# De-embedding test fixtures for high speed digital applications

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ROHDE&SCHWARZ
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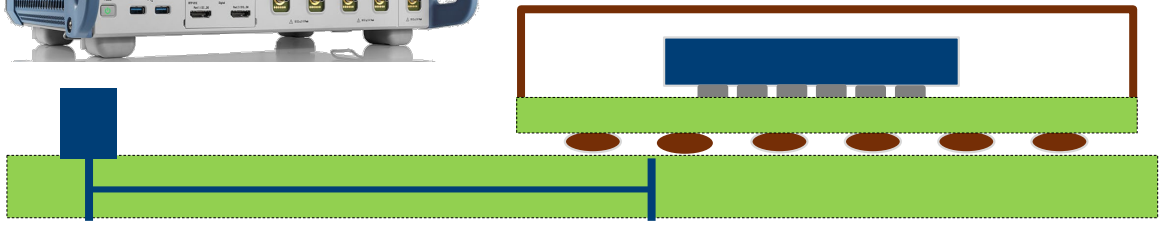
## Agenda

- Why use de-embedding in high speed digital scope measurements
- VNA and S-parameter measurement basics
- How to create fixture modelling files with a VNA
- Automotive Ethernet VNA De-embedding example

# De-embedding test fixtures for high speed digital applications



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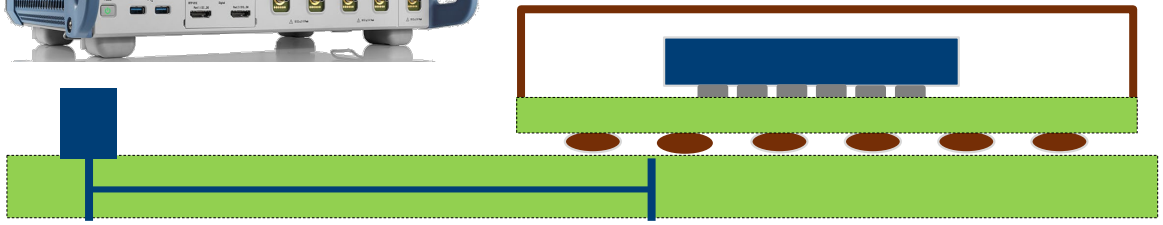
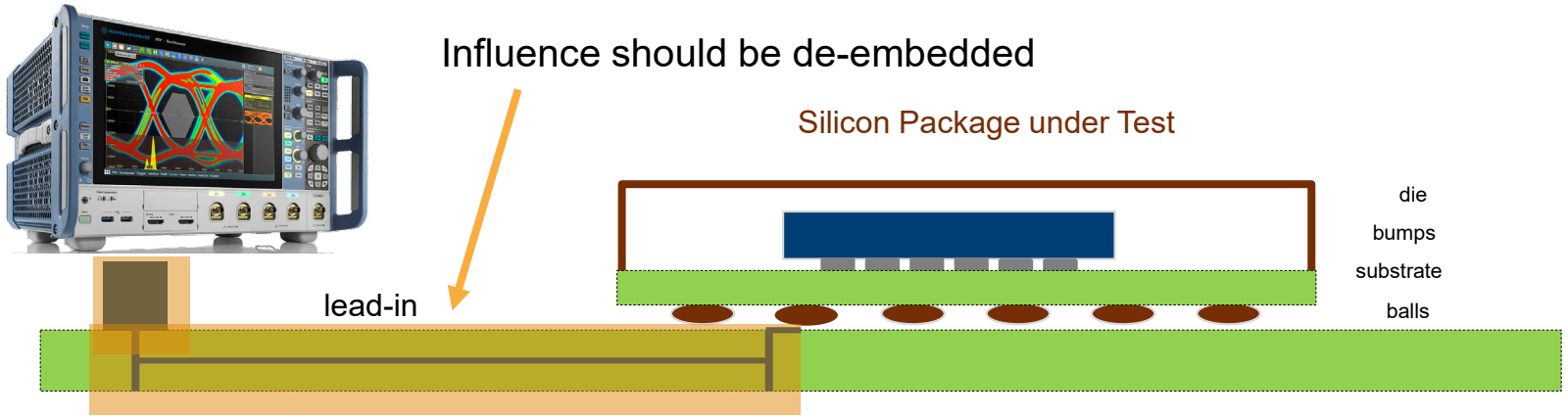


# Compensation of fixture influence for Oscilloscope transmitter test

- Task is to measure a transmitter signal without influence of your fixture
- For a differential signal analysis symmetry of the measurement setup is key
- De-skew of oscilloscope channels (not scope of this presentation)
- A Vector Network Analyzer (VNA) can create fixture de-embedding files for compensation
- Loading created file in the Oscilloscope for compensation



