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Federal Institute of Metrology METAS

Adapter characterization up to 110 GHz

EMRP HF Circuits project: 6th European ANAMET meeting
28.06.2016

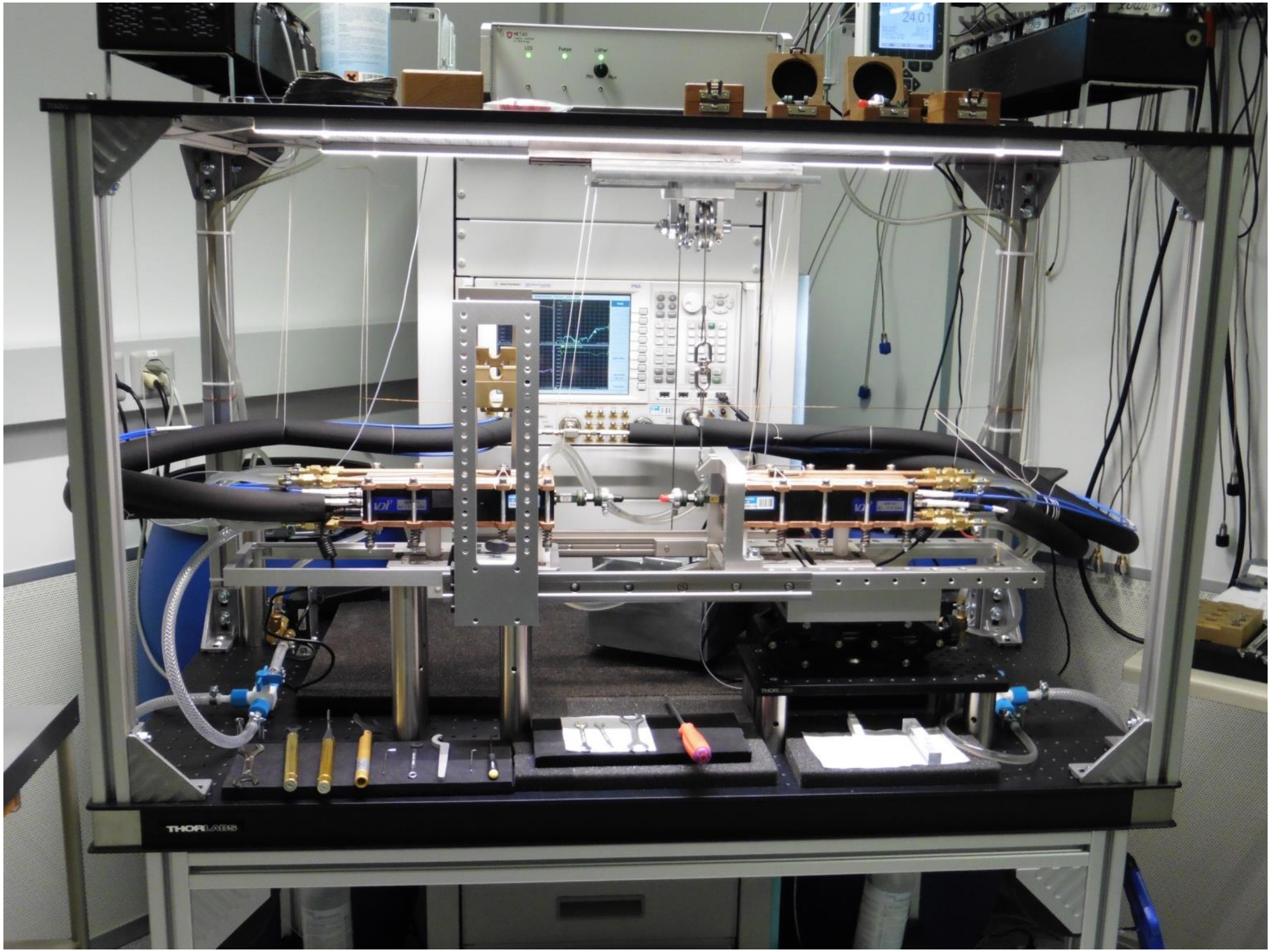
The challenges of an adapter characterization:

- **insertable** vs **non-insertable** (same connector family)
- **non-insertable** (between different connector families)
- **Waveguide to coax** (straight vs angular)





Waveguide and 1.0 mm setup at METAS



Agenda

1. **Typical adapter characterization techniques**
2. **Pro and cons of these adapter measurement techniques**
3. **New findings in coaxial VNA metrology**
   - Systematic connector effects
   - ***VNA Tools*** : GUM compliant uncertainty process
4. **Two practical 1.0 mm adapter characterization examples**
5. **Conclusions**

The ideal case: an insertable adapter

Step 1:

Forward reflection calibration
measures: E_{DF}, E_{SF}, E_{RF}
using on P1: Open, Short, Load

Step 2:

Reverse reflection calibration
measures: E_{DR}, E_{SR}, E_{RR}
using on P2: Open, Short, Load

Step 3:

Forward and Reverse transmission calibration
measures: E_{LF}, E_{TF}, E_{LR} , E_{TR}
with Port 1 and Port 2 connected together

Step 4:

Device measurement
measures: S_{11}, S_{21} **then reverse stimulus**
to measure: S_{22}, S_{12}

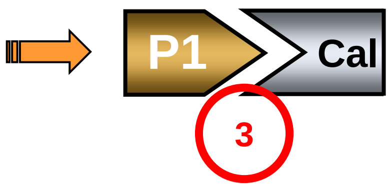
Minimal number of connections = 9; minimal cable movements = 2

The ideal case: an insertable adapter

VNA Port 1

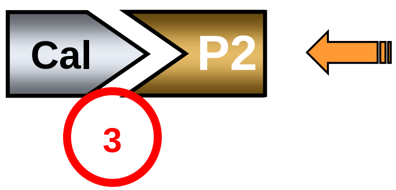
VNA Port 2

Step 1:



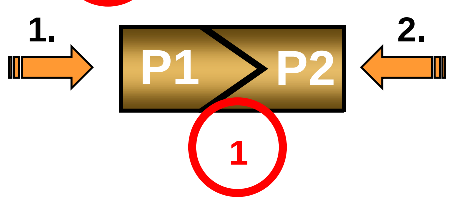
Forward reflection calibration
measures: E_{DF}, E_{SF}, E_{RF}
using on P1: Open, Short, Load

Step 2:



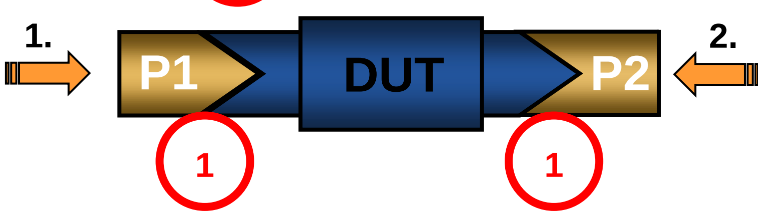
Reverse reflection calibration
measures: E_{DR}, E_{SR}, E_{RR}
using on P2: Open, Short, Load

