DesignCon® 2014

Mixed-Reference for Optimum Cost & Performance in High-Speed Memory Interface

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- Expected SI/PI Issues from Mixed-Reference
- Mixed-Reference Impact on System Performance
- Summary

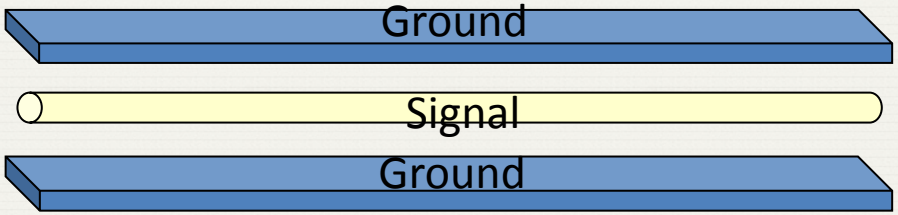
Motivation

1 billion shipped

- Cost reduction is valuable in making products competitive
  - Reducing substrate layer-count/decaps greatly lowers the cost: $$$
  - Cost reduction requires careful SI/PI analysis not to lose performance

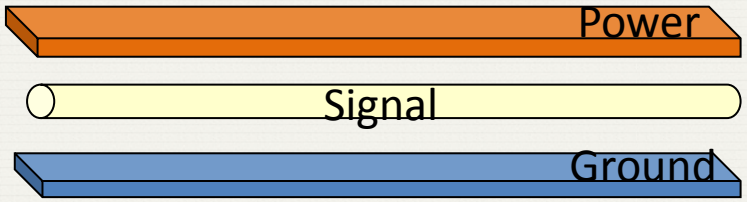
Why and What is Mixed-Reference?

Single-reference



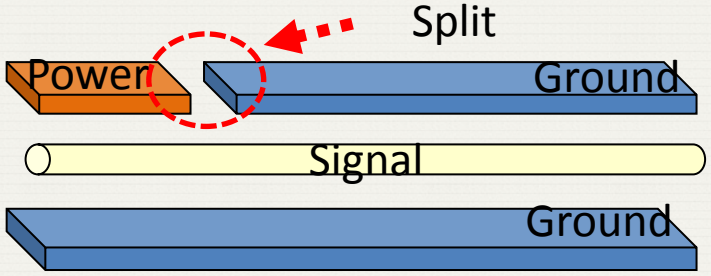
Mixed-reference

Power/ground reference



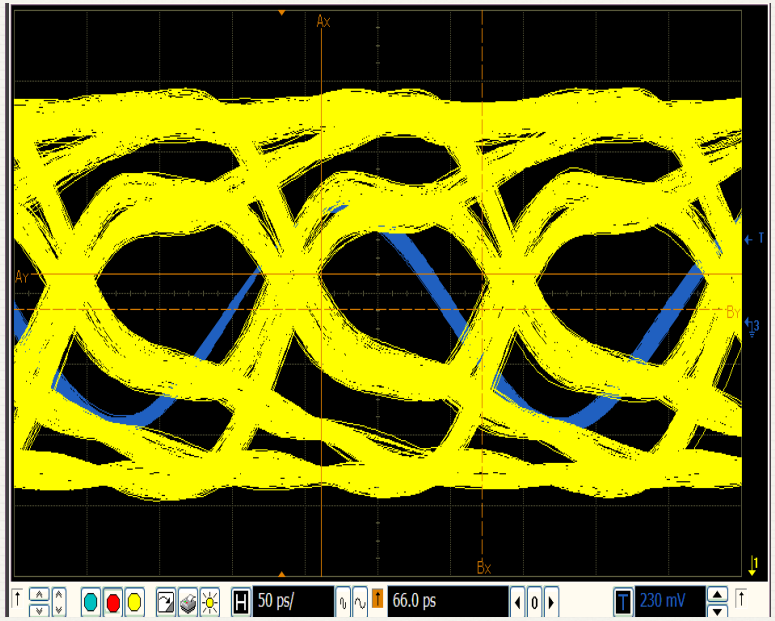
- Ideal reference type for minimizing SI issues
- Reducing substrate layer count typically leads to evaluate mixed-reference option

Split-plane reference

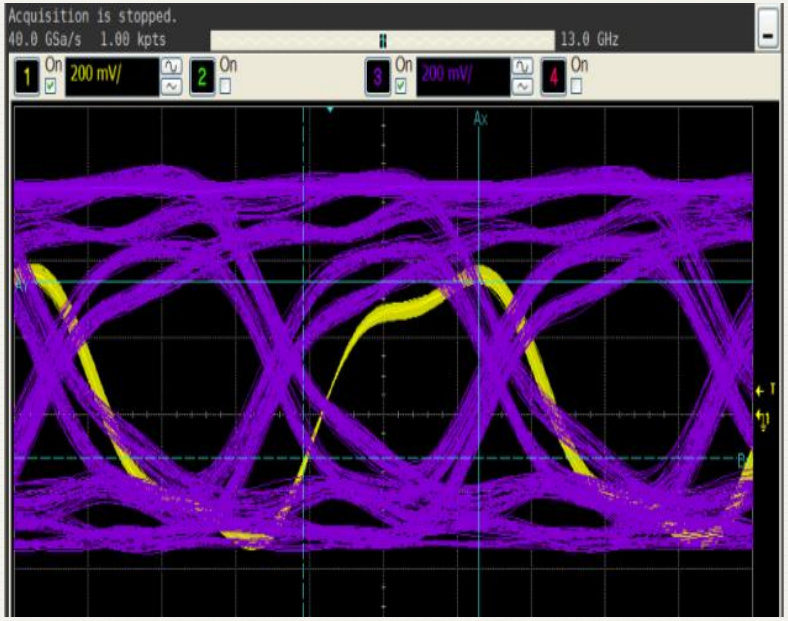


Measured Performance Difference on Mixed-Reference at 6.6 Gbps

Split-plane reference



Single-reference



- Why do we see performance difference?
- How do we analyze mixed-reference?

- Introduction
- **Mixed-Reference Analysis using 3D Tool**
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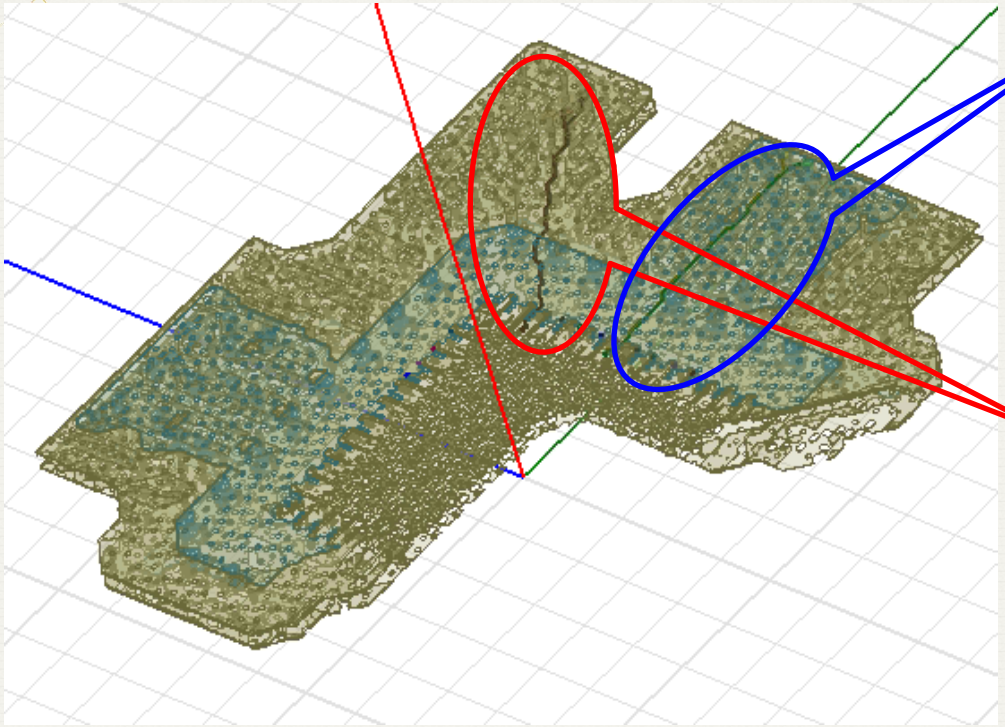
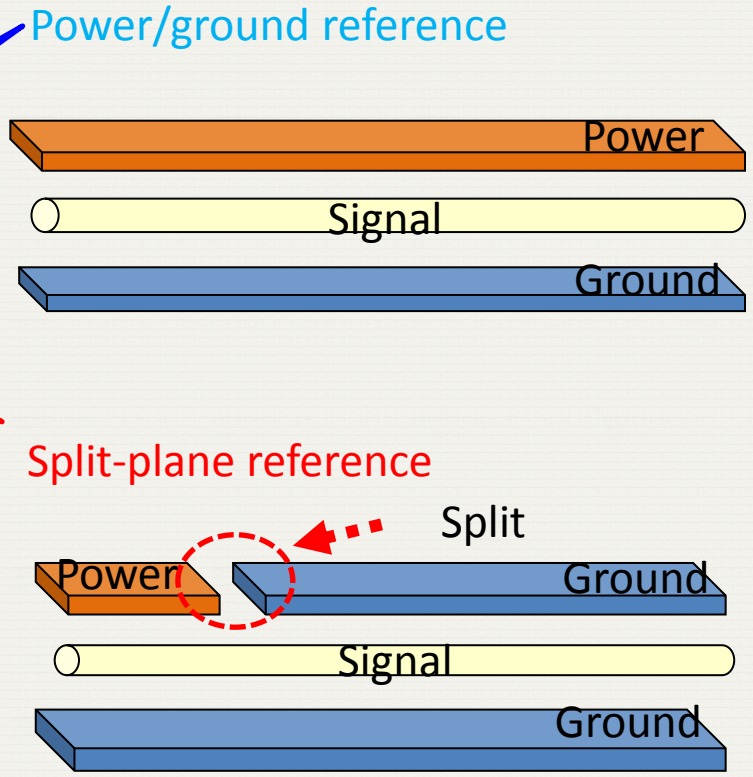
Need for SI/PI Co-Simulation Model

- Generally, SI and PI are modelled separately using different tools
  - Computationally expensive
- Mixed-reference analysis needs to use SI/PI combined model
  - Additional power noise directly coupled to channel response

