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27 November 2026

The S-matrix Method for High Frequency Capacitance Calibration

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S-MATRIX METHOD

- Measurement of a four terminal pair (Z_{4TP}) air capacitance standard in terms of S-parameters
- The capacitance is measured using a two-port vector network analyzer (VNA)
- The VNA is equipped with BNC connectors
- The two ports of the device not employed are terminated on matched impedances

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S-MATRIX METHOD

- The measurement results are combined according to the following equation [1]:

$$Z_{4TP} = 2Z_0 \{s_{21}s_{34} - s_{31}s_{24}\}\{s_{31} + (s_{21}s_{32} - s_{31}s_{44} - s_{31}s_{22} + s_{41}s_{34} - s_{21}s_{32}s_{44} + s_{21}s_{34}s_{42} + s_{31}s_{22}s_{44} - s_{31}s_{42}s_{24} - s_{41}s_{34}s_{22} + s_{41}s_{24}s_{32})\}^{-1}$$

- All measurements are performed with the VNA Tools II program developed by METAS
- The data analysis is performed using the METAS.UncLib library in MATLAB

[1] L. Callegaro, F. Durbiano, “Four-terminal-pair impedances and scattering parameters”, Meas. Sci. Technol. 14 (2003), 523-529

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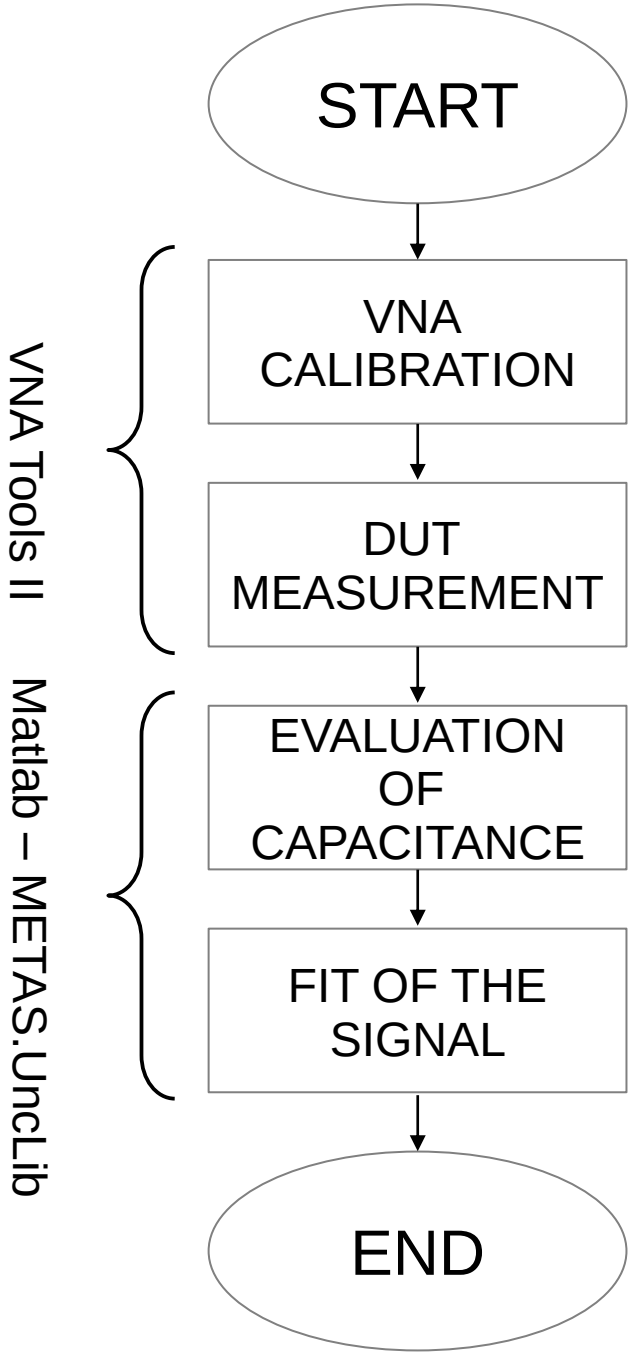
FLOW CHART



