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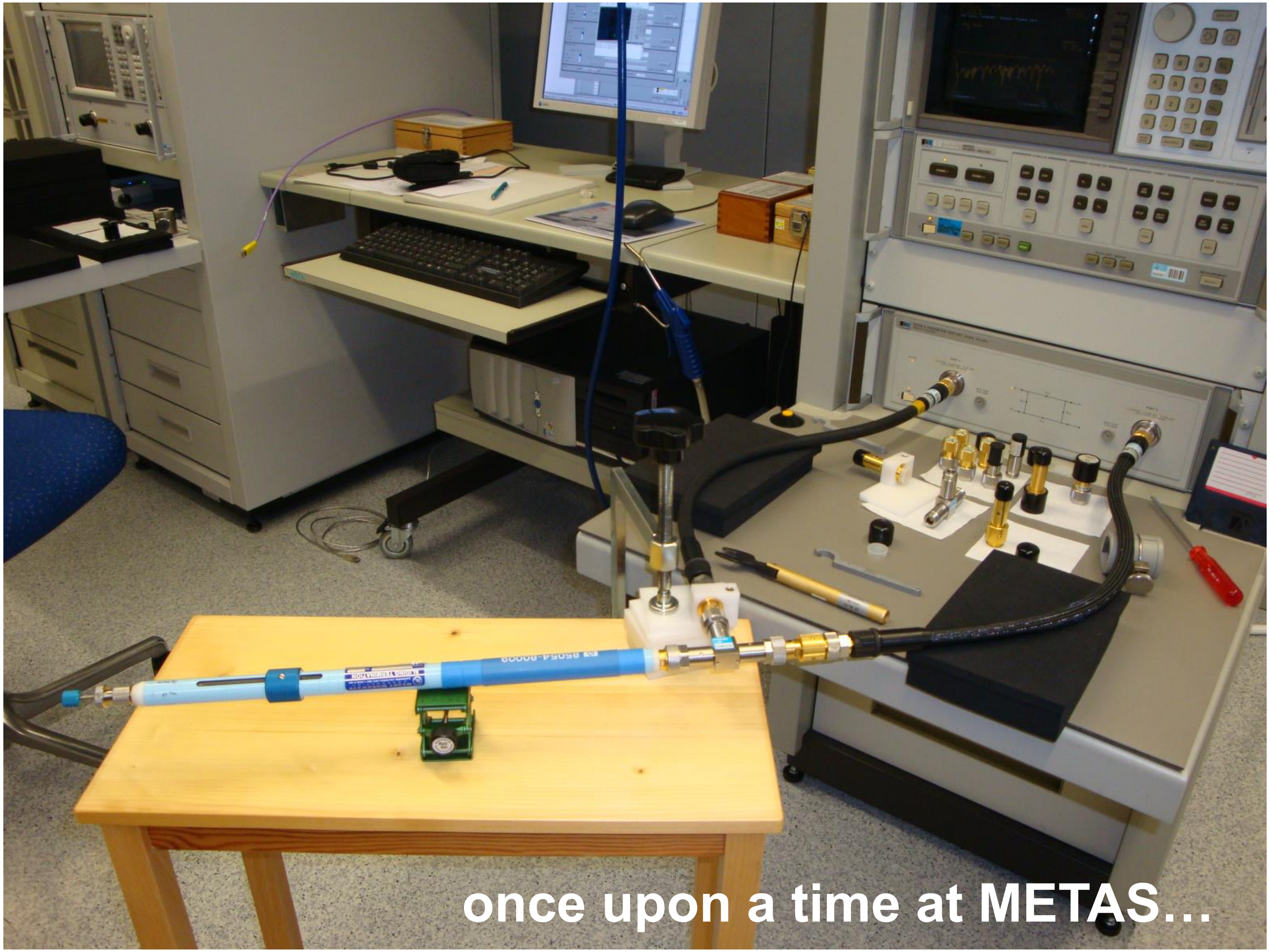
Federal Institute of Metrology METAS

Practical hints: splitter characterization

J. Ruefenacht, M. Wollensack, J. Hoffmann, M. Zeier

Motivation

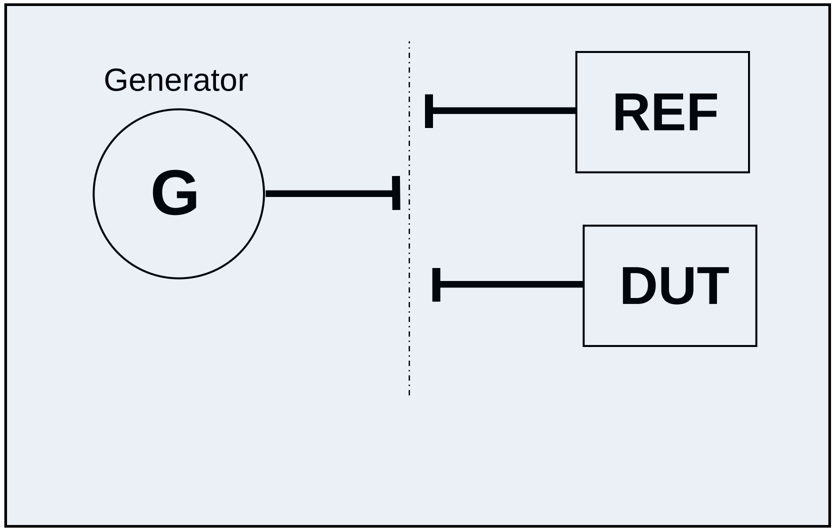


Agenda

1. Power splitter or divider (choose the right one…)
2. 2-resistor power splitter (ratio method)
3. Measurement restrictions we had in our laboratory
4. Power splitter measurement techniques used in the past
5. How to identify a stability issue of a power splitter?
6. Actual splitter measurement methods used at METAS
7. Conclusions

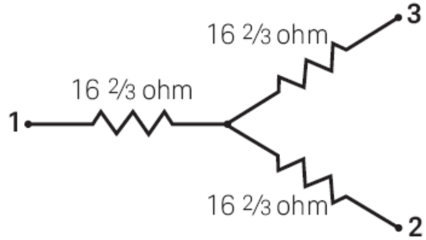
Power splitter or divider
-> choose the right one…

How to divide the generator signal equally?

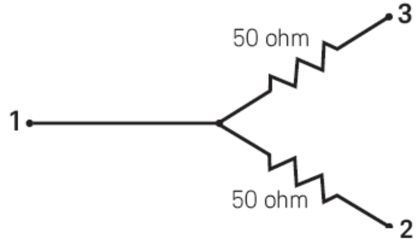


Power divider and splitter
-> choose the right one (list not complete)

- **3-resistor power divider (3 * 16.7 Ω):** good match from DC to GHz, ideal e.g. for pulse signal / oscilloscope – applications, very high bandwidth, low power applications. Can be used as power combiner.

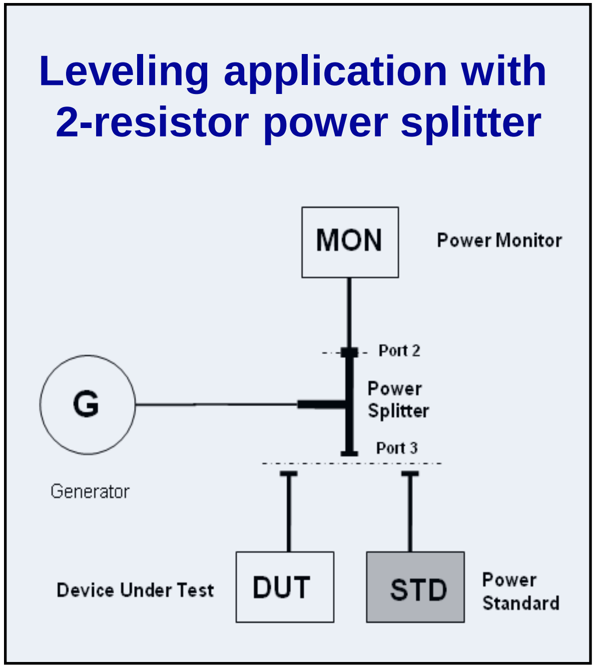


- **2-resistor splitters (2 * 50 Ω):** mainly used for ratio measurements and leveling loop applications, low Equivalent Source Match (Γ_{Eq}), very high bandwidth, low power applications. Only the input port has 50 Ω resistance the other two ports have 83.33 Ω resistance.



2-resistor power splitter

Equivalent Source Match Γ_{Eq}



- **Leveled system, can be active (ALC) or passive -> ratio method required:** Ratio measurements between the two output arms of the 2-resistor splitter.
- **The equivalent source match** (e.g. Port 3) **depends only on the S-parameters of the 2-resistor power splitter.**

$$\Gamma_{Eq3} = S_{33} - \frac{S_{23}S_{31}}{S_{21}}$$

2-resistor power splitter measurement technique restrictions we had in our laboratory

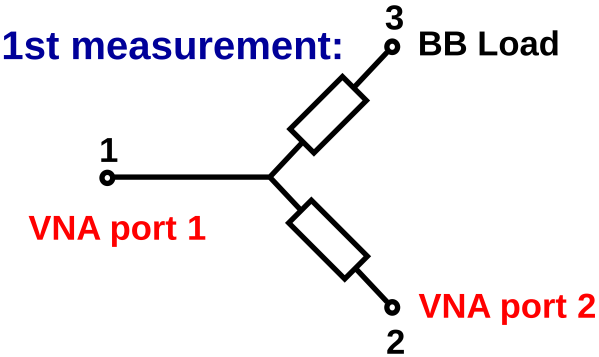
(to determine the equivalent source match or the tracking terms)

- Only 2-port VNA available in the past.
- An **ideal load** is needed to terminate the third splitter port.
- No data base standard definitions available (ideal 50 ohm).
- Broad band load or combination of a fixed and sliding load (circle fitting over all four S-parameters).
- Splitter with a non-insertable connector setup (e.g. 3 x female).
- Using the swap equal adapters method (uncertainties?).
- Unknown Thru not working accurately (Open, Short definitions: issue with the cal standard traceability - badly defined reference planes due to ignoring the systematic connector effects).
- Increased cable effects due to the large cable flexure.

