# Modeling differential via-holes without stitching vias

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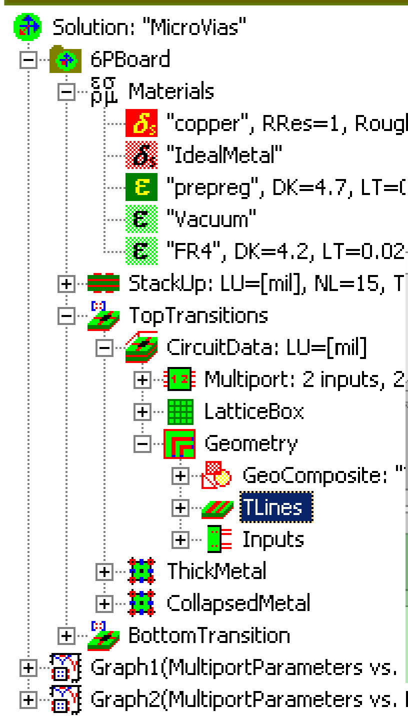


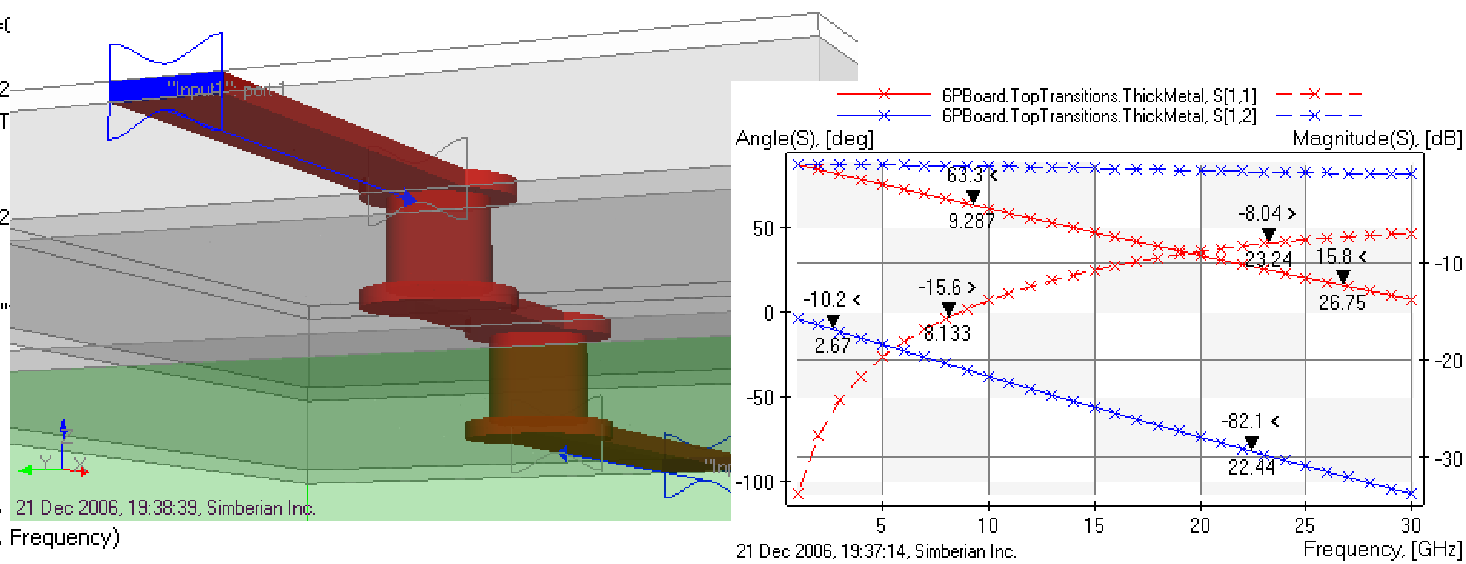


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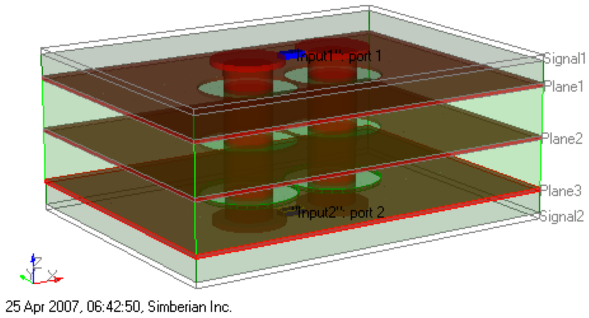
# Introduction

- Electromagnetic simulation of differential vias without vias stitching the reference planes introduces uncertainty in the analysis of the multi-gigabit data channels
- The goal is to investigate possible ways to simulate differential multi-gigabit channels with localizable 3D full-wave S-parameter models extracted with Simbeor 2007
- Use HyperLynx 7.7 with Eldo from Mentor Graphics Corporation for system-level analysis

# What is the differential via?

- Differential vias are two-viahole transitions through multiple parallel planes

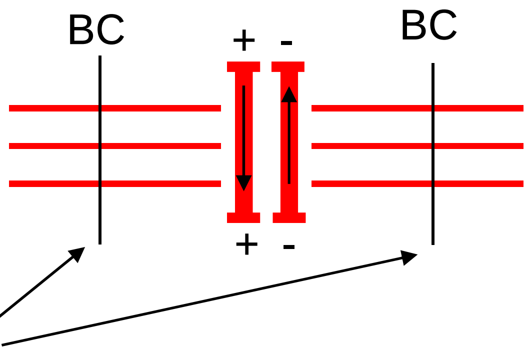



- Two modes propagate independently trough a **symmetrical** via pair
  - Differential (+-) – two vias are two conductors
  - Common (++) – two vias one conductor and parallel planes with everything attached to them is another conductor
- Signal in differential pair always contain differential mode (useful) and may contain common mode induced by asymmetries in driver and discontinuities