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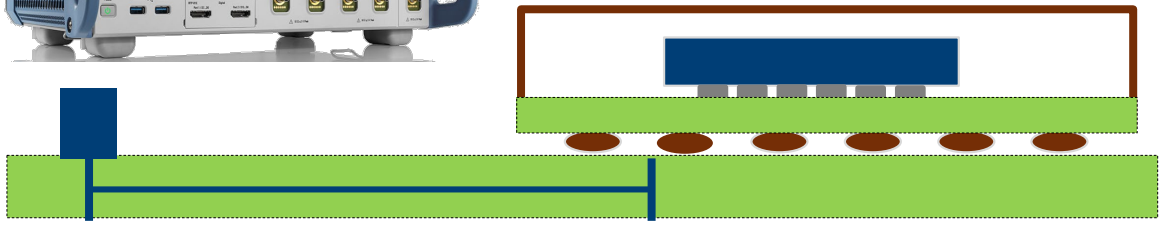
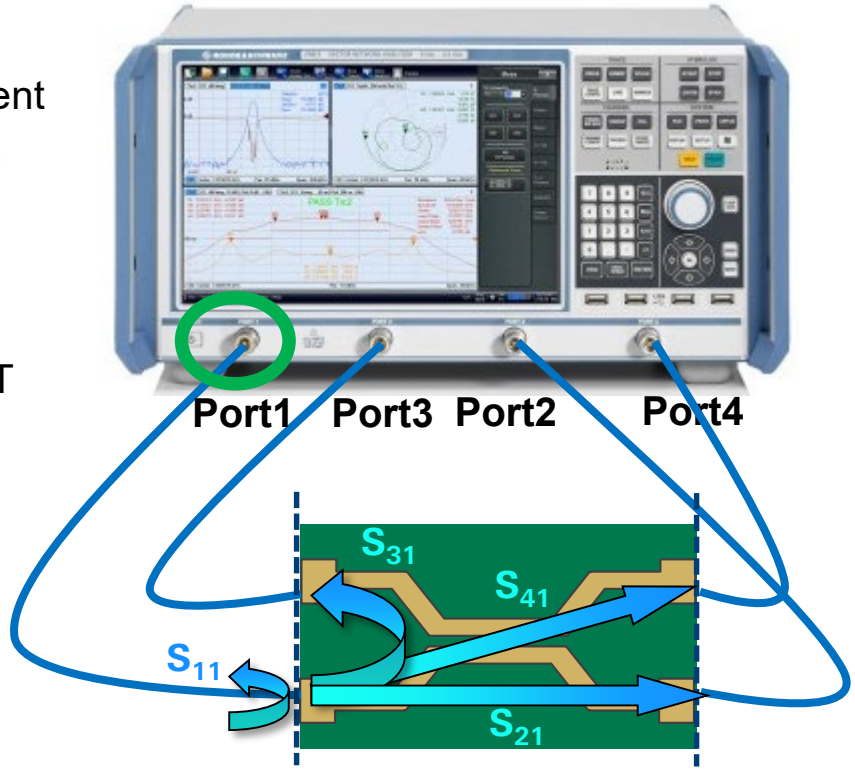


# VNA and S-parameter basics

- VNAs combine source and receiver in one device
- Typically continuous frequency sweep measurement
- Measure S-parameter, reflection and transmission behavior of components
- Each port needs to be the driving port once
- In total four sweeps needed to create a full S-parameter characterization of a 4-port DUT

$$\begin{matrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{matrix}$$

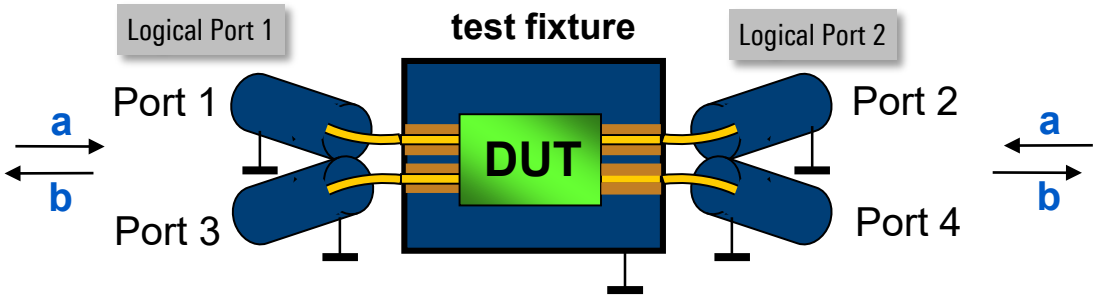
receiving port driving port



# Balanced/ Mixed Mode S-Parameters

Measure the balanced 2-port device as unbalanced 4-port device with unbalanced VNA.
VNA Calculates mixed mode S-Parameters out of measured single ended S-Parameters.

a, b = power waves




$$\begin{bmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{bmatrix} * \begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \end{bmatrix}$$

| | |
|---|---|
| Differential-mode Response | Port 1 |
| | Port 2 |
| Common-mode Response | Port 1 |
| | Port 2 |

| Differential-Mode stimulus | | Common-Mode stimulus | |
|---|---|---|---|
| Port 1 | Port 2 | Port 1 | Port 2 |
| $S_{dd11}$ | $S_{dd12}$ | $S_{dc11}$ | $S_{dc12}$ |
| $S_{dd21}$ | $S_{dd22}$ | $S_{dc21}$ | $S_{dc22}$ |
| $S_{cd11}$ | $S_{cd12}$ | $S_{cc11}$ | $S_{cc12}$ |
| $S_{cd21}$ | $S_{cd22}$ | $S_{cc21}$ | $S_{cc22}$ |

$S_{mm}$ = Reflection at Port m

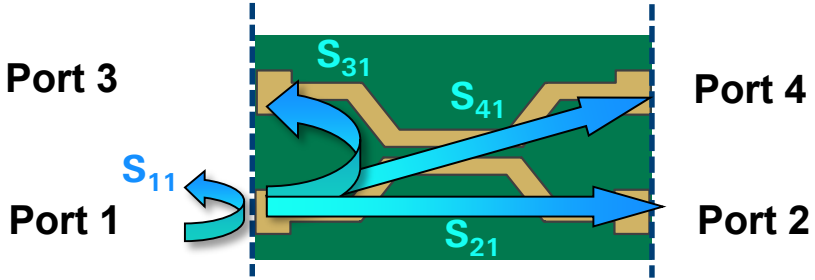
$S_{mn}$ = Transmission from Port n to Port m