Russell A. Johnson method

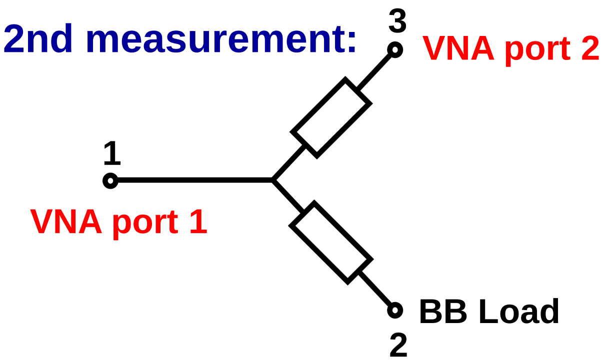
Russell A. Johnson (**hp**), „Understanding Microwave Power Splitters“, Microwave Journal, December 1975

1st measurement:



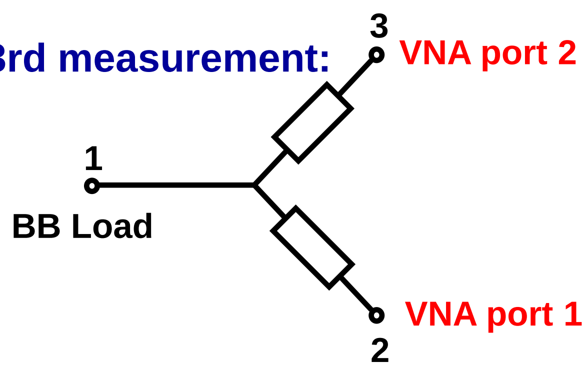
S11 ->	S11
S21 ->	S21
S12 ->	
S22 ->	S22

2nd measurement:



S11 ->	
S21 ->	S31
S12 ->	
S22 ->	S33

3rd measurement:



S11 ->	
S21 ->	S32
S12 ->	S23
S22 ->	

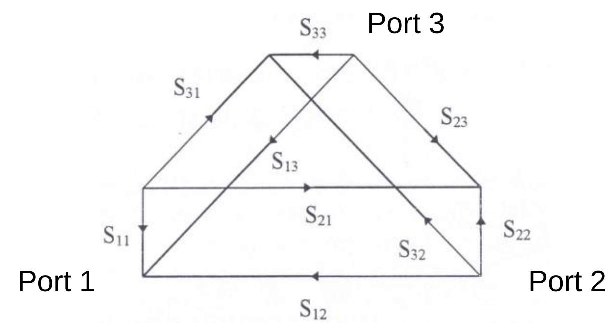
2-resistor splitter:

$$\Gamma_{Eq2} = S_{22} - \frac{S_{32} S_{21}}{S_{31}}$$

$$\Gamma_{Eq3} = S_{33} - \frac{S_{23} S_{31}}{S_{21}}$$

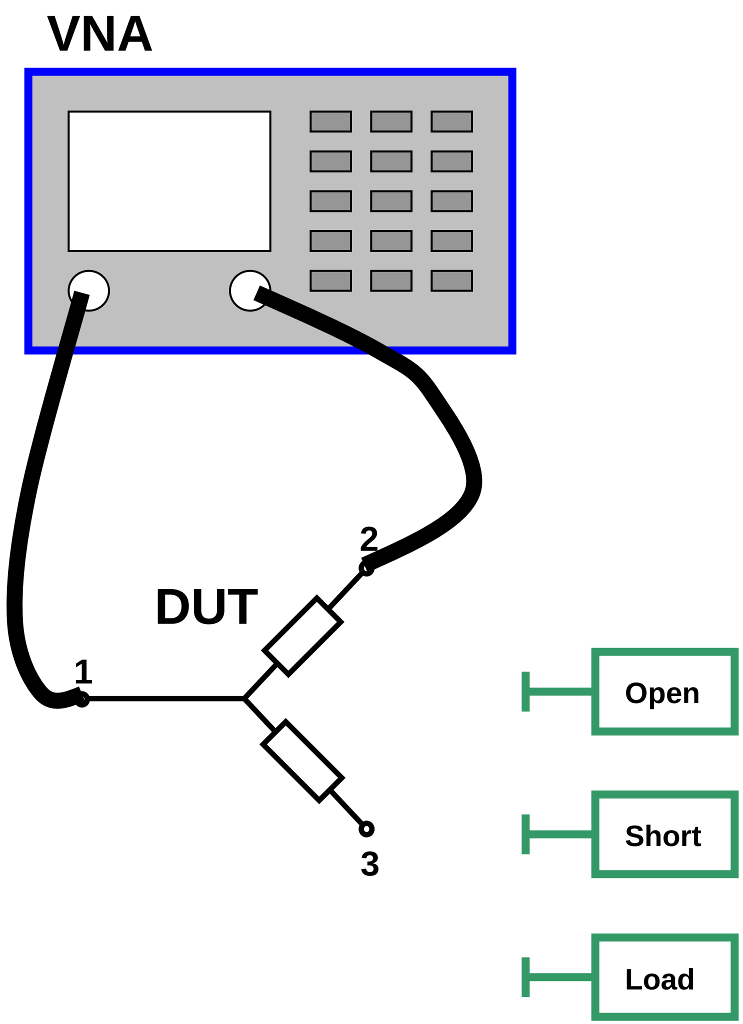
$$Tracking = \frac{S_{21}}{S_{31}}$$

Three port device flow-graph:



Juroshek method (2-port VNA but OnePort cal)

John R. Juroshek, „A direct calibration method for measuring equivalent source mismatch“, Microwave Journal, October 1997



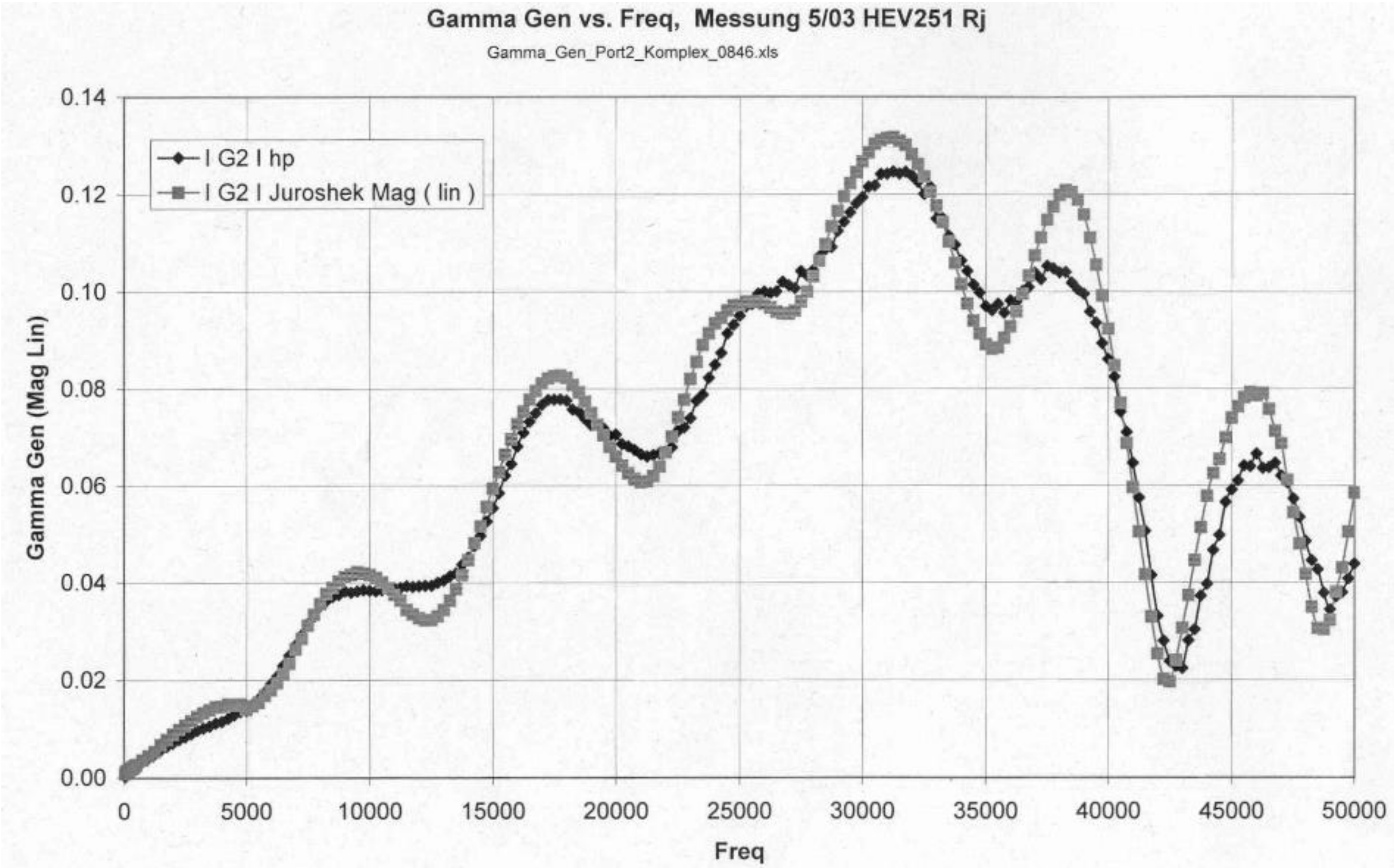
- **Perform a OnePort calibration using the converted S-parameters**

$$J_{33} = \frac{S_{11}}{S_{21}}$$

- **Equivalent source match Γ_{Eq3} :**
  -> equals the VNA source match

Comparison: Russell Johnson (**hp**) vs Juroshek

Example: 11667C, 2.4 mm(f) splitter measurements done in 2004



Some typical splitter stability issues

- Pin-depth values do change after each connection:
  - centre conductors are not fixed.
  - bead structure loose.