# S-parameter models for differential vias

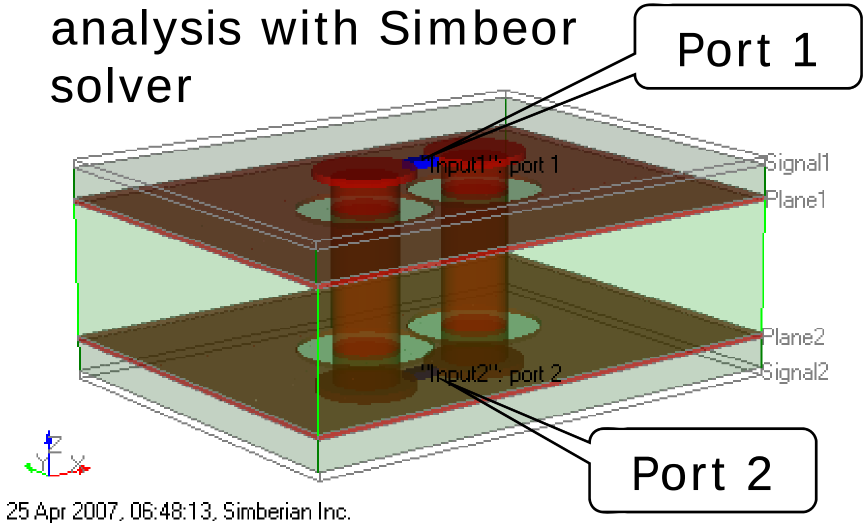
- Differential mode has two identical currents on the via barrels

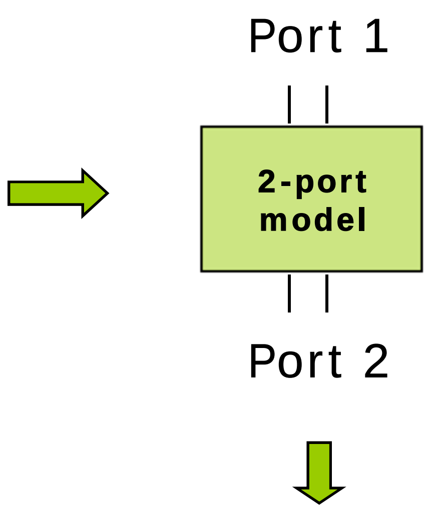



- The vias can be isolated from the rest of the board for the electromagnetic analysis with any boundary conditions (BC)
  - Distance from the vias to the simulation area boundaries should be larger than the largest distance between the planes to reduce the effect
  - In that case, the differential mode S-parameters are practically independent of the boundary conditions

# Any 3D full-wave solver can be used to generate a differential via model

Differential via-holes analysis with Simbeor solver

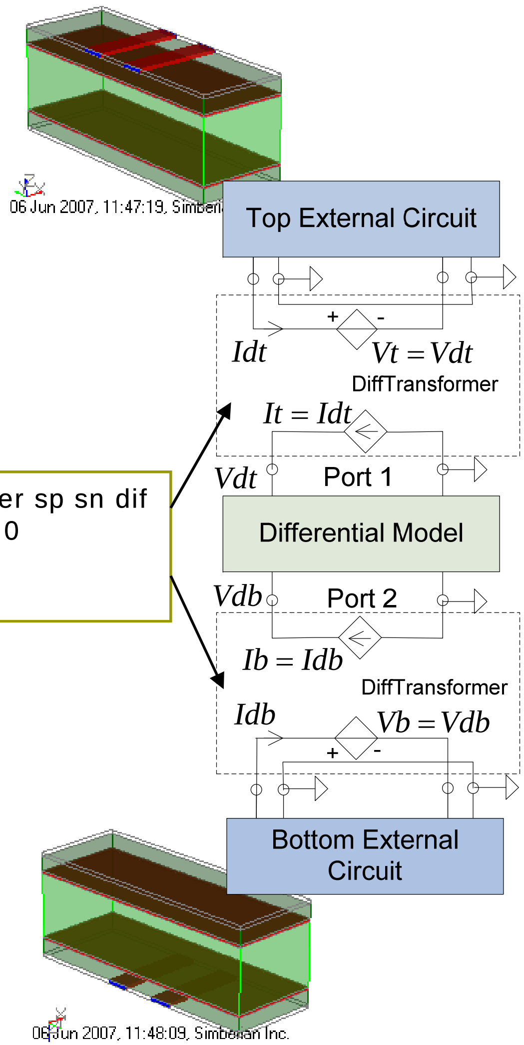



Solver generates Touchstone s2p file with tabulated scattering (S) parameters

```
# Hz S MA R 50
!Touchstone multiport model file <Project1_DifVias_Simulation1.s2p>
!Created with Simbeor 2007.05

!Frequency Hz |S[1,1]| arg(S[1,1]) |S[1,2]| arg(S[1,2]) |S[2,1]| arg(S[2,1]) |S[2,2]| arg(S[2,2])
1e+007 0.00019967204037128 80.2602696805706 0.99996135358717 -0.0323490304593697 0.999961353587184 -0.0323490304593693 0.000199673211473872 80.2582768233478
 1.6681e+007 0.000322468838468293 82.6000881350992 0.999950431873029 -0.0533202384129493 0.999950431873026 -0.0533202384194636 0.000322467239270051 82.6017028071304
 …
 …
 1.9e+010 0.244570464339174 35.2840265413718 0.961777164971986 -55.3104068976763 0.961777164971987 -55.3104068976763 0.244498847955767 35.2671173277359
 2e+010 0.248547099289332 32.5237839600036 0.960378206732979 -58.1318674656129 0.960378206732979 -58.1318674656129 0.248469713303658 32.5058580236588
```

