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Simberian
Electromagnetic Solutions

Primer of investigation of 90-degree, 45-degree and arched bends in differential line

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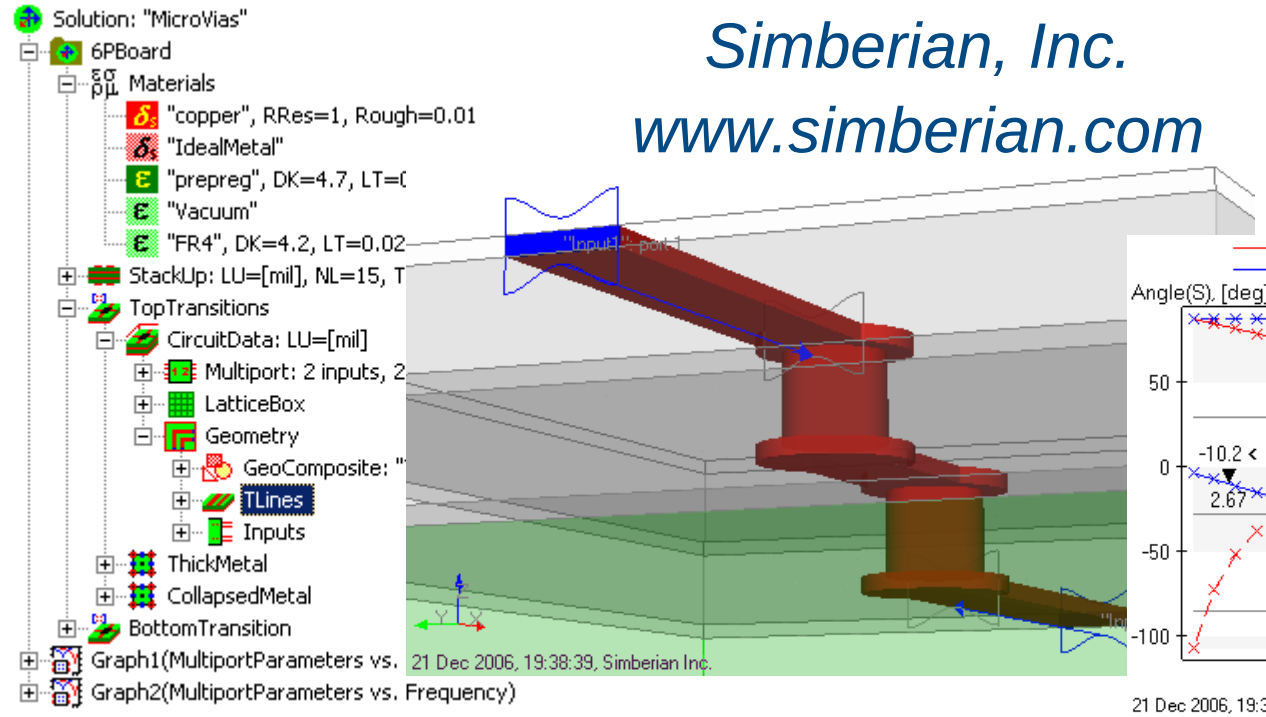

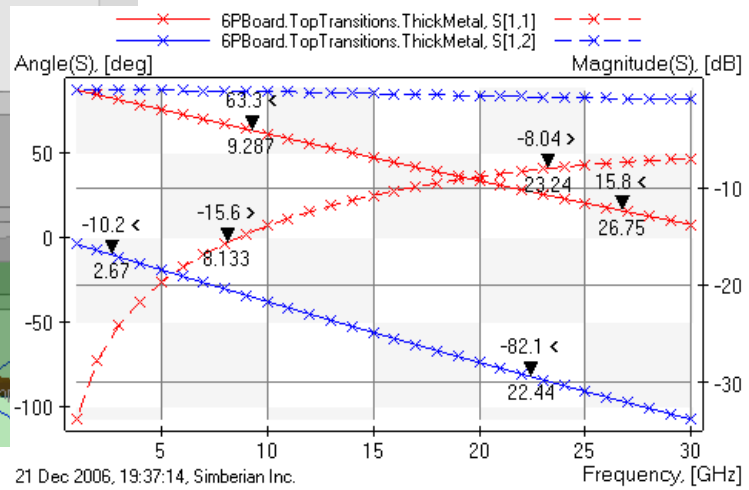

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Overview

- Introduction
- Mixed-mode S-parameters
- Qualitative comparison of bends
- 90-degree bend
- Two 45-degree bends
- Arched bend
- Micro-strip channel with two reversed bends
- Conclusion
- Solutions and contacts

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Introduction

- Investigation of mode transformations in differential bends (App Note #2009_01 available at www.simberian.com/AppNotes.php) generated many questions and comments on comparison of different types of differential bends
- The most common question is "**What type or bend is better?**"
- The answer depends on multiple factors and may be even counter-intuitive
- This app note is an illustration of how to investigate different configurations with the electromagnetic solver – actual results may vary depending on a particular stackup and geometry of t-lines
- One of the requirements for such investigation is the **full-wave electromagnetic analysis with pristine numerical de-embedding of S-parameters**
- Simbeor 2008.01 built on March 30, 2009 has been used for all computations

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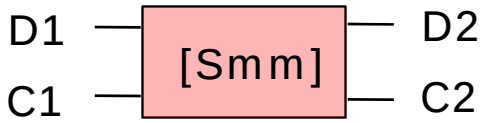
Mixed-Mode S-parameters



See more on definitions in Simberian App Note #2009_01

Notation used here:

