

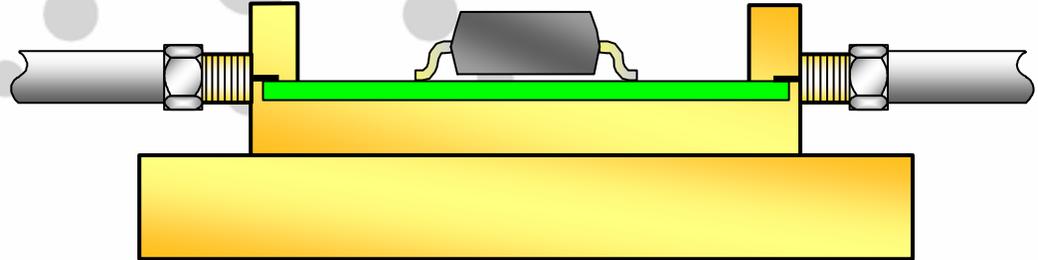
## Agilent EEsof EDA

### De-embedding Techniques in Advanced Design System

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# De-embedding Techniques in Advanced Design System

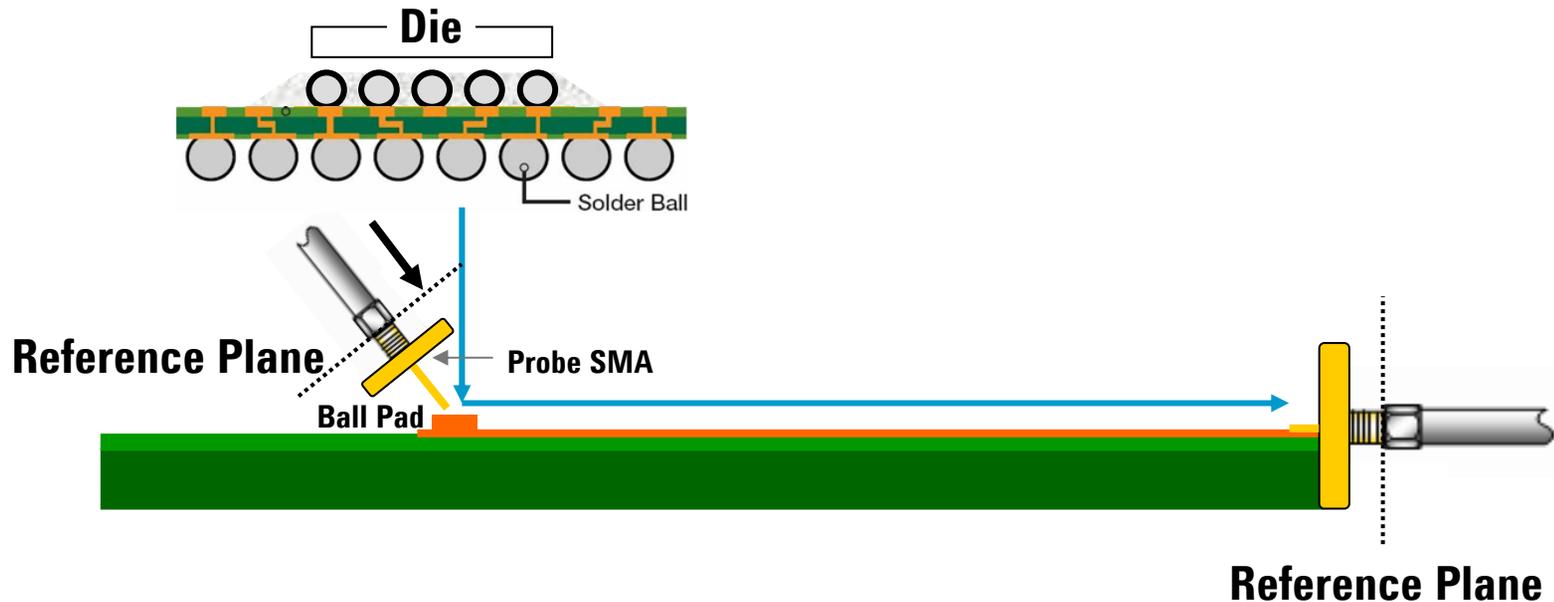


**Agilent Technologies**

# Agenda

- Why de-embedding?
- 2-port de-embedding
- Mixed mode S-parameters
- Four port de-embedding
- TRL based de-embedding
- Summary

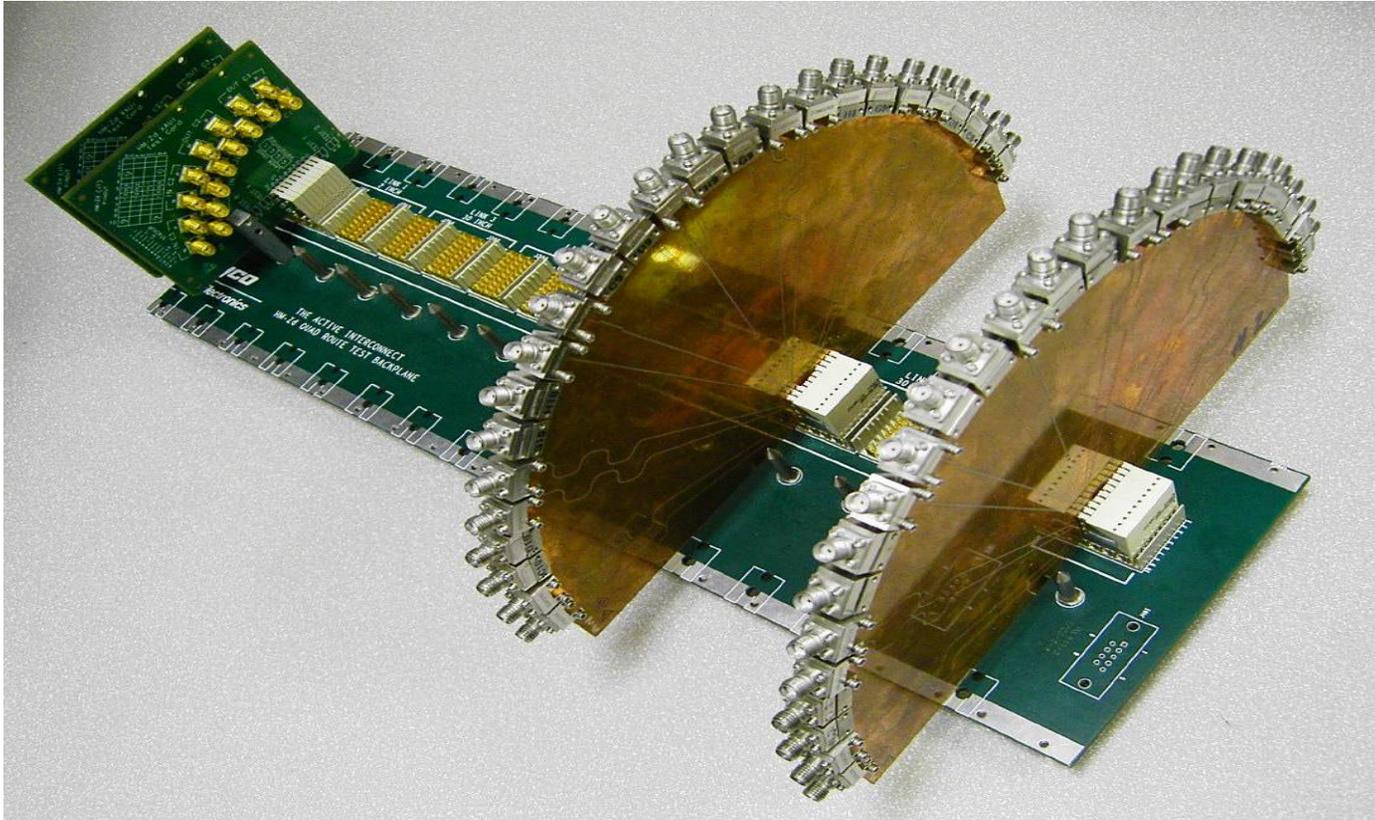
# Non Insertable Measurements



Board Response = Total Response – Probe SMA Response

Require accurate modeling of Probe SMA response

# DUT with Test Fixtures

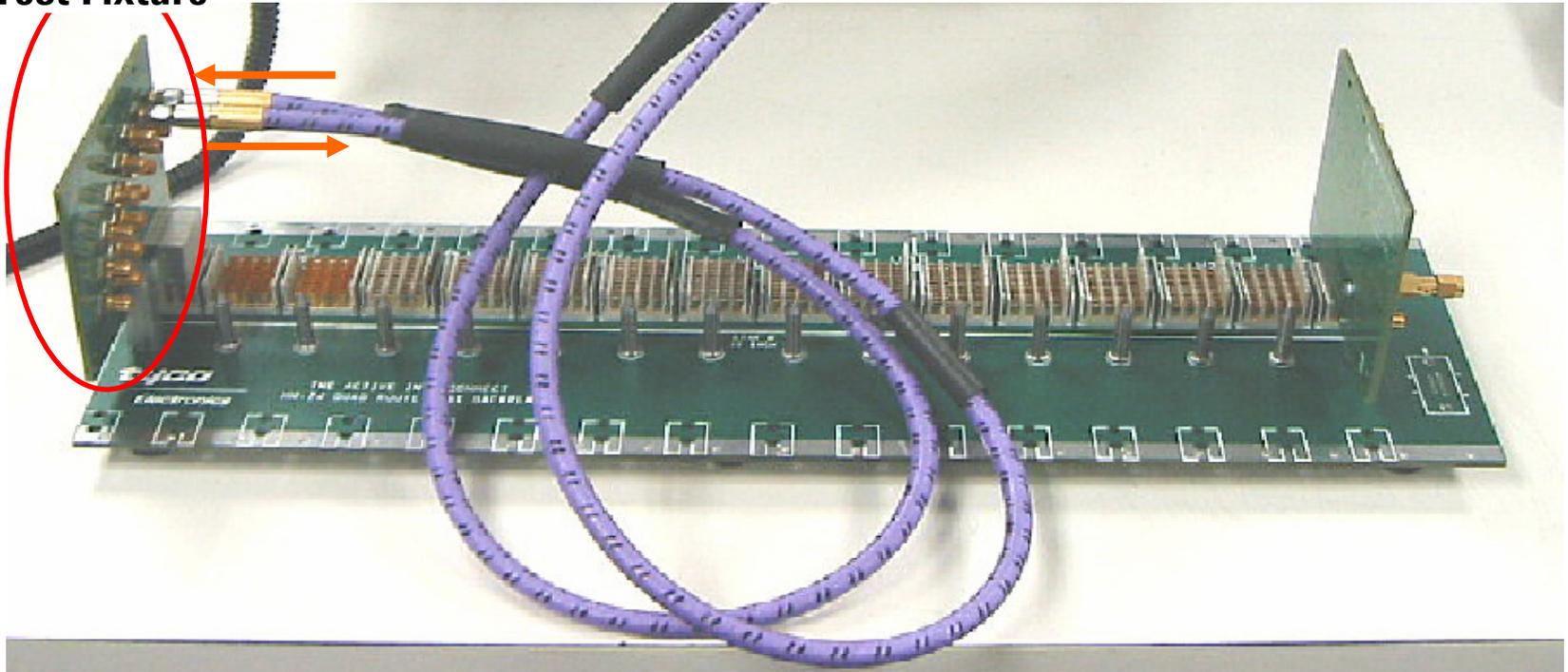


**Requires test fixture: Not a part of the back plane structure**

**How to remove test fixture effects from the overall measurement?**

# Backplane measurements

Test Fixture

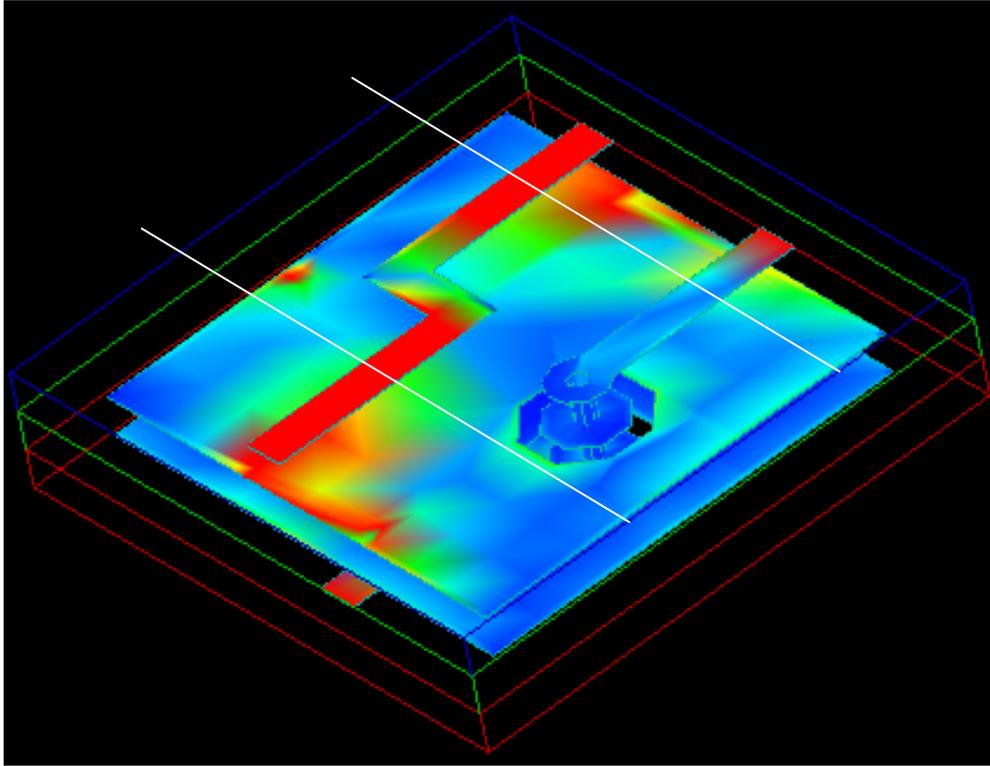


Backplane Response = Total Response – Test Fixture Response

Sometimes it is not feasible to remove test fixture effects using various calibration techniques

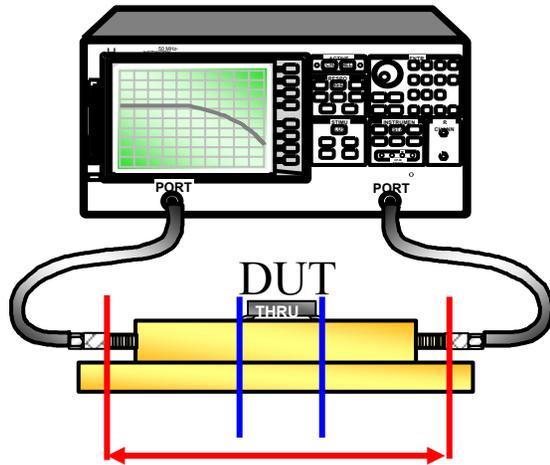
# De-embedding Requirements in EM Simulation

## Moving Reference Plane



**Sometimes it is not feasible to move the reference plane in EM tools.**

# What is De-embedding?

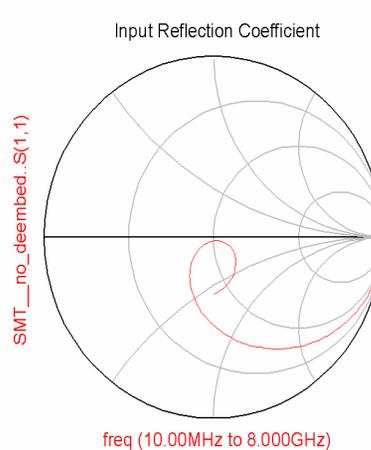


“Real” DUT SP = Measured SP – Fixture Characteristic  
De-embedding : Negating effects of unwanted portion

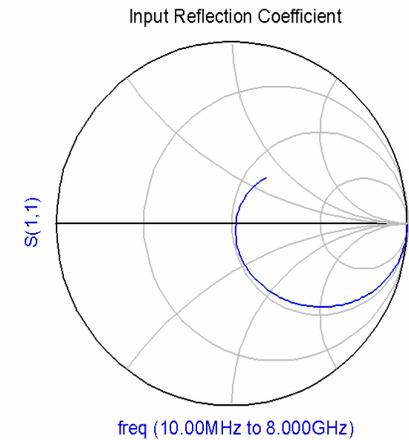
De-embedding is a mathematical process that removes the effects of unwanted portions of the structure that are embedded in the measured data by subtracting their contribution.