Step 3:



Forward and Reverse transmission calibration
measures: E_{LF}, E_{TF}, E_{LR} , E_{TR}
with Port 1 and Port 2 connected together

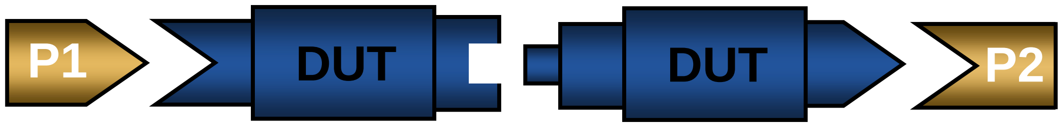
Step 4:



Device measurement
measures: S_{11}, S_{21} then reverse stimulus
to measure: S_{22}, S_{12}

Divide-by-two methodologies

VNA Port 1



VNA Port 2

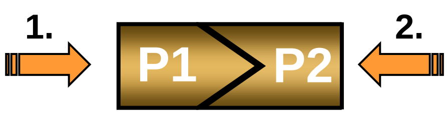
Step 1:

Forward reflection calibration

Step 2:

Reverse reflection calibration

Step 3:



Forward and Reverse transmission calibration

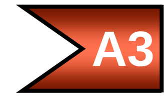
Step 4:

Device measurement

Step 5: Pair of two back-to-back adapters to get the S-parameter data set of one adapter
-> Made assumptions: same length, no reflection between the DUT adapters

Swap equal adapter technique

Thru measurement using a:



„Wrong“ Adapter

Step 1:

Forward Transmission: ETF
Forward Match: ELF

Step 2:

Reverse Transmission: ETR
Reverse Match: ELR

Step 3:

Forward reflection calibration

Step 4:

Reverse reflection calibration

Step 5:

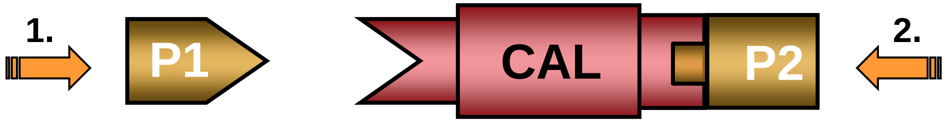
Device measurement

Adapter removal technique

Test Set Port 1

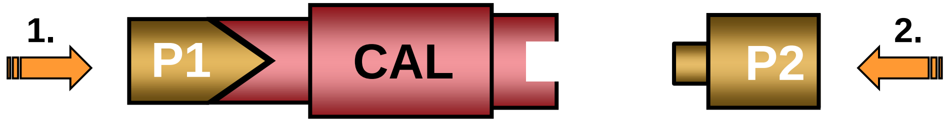
Test Set Port 2

Step 1:



First full 2-port calibration set

Step 2:



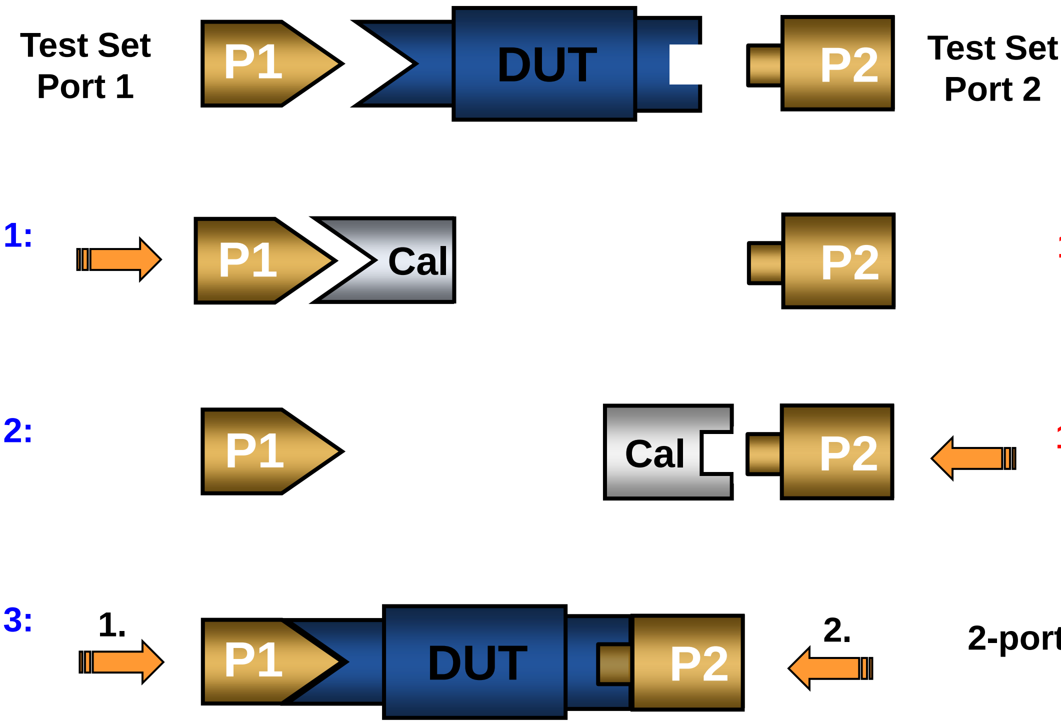
Second full 2-port calibration set

Step 3: To apply the adapter removal algorithm in order to define the P1 and P2 reference planes (this algorithm is directly supported by most commercial VNA firmware).

Step 4:

DUT measurements

Unknown Thru calibration (SOLR, UOSM)



Step 1: 1-port calibration on P1

Step 2: 1-port calibration on P2

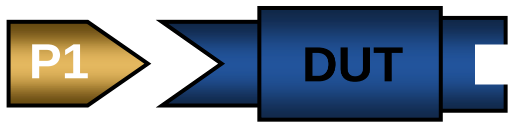
Step 3: 2-port and switch term measurement

Step 4: To apply the Unknown Thru calibration algorithm
-> Made assumption of a passive and reciprocal DUT (S21 = S12)
-> Additional measurements of the switch terms needed (two more sweeps)

Minimal number of connections = 7; minimal cable movements = 0

1-port measurements de-embedding technique

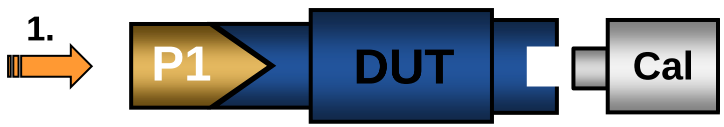
Test Set Port 1



Step 1:

First:
1-port calibration on P1

Step 2:



Second:
1-port calibration at the DUT adapter end

Must be repeated for each adapter!