Block DD

Block DC

$$Smm = \begin{bmatrix} S_{D1,D1} & S_{D1,D2} & S_{D1,C1} & S_{D1,C2} \\ S_{D1,D2} & S_{D2,D2} & S_{D2,C1} & S_{D2,C2} \\ S_{D1,C1} & S_{D2,C1} & S_{C1,C1} & S_{C1,C2} \\ S_{D1,C2} & S_{D2,C2} & S_{C1,C2} & S_{C2,C2} \end{bmatrix}$$

Block CC

Alternative forms:

$$Smm = \begin{bmatrix} S_{DD11} & S_{DD12} & S_{DC11} & S_{DC12} \\ S_{DD12} & S_{DD22} & S_{DC21} & S_{DC22} \\ S_{DC11} & S_{DC21} & S_{CC11} & S_{CC12} \\ S_{DC12} & S_{DC22} & S_{CC12} & S_{CC22} \end{bmatrix}$$

$$Smm = \begin{bmatrix} S_{1,1}^{dd} & S_{1,2}^{dd} & S_{1,1}^{dc} & S_{1,2}^{dc} \\ S_{1,2}^{dd} & S_{2,2}^{dd} & S_{2,1}^{dc} & S_{2,2}^{dc} \\ S_{1,1}^{dc} & S_{2,1}^{dc} & S_{1,1}^{cc} & S_{1,2}^{cc} \\ S_{1,2}^{dc} & S_{2,2}^{dc} & S_{1,2}^{cc} & S_{2,2}^{cc} \end{bmatrix}$$

S[D1,D1] and S[D1,D2] – **differential mode reflection and transmission**

S[D1,C1], S[D2,C2] – **near end mode transformation** or transformation from differential to common mode at the same side of the multiport

S[D1,C2], S[D2,C1] – **far end mode transformation** or transformation from differential mode on one side to the common mode on the opposite side of the multiport

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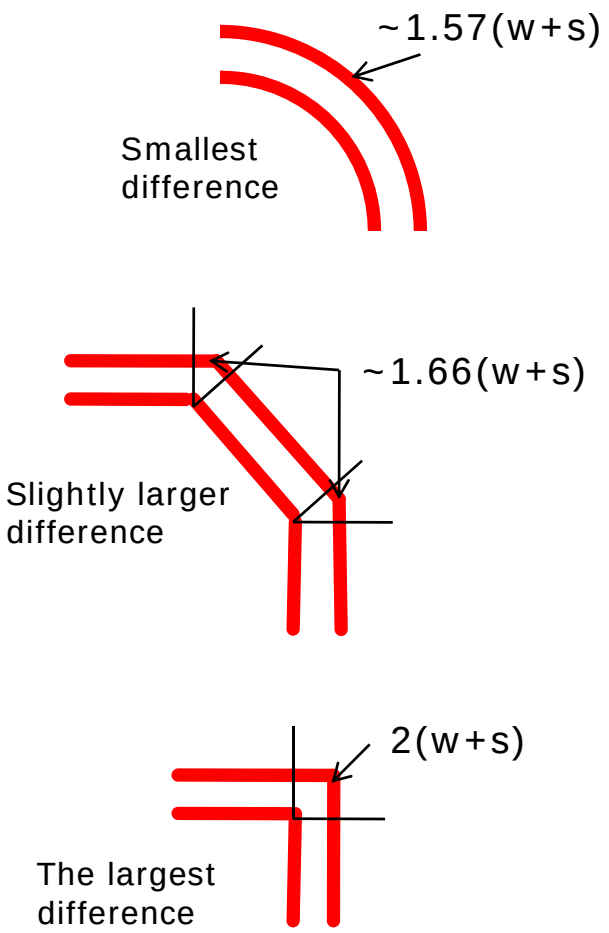
Qualitative analysis of differential bends

- Skew or mode transformation in bends is usually attributed to differences in lengths of the traces
  - That is how it is usually modeled in traditional SI software that uses static field solvers to extract t-line parameters and ignore the discontinuities like bends
- According to that measure the arched bend is better than two 45-degree and two 45-degree bend is better than 90-degree bend
- Is this correct statement? - Let's verify it with the rigorous EM analysis!



w is strip width and s is separation

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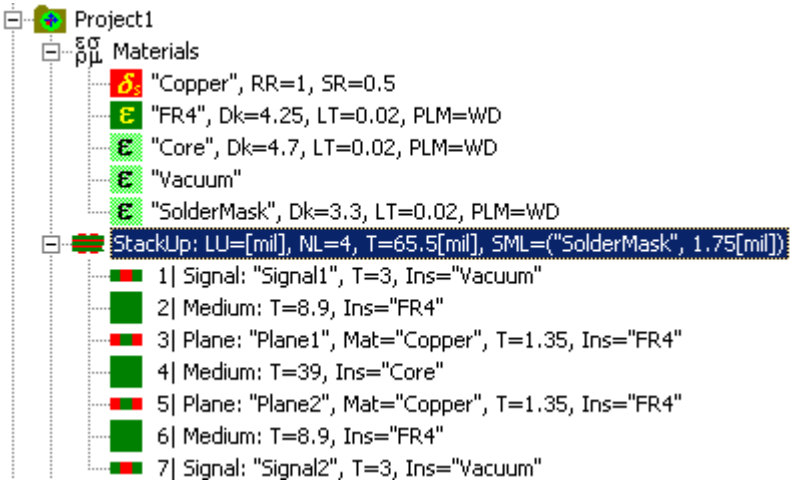
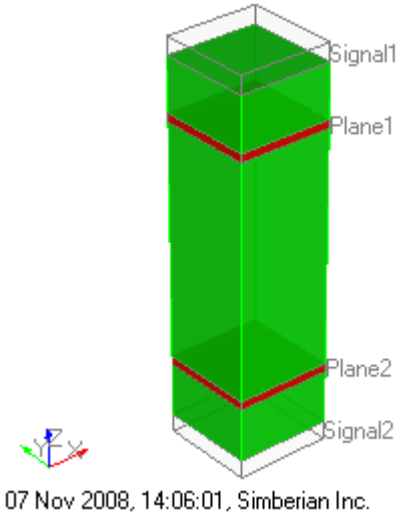
Materials and stackup for the experiment





