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Federal Institute of Metrology METAS

3.5 mm Primary VNA calibration experiment

EURAMET RF&MW expert meeting (Ljubljana)

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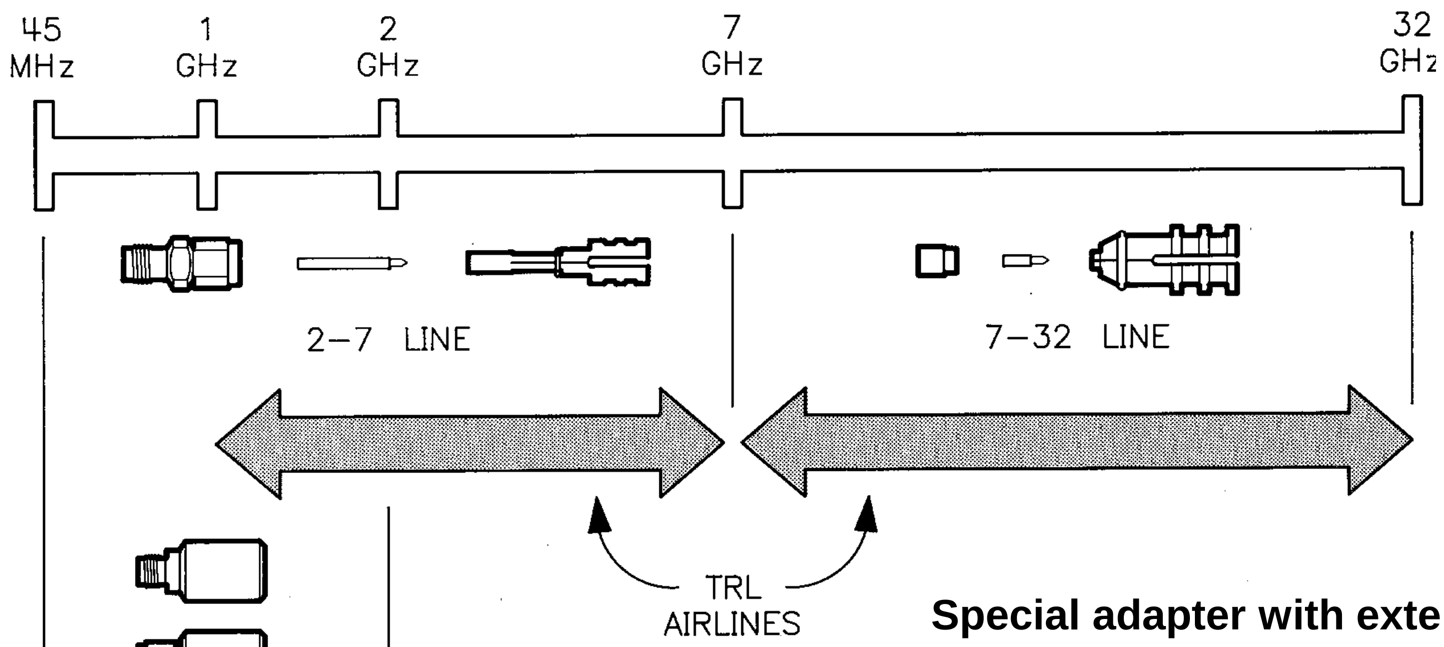
22.04.2013

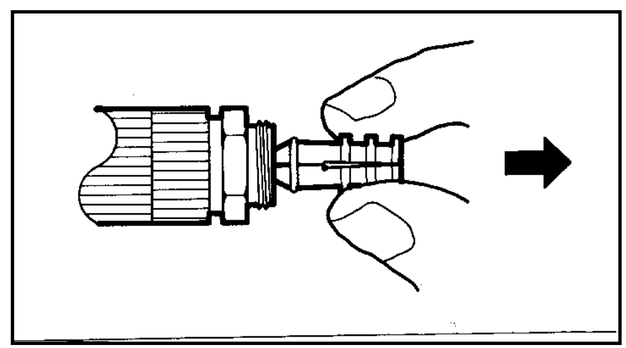
Topics

- 3.5 mm S-parameter traceability used until 2011
- Impact from the VNA project outcomes
- Actual S-parameter traceability chain
- The new 3.5 mm primary calibration kit
- Lab practise: the primary calibration experiment
- De-cascading of the 3.5 mm Kapton disc effects

85052B + 85052C 3.5 mm TRL cal kit (used up to 2011)



Special adapter with extended position



Impact from the VNA research project outcomes

- **The concept of the half connectors:** (*CoMo70*)
  - Enables an accurate definition of the electrical reference plane.

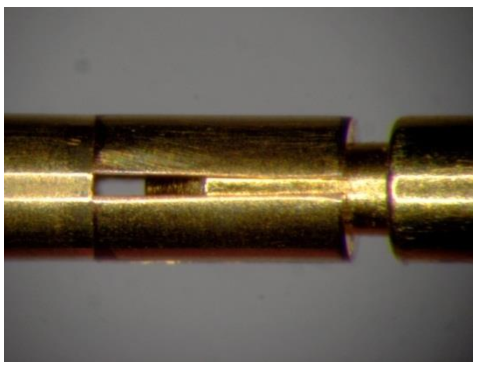
- **Centre conductor coupling issues:** (*CoMo70*)
  - Very small pin gaps provoke unpredictable near field effects.

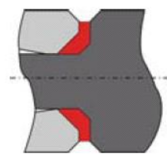
- **Beadless airline handling concept:** (*CoMo70*, *CalCon*)
  - Dielectric disc to control the longitudinal position of the centre conductor.

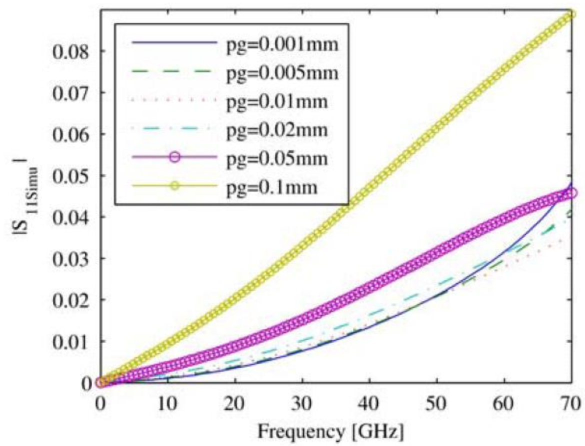
- **GUM compliant uncertainty process:** (*VNA Tools II* and *Metas.UncLib*)
  - Linear uncertainty propagation using a VNA measurement model and defined input quantities (avoiding the inaccurate residual ripple techniques).

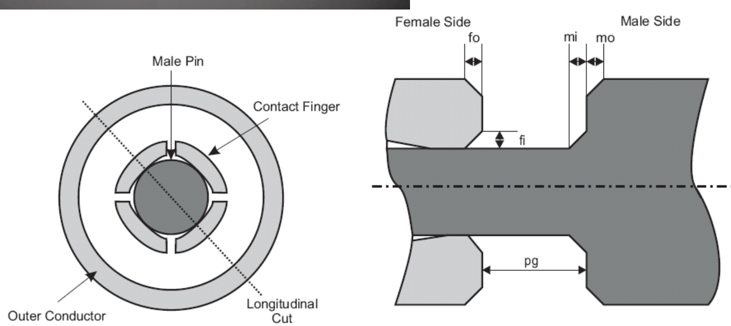
Result: new S-parameter traceability concept including the new outcomes (e.g.: systematic connector effects, ...)

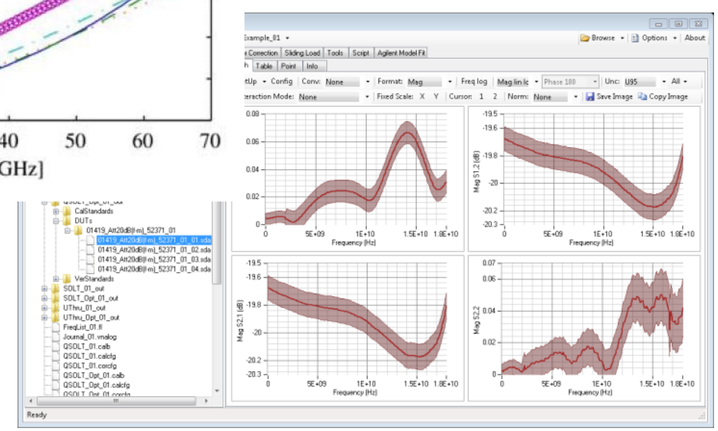
- **Supported coaxial line systems** : **1.85 mm, 2.4 mm, 3.5 mm**
- **Currently working on** : **1.0 mm, 2.92 mm**
- **Planned activities** : **Type-N (50 ohm), Type-N (75 ohm)**



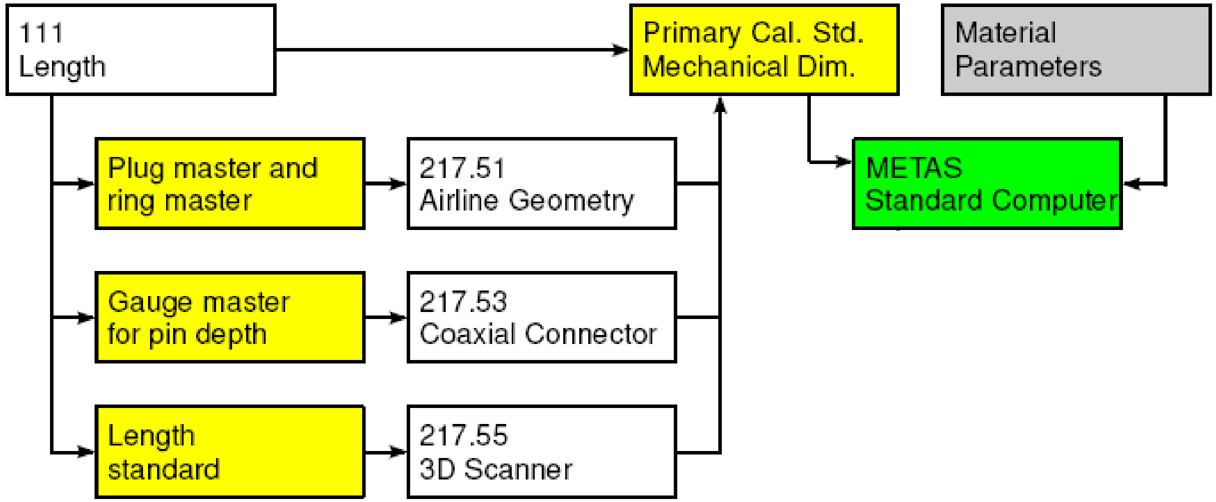








Actual S-parameter traceability chain used at METAS



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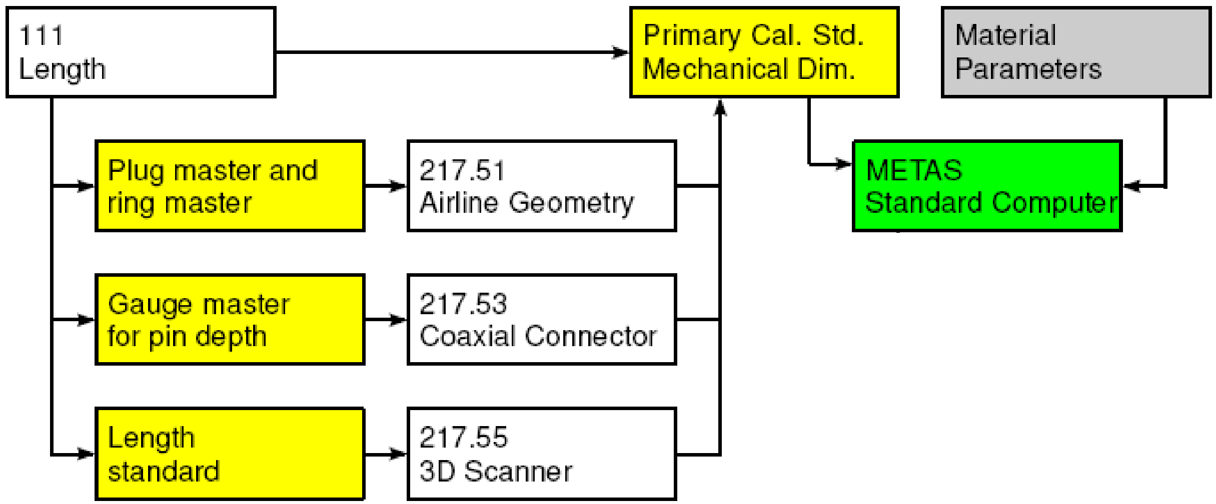
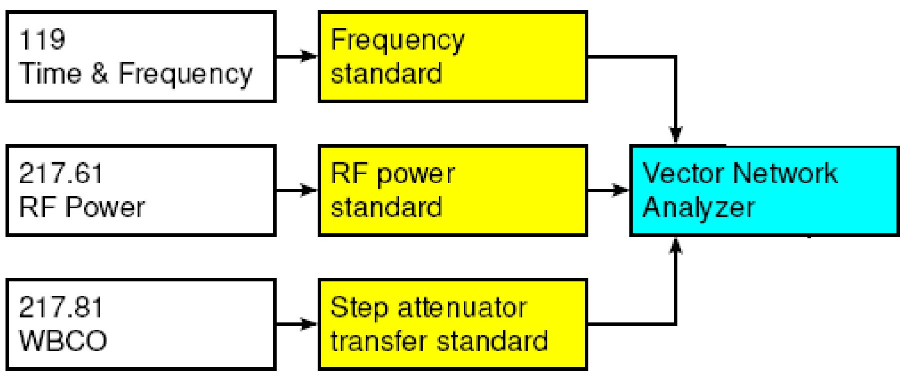
Actual S-parameter traceability chain used at METAS

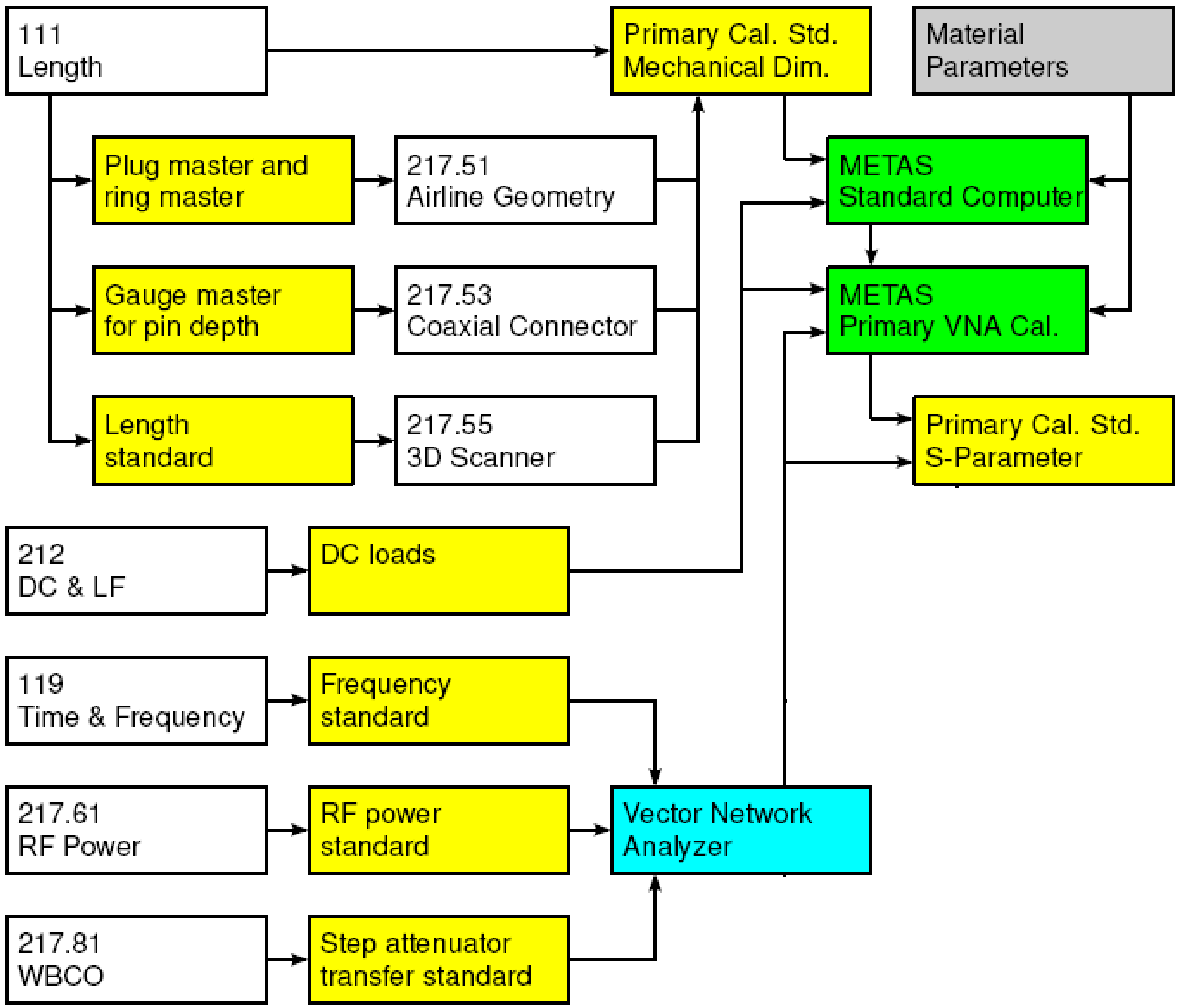




Additional VNA and used set-up characteristics:

- **Noise floor and trace noise of VNA**
- **Drift (switch and error terms)**
- **Cable stability**
- **Connector repeatability**

Actual S-parameter traceability chain used at METAS



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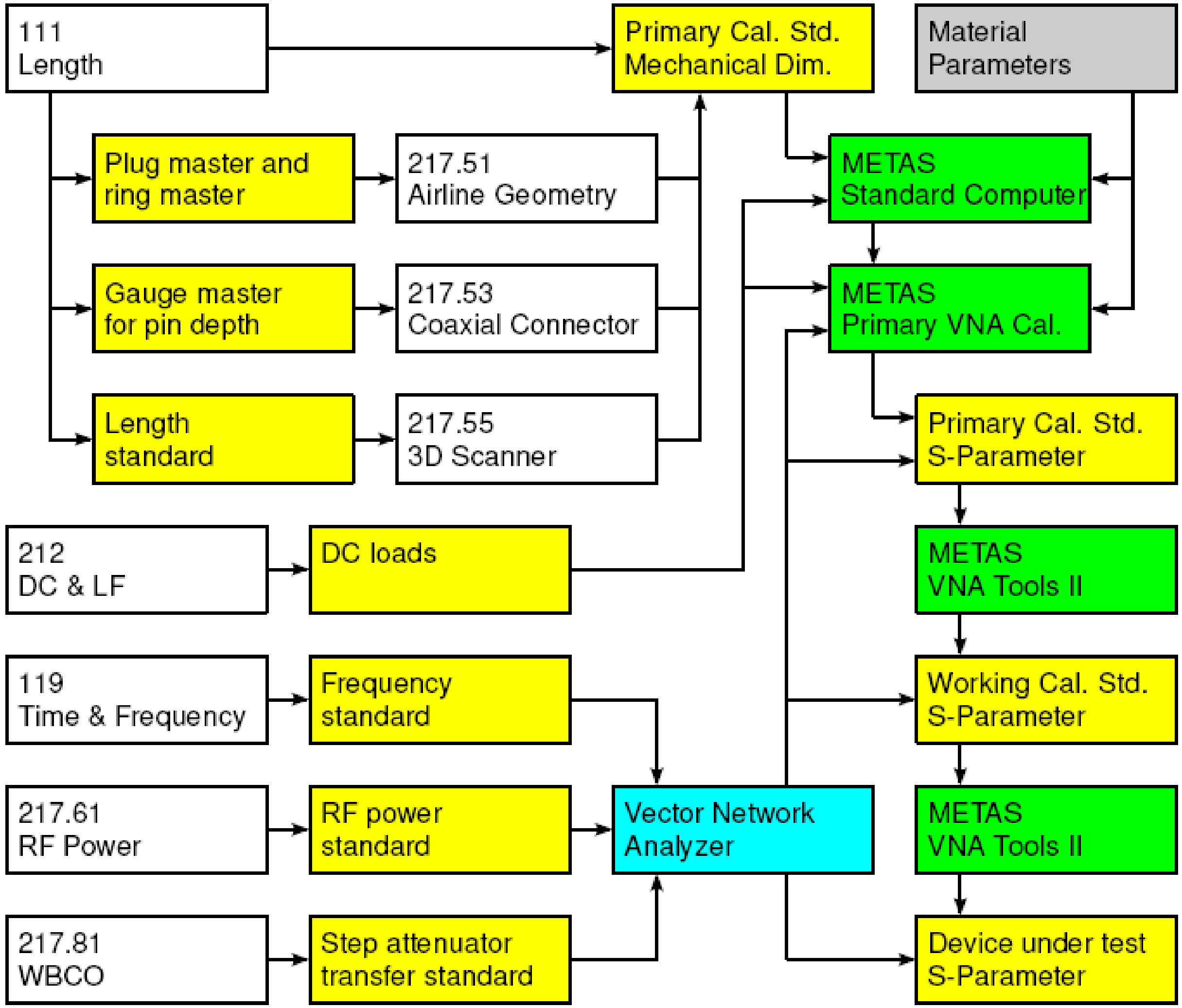
Actual S-parameter traceability chain used at METAS



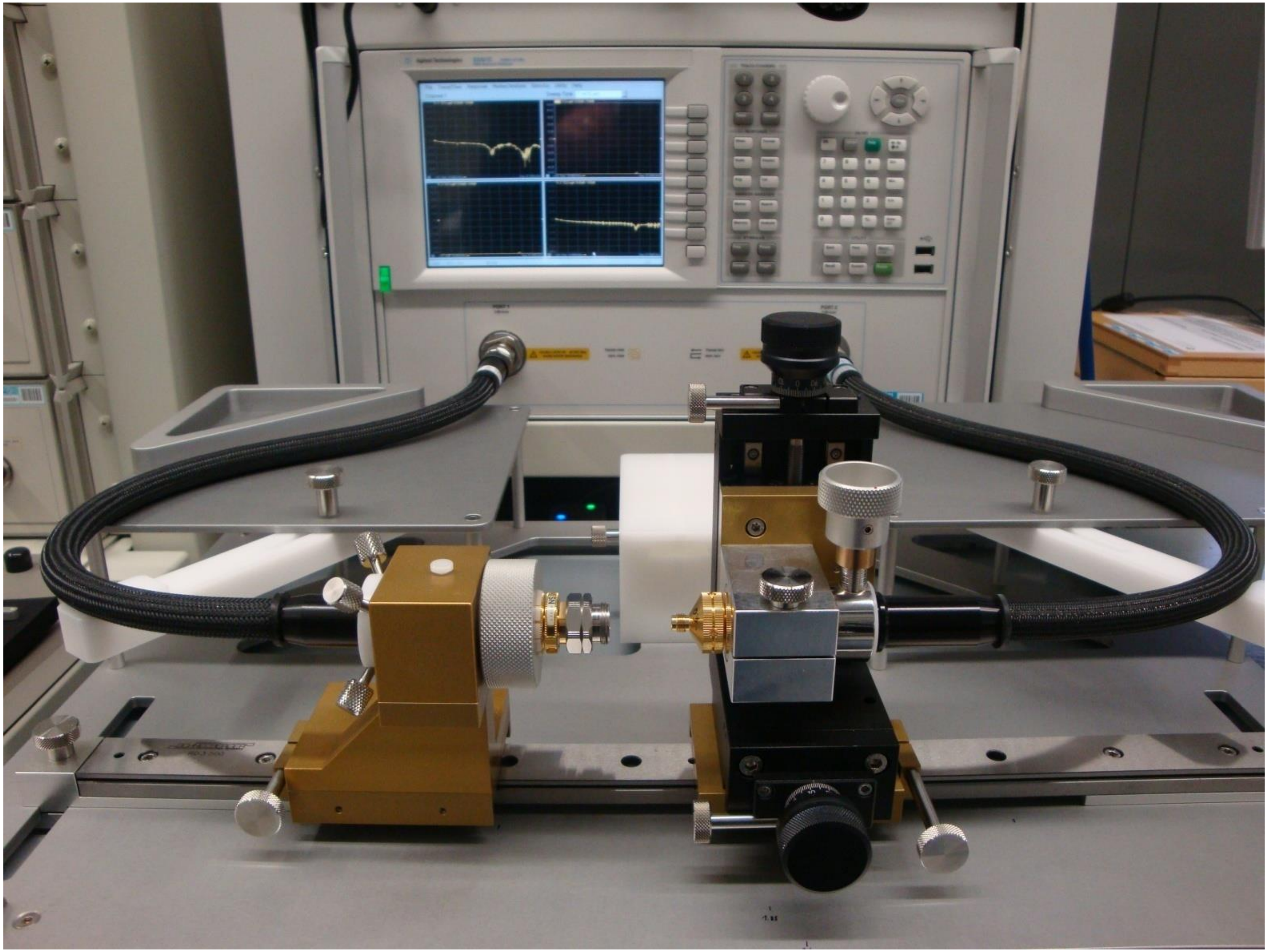
The new 3.5 mm primary calibration kit from METAS

- **Development of a new customised 3.5 mm LRL cal kit:**
  - Set of 6 Air Lines: designed by METAS (manufactured from Maury).
  - Open's, Short's and Flush Short's from Agilent (85052 series components).
  - Optimised Test Port adapters from Agilent (NMD 2.4 mm to 3.5 mm).

