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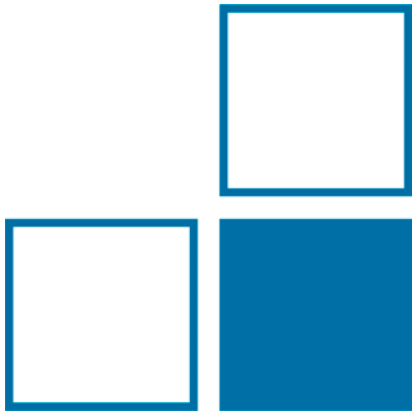
FormFactor™

Transferring the accuracy of Multiline TRL to industrial calibrations

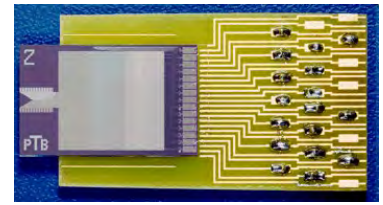
Dr. Uwe Arz, AG 2.23

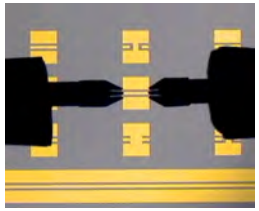
Physikalisch-Technische Bundesanstalt (PTB)



Dissemination of the Units: PTB

…or using multipliers





???

National Standards
PTB and DIs (BAM, UBA, BVL)

Reference Standards
Accredited Calibration Laboratory

Working Standards
In-Plant Calibration Laboratory

In-Plant Test Equipment

Products

Motivation: EMPIR-Project 14IND02 PlanarCal

Microwave measurements for planar circuits and components

Scientific goals

- Establish traceability of planar scattering parameter measurements
- Extension to higher frequencies (at least 325 GHz)
- Develop methods for measurements of RF nano-devices

Partners:

PTB, NPL National Physical Laboratory, FAU, Leibniz Ferdinand-Braun-Institut, Fraunhofer IAF, Université de Lille, TU Delft, University of Leeds, Rohde & Schwarz, TDK, METAS

Support from Industry

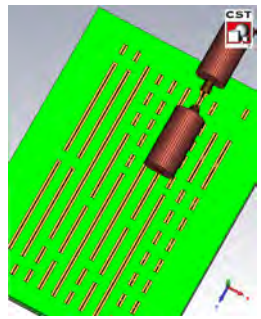
Airbus, NXP, Thales, intel, infineon, Rohde & Schwarz, Anritsu, Keysight Technologies, MPI

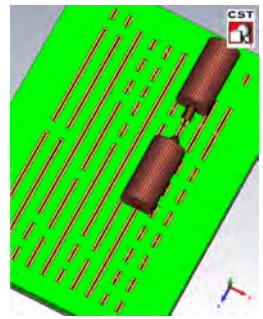
Website: planarcal.ptb.de

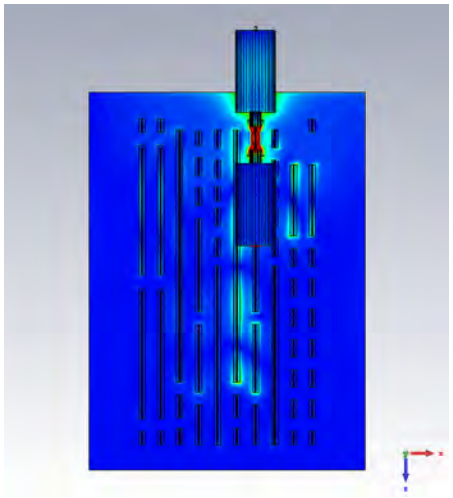
Influence of Neighborhood on Multiline TRL Calibrations

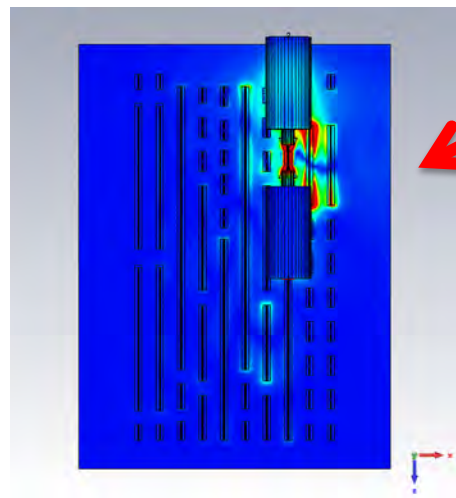
DUT measurement and simulation results on GaAs wafer

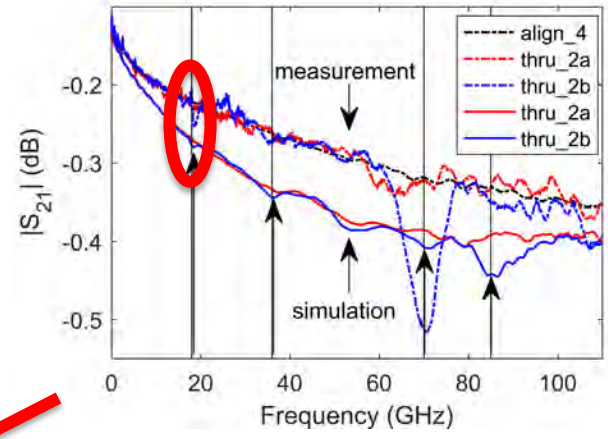
thru_2a thru_2b











(Simulations: FBH)