- **Materials**:
  - Copper bulk resistivity 1.724e-8 Ohm meters, roughness 0.5 um (roughness factor 2 is guessed)
  - Solder mask: DK=3.3, LT=0.02
  - FR-4 core dielectric: DK=4.7, LT=0.02 @ 1 GHz
  - FR-4 dielectric between signal and plane layers: DK=4.25, LT=0.02 @ 1 GHz
  - All dielectrics are modeled with the Wideband Debye model

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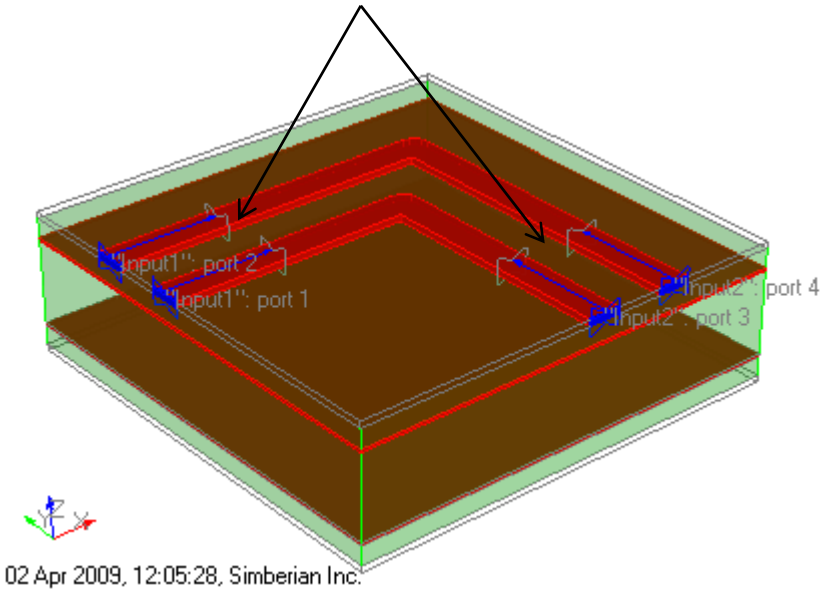
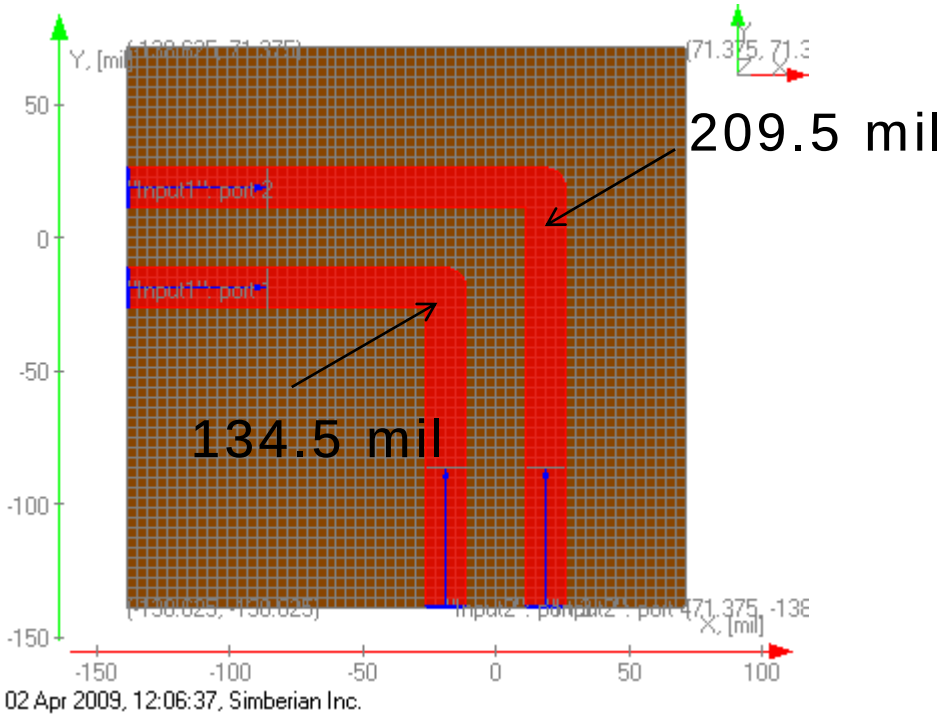
One 90-degree bend geometry

- Strip width 15 mil, separation 22 mil

Two-port inputs are de-embedded and S-parameters phase reference planes are shifted to these planes **(the same for all bends)**



