

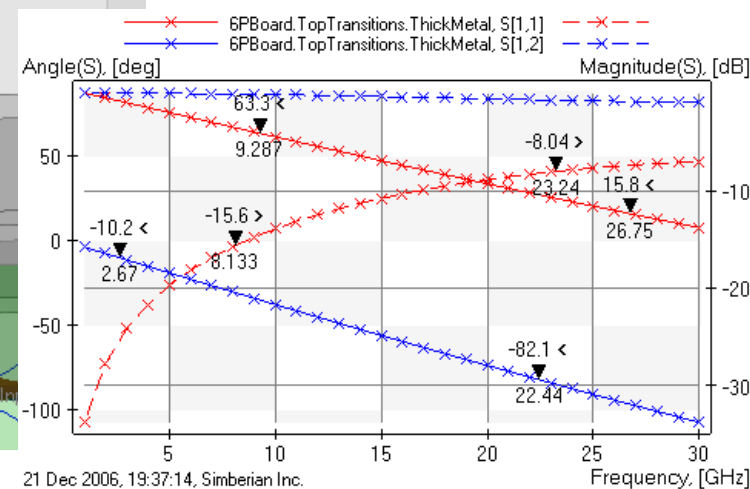
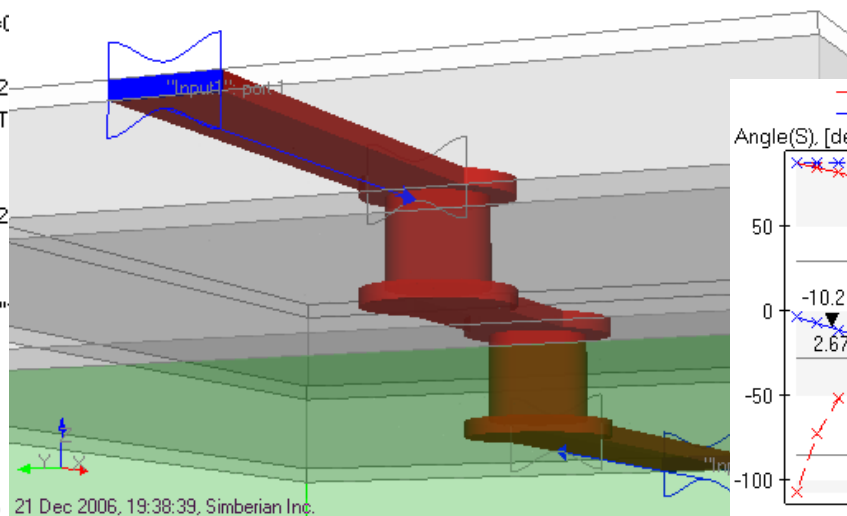
# Benchmarking Simbeor 2008.01 with resonant micro-strip planar structures from PLRD-1 board

Solution: "MicroVias"

- 6PBoard
  - Materials
    - "copper", RRes=1, Rough=0.01
    - "IdealMetal"
    - "prepreg", DK=4.7, LT=(
    - "Vacuum"
    - "FR4", DK=4.2, LT=0.02
  - StackUp: LU=[mil], NL=15, T
  - TopTransitions
    - CircuitData: LU=[mil]
    - Multiport: 2 inputs, 2
    - LatticeBox
    - Geometry
      - GeoComposite: "
      - TLines
      - Inputs
    - ThickMetal
    - CollapsedMetal
    - BottomTransition
  - Graph1(MultiportParameters vs. 21 Dec 2006, 19:38:39, Simberian Inc.
  - Graph2(MultiportParameters vs. Frequency)

Simberian, Inc.

[www.simberian.com](http://www.simberian.com)



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# Overview

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- Introduction
- Beatty 25-Ohm micro-strip standard
- Beatty 80-Ohm micro-strip standard
- Two-stub micro-strip resonator
- Micro-strip resonator with two offset stubs
- Meandering micro-strip line
- Low-pass micro-strip filter
- Conclusion
- Solutions and contacts

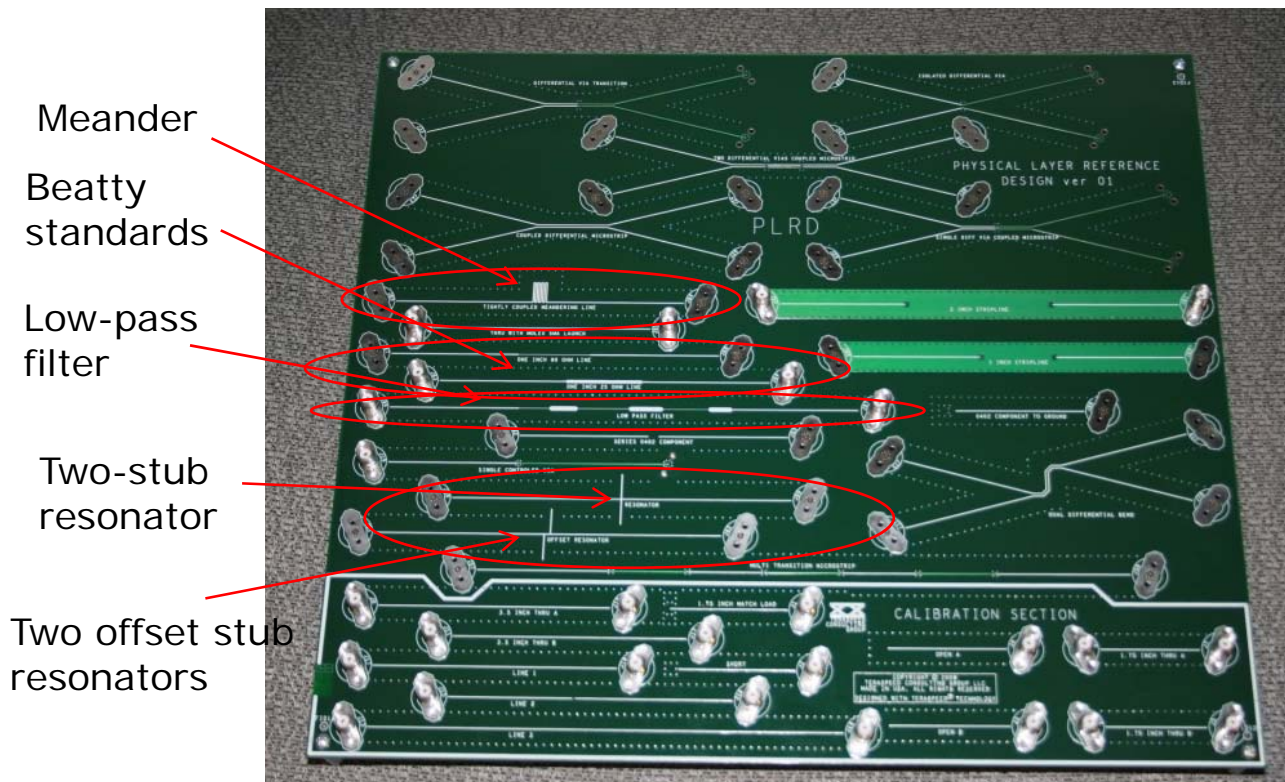
# Introduction

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- ❑ Accuracy of the electromagnetic software can be determined by three complementary techniques:
  - Investigation of internal convergence by making finer mesh for instance – **this technique may fail due to the relative convergence phenomenon** (convergence to wrong result) discovered first in *R. Mittra, T. Itoh, T-S. Li - IEEE Trans, v. MTT-20, N2 1972*
  - Comparison with the results obtained by different method – **similar modeling assumptions may lead to close but not accurate results** (assumption of frequency-independent dielectric constant or assumption of static nature of fields)
  - Comparison with the measured results – **very difficult to do the measurements and de-embedding for structures on FR-4 materials** (large manufacturing tolerances, weave effect)
- ❑ A solver is accurate if it converges and the results correlate well with the other solvers and with the experimental results – though, the experimental validation is often perceived as the ultimate proof of accuracy
- ❑ To benchmark Simbeor software, high-quality measured data from Physical Layer Reference Design 1 (PLRD-1) board can be used - PLRD-1 board has been designed and independently investigated by Teraspeed Consulting Group
- ❑ **Resonant planar structures are perfectly suitable for benchmarking of dielectric, conductor and discontinuity modeling capabilities of electromagnetic software**
- ❑ Simbeor 2008.01 built on May 16, 2009 has been used for all computations

# PLRD-1 board overview

- ❑ 4-layer stackup with two planes and 2 signal layers
- ❑ 30 test structures – all equipped with SMA connectors



PLRD-1 board created and independently investigated by Teraspeed Consulting Group [www.teraspeed.com](http://www.teraspeed.com)

Precise measurement and de-embedding methodologies with the board are available from Teraspeed

For more information contact to Alfred Neves at [al@teraspeed.com](mailto:al@teraspeed.com)

Phones: (503) 430-1065  
(503) 718-7172

# Setting up analysis in Simbeor

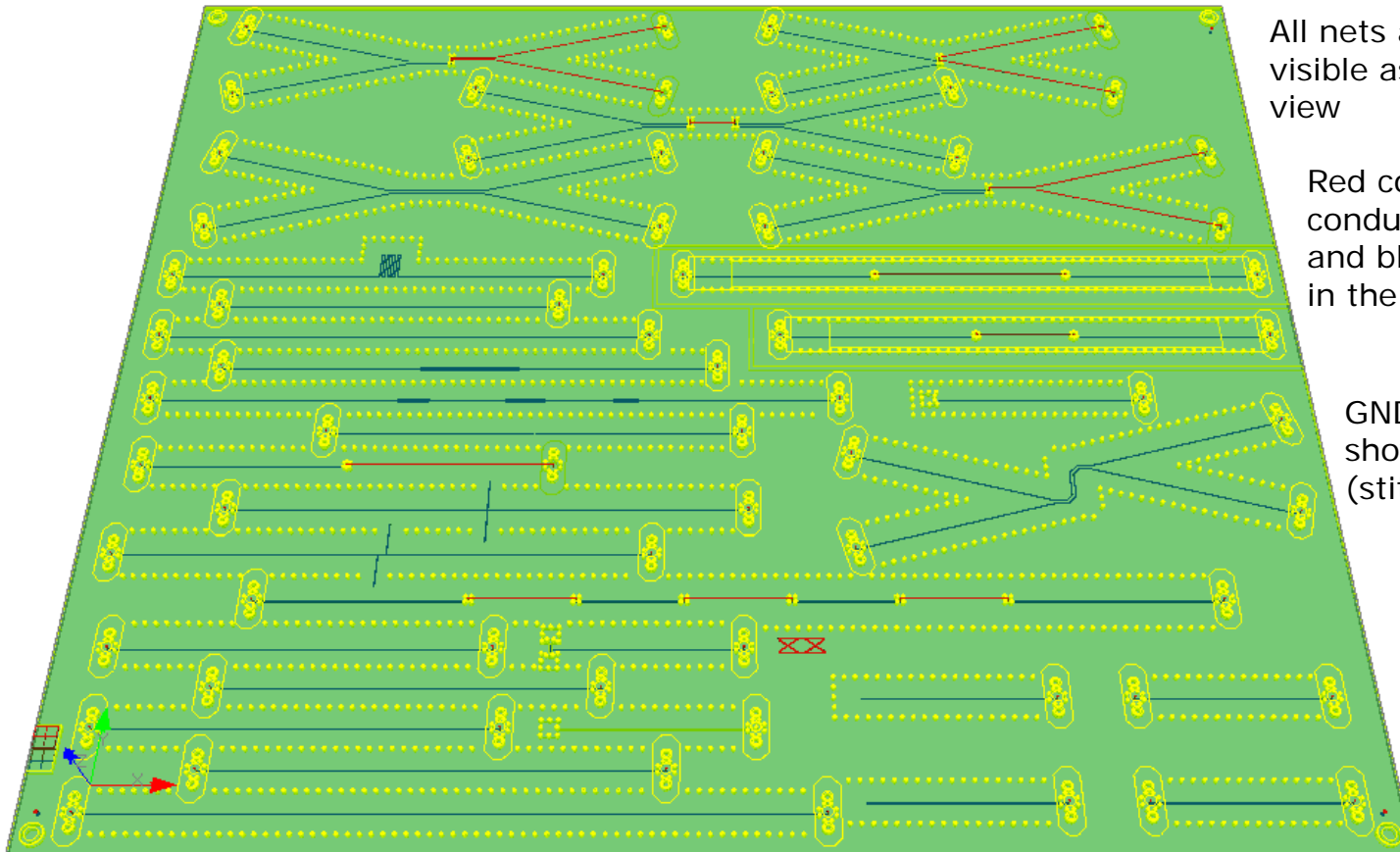
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1. Import board geometry from Allegro's brd or mcm file
2. Verify and adjust stackup and properties of the materials
3. Create a network selector and discontinuity selectors for a particular structure to simulate
4. Extract linear network circuit and circuits for electromagnetic analysis of discontinuities and transmission line (**the extraction is automatic**)
5. Optionally adjust micro-strip line lengths in the linear network to have correspondence with the reference planes used in the de-embedding
6. Run electromagnetic and linear network analysis and plot the results
7. Optionally import measured data and plot them on the same graph for comparison
8. Optionally build rational compact model and output SPICE macro-model and do TDR/TDT analysis



# Preparing for the analysis in Simbeor 2008.01

1) PLRD-1 design is imported from Allegro's brd-file (see screen-cast #2009\_02 at <http://www.simberian.com/ScreenCasts.php> on step-by step geometry import and selection demo)



All nets are "checked" to be visible as solid objects on 3D view

Red color is used for conductors in the TOP layer and blue color for conductors in the BOTTOM layer

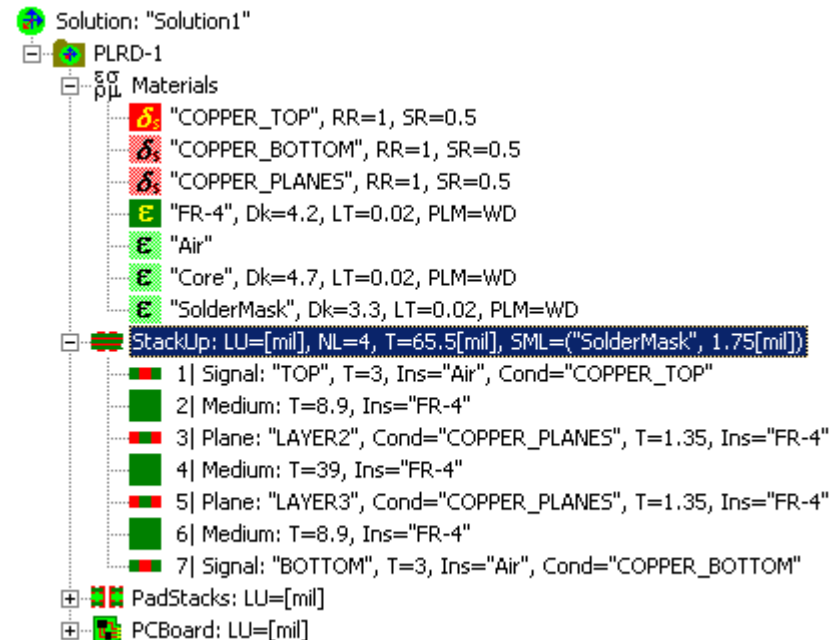
GND net is selected and shown with yellow color (stitching vias)