Requires accurate fixture model

- Empirical models from measured data
- Simulation based models



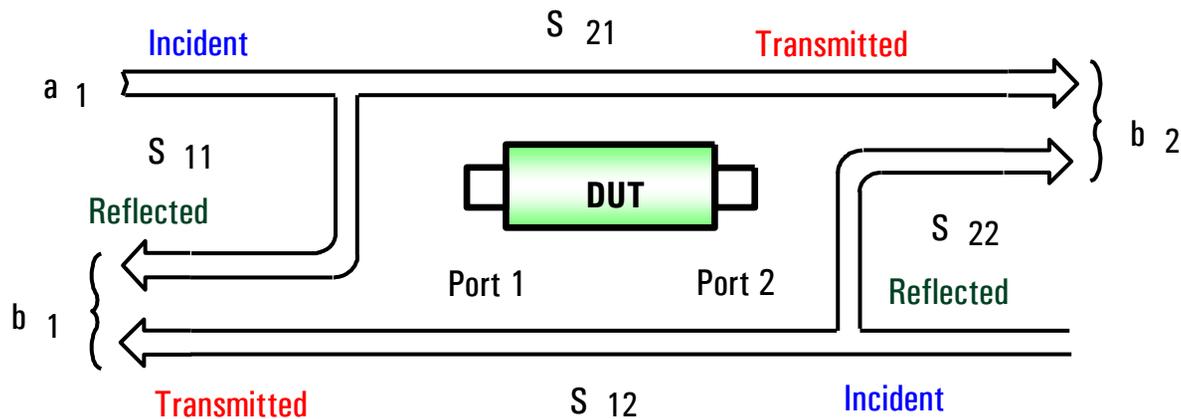
Before De-embedding



After De-embedding

# Why use S-Parameters?

- relatively easy to obtain at high frequencies
- relate to familiar measurements (gain, loss, reflection coefficient ...)
- can cascade S-parameters of multiple devices to predict system performance
- can compute H, Y, or Z parameters from S-parameters if desired
- can easily import and use S-parameter files in our simulation tools



$$S_{11} = \frac{\text{Reflected}}{\text{Incident}} = \frac{b_1}{a_1} \Big|_{a_2 = 0}$$

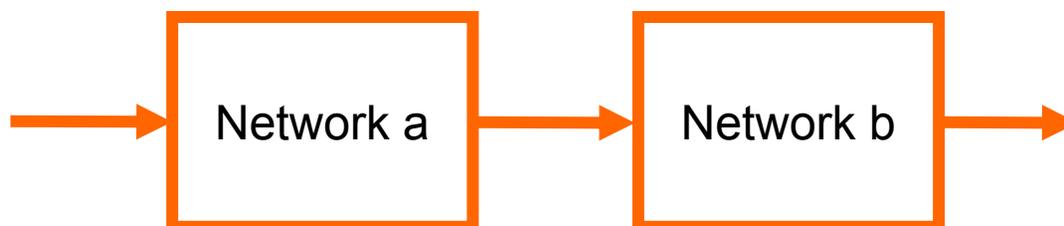
$$S_{21} = \frac{\text{Transmitted}}{\text{Incident}} = \frac{b_2}{a_1} \Big|_{a_2 = 0}$$

$$S_{22} = \frac{\text{Reflected}}{\text{Incident}} = \frac{b_2}{a_2} \Big|_{a_1 = 0}$$

$$S_{12} = \frac{\text{Transmitted}}{\text{Incident}} = \frac{b_1}{a_2} \Big|_{a_1 = 0}$$

# De-embedding two port network

To de-embed with transfer scattering parameters, the matrix math is straightforward...



$$\begin{pmatrix} T_{\text{total}} \end{pmatrix} = \begin{pmatrix} T_a \end{pmatrix} \begin{pmatrix} T_b \end{pmatrix}$$

$$\begin{pmatrix} T_a \end{pmatrix} = \begin{pmatrix} T_{\text{total}} \end{pmatrix} \begin{pmatrix} T_b \end{pmatrix}^{-1}$$

$$\begin{pmatrix} T_b \end{pmatrix} = \begin{pmatrix} T_a \end{pmatrix}^{-1} \begin{pmatrix} T_{\text{total}} \end{pmatrix}$$

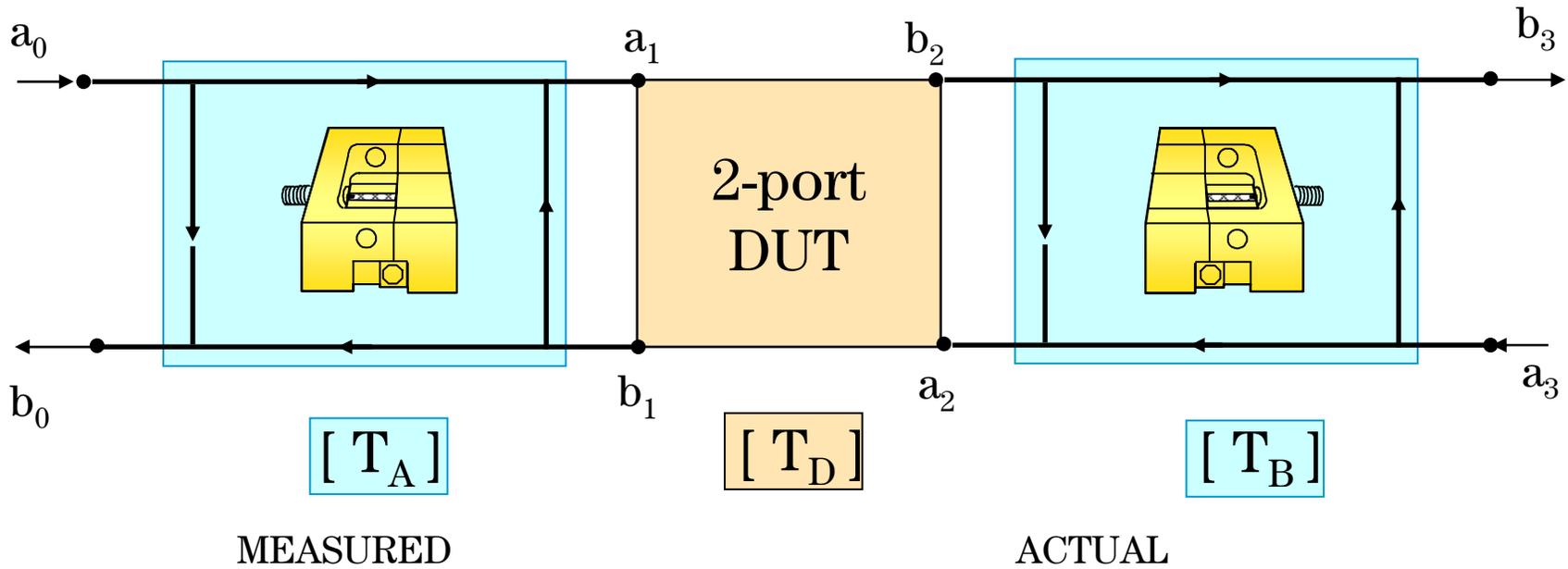
## Relationship between S and T-Parameters

$$\begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} = \left( \frac{1}{S_{21}} \right) \begin{bmatrix} S_{12}S_{21} - S_{11}S_{22} & S_{11} \\ -S_{22} & 1 \end{bmatrix}$$

$$\begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} = \left( \frac{1}{T_{22}} \right) \begin{bmatrix} T_{12} & T_{11}T_{22} - T_{12}T_{21} \\ 1 & -T_{21} \end{bmatrix}$$

Order is very important

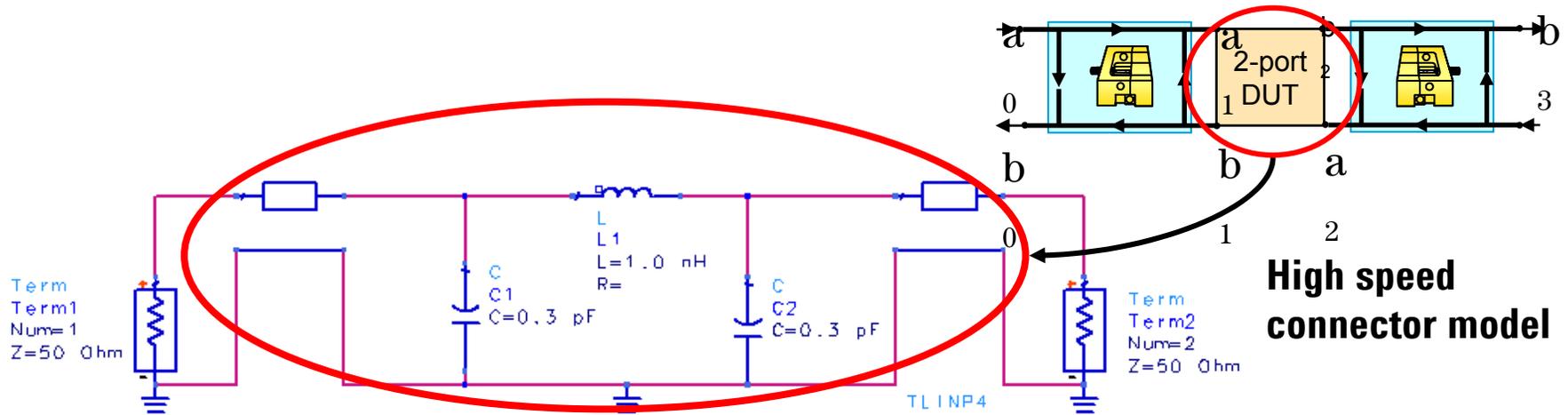
# Getting DUT data using De-embedding



$$[T_m] = [T_A][T_D][T_B] \quad [T_D] = [T_A]^{-1} [T_m][T_B]^{-1}$$

Let us build a sample network to demonstrate the de-embedding process in ADS

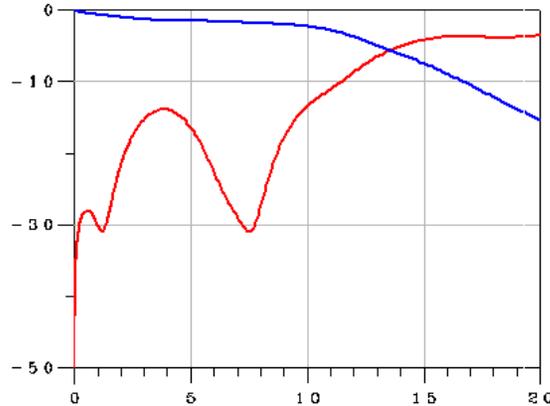
# De-embedding Example - DUT



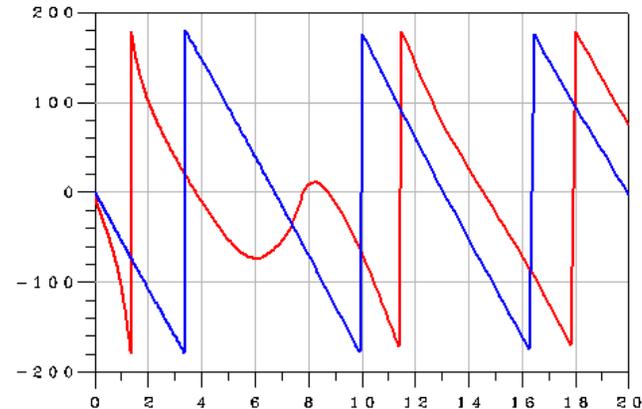
S-PARAMETERS

S\_Param  
SP1

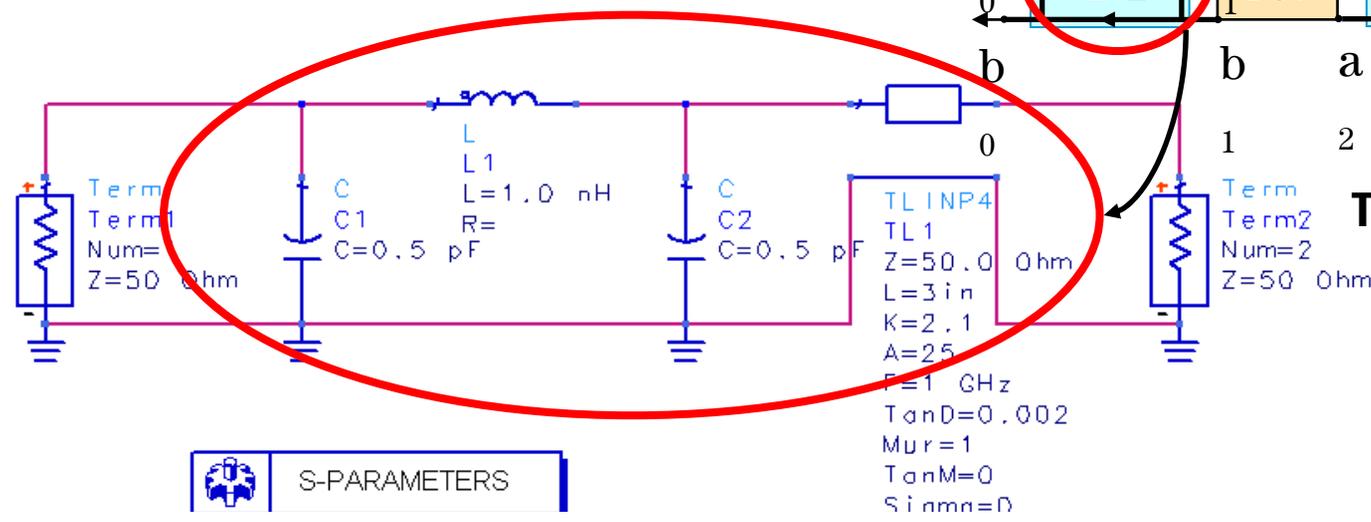
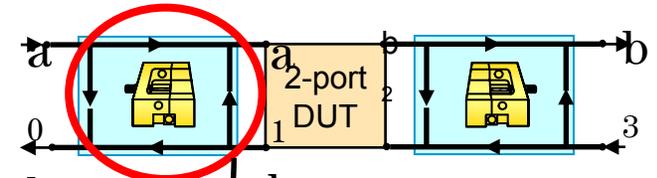
TLINP4  
TL3  
Z=55.0 Ohm  
L=0.5 in  
K=2.1  
A=25  
F=1 GHz  
TanD=0.002



