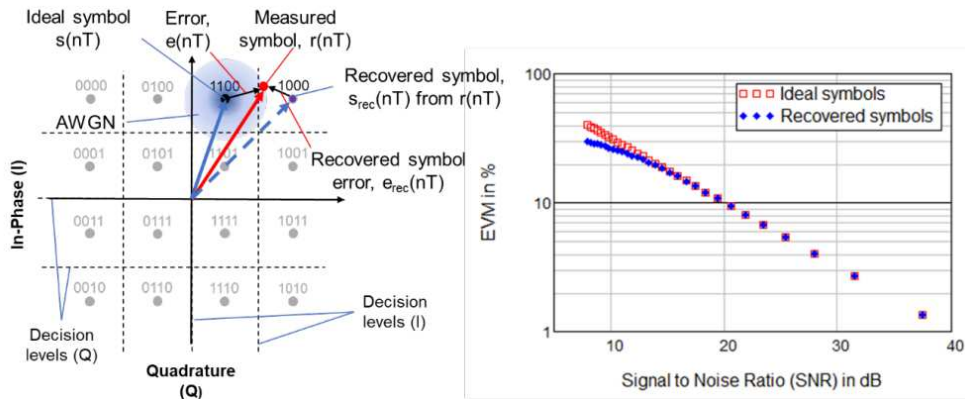


CHALLENGES – PHASE RELATION

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

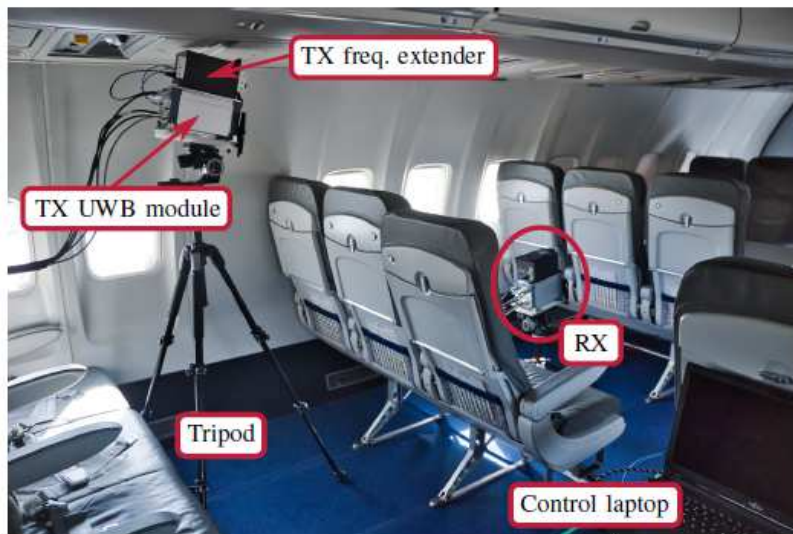


Fig. 2: Partial illustration of the general measurement setup.

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.

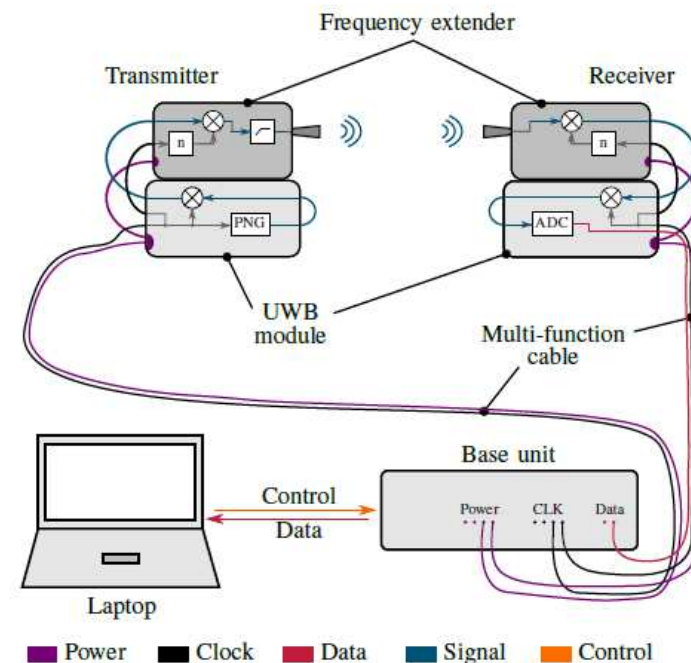


Fig. 3: Schematic block diagram of the channel sounder.