- **The slotless 3.5 mm(f-m) BeCu Air Lines have the following length:**
  - **27.419 mm**
  - **31.929 mm**
  - **39.836 mm**
  - **42.906 mm**
  - **50.000 mm**
  - **70.000 mm**

In order to minimise oxidation each un-plated BeCu Air Line is stored in special storage box which is filled with Argon gas and a desiccant bag.

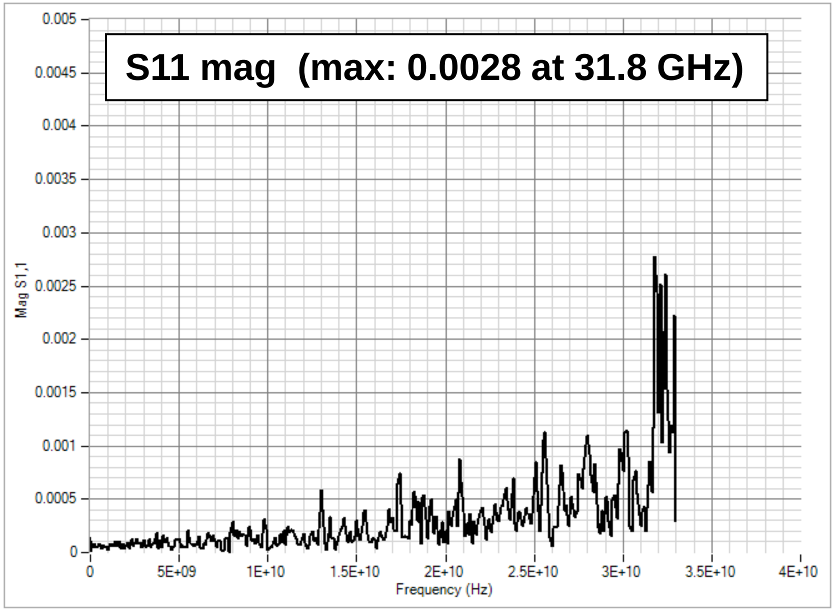
Lab practise: the primary 3.5 mm calibration experiment

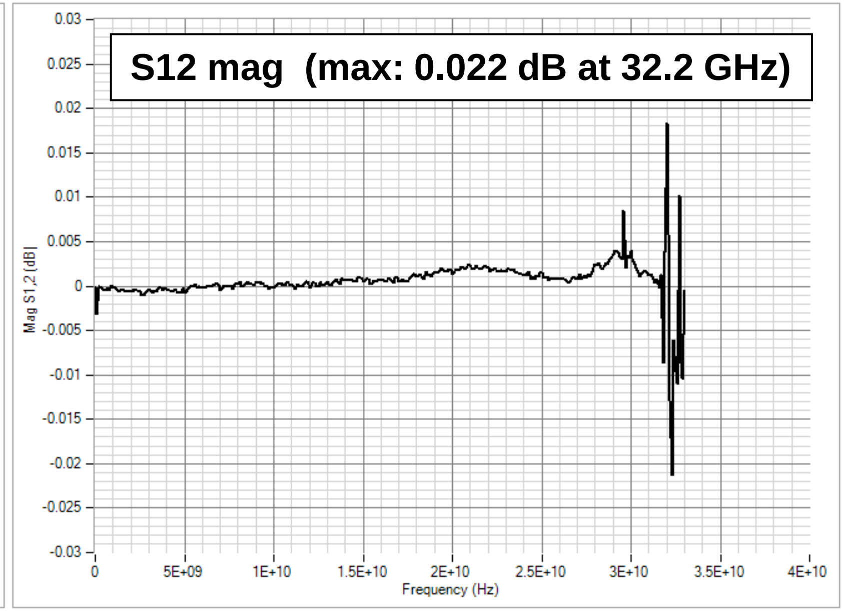


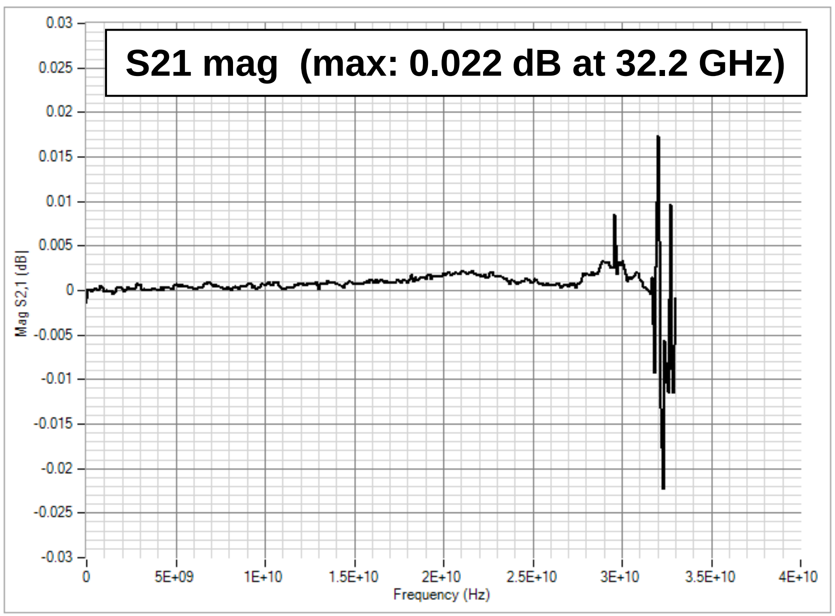
Unwanted 3.5 mm Test Port cable effects >26.5 GHz

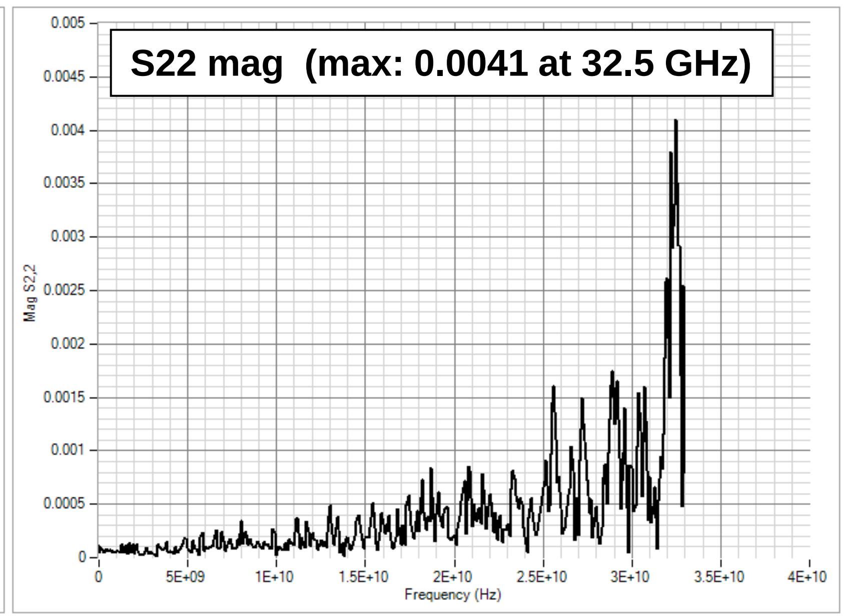
- **3.5 mm line system allows mode free measurement up to 34 GHz** (Upper frequency limit for the CCEM.RF-k5c key comparison: 33 GHz).
- **VNA test port equipped with 3.5 mm connectors: (limited to 26.5 GHz)**
  - e.g.: 85131F/E (3.5 mm to 3.5 mm), or any other product.
- **VNA test port equipped with 2.4 mm or 1.85 mm connectors:**
  - 85134F/E (2.4 mm to 3.5 mm), or any other product.
  - 85133F/E (2.4 mm to 2.4 mm) with adapter set 85130F (2.4 mm to 3.5 mm).
  - Cable set (1.85 mm to 1.85 mm) with adapter 85130F (2.4 mm to 3.5 mm).
- **Be careful when using the 85134F/E series test port cables:**
  - Resonances (higher modes) are provoked above 29 GHz!
- **We found best stability results using the 1.85 mm test port cables**
  - with optimised 85130F test port adapters (avoid near field effects).

3.5 mm 85134F test port cable issues > 29 GHz (3rd Thru)





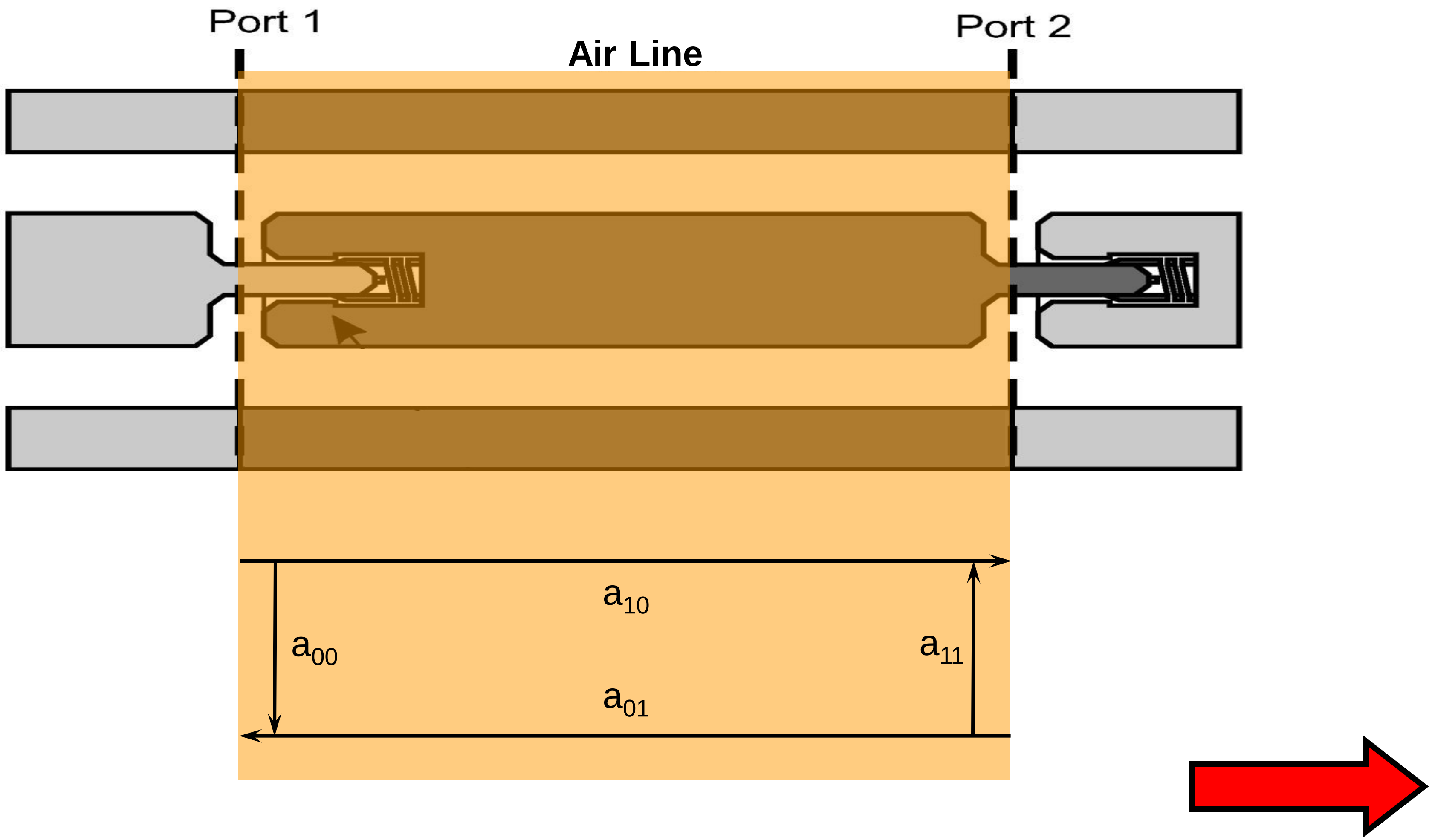




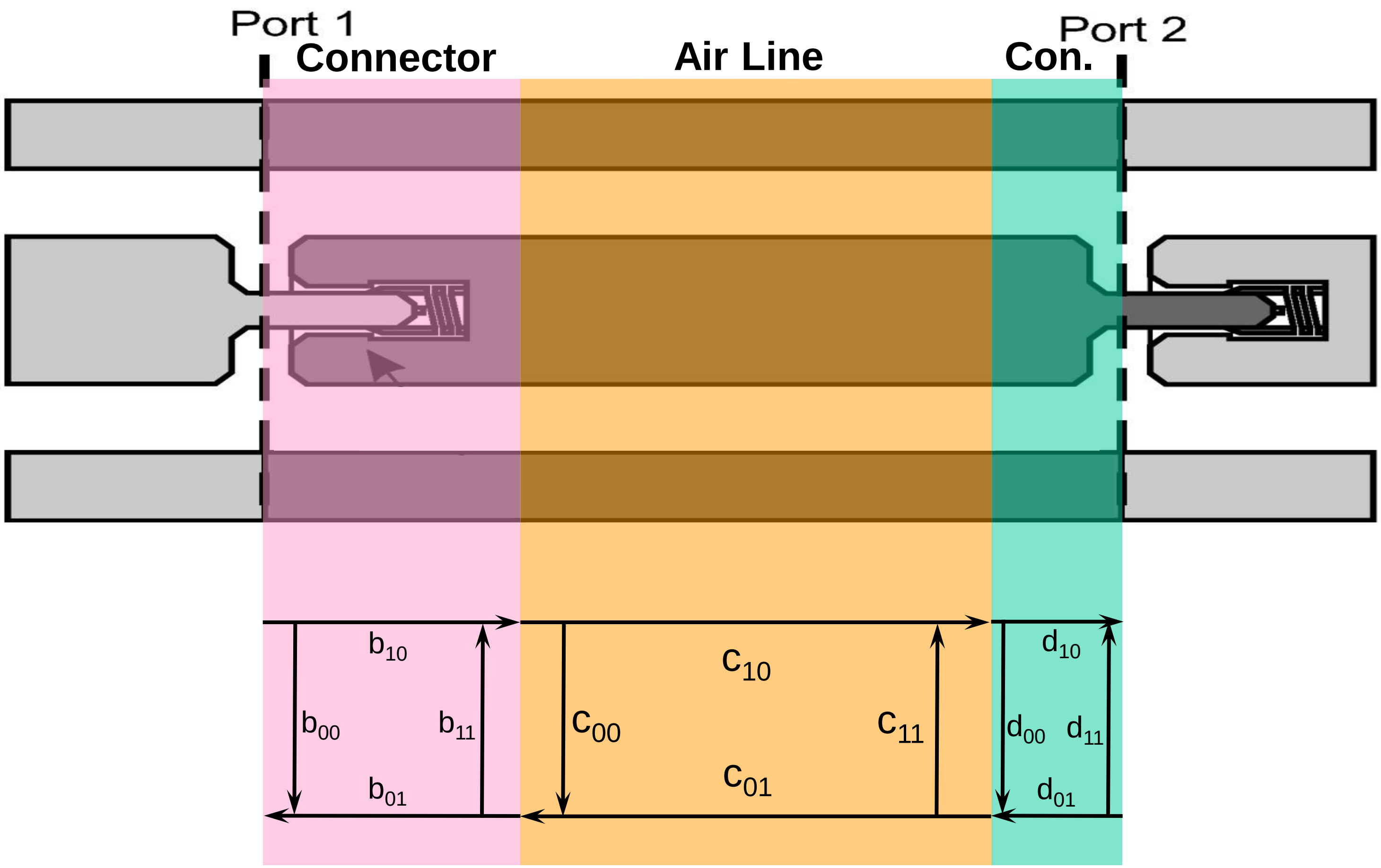
The concept of the half connector

The half connector concept allows a consistent definition of the reference plane and an increase in accuracy if compared to ignoring systematic connector effects.

Example 1: Air Line model without connector effects



Example 2: Air Line model including the systematic connector effects (using the half connectors concept)



1st step: mechanical characterisation of the Standards

- **Air Line geometry** (with a longitudinal resolution of 0.1 mm)
  - Mechanical outer conductor (OC) characterisation:
    - **Air Gauging:** OC line section.
    - **3D coordinate system**: both end zones of the OC line section.

  - Mechanical centre conductor (CC) characterisation:
    - **Laser Scanner:** CC line including the connector sections.

  - Mechanical connector characterisation (3.5 mm slotless connectors):
    - **Connector Gauges:** pin depth measurement (peak to peak value). Using a 3.5 mm male Flush Short mated on the female side of the Air Line.
    - **3D Scanner:** resulting pin depth profile (mating plane to pin shoulder).
    - **Toolmakers Microscope**: connector chamfers and eccentricity.

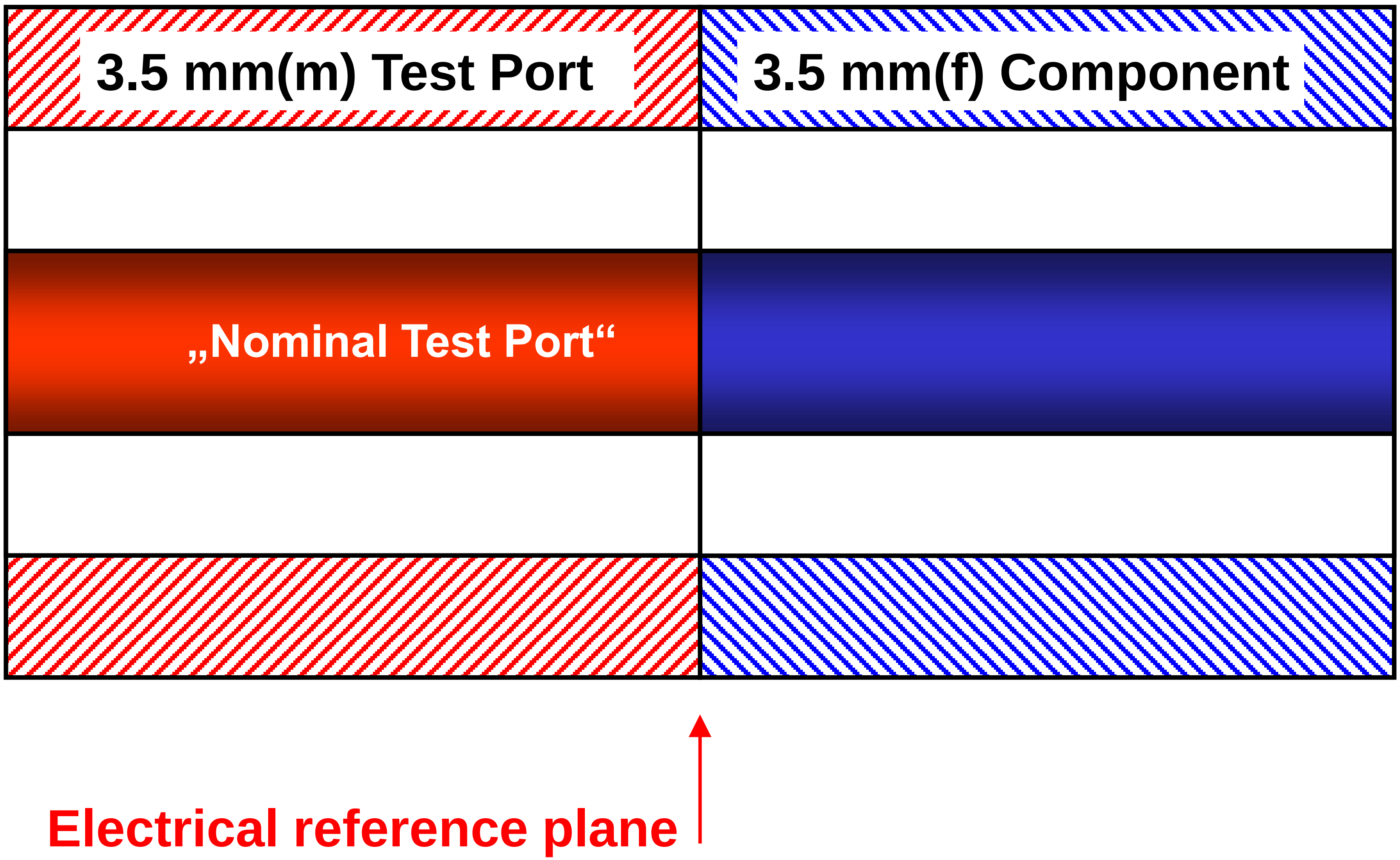
2nd step: modelling of the Air Lines and Flush Shorts

- **METAS Standard computer** (Air Lines, Flush Shorts and Offset Shorts)

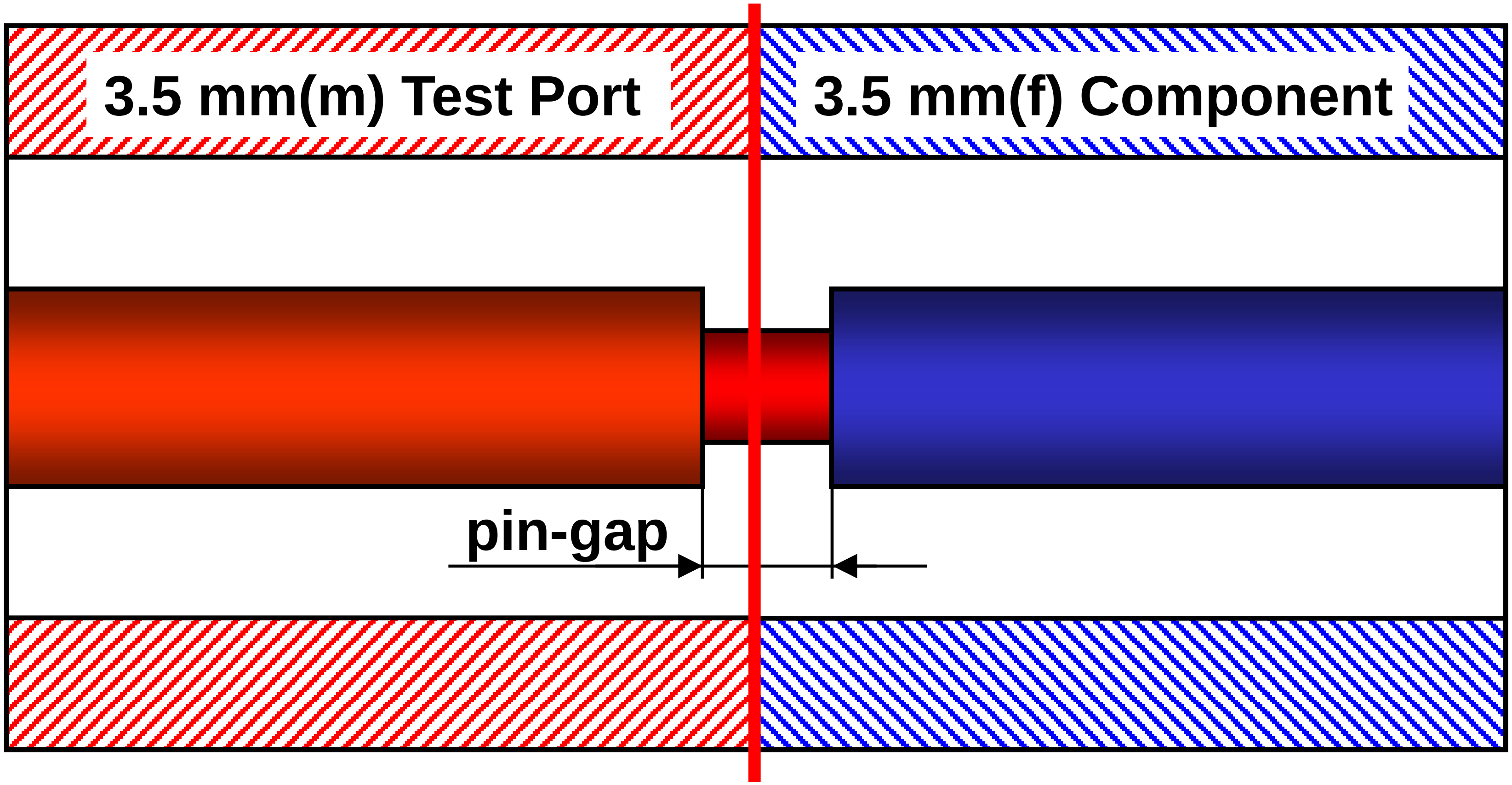
Centre conductor near field coupling issues

Metrology grade test port adapters showing a very small pin depth must be shimmed back to a defined minimal pin depth value.