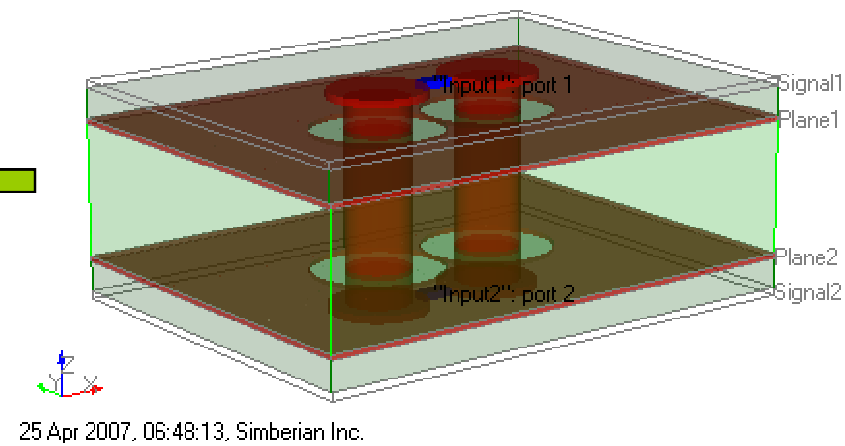
# Differential via-hole model in the system-level analysis




```
.subckt DiffTransformer sp sn dif
e1 sp sn trans dif 0 1.0
f1 0 dif e1 1.0
.ends DiffTransformer
```

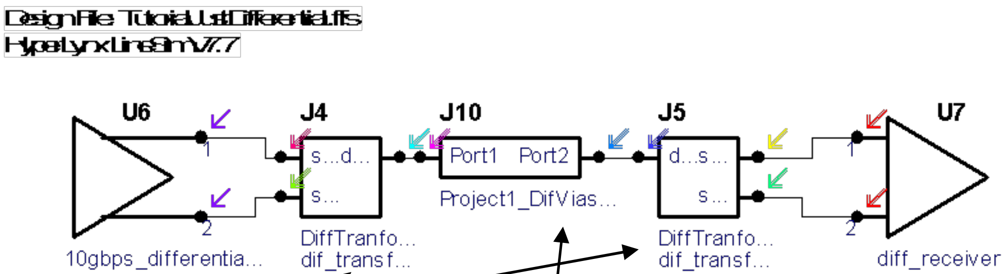
2 CCCS and 2 VCVS can be used to convert the 2-port differential model into 4-port

Common mode is open-circuited (reflected)



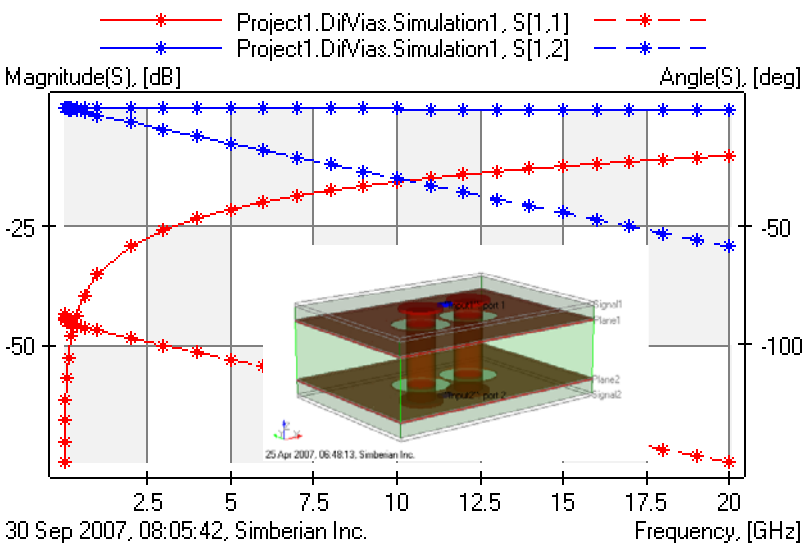

  

