EXAMINING THE IMPACT OF SPLIT PLANES ON SIGNAL AND POWER INTEGRITY

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AGENDA

- Introduction
- Simulation Considerations
  - Four different port configurations
- Simulation Results
  - Single Ended Split Crossings
  - Single Ended Slot Crossings
  - Differential Split Crossings
  - Interesting Split Plane Cases
- Correlations
- Impact of Trace and Pad Crossings on PDN Isolation
- Conclusions

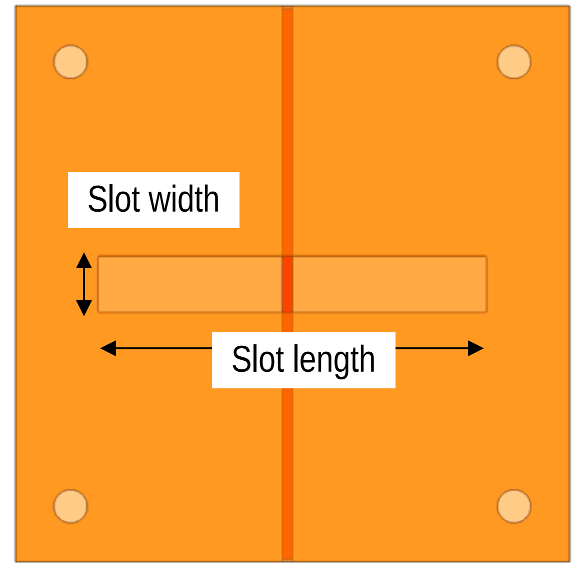
INTRODUCTION (1/3)

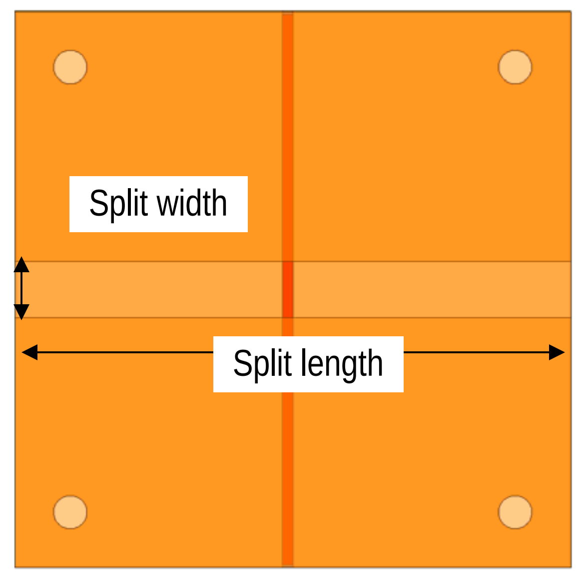
- Increased functionality and decreased form factor, push PCB designs to be smaller and more densely packed
- This trend coupled with the differing device voltage and power requirements lead to splits in P/G planes, creating multiple plane puddles or islands
- Last year we looked at the impact of these islands on resonances[1]
- This year, we look at the impact of splits on signal traces and on PDN isolation.

1. J. Miller, G. Blando, B. Williams I. Novak, “Impact of PCB Laminate Parameters on Suppressing Modal Resonances”, DesignCon 2008.

INTRODUCTION (2/3)

- In addition to splits, signals can be forced to cross *slots*, which can arise due to various PCB or package cutouts
- Due to the splits or slots, signal integrity can be compromised, exhibiting increased crosstalk and exciting resonances.
- Signal crossings can also impact isolation between power domains, manifest as a higher transfer impedance.

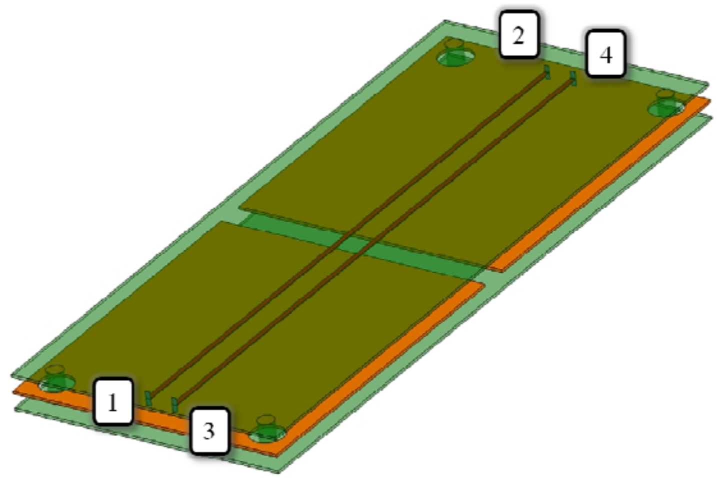




INTRODUCTION (3/3)

Overview of Test Cases

- Three plane layers: GND-POWER-GND
- Signal layer is GND-POWER referenced
- Split/slot exists on POWER layer ONLY
- Four GND vias connect upper and lower grounds together
- Uses one or two SE traces and then one or two differential pairs
- Port numbering
- Ports definition will be discussed in next slides



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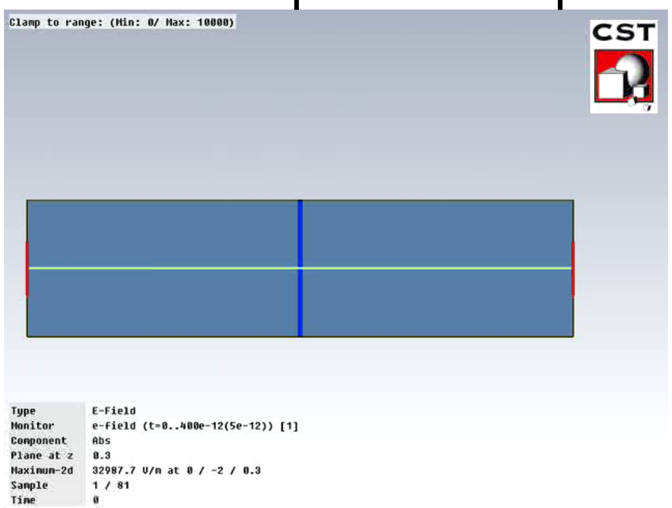
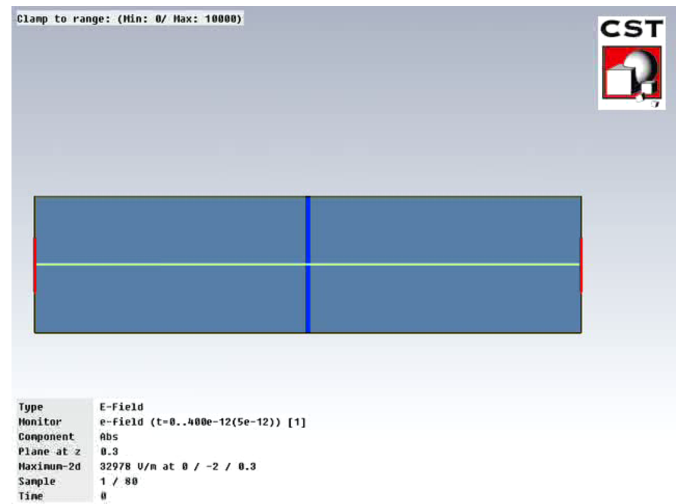
SIMULATION CONSIDERATIONS

Overview (1/2)

- Splits and slots create a discontinuity which scatters energy to the plane boundary and back to the ports
- In the first part of this study we wish to understand these. Thus we need to offset the absorbing boundary
- Later on, we will use an absorbing boundary so we can look at the effect of the split without plane resonances

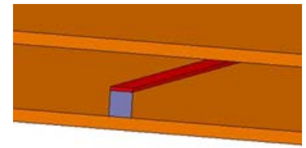


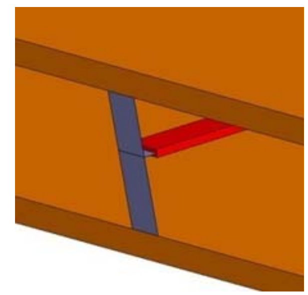


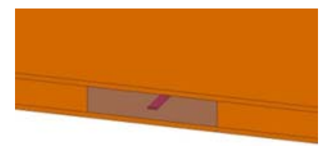
SIMULATION CONSIDERATIONS

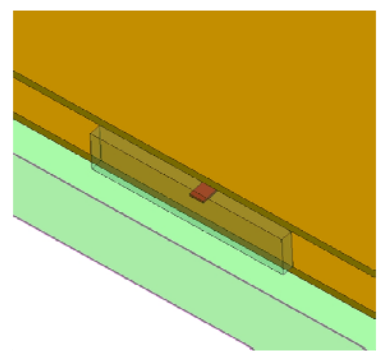
Overview (2/2)

- Several alternatives exist for ports:
  1. Lumped port defined between the trace and lower power plane
  2. Modified lumped port
  3. Wave port which is coplanar with the radiation boundary
  4. Modified wave port which is internal to the problem using a PEC extension
- We will go over each of these in the following slides