CHALLENGES – CHANNEL SOUNDING

Traceability of Channel Impulse Response

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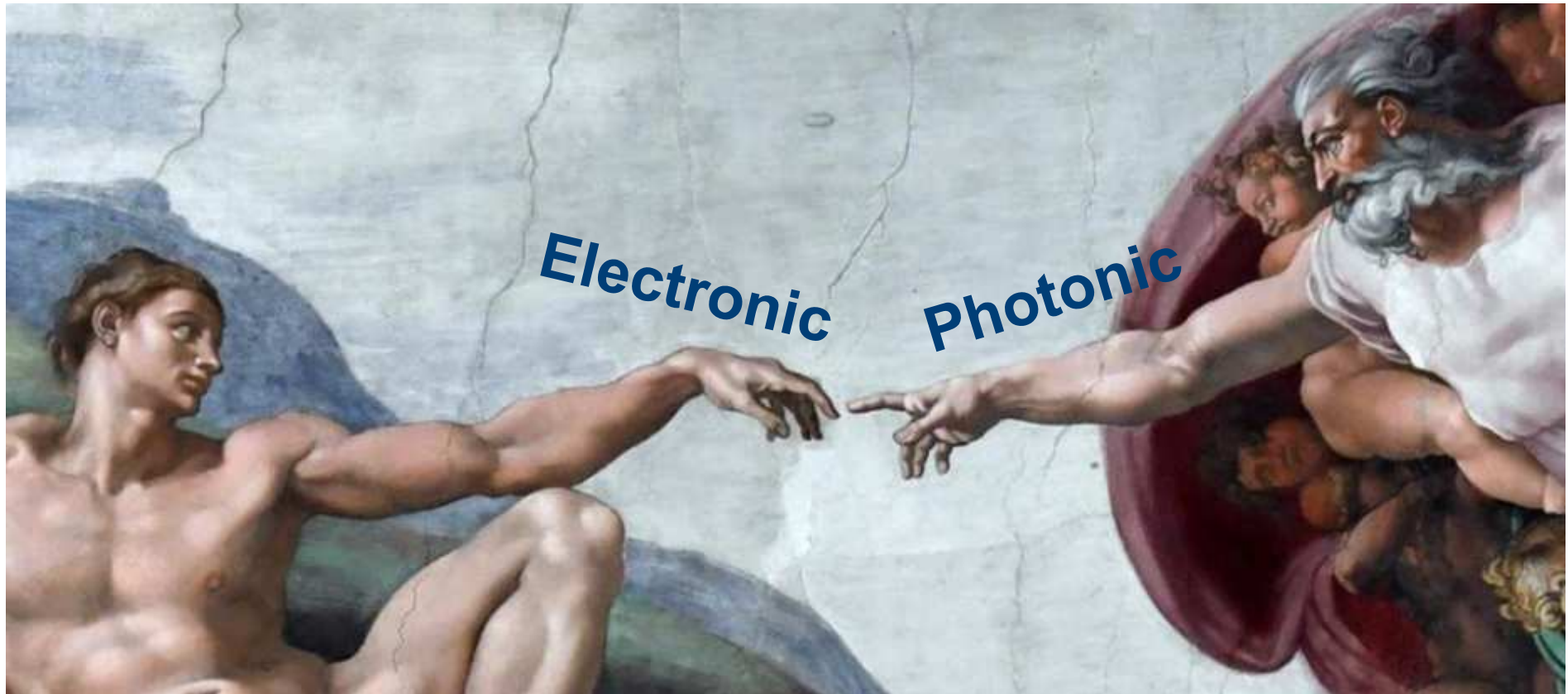
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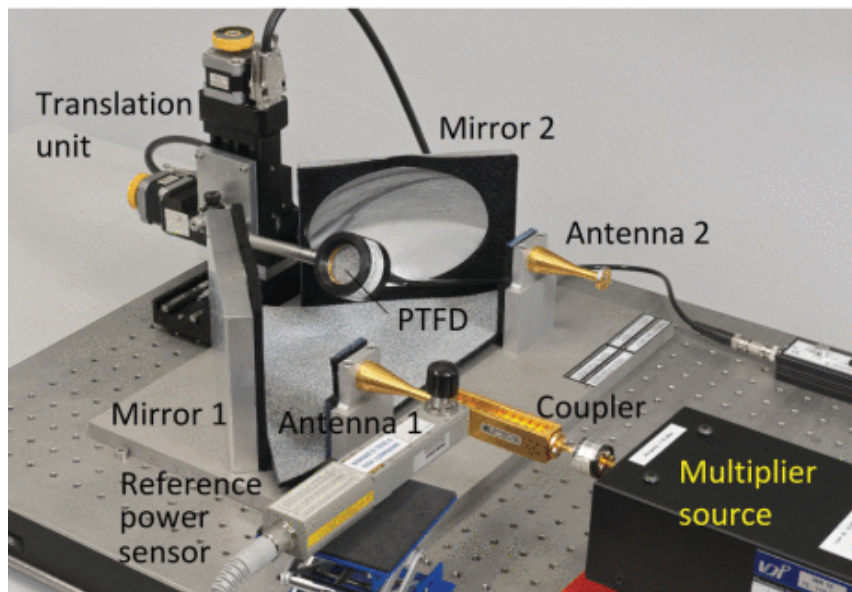
3 Problem Solving Approaches