- The center conductors are badly contacted to the splitter circuitry.

- Showing a bad long term stability (option: whit heat cycling -> burn-in)

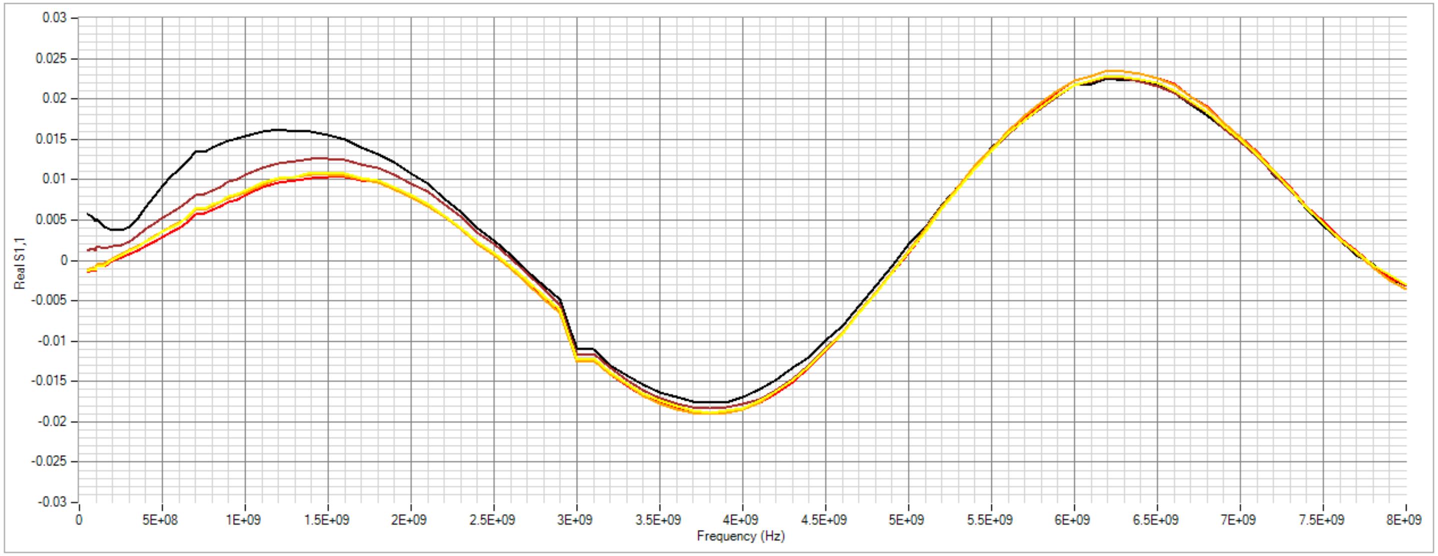
- Resulting effect after reconnecting the cal standards:
  The S-parameters of the splitter change during each of the performed characterisation measurements!

Type-N splitter stability issue (instable Γ_{Eq})

0.03

Γ_{Eq} real (lin)

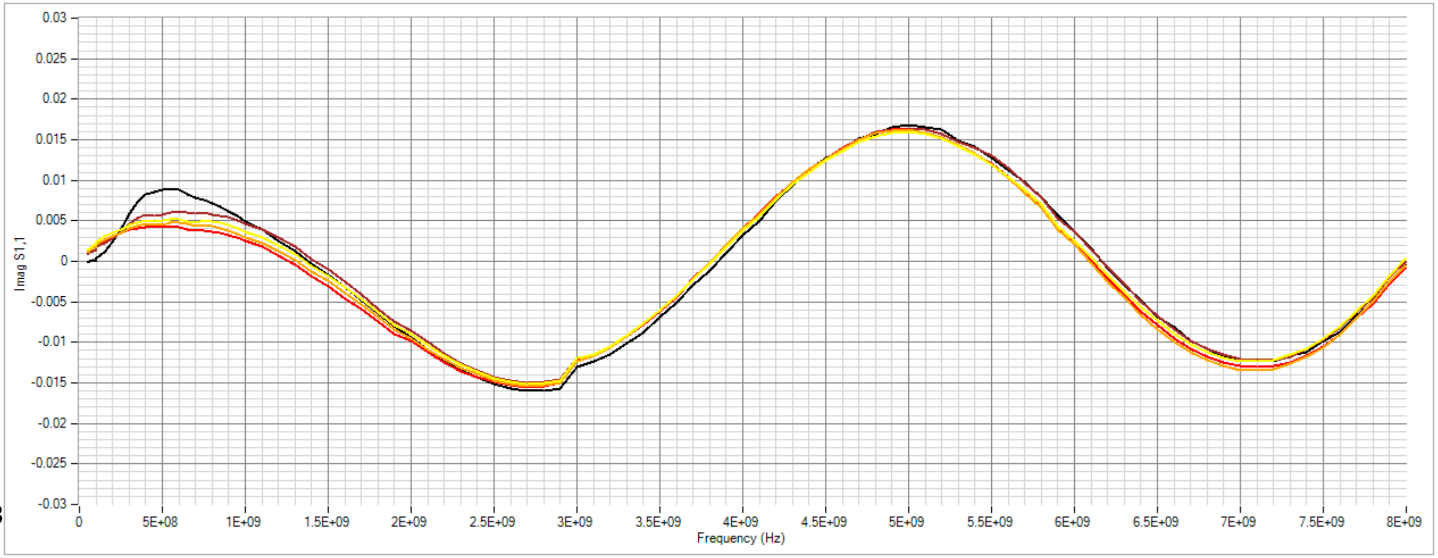
-0.03



0.03

Γ_{Eq} imag (lin)

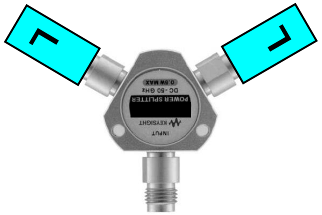
-0.03



Power splitter stability pre-check

S11 measurements at different connector orientations

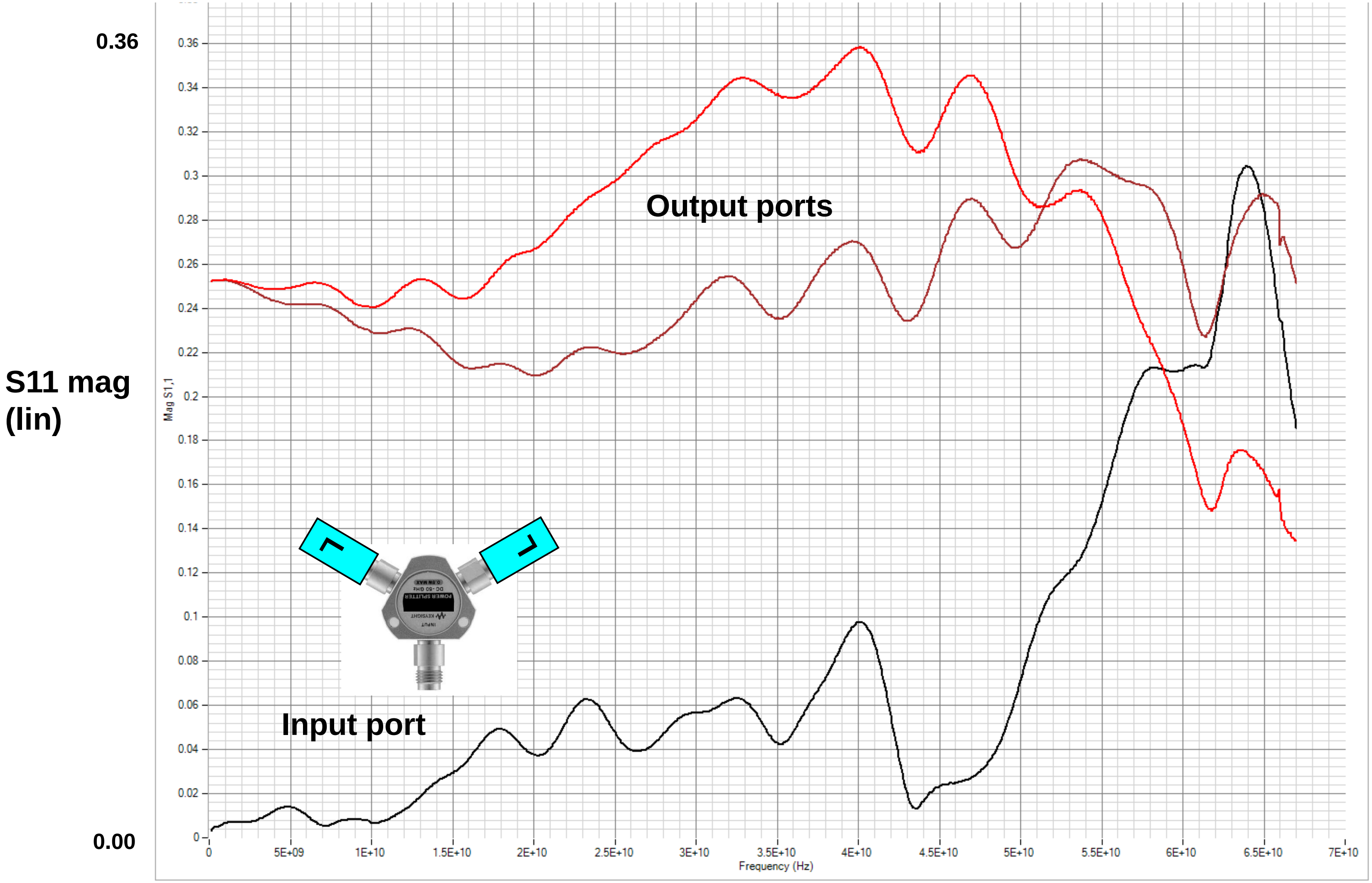
- No VNA calibration needed: just measure the raw data.
- Connect two loads (or shorts) to port 2 and port 3 of the splitter.
- Measure S11 from port 1 of the splitter at different connector orientations.
- Normalize the collected data to its mean value.