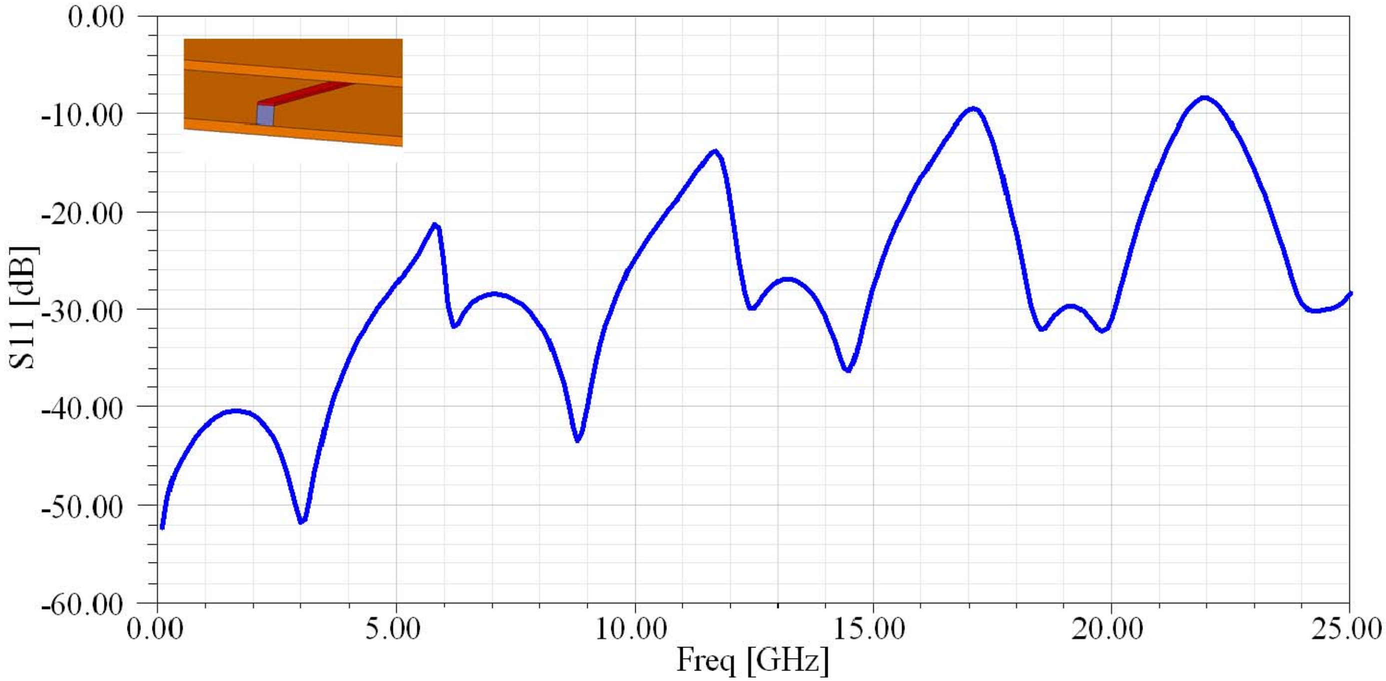




SIMULATION CONSIDERATIONS

Case 1: Lumped Port

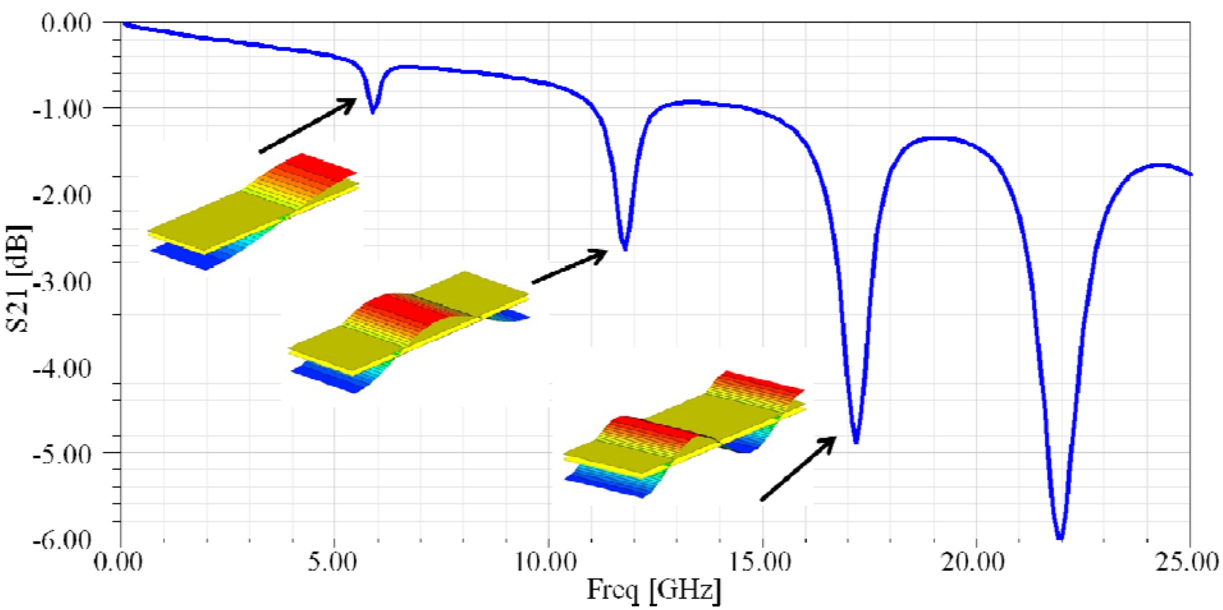
- Nominally 50 ohms at low frequencies
- At higher frequencies, increasing return loss due to asymmetric port configuration relative to two planes



SIMULATION CONSIDERATIONS

Case 1: Lumped Port (cont)

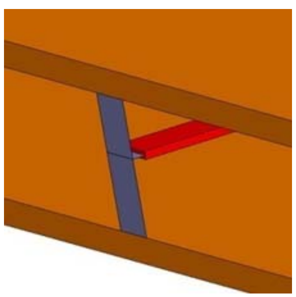
- Shows resonances in loss profile
- These are due to port discontinuity (scattering of energy) interacting with plane boundaries and exciting standing waves (radiation boundary pulled back)

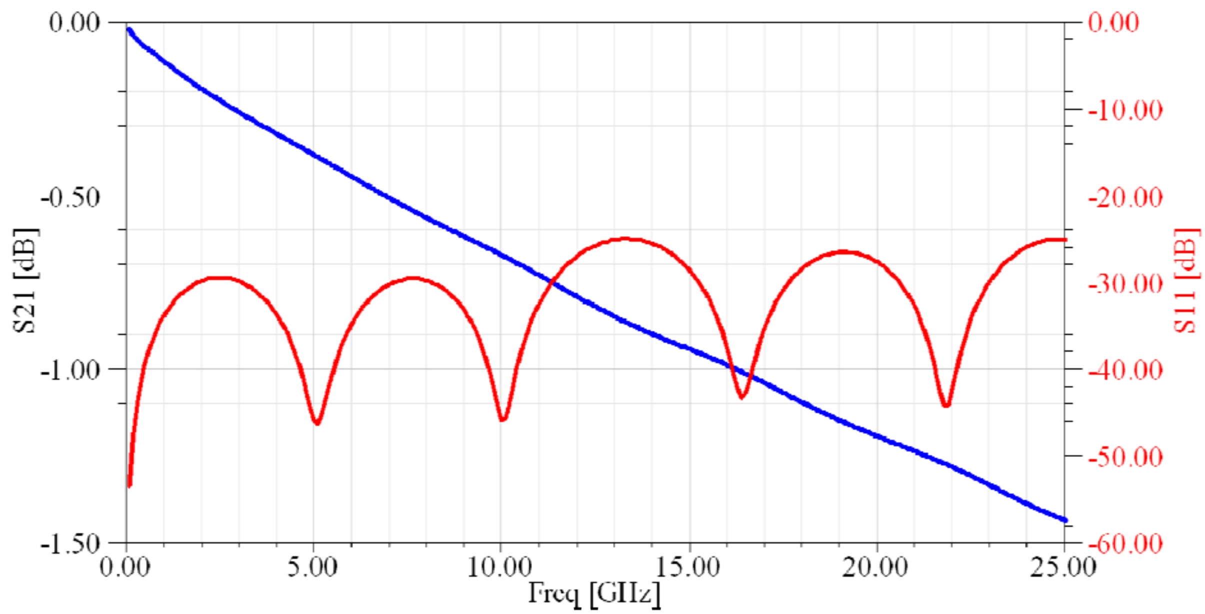


SIMULATION CONSIDERATIONS

Case 2: Modified Lumped Port

- Modified lumped port uses PEC to redistribute currents to upper and lower planes creating a more symmetric launch
- Lumped port is defined horizontally between PEC and trace edge

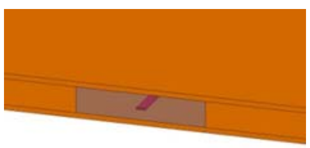


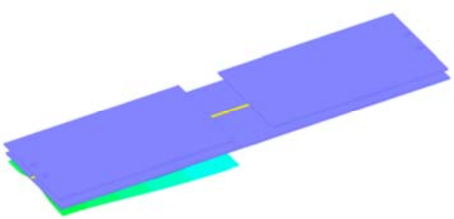


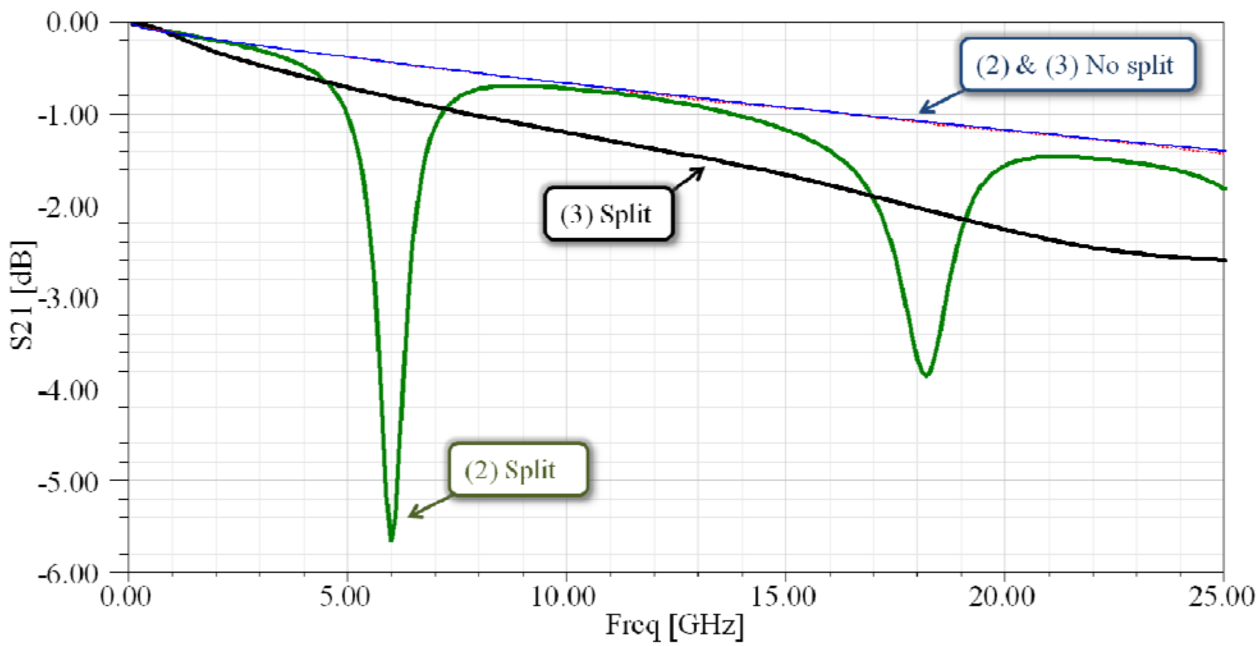
SIMULATION CONSIDERATIONS

Case 3: Wave Port

- Wave port shows resonance-free loss profile
- None of the issues with (1) are observed
- Disadvantage is that wave port must not be internal to problem geometry so rad boundary is flush with plane edge – suppressing resonances