4 Example Phase Traceability

5 Wrap-Up



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

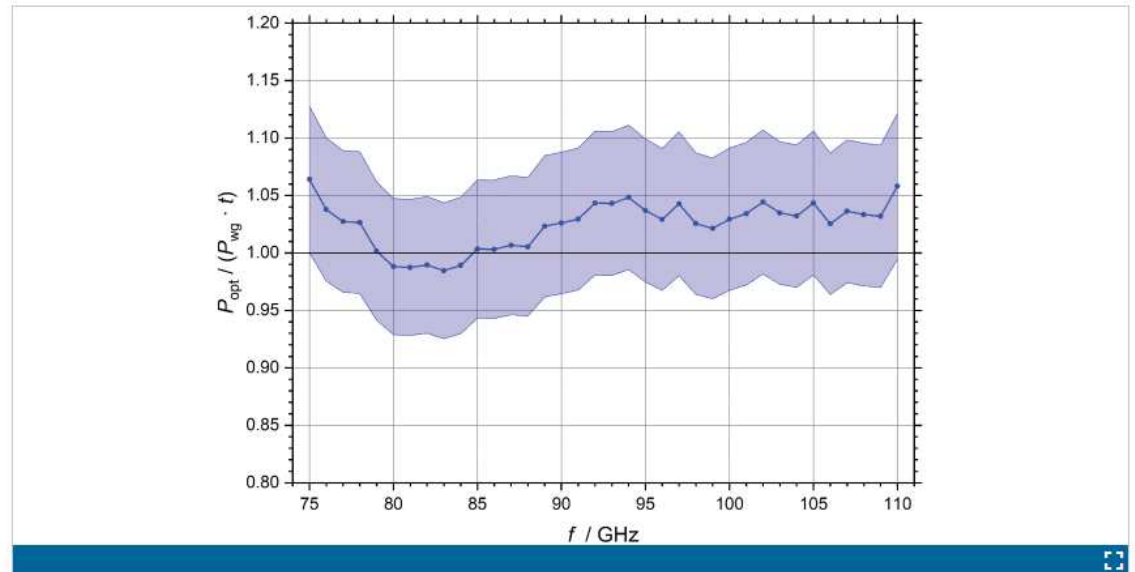
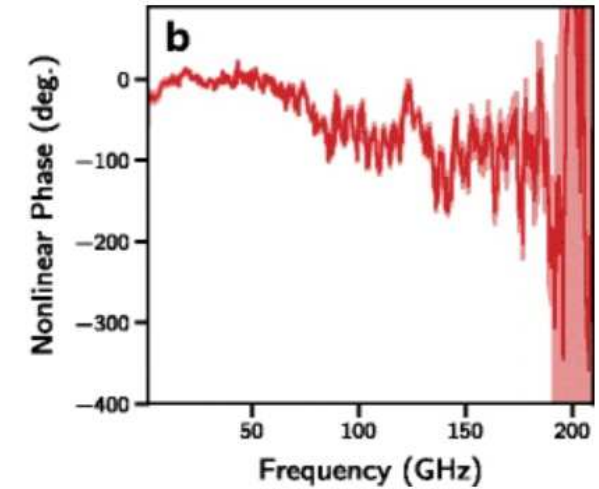
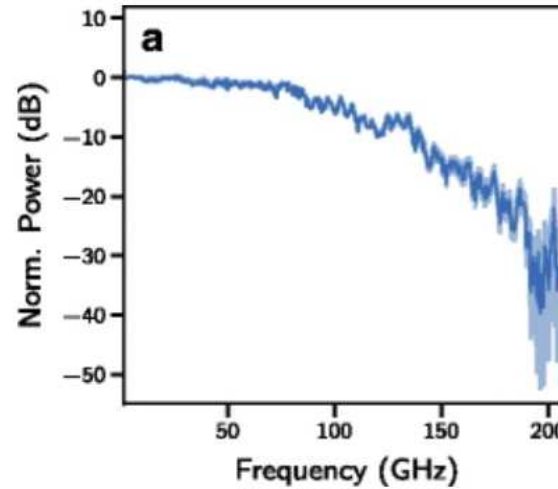
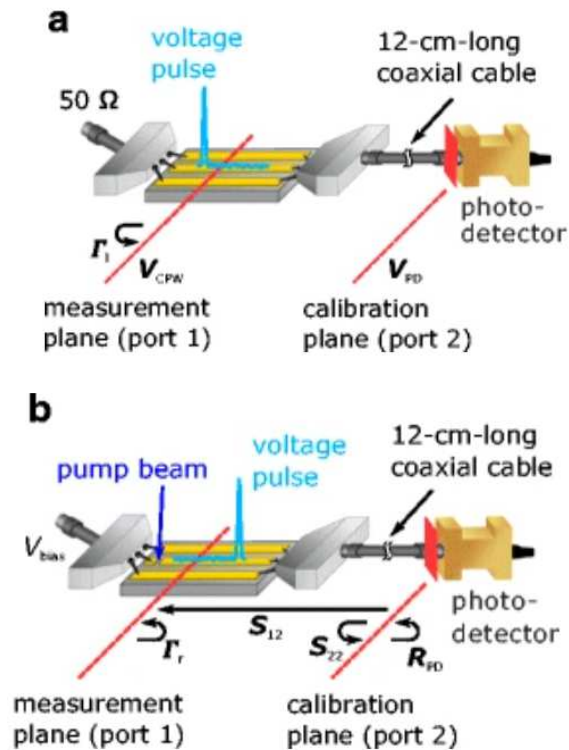


Fig. 7. Ratio of measured optical power P_{opt} in plane B and waveguide power P_{wg} in plane A divided by transmission coefficient t .