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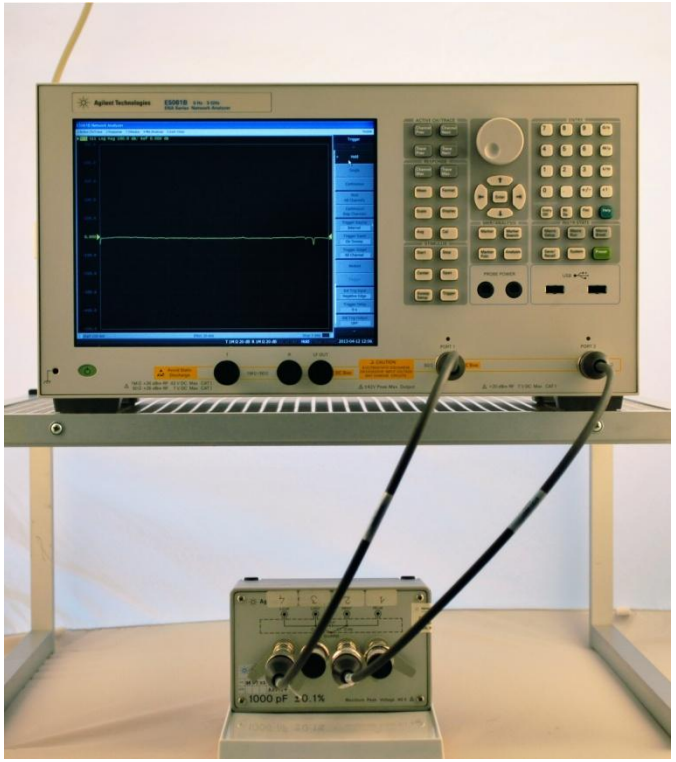
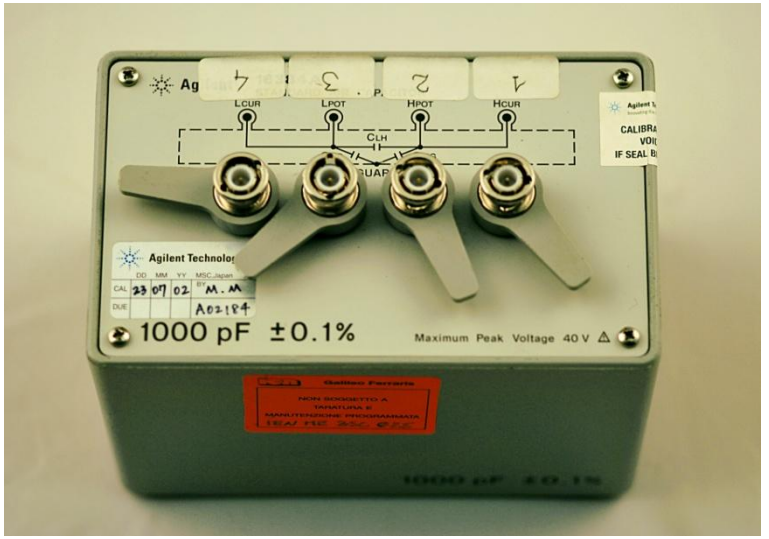
MEASUREMENT SETUP



