Simberian
Electromagnetic Solutions

Effect of slots in reference planes on signal propagation in single and differential t-lines

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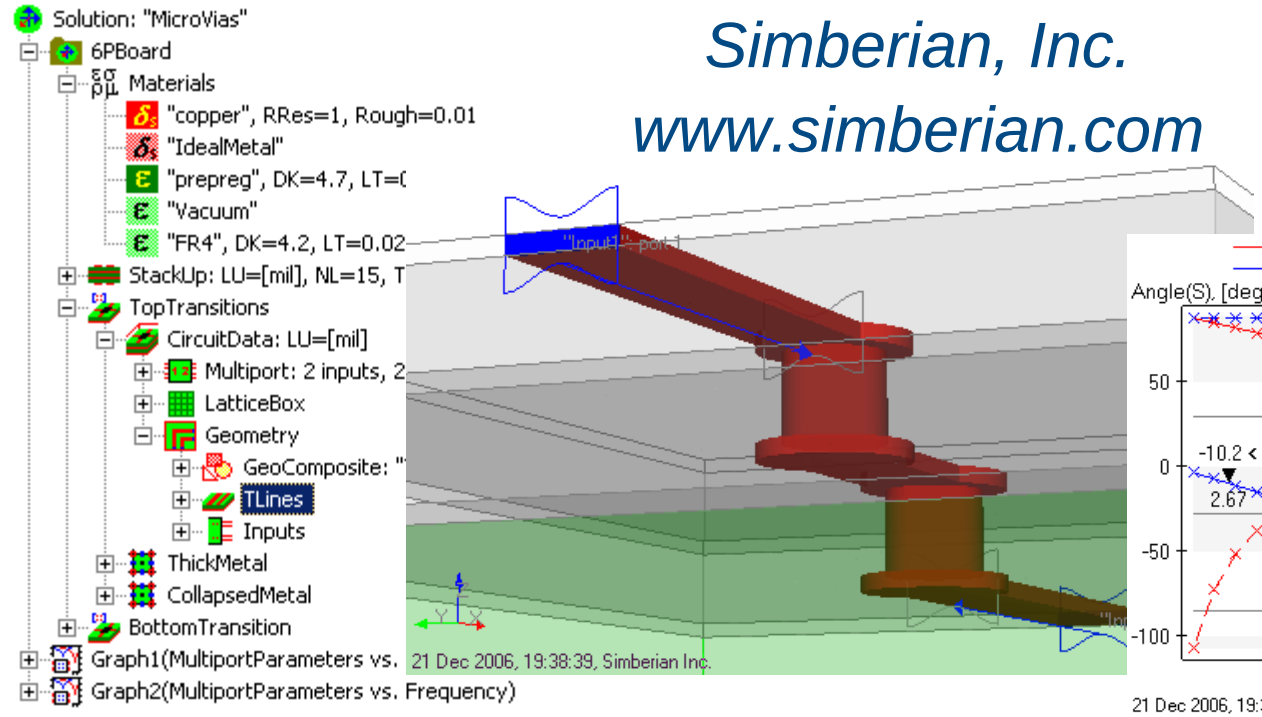
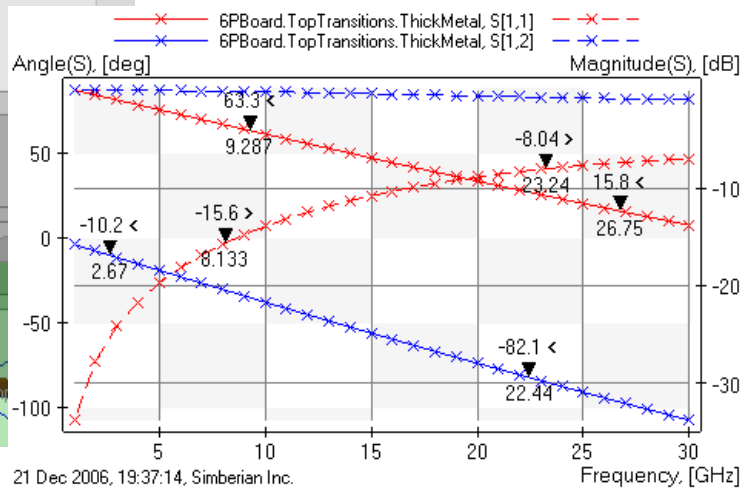




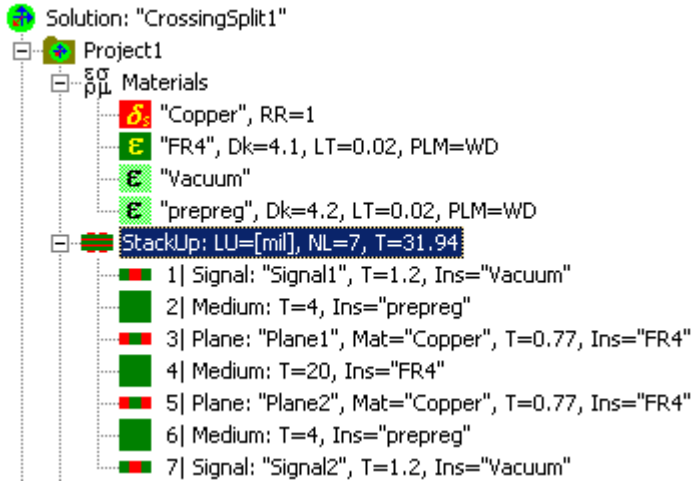
Introduction

- Routing traces over splits in reference planes may cause significant signal degradation in multi-gigabit data channels
- To maximize the transition of the signal over the splits and minimize the reflection, stack-up has to be optimized to minimize the effect of the splits
- This example demonstrates how to use electromagnetic simulator for quantitative analysis of the effect of slot in a reference plane on S-parameters of a small trace segment
- Simbeor 2007 full-wave 3D solver for multilayered circuits is used to generate the results

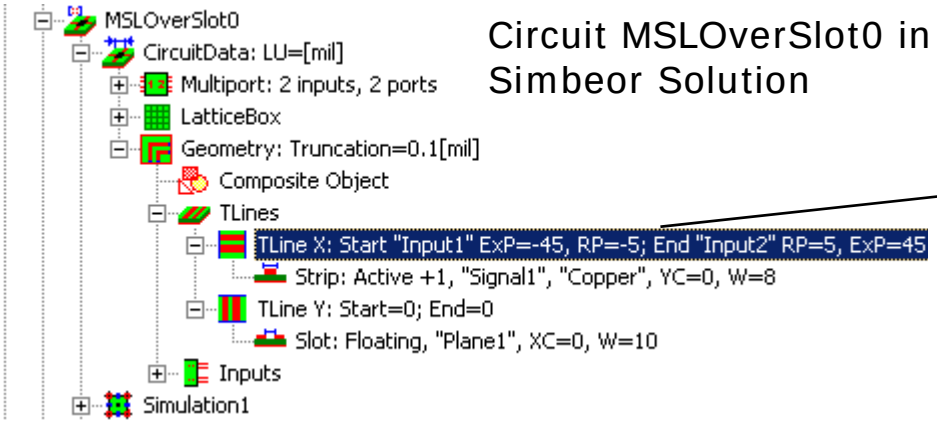
Micro-strip line segment (no slot yet)

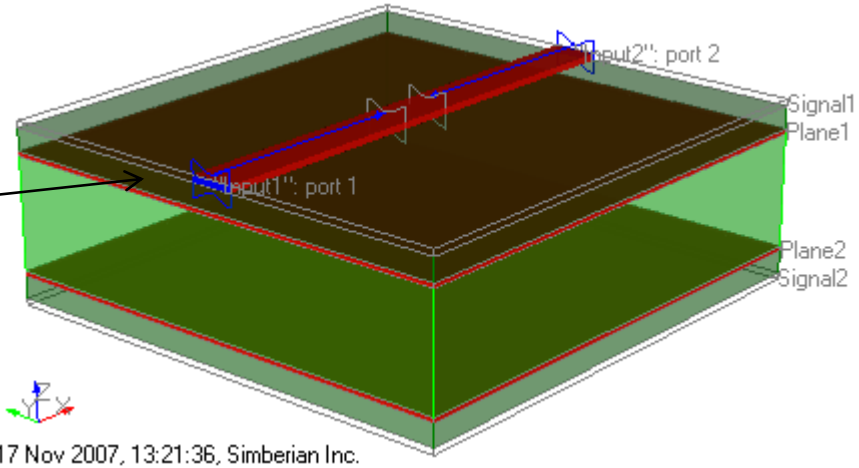
- Simple 4-layer stackup
- Wideband Debye dispersion and loss models used for the dielectrics
- 8-mil wide micro-strip line segment in the topmost layer “Signal1”

