



Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Federal Department of Justice and Police FDJP
Federal Office of Metrology METAS

“Pin gap aspects in metrological practice”

29th ANAMET meeting (Fleet, UK)

Juerg Ruefenacht

March 6th, 2008



Pin gap aspects in metrological practice

- **Random & Systematic connector errors**
- **CoMo70 Project**
- **Dimensional connector measurements**
- **Pin gap effects in electrical measurements**



Random connector errors (bad repeatability)

- **Connector quality (mechanical or electrical)**

mechanical tolerances, centre conductor (CC) concentricity, tilted CC, chamfers, ineffective torque, worn contacts, plating issues, oxidation, loose support beads, rough contact surfaces, slotted contact finger interaction with male pin diameter variations, spreading of contact fingers, quality and alignment of the threads, non parallel planes (outer to centre contact), ...

- **Connector handling**

Mating process, misalignment, cleaning (dirt), used torque (outer conductors mating planes not flush / compression different), ...

- **Other effects**

Non-uniform centre conductor recess of the calibration standards used during the VNA calibration process (pin gaps different), ...

J. Ruefenacht: „Connector problems and their mechanical and electrical characterisation“ ANAMET 24th, 2005



Systematic connector errors (impedance mismatch)

Different connector families and designs

- Type-N (offset), etc.
- Slotless vs. slotted contact, LPC (air), GPC (dielectric), etc.



Modelling of a coaxial connector

- based on the mechanical tolerances, plating, dielectric, etc.
- based on the measured mechanical parameters, etc.



Correction of systematic errors

- Mechanical compensation (design)
- Mathematical correction (cal standard definitions, cal algorithm, etc.)
- Represented as part of the uncertainty budget



Connector traceability projects:

- **Project: ETHZ / H+S / AGILENT / METAS**

Modelling of coaxial connectors, adapters and impedance standards

Title: **CoMo70** (Connector Modelling up to 70 GHz)

→ PhD project (Johannes Hoffmann) started: October 1st, 2006
Duration: 3 years

- **EUROMET Project 648**

The Challenge of New Technologies in Electrical Metrology at RF, Microwave and Higher Frequencies.

“Impedance in small coaxial connectors and interconnects”

Action: **watching brief**

- **Previous work (i.e.: IEEE Std 287TM - 2007)**



Connector traceability project **CoMo70**

The main activities of the CoMo70 project are:

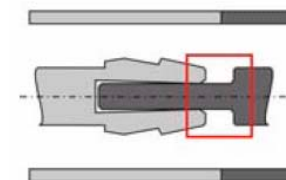
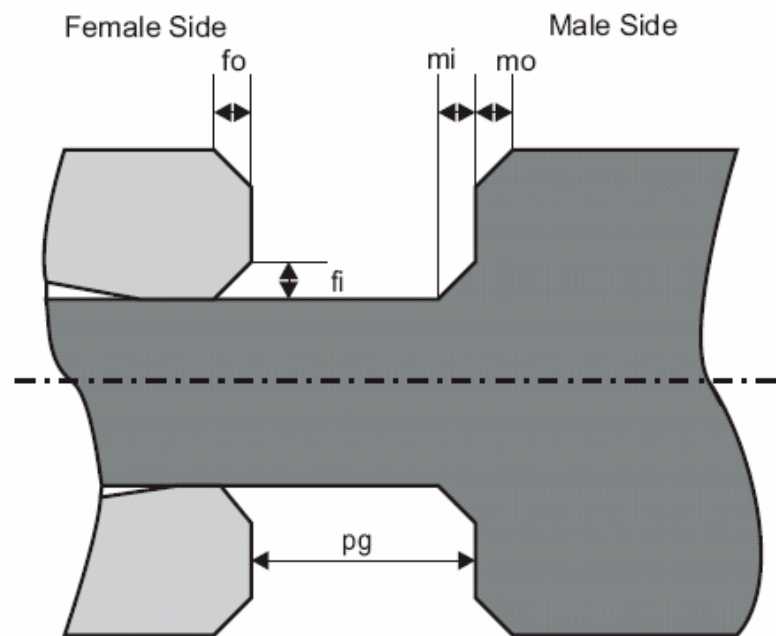
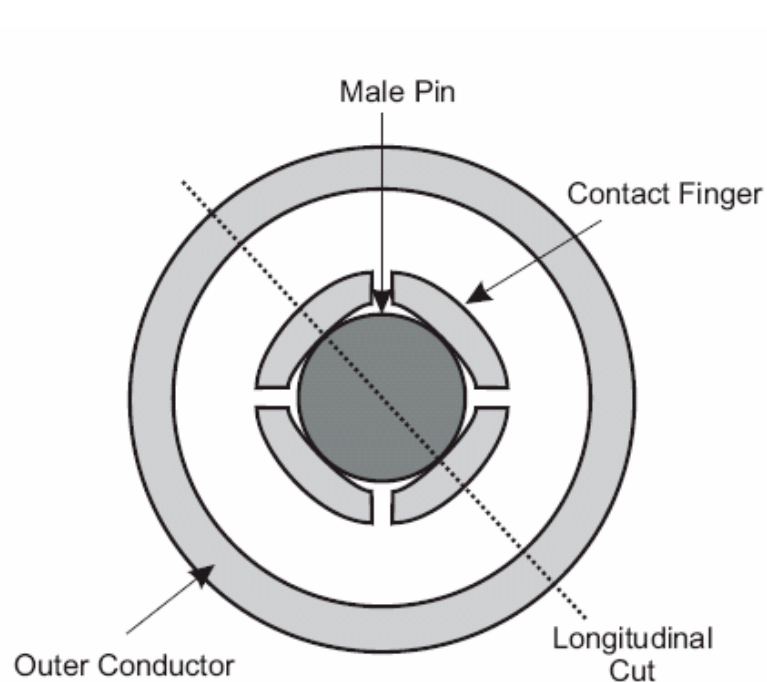
- **Modelling of coaxial connectors**
- **Modelling of coaxial calibration standards**
- **Traceability for industry grade connectors**
- **Development of new VNA calibration algorithms**

More information: <http://people.ee.ethz.ch/~tcm70/>



first CoMo70 project results:

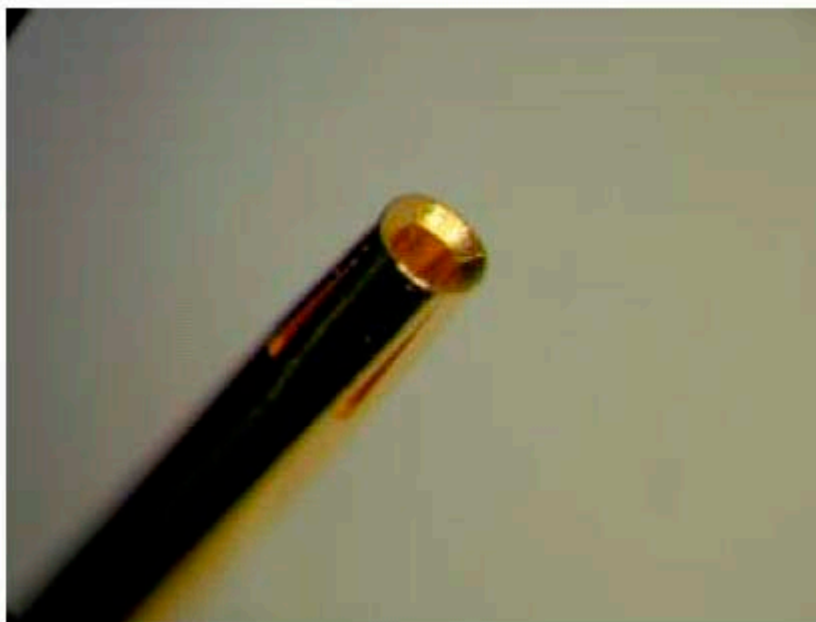
1.85 mm connector interface effects



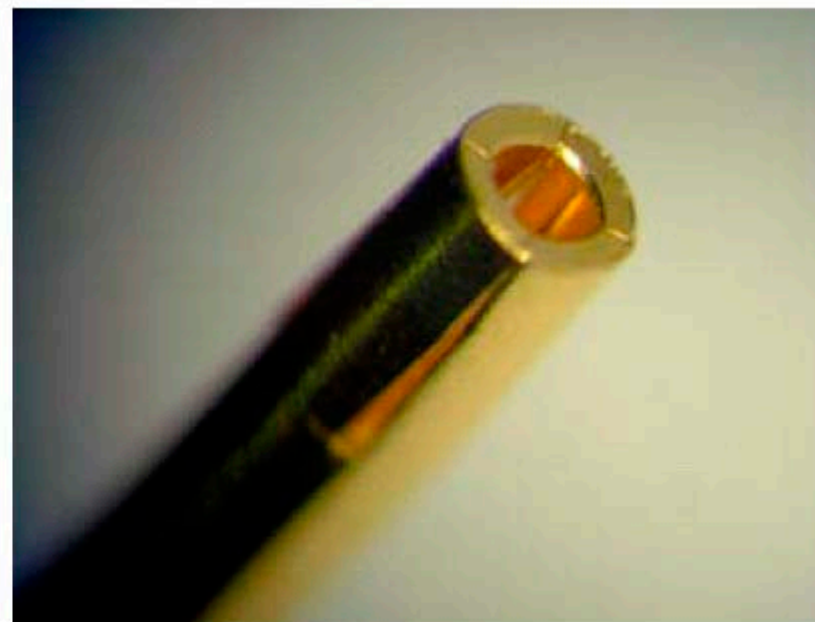
Johannes Hoffmann, ETHZ, CoMo70 project (Paper published at the EuMW 2007)



first CoMo70 project results:



Big inner female chamfer

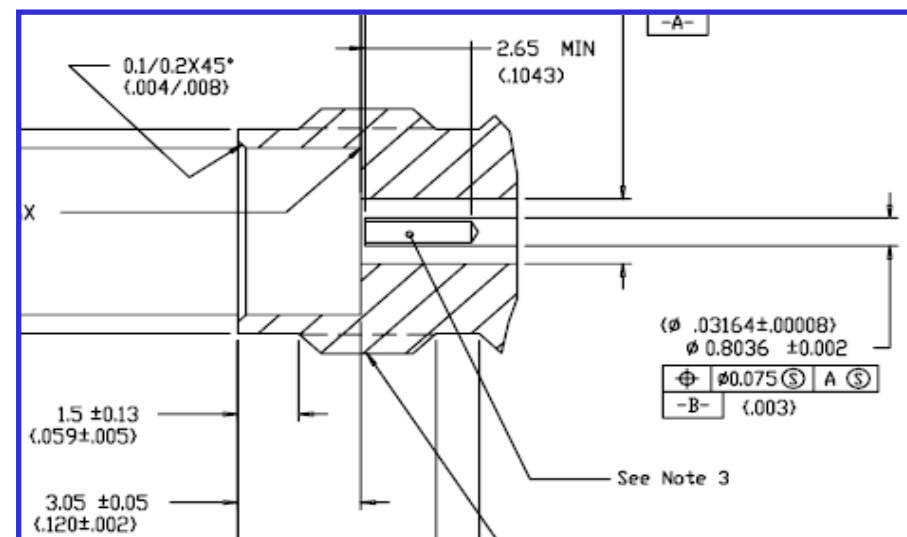
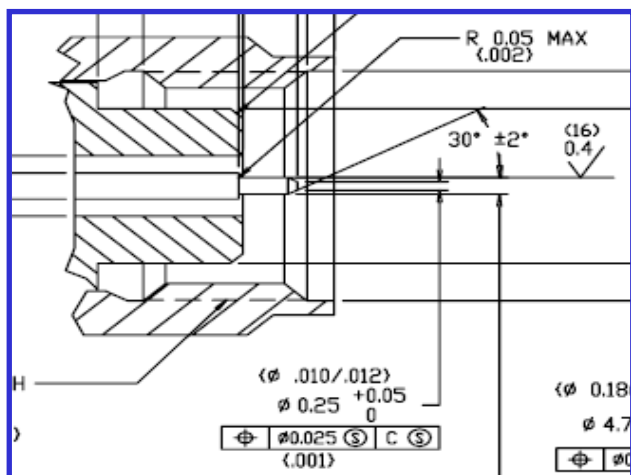


Small inner female chamfer

IEEE Std 287™-2007
(Revision of
IEEE Std 287-1968)

IEEE Standard for Precision Coaxial Connectors (DC to 110 GHz)

Detail specifications for precision coaxial 1.85 mm connectors



Critical mechanical specifications are missing!

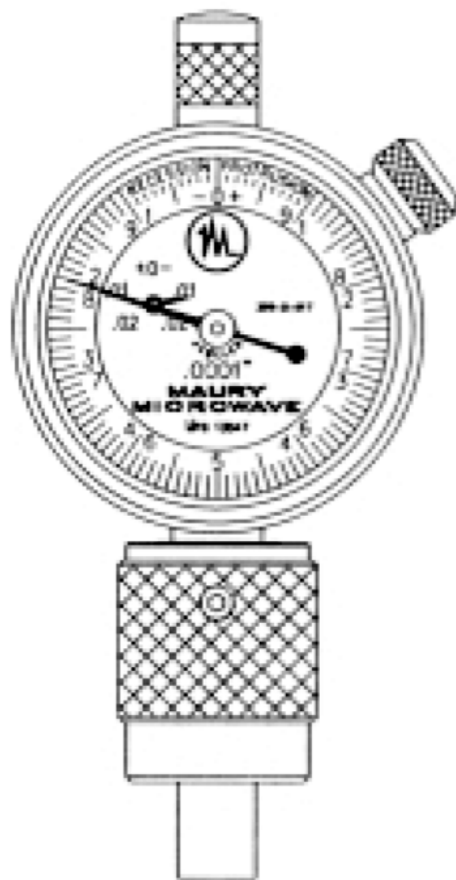


Pin-depth measurements and **traceability**

- **Pin-depth measurement systems**
- **Compressed or uncompressed measurements?**
- **Example: gauge master issues**
- **Summary: pin-depth measurement problems**

**Compressed measurement
(undefined – no control)**

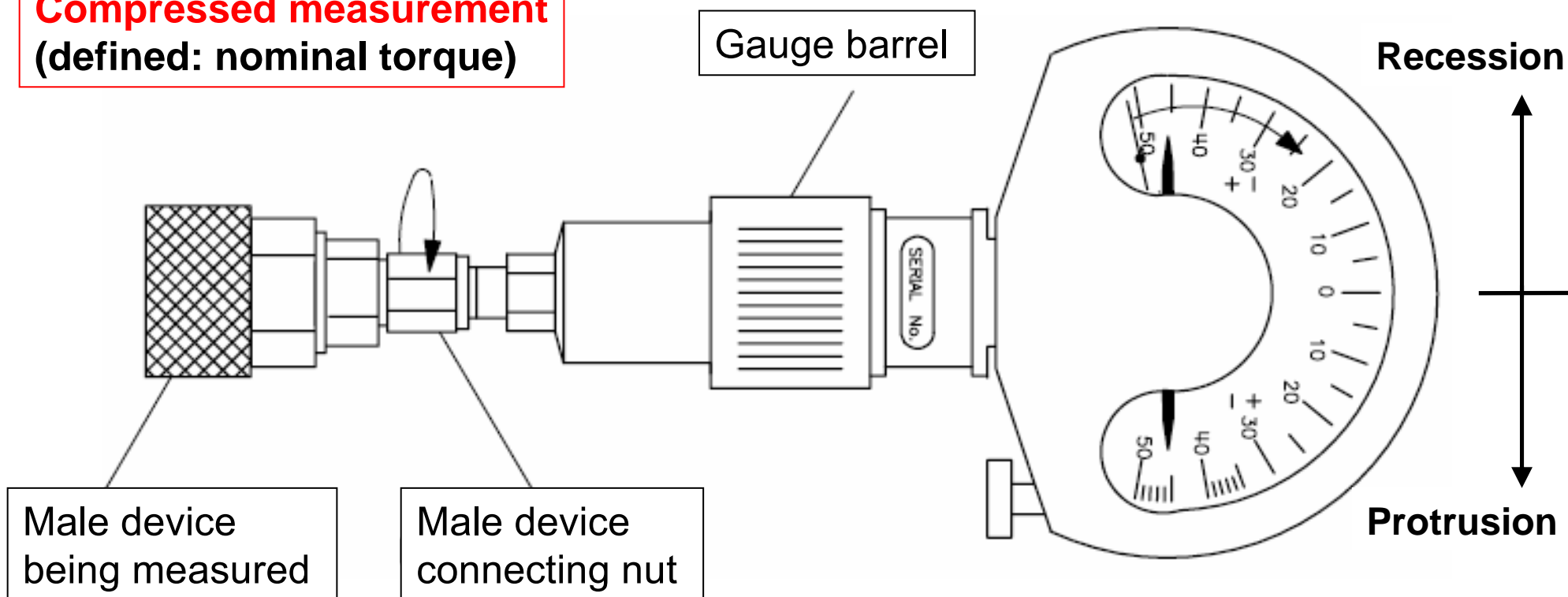
„Push-on” connector gauges



„Screw-on” or “thread-on” connector gauges

Example of a Male type connector gauge:

**Compressed measurement
(defined: nominal torque)**

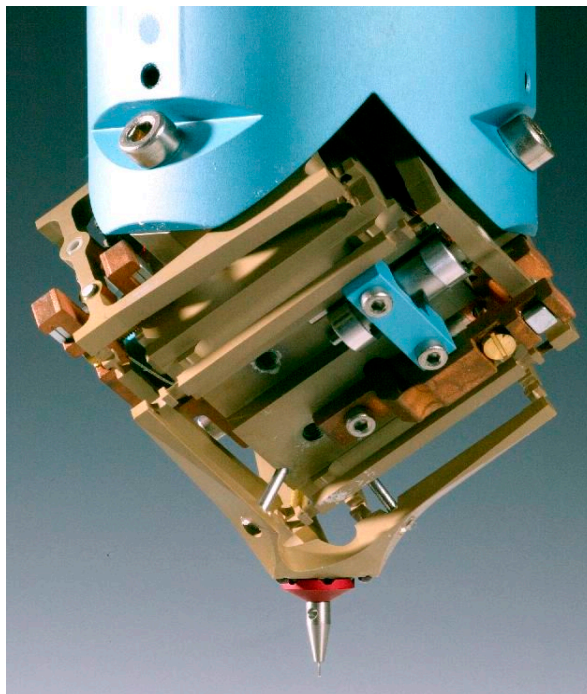


Agilent 85058B 1.85 mm calibration kit



μ -CMM project at METAS

Uncompressed measurement
(different from electrical
measurement situation)

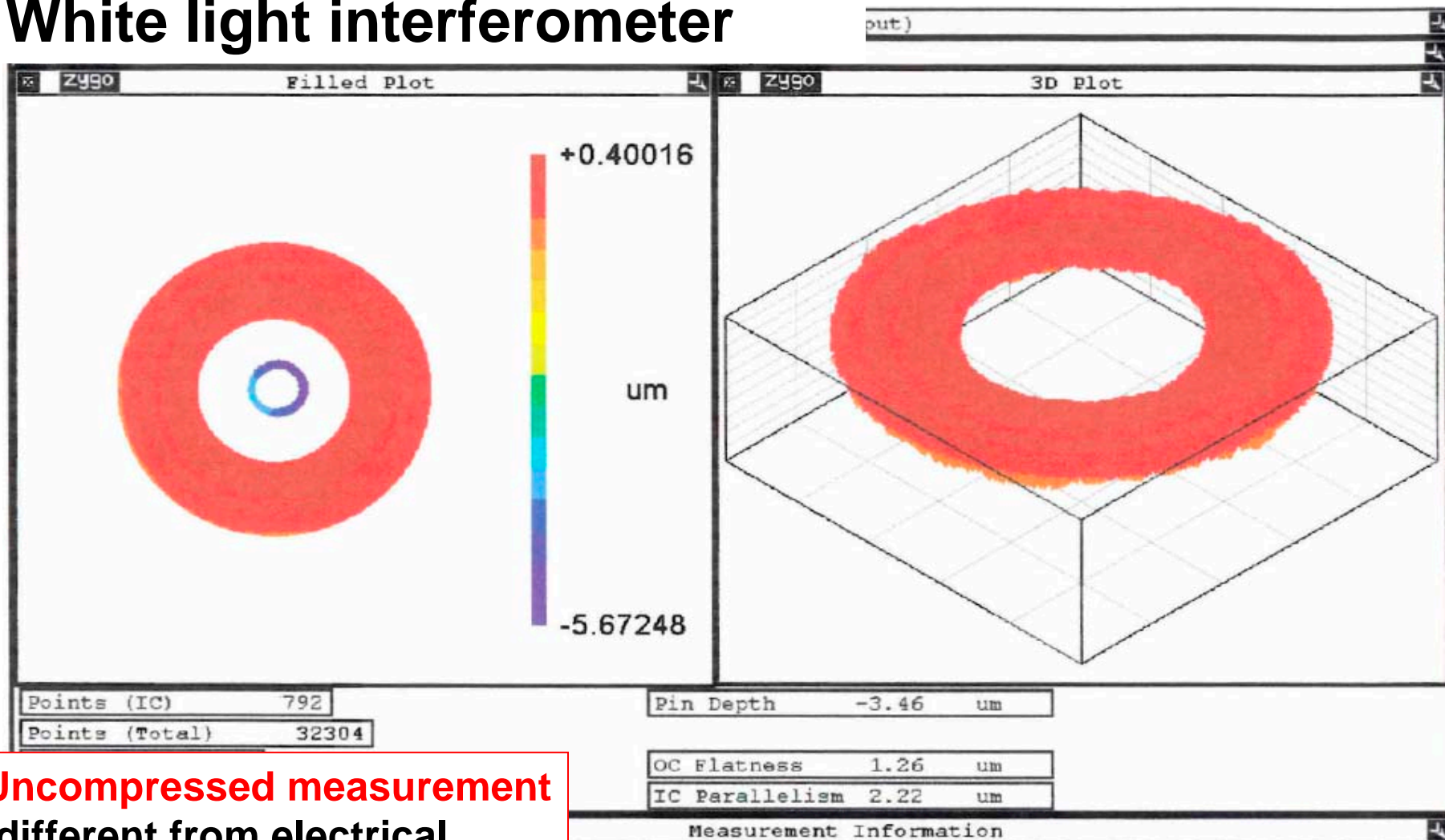


μ -CMM: 80 mm x 80 mm x 40 mm, 3D interferometer, no Abbe offset, target uncertainty 50 nm