Vector Network Analyzer:
Agilent E5061B



Standard: Agilent 16384A
1000 pF capacitor



Calibration Kit: Maury Microwave
8550 - Coaxial BNC

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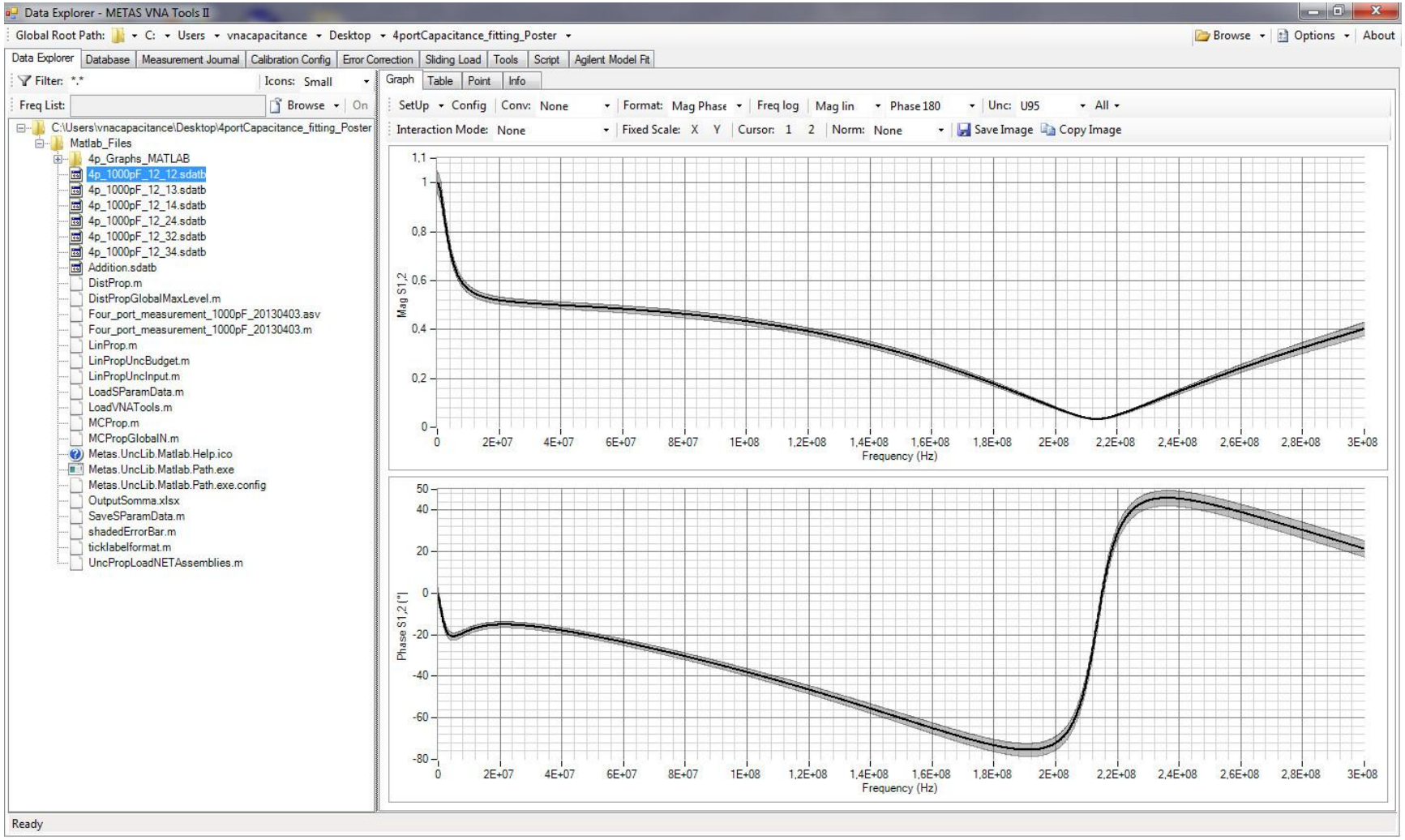
RESULTS