Materials and stackup in Simbeor Solution

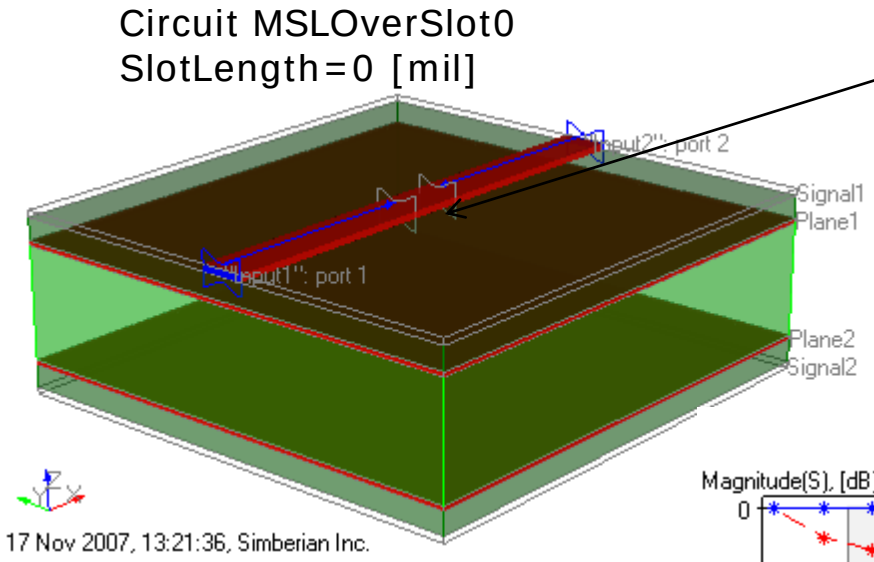


Circuit MSLOverSlot0 in Simbeor Solution



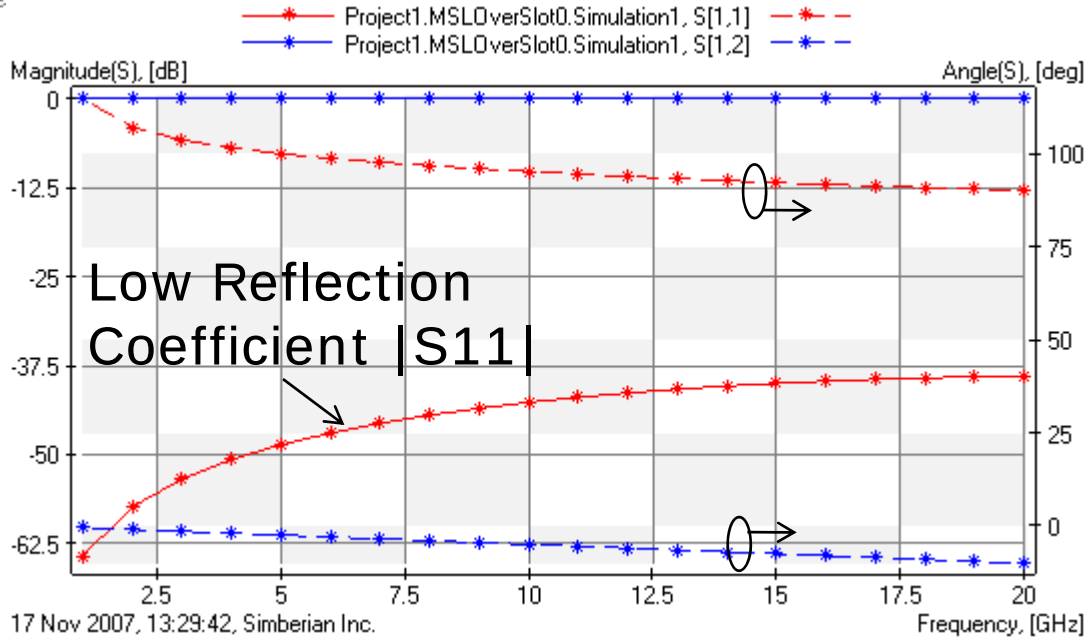


S-parameters of a small micro-strip line segment (simulation set-up calibration)



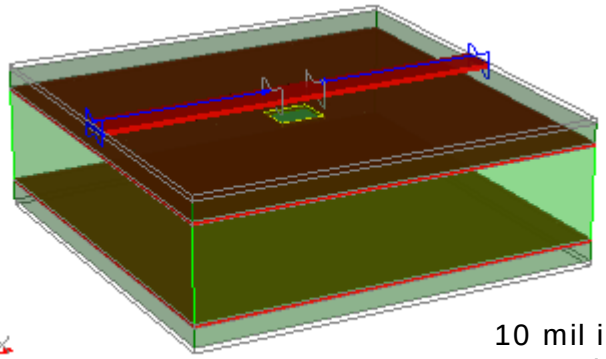
Ports de-embedded to have just 10-mil line segment in the middle (where the slot will be located)

S-parameters are normalized to 50 Ohm and characteristic impedance changes with frequency, that causes increase of reflection at higher frequencies (reaches about -40 dB at 20 GHz)



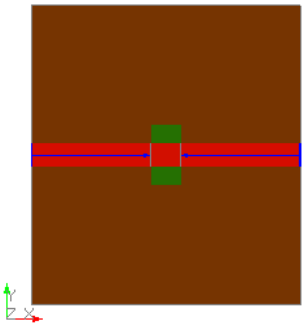
5 circuits with different slot length and slot width 10 mil (size along the t-line)

Circuit MSLOverSlot1
SlotLength=8 [mil]



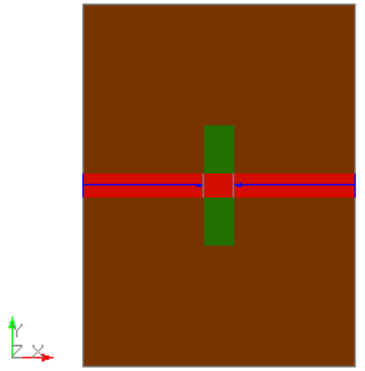
17 Nov 2007, 13:55:29, Simberian Inc.

Circuit MSLOverSlot2
SlotLength=20 [mil]



17 Nov 2007, 13:56:34, Simberian Inc.

Circuit MSLOverSlot3
SlotLength=40 [mil]



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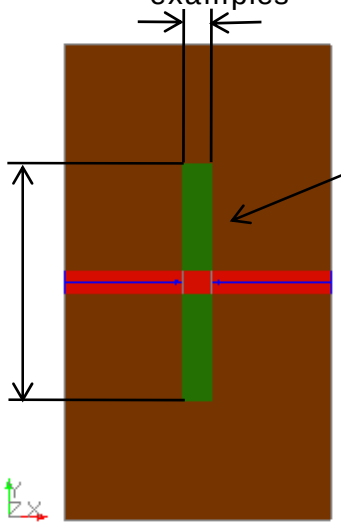
10 mil in all examples

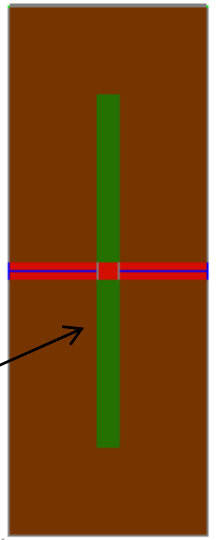
SlotLength is a parameter



17 Nov 2007, 13:57:44, Simberian Inc.

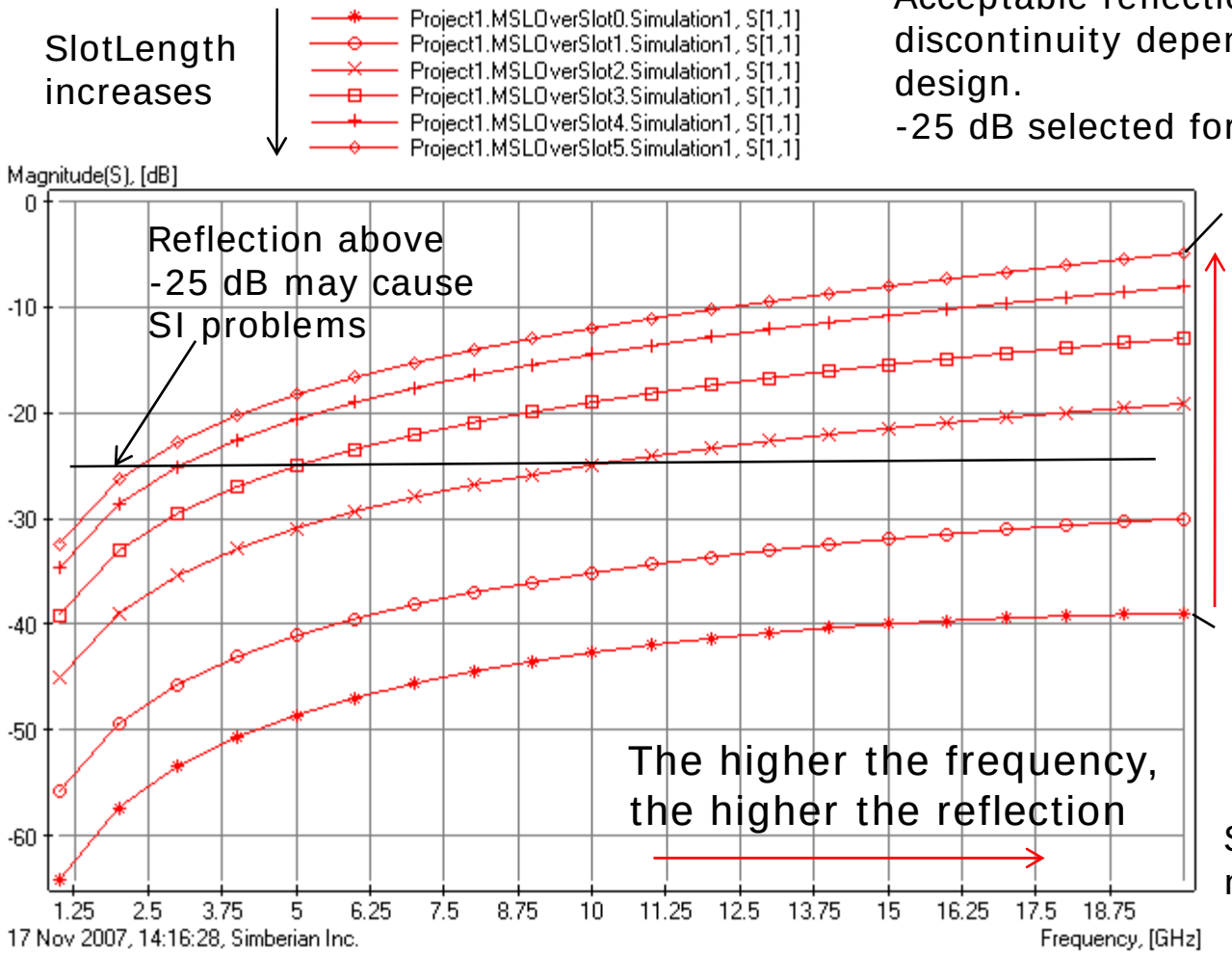
Circuit MSLOverSlot4
SlotLength=80 [mil]

