Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

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

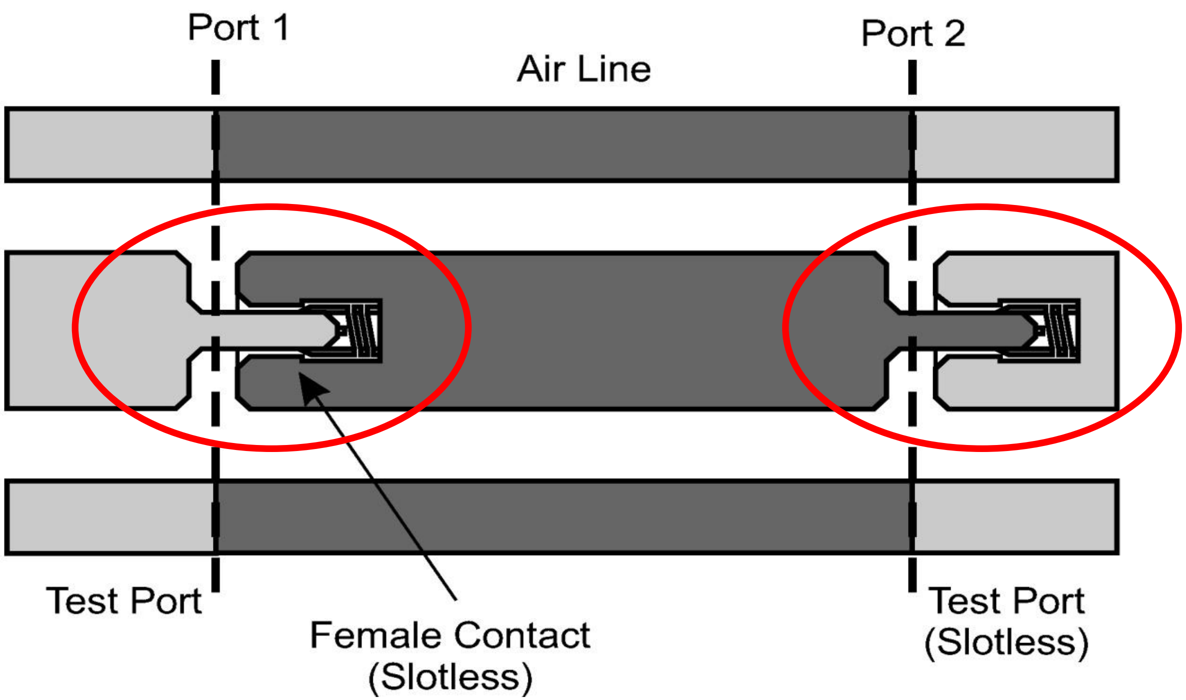
# 2.4 mm slotless connector investigations

**European Metrology workshop** (LNE, Paris)

Juerg Ruefenacht
Johannes Hoffmann

19.-21. April 2010

# How to prove the claimed connector effects?




- **Up to now :** connector effects have (mostly) been ignored
- **CoMo70** : significant effects from small coaxial connectors

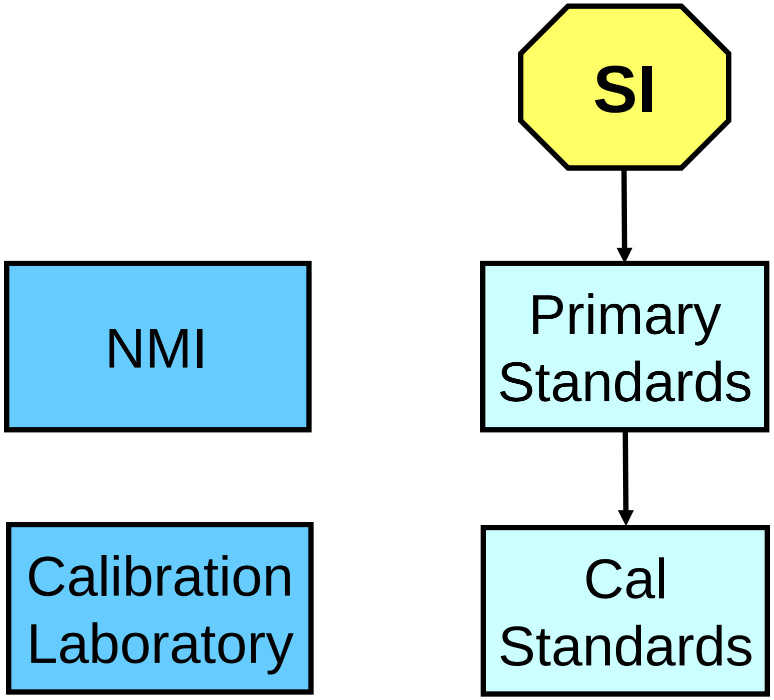
# Topics

- **How to verify VNA traceability?**
- **Out-dated connector dogmas**
- **The actual 2.4 mm connector experiments**

## Round table discussions

- **Relevance to the S-parameter traceability work**
- **Impact on the NMI level and the accredited labs**

# Traceability chain in metrology




**It can be related to stated references through an unbroken chain of comparisons all having stated uncertainties.**

**Current state-of-the-art in VNA metrology:**

- **Reproducibility** 


- **ConsistenSI** 

- Accredited laboratories or NMI's (with MRA)
- **Accepted and documented methods**
- Accepted uncertainty calculations (GUM)

# Concepts to ensure S-parameter consistency

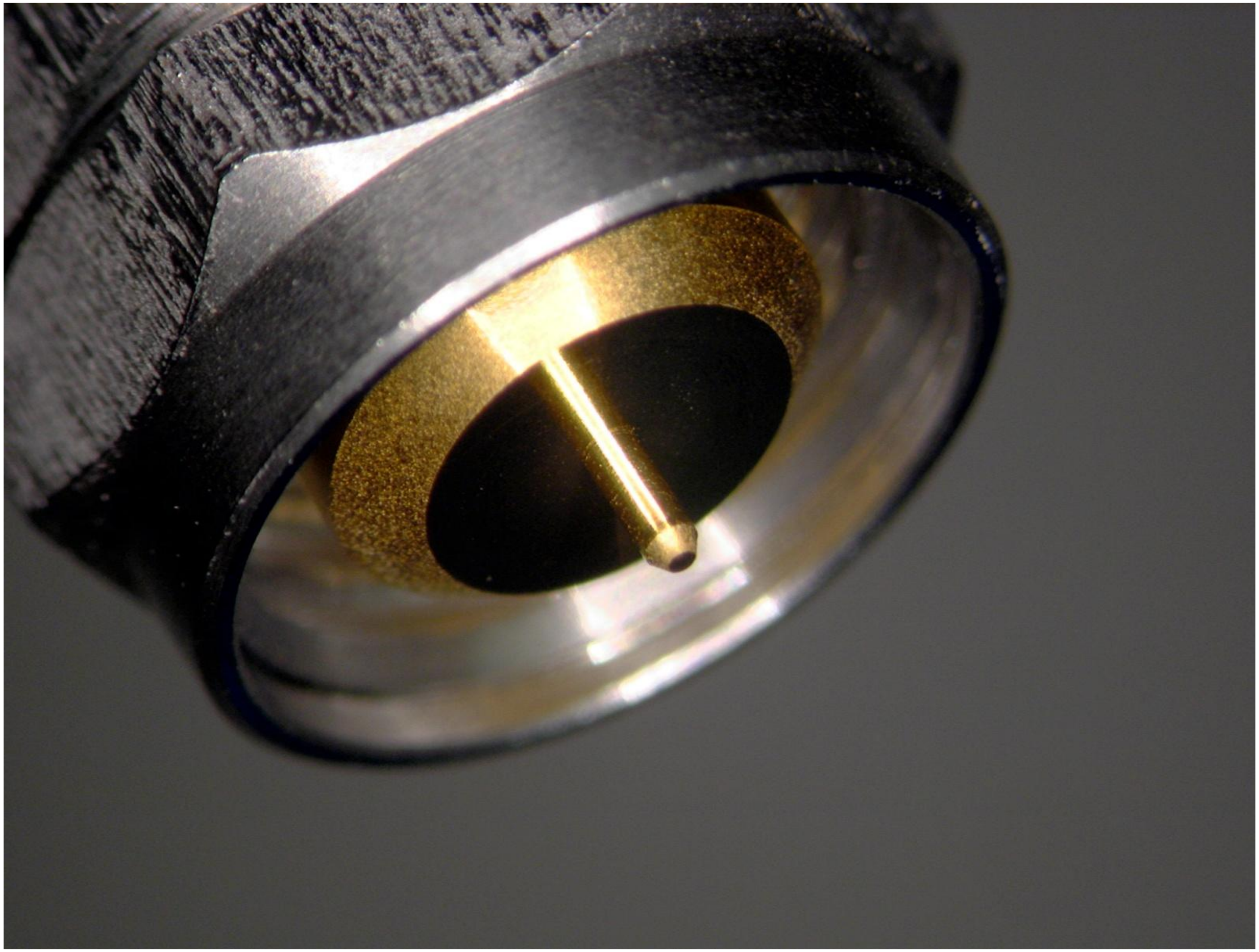
- **Physical behaviour of passive standards**
  - All passive devices : fulfil passivity conditions
  - e.g.: short and flush short : reflection coefficients not larger than 1
  - e.g.: flush short : no positive phase behaviour
  - e.g.: air line : no ripple on transmission coefficients

- **Over-determined calibration process**
  - More standards measured than needed to solve the error terms
  - For all standards: compare modelling with measurement results

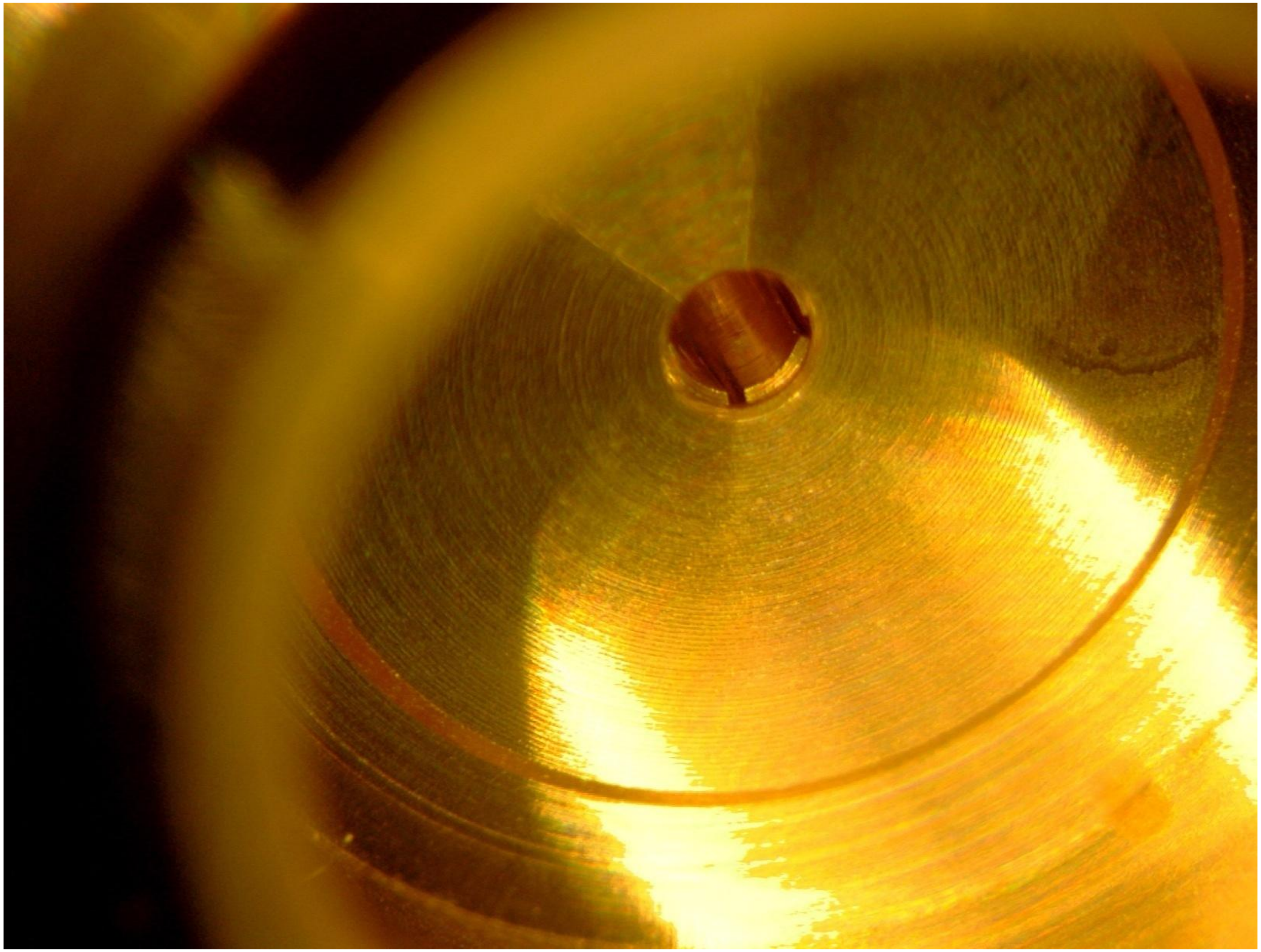
- **Consistent results by using different cal methods**
  - e.g.: S11 and S22 measurements of low loss components

- **Measurement comparisons ?**

# 2.4 mm male flush short standard



# 2.4 mm female flush short standard



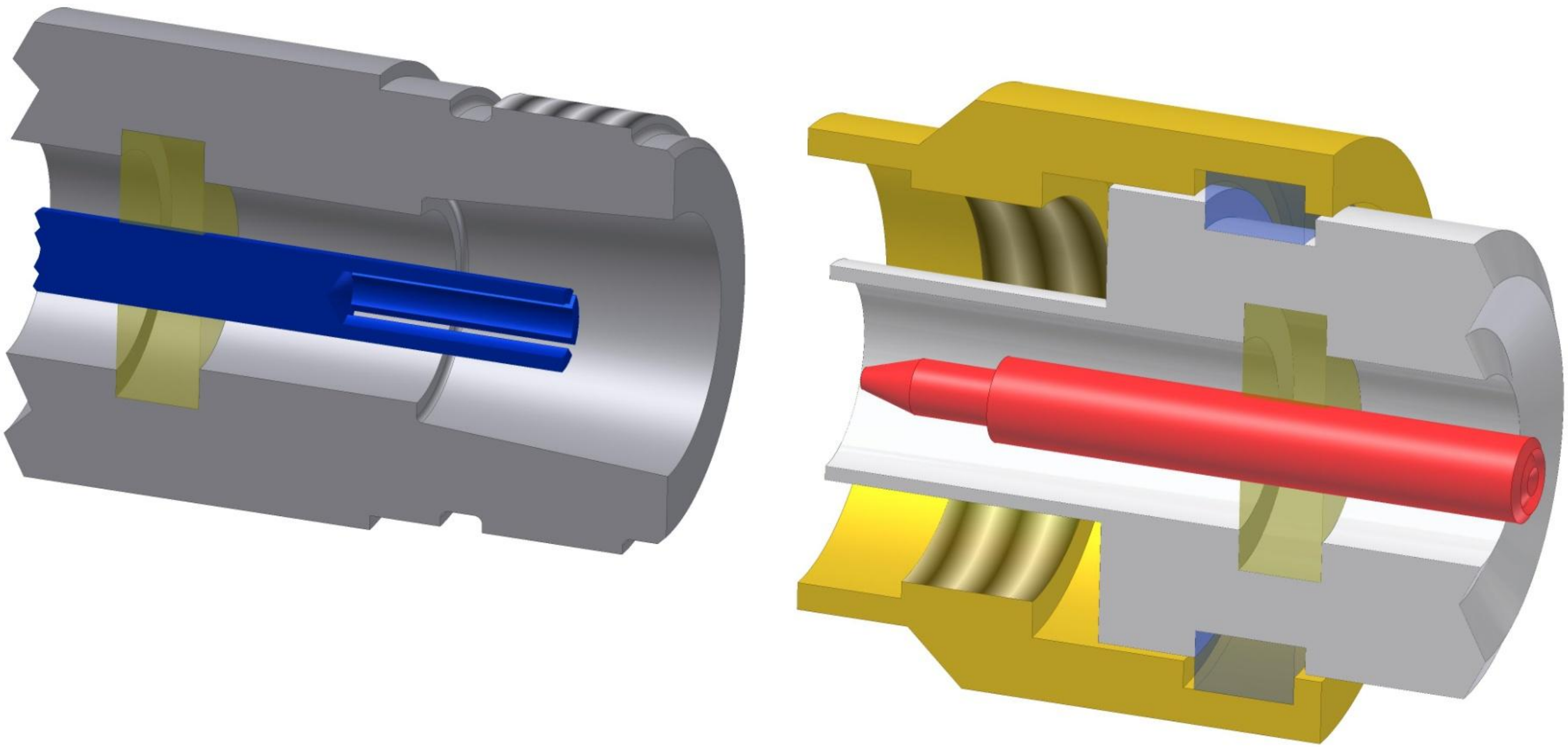
# Out-dated connector dogmas

- Interconnects are designed to be almost perfect
- Connector effects are corrected during calibration
- Cal definitions include the connector effects
- Mind the gap
- Slotless connectors are always better

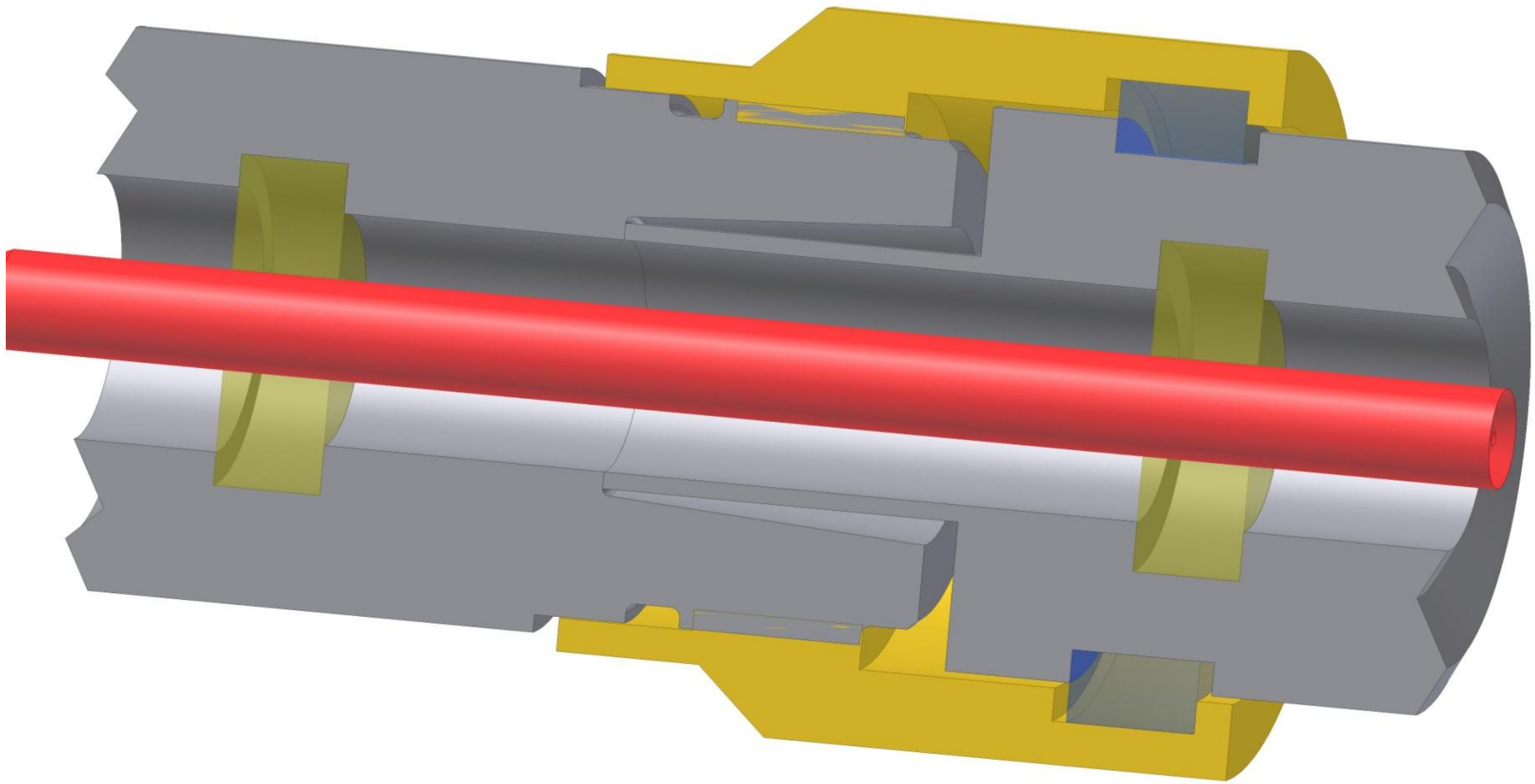
# Out-dated connector dogmas

- **Interconnects are designed to be almost perfect**

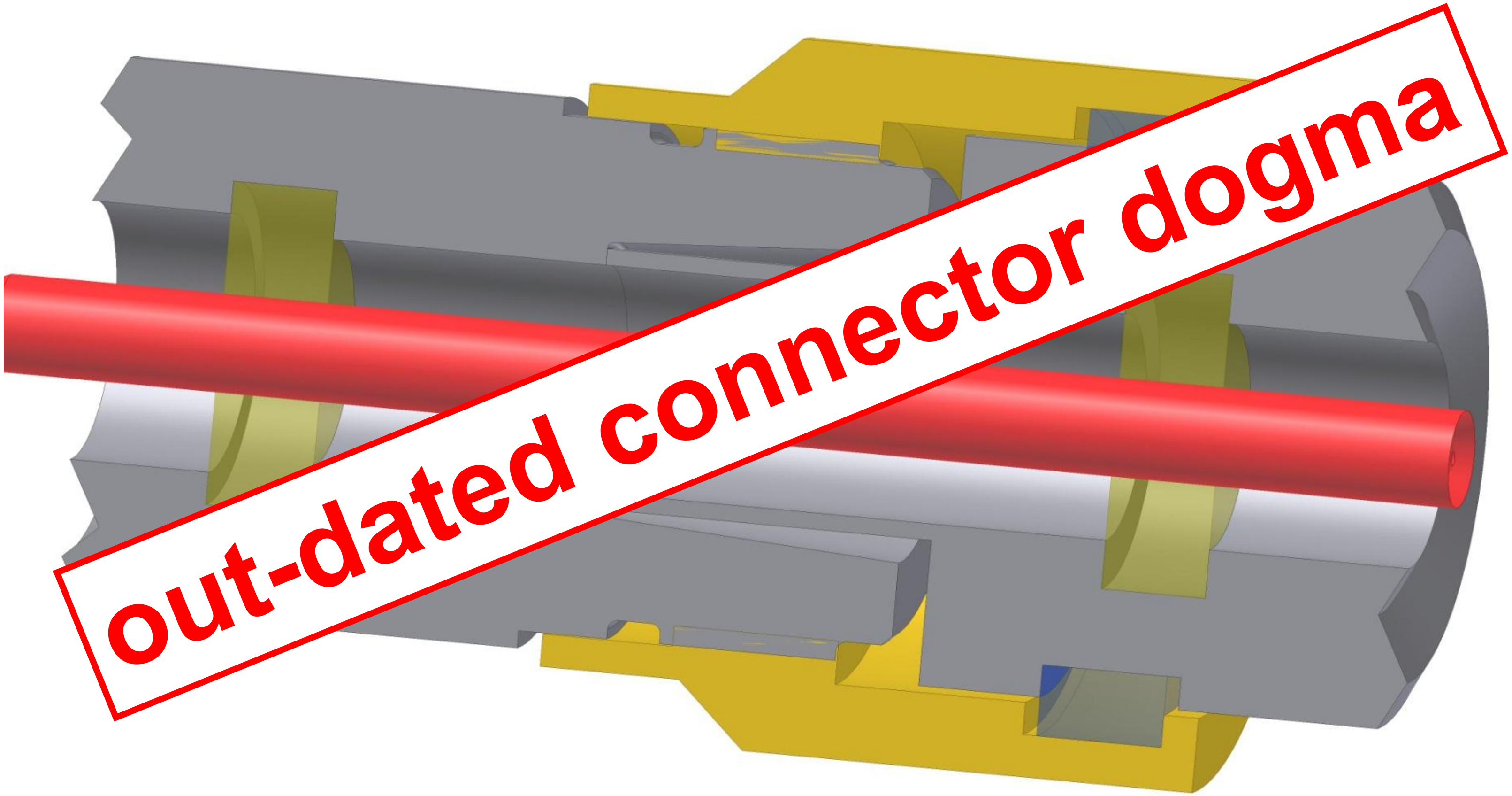
# Interconnects are designed for low reflection