Lengths difference is 75 mil



Circuit One90

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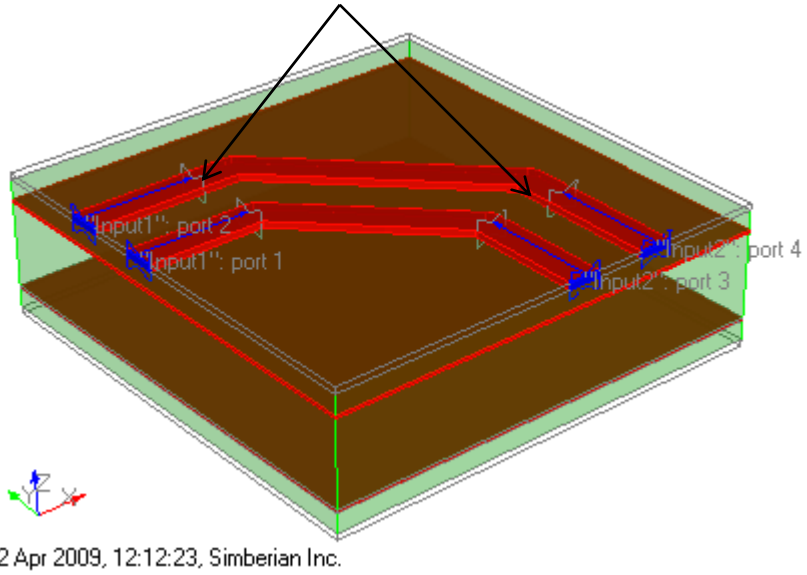
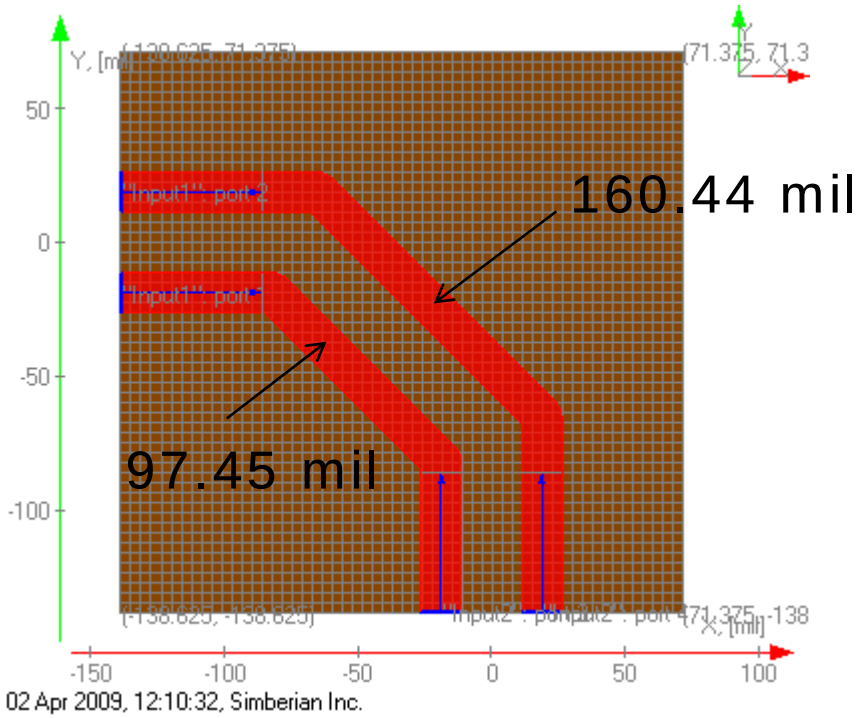
Two 45-degree bends geometry

- Strip width 15 mil, separation 22 mil

Two-port inputs are de-embedded and S-parameters phase reference planes are shifted to these planes **(the same for all bends)**



Lengths difference is 63 mil



Circuit Two45

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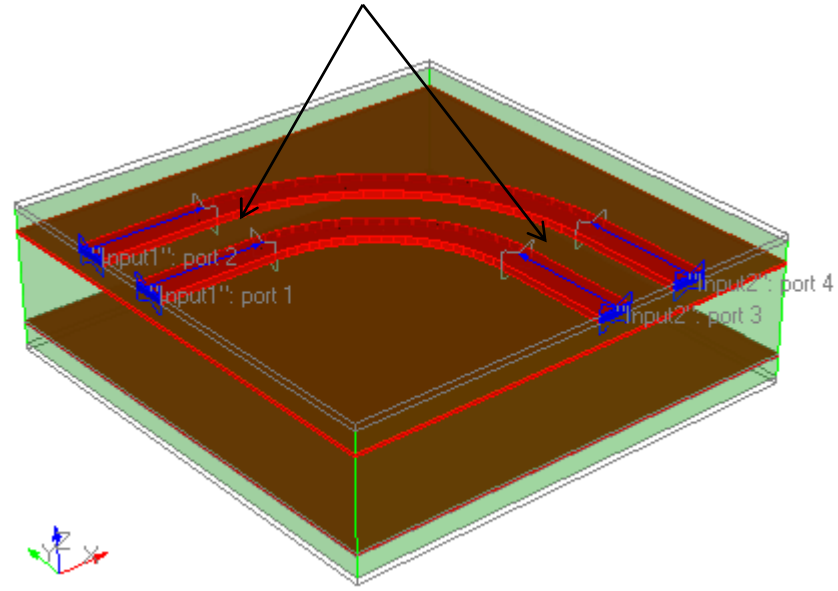
One arched bend geometry

- Strip width 15 mil, separation 22 mil

Two-port inputs are de-embedded and S-parameters phase reference planes are shifted to these planes **(the same for all bends)**