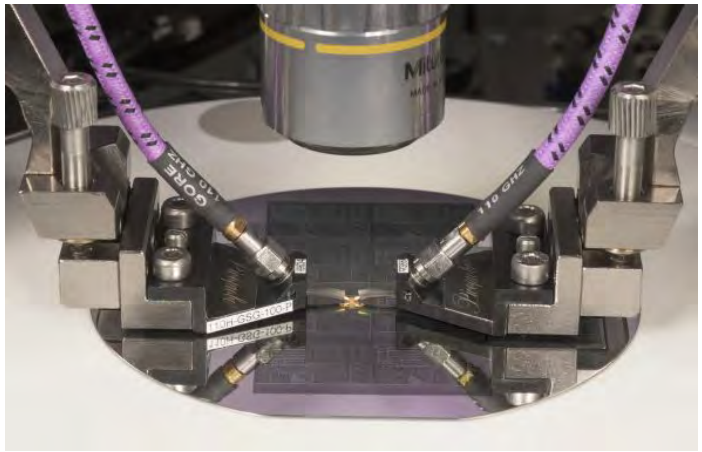
- despite identical DUT geometry different measurement results
- Design guidelines for calibration substrates essential! (see planarcal.ptb.de)

Only possible conclusion:

Reliable uncertainties can only be specified in a given environment/ DUT neighborhood for a selected combination of

- substrate materials
- planar waveguides
- and microwave probes!

PTB on-wafer measurement setup



- Anritsu VectorStar VNA
- FormFactor PA 200 wafer prober
- choice of ceramic/metal chuck
- microwave probes with 100 um pitch

S-Parameter Uncertainty Evaluation

Software packages for S-parameter uncertainty evaluation:

- NIST Microwave Uncertainty Framework
- METAS VNATools
- Keysight firmware (originally MMS4 by HFE)

Generic software for automatic calculation of uncertainty propagation:

- MSL GUM Tree Calculator (GTC)
- METAS UncLib
- …

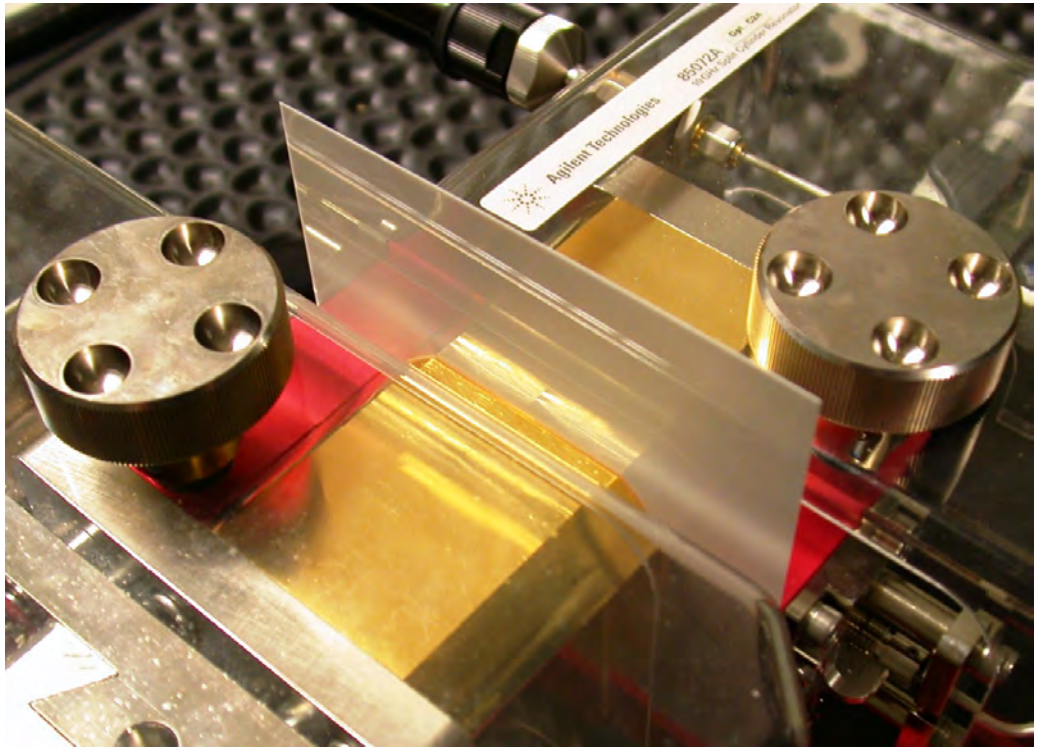
<u>This work:</u>

- Matlab multiline TRL implementation using METAS UncLib
- VNA characterization in accordance with new EURAMET guide CG-12

Fused Silica Substrates

Again: Reliable uncertainties can only be specified in a given environment for a selected combination of substrate materials, planar waveguides and probes!

Wideband extraction of dielectric material properties



Reference method:

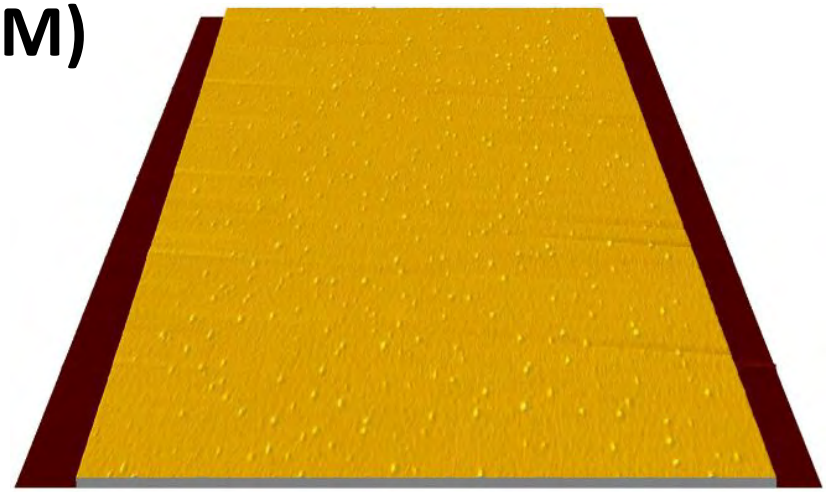
- split-cylinder resonator

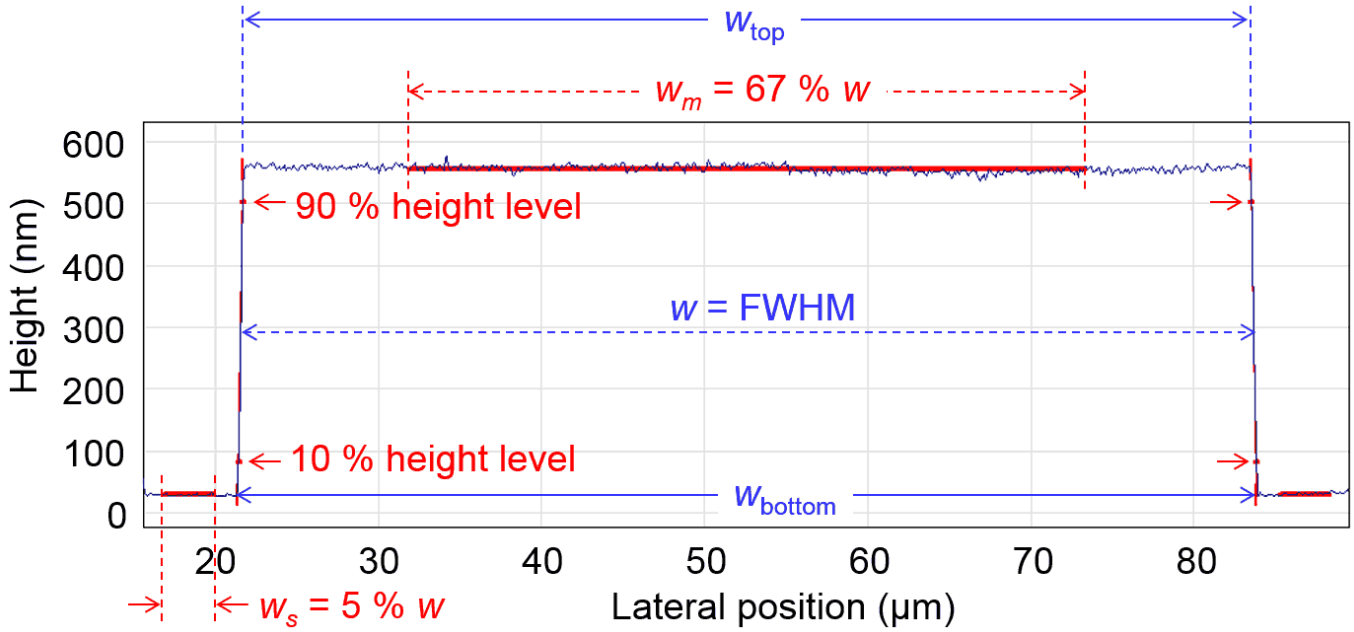
Other methods/sources:

- on-wafer methods
- manufacturer data

Dimensional Characterization (AFM)

3D view of
center conductor
(z shown 3x enlarged)