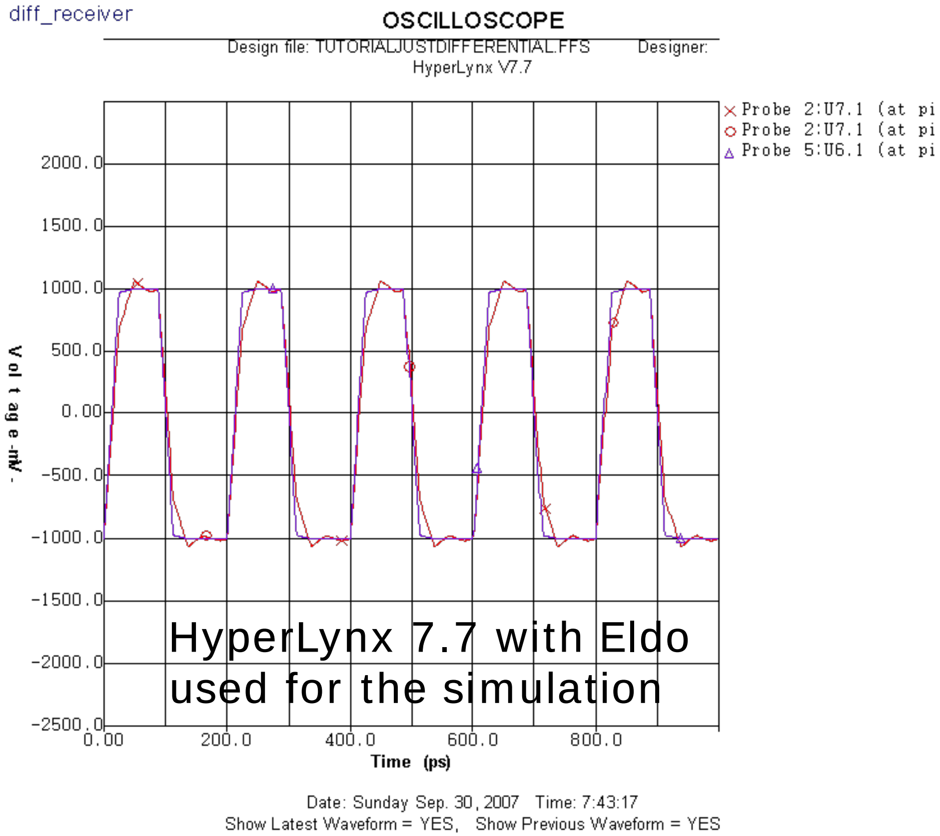
# Example of a differential channel analysis with just differential model of via-holes




Propagation of 10 Gbps differentia signal through pair of via-holes (not optimal vias are from Simbeor Tutorial 3)

```
.subckt DiffTransformer sp sn dif
e1 sp sn trans dif 0 1.0
f1 0 dif e1 1.0
.ends DiffTransformer
```

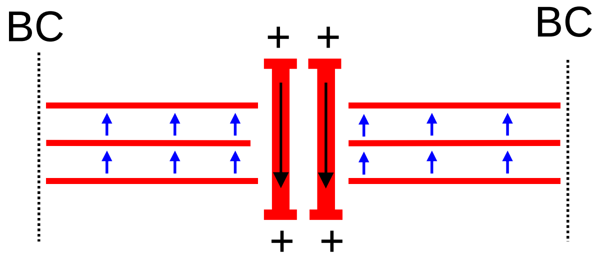


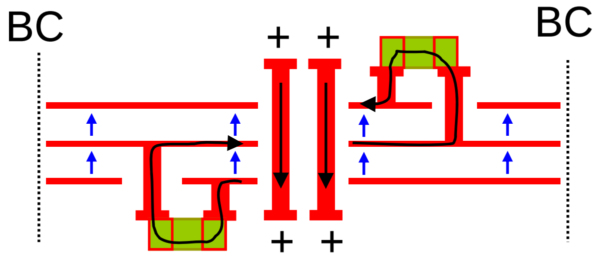

HyperLynx 7.7 with Eldo used for the simulation

# What about modeling vias with the common mode?

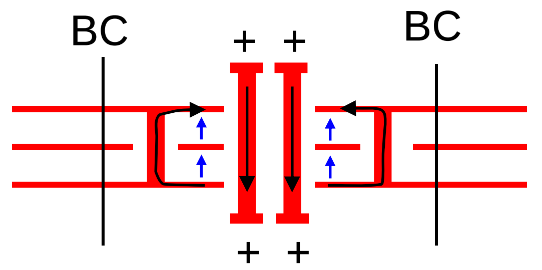
- Planes are not terminated and the return current for common mode is the "displacement" current between the planes
  - The problem is non-localizable – may require analysis of the whole board




- Planes are terminated with the decoupling capacitors and the return current is a combination of the "displacement" currents through capacitors and planes
  - Decaps have low impedance only in a narrow band – thus the problem again is non-localizable for broadband EM analysis




- Stitching vias are used to connect the reference planes for the connected layers and the return current is mostly conductive
  - Problem can be localized (localizable) and solved with any boundary conditions



# Non-localizable cases without stitching vias

- In general, the common-mode part of S-parameter model becomes dependent on the simulation area and boundary conditions
  - Independence of the boundary conditions indicates that the problem is localizable
- Any type of locally enforced boundary conditions is not correct for the non-localizable problem
  - PEC (perfect electric conductor walls) are equivalent to short-circuiting the planes at a distance from vias – preferable
  - PMC (perfect magnetic conductor walls) are equivalent to open-circuiting the planes at a distance from vias – incorrect low frequency asymptotic of S-parameters
  - PML (perfectly matched layer) or ABC (absorbing boundary conditions) – absorbs energy at a distance from vias
    - Not equivalent to the infinite planes (infinite planes or radial waveguides reflect energy at any location because of changing impedance)
    - Common mode energy is completely lost for the system level analysis (it will appear somewhere)

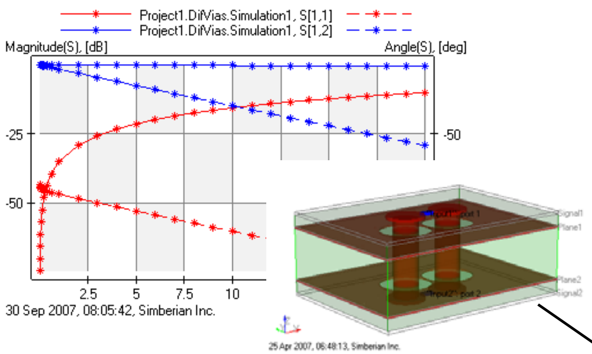
# How to simulate differential vias with the common mode?