- Repeat the same process for all three splitter ports.
- optional: use a calibrated VNA for absolute measurements.

1.85 mm splitter stability pre-check

measuring S11 of each port (others terminated with 50 Ω), using a calibrated VNA

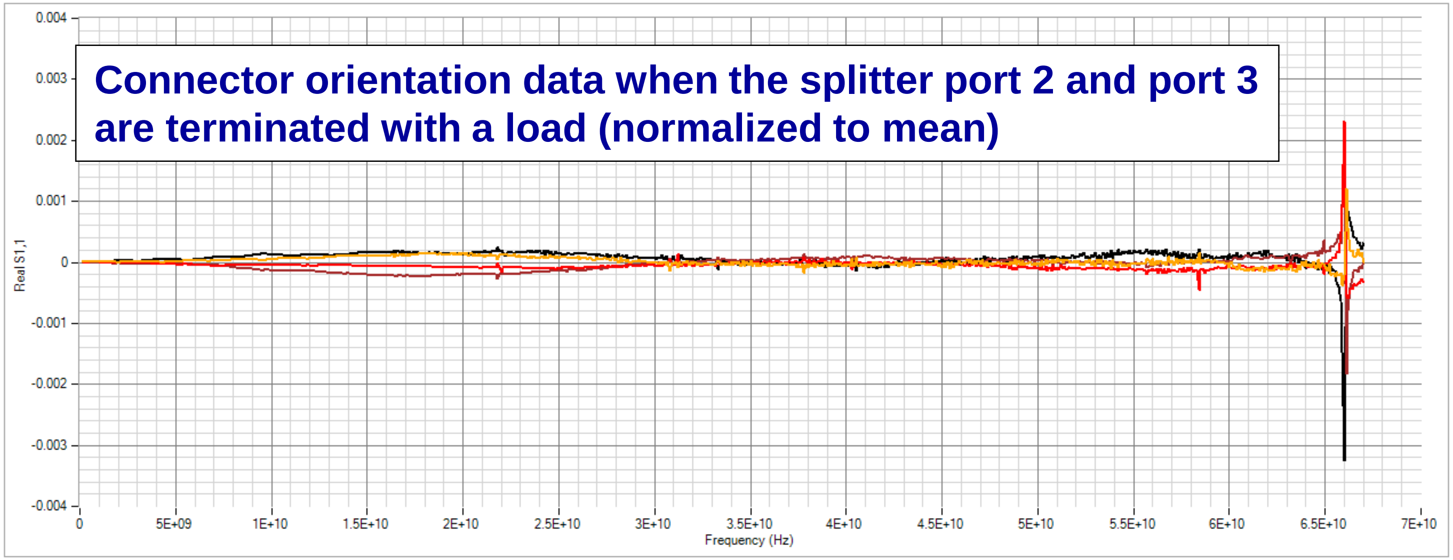


1.85 mm splitter stability pre-check (on port 1)

0.004

S11 real (lin)

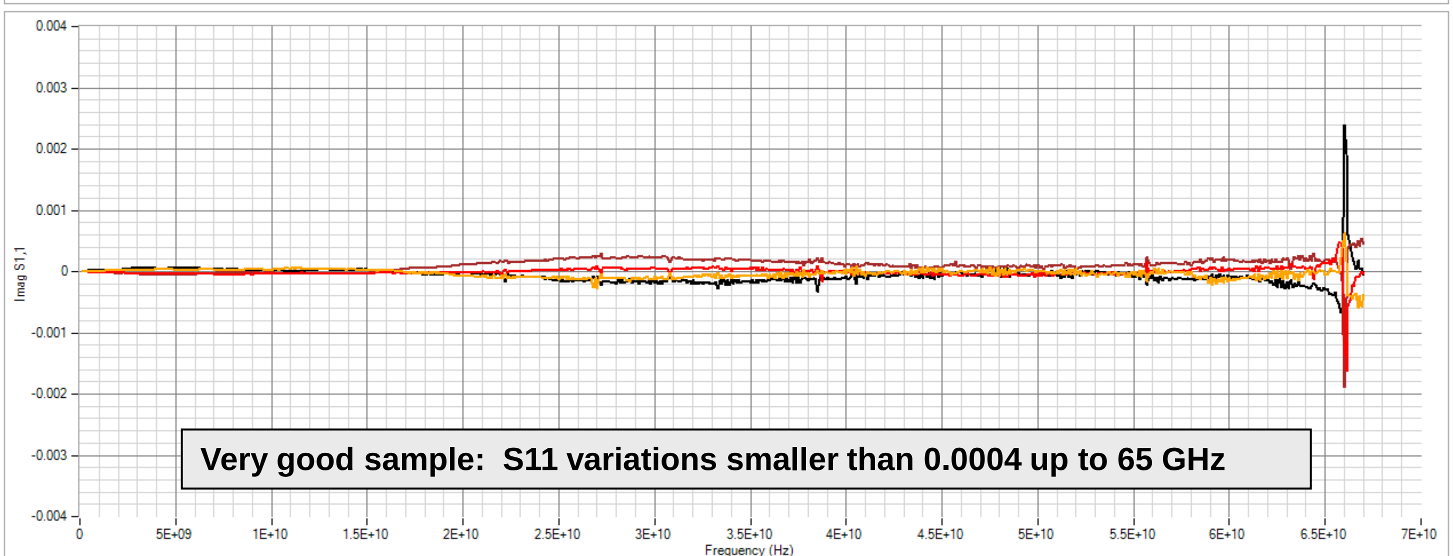
-0.004



0.004

S11 imag (lin)

-0.004

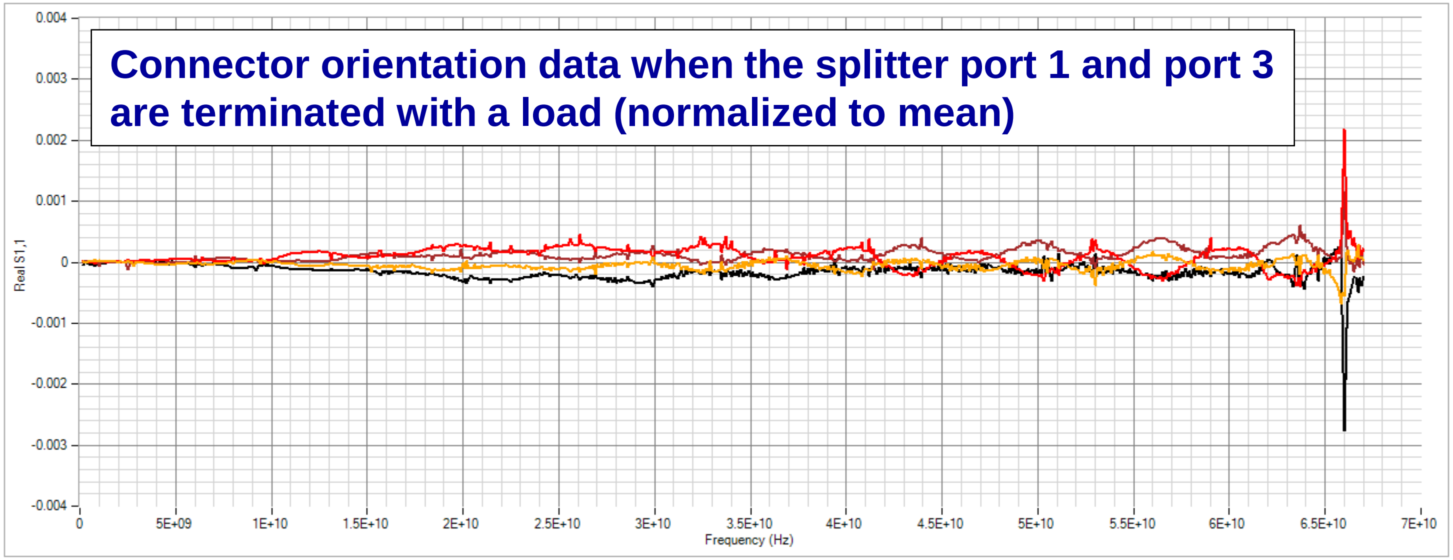


1.85 mm splitter stability pre-check (on port 2)