Old paradigm: keep pin-gaps as small as possible

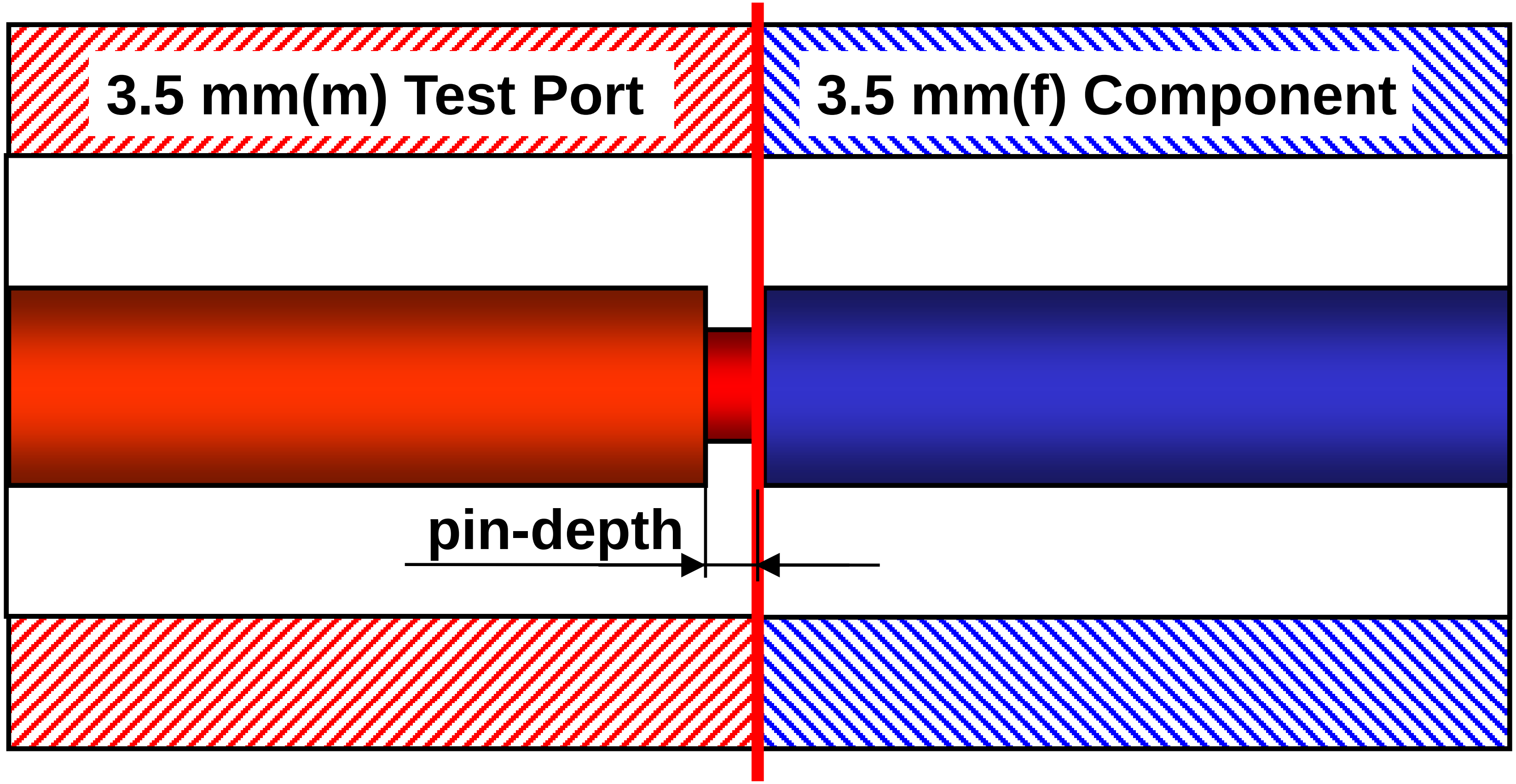


New paradigm: neither to small nor to large (minimal pin-depth)



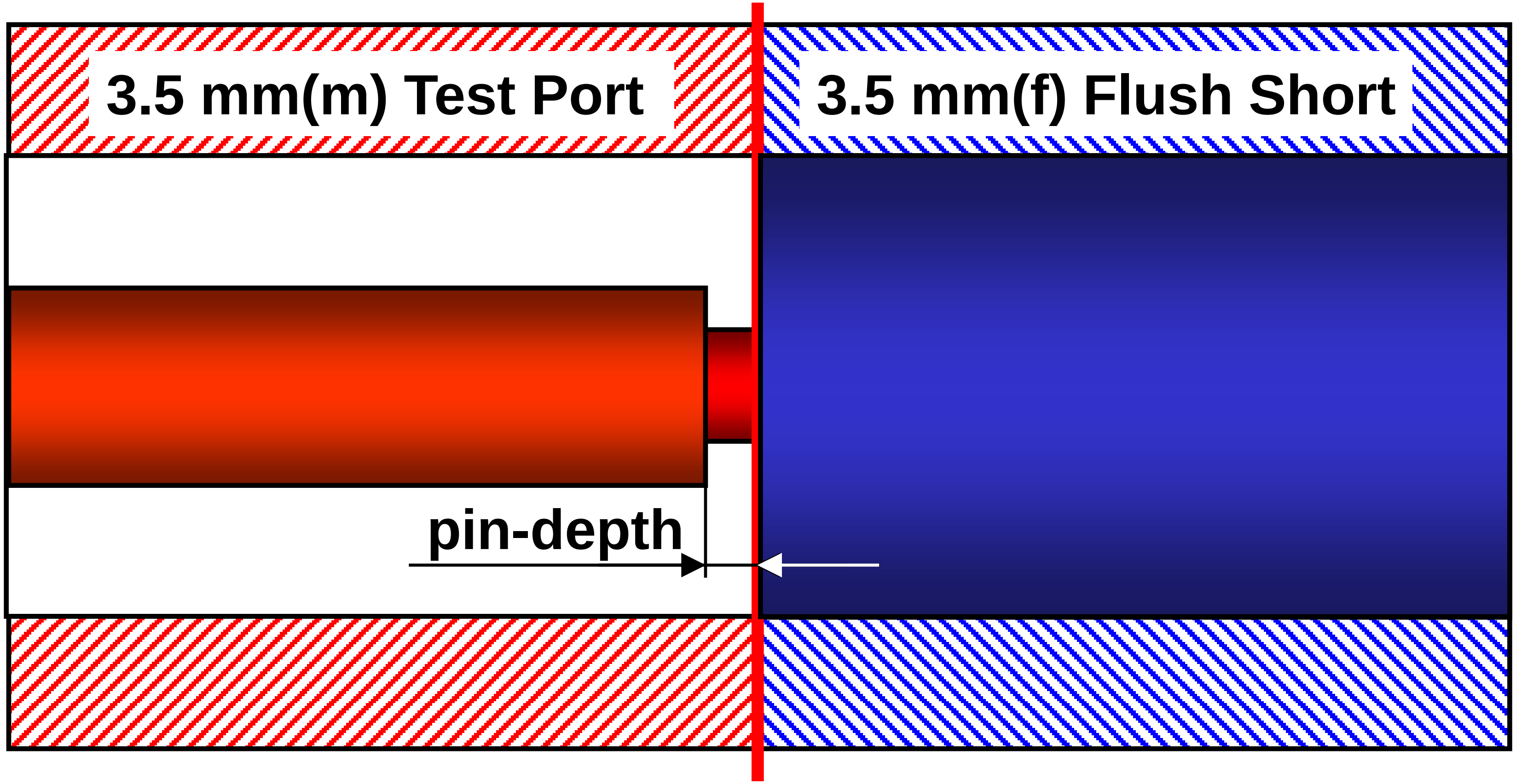
IEEE paper from Johannes: Pin Gap investigations, 2007

Tolerance on component side allows a flush pin-depth value



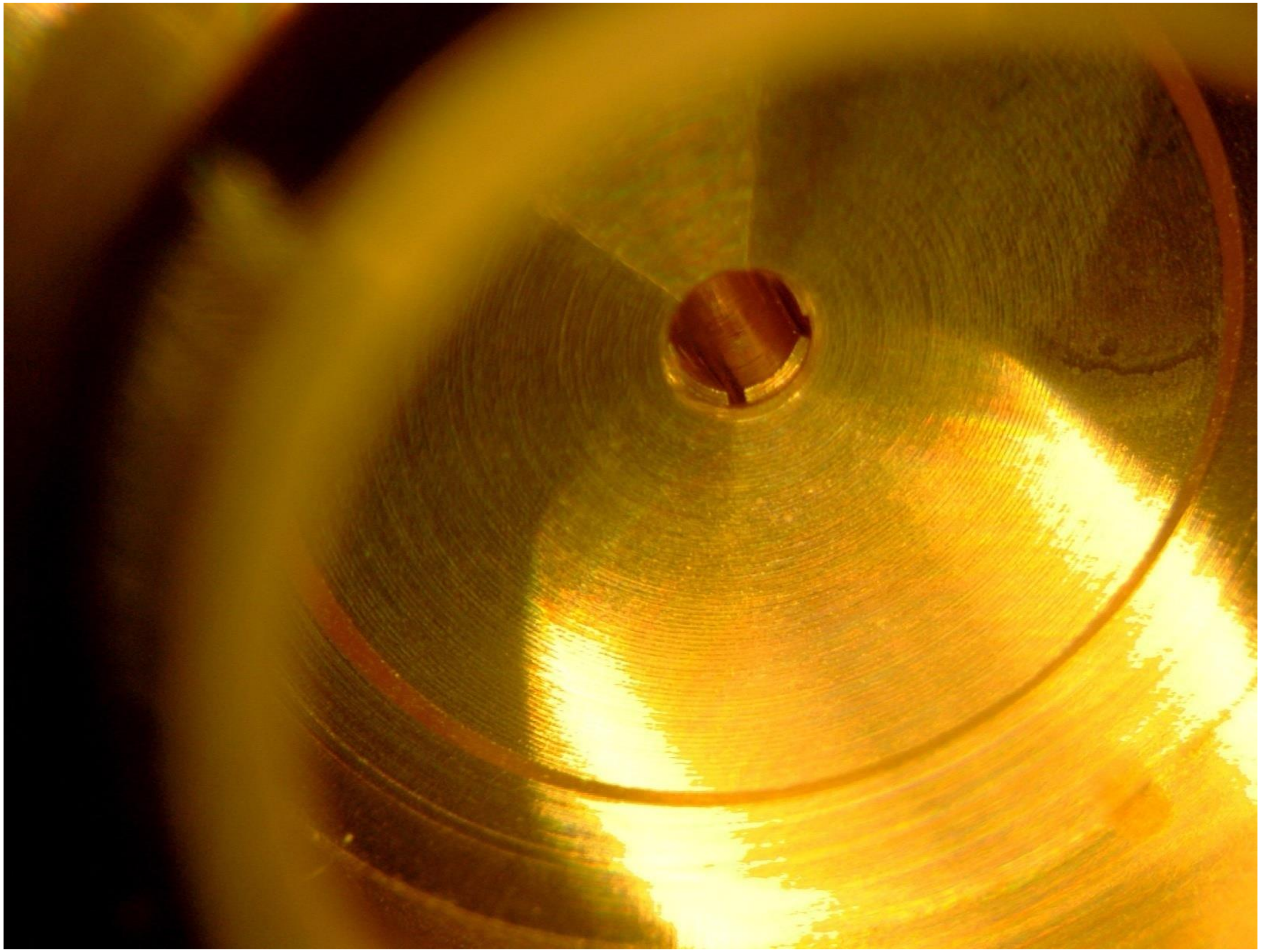
Conclusion: minimal gap must be realised at the test port side!

Example with a female Flush Short (pin-depth = 0 mm = flush)

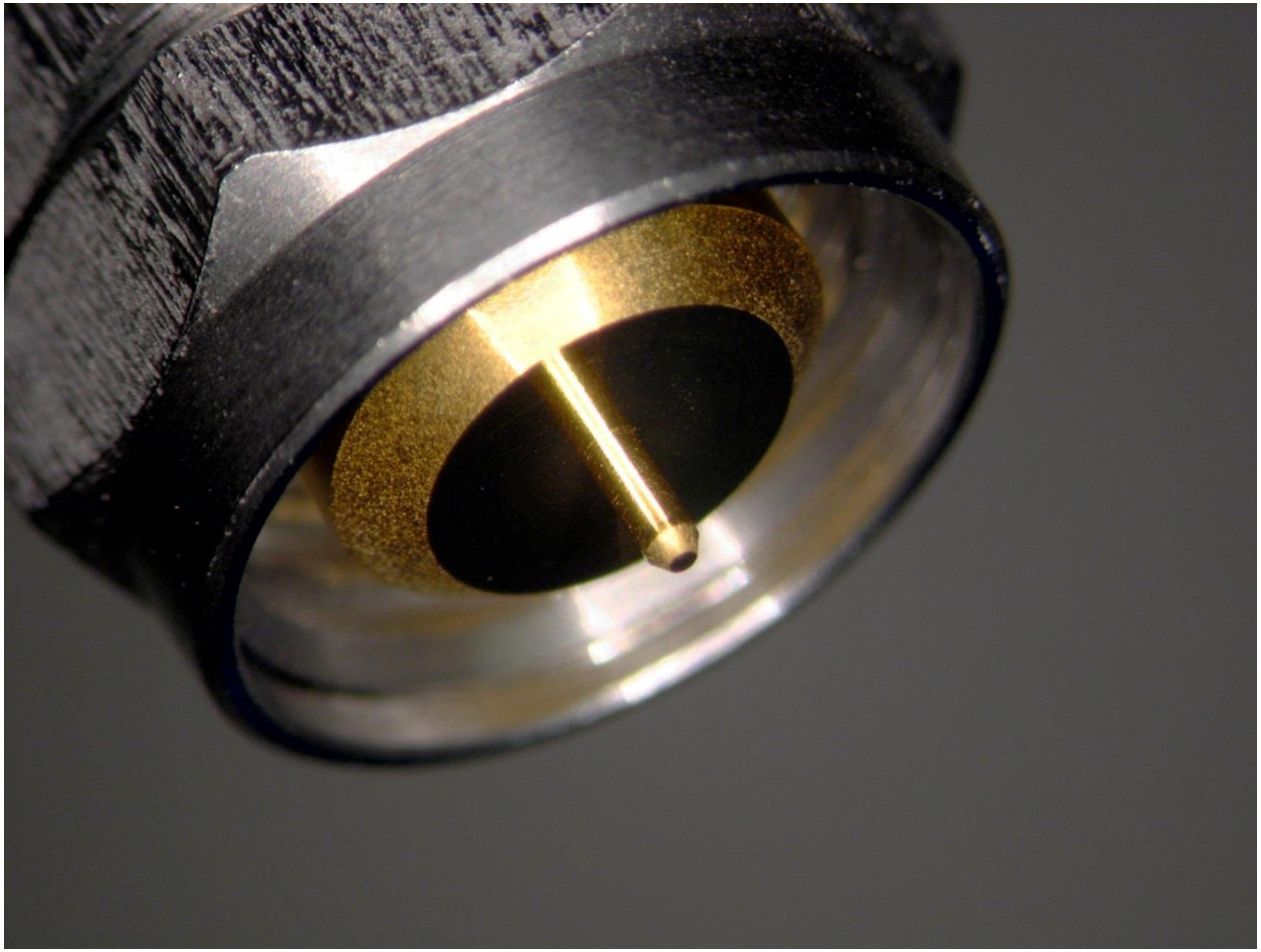


Coupling issue: if the Test Port has a too small pin-depth value!

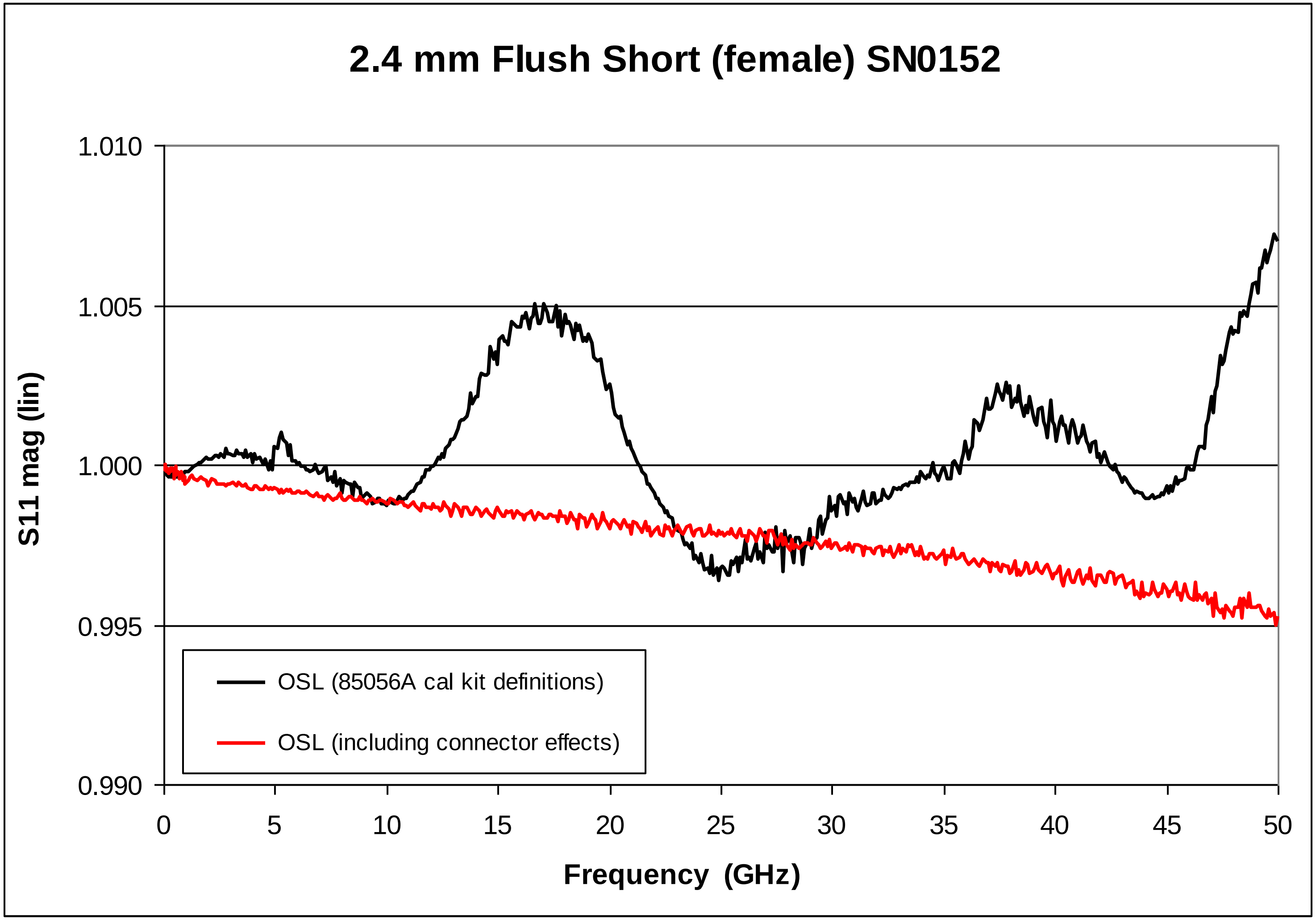
Flush Short measurements – test port coupling issue



Male and female Flush Shorts standards are part of the 3.5 mm CCEM.RF-K5c key comparison



Flush short: S11 magnitude (OSL including connector effects)



Calculated minimal distances to avoid near field effects

based on the Agilent connector blue prints:

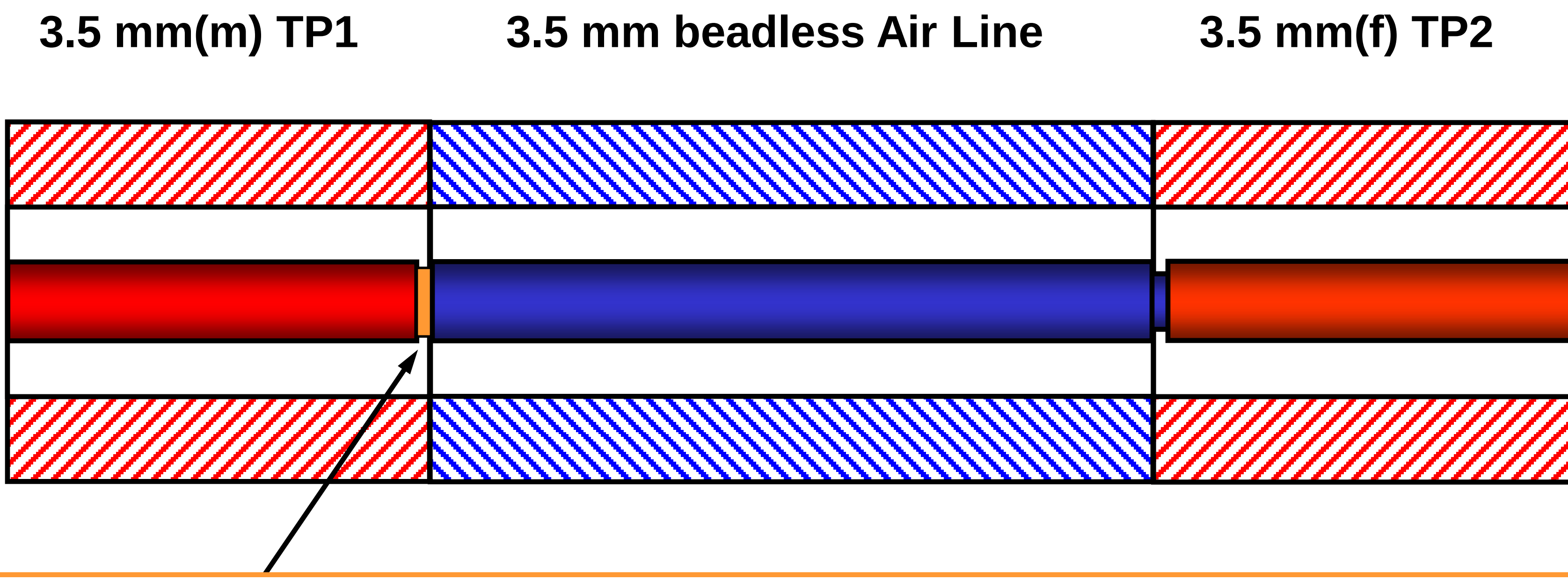
- **1.0 mm (slotted) : ?? µm**
- **1.85 mm (slotted) : 5 µm**
- **2.4 mm (slotless) : 15 µm**
- **2.92 mm (slotted) : ?? µm**
- **3.5 mm (slotless) : 15 µm**
- **Type-N (slotless) : ?? µm**

General: a slotless design needs more distance!

Airline handling (beadless center conductors)

A dielectric disc does allow to control the longitudinal position of center conductor when using recessed test port adapters.