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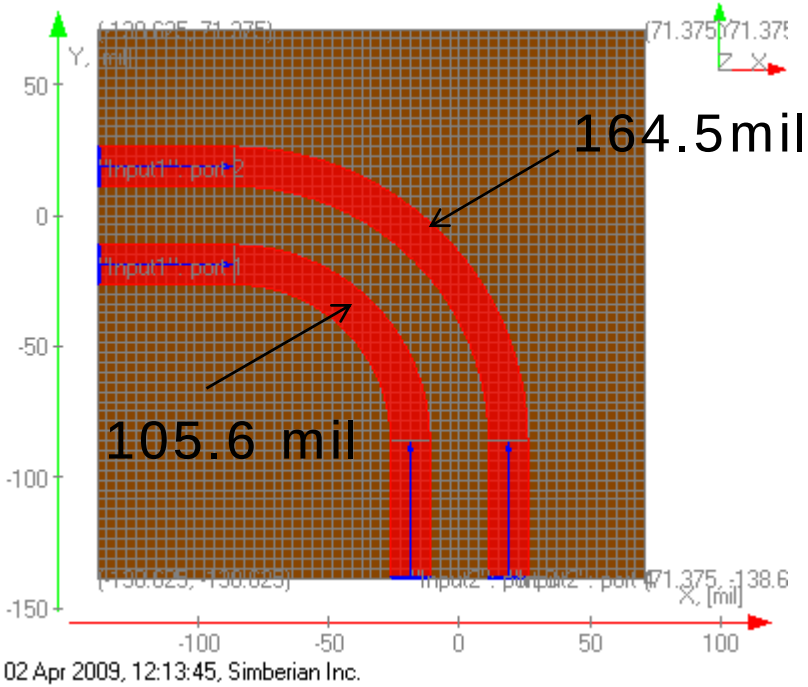
Lengths difference is 59 mil



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Circuit OneArched

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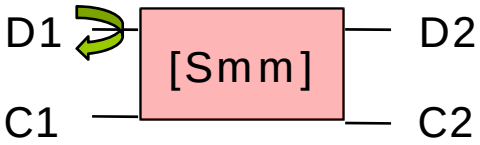
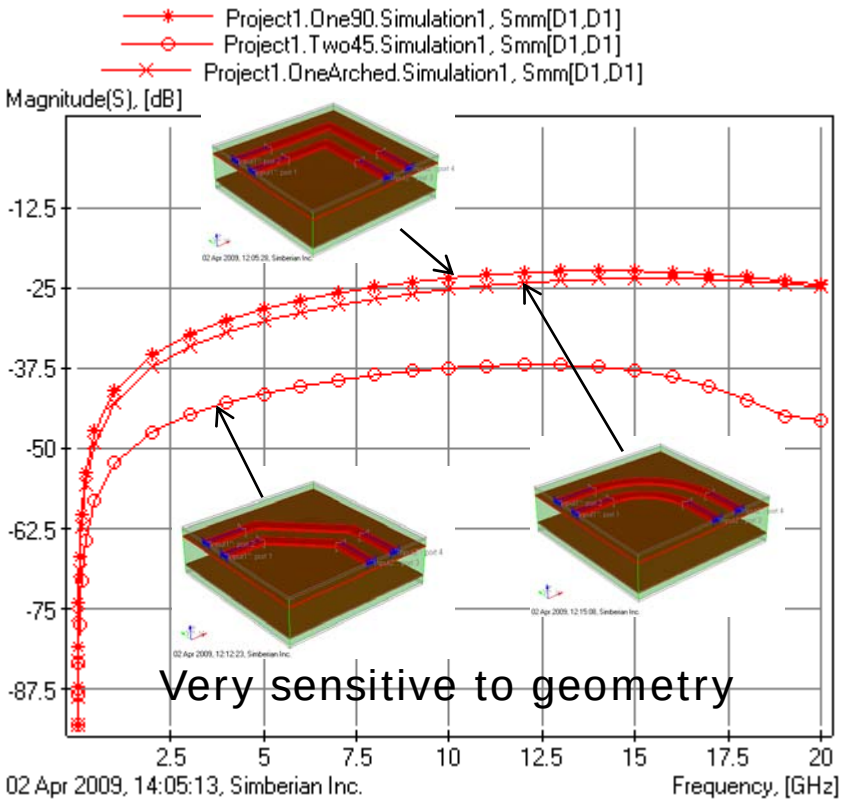
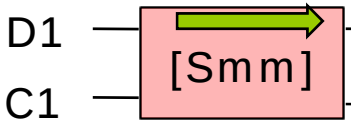
Differential reflection and transmission

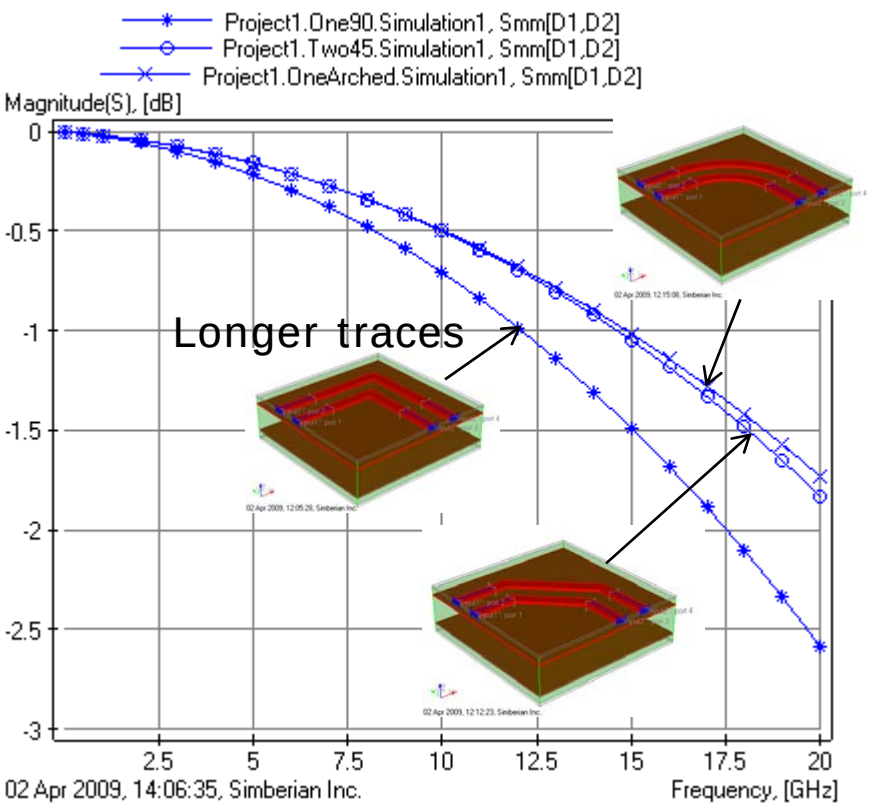
Differential reflection S[D1,D1]