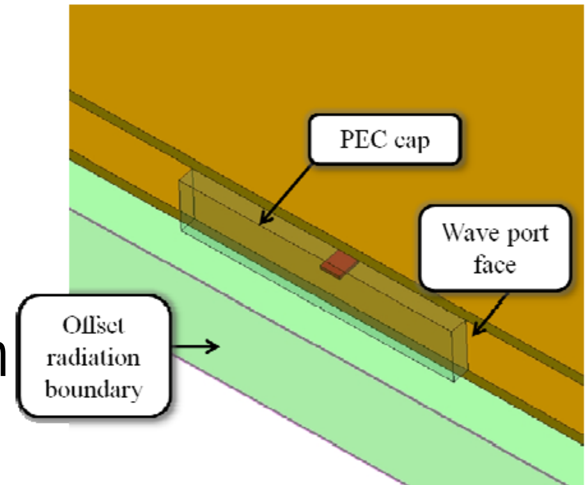


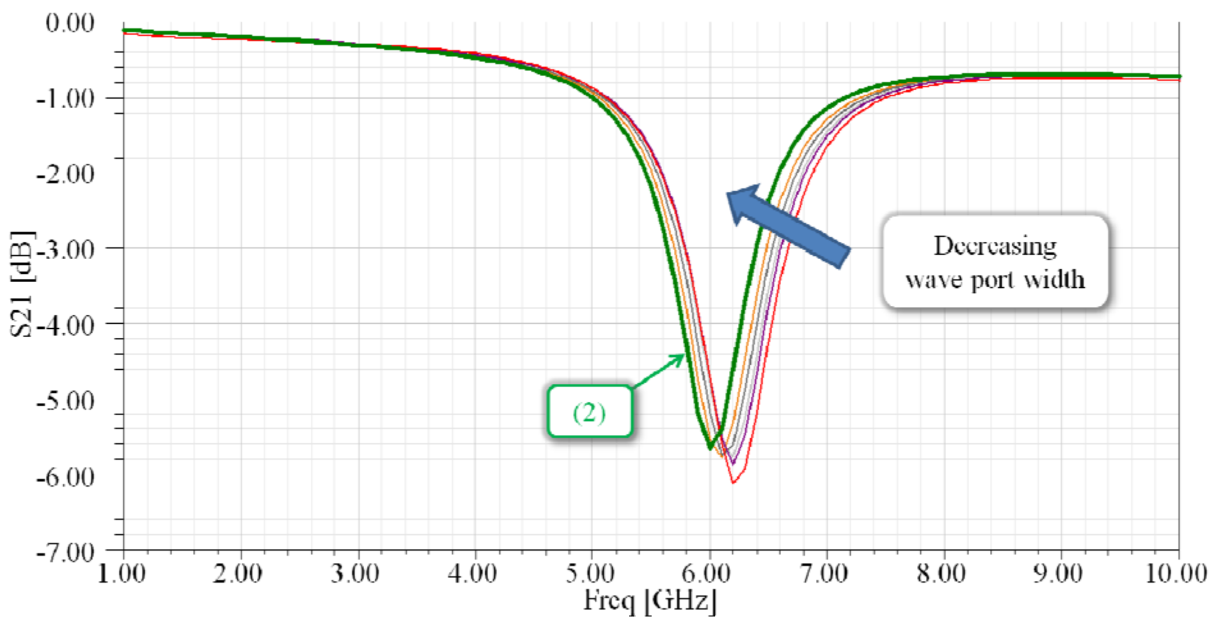


SIMULATION CONSIDERATIONS

Case 4: Modified Wave Port

- Circumvents requirement to place wave port on problem boundary using a PEC cap
- Problem here is PEC width introduces its own boundary condition, which depends on the width of the wave port





SIMULATION CONSIDERATIONS
Conclusions

- Port definition has a significant impact on the simulation results
- Ports can act like a discontinuity, scattering energy to the plane boundary
- Splits act as a discontinuity, scattering energy to its surroundings
- These resonances depend on the plane dimensions and location of split relative to plane boundaries – i.e., they are very particular to the PCB design
- As such, going forward we will segment the problem and look at the impact of the split in the absence of plane reflections. This will be achieved using a flush radiation boundary
- This represents the case, for example, with perfectly terminated plane pair or electrically large boards
- Also, going forward we will use the modified lumped port, I.e., (2)

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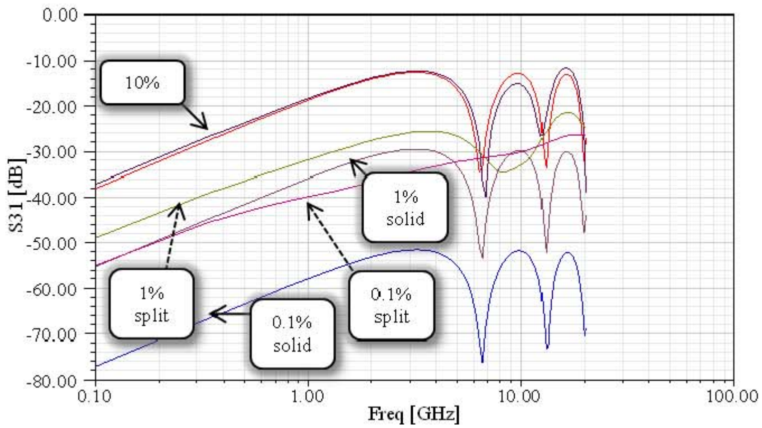
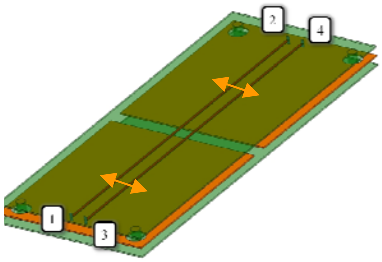
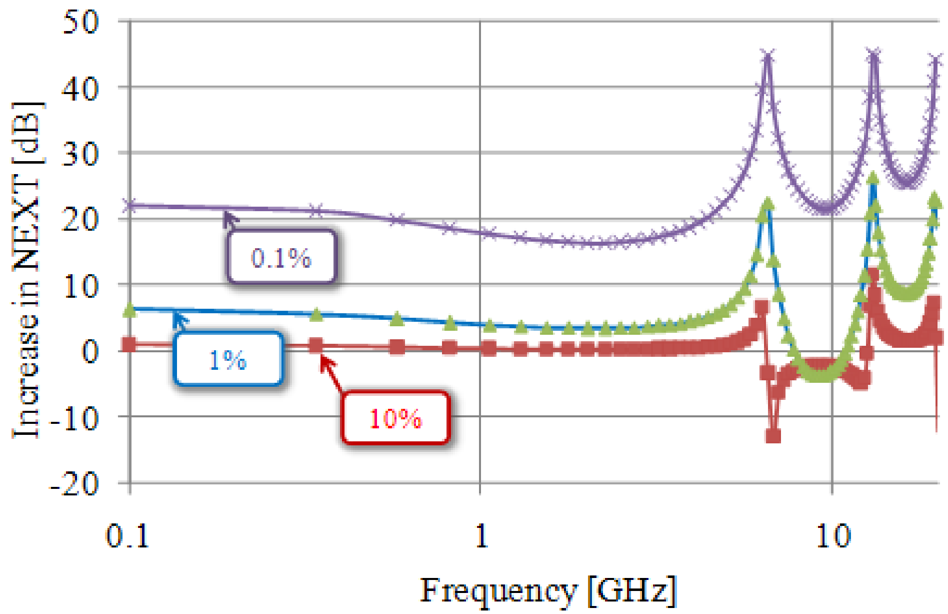
SIMULATION RESULTS