Circuit MSLOverSlot5
SlotLength=120 [mil]



17 Nov 2007, 13:58:24, Simberia

Magnitude of reflection coefficient |S11| for circuits with different Slot Length

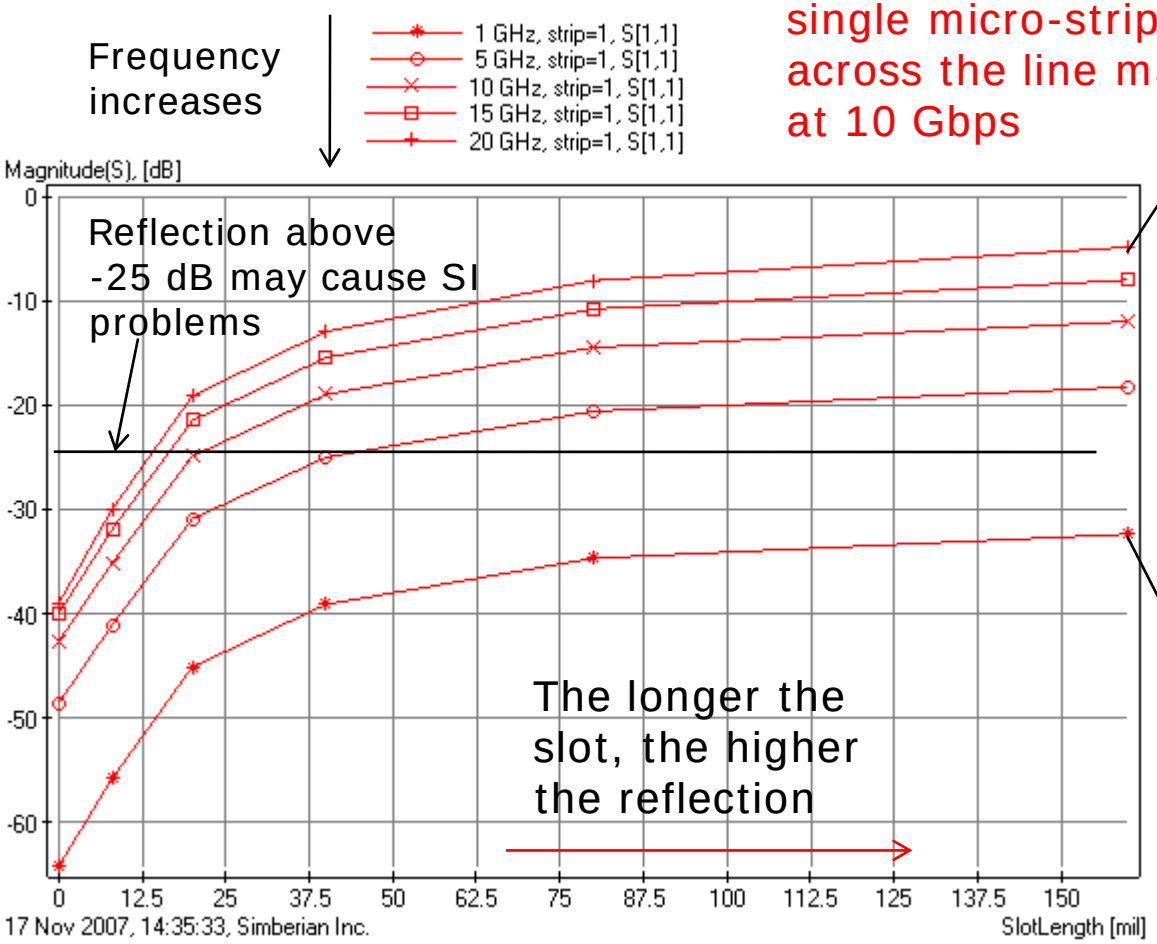


Acceptable reflection loss for a single discontinuity depends on a particular design.
-25 dB selected for this example.

S-parameters are normalized to 50 Ohm

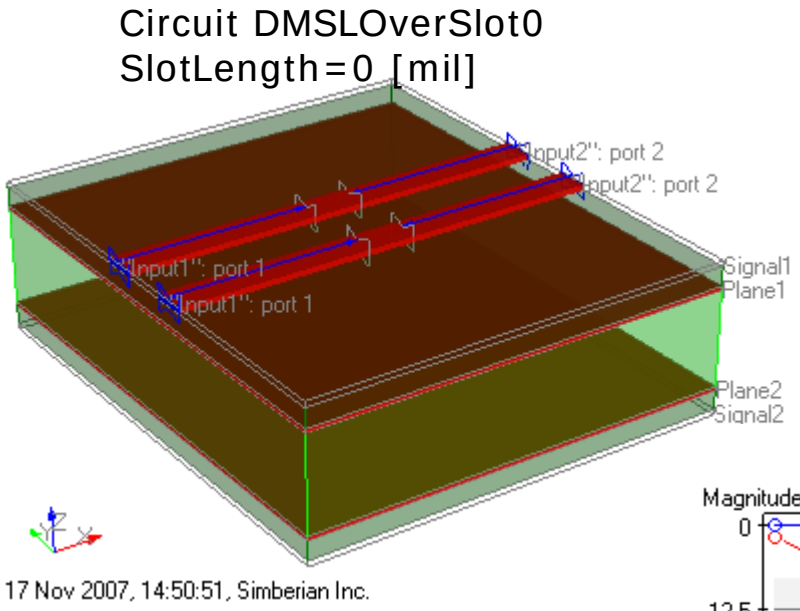
Magnitude of reflection coefficient |S11| as a function of the Slot Length

Cut-outs in plane 10 mil along the single micro-strip line and 20 mil across the line may cause SI problems at 10 Gbps



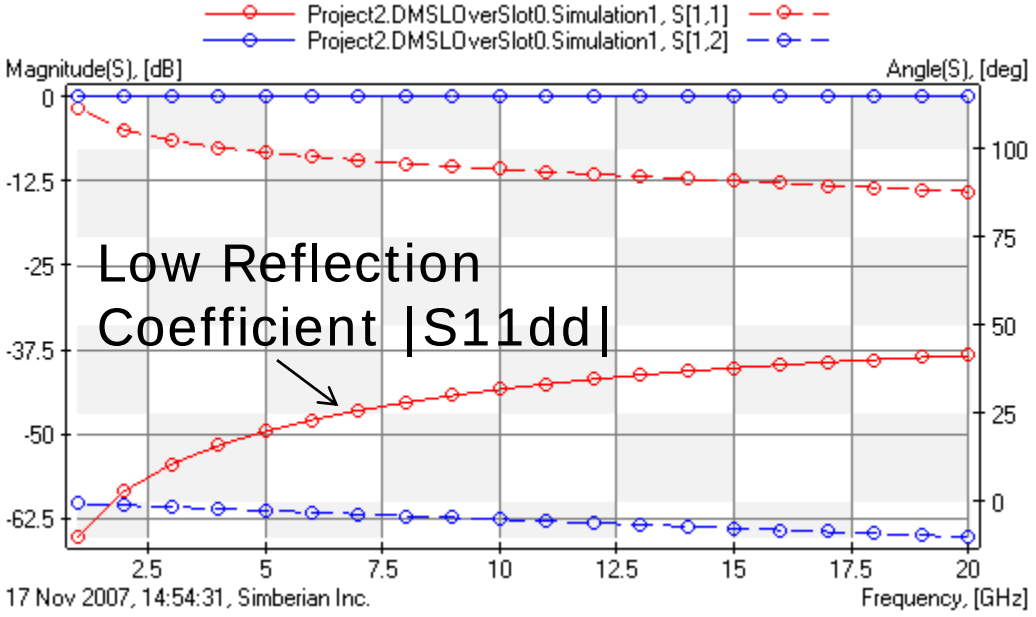
S-parameters are normalized to 50 Ohm

S-parameters of a small differential micro-strip line segment (simulation set-up calibration)



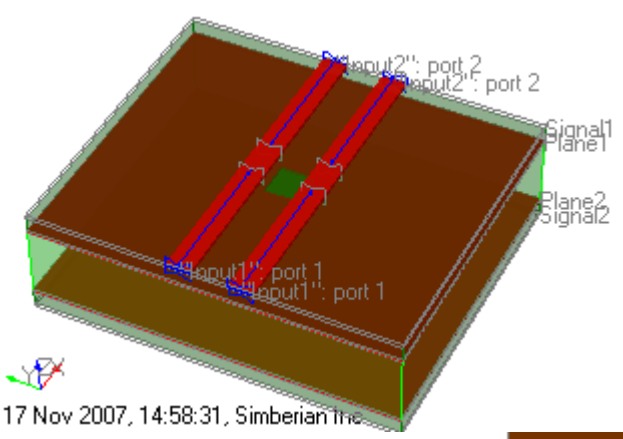
Two microstrips 7 mil wide and 17.5 mil apart (about 100 Ohm differential impedance).
Ports de-embedded to have just 10-mil line segment in the middle (where the slot will be located)