Probe head: Low isotropic probing force (<0.5 mN), 5 nm repeatability (1s)

Probe: Smallest ruby sphere diameter = 125 μ m

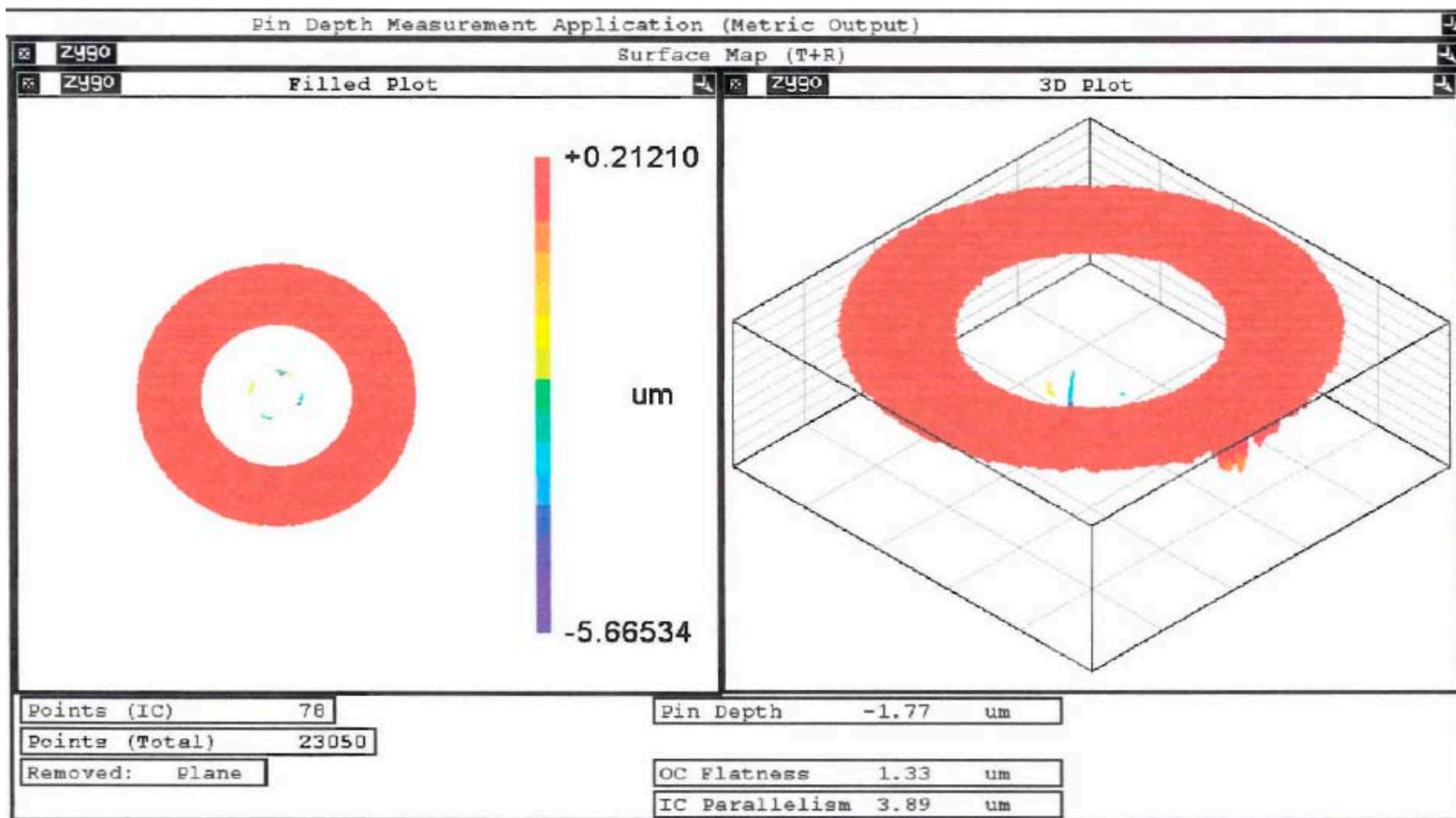
White light interferometer



**Uncompressed measurement
(different from electrical
measurement situation)**



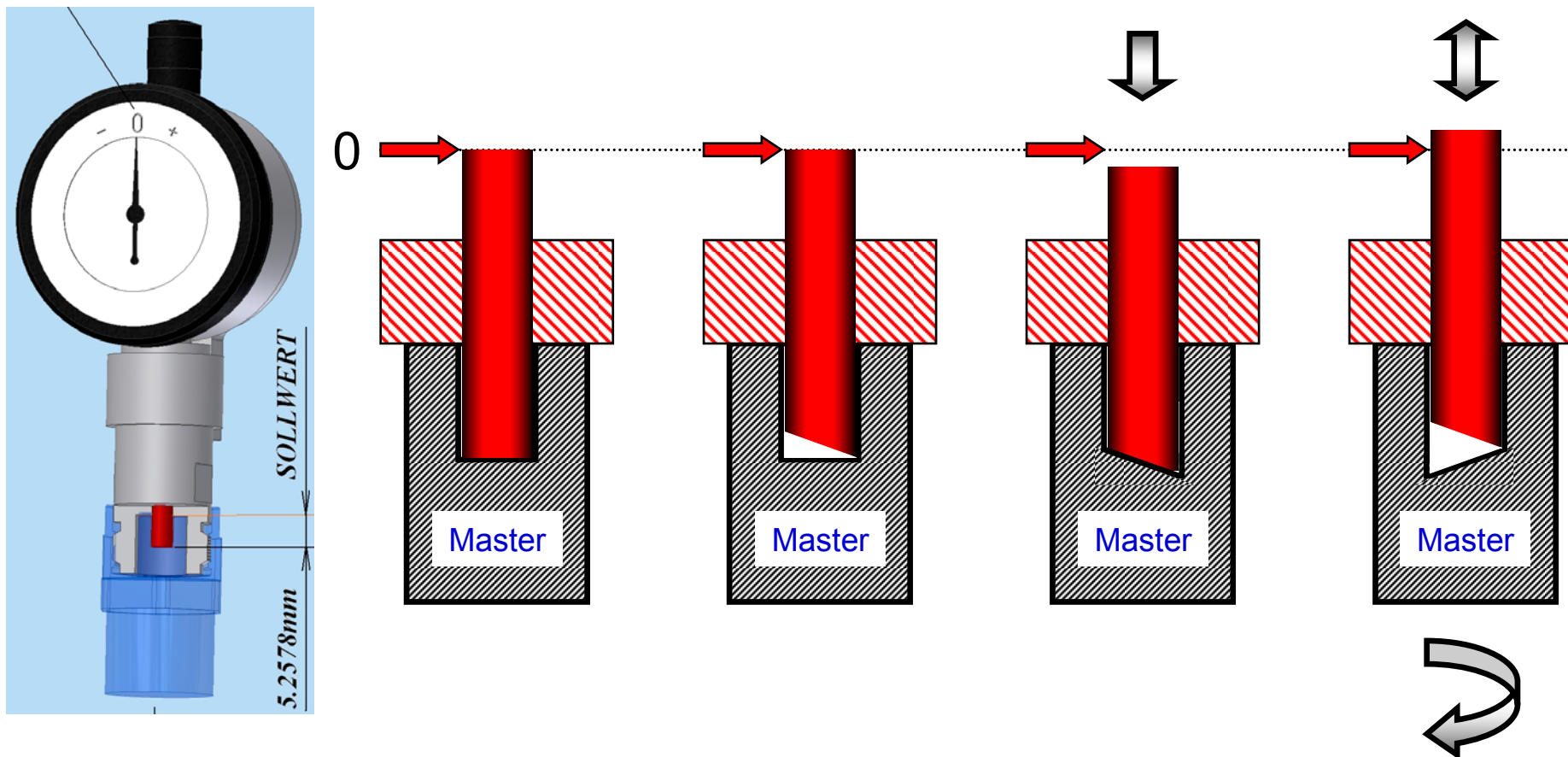
DUT: female connector





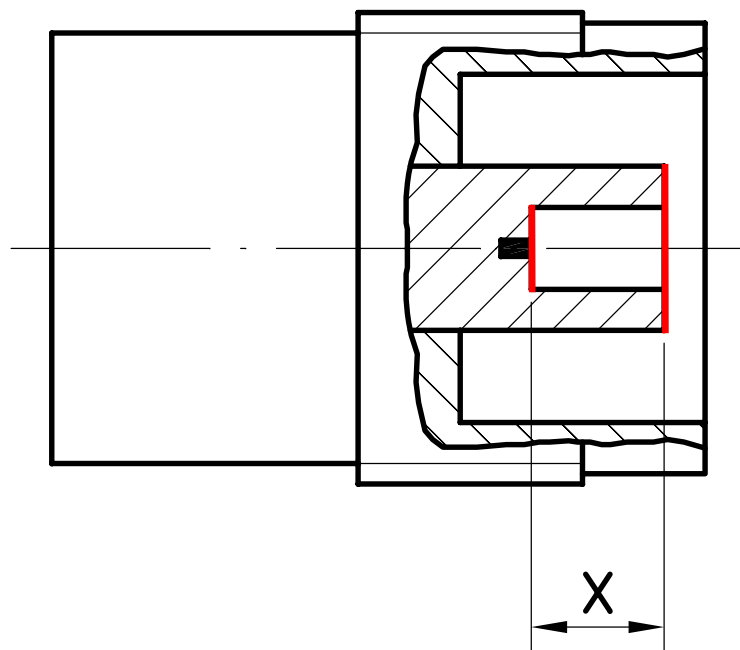
Example: Pin-depth measurement problems using gauges

Effects due to non parallel reference planes:



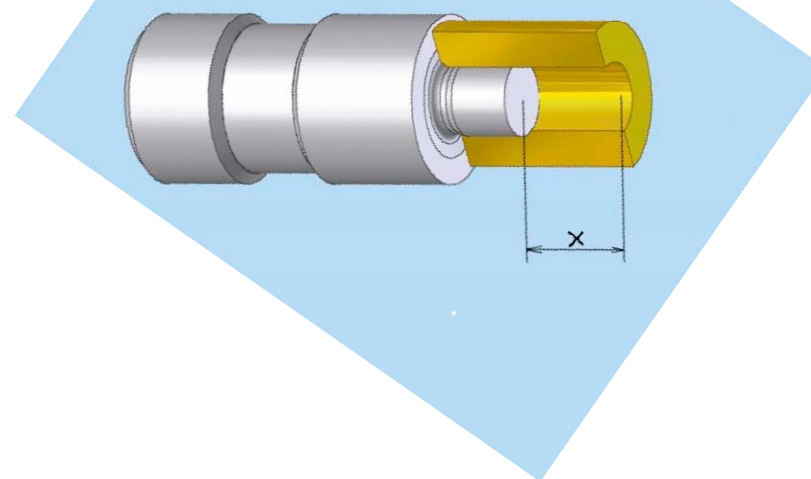


Pin-depth measurement problems using gauges: Bad defined **planes** (surface quality and parallelism)



CMM uncertainty: 0.0040 mm

Modified master centre part:



CMM uncertainty: 0.0010 mm



Pin-depth measurement problems using gauges:

- **Uncalibrated connector gauge masters (traceability?)**
- **Worn gauge connector interface and gauge masters**
- **Not well defined mating planes (not parallel, surface quality, ...)**
- **Can only measure the highest point of the mating plane**
- **Applied Torque**
- **Big variations seen in key comparisons, ...**

Pin-depth measurement problems using CMM or light:

- **Expensive hardware and time consuming**
- **High uncertainties for mating planes with bad quality**
- **No torque used – uncompressed condition**
- **Significance of the measurement results**
- **...**



Pin gap effects in electrical measurements

Some typical pin gap issues:

- **Recession versus protrusion**
- **Nominal Test Port (TP) – 50 ohm definition**
- **slotless versus slotted interface (male pin diameter)**
- **Beadless airlines and the Test Port**



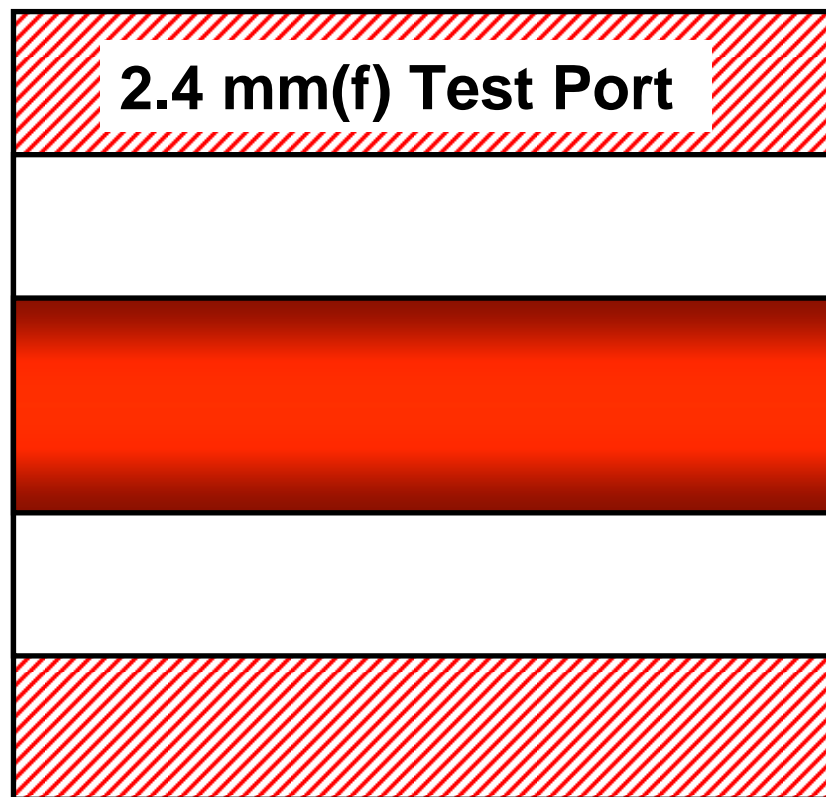
Pin gap effects in electrical measurements

Some typical pin gap issues:

- **Recession versus protrusion**
- Nominal Test Port (TP) – 50 ohm definition
- slotless versus slotted interface (male pin diameter)
- Beadless airlines and the Test Port