Dielectric transparency is adjusted to see both sides of the board

27 May 2009, 06:55:46, Simberian Inc.

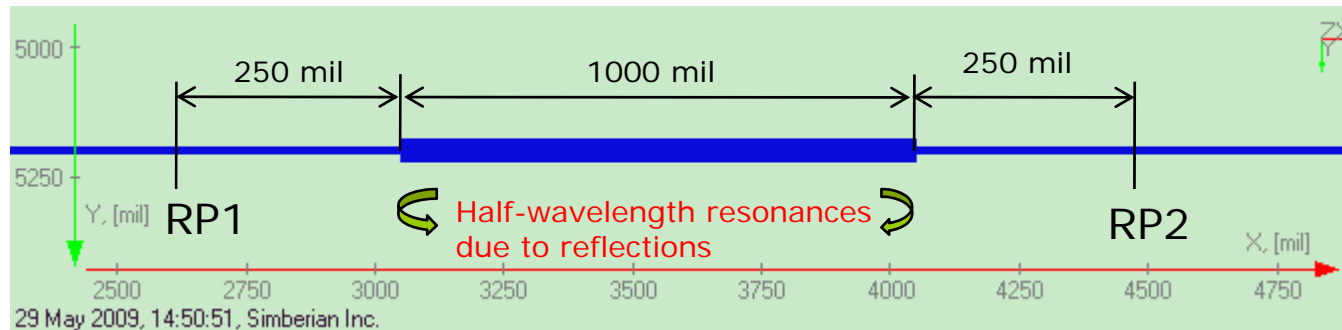
# Materials and stackup

- Given: copper bulk resistivity  $1.724e-8$  Ohm meters, roughness 0.5  $\mu\text{m}$ , roughness factor 2
- Given: Solder mask 1.75 mil thick DK=3.3, LT=0.02 at 1 GHz
- Given: Core FR-4 DK=4.7, LT=0.02 at 1 GHz
- Detected: DK=4.0-4.3, LT=0.018 (adjusted where necessary)
- Wideband Debye models are used for solder mask and FR-4 dielectrics to capture dispersion





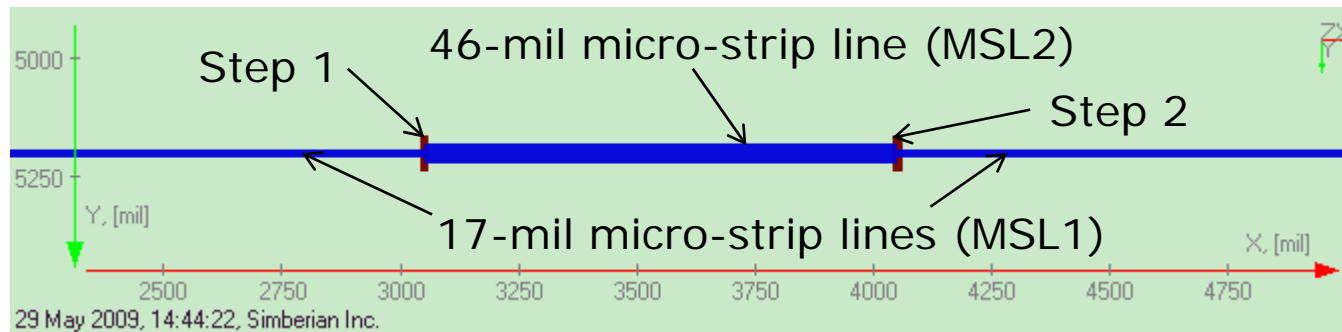
# 25-Ohm micro-strip Beatty standard



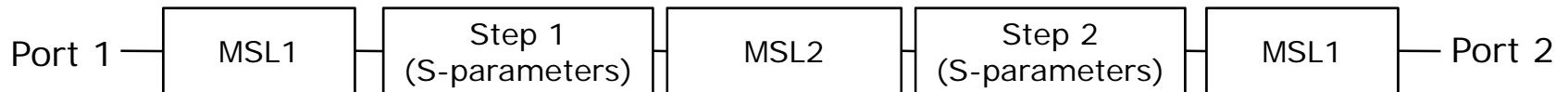
- ❑ 1-inch 46 mil wide micro-strip line segment connected in series into 17-mil wide micro-strip line
- ❑  $DK=4.0$ ,  $LT=0.018$  @ 1 GHz, WD model – lower DK for wider line
- ❑ Conductor roughness 0.5  $\mu\text{m}$
- ❑ De-embedded to reference planes to keep 250 mil micro-strip segments on both sides of the structure
- ❑ Can be analyzed as a whole or with decomposition into two step discontinuities and line segments
- ❑ De-compositional analysis is faster and more accurate

# De-composition of 25-Ohm Beatty standard

*Two rectangular discontinuity selectors created to de-compose the structure in 5 elements*



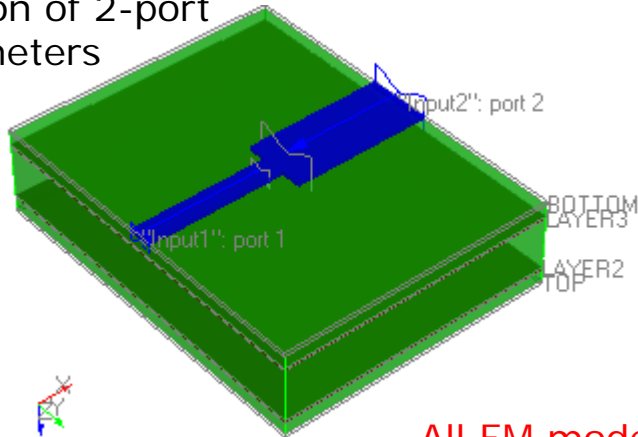
Simbeor de-compositional model (linear network)



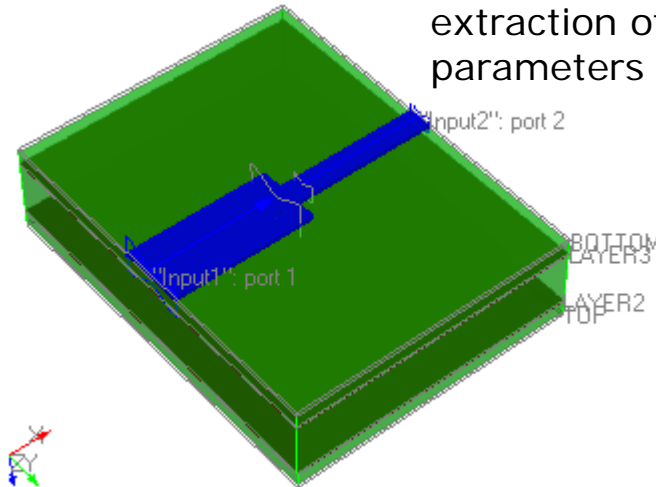
Auto-decomposition is used here as demonstrated in screen-cast #2009\_03 at <http://www.simberian.com/ScreenCasts.php>

# Circuit elements automatically created for the electromagnetic extraction

Step 1 – full-wave extraction of 2-port S-parameters

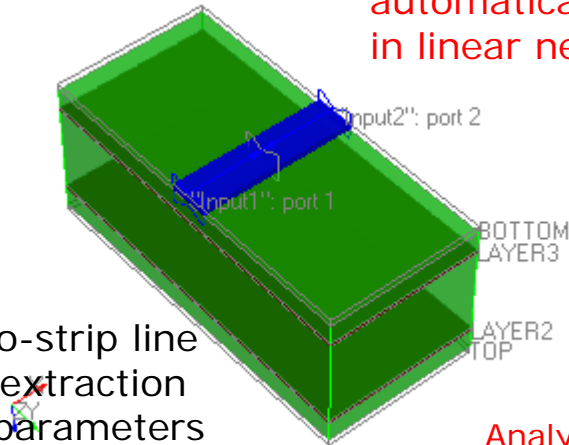


Step 2 – full-wave extraction of 2-port S-parameters

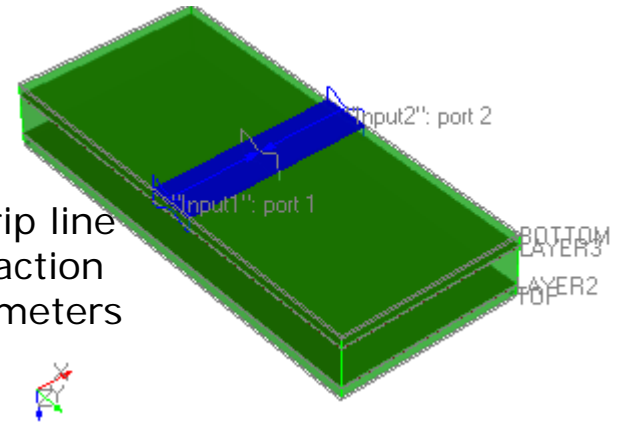


All EM models are automatically re-composed in linear network "Beatty25"

17-mil micro-strip line – full-wave extraction of RLGC(f) parameters



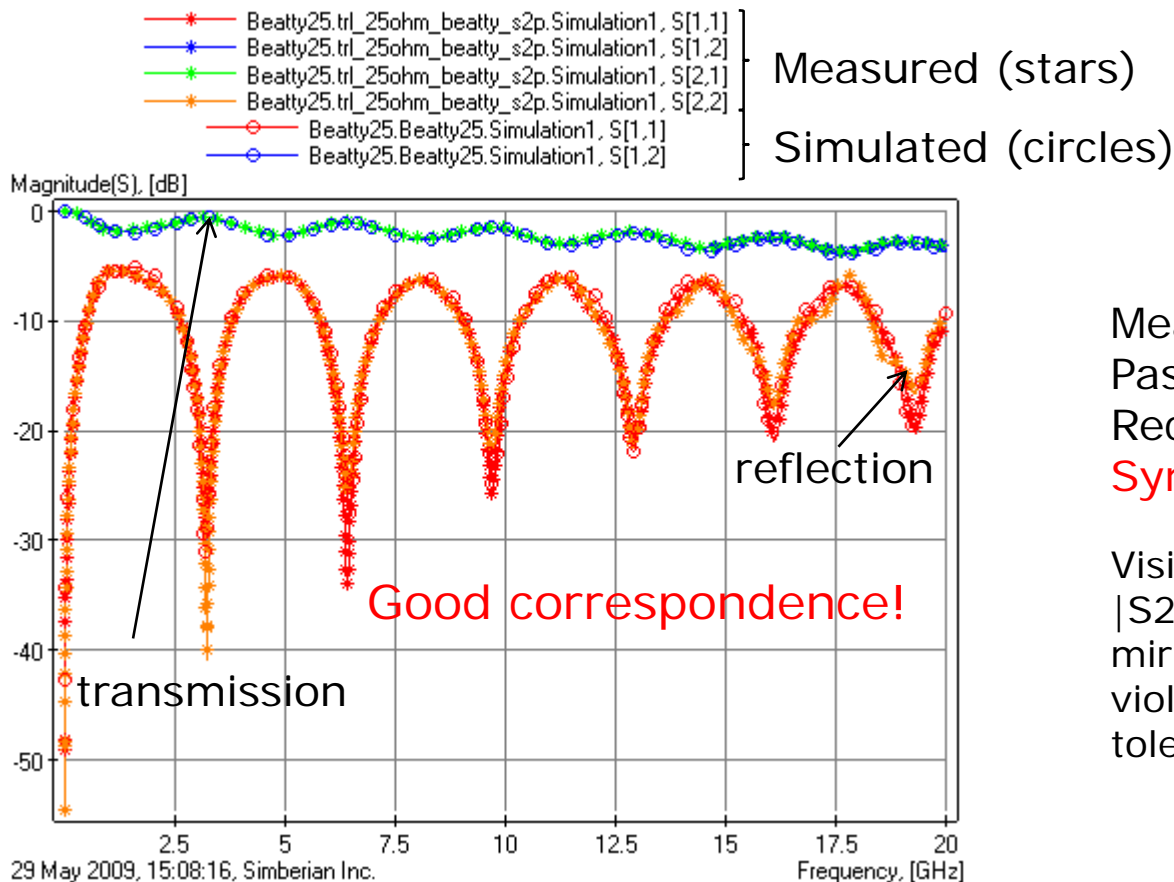
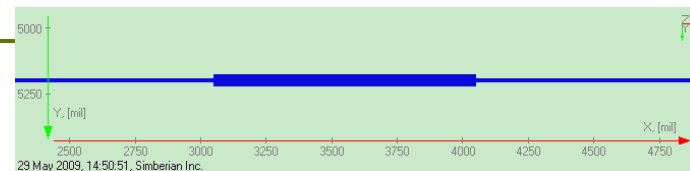
46-mil micro-strip line – full-wave extraction of RLGC(f) parameters



Analysis takes less than 1 min and all models are re-usable for possible fast "tuning" by adjustment of the t-line lengths

# Comparison with measurement results de-embedded with TRL

## □ Magnitudes of S-parameters

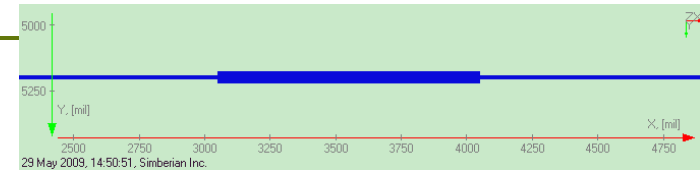


Measured Data Quality Metric:  
 Passivity QM=99.9999%  
 Reciprocity QM=99.21%  
 Symmetry QM=38.6%

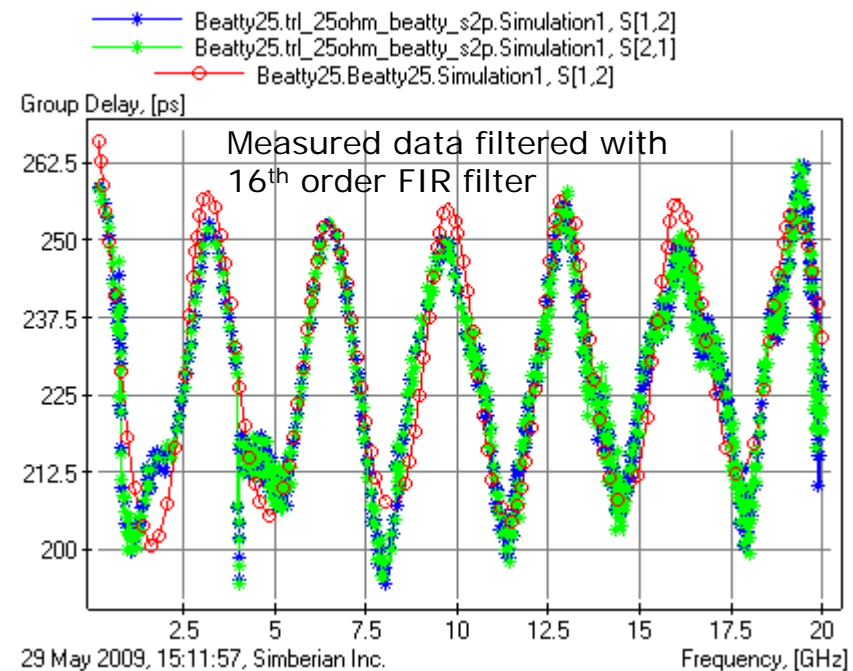
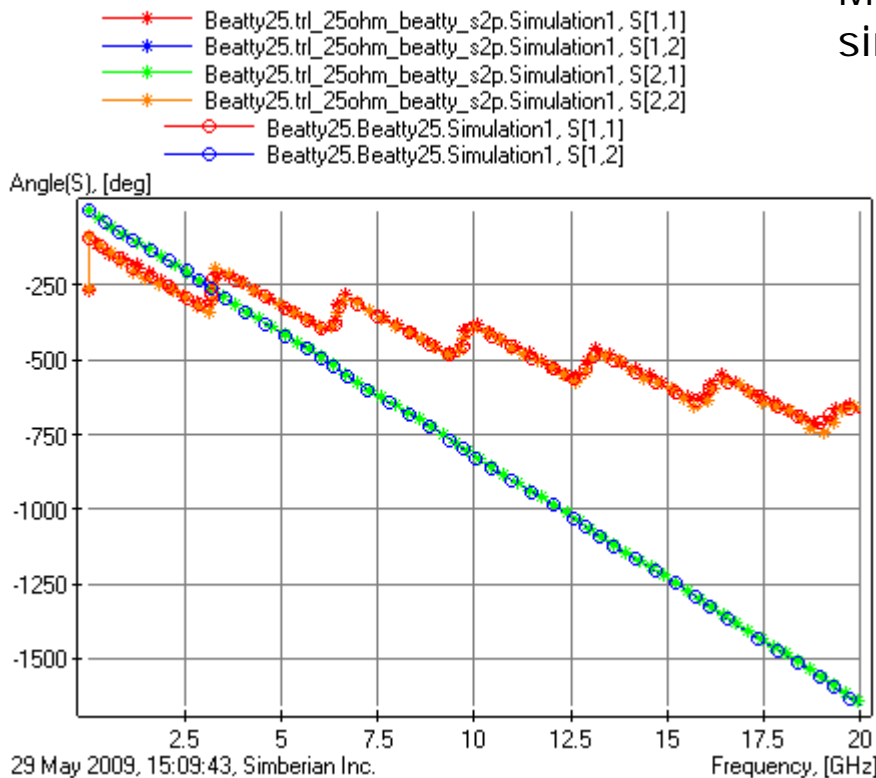
Visible difference in  $|S_{11}|$  and  $|S_{22}|$  - the actual structure has mirror geometric symmetry violations (manufacturing tolerance and the weave effect)

# Comparison with measurement results de-embedded with TRL

## Phase and group delay

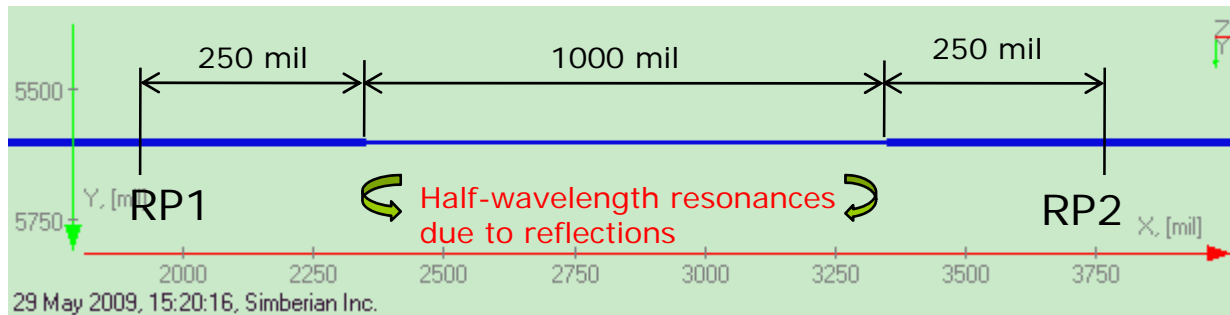


Measured – stars,  
simulated - circles



Good correspondence!