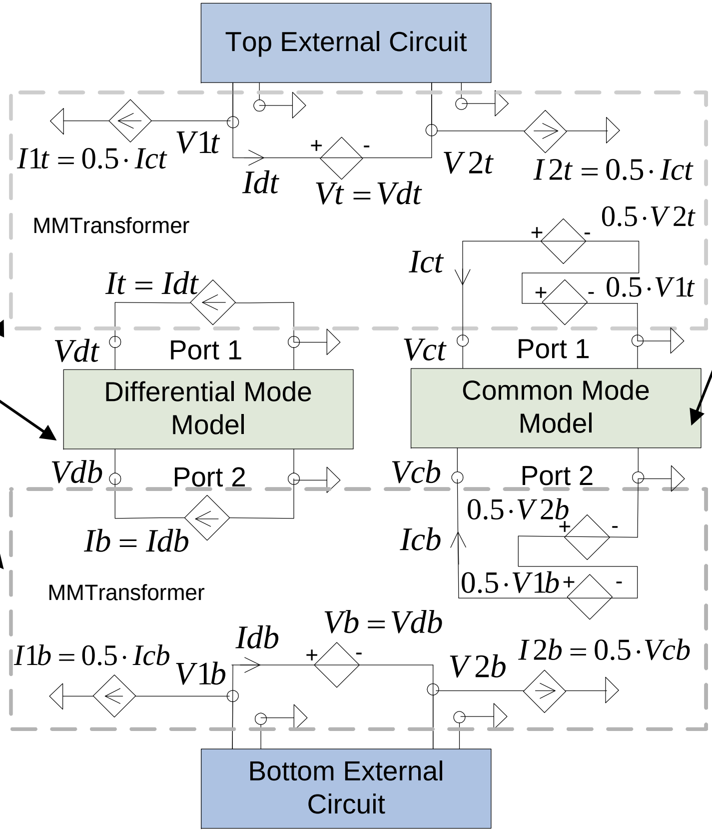
- Simulate the whole board in a 3D full-wave solver with all plane terminations
  - Hardly ever possible and not practical
- Use a hybrid solver with 2D parallel-plane models
  - Practical, but accurate only if such solvers include 3D full-wave models for differential mode (<u>no such solvers available so far</u>)
- Localize the problem with asymptotically correct PEC boundary conditions
  - Influence of the boundary conditions on the performance at the system level may be insignificant in many cases
  - May work if no common mode or it is very small at the connections to the vias

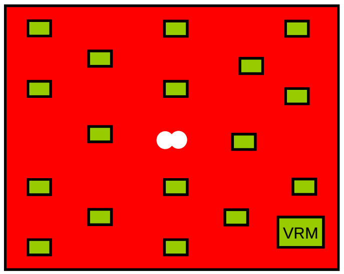
# Separation of differential and common mode at a differential via-holes for hybrid analysis

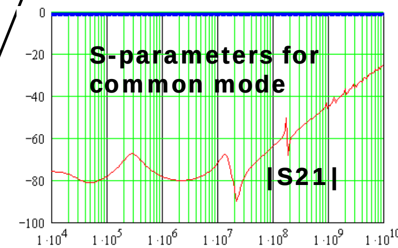
Differential mode model can be created with any 3D full-wave solver

Common mode models can be created with a 2D transmission plane solver



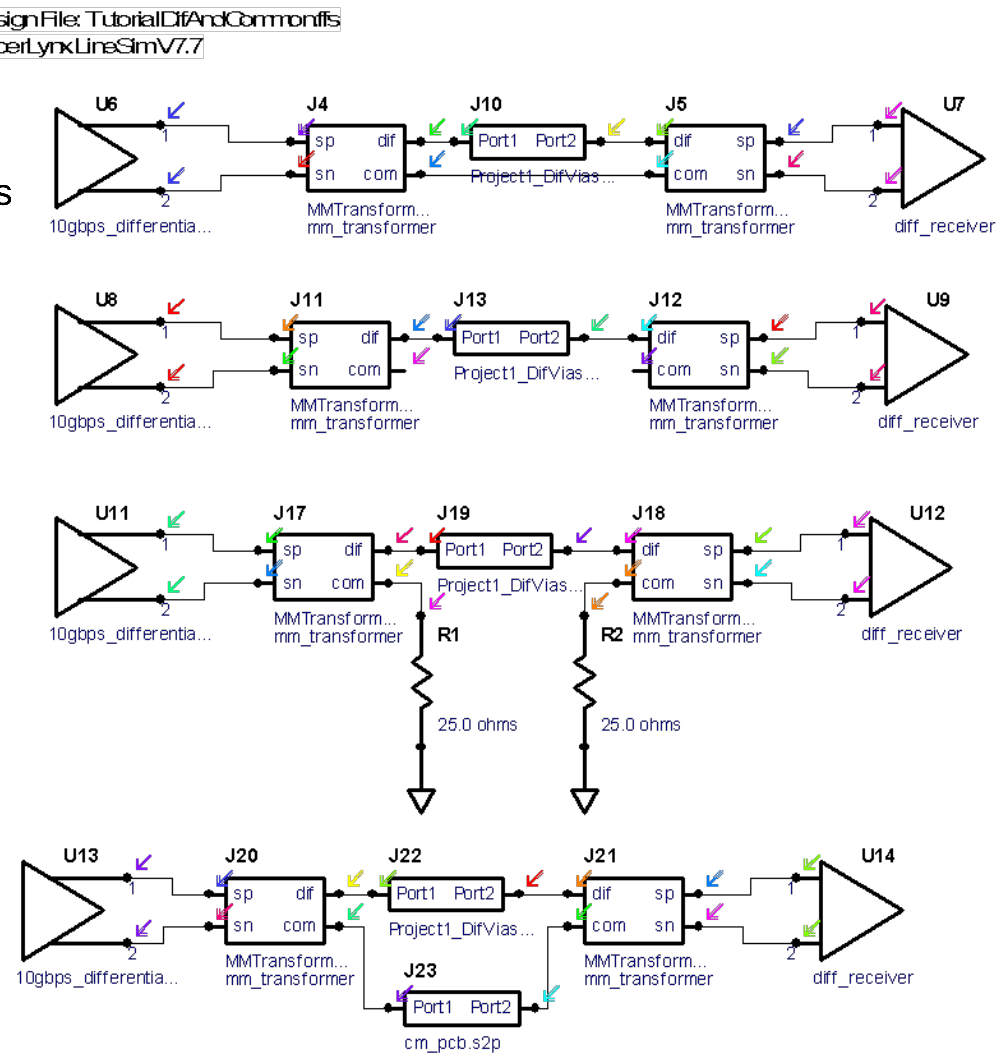




```
subckt MMTransformer sp sn dif com

*transformeter to and from differential
e1 sp sn trans dif 0 1.0
f1 0 dif e1 1.0

*transformer to and from common
f2 sp 0 e2 0.5
f3 sn 0 e3 0.5

e2 0 n1 trans sp 0 0.5
e3 n1 com trans sn 0 0.5

.ends MMTtransformer
```