TLINP4  
TL4  
Z=45.0 Ohm  
L=0.5 in  
K=2.1  
A=25  
F=1 GHz  
TanD=0.002

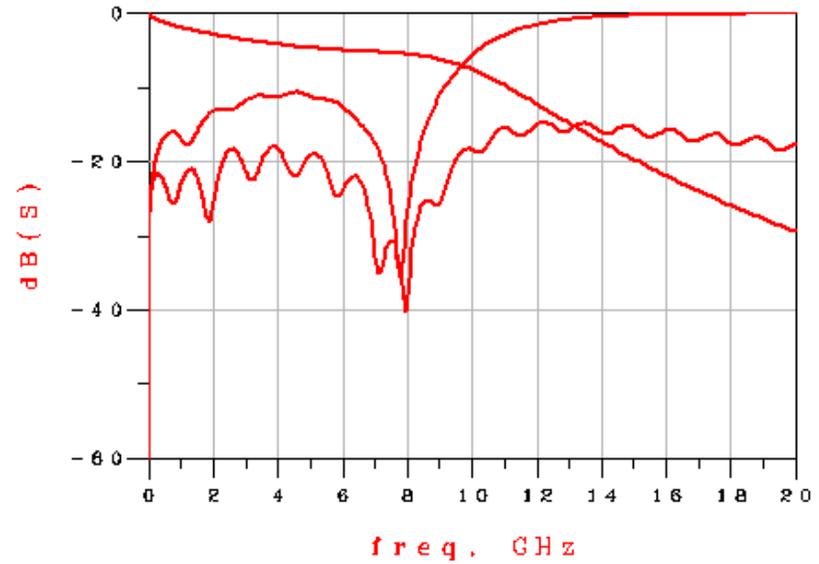


# Representing the Test Fixture

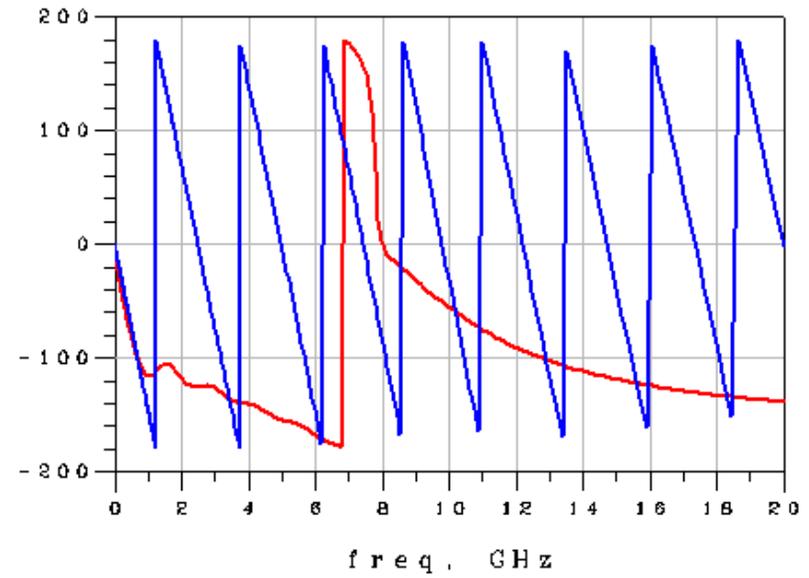


**Test fixture**

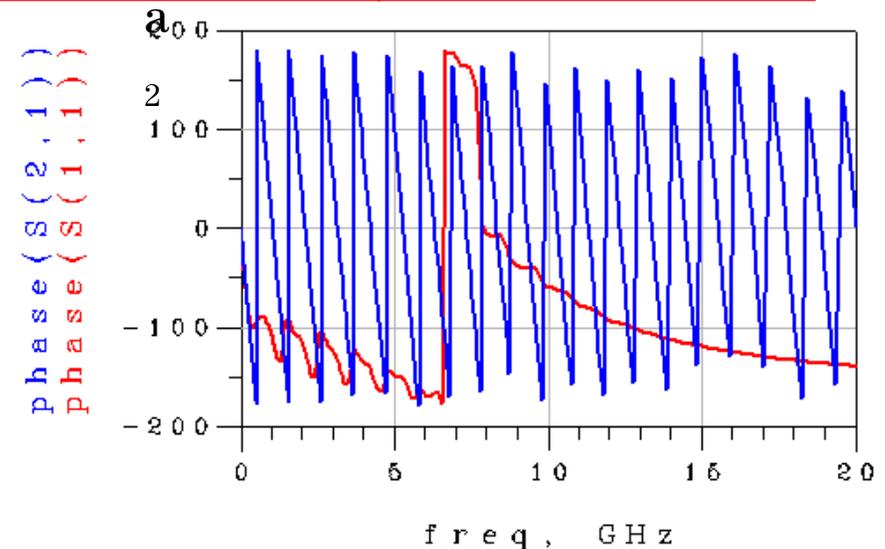
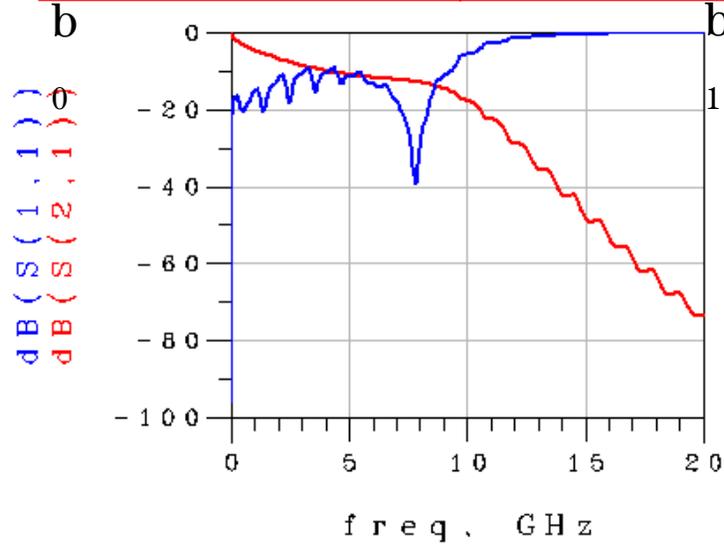
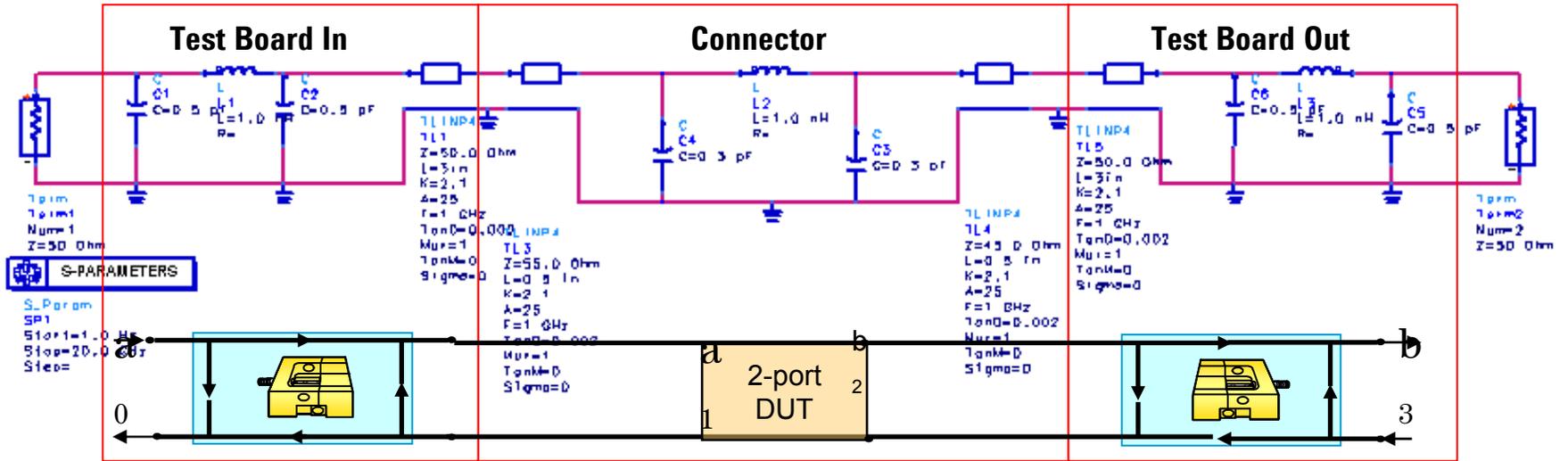
S-PARAMETERS



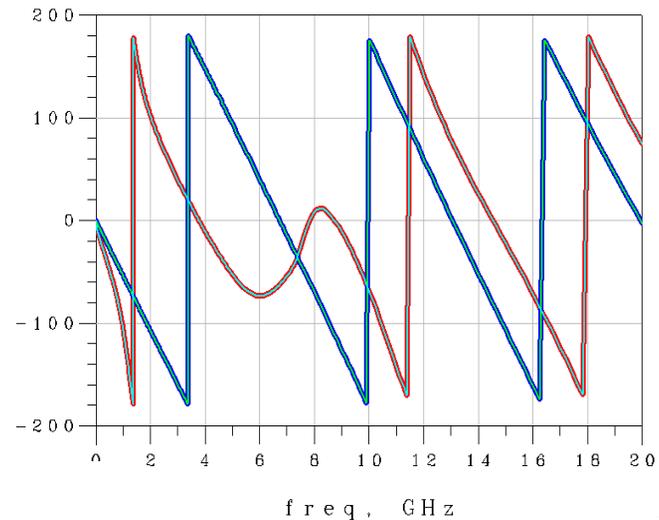
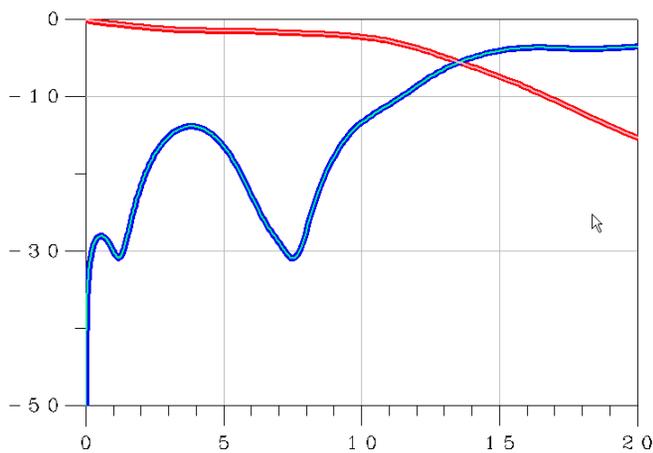
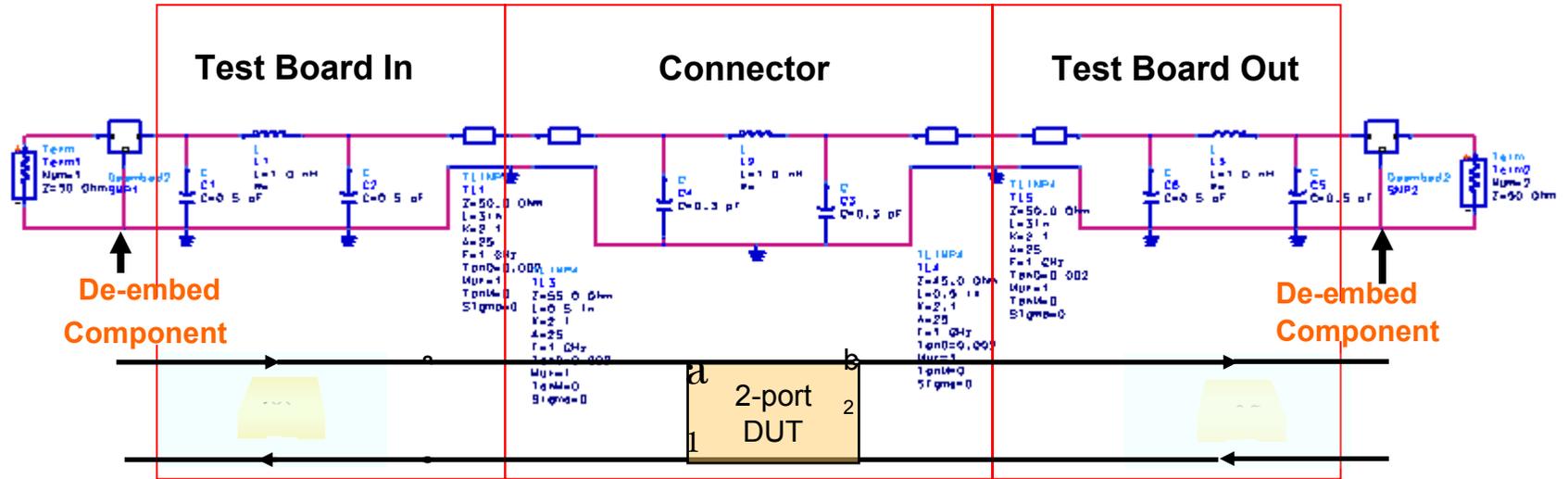
phase(S(2,1))  
phase(S(1,1))