0.004

S11 real (lin)

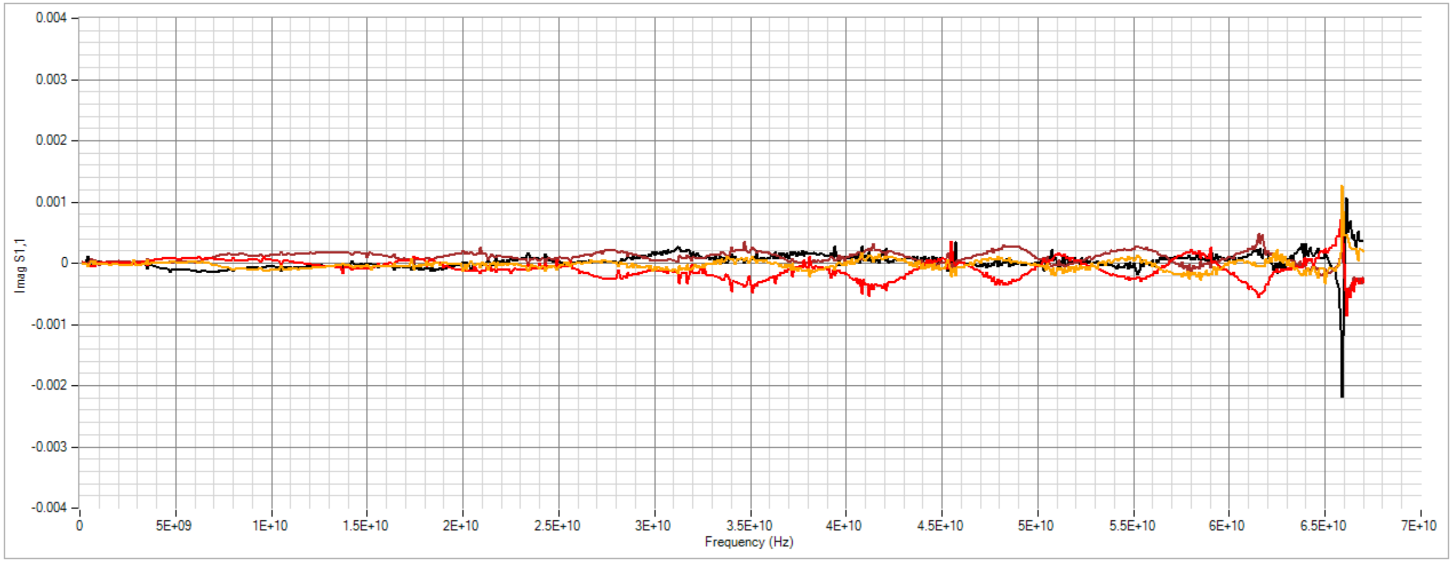
-0.004



0.004

S11 imag (lin)

-0.004

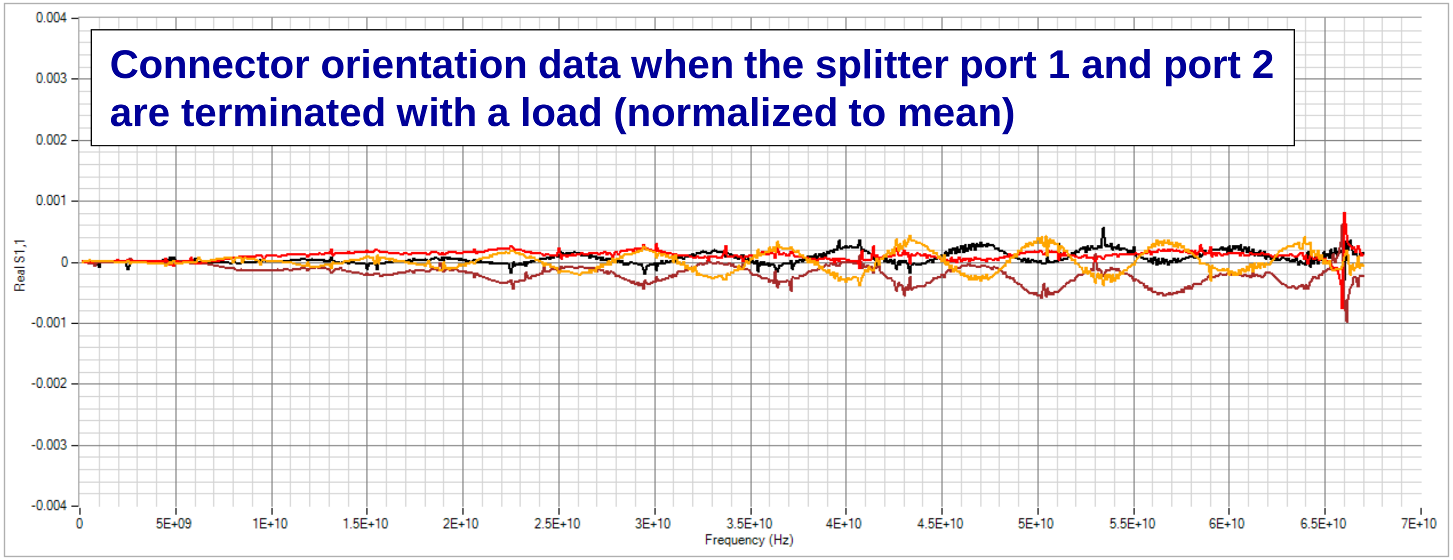


1.85 mm splitter stability pre-check (on port 3)

0.004

S11 real (lin)

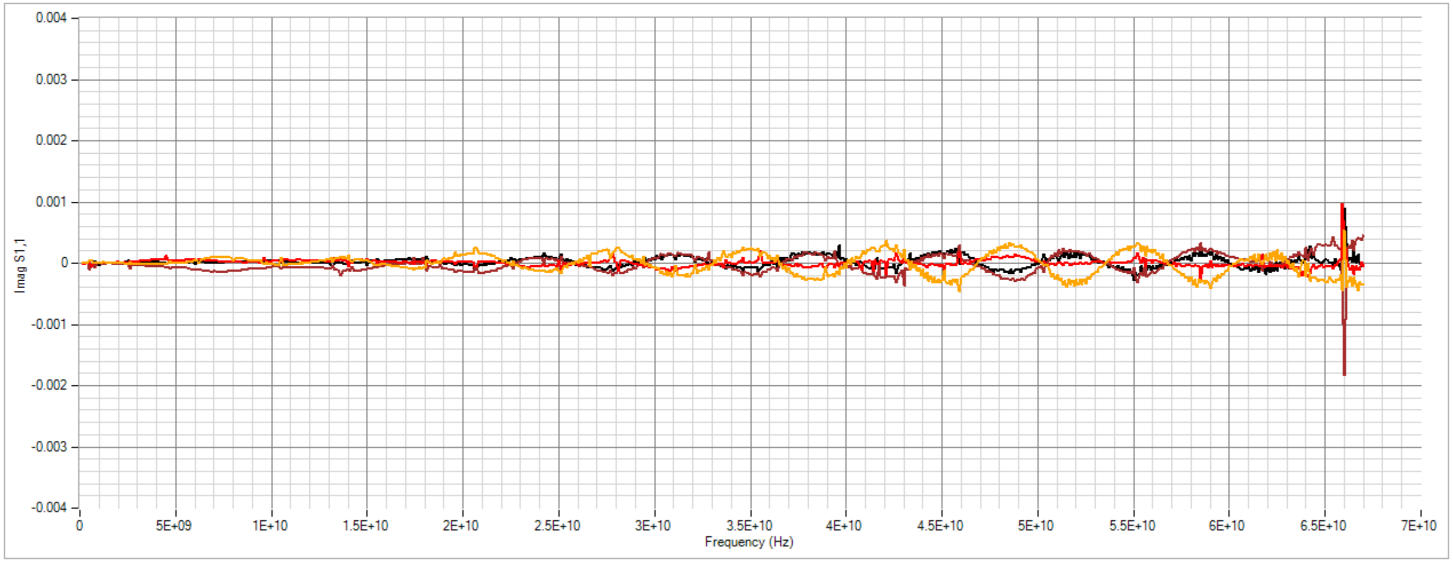
-0.004



0.004

S11 imag (lin)