**Naming Convention: S** mode res., mode stim., port res., port stim.

# What is a Touchstone File *.s*n*p? (*n* is number of ports)

- Industry standard for S-parameter files
- Full description of frequency response of a component
- Complex values in *magnitude / angle (phase)* or *real / imag*
- One set of S-parameters per frequency point

$$\begin{matrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{matrix}$$



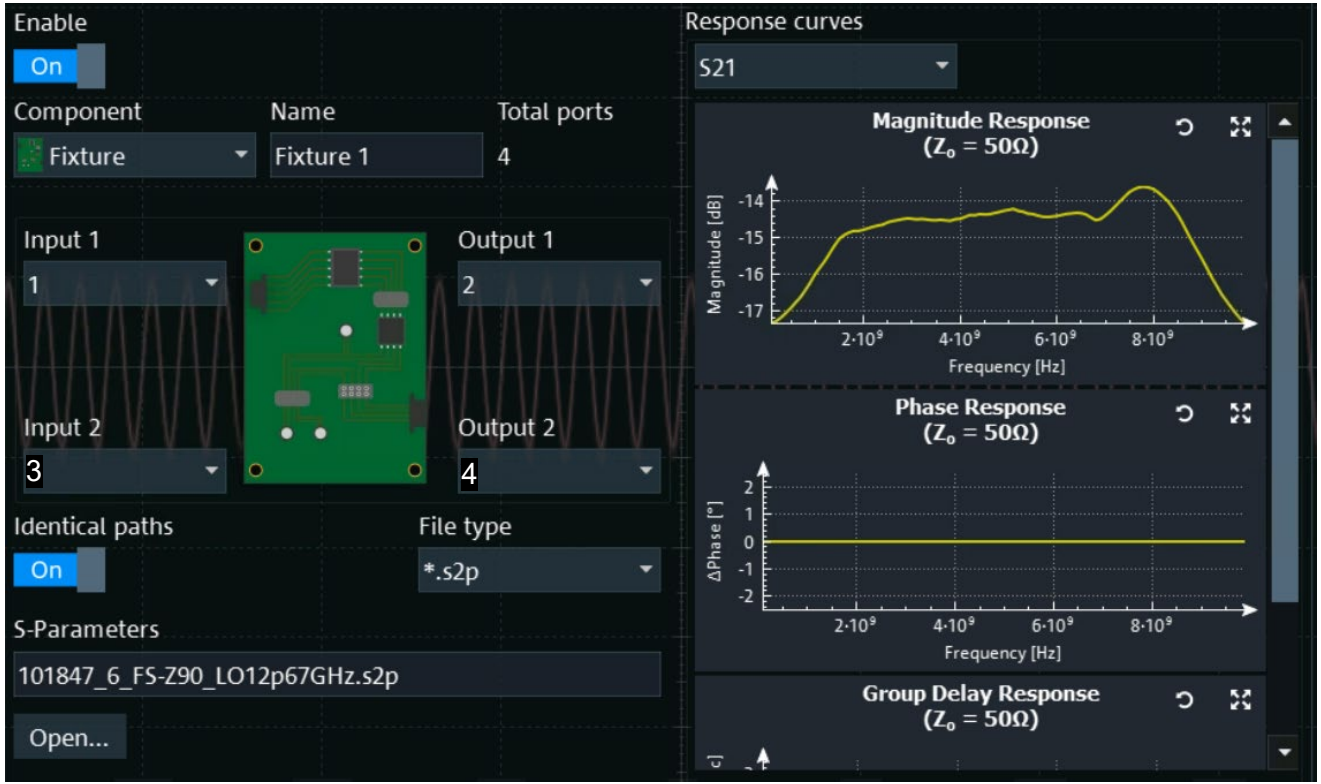

Take care about consistent port assignments during creation and use in VNA and Scope

```
# HZ   S   DB   R     50.00
! Rohde & Schwarz Vector Network Analyzer
! Rohde-Schwarz,ZNB8-4Port,1311601044103485,2.94
! Created: UTC 6/5/2020, 8:58:28 AM
! freq[Hz]          db:S11                ang:S11               db:S12
!                   db:S21                ang:S21               db:S22
!                   db:S31                ang:S31               db:S32
!                   db:S41                ang:S41               db:S42
!
 1.0000000000000000E6   7.030191930505213E-3   2.602916756534536E-2   -1.147839
                       -1.079817243963495E2   -1.486860327997170E2   -4.416523
                       -1.129092361182286E2    6.909905623452955     -1.094483
                       -1.067097263043102E2   -8.517666928925952     -1.067053

 2.0000000000000000E6    6.680282270222103E-3  -5.620099899660941E-3  -1.056192
                       -1.053286425696122E2   -8.232411897211276E1    7.924377
                       -1.071932533652798E2   -2.784612316253055E1   -1.035747
                       -1.092420136717747E2    8.535329241291025E1   -1.231045

 3.0000000000000000E6    8.013858121994550E-3   9.440017586267023E-3  -1.108921
                       -1.196678687080890E2    8.309343598600998E1   -1.828560
                       -1.072067375084436E2    1.649301748588150E2   -1.132420
```

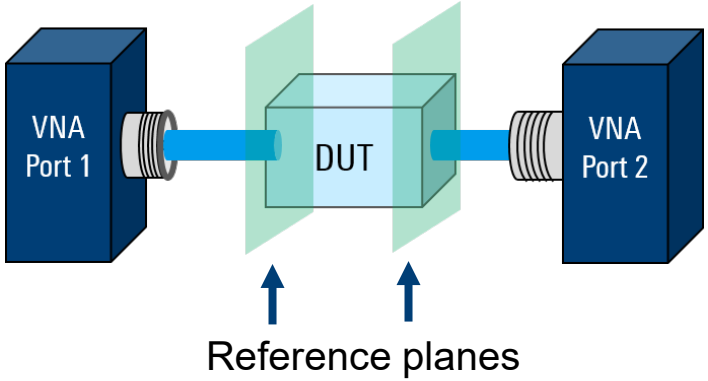
# Scope import of S-parameter file for de-embedding




Take care about consistent port assignments during creation and use in VNA and Scope