# Effects from interconnects can be ignored



# Effects from interconnects can be ignored



# Out-dated connector dogmas

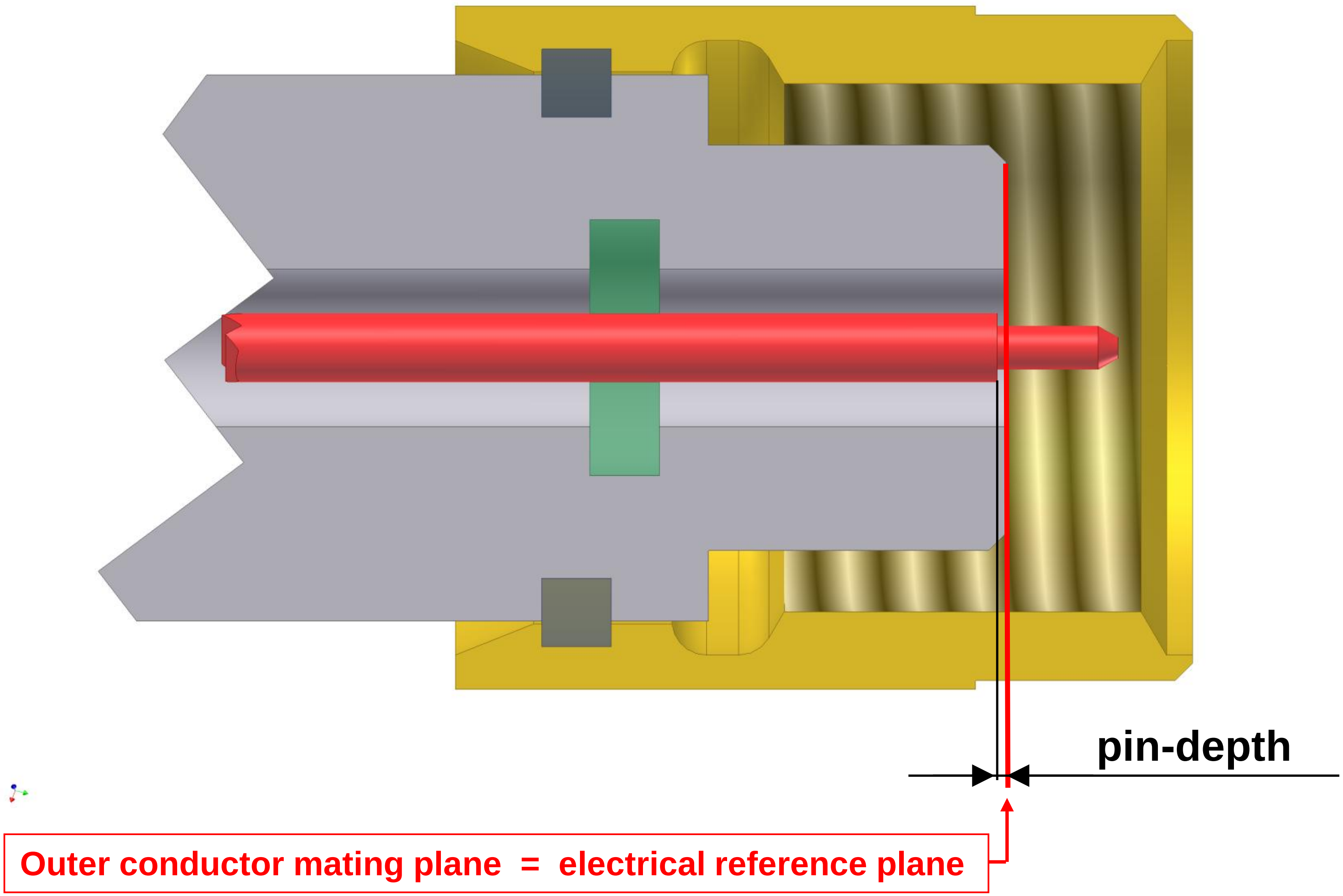
- **Connector effects are corrected during calibration**
  - **Effects from the calibration standard connector and the DUT connector are the same: effect can be ignored**
  - **Connectors have always to be treated as a pair: Ignoring the reference plane definition**

# Out-dated connector dogmas

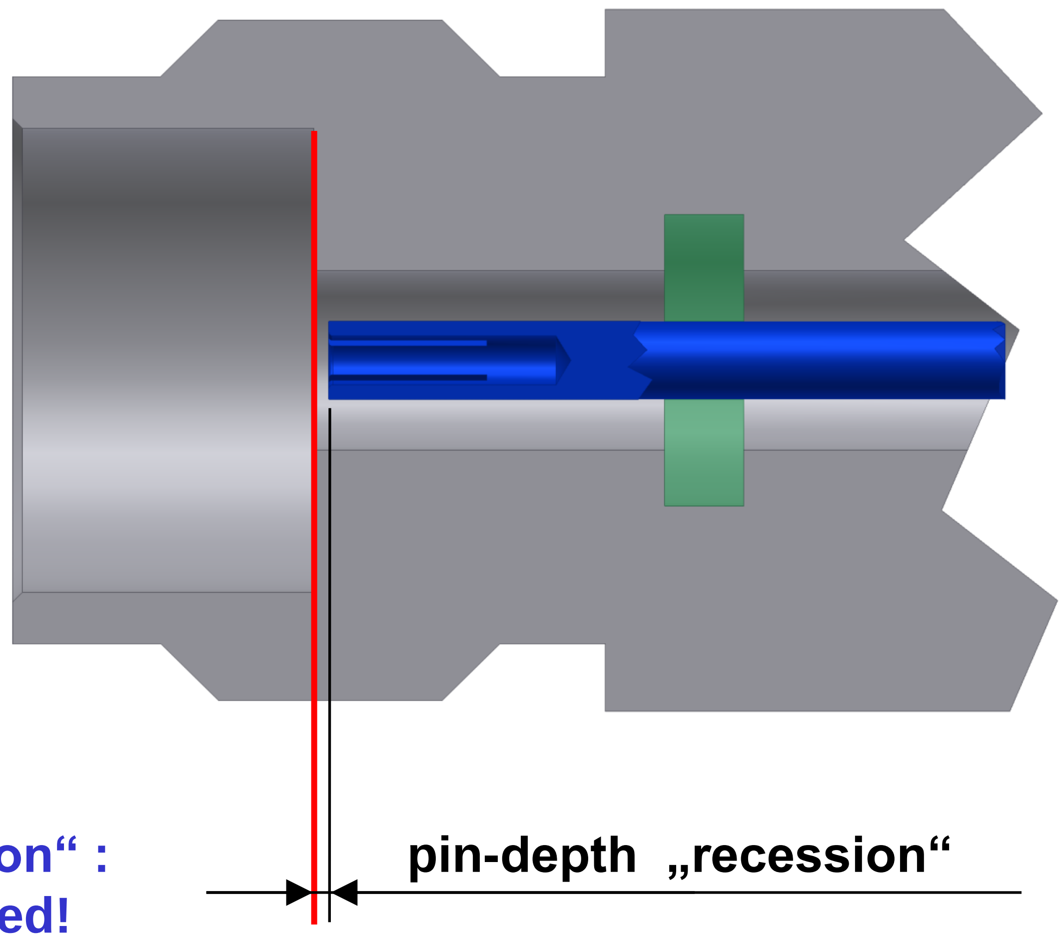
- Connector effects are co… …ng calibration
  - Effects from th… …standard connector and the DUT … the same: effect can be ignored
  - …s have always to be treated as a pair: I…ng the reference plane definition

**out-dated connector dogma**

# 2.4 mm (male) connector interface



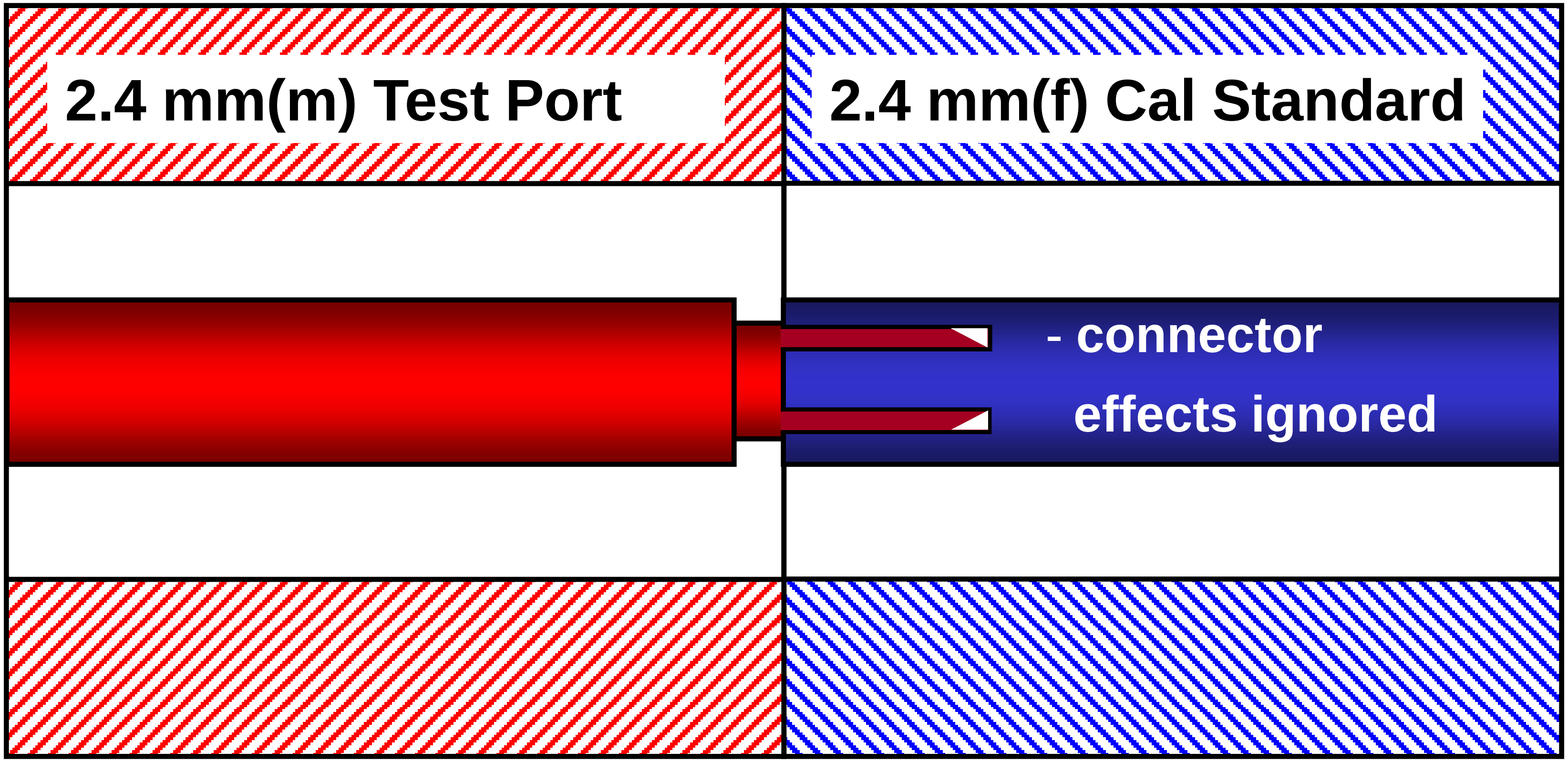
# 2.4 mm (female) connector interface „slotted“




„protrusion“ : not allowed!

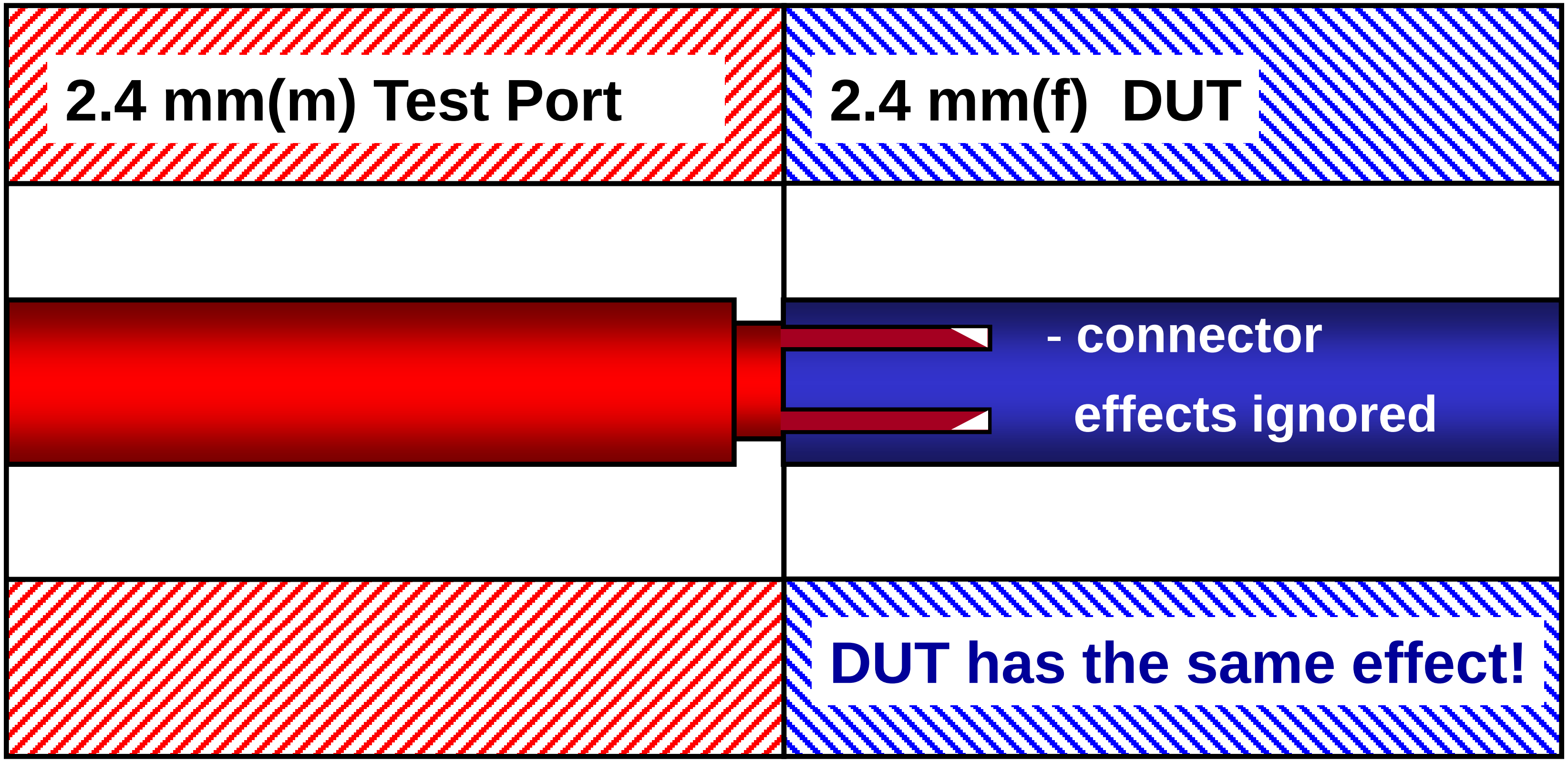
Outer conductor mating plane = electrical reference plane