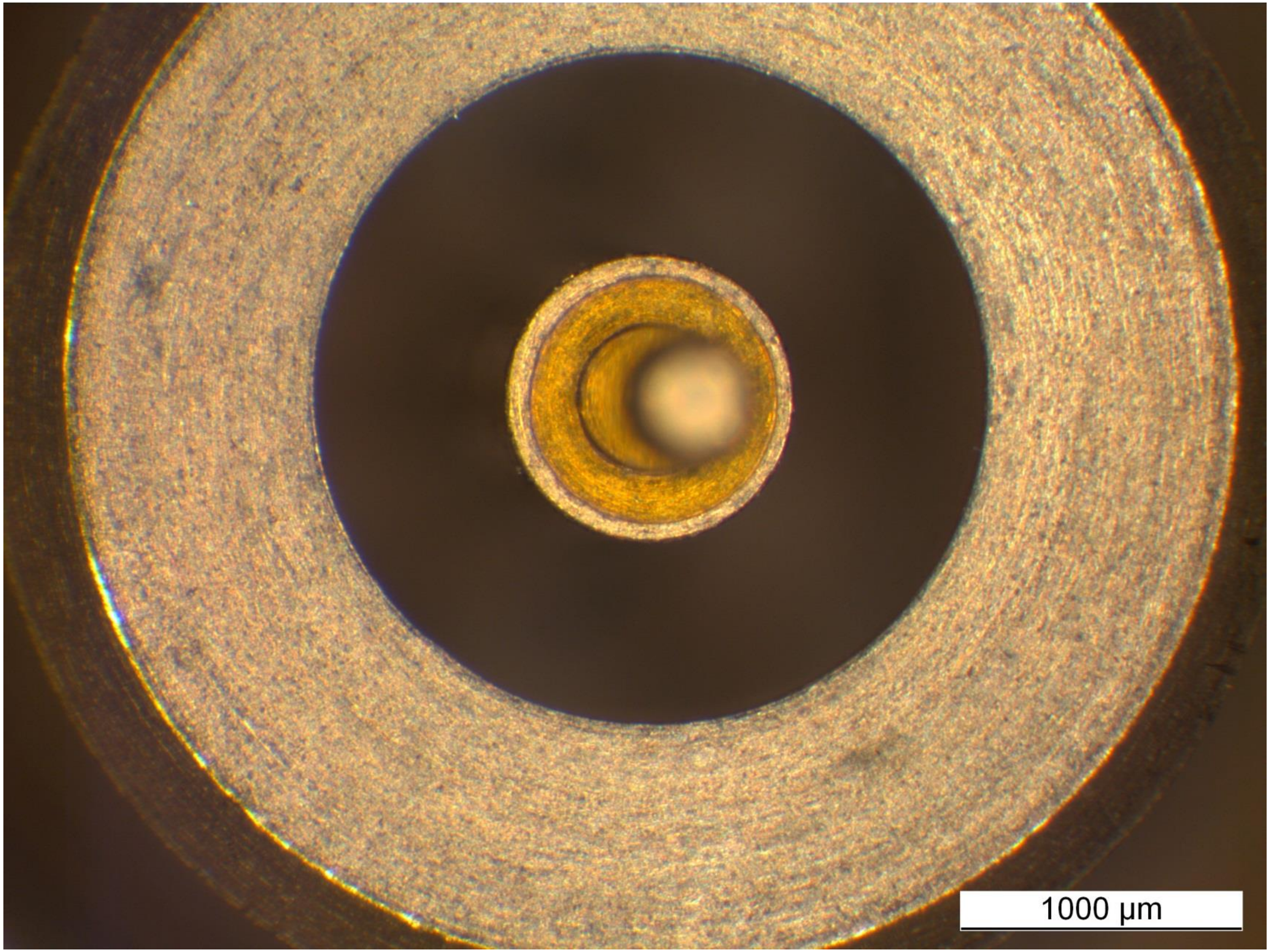
TP1 mounted with Kapton disc to avoid near field effects and to control a flush centre conductor position



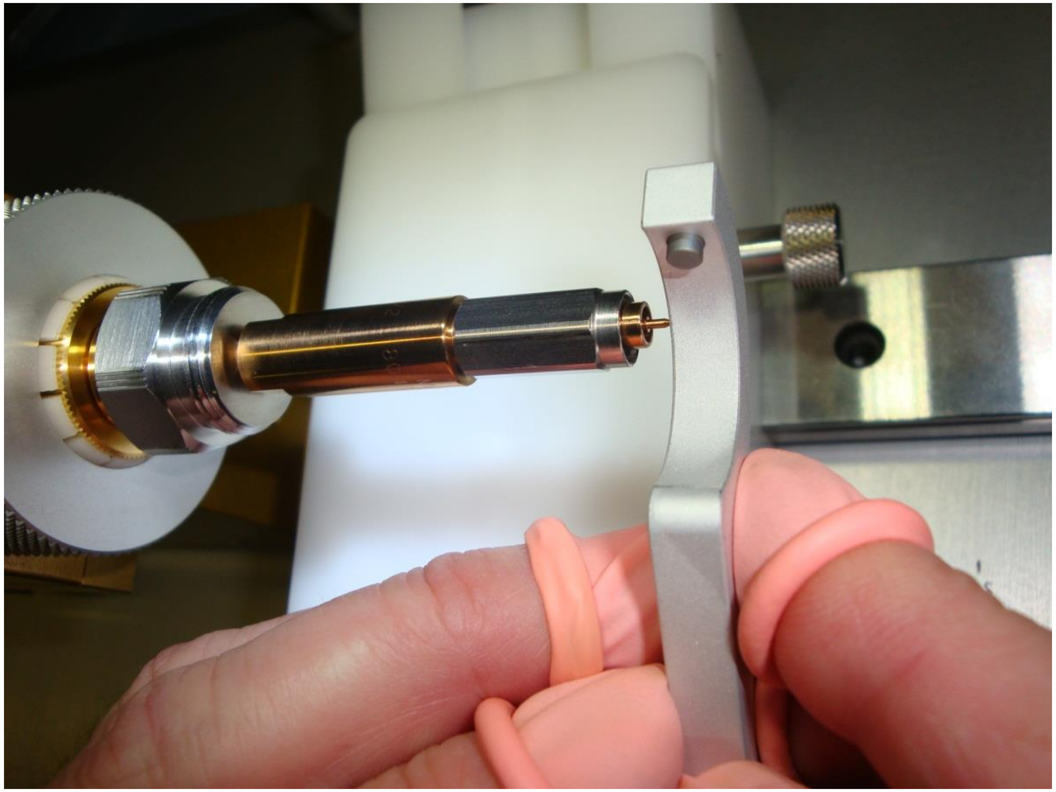
Kapton disc sizes used at METAS: 12.7 µm or 19 µm

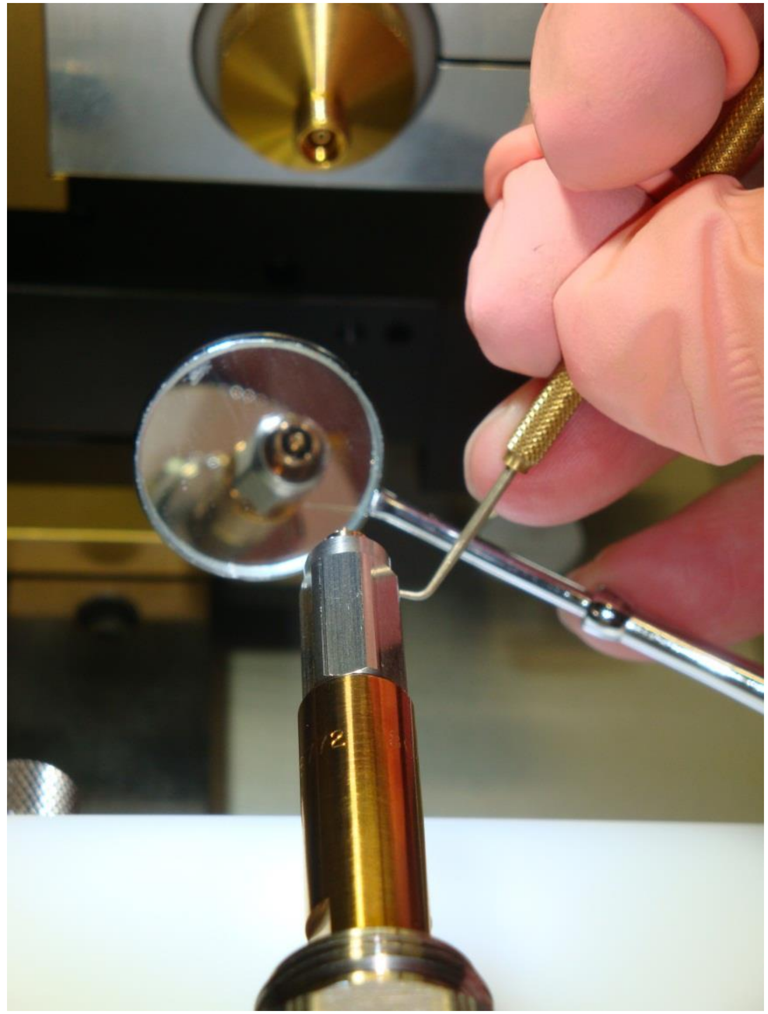
Note: optimal CC pin-depth recession for the 3.5 mm line system = 15 µm

Kapton disc mounted on a test port male pin



3.5 mm Air Line CC adjustment procedure on Port 2





3rd step: measurement of all 3.5 mm primary cal kit components and the additional working standards:

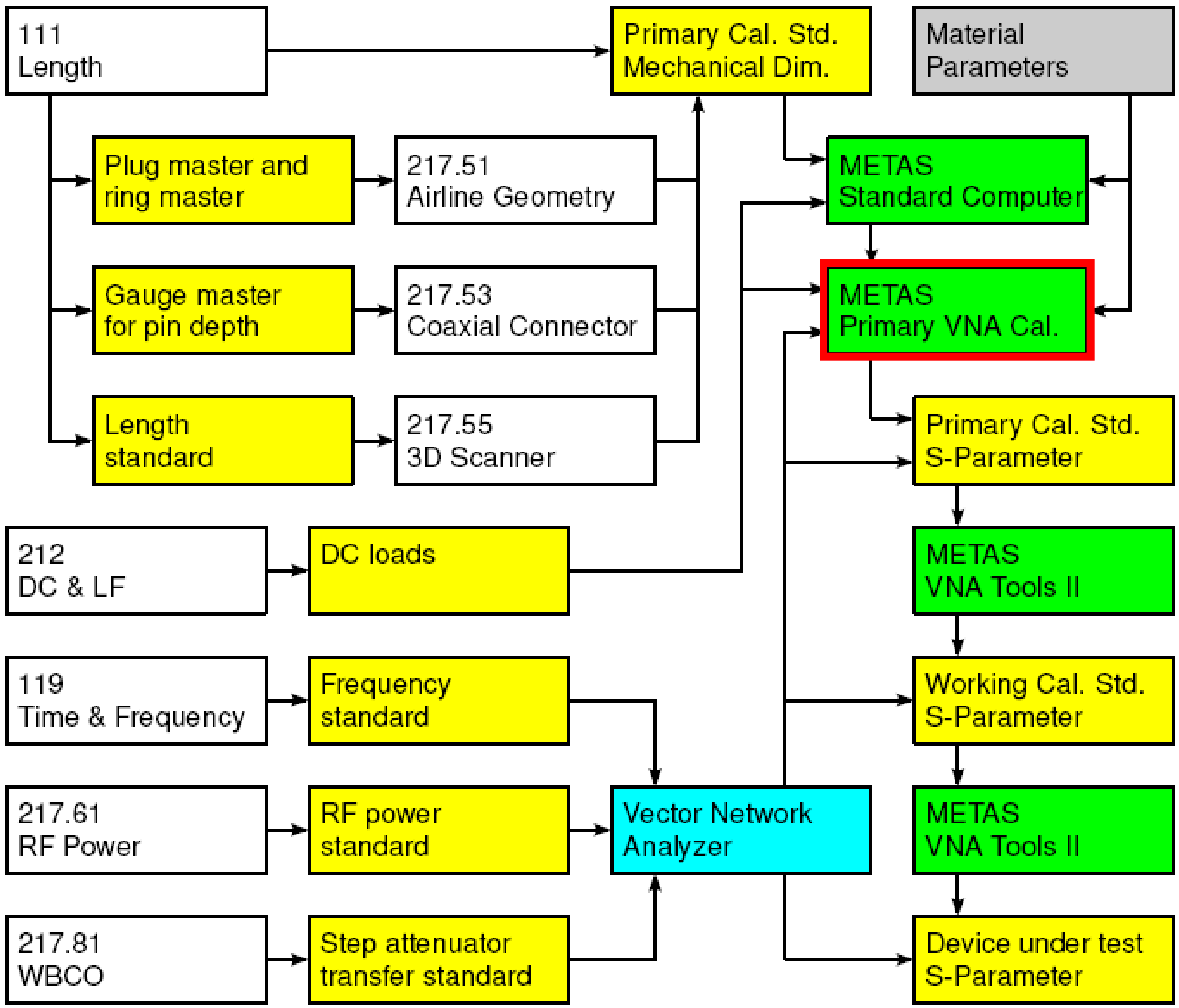
- 6 Air Lines, Open's, Short's, Load's and Flush Short's (male and female).
- Pre-selected 1-port working standards showing a good repeatability:
  - Open's, Short's, Load's and Flush Short's (male and female).
- Pre-selected 2-port working standards showing a good repeatability:
  - Attenuator Set, 50 ohm line, 25 ohm line, Adapter (f-m).

Important notes about the experiment procedure:

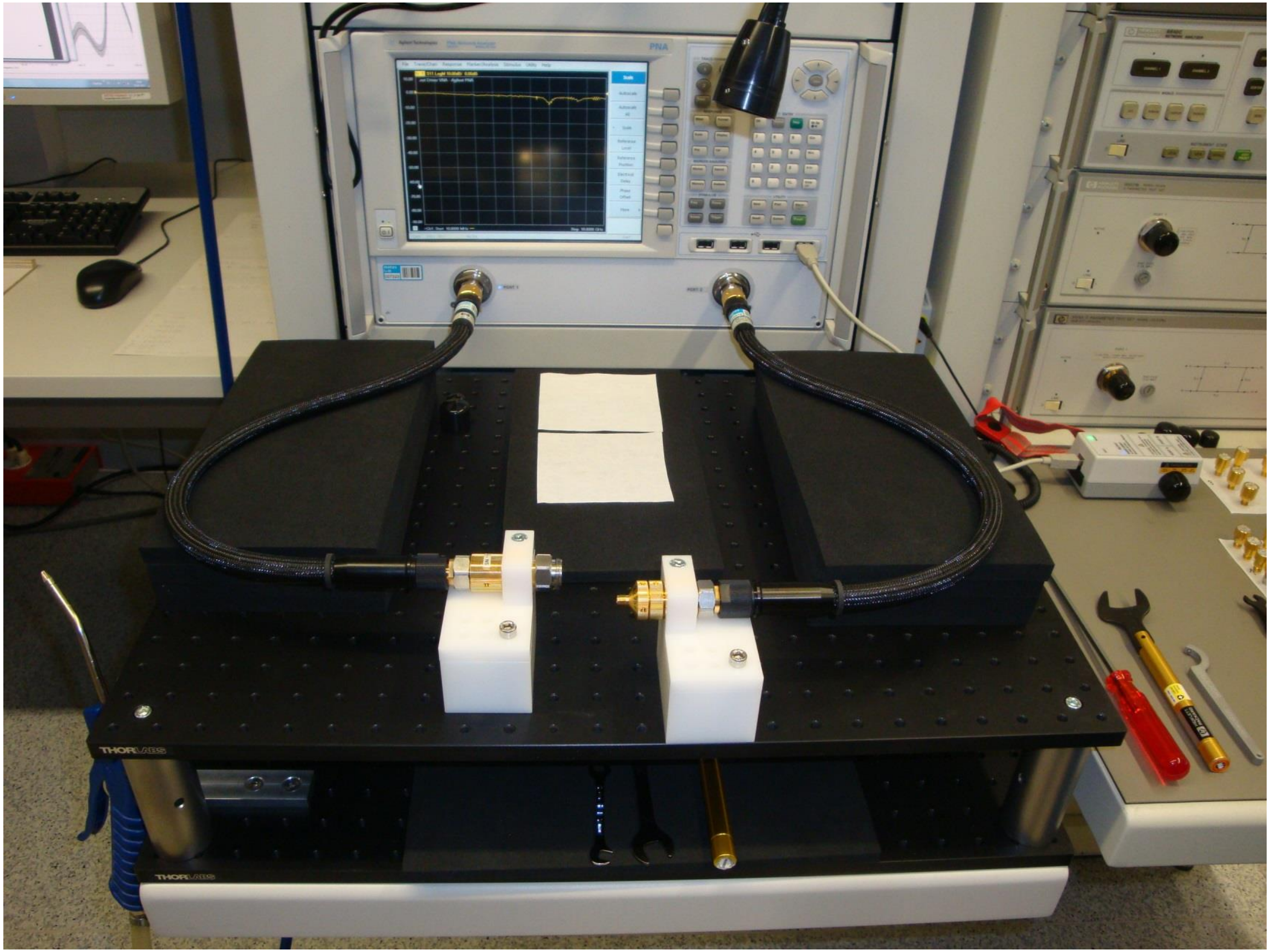
- first measure all 1 port standards (both cables fixed = stable error box)**.**

- Kapton disc only used for the beadless Air Line measurements.

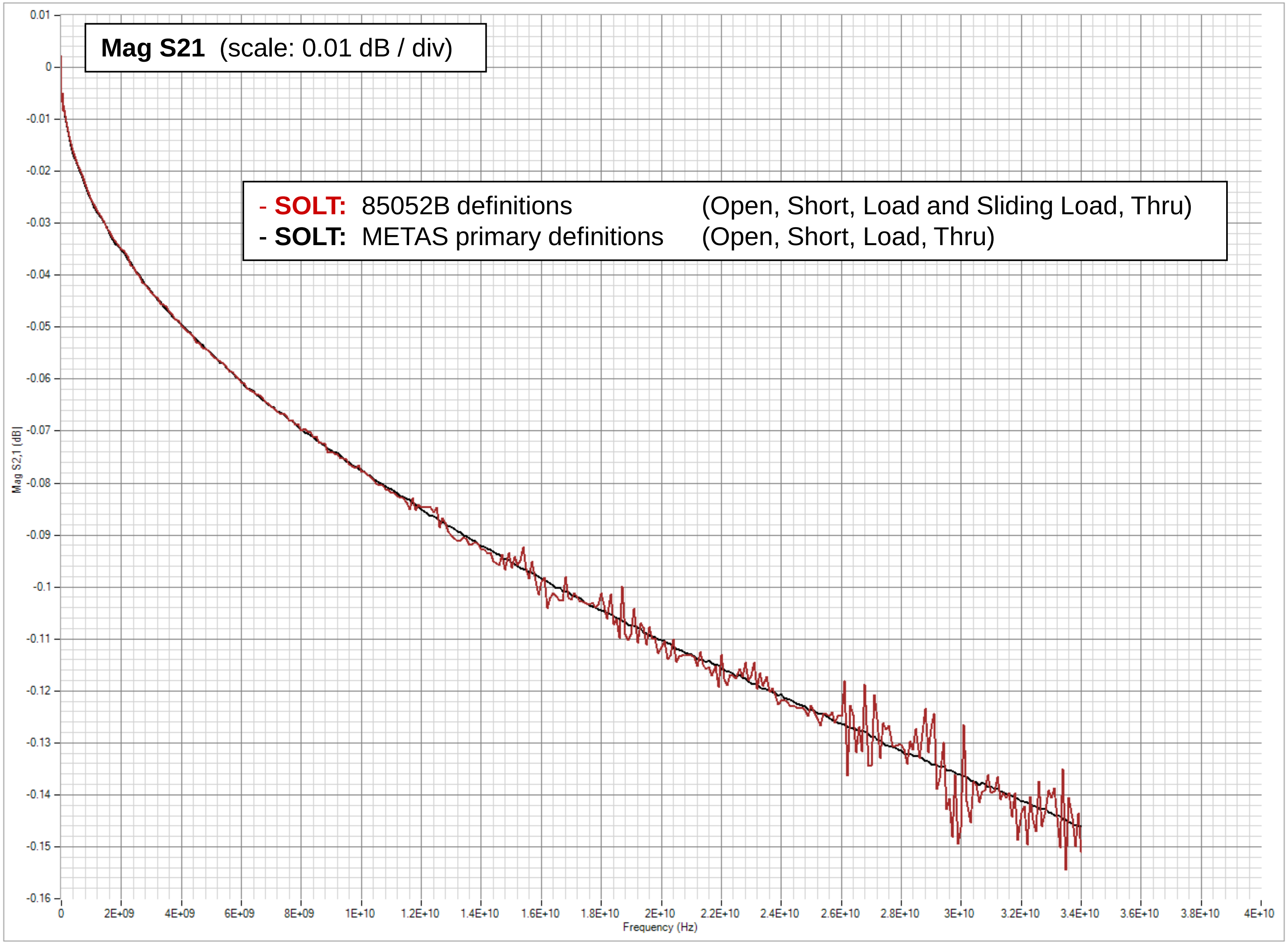
4th step: optimization of the Primary VNA Calibration



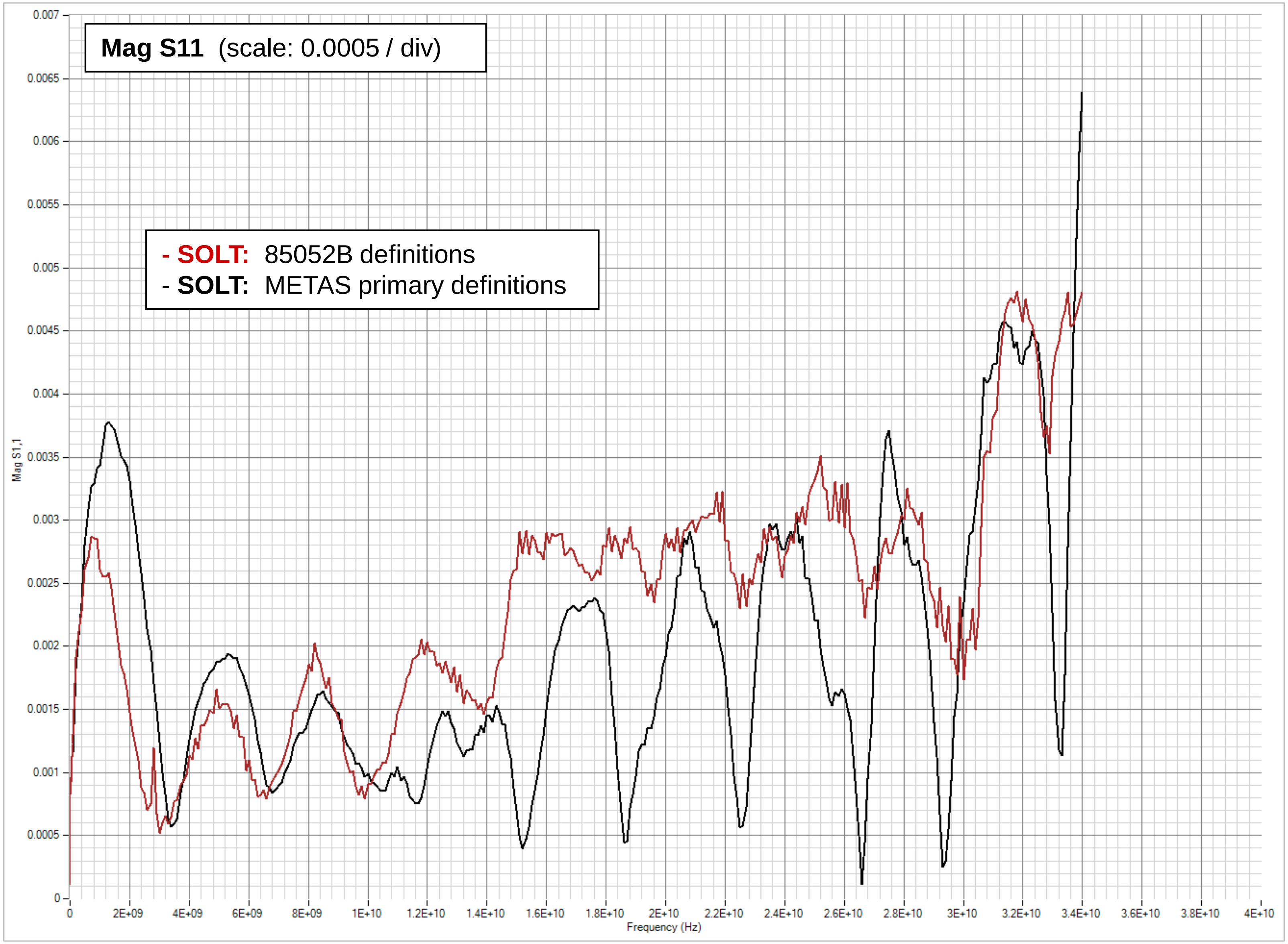
VNA Calibration using the working standards (data base)