-0.004



Actual used splitter measurement methods

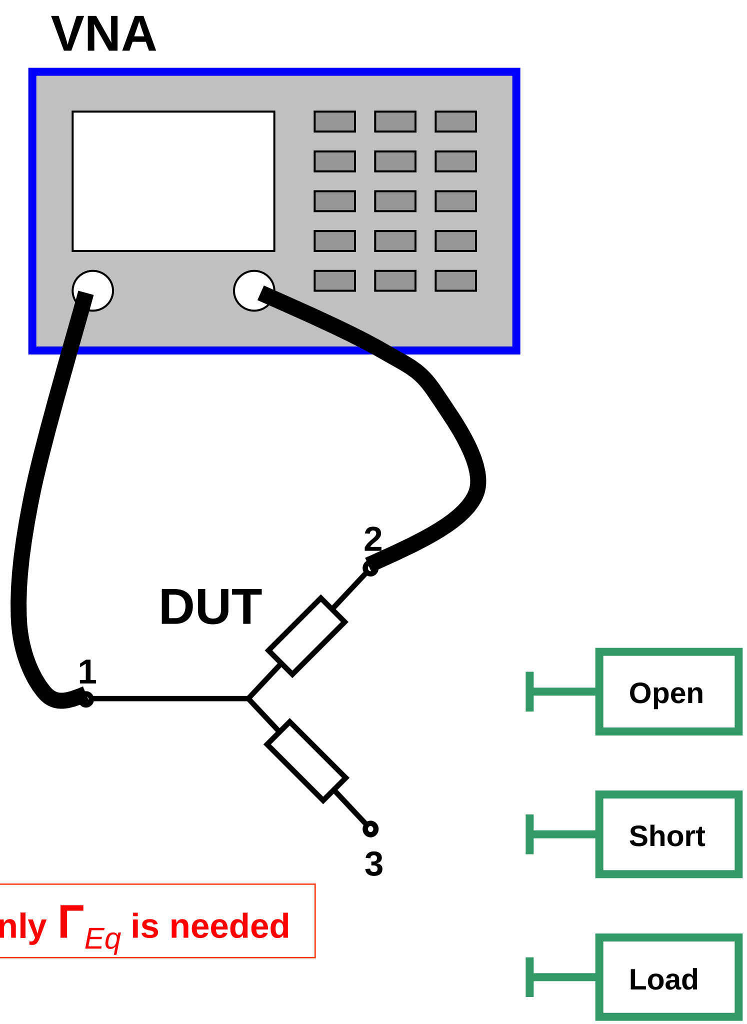
- Currently preferred method at METAS (1st priority: “Palmer”):
  2-Port method measuring a Load and Short on the input port
  - Rather easy and straight forward measurement setup.
  - Load and Short must ***not be known*** (connected to the splitter input port).
  - Requires at least 10 connections.
  - Γ_{Eq} mainly dependent on the used load calibration standard definitions.

- 2nd priority method:
  Direct 3-Port measurement method using a 4-port VNA
  - More demanding test port cable layout.
  - Requires at least 12 connections.
  - Γ_{Eq} mainly dependent on the used load calibration standard definitions.

- 3rd priority method:
  Juroshek measurement method using a 2-port VNA
  - Demanding VNA performance needs (directivity, linearity and noise).
  - Easy and straight forward measurement setup.
  - Requires at 5 connections (10 connections for Γ_{Eq} of both splitter ports).
  - Γ_{Eq} mainly dependent on the used Open and Short cal standard definitions.

Juroshek method (2-port VNA but OnePort cal)

John R. Juroshek, „A direct calibration method for measuring equivalent source mismatch“, Microwave Journal, October 1997