VNA Tools II – Display of S-parameters

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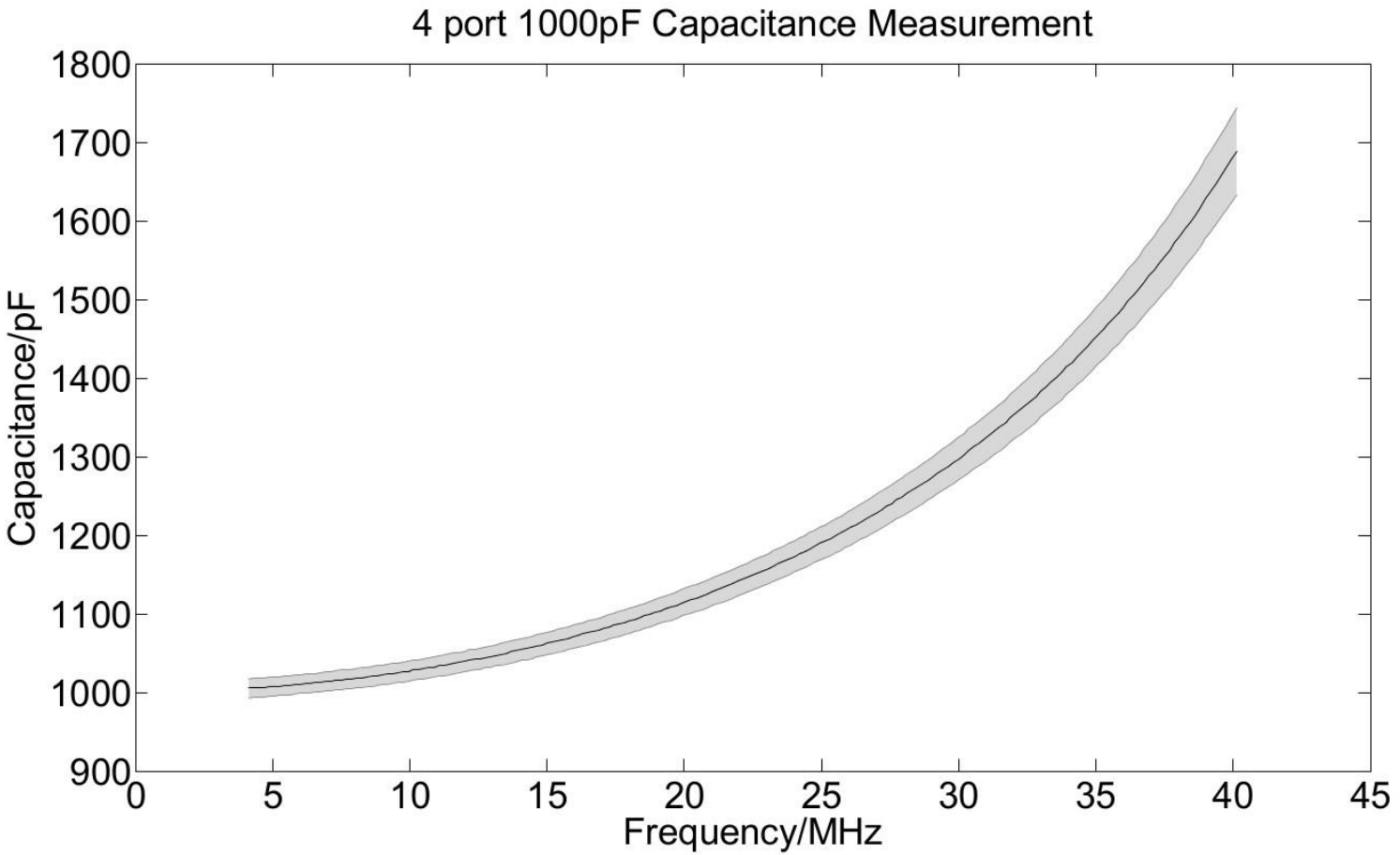
RESULTS



1000 pF capacitance graph(grey)
with uncertainty (MATLAB METAS.UncLib)