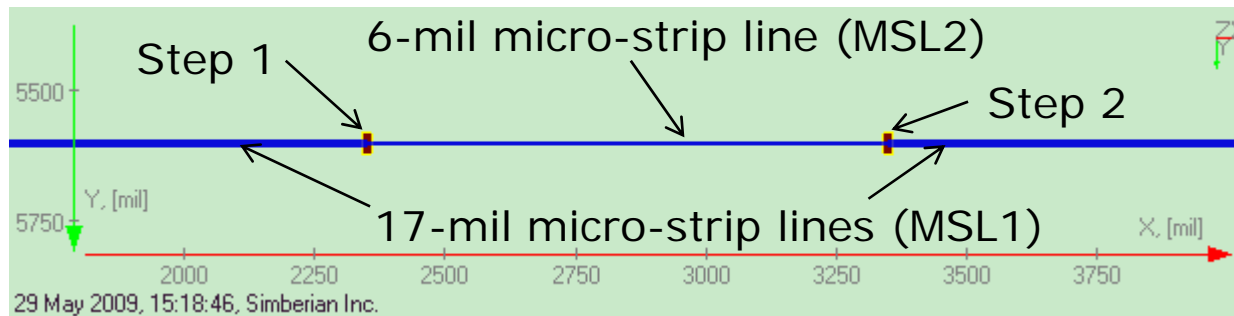
# 80-Ohm micro-strip Beatty standard



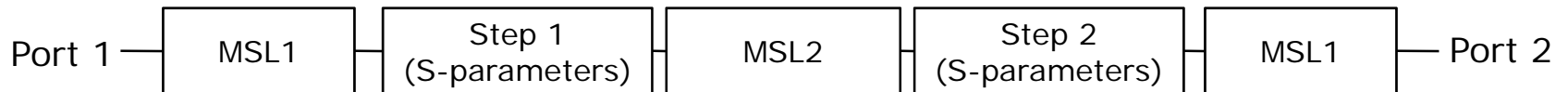
- ❑ 1-inch 6 mil wide micro-strip line connected in series into 17-mil wide micro-strip line
- ❑  $DK=4.3$ ,  $LT=0.018$  @ 1 GHz, WD model – higher DK for narrower line
- ❑ Conductor roughness 0.5  $\mu\text{m}$
- ❑ De-embedded to reference planes to keep 250 mil micro-strip segments on both sides of the structure
- ❑ Can be analyzed as a whole or with decomposition into two step discontinuities and line segments
- ❑ De-compositional analysis is faster and more accurate

# De-composition of 80-Ohm Beatty standard

*Two rectangular discontinuity selectors created to de-compose the structure in 5 elements*



Simbeor de-compositional model (linear network)

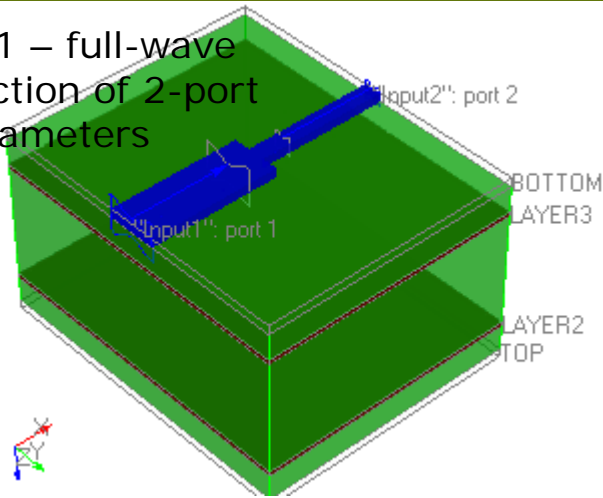


Auto-decomposition is used here as demonstrated in screen-cast #2009\_03 at <http://www.simberian.com/ScreenCasts.php>

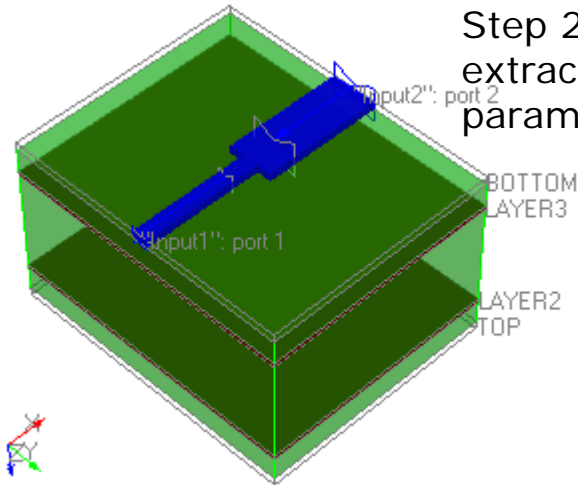


# Circuit elements automatically created for the electromagnetic extraction

Step 1 – full-wave extraction of 2-port S-parameters

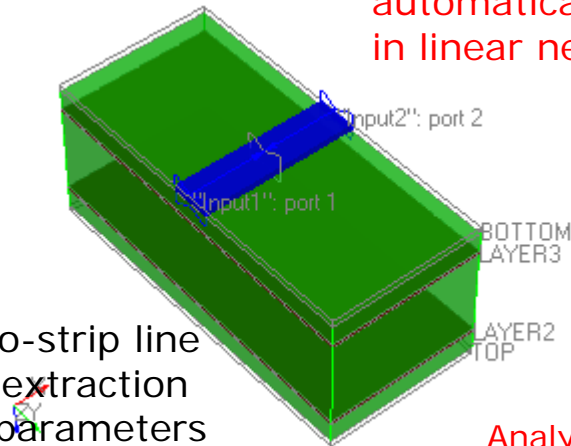


Step 2 – full-wave extraction of 2-port S-parameters

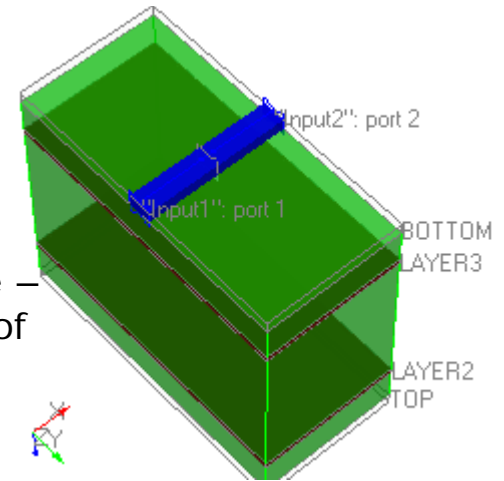


All EM models are automatically re-composed in linear network "Beatty80"

17-mil micro-strip line – full-wave extraction of RLGC(f) parameters



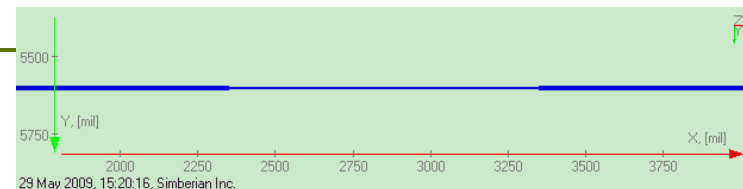
6-mil micro-strip line – full-wave extraction of RLGC(f) parameters



Analysis takes less than 1 min and all models are re-usable for possible fast "tuning" by adjustment of the t-line lengths

# Comparison with measurement results de-embedded with TRL

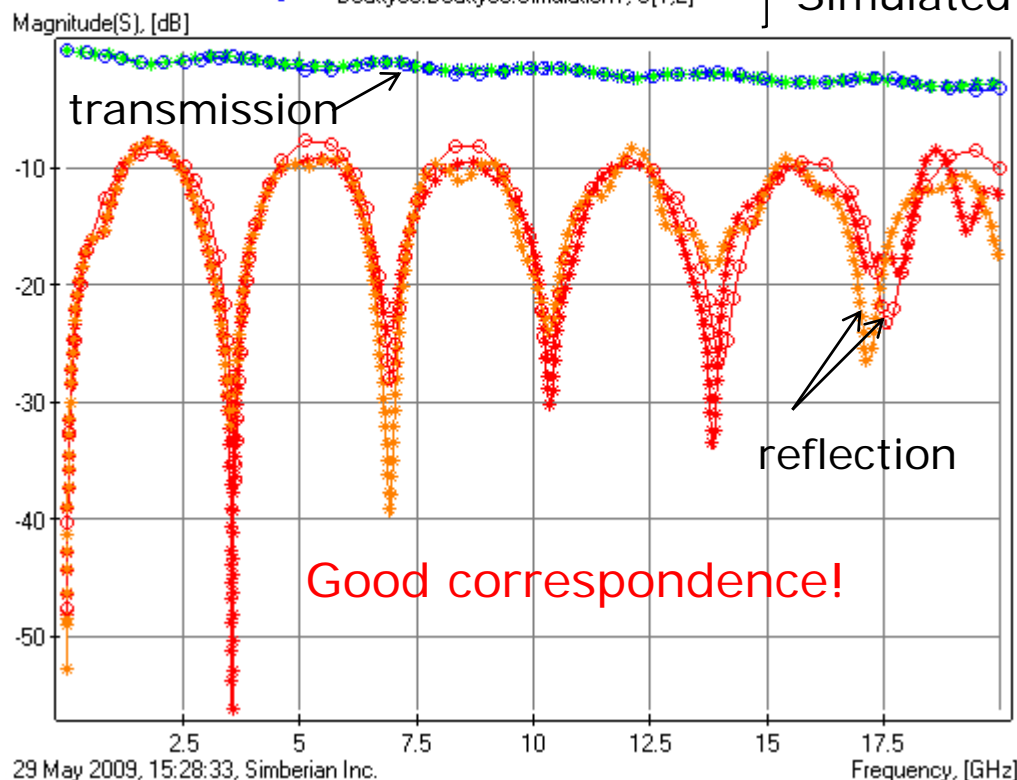
## □ Magnitudes of S-parameters



- \*— Beatty80.trl\_80ohm\_beatty\_s2p.Simulation1, S[1,1]
- \*— Beatty80.trl\_80ohm\_beatty\_s2p.Simulation1, S[1,2]
- \*— Beatty80.trl\_80ohm\_beatty\_s2p.Simulation1, S[2,1]
- \*— Beatty80.trl\_80ohm\_beatty\_s2p.Simulation1, S[2,2]
- Beatty80.Beatty80.Simulation1, S[1,1]
- Beatty80.Beatty80.Simulation1, S[1,2]

Measured (stars)

Simulated (circles)

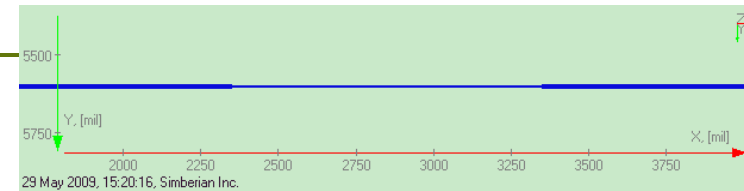


Measured Data Quality Metric:  
 Passivity QM=100%  
 Reciprocity QM=99.29%  
 Symmetry QM=22.8%

Visible difference in  $|S_{11}|$  and  $|S_{22}|$  - the actual structure has mirror geometric symmetry violations (manufacturing tolerance and the weave effect)

# Comparison with measurement results de-embedded with TRL

## Phase and group delay

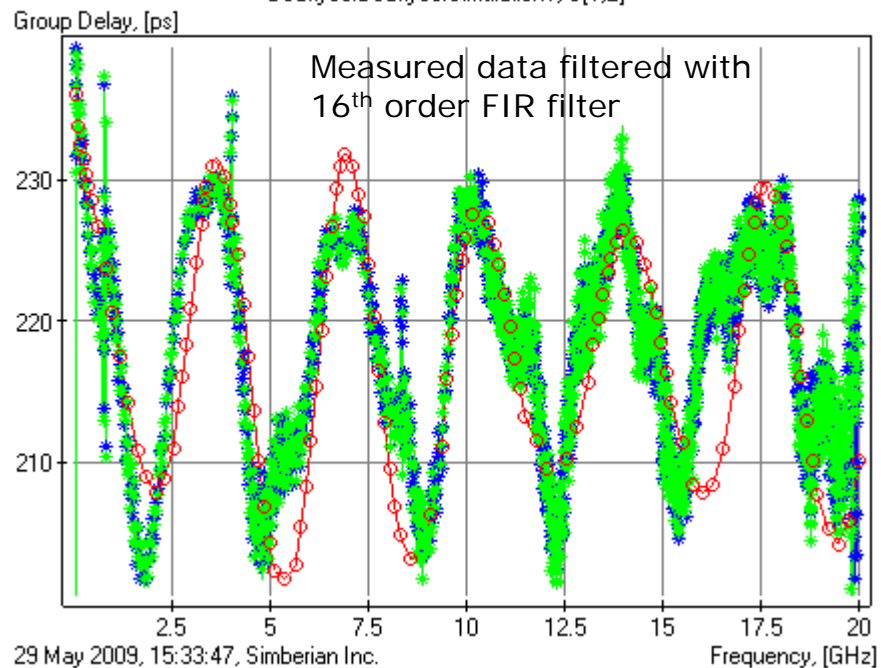
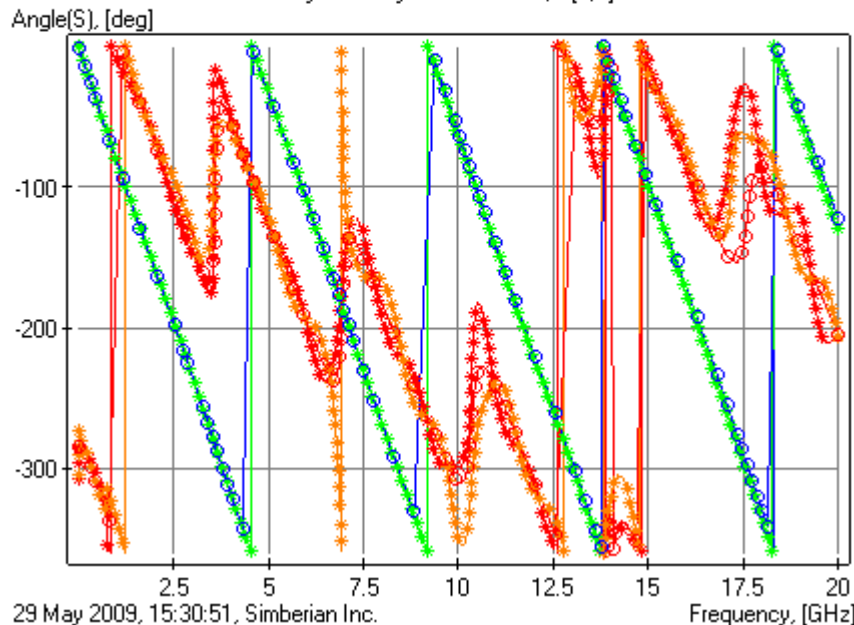