- slotless female CC
- no pin-depth present

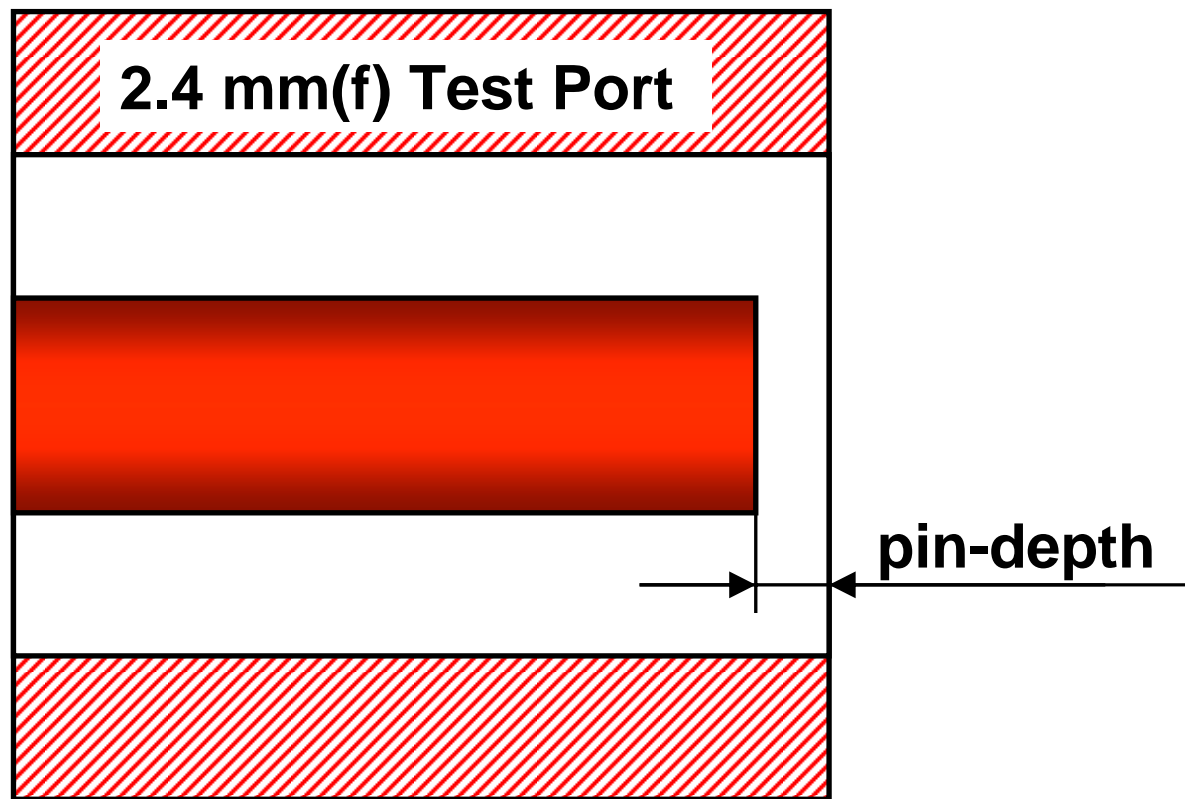


Electrical reference plane





- Slotless female CC
- pin-depth: recession

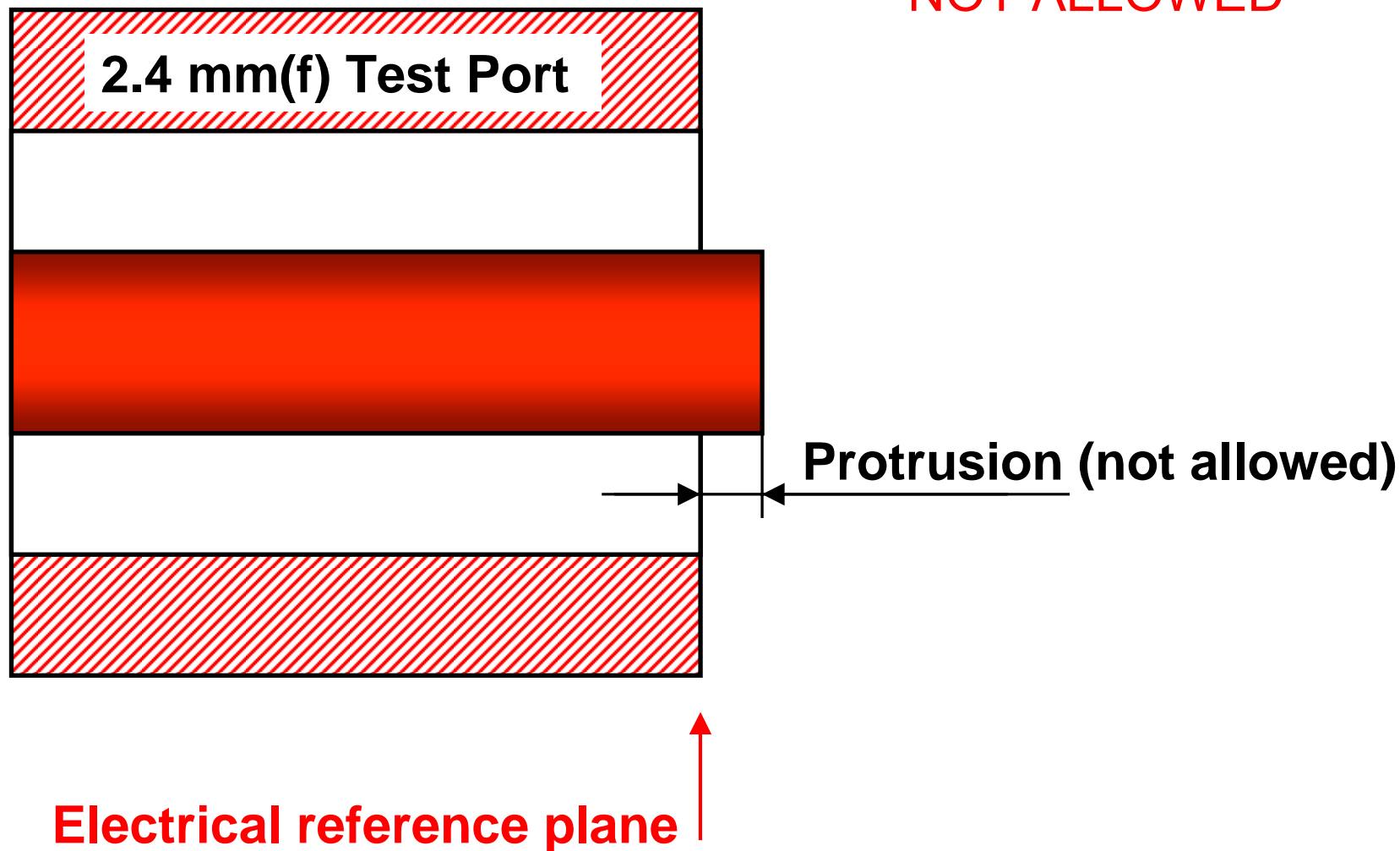


Electrical reference plane



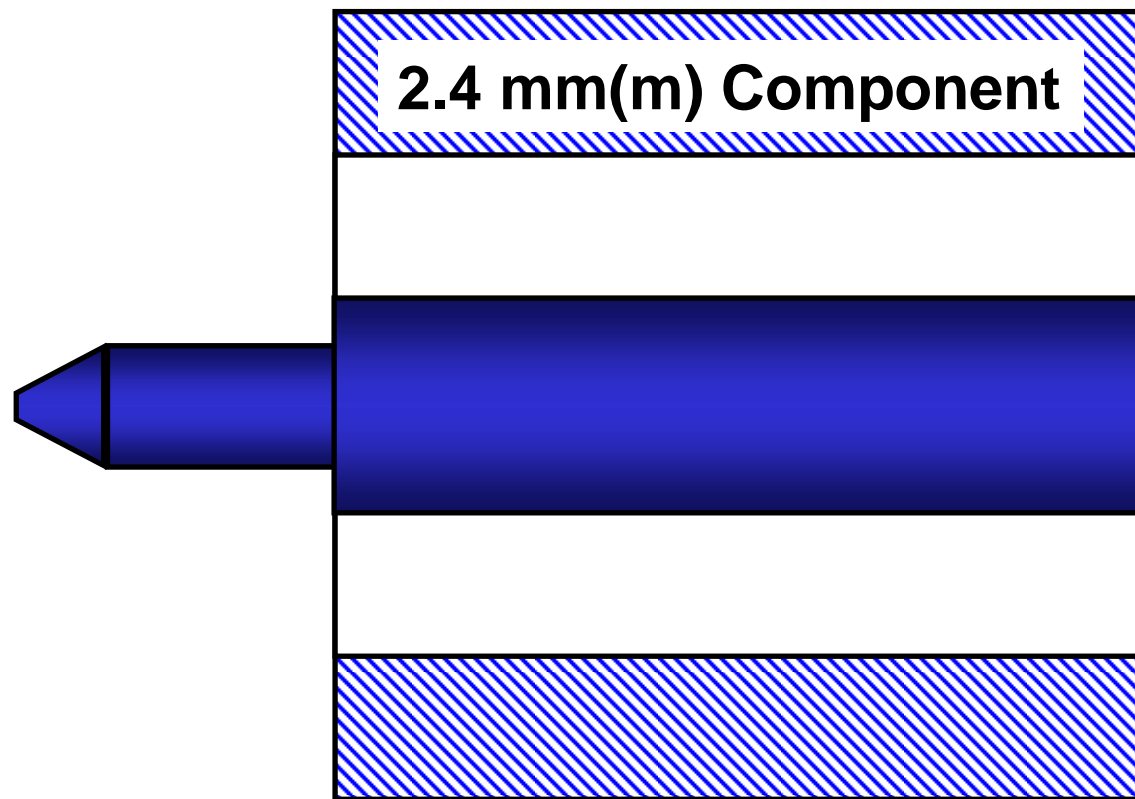


- Slotless female CC
- pin-depth: protrusion
- NOT ALLOWED





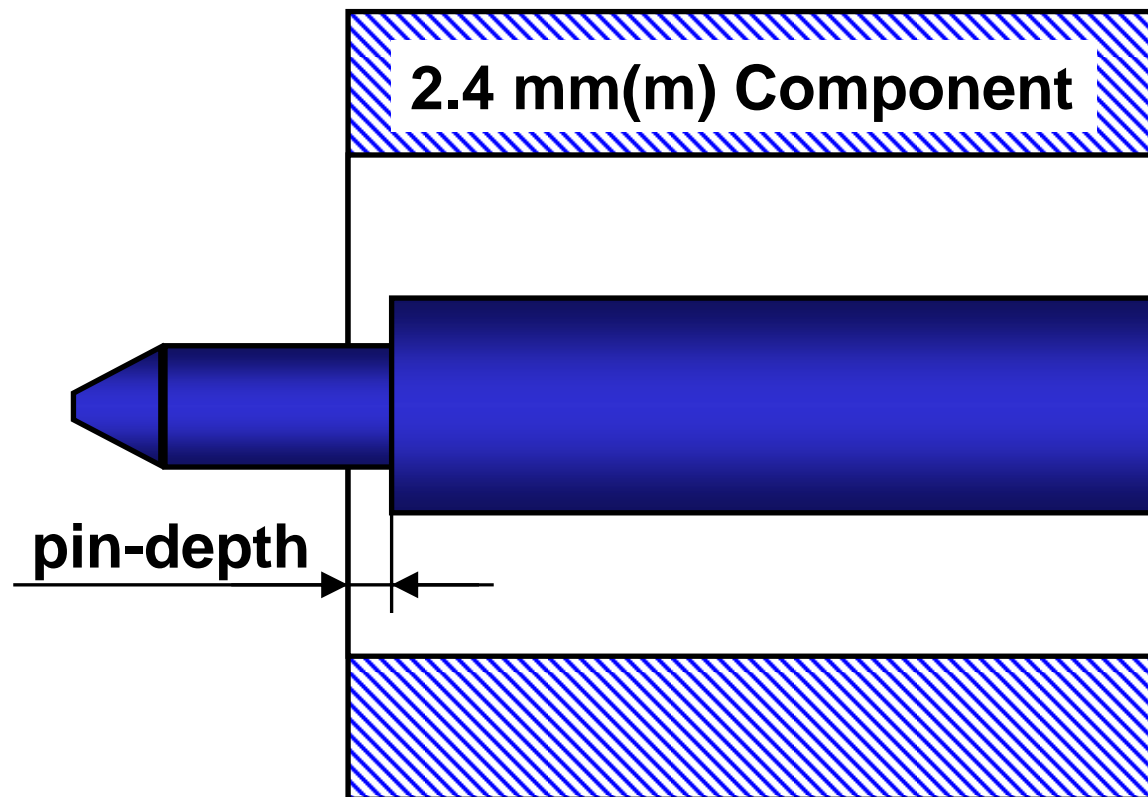
- male CC
- no pin-depth present



Electrical reference plane

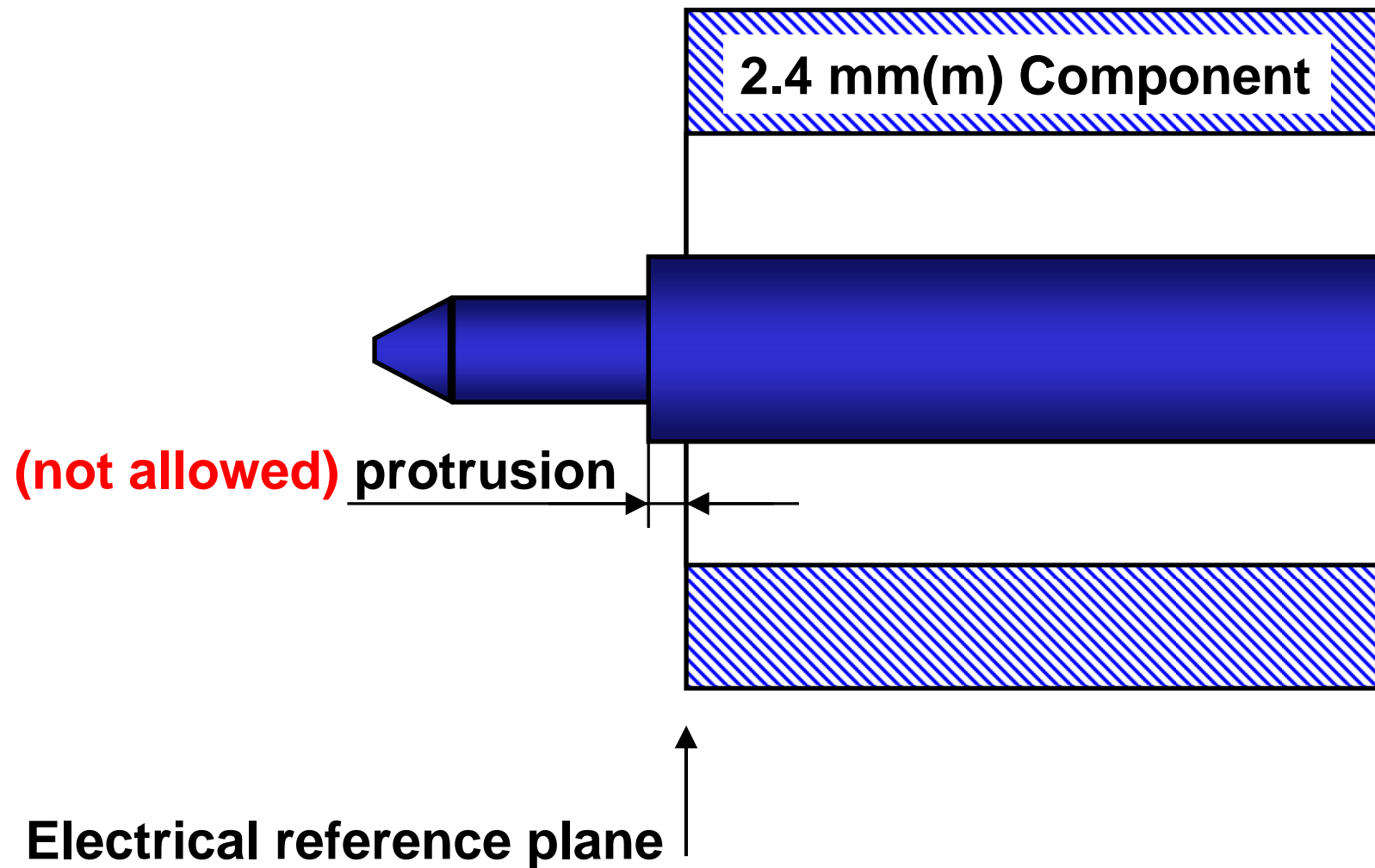


- male CC
- no pin-depth present



Electrical reference plane

- male CC
- no pin-depth present





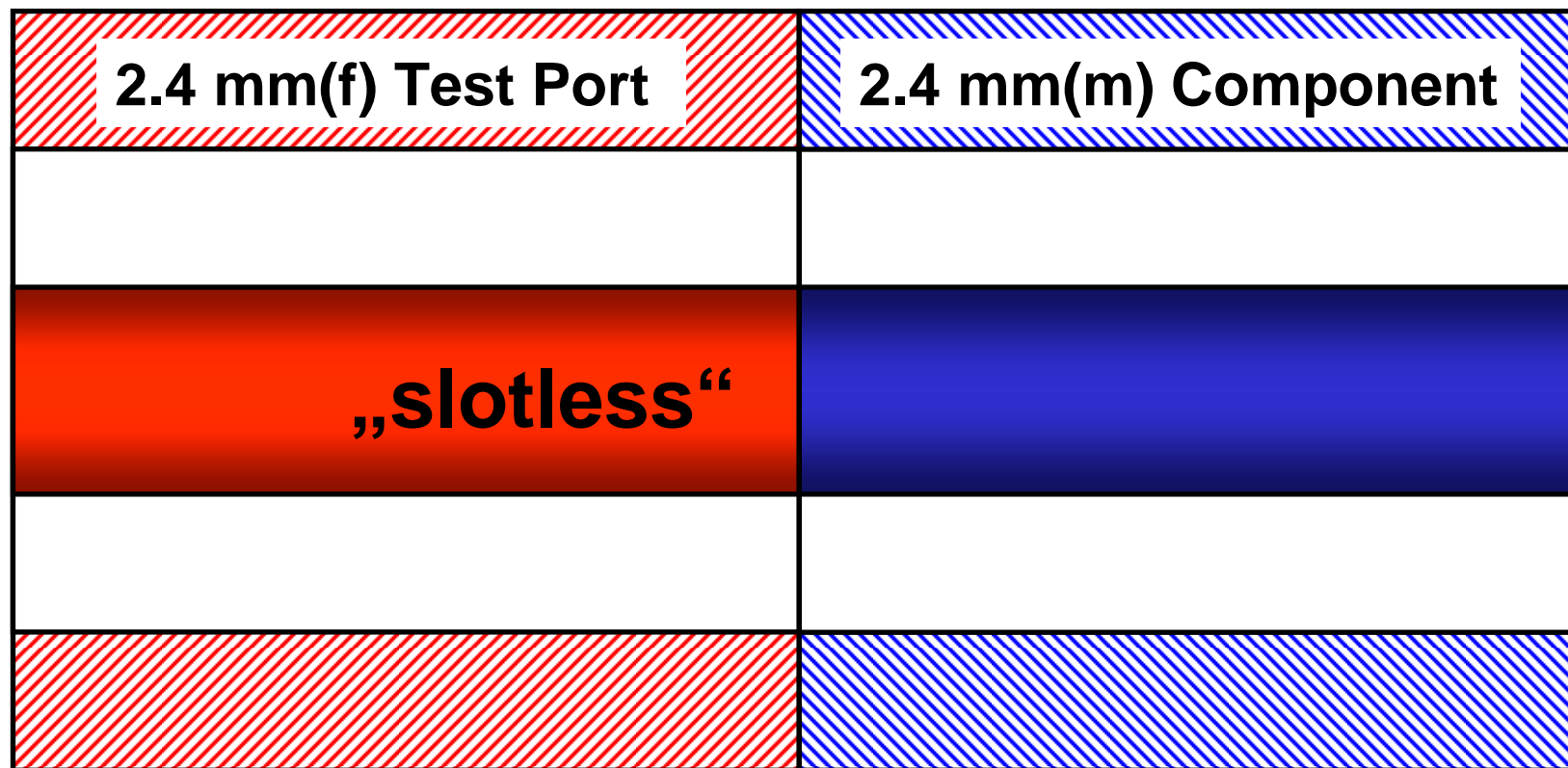
Pin gap effects in electrical measurements

Some typical pin gap issues:

- Recession versus protrusion
- **Nominal Test Port (TP) – 50 ohm definition**
- slotless versus slotted interface (male pin diameter)
- Beadless airlines and the Test Port



- Slotless female CC
- Ideal connection (50 ohm)



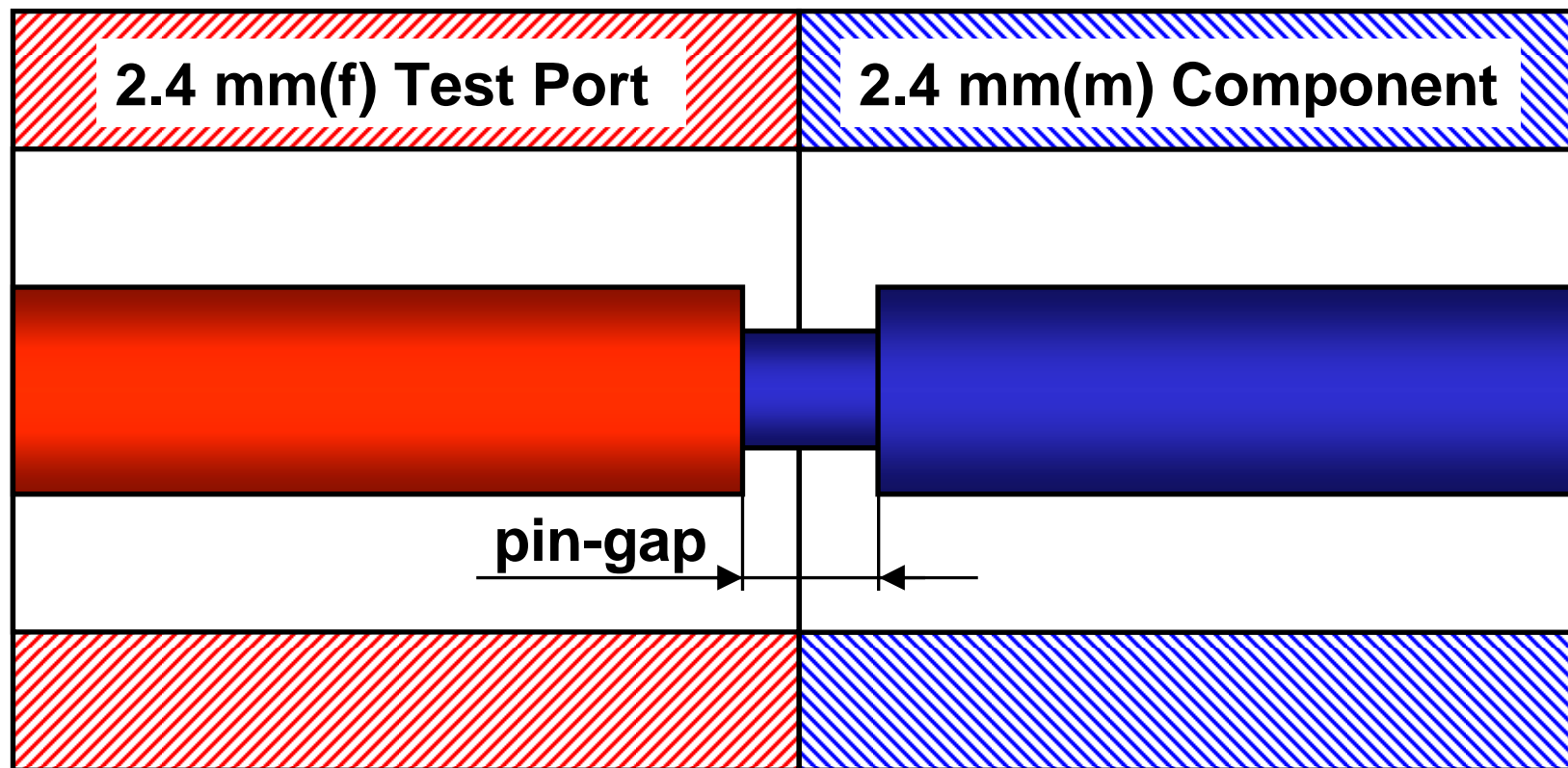
Electrical reference plane



„nominal TP“



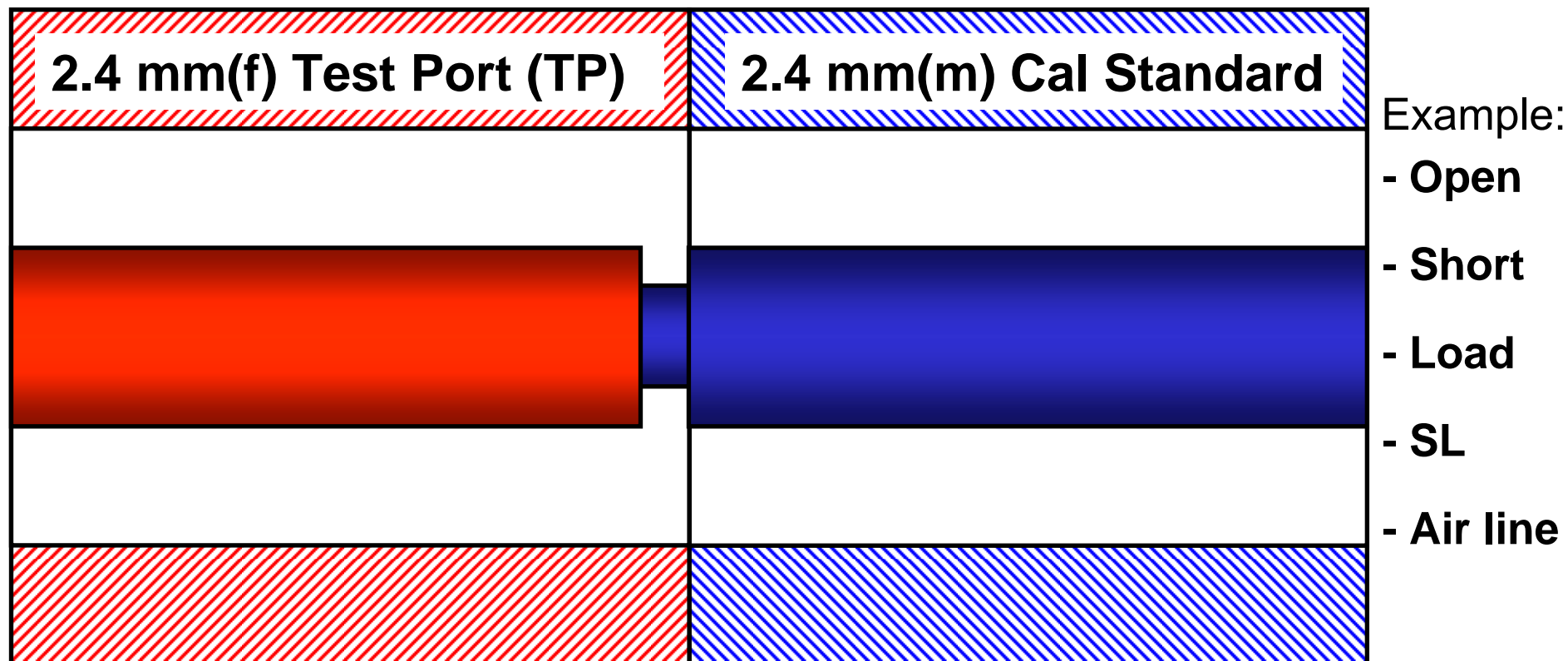
- Typical connection
- Pin-depth on both sides