SI/PI Co-Simulation 3D Model for Mixed-Reference



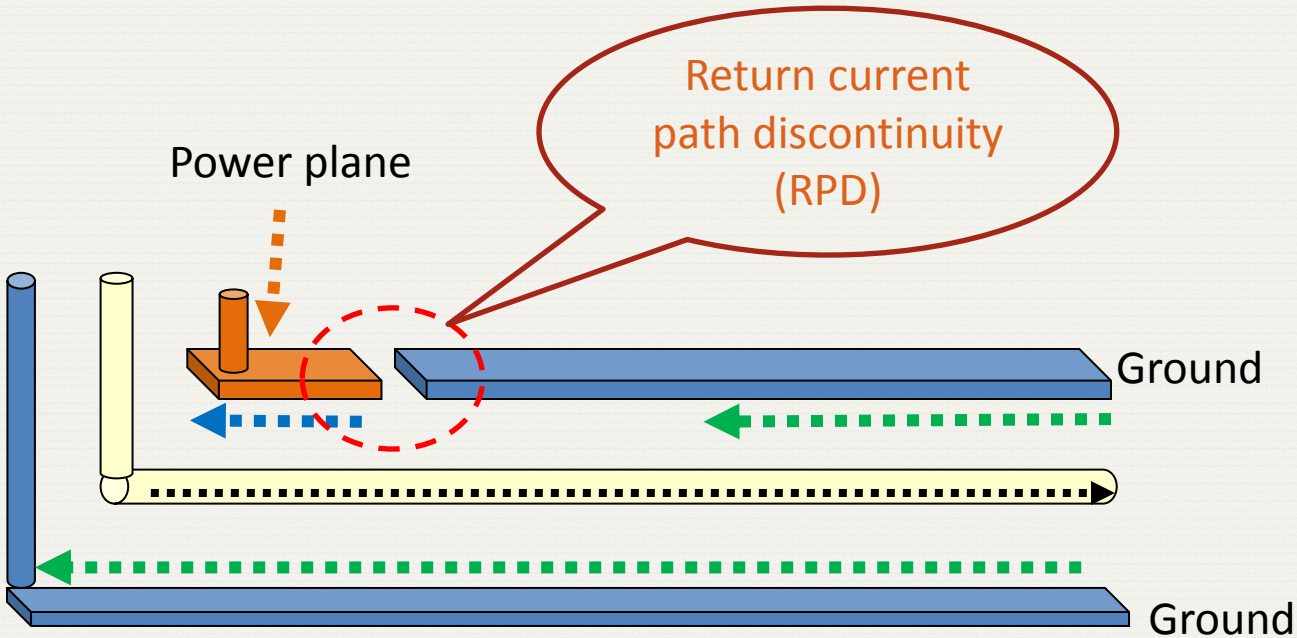


- PI: Entire PDN model
- SI: Mixed-reference channels

Caveat on 3D Model Generation Flow for Mixed-Reference Analysis

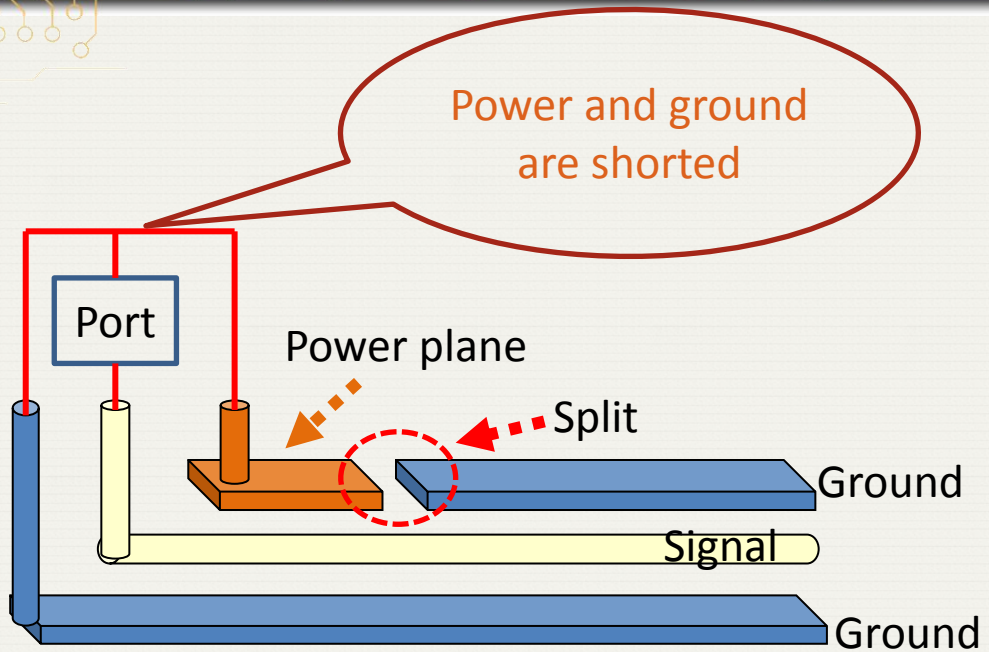
- By default, auto port generation feature shorts power and ground when it generates signal ports
  - For single-reference channel, signal port referenced to ground without shorting power and ground should give identical results as automatically generated one
- For mixed-reference analysis, power and ground connection for port definition greatly affects the result

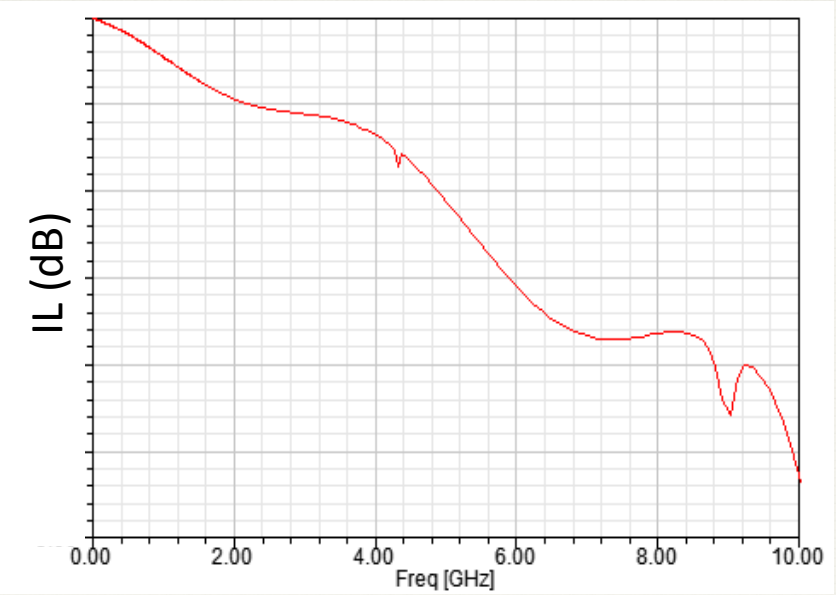
Return Path Discontinuity on Split Plane



- Expect to have RPD effect, which will affect signal integrity

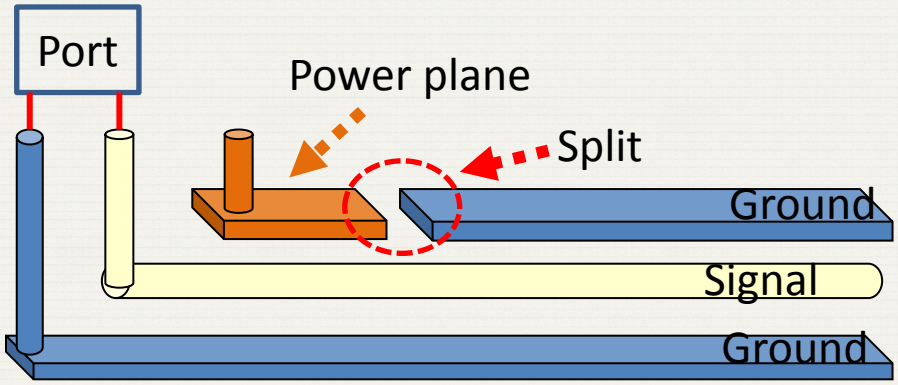
Incorrect Channel Response by Conventional Automatic Port Setup

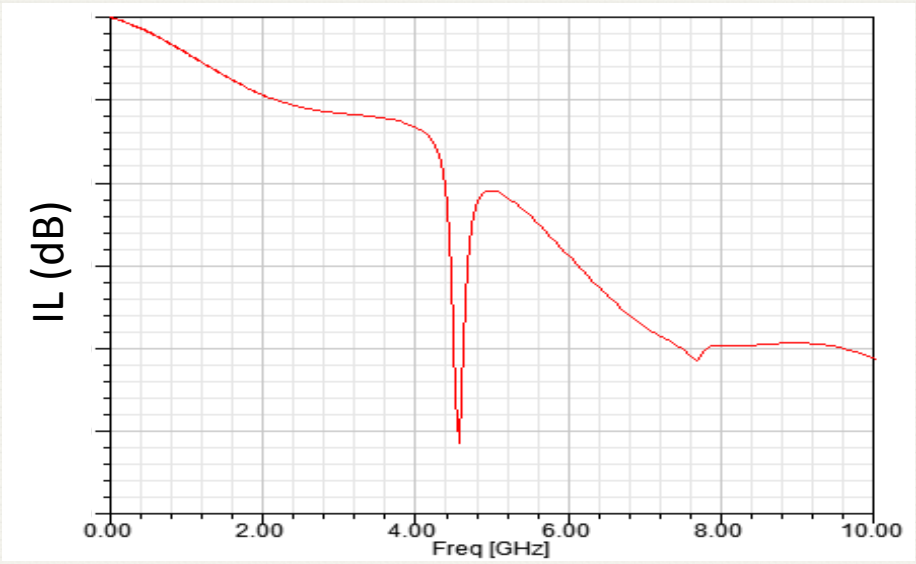




- Power and ground are shorted
  - Channel response looks too clean although we expect RPD
  - Is this right setup since ground plane dominates most of reference?

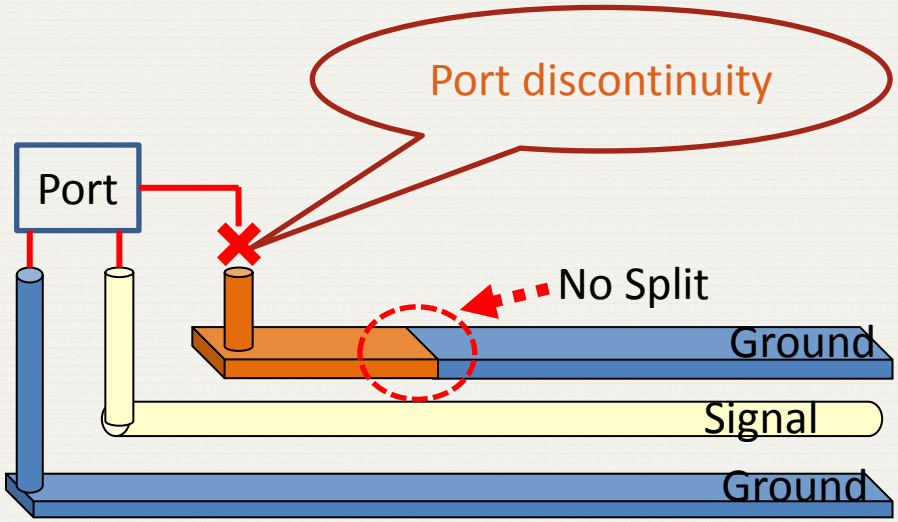
Incorrect Channel Response by Conventional Manual Port Setup

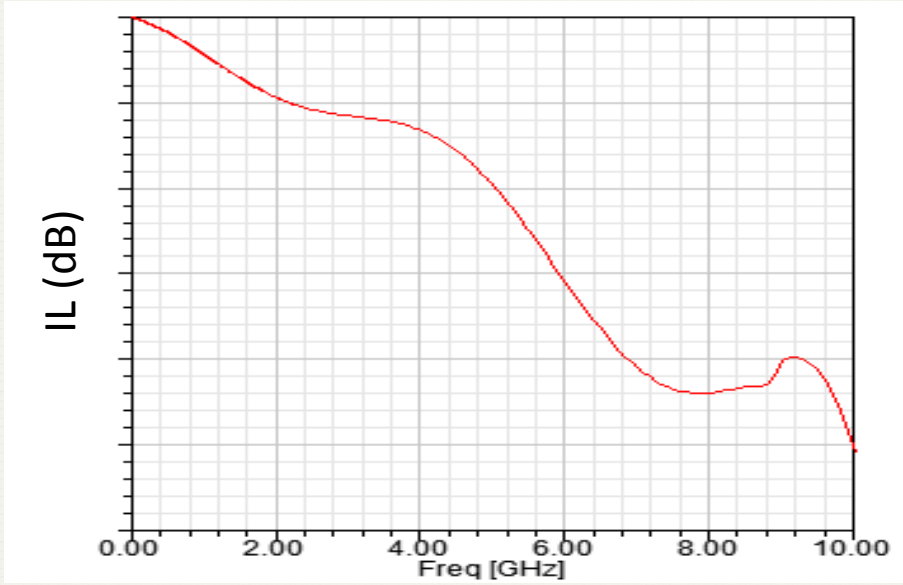




- Power and ground are not shorted
  - Signal port is referenced to ground only
  - Huge resonant around 4 GHz
  - Is this false resonant caused by port discontinuity?