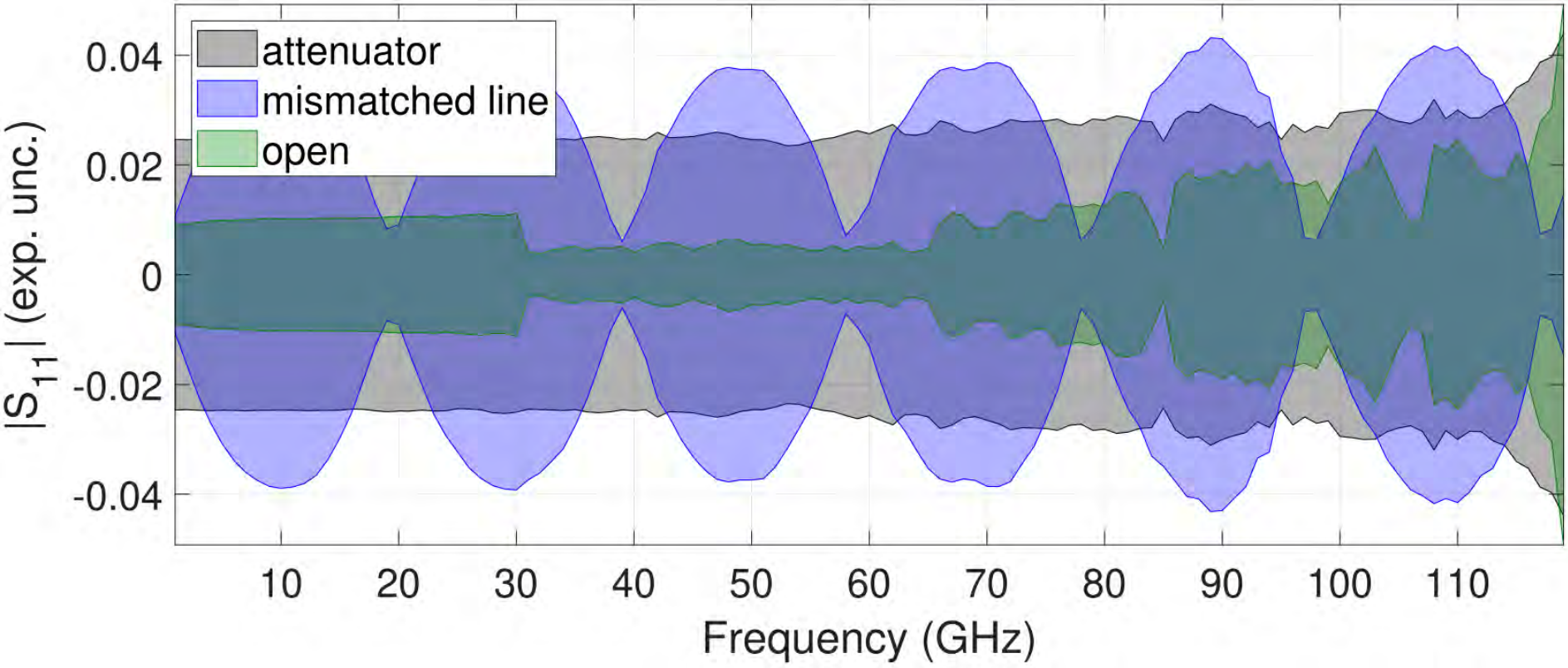




measured profile
of center conductor

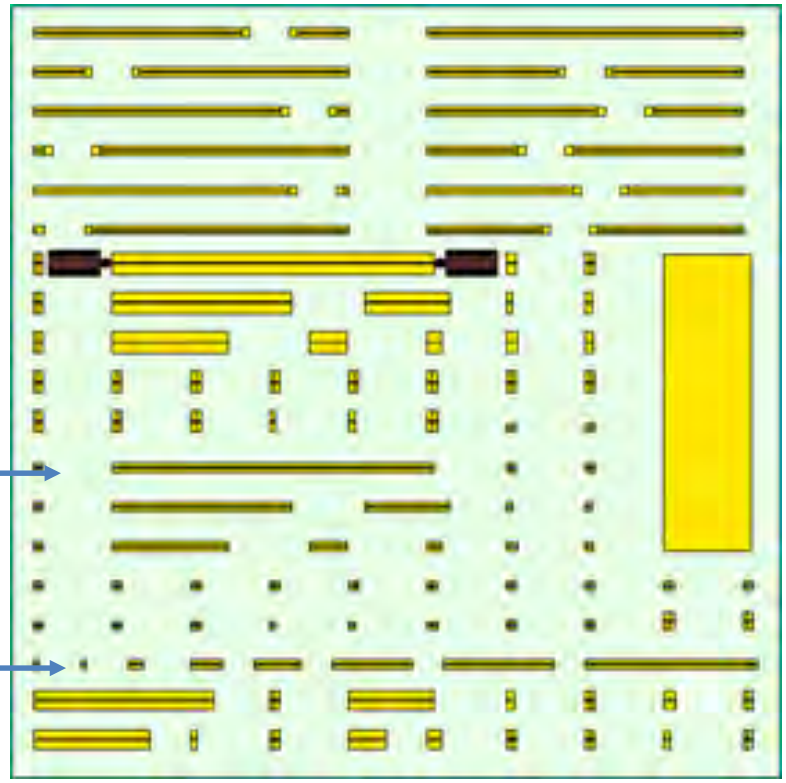
|S11| Expanded Uncertainty Intervals (k=2) for MTRL

Different DUTs on fused silica substrate

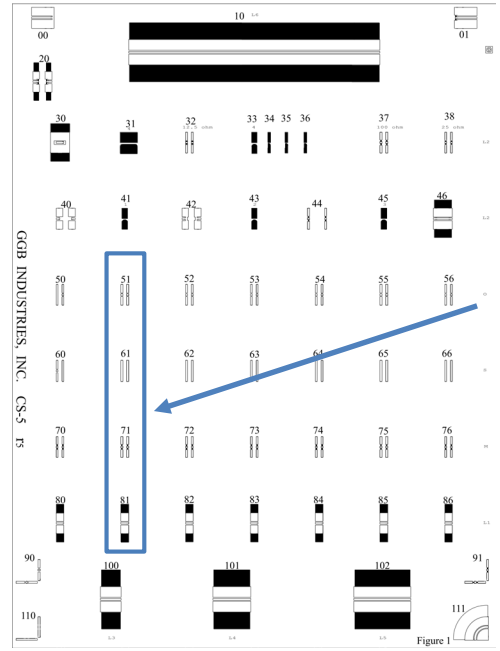


Transfer of Uncertainties (DUTs on Fused Silica)

- Situation: DUTs/calibration set built on custom-made R&S fused silica wafer
- for high-throughput measurements only ISS can be used (here: GGB CS-5)



fused silica wafer



(https://www.ggb.com)

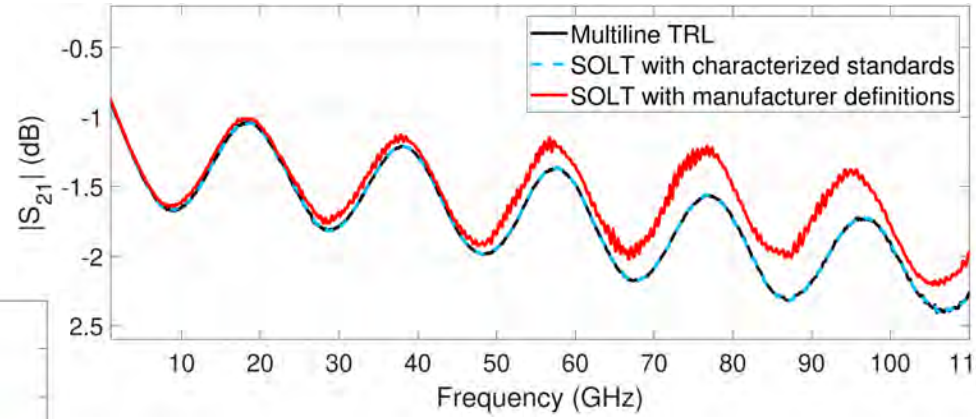
SOLT transfer standards

GGB CS-5*)