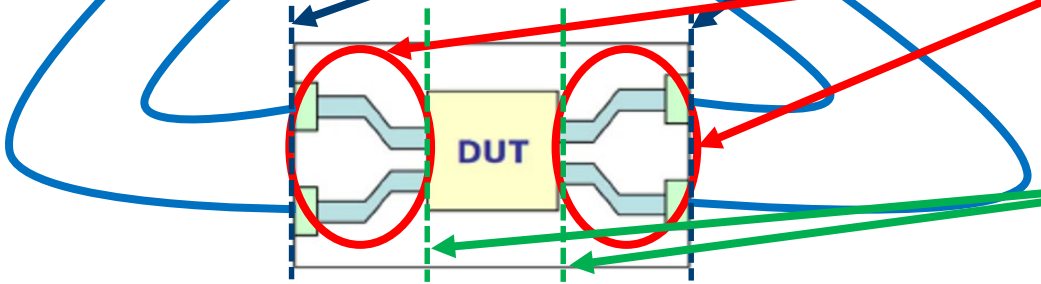
# VNA system error correction (calibration): coaxial interface

- Correction of systematic errors of the instrument and cables (test set)
- Reference plane: the point where the **known** calibration standards are presented, typically coaxial connector
- Typically used calibration kits consists of Through, Open, Short and Match standards (TOSM)
- Also automatic calibration units available
- Deembedding can be used when reference plane of DUT is not a coaxial connector





# What if DUT does not have coaxial connectors?




Calibration plane after coaxial calibration

Creation of fixture modelling files if coaxial calibration is not possible

New reference plane after De-embedding

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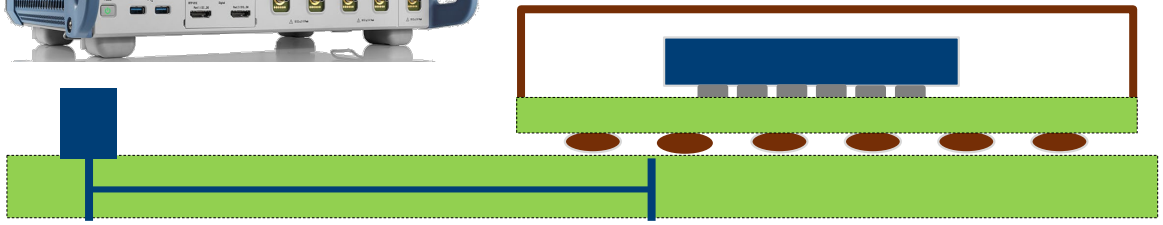
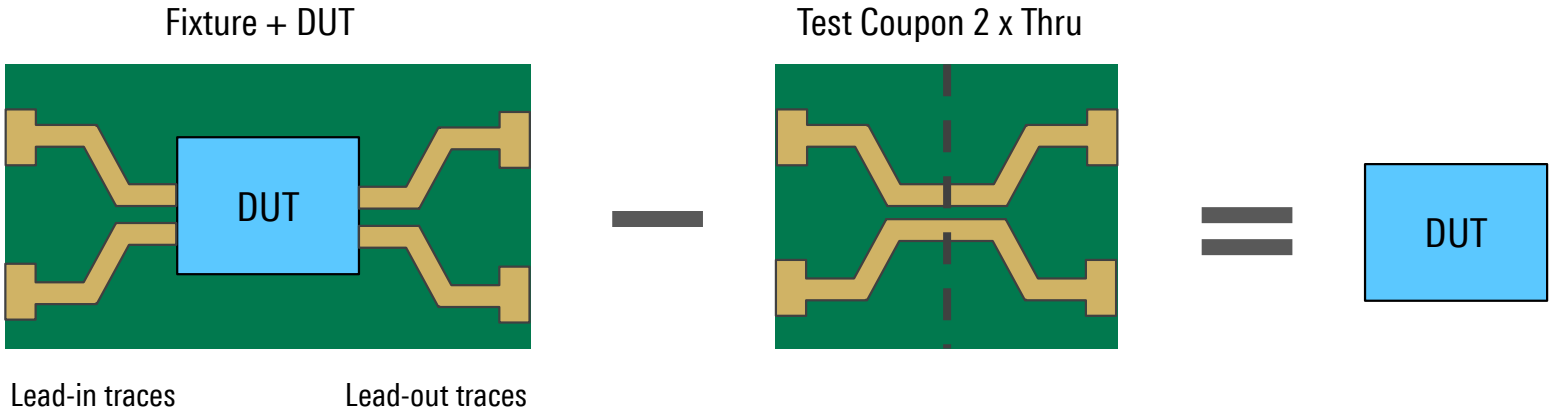


# Creation of de-embedding files for VNA measurements




- Files can be created out of 2 x Thru itself
- Problem: Differences between coupon and test fixture would lead to errors (different connector and line impedances (e.g. fiber weave), different signal routing, etc.)
- Solution:
  - “Impedance Correction” feature creates fixture *.snp files out of Fixture + DUT measurement
  - Length of fixtures determined out of coupon measurement file
  - Two measurements needed: Coupon and Fixture + DUT measurement