If only Γ_{Eq} is needed

- **Perform a OnePort calibration using the converted S-parameters**

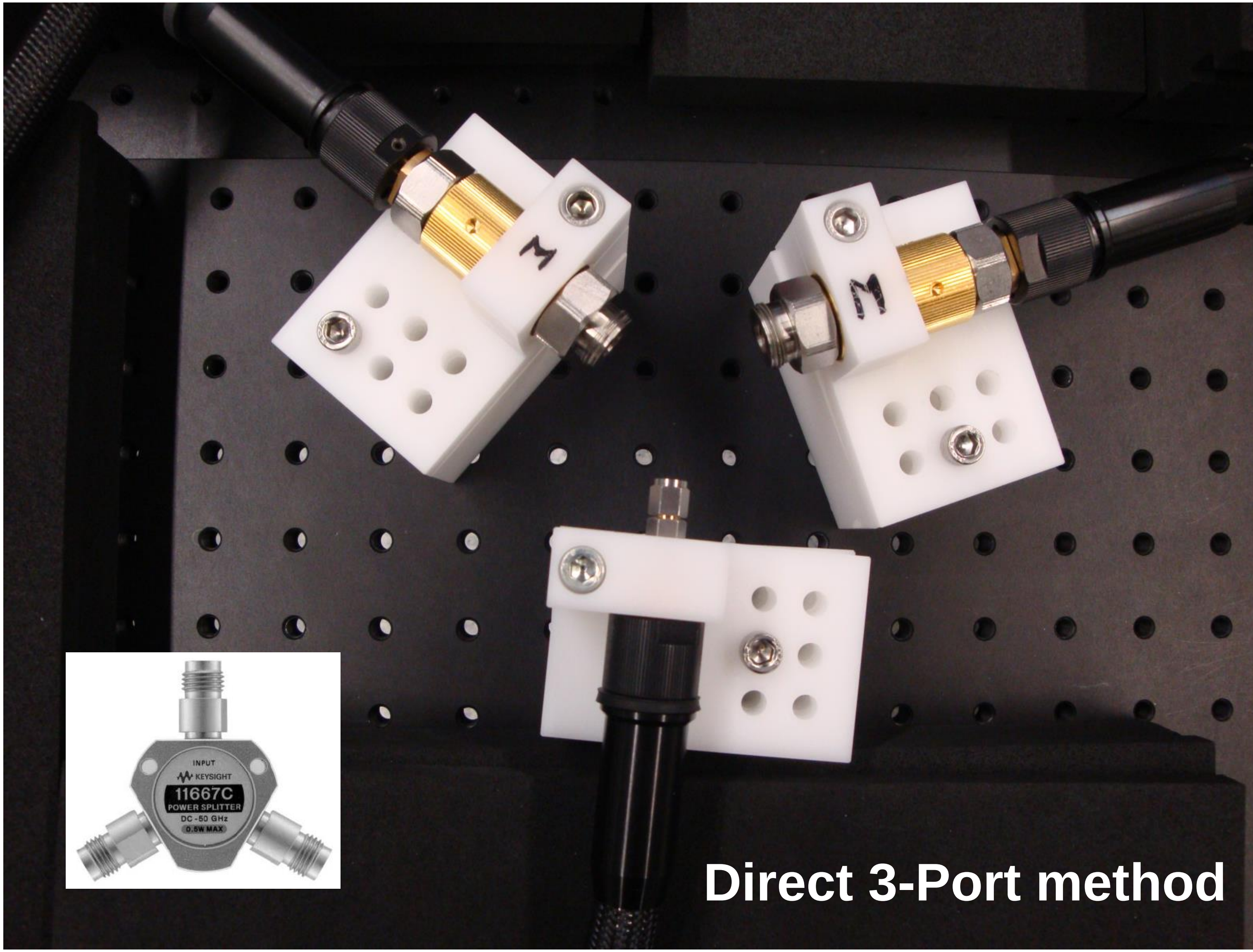
$$J_{33} = \frac{S_{11}}{S_{21}}$$

- **Equivalent source match Γ_{Eq3} :**

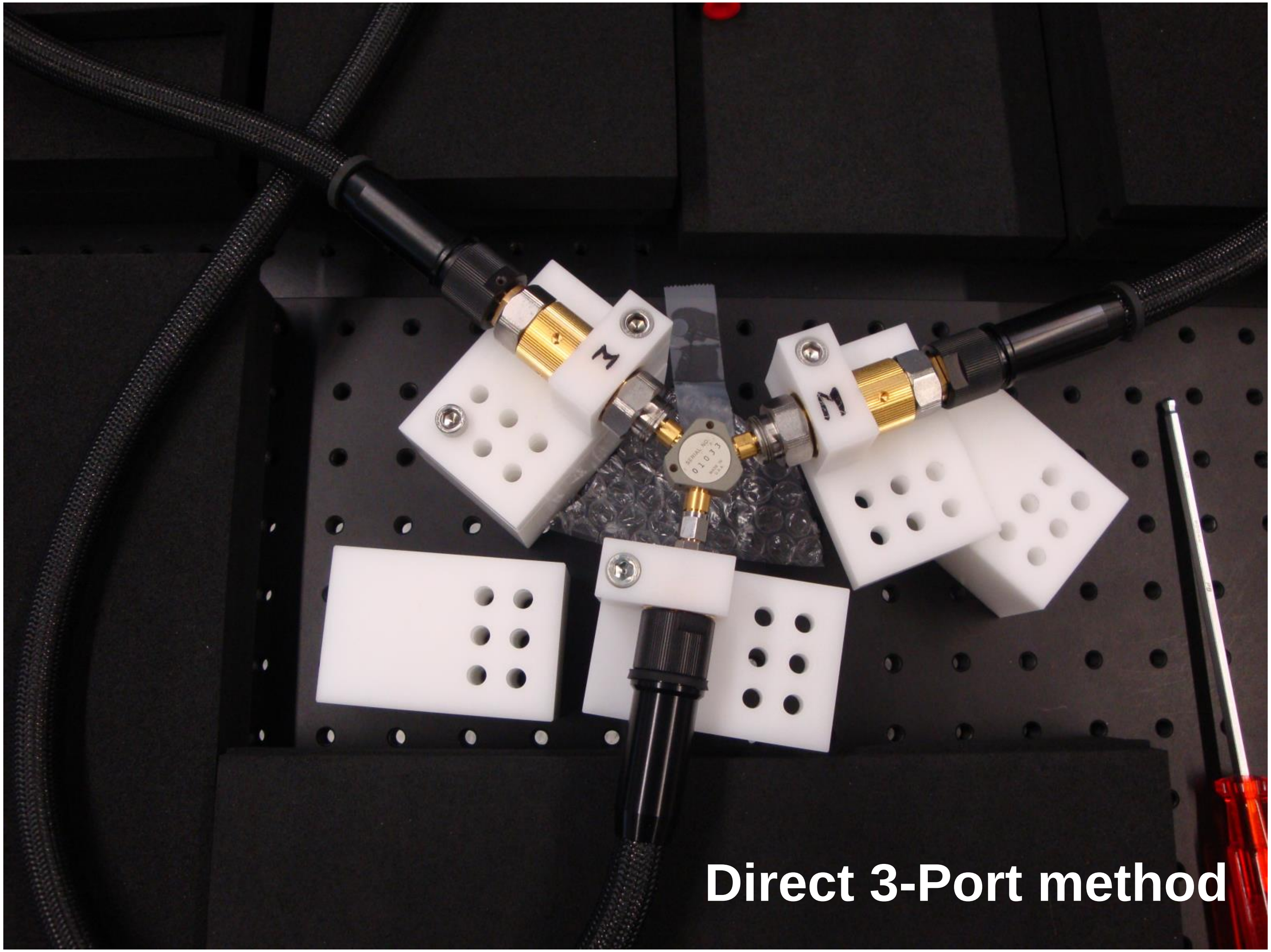
  -> equals the VNA source match

- **Ratio of two VNA receiver ratios: thus the resulting directivity is the added directivity of both ports plus attenuation of the splitter.**
- **Mainly dependant on the accuracy of the Open and Short calibration standard definitions.**
- **Demands on noise and linearity of the VNA.**

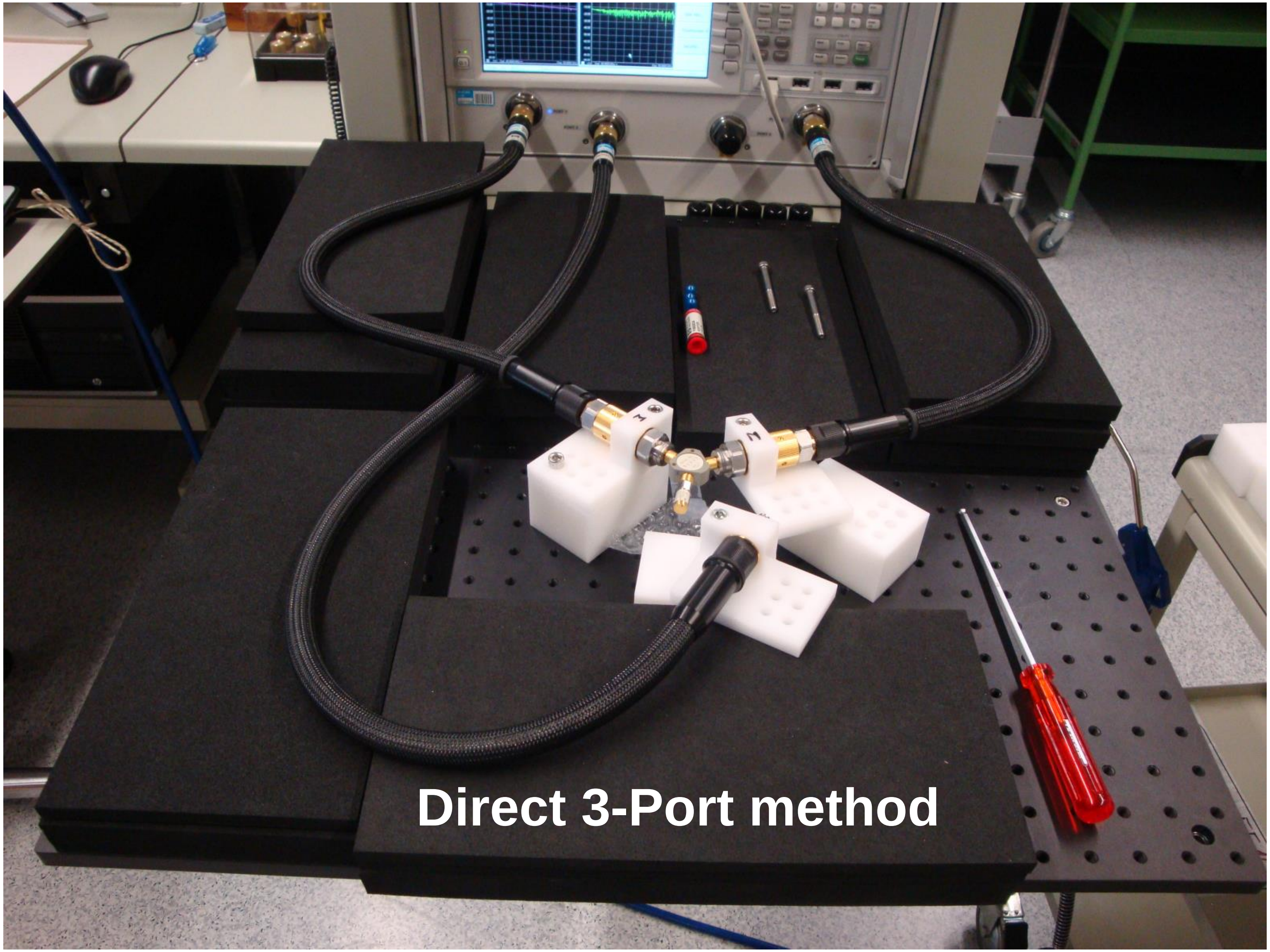
2.4 mm splitter setup using a 4-port VNA



2.4 mm splitter setup using a 4-port VNA

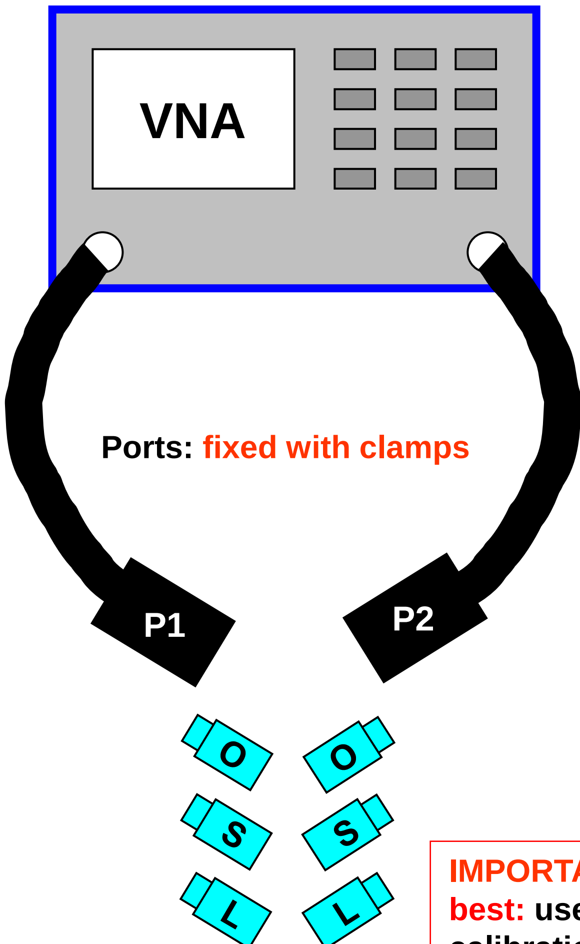


2.4 mm splitter setup using a 4-port VNA

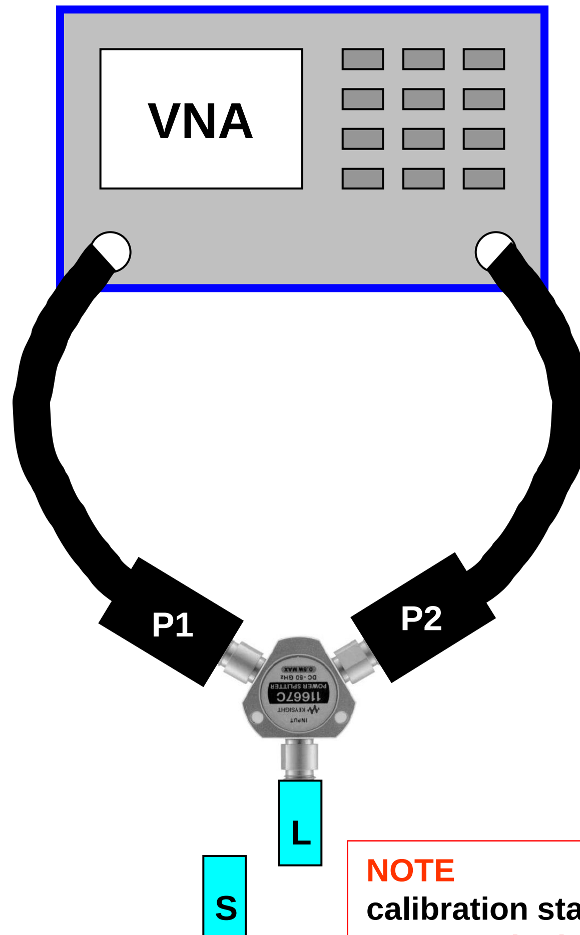


2-Port “Palmer” VNA measurement method

how to minimize the cable movement effects?



