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"

European Metrology workshop (Berlin)

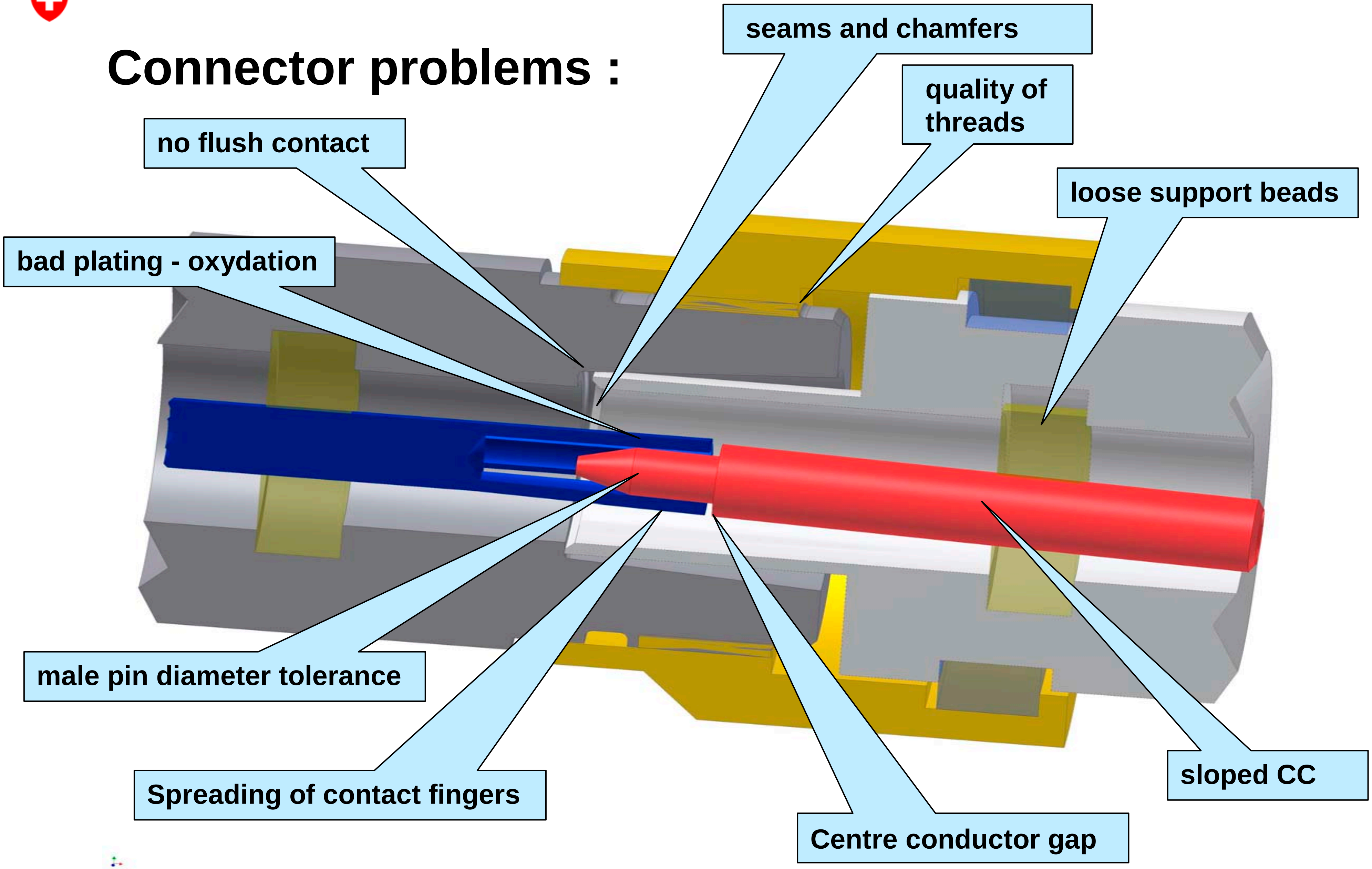
Juerg Ruefenacht

14.-16. April 2008

Pin gap aspects in metrological practice

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

Connector problems :



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 error effect**

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 287^{TM} - 2007)

Connector traceability project CoMo70

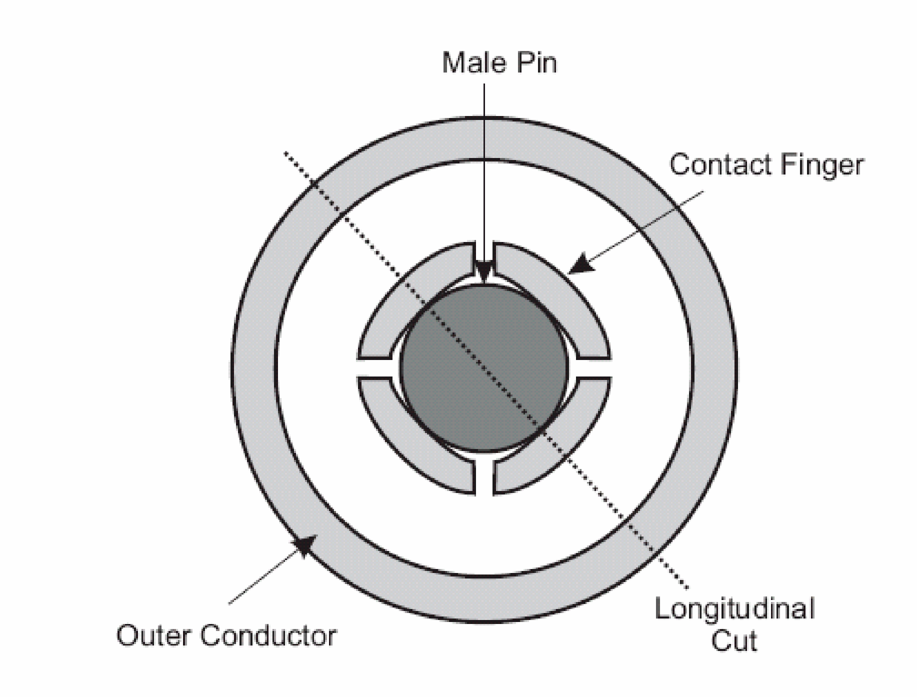
The main activities of the CoMo70 project are:

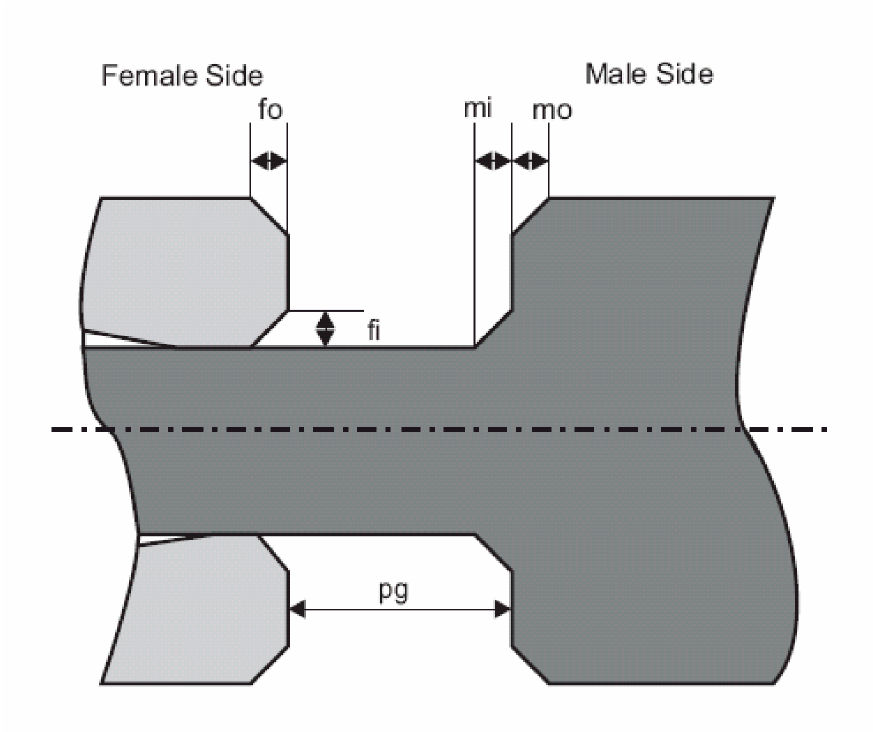
- **Modelling of coaxial connectors**
- **Modelling of coaxial calibration standards**
- **Traceability for industry grade connectors**
- **Development of new VNA calibration algorithms**

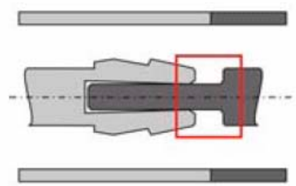
More information: http://people.ee.ethz.ch/~tcm70/

first CoMo70 project results:

1.85 mm connector interface effects

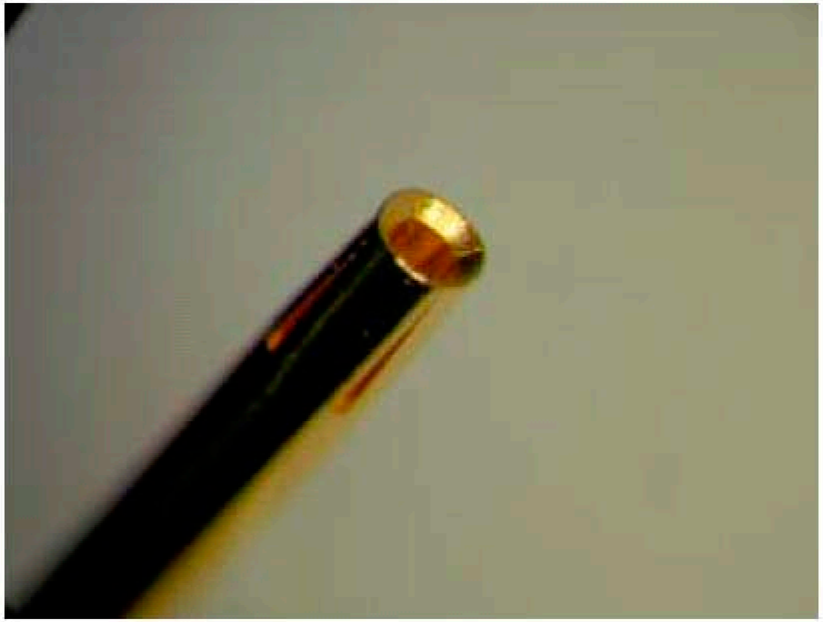




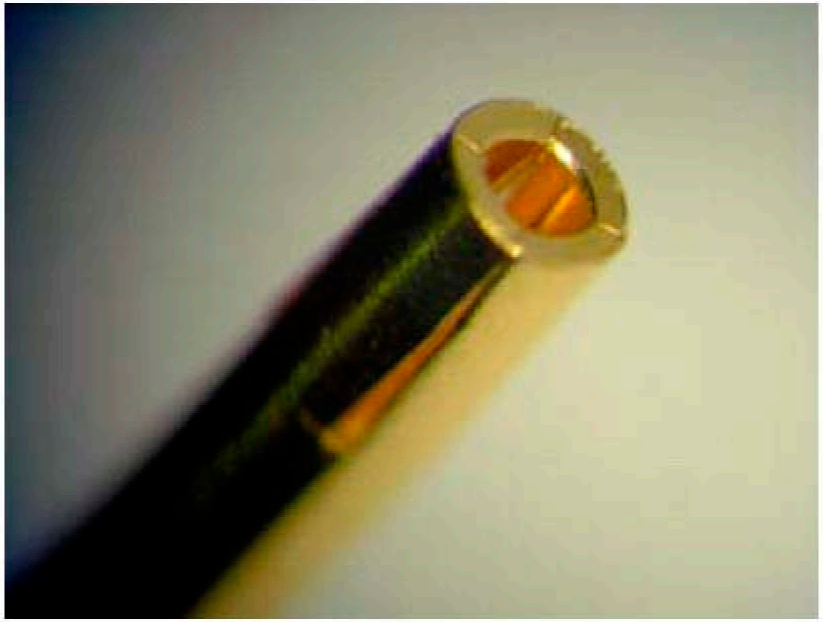


Johannes Hoffmann, ETHZ, CoMo70 project (Paper published at the EuMW 2007)

first CoMo70 project results:



Big inner female chamfer



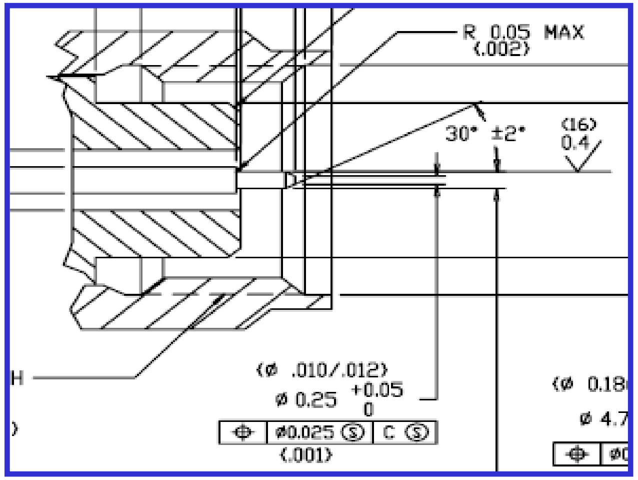
Small inner female chamfer

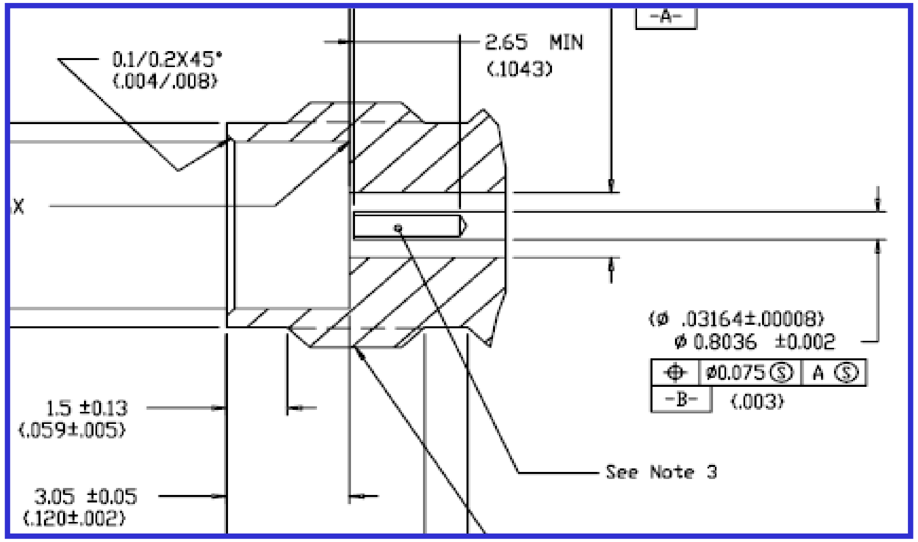
IEEE Standard for Precision Coaxial Connectors (DC to 110 GHz)

IEEE Std 287™-2007

(Revision of IEEE Std 287-1968)

Detail specifications for precision coaxial 1.85 mm connectors





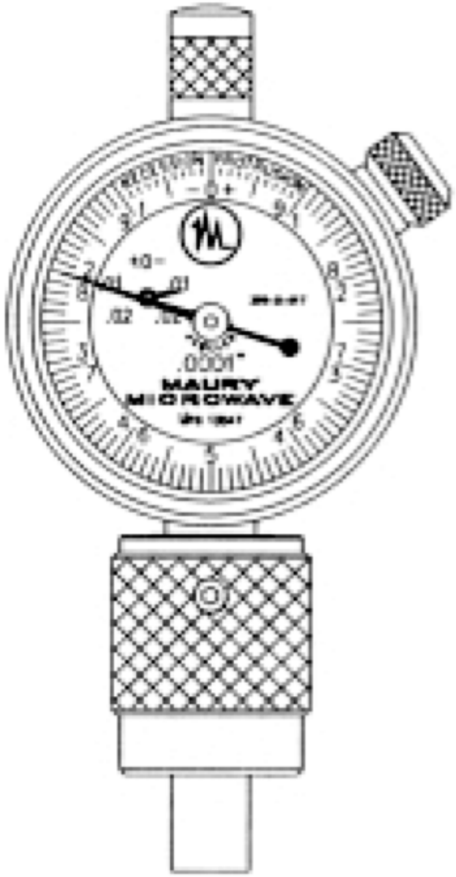
Critical mechanical specifications are missing!

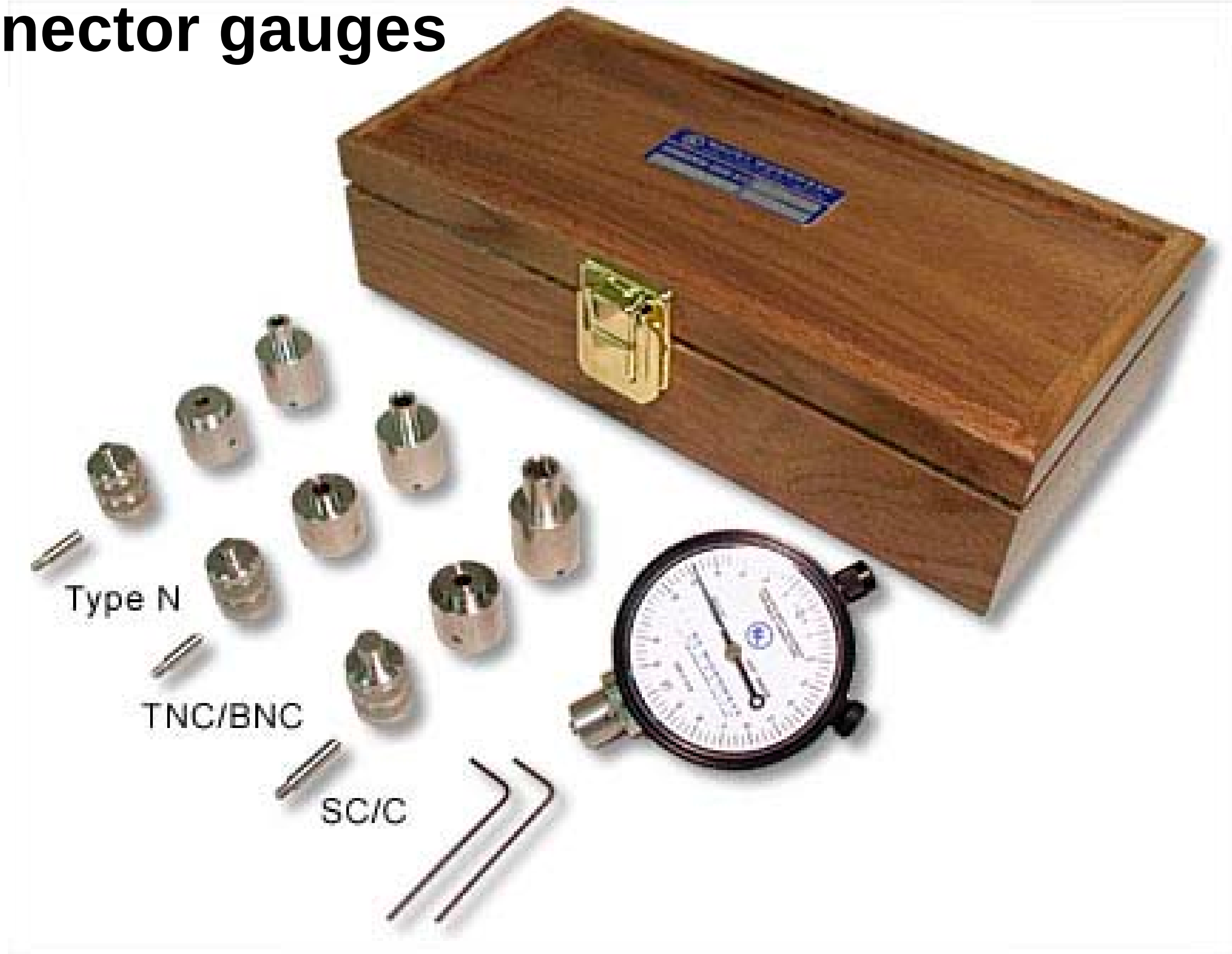
Pin-depth measurements and traceability

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

Compressed measurement
(undefined – no control)

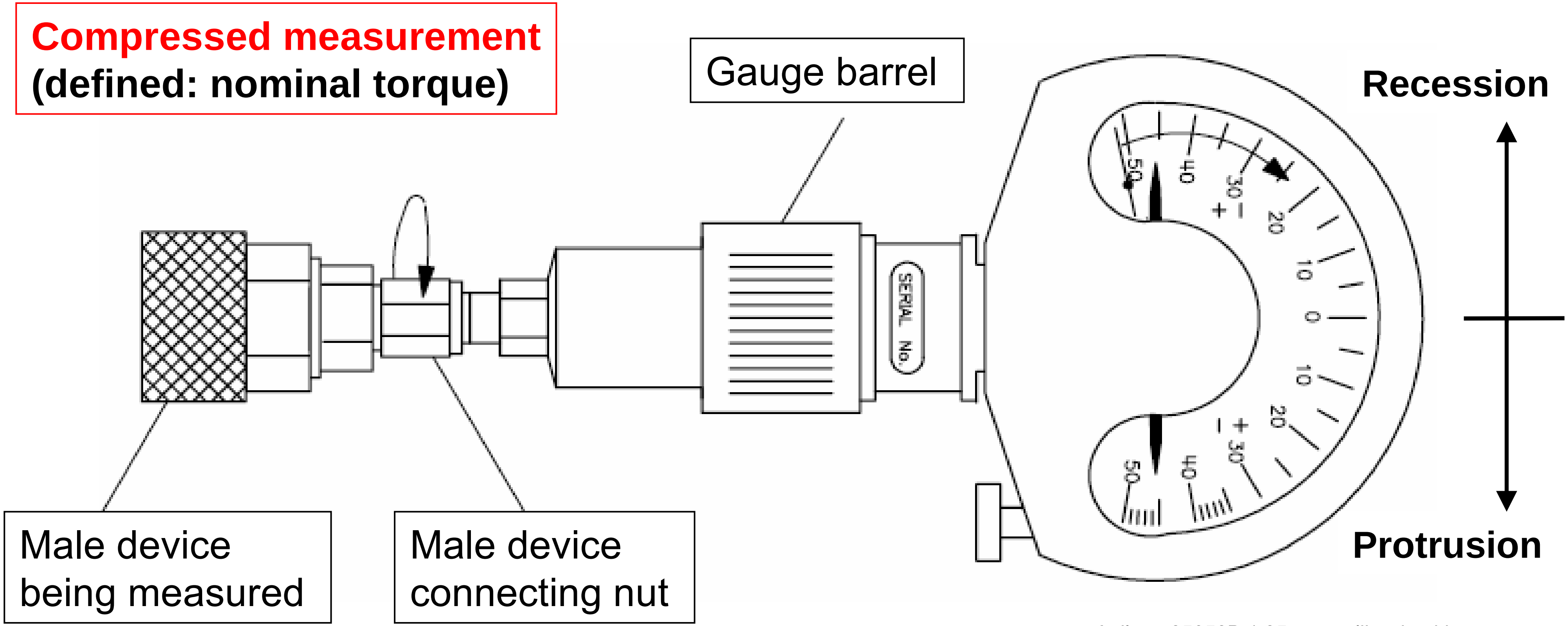
„Push-on" connector gauges





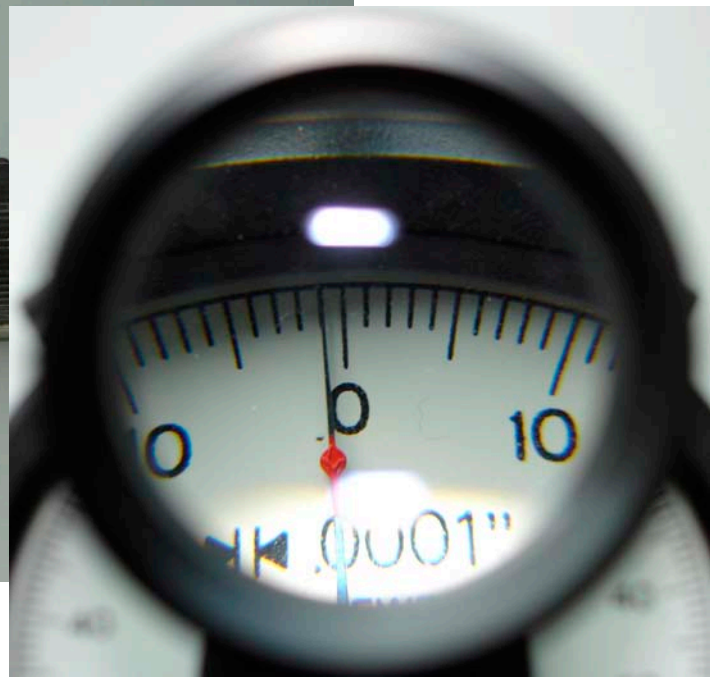
„Screw-on" or "thread-on" connector gauges