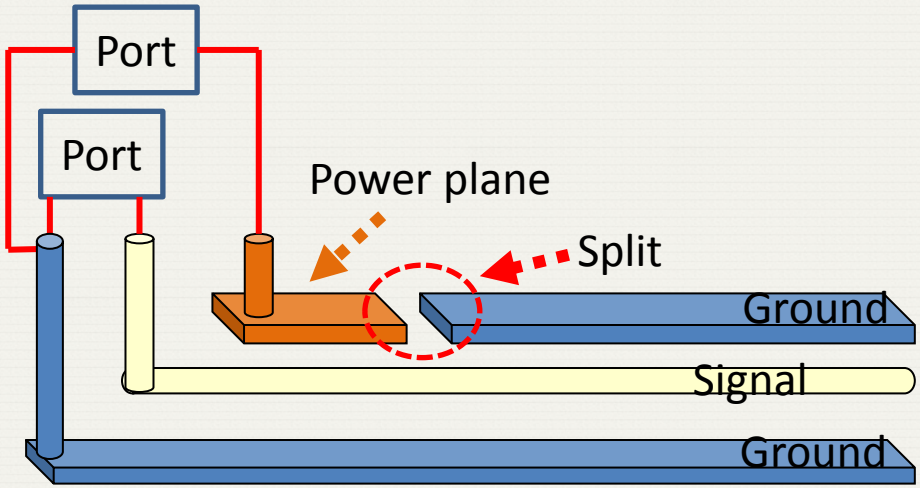
Effect of Port Discontinuity

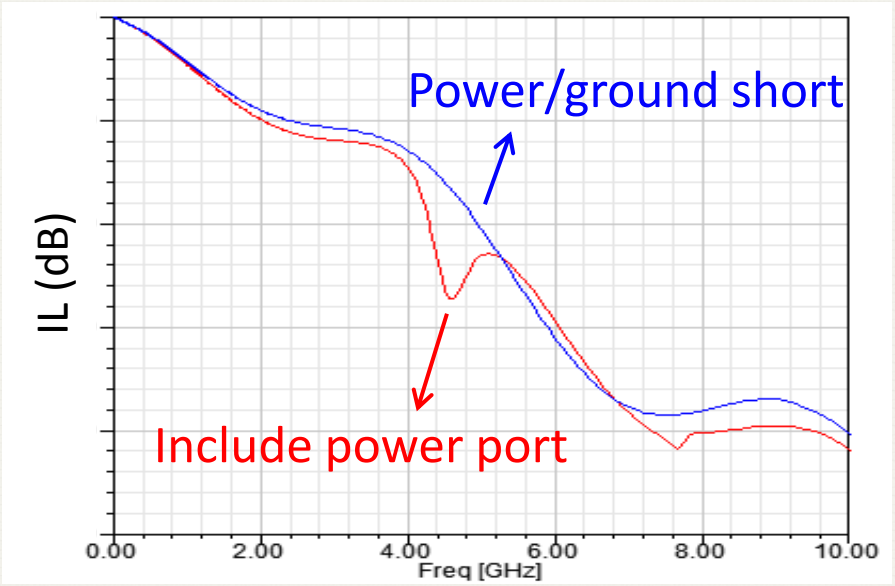




- Filled split, but maintain port discontinuity
  - No resonant in entire frequency range
  - Very similar result as power and ground short result

Mixed-Reference Port Setup

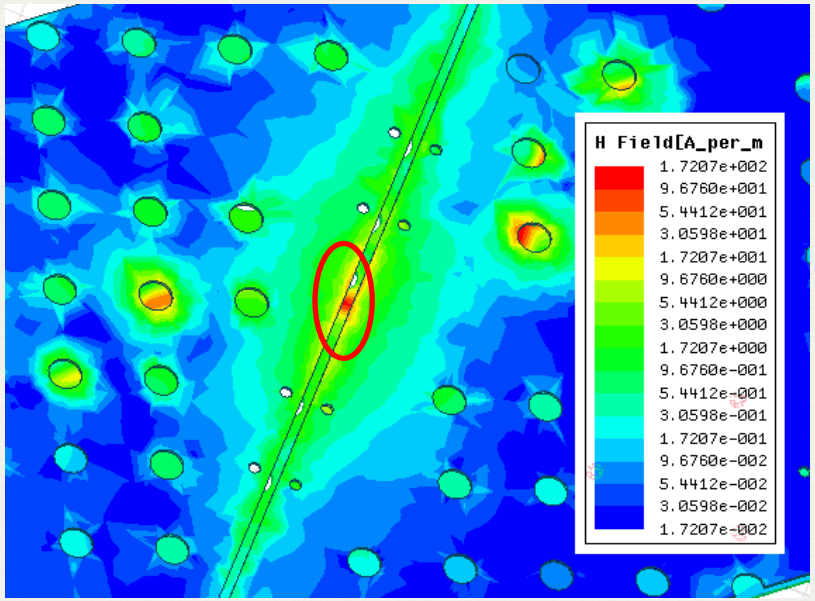




- Additional power port referenced to ground is needed
  - Capture return currents in both power and ground plane
  - Power port can be used for on-die connection for SI/PI co-analysis
  - Power/ground shorts changed return current flow

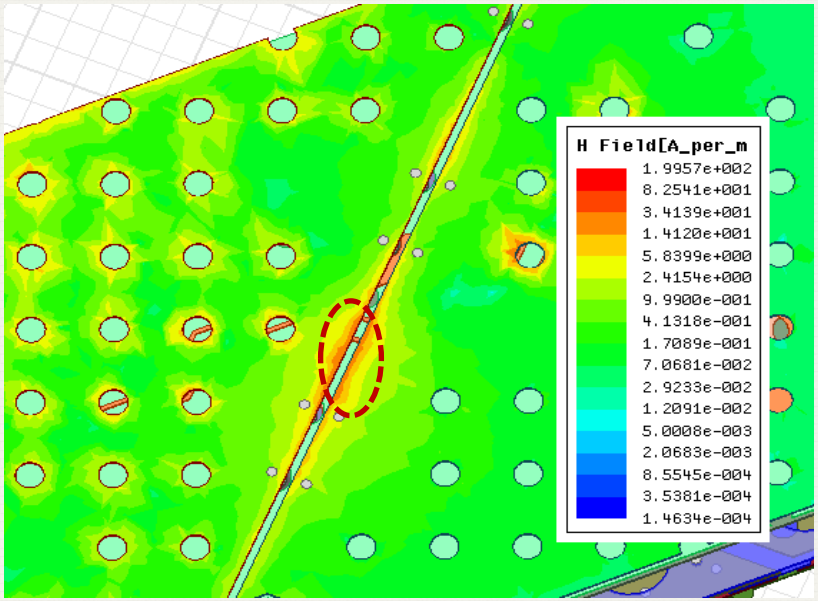
Comparison of H-Field Distribution

With power port



- The strongest field is seen at split region

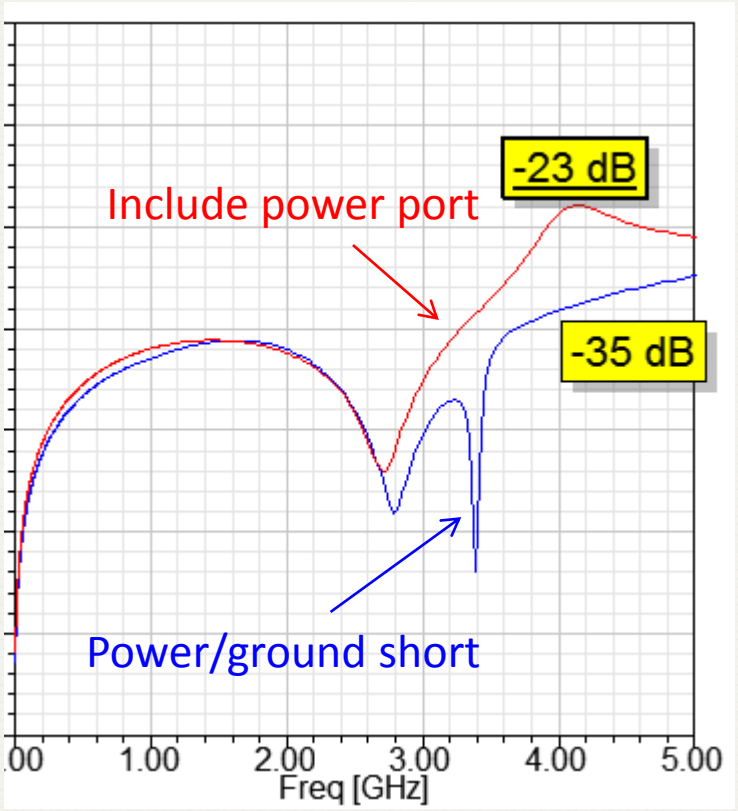
No power port & power/ground short



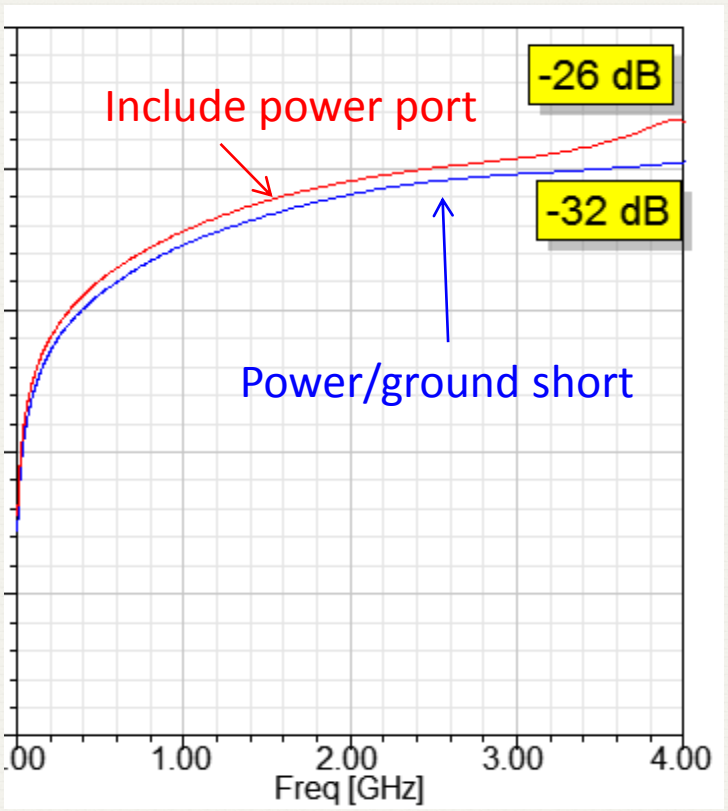
- Reduced magnitude of field at split
  - Demonstrates that RPD is mitigated by port setup