SE Split

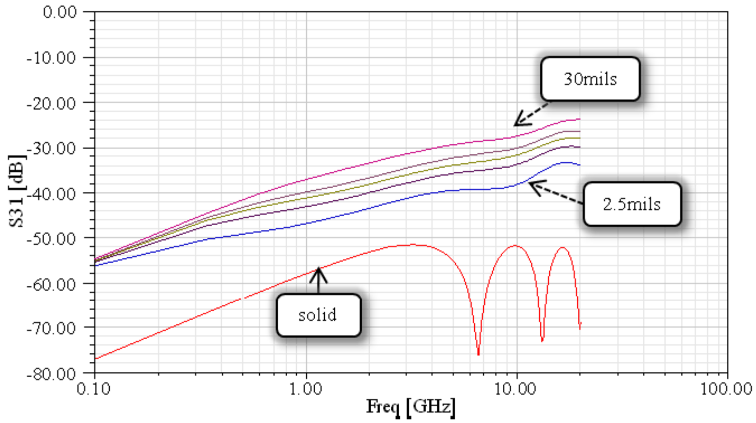


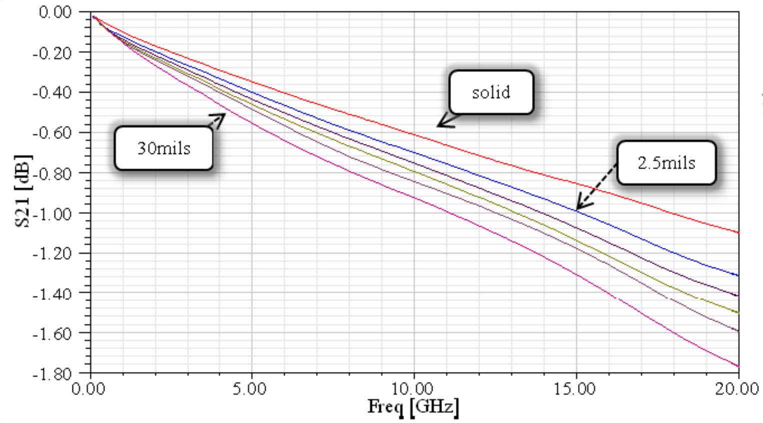


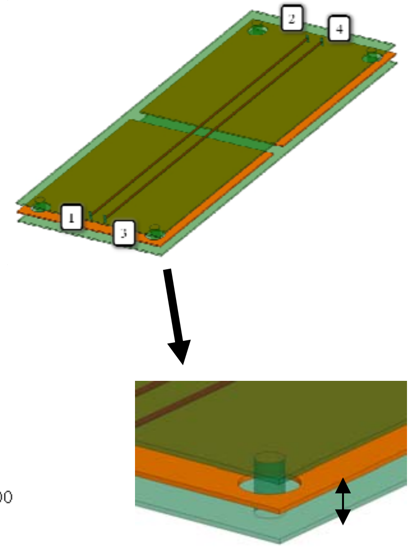


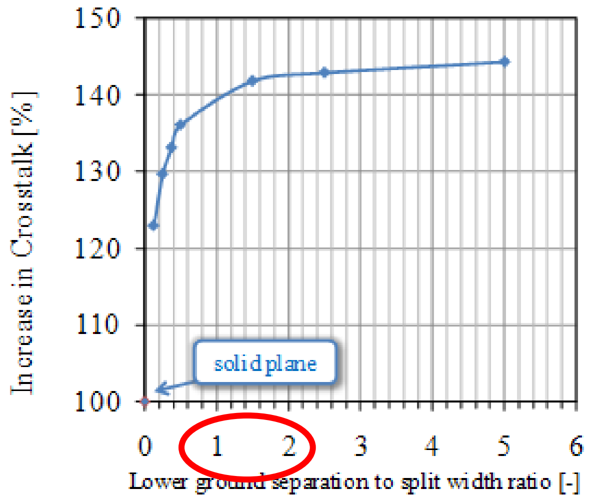
SIMULATION RESULTS

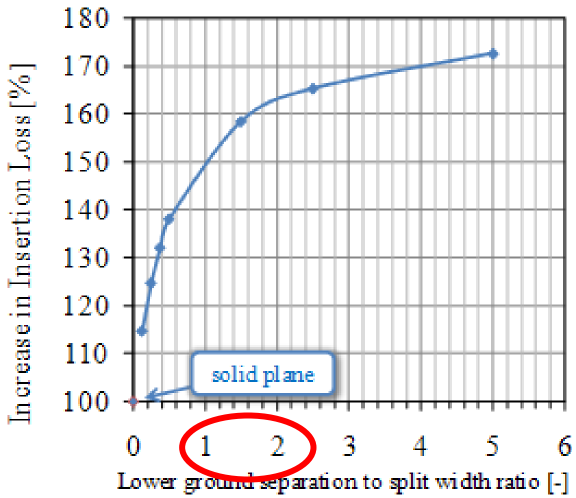
SE Split – Impact of Ground Offset





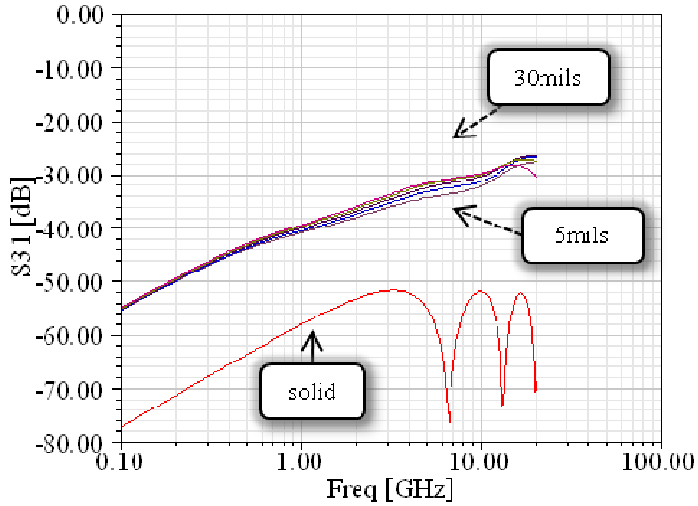


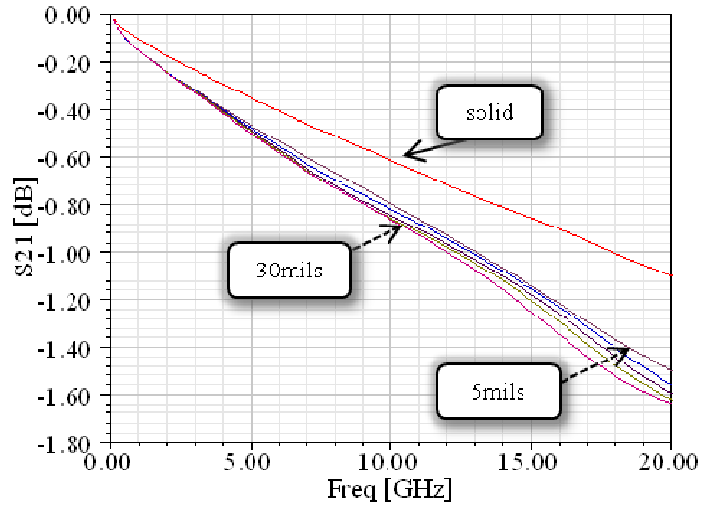


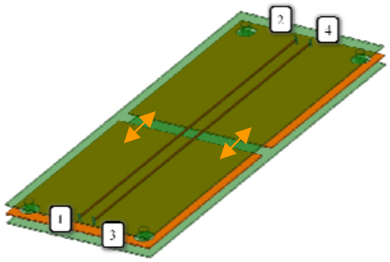


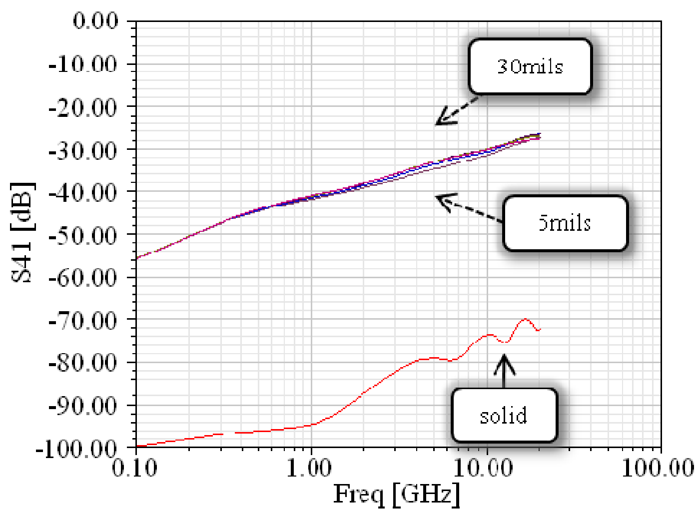
SIMULATION RESULTS

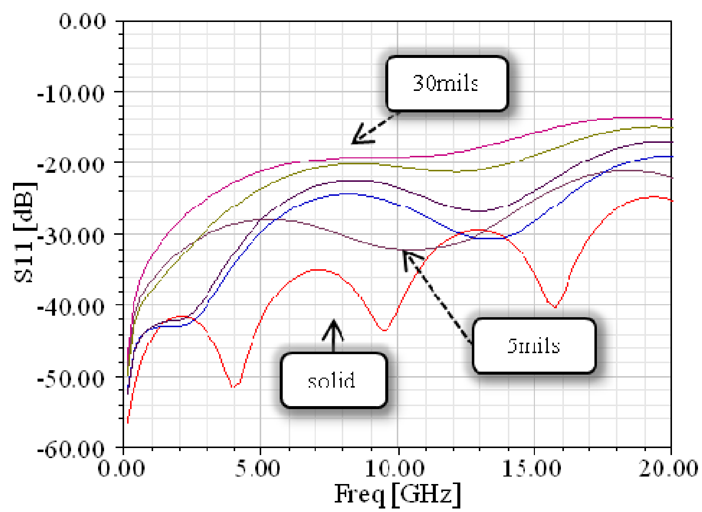
SE Split – Impact of Split Width











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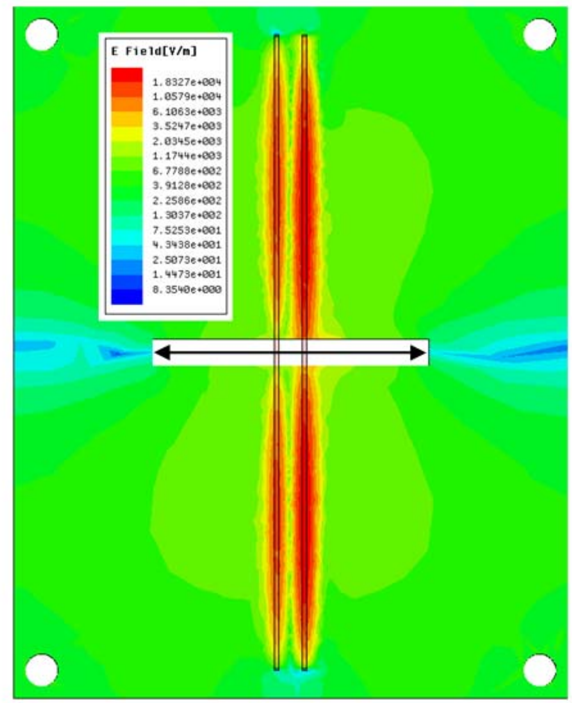
SIMULATION RESULTS

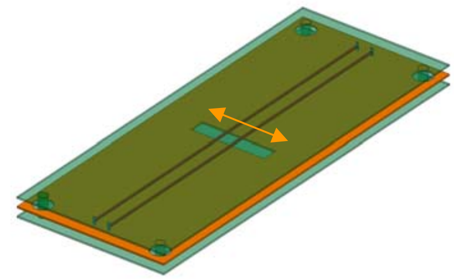
SE Slot

- Next we look at the slot case
- A slot is different than split in that energy can be reflected due to metal sides of the slot allowing for additional losses and resonances
- And these resonances won't be suppressed by a flush radiation boundary
- The lowest possible resonances is the half-wave resonance