Example of a Male type connector gauge:



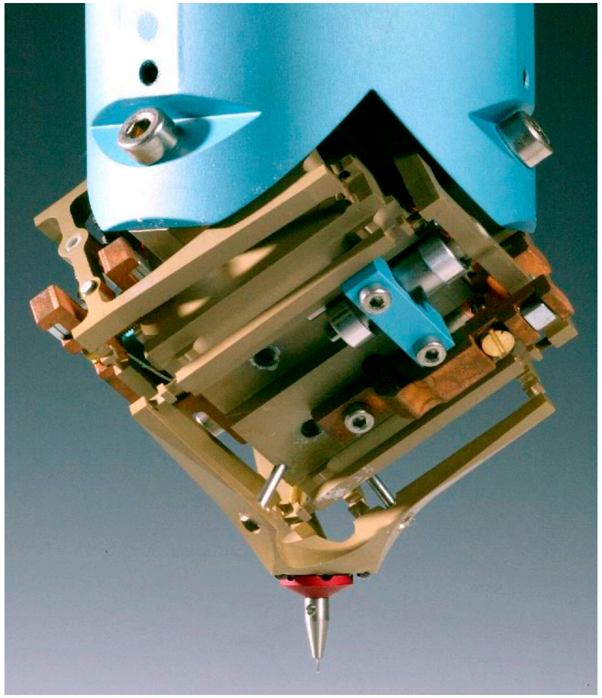
Agilent 85058B 1.85 mm calibration kit

More accurate pin-depth reading:



µ-CMM project at METAS

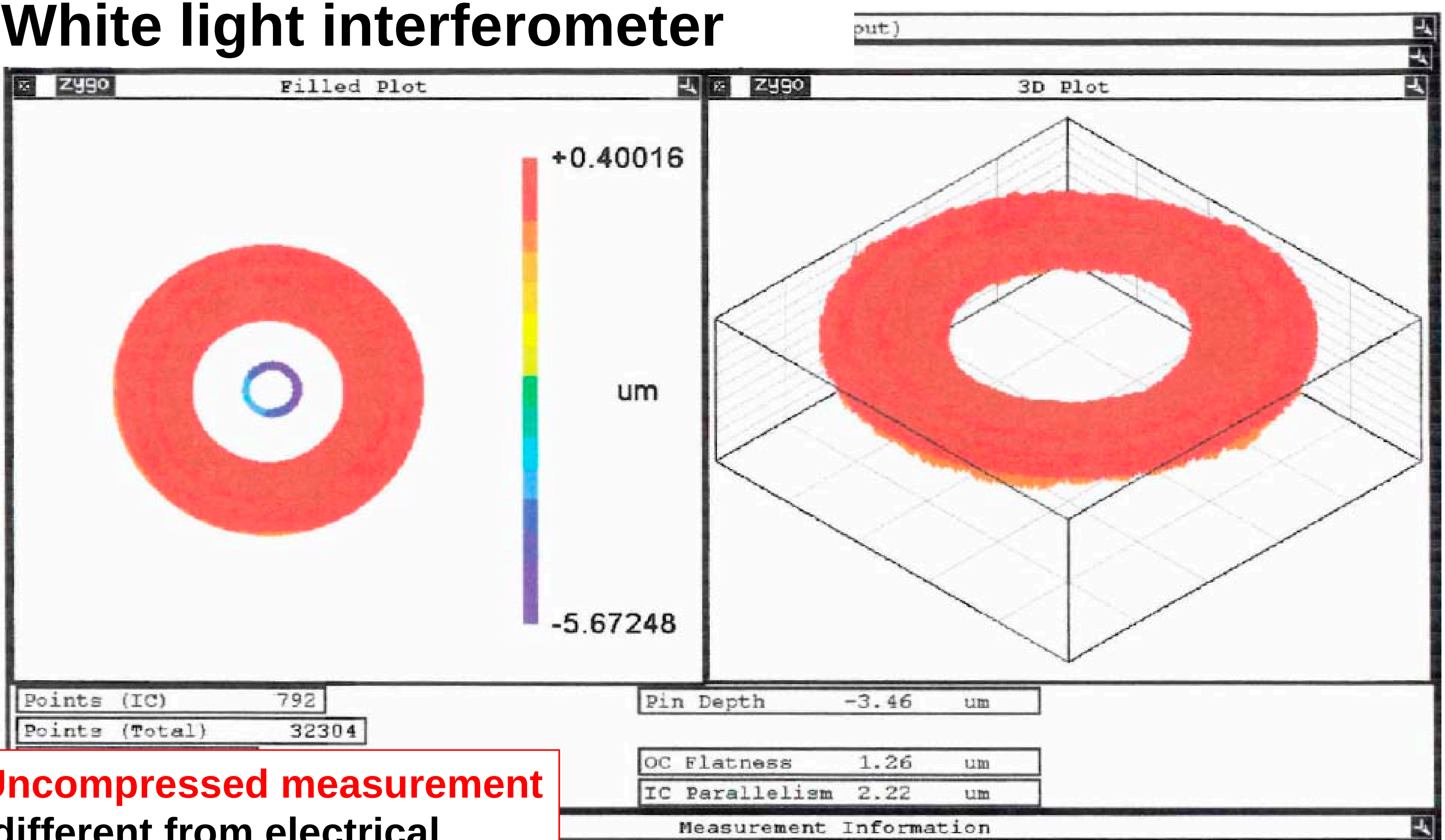
Uncompressed measurement
(different from electrical measurement situation)


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 µm

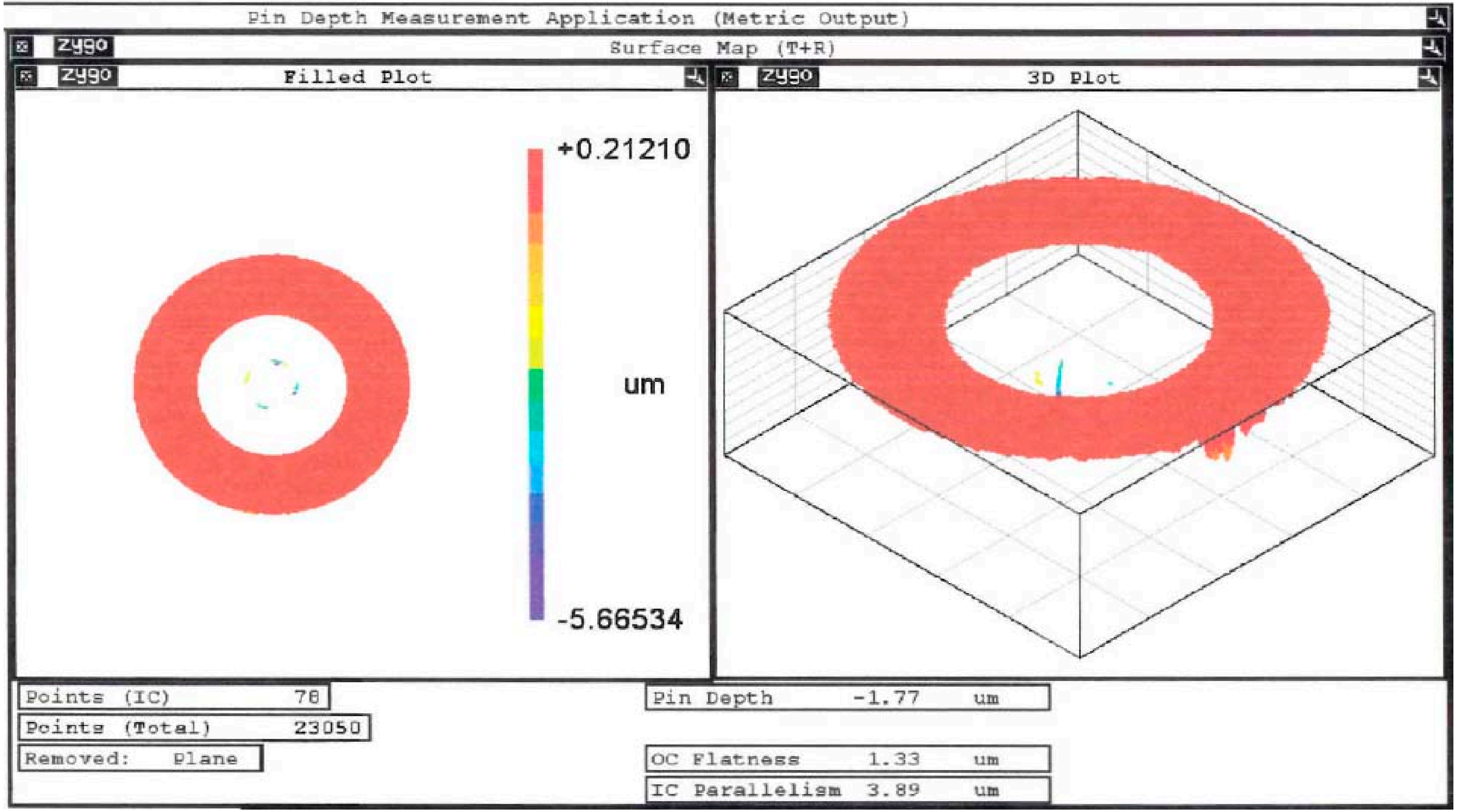
DUT: male connector

White light interferometer



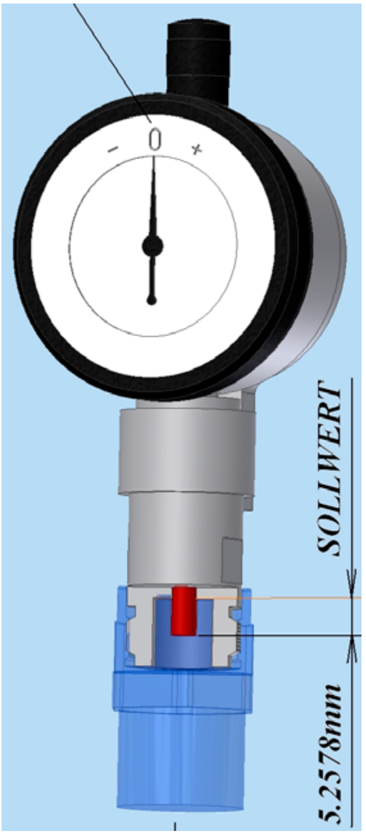
Uncompressed measurement
(different from electrical measurement situation)

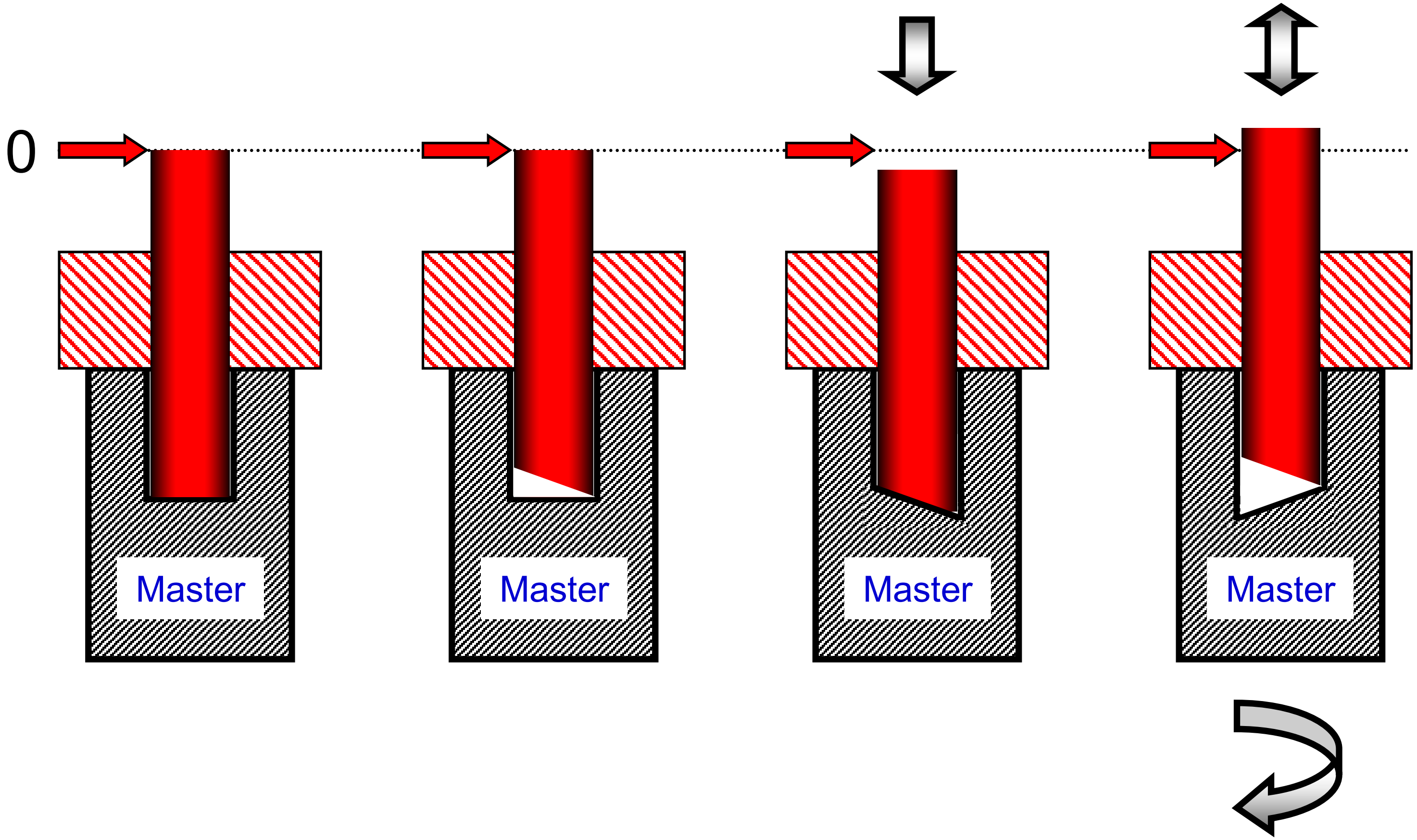
DUT: female connector



Example: Pin-depth measurement problems using gauges

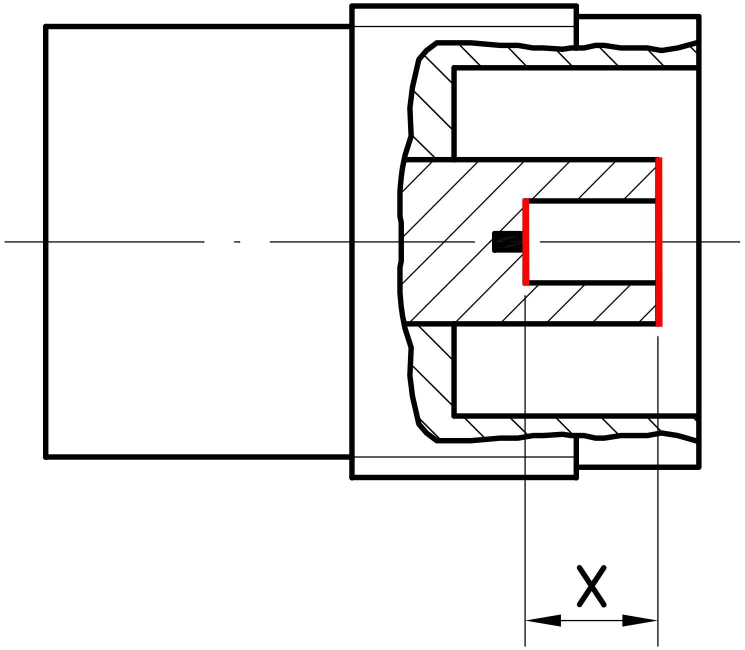
Effects due to non parallel reference planes:





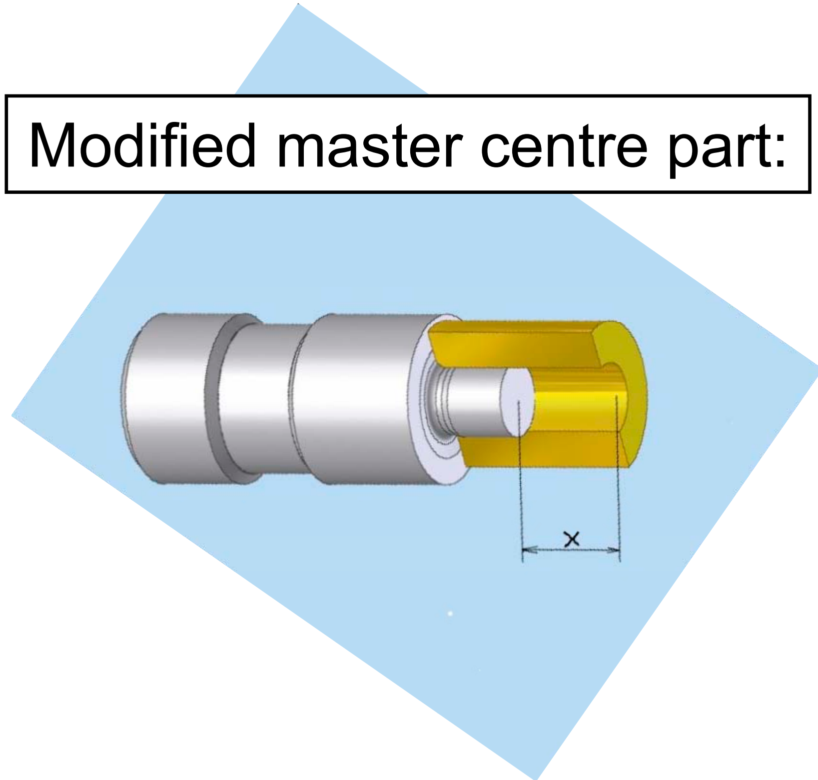
Pin-depth measurement problems using gauges:

Bad defined planes (surface quality and parallelism)



CMM uncertainty: 0.004 mm

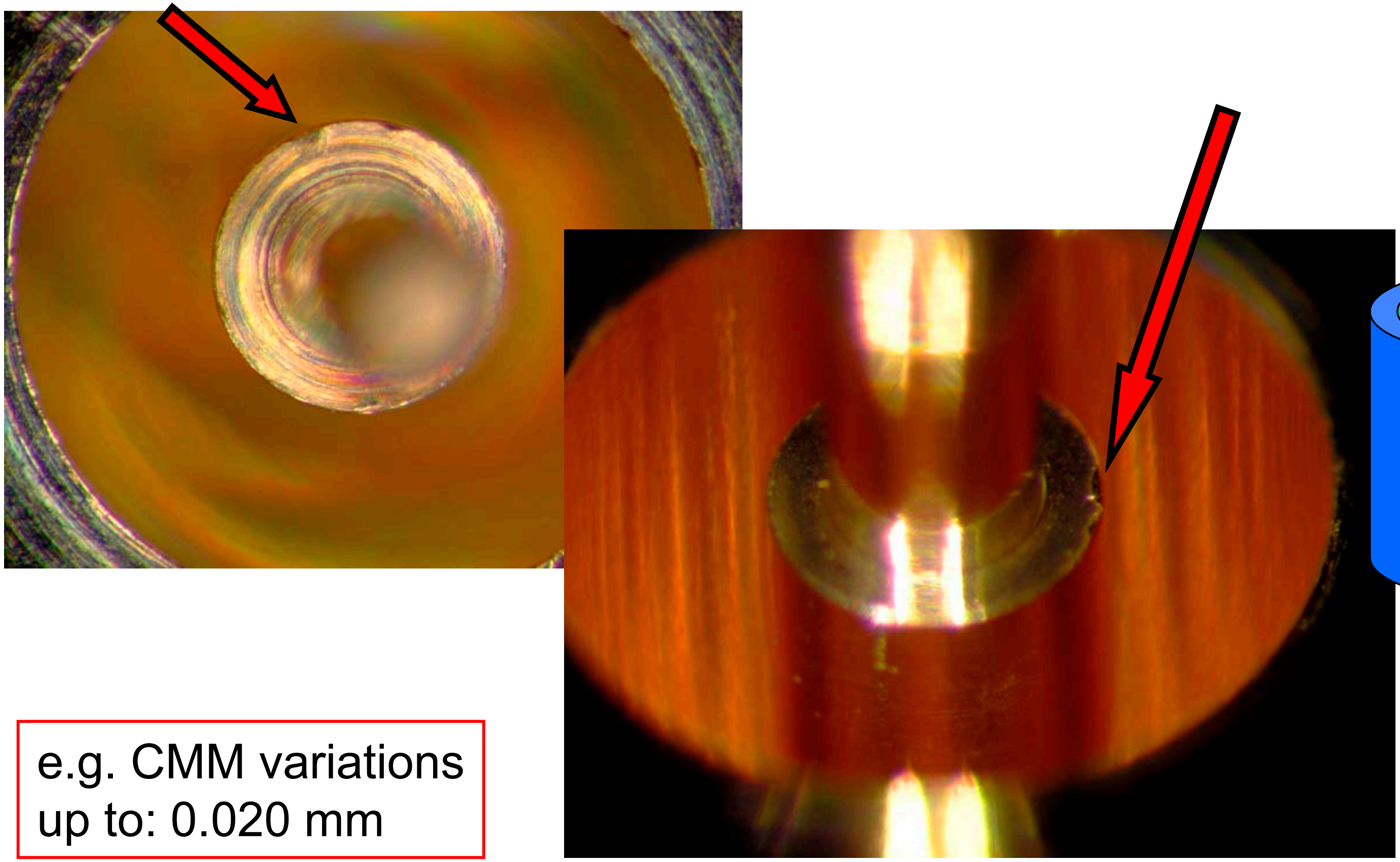
Modified master centre part:

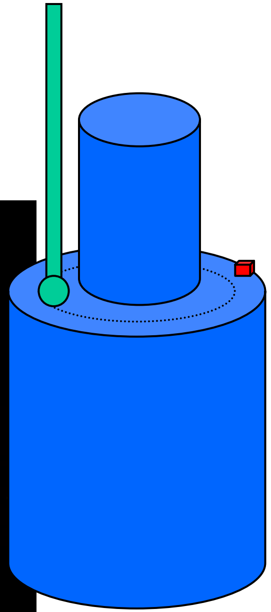


CMM uncertainty: 0.001 mm

µ-CMM probing issue: CC pin shoulder not well definded

Bad defined planes (surface quality and parallelism)





e.g. CMM variations
up to: 0.020 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:

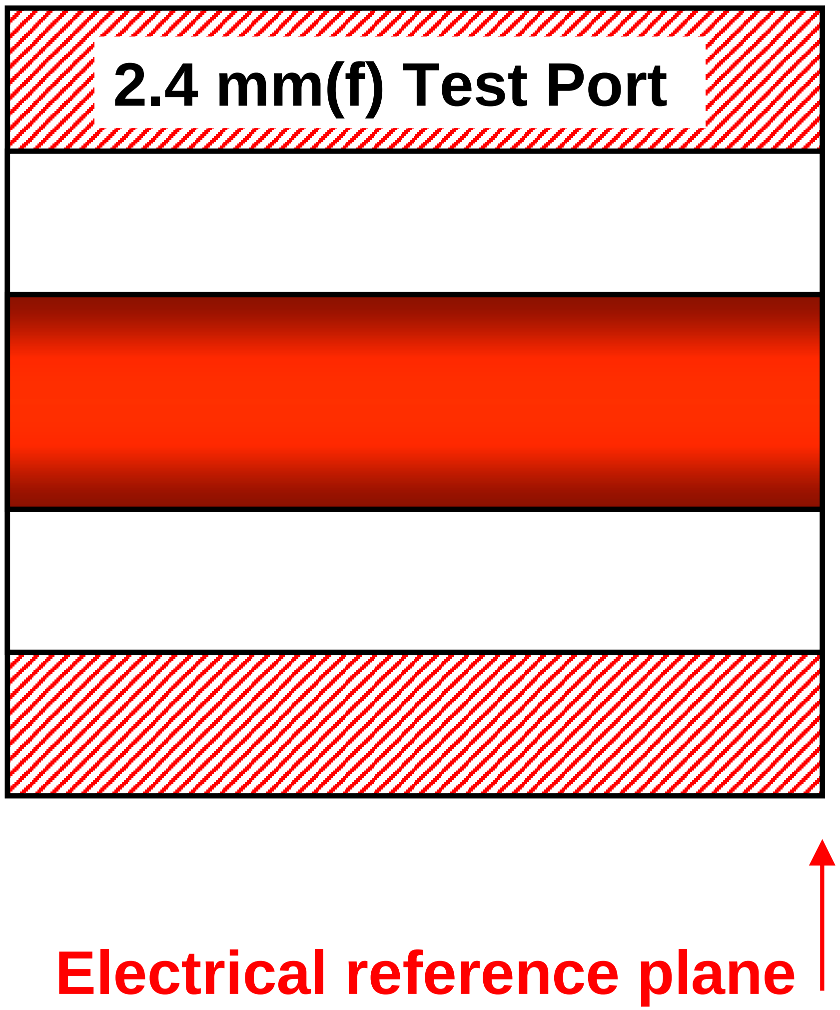
- **Expensive hardware and time consuming**
- **High uncertainties for mating planes with bad quality**
- **No torque used – uncompressed condition**
- **Significance of the measurement results**
- **…**

Pin gap effects in electrical measurements

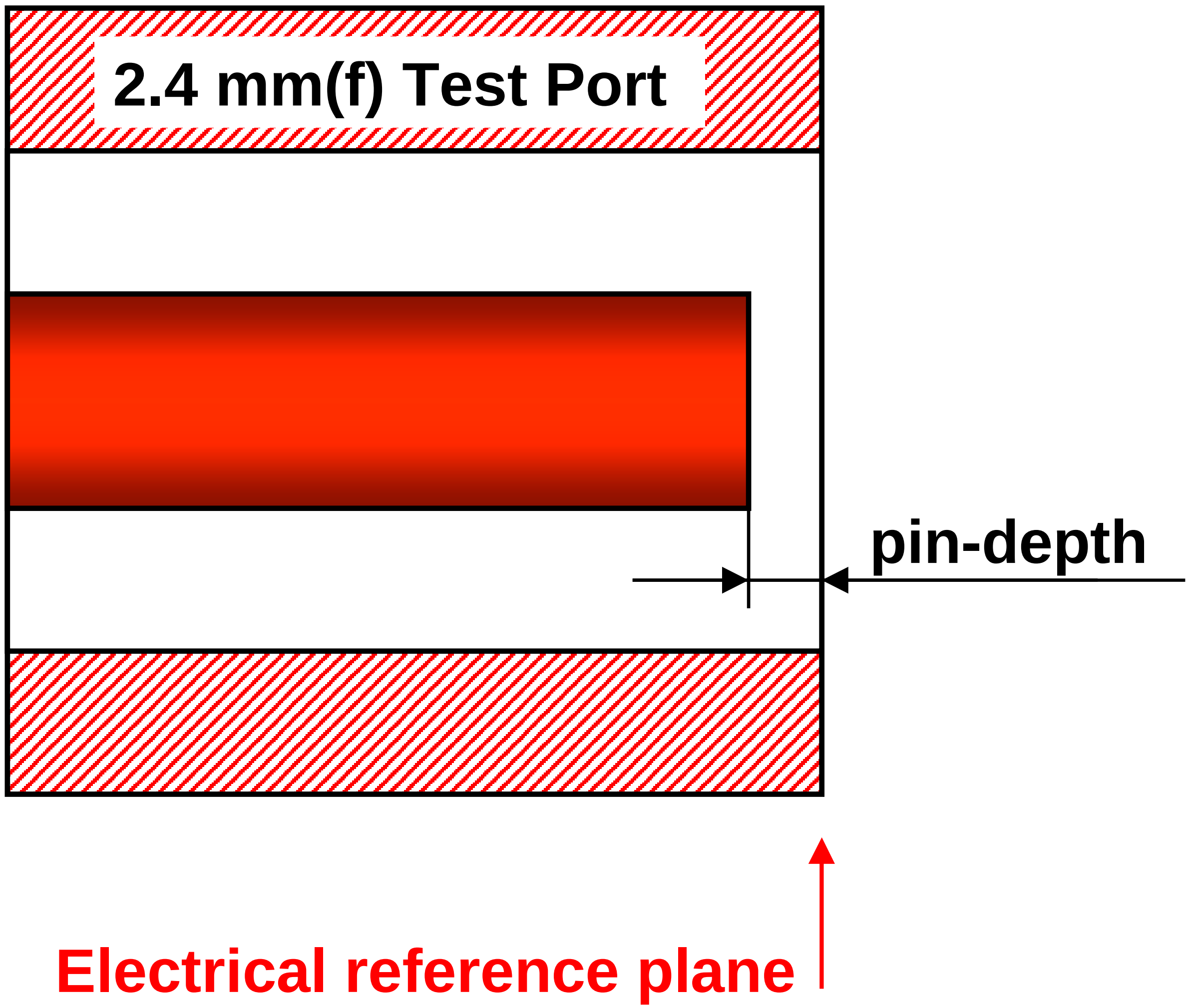
Some typical pin gap issues:

- **Recession versus protrusion**

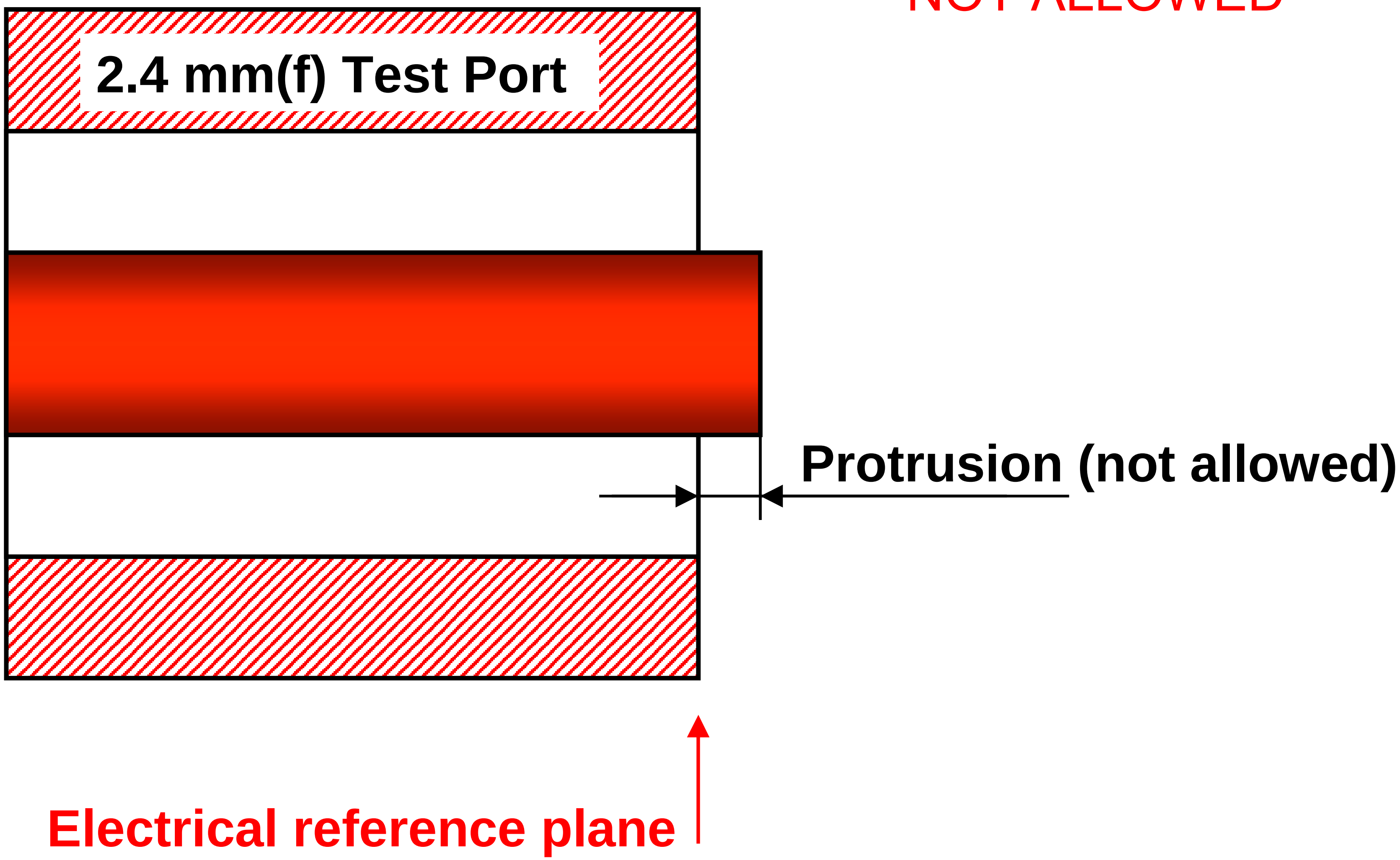
- slotless female CC
- no pin-depth present



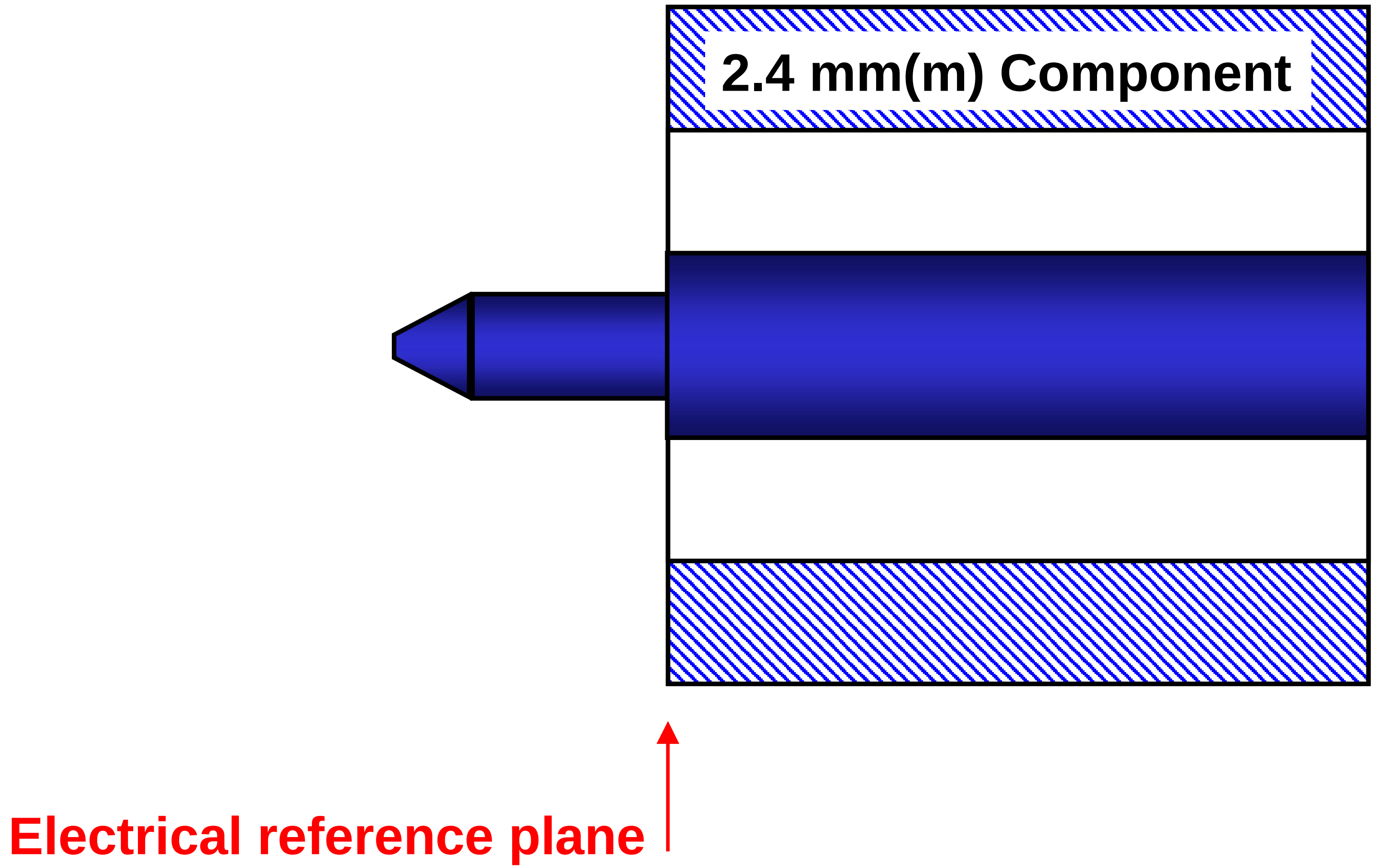
- Slotless female CC
- pin-depth: recession



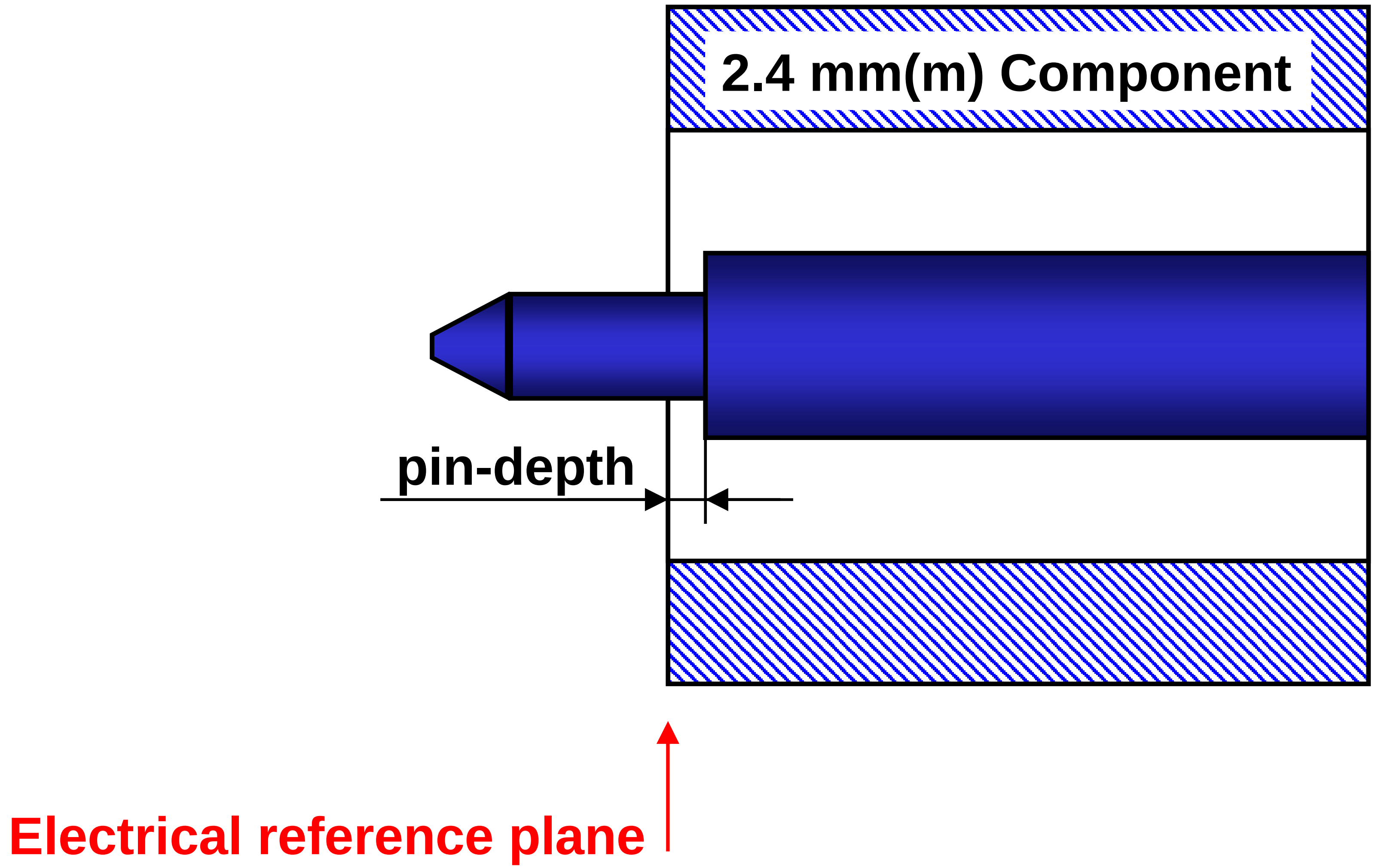
- Slotless female CC
- pin-depth: protrusion
- NOT ALLOWED



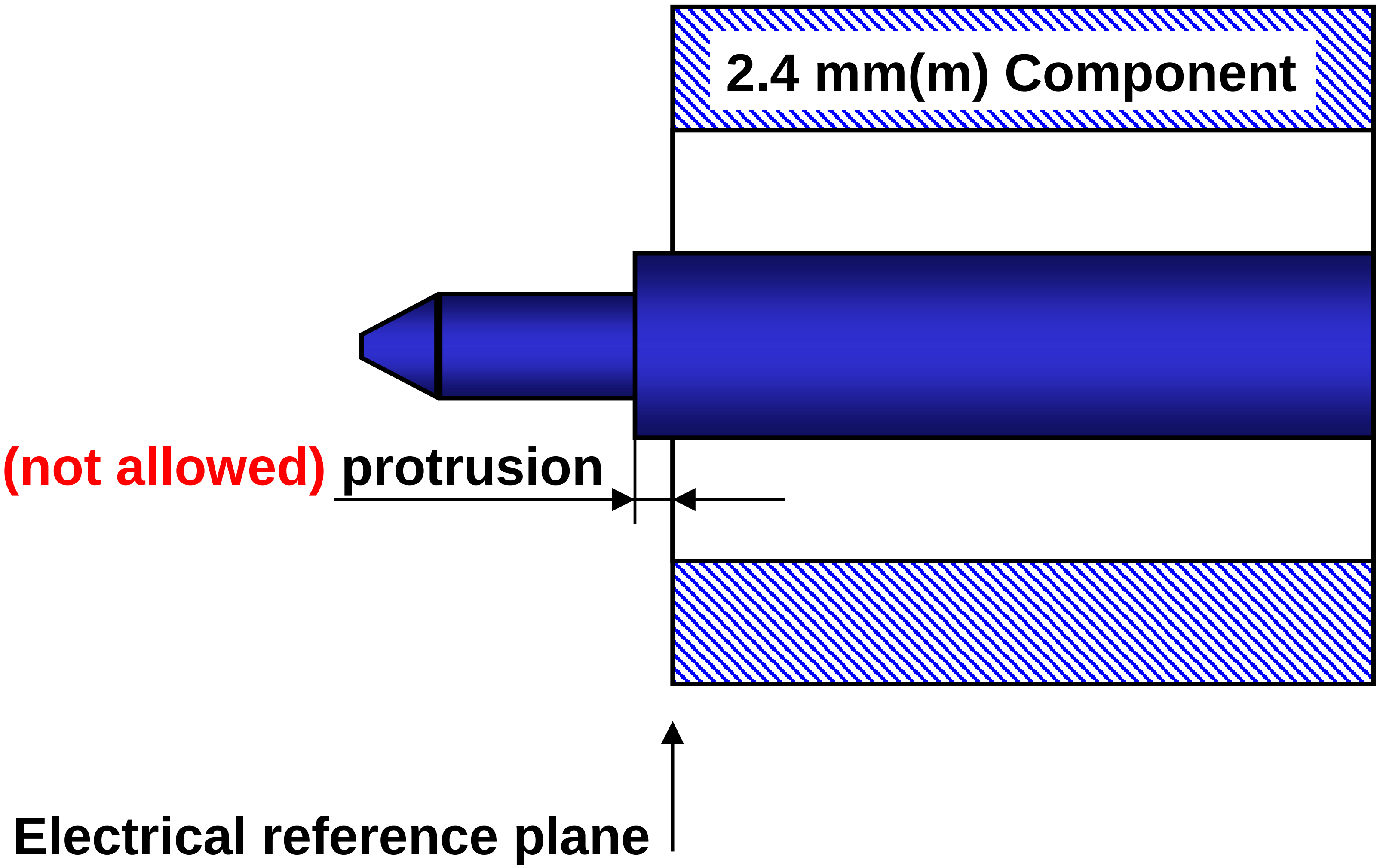
- male CC
- no pin-depth present



- male CC
- no pin-depth present



- male CC
- no pin-depth present



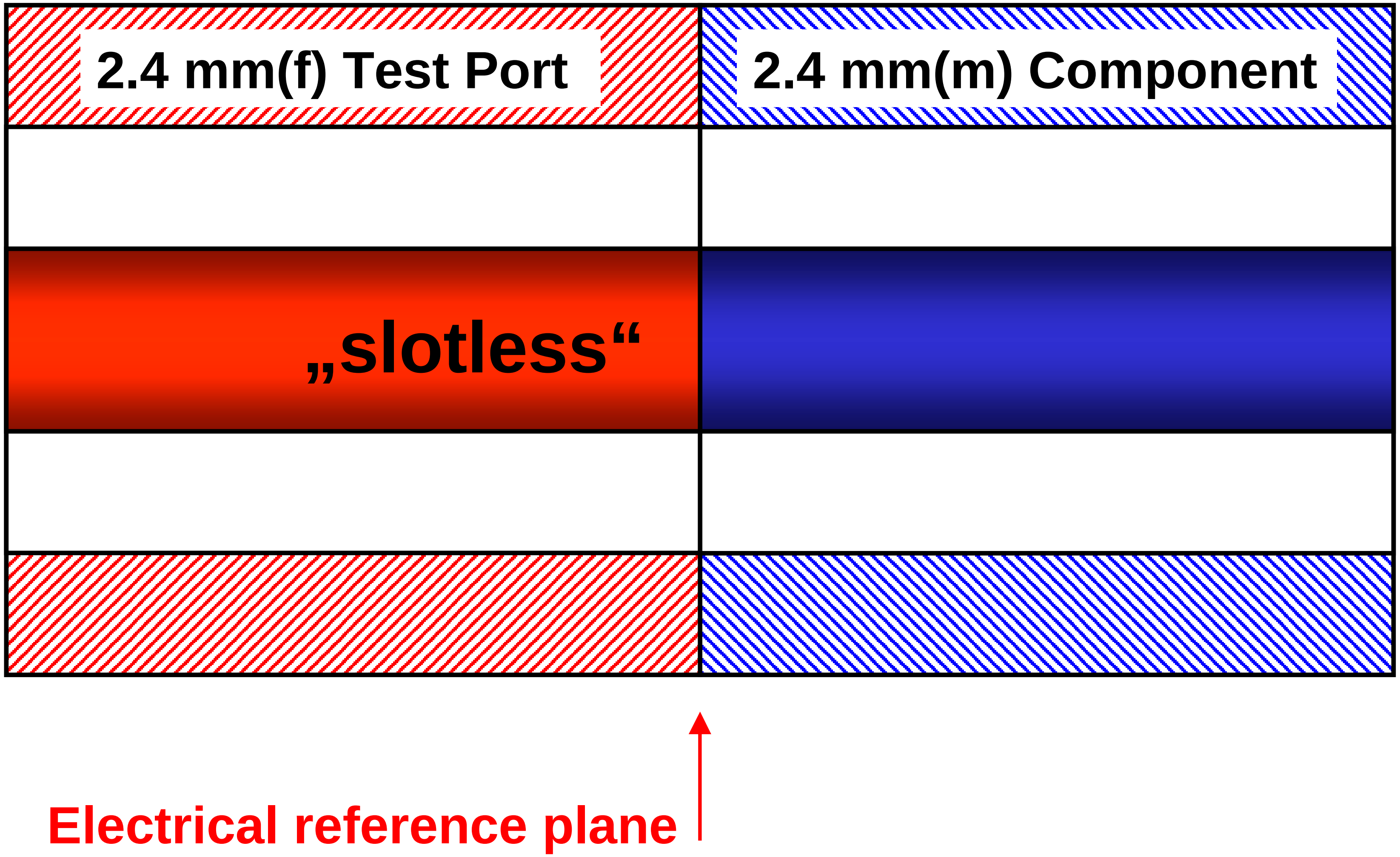
Pin gap effects in electrical measurements