Electrical reference plane (in the middle of a discontinuity)



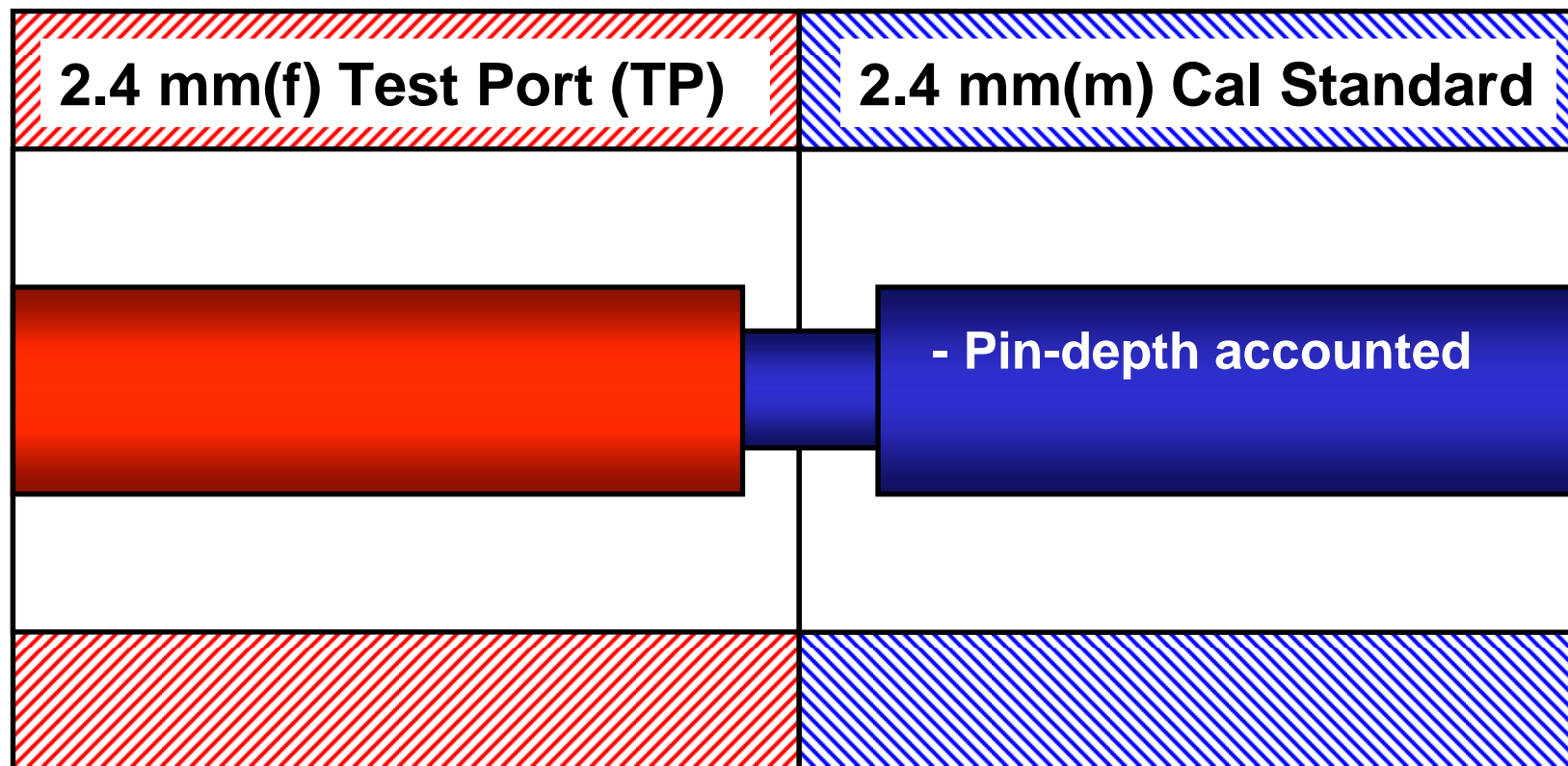
- 1 Port calibration (OSL)
- Cal Standard ideal



**The error introduced by the TP gap is „absorbed“
in the error box of the calibration model of the VNA**



- 1 Port calibration (OSL)
- Cal Standard „corrected“



**The error introduced by the TP gap is „absorbed“
in the error box of the calibration model of the VNA**



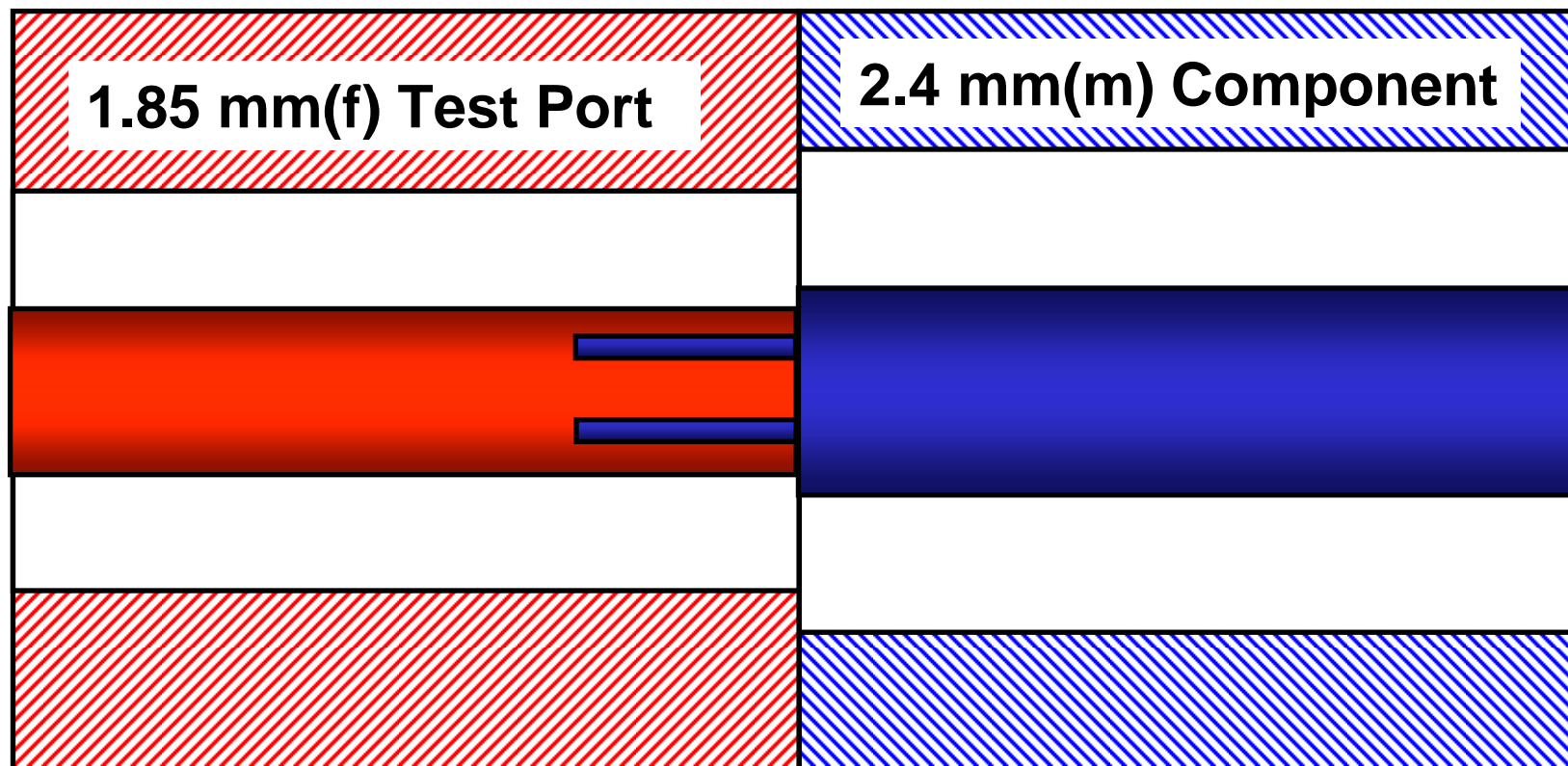
Pin gap effects in electrical measurements

Some typical pin gap issues:

- Recession versus protrusion
- Nominal Test Port (TP) – 50 ohm definition
- **slotless versus slotted interface (male pin diameter)**
- Beadless airlines and the Test Port



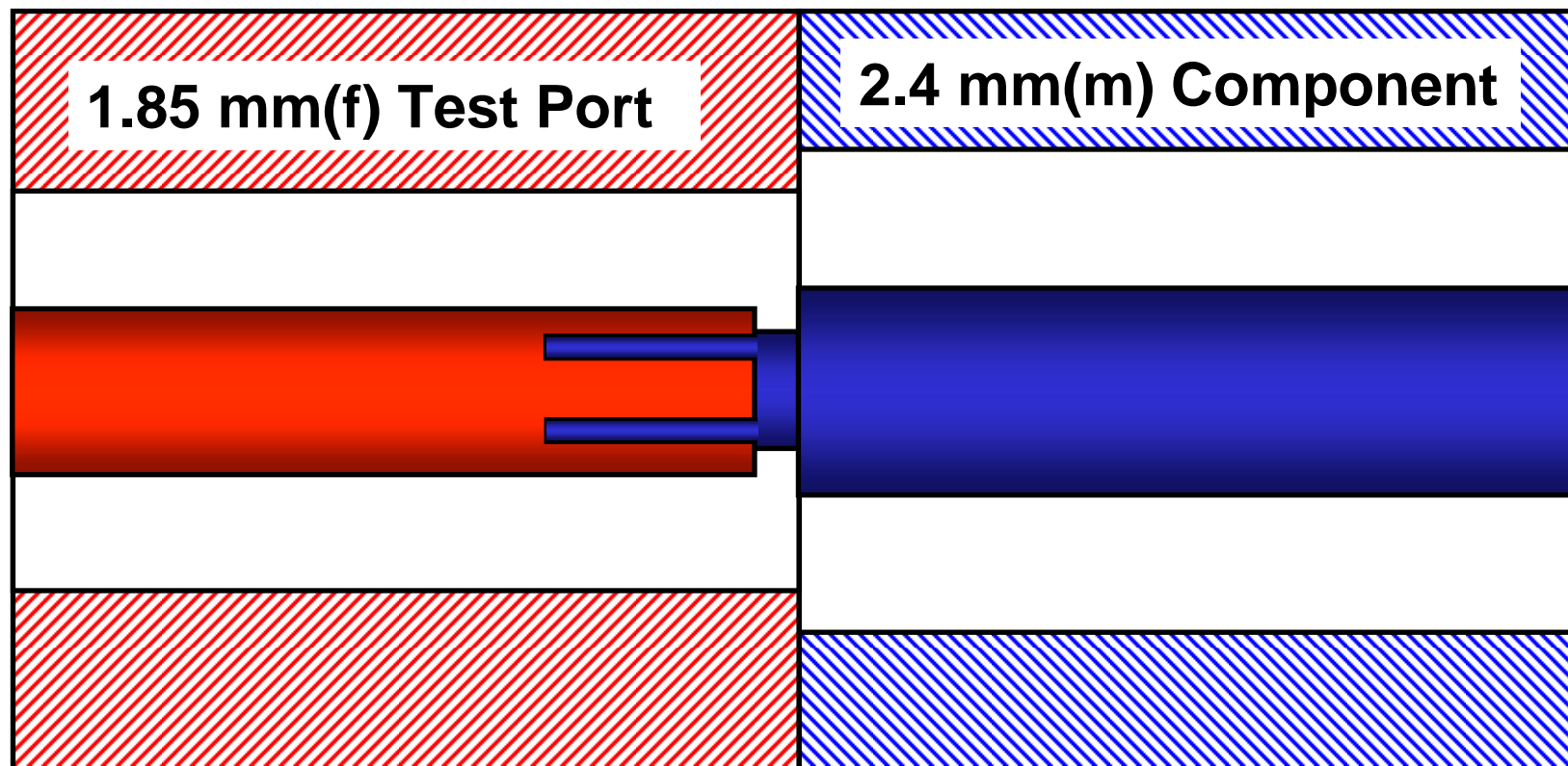
- Slotted female CC
- Matable interfaces



1.85 mm to 2.4 mm compatibility requirement:
huge challenge in the design of slotless 1.85 mm connectors



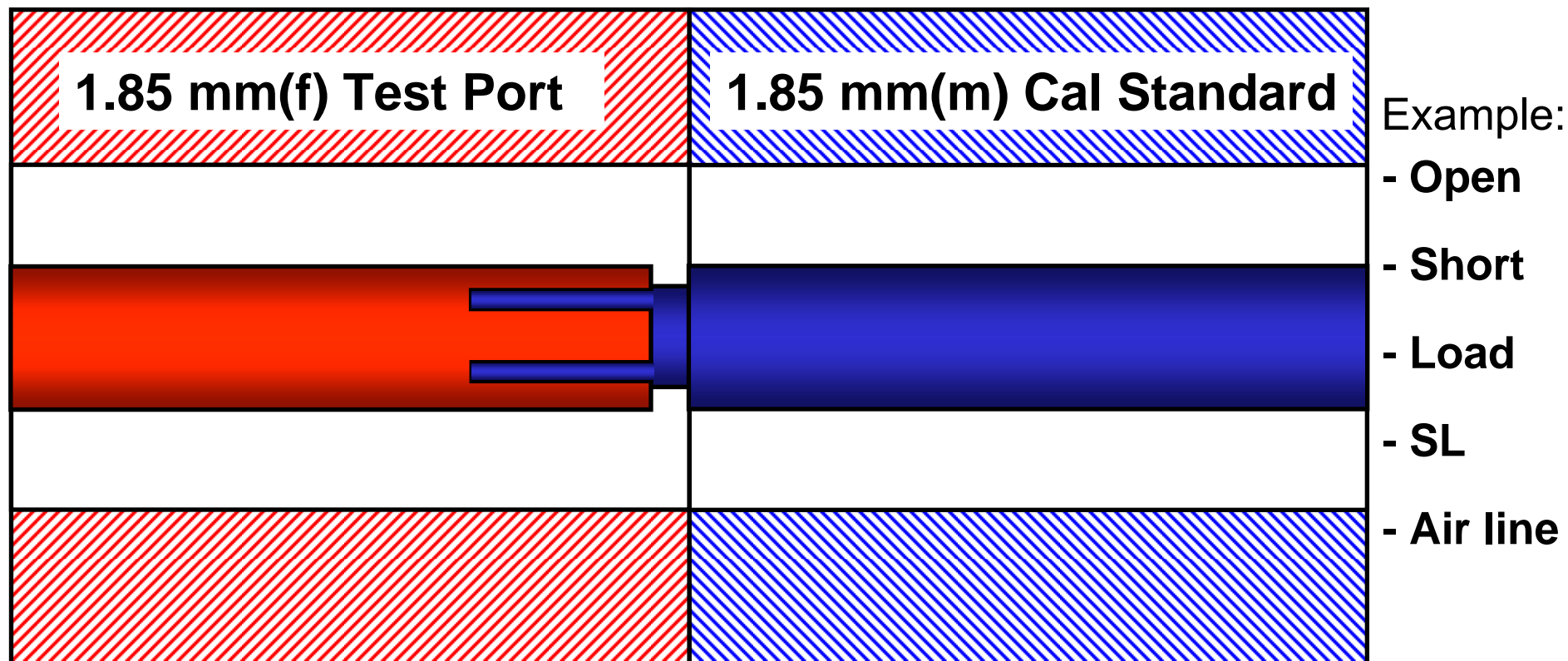
- Slotted female CC
- same male pin diameter



1.85 mm to 2.4 mm compatibility requirement
design space for the contact fingers: only (0.2926 mm / 2)



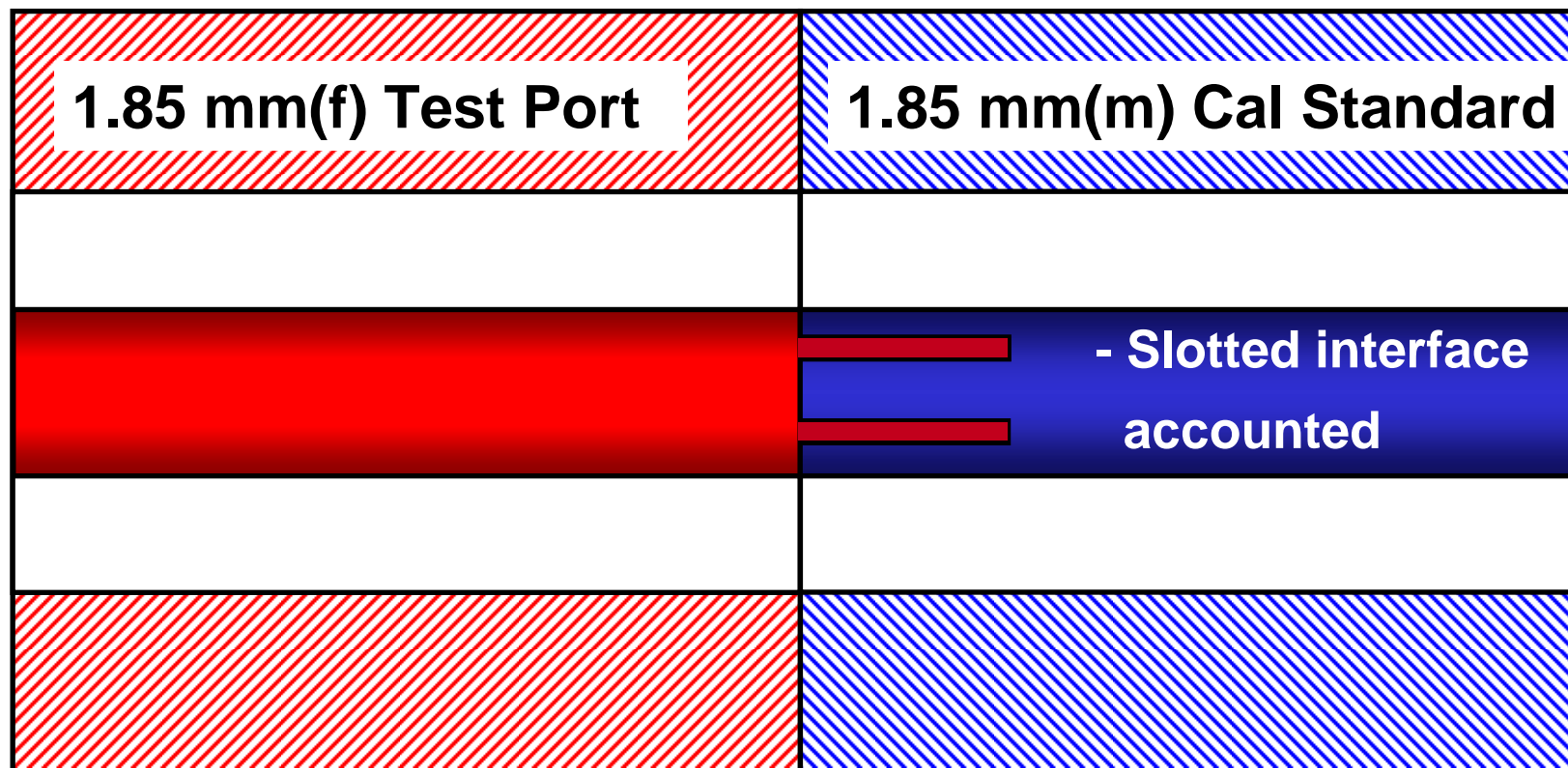
- Slotted female CC
- Cal Standard ideal