# Connectors have always to be treated as a pair



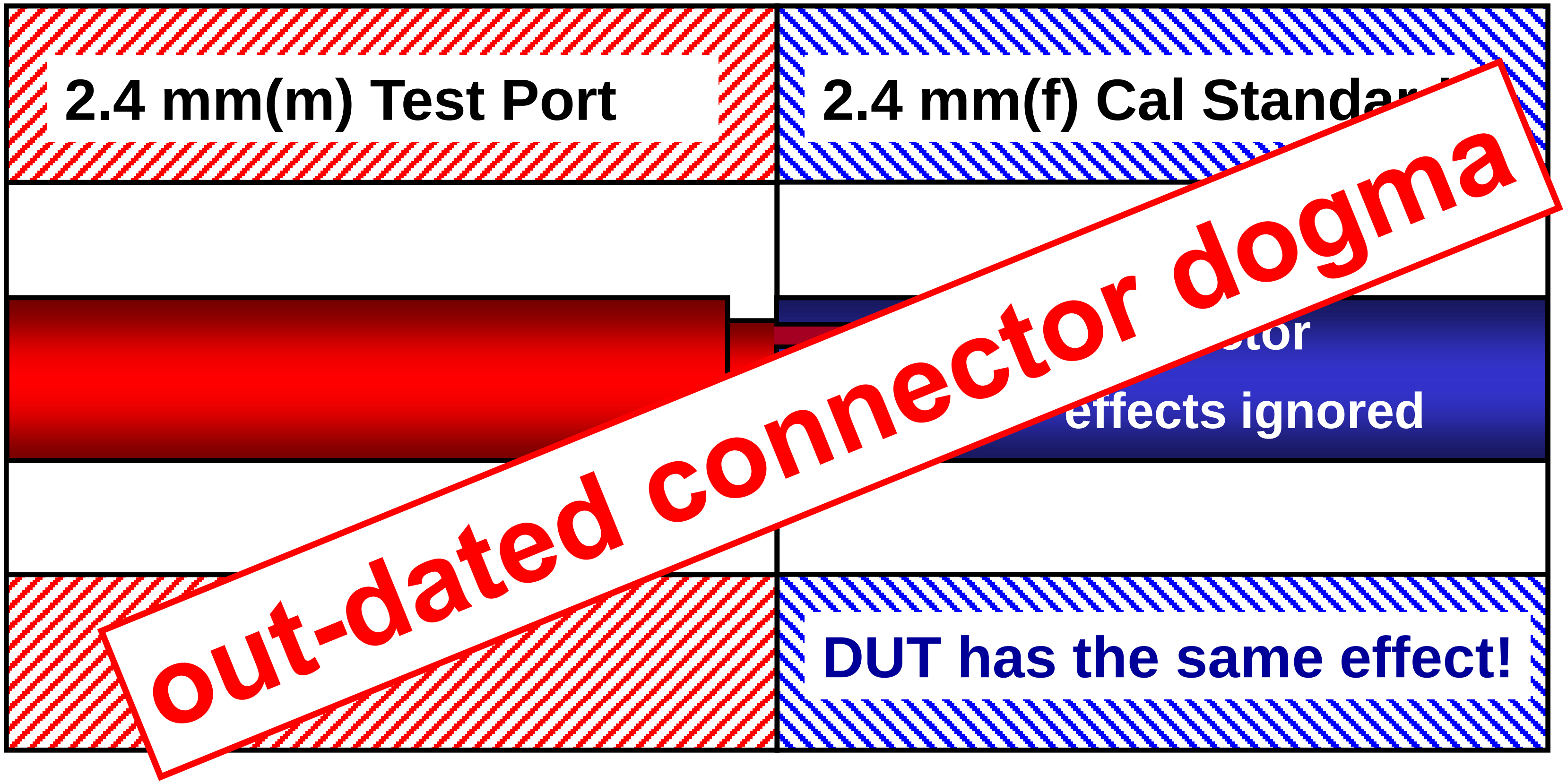

**The standard definitions do not take into account for any connector effects**

# Connectors have always to be treated as a pair

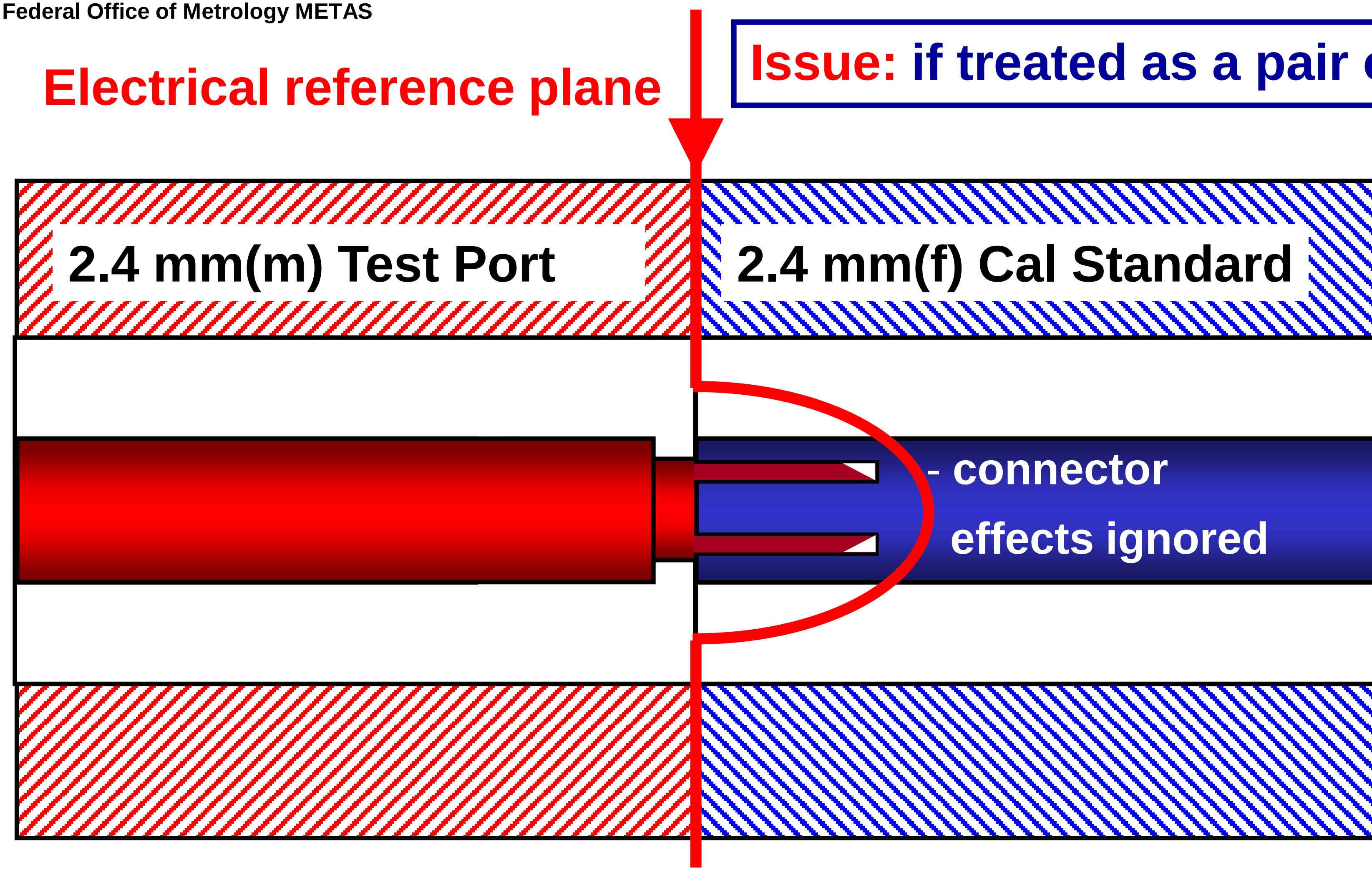



**Dogma: the same design is used for cal standards and DUTs therefore the connector effects are calibrated out**

# Connectors have always to be treated as a pair



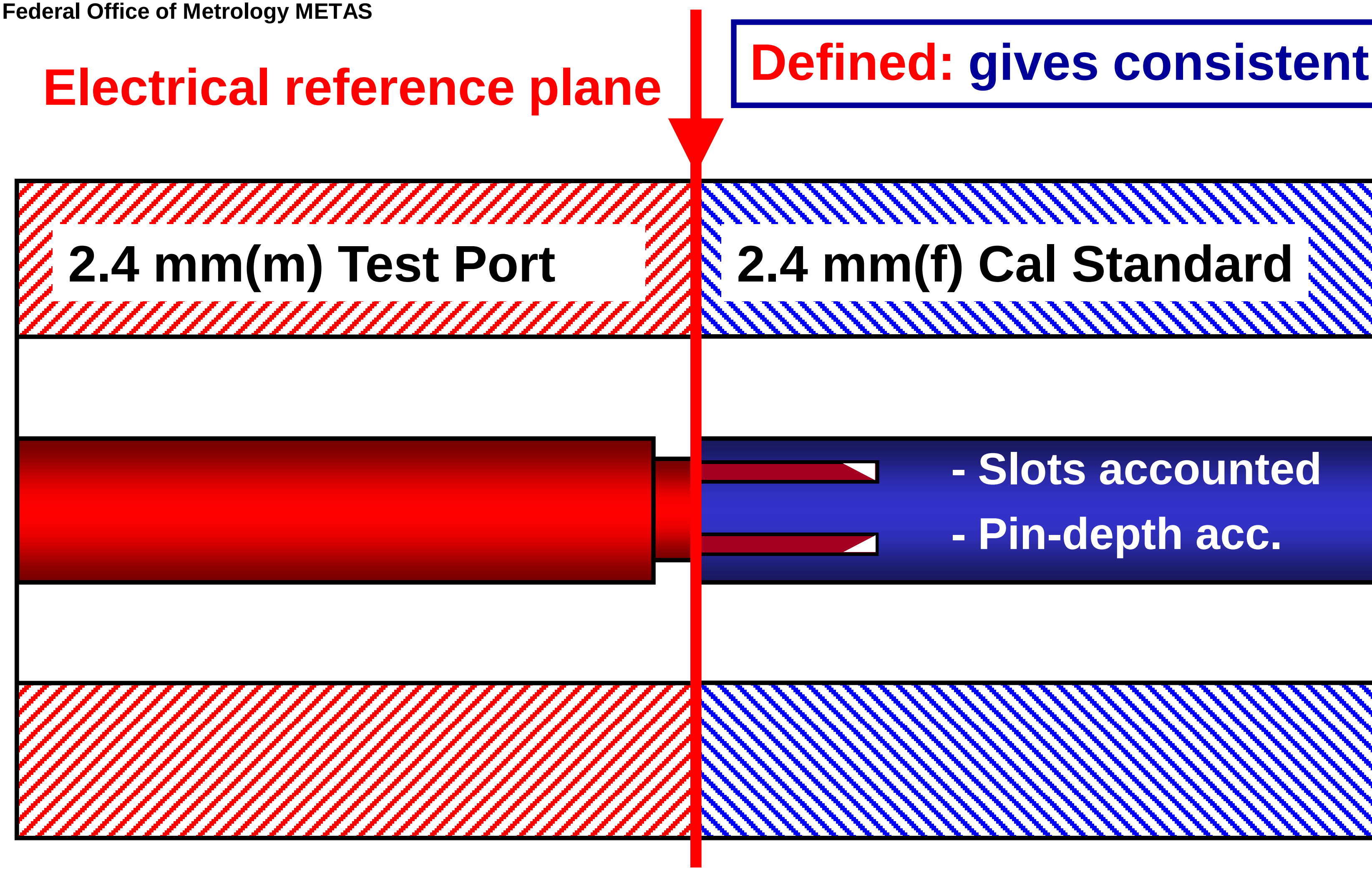
**Issue: if treated as a pair only**




**The electrical reference plane is not correctly defined: effects of female connector absorbed in test port error box**

# Electrical reference plane

**Defined: gives consistent results**




**Only the error introduced by the TP will be „absorbed“ into the error box of the calibration model of the VNA**

# Out-dated connector dogmas

- **Cal definitions include the connector effects**

# 85054B Type-N Cal kit standard definition table

**Table A-7 Standard Definitions for the 8510 Network Analyzer**

System $Z_0$[a] = 50.0 Ω
Disk File Name: CK_NTYPB2

Calibration Kit Label: TYPE N B.2
File Number: * FILE 1

| Standard[b] | | $C0 \times 10^{-15}$ F | $C1 \times 10^{-27}$ F/Hz | $C2 \times 10^{-36}$ F/Hz$^2$ | $C3 \times 10^{-45}$ F/Hz$^3$ | Fixed or Sliding[c] | Offset | | | Frequency in GHz[d] | | Coax or Waveguide | Standard Label |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Number | Type | $L0 \times 10^{-12}$ H | $L1 \times 10^{-24}$ H/Hz | $L2 \times 10^{-33}$ H/Hz$^2$ | $L3 \times 10^{-42}$ H/Hz$^3$ | | Delay | $Z_0$ Ω | Loss in GΩ/s | Min | Max | | |
| 1 | Short[e] | –0.1315 | 606.21 | –68.405 | 2.0206 | | 27.990 | 50 | 1.3651 | 0 | 999 | Coax | Short (m)[f] |
| 2 | Open[e] | 104.13 | –1943.4 | 144.62 | 2.2258 | | 22.905 | 50 | 0.93 | 0 | 999 | Coax | Open (m)[f] |
| 3 | Short[e] | 0.7563 | 459.88 | –52.429 | 1.5846 | | 63.078 | 50 | 1.1273 | 0 | 999 | Coax | Short (f)[f] |
| 4 | Open[e] | 89.939 | 2536.8 | –264.99 | 13.4 | | 57.993 | 50 | 0.93 | 0 | 999 | Coax | Open (f)[f] |

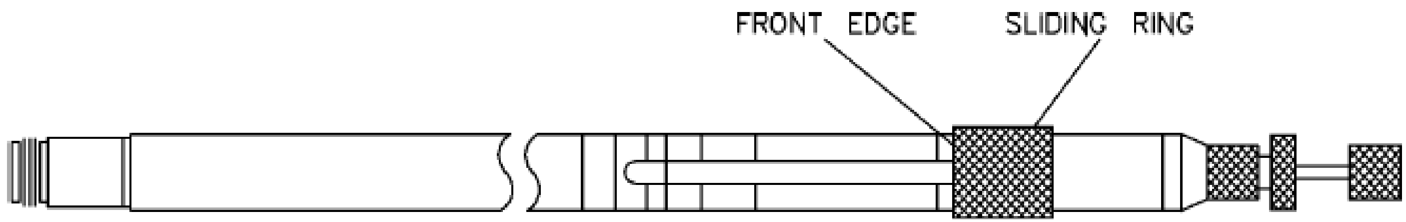
# **85056A Cal kit standard definition table** (male = female)

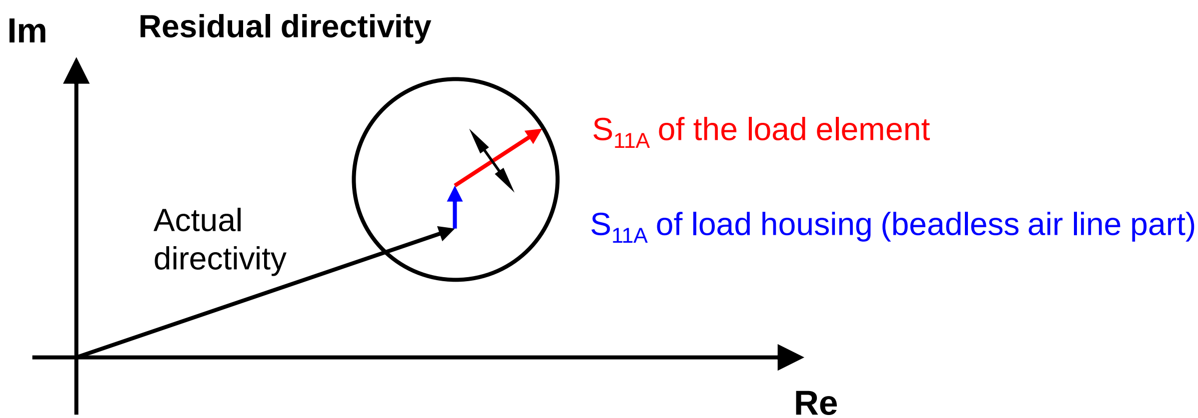
**Table A-9 Standard Definitions for the PNA Series Network Analyzers**

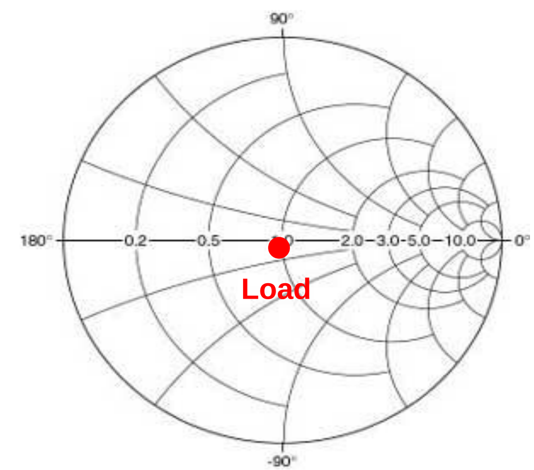
System $Z_0$[a] = 50.0 Ω — Calibration Kit Label: 2.4 mm Model 85056A

| Standard[b] | | $C0 \times 10^{-18}$ F | $C1 \times 10^{-30}$ F/Hz | $C2 \times 10^{-39}$ F/Hz$^2$ | $C3 \times 10^{-48}$ F/Hz$^3$ | | Offset | | | Frequency in GHz | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Number | Type | $L0 \times 10^{-12}$ H | $L1 \times 10^{-24}$ H/Hz | $L2 \times 10^{-33}$ H/Hz$^2$ | $L3 \times 10^{-45}$ H/Hz$^3$ | Fixed or sliding | Delay in ps | $Z_0$ Ω | Loss in GΩ/s | Min | Max | Coax or Waveguide | Standard Label |
| 1 | Short[c] | 2.1636 | –146.35 | 4.0443 | –0.0363 | | 22.548 | 50 | 3.554 | 0 | 999 | Coax | Short |
| 2 | Open[c] | 29.722 | 165.78 | –3.5385 | 0.0710 | | 20.837 | 50 | 3.23 | 0 | 999 | Coax | Open |
| 3 | Load | | | | | Fxd | 0 | 50 | 3.554 | 0 | 999 | Coax | Broadband |
| 4 | Delay/ thru | | | | | | 0 | 50 | 3.554 | 0 | 999 | Coax | Thru |
| 5 | Load | | | | | Sliding | 0 | 50 | 3.554 | 3.999 | 999 | Coax | Sliding |
| 6 | Load | | | | | Fxd | 0 | 50 | 3.554 | 0 | 4.001 | Coax | Lowband |
| 7 | | | | | | | | | | | | | |

# Sliding load (connector assumed to be perfect)

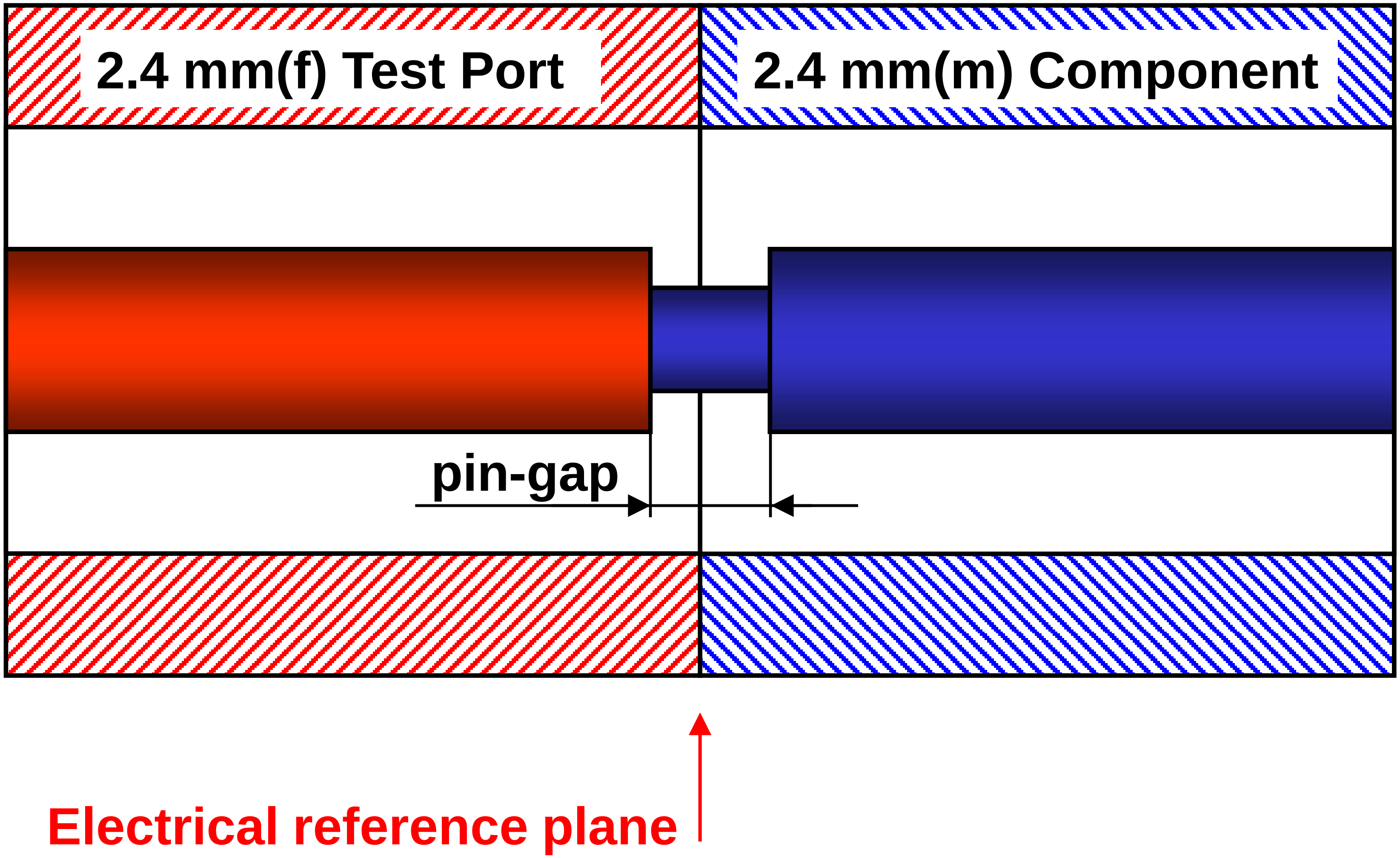


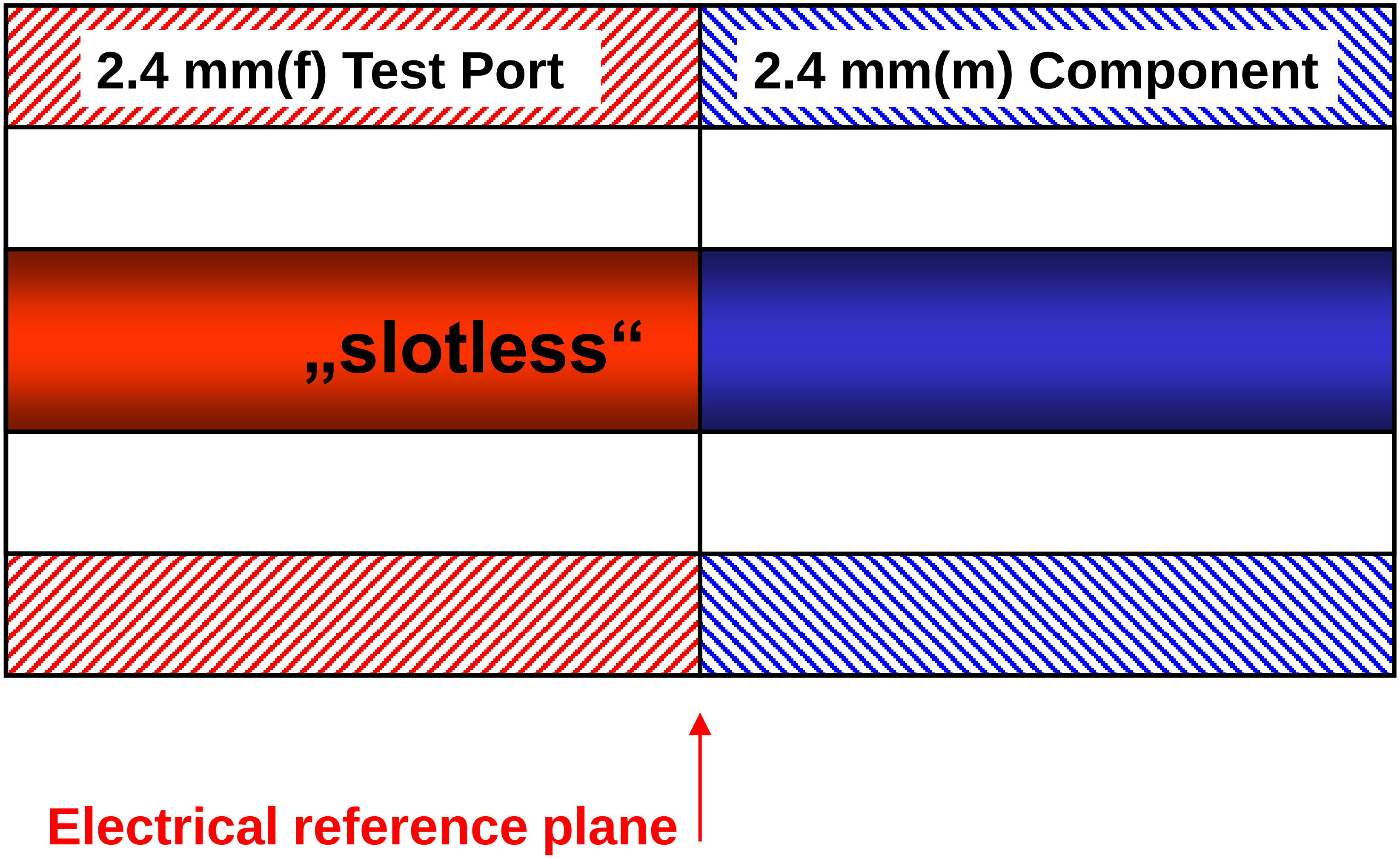
# out-dated connector dogma

- Typical connection
- Pin-depth on both sides

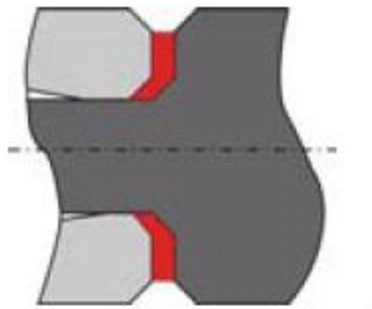


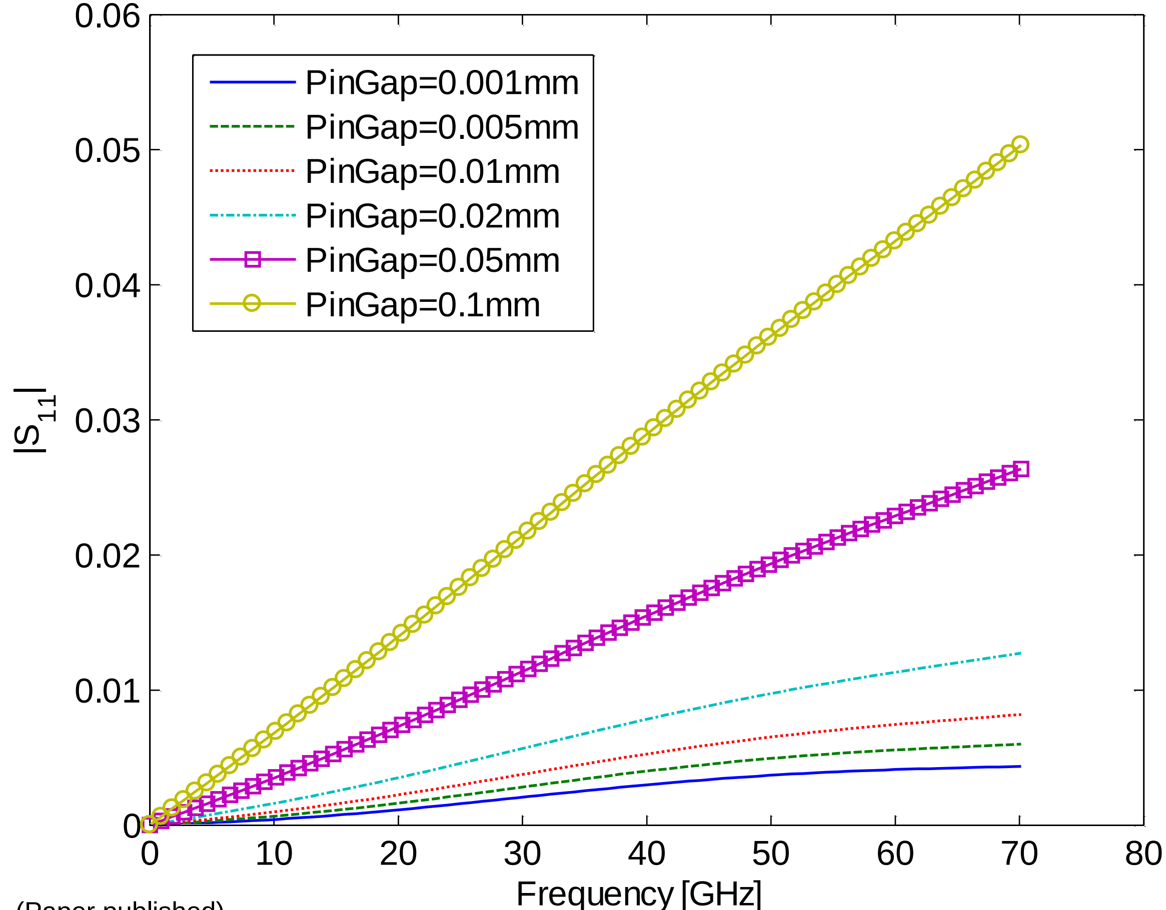
# „nominal TP“

- Slotless female CC
- Ideal connection (50 ohm)