Some typical pin gap issues:

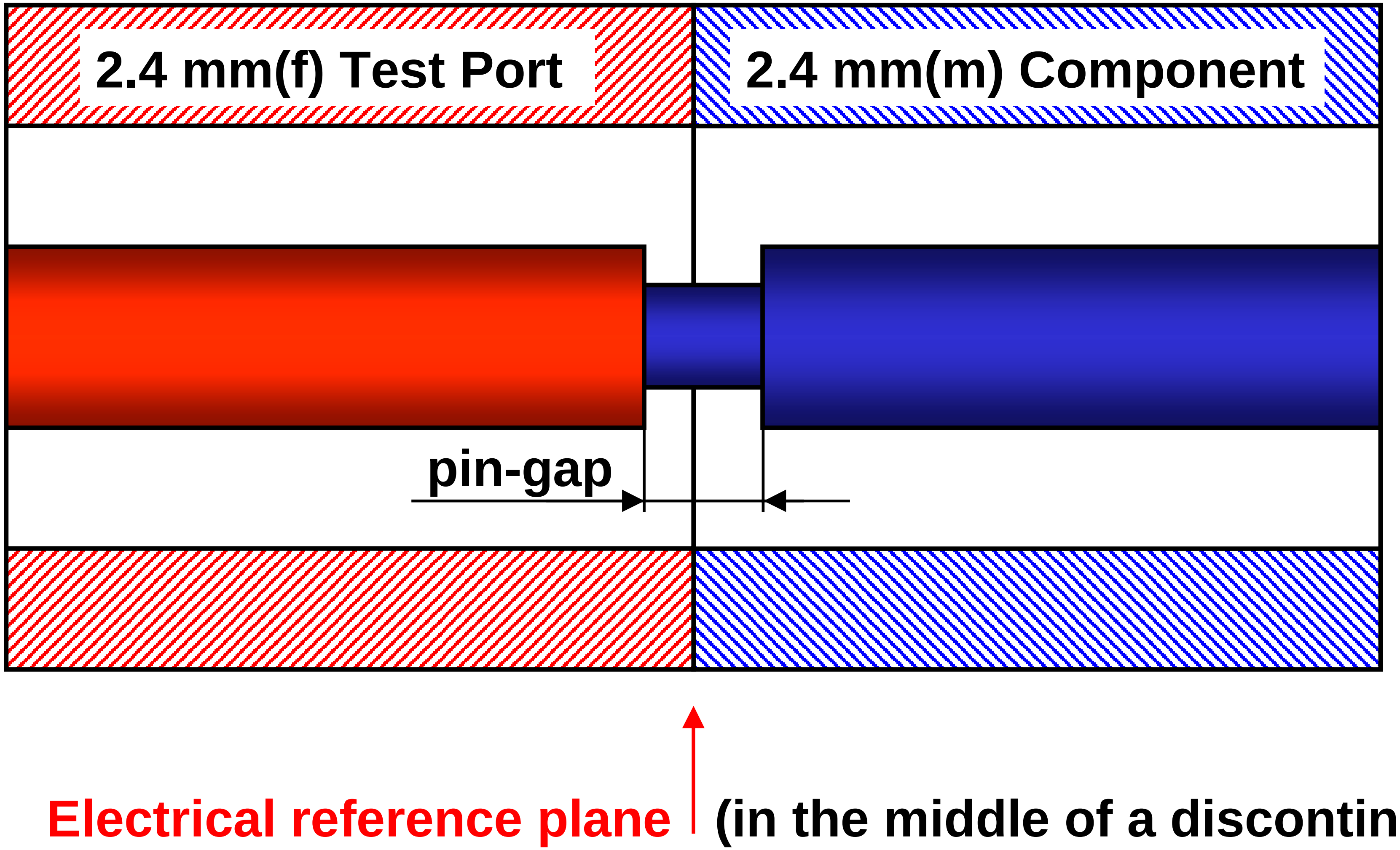
- Recession versus protrusion
- Nominal Test Port (TP) – 50 ohm definition

„nominal TP“

- Slotless female CC
- Ideal connection (50 ohm)

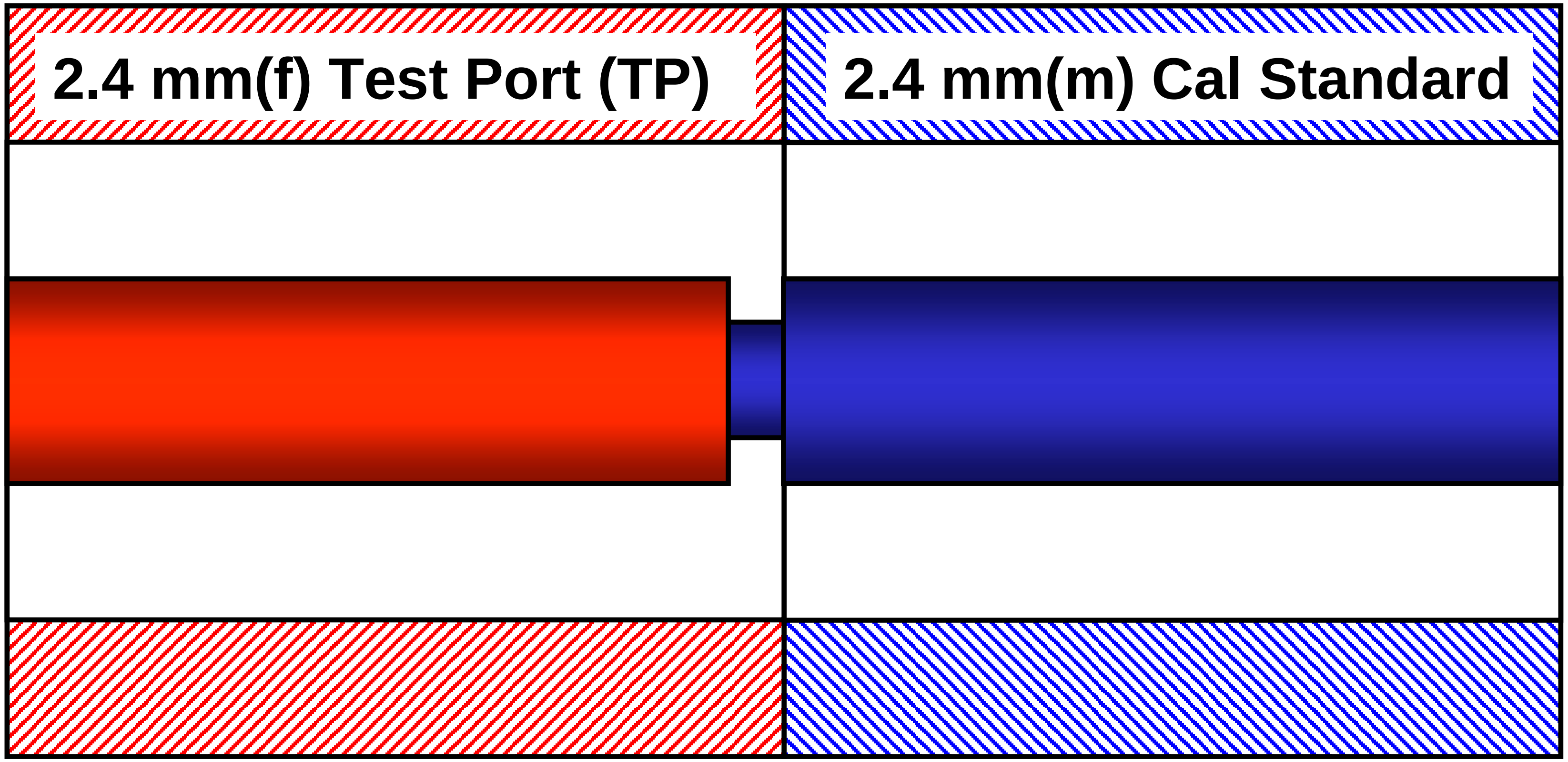


- Typical connection
- Pin-depth on both sides



Electrical reference plane (in the middle of a discontinuity)

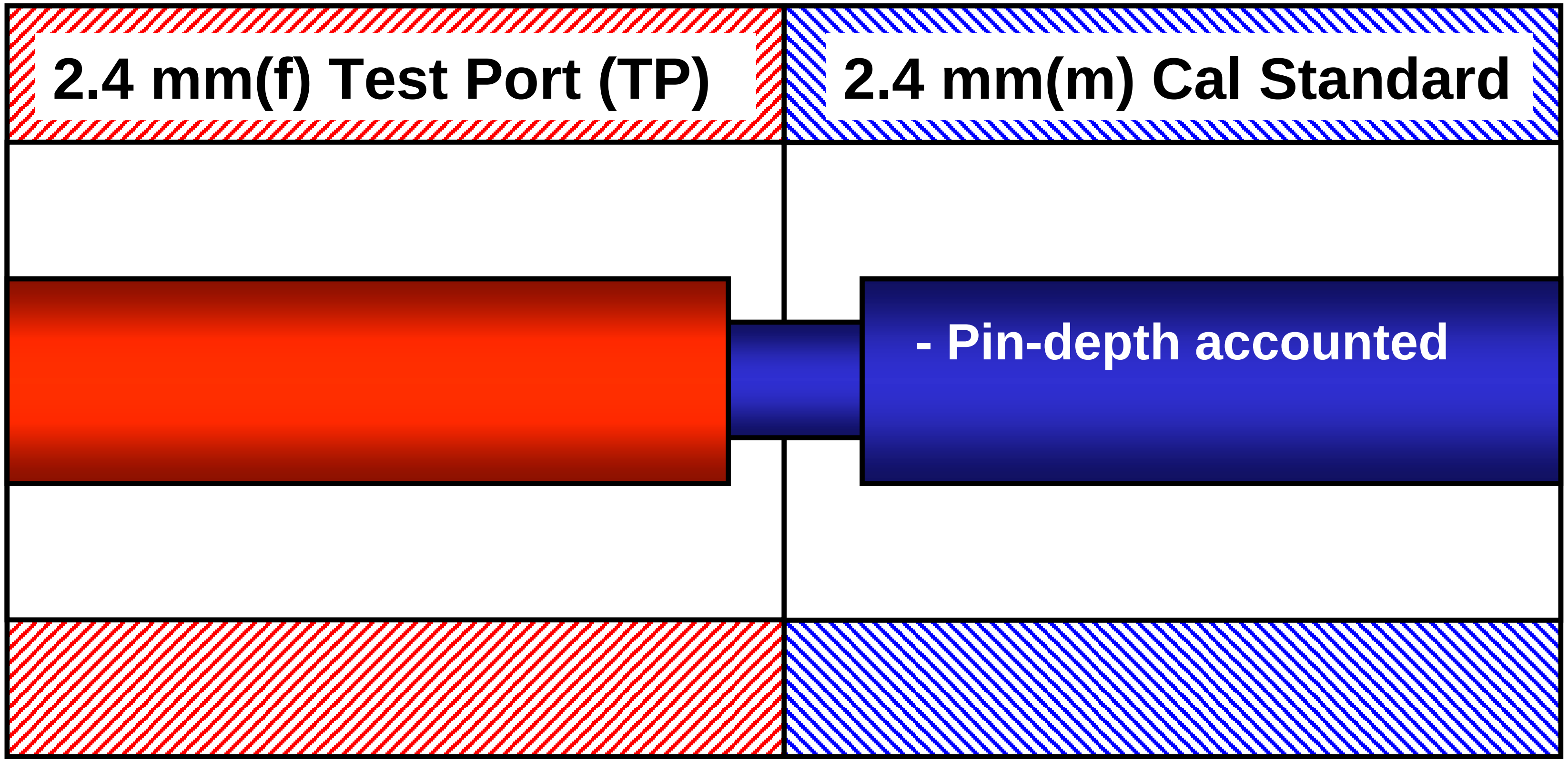
- 1 Port calibration (OSL)
- Cal Standard ideal



Example:
- Open
- Short
- Load
- SL
- Air line

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“



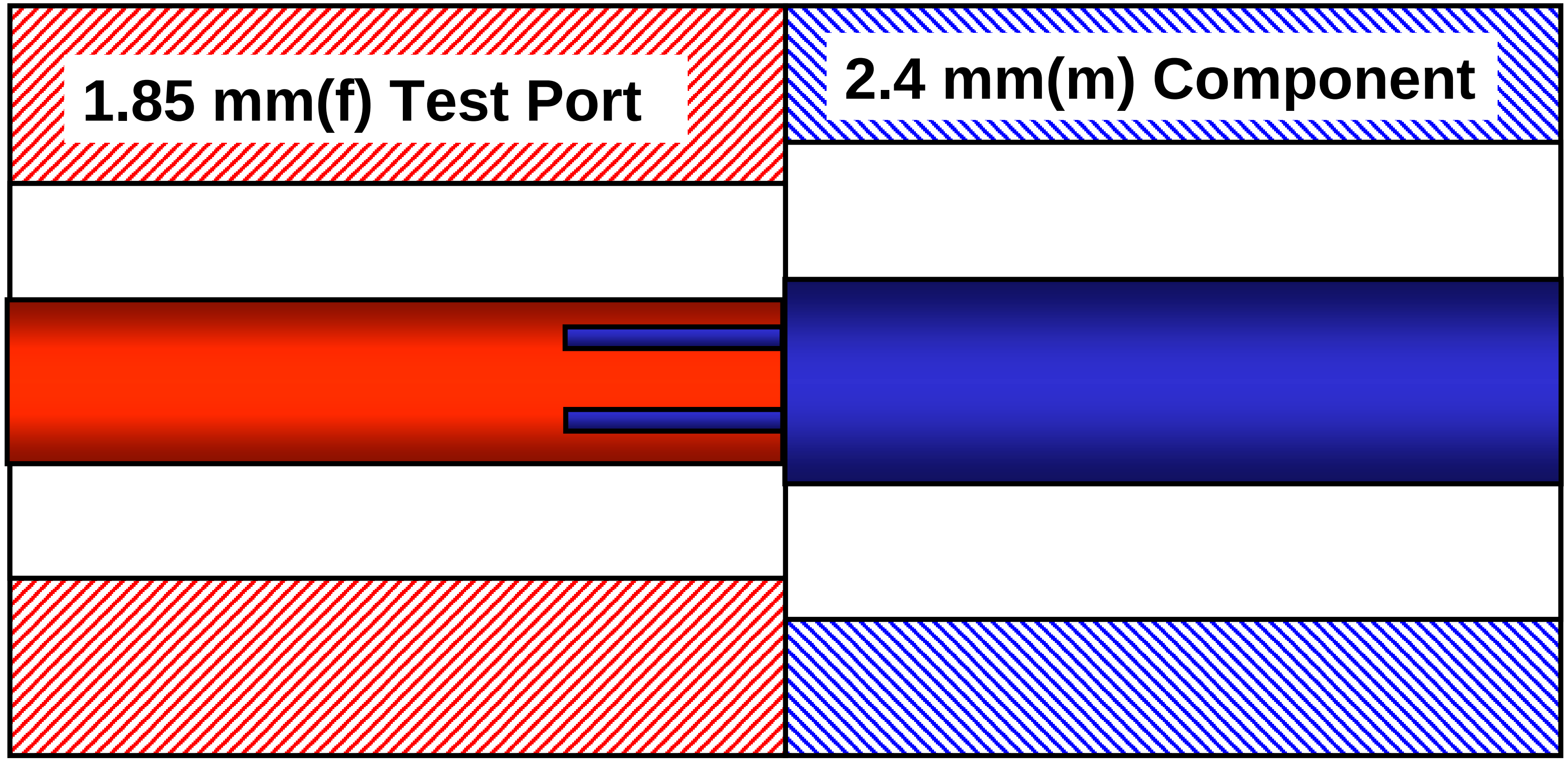
The error introduced by the TP gap is „absorbed“ in the error box of the calibration model of the VNA

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)

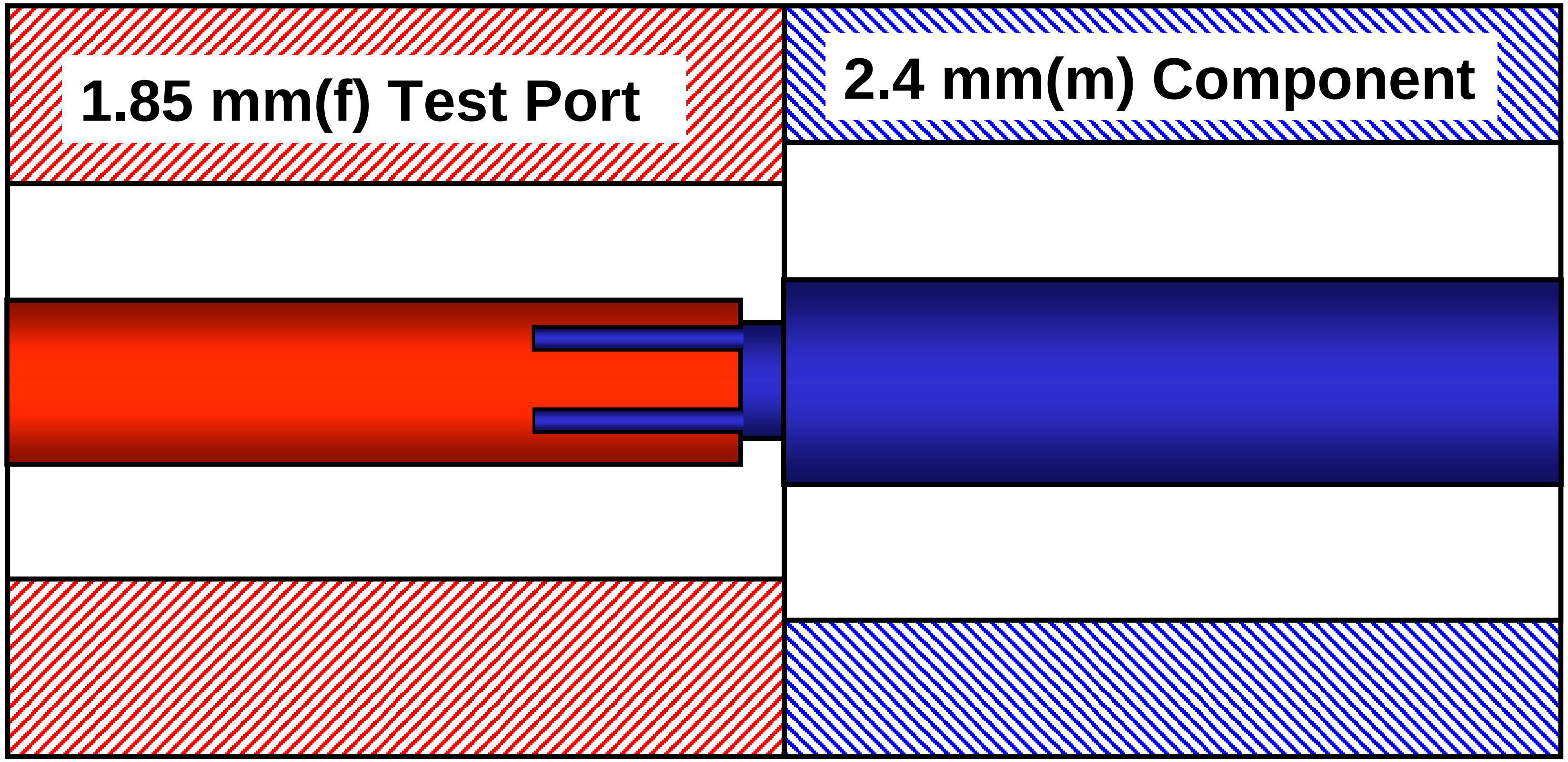
- Slotted female CC
- Matable interfaces



1.85 mm to 2.4 mm compatibility requirement:

huge challenge in the design of slotless 1.85 mm connectors

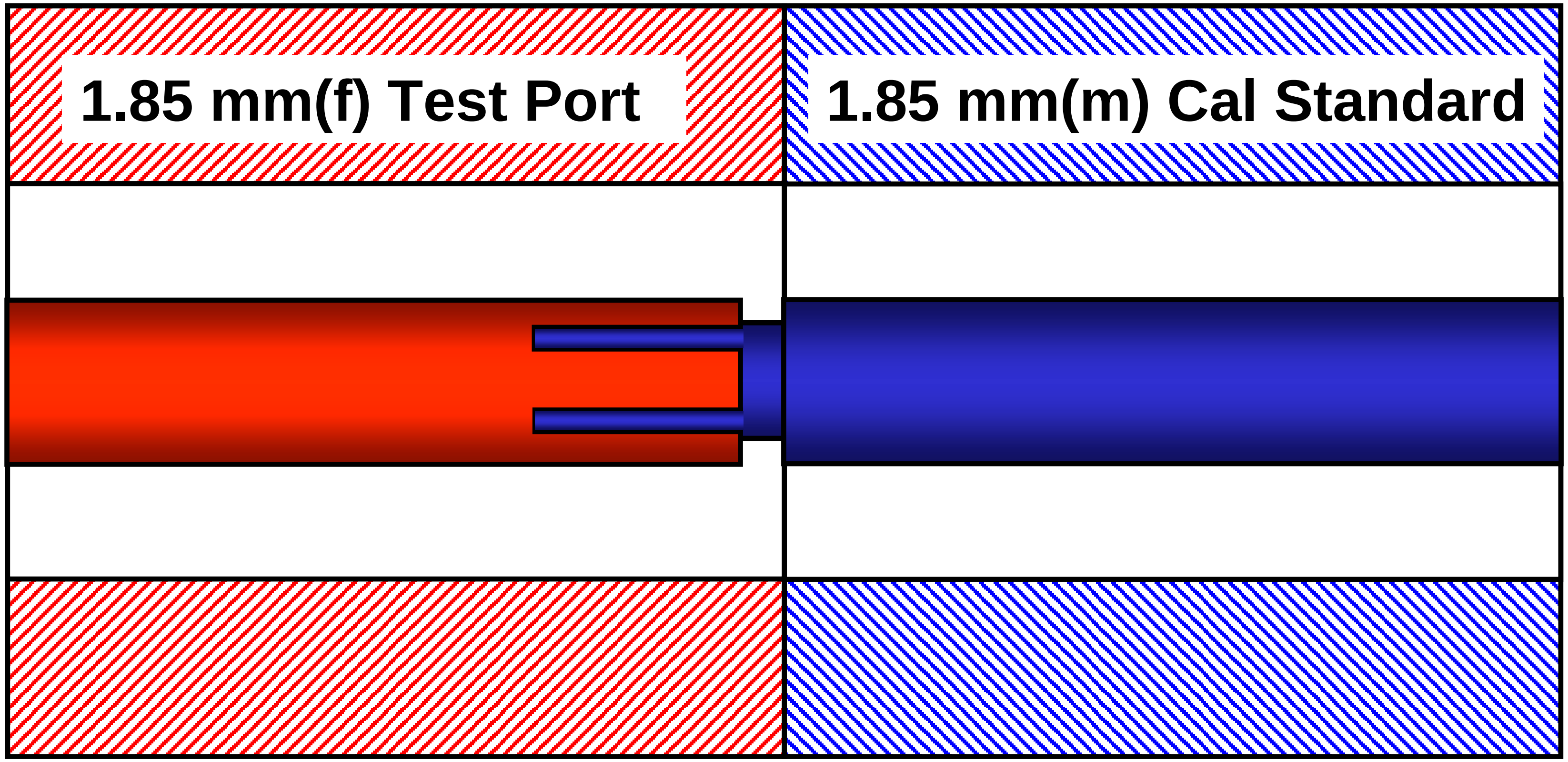
- Slotted female CC
- same male pin diameter