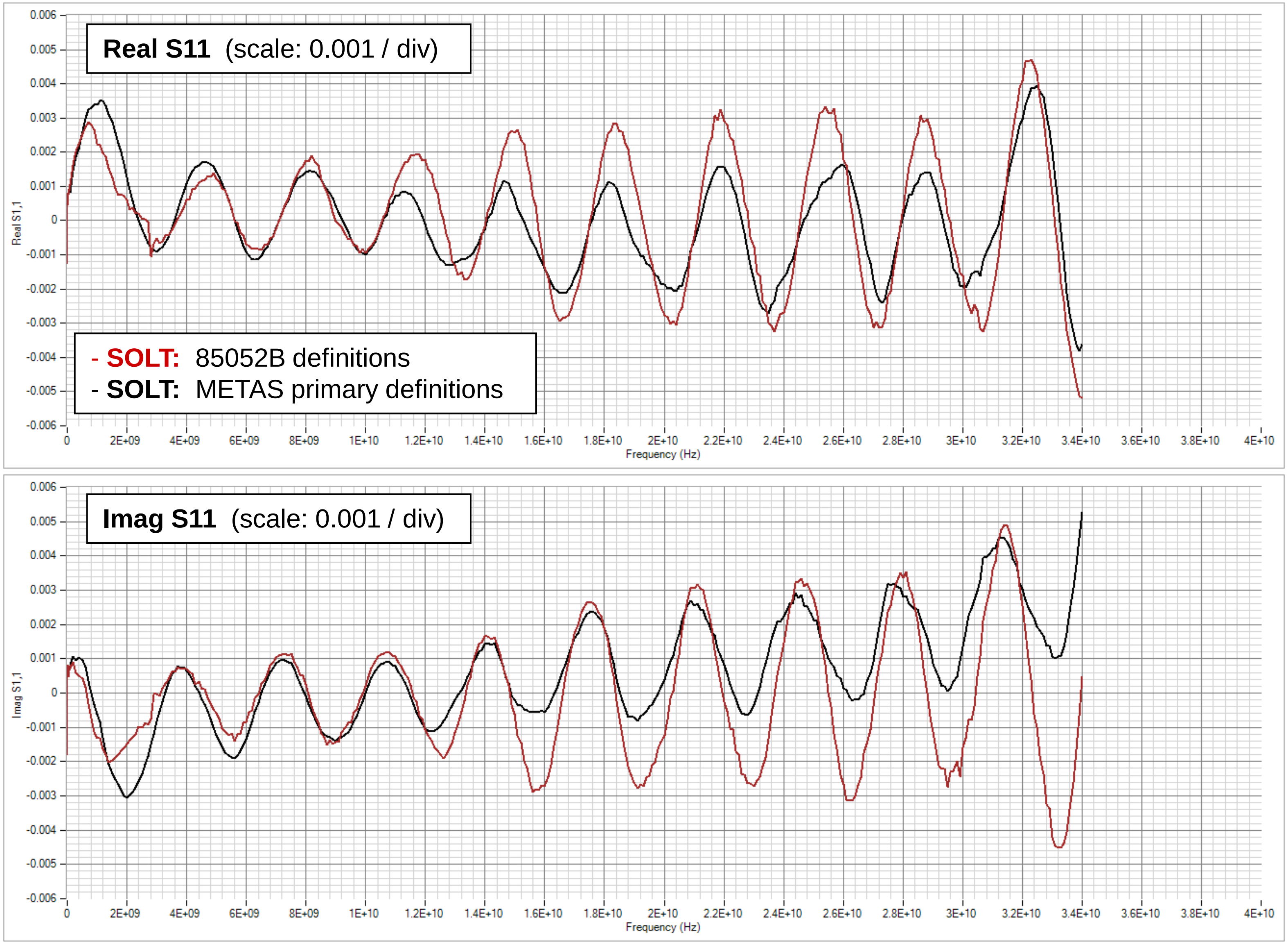
3.5 mm example: 42.096 mm Airline measurement up to 34 GHz



3.5 mm example: 42.096 mm Airline measurement up to 34 GHz



3.5 mm example: 42.096 mm Airline measurement up to 34 GHz

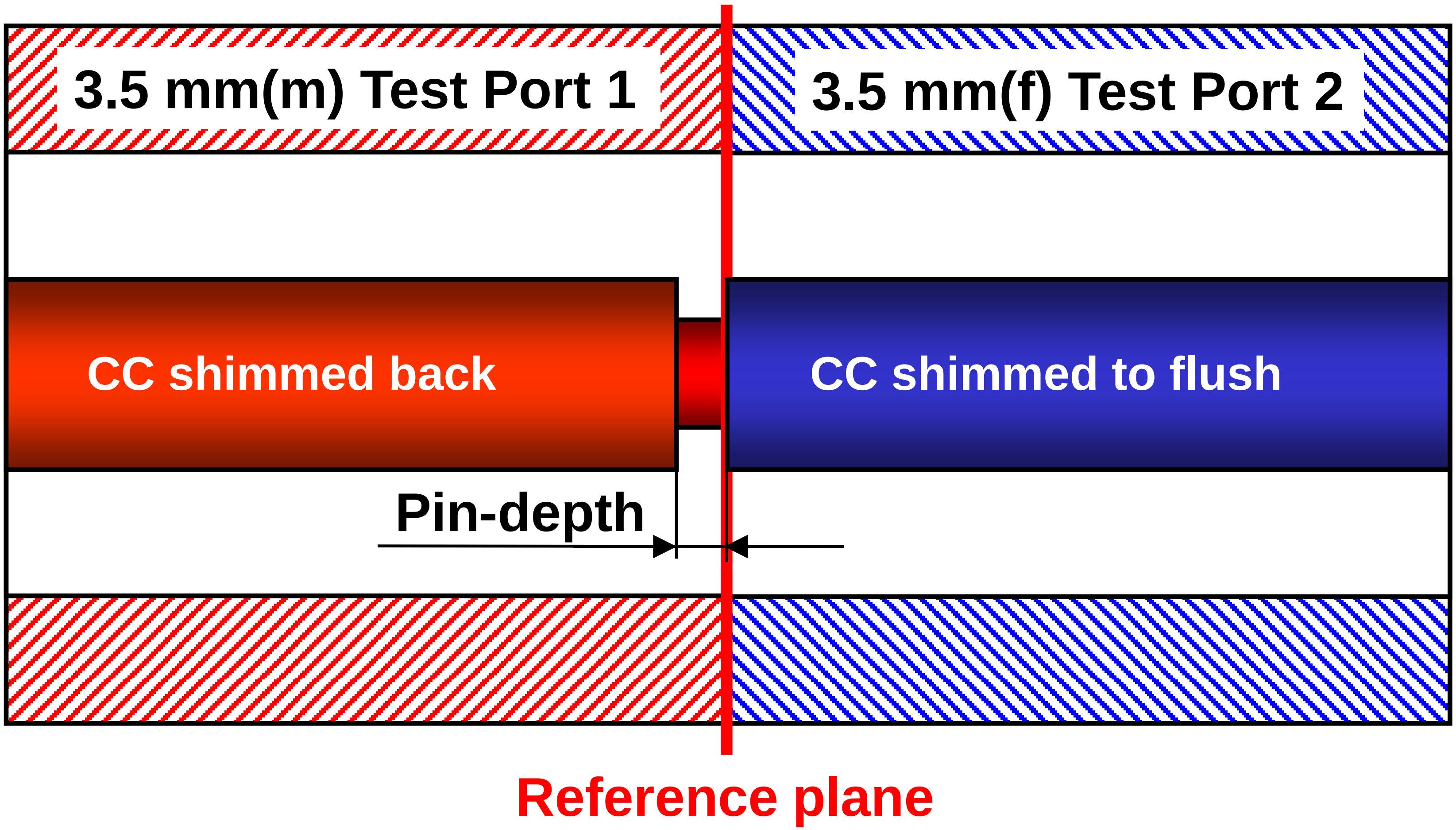


Used correction method at METAS to determine the electrical Kapton ring effect

(used to de-cascade the S-parameters of the Kapton ring)

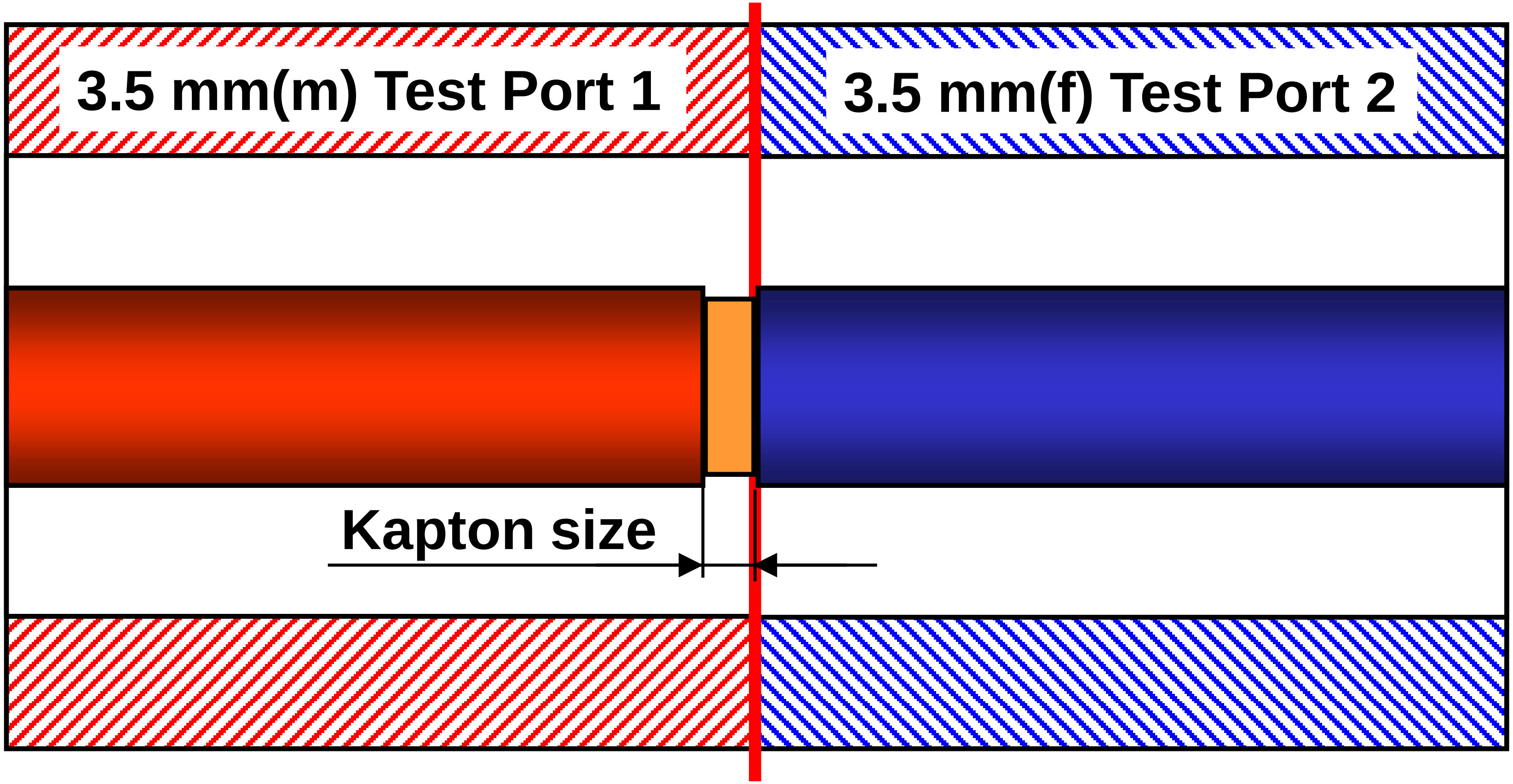
- **Process not part of the LRL calibration experiment** (a different set-up).
- **Full 2-port measurement set-up with optimised cable stability.**
- **Use on Port 1 a Test Port Adapter shimmed to the Kapton ring size.**
- **IMPORTANT:**
  Use on Port 2 a flush Test Port Adapter (set to zero pin-depth).

1. Perform a SOLT (or QSOLT) cal without any Kapton disc



Pin-depth: shimmed to the same size as the used Kapton disc!

2. Quantify the S-parameters of the mounted Kapton disc



Pin-depth: shimmed to the same size as the used Kapton disc!

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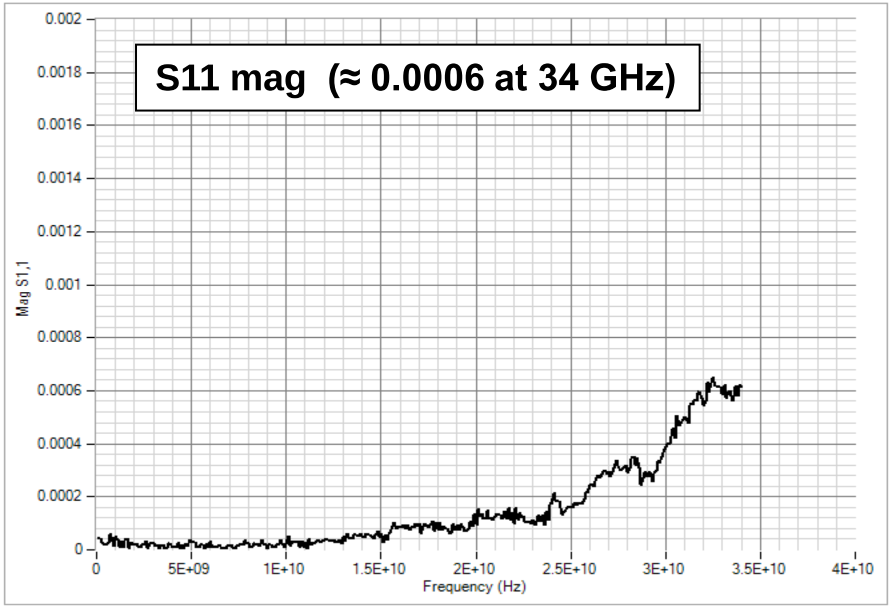
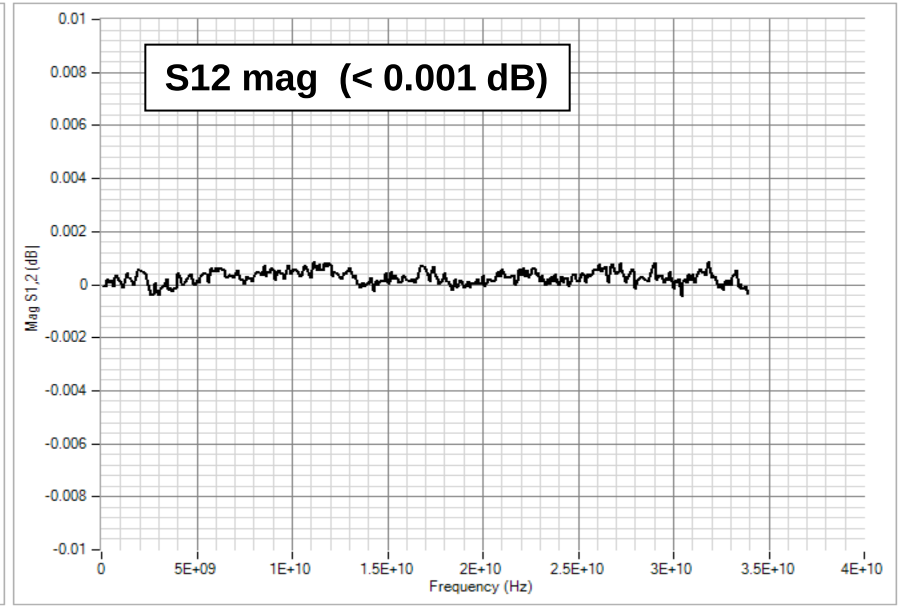
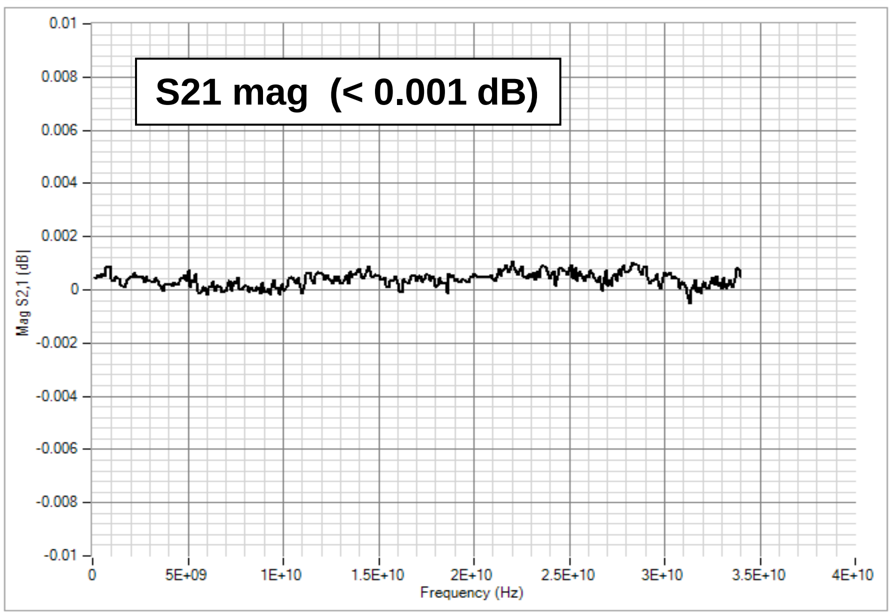
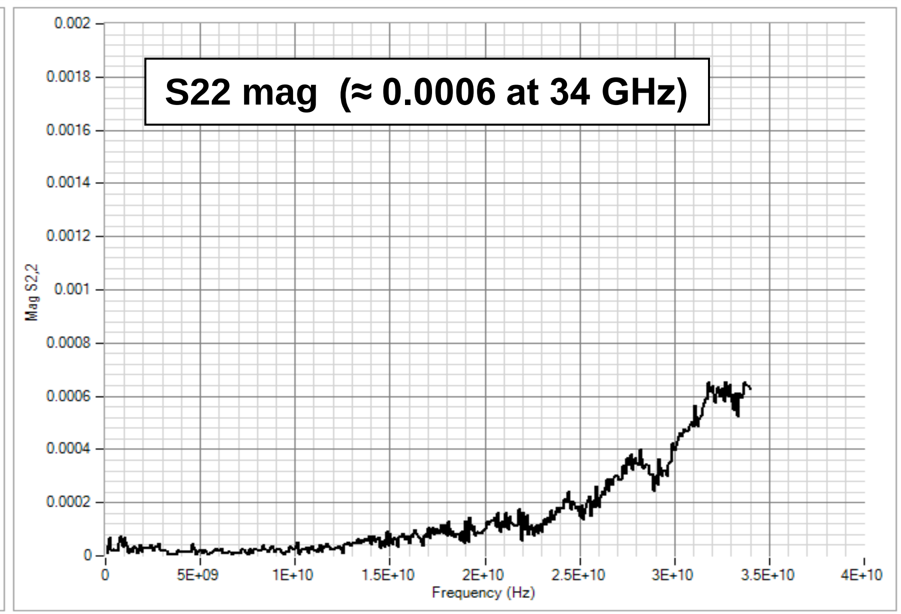
Example: 3.5 mm Kapton ring (19.0 µm)

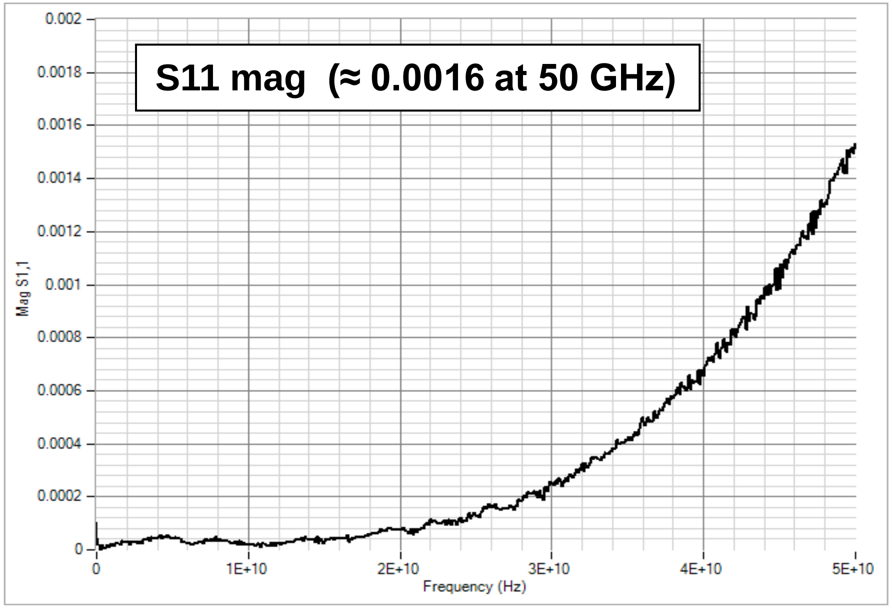


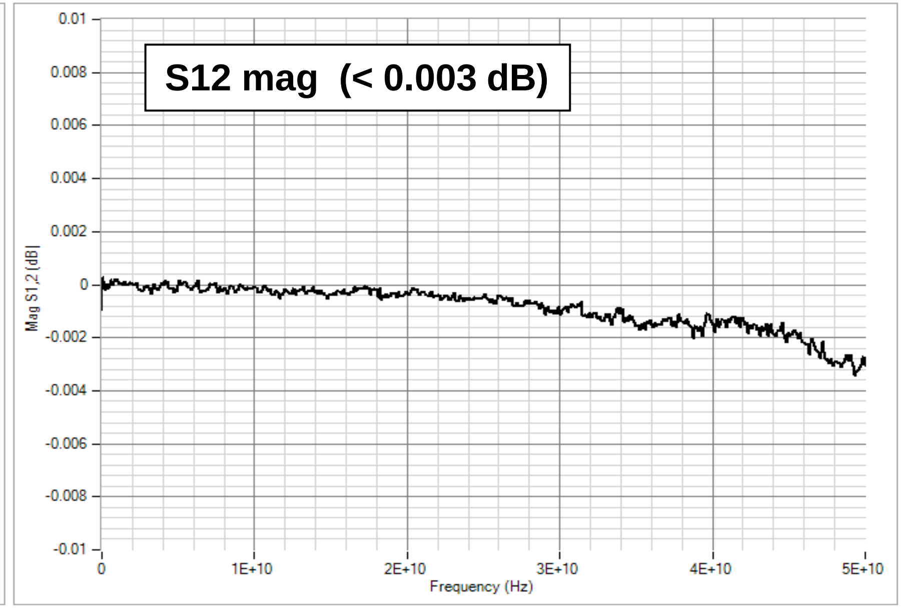


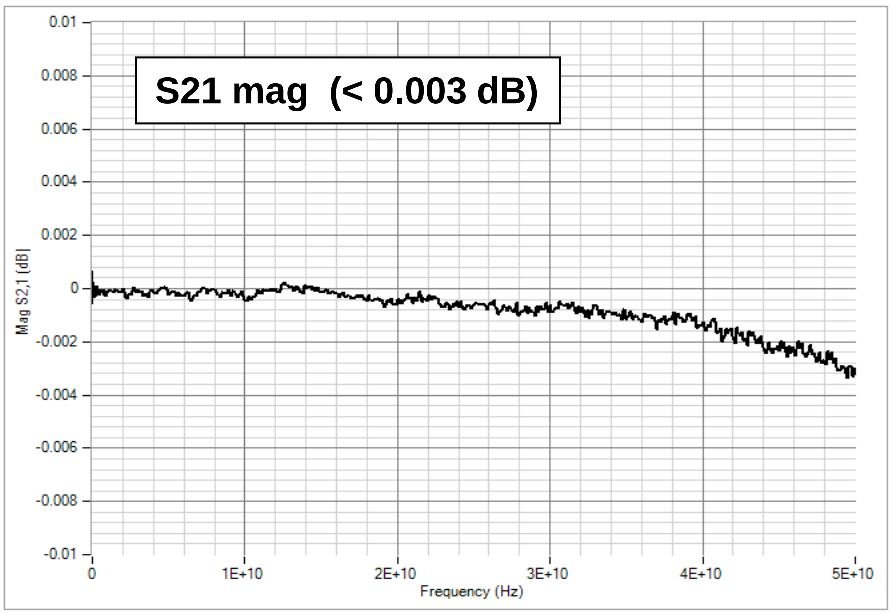


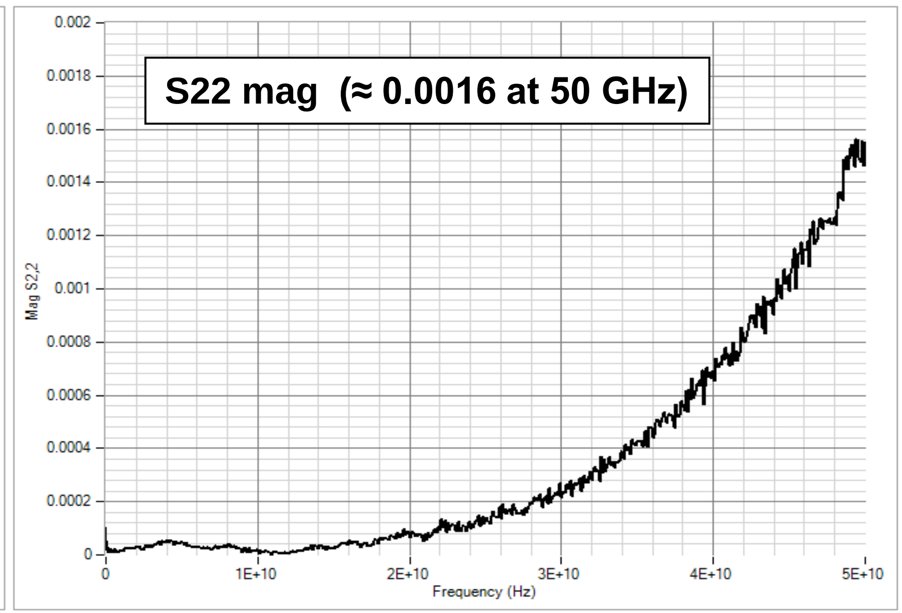


Example: 2.4 mm Kapton ring (12.7 µm)