# Test Fixture plus Connector

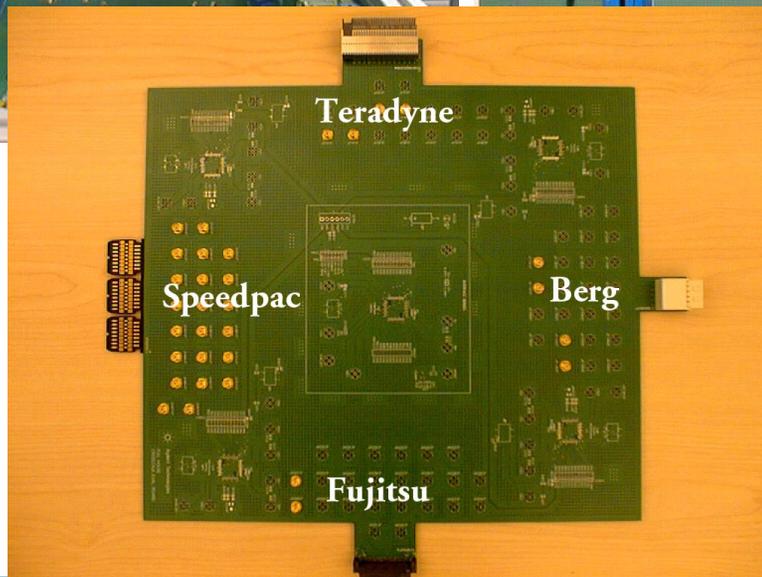
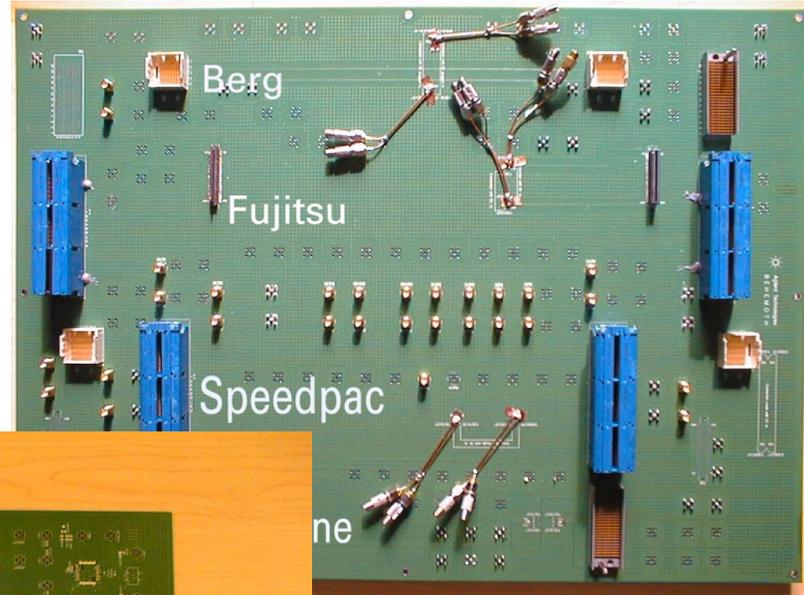
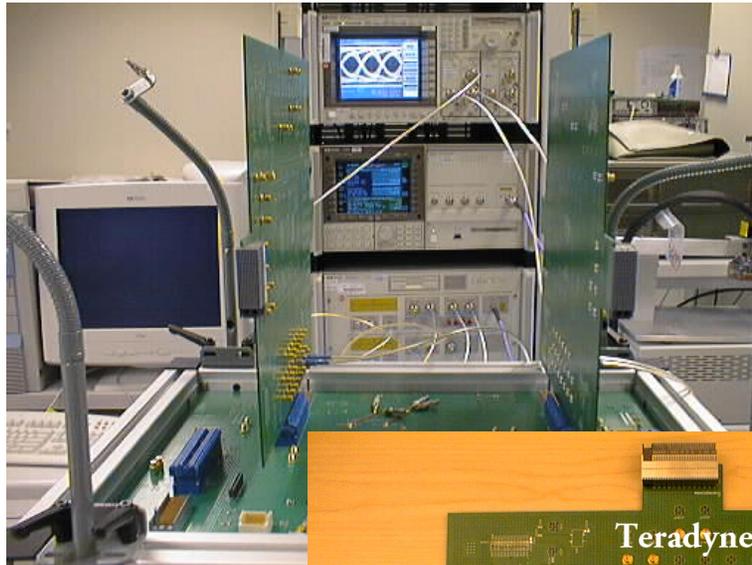


# Using 2-Port ADS De-embedding Component



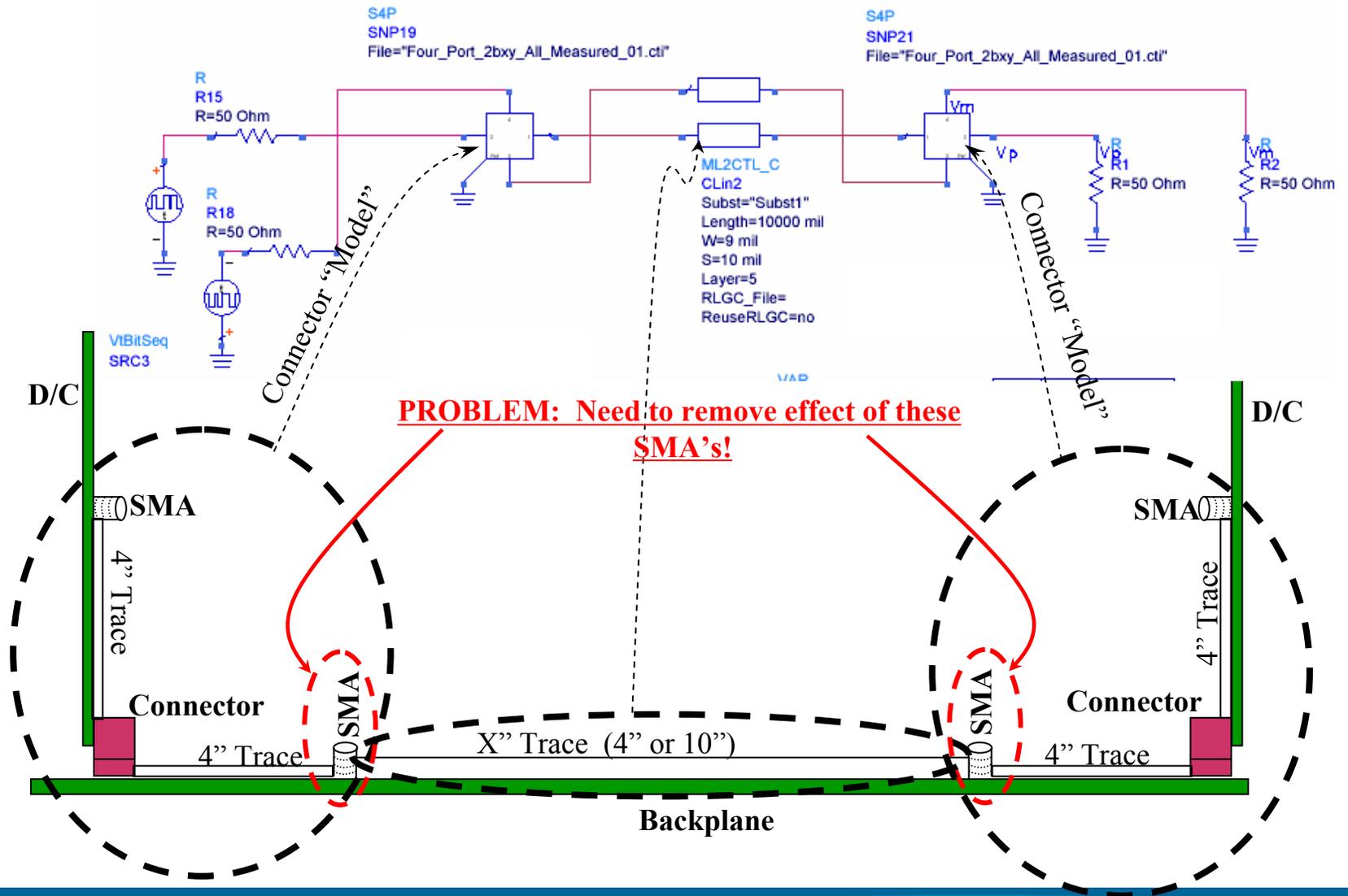
**Comparison with original Connector Model (Magnitude and Phase Response)**

# Backplane Performance Evaluation

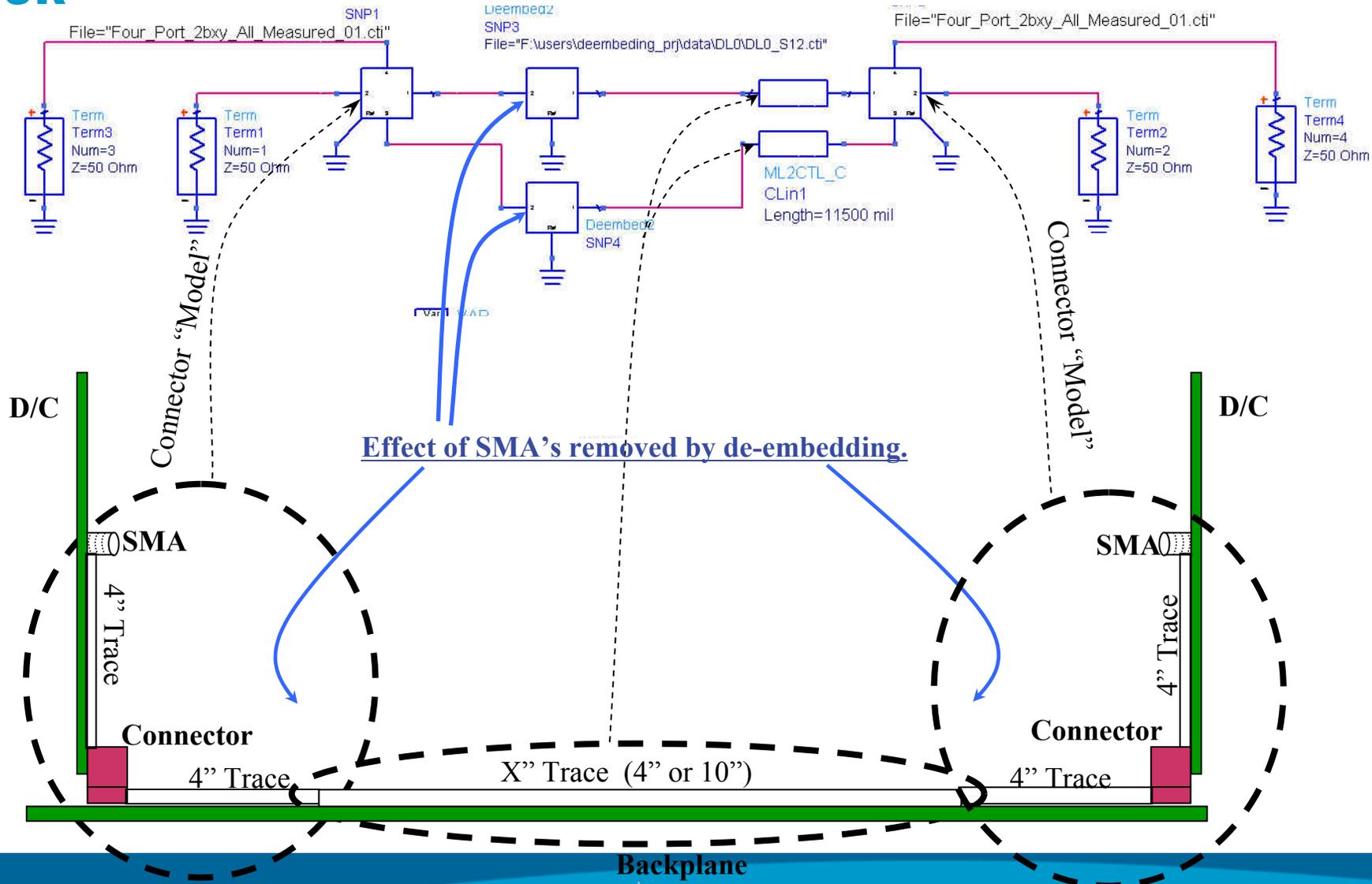


Backplane and Daughter card

# The Simulation Circuit Problem

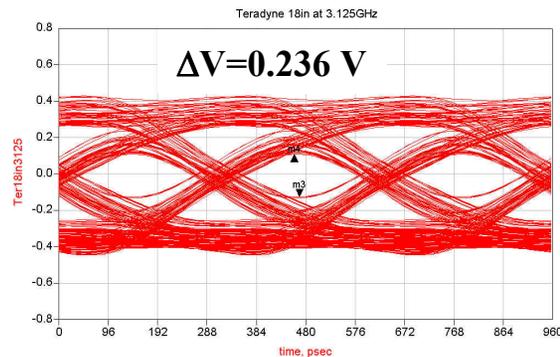
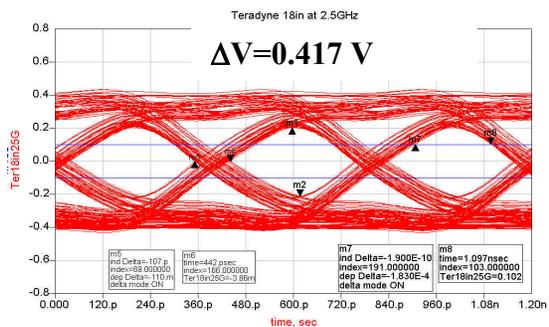