Effect of Port Setup on Crosstalk Result

Near-end crosstalk



Far-end crosstalk



- Incorrect port setup provides optimistic crosstalk
  - Non-negligible difference between results
  - Deviation becomes higher as frequency increases

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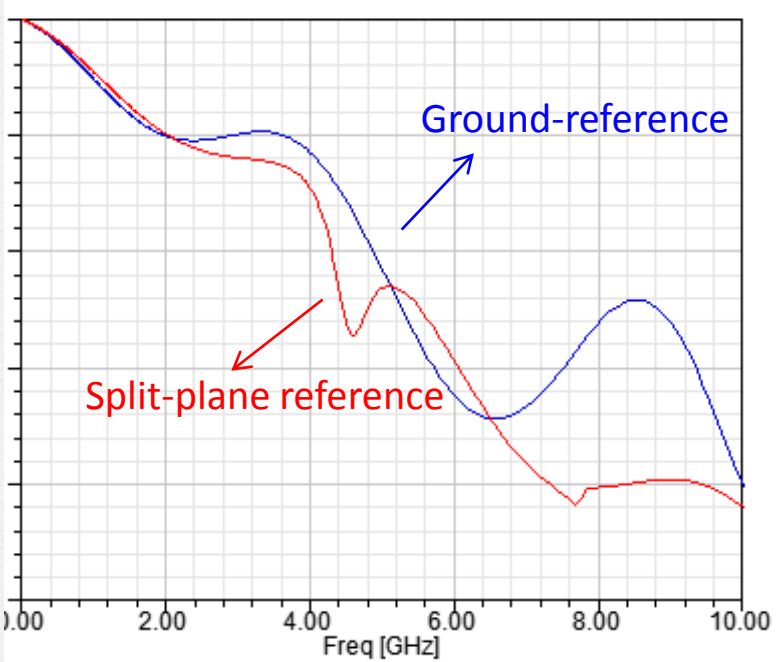
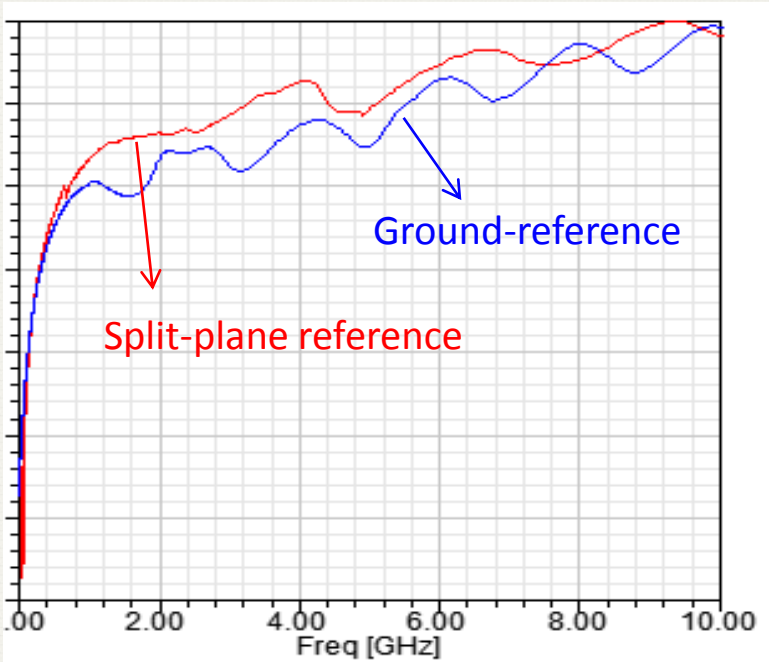
Mixed-Reference vs Single-Reference in Channel Frequency Response

Insertion loss



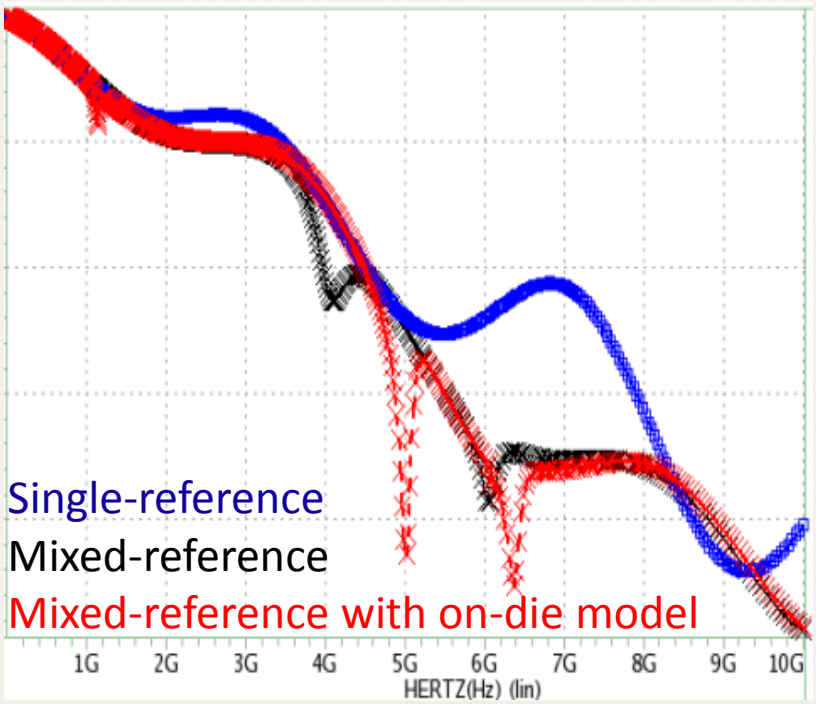
Crosstalk



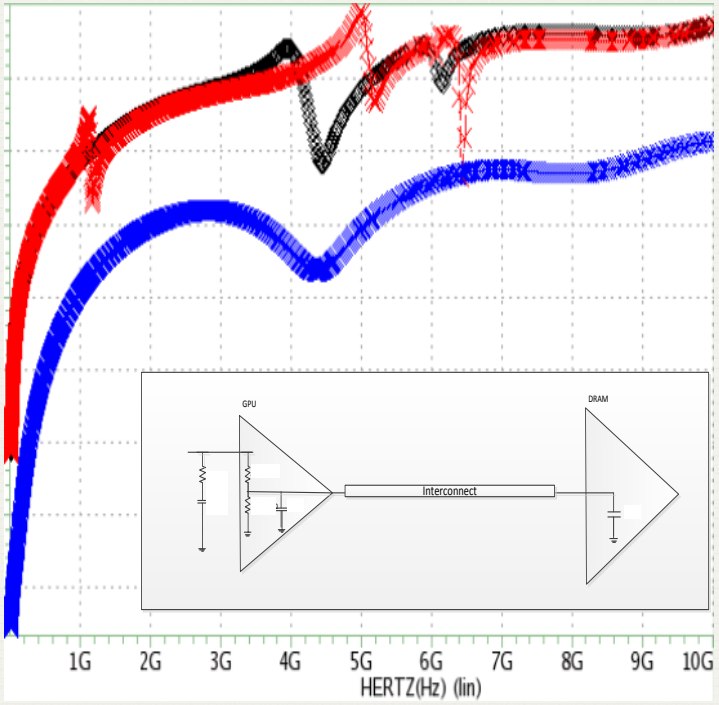
- Higher channel loss along with resonant
  - PKG + PCB result with the same channel length
- Higher crosstalk
  - Difficult to generalize crosstalk delta, but trace routing and space are the same condition

Impact of On-Die Connection

Insertion loss



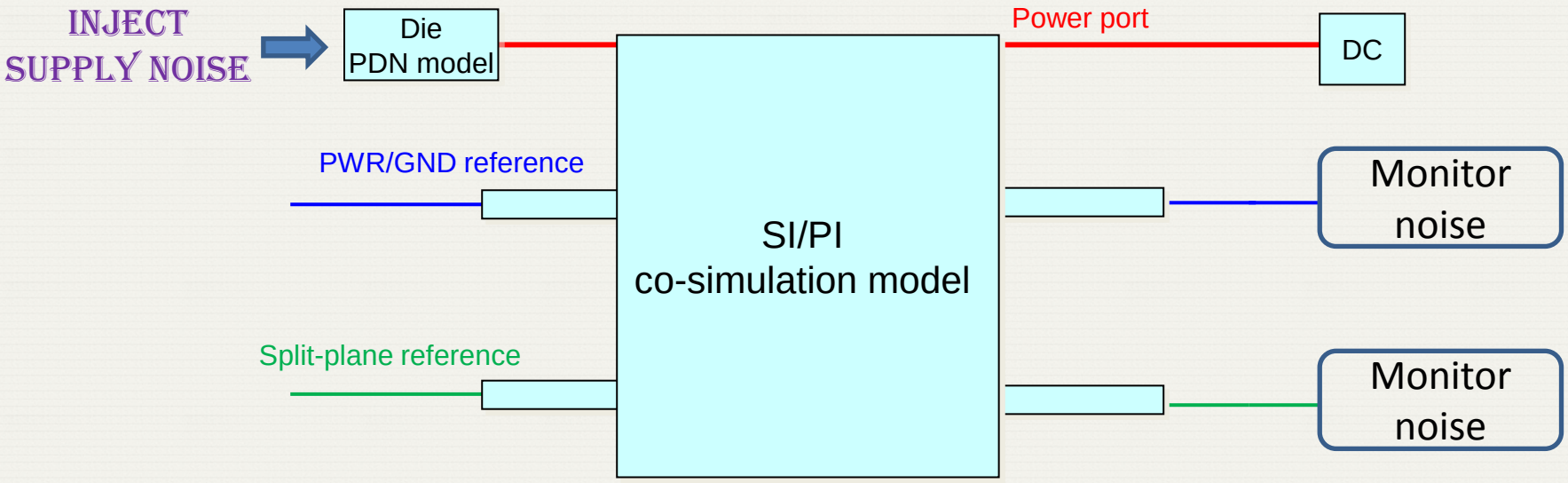
Far-end crosstalk



- Channel response of mixed-reference is affected by including on-die model
  - Capacitor in on-die model affects return current flow b/w power and ground

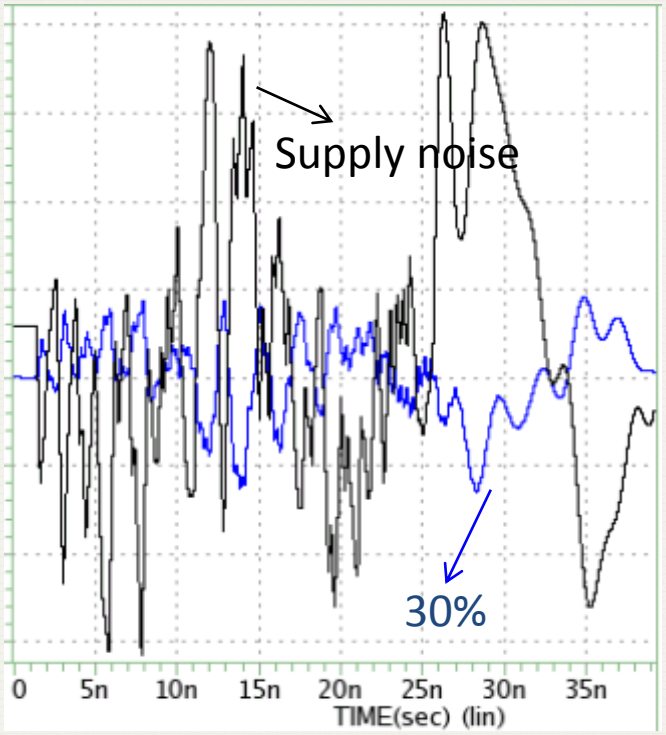
Simulation Setup for Power Noise Coupling to Channel