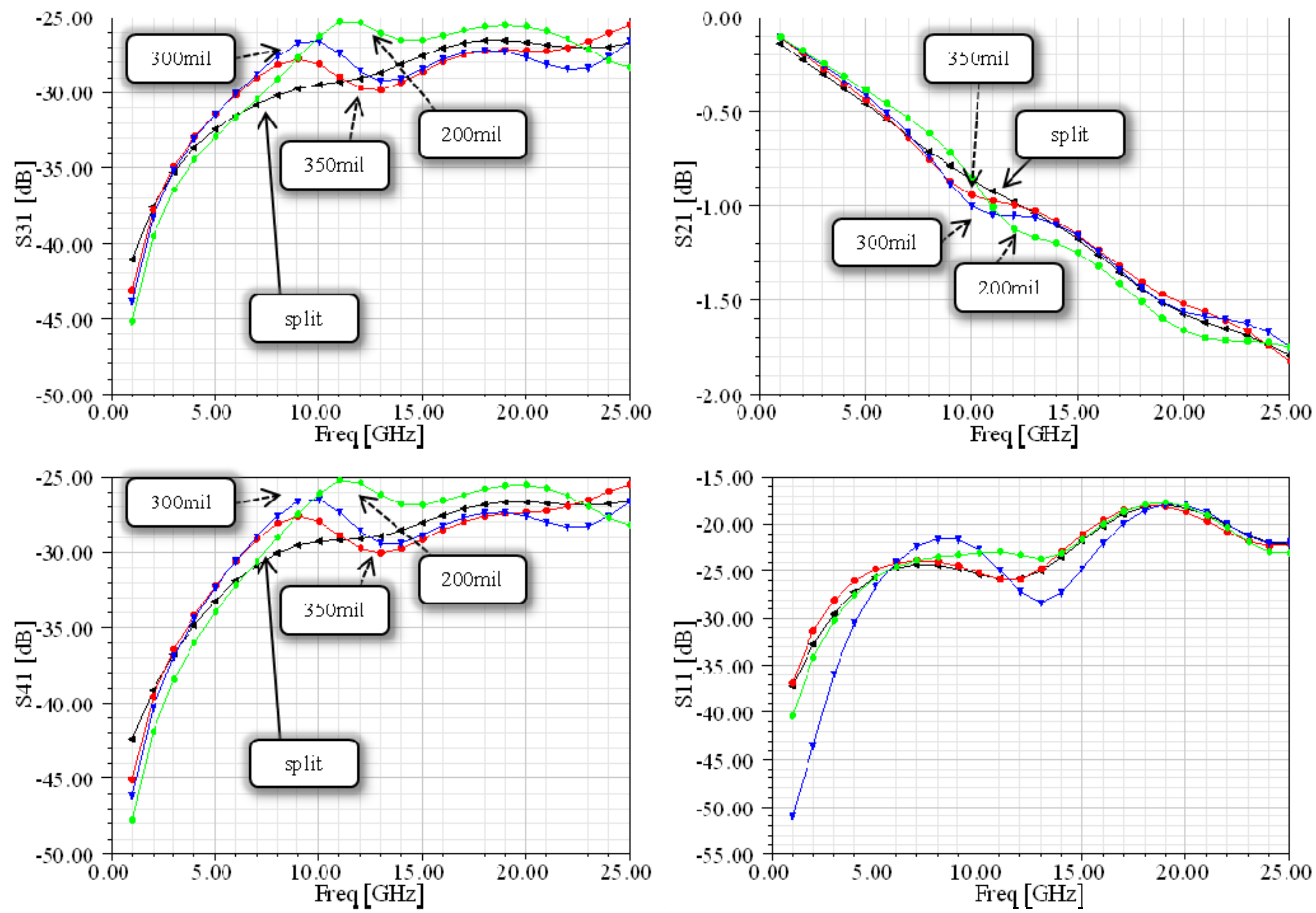


SIMULATION RESULTS

SE Slot – Impact of Slot Length

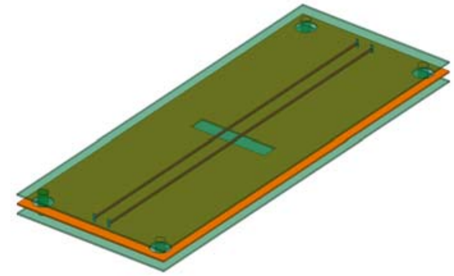


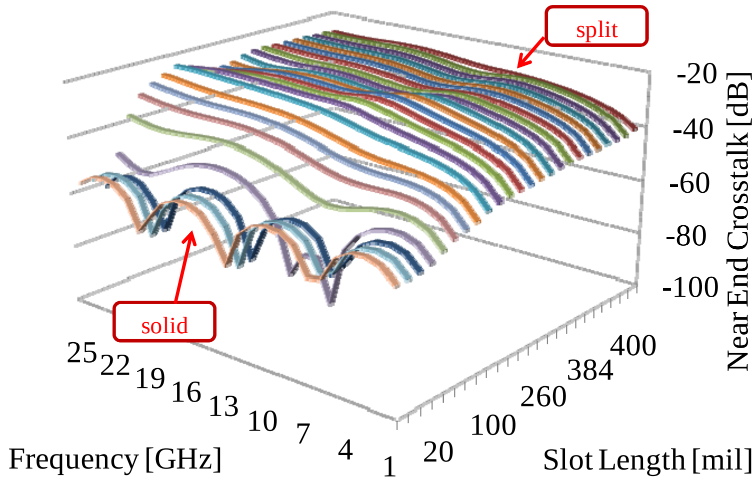
- Notice that there is a peak in the crosstalk and IL depending on the slot length
- Also notice that the NEXT, FEXT and IL are WORSE than the split case for all slot lengths

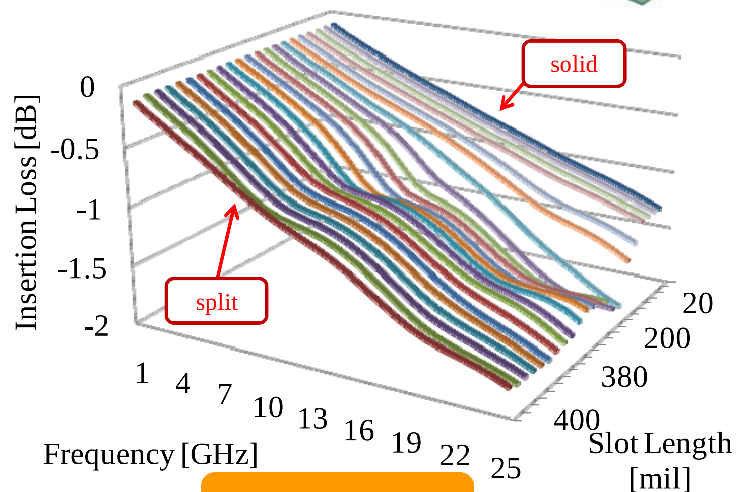


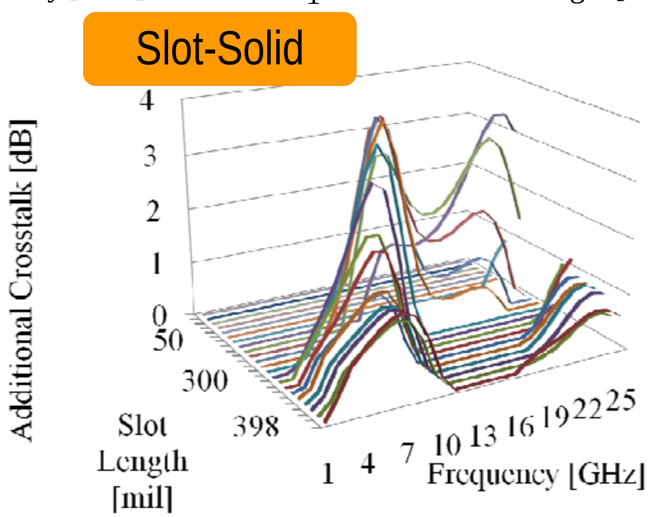
SIMULATION RESULTS

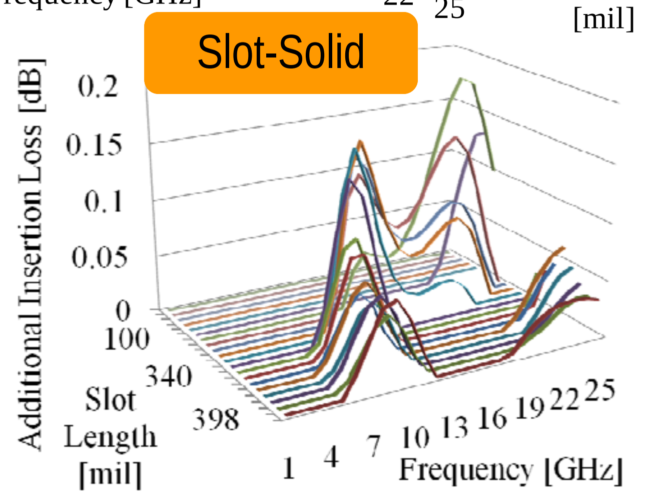
SE Slot – Impact of Slot Length (cont)





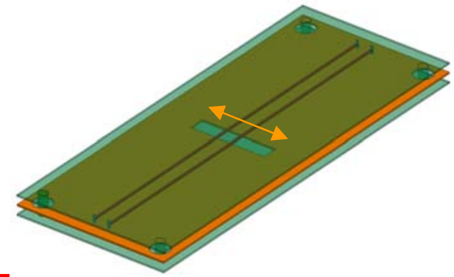






SIMULATION RESULTS

SE Slot – Impact of Slot Length (cont)

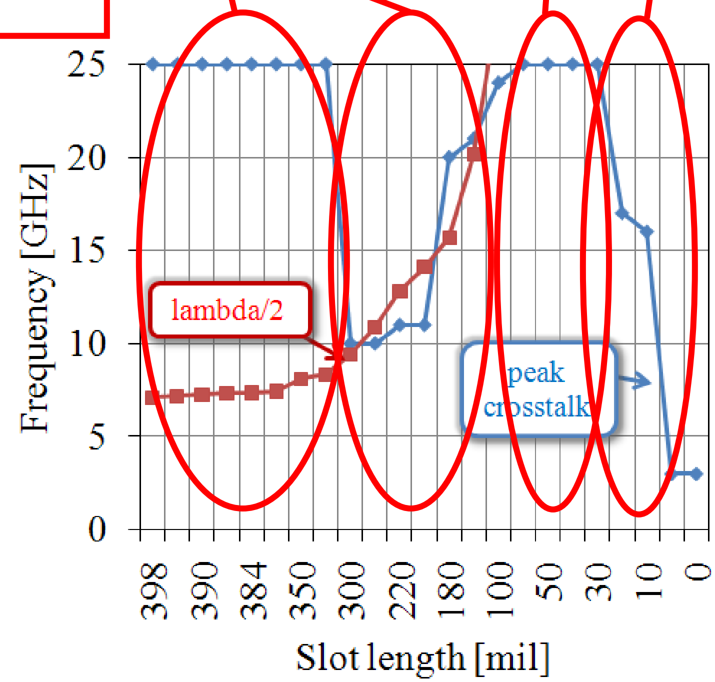


- Half wavelength is so low that we don't see the effect of the slot on crosstalk
- See the effect of the split more than slot – with increasing frequency, we see increasing crosstalk

Above 140 mils, the half wavelength of the slot is beyond what we simulated

Finally, for the shortest slots, we return to the solid plane case where we observe the peak NEXT occurring at the quarter-wave peak

As the slot gets shorter, we start to see the peak in the NEXT lining up with the half wavelength of the slot