# 1.85 mm connector: S11 with small female chamfer



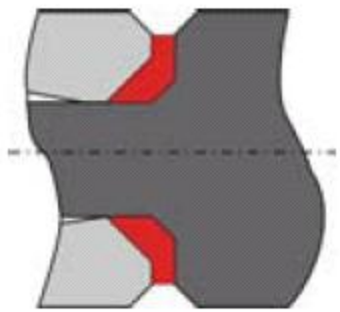


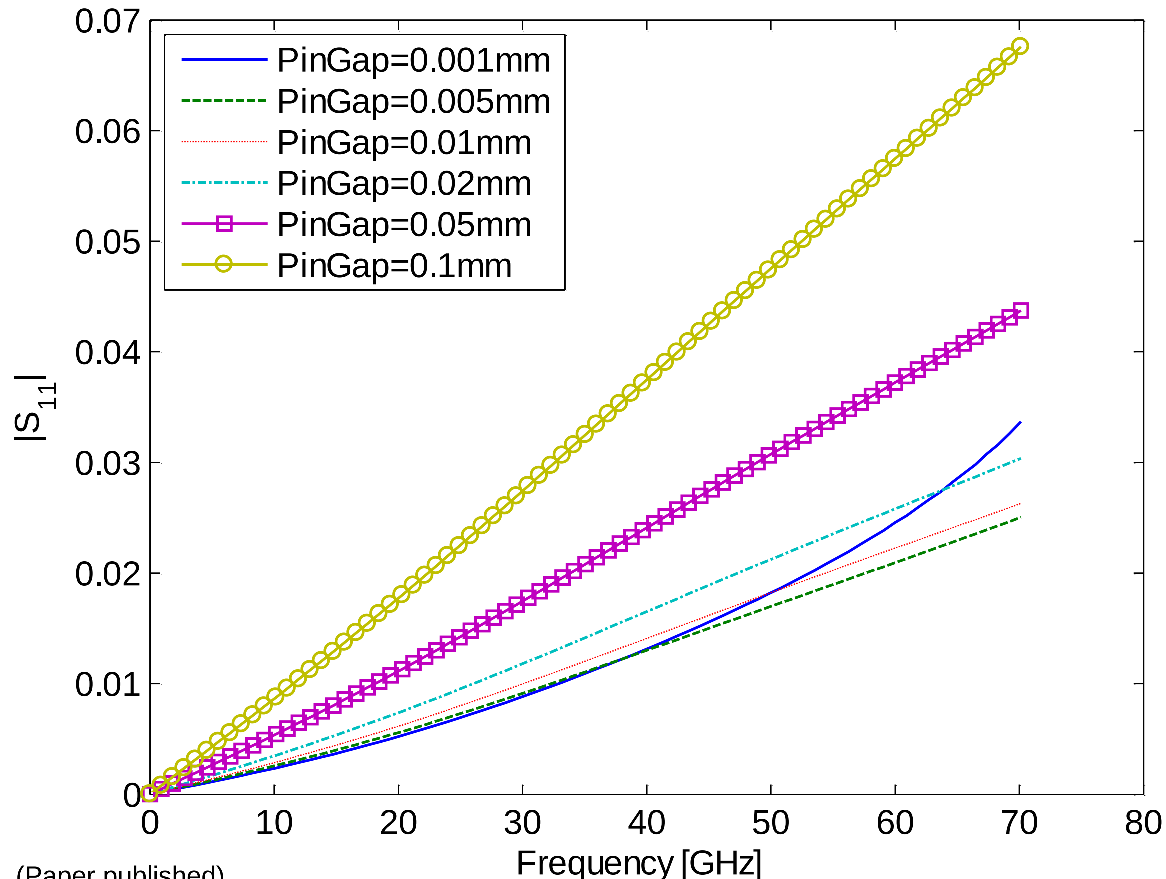

## CoMo70 outcomes:

**Johannes Hoffmann, ETHZ, CoMo70 project** (Paper published)

Near field effects

# 1.85 mm connector: S11 with big female chamfer



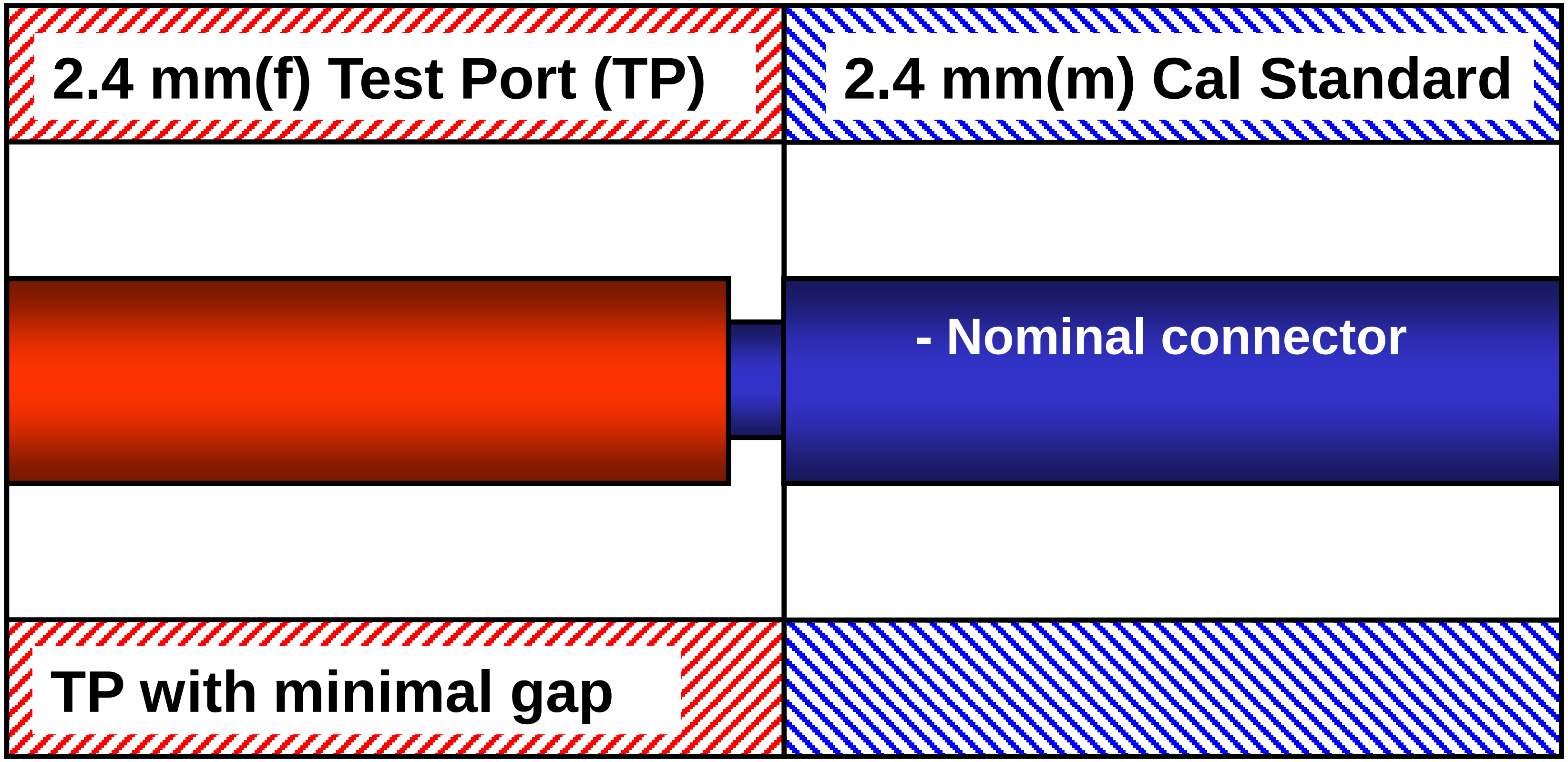



## CoMo70 outcomes:

**Johannes Hoffmann, ETHZ, CoMo70 project** (Paper published)

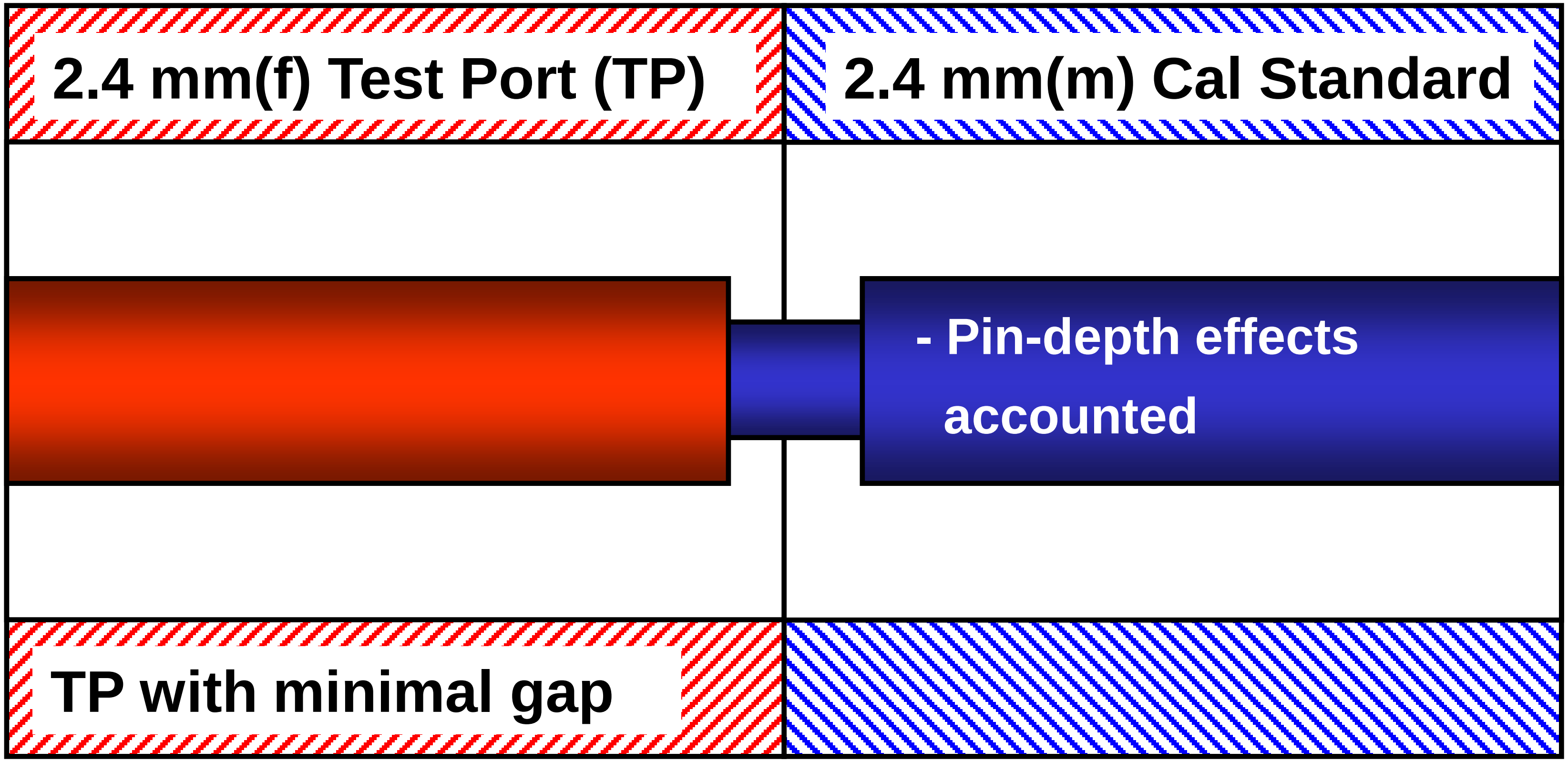

CONTROL THE GAP

# A defined TP gap size will avoid the potential near field effects




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

# A defined TP gap size will avoid the potential near field effects

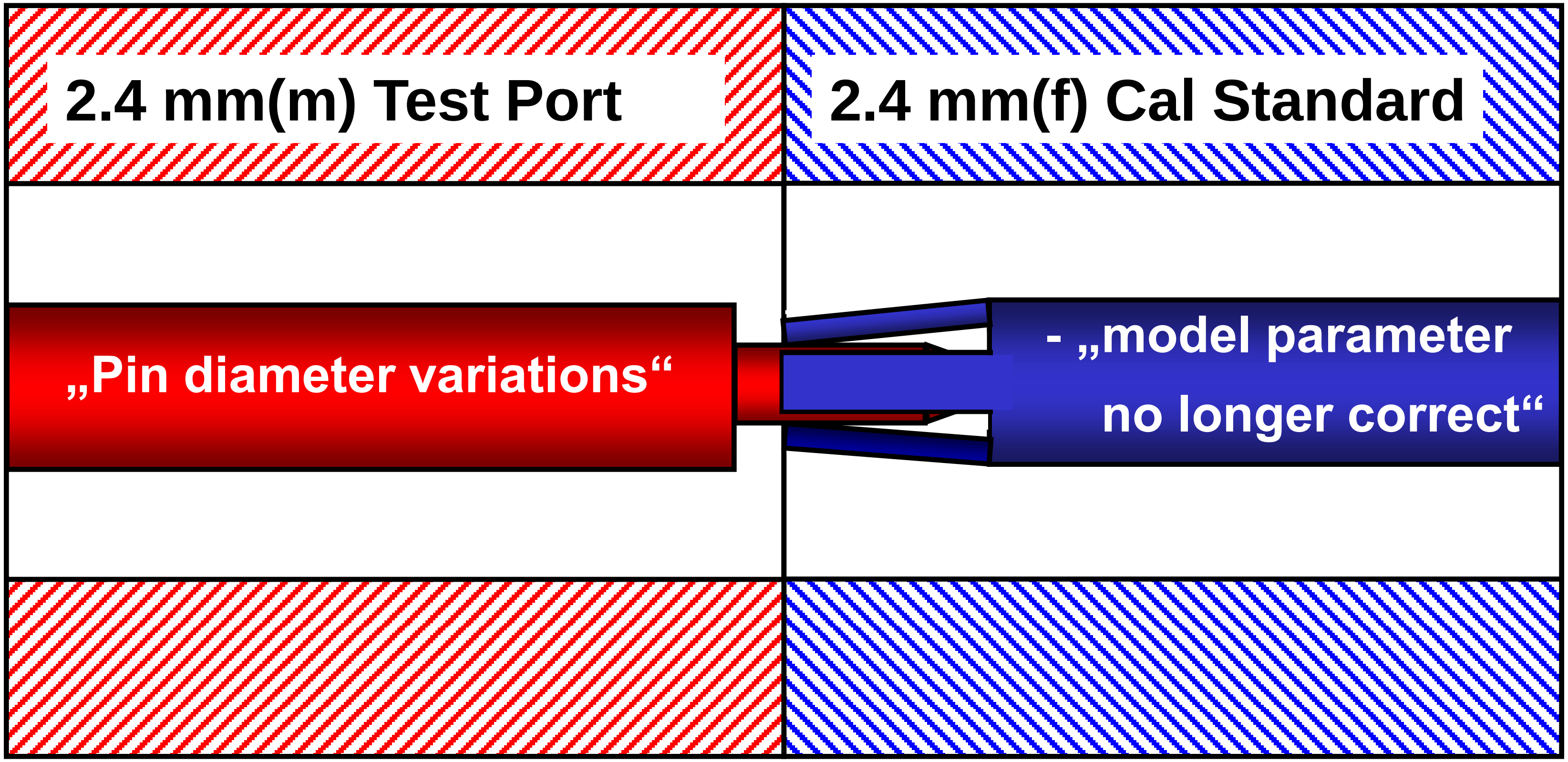



→ **Pin-depth tolerances on the Standard/DUT side will not stimulate the unwanted and undefined near field effects**

# Out-dated connector dogmas

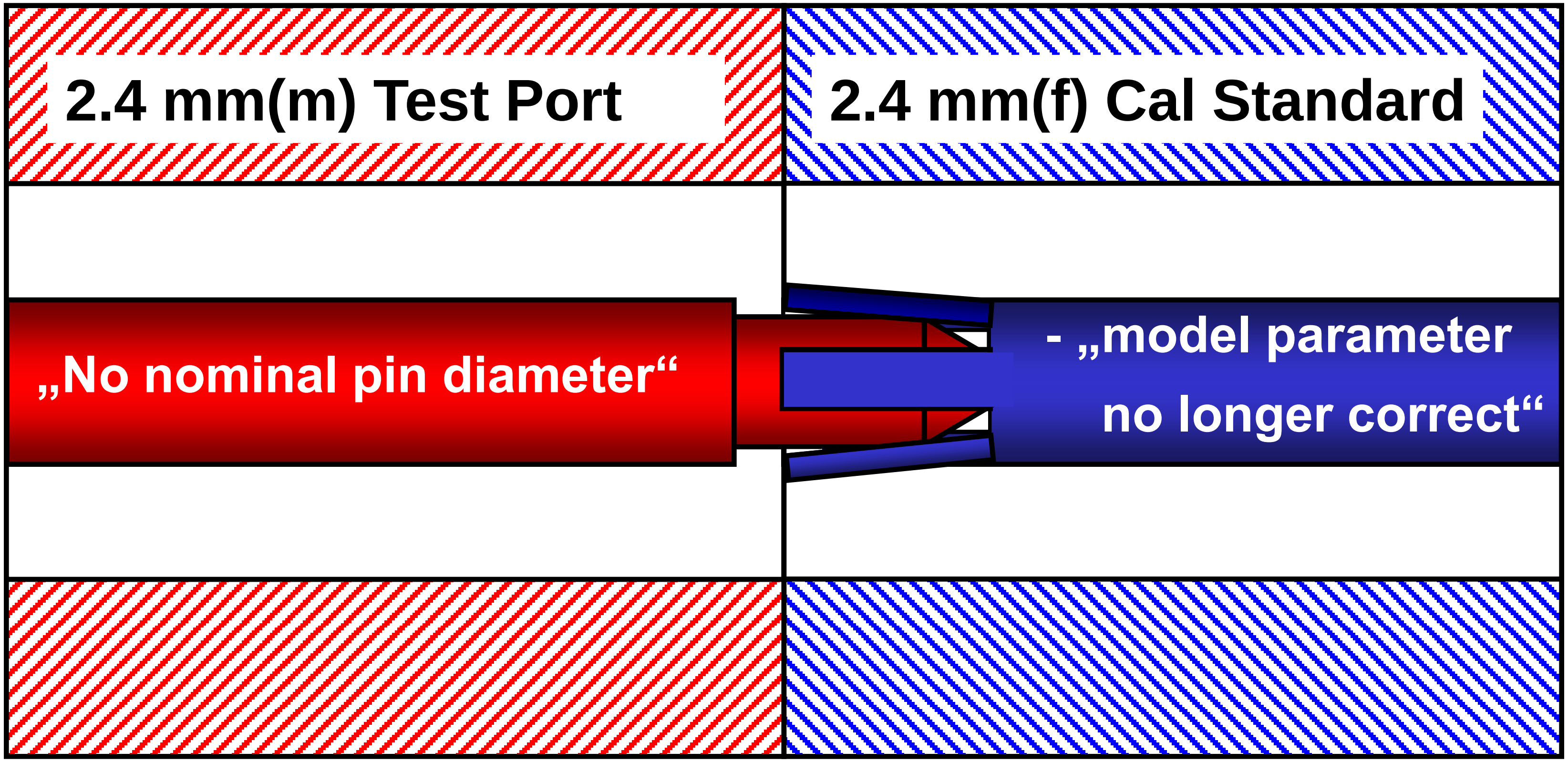
- **Slotless connectors are always better**