# Comparison of different common-mode termination conditions without skew



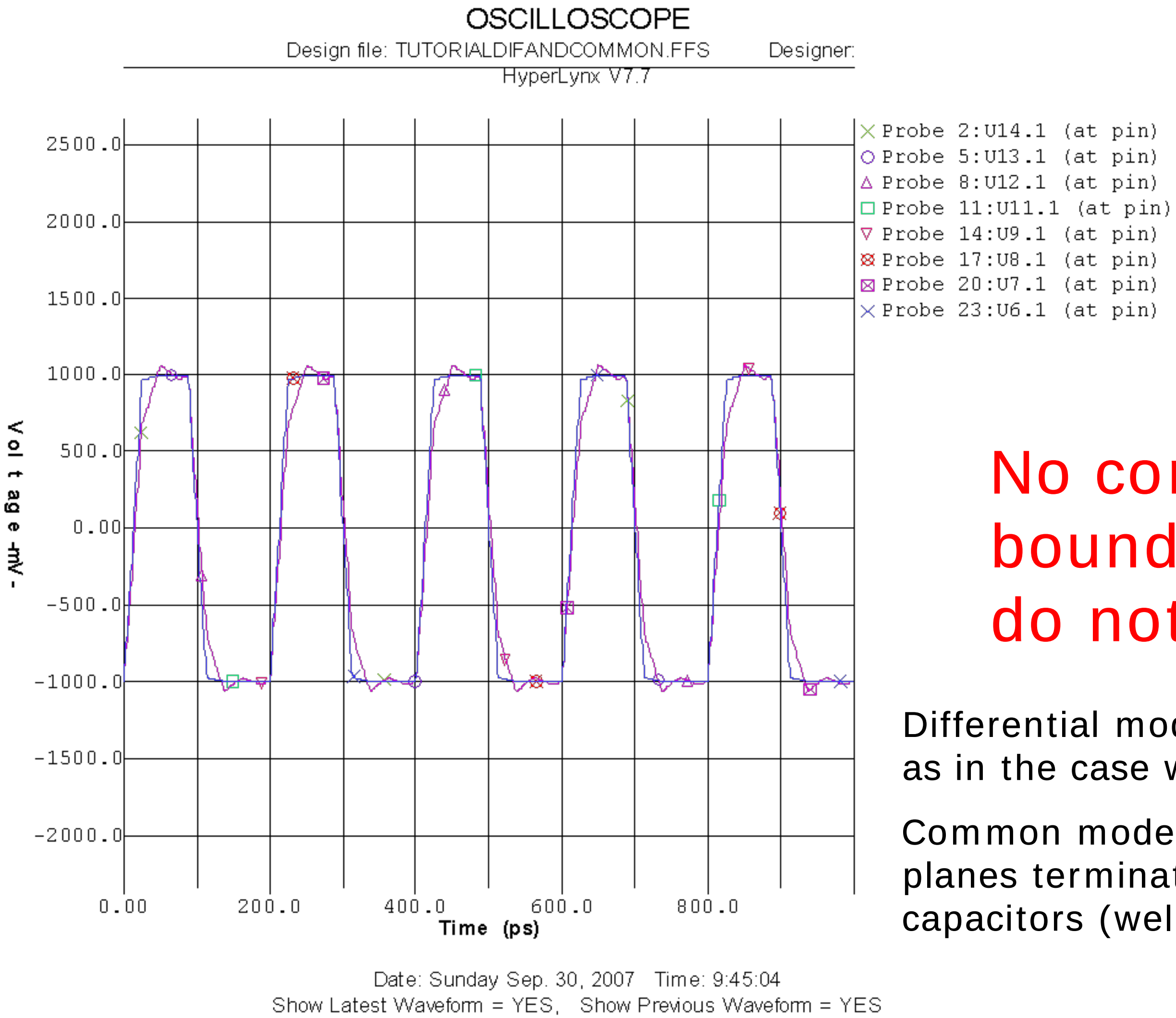

1. Common mode propagate through vias – PEC-like conditions

2. Common mode reflected – PMC-like conditions

3. Common mode absorbed – ABC-like conditions

4. Common mode terminated with 2-port model of decoupled PDN

# All terminations are identical because of no common mode in the channel




No common mode – boundary conditions do not matter!