# Creation of de-embedding files for scope measurements

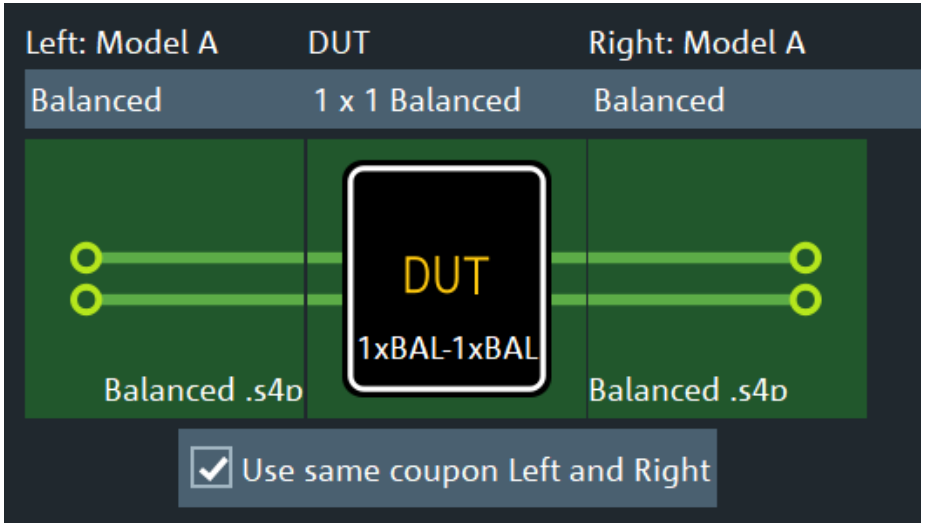
- To be de-embedded for ideal scope measurements
- Without coaxial interface fixture cannot be measured directly with VNA
- Use VNA De-embedding tools to create fixture S-parameter file
- Choose Coupon:
  - 2 x Thru (replica)
  - 1 x Open (open fixture)
  - 1 x Short (shorted fixture)
  - 1 x Open + 1 x Short

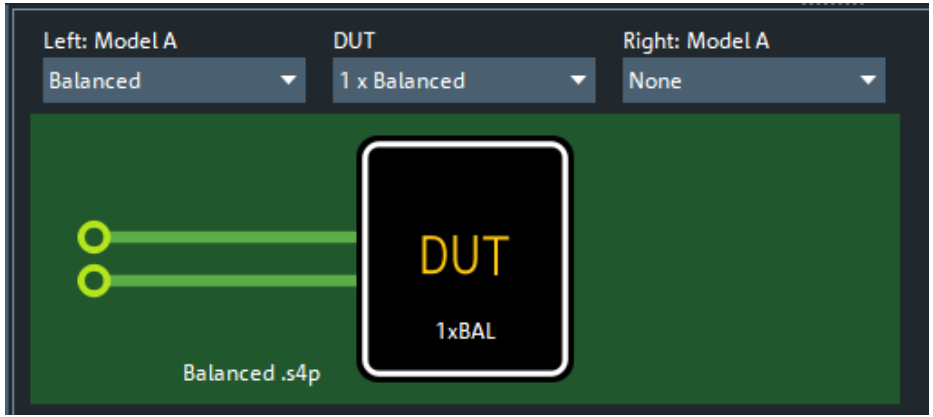




# R&S VNA de-embedding file creation

- Choose de-embedding use case
- Balanced / Single Ended
- Symmetric fixtures left/ right
- one port setup (FIX DUT)
  for Oscilloscope test case
- Also possible to create file
  with 1x Balanced (e.g. 1 x Open) only

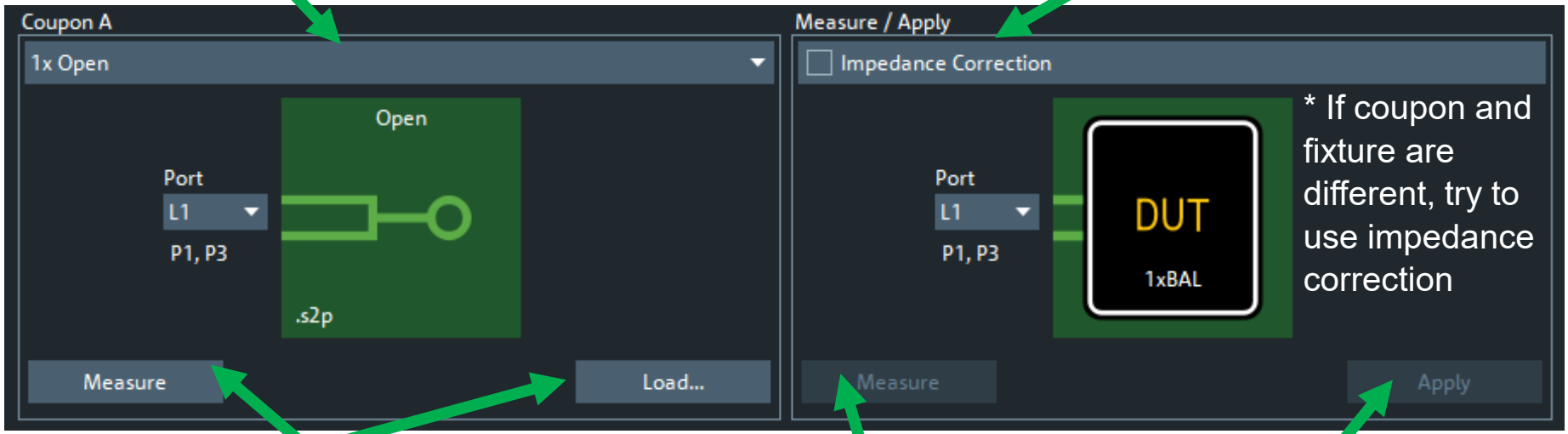


# R&S VNA de-embedding modeling file creation

Choose coupon type
(2x Thru, 1x Open ,…)

Impedance correction on / off *
On: → create fixture file from Fixture-DUT-Fixture
Off: → creates fixture files from coupon