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



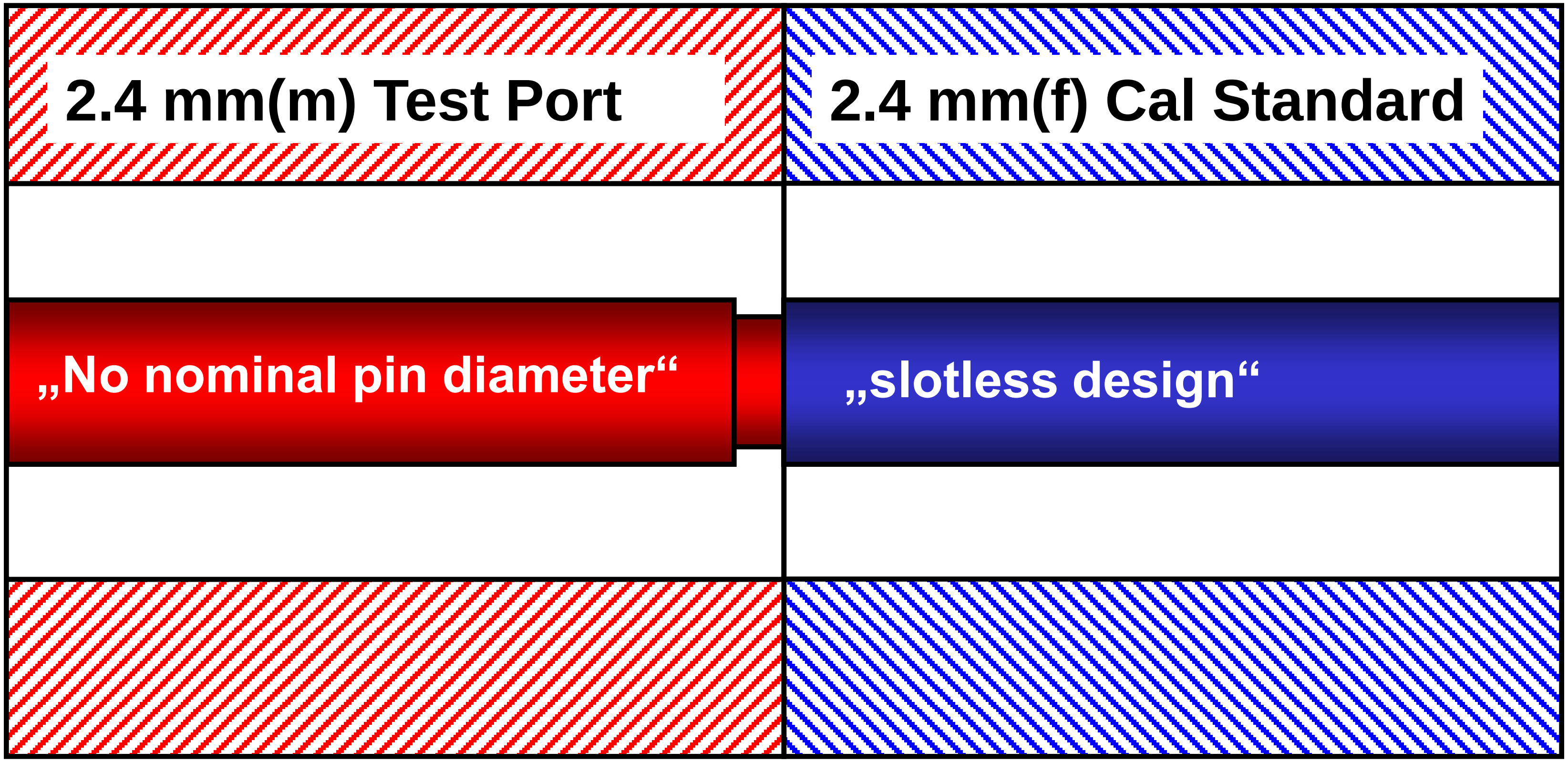

**The impedance characteristics of the connected calibration standard is changed by the size of the TP pin diameter**

- Slotted female CC
- Problem: pin diameter



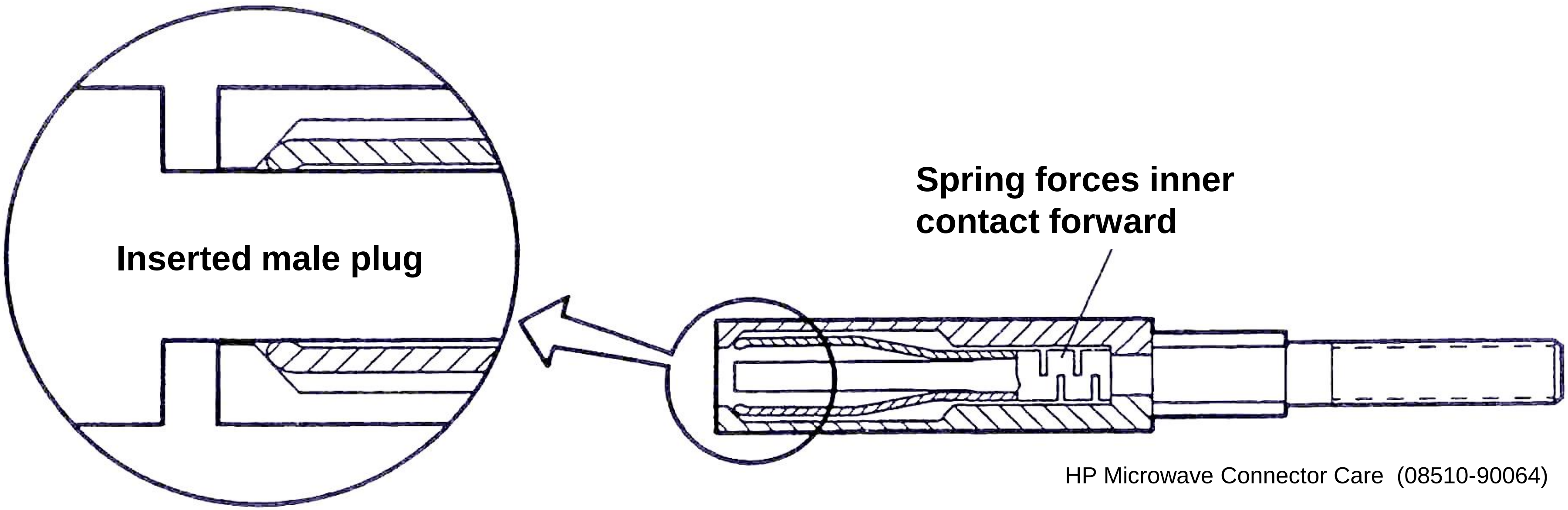

**The impedance characteristics of the connected calibration standard is changed by the size of the TP pin diameter**

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




**The slotless design is more robust against pin diameter variations: female cal standard characteristic will not change**

# Slotted versus slotless female connector design

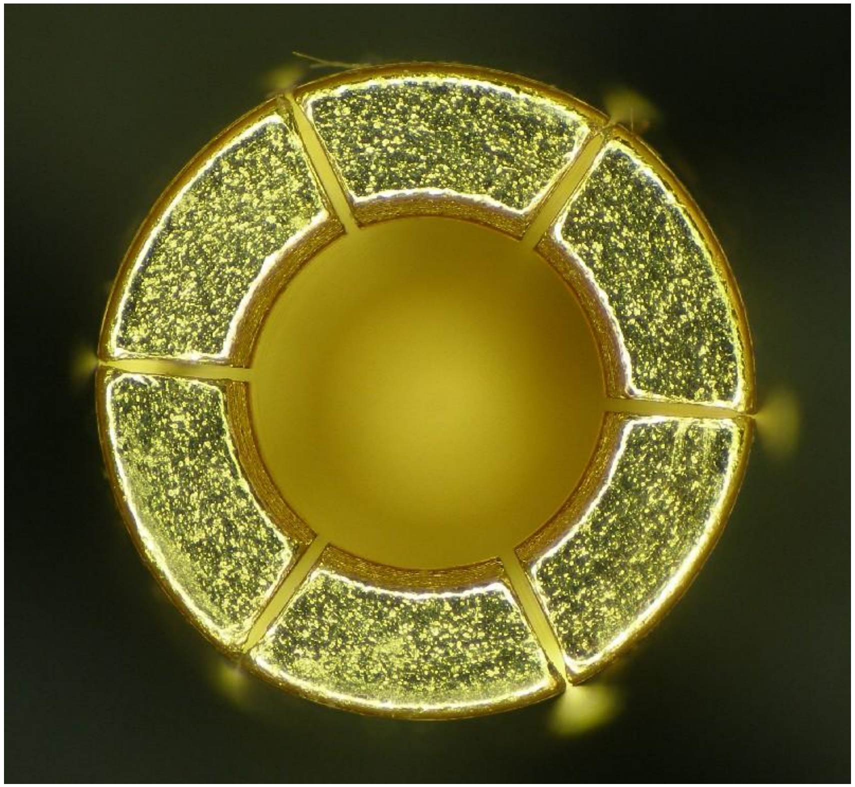



HP Microwave Connector Care (08510-90064)

**Detail of precision slotless female centre conductor developed by Agilent**

(Slotless female conductors are available for Type-N, 3.5 mm and 2.4 mm connectors)

# Slotted versus slotless connector interface (Type-N)



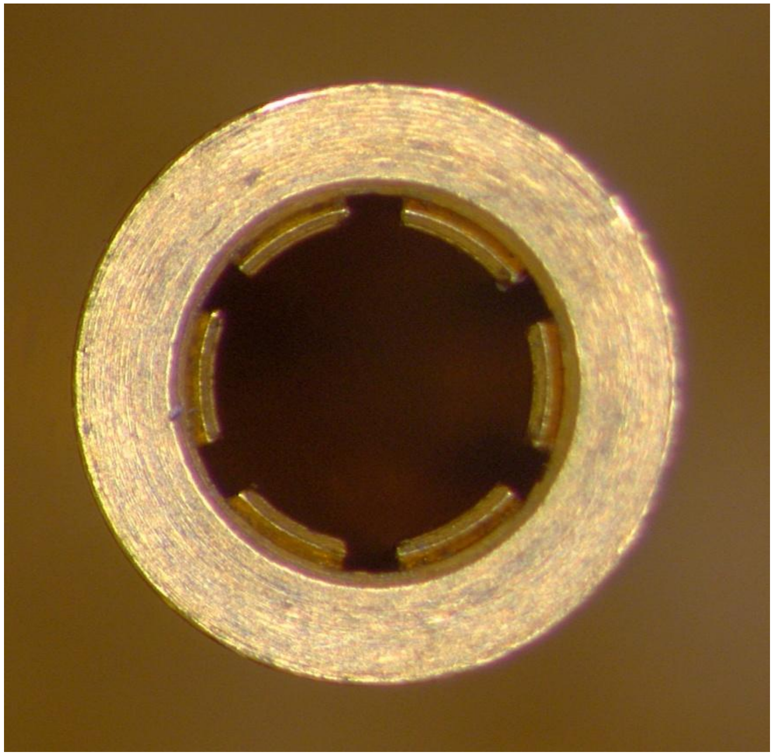
Blair Hall, MSL

METAS

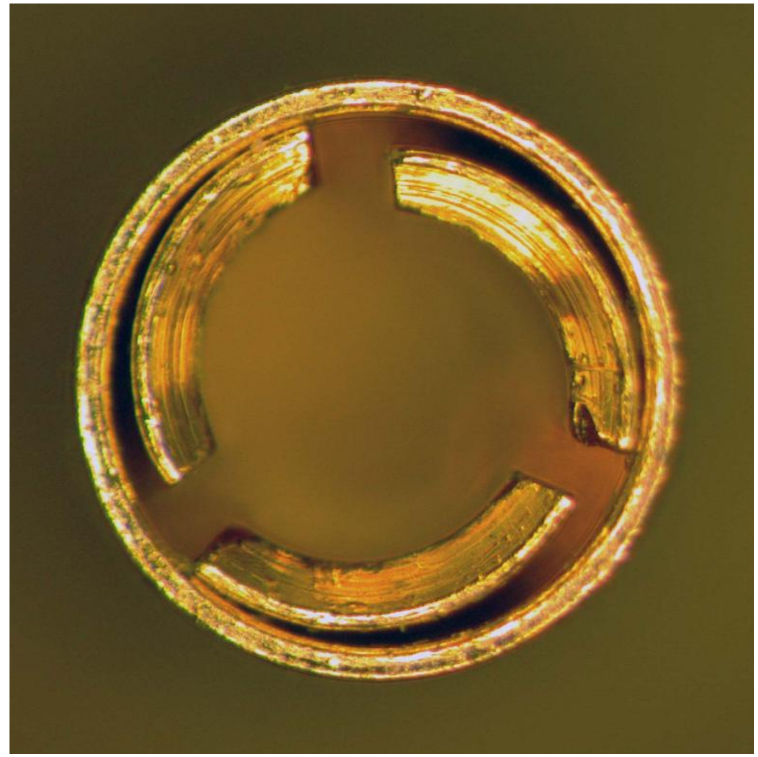
**Slotted** (2-, 4-, 6- or 8-slots)

**Slotless** (precision)

# Slotless female connector design examples: 3.5 mm

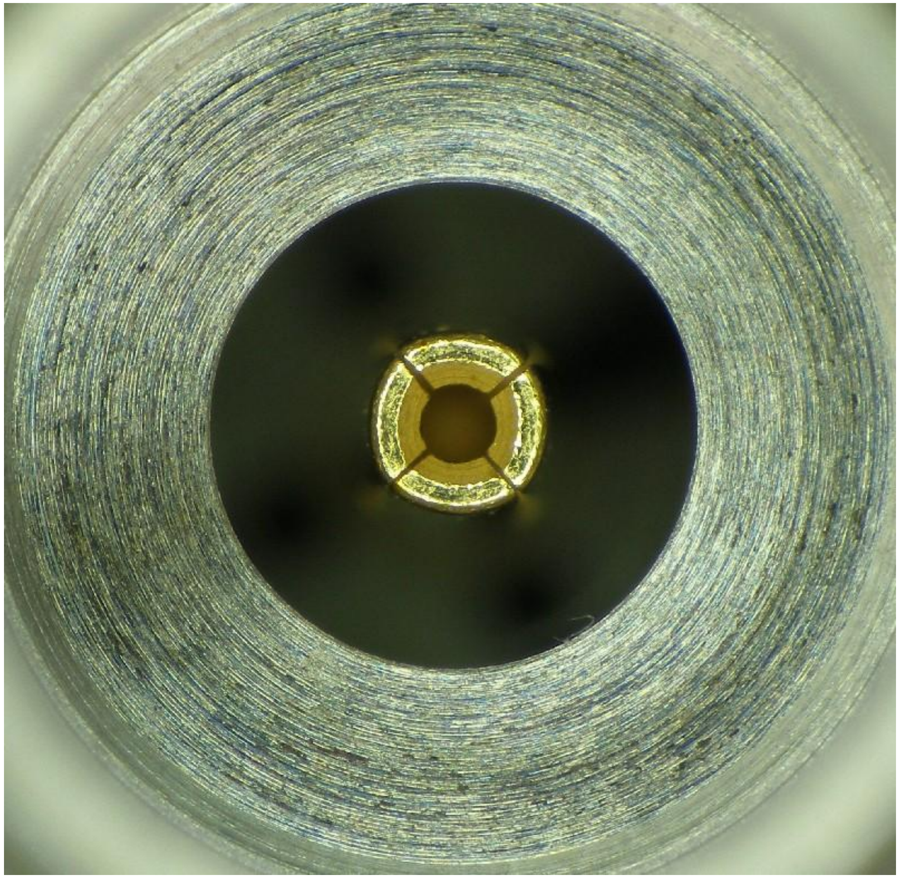


**3.5 mm contact developed by Agilent**



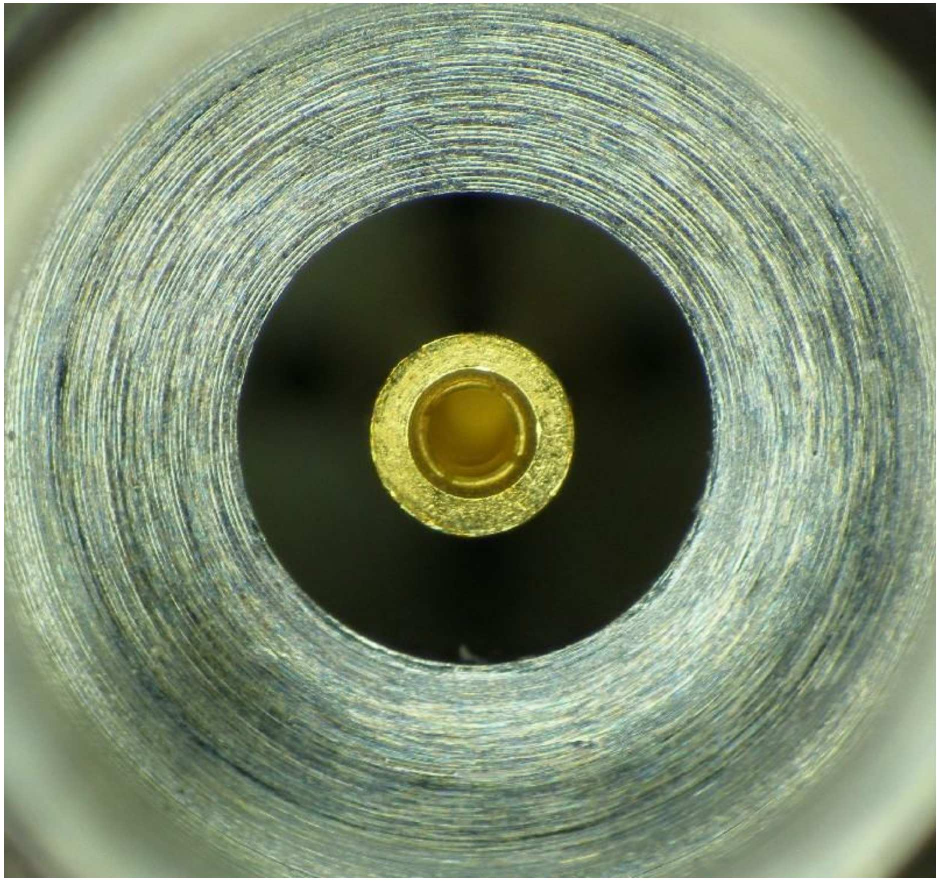
**WSMA contact developed by Anritsu**

# 2.4 mm (female) connector interface designs:



Blair Hall, MSL

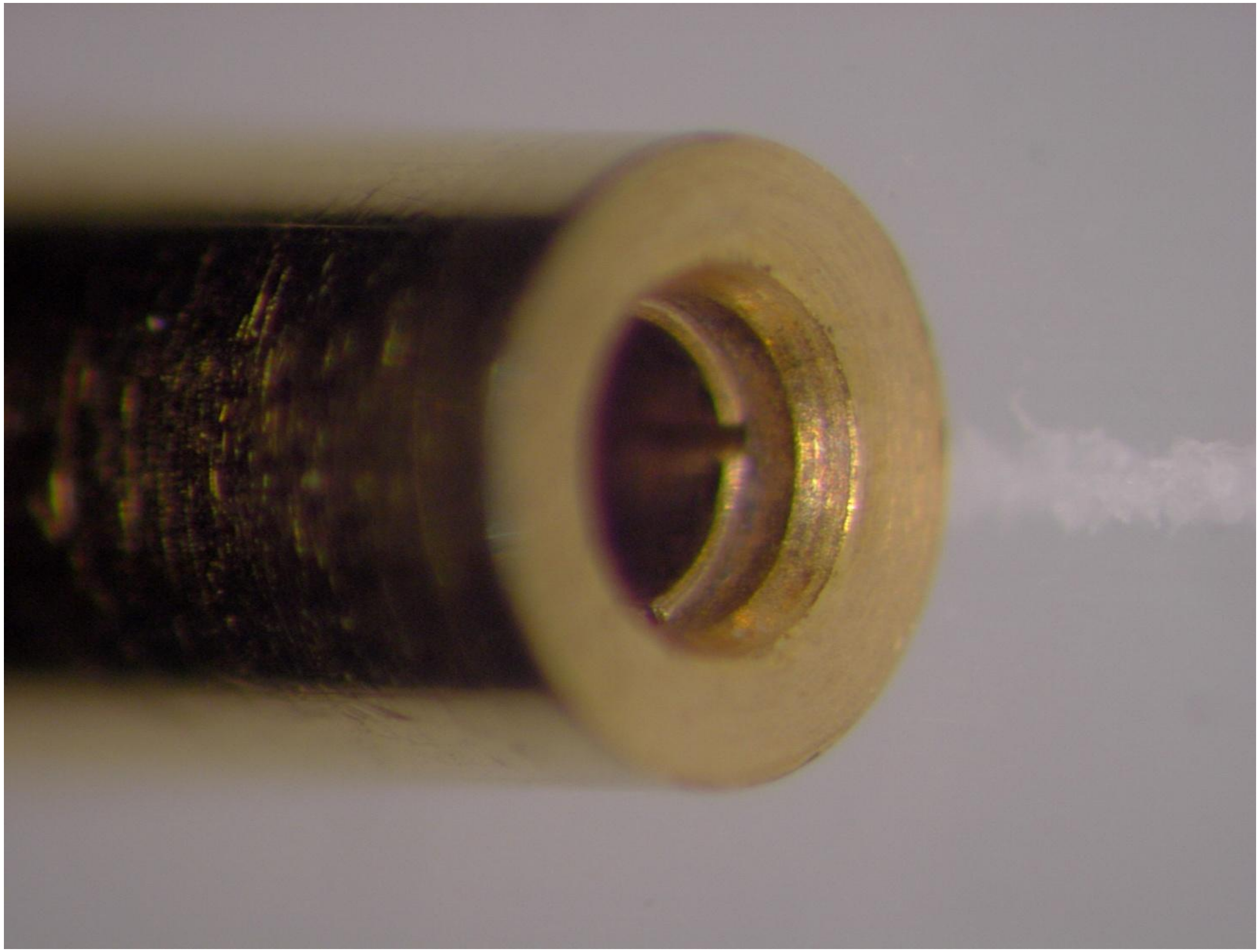
**Slotted** (4-slots)



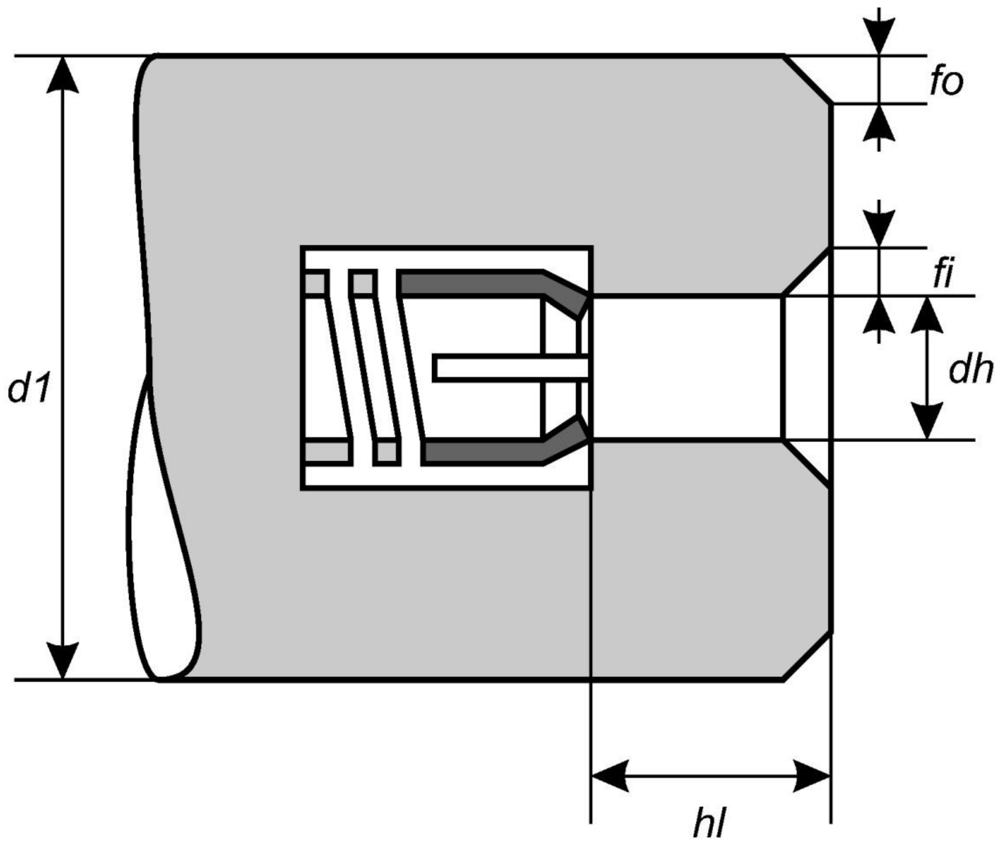
Blair Hall, MSL

**Slotless** (precision)

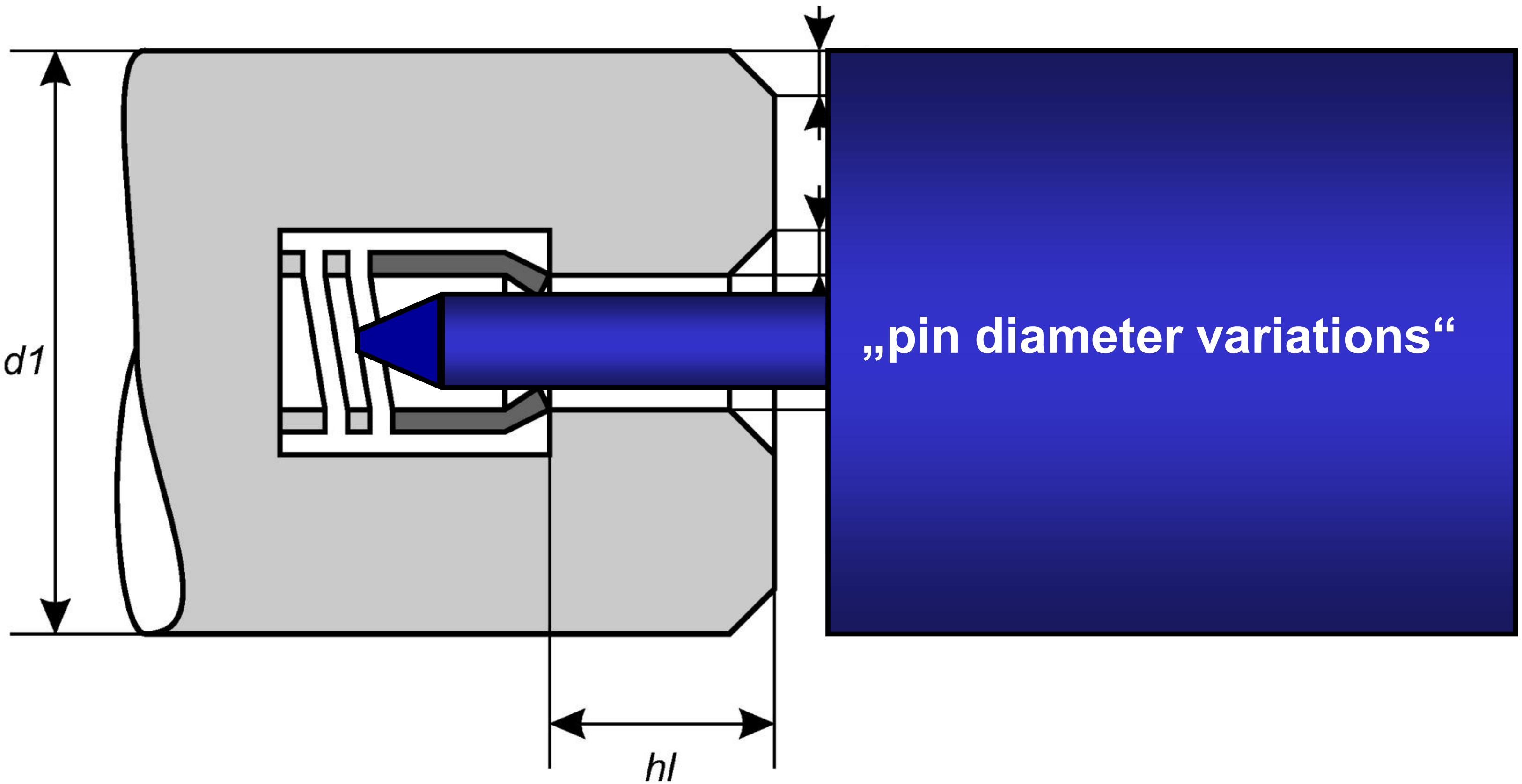
# 2.4 mm slotless connector section from a sliding load