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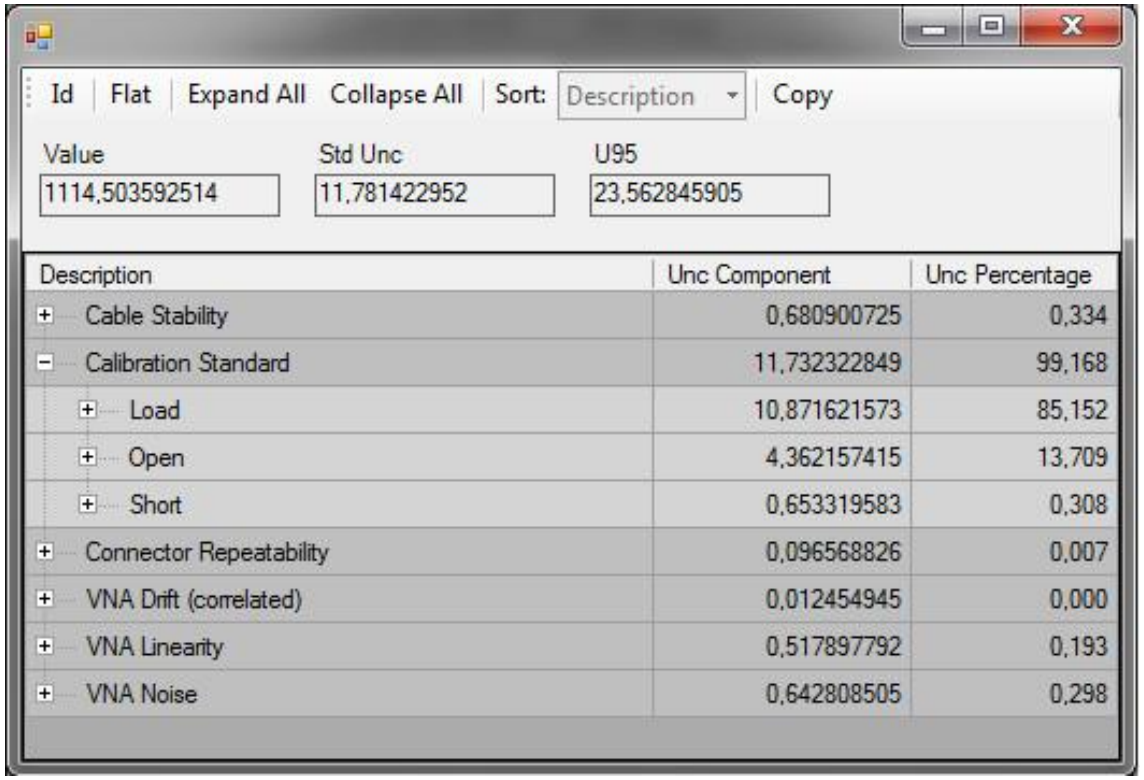
RESULTS



Description	Unc Component	Unc Percentage
Cable Stability	0,680900725	0,334
Calibration Standard	11,732322849	99,168
Load	10,871621573	85,152
Open	4,362157415	13,709
Short	0,653319583	0,308
Connector Repeatability	0,096568826	0,007
VNA Drift (correlated)	0,012454945	0,000
VNA Linearity	0,517897792	0,193
VNA Noise	0,642808505	0,298

Uncertainty budget of capacitance fit [pF] (MATLAB METAS.UncLib)
@ 15 MHz

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SUMMARY

- With the proposed method it is possible to measure a four terminal pair capacitance with a 2-port VNA
- METAS VNA Tools II assists the measurement process and collects data
- With METAS.UncLib it is possible to evaluate the desired results together with an uncertainty estimation compliant with the GUM
- Reduction of the uncertainty due to the standards (that now use manufacturer specifications) by characterizing the Load standard
- Future work will involve a comparison of the S-matrix method with a different one

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THANK YOU!!!

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