- For mixed-reference, there is coupling between power plane and traces
- No circuit is switching to exclude ISI/crosstalk effect
- Channel is terminated to DC

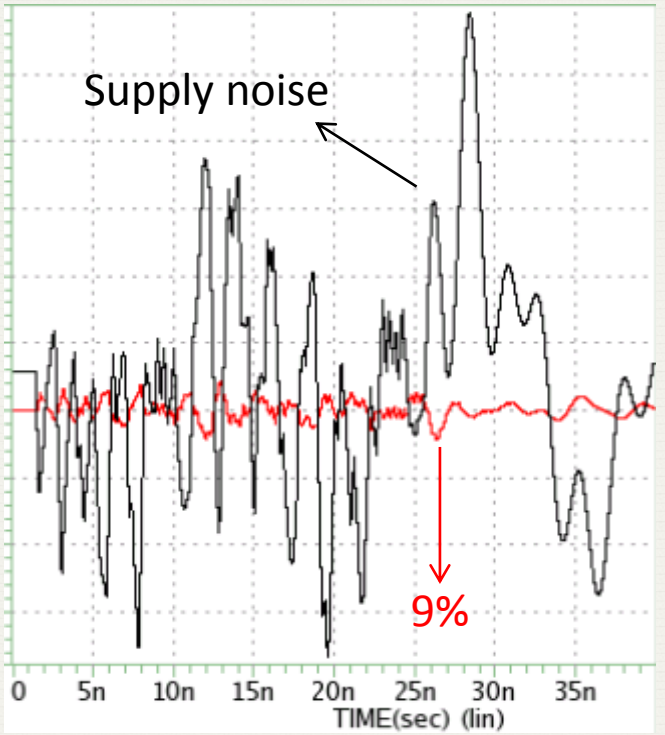


Power Noise Coupling to Channel in Mixed-Reference

Power/ground reference

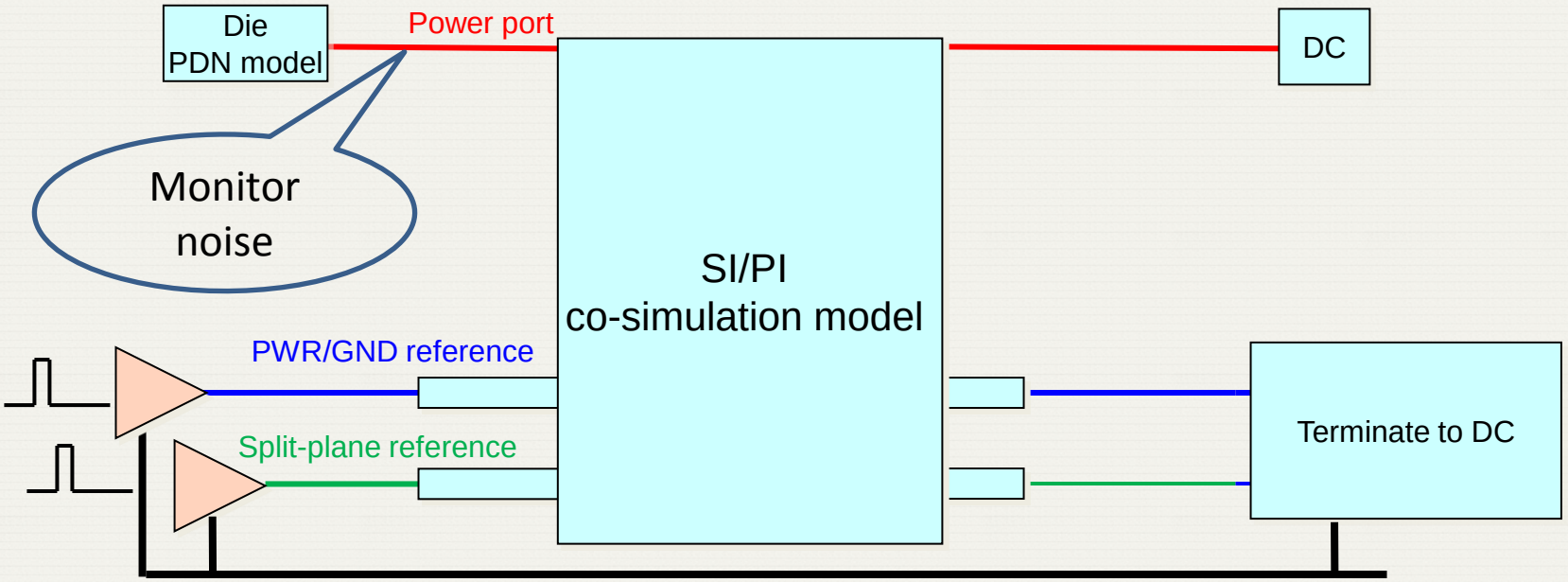


Split-plane reference



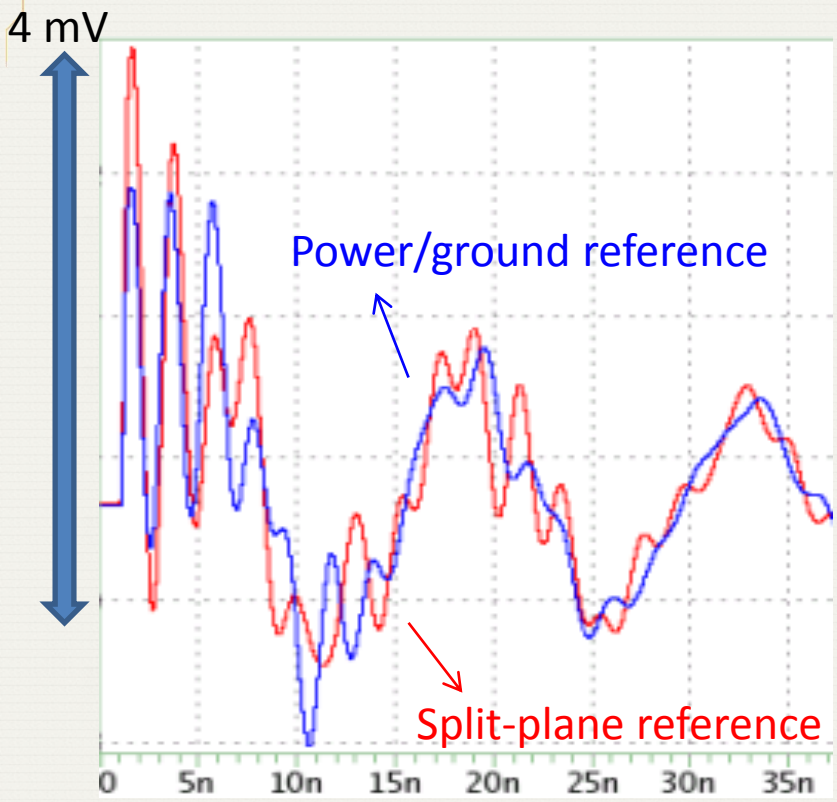
- Supply noise and power noise coupled in trace are shown
  - Crosstalk is not included
- Power/ground reference shows higher coupled noise than split-plane reference

Simulation Setup for Channel Induced Power Noise



- Hundreds of channels toggling in memory interface can add noise in power plane
- Power port is connected to ideal power supply
- Circuit is switching, but driver has ideal power connection

Channel Induced Power Noise in Mixed-Reference



Noise seen in power plane by signal toggling

- Noise measured in power plane when signal is toggling
  - From only one aggressor
  - Very high noise is seen on power plane
  - ~ 4mV noise after including on-die connection
- Mixed-reference may have higher power noise than single-reference
  - Impact of hundreds of aggressors may not be negligible

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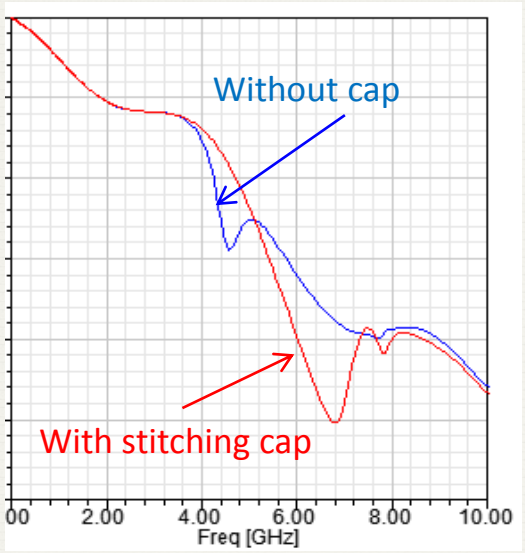
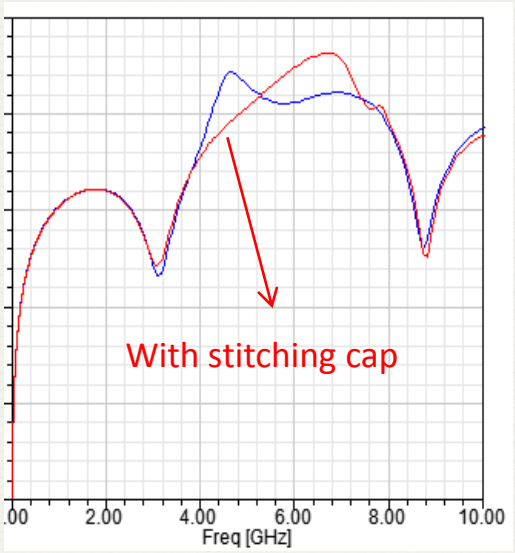
Effectiveness of PKG Stitching Capacitors on Mixed-Reference

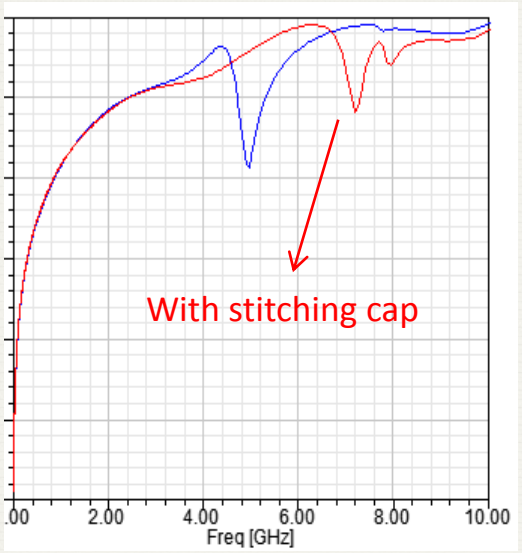
Insertion loss



Near-end crosstalk



Far-end crosstalk



- PKG caps are often used to reduce RPD caused by split
- PKG caps can provide AC current return path
  - Resulted in resonant shift
  - Effective frequency range is too narrow
  - Hard to say PKG cap improves crosstalk

System Level Measurement Case

- 6L package
  - Mixed-reference: Split-plane reference
- 8L package
  - Single-reference: Ground-reference