PROBLEM – SOLVING APPROACHES

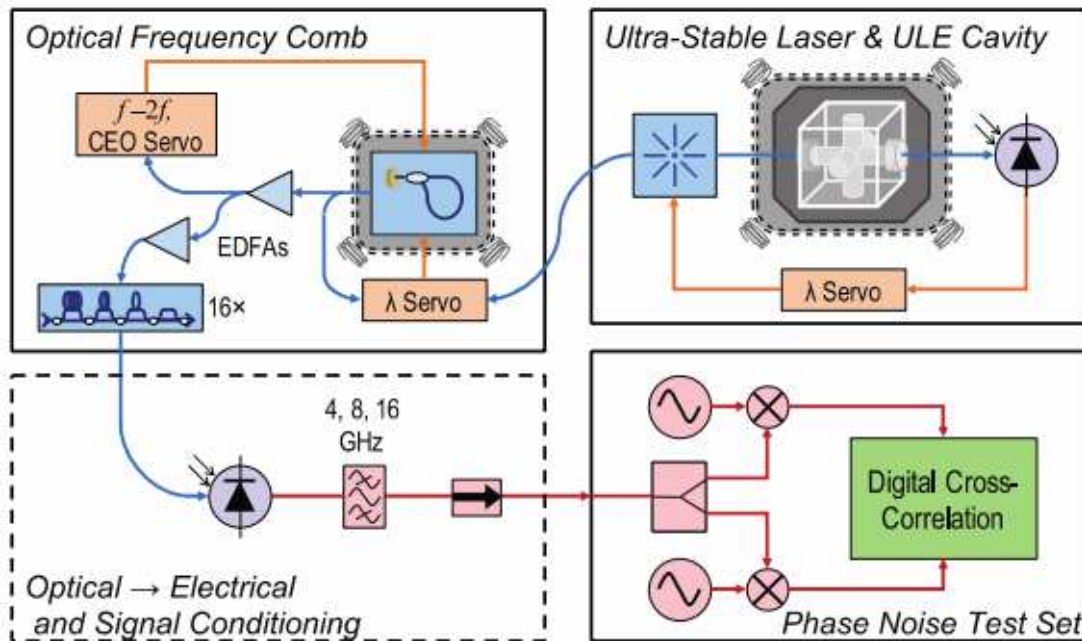
Comparison of different RF power traceability chains



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



SELECTED PHASE NOISE LEVELS (dBc/Hz †)

Offset Frequency	SLCO, 3 GHz	PMO, 4 GHz	PMO, 8 GHz	PMO, 16 GHz
10 Hz	-96	-109	-101	-98
100 Hz	-128	-130	-123	-115
1 kHz	-149	-146	-146	-143
10 kHz	-161	-162	-164	-152
100 kHz	-168	-167	-164	-155

† SLCO: Sapphire loaded cavity oscillator; PMO: photonic microwave oscillator.

J. W. Zobel *et al.*, "Comparison of Optical Frequency Comb and Sapphire Loaded Cavity Microwave Oscillators," in *IEEE Photonics Technology Letters*, vol. 31, no. 16, pp. 1323-1326, 15 Aug. 15, 2019