# Solve the Problem with De-embedding block

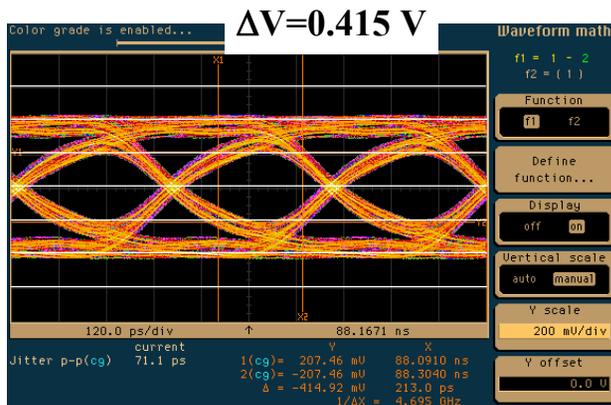


# Simulation vs. Measured Data

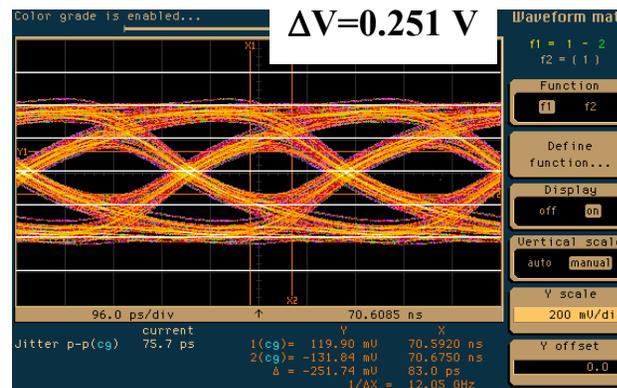
( Only two port de-embedding element was used)



ADS Eye Simulation



Scope Eye

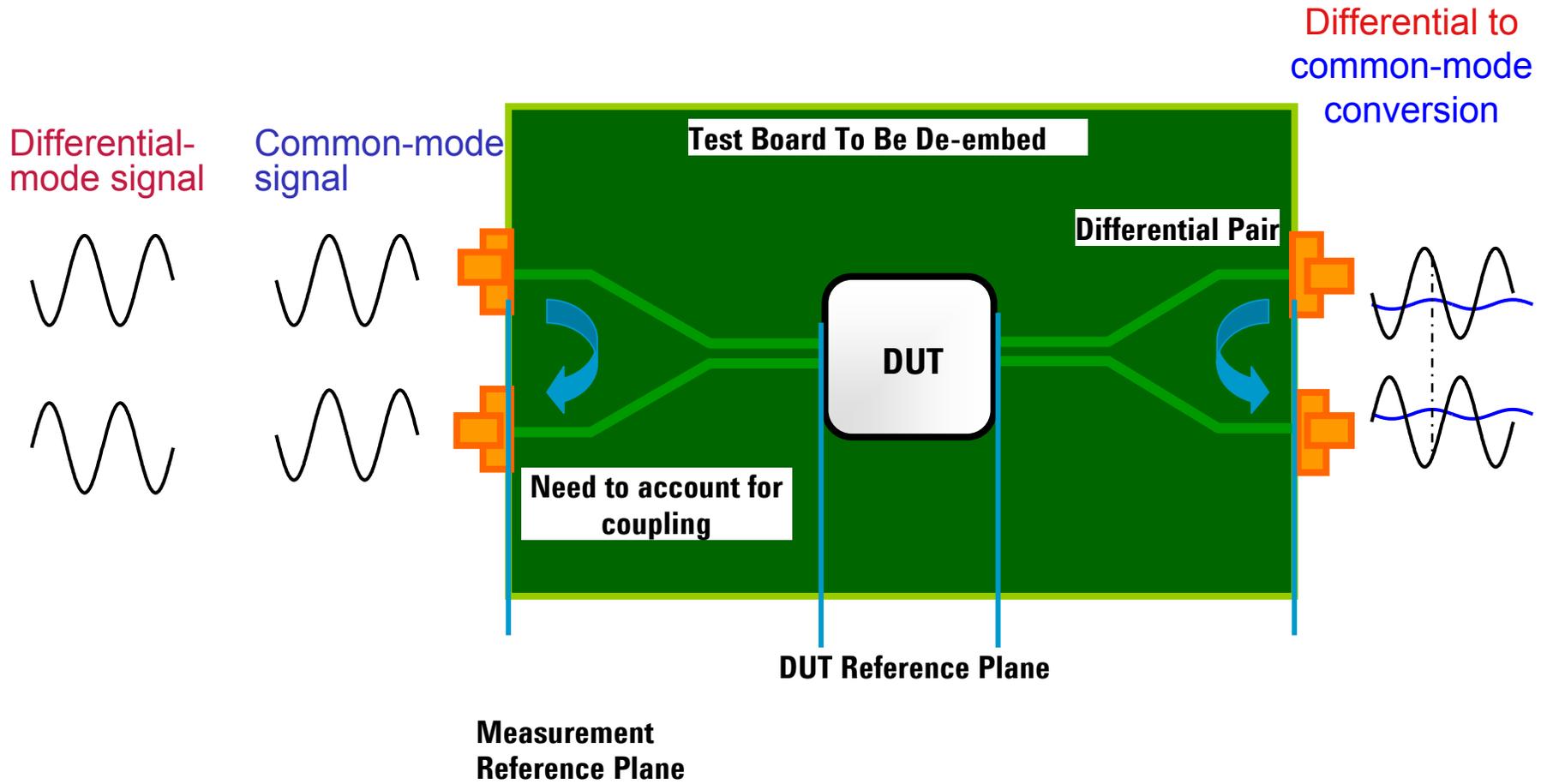


Teradyne + 18'' at 2.5Gb/s  
 $D(\text{sim vs. scope}) < 1\%$

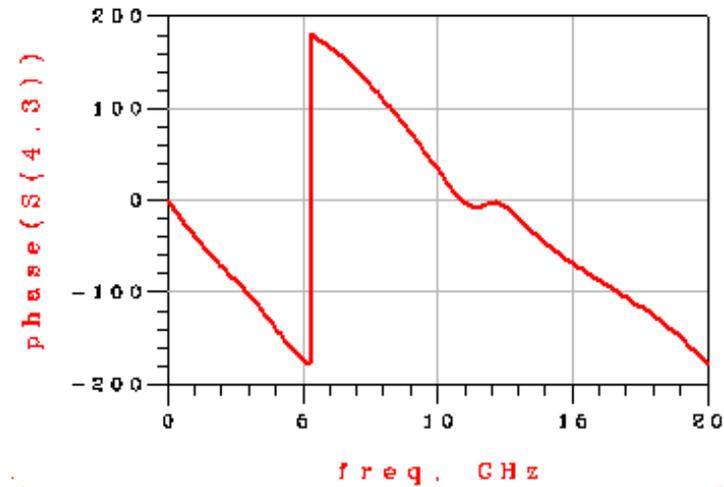
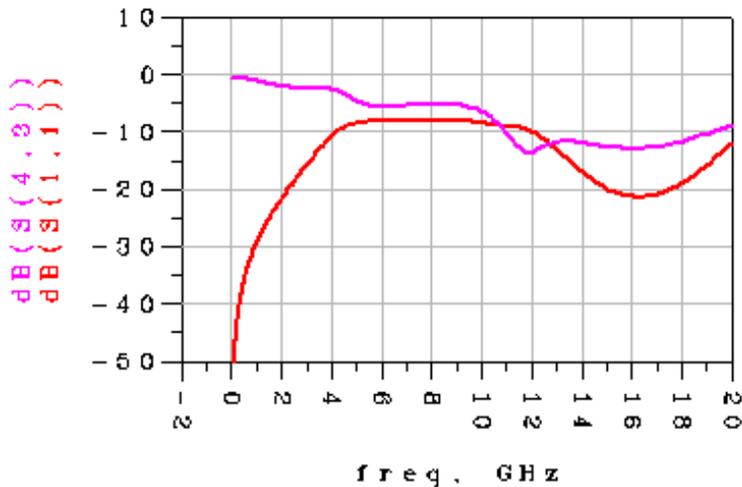
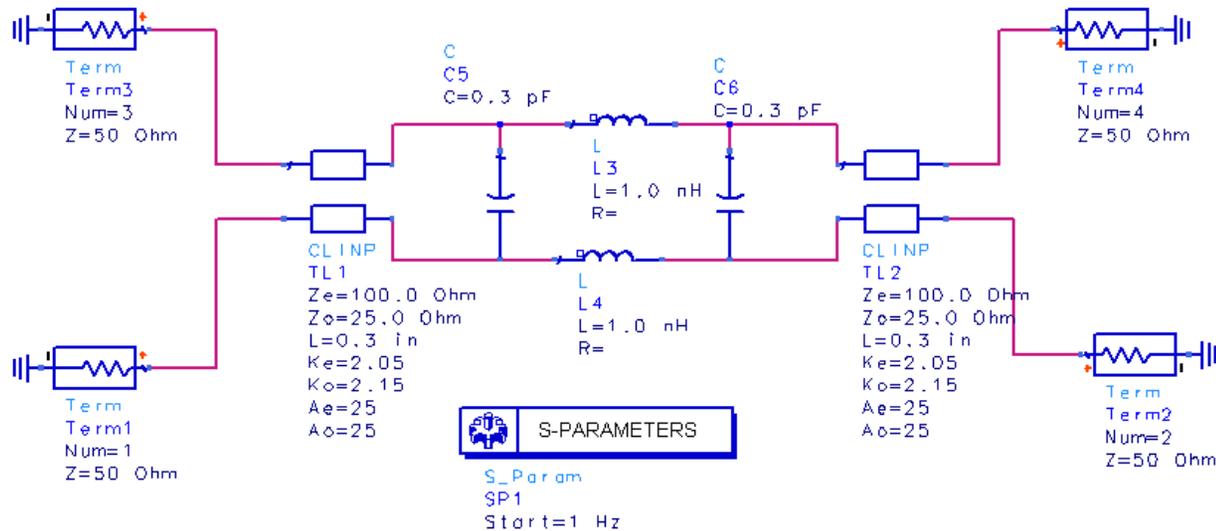
Teradyne + 18'' at 3.125Gb/s  
 $\Delta(\text{sim vs. scope}) = 6\%$