The error introduced by the TP will become „absorbed“ into the error box of the calibration model of the VNA



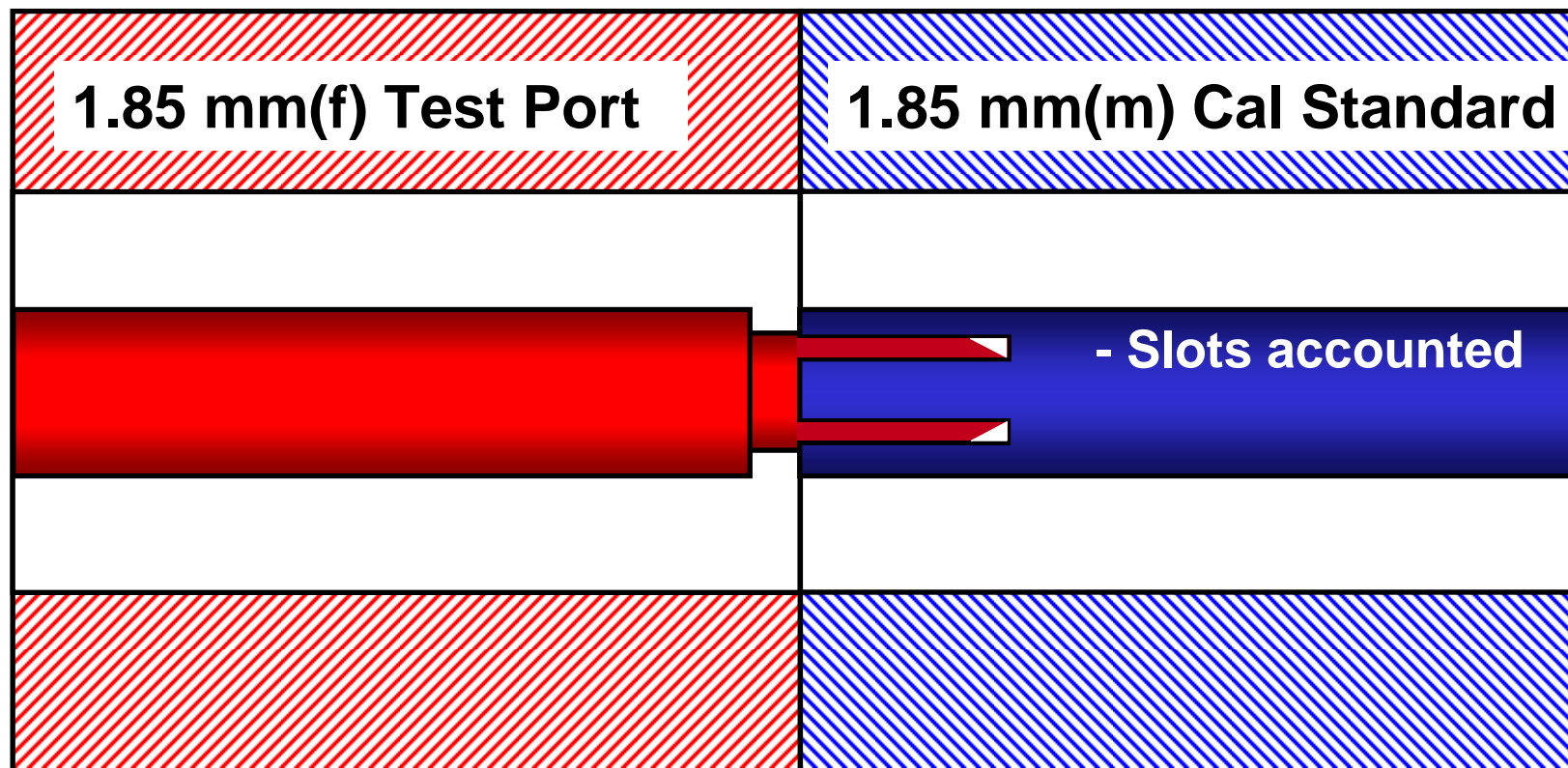
- Slotted female CC
- Cal Standard corrected



The error introduced by the slotted interface is taken into account in the standard definitions of the calibration standard



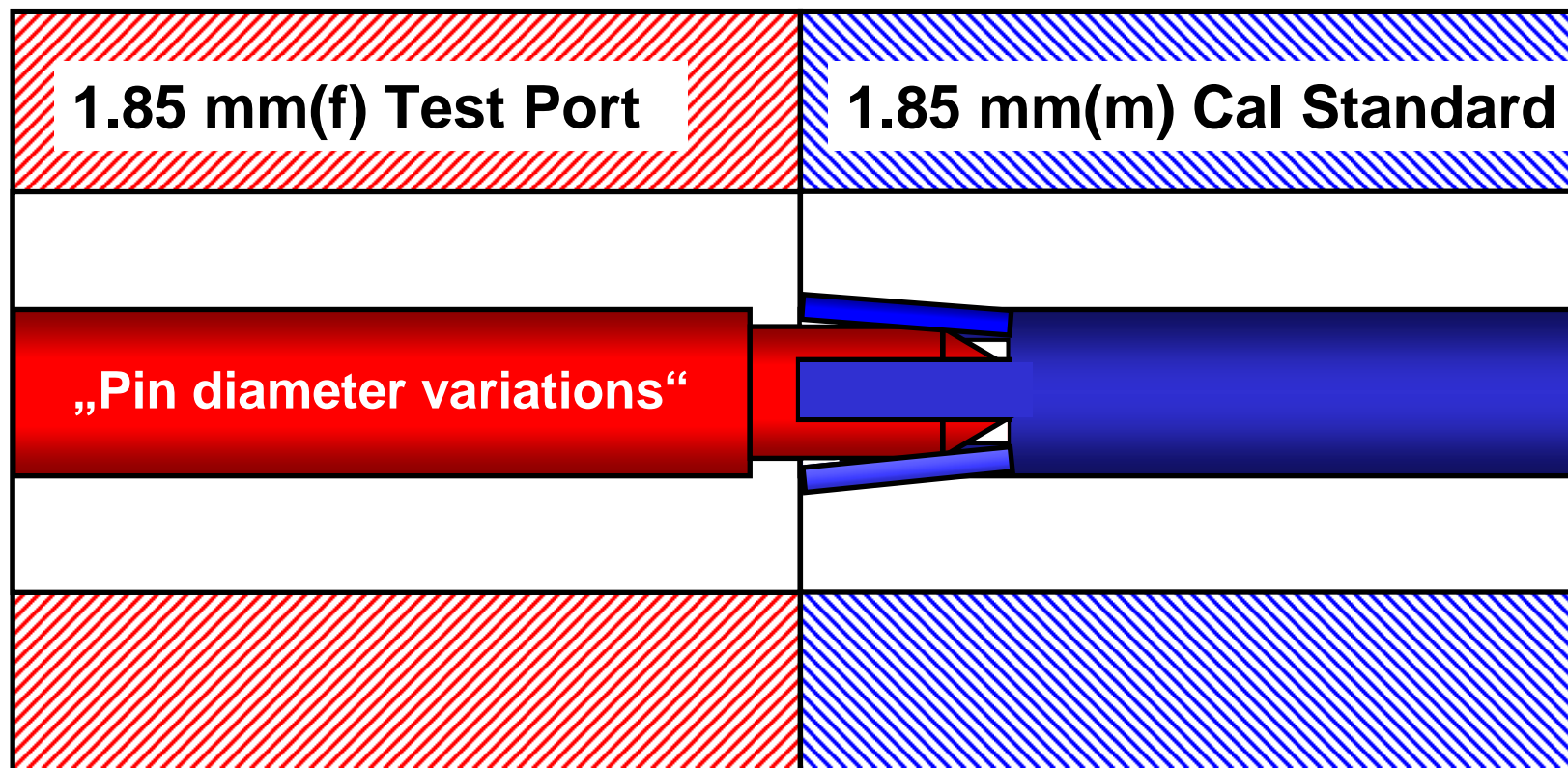
- Slotted female CC
- Cal Standard „corrected“



The error introduced by the TP will become „absorbed“ into the error box of the calibration model of the VNA



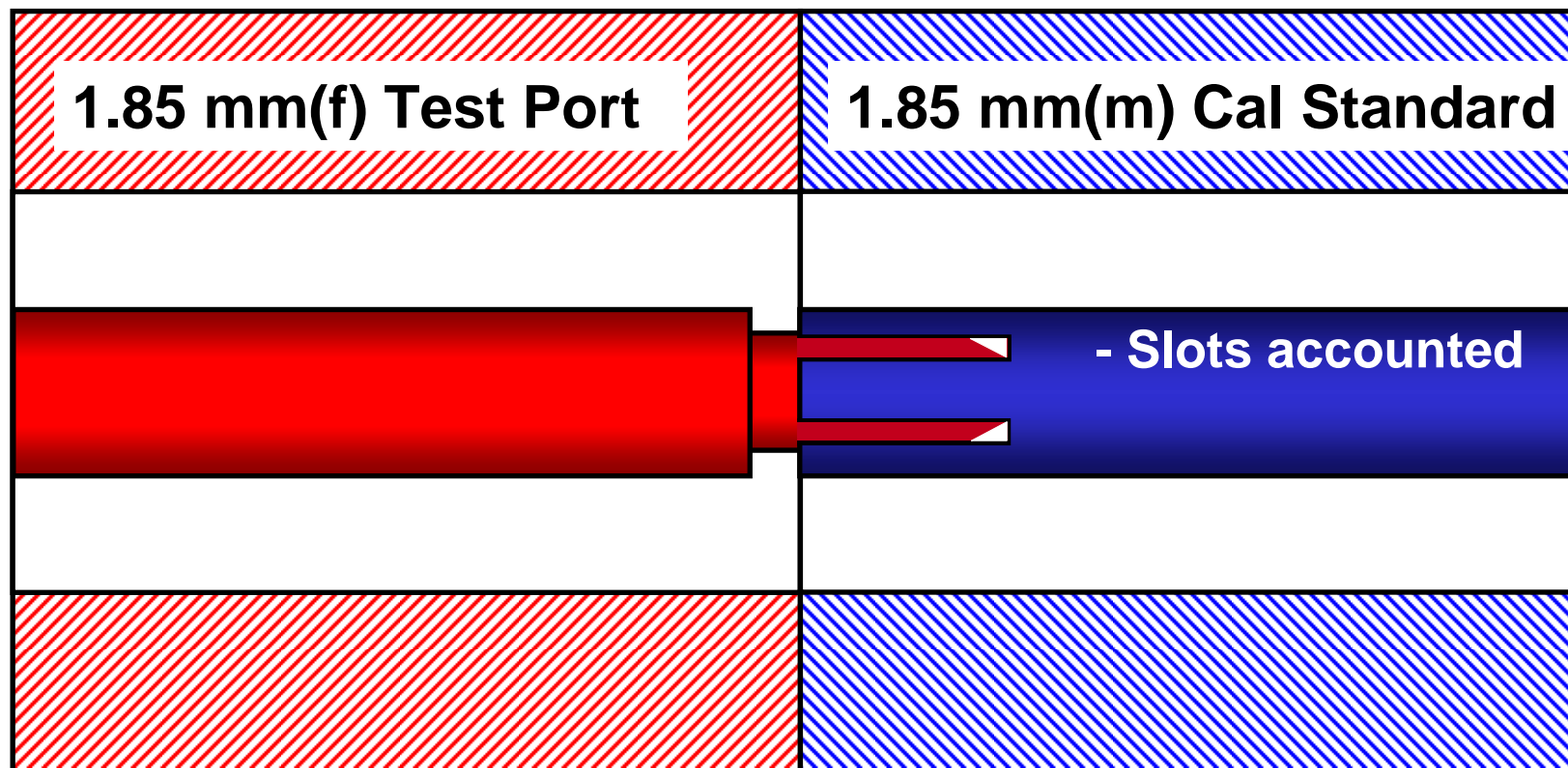
- Slotted female CC
- **Problem:** pin diameter



The error introduced by the TP will change the impedance characteristics of the connected calibration standard



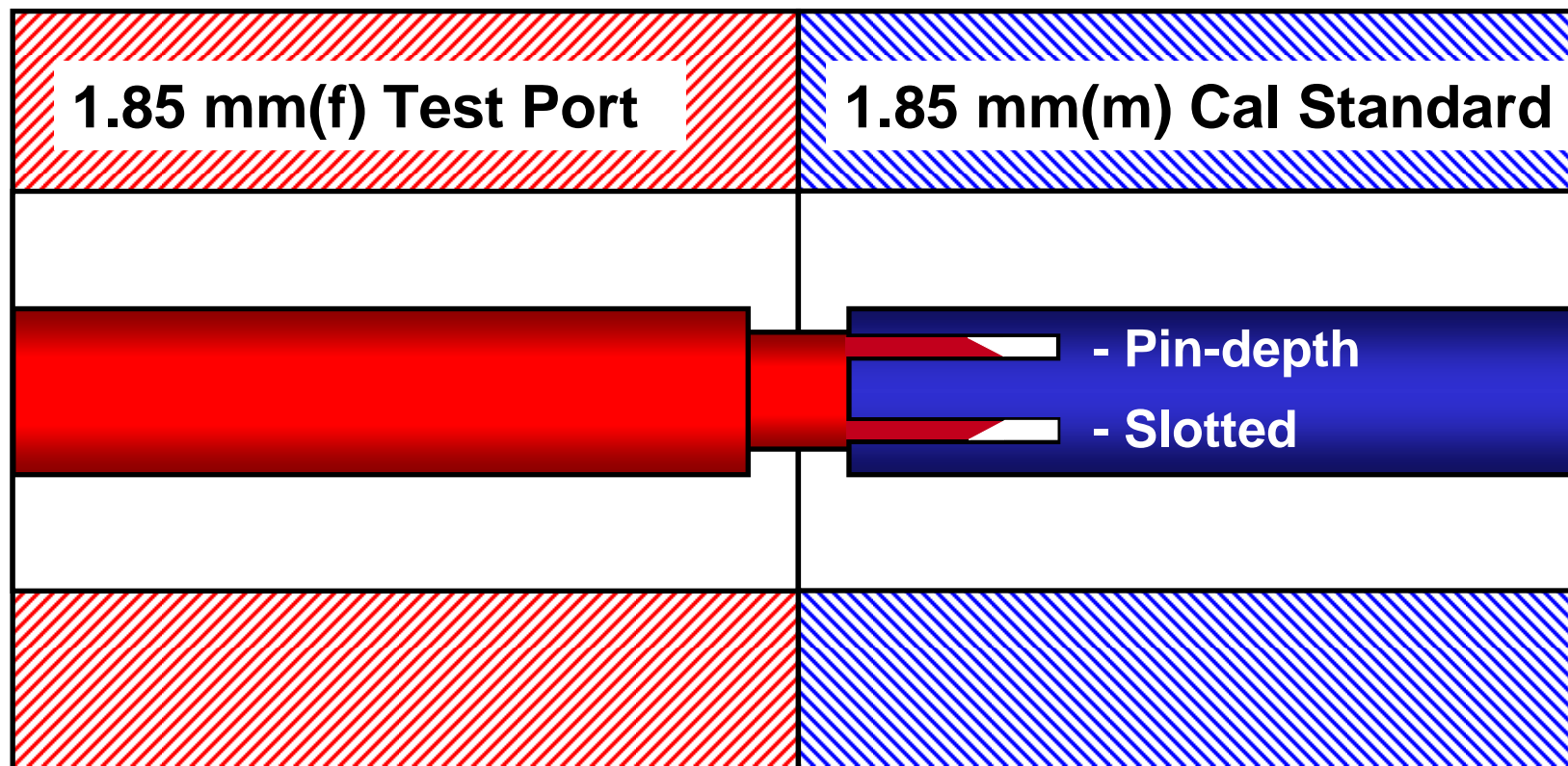
- Slotted female CC
- Cal Standard „corrected“



**TP with a nominal male pin diameter:
slotted contact fingers in their nominal design position**



- Slotted female CC
- Cal Standard „corrected“



The error introduced by the pin-depth and the slotted interface is taken into account in the standard definitions of the calibration standard



Pin gap effects in electrical measurements

Some typical pin gap issues:

- Recession versus protrusion
- Nominal Test Port (TP) – 50 ohm definition
- slotless versus slotted interface (male pin diameter)
- **Beadless airlines and the Test Port**

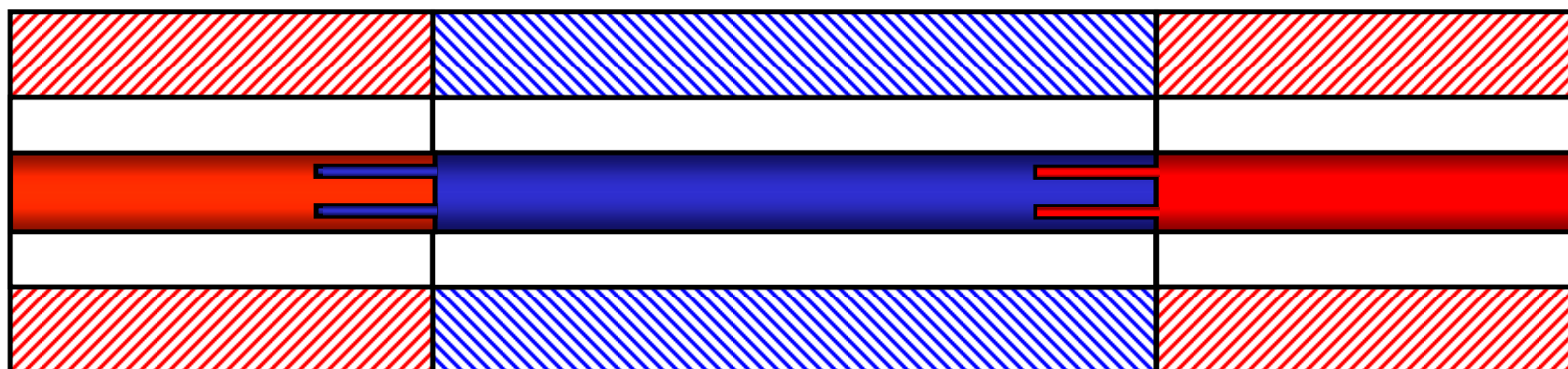


Cross sectional view of a coaxial air-dielectric line with slotted centre conductors, mounted between two TP's

1.85 mm(f) TP

1.85 mm airline section

1.85 mm(m) TP



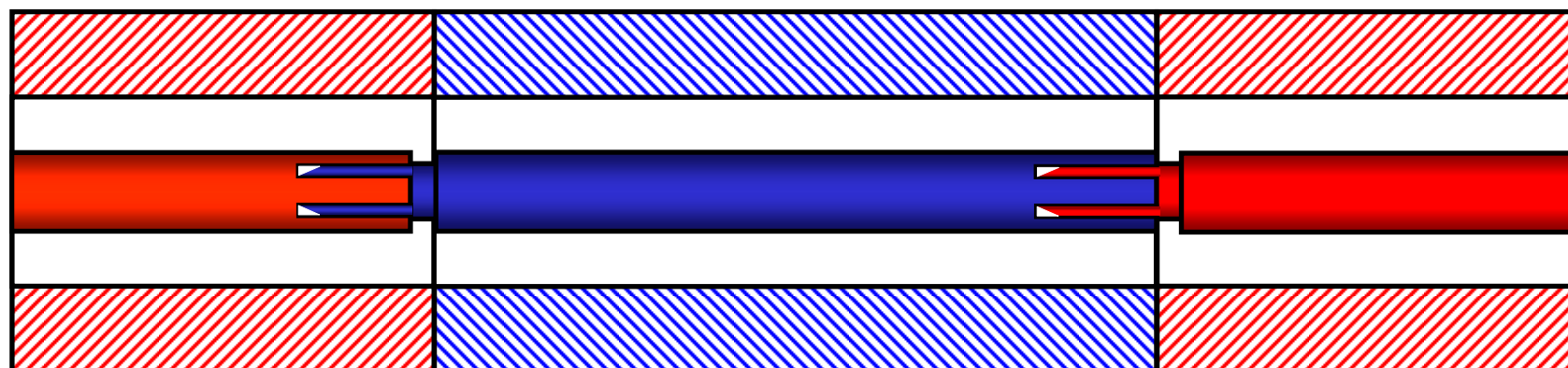


Cross sectional view of a coaxial air-dielectric line with slotted centre conductors, mounted between two TP's