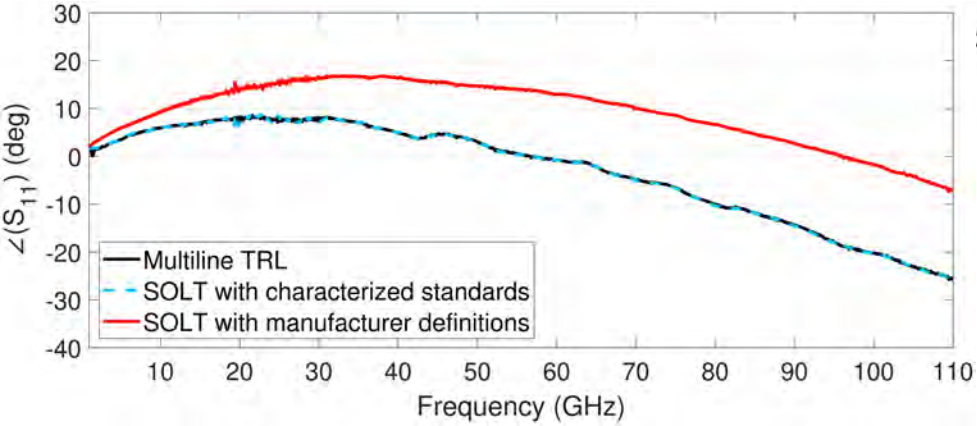
*) We use brand names only to better specify the experimental conditions. PTB does not endorse commercial products. Other products may work as well or better.

Transfer of Uncertainties (DUTs on Fused Silica)

Transmission of mismatched line



Reflection of attenuator device



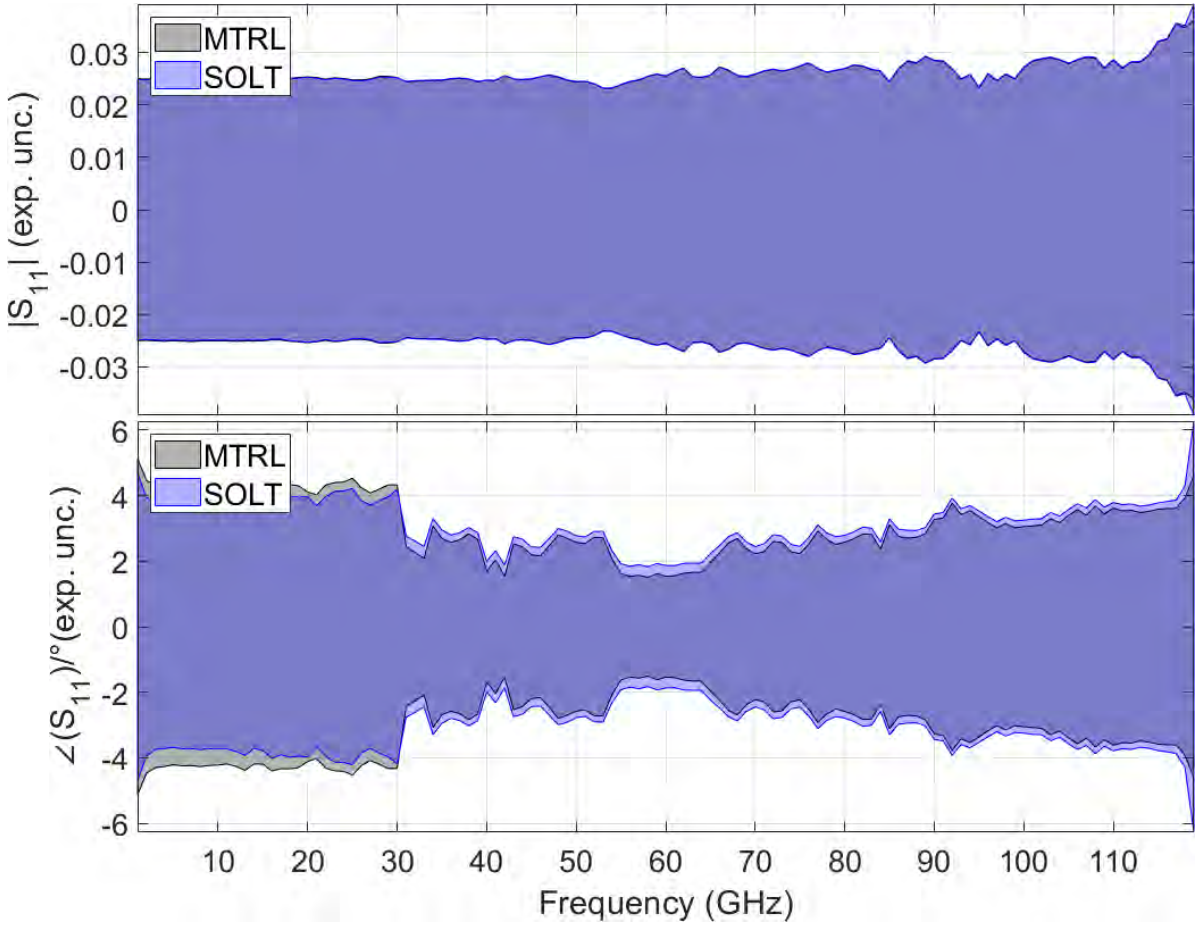
- SOLT with characterized ISS standards yields same result as reference multiline TRL!
- Change of reference planes easily possible in multiline TRL

=> SOLT with characterized standards will have same reference plane location!