Un-wrapping of reflection angle is not possible

- \*— Beatty80.trl\_80ohm\_beatty\_s2p.Simulation1, S[1,1]
- \*— Beatty80.trl\_80ohm\_beatty\_s2p.Simulation1, S[1,2]
- \*— Beatty80.trl\_80ohm\_beatty\_s2p.Simulation1, S[2,1]
- \*— Beatty80.trl\_80ohm\_beatty\_s2p.Simulation1, S[2,2]
- Beatty80.Beatty80.Simulation1, S[1,1]
- Beatty80.Beatty80.Simulation1, S[1,2]

Measured – stars,  
simulated - circles

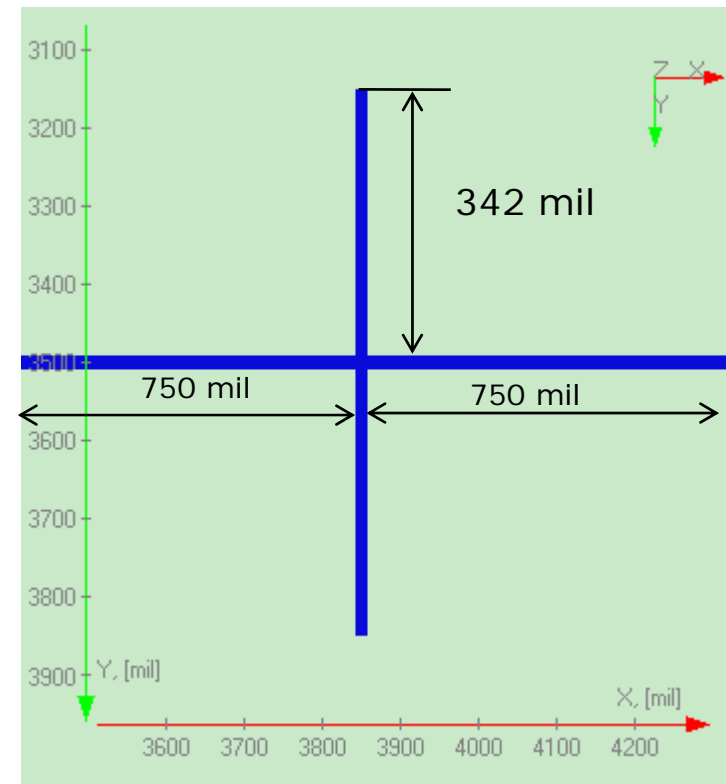
- \*— Beatty80.trl\_80ohm\_beatty\_s2p.Simulation1, S[1,2]
- \*— Beatty80.trl\_80ohm\_beatty\_s2p.Simulation1, S[2,1]
- Beatty80.Beatty80.Simulation1, S[1,2]



**Good correspondence!**

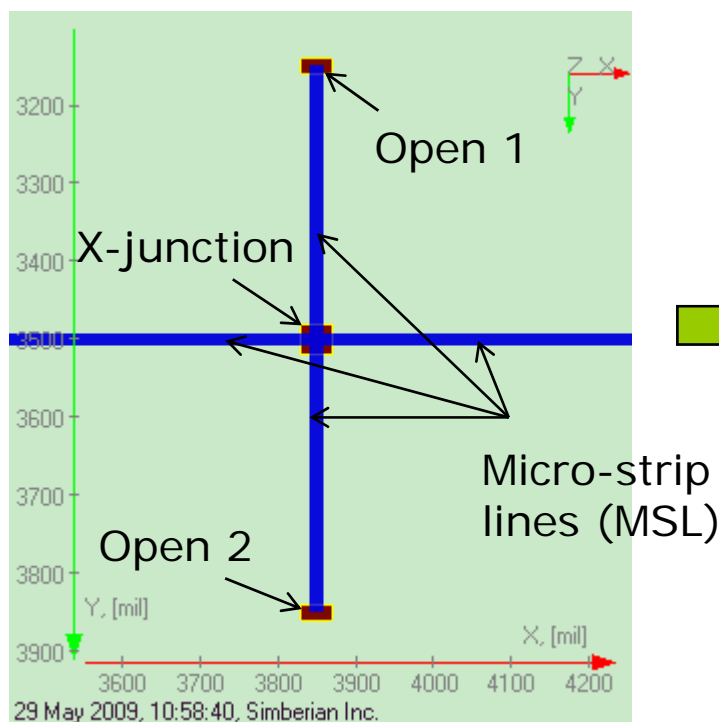
# Micro-strip resonator with two stubs

- Two 17-mil wide micro-strip stubs at the same location
- $DK=4.2$ ,  $LT=0.018$  @ 1 GHz, WD model
- Conductor roughness 0.5  $\mu\text{m}$
- De-embedded to reference planes to keep 750 mil micro-strip segments on both sides of the structure
- Can be analyzed as a whole or with decomposition into three discontinuities and line segments
- **De-compositional analysis is faster and more accurate**

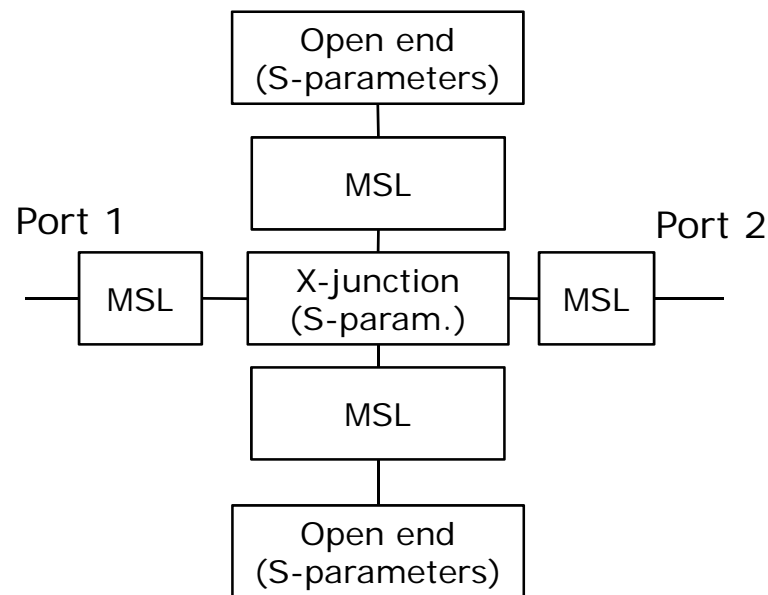


# De-composition of two-stub resonator

Three rectangular discontinuity selectors created to de-compose the structure in 7 elements



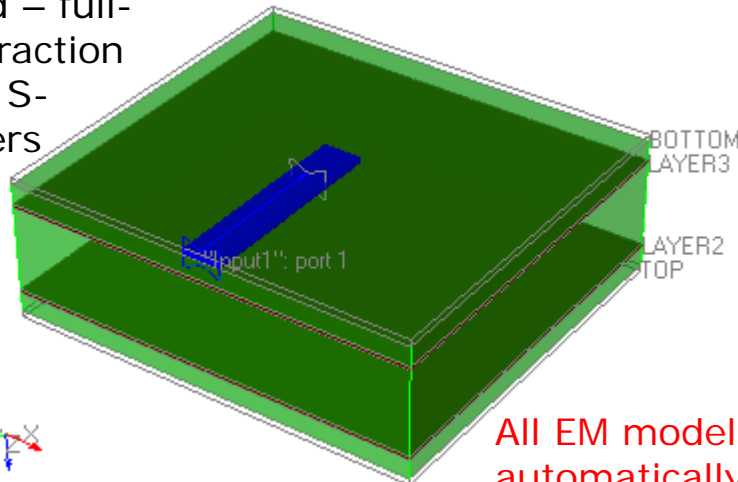
Simbeor de-compositional model (linear network)



Auto-decomposition is used here as demonstrated in screen-cast #2009\_03 at <http://www.simberian.com/ScreenCasts.php>

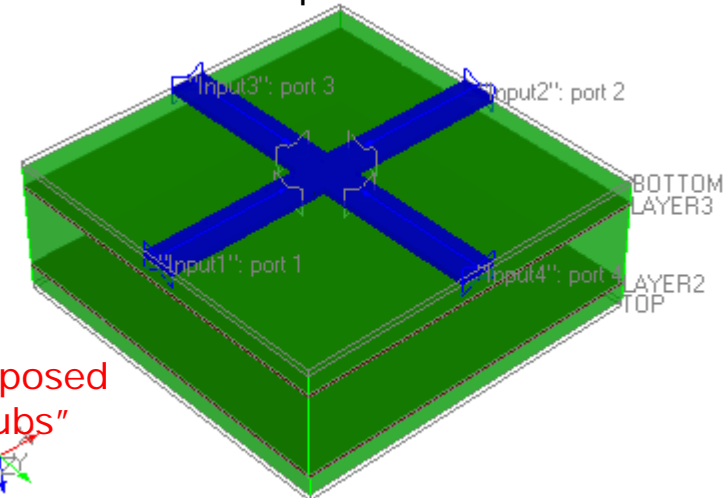
# Circuit elements automatically created for the electromagnetic extraction

Open end – full-wave extraction of 1-port S-parameters

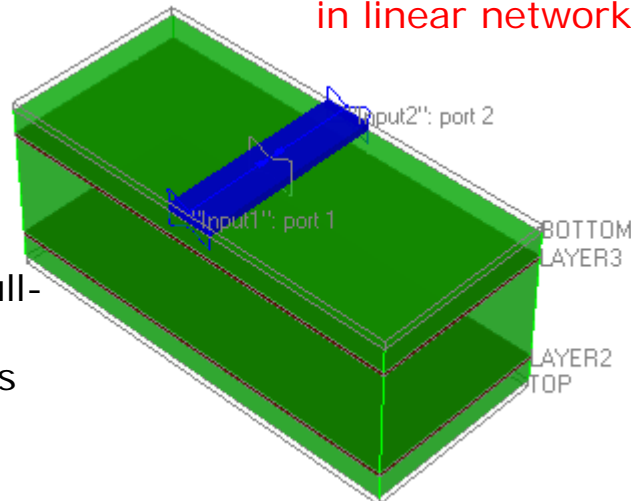


All EM models are automatically re-composed in linear network "Stubs"

X-junction – full-wave extraction of 4-port S-parameters



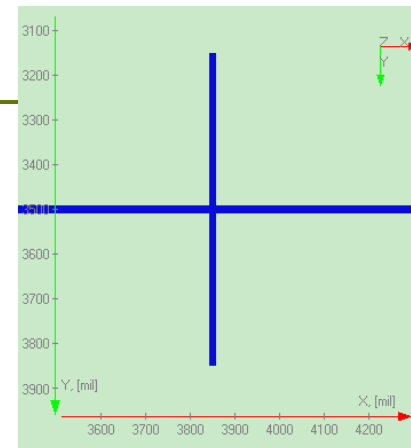
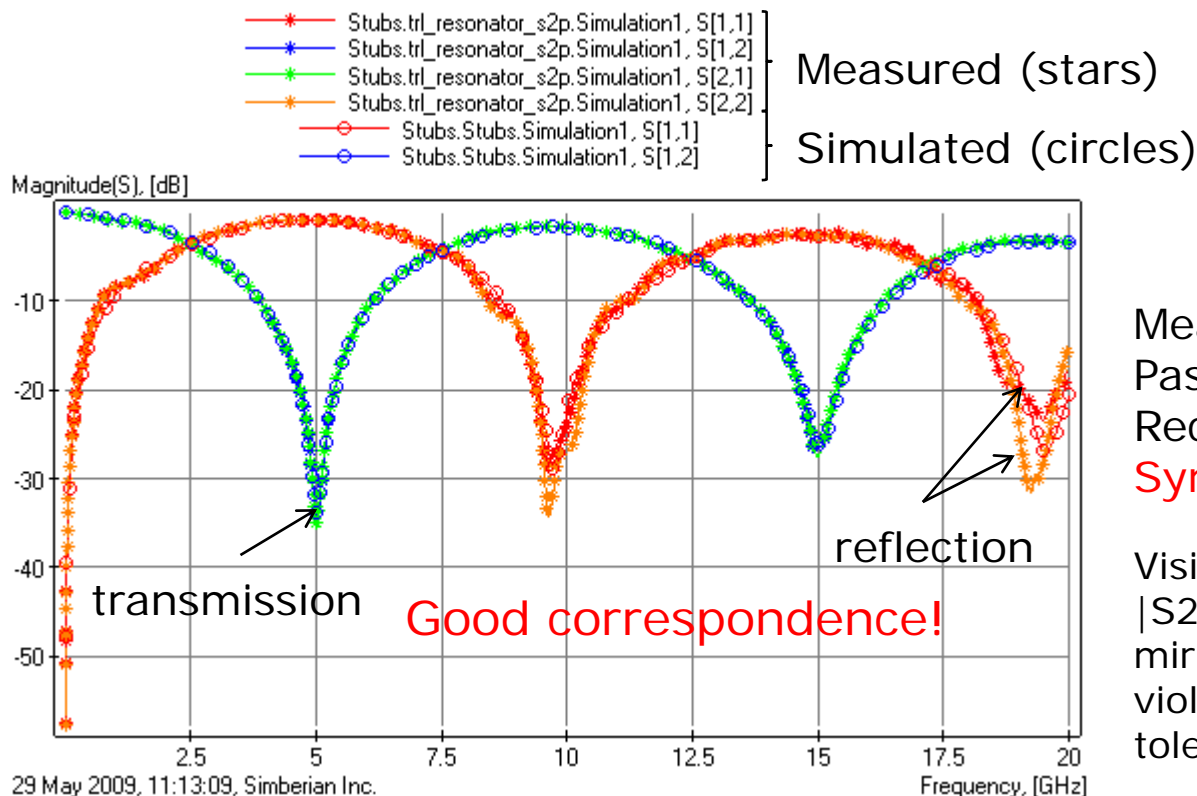
Micro-strip line – full-wave extraction of RLGC(f) parameters



Analysis takes less than 1 min and all models are re-usable for possible fast "tuning" by adjustment of the t-line lengths

# Comparison with measurement results de-embedded with TRL

## □ Magnitudes of S-parameters



Measured Data Quality Metric:  
 Passivity QM=99.9999%  
 Reciprocity QM=99.37%  
 Symmetry QM=19.6%

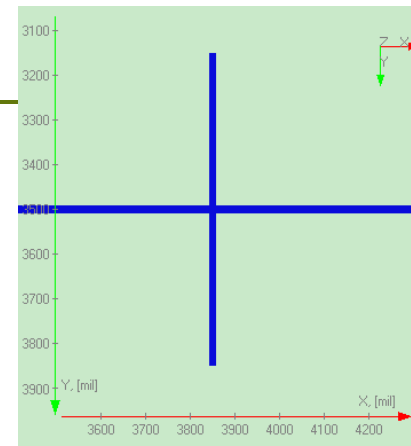
Visible difference in  $|S_{11}|$  and  $|S_{22}|$  - the actual structure has mirror geometric symmetry violations (manufacturing tolerance and the weave effect)