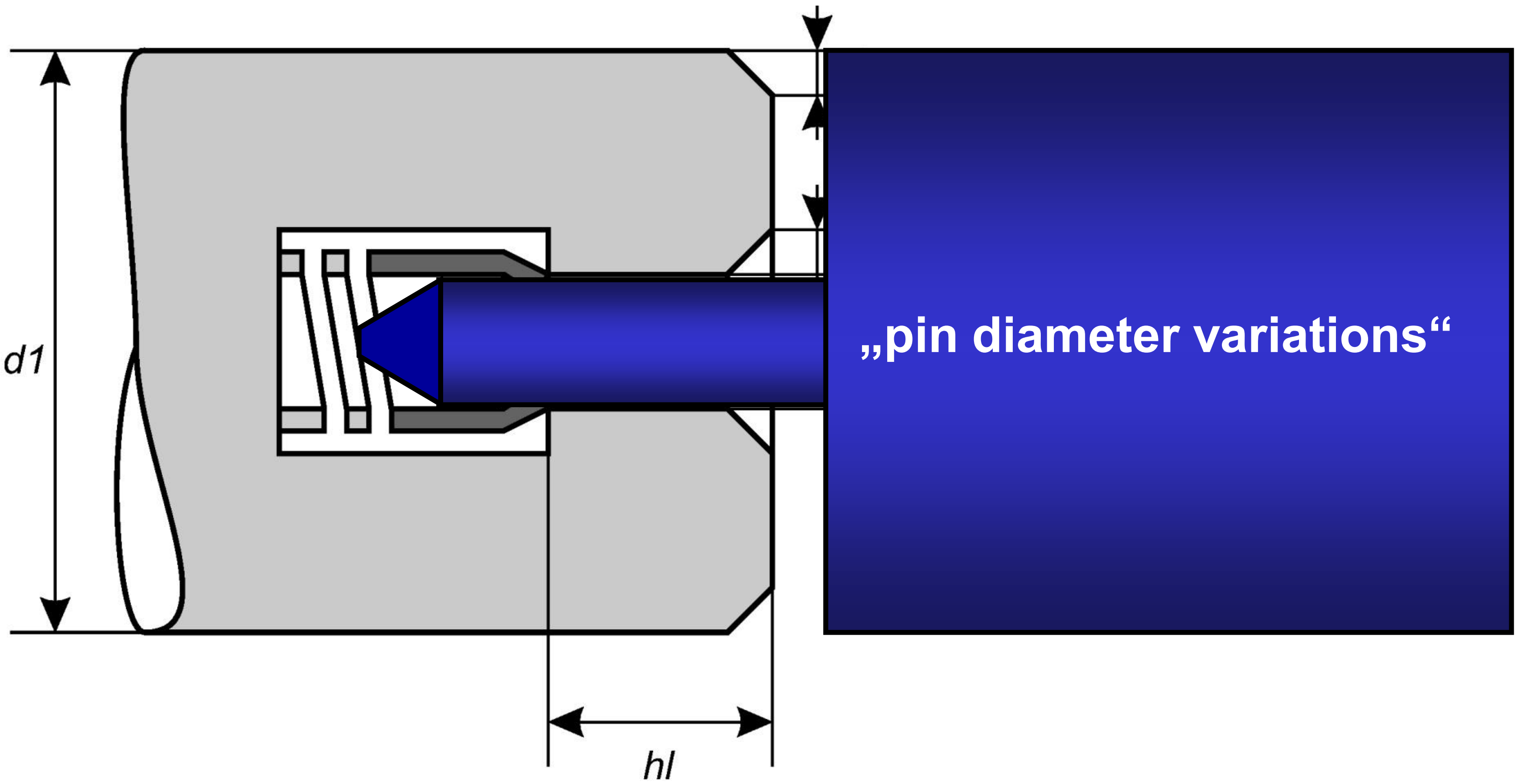
# 2.4 mm (female) connector interface design:



# 2.4 mm (female) connector interface design:



# 2.4 mm (female) connector interface design:



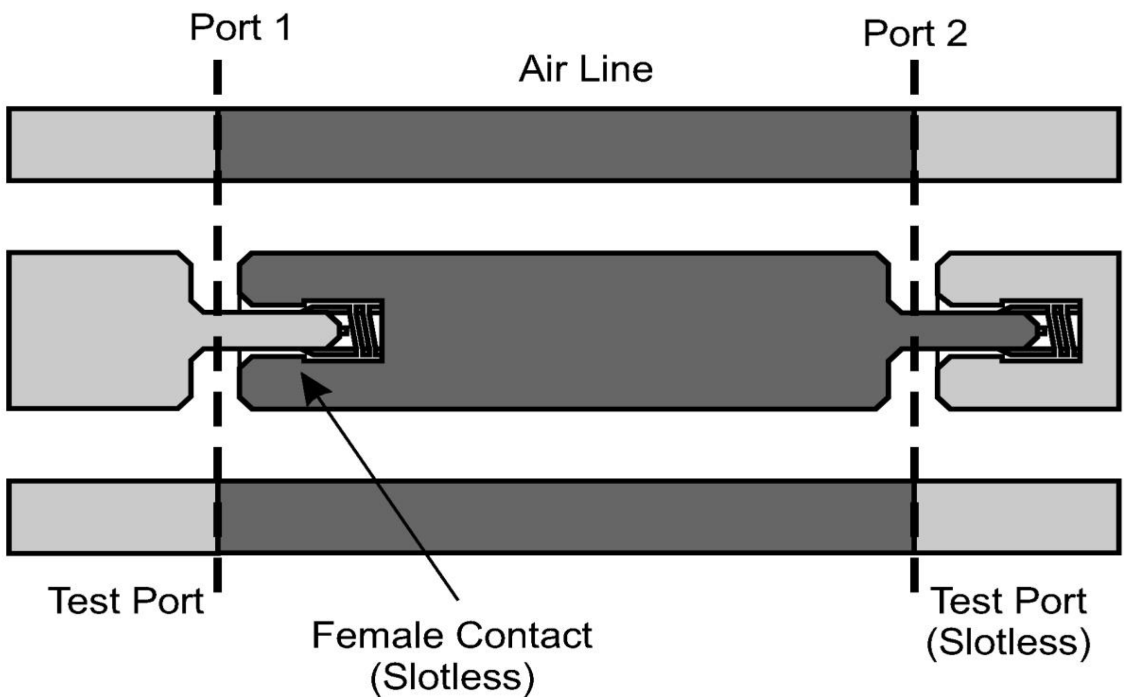
# Are Slotless connectors always better ?

- **Slotted connectors are more sensitive to male pin diameter variations compared to an optimised slotless connector design.**
- **Slotless connectors may have a higher reflection coefficient compared to an optimised slotted connector design.**
- **Slotless connectors can be better characterised mechanically.**

# The 2.4 mm connector investigations

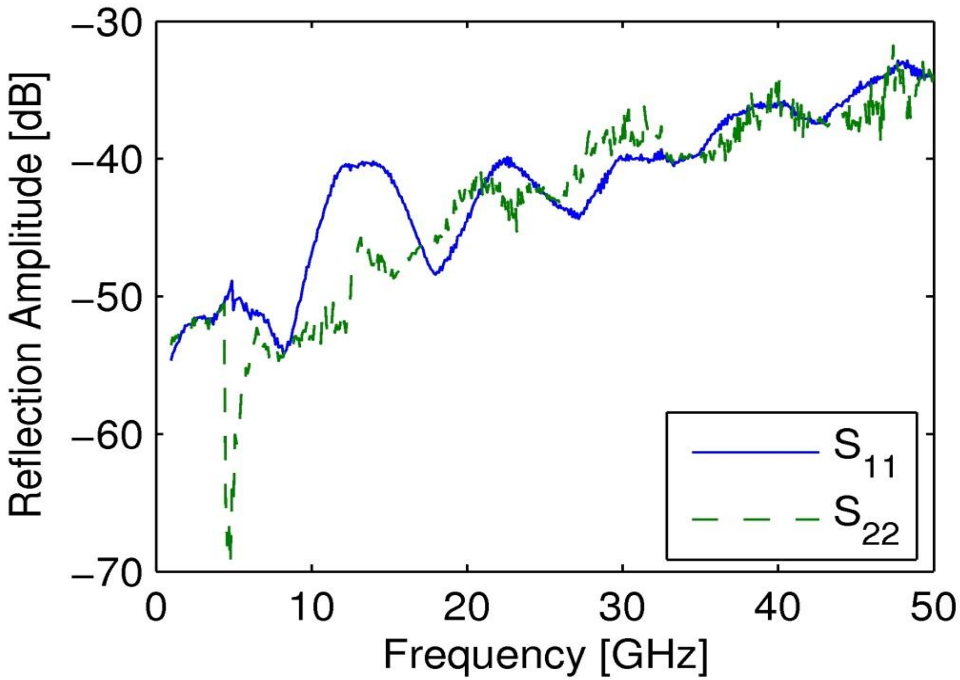
- **Based on the CoMo70 work presented at ARFTG**
- **Measurement setup**
- **Sliding load calibration including connector model**
- **Some results of the 2.4 mm slotless investigations**

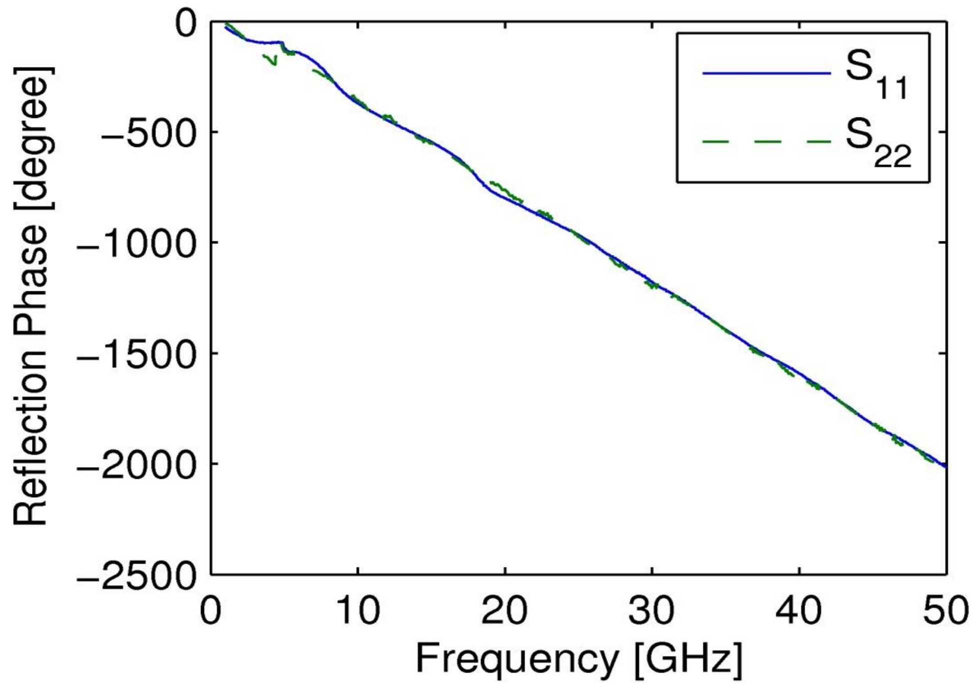
# Measurement of a 2.4 mm Air Line




- **Air Line:** length = 17 mm, beadless, slotless
- **Test Port 2:** slotless

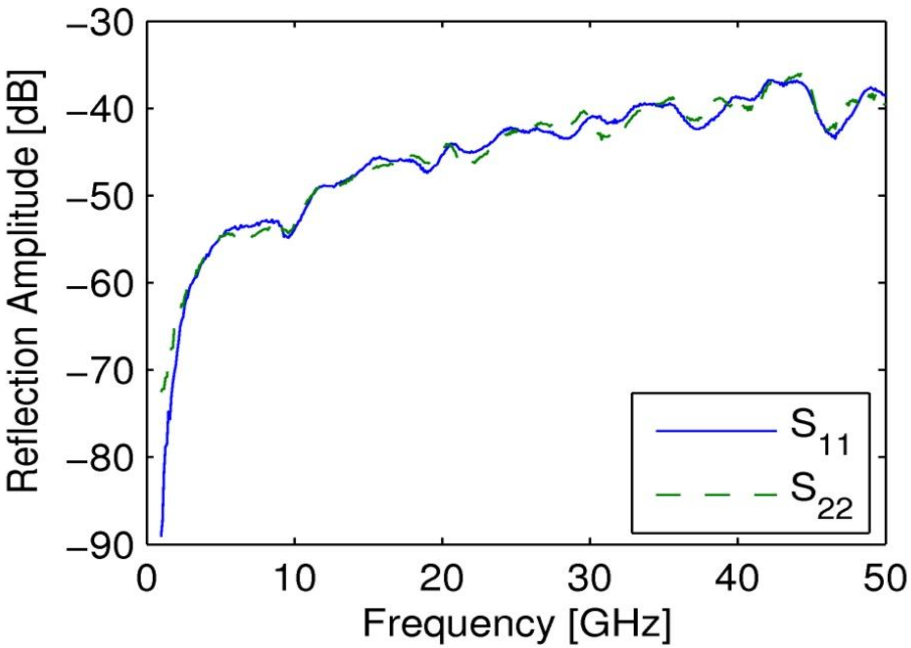
# Reflections of the 17 mm Air Line (based on a sliding load calibration)

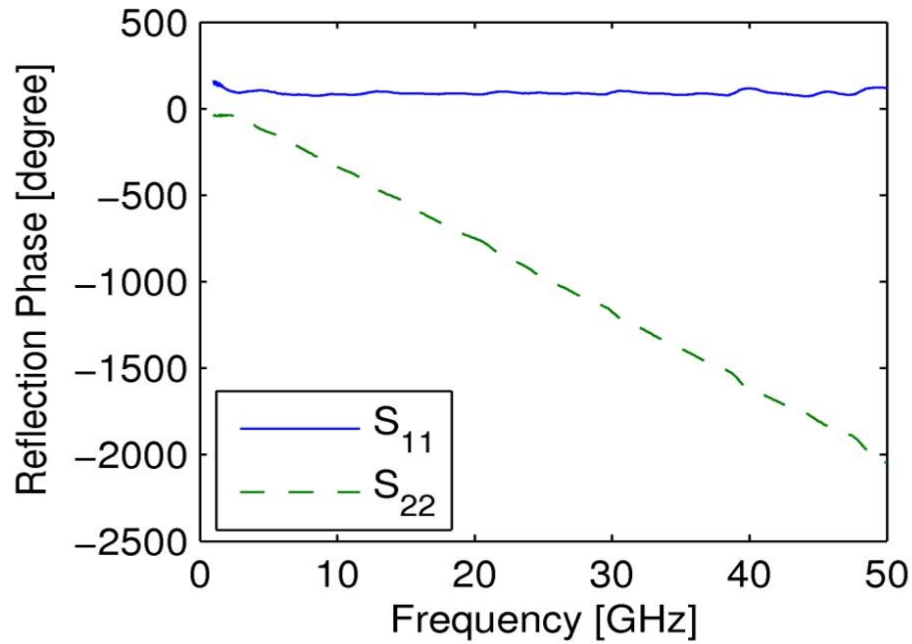



- **S11 → dominant reflection at Port 2 !**
- **S22 → dominant reflection at Port 1 !**

# Reflections of the 17 mm Air Line (based on a LRL Multi Line calibration)



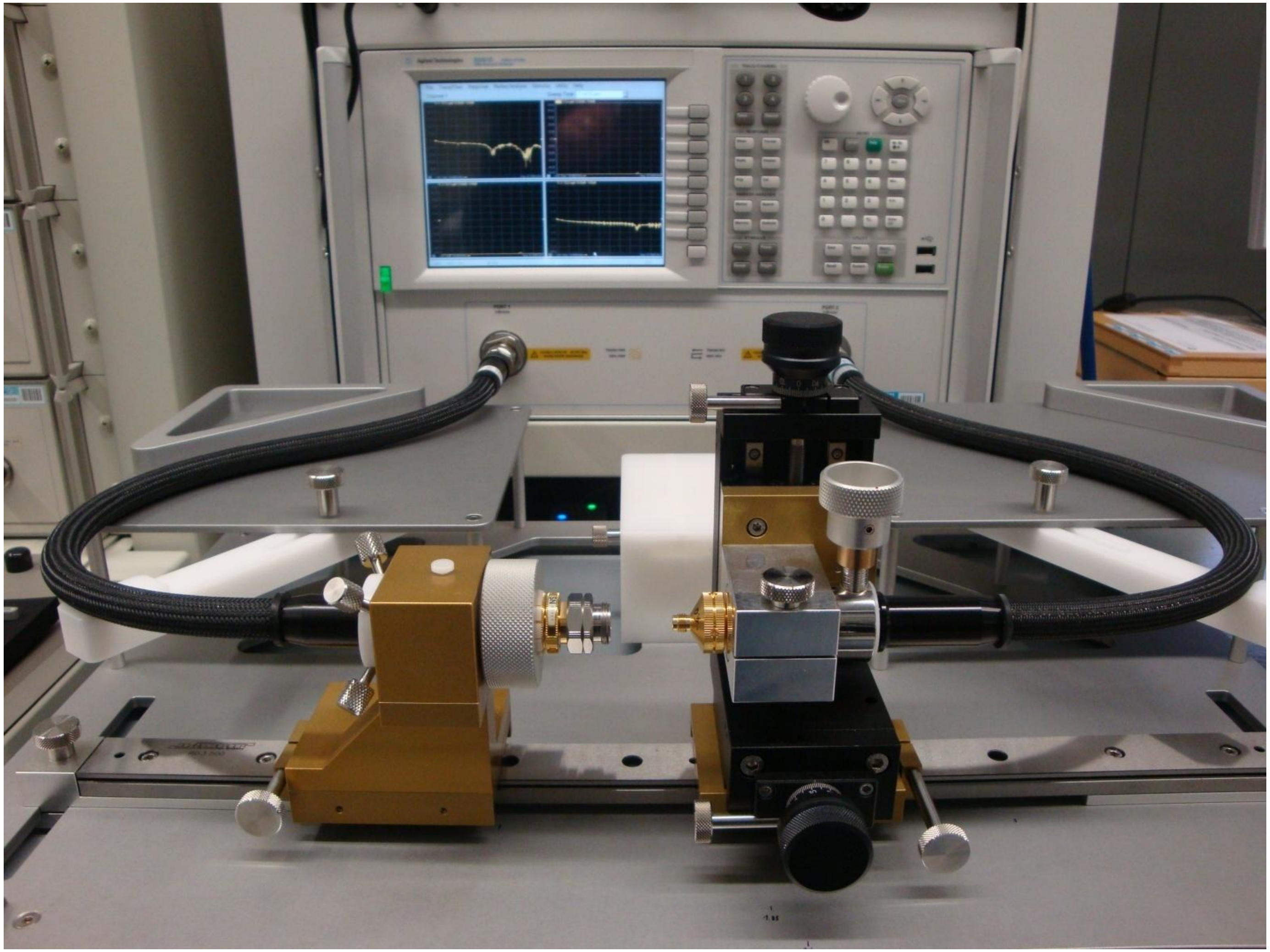




- **S11 → dominant reflection at Port 1**
- **S22 → dominant reflection at Port 1**

# Measurement setup for the 2.4 mm investigation

- **85057B verification kit** (two attenuators and two airlines)
- **E555 comparison artefacts and other transfer standards**
- **85056A OSL calibration kit with sliding loads** (monitor cal)
- **85056A_K08 Multiline LRL calibration kit with flush shorts**
- **Mechanical characterisation: lines and female connectors**
- **Bayesian calibration algorithm** (incl. connector modelling)