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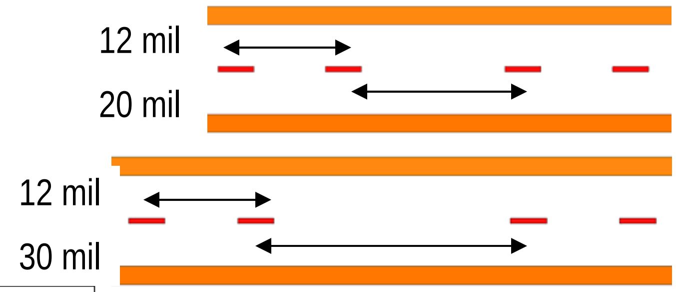
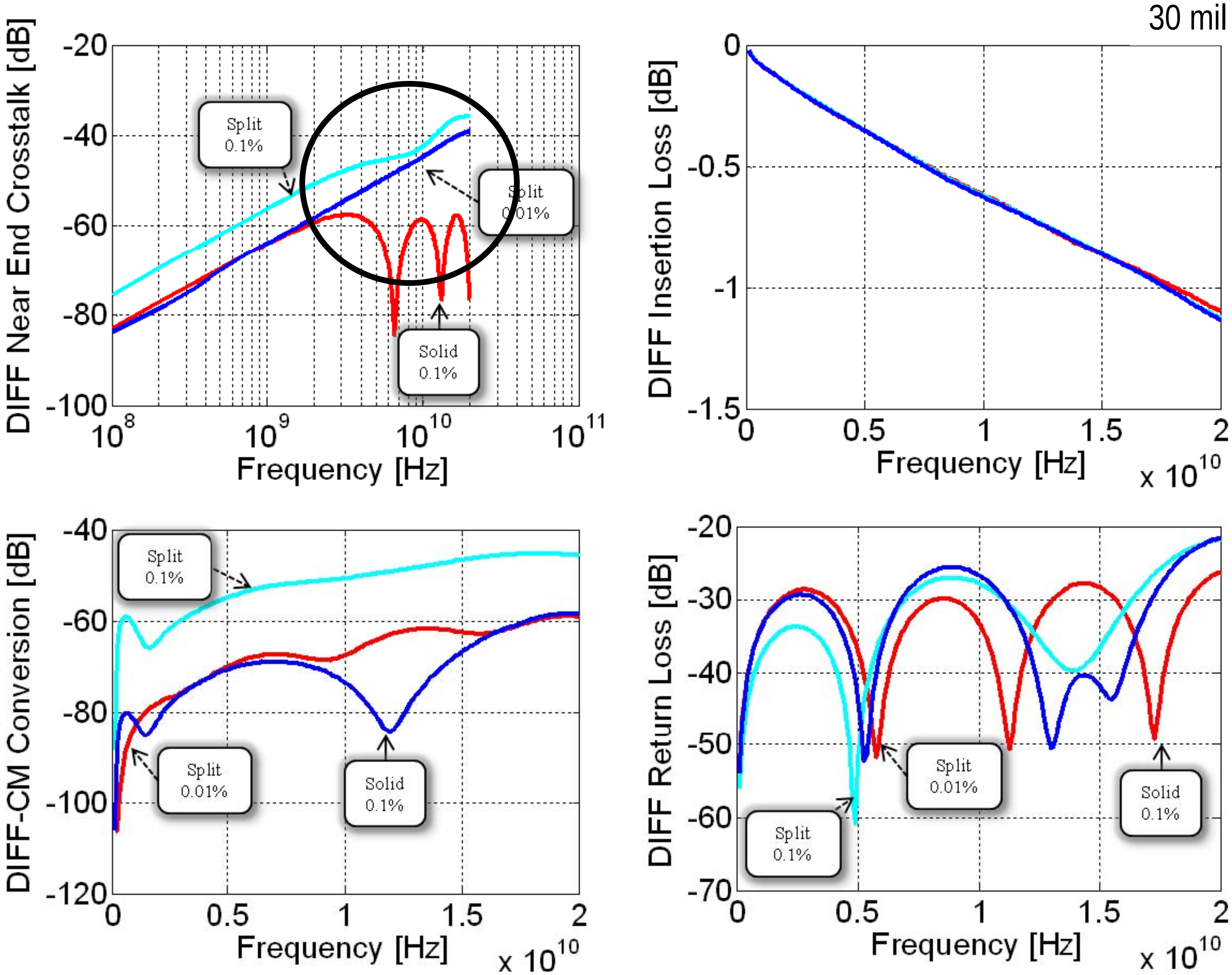
SIMULATION RESULTS

Differential Split



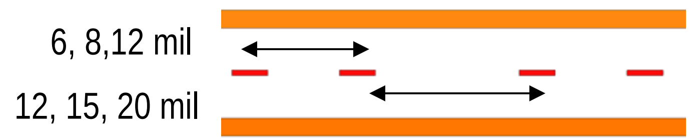
NOTE: center-to-center distances

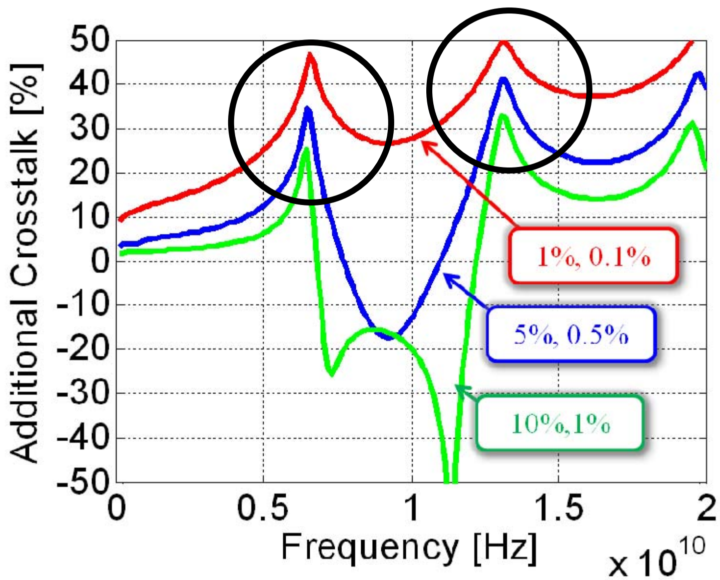


SIMULATION RESULTS

Differential Split – Impact of Intra Pair Coupling

- Pair to pair coupling stayed constant at about 10% of the intra coupling
- In general, tightly coupled diff pairs show less impact of the split on crosstalk
- The greatest increase in NEXT occurs at λ/4 of the coupled line length
- At these frequencies, the coupling can be significantly more even for tightly coupled pairs





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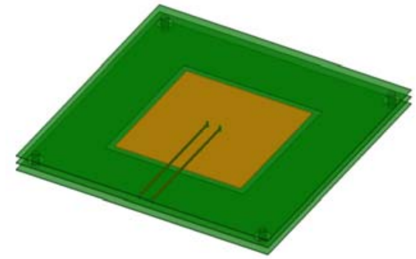
SIMULATION RESULTS

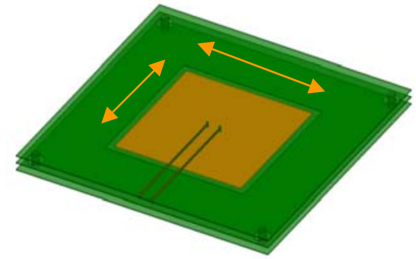
Interesting Split Plane Cases: The Power Puddle

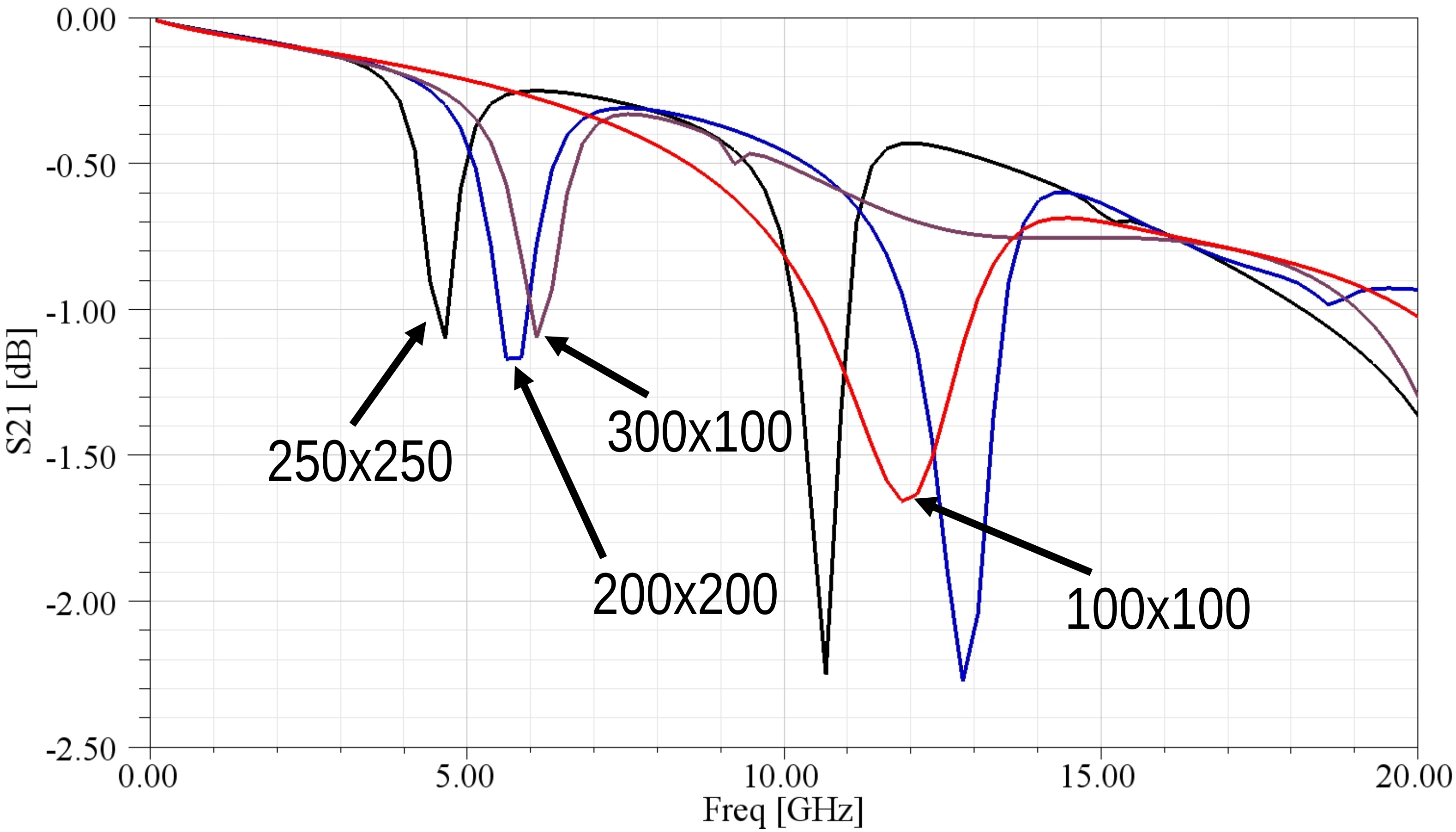


- Power islands or puddles create a split boundary on all sides around the plane’s periphery
- Like the slot, the moat around the island can serve as a resonator
- This “ring resonator” can be excited by a trace crossing, for example
- The difference is that the lowest resonance frequency is when the perimeter is equal to one wavelength
- This makes the plane resonance frequency twice as low as the slot resonance