PROBLEM – SOLVING APPROACHES

Generation of ultralow THz noise sources by optical frequency combs

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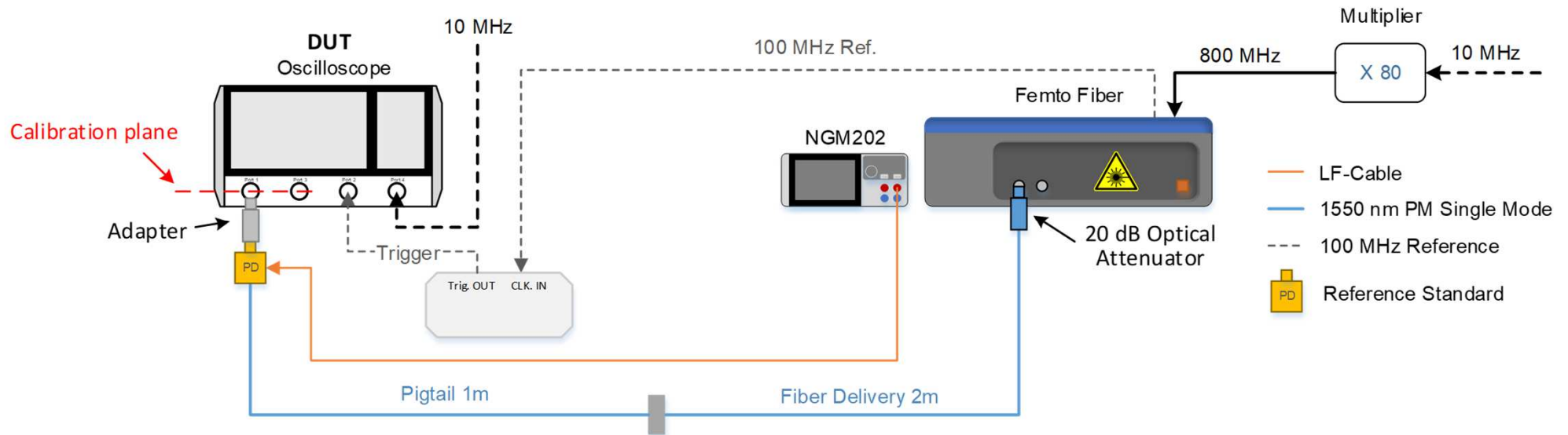
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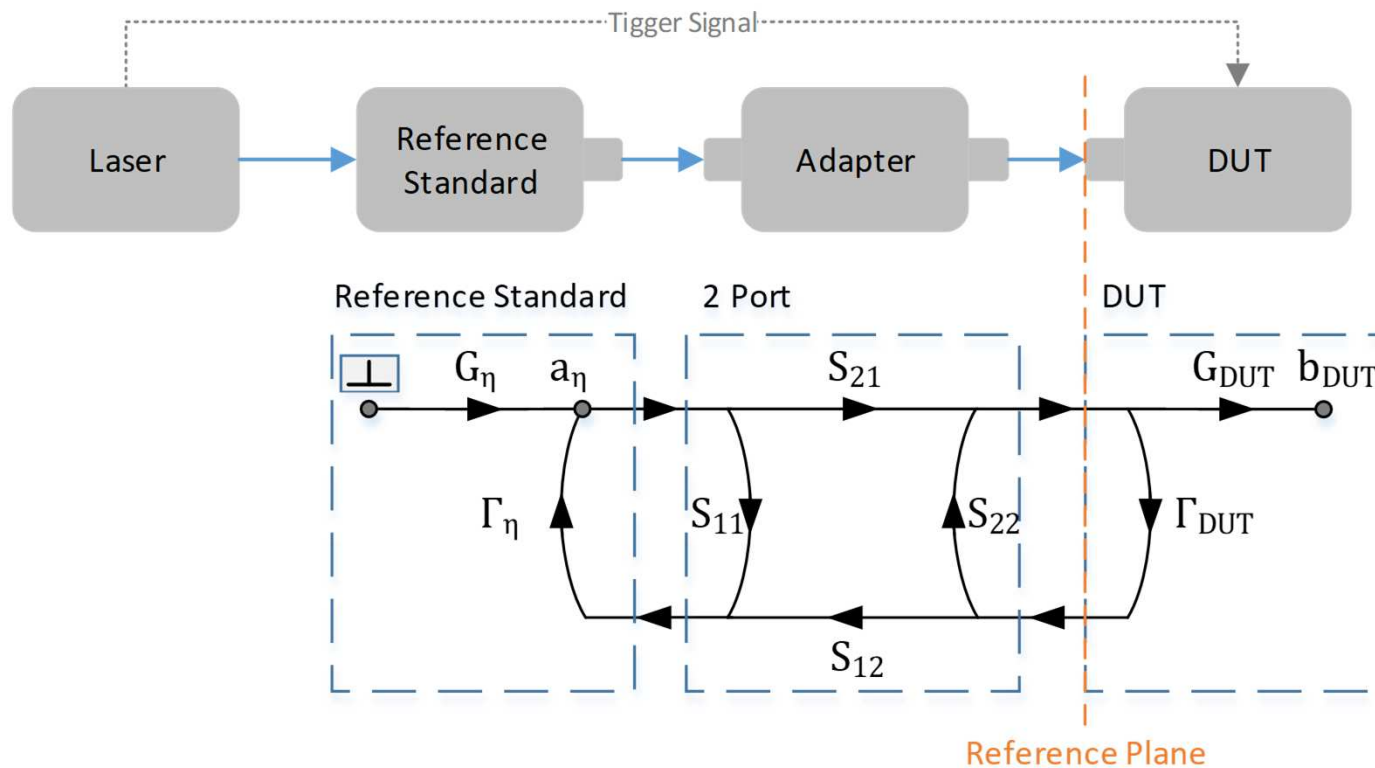
4 **Example Phase Traceability**