Step 3: **De-embedding of the error box 1 from the error box 2 plus to mathematical correct for the assumptions of a passive and reciprocal DUT (S21 = S12)**

Transmission coefficient post processing correction (passive and reciprocal)**:**

$$S21 := S12 := \sqrt{S21 \times S12}$$

Typical non-insertable adapter characterization techniques summary:

- **Divide-by-two methodologies (only poor accuracy)**
  Many ‘wrong’ assumptions
  Minimal connections: **10**, minimal cable movements: **2**

- **Swap equal adapter technique (only modest accuracy)**
  Assumption: well matched swapping adapters showing good repeatability.
  Minimal connections: **14**, minimal cable movements: **3**

- **Adapter removal technique based on two full 2-port calibrations**
  Many connections and cable movements -> therefore time intensive.
  Minimal connections: **18** (16), minimal cable movements: **3** (2)

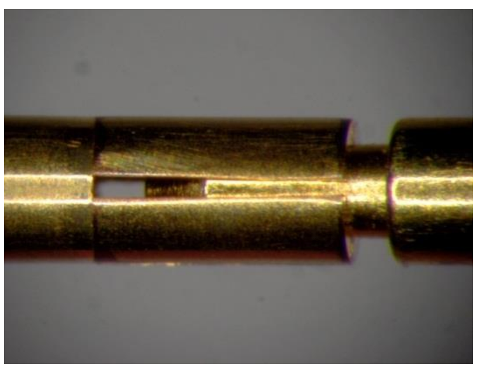
- **SOLR** (Short, Open, Load, Reciprocal) **also known as Unknown-Thru**
  No cable movements but sensitive to the knowledge of all calibration standards.
  Minimal connections: **8**, minimal cable movements: **1**

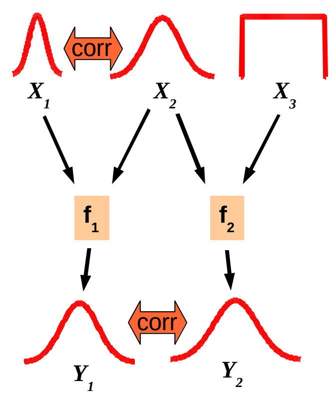
- **1-port measurements de-embedding technique** (repeat for each single adapter)
  No cable movements but sensitive to the knowledge of all calibration standards.
  Minimal connections: **7**, minimal cable movements: **0** (no additional cable needed)

How was METAS able to improve the accuracy of the adapter characterization techniques?

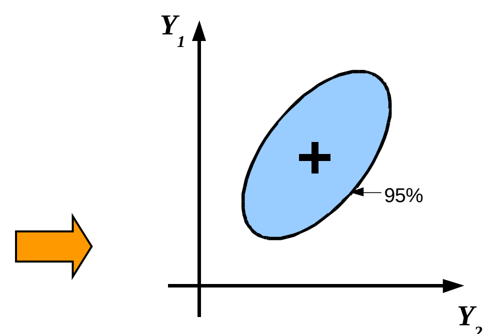
New: Connector effects and *VNA Tools* (*METAS UncLib*)

Supported coaxial line systems: **1.0 mm, 1.85 mm, 2.4 mm, 2.92 mm, 3.5 mm, Type-N (50 ohm), 4.3-10 connector**





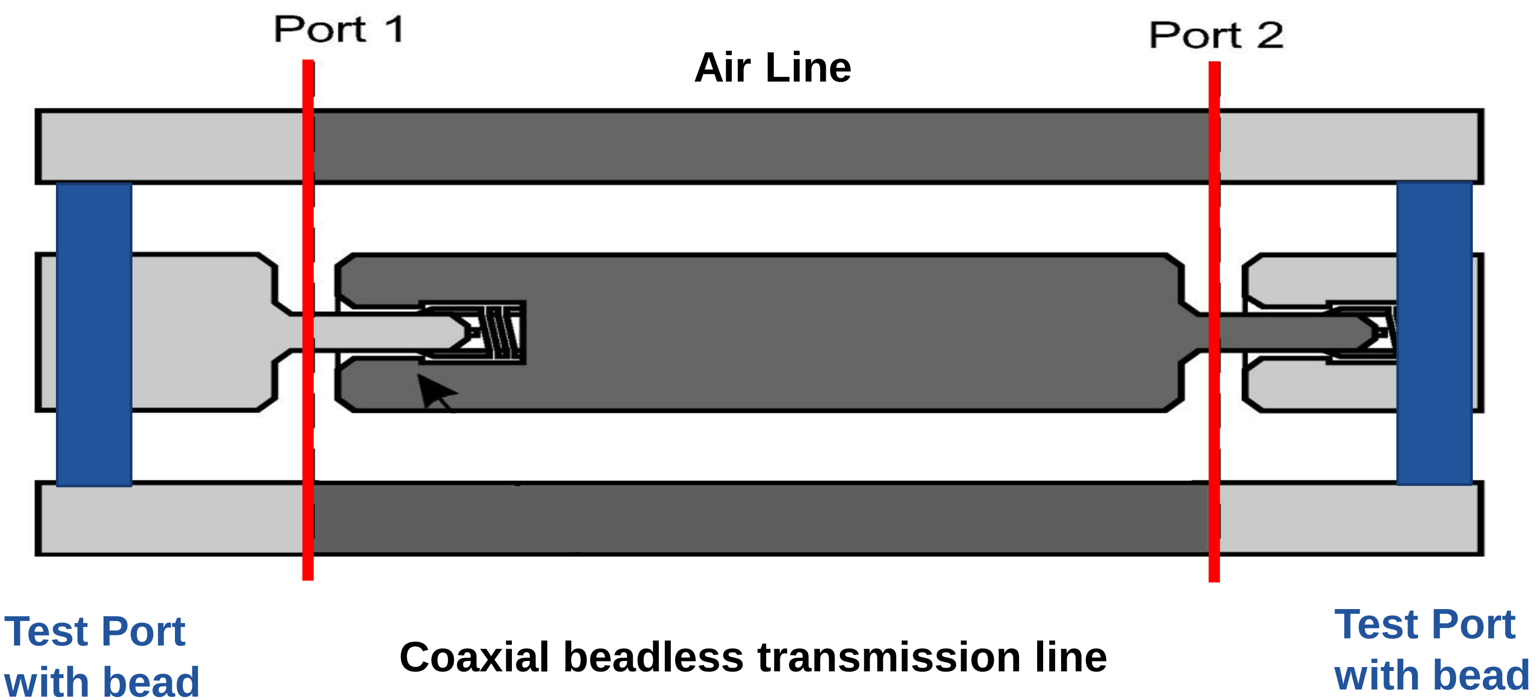
$$\mathbf{V_Y} = \mathbf{J_{f,X}} \mathbf{V_X} \mathbf{J_{f,X}}^T$$



Before 2006

Effects observed in practical VNA measurements:

- Inconsistencies between different calibration algorithms
- Erratic variations in airline based measurements



Relevant VNA research projects (2006 – 2016)

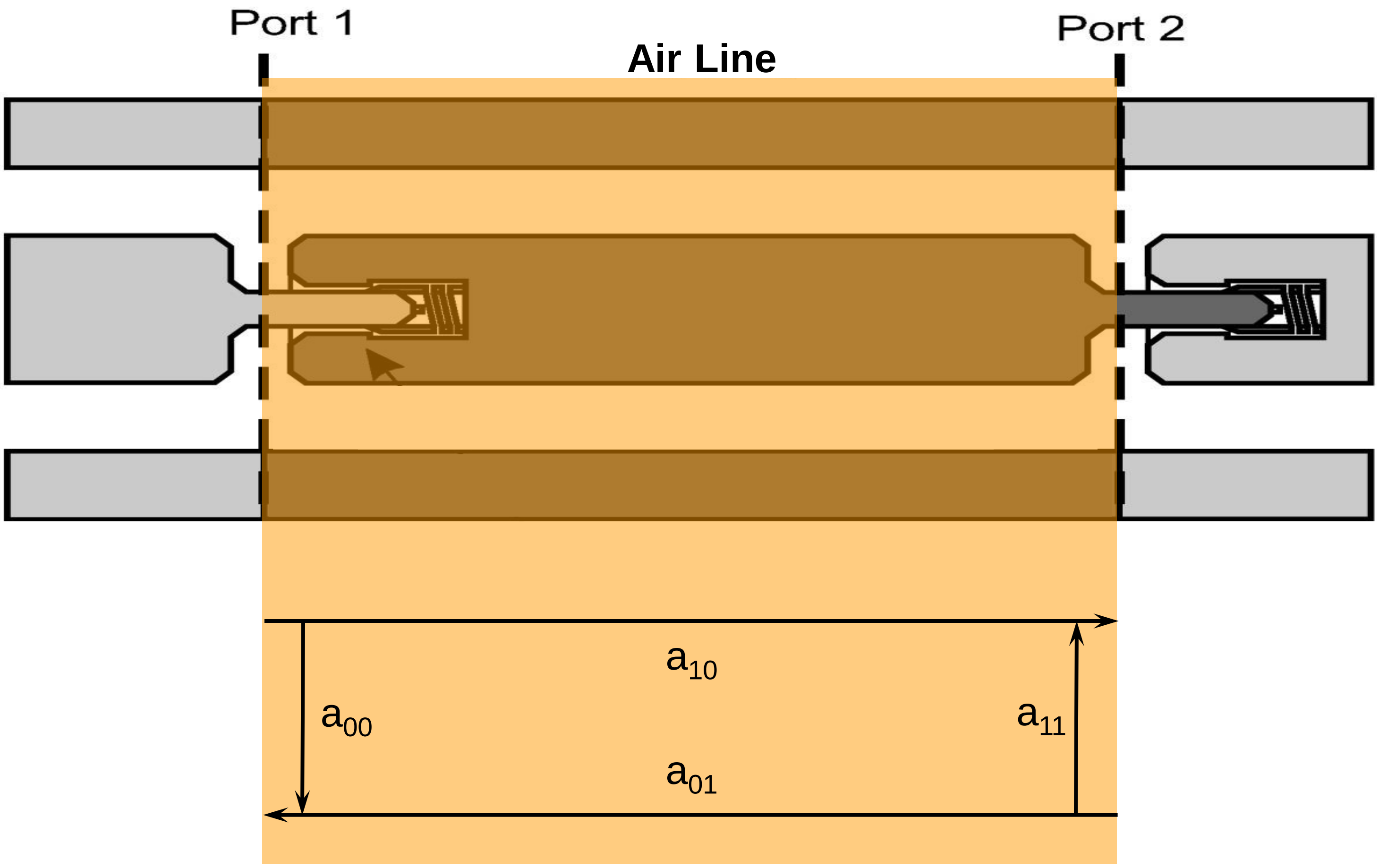
linked with coaxial S-parameter measurement metrology

Industry partner(s): ***CoMo70, CalCon, VNA Tools, ONE-mm***

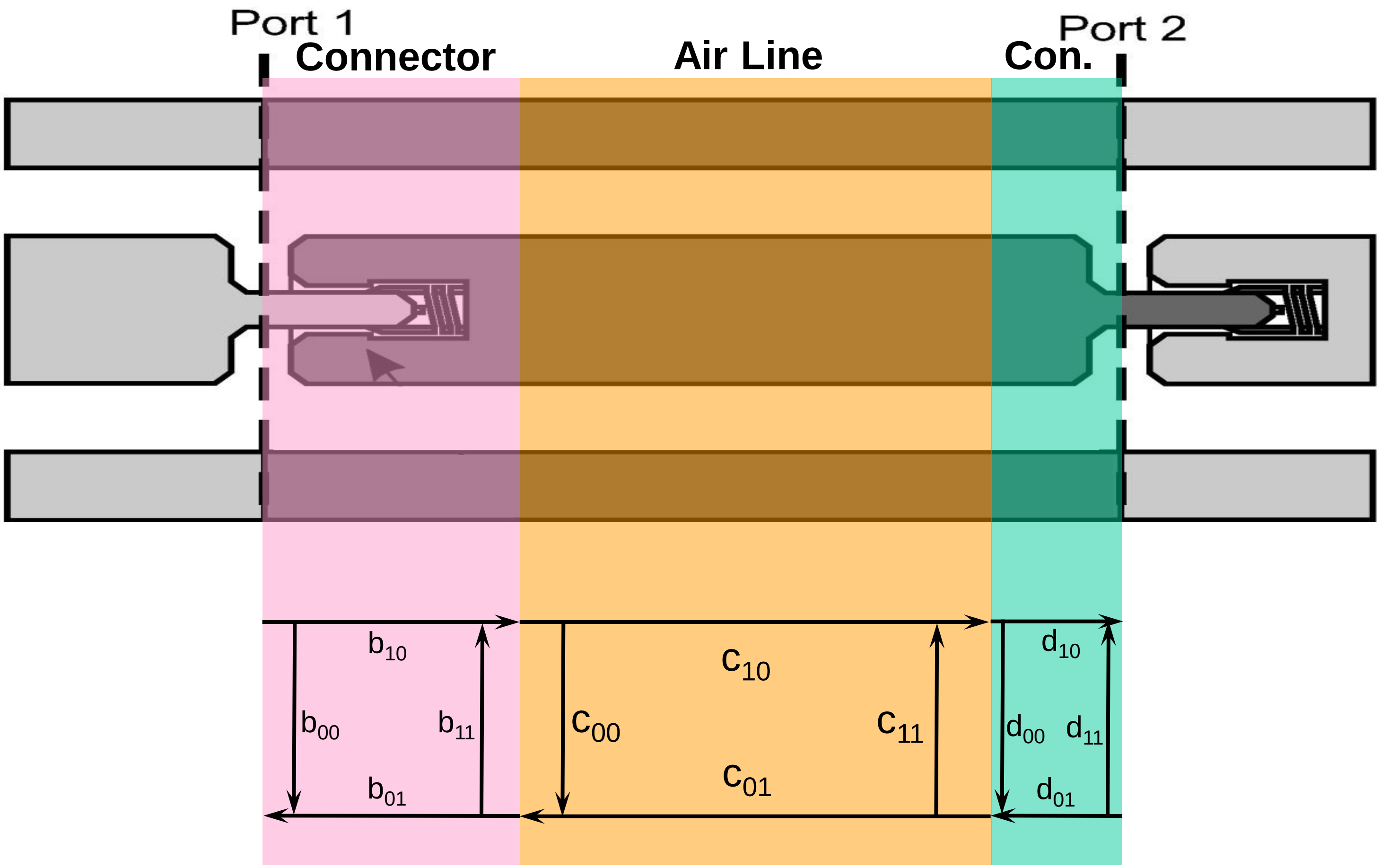
EMRP: ***HF-Circuits*** (NPL, CMI, LNE, METAS, PTB, SP, VSL)