# Measurement setup used for the 2.4 mm experiments

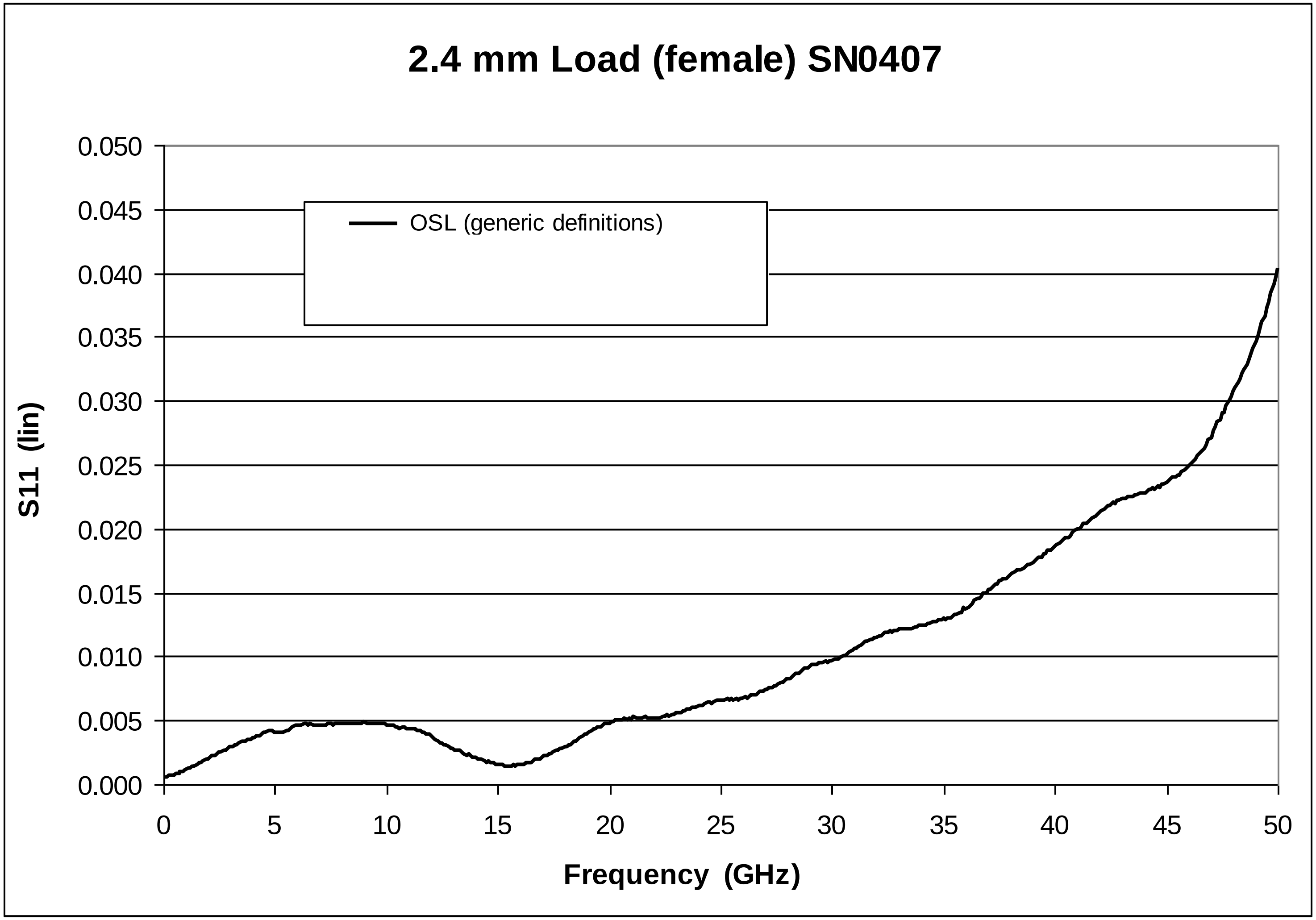


# Investigations / experiments

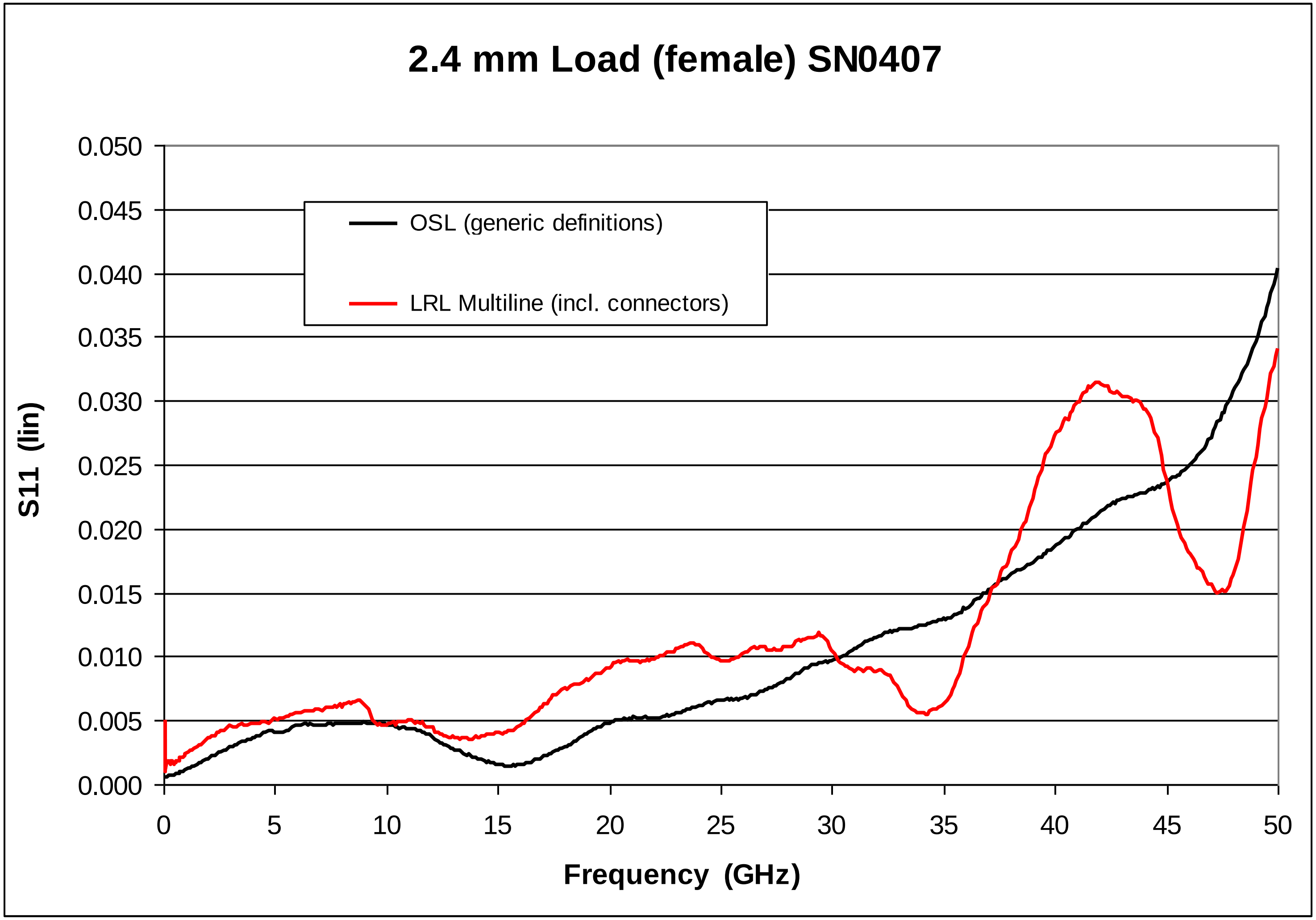
- Shown calibration method examples:
  - **OSL** (*all standards*: generic definitions from the cal kit manufacturer)
  - **OSL** *sliding load:* with connector effect (*other standards*: generic definitions)
  - **LRL Multiline**: *female standards:* with connector effect

- Effects on a load measurement
- Effects on a flush short measurement (S-parameter consistency)
- Effects on a 50 ohm airline measurement (Ripple effect)
- …

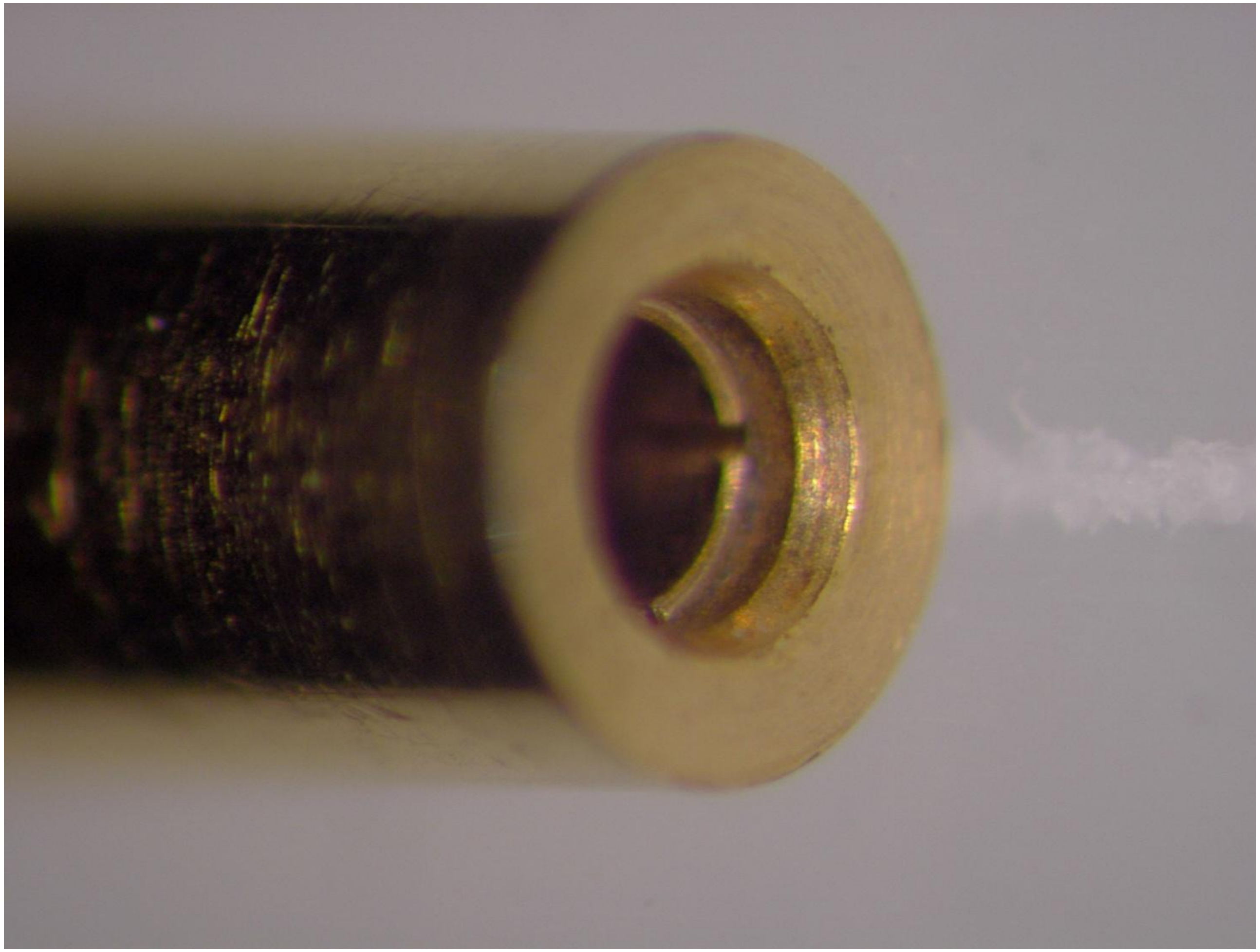
# Female Load measurements: OSL with generic definitions



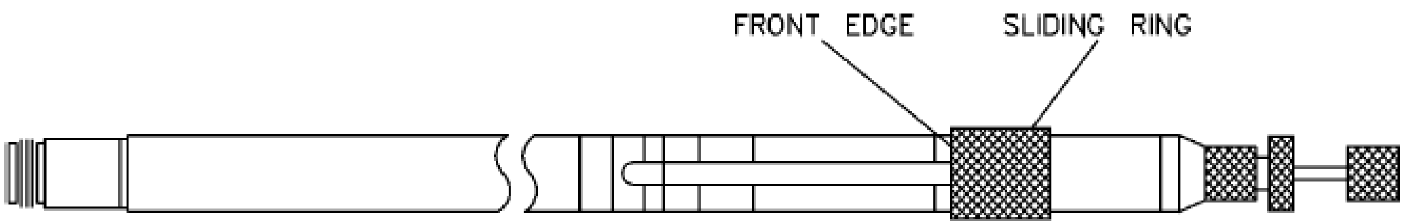
# Female Load measurements: OSL versus LRL with connectors

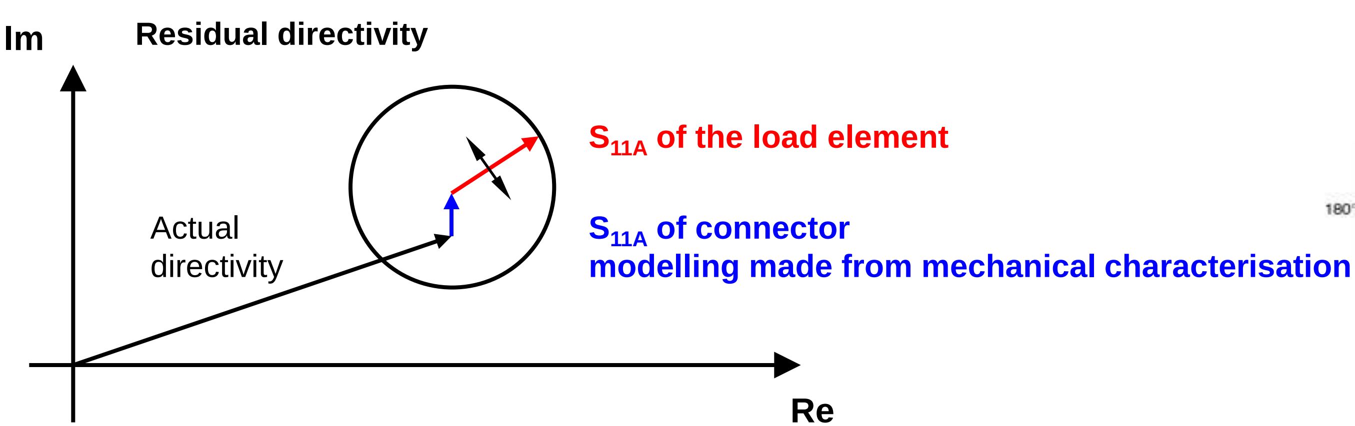


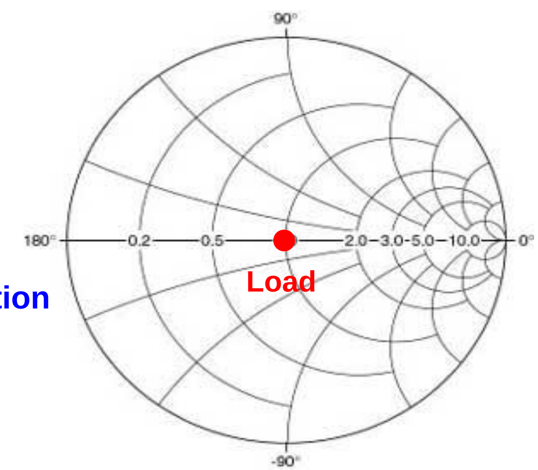
# 2.4 mm slotless connector section from the sliding load



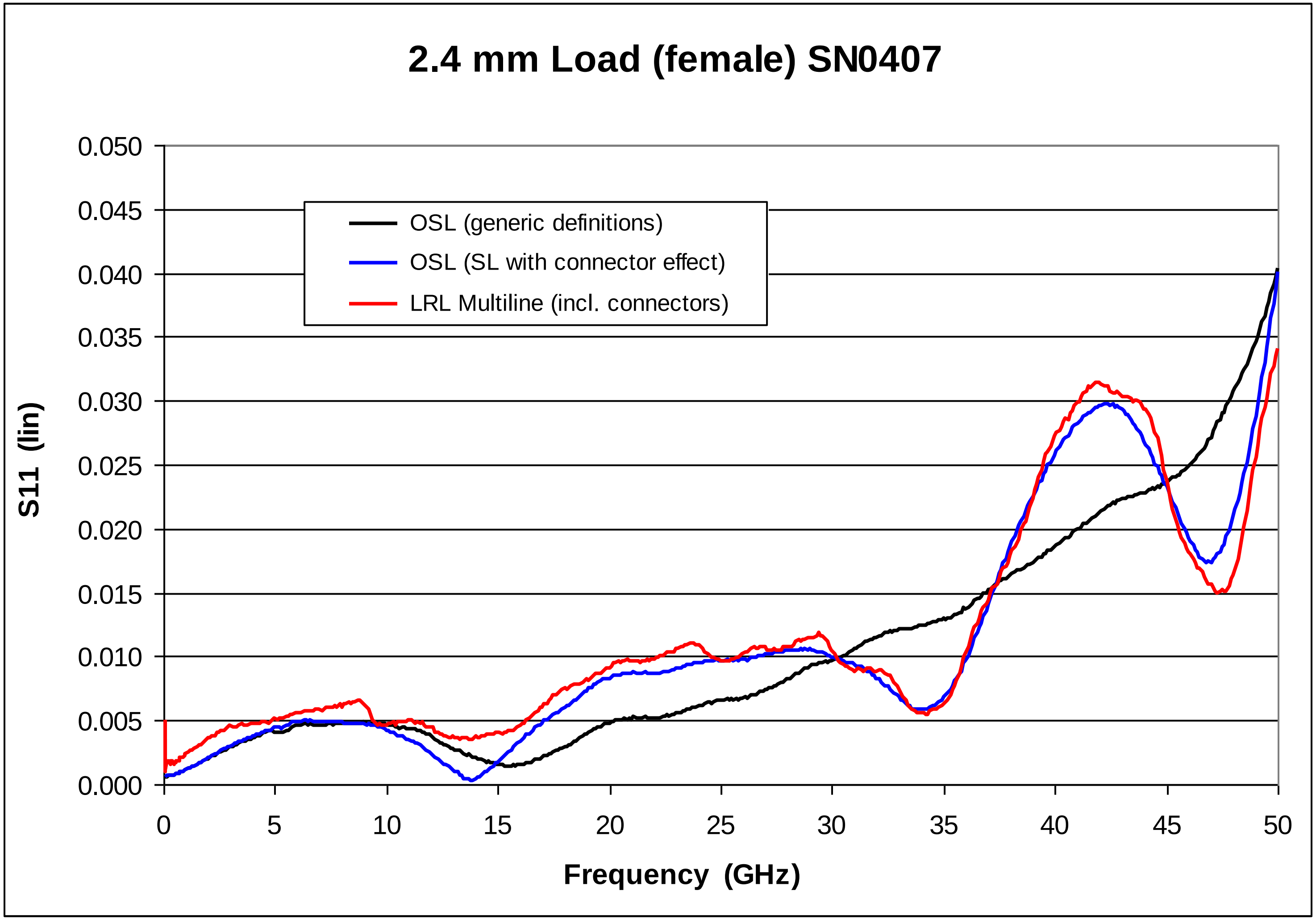
# Modified data based definitions for the sliding load
(now including the female connector effect)



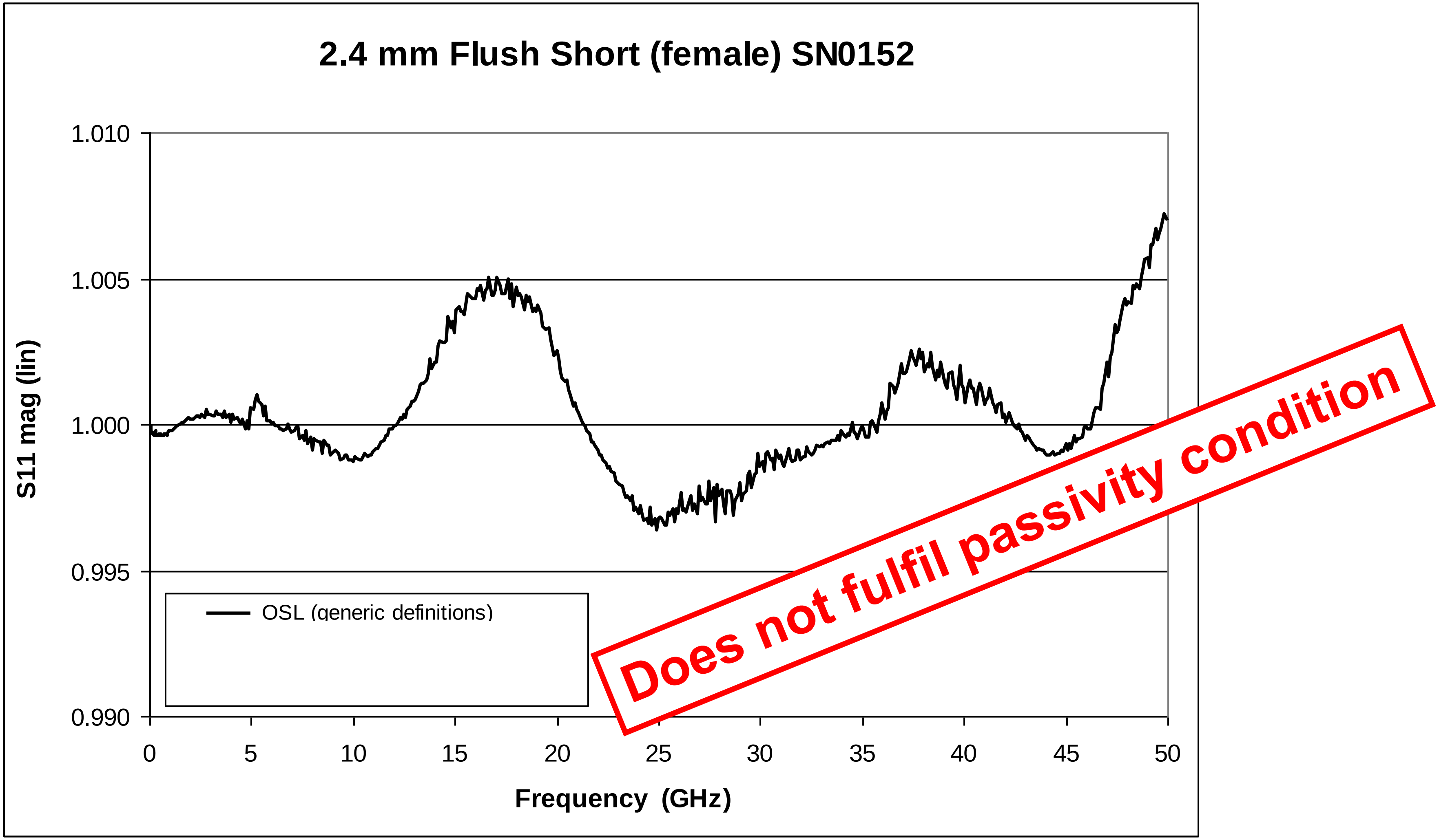



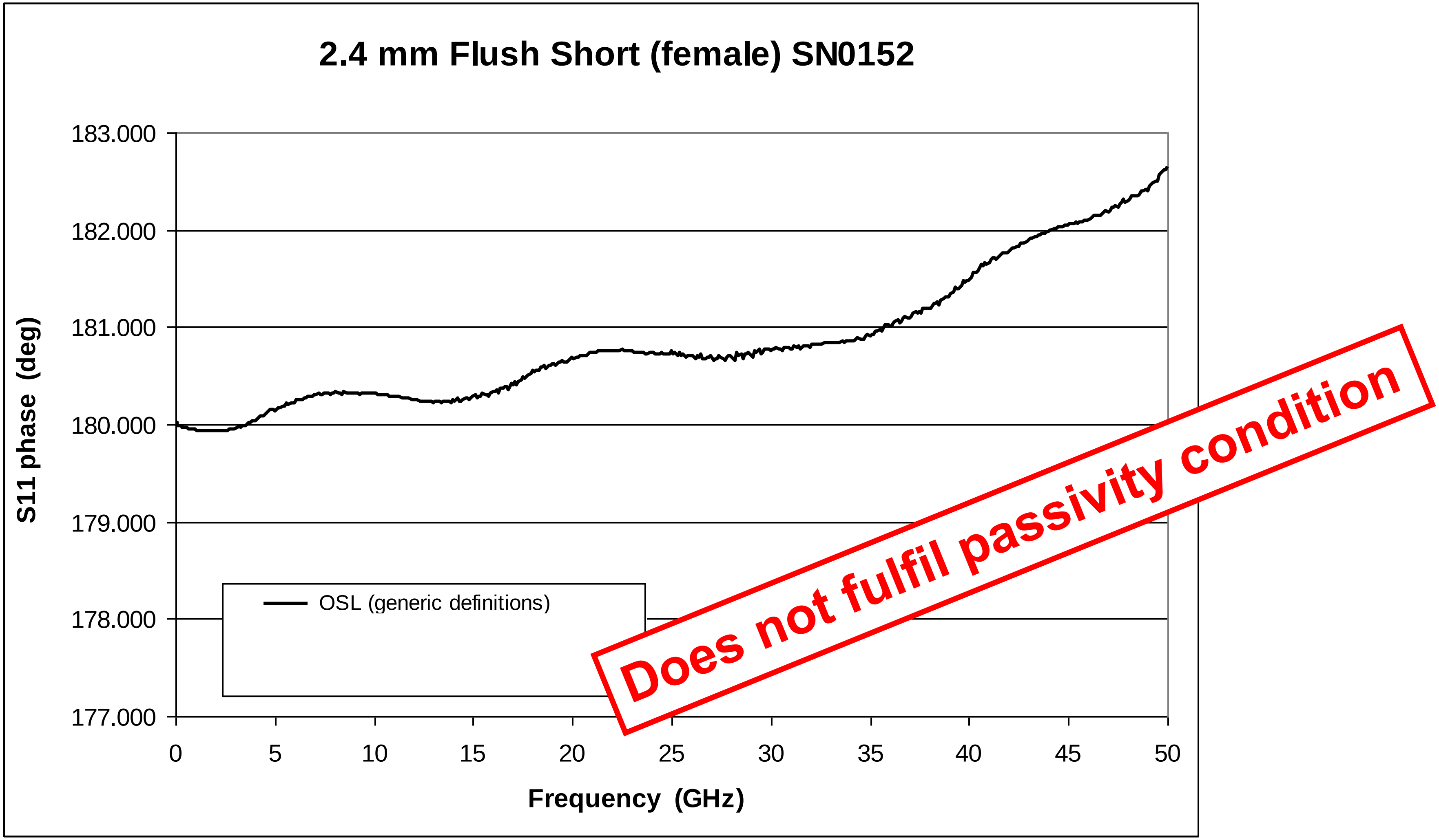
# Change of the female measurements: OSL with SL corr