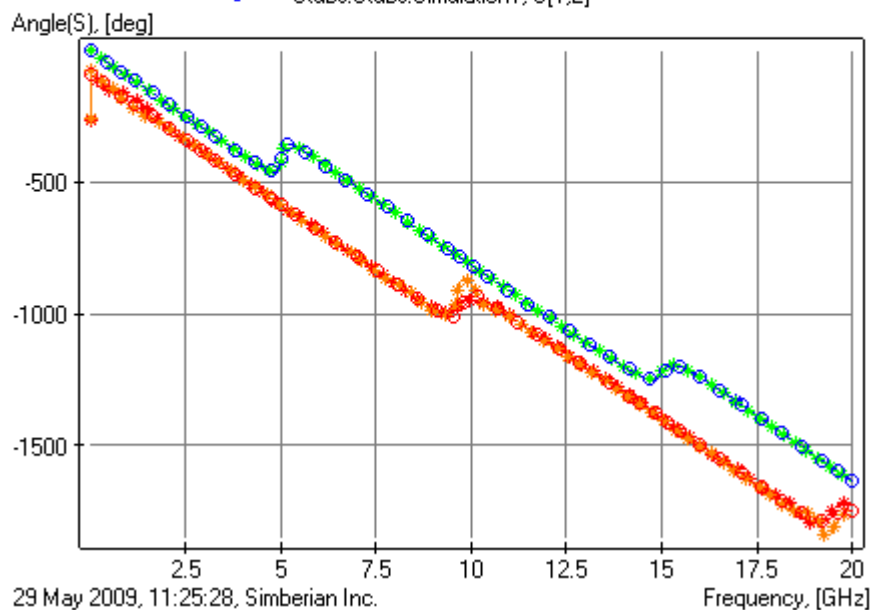
# Comparison with measurement results de-embedded with TRL

## Phase and group delay

Measured – stars,  
simulated - circles

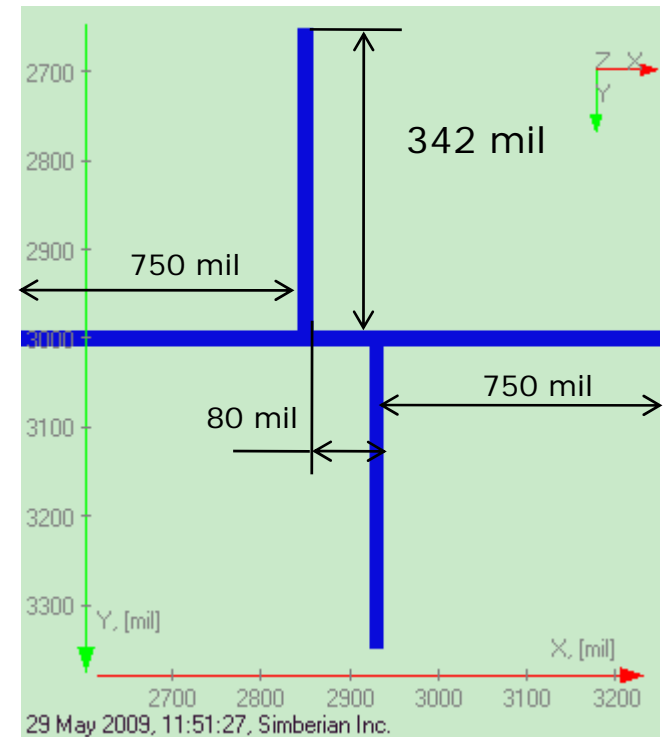


- Stubs.tr\_resonator\_s2p.Simulation1, S[1,1]
- Stubs.tr\_resonator\_s2p.Simulation1, S[1,2]
- Stubs.tr\_resonator\_s2p.Simulation1, S[2,1]
- Stubs.tr\_resonator\_s2p.Simulation1, S[2,2]
- Stubs.Stubs.Simulation1, S[1,1]
- Stubs.Stubs.Simulation1, S[1,2]



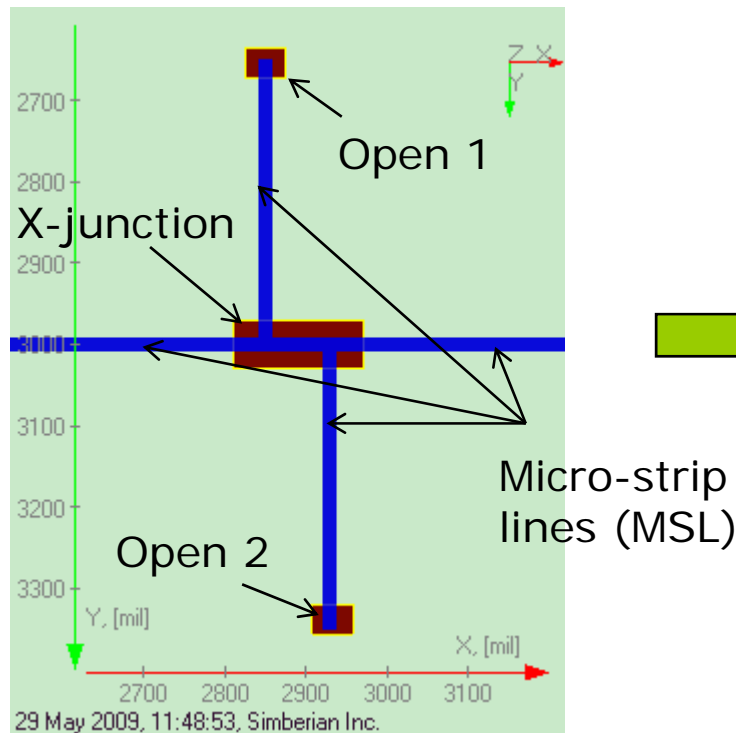
# Micro-strip resonator with two offset stubs

- Two 17-mil wide micro-strip stubs separated by 80 mil as shown
- $DK=4.2$ ,  $LT=0.018$  @ 1 GHz, WD model
- Conductor roughness 0.5  $\mu\text{m}$
- De-embedded to reference planes to keep 750 mil micro-strip segments on both sides of the structure
- Can be analyzed as a whole or with decomposition into three discontinuities and line segments
- **De-compositional analysis is faster and more accurate**

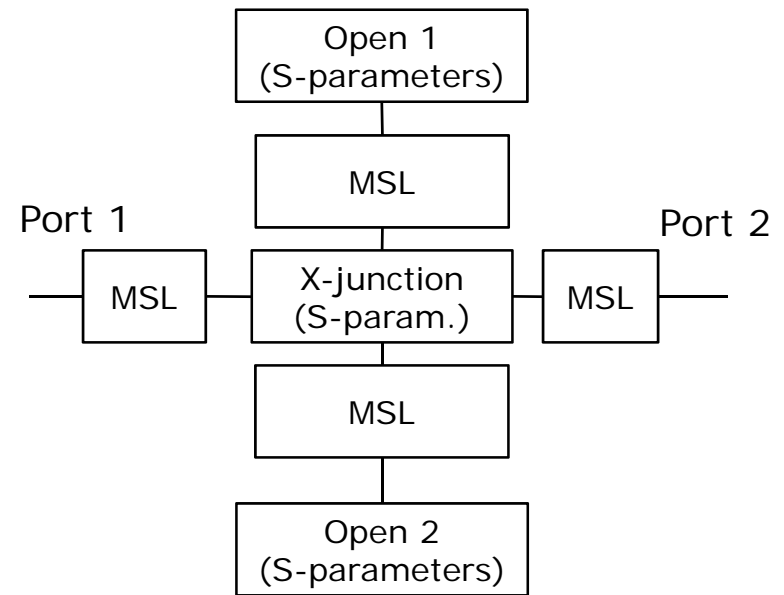


# De-composition of two-stub resonator

Three rectangular discontinuity selectors created to de-compose the structure in 7 elements



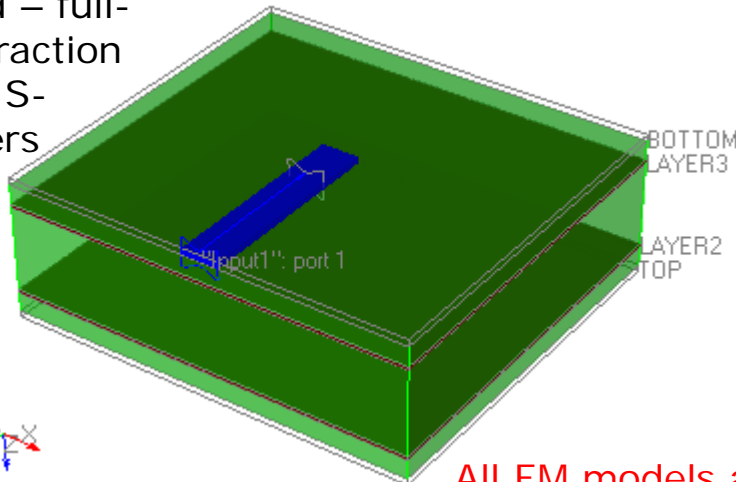
Simbeor de-compositional model (linear network)



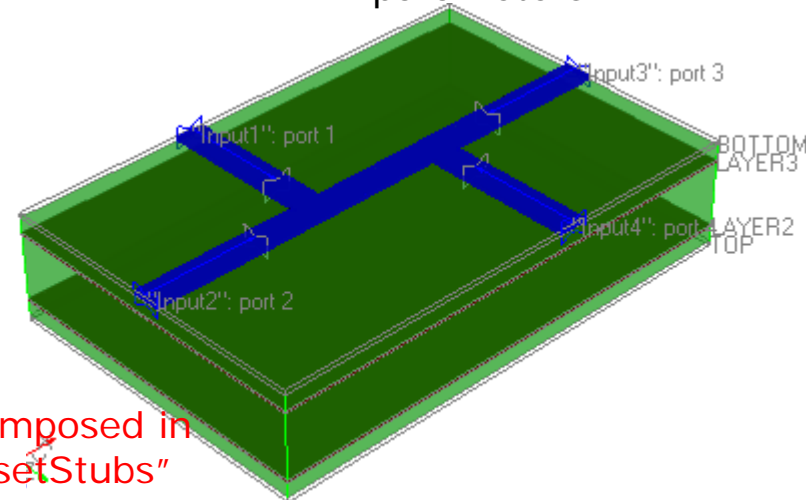
Auto-decomposition is used here as demonstrated in screen-cast #2009\_03 at <http://www.simberian.com/ScreenCasts.php>

# Circuit elements are automatically created for the electromagnetic extraction

Open end – full-wave extraction of 1-port S-parameters

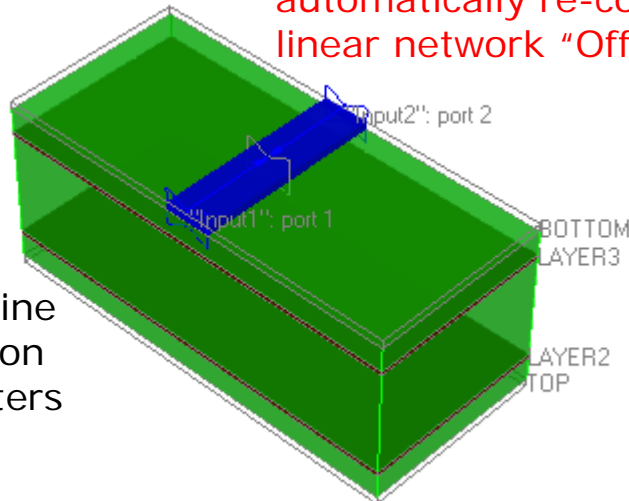


X-junction – full-wave extraction of 4-port S-parameters



All EM models are automatically re-composed in linear network "OffsetStubs"

17-mil micro-strip line – full-wave extraction of RLGC(f) parameters

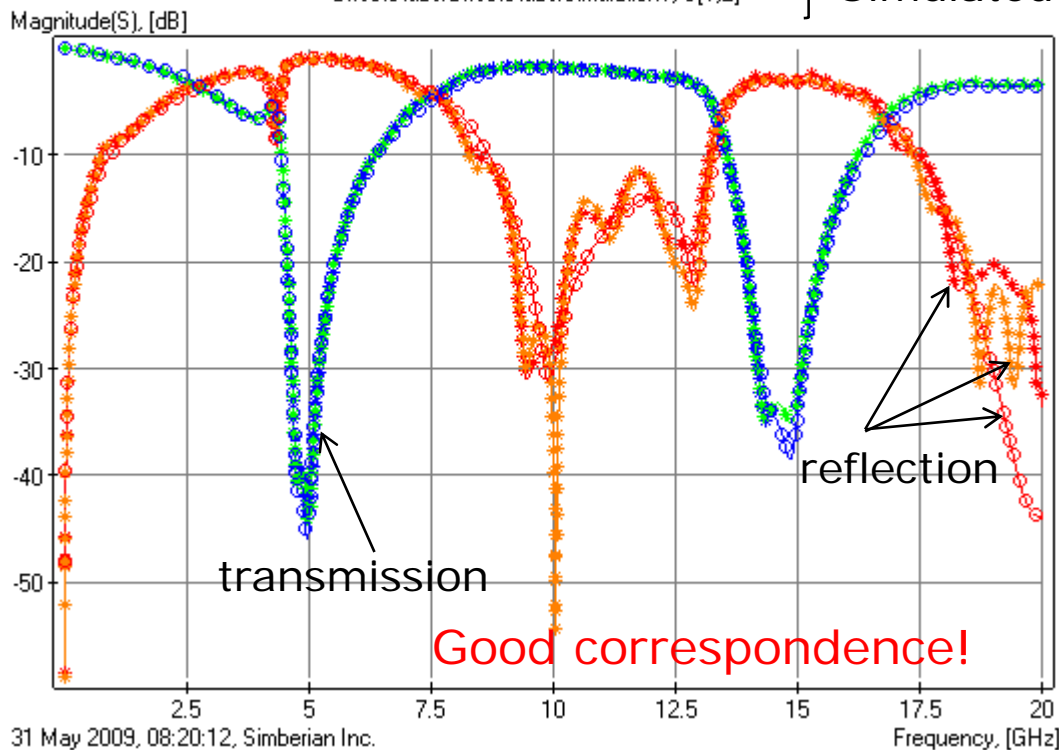


Analysis takes less than 1 min and all models are re-usable for possible fast "tuning" by adjustment of the t-line lengths

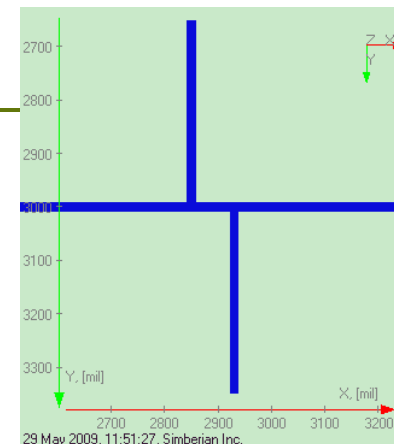
# Comparison with measurement results de-embedded with TRL

## □ Magnitudes of S-parameters

- \*— OffsetStubs.tri\_offset\_resonator\_s2p.Simulation1, S[1,1]
  - \*— OffsetStubs.tri\_offset\_resonator\_s2p.Simulation1, S[1,2]
  - \*— OffsetStubs.tri\_offset\_resonator\_s2p.Simulation1, S[2,1]
  - \*— OffsetStubs.tri\_offset\_resonator\_s2p.Simulation1, S[2,2]
  - OffsetStubs.OffsetStubs.Simulation1, S[1,1]
  - OffsetStubs.OffsetStubs.Simulation1, S[1,2]
- Measured (stars)  
Simulated (circles)