- **The concept of the half connectors and numerical modelling:**
  - Enables an accurate definition of the electrical reference plane and therefore a better modelling of the primary calibration standards.
- **Centre conductor coupling issues:**
  - Very small pin gaps provoke unpredictable near field effects.
- **Beadless airline handling concept:**
  - Dielectric disc to control the longitudinal position of the centre conductor.
- **GUM compliant uncertainty process:**
  - Linear uncertainty propagation using a VNA measurement model and defined input quantities.

Air Line model without connector effects



Air Line model including the systematic connector effects (with half connector concept)



1.0 mm adapter cascadation example, 116.5 GHz (‘measured pair’ versus a ‘numeric cascaded pair’)

Comparing two calibration kit standard definitions concepts:

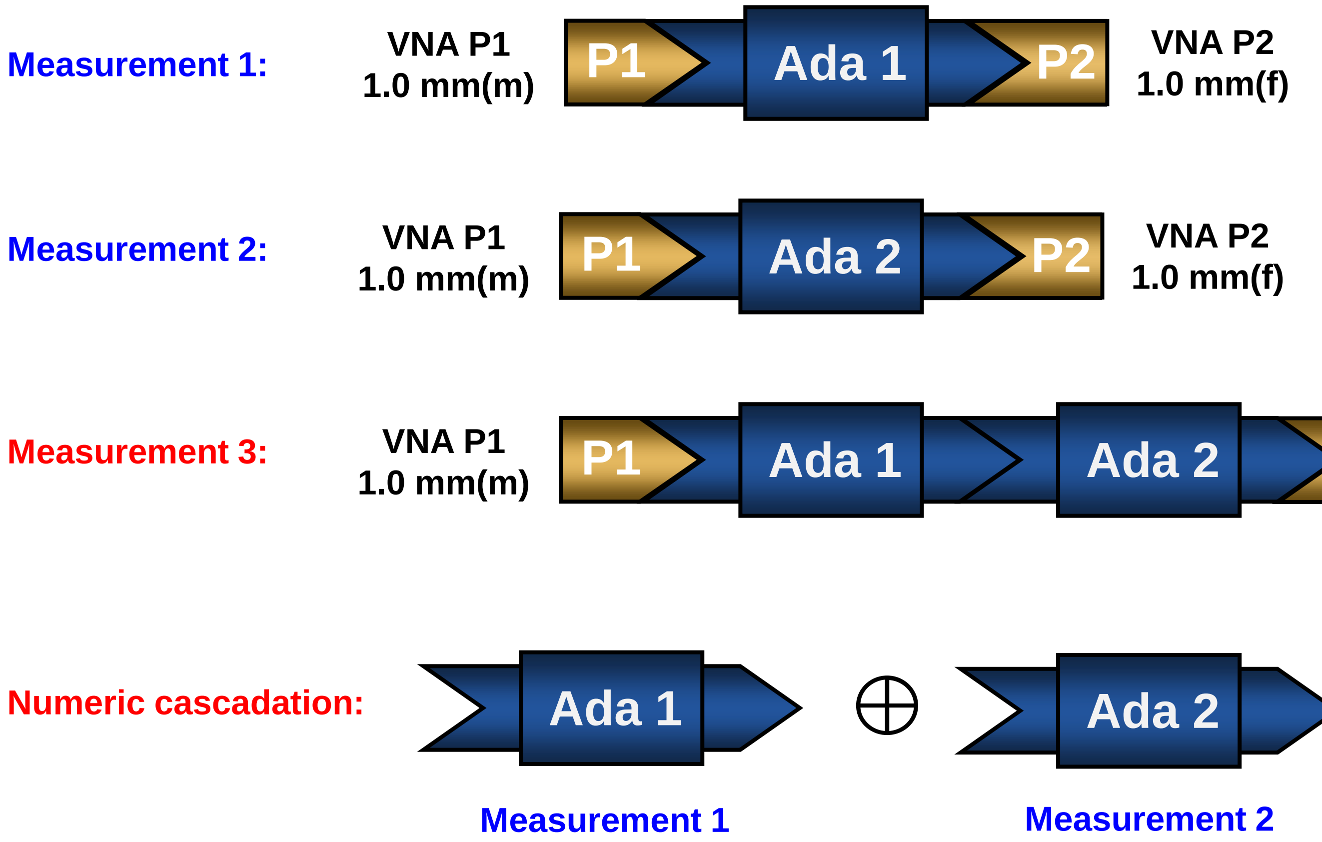
- **Keysight** (generic and ignoring the systematic connector effects)
- **METAS** (serialized and including the systematic connector effects)

2-port over-determined optimization calibration (85059A)