1.85 mm to 2.4 mm compatibility requirement

design space for the contact fingers: only (0.2926 mm / 2)

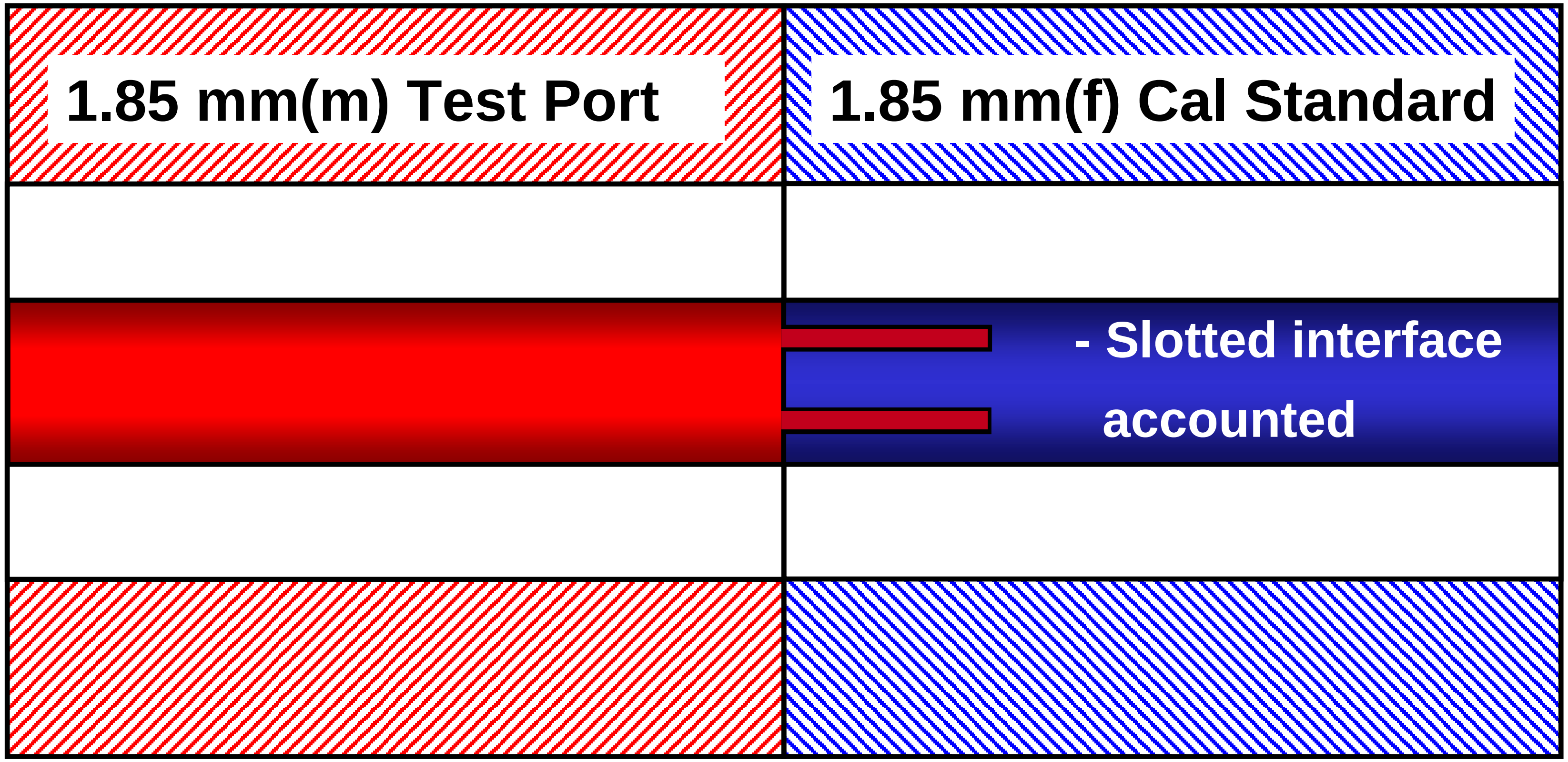
- Slotted female CC
- Cal Standard ideal



Example:
- **Open**
- **Short**
- **Load**
- **SL**
- **Air line**

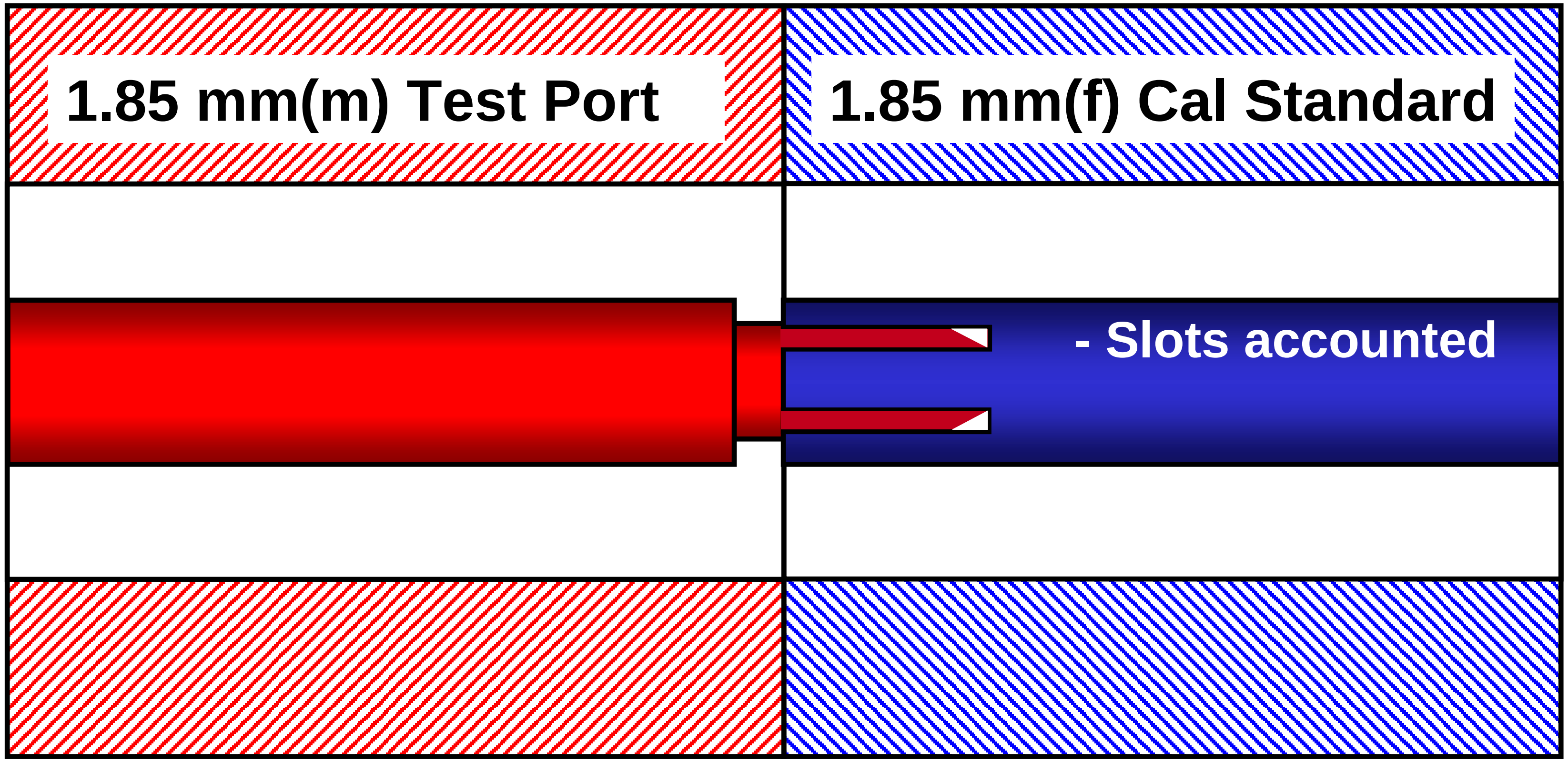
The error introduced by the TP will become „absorbed“ into the error box of the calibration model of the VNA

- Slotted female CC
- Cal Standard corrected



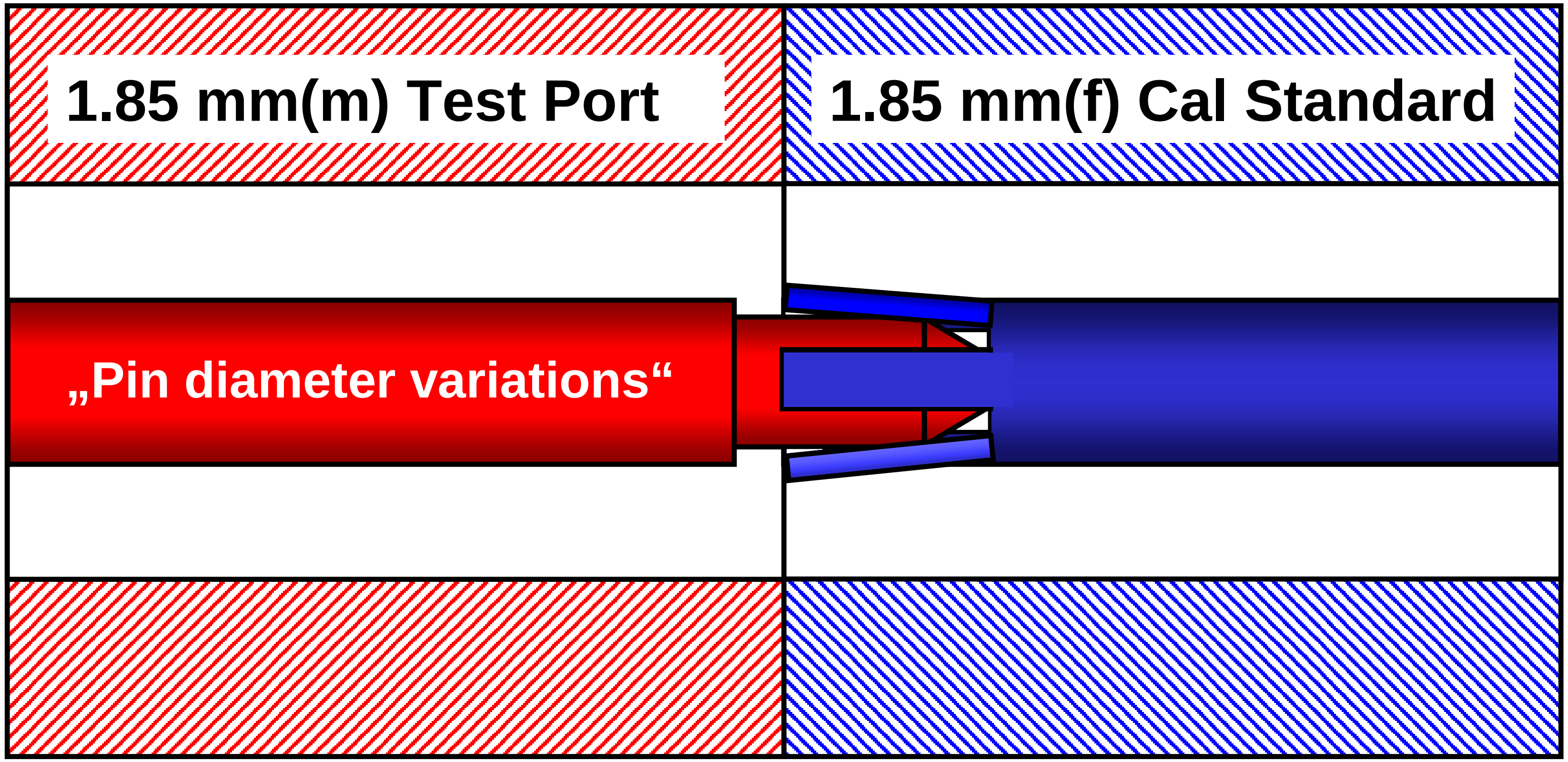
The error introduced by the slotted interface is taken into account in the standard definitions of the calibration standard

- Slotted female CC
- Cal Standard „corrected“



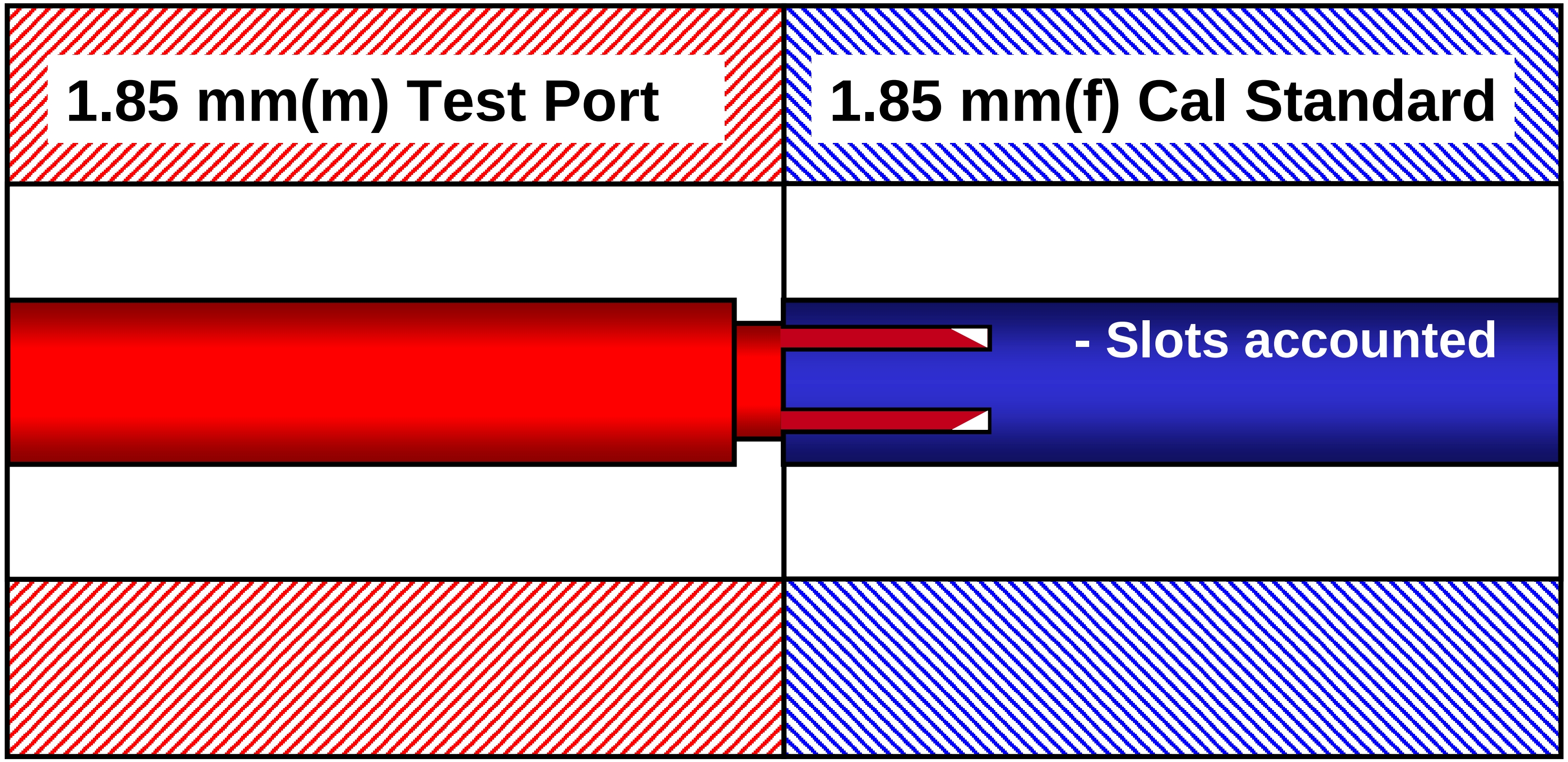
The error introduced by the TP will become „absorbed“ into the error box of the calibration model of the VNA

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



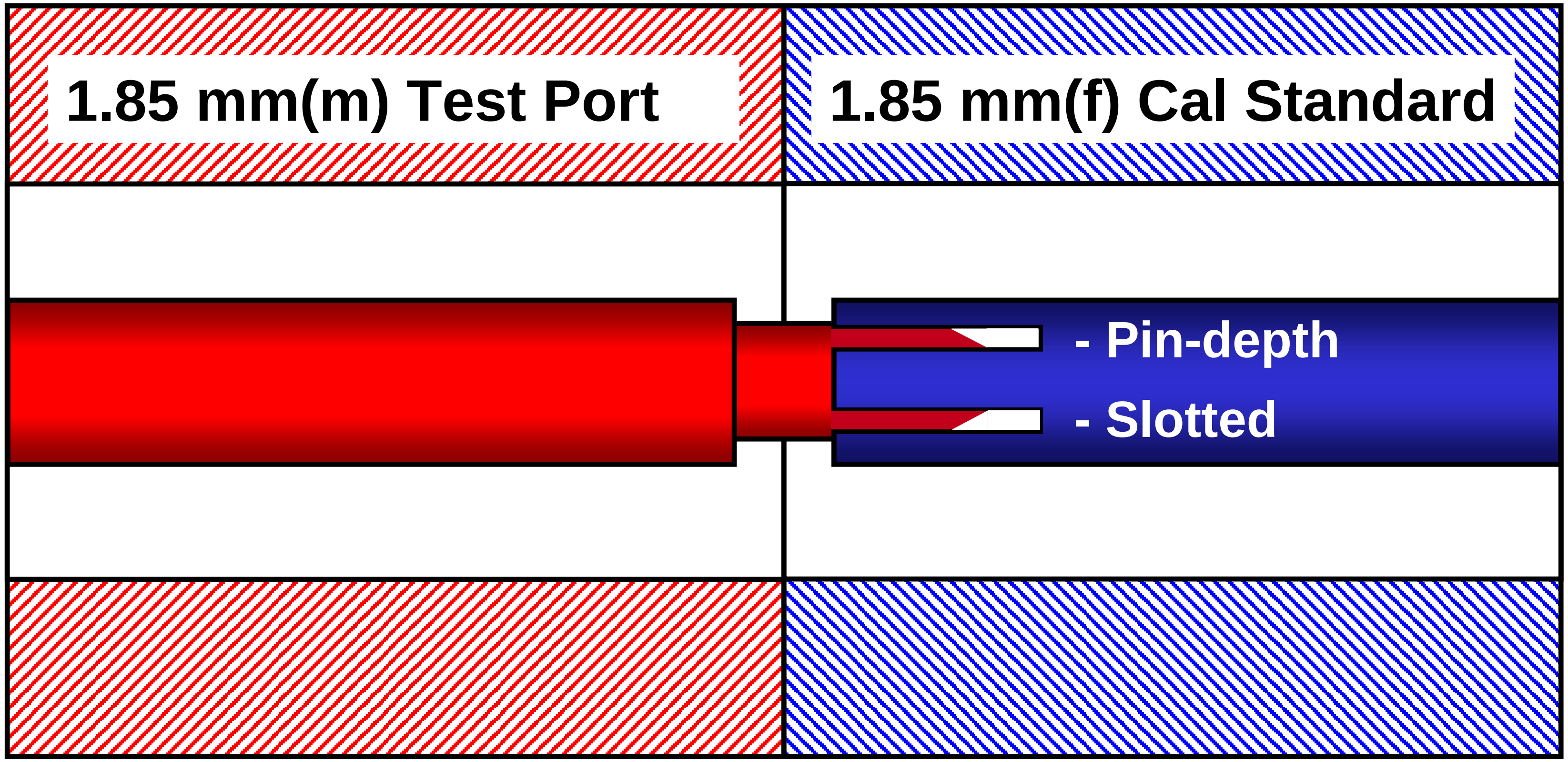
The error introduced by the TP will change the impedance characteristics of the connected calibration standard

- 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“



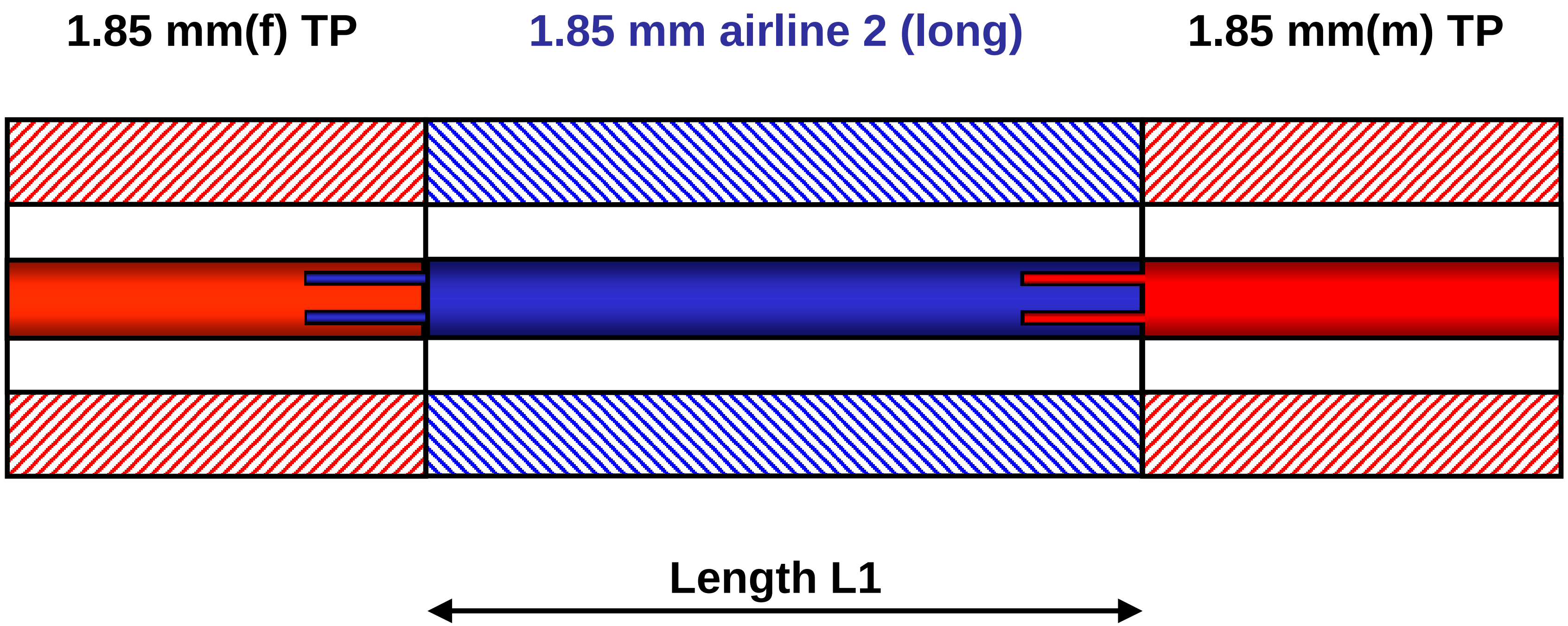
The error introduced by the pin-depth and the slotted interface is taken into account in the standard definitions of the calibration standard

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 airline centre conductor and the Test Port**