31 May 2009, 08:20:12, Simberian Inc.

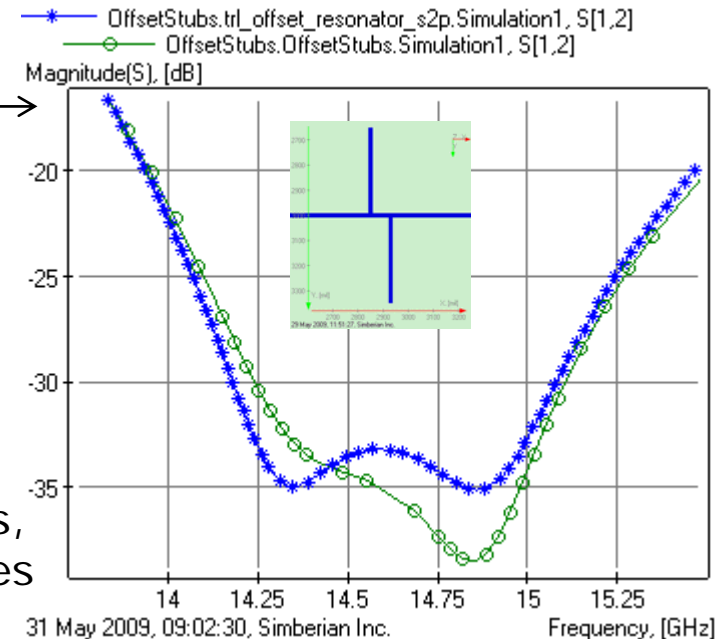
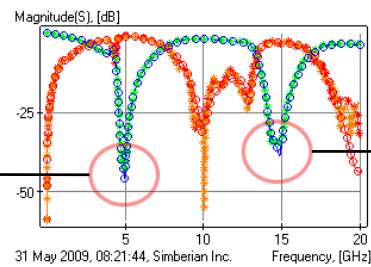
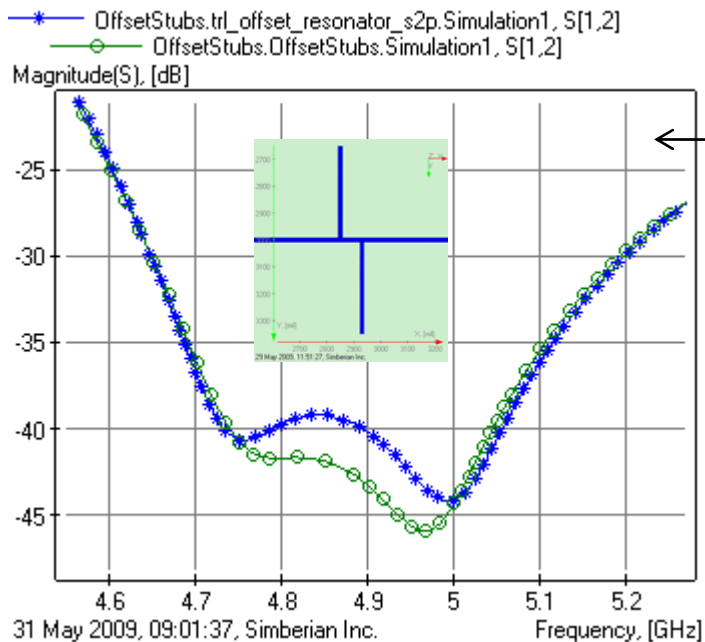
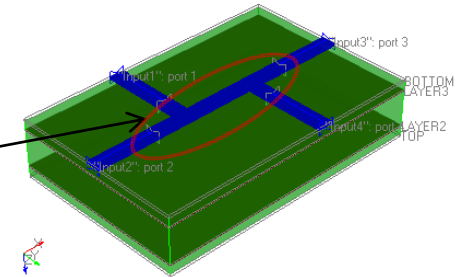


Measured Data Quality Metric:  
Passivity QM=100%  
Reciprocity QM=99.41%  
Symmetry QM=0%

Visible difference in  $|S_{11}|$  and  $|S_{22}|$  - the actual structure has rotational geometric symmetry violations (manufacturing tolerance and the weave effect)

# Double resonance effect

- The effect of interaction between the resonators first observed by M. Goldfarb and A. Platzker in “The effects of electromagnetic coupling on MMIC design”, Int. J. of Microwave and Millimeter-wave Computer-Aided Engineering, 1991, v.1, p. 38-47
- The de-compositional analysis proves that the effect is due to the interactions of two T-junctions through the high-order modes in micro-strip line connecting them

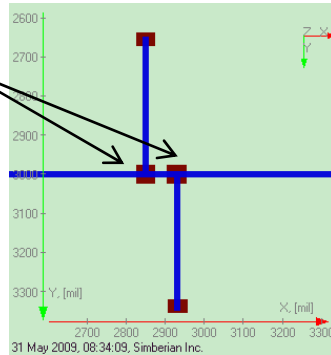


Measured – stars,  
 simulated - circles

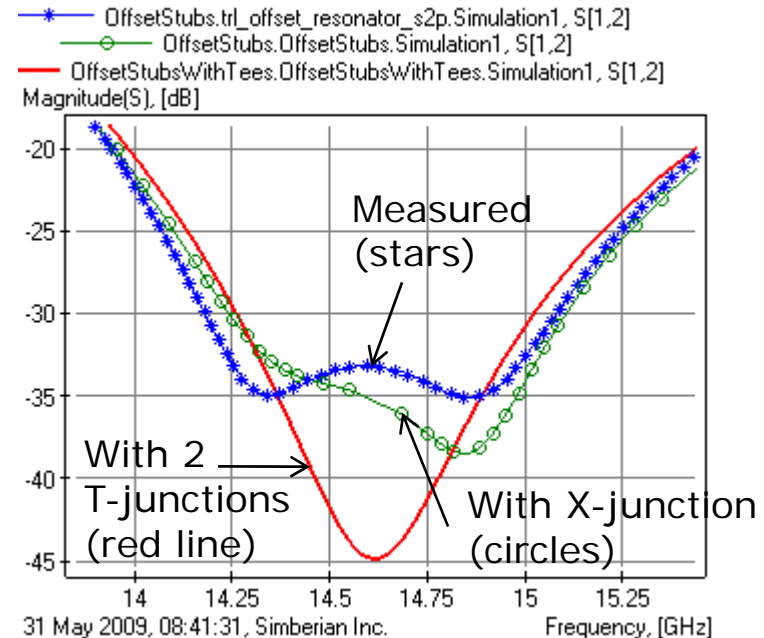
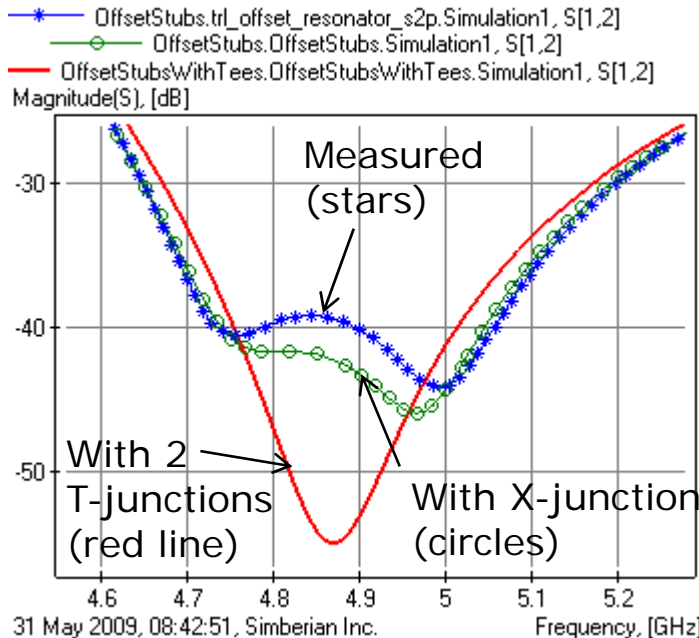
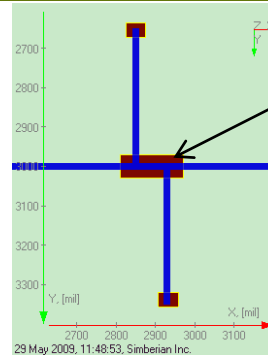
The effect cannot be observed without the EM analysis!

# What if the interaction is ignored?

With two separate T-junction (no high-order mode interactions) – red lines on graphs



With single X-junction (high-order mode interactions) – green circles on graphs



The effect cannot be observed without coupled discontinuities!

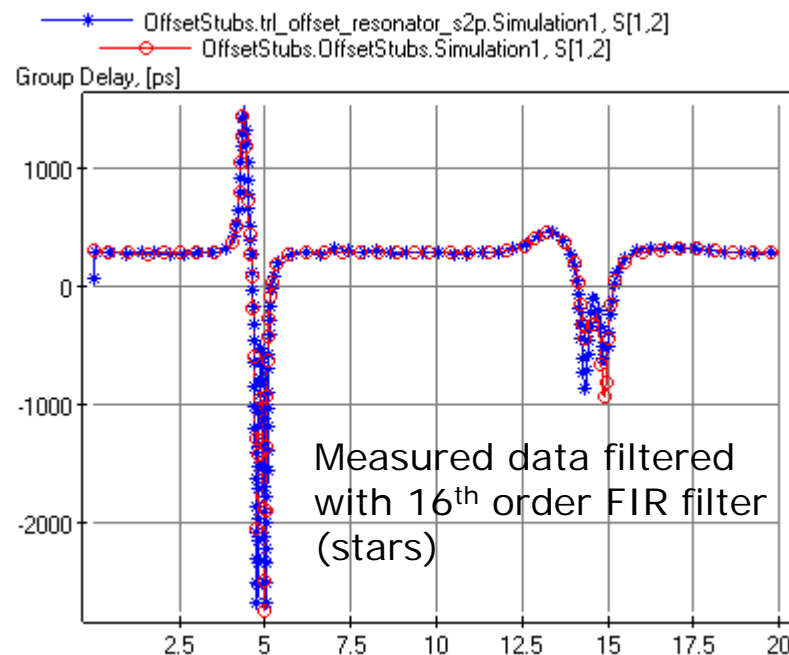
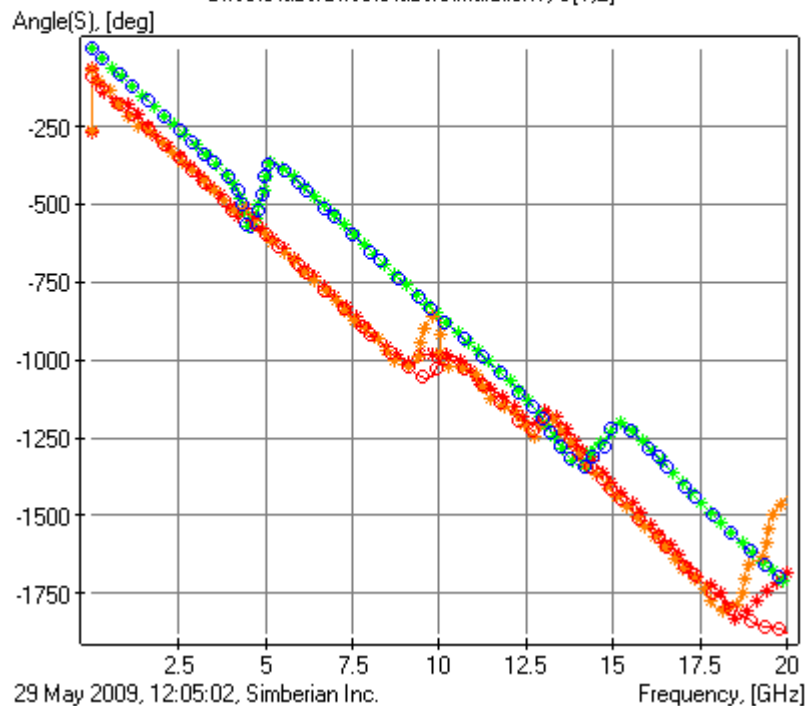
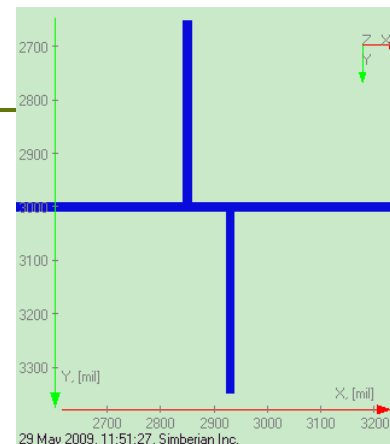


# Comparison with measurement results de-embedded with TRL

## Phase and group delay

- OffsetStubs.trl\_offset\_resonator\_s2p.Simulation1, S[1,1]
- OffsetStubs.trl\_offset\_resonator\_s2p.Simulation1, S[1,2]
- OffsetStubs.trl\_offset\_resonator\_s2p.Simulation1, S[2,1]
- OffsetStubs.trl\_offset\_resonator\_s2p.Simulation1, S[2,2]
- OffsetStubs.OffsetStubs.Simulation1, S[1,1]
- OffsetStubs.OffsetStubs.Simulation1, S[1,2]

Measured – stars,  
simulated - circles

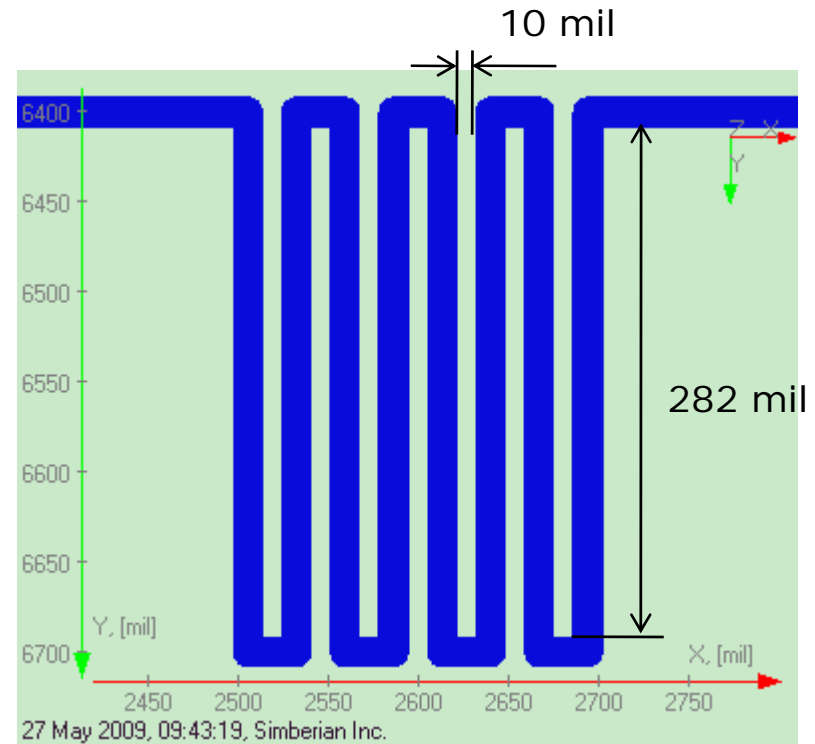


Measured data filtered  
with 16<sup>th</sup> order FIR filter  
(stars)

Good correspondence!