Differential to differential S-parameters are normalized to 100 Ohm and characteristic impedance changes with frequency, that causes increase of reflection at higher frequencies (reaches about -40 dB at 20 GHz)

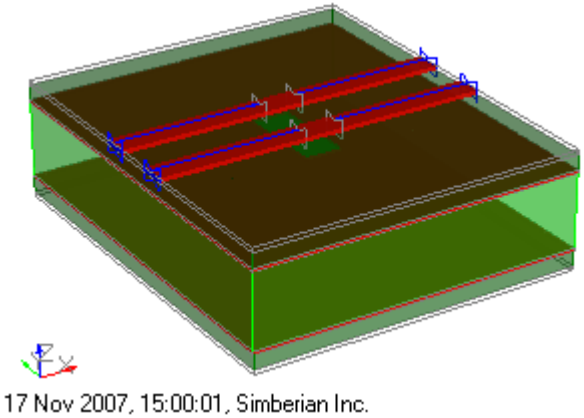


5 circuits with different slot length and slot width 10 mil (size along the t-line)

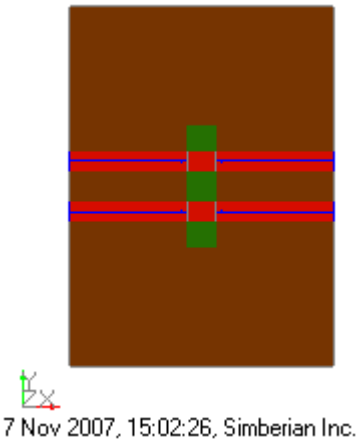
Circuit DMSLOverSlot1
SlotLength=10.5 [mil]



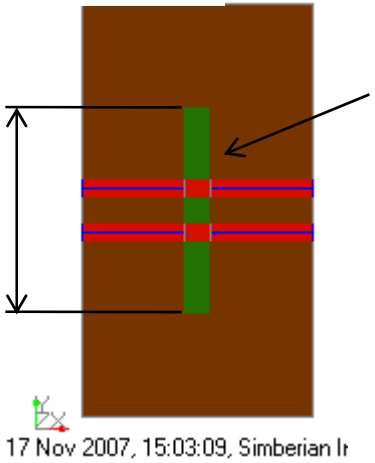
Circuit DMSLOverSlot2
SlotLength=24.5 [mil]



Circuit DMSLOverSlot3
SlotLength=42 [mil]

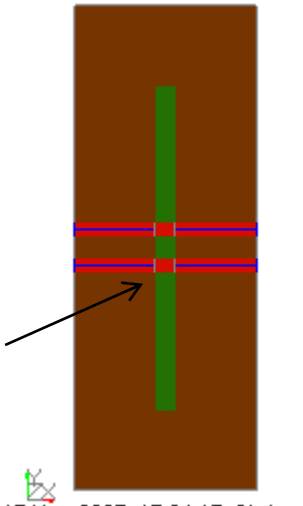


SlotLength is a parameter

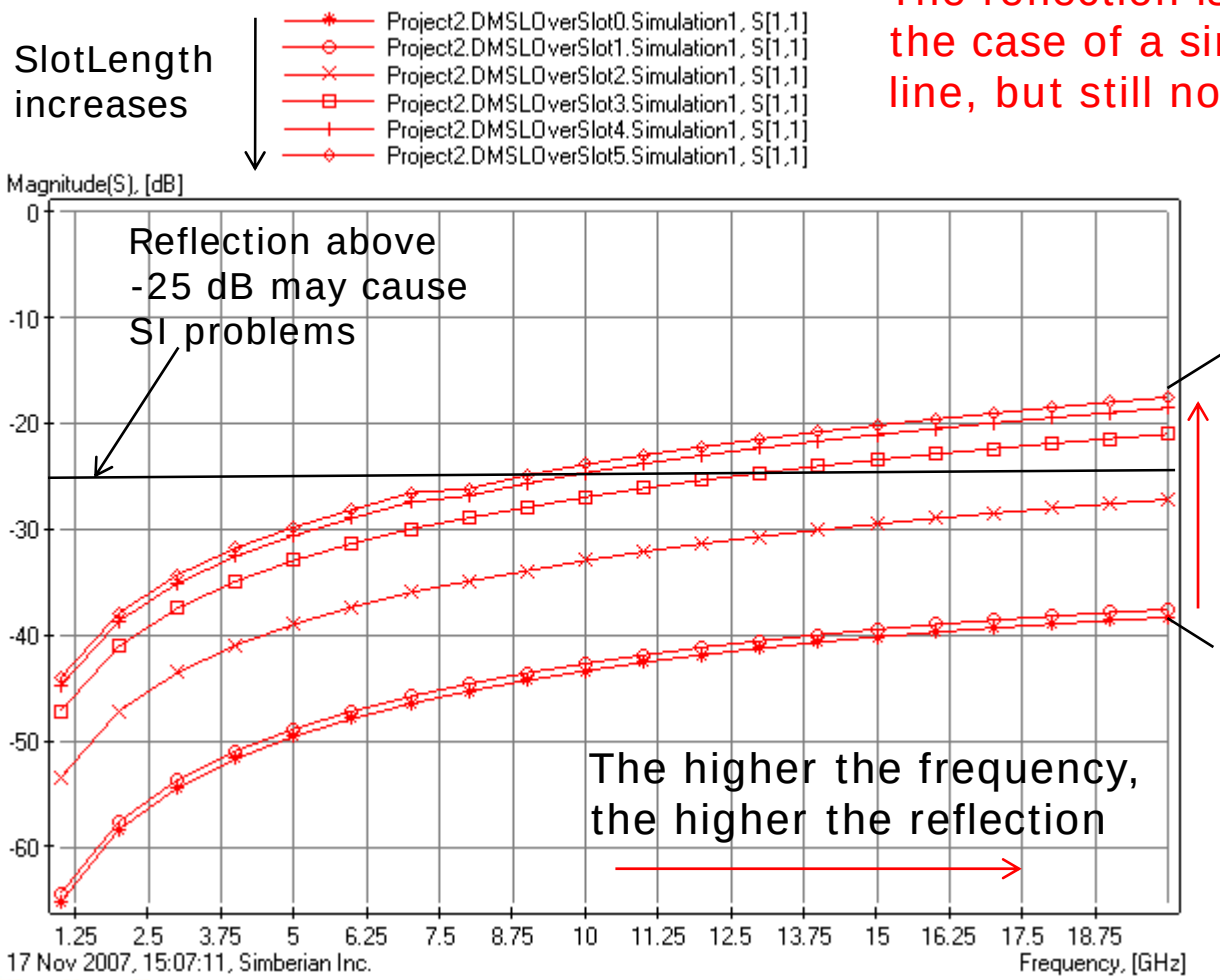


Circuit DMSLOverSlot4
SlotLength=161 [mil]

Circuit DMSLOverSlot5
SlotLength=80.5 [mil]



Magnitude of reflection coefficient |S11dd| for circuits with different Slot Length



The reflection is smaller than in the case of a single micro-strip line, but still not negligible

161 mil

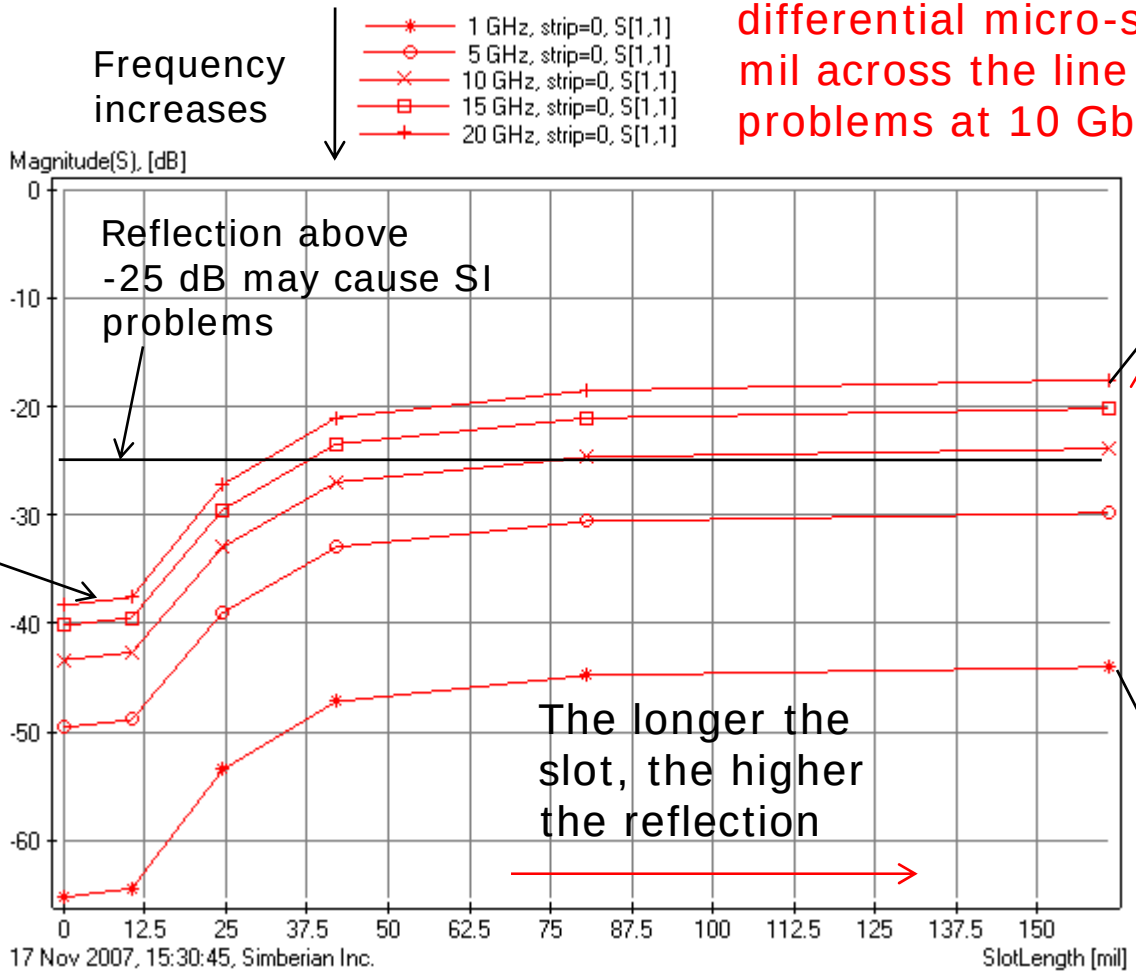
The longer the slot, the higher the reflection