SIMULATION RESULTS

Interesting Split Plane Cases: The Power Puddle





SIMULATION RESULTS

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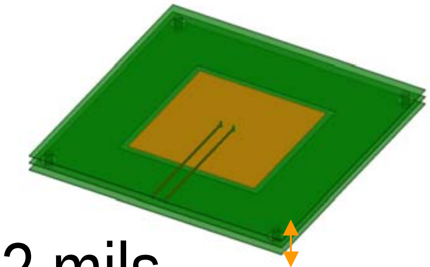
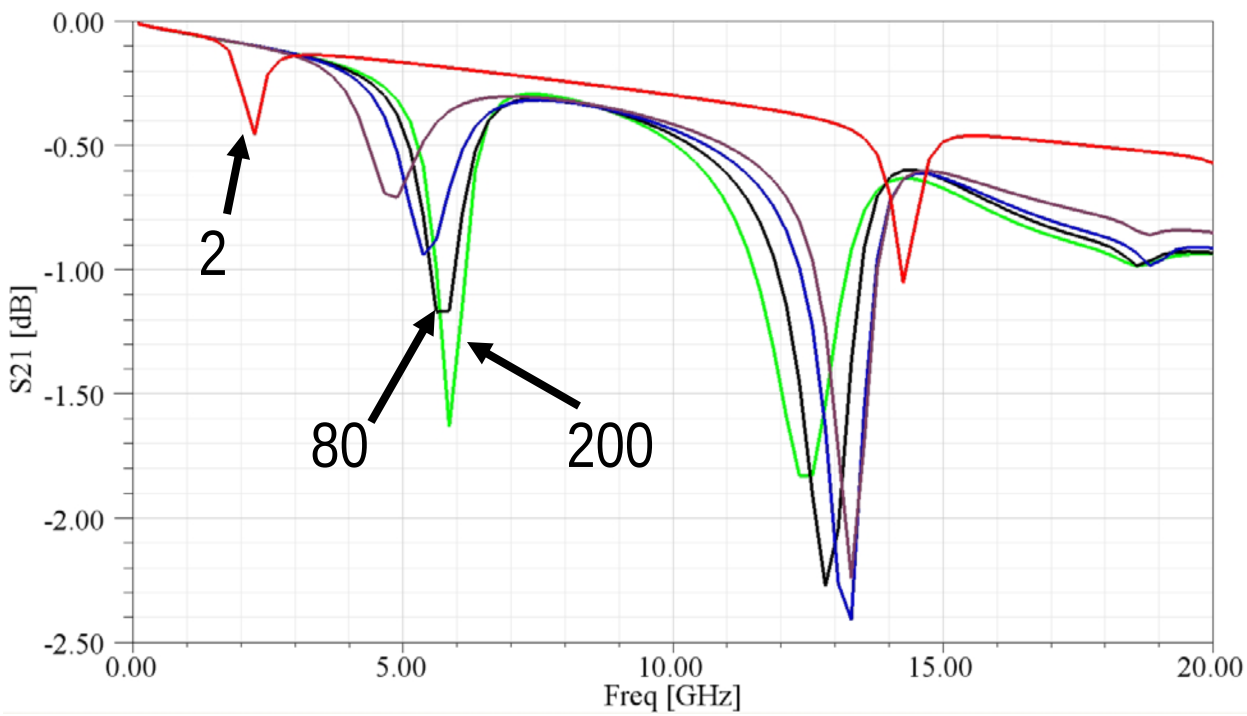
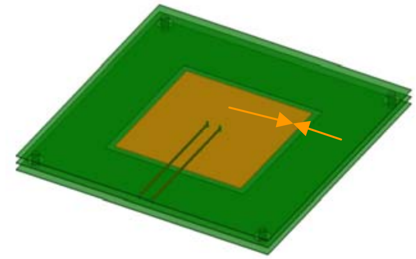


- Sweep PWR-GND separation from 200 mils to 2 mils
- Thinner PWR-GND dielectrics will reduce the plane puddle resonance and lower the Q

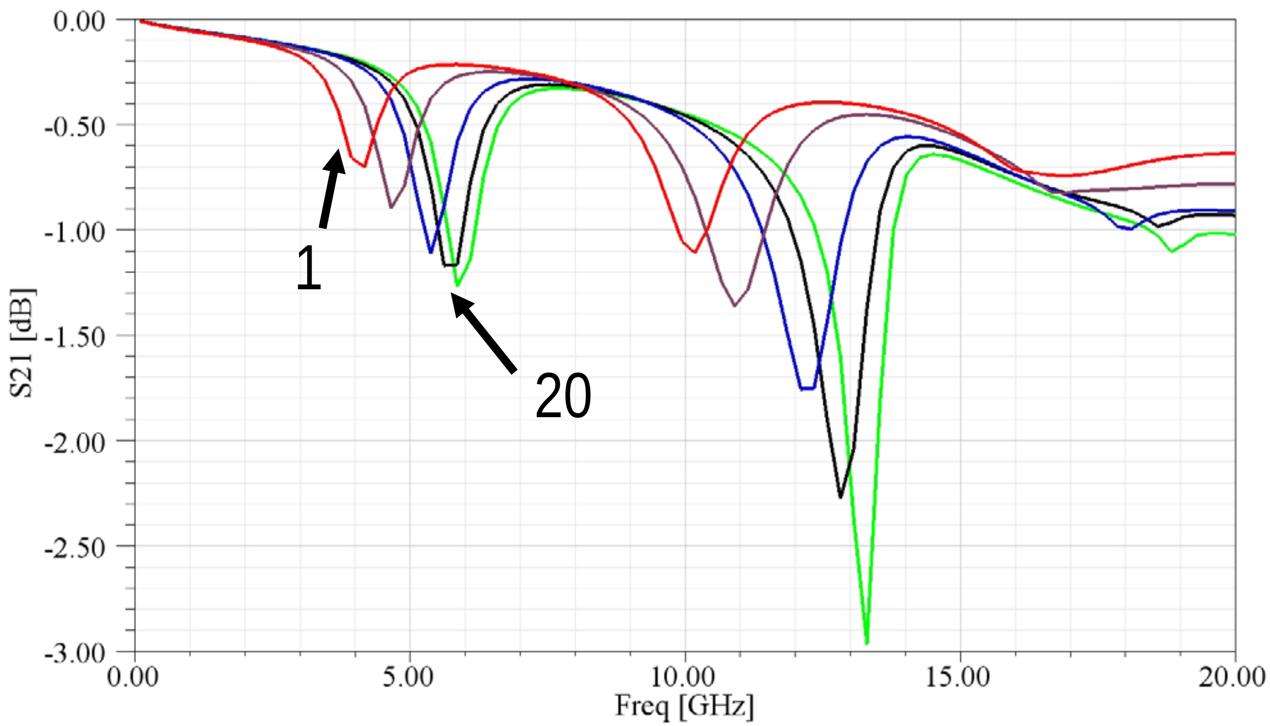


SIMULATION RESULTS

Interesting Split Plane Cases: The Power Puddle



- Sweep the moat width 20 mils to 1 mils
- Smaller moat widths will reduce the resonance and make it lower Q



SIMULATION RESULTS

Conclusions

- Solid ground planes immediately below splits can minimize the effect of the split on signal propagation if separated less by than 1-2X the split width vertically.
- Split width is not nearly as important a parameter as the presence of a split.
- Crosstalk between single ended traces is significantly higher in the presence of a split plane.
- Slots can introduce greater peak crosstalk than splits due to resonances setup by the slot edges.
- Splits increase the crosstalk between differential pairs and increase the differential to common-mode noise conversion.
- The greatest increase in crosstalk due to a split (relative to a solid plane) occurs above the $\lambda/4$ of the coupled line length. When one considers this frequency region, it is practically difficult to separate differential pairs in the presence of a split such that the crosstalk is the same as if the plane was solid.

SIMULATION RESULTS

Conclusions

- Power puddles or islands also resonate like slots but have a resonance frequency two times lower

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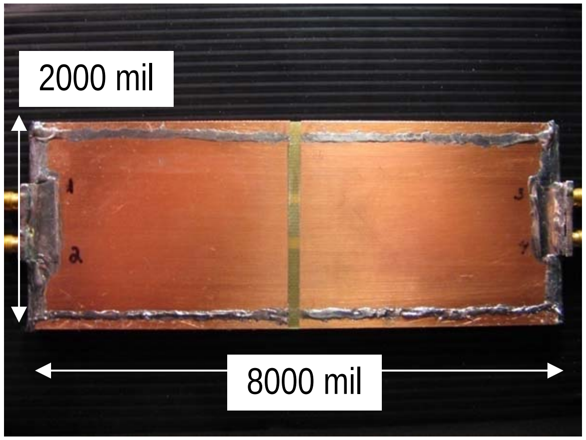
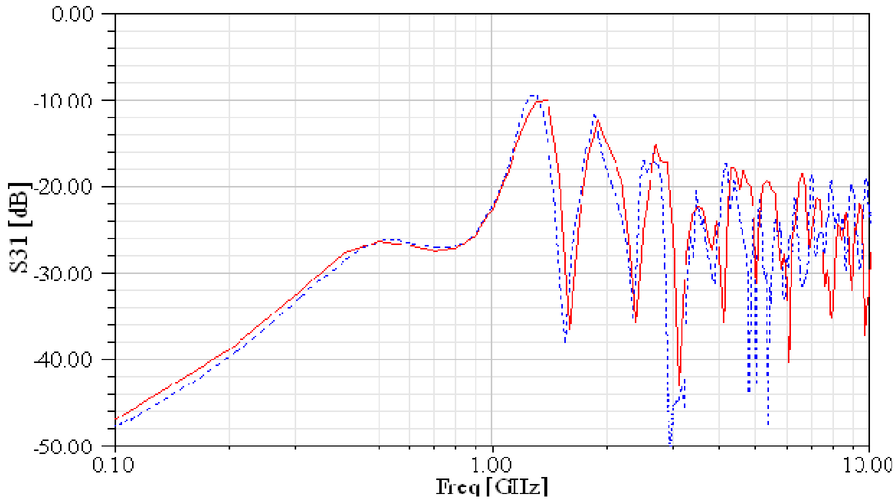
CORRELATION RESULTS
Overview