5 Wrap-Up



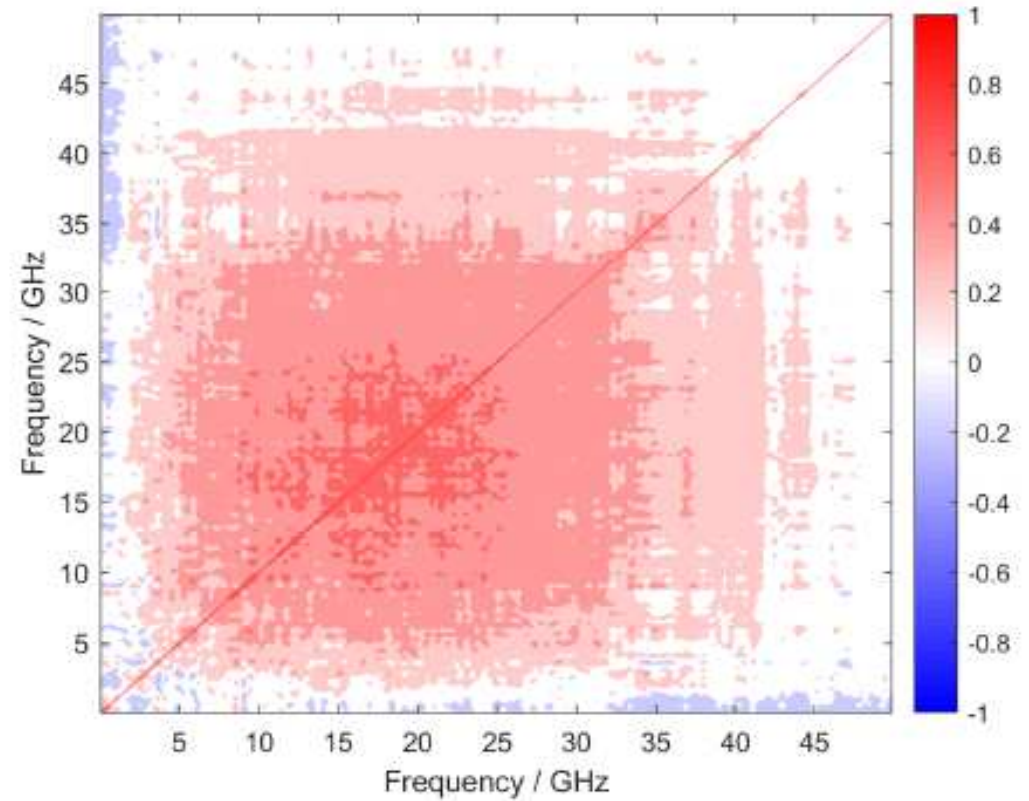
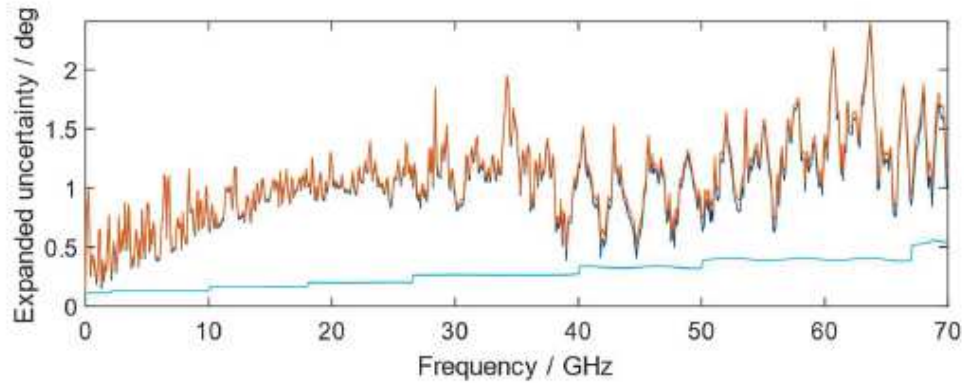
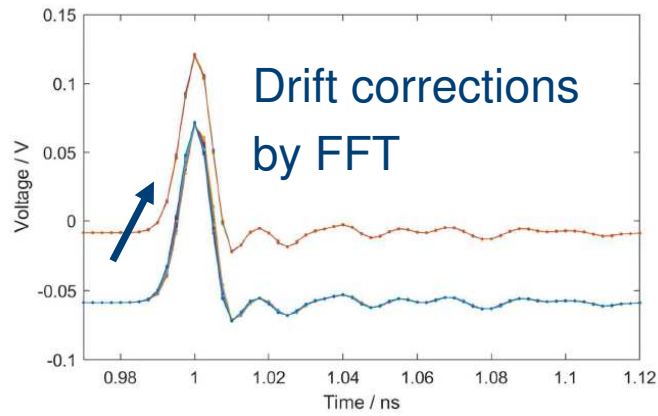
EXAMPLE PHASE TRACEABILITY