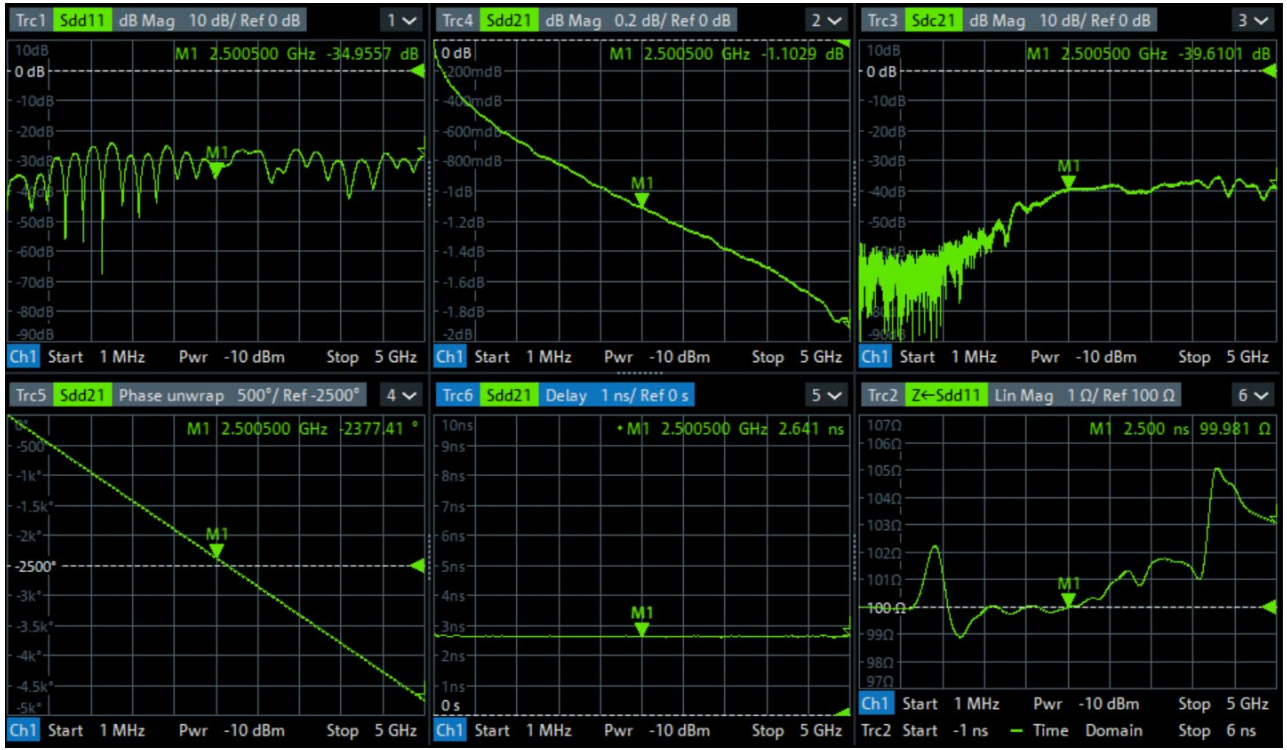

**1:** Measure or load Coupon S-parameter

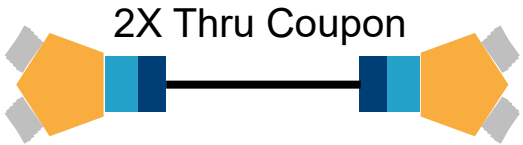
**2:** Measure Fixture - DUT - Fixture

**3:** Create fixture files

# S-parameters of a transmission channel

- Sdd11 Reflection in dB
- Sdd21 Transmission in dB
- Sdc21 Mode Conversion
- Sdd21 Phase
- Sdd21 Delay
- Z←Sdd11 TDR Impedance



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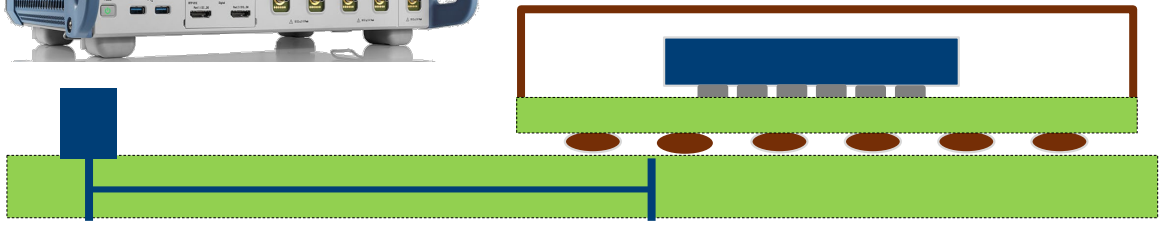
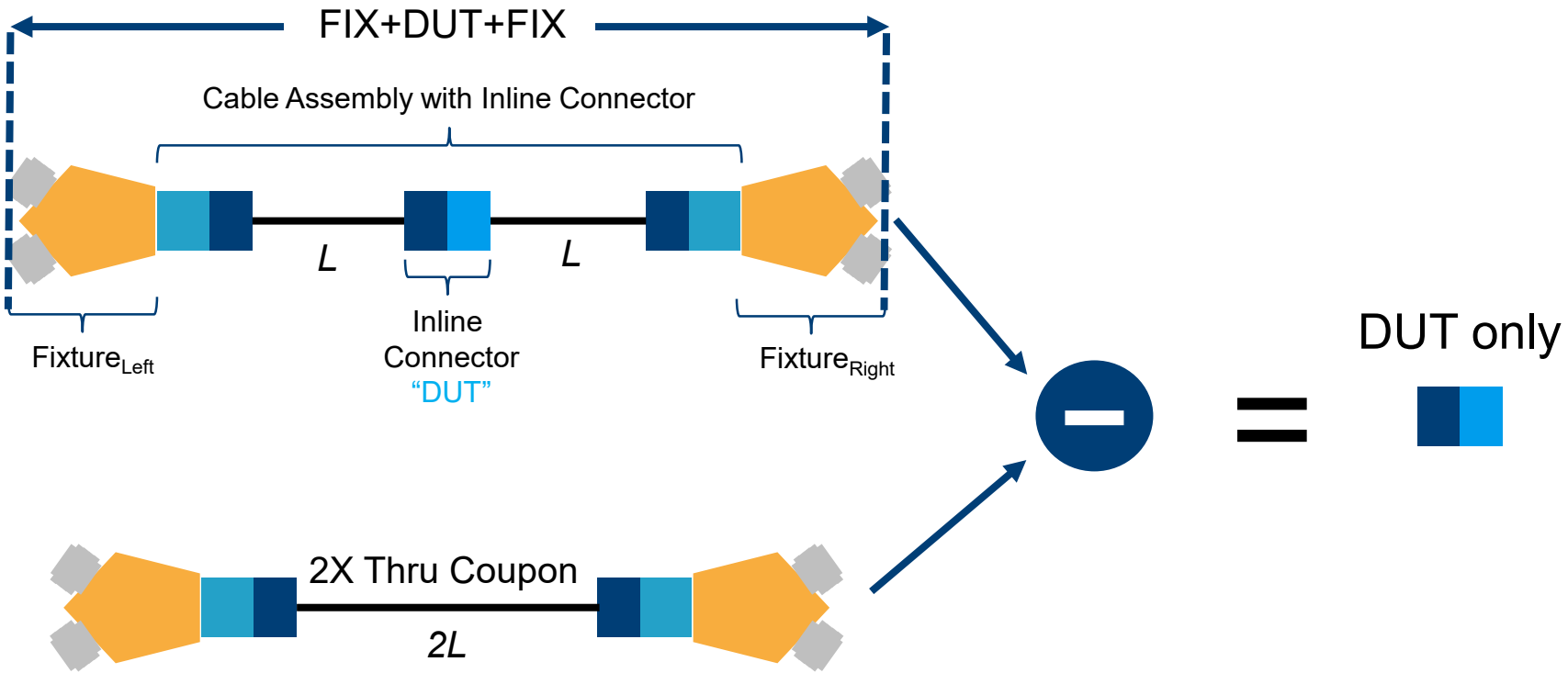
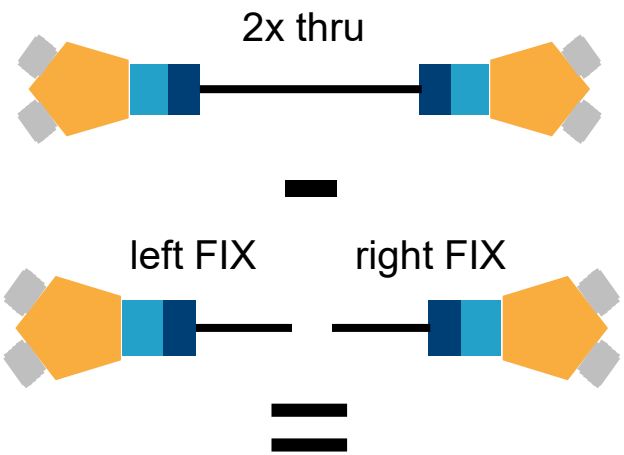