-> the cal kit consists of 4 Offset Shorts including an Open and Load

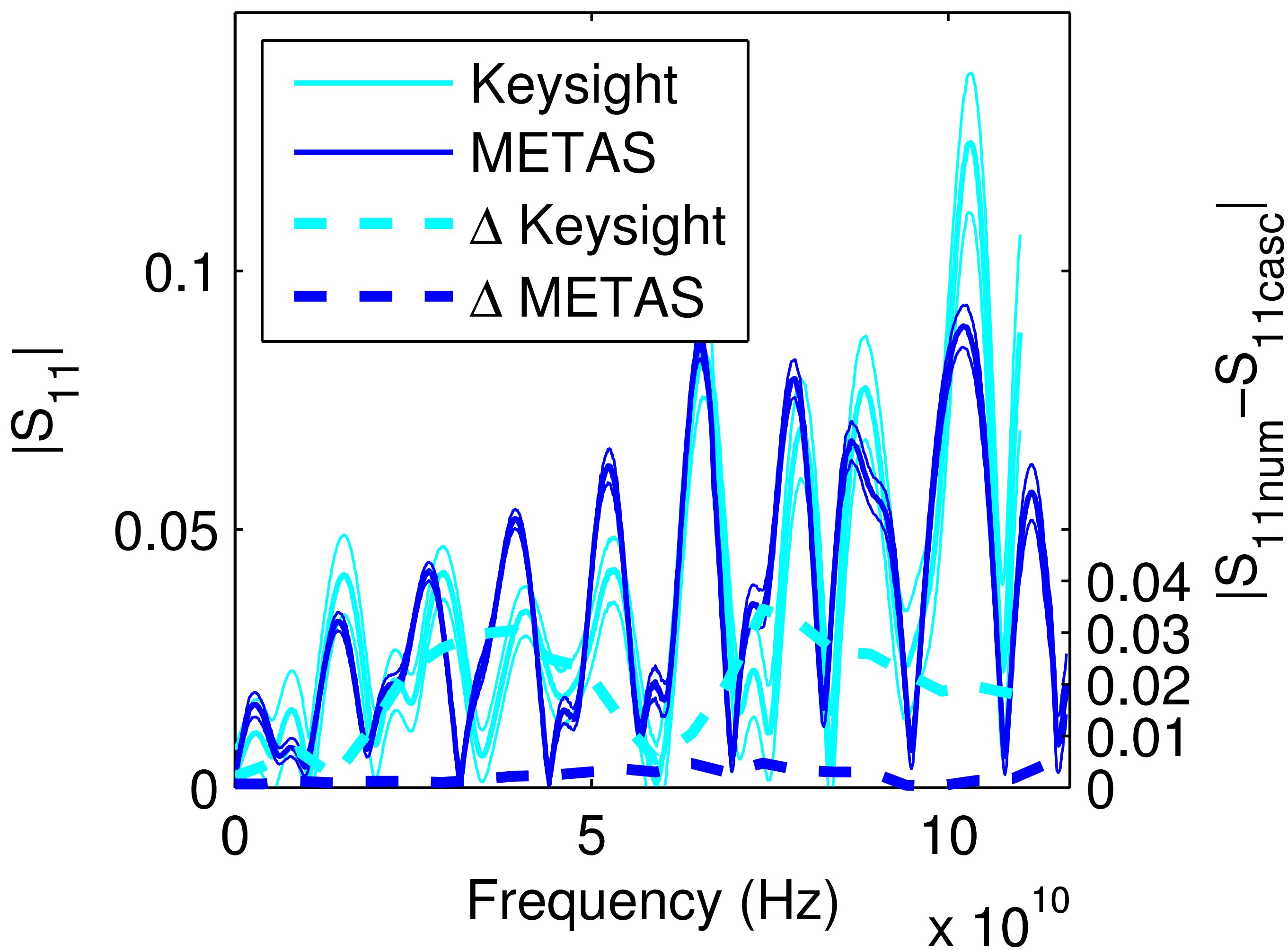
Starting from exactly the same S-parameter raw data files!

1.0 mm adapter cascadation example, 116.5 GHz
(‘measured pair’ versus a ‘numeric cascaded pair’)



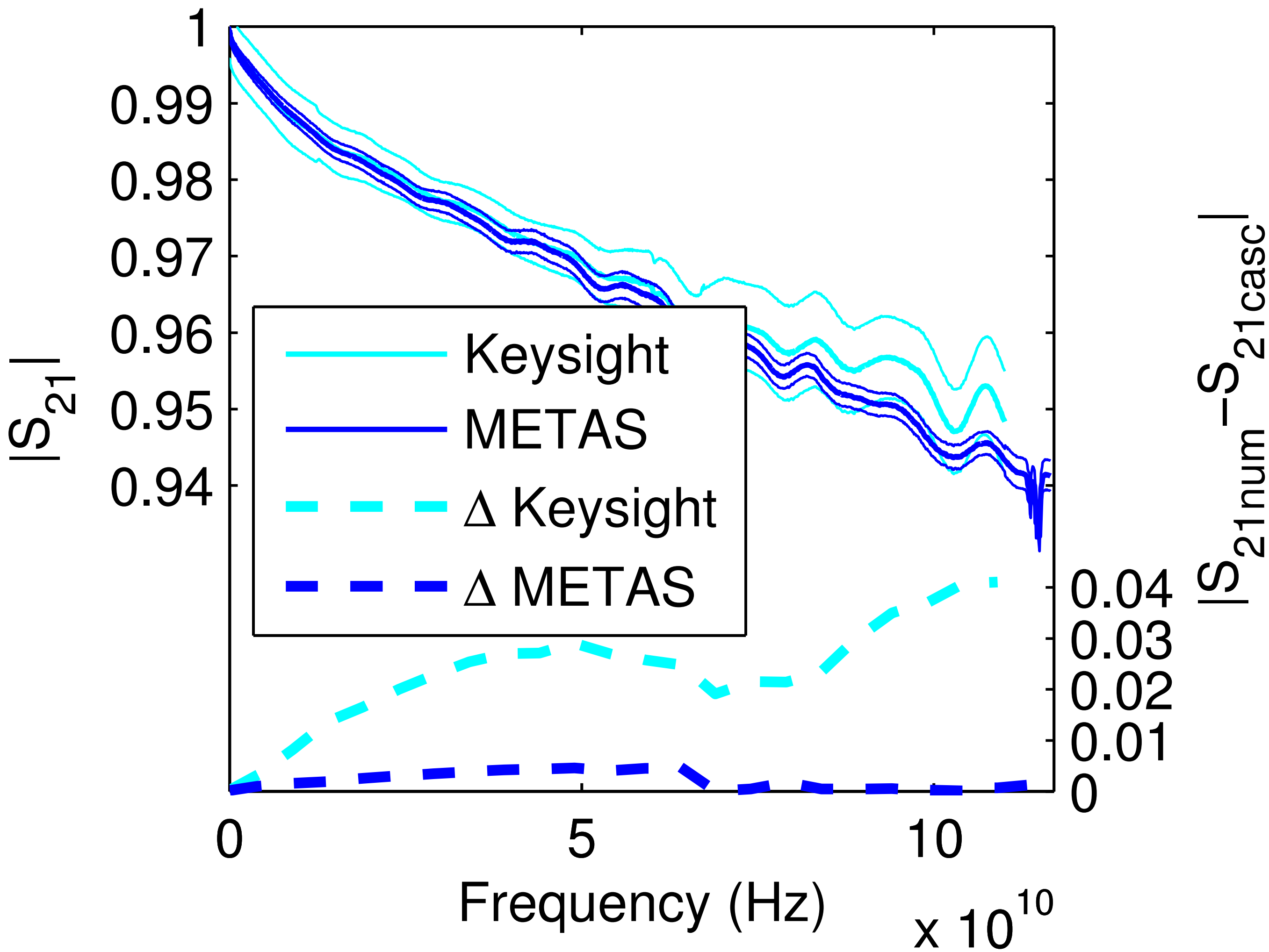
Paper: Johannes Hoffmann et al., Traceable Calibration with 1.0 mm Coaxial Standards, ARFTG 87th, May 2016