0 mil

|S11dd| is reflection of differential mode in 100-Ohm channel

Magnitude of reflection coefficient |S11dd| as a function of the Slot Length

Cut-outs in plane 10 mil along the differential micro-strip line and 80 mil across the line may cause SI problems at 10 Gbps



Slot Length smaller than distance between strip edges

20 GHz

The higher the frequency, the higher the reflection

1 GHz

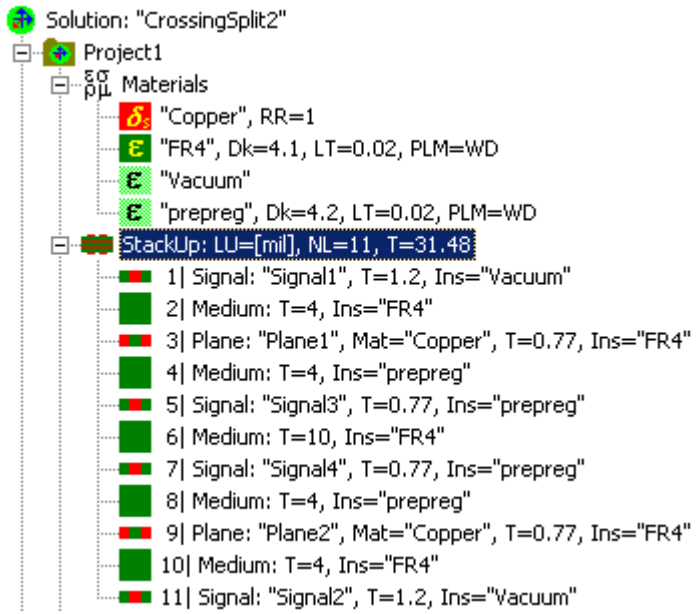
The longer the slot, the higher the reflection

|S11dd| is reflection of differential mode in 100-Ohm channel

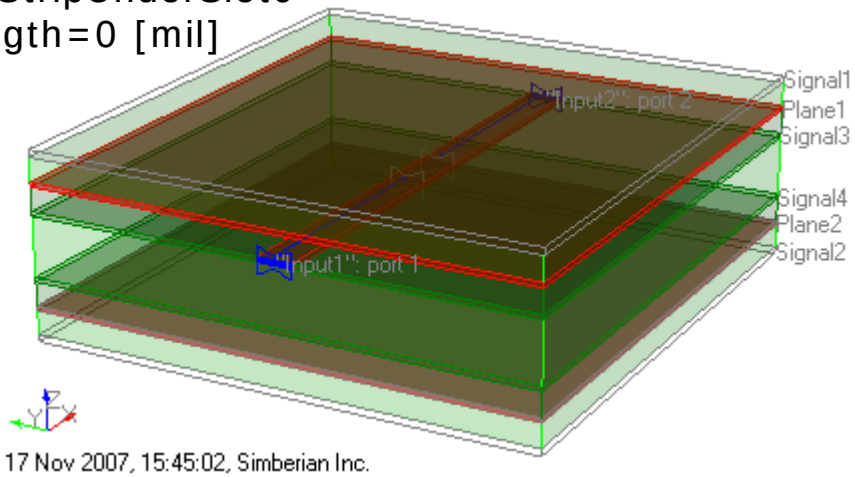
Strip line configuration to investigate effect of slot in the closest plane layer “Plane1”

- Simple 6-layer stackup
- Wideband Debye dispersion and loss models used for the dielectrics
- 6-mil wide strip line segment in the inner layer “Signal3”

Materials and stackup in Simbeor Solution

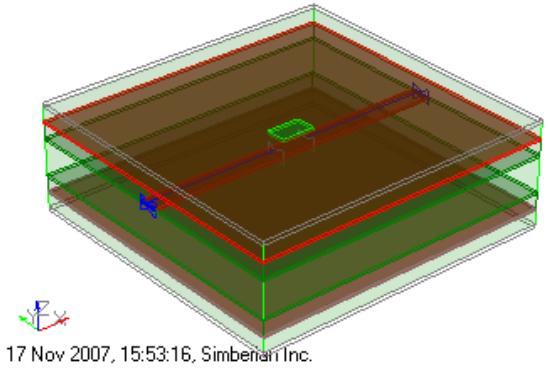


Circuit StripUnderSlot0
SlotLength=0 [mil]

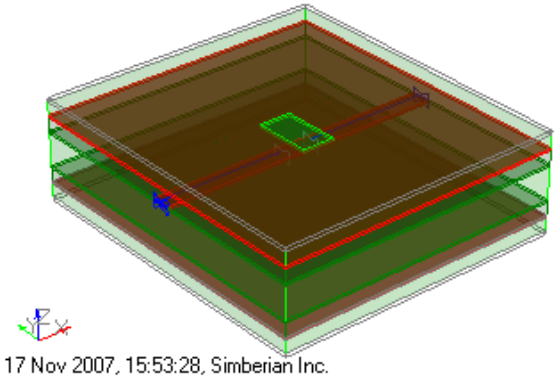


5 circuits with different slot length and with slot width 10 mil (size along the t-line)

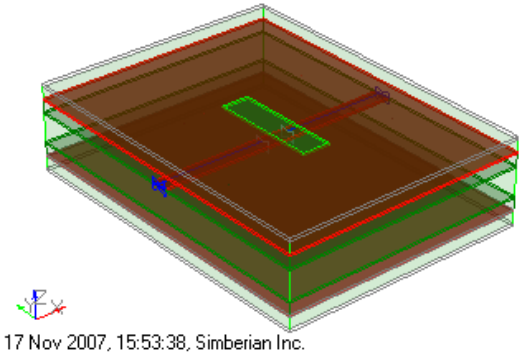
Circuit StripUnderSlot1
SlotLength=6 [mil]



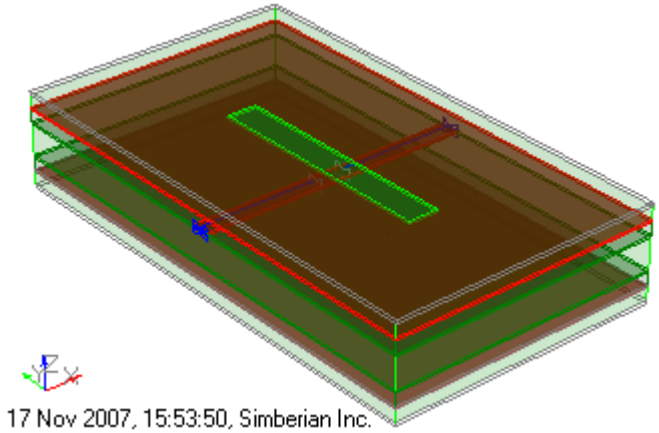
Circuit StripUnderSlot2
SlotLength=18 [mil]



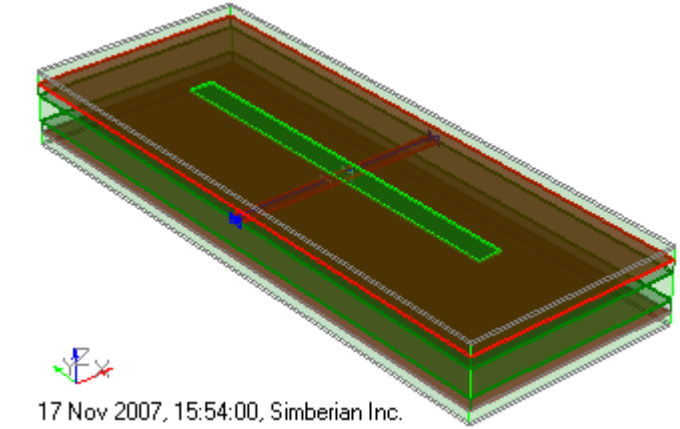
Circuit StripUnderSlot3
SlotLength=39 [mil]



Circuit StripUnderSlot4
SlotLength=78 [mil]