Differential mode model of via is the same as in the case with differential only model

Common mode model is transmission planes terminated with multiple decoupling capacitors (well-decoupled planes)

# Comparison of different common-mode termination conditions with 20 ps skew

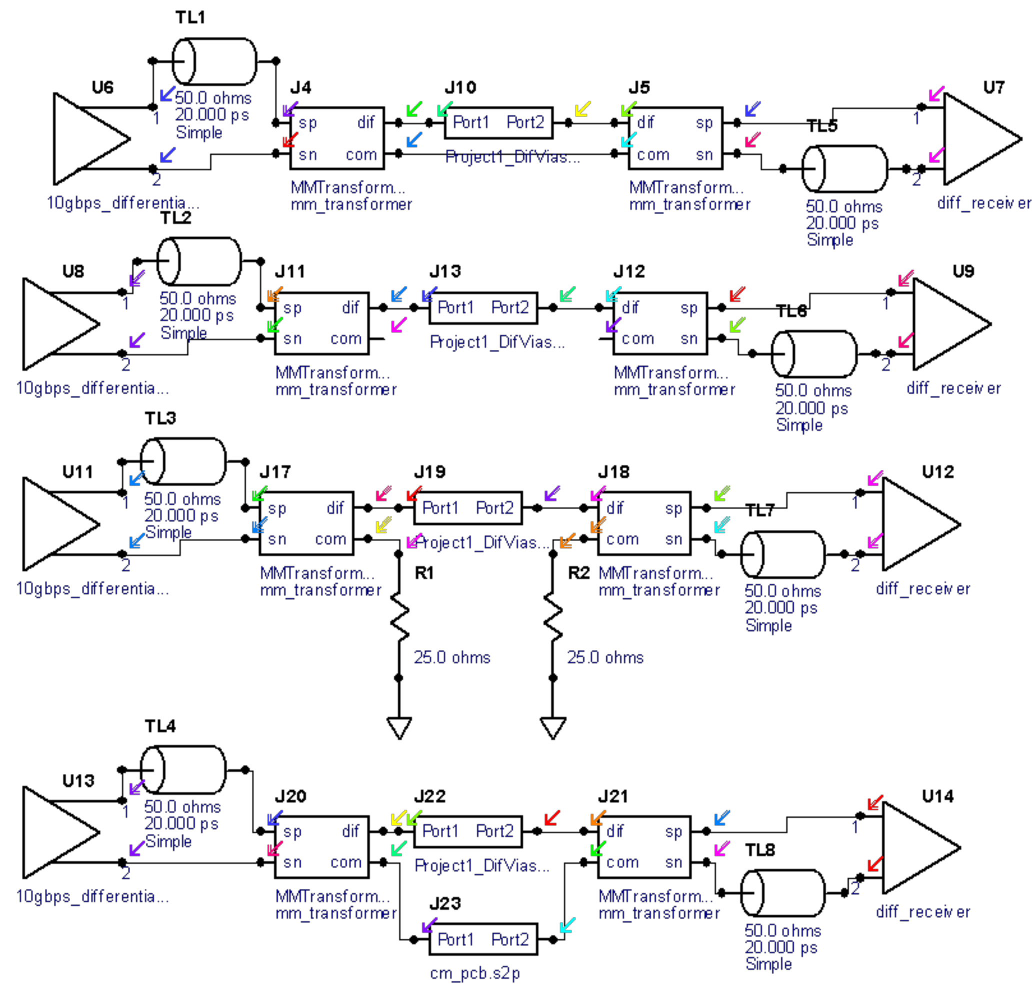
Design File: TutorialDifAndCommonSkewed.ffs
HyperLynx LineSim V7.7