Differential transmission S[D1,D2]





Practically no difference!

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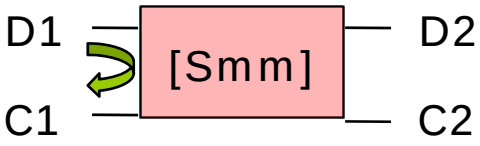
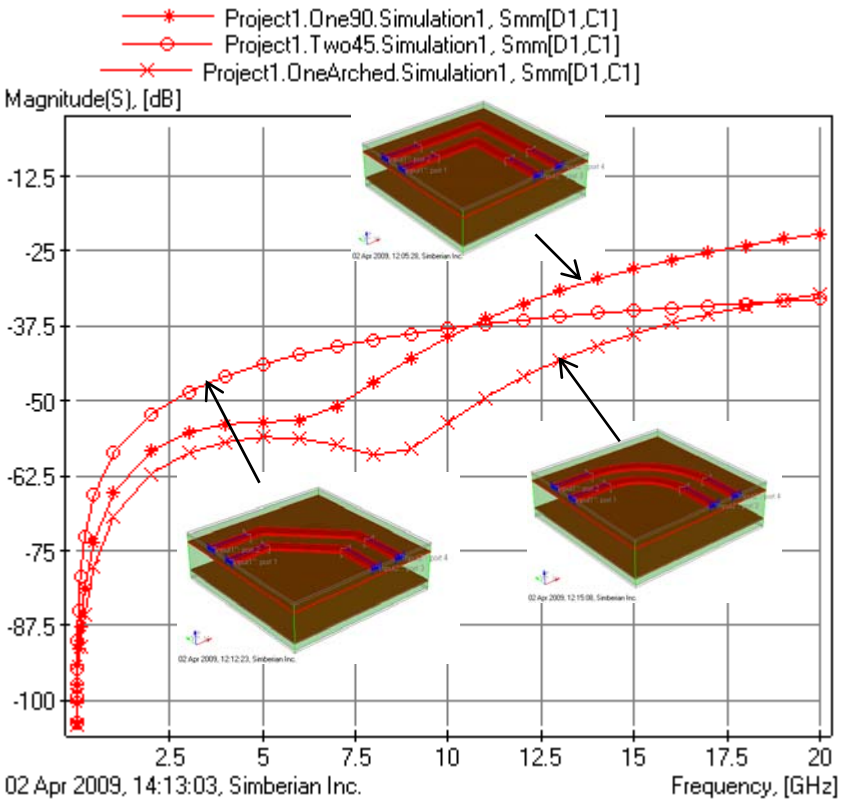
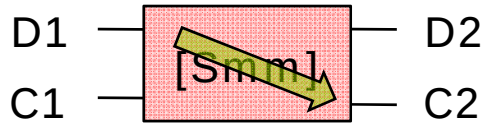
Mode transformation – EMI problem

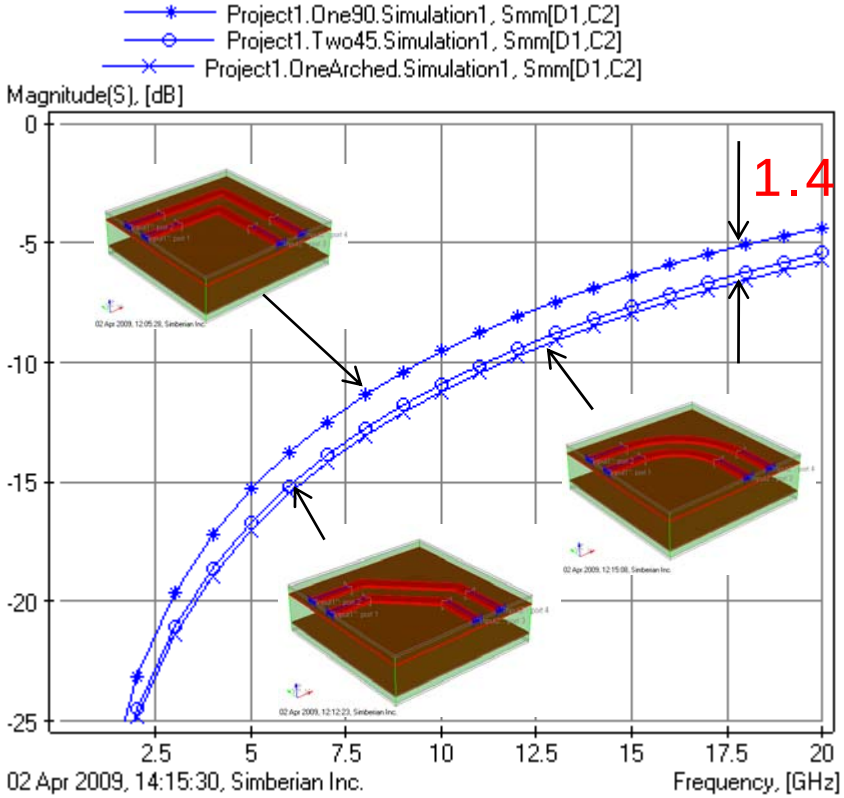
Near end S[D1,C1]





Far end S[D1,C2]





More transformation at 90-degree bend!