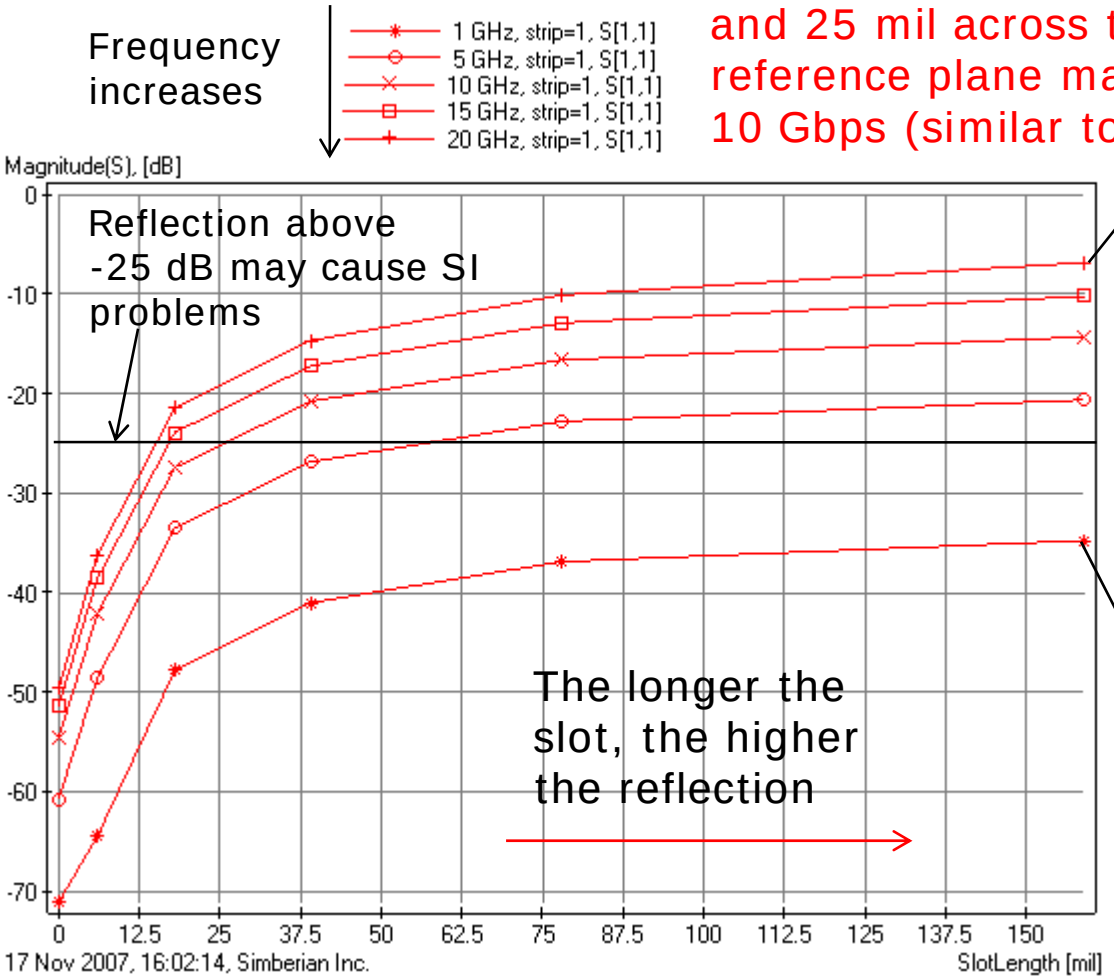


Circuit StripUnderSlot5
SlotLength=159 [mil]



Magnitude of reflection coefficient |S11| as a function of the Slot Length

Cut-outs 10 mil along the single strip line and 25 mil across the line in the closest reference plane may cause SI problems at 10 Gbps (similar to the micro-strip case)

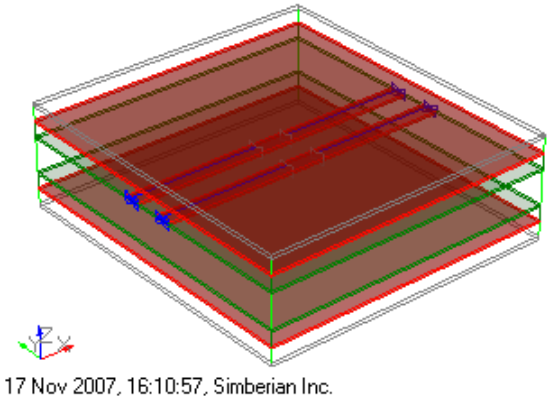


S-parameters are normalized to 50 Ohm

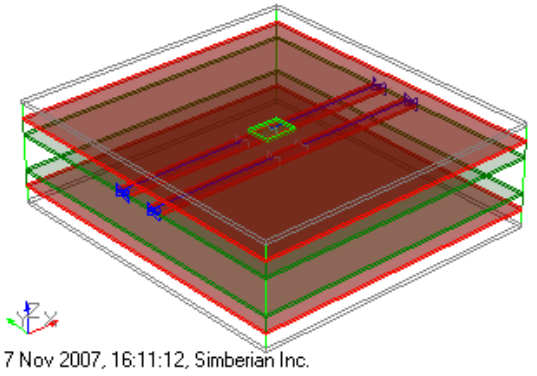
5 circuits describing differential strip-lines with a slot in the closest plane layer

Two 5-mil wide strips in the layer “Signal3”, 12.5 mil apart (about 100 Ohm differential impedance)

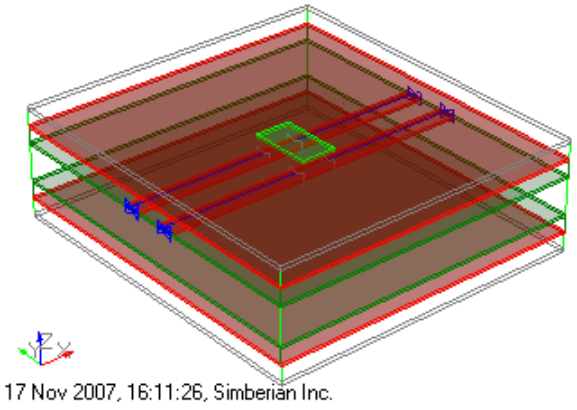
Circuit DStripUnderSlot0
SlotLength=0 [mil]



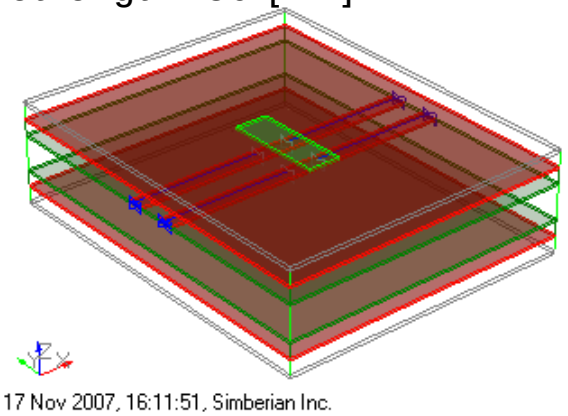
Circuit DStripUnderSlot1
SlotLength=7.5 [mil]



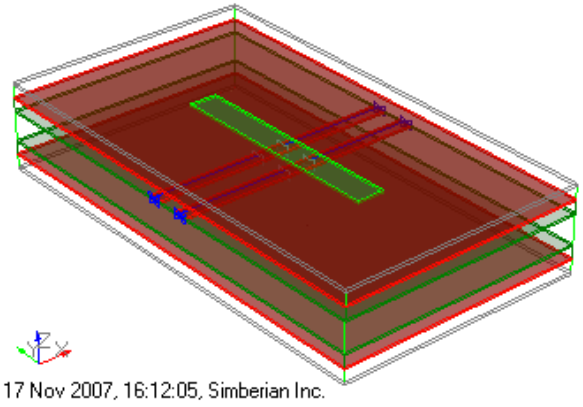
Circuit DStripUnderSlot2
SlotLength=17.5 [mil]



Circuit DStripUnderSlot3
SlotLength=30 [mil]