1.85 mm(f) TP

1.85 mm airline section

1.85 mm(m) TP



The error introduced by the TP's is „absorbed“
in the error box of the calibration model of the VNA

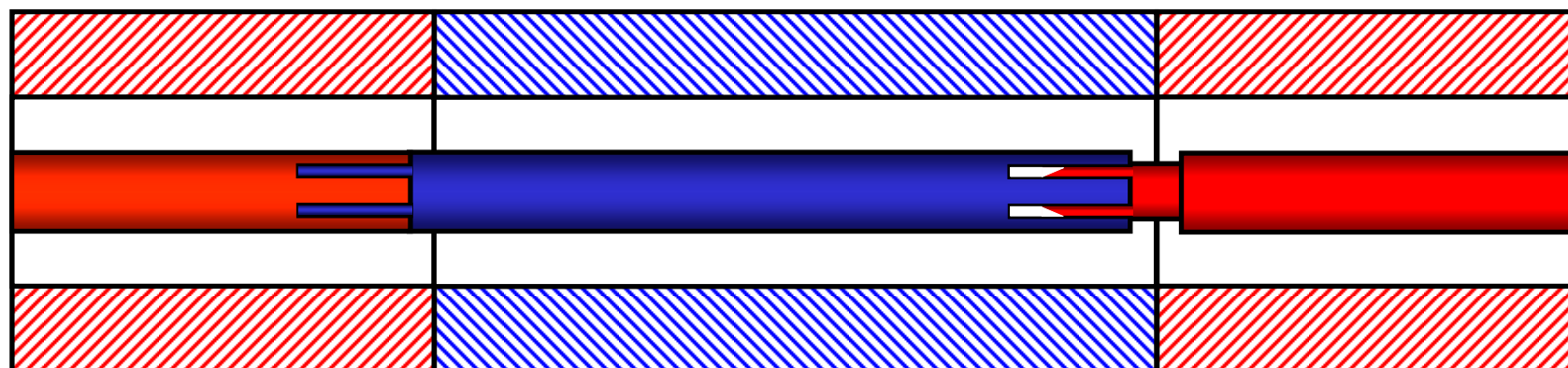


**Shifted centre conductor: no control on the pin-depths
- TP 1: has no pin gap present -> seems to be better ?**

1.85 mm(f) TP

1.85 mm airline

1.85 mm(m) TP



**Electrical reference
plane TP 1**

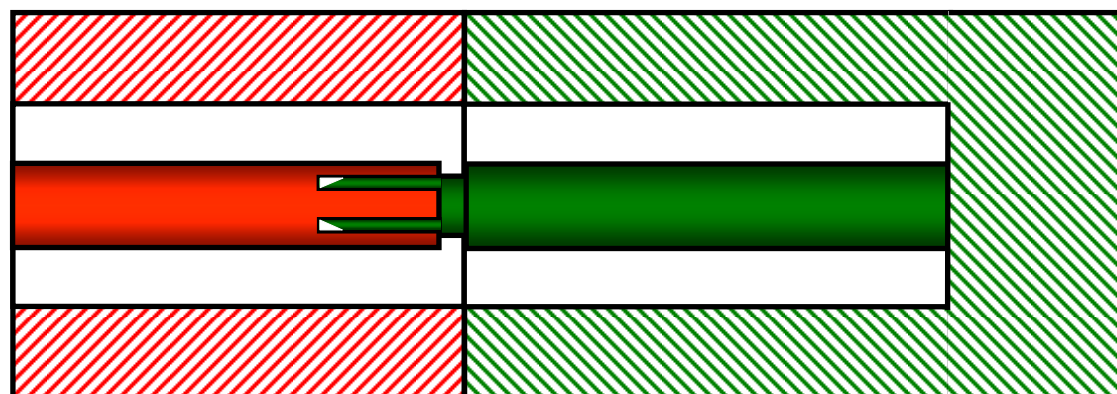
**Electrical reference
plane TP 2**



TP 1 interface looks now different as during the previous calibration process with the shifted CC (error box has changed)

1.85 mm(f) TP

1.85 mm DUT



Example: DUT with no pin-depth

Electrical reference plane TP 1



A practical experiment showing this pin gap effect



E555: „Comparison of scattering parameter measurements in the coaxial 2.4 mm line system“

12 Participants: (9 **NMI**, 3 **Industrial**)

- BNM-LNE/LAMA
- CSIR-NML
- IEN
- INMS NRC
- INTA
- NIST
- NMi VSL
- NPL
- METAS (pilot laboratory)
- EPSG/MTA
- SQF
- UKAS No“0147“

Status: Final Report November 2004

Devices: 2.4 mm line system

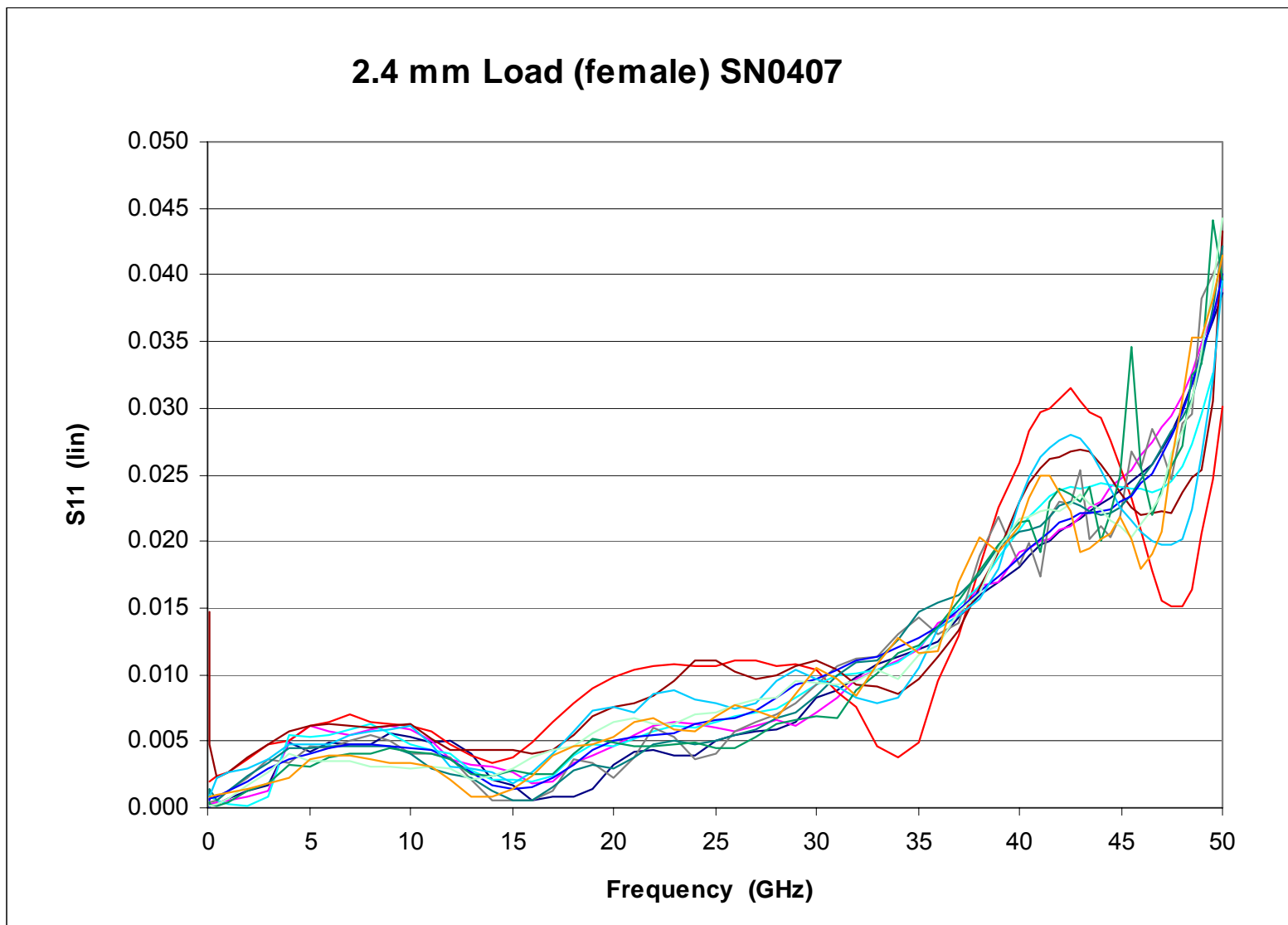
- Attenuator: 3 dB, 20 dB, 40 dB
- 50 Ohm Load: male, female
- Mismatch VSWR 2.0: male, female

Frequencies: 50 MHz - 50 GHz



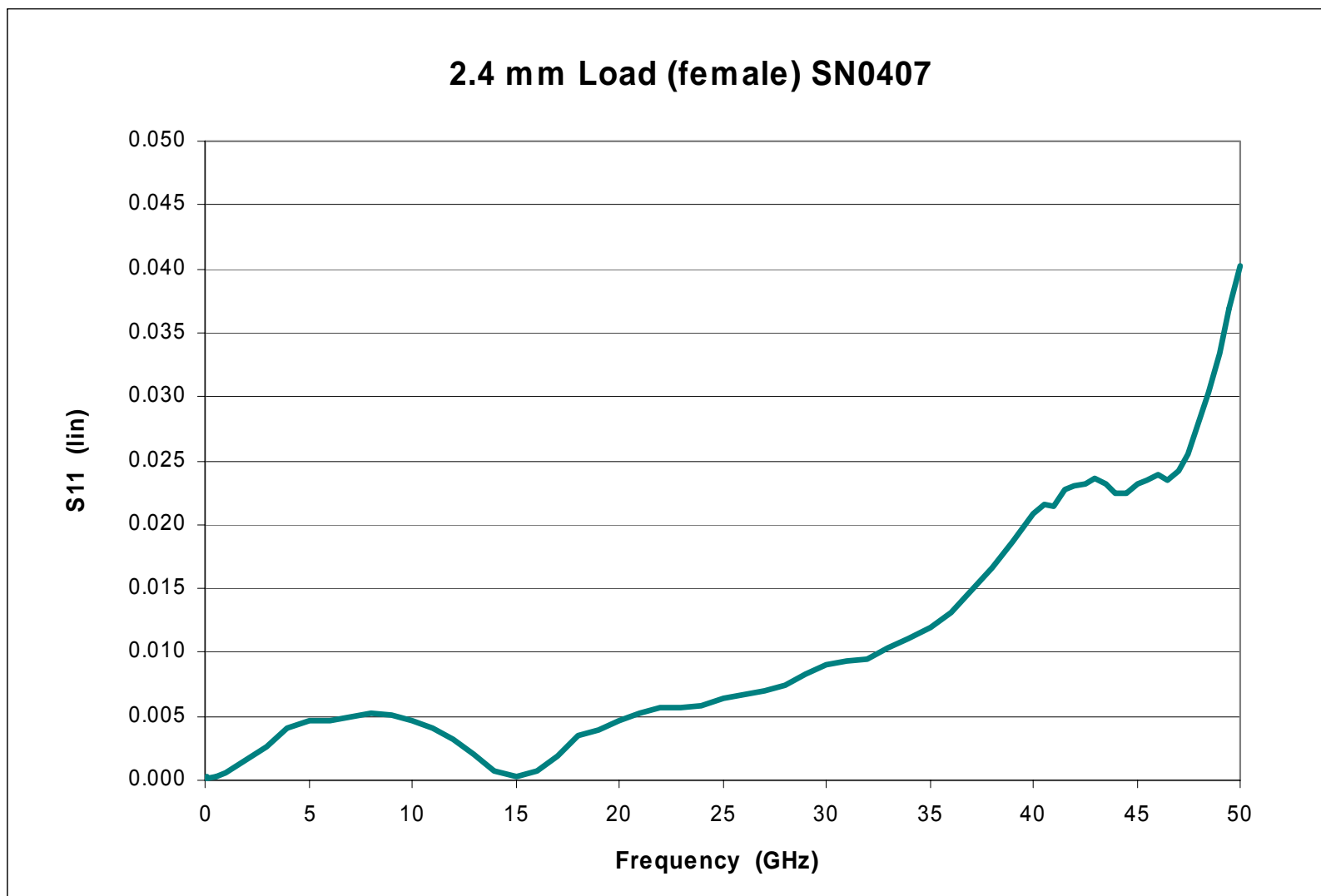


E555 showing all participants



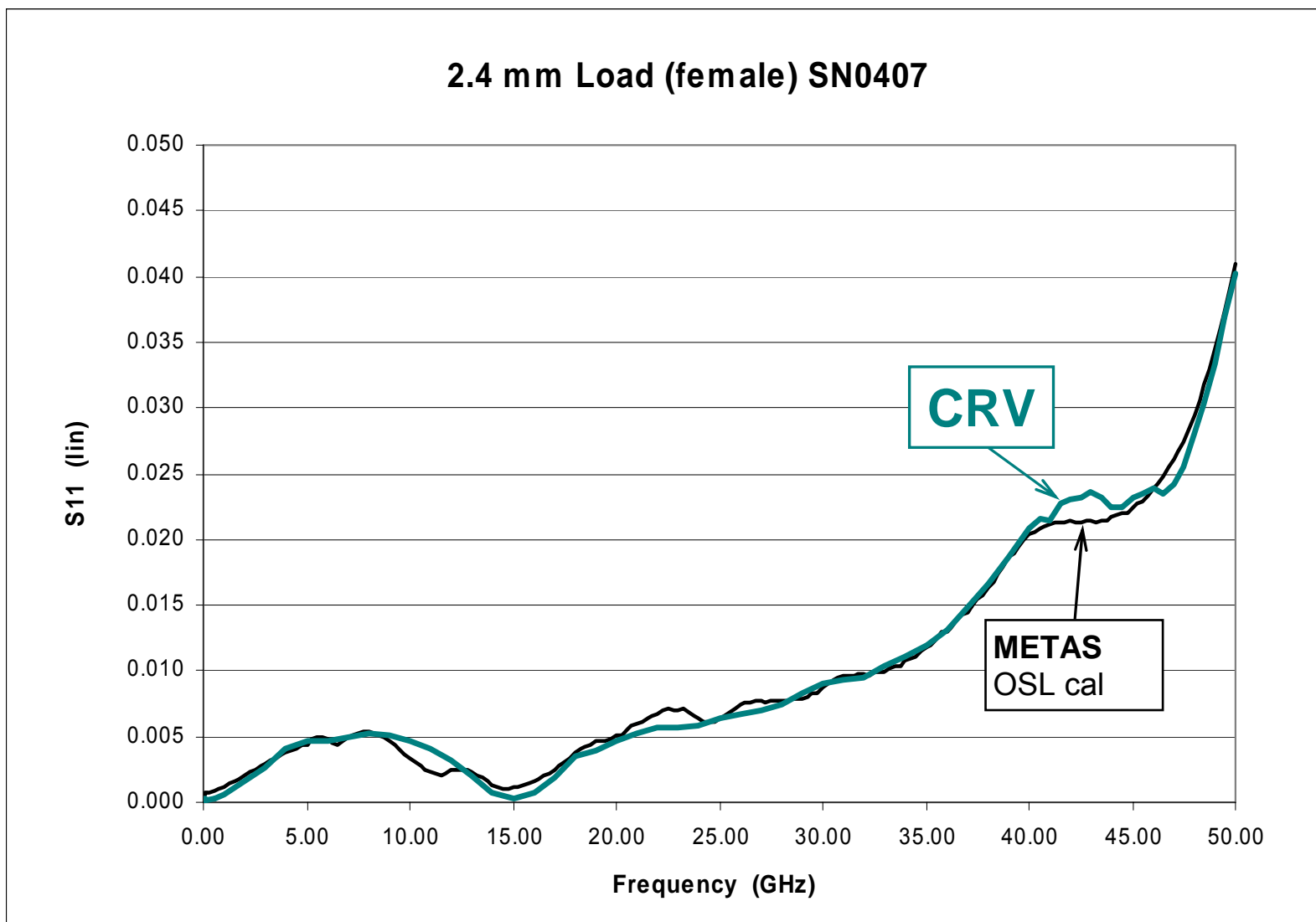


E555 Comparison Reference Value CRV

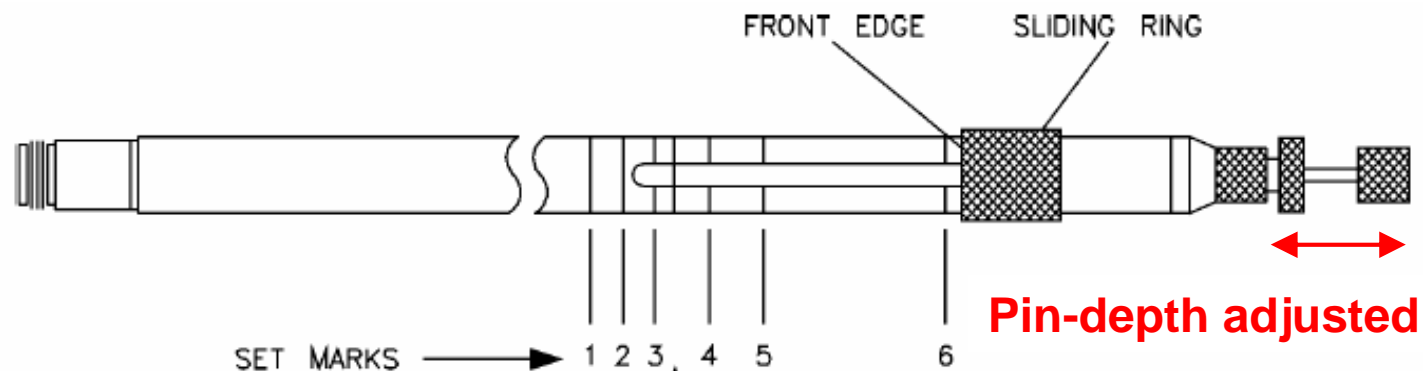




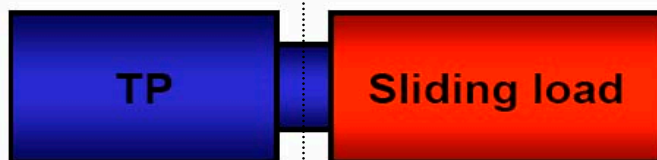
SL pin-depth: 0.0000 mm (0.00000 in)



Pin-depth effects from the sliding load (used during the VNA calibration)

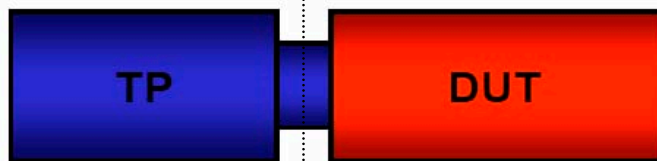


Calibration :
(OSL)



Test Port recession:
pin-depth: -0.0076 mm

Measurement :