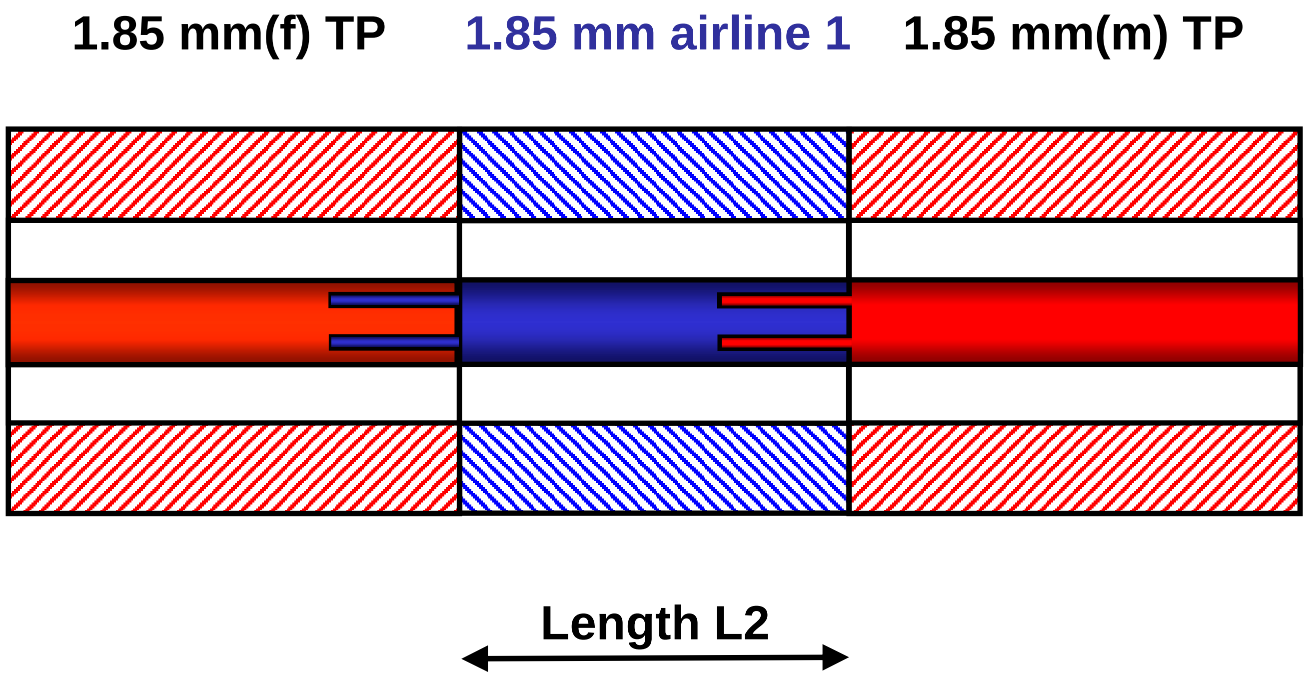
TRL or LRL calibration scheme: zero-length through issue
(ignoring any pin gap effects)



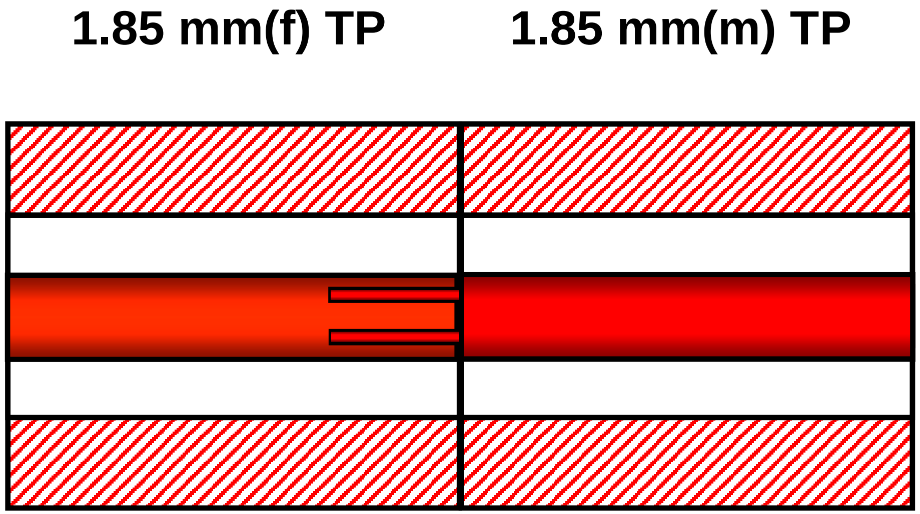
Paper: G.K.C. Kwan, “On the Modeling of Test Ports in Microwave and Millimeterwave Vector Network Analyzer Calibrations”, 2003 NCSL Workshop and Symposium, Item #CP-C03-3b-1.

TRL or LRL calibration scheme: zero-length through issue

(ignoring any pin gap effects)



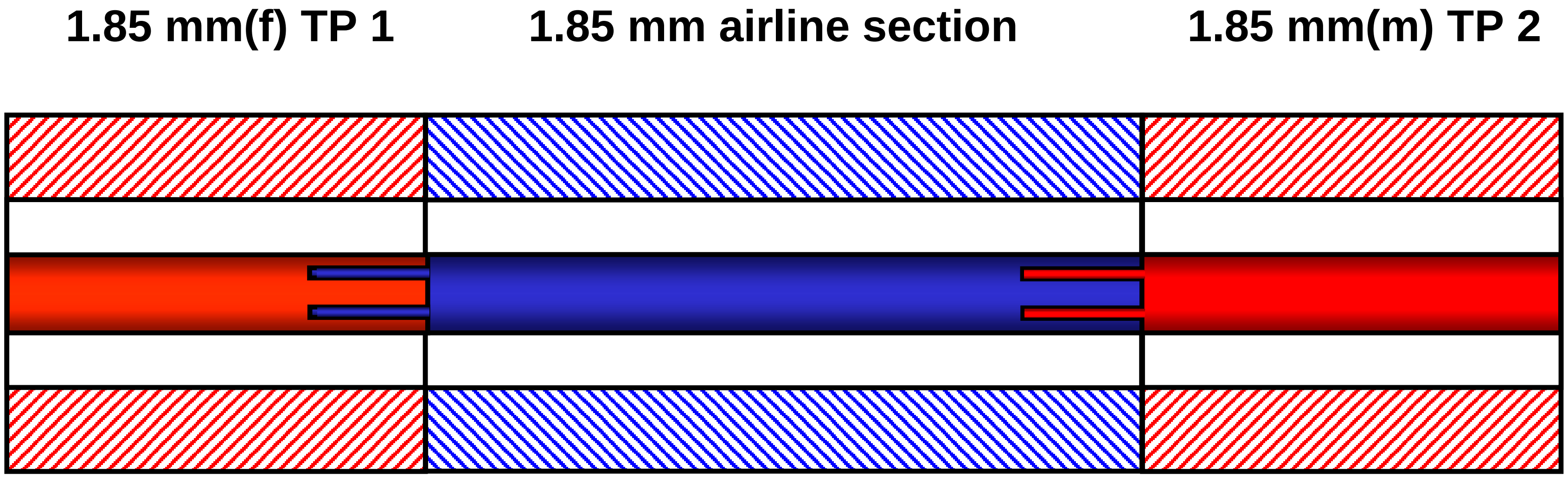
TRL or LRL calibration scheme: zero-length through issue
(ignoring any pin gap effects)



Through calibration step:
Only one slotted contact present!

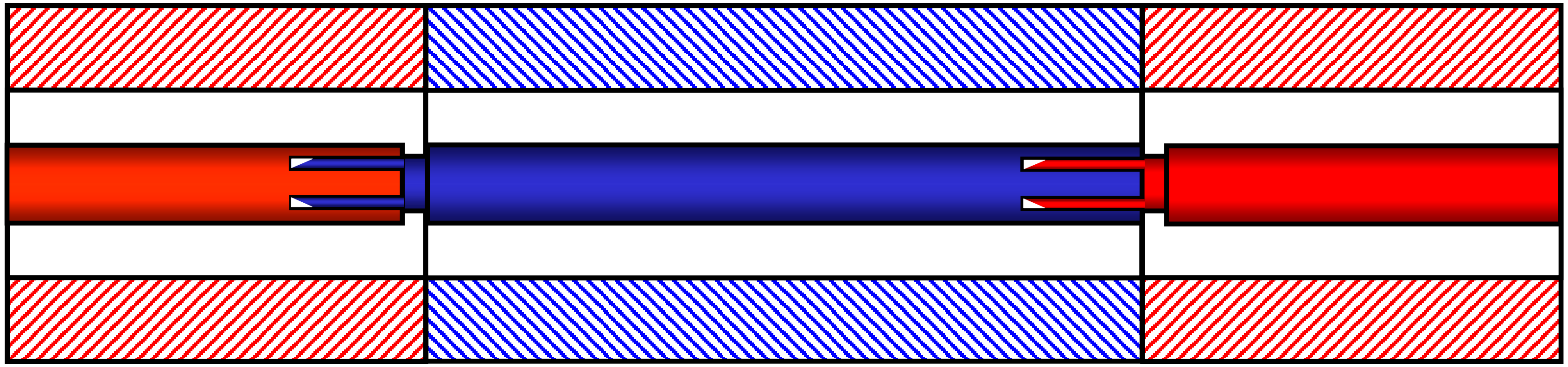
Zero length through: but not the equivalent of the previous connections using airline1 and airline 2 (two slotted contacts)

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



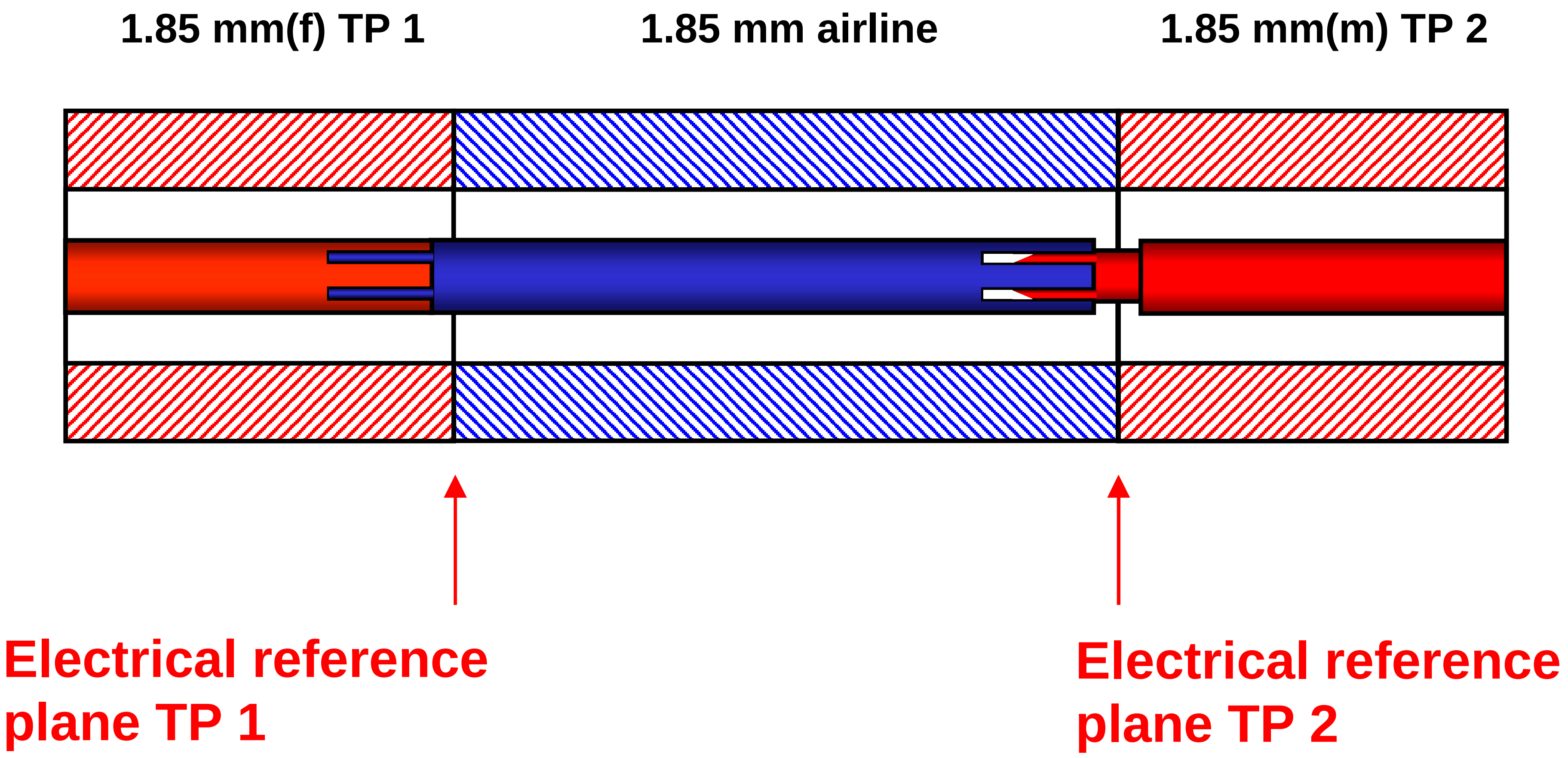
Cross sectional view of a coaxial air-dielectric line with slotted centre conductors, mounted between two TP´s

1.85 mm(f) TP 1 | 1.85 mm airline section | 1.85 mm(m) TP 2



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

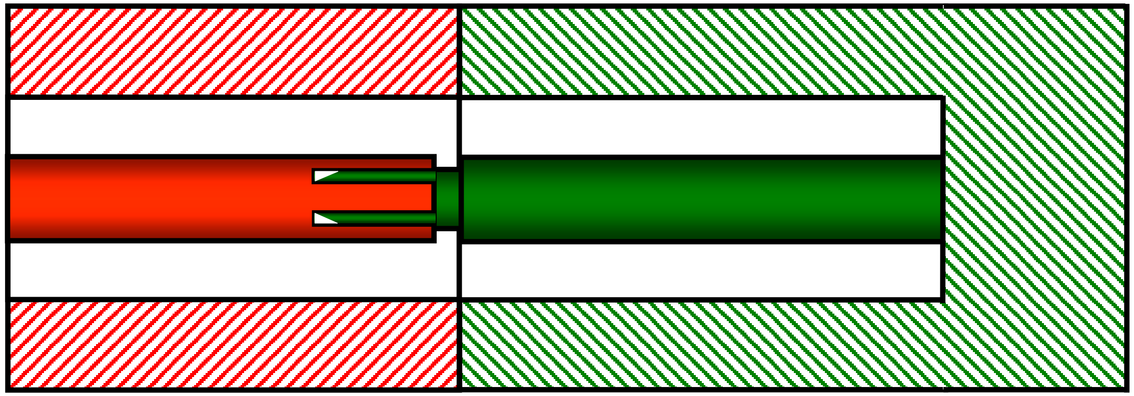
Shifted centre conductor: no control on the pin-depths
- TP 1: has no pin gap present -> seems to be better ?



TP 1 interface looks now different as during the previous calibration process when the airline CC was set flush to TP 1

1.85 mm(f) TP 1

1.85 mm DUT



Example: DUT with or with no pin-depth

TP 1 interface is different as during thr VNA calibration!

-> the VNA error box has changed !

A practical experiment showing the pin gap effect

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

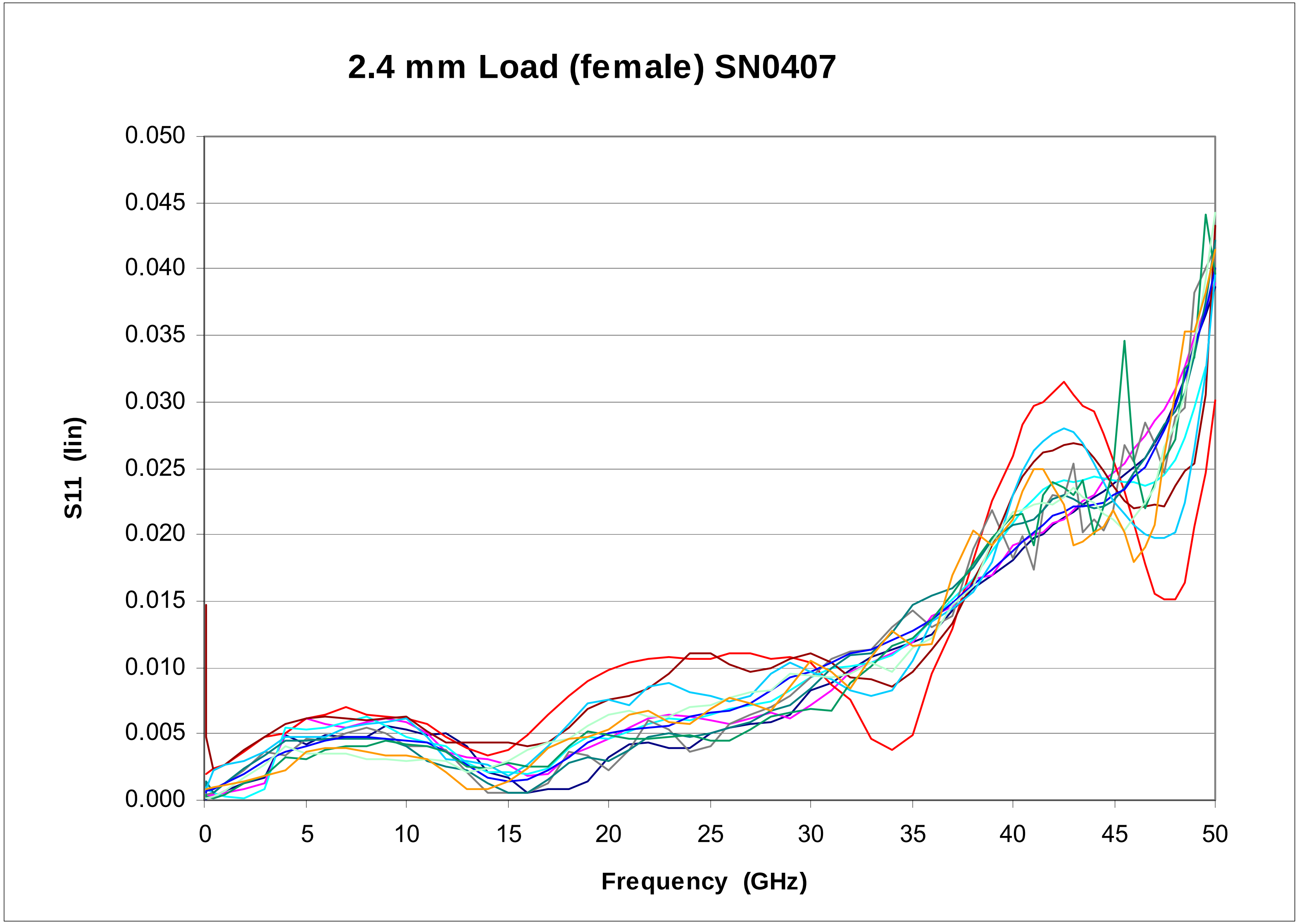
Devices: 2.4 mm line system
- **Attenuator: 3 dB, 20 dB, 40 dB**
- **50 Ohm Load: male, female**
- **Mismatch VSWR 2.0: male, female**

Frequencies: 50 MHz - 50 GHz

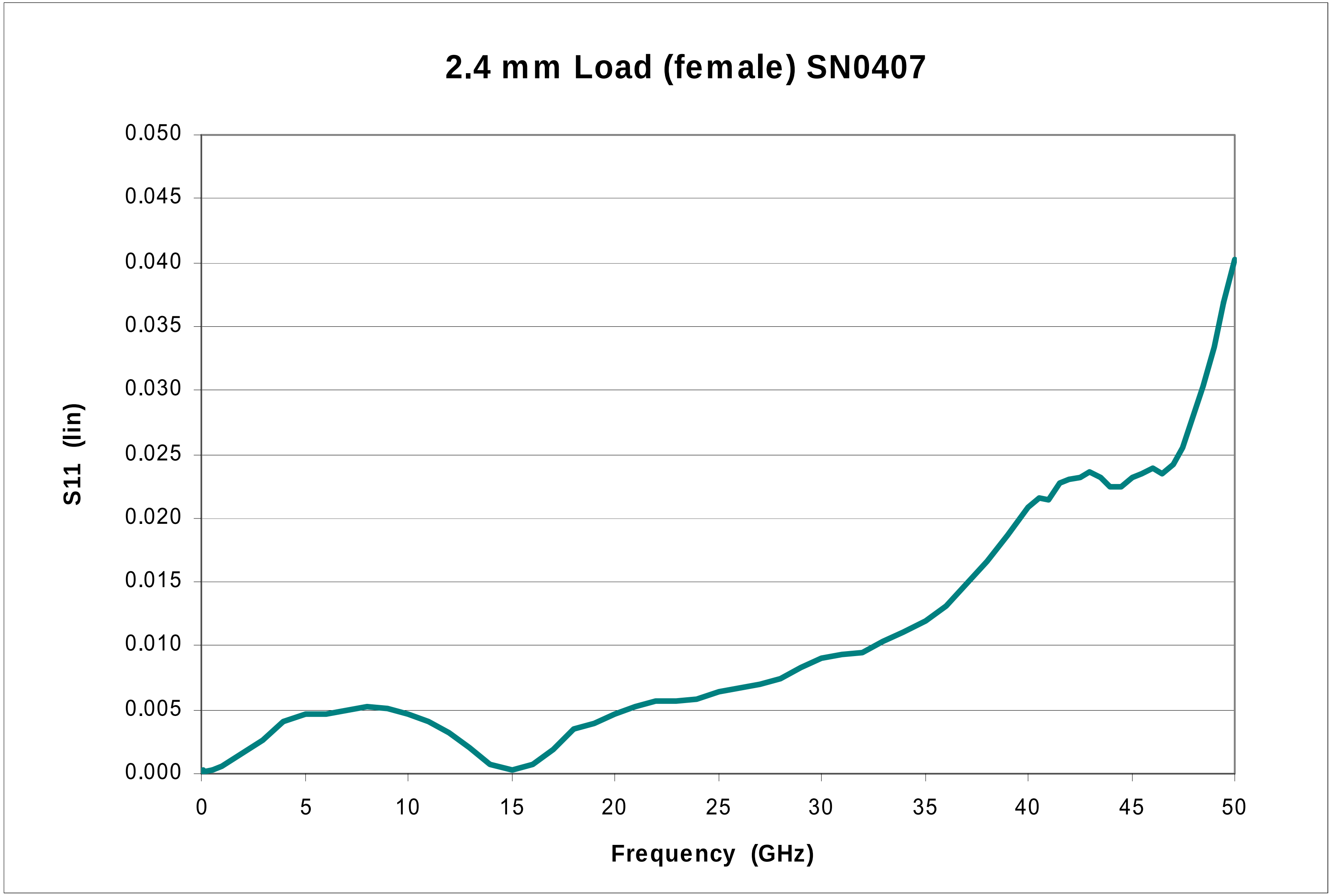
12 Participants: (**9 NMI, 3 Industrial**)
- BNM-LNE/LAMA
- CSIR-NML
- IEN
- INMS NRC
- INTA
- NIST
- NMi VSL
- NPL
- METAS (pilot laboratory)
- EPSG/MTA
- SQF
- UKAS No“0147“