1.0 mm adapter cascadation (reflection)



- Strong difference in agreement of numeric and measured cascadation

1.0 mm adapter cascadation (transmission)



- H+S adapter specified up to 110 GHz
- Higher mode at 114 GHz

Non-insertable adapter characterization: 1.85 mm (male) to 1.0 mm (female)

Comparing two different adapter characterization techniques:

- **Unknown Thru calibration (SOLR)**
- **1-port measurement de-embedding**

Comparing two calibration kit standard definitions concepts:

- **Keysight** (generic and ignoring the systematic connector effects)
- **METAS** (serialized and including the systematic connector effects)

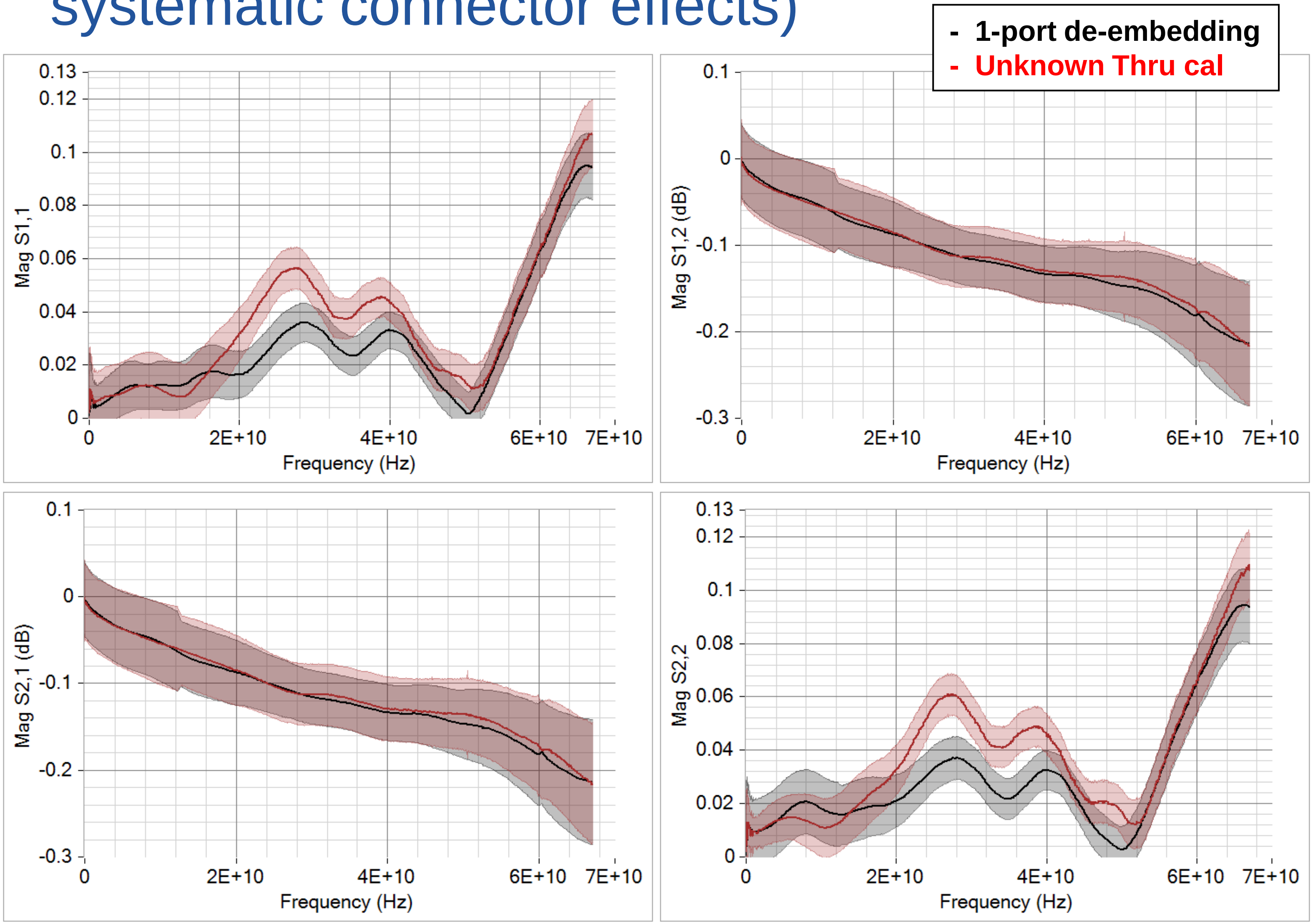
S11 side: 1.85 mm, 1-port optimization calibration (85058B)

S22 side: 1.0 mm, 1-port optimization calibration (85059A)

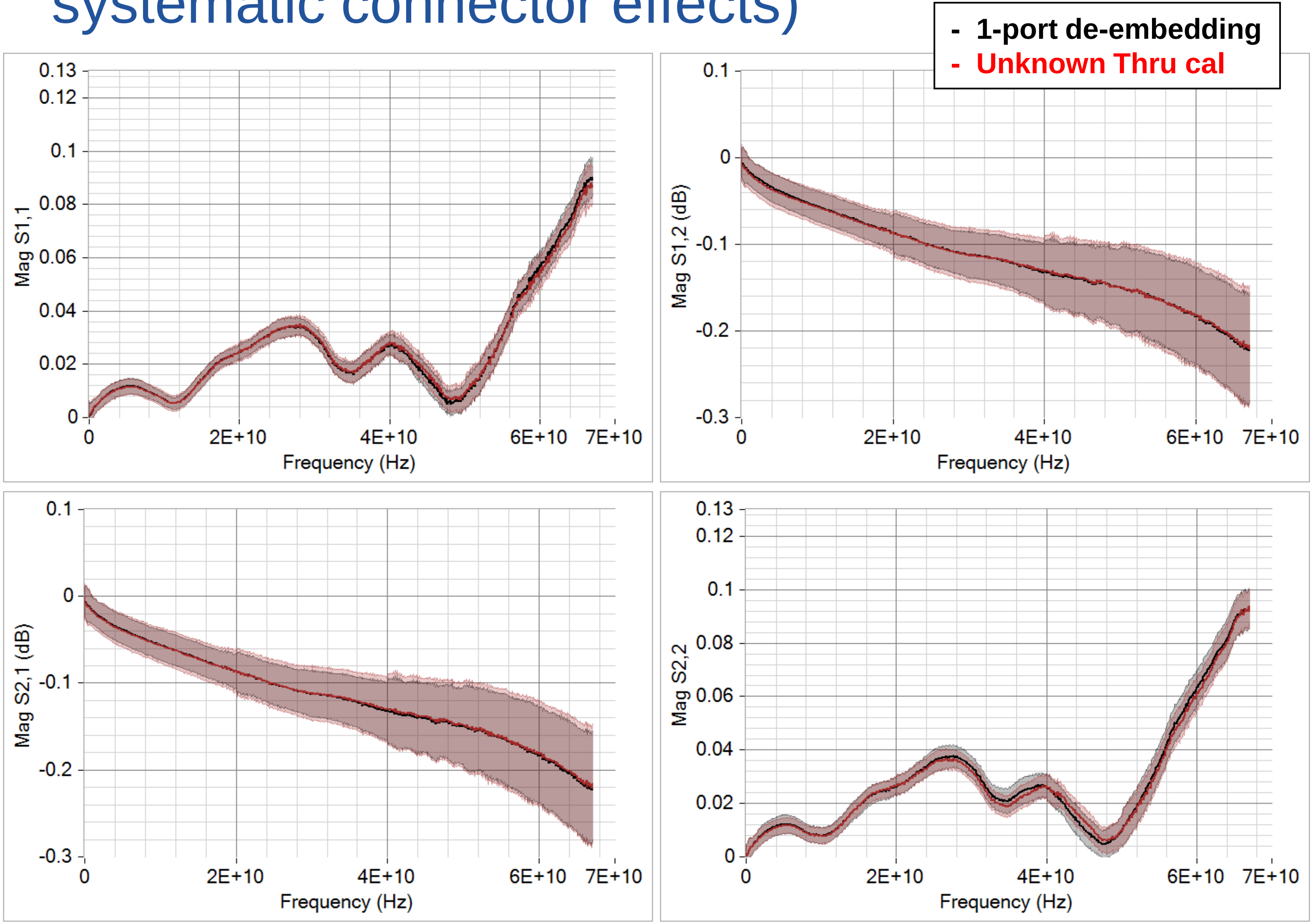
-> both cal kits are Offset Shorts based including an Open and Load