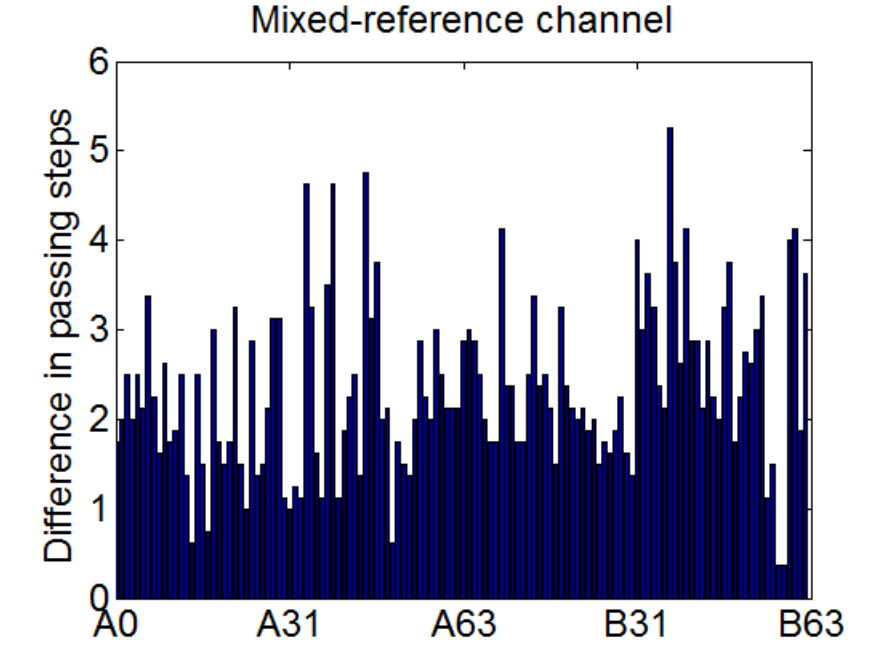
- Signal routings on both packages are exactly the same
- 6L package will save $$, but need to consider mixed-reference impact

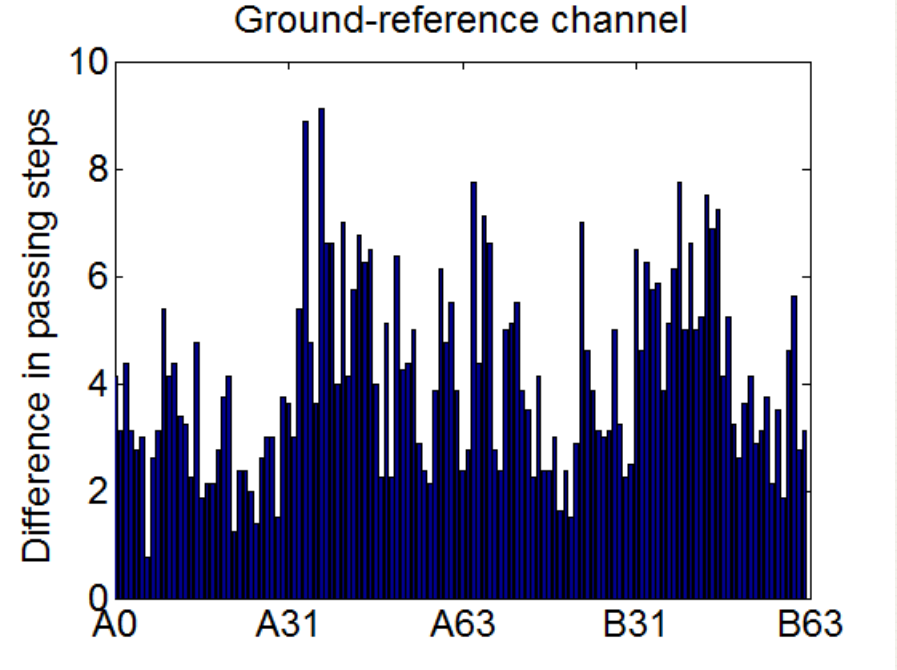
System Level Measurement Detail

- Characterization engine sweeps interpolator from -32 to +32 for every DQ signals and counting number of passing taps

- For measurement consistency, each measurement is repeated 8 times and averaged
  - PKG caps vs NO PKG caps
  - DBI on vs DBI off

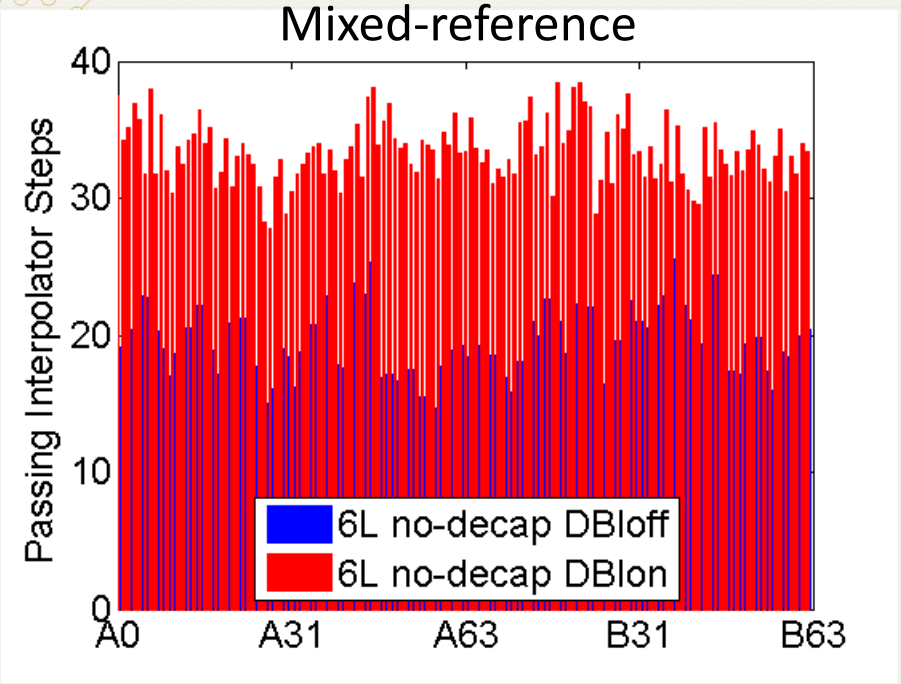
Measurement Comparison of With and Without PKG Caps

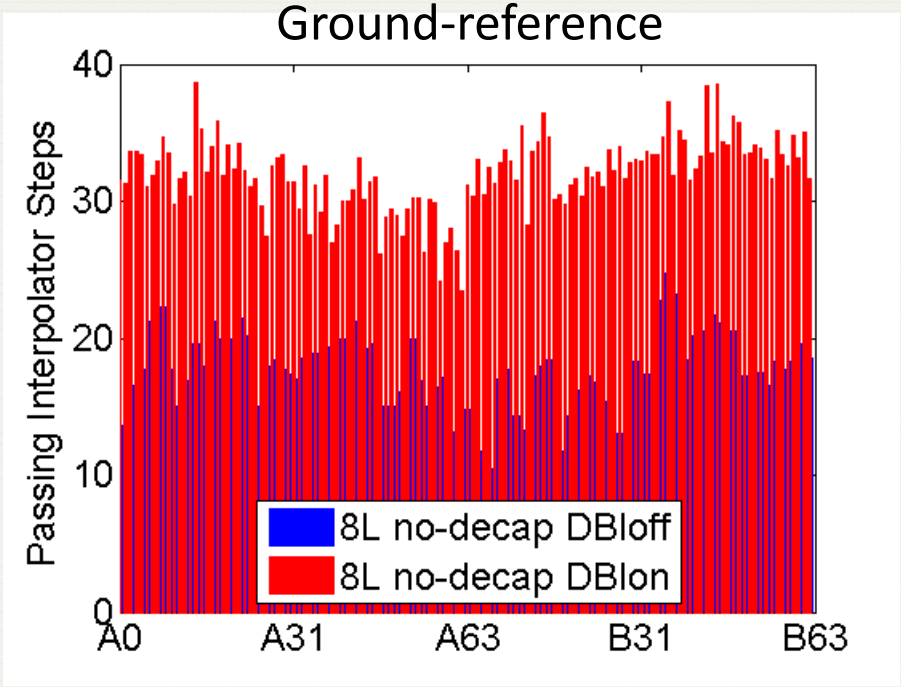




- To distinguish the performance impact, measured data are subtracted from each other: with decaps case shows higher passing taps
- Performance difference by having PKG caps
  - Mixed-reference PKG: 0.03 UI Ground-reference PKG: 0.045 UI
- No clear distinction b/w 6L vs 8L

Measurement Comparison of DBI Impact

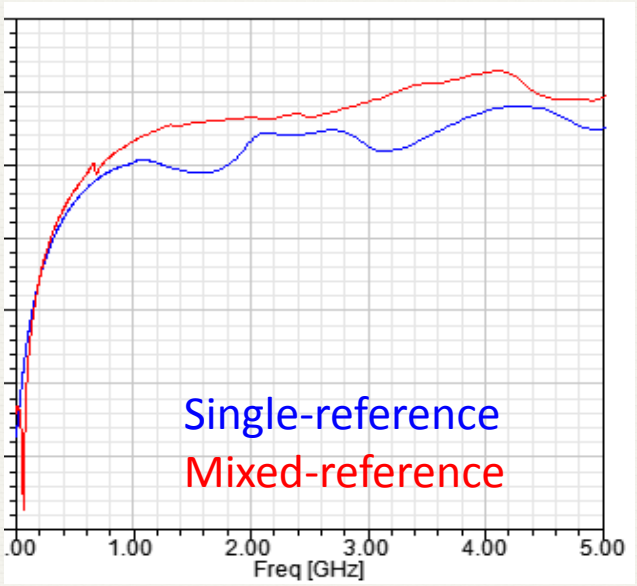




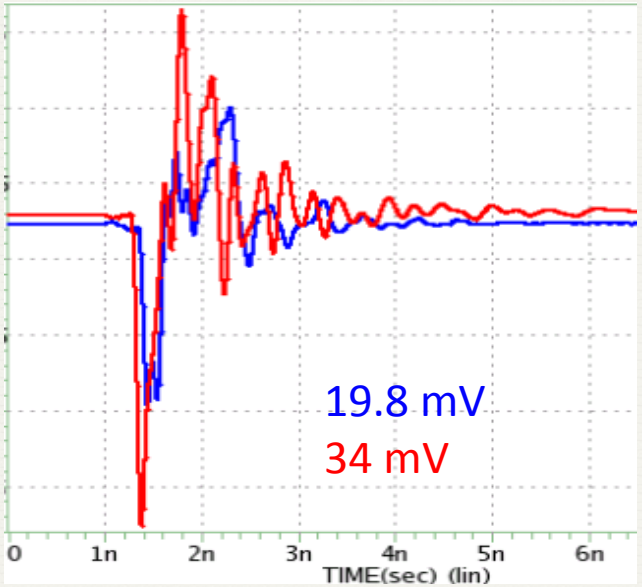
- All of PKG caps have been removed
- Impact of DBI is far significant than PKG caps
  - 0.23 UI for both 6 & 8L PKG
  - Mixed-reference does not increase overall sensitiveness of power noise