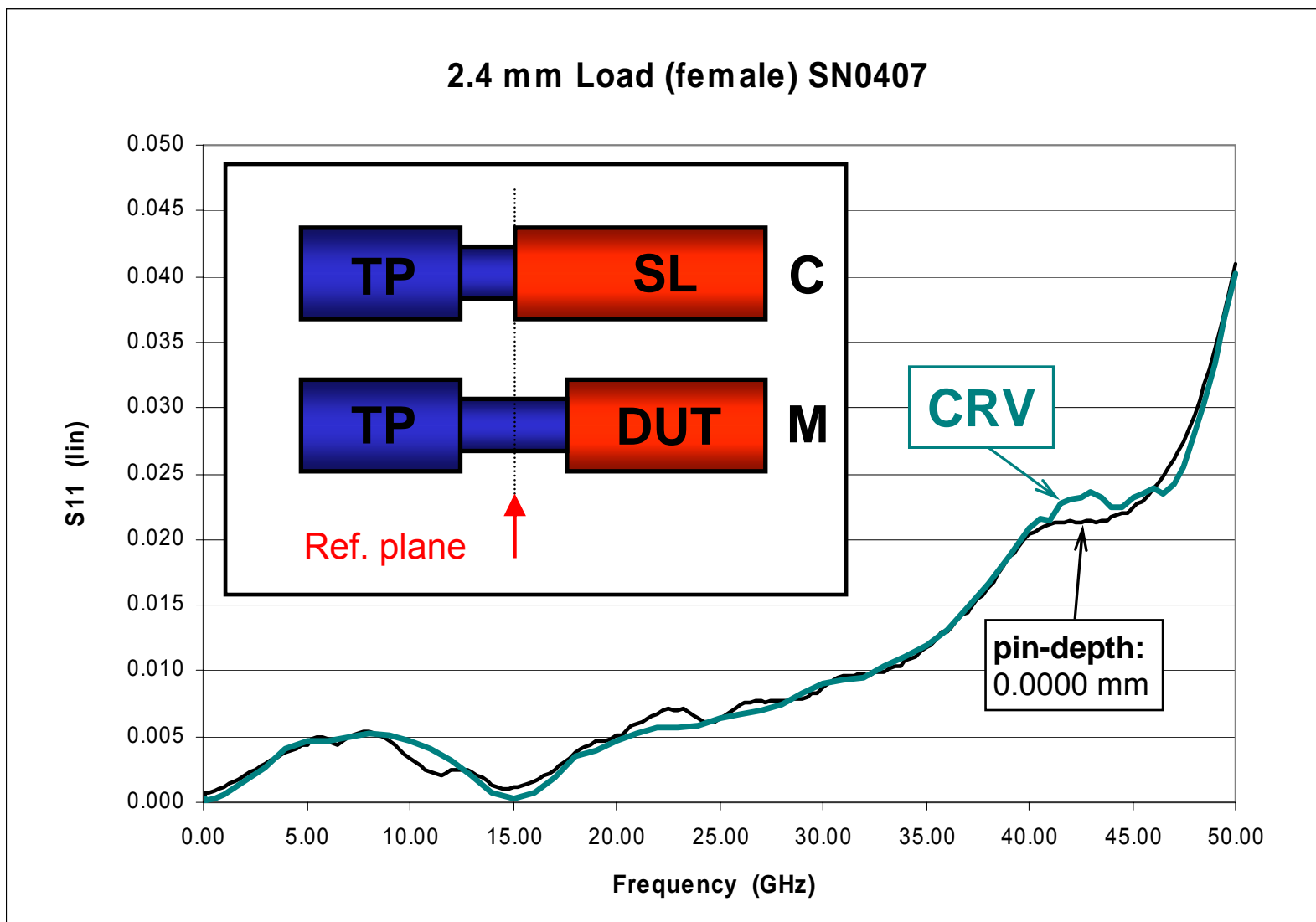


DUT:
2.4 mm (f) Load SN:407
pin-depth: -0.0084 mm

Electrical reference plane

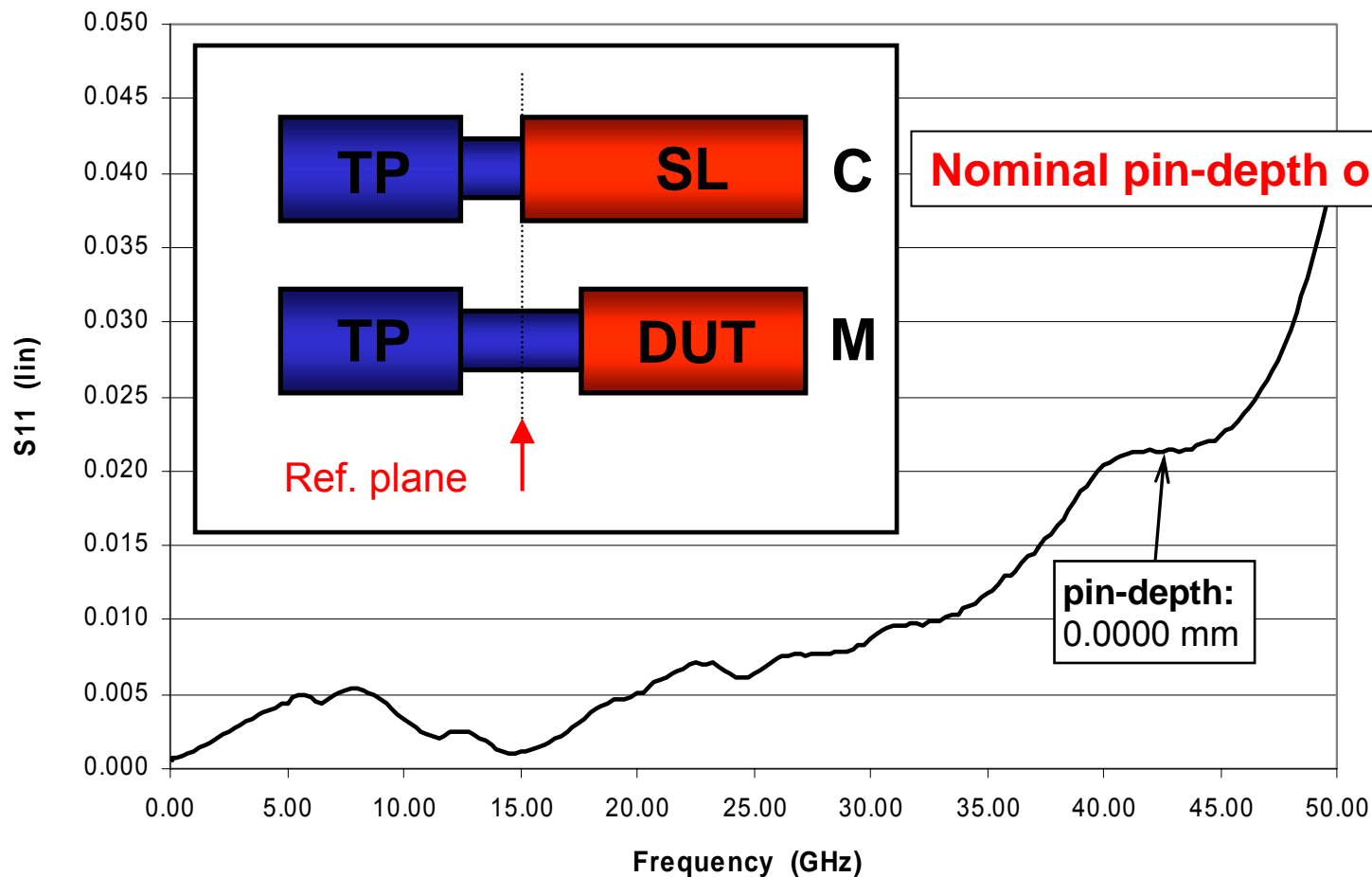


SL pin-depth: 0.0000 mm (0.00000 in)



SL pin-depth: 0.0000 mm (0.00000 in)

2.4 mm Load (female) SN0407



TP (m):
-0.0076 mm

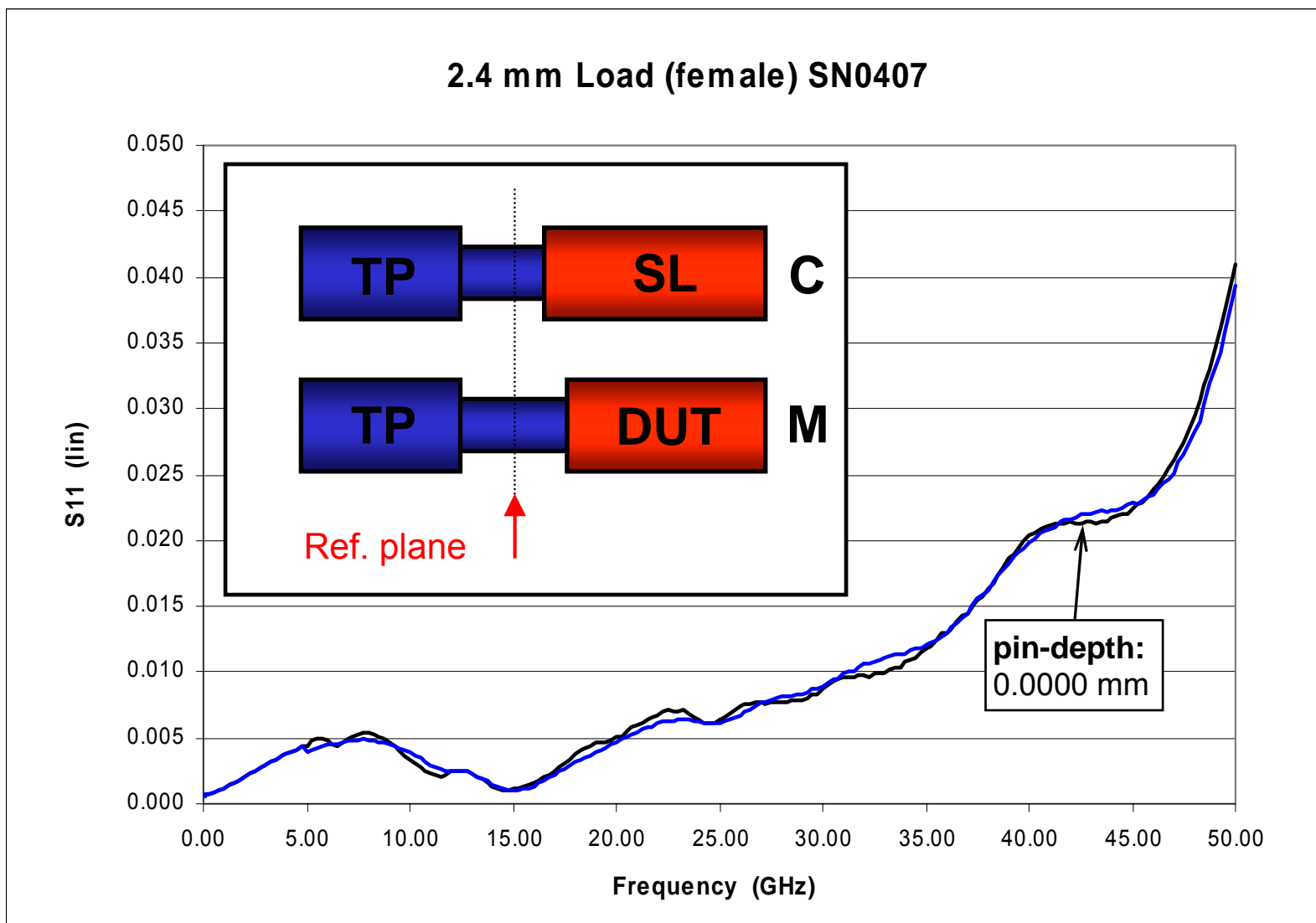
DUT (f):
-0.0084 mm

Open (f):
-0.0010 mm

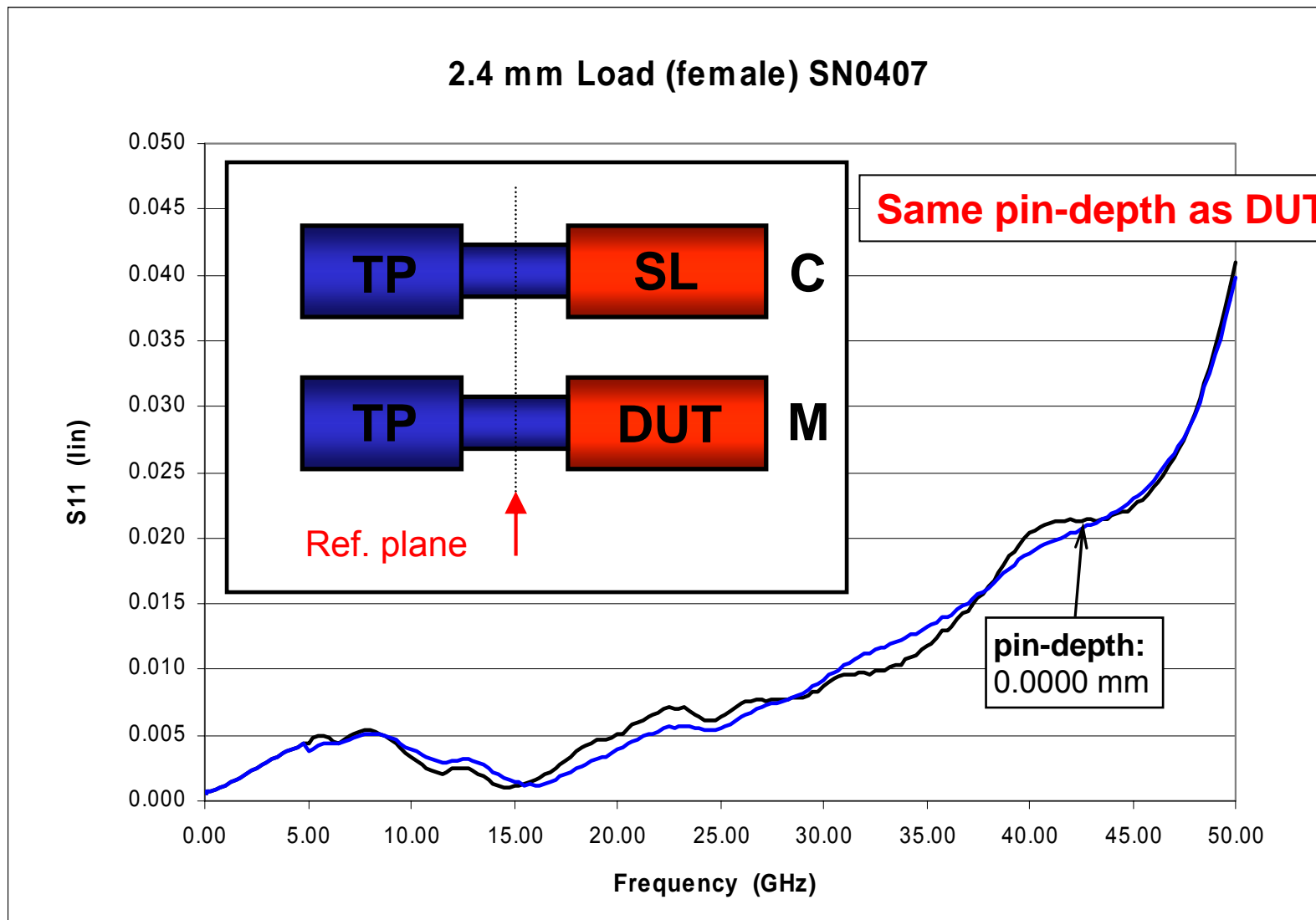
Short (f):
-0.0015 mm



SL pin-depth: -0.0038 mm (-0.00015 in)

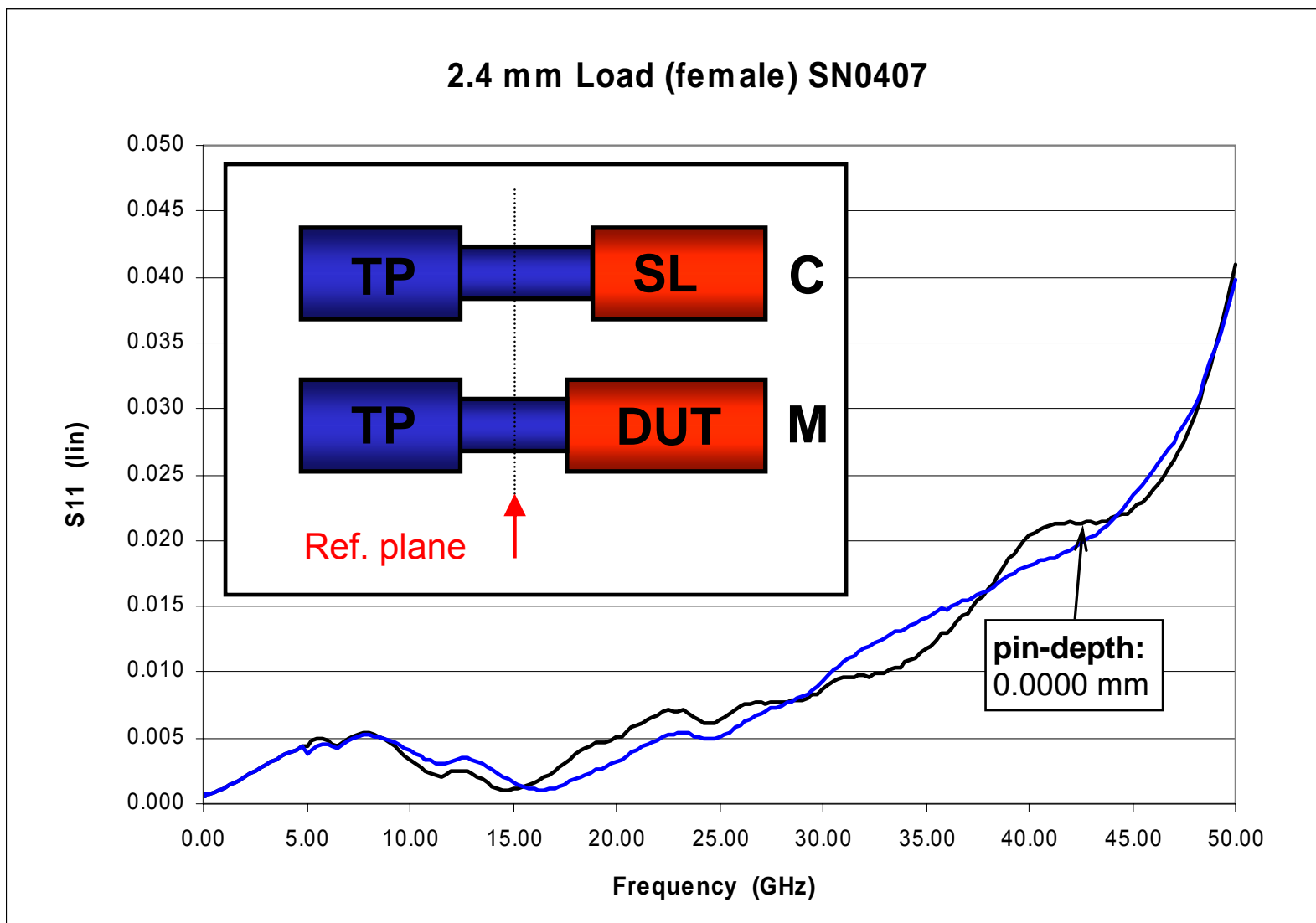


SL pin-depth: -0.0076 mm (-0.00030 in)





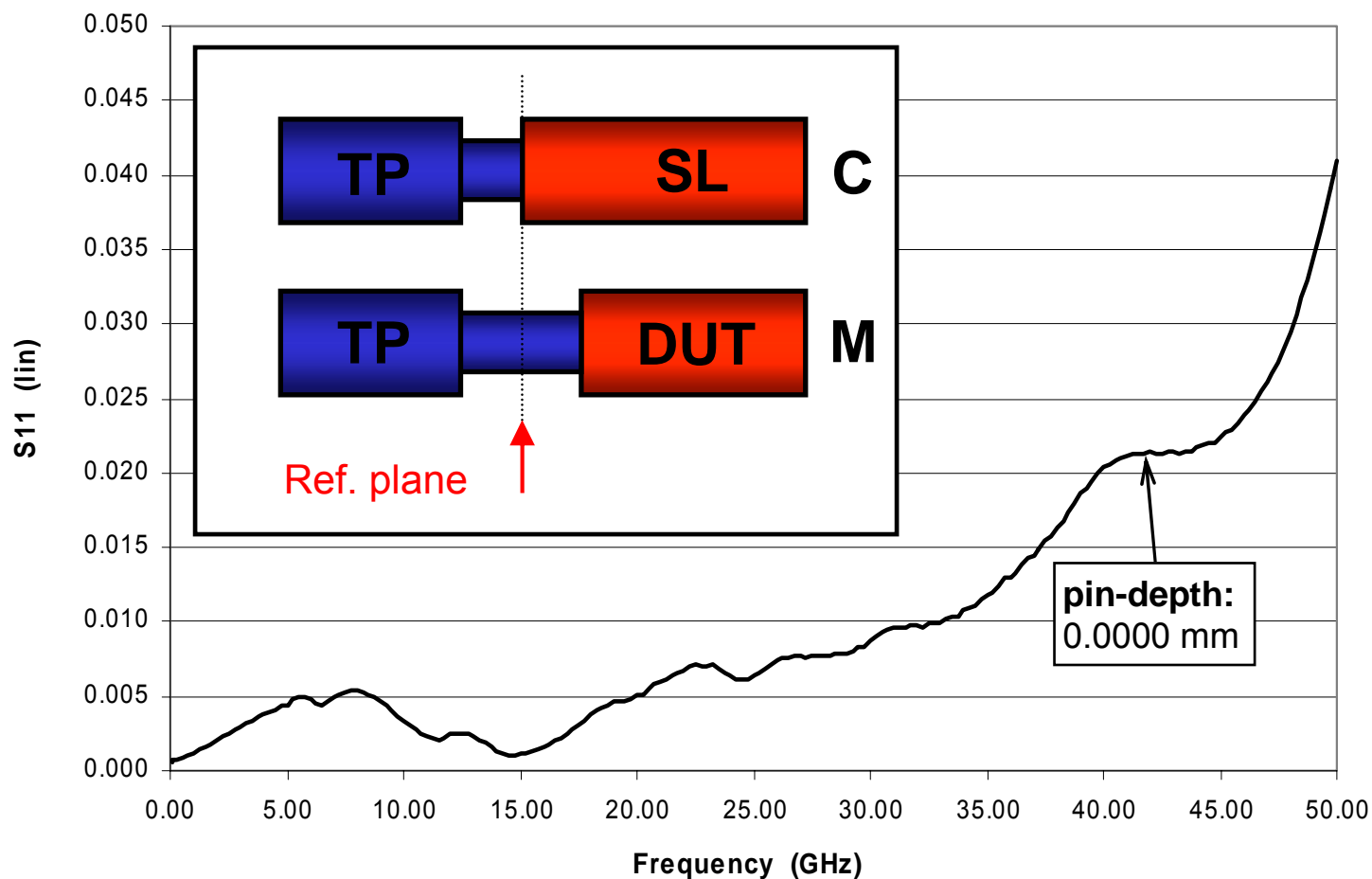
SL pin-depth: -0.0114 mm (-0.00045 in)