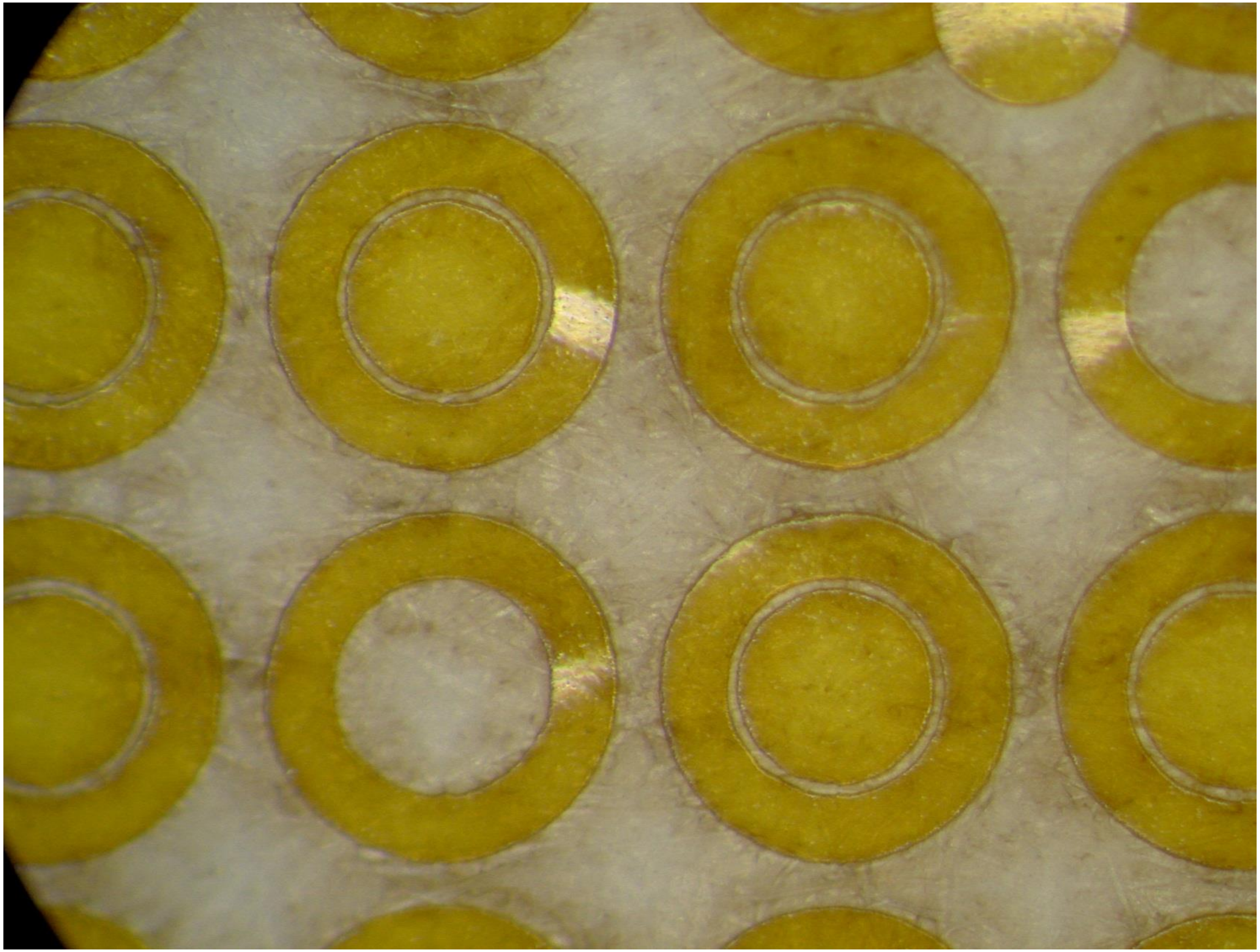


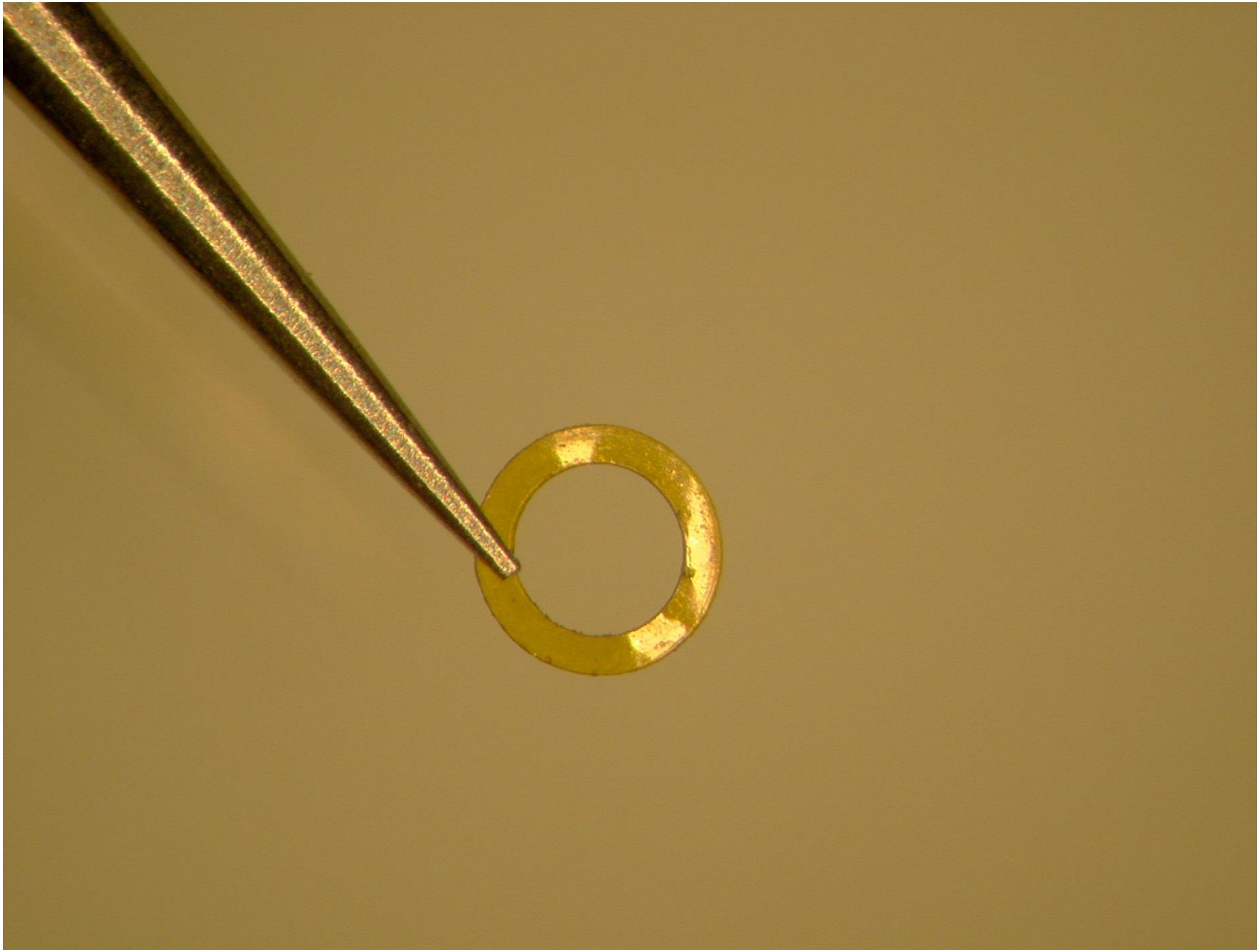
Conclusions : "consistent S-parameters"

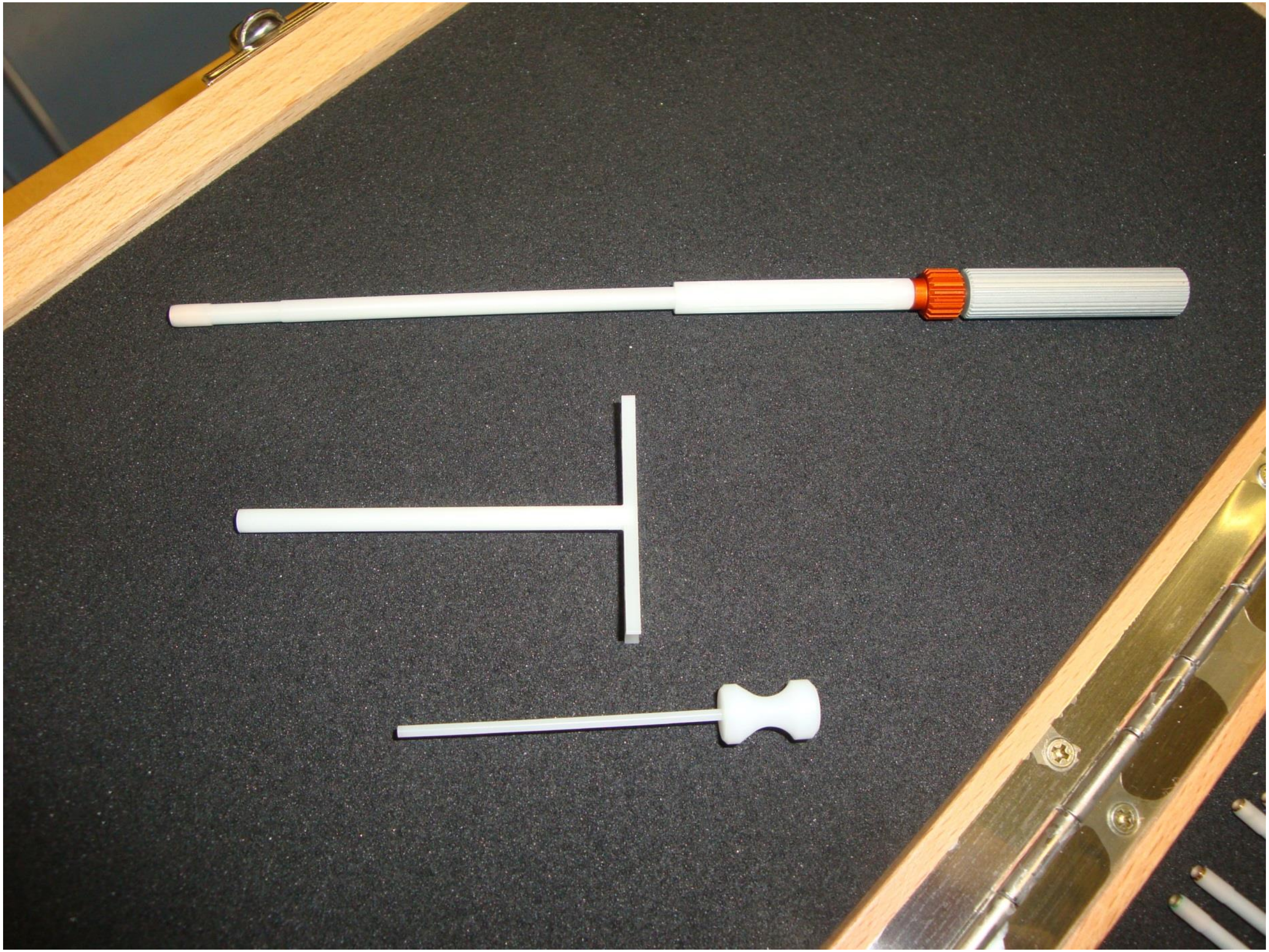
- **METAS has developed a new 3.5 mm primary cal kit.**
- **New VNA metrology outcomes are taken into account.**
- **Minimal 3.5 mm pin-depth to avoid coupling effects.**
- **Limiting factor of the experiment: the cable stability.**
- **3.5 mm Kapton disc experiment** (S-parameter effect)**.**
- **Traceability to SI - consistent S-parameter results.**

Thank you very much for your attention !

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

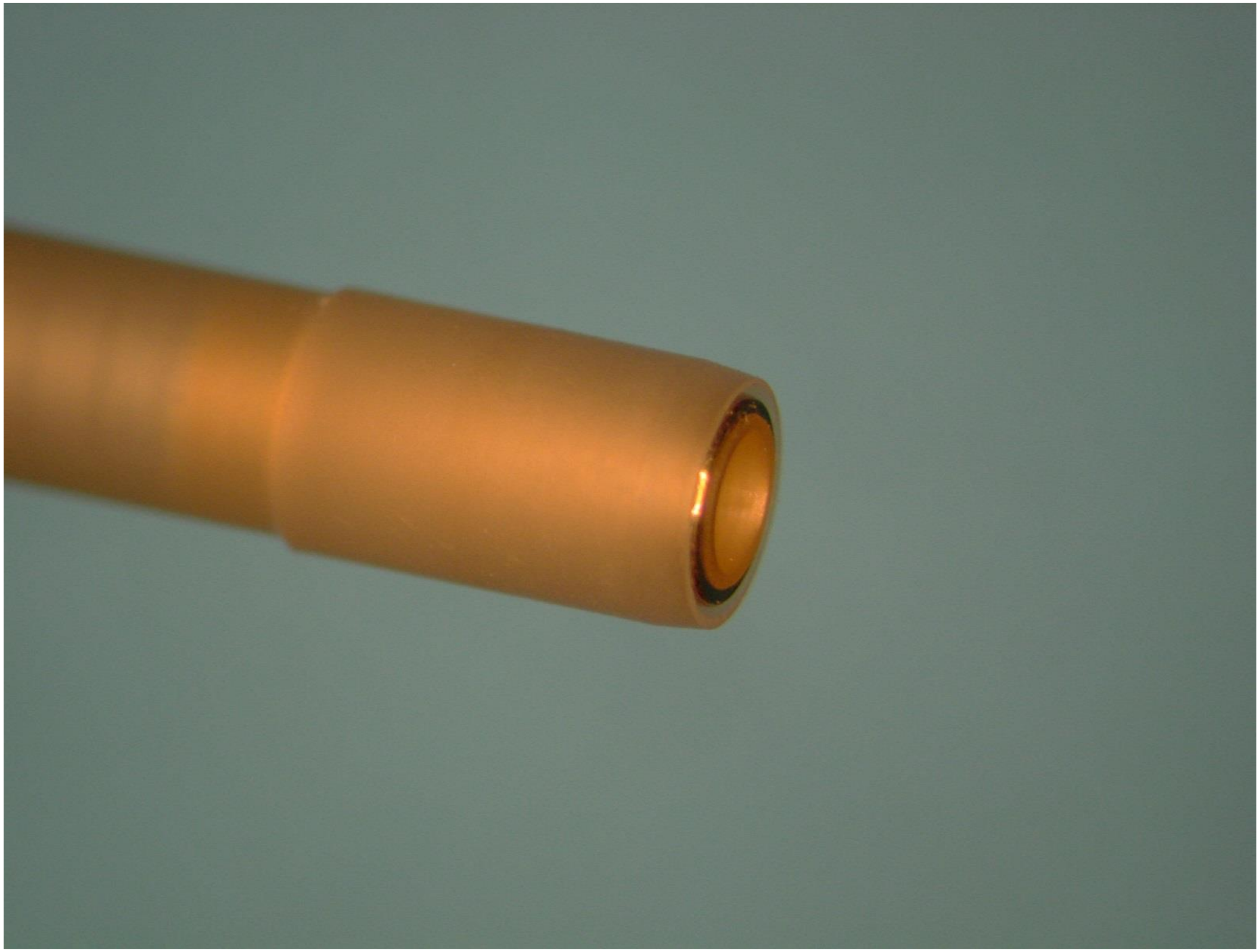




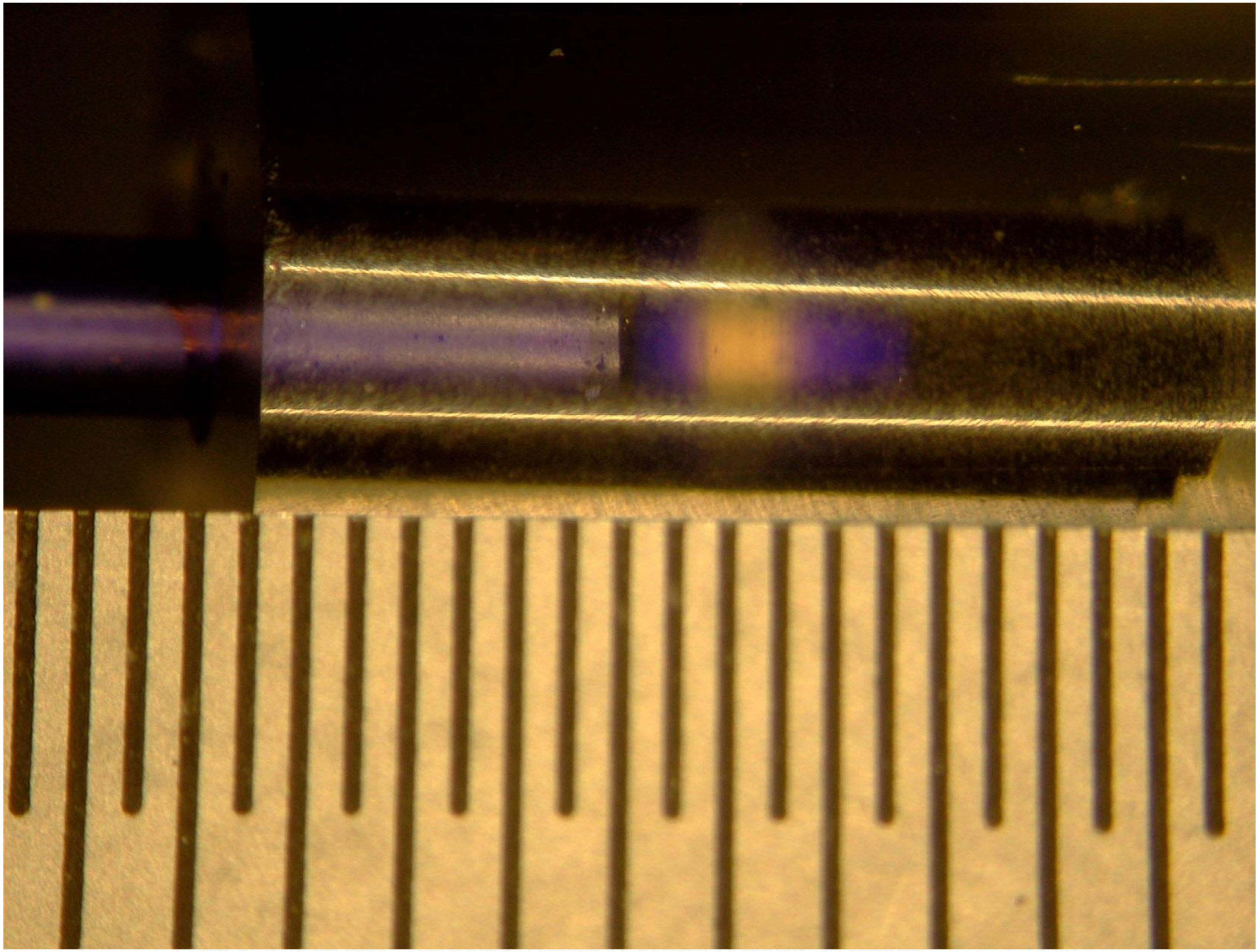


OCID alignment tool (shown example: Type-N)

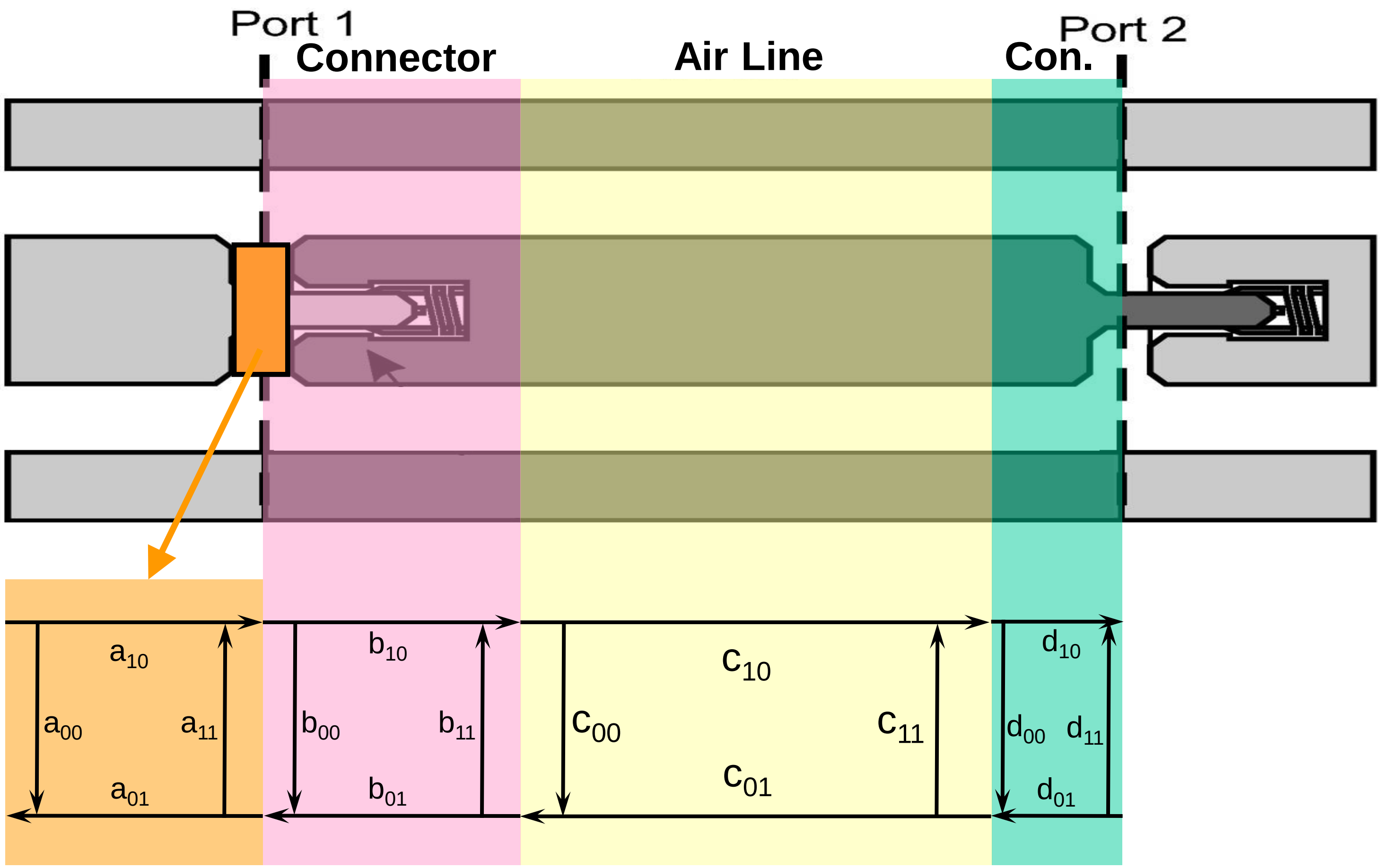
Front part of the 1.85 mm tool



Expanded area of the 1.85 mm tool



Example 2: Air Line model including the systematic connector effects (using the half connectors concept)