Status: Final Report November 2004

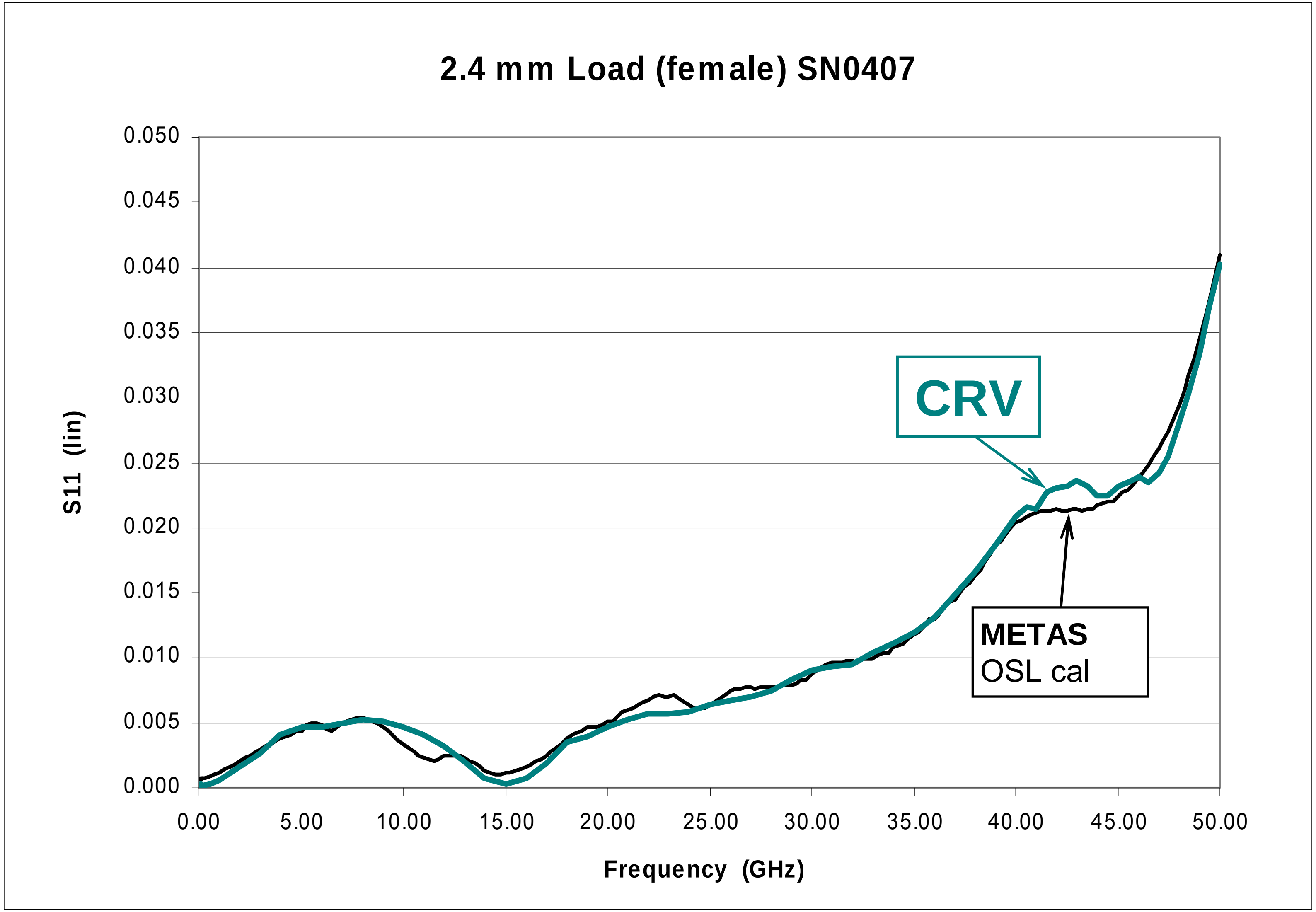
E555 showing all participants



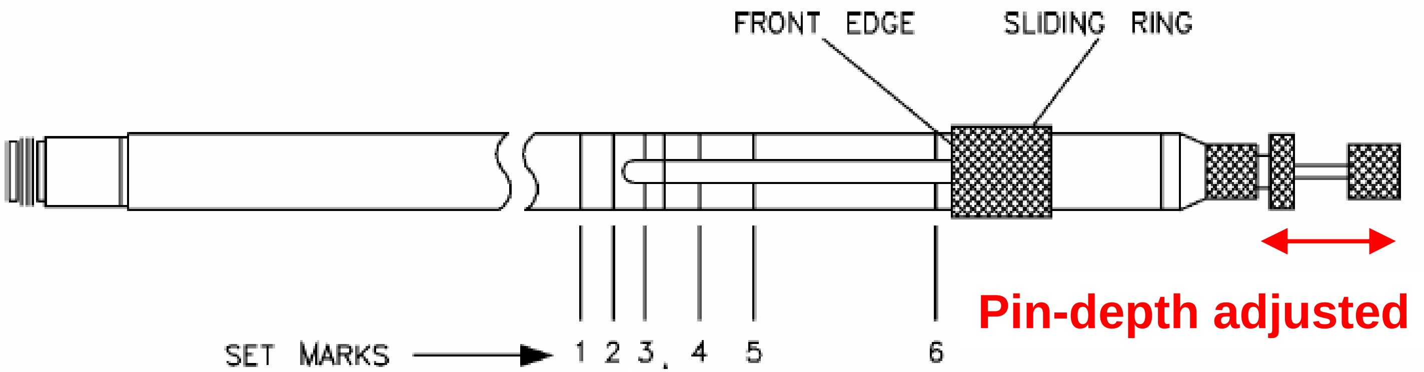
E555 Comparison Reference Value CRV

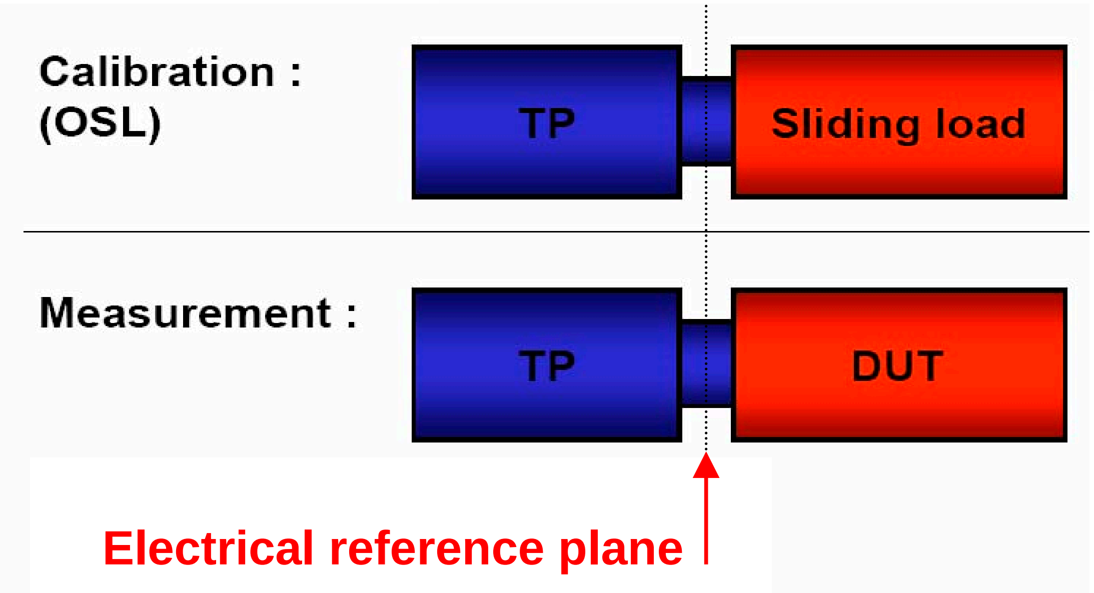


SL pin-depth: 0.0000 mm (0.00000 in)



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

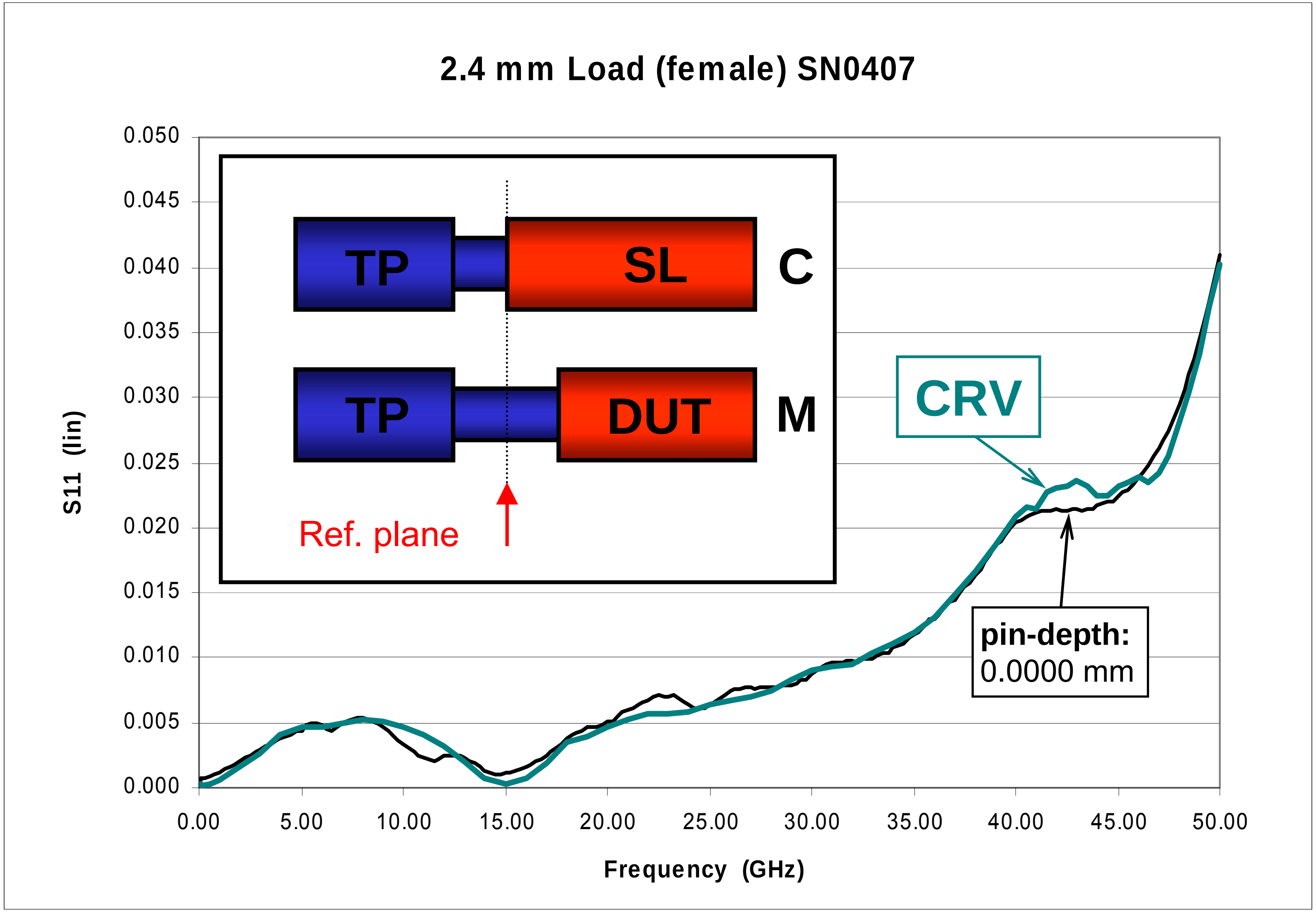




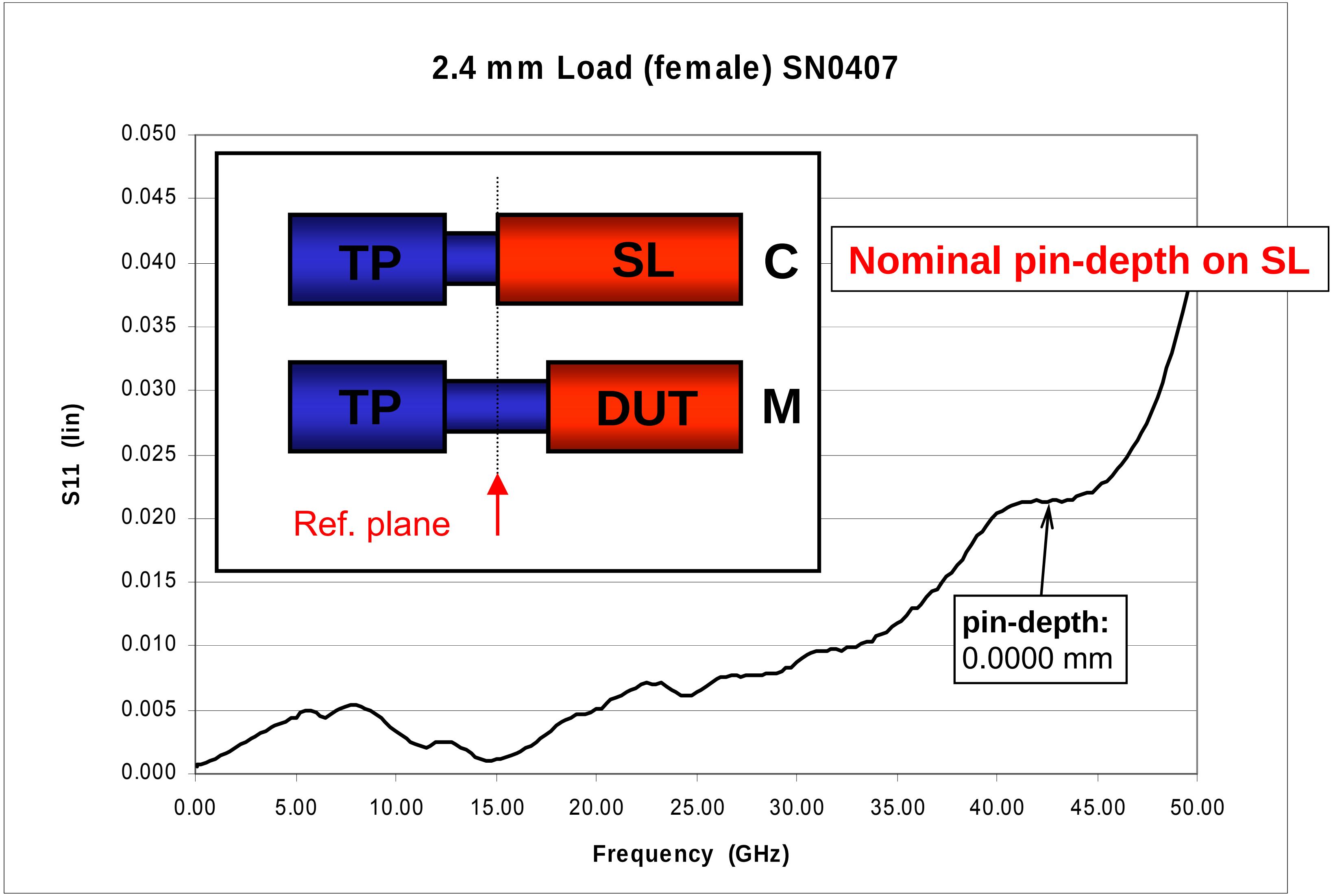
Test Port recession:
pin-depth: -0.0076 mm

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

SL pin-depth: 0.0000 mm (0.00000 in)



SL pin-depth: 0.0000 mm (0.00000 in)



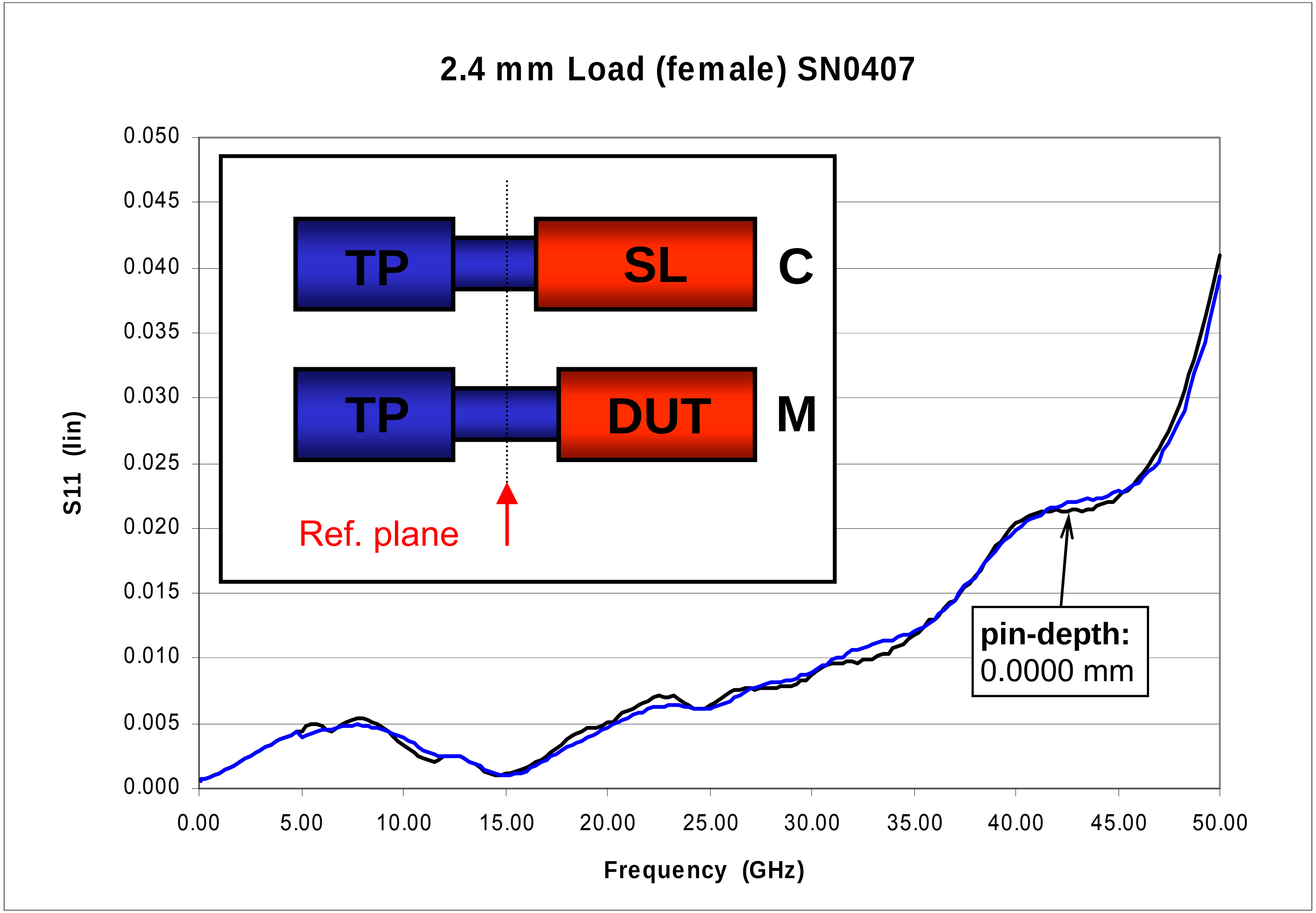
TP (m):
-0.0076 mm

DUT (f):
-0.0084 mm

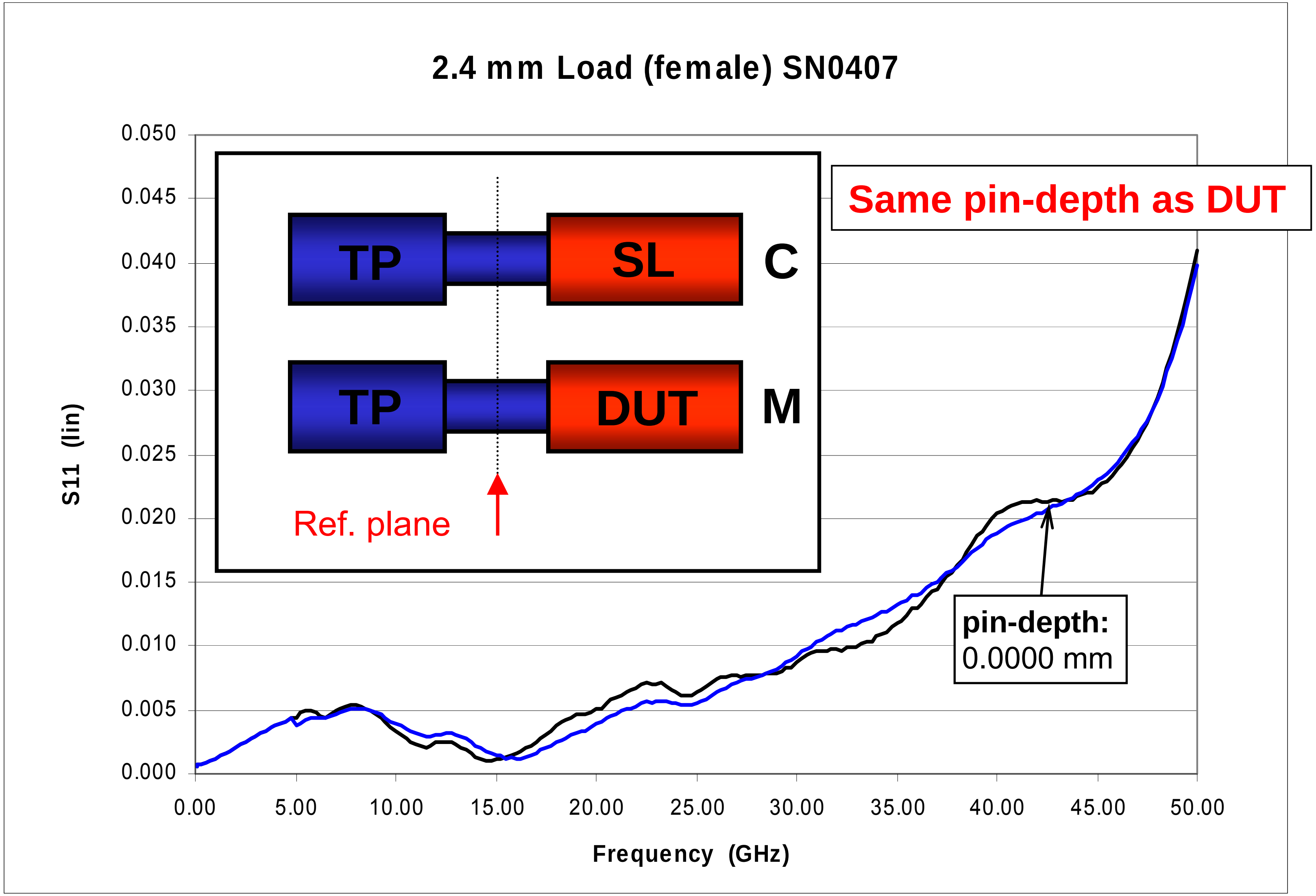
Open (f):
-0.0010 mm

Short (f):
-0.0015 mm

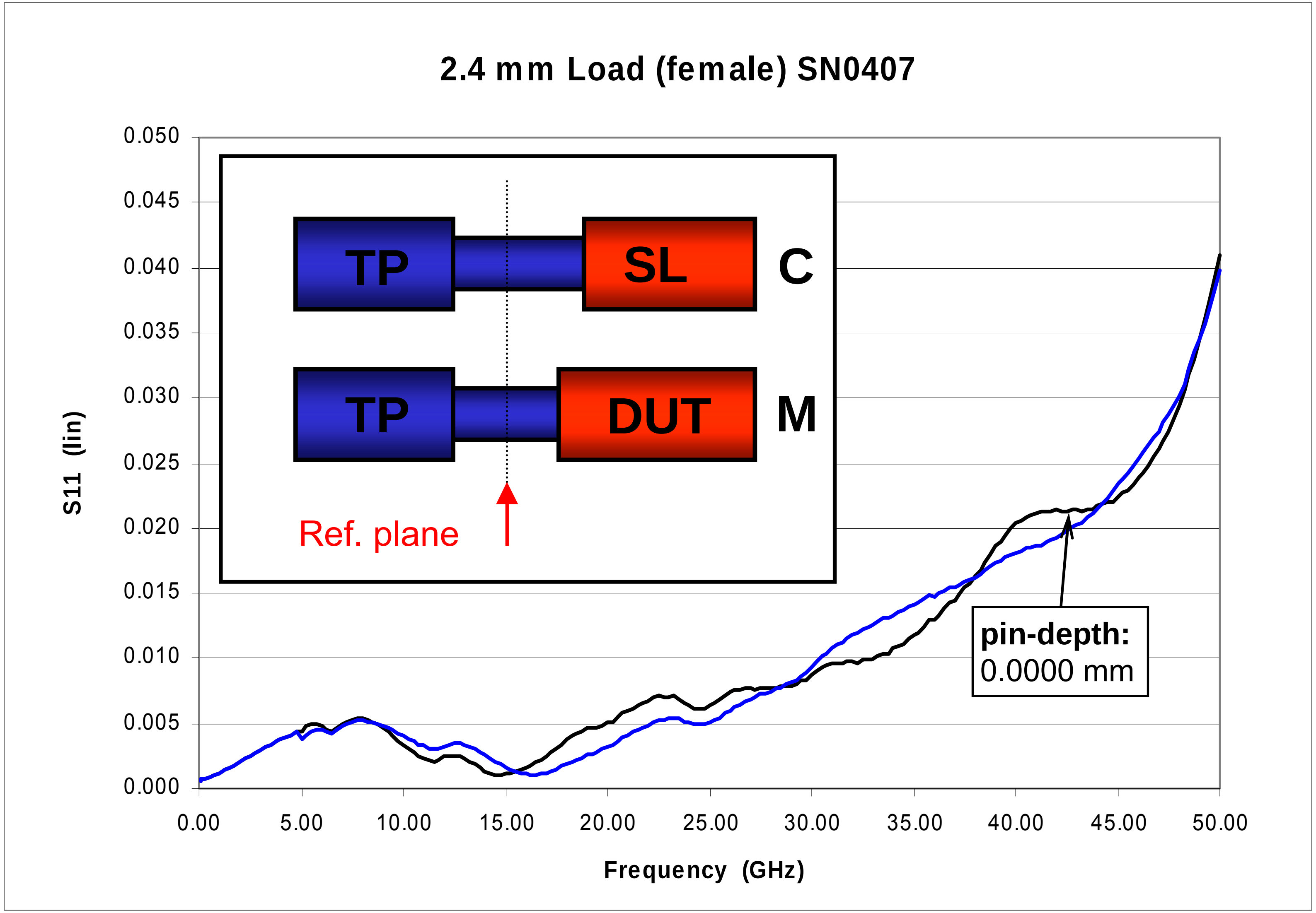
SL pin-depth: -0.0038 mm (-0.00015 in)