Evaluation of the Oscilloscope transfer function by electro-optical dirac pulse



EXAMPLE PHASE TRACEABILITY

Well known S-parameter metrology



EXAMPLE PHASE TRACEABILITY

Uncertainty analysis using fourier transformation and correlation matrices

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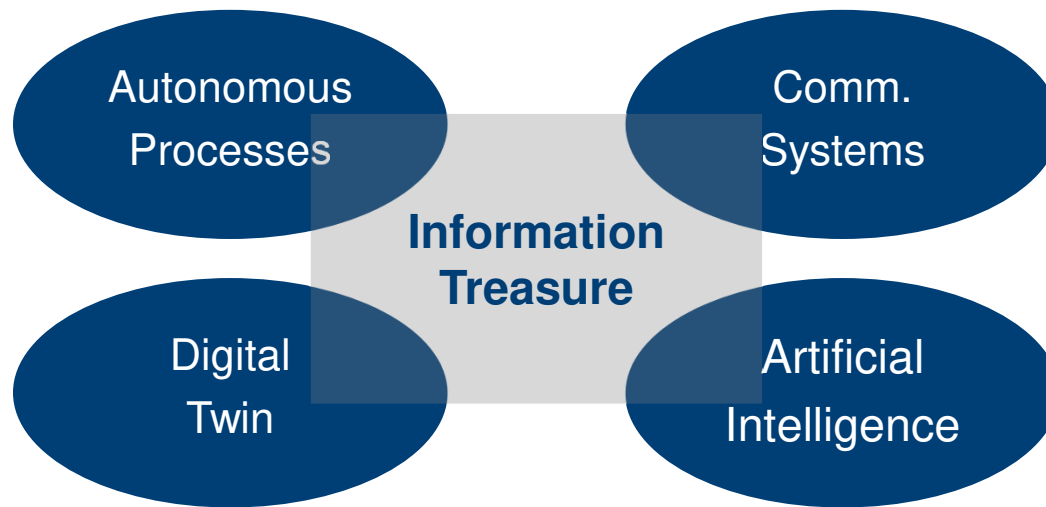
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5 **Wrap-Up**

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



THANK YOU

ROHDE & SCHWARZ