1. Common mode propagate through vias – PEC-like conditions

2. Common mode reflected – PMC-like conditions

3. Common mode absorbed – ABC-like conditions

4. Common mode terminated with 2-port model of decoupled PDN

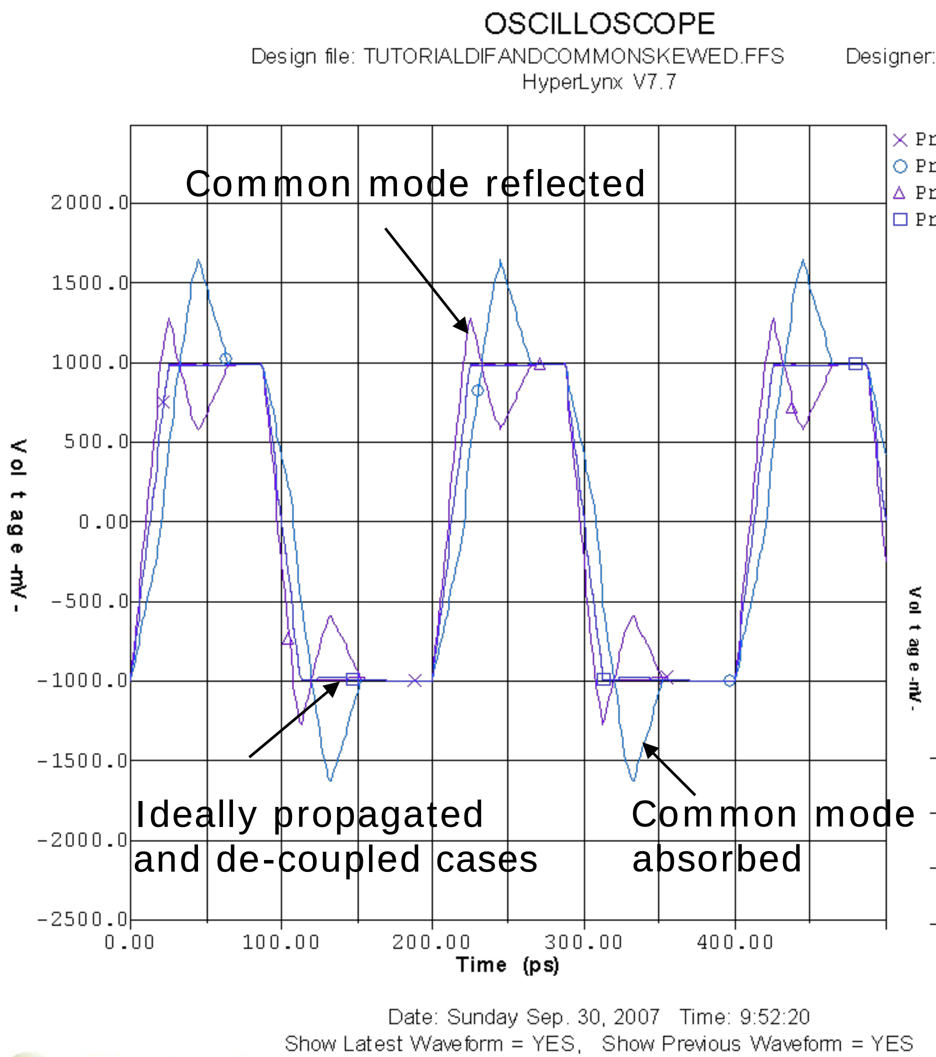


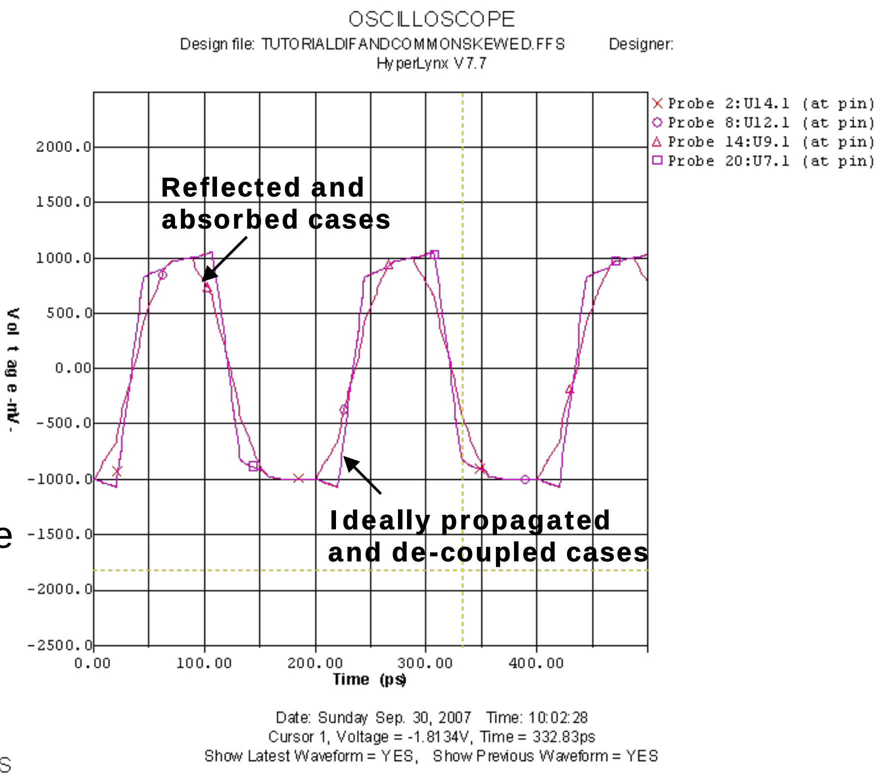

  

# Differential signal reflection and transmission

Now termination matters!

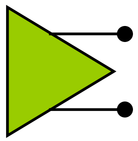
Different boundary conditions produce different results!



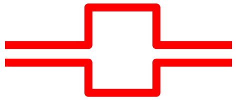



# Avoid conversion from differential to common mode by design!

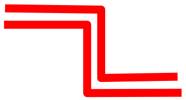
- Use symmetrical drivers and receivers that do not generate common mode



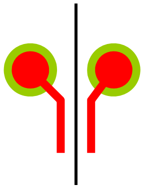
- Keep traces at the same distance and bypass discontinuity symmetrically if absolutely necessary



- If a discontinuity converts differential mode into common – use mirror discontinuity to convert it back into differential mode



- Via-holes and transition to the traces have to be symmetrical



- Common mode analysis is not necessary if no common mode generated

# Conclusion

- Localized 3D full-wave analysis of the common mode propagation through differential vias without stitching vias is not correct with any type of boundary conditions
  - Only hybrid model combining 3D full-wave differential mode model with a system-level 2D transmission plane model of PDN can reliably predict the transition of common mode through the via pair
- Stitching vias connecting reference planes of the input and output transmission lines allow to localize the problem and to avoid the hybrid system-level analysis
- Common mode can be reduced by design – any localized model for common mode can be used in this case

# Solutions and contact

- Solution files and HyperLynx schematic files are available for download from the simberian web site
  http://www.simberian.com/AppNotes/Solutions/DiffViasWithCommonMode_2007_07.zip
- Send questions and comments to
  - General: info@simberian.com
  - Sales: sales@simberian.com
  - Support: support@simberian.com
- Web site www.simberian.com