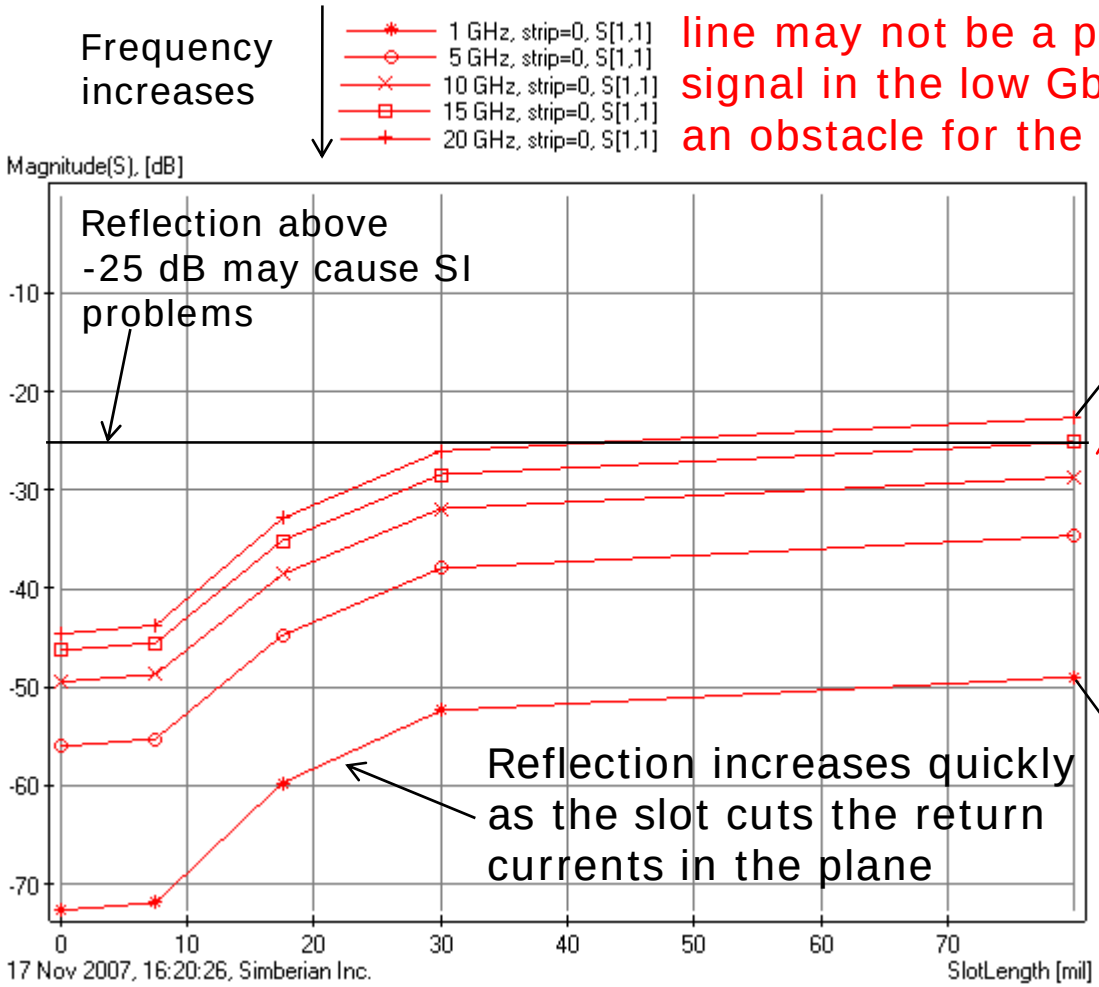


Circuit DStripUnderSlot4
SlotLength=80 [mil]



Magnitude of reflection coefficient |S11dd| as a function of the Slot Length

Cut-outs in the closest plane of differential strip line may not be a problem for the differential signal in the low Gbps range (though it is still an obstacle for the common mode)



20 GHz

The higher the frequency, the higher the reflection

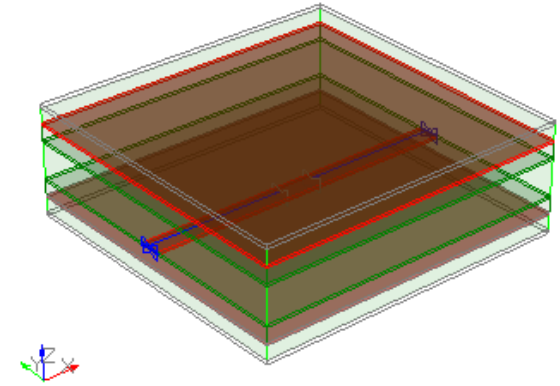
1 GHz

Reflection increases quickly as the slot cuts the return currents in the plane

|S11dd| is reflection of differential mode in 100-Ohm channel

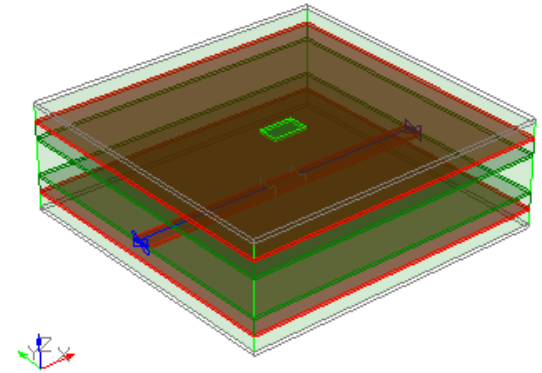
6 circuits with strip in layer “Signal4” and cut-outs in the remote plane layer “Plane1”

Circuit StripUnderSlot1
SlotLength=0 [mil]



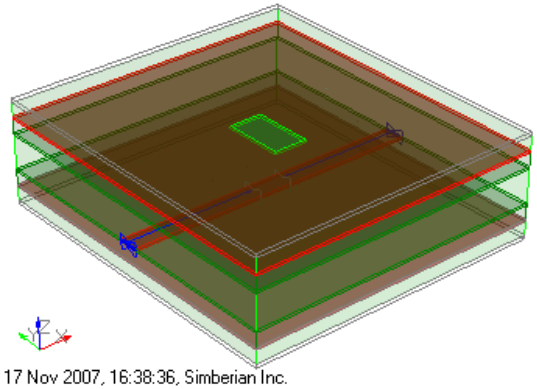
17 Nov 2007, 16:37:58, Simberian Inc.

Circuit StripUnderSlot1
SlotLength=6 [mil]



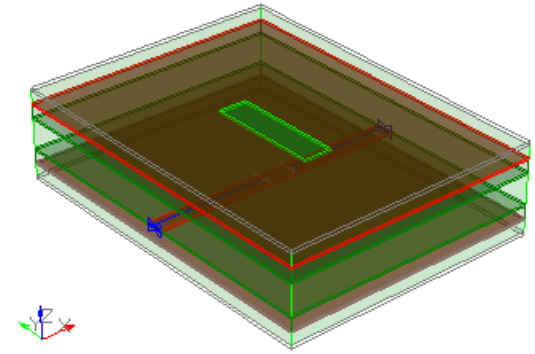
17 Nov 2007, 16:38:12, Simberian Inc.

Circuit StripUnderSlot2
SlotLength=18 [mil]



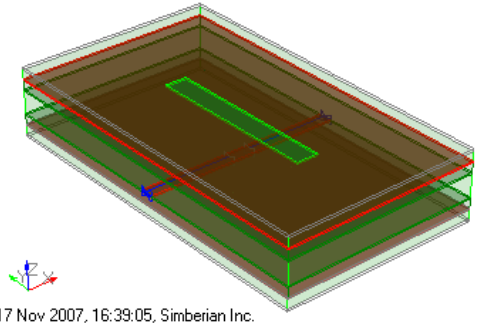
17 Nov 2007, 16:38:36, Simberian Inc.

Circuit StripUnderSlot3
SlotLength=39 [mil]



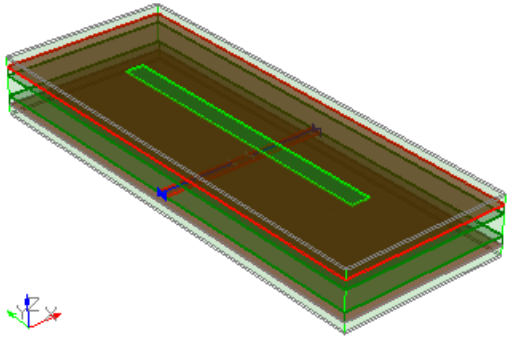
17 Nov 2007, 16:38:49, Simberian Inc.

Circuit StripUnderSlot4
SlotLength=78 [mil]



17 Nov 2007, 16:39:05, Simberian Inc.

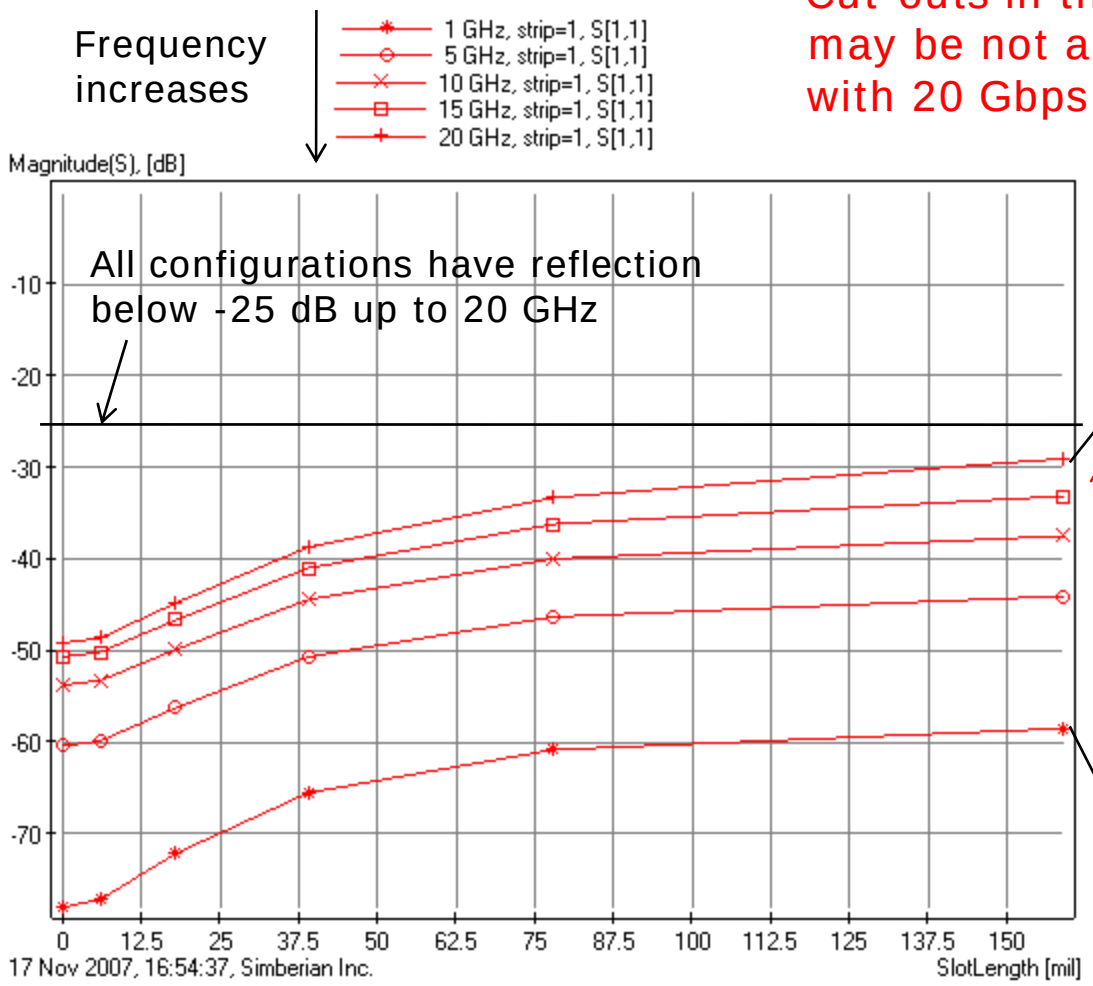
Circuit StripUnderSlot5
SlotLength=159 [mil]