- Other techniques to correct ISS calibration have been investigated (permittivity compensation, residual error correction) – only of limited use.

Reflection of Attenuator Device on Fused Silica

Normalized S11 measurements including 95% coverage intervals



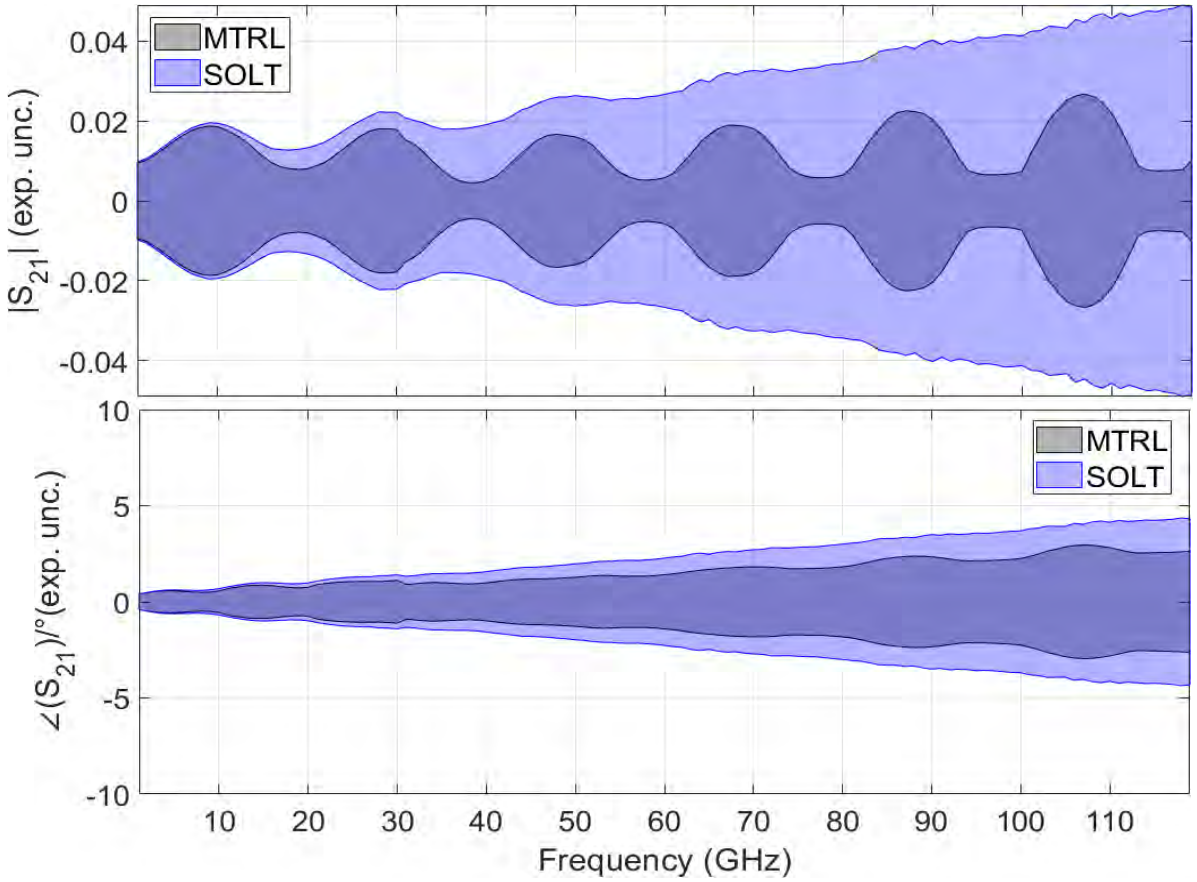
black: MTRL

blue: SOLT (char. stds)

- with e.g. SOLT no need for time-consuming MTRL calibration
- wear on MTRL standards reduced!

Transmission of Mismatched Line on Fused Silica

Normalized S21 measurements including 95% coverage intervals



black: MTRL

blue: SOLT (char. stds)

- SOLT uncertainties typically increased (depending on quantity)
- **ISS can be used as transfer standard after characterization with custom-made, application-specific calibration standards**

Suggested Workflow for Industrial Calibrations

1. Design custom reference mTRL/TRL calibration kit suitable for your application and technology (on alumina, HRSi, GaAs,…)!