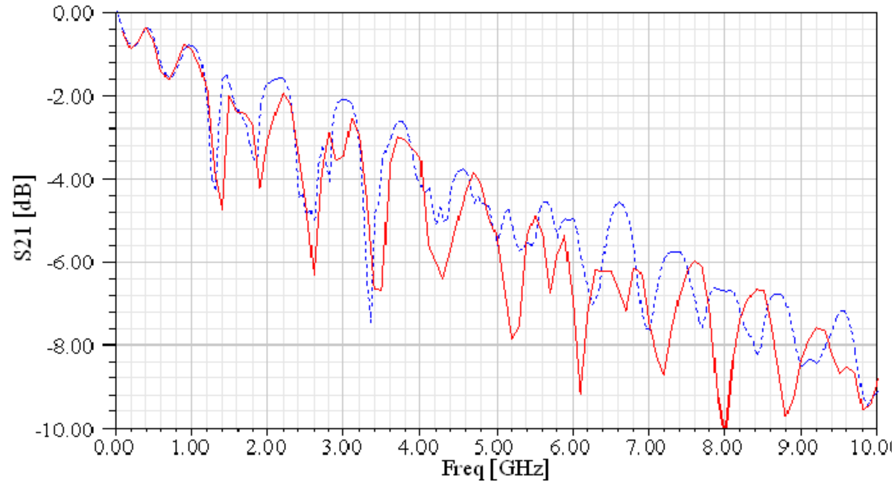
- Utilize scaled test structure to facilitate milling the split
- To make sure our parameterized results are accurate, the same deck was used and only the dimensions were scaled
- Consists of two 3 mm wide striplines routed 10 mm center to center
- The two traces are vertically centered in 126 mil thick FR4 dielectric
- Measured using Agilent E8363A VNA
- Simulated with HFSS v11

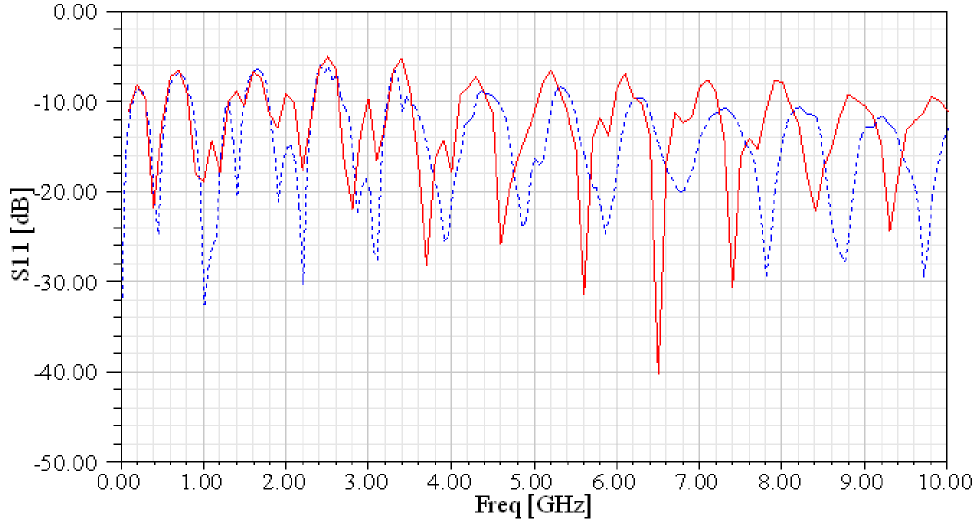


CORRELATION RESULTS

NEXT, IL and RL





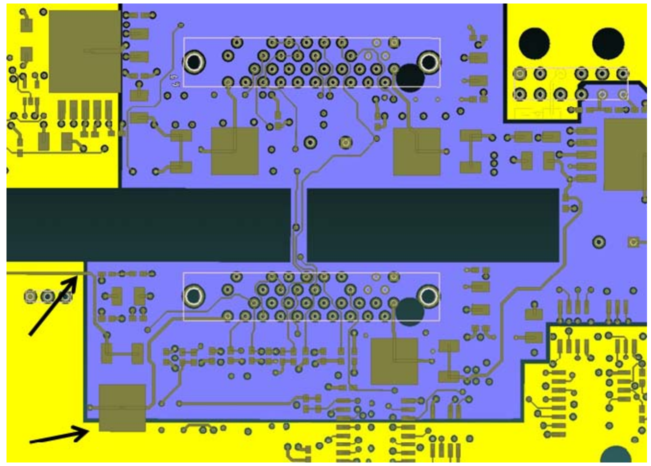


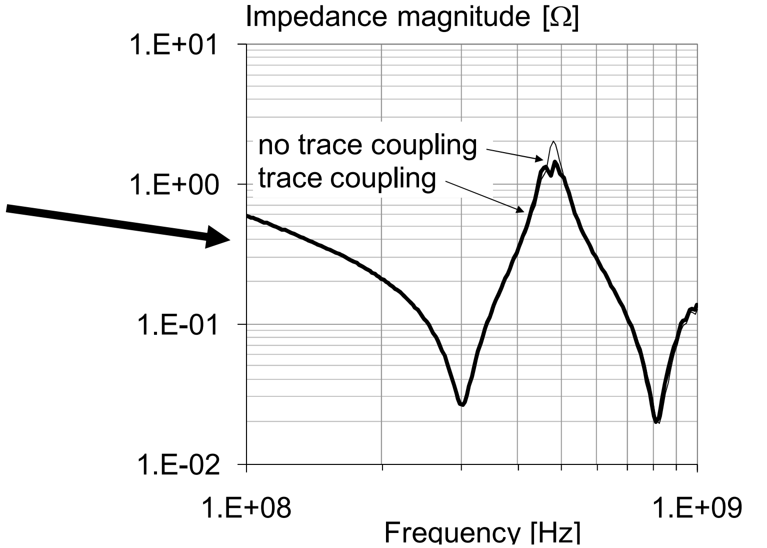
AGENDA

- Introduction
- Simulation Considerations
  - Four different port configurations
- Simulation Results
  - Single Ended Split Crossings
  - Single Ended Slot Crossings
  - Differential Split Crossings
  - Interesting Split Plane Cases
- Correlations
- Impact of Trace and Pad Crossings on PDN Isolation
- Conclusions

IMPACT OF TRACE AND PAD CROSSINGS ON PDN ISOLATION

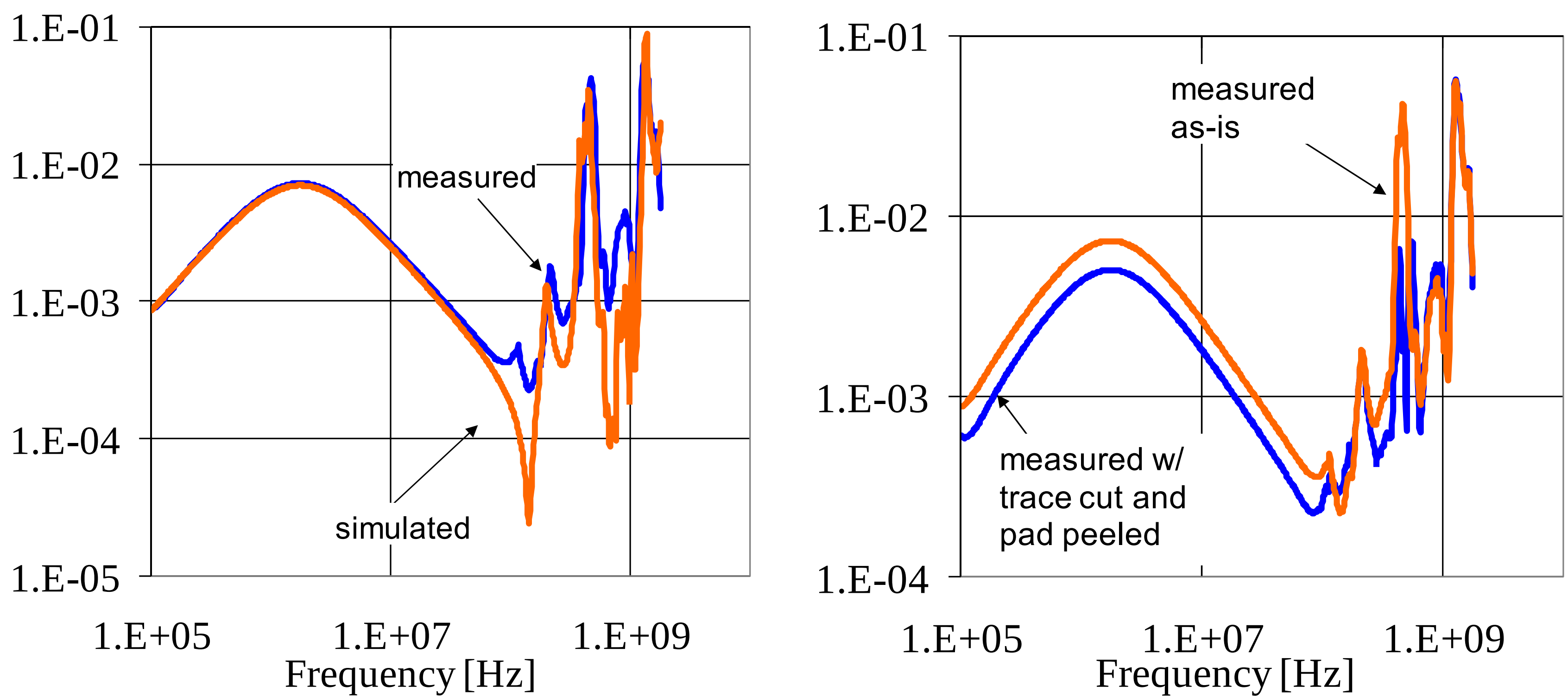
- Coupling between independent power domains can happen due to a variety of reasons
  1. Edge coupling of plane shapes
  2. Broadside coupling of plane layers
  3. Intentional stitching caps
  4. Traces or pads running over shapes
- We look at (4) here
- The impact of (4) can be small on the *self*-impedance profile
- The impact on the transfer impedance and isolation can be much greater





IMPACT OF TRACE AND PAD CROSSINGS ON PDN ISOLATION

Simulation and Measurement Results



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CONCLUSIONS

- Signals transversing splits or slots can have energy reflected due to the discontinuity. This energy will introduce a host of issues which we have explored
- We specifically divided the problem into plane resonance issues and non-plane resonance issues by carefully defining the port and boundary conditions
- Plane resonance issues can have a DOMINANT effect on the SI picture if the planes aren't perfectly terminated, well bypassed or electrically large
- Non-plane resonance issues include more crosstalk and more losses. Differential traces may not side step these issues, especially at $\lambda/4$ frequencies
- We showed that slots can be excited (just like planes) and introduce additional crosstalk and loss beyond the split plane case. Plane islands can also introduce unique issues worth paying attention to.
- Finally, we showed that fairly innocent-looking split crossings can significantly reduce power domain isolation

To download source files for the solver simulation decks: www.hfss-forum.com