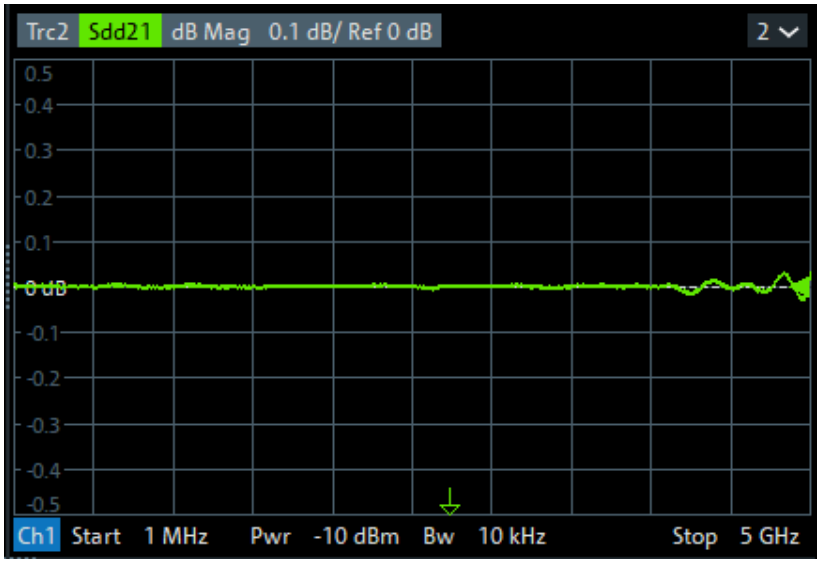
# Automotive ethernet mated cable connector Impedance-corrected de-embedding



# Self de-embedding of 2x Thru




“Ideal Thru“

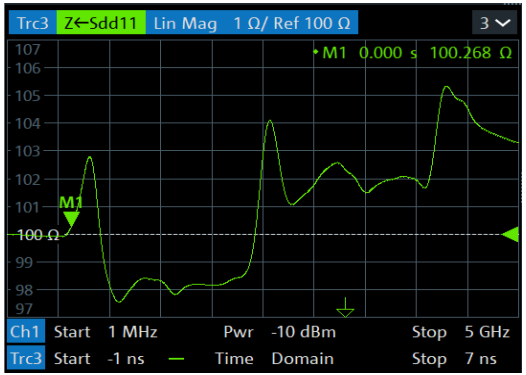



IEEE370 $S_{DD}21$ Criteria:

Magnitude < +/- 0.1 dB
Phase < +/- 1°

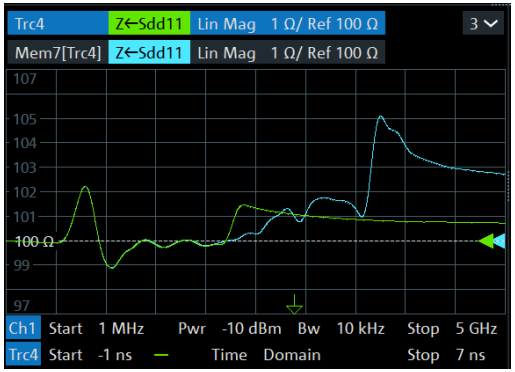
# Standard 2x Thru de-embedding

Fixture$_{Left}$ + DUT + Fixture$_{Right}$




−

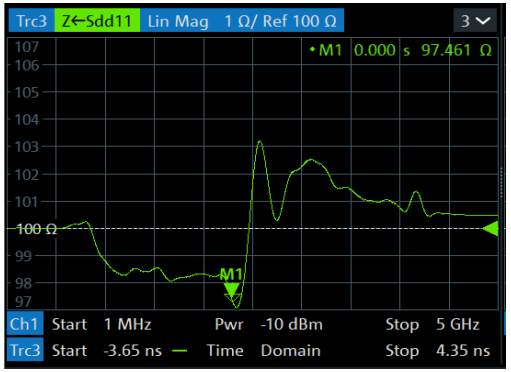
2X Thru




Whole 2xThru
Fixture$_{Left}$ Generated Model

=

Fixture$_{Left}$ + DUT + Fixture$_{Right}$

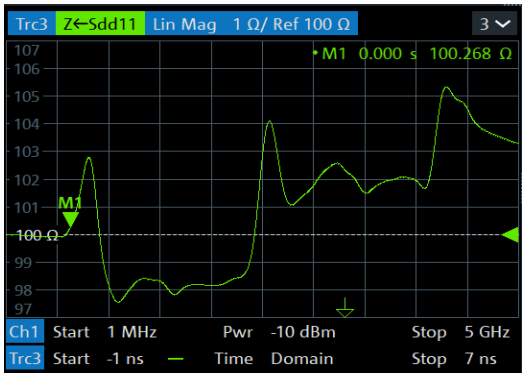



DUT
(including “Phantom limbs“)

→ Bad result because TDR Impedance of 2x Thru is different than of FIX+DUT+FIX

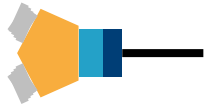
# Automotive ethernet mated cable connector
# Impedance-corrected de-embedding result

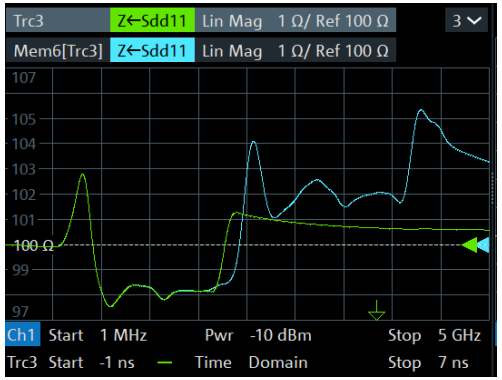
$Fixture_{Left}$ + DUT + $Fixture_{Right}$




−

$Fixture_{Left}$

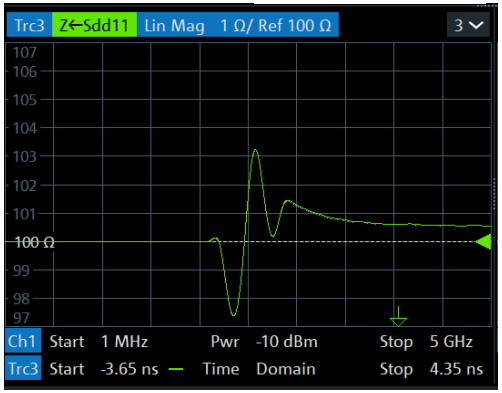





$Fixture_{Right}$

=

DUT




$Fixture_{Left}$ + DUT + $Fixture_{Right}$

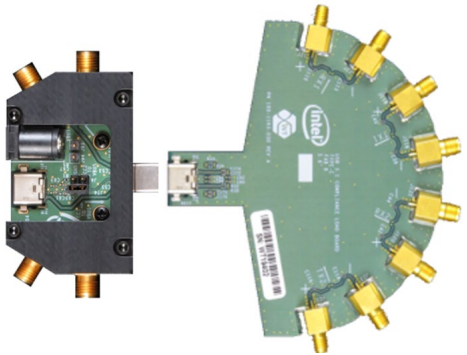
$Fixture_{Left}$ Generated Model

→ Perfect result: no influence of fixture left

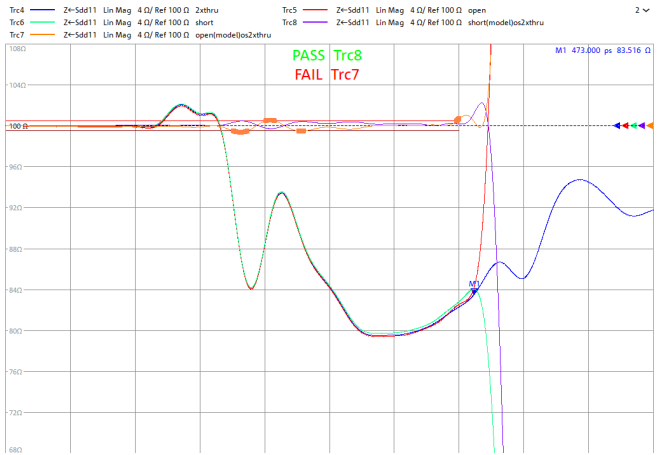
# Conclusion
# De-embedding test fixtures for high speed digital applications

- **Compensation of fixture** is needed
- **S-parameter de-embedding** is best way
- **Corrects** precisely the **frequency response** in reflection and transmission behaviour
- **Creation of precise fixture S-parameter files** with VNA
- A **coupon reference structure** is needed (1xOpen, 2xThru, …)
- Use consistent **port assignments** of fixture file during creation and use

# Upcoming Appnote: De-embedding test fixtures for high speed digital applications



- Used example is transmitter test USB 3.2 Type C
- Different methods for fixture creation
  - Coupon (reference):
    1x Open / 1x Short / 1x Open + 1x Short
  - Fix DUT Fix = modelling file created based on:
    Coupon only / mated pair / fixture + transmitter
- Oscilloscope result with and without de-embedding



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# Thank you!

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