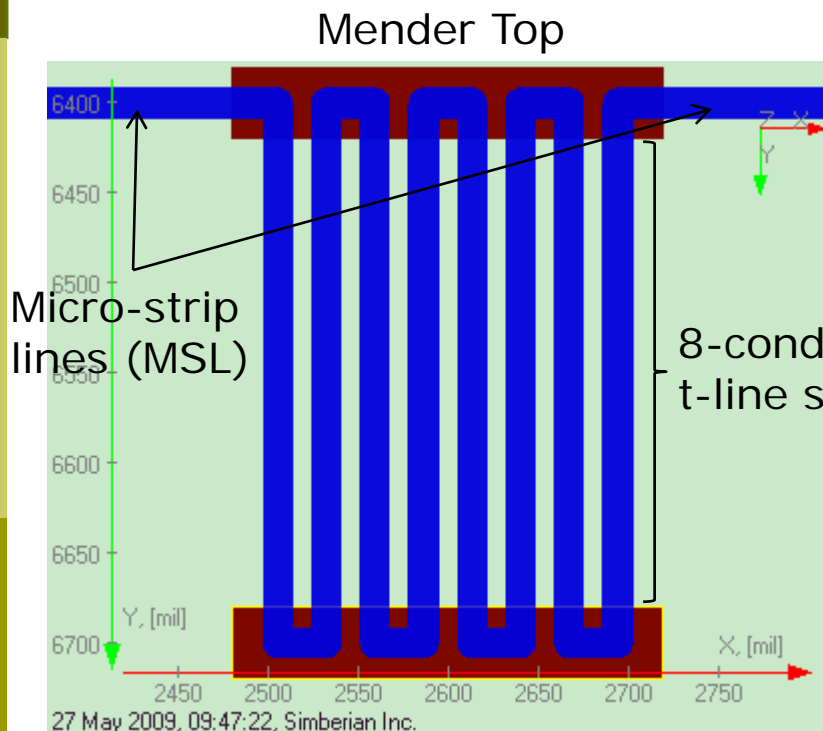
# Meandering micro-strip line

- Meandering 17-mil 2.6 inch long micro-strip line
- $DK=4.2$ ,  $LT=0.018$  @ 1 GHz, WD model
- Conductor roughness 0.5  $\mu\text{m}$
- De-embedded to reference planes to keep 390 mil micro-strip segments on both sides of the meander – total length of the line is 3380 mil
- Can be analyzed as a whole or with decomposition into two discontinuities and line segments
- **De-compositional analysis is faster and more accurate**



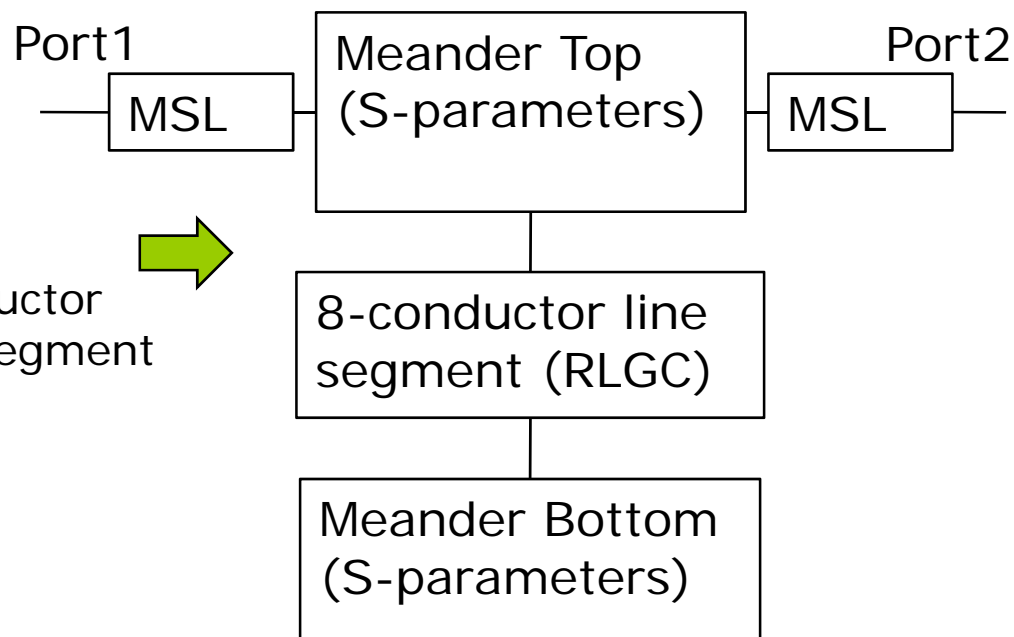
# De-composition of the meander

*Two rectangular discontinuity selectors created to de-compose the meander in 5 elements*



Meander Bottom

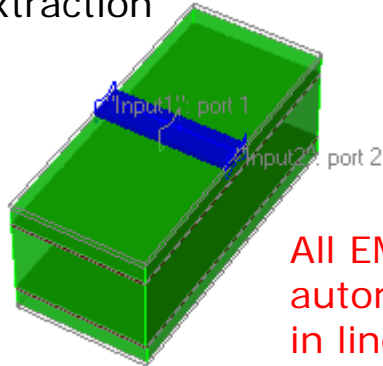
Simbeor de-compositional model (linear network)



Auto-decomposition is used here as demonstrated in screen-cast #2009\_02 at <http://www.simberian.com/ScreenCasts.php>

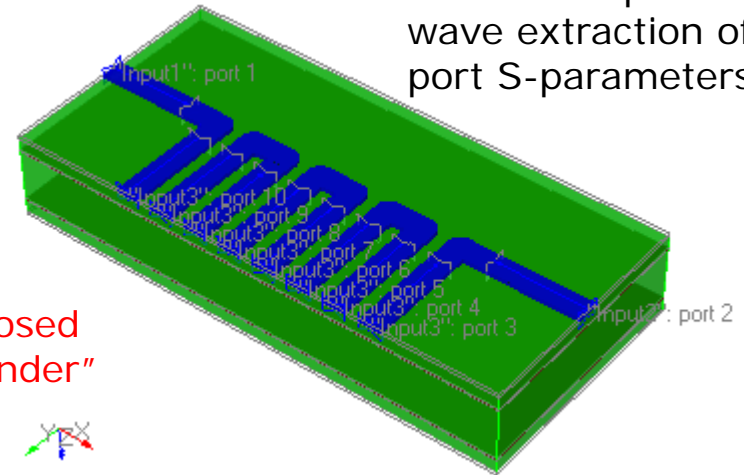
# Circuit elements automatically created for the electromagnetic extraction

17-mil micro-strip line  
– full-wave extraction  
of RLGC p.u.l  
parameters

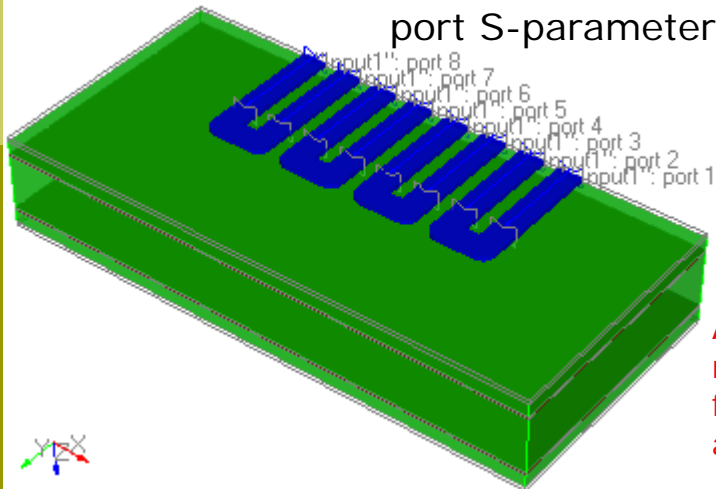


All EM models are  
automatically re-composed  
in linear network "Meander"

Meander Top – full-  
wave extraction of 10-  
port S-parameters

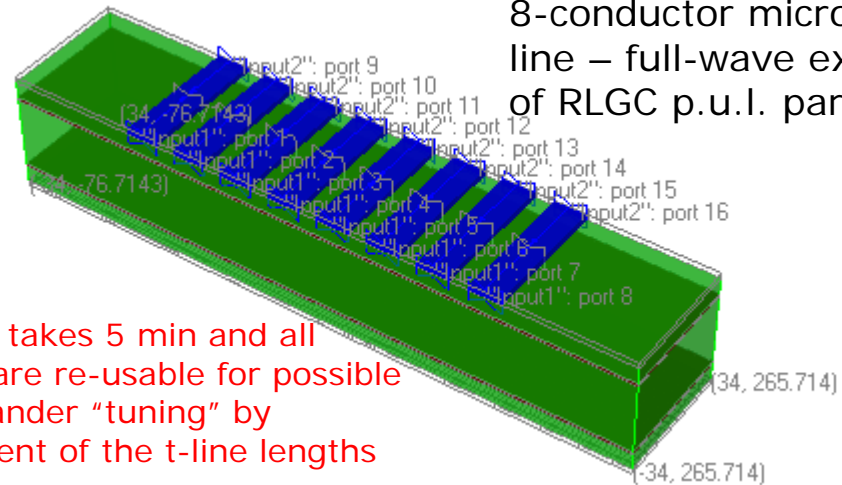


Meander Bottom – full-  
wave extraction of 10-  
port S-parameters



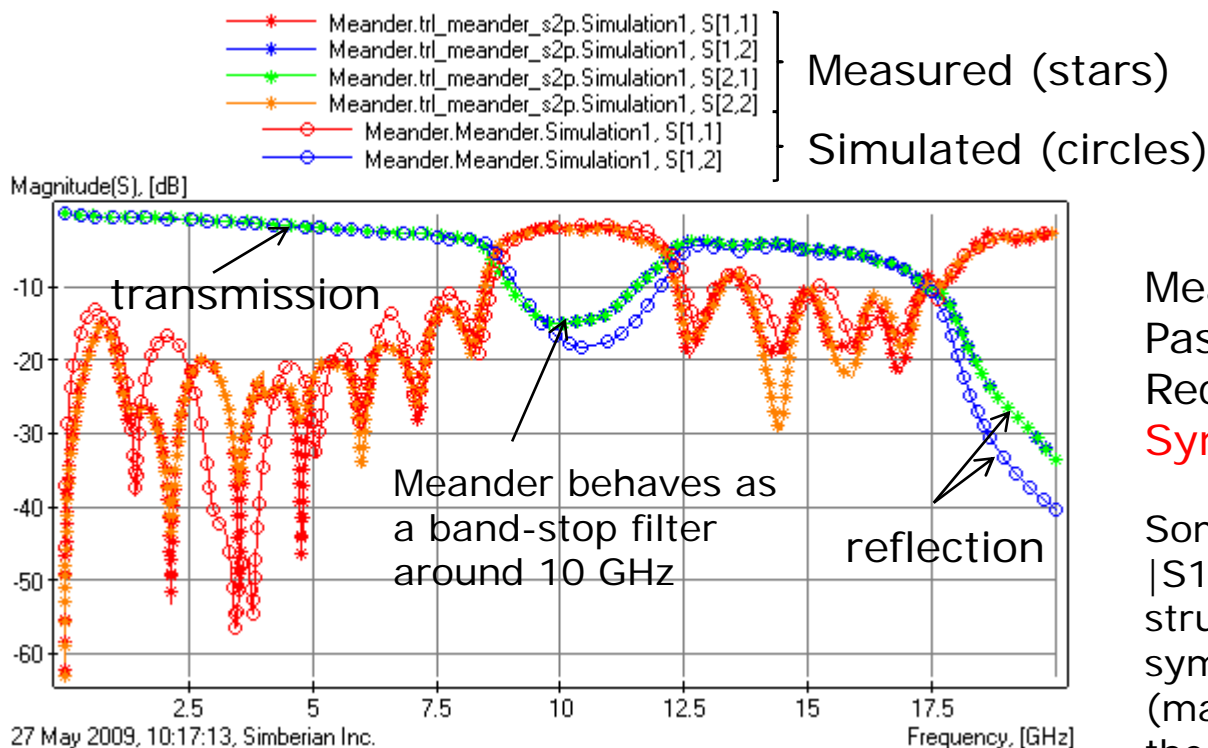
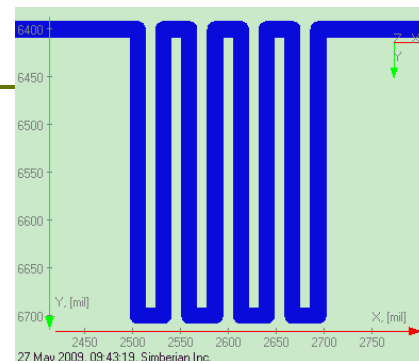
Analysis takes 5 min and all  
models are re-usable for possible  
fast meander "tuning" by  
adjustment of the t-line lengths

8-conductor micro-strip  
line – full-wave extraction  
of RLGC p.u.l. parameters



# Comparison with measurement results de-embedded with TRL

## □ Magnitudes of S-parameters



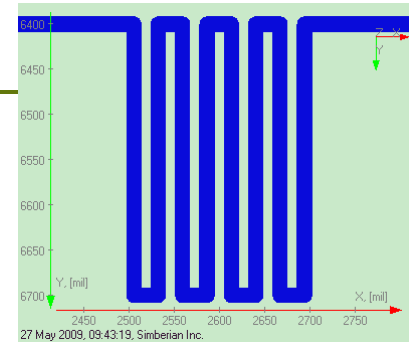
Measured Data Quality Metric:  
Passivity QM=100%  
Reciprocity QM=99.6%  
Symmetry QM=49.3%

Some visible differences in  $|S_{11}|$  and  $|S_{22}|$  - the actual structure has mirror geometric symmetry violations (manufacturing tolerance and the weave effect)

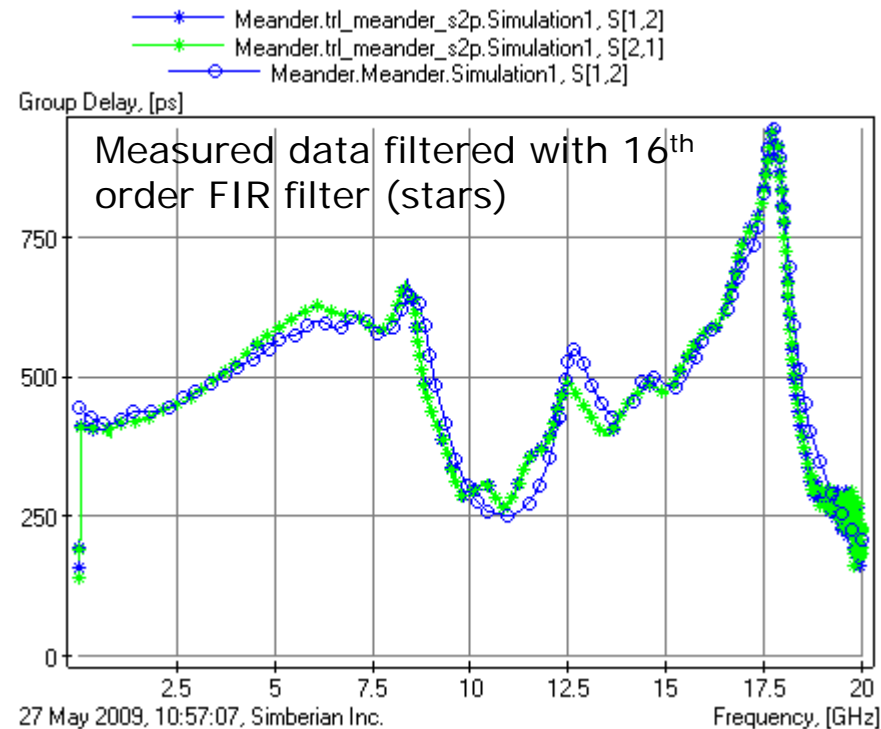
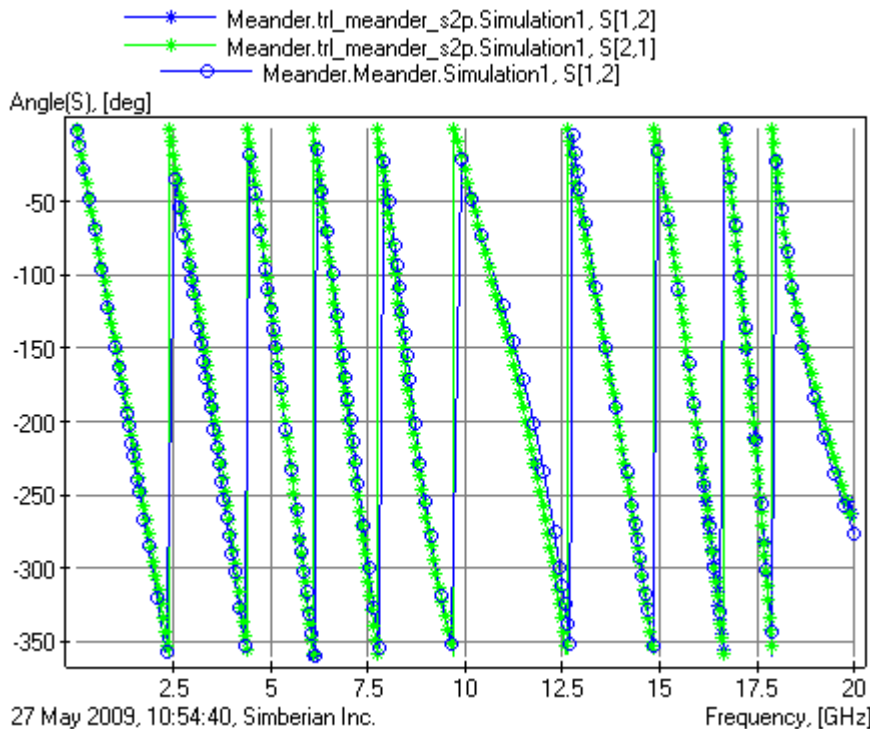
Good correspondence!