Starting from exactly the same S-parameter raw data files!

Keysight definitions (generic and without the systematic connector effects)



METAS definitions (serialized and including the systematic connector effects)



Conclusions

- **Including the systematic connector effects results in consistent S-parameter data by using different calibration methods and different adapter characterization techniques.**

- **The accuracy of the Open, Short and Load standard definitions is most important to get a good agreement between the techniques.**

- **The 1-port measurements de-embedding adapter technique needs the least number of connections and no additional cable is needed.**
  -> my personal favourite for a single adapter characterization!

- ***VNA Tools* directly supports adapter characterization techniques:**
  - embedding and de-embedding by 'mouse-click'
  - systematic analysis (cal methods, cal definitions, uncertainties)
  - analysis and visualization of the resulting correlation effects
  www.metas.ch/vnatools

Thank you very much for your attention

Research project partners

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Excellence in Connectivity Solutions

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More information: http://www.metas.ch/hf

Acknowledgment

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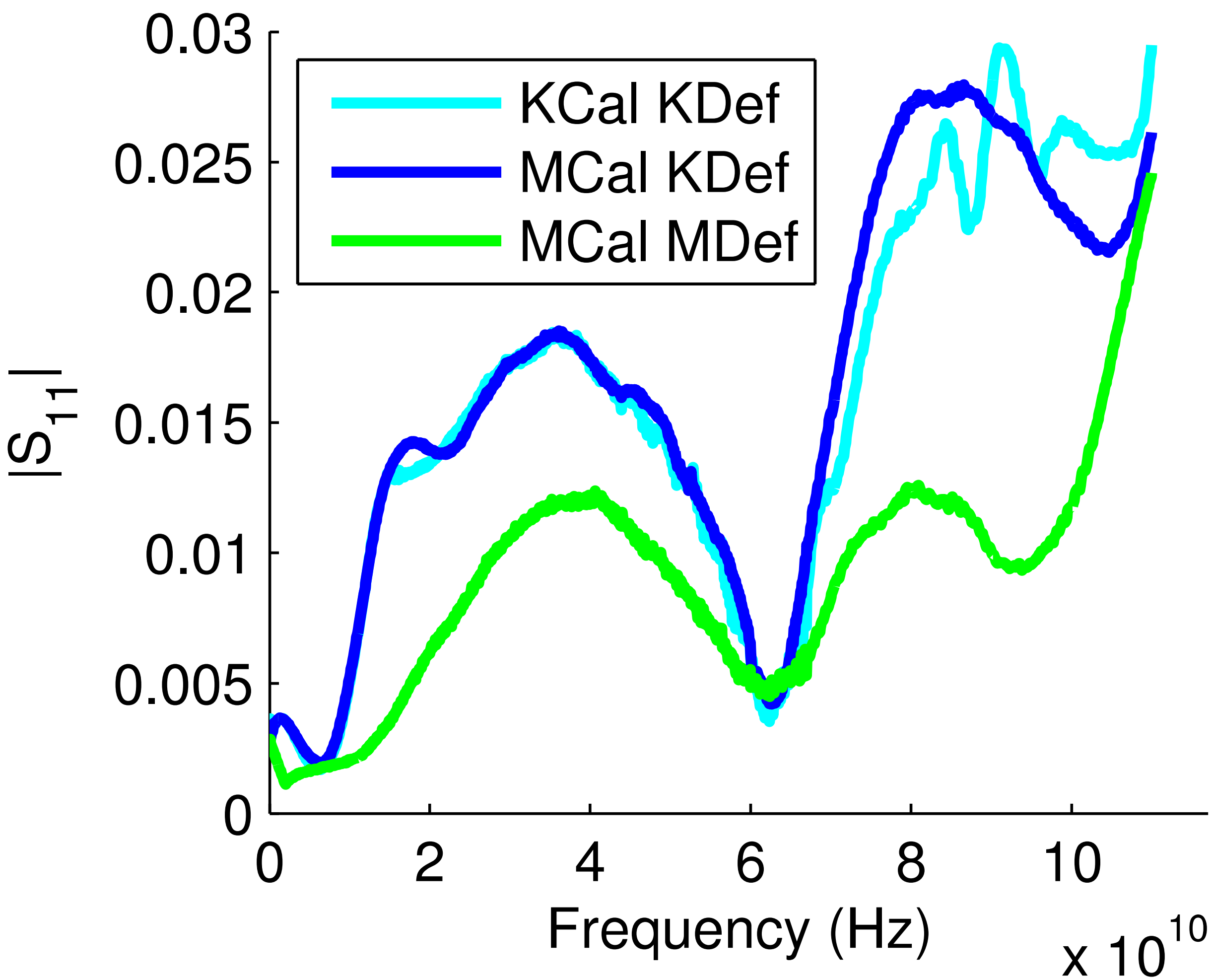
1.0 mm adapter cascadation
Dependency Keysight versus METAS (Cal and Def)



- Load measurement
- Standard definitions have more influence than cal algorithm