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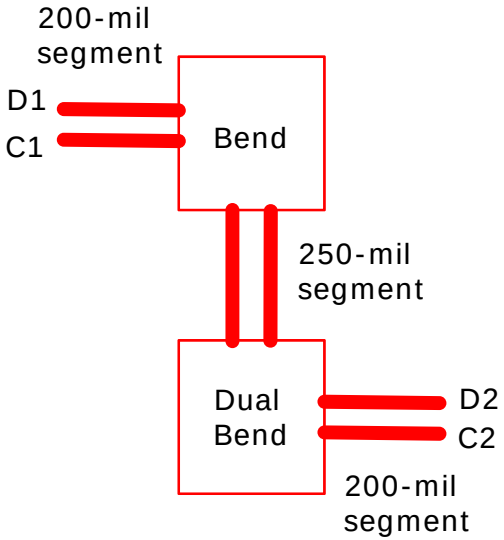
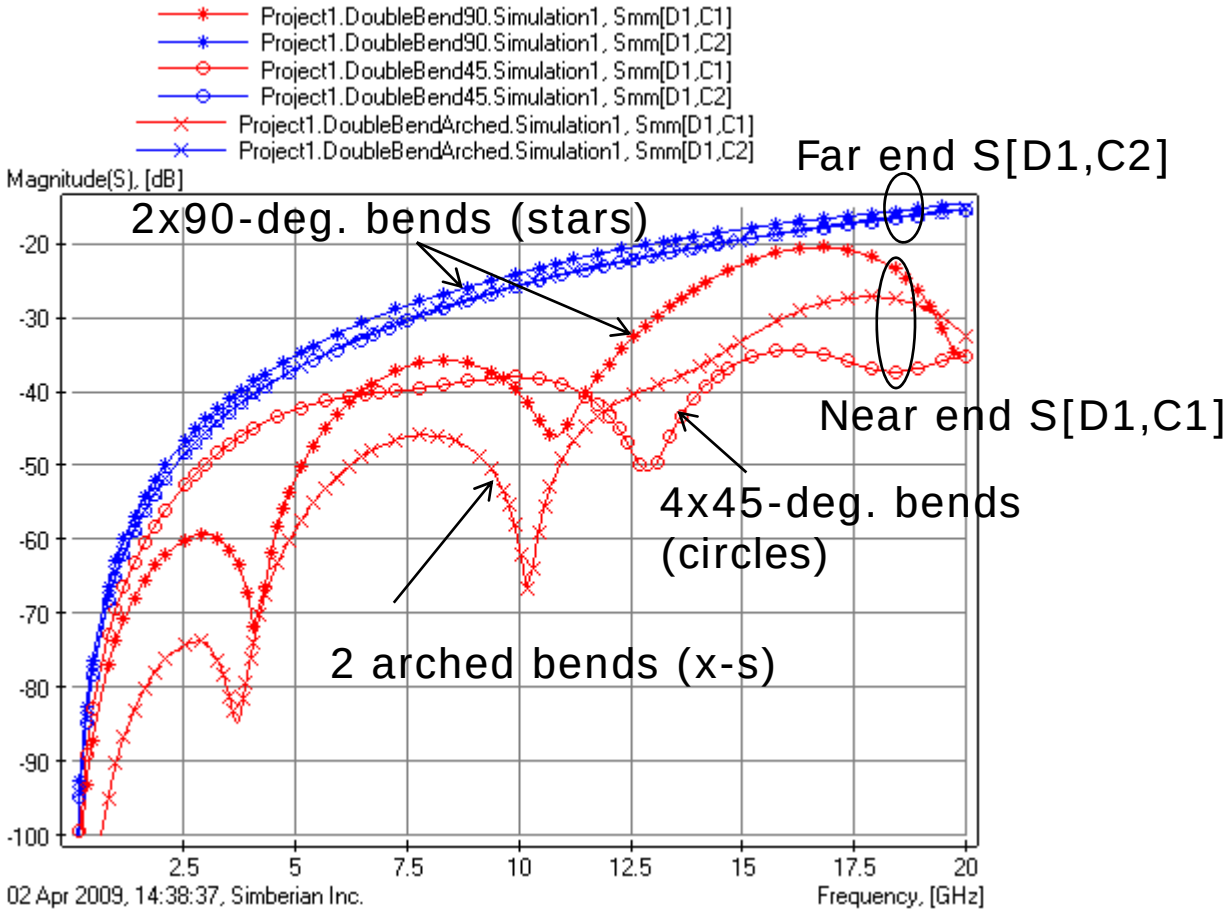
Use of dual bends to compensate mode transformation (close bends)

More transformation in two 90-degree bends!