SL pin-depth: 0.0000 mm (0.00000 in)

2.4 mm Load (female) SN0407



TP (m):
-0.0076 mm

DUT (f):
-0.0084 mm

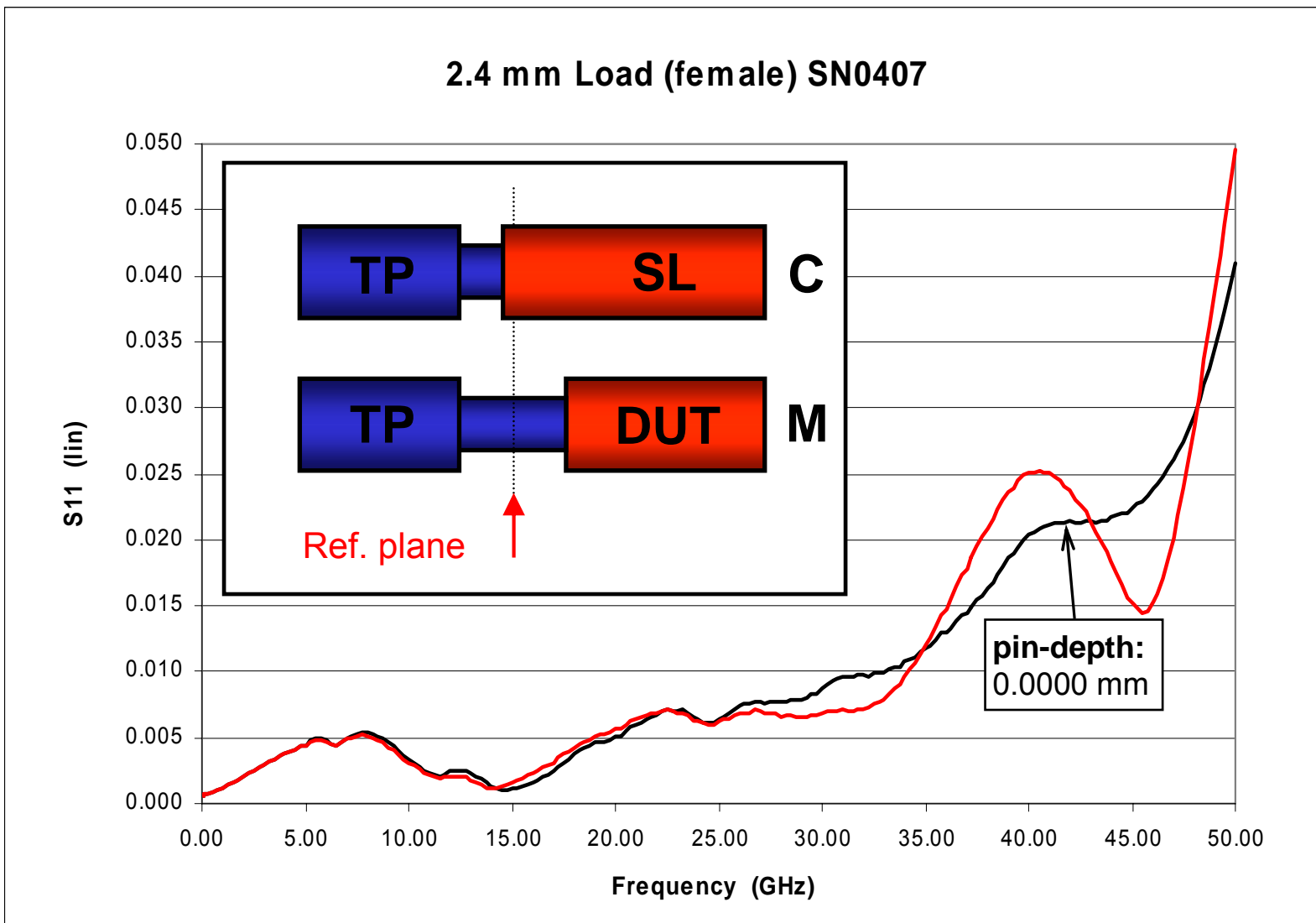
Open (f):
-0.0010 mm

Short (f):
-0.0015 mm



Protrusion

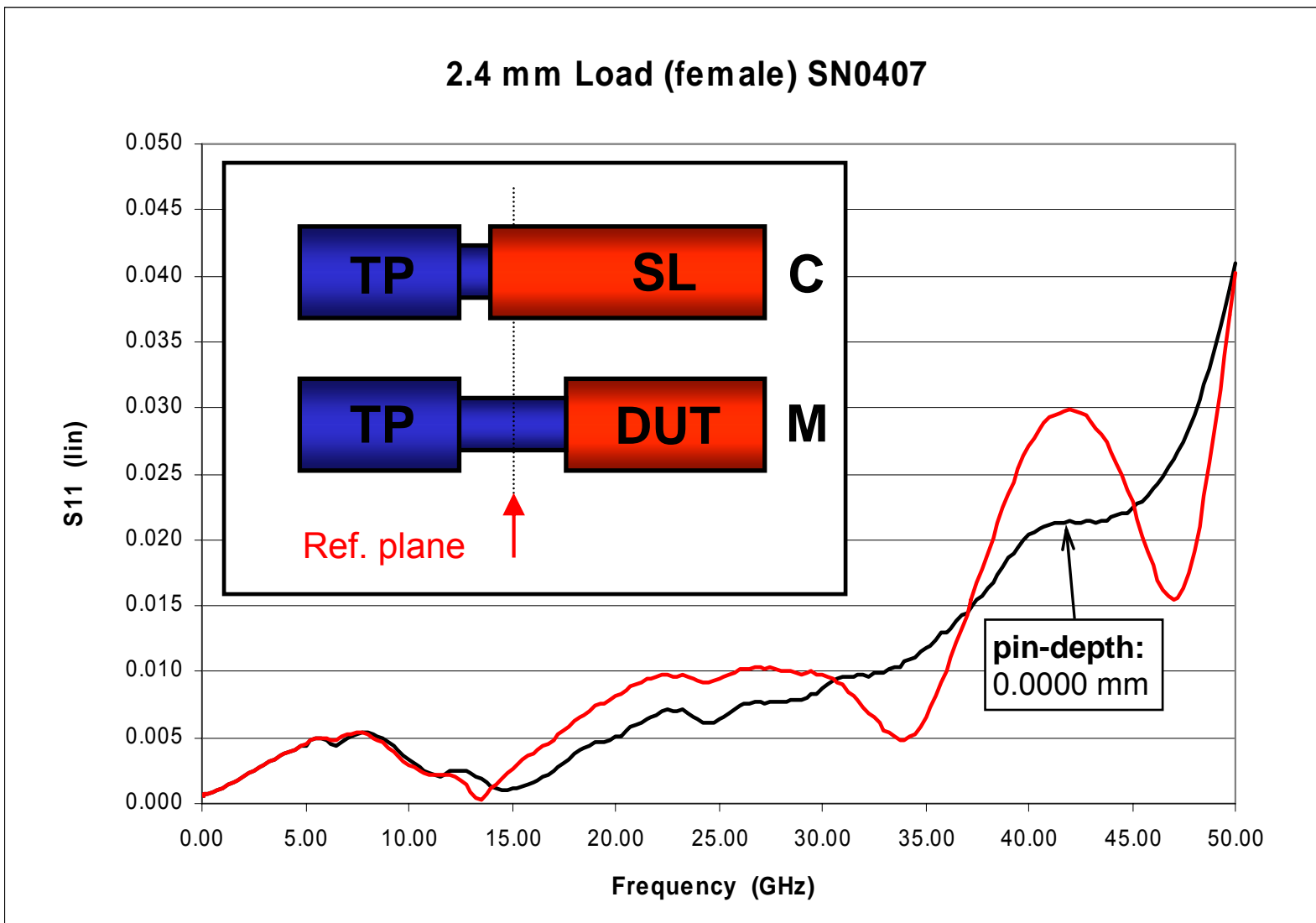
SL pin-depth: +0.0013 mm (+0.00005 in)





Protrusion

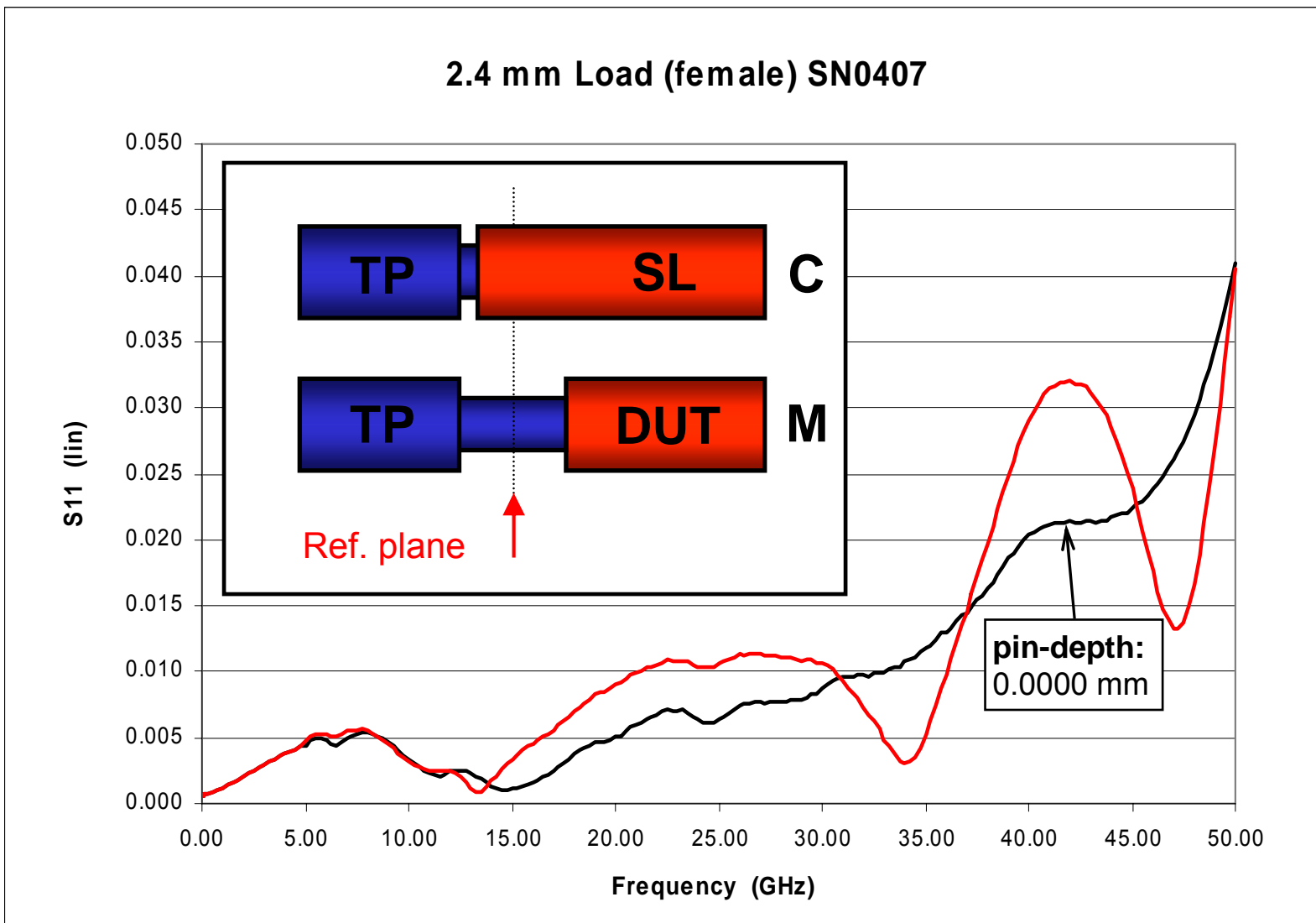
SL pin-depth: +0.0025 mm (+0.00010 in)





Protrusion

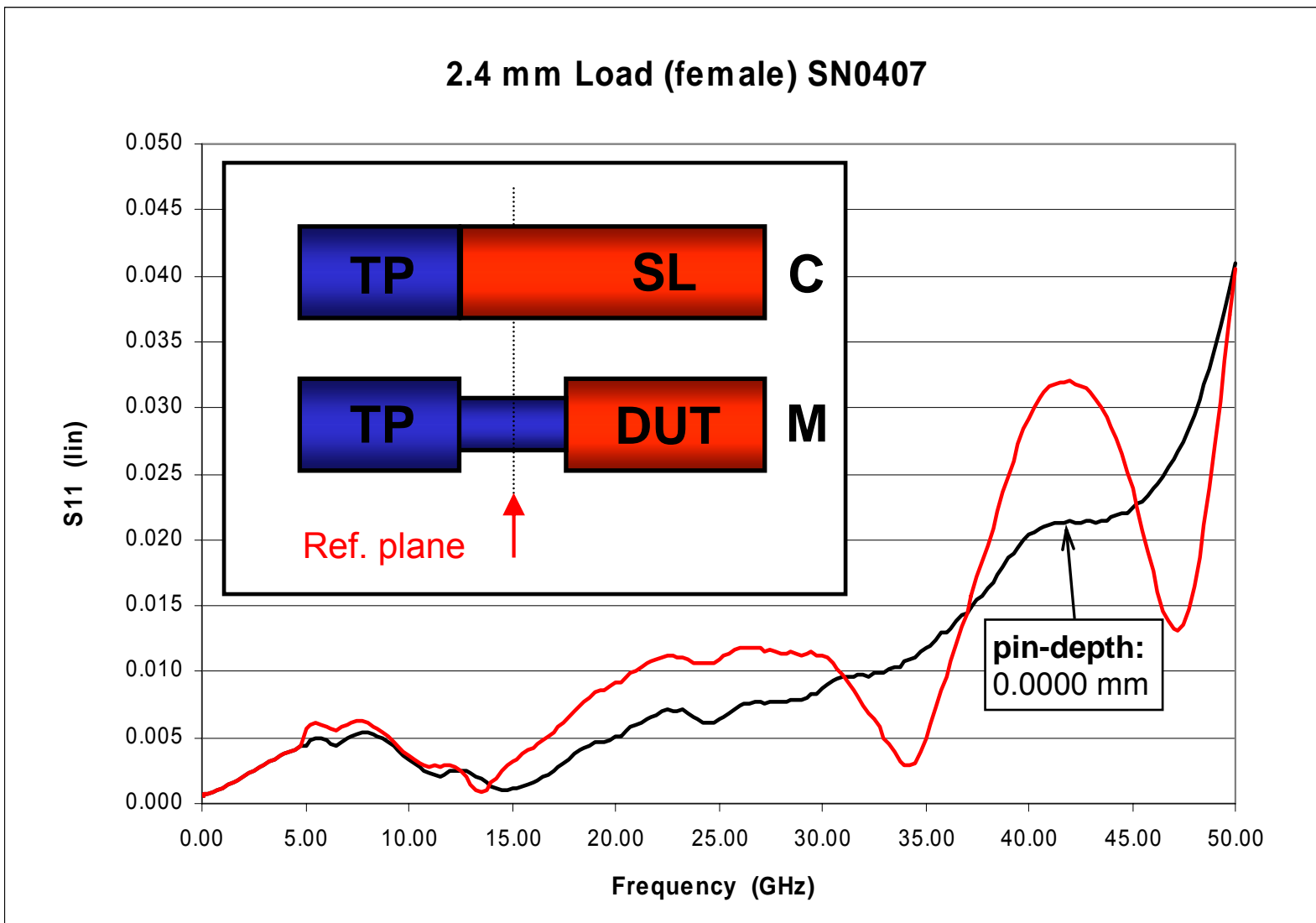
SL pin-depth: +0.0051 mm (+0.00020 in)





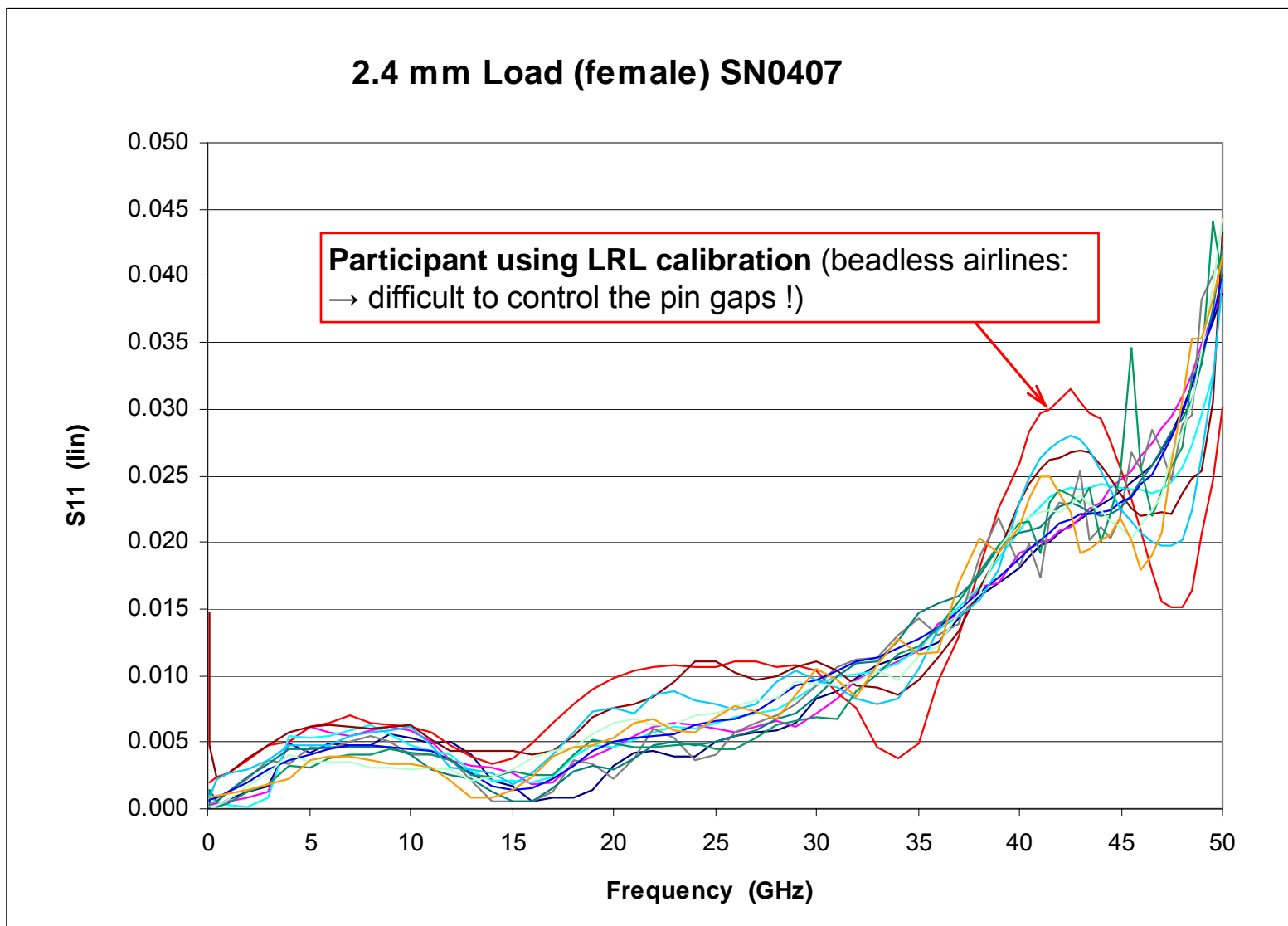
Protrusion

SL pin-depth: +0.0076 mm (+0.00030 in)





E555 showing all participants





Conclusions : “Mind the (pin) gap”

- **Modelling: a must for millimetre-wave coaxial connectors**
- **Traceable pin-depth measurements – a must for modelling**
- **Minimise the potential Test Port interactions**
- **Impact of pin gap issues in measurement comparisons?**
- **Other critical effects not discussed (gap of the outer, ...)**

Federal Department of Justice and Police FDJP
Federal Office of Metrology METAS

Thank you very much for your attention !





References:

J. Hoffmann, P. Leuchtman and R. Vahldieck, “Pin Gap Investigations for the 1.85mm Coaxial Connector”, 37th European Microwave Conference 2007, pp388-391, October 2007

• J. Ruefenacht, “Coaxial Connectors (theory)”, Microwave Measurement Training Course, METAS, November 2007

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