Performance and Cost Trade Off

FEXT in frequency domain



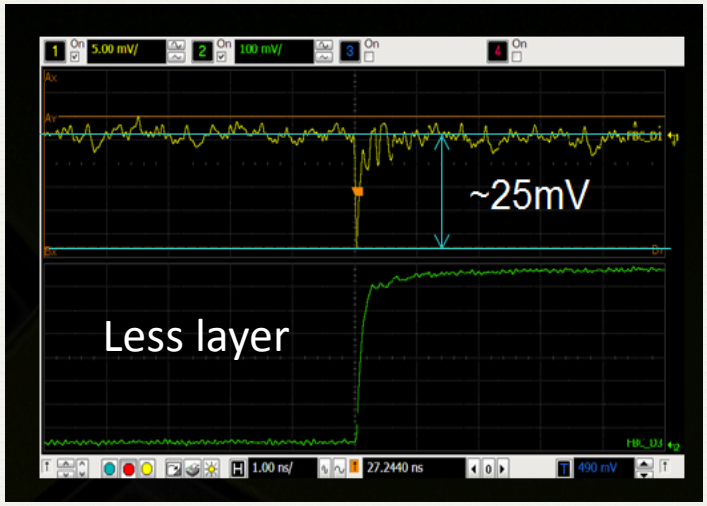
Crosstalk P2P noise

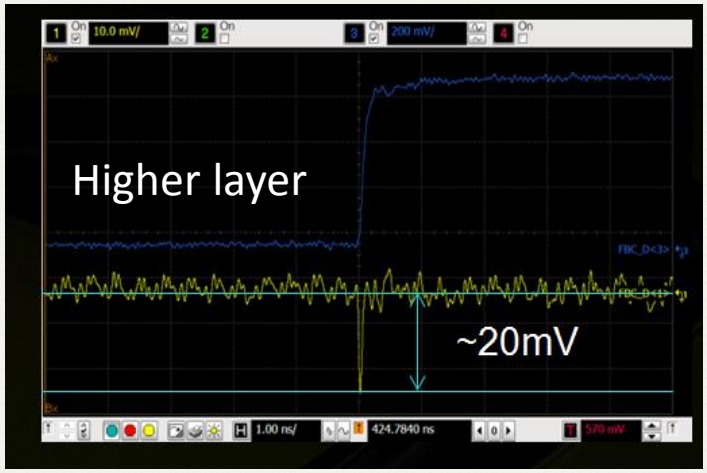


- Pursue higher layer count PKG for better performance with additional cost
- Within same PKG, there can be mixed-reference and ground-reference
  - Even with the same trace to trace spacing rule, crosstalk is dramatically different
  - 7~ 10 dB difference -> 70 % higher peak-to-peak crosstalk noise
- Performance will be limited by mixed-reference channel
  - Accurate mixed-reference analysis has to be used

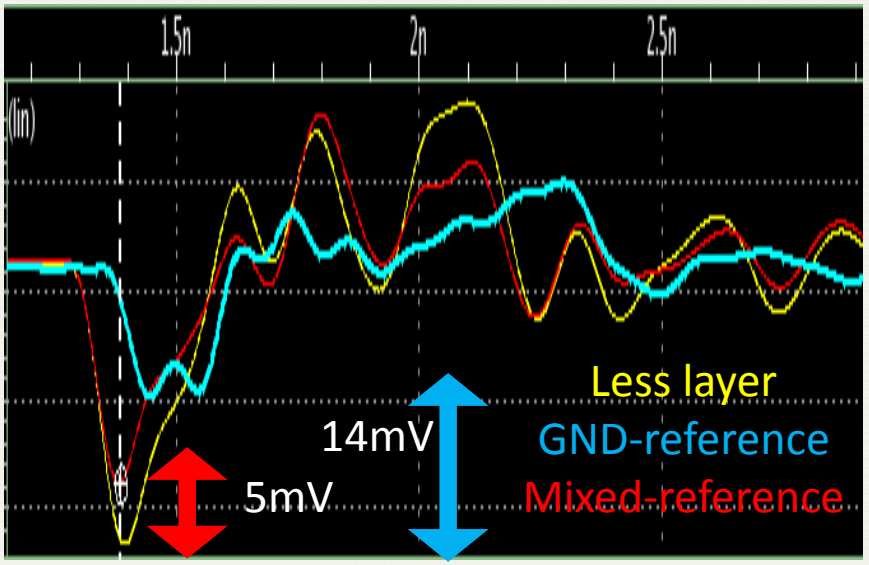
Mixed-Reference Crosstalk Correlation

Measurement



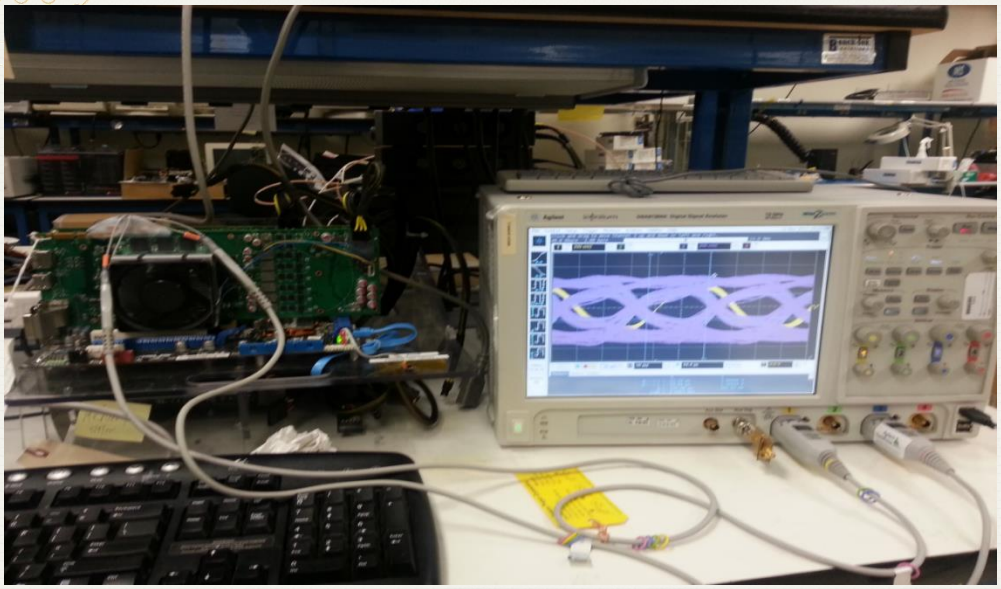


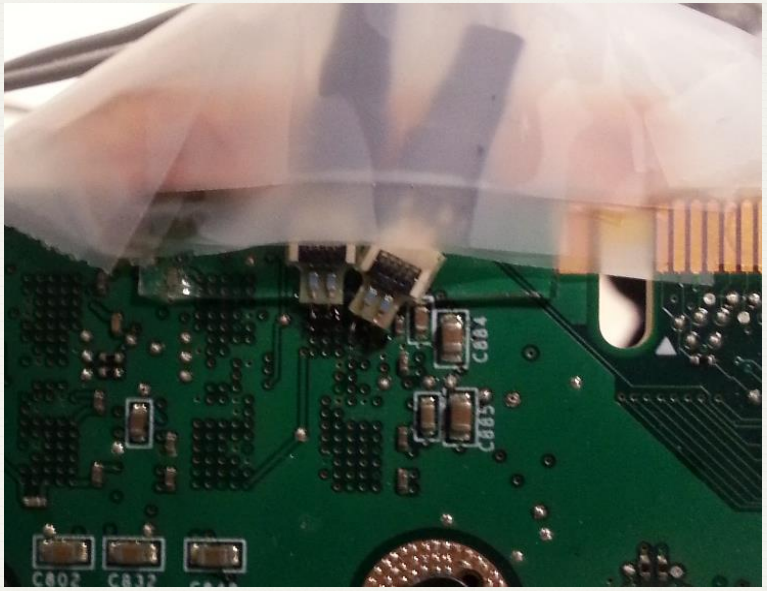
Simulation



- Wanted 14mV less crosstalk noise from higher layer count package
- Measurement showed ~5 mV difference
- Considering mixed-reference channel, 5 mV difference in simulation
  - Split offsets 9 mV gain

Measurement Setup

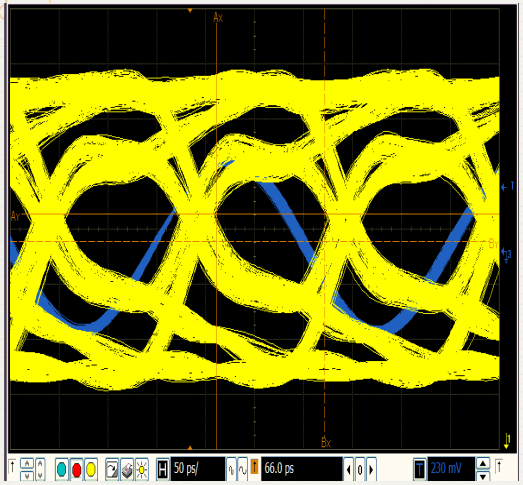




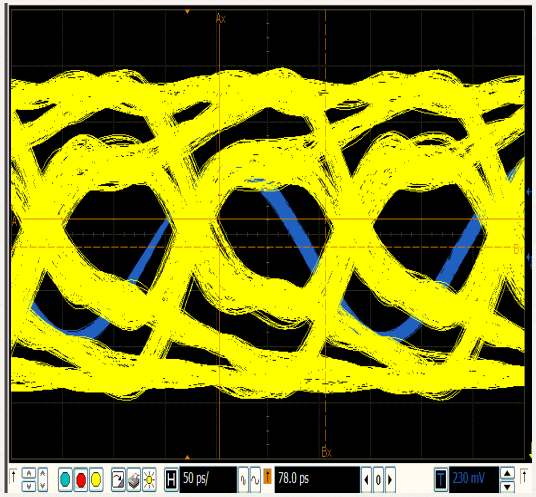
- Agilent Zif tip probes
  - Ensure short probe wire length to avoid artifact
  - 13 GHz to have high enough bandwidth
- PRBS7 is outputted by memory controller
- Signals are probed at the bottom of DRAM (x32)
- Measured channels have full trace coupling from PKG to PCB with similar length