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

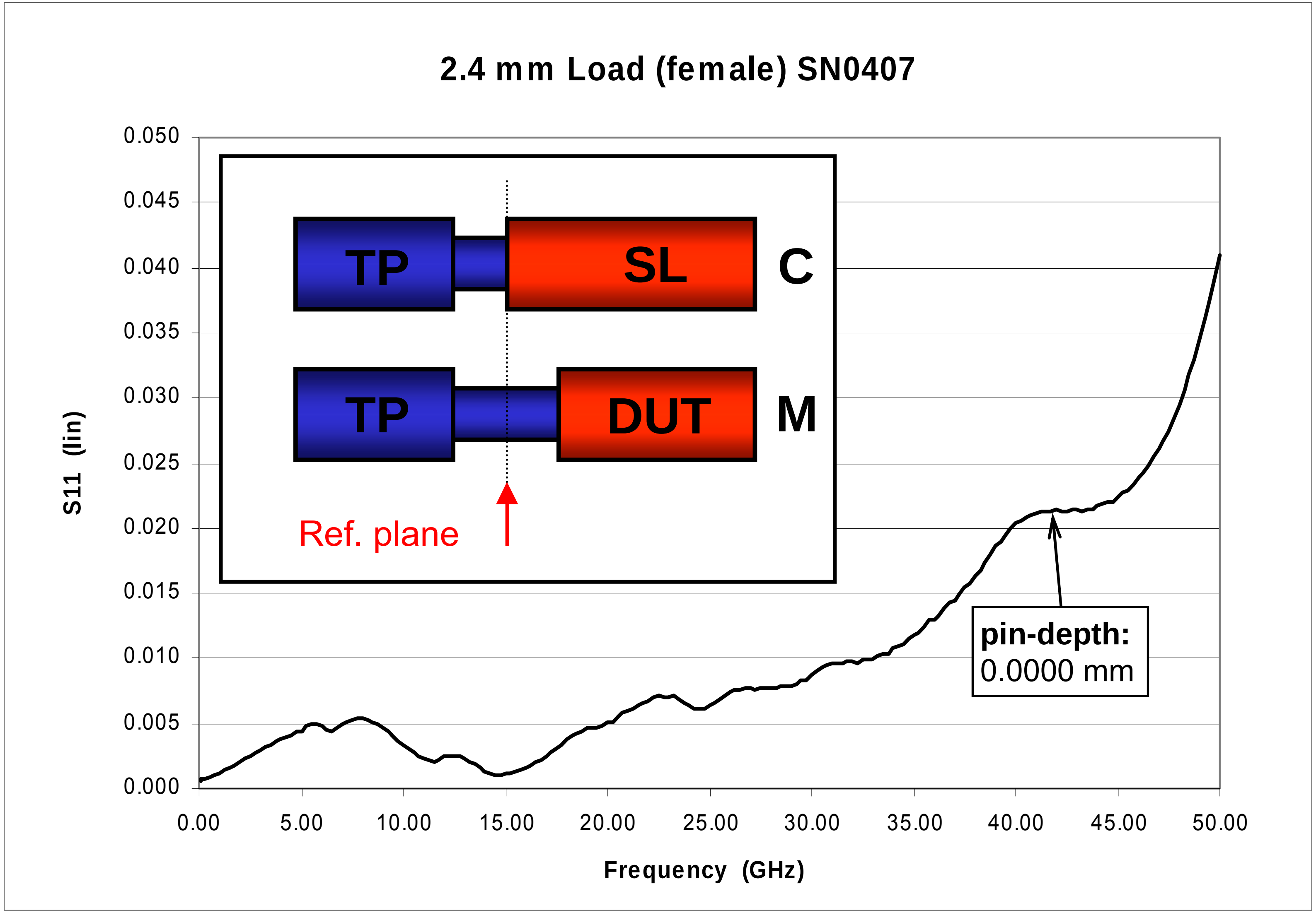


SL pin-depth: -0.0114 mm (-0.00045 in)



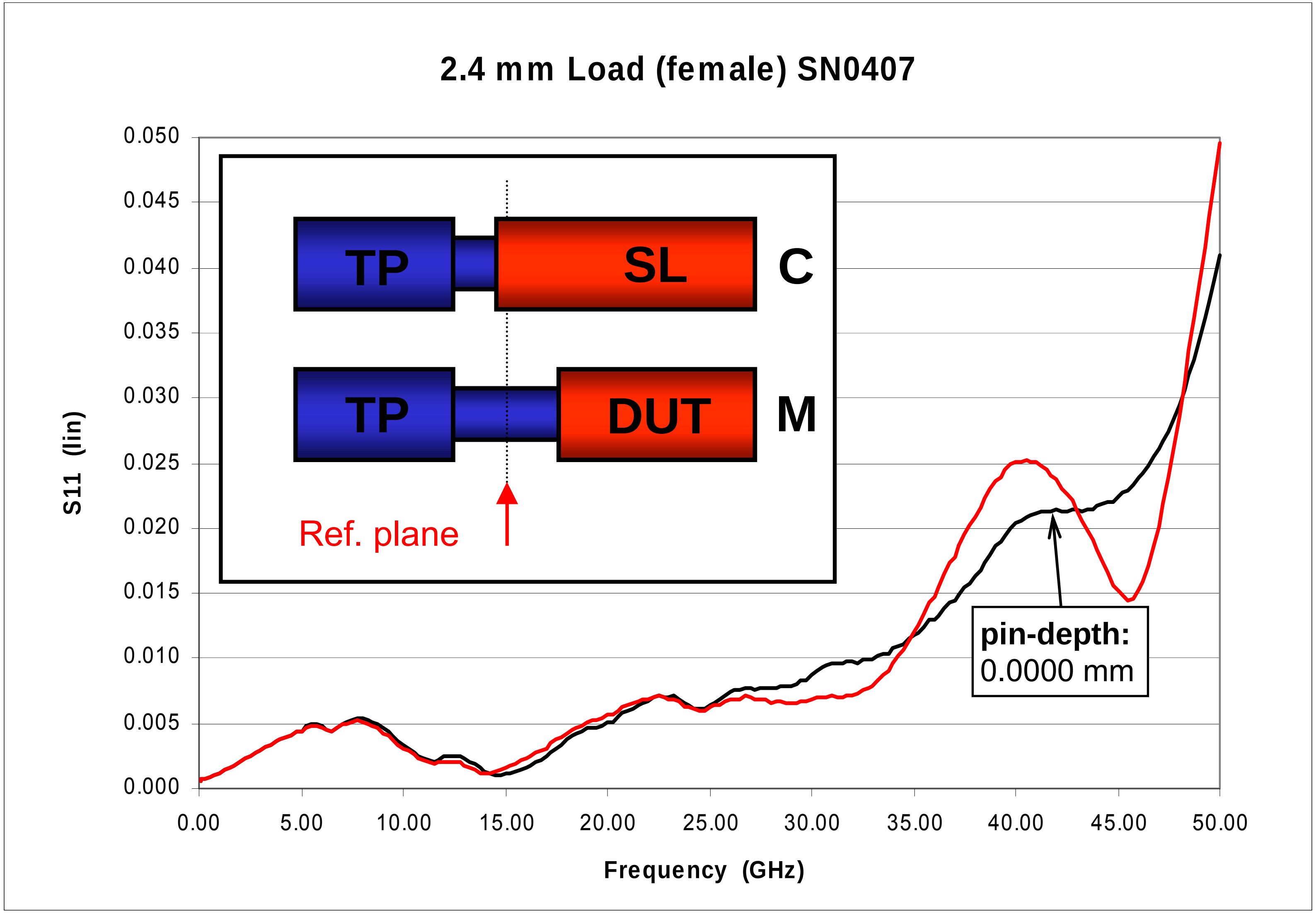
SL pin-depth: 0.0000 mm (0.00000 in)

TP (m): -0.0076 mm
DUT (f): -0.0084 mm
Open (f): -0.0010 mm
Short (f): -0.0015 mm



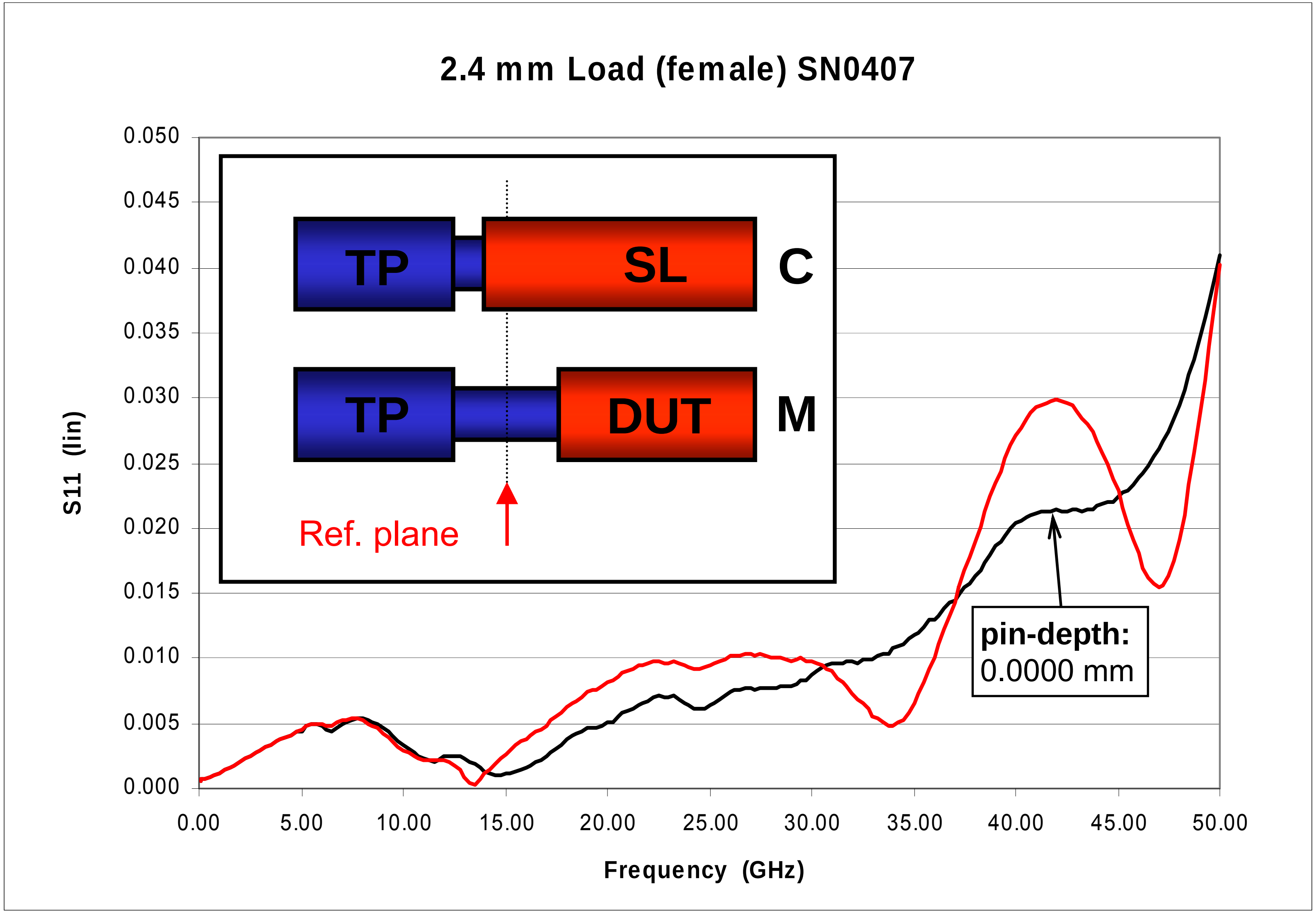
Protrusion

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



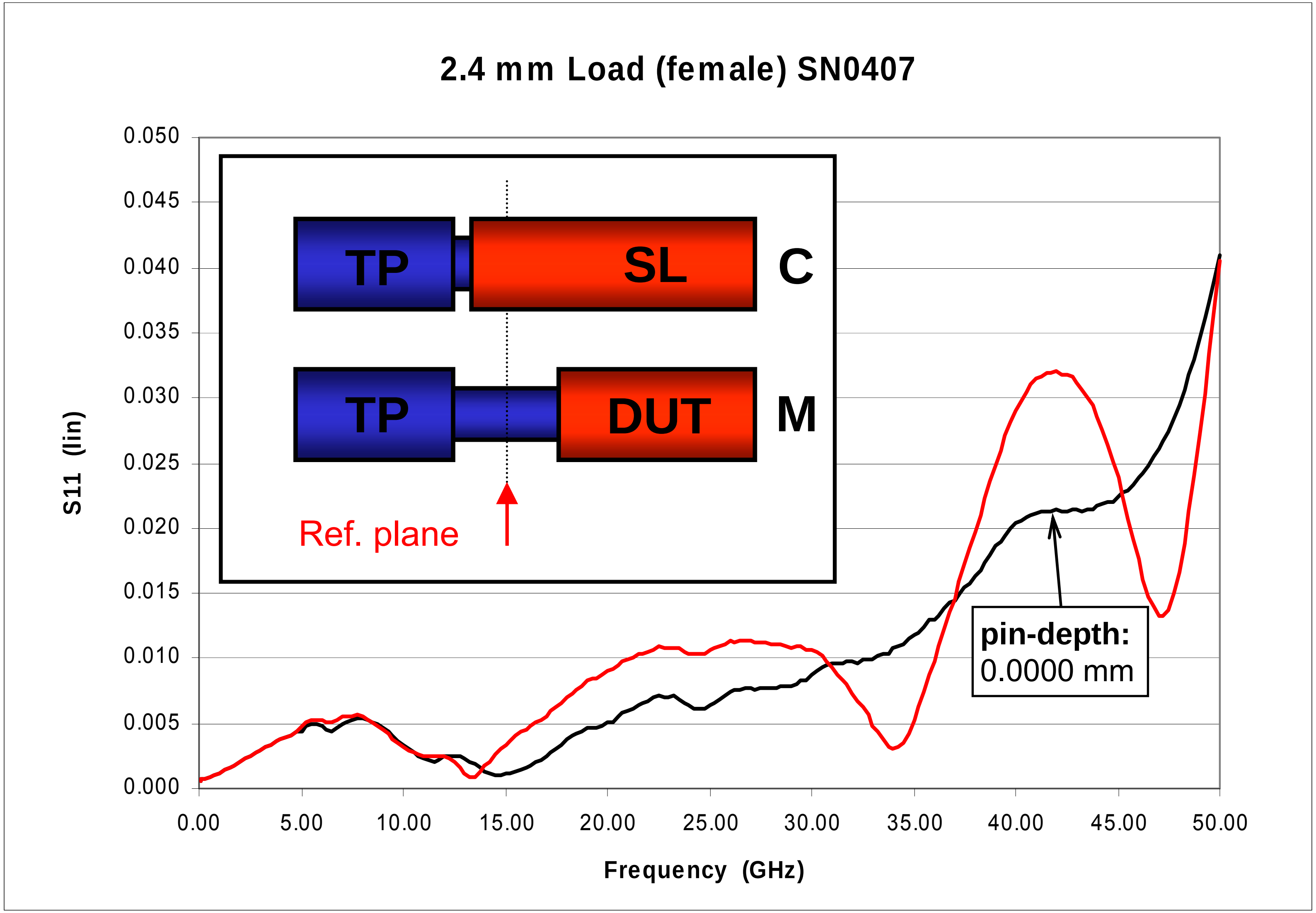
Protrusion

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



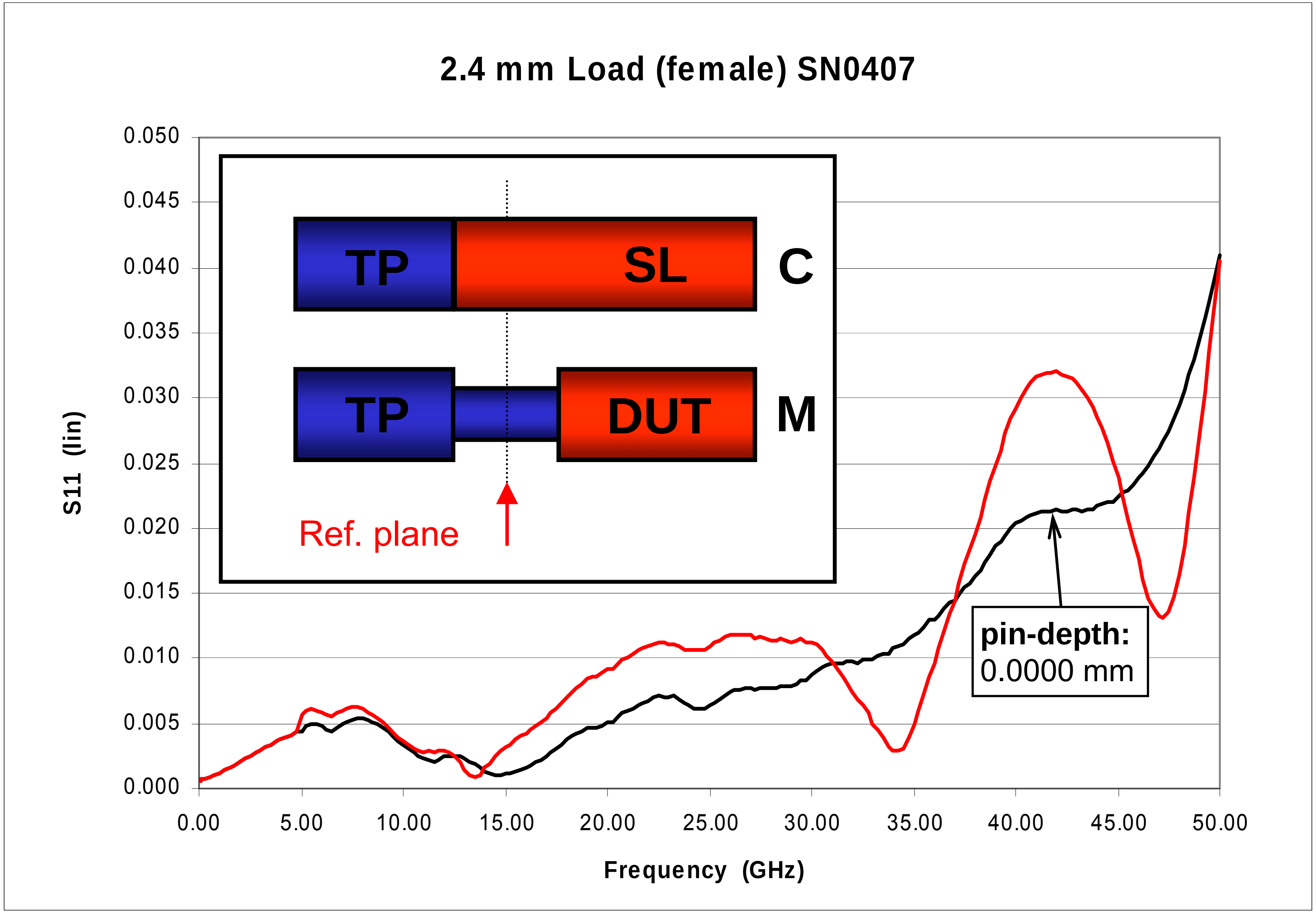
Protrusion

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

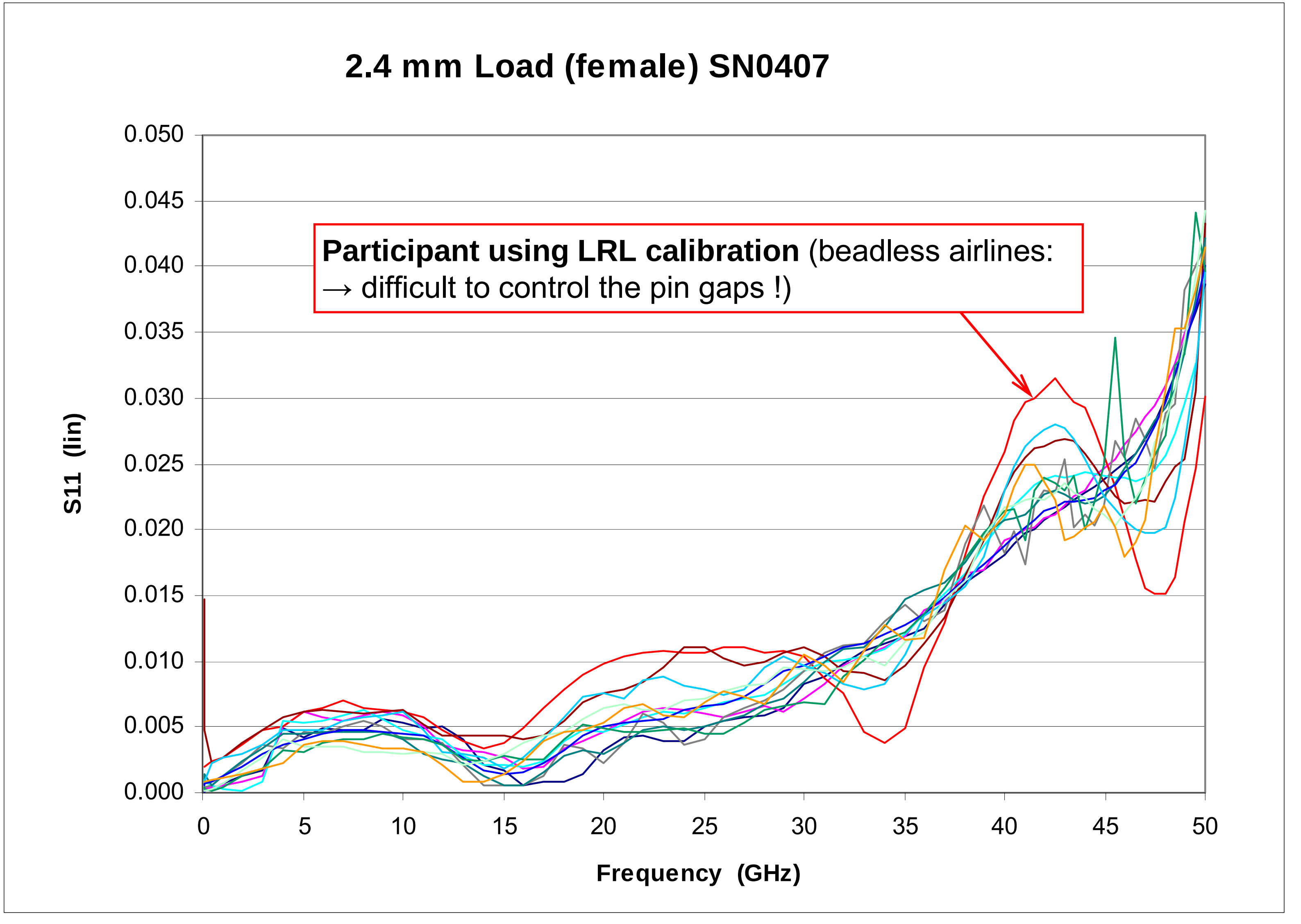


Protrusion

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** (alignment, …)

Federal Department of Justice and Police FDJP

Federal Office of Metrology METAS

Thank you very much for your attention !

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