# Comparison with measurement results de-embedded with TRL

- Transmission coefficient phase (angle) and group delay

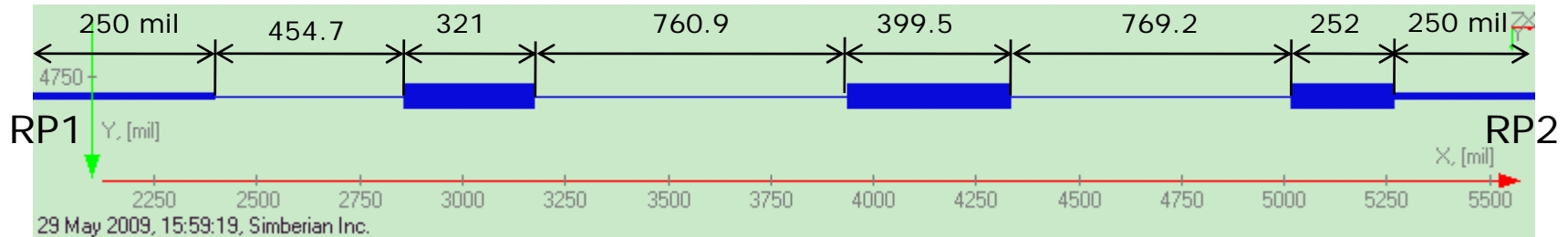


Measured – stars, simulated - circles



Good correspondence!

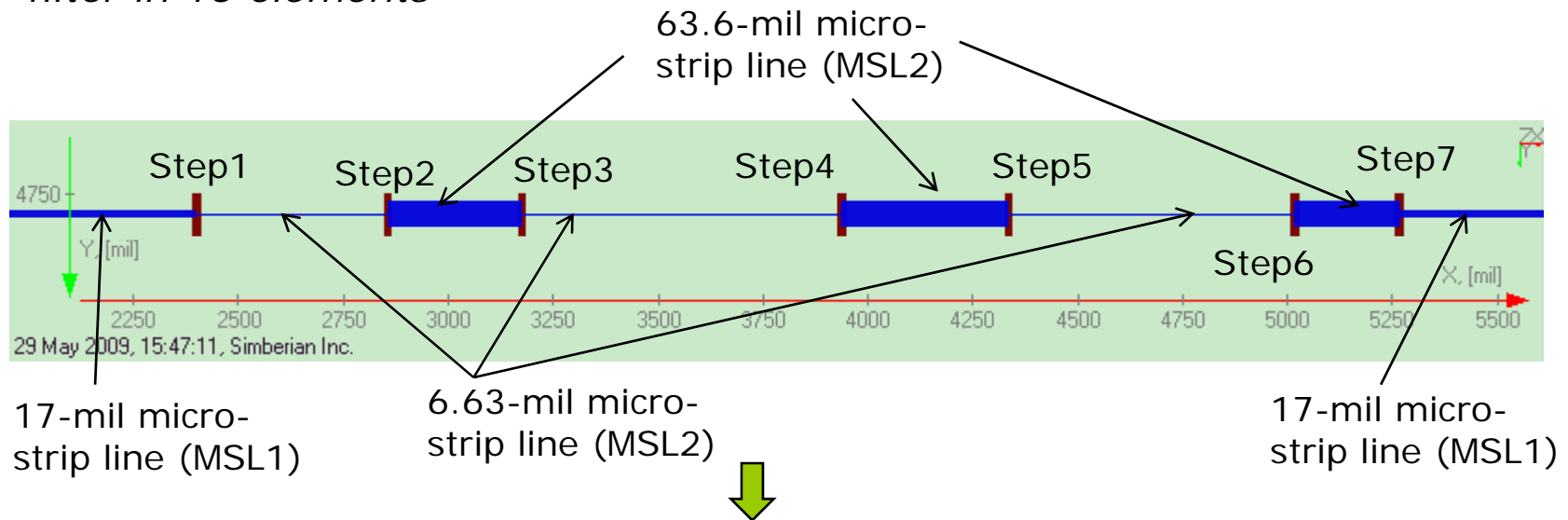
# Low-pass micro-strip filter



- Low-pass filter in 17-mil micro-strip line: high-impedance segments – 6.63 mil, low impedance segments – 63.6 mil (lengths are on the picture)
- $DK=4.3$ ,  $LT=0.018$  @ 1 GHz, WD model – **higher DK for narrower lines**
- Conductor roughness 0.5  $\mu\text{m}$
- De-embedded to reference planes to keep 250 mil micro-strip segments on both sides of the structure
- Can be analyzed as a whole or with decomposition into two step discontinuities and line segments
- **De-compositional analysis is faster and more accurate**

# De-composition of low-pass filter

Seven rectangular discontinuity selectors created to de-compose the filter in 15 elements



Simbeor de-compositional model (linear network)

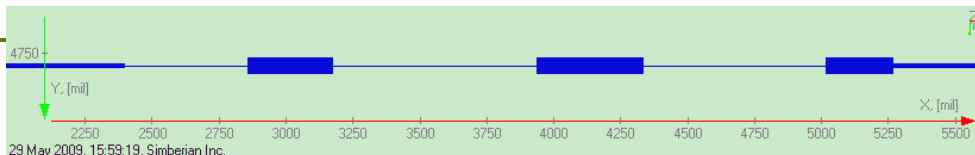
Port1 = MSL1 = Step1 = MSL2 = Step2 = MSL3 = Step3 = MSL2 = Step4 = MSL3 = Step5 = MSL2 = Step6 = MSL3 = Step7 = MS1 = Port2

Auto-decomposition is used here as demonstrated in screen-cast #2009\_03 at <http://www.simberian.com/ScreenCasts.php>



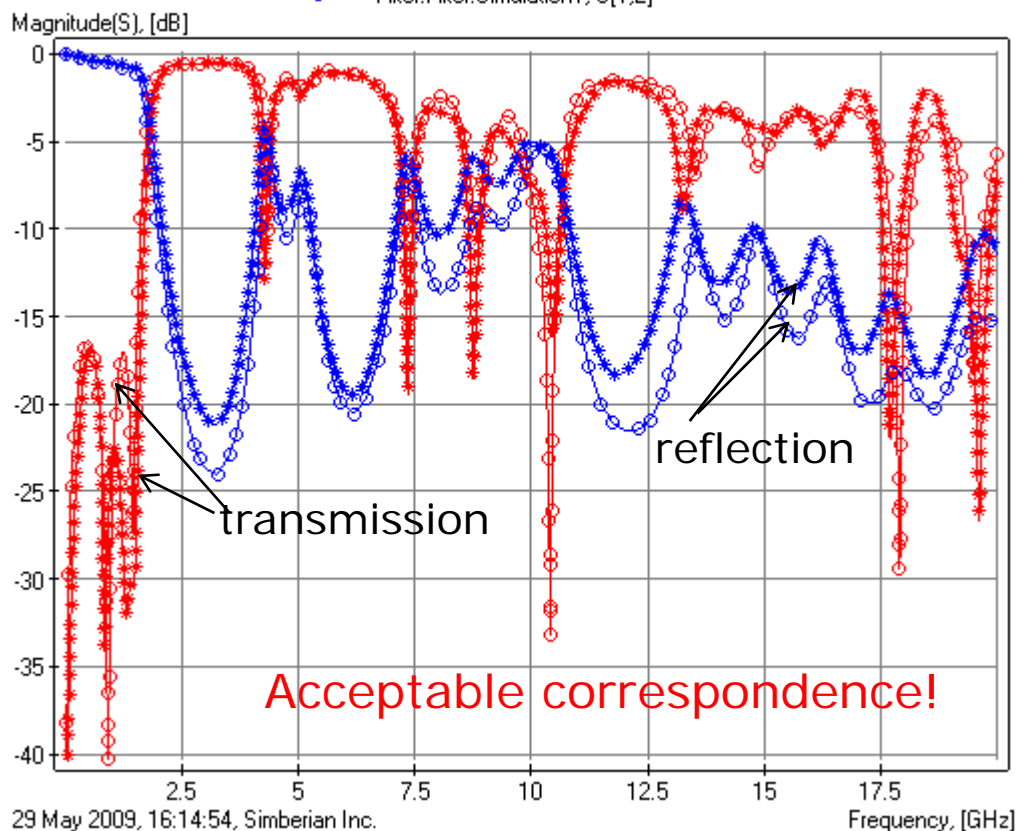
# Comparison with measurement results de-embedded with TRL

## □ Magnitudes of S-parameters



- \*— Filter.tr\_lowpassfilter\_s2p.Simulation1, S[1,1]
- \*— Filter.tr\_lowpassfilter\_s2p.Simulation1, S[1,2]
- Filter.Filter.Simulation1, S[1,1]
- Filter.Filter.Simulation1, S[1,2]

Measured – stars,  
simulated - circles

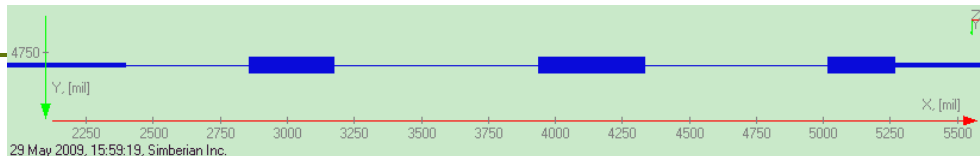


Measured Data Quality Metric:  
Passivity QM=100%  
Reciprocity QM=99.53%

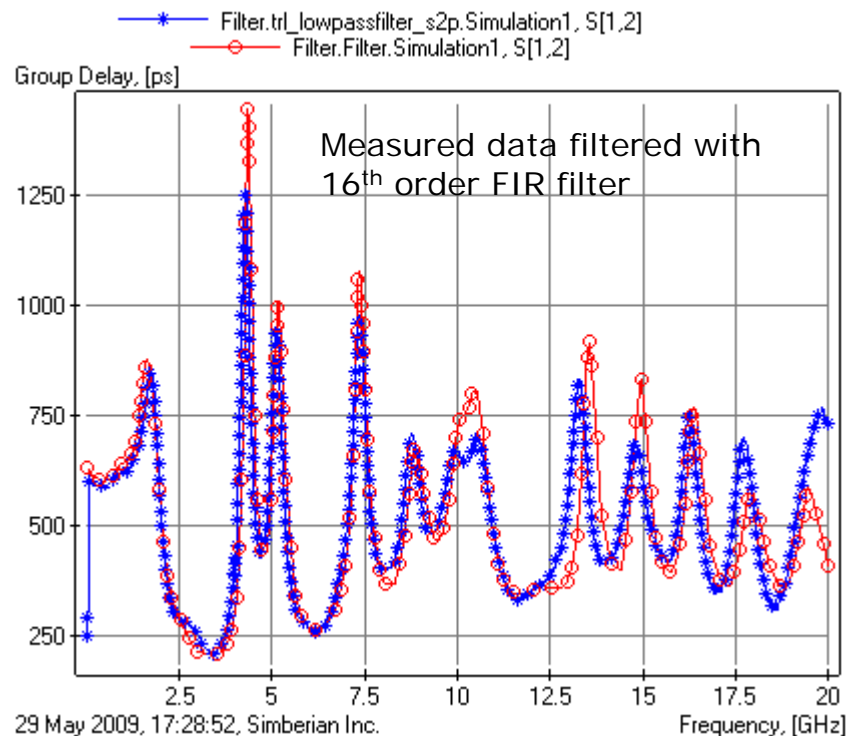
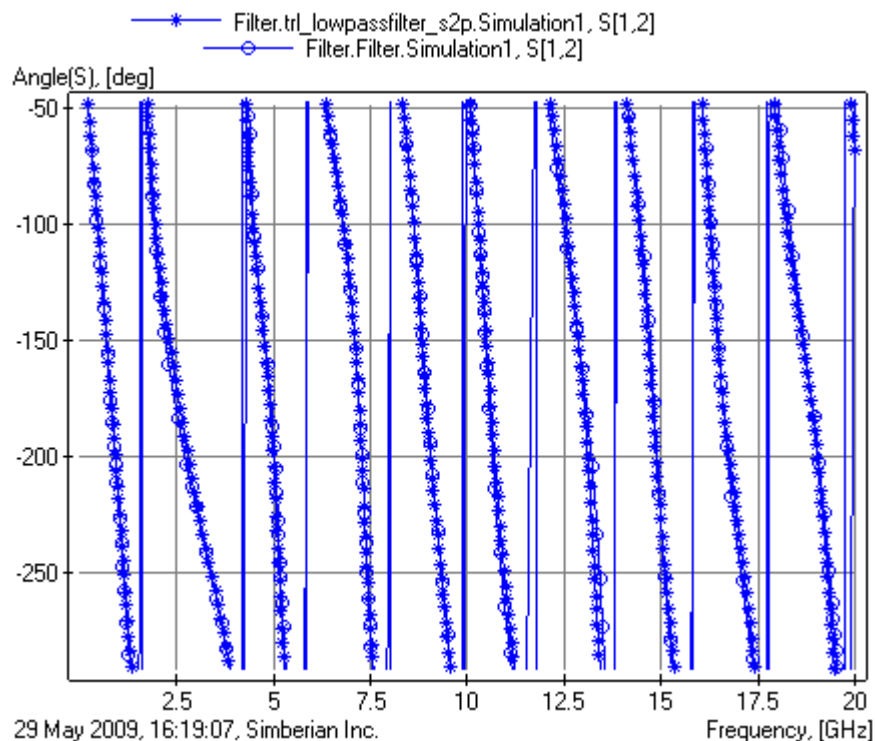
The apparent DK is different for narrow and wide lines (the weave effect) – it contributes to the discrepancies

# Comparison with measurement results de-embedded with TRL

## Phase and group delay



Measured – stars,  
simulated - circles



Good correspondence!

# Conclusion

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- Models created with Simbeor 2008.01 show good correspondence with the measured results up to 20 GHz
  - Such models can be used for analysis of 10-20 Gb/s data channels
  - Non of the planar resonant structures can be simulated with a static field solver (classical SI approach) with acceptable accuracy up to 20 GHz
  - 20 GHz is not actual limit for Simbeor models – **EM models do not have frequency limits in general**
  
- De-compositional analysis is a fast and accurate way to simulate complex structures on the board
  - Very accurate full-wave models of transmission lines connected with models of discontinuities simulated locally (more efficient)
  - Auto-de-compositional analysis with the precise full-wave models of t-lines and discontinuities is the unique feature of Simbeor 2008.01 – **enables reliable electromagnetic verification of interconnects for multi-gigabit data channels**

# Solutions and contact

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- ❑ Setting up all simulations and analysis took about 1 hour
- ❑ Simbeor solution file used to illustrate these notes is available for download from Simberian web site
  - <http://kb.simberian.com/SimbeorExample.php?example=42>
- ❑ Send questions and comments to
  - General: [info@simberian.com](mailto:info@simberian.com)
  - Sales: [sales@simberian.com](mailto:sales@simberian.com)
  - Support: [support@simberian.com](mailto:support@simberian.com)
- ❑ Web site [www.simberian.com](http://www.simberian.com)