17 Nov 2007, 16:39:27, Simberian Inc.

Magnitude of reflection coefficient |S11| as a function of the Slot Length

Cut-outs in the remote reference plane may be not a problem even for signals with 20 Gbps data rate



20 GHz

The higher the frequency, the higher the reflection, though it is relatively low

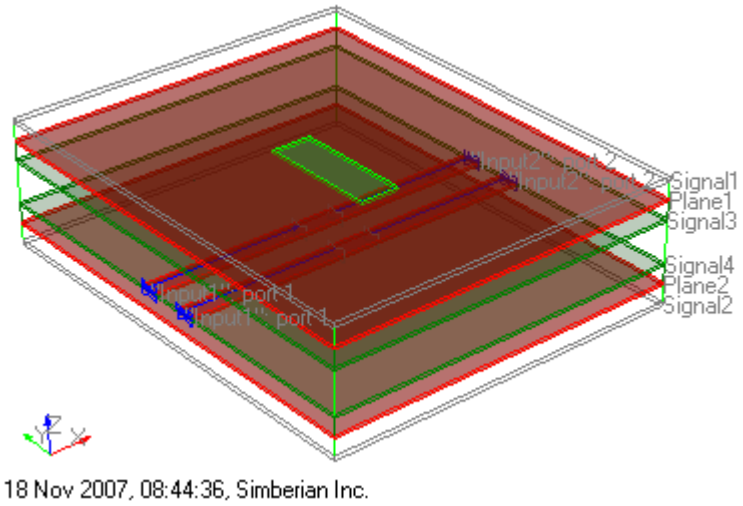
1 GHz

S-parameters are normalized to 50 Ohm

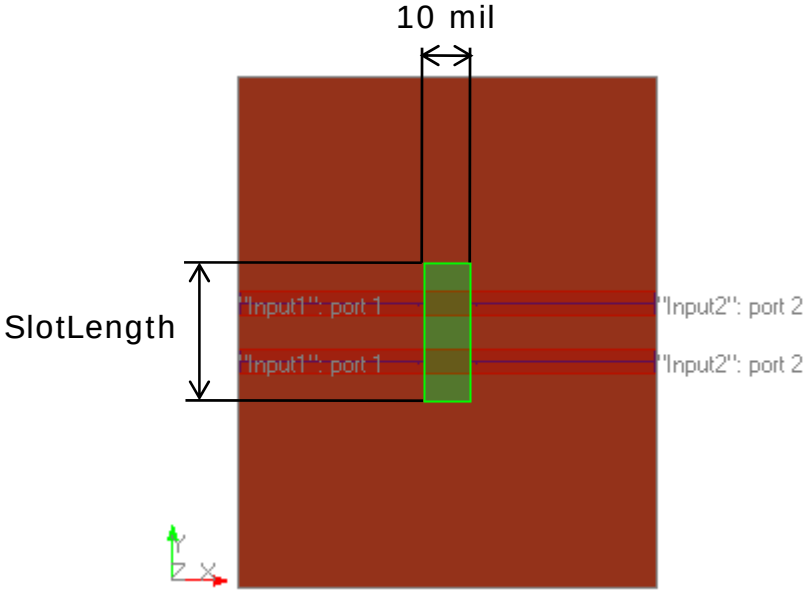
Differential strips in layer “Signal4” and slots in the remote plane layer “Plane2”

Two 5-mil wide strips in the layer “Signal4”, 12.5 mil apart (about 100 Ohm differential impedance)

SlotLength is a parameter changing from 0 to 80 mil

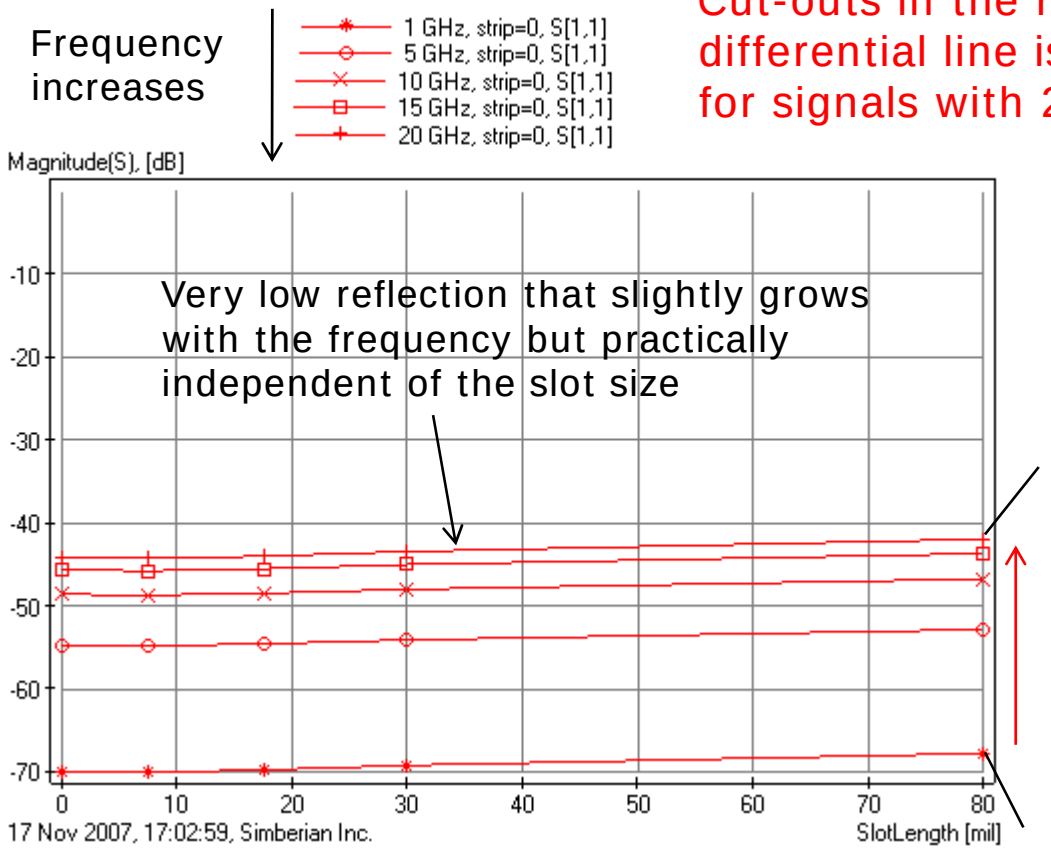


18 Nov 2007, 08:44:36, Simberian Inc.



17 Nov 2007, 17:01:09, Simberian Inc.

Magnitude of reflection coefficient |S11dd| as a function of the Slot Length



Cut-outs in the remote reference plane of a differential line is clearly not a problem even for signals with 20 Gbps data rate

|S11dd| is reflection of differential mode in 100-Ohm channel

Increase of the reflection with the frequency caused mostly by the dispersion of the line characteristic impedance

How to use these results?

- Such numerical experiments can be used to plan positions of plane layers with cut-outs in a stack-up for a particular data rate and to generate rules for routing multi-gigabit nets for instance
- In case if cut-outs cannot be avoided, S-parameter models for localized cut-outs can be generated and used in a system-level solver
- Slot de-coupling or by-passing with capacitors can be also investigated with a full-wave solver
  - Such configuration may not reduce the reflection over a wide frequency band but may be helpful to reduce the radiation from the oversized slots (valid also for common mode in case of differential t-lines)

What about more complicated split-plane configurations?

- In case of moats or complicated plane splits the signal may be not just reflected but transmitted by the slot line across the board and either radiated or coupled to the other t-lines crossing the same slot
  - It may cause both cross-talk (SI) and radiation (EMI) problems
  - Complete electromagnetic analysis of such structures is rarely possible and not practical in many cases
  - Only hybrid de-compositional system-level analysis of such structures with strip, slot and parallel-plane models may predict the behavior (multiple components of a system have to be included into such analysis)
- Even if differential signal in differential pair is not affected by the slot, the common mode may be affected and either reflected or coupled to the slot-line and require either the system-level analysis or slot-line loading or termination preventing SI and EMI problems
- Decoupling capacitors can help to reduce the coupling to the slot and dump propagation of energy along the slots in complicated cut-outs, both in single line and common mode in differential line cases

Solutions and contact

- Solution files are available for download from the simberian web site
  - http://www.simberian.com/AppNotes/Solutions/SlotsInReferencePlanes_2007_09.zip
- Send questions and comments to
  - General: info@simberian.com
  - Sales: sales@simberian.com
  - Support: support@simberian.com
- Web site www.simberian.com