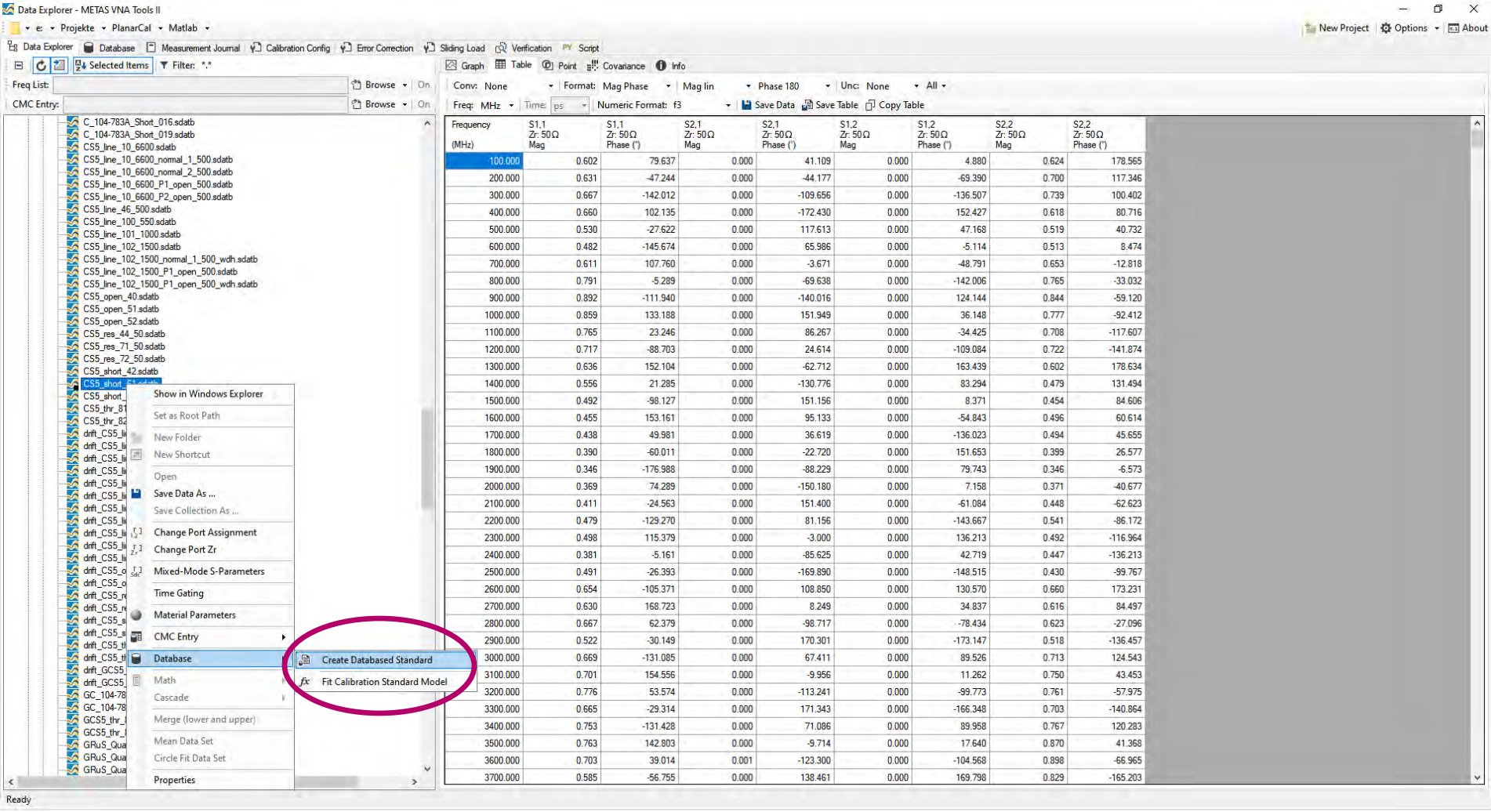
2. PTB: - characterizes custom kit and transfer standards (ISS)
- issues calibration certificate (ISO17025)

3. Use transfer standards for e.g. SOLT calibration in the field!

N.B.:

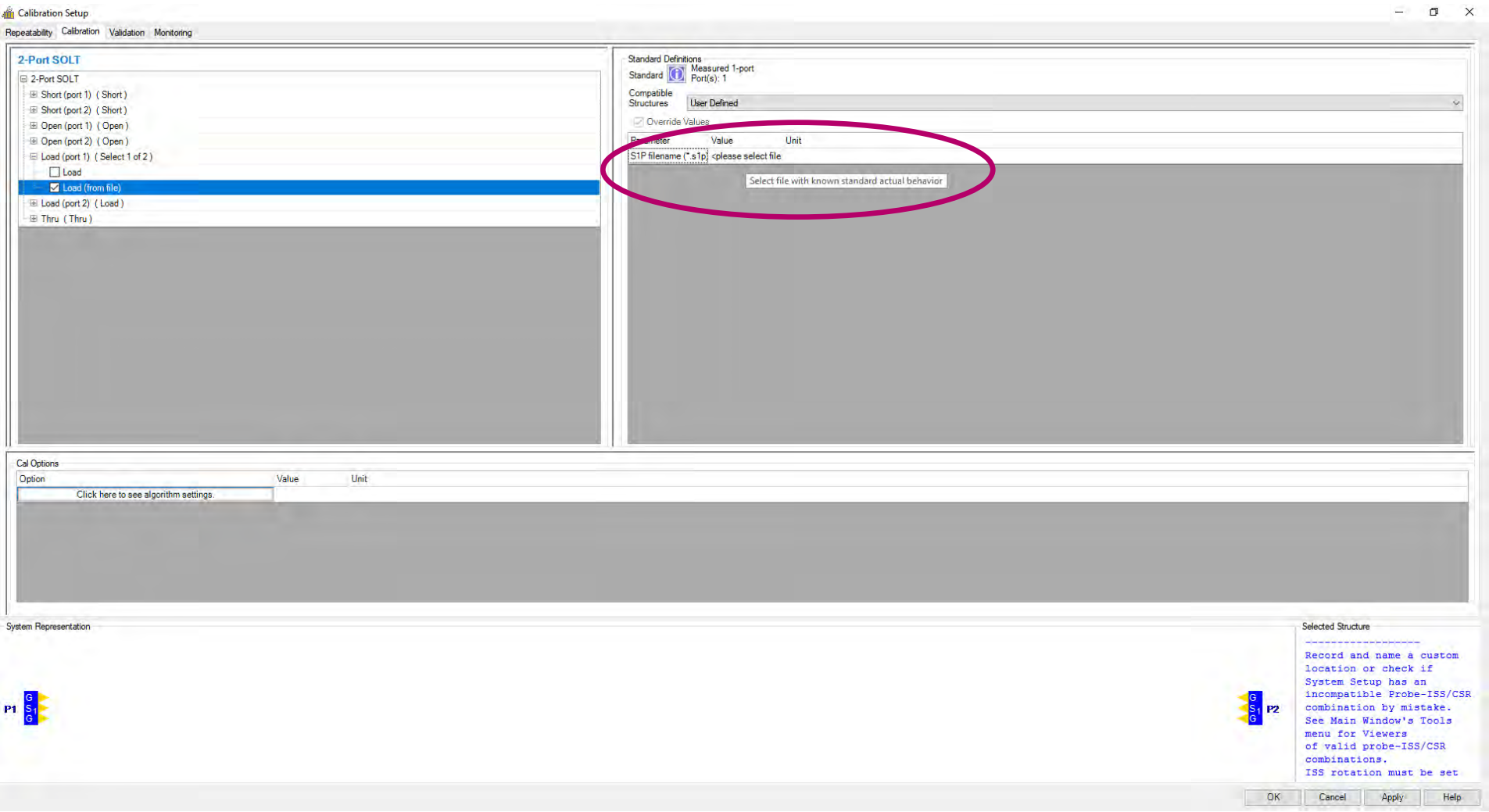
- ✓ Custom reference kit is only needed for characterizing transfer standards!
- ✓ Transfer standards can be short/open/load/thru on commercial ISS!