# Four Port Measurements

## Four Port Fixture: Four Port De-embedding

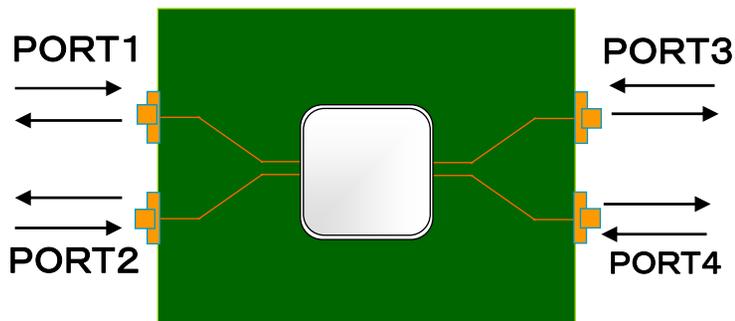


# Single Ended Simulation of Differential Pins



# What is Mixed Mode S-parameters?

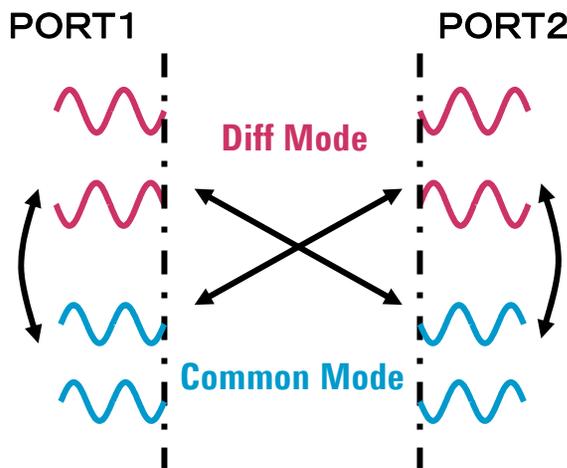
**Nodal S-parameter**



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

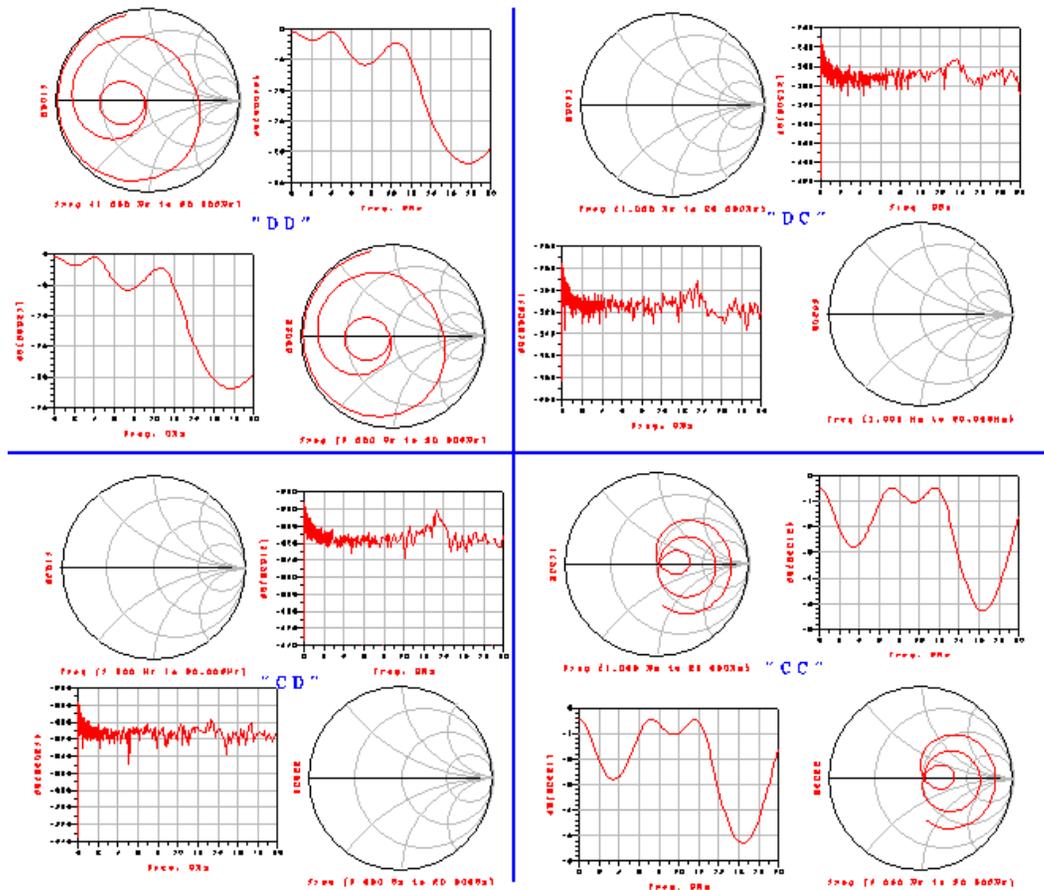
↕  
**reciprocal**  
↕

**Mixed Mode S-parameter**



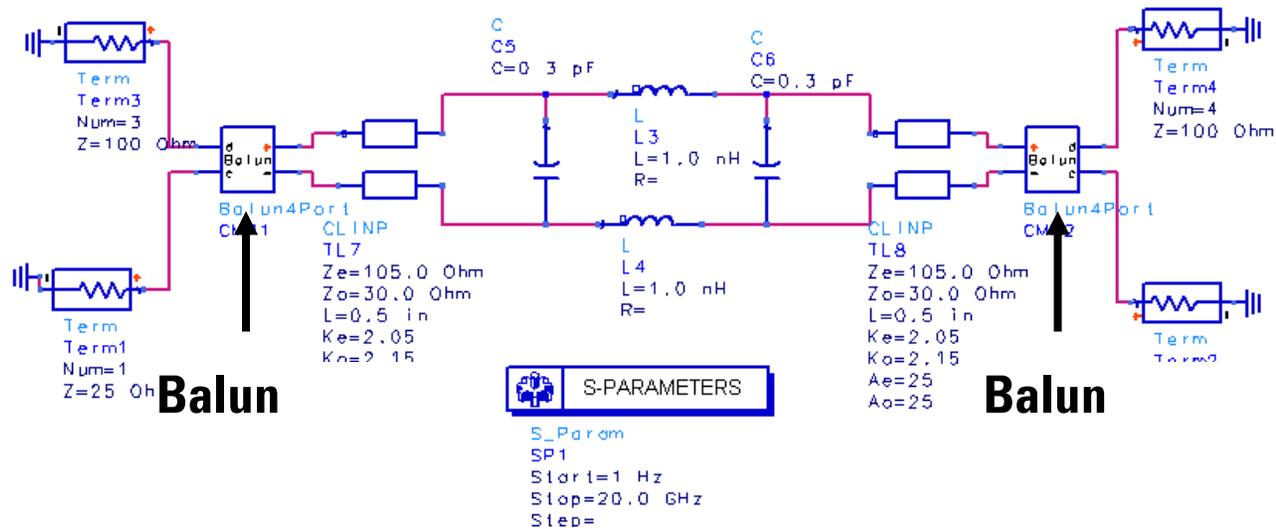
<b>SDD11</b>	<b>SDD12</b>	<b>SDC11</b>	<b>SDC12</b>
<b>SDD21</b>	<b>SDD22</b>	<b>SDC21</b>	<b>SDC22</b>
<b>SCD11</b>	<b>SCD12</b>	<b>SCC11</b>	<b>SCC12</b>
<b>SCD21</b>	<b>SCD22</b>	<b>SCC21</b>	<b>SCC22</b>

# Driving Mixed Mode S-Parameter from Single Ended Measurements



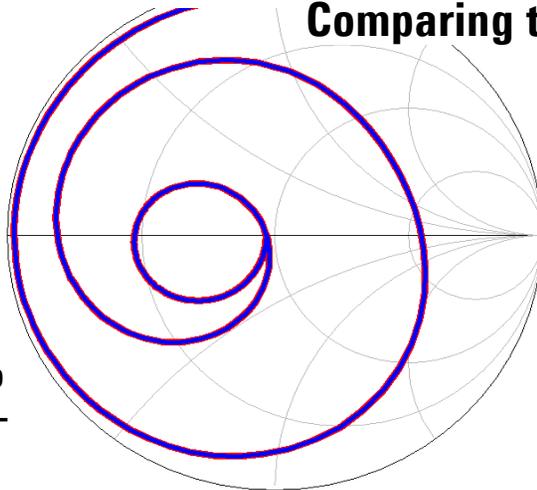
# Direct Mixed Mode S-Parameter Simulation

Advantage – Mixed Mode S-Parameter Optimization

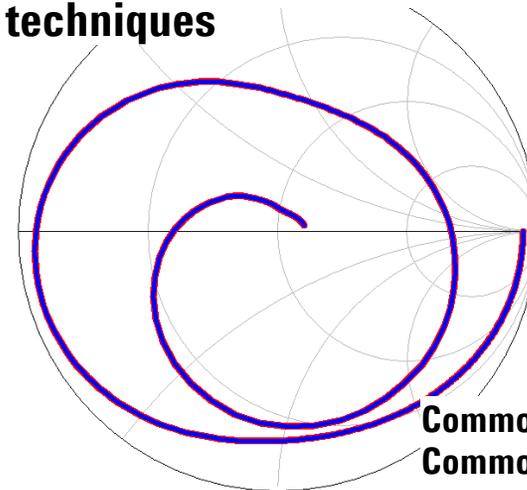


## Comparing two techniques

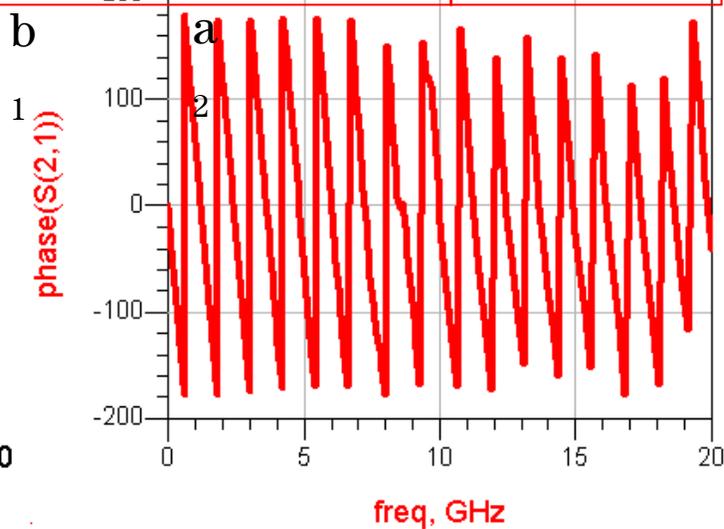
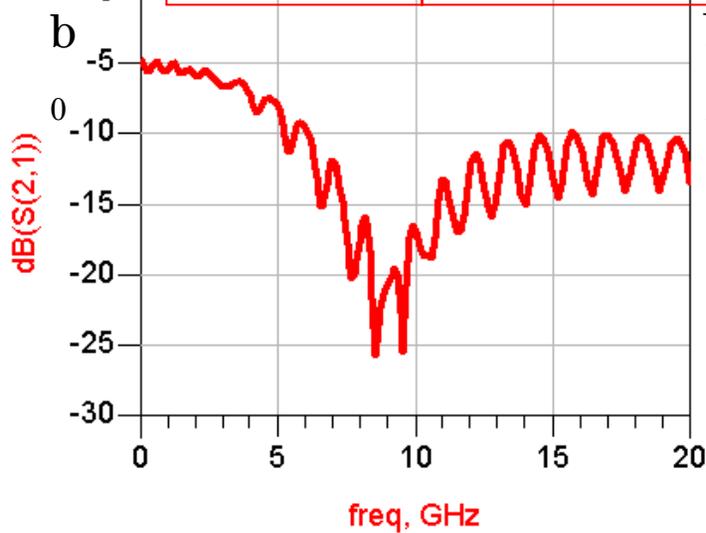
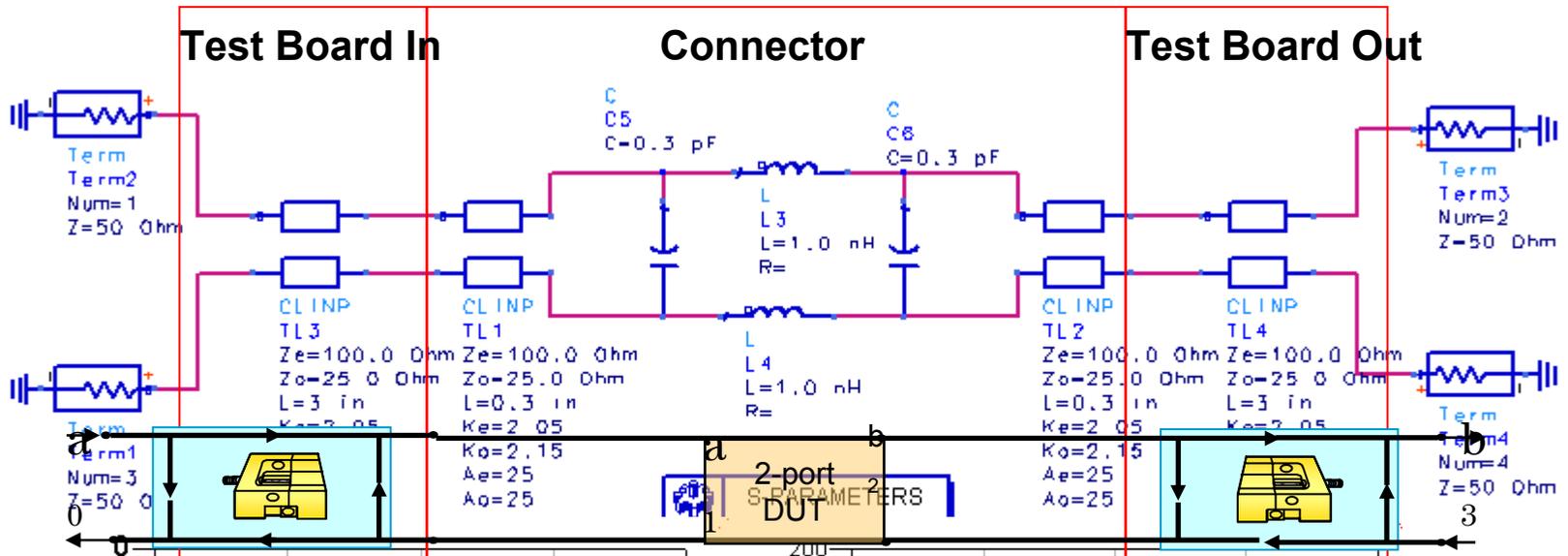
Differential Mode to  
Differential Mode S-  
parameter



Common Mode to  
Common Mode S-  
parameter

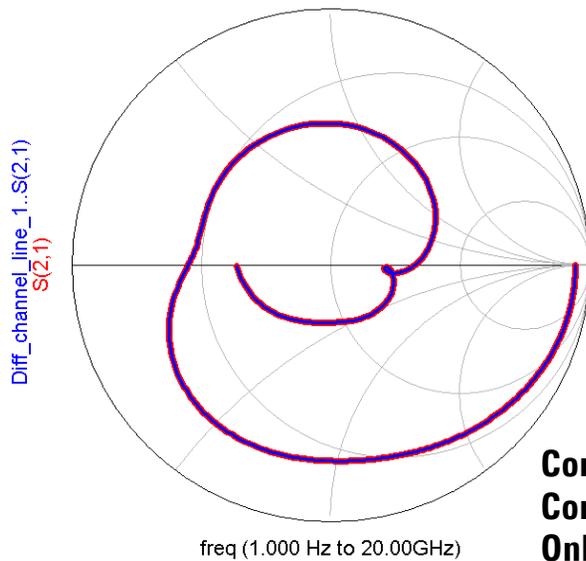
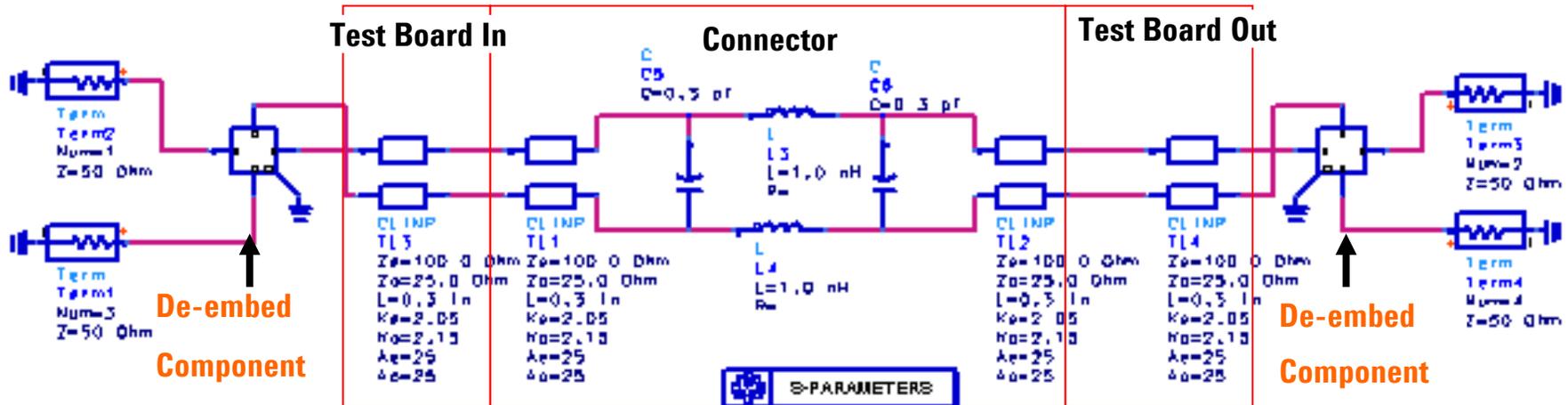


# Connector With Fixture Model

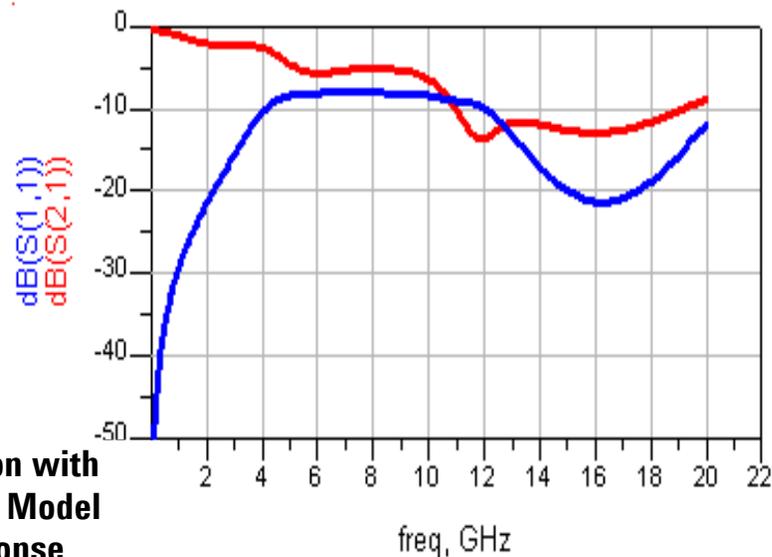


# Using ADS Four Port De-embedding Component

Accounts for coupling between feed transmission lines



Comparison with Connector Model Only Response



# De-embedding Components

Standard de-embedding components in ADS

- One Port de-embedding
- Two Port de-embedding

New standard de-embedding components in ADS2006A

Aggressor and Victim differential pair characterization requires  
multi-port De-embedding