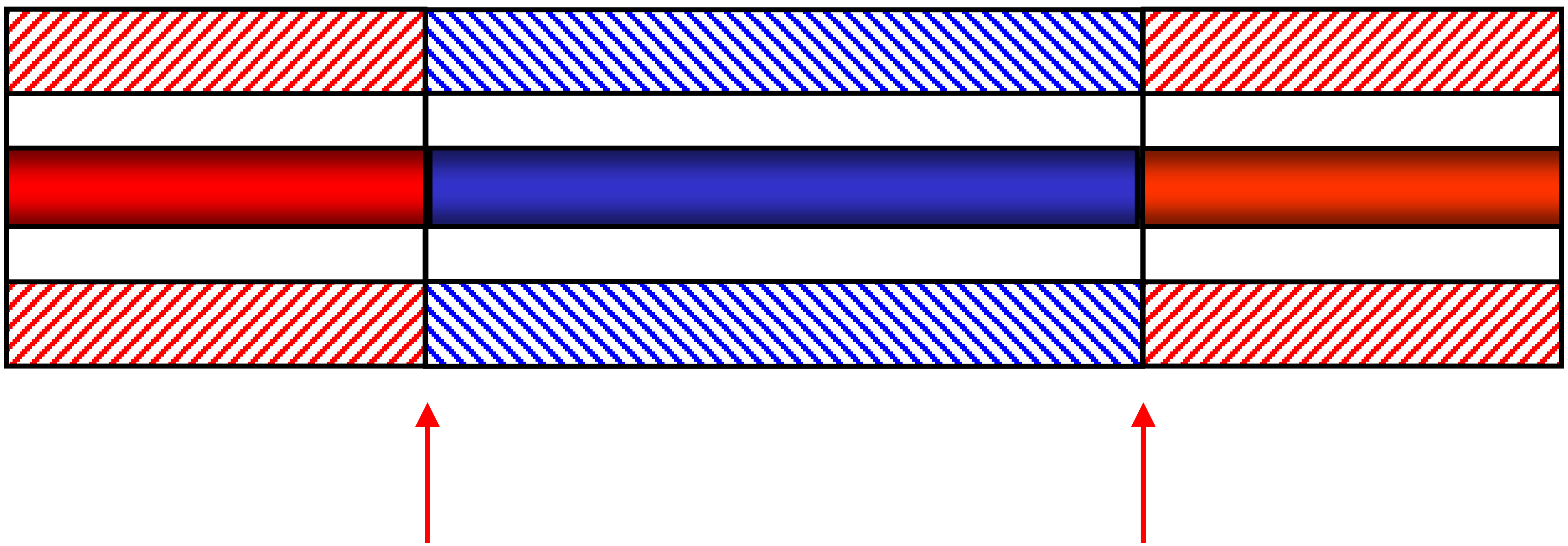
3D scanning white light interferometer from Zygo

PERFORMANCE	
Vertical Scan Range	150 µm (5906 µin); Extended scan range to 20 mm (0.79 in.)
Vertical Resolution	< 0.1 nm (0.004 µin)
Optical Resolution	0.36 to 9.5 µm (14.2 to 374 µin); objective dependent
Data Scan Rate	≤26 µm/sec, user-selectable; camera and scan mode dependent
Maximum Data Points	307,200 (VGA camera) 984,064 (1K camera)
RMS Repeatability	< 0.01 nm (0.0004 µin) RMSσ
Step Height	Accuracy ≤ 0.75% Repeatability ≤ 0.1% @ 1σ

Old paradigm: Test Port Adapters pin-depth set close to zero

Advantage: Centre Conductor position can be controlled

3.5 mm(m) TP1 | 3.5 mm beadless Air Line | 3.5 mm(f) TP2

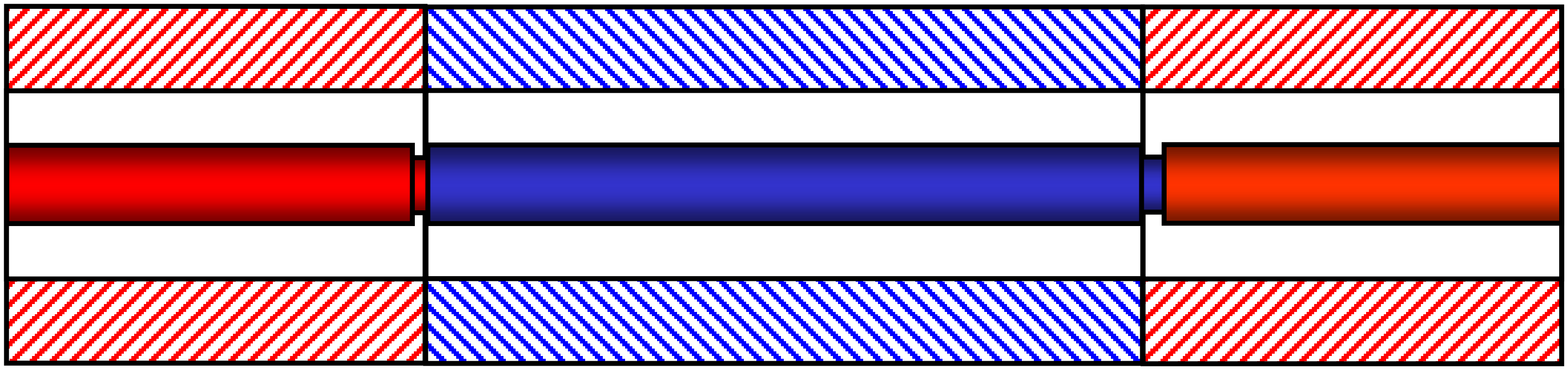


Electrical reference plane TP1

Electrical reference plane TP2

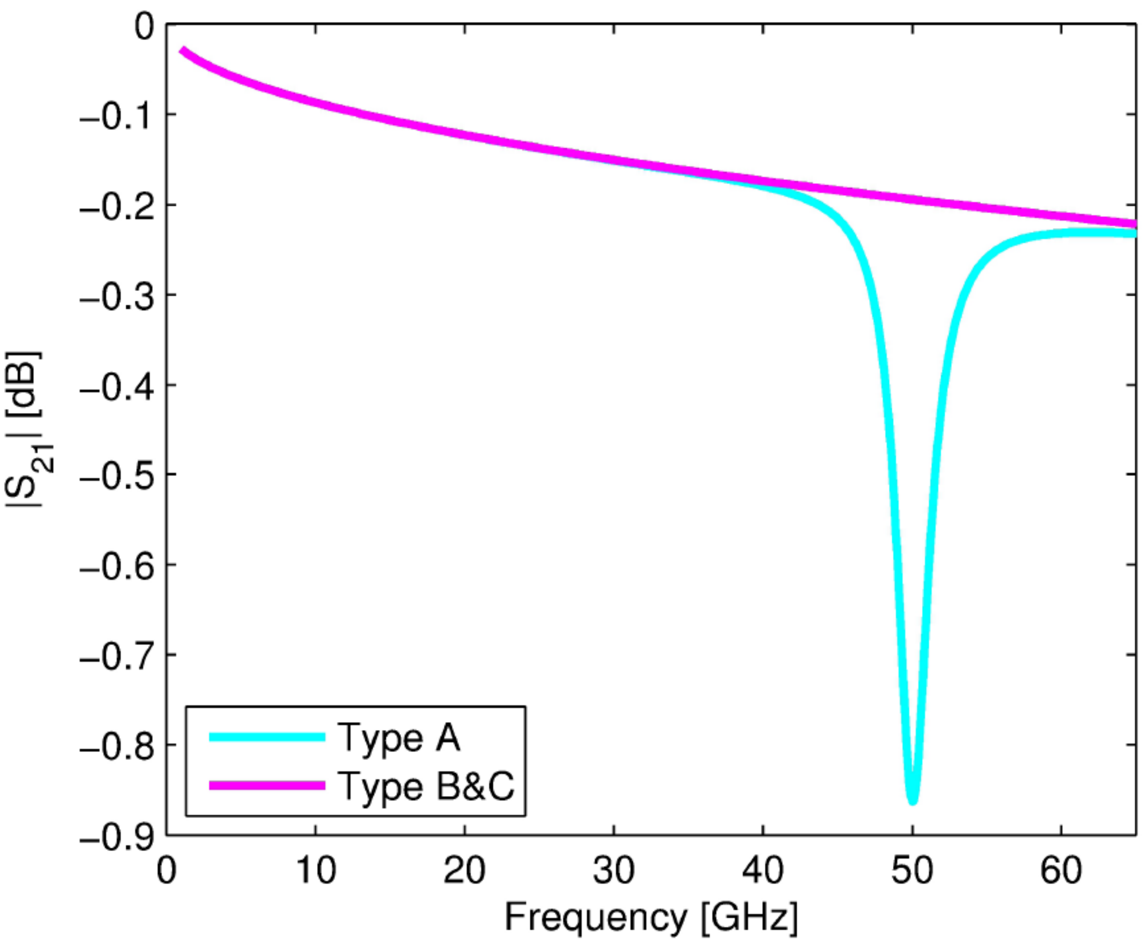
New paradigm: TP's recessed to avoid near field effects

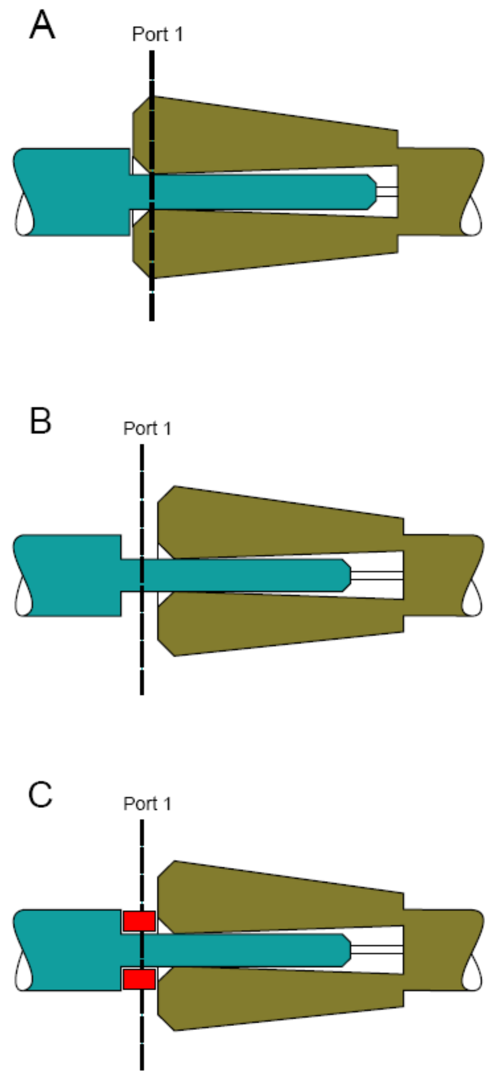
3.5 mm(m) TP1 3.5 mm beadless Air Line 3.5 mm(f) TP2



Problem: undefined Centre Conductor position

Typical coupling effects when measuring beadless air lines





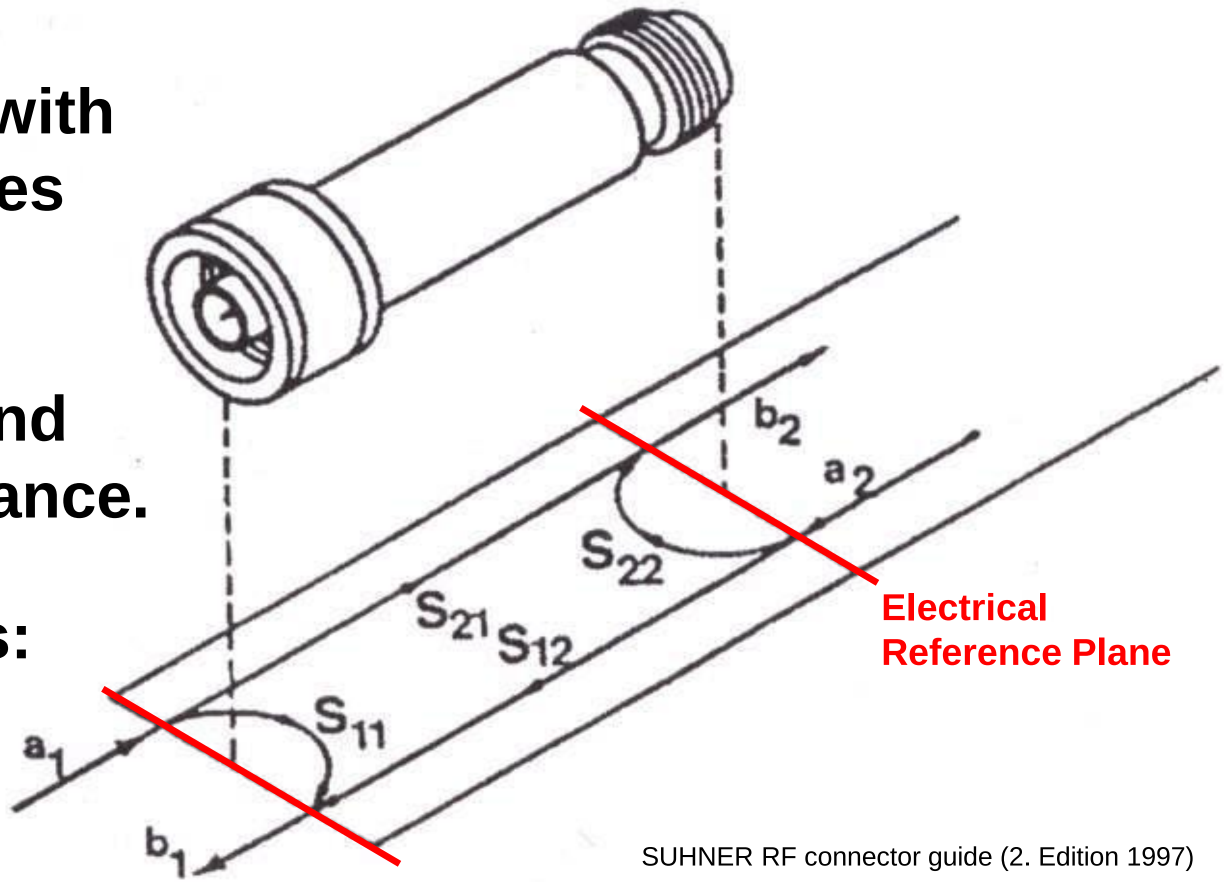
Resonance due to zero pin gap

R&D projects: - CoMo70
- CalCon

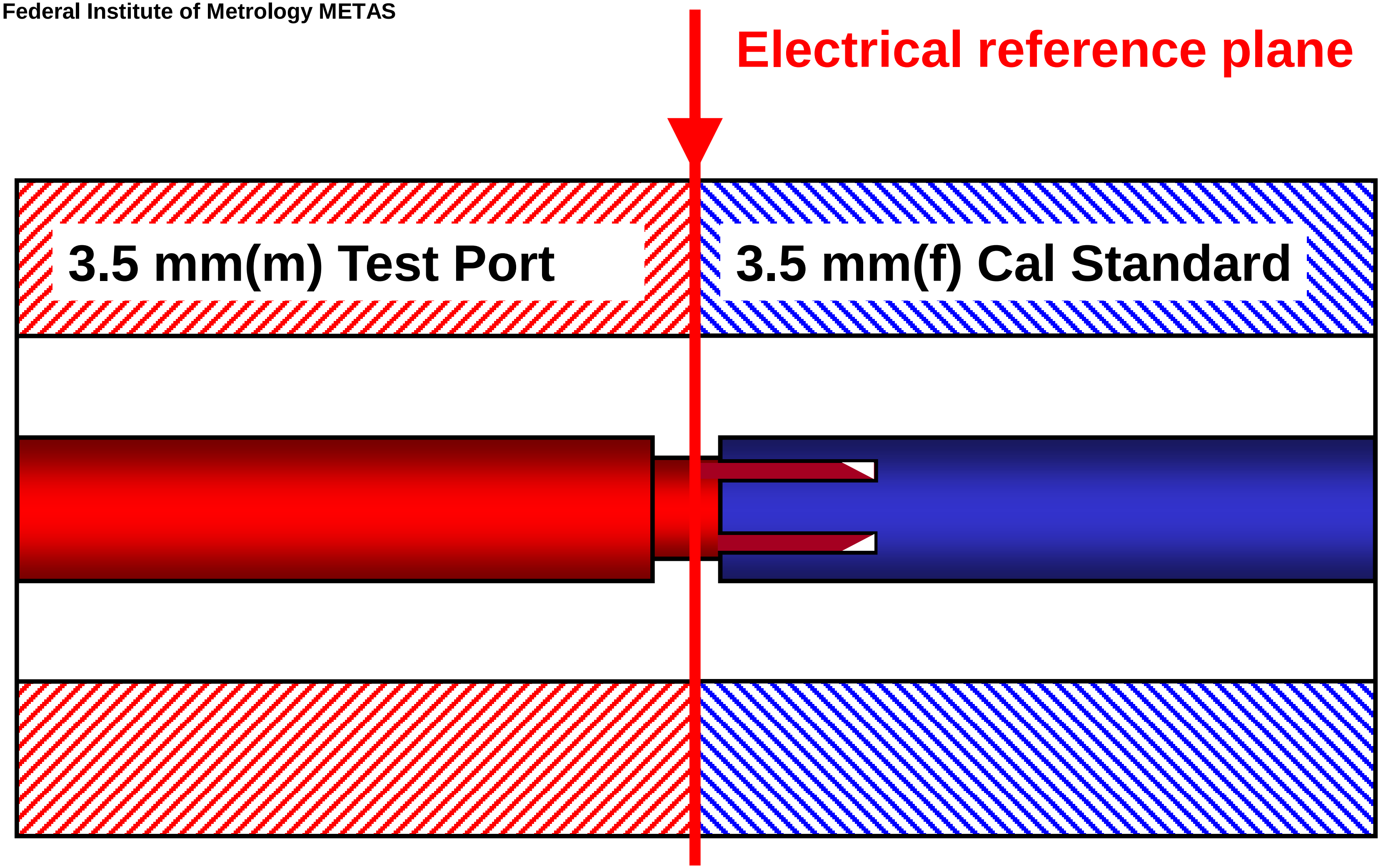
MOTIVATION: consistent S-Parameter definition

Characterizing microwave devices with S-parameters requires the definition of S-parameters in reference plane(s) and for a specific impedance.

Coaxial components:
Reference plane in the connector -
in the middle of a discontinuity!



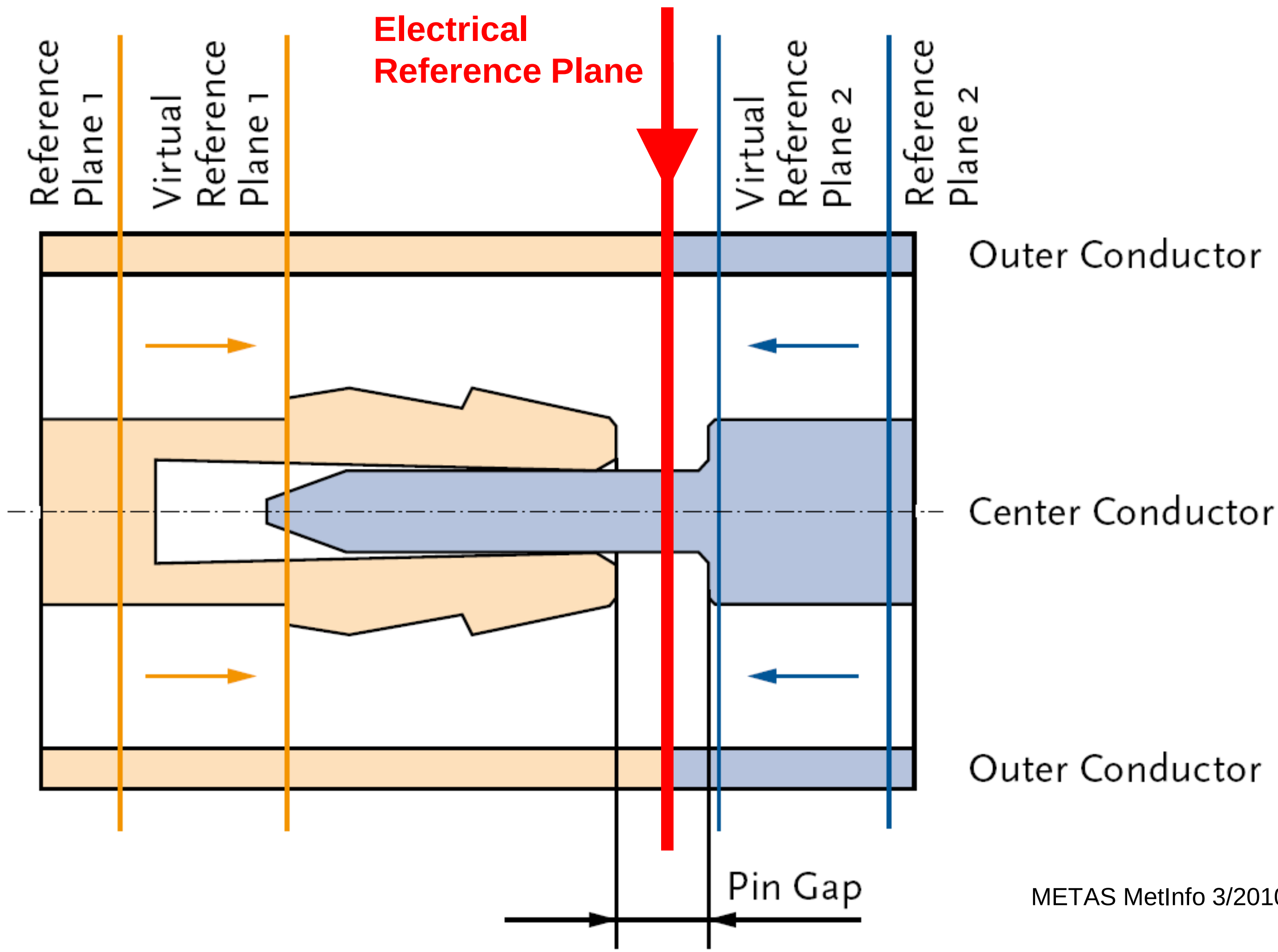
SUHNER RF connector guide (2. Edition 1997)