Measured Eye-Diagram at 6.6 Gbps for Crosstalk Impact Difference

Mixed-reference

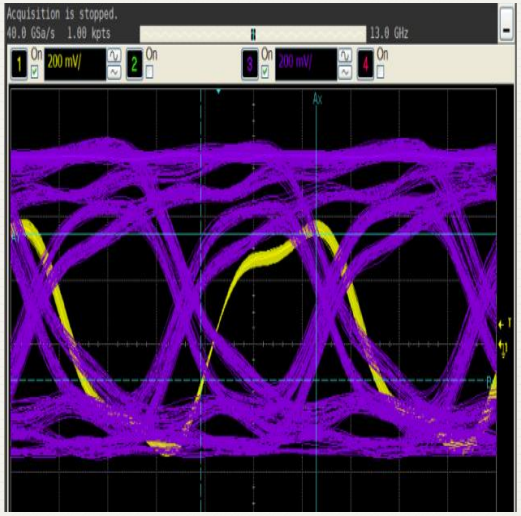


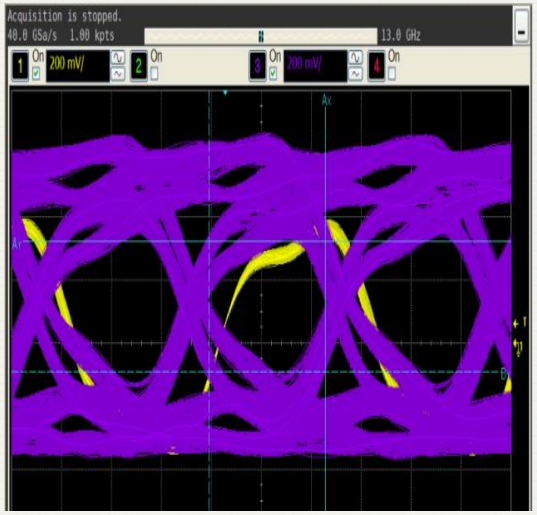
ISI



ISI + crosstalk

Single-reference

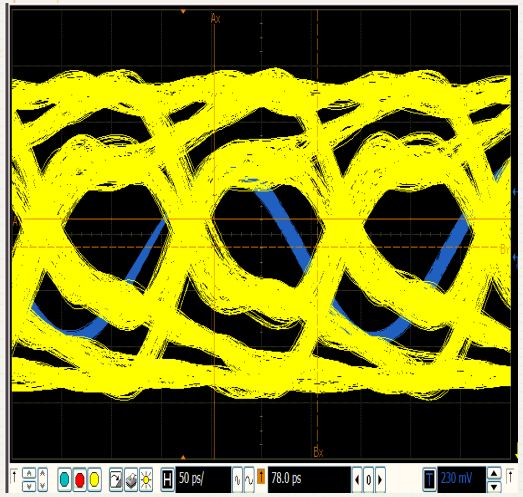




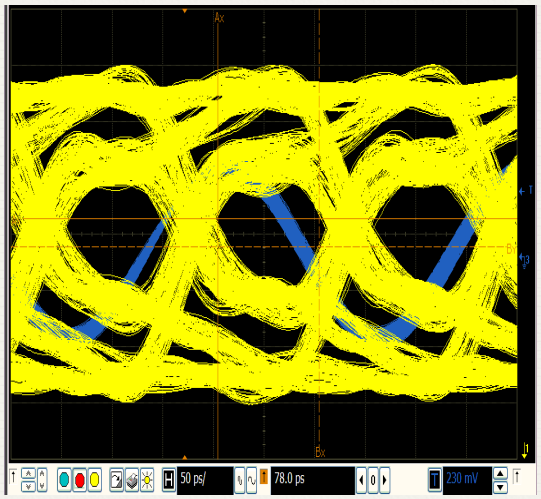
- ‘ISI’ has only one bit switching
- Bigger eye opening in single-reference channel
- ‘ISI+crosstalk’ has two aggressors switching
- Higher crosstalk impact in mixed-reference channel

Measured Eye-Diagram at 6.6 Gbps for Power Noise Impact Difference

Mixed-reference

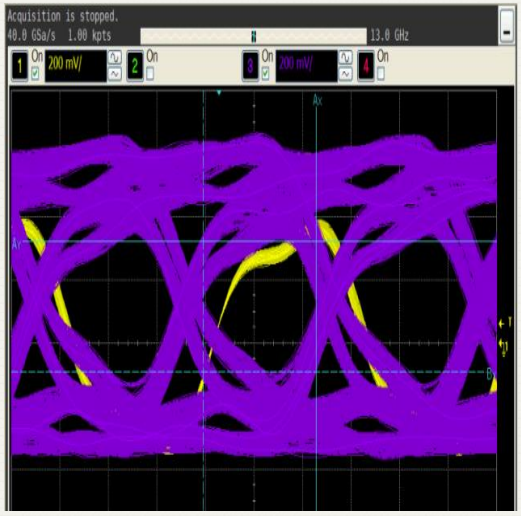


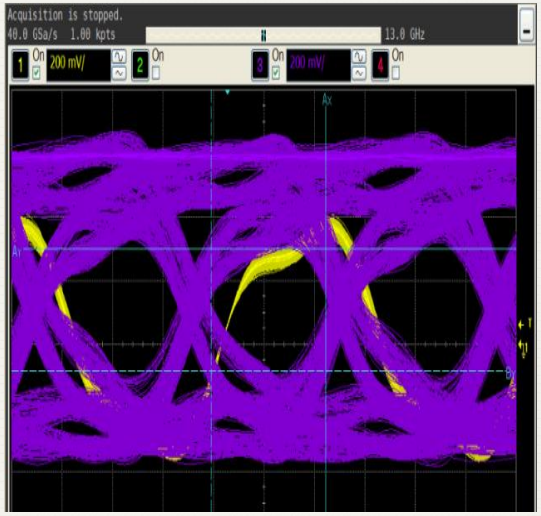
ISI + crosstalk



ISI + crosstalk + SSN

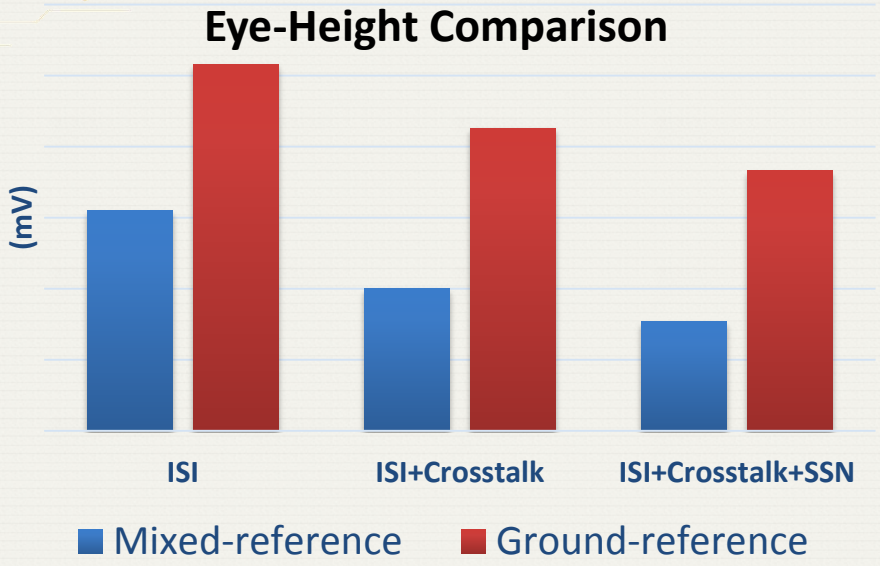
Single-reference

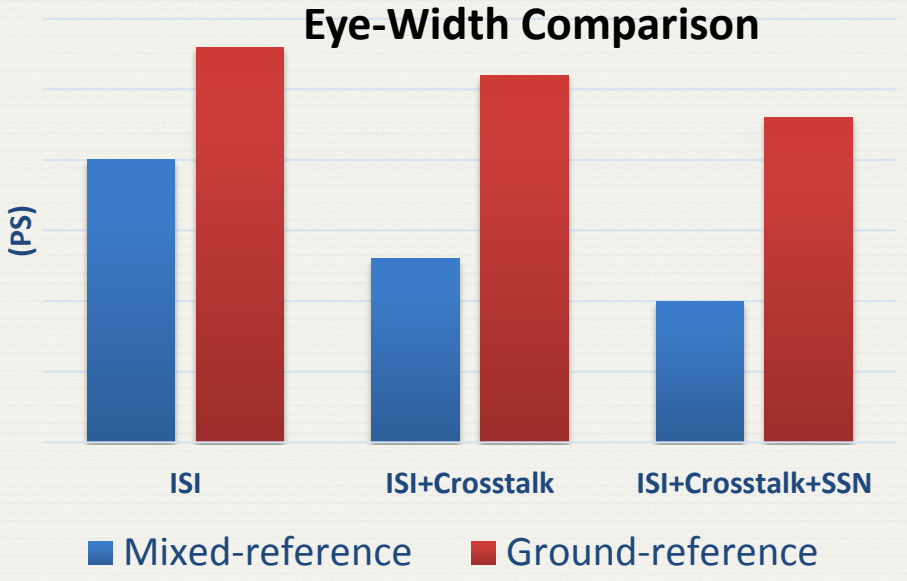




- 'ISI+crosstalk+SSN' has all memory bits switching
- There is no significant degradation in mixed-reference channel through power noise coupling

Measurement Summary

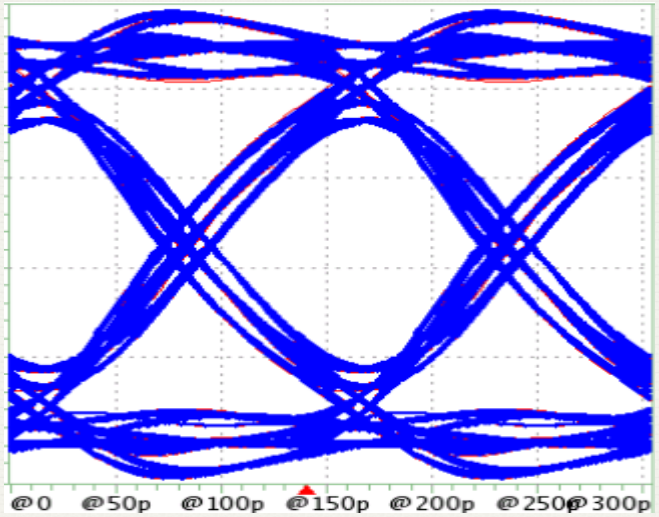




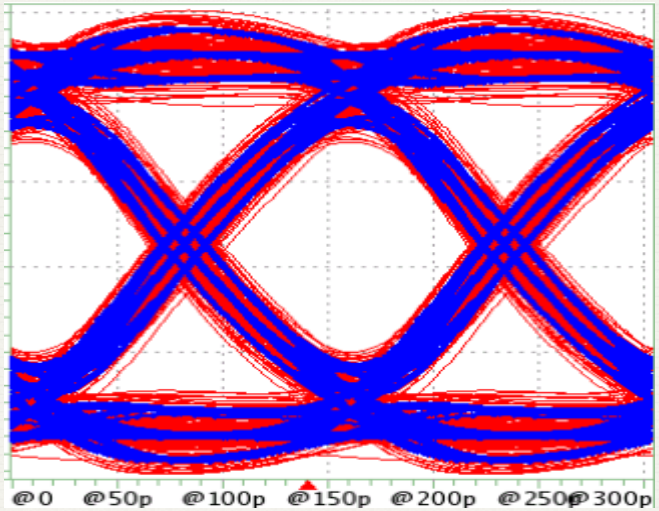
- Comparing ISI and ISI+Crosstalk
  - Mixed-reference
    - 16% EH & 6.3% EW reduction
  - Ground-reference
    - 10% EH & 1.7% EW reduction
- Slightly higher power noise impact on mixed-reference

Demonstration of Power Noise Coupling in Mixed-Reference

Split-plane reference



Power/ground reference



- 6.6 Gbps PRBS7 without crosstalk
- Supply noise is applied to power port
  - Blue: without power noise Red: adding power noise
- No noticeable difference in split-plane reference after adding power noise
- The impact of power noise coupling on power/ground reference is noticeably worse than split plane

Summary

- SI/PI co-simulation of mixed-reference analysis using 3D tool has been introduced
  - Need to include power port
- Mixed-Reference impact on system performance has been demonstrated
  - Adding more PKG caps to compensate mixed-reference impact is not cost-effective
  - Split-plane reference adds more crosstalk
  - Non-negligible power noise coupling to trace should be considered for power/ground reference
- Analyzing SI/PI together will provide a better guidance on cost and performance optimization

THANKS!

Q/A