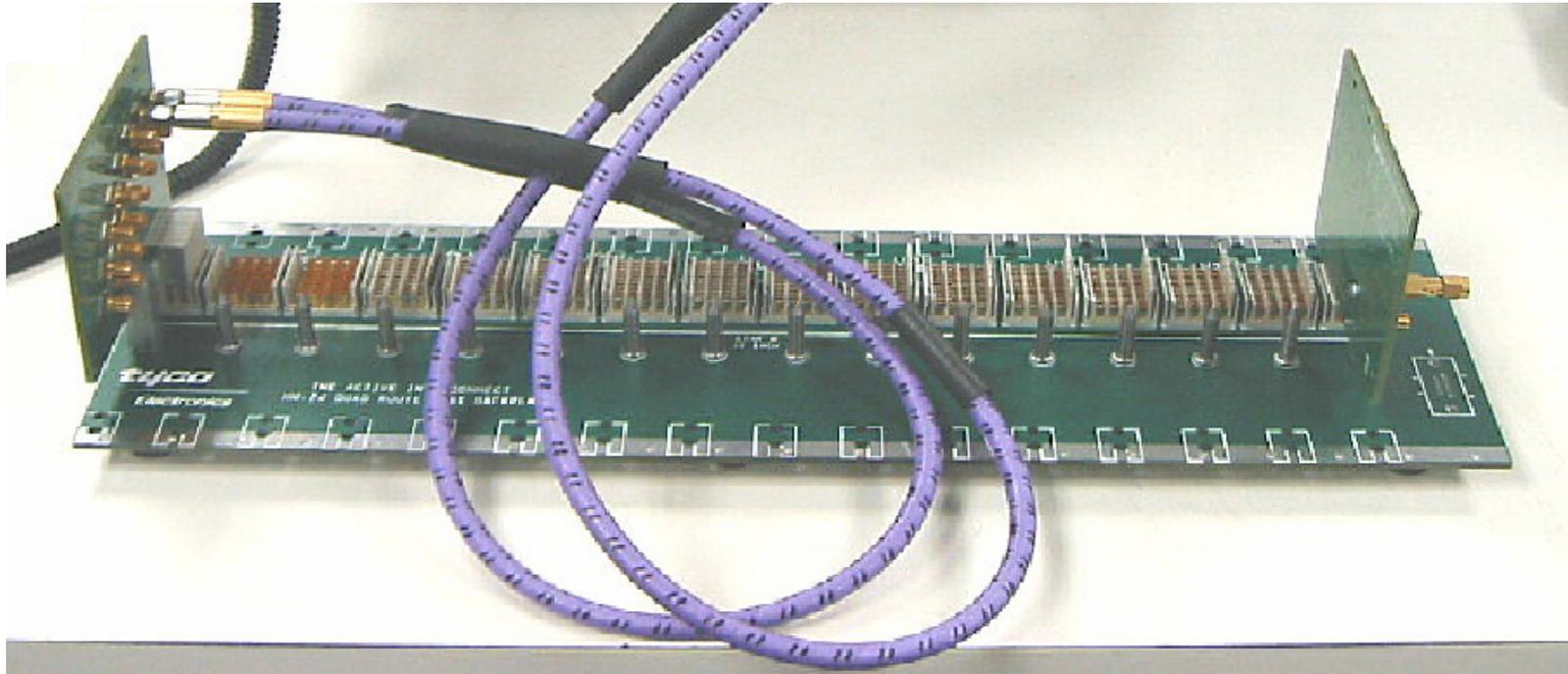
- Four port de-embedding
- Six port de-embedding
- Eight port de-embedding
- Twelve port de-embedding



**Requirements:**

**Measured/Simulated S-parameters to be available**

# Test Cases?



**Fixture S-parameter cannot be obtained directly?**

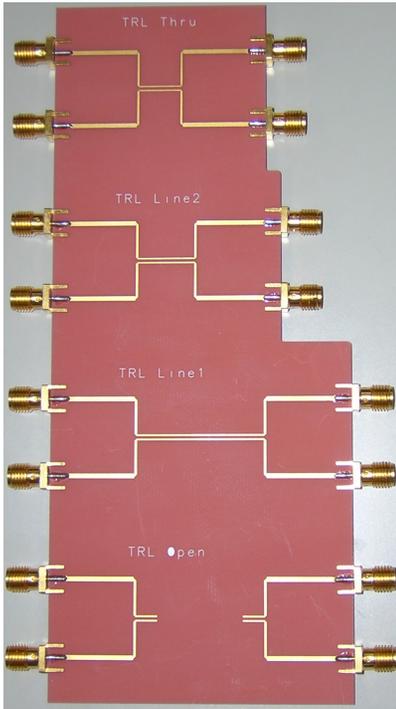
**Can one use TRL calibration standards?**

# TRL measurement based De-embedded Component

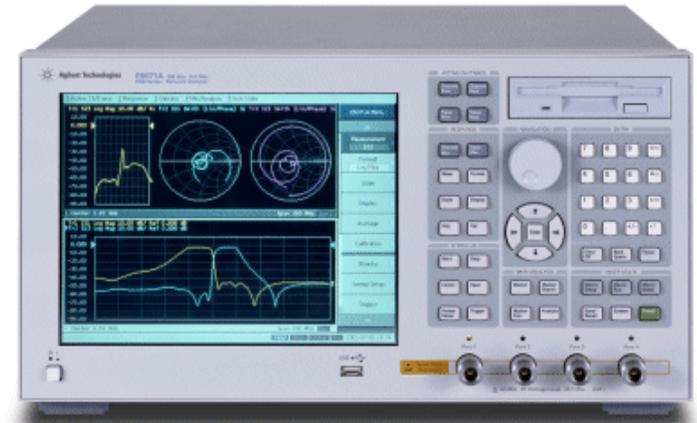
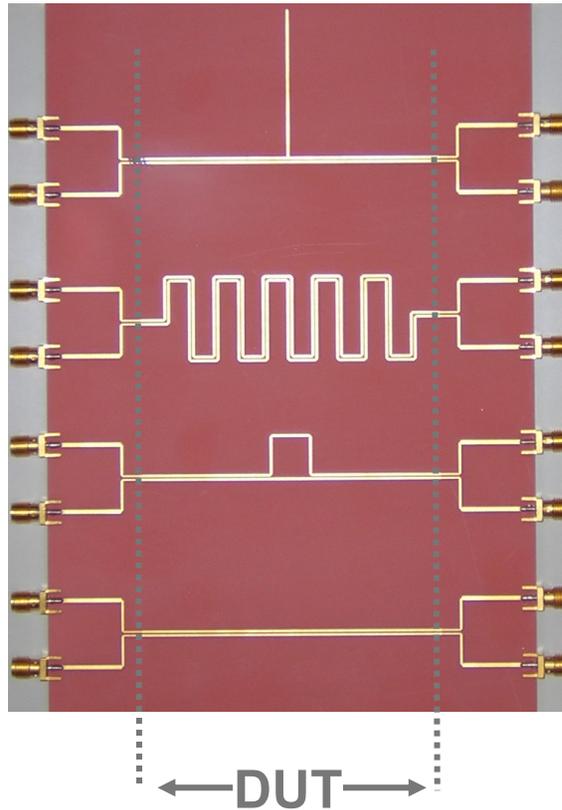
- Used when the test fixture S-parameter response is not available
- Ability to fabricate test fixtures and calibration standard
- Test fixtures are created using the same feed line structure as in the TRL standard.

# DUT & Fixture/Calibration Kit

TRL  
Calibration Kit



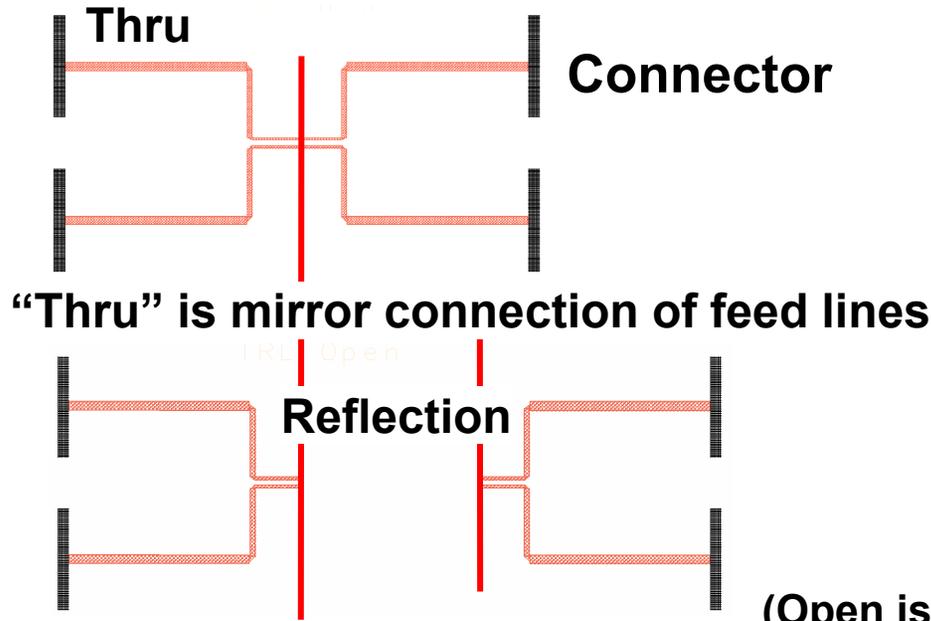
DUT Board



Material - FR4  
Er=4.2  
Thickness=0.6mm  
Tand=0.025  
T=18[mm] (Metal Thickness)  
S=5.8\*10<sup>7</sup>[S/m](Conductivity)

**TRL calibration standard.**

# Design of TRL Calibration kit



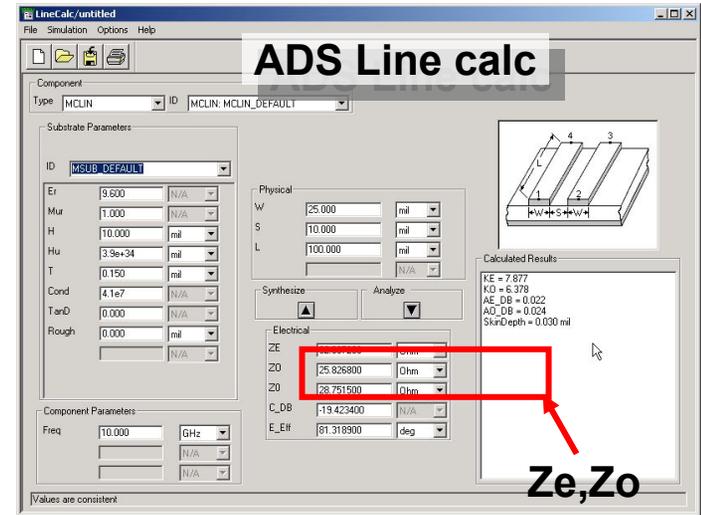
\*Red line is reference plane of DUT

## Line

Length of Line must be determined by frequency range

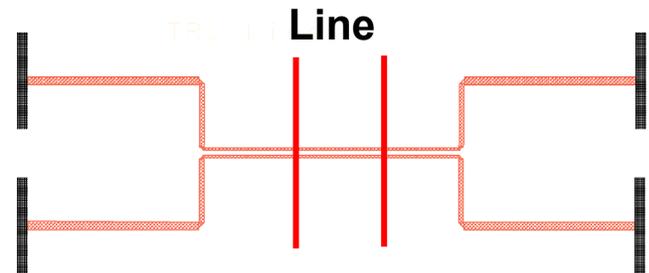
$$20\text{deg} < f < 160\text{deg}$$

\* This condition must meet on both Common/Diff modes

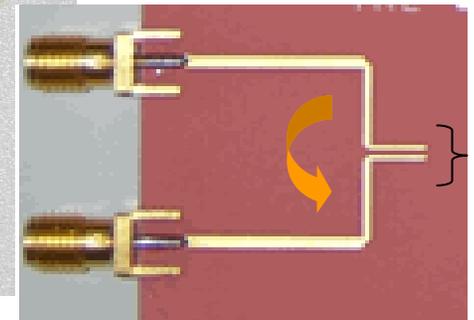
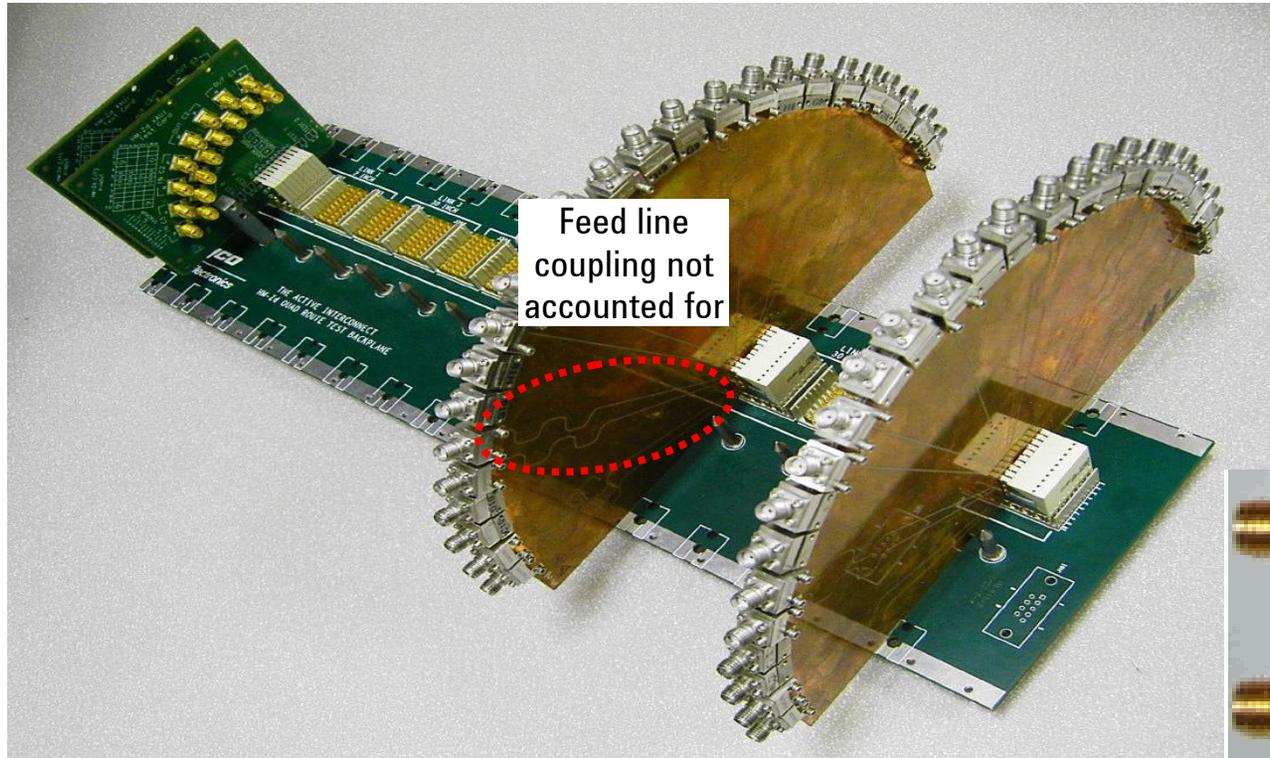