Software Options (besides VNA): METAS VNATools



Frequency (MHz)	S1,1 Zr: 50Ω Mag	S1,1 Zr: 50Ω Phase (°)	S2,1 Zr: 50Ω Mag	S2,1 Zr: 50Ω Phase (°)	S1,2 Zr: 50Ω Mag	S1,2 Zr: 50Ω Phase (°)	S2,2 Zr: 50Ω Mag	S2,2 Zr: 50Ω Phase (°)
100.000	0.602	79.637	0.000	41.109	0.000	4.880	0.624	178.565
200.000	0.631	-47.244	0.000	-44.177	0.000	-69.390	0.700	117.346
300.000	0.667	-142.012	0.000	-109.656	0.000	-136.507	0.739	100.402
400.000	0.660	102.135	0.000	-172.430	0.000	152.427	0.618	80.716
500.000	0.530	-27.622	0.000	117.613	0.000	47.168	0.519	40.732
600.000	0.482	-145.674	0.000	65.986	0.000	-5.114	0.513	8.474
700.000	0.611	107.760	0.000	-3.671	0.000	-48.791	0.653	-12.818
800.000	0.791	-5.289	0.000	-69.638	0.000	-142.006	0.765	-33.032
900.000	0.892	-111.940	0.000	-140.016	0.000	124.144	0.844	-59.120
1000.000	0.859	133.188	0.000	151.949	0.000	36.148	0.777	-92.412
1100.000	0.765	23.246	0.000	86.267	0.000	-34.425	0.708	-117.607
1200.000	0.717	-88.703	0.000	24.614	0.000	-109.084	0.722	-141.874
1300.000	0.636	152.104	0.000	-62.712	0.000	163.439	0.602	178.634
1400.000	0.556	21.285	0.000	-130.776	0.000	83.294	0.479	131.494
1500.000	0.492	-98.127	0.000	151.156	0.000	8.371	0.454	84.606
1600.000	0.455	153.161	0.000	95.133	0.000	-54.843	0.496	60.614
1700.000	0.438	49.981	0.000	36.619	0.000	-136.023	0.494	45.655
1800.000	0.390	-60.011	0.000	-22.720	0.000	151.653	0.399	26.577
1900.000	0.346	-176.988	0.000	-88.229	0.000	79.743	0.346	-6.573
2000.000	0.369	74.289	0.000	-150.180	0.000	7.158	0.371	-40.677
2100.000	0.411	-24.563	0.000	151.400	0.000	-61.084	0.448	-62.623
2200.000	0.479	-129.270	0.000	81.156	0.000	-143.667	0.541	-86.172
2300.000	0.498	115.379	0.000	-3.000	0.000	136.213	0.492	-116.964
2400.000	0.381	-5.161	0.000	-85.625	0.000	42.719	0.447	-136.213
2500.000	0.491	-26.393	0.000	-169.890	0.000	-148.515	0.430	-99.767
2600.000	0.654	-105.371	0.000	108.850	0.000	130.570	0.660	173.231
2700.000	0.630	168.723	0.000	8.249	0.000	34.837	0.616	84.497
2800.000	0.667	62.379	0.000	-98.717	0.000	-78.434	0.623	-27.096
2900.000	0.522	-30.149	0.000	170.301	0.000	-173.147	0.518	-136.457
3000.000	0.669	-131.085	0.000	67.411	0.000	89.526	0.713	124.543
3100.000	0.701	154.556	0.000	-9.956	0.000	11.262	0.750	43.453
3200.000	0.776	53.574	0.000	-113.241	0.000	-99.773	0.761	-57.975
3300.000	0.665	-29.314	0.000	171.343	0.000	-166.348	0.703	-140.864
3400.000	0.753	-131.428	0.000	71.086	0.000	89.958	0.767	120.283
3500.000	0.763	142.803	0.000	-9.714	0.000	17.640	0.870	41.368
3600.000	0.703	39.014	0.001	-123.300	0.000	-104.568	0.898	-66.965
3700.000	0.585	-56.755	0.000	138.461	0.000	169.798	0.829	-165.203

Software Options (besides VNA Firmware): WinCal



Summary and Conclusions

- Traceability demonstrated up to now for membrane and fused silica substrates – also applicable to other industrial substrates!
- Characterized standards on commercial ISS fully suitable as transfer standards
- Simple calibrations such as SOLT yield same nominal results as multiline TRL
- Changes of reference plane easily possible
- Wear on reference multiline standards significantly reduced
- Uncertainties typically slightly increased

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Thank you!

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