Issue: the reference plane is located in a discontinuity

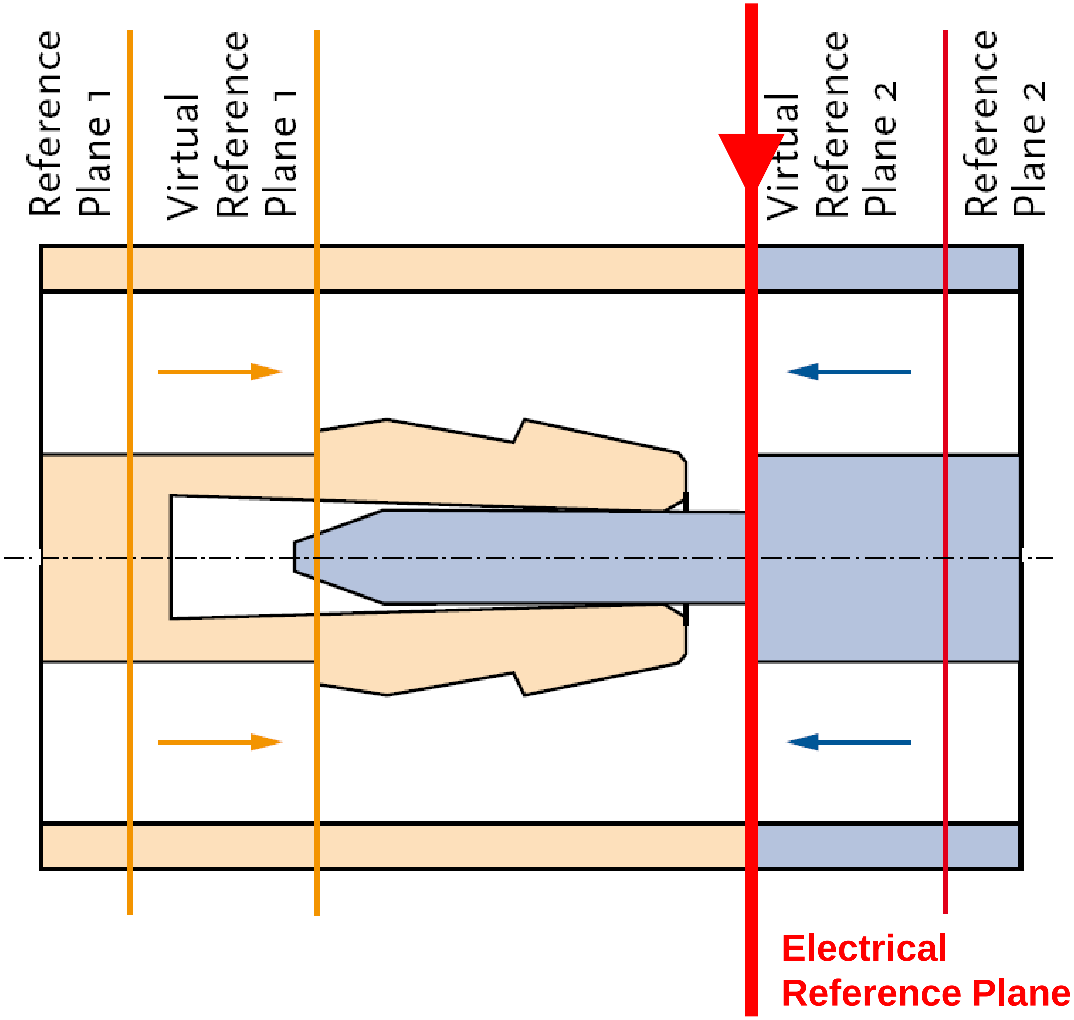
Discontinuities provoke higher modes -> would require multimode S-Parameters

Solution: The concept of the half-connectors



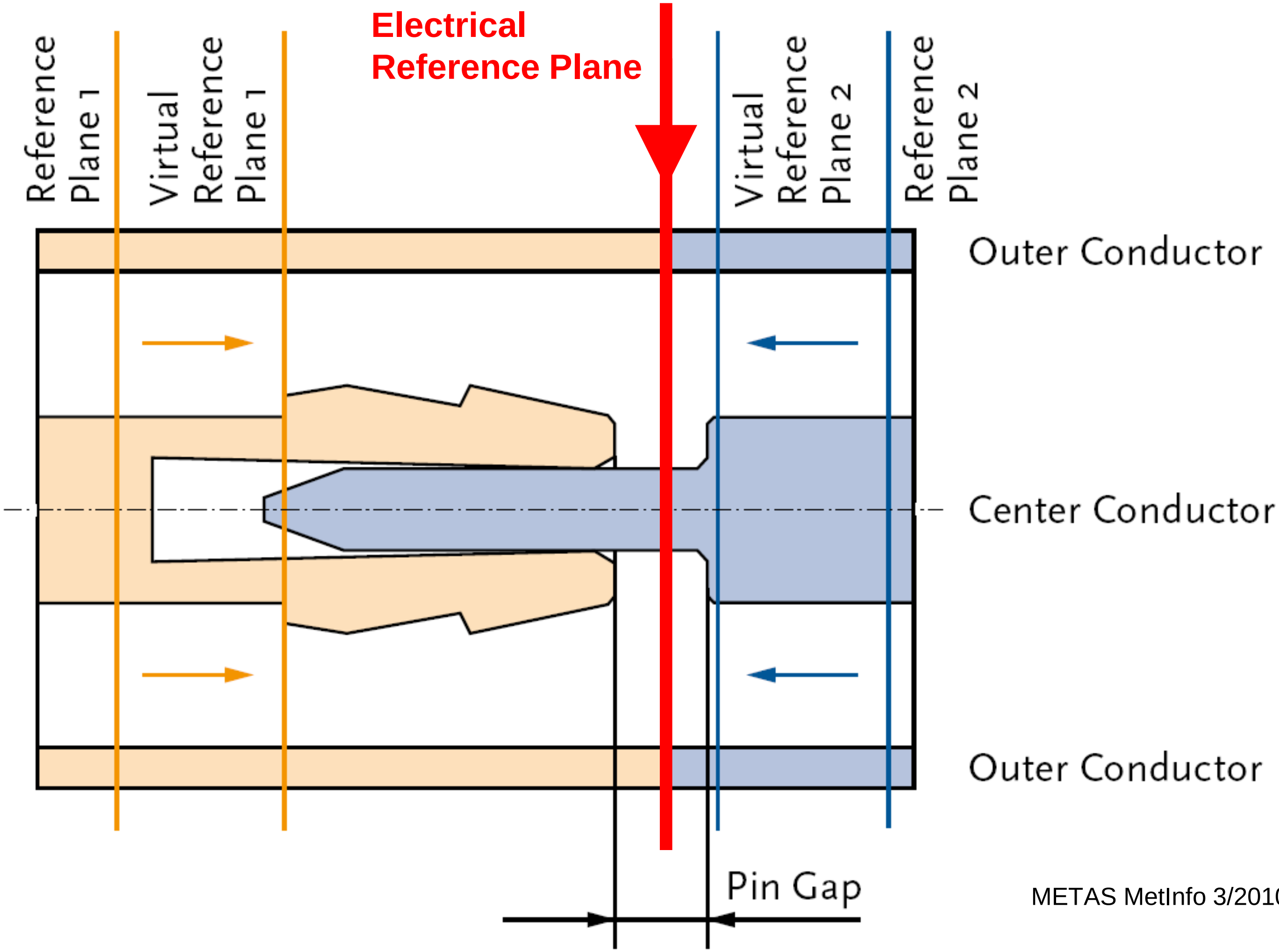
METAS MetInfo 3/2010: Mating Habits

The female half-connector



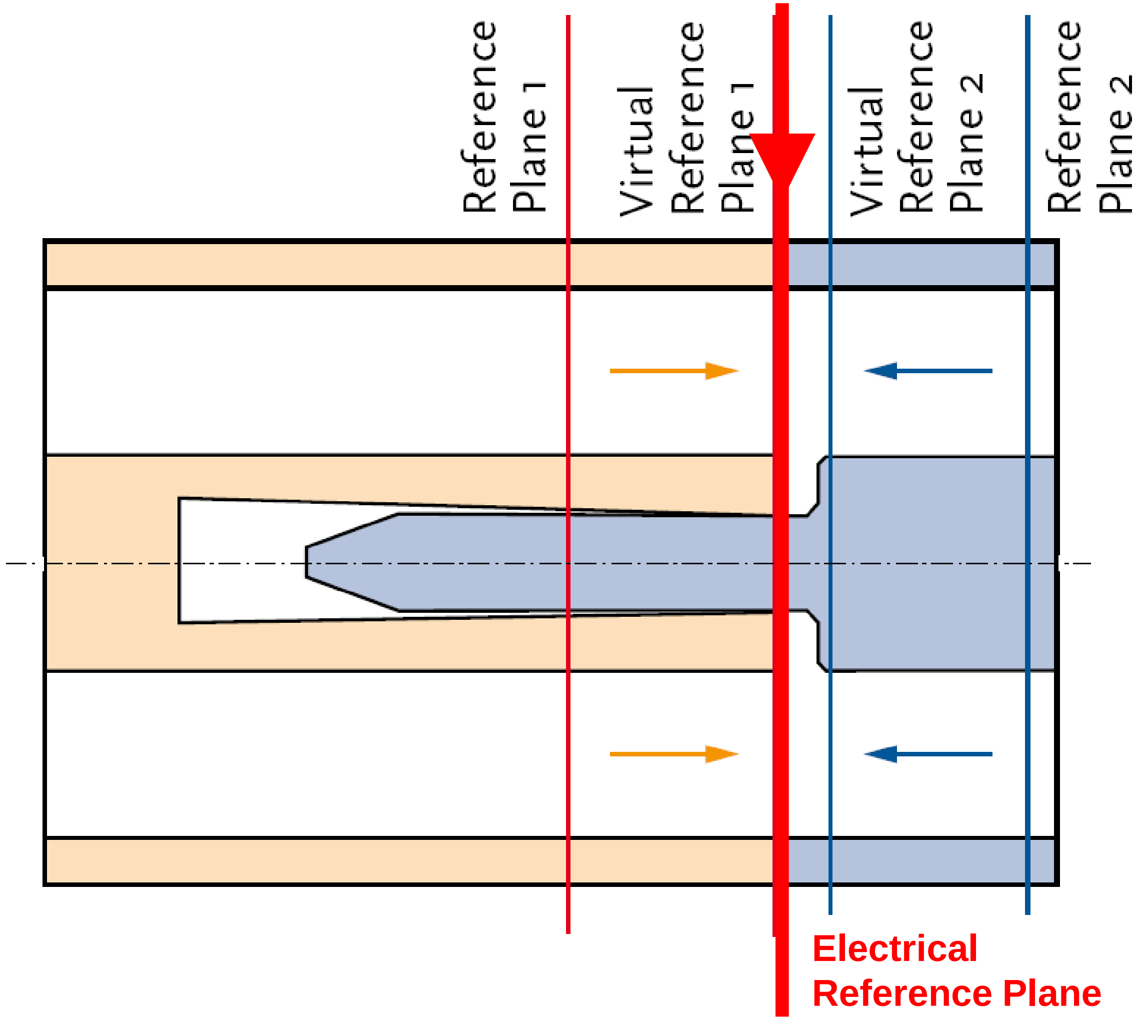
METAS MetInfo 3/2010: Mating Habits

Solution: The concept of the half-connectors



METAS MetInfo 3/2010: Mating Habits

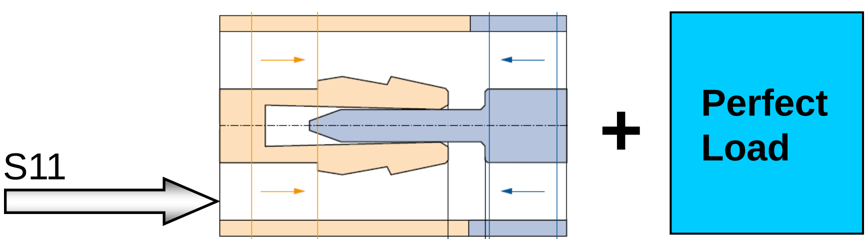
The male half-connector

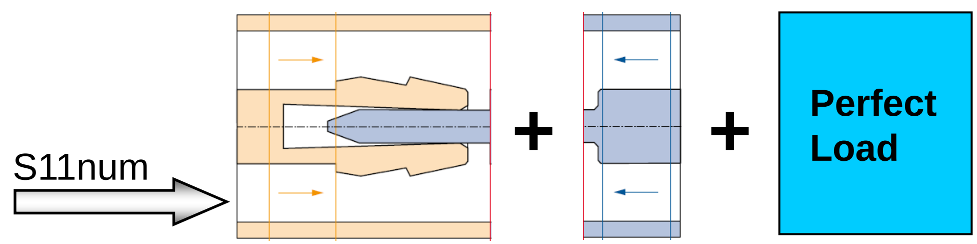


METAS MetInfo 3/2010: Mating Habits

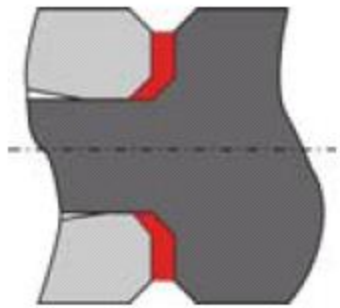
Systematic connector effects

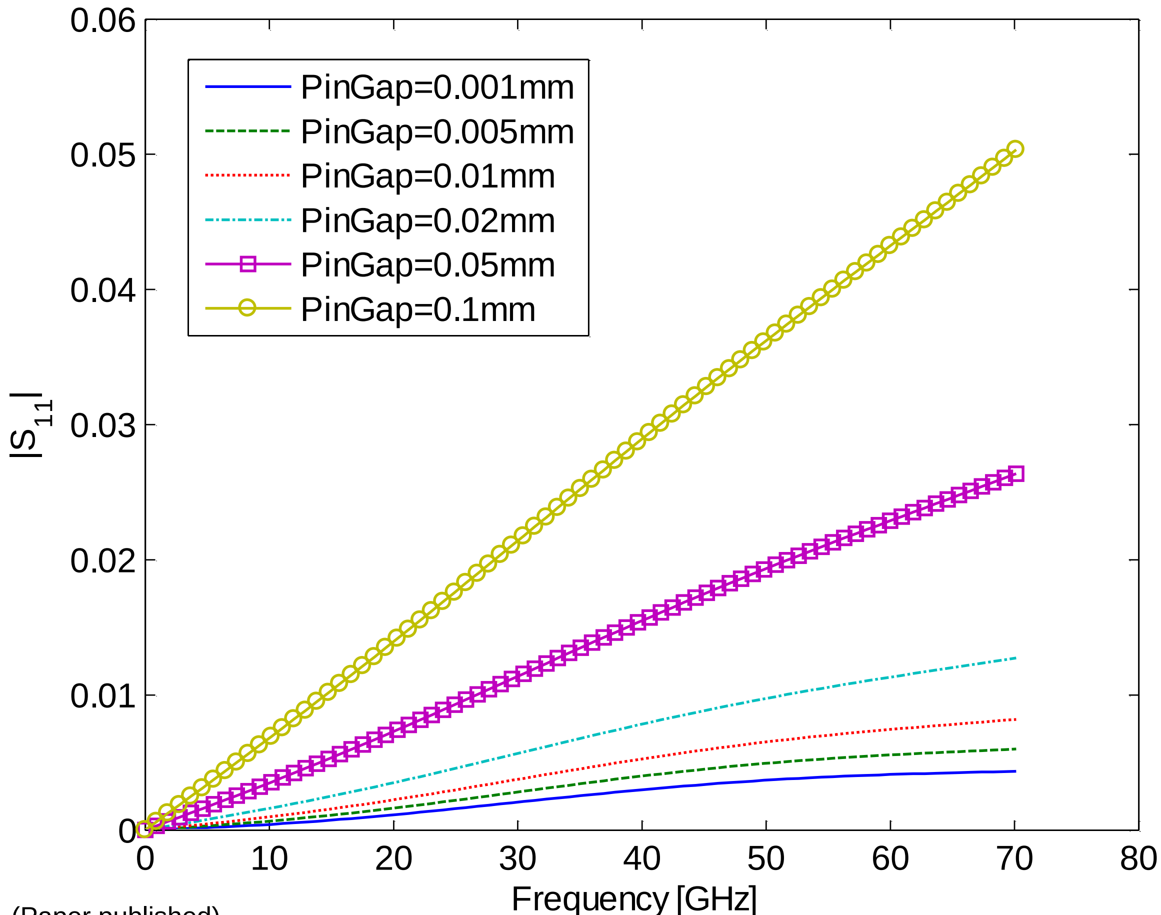
- 2.4 mm CMC entries are in the order of | S11 | **=** 0.020 (@ 50 GHz)
  2.4 mm connector effects are in the same order!
- For a typical 1.85 mm connector the S-parameter of a complete pair is in the order of | S11 | = 0.014 (at 67 GHz)
- For a typical 1.85 mm connector the S-parameters of a complete pair and the cascaded S-parameters differ by about:
  | S11 – S11num | = 0.00033 (at 67 GHz)





1.85 mm connector: S11 with small female chamfer



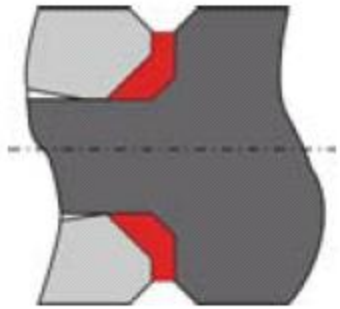


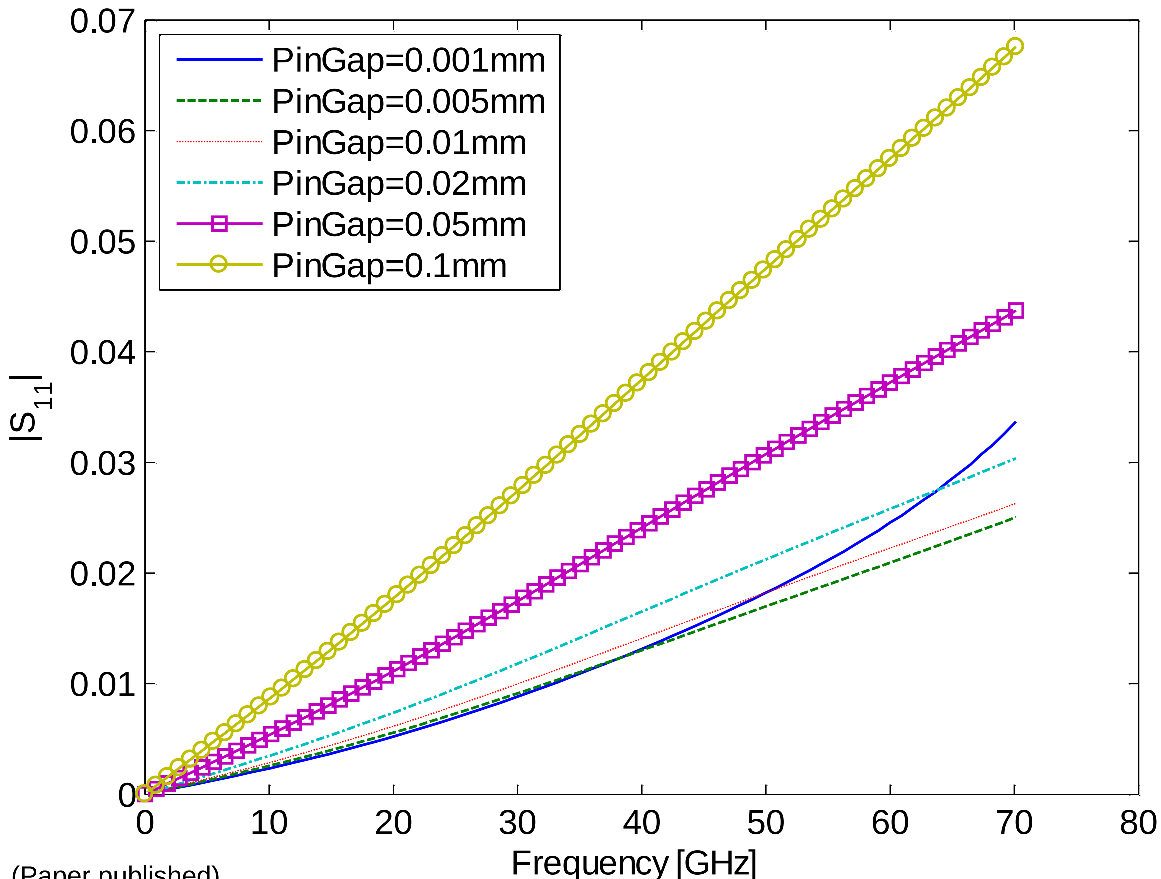
CoMo70 outcomes:

Johannes Hoffmann, ETHZ, CoMo70 project (Paper published)

Issue: near field coupling effects

1.85 mm connector: S11 with big female chamfer





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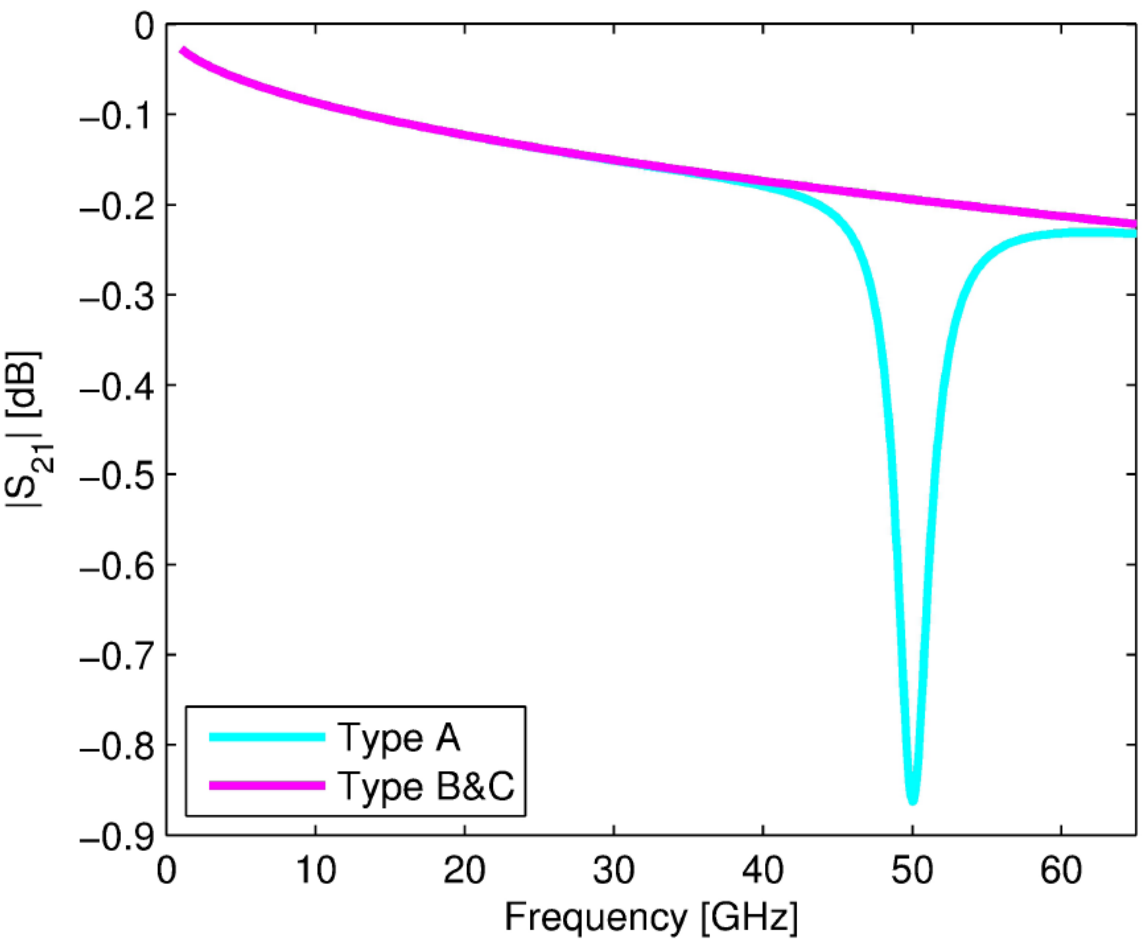
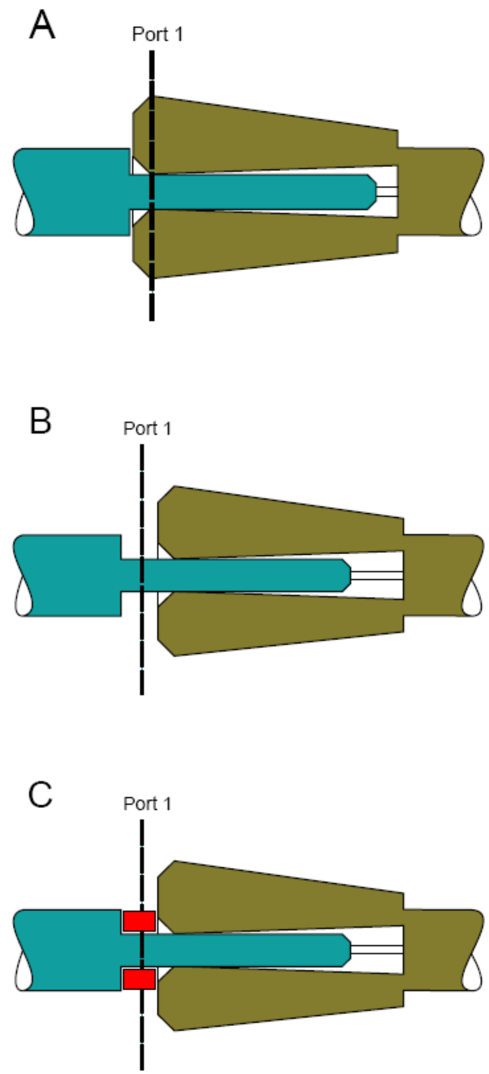
Typical coupling effects when measuring beadless air lines





Resonance due to zero pin gap