Reflect is open

(Open is more suitable than Short)



# Why ADS based TRL De-embedding?



**Some test fixture might have significant coupling.**

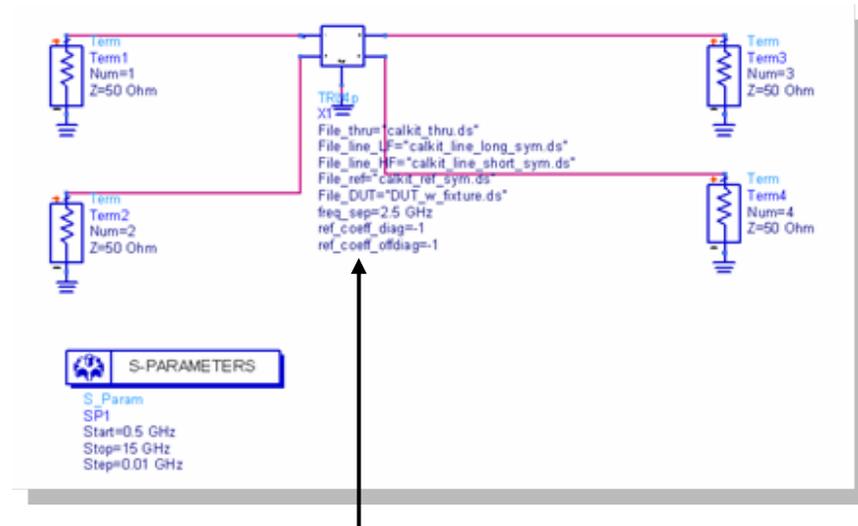
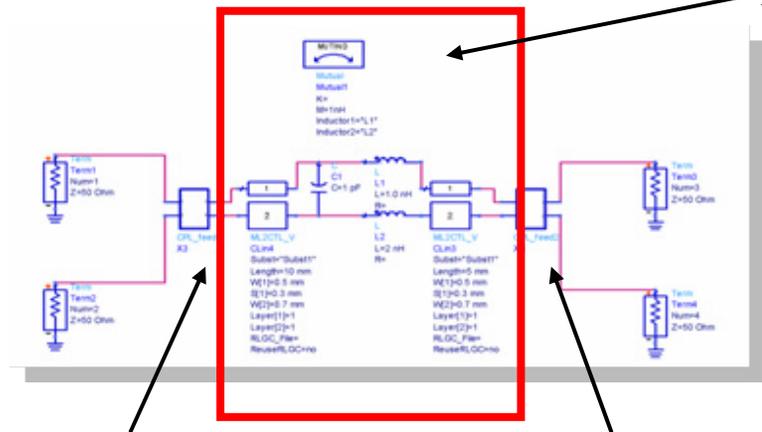
**How one can account for the coupling effects?**

# Custom De-embedding using TRL Calibration Standards

DUT with “Coupled” feed lines

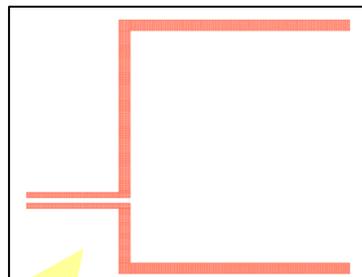
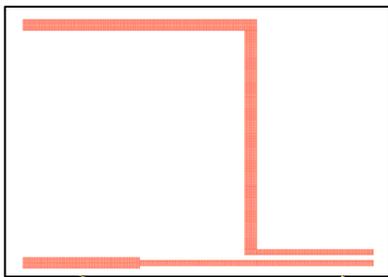
DUT

4-port De-embedding



Coupled Feed line1

Coupled Feed line2



Feed lines can be Asymmetric

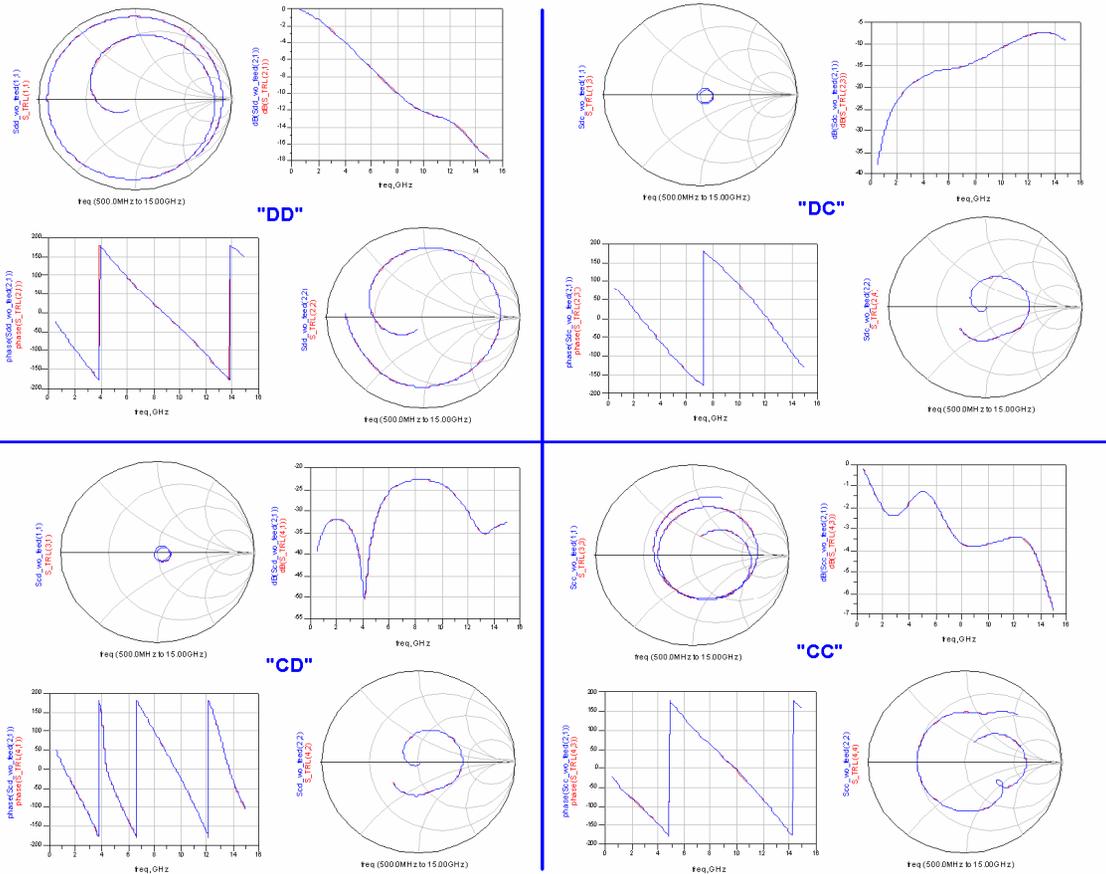
Our “New” 4-port De-embedding model  
created using C code  
Custom solution- *Not available as standard  
feature of ADS*

Contact EEsof for details

•Can not use TRL on Si Substrate

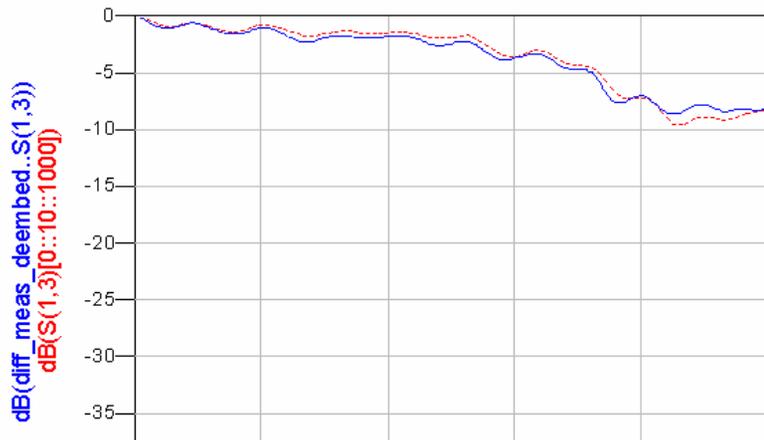
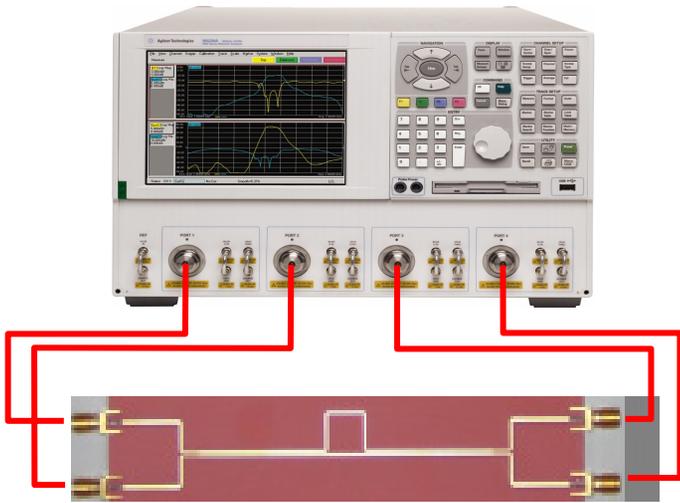
# "New" 4-port De-embedding verification results

## Comparison between De-embedded S-parameters & DUT without feed lines.



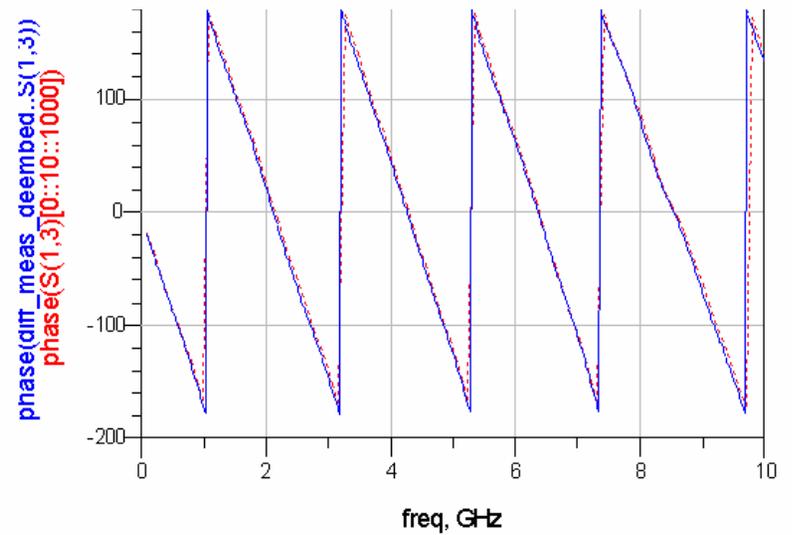
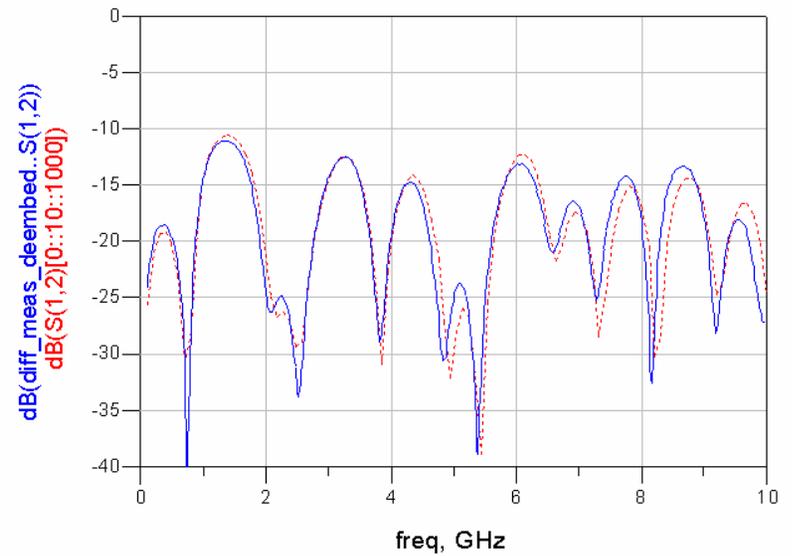
2 types of S-parameters are **completely identical!!**

# Compare to ADS model



Simulated (ADS Coupled line model)

Measured



# Conclusion

- Demonstrates the use of ADS for a typical SI problem
- Provide powerful measurement based modeling
- ADS De-Embedding capabilities
  - Two port de-embedding
  - Powerful Multi-port de-embedding essential for bus/ differential bus ( one pair, two pair, & three pair ) 
  - TRL calibration based de-embedding
- ADS has been used for SI design for over 20 years
- ADS has a multitude of accurate built in models
- ADS allows you to build accurate physical models
- ADS brings IP, simulation and measurement together

Questions?

For more information about Agilent EEs of EDA, visit:

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