IMPORTANT
best: use traceable calibration standards

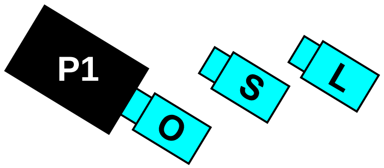


NOTE
calibration standards must not be known

2-Port setup introducing the least cable effects

1st step: calibration on P1

Port 1: fixed with a clamp

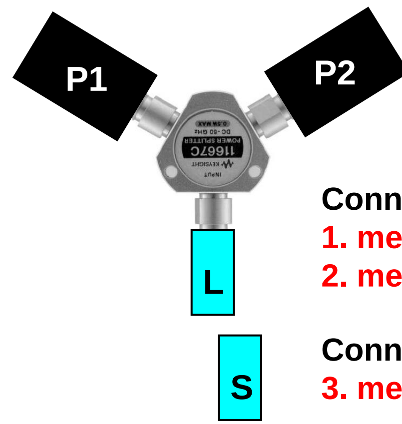


Measure Open, Short, Load on P1:
- measure S11 only
- best: include the connector effects

2nd step: connect splitter outputs to P1 and P2

Port 1: fixed

Port 2: free



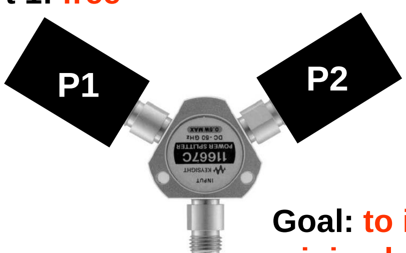
Connect a Load to the input port:
1. measure all 4 S-parameters
2. measure the Switch Terms

Connect a Short to the input port:
3. measure all 4 S-parameters

3rd step: first loose the P1 clamp, then fix P2 and remove the splitter

Port 1: free

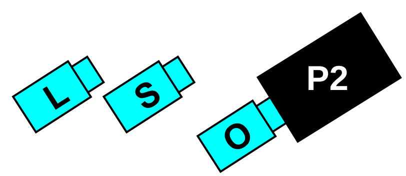
Port 2: fixed



Goal: to introduce minimal cable effects!

4th step: calibration on P2

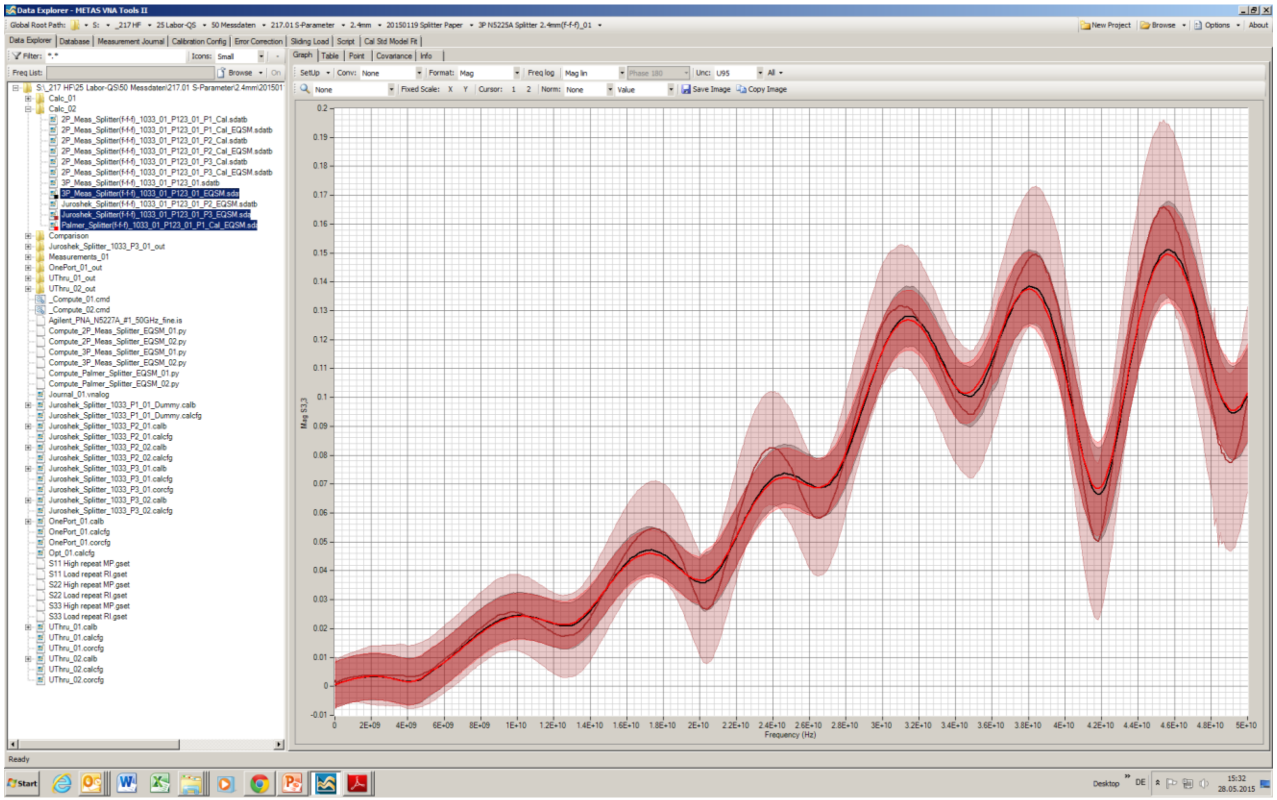
Port 2: fixed with a clamp



Measure Open, Short, Load on P2:
- measure S22 only
- best: include the connector effects

VNA Tools

- VNA Tools II supports the Juroshek, 3-Port and 2-Port (using an unknown Load and Short) technique. All methods work with linear uncertainty propagation.



http://www.metas.ch/vnatools

Conclusions
splitter measurements at METAS

- **No need for an expensive 4-port VNA.**
- **Better invest the money for traceable calibration standard definitions** (including the systematic connector effects)**.**
- **Each method has its pro and cons** (best: 2-Port “Palmer”)**.**
- **Pre-select the power splitter for its repeatability behaviour.**
- **Avoid the unpredictable near field coupling effects:**
  Use test port adapters showing a minimal pin-depth value.

Thank you very much for your attention

References

- J. Hoffmann, M. Wollensack, J. Ruefenacht, M. Zeier, "Comparison of Methods for Measurement of Equivalent Source Match", 45th European Microwave Conference, EuMC 2015, Paper ID: EuMC40-01, September 2015.

- J. Hoffmann, K. Wong, " Improving VNA measurement accuracy by including connector effects in the models of calibration standards", Microwave Measurement Conference, 2013, 82nd ARFTG, pages 1-7.

Appendix

METAS

Swap equal adapter method (non-insertable)

Step 1:

Forward Transmission: E_{TF}
Forward Match: E_{LF}

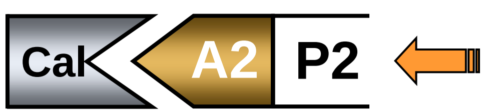
Step 2:

Reverse Transmission: E_{TR}
Reverse Match: E_{LR}

Step 3:

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

Step 4:

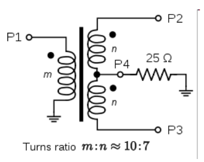


Reverse Reflection Calibration
measures: E_{DR}, E_{SR}, E_{RR}
using on P2: Open, Short, Load

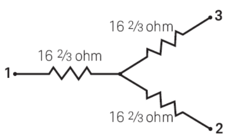
Step 5:

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

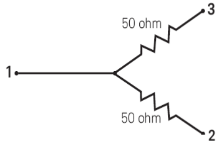
Power splitter or divider
-> choose the right one (list not complete)



- **„Real“ 3 dB power divider:** hybrid type, realized with transformer circuits, only small loss (0.2 dB), no DC – response, high decoupling of the output ports, low to medium power applications, 0° or 90° phase types available.

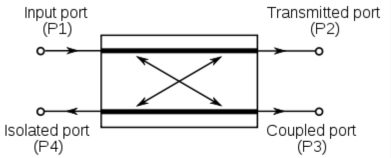


- **3-resistor divider (3 * 16.7 Ω):** good match from DC to GHz, ideal e.g. for pulse signal / oscilloscope – applications, very high bandwidth, low decoupling between the output ports, low power applications.



- **2-resistor splitter (2 * 50 Ω):** mainly used for ratio measurements and leveling applications, to maintain low source match (Γ_{Eq}), very high bandwidth, low power applications.

- **3 dB directional coupler:** „real“ 3 dB power dividers (coupled transmission lines), band pass frequency response, very high power possible.



METAS

Calculated minimal distances to avoid near field effects

based on the Agilent connector blue prints:

- **1.0 mm (slotted) : 5 µm**
- **1.85 mm (slotted) : 5 µm**
- **2.4 mm (slotless) : 15 µm**
- **2.92 mm (slotted) : 10 µm**
- **3.5 mm (slotless) : 15 µm**
- **Type-N (slotless) : 12 µm**

General: a slotless design needs more distance!