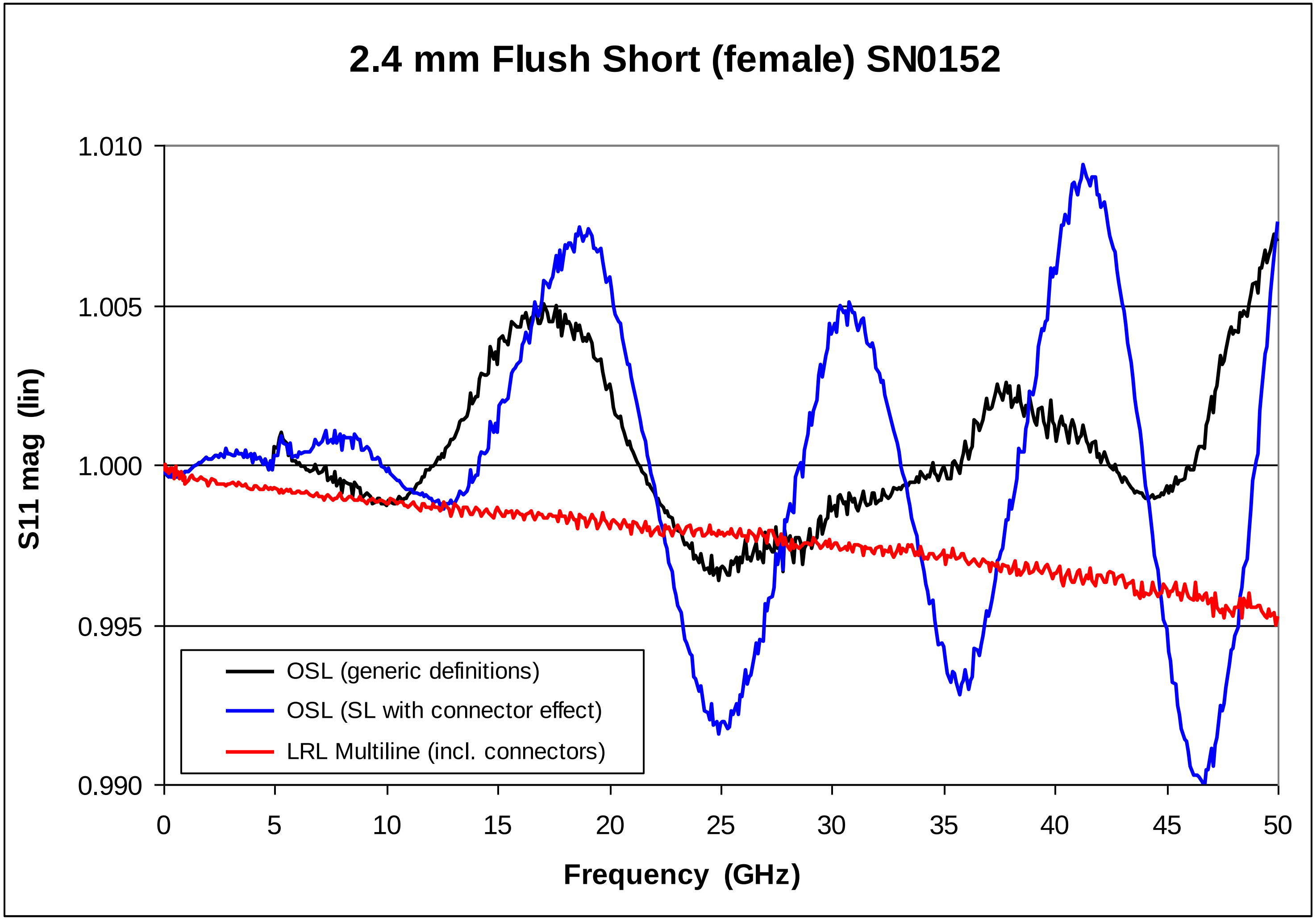
# Flush short: S11 magnitude (OSL with generic definitions)



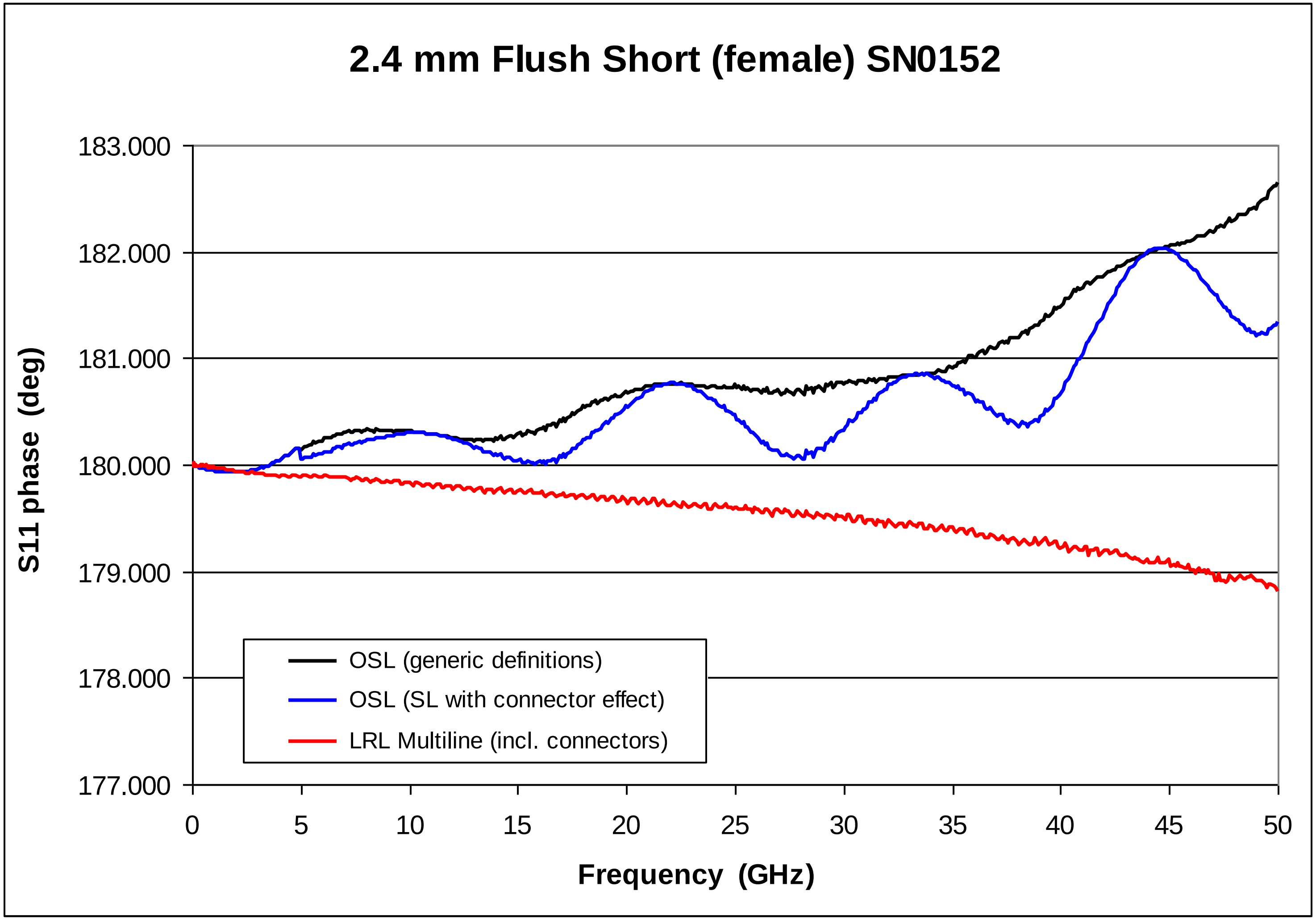
# **Flush short: S11 phase** (OSL with generic definitions)



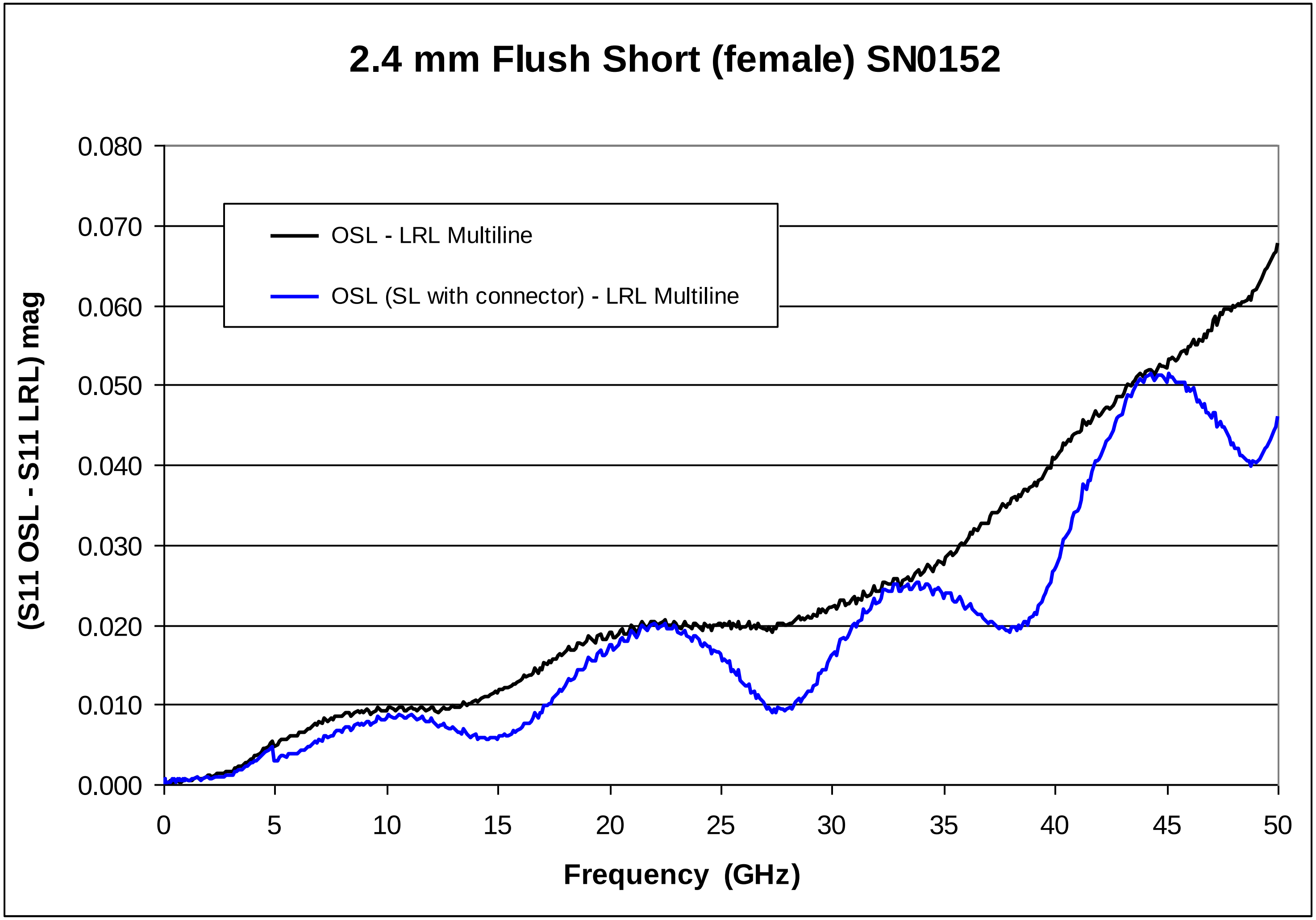
# Flush short: S11 magnitude changes



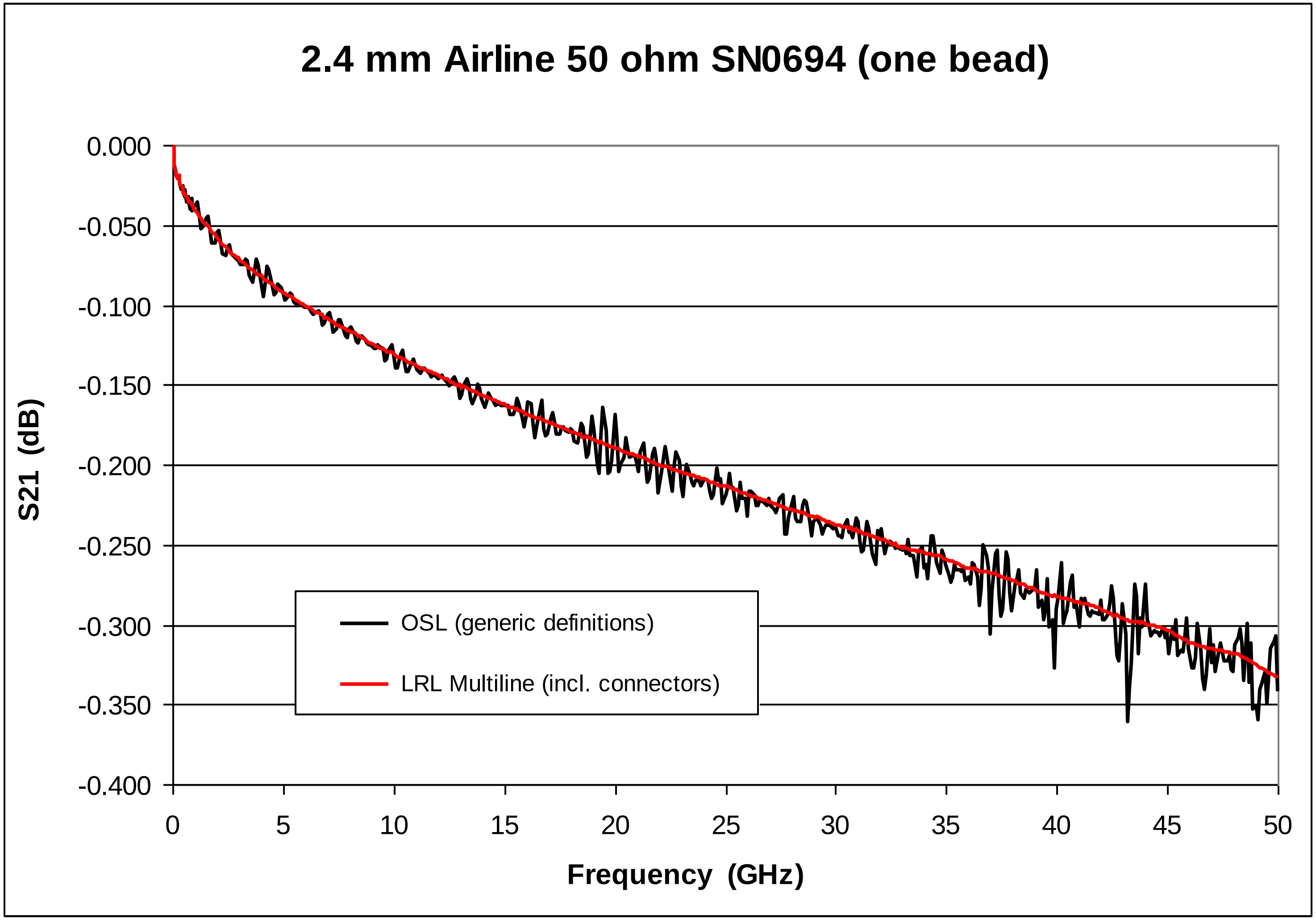
# Flush short: S11 phase changes



# Flush short: complex difference of the S11 measurements



# Airline from 85057B verification kit: S21 magnitude ripple



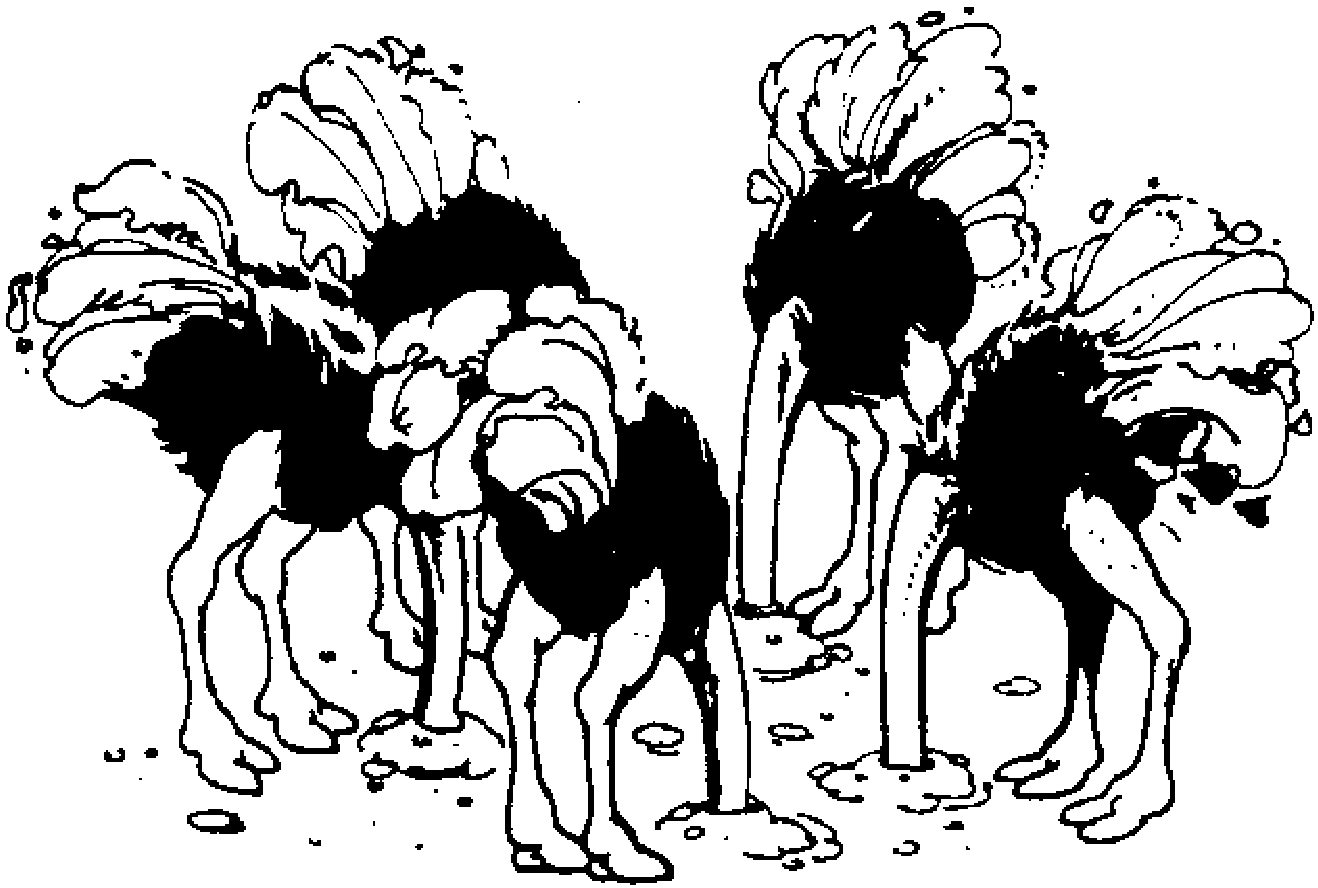
# Conclusions : “consistent S-parameters”

- Traceability to SI - consistent S-parameter results
- NMI - challenged by customer requests
- Change of paradigm:
  - Systematic connector errors have to be known
  - New standard definitions needed
- Dissemination:
  - NMI – accredited laboratories - industry
  - Cal kit manufacturers
- VNA calibration schemes including connector errors

# Round table discussion

# Effect on the S-parameter traceability work

**e.g.: 2.4 mm female DUTs change by ΔS11 ≈ 0.02**



# Effect on the S-parameter traceability work

**e.g.: 2.4 mm female DUTs change by ΔS11 ≈ 0.02**

- **NMI´s have to ensure traceability to SI** (not only repeatability)
- **At least: increased uncertainty budgets**
- **Mechanical characterisation of the connector sections**
- **Connector modelling of primary standards is a must**
  **e.g.: air lines and offset shorts** (slotted and slotless)
- **Update of the existing standard definitions**
- **Improved calibration schemes and uncertainty calculations**

# Impact on the NMI level and the industry

- **Significant change of the female S-parameter measurements**
- **Dissemination to industry thru the NMI´s and manufacturers**
- **Information to the national accreditation bodies**
- **Need for new S-parameter measurement comparisons**
- **EMRP project with general connector model?**
- **Transition period: data according to old and new definition**
- **In future: only data based definitions for industry**

Federal Department of Justice and Police FDJP

**Federal Office of Metrology METAS**

# Thank you very much for your attention !