Simbeor linear network solver is used to connect S-parameter models of bends with full-wave models of t-line segments



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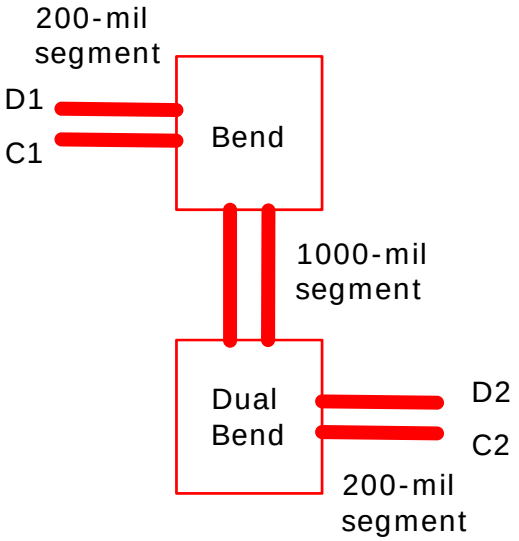
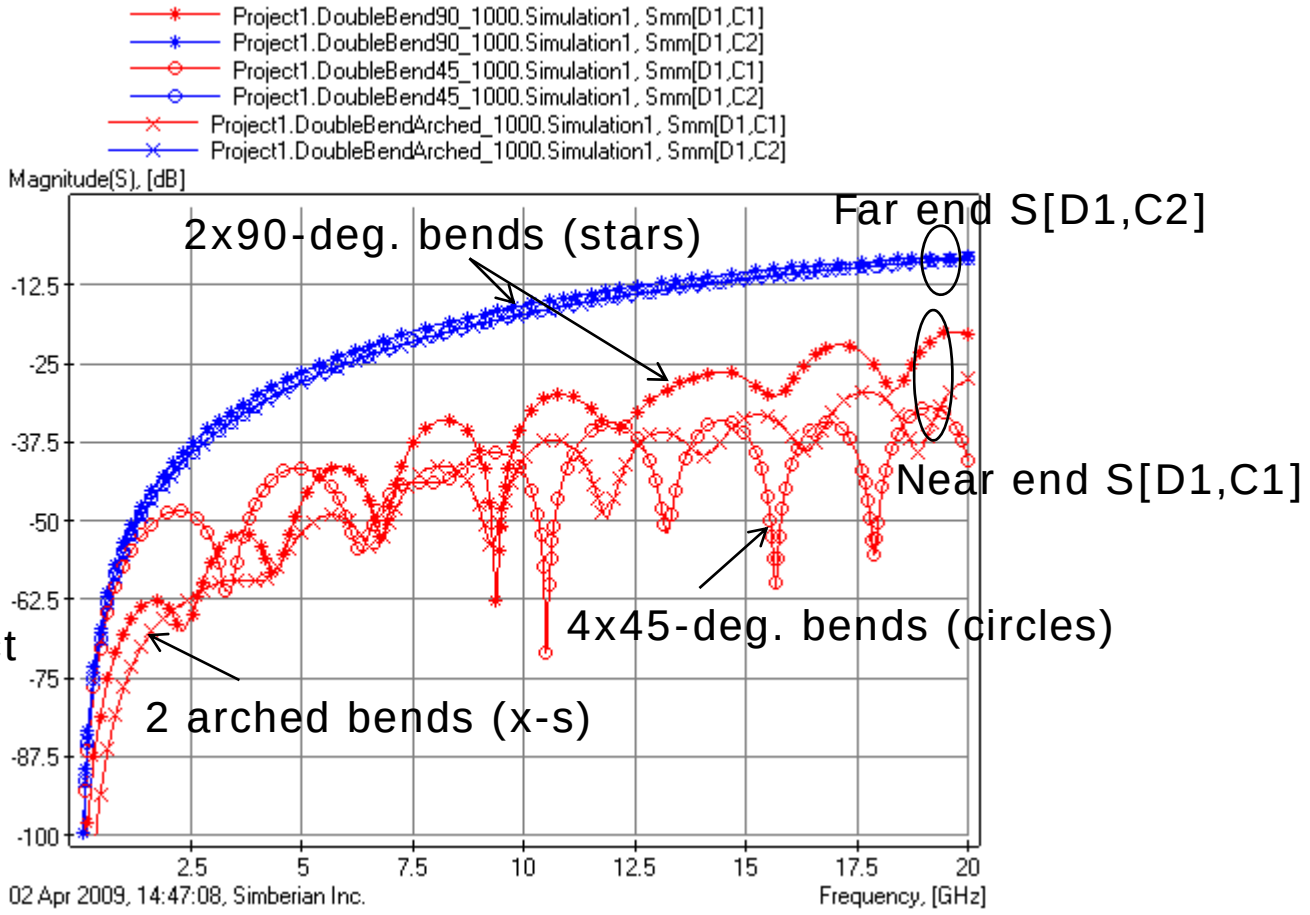
Use of dual bends to compensate mode transformation (remote bends)

More transformation in two 90-degree bends!





Simbeor linear network solver is used to connect S-parameter models of bends with full-wave models of t-line segments

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Conclusion

- In investigated case we observed more differential to common mode transformation at 90-degree bends
- Two 45-degree bends behaved practically identical to the arched bends (difference may be not distinguishable in practice)
- The observed mode transformation may have minor effect on signal quality in all cases (signal integrity), but may have more serious consequences on EMI if common mode is not appropriately terminated
- The results cannot be generalized
- Different stackup and trace geometry may produce different results and lead to a different conclusion
- 3D full-wave analysis is recommended in each case to create design rules or to simulate signal path at multi-gigabit data rates!

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Solutions and contact

- Setting up all simulations and analysis took less than 1 hour
- Simbeor solution file used to illustrate these notes is available for download from Simberian web site
  - http://www.simberian.com/AppNotes/Solutions/ComparisonOfDiffBends_2009_02.zip
- Send questions and comments to
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