Welcome to

DesignCon® 2023

WHERE THE CHIP MEETS THE BOARD

Conference
January 31 – February 2, 2023

Expo
February 1 – 2, 2023

Santa Clara Convention Center

Managing Differential Via Crosstalk and Ground Via Placement for 40+ Gbps Signaling

Michael Steinberger, MathWorks
Donald Telian, SiGuys
Orlando Bell, GigaTest Labs
Kevin Rowett, Xconn Technologies

SPEAKERS

Donald Telian

SI Consultant / Owner, SiGuys

telian@siguys.com | siguys.com

Building on 40 years of SI experience at Intel, Cadence, HP, and others, his focus is helping customers implement today's highest-speed serial links. With tens of thousands of serial links in production spanning all types of electronic standards and products, he consistently helps his customers migrate to next-generation data rates again and again. Donald is widely known as the SI designer of the PCI bus and the originator of IBIS modeling and has taught SI techniques to thousands of engineers in more than 15 countries. His new book "Signal Integrity, In Practice" brings fresh articulation to the changing practice of SI in the decades ahead.

Michael Steinberger

Consultant Software Engineer, MathWorks

msteinbe@mathworks.com | mathworks.com

Michael has over 30 years of experience designing very high-speed electronic circuits. Dr. Steinberger holds a Ph.D. from the University of Southern California and has been awarded 14 patents. He was DesignCon 2015's Engineer of the Year. He is currently responsible for the behavioral modeling of mixed analog and digital circuits. Before joining MathWorks, Dr. Steinberger was the lead architect for high-speed serial channel analysis at SiSoft.

SPEAKERS

Orlando Bell

VP of Engineering, GigaTest Labs

orlando@gigatest.com | gigatest.com

Orlando's key responsibilities include managing the high-frequency characterization lab and driving the research and development of advanced test hardware for the Signal Integrity market. He holds a BSEE and MSEE from the University of Florida in Gainesville, Florida.

Kevin Rowett

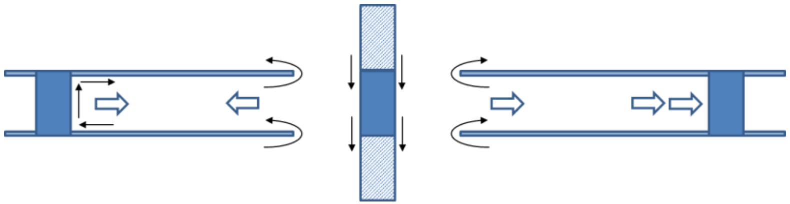
VP Systems Engineering, Xconn Technologies – Owner, Iron Heart Consulting

kevin.rowett@xconn-tech.com | xconn-tech.com

Providing engineering consulting services for technology companies at all stages and sizes, Kevin brings skills in hardware, software, project management, technical communications, and organizational management. Well-known in Silicon Valley, he has worked as an engineering team lead, engineering manager, and executive at many high tech companies including Tandem, IBM, and Cisco. He has founded six startup high technology companies, including Force10 Networks, Mistletoe Technologies, and Violin Memory.

AGENDA: Managing Differential Via Crosstalk

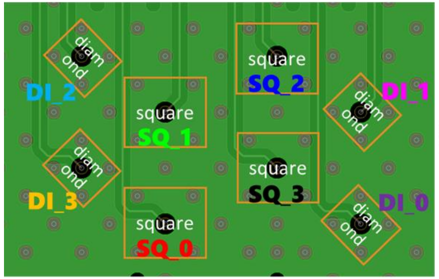
- Introduction
- Test Structure
- Measurement
- Model vs. Measured Data
- Circuit Model
- Summary

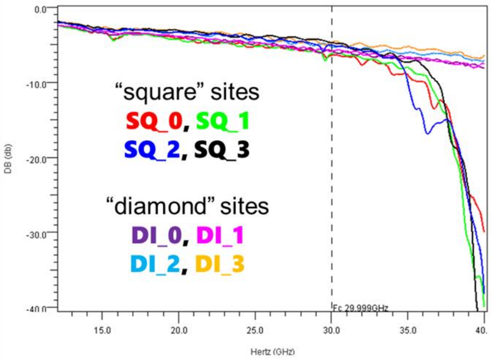


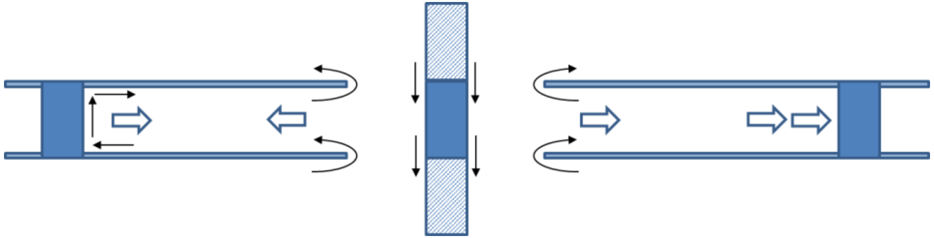
Refresher – Previous Paper

[link to paper]

- **IL / TDR / Crosstalk tracks with GRV placement**
  - GRV = Ground Return Via
  - Single-ended
- **Two phenomena:**
  - Return currents
    - *IL / TDR*
  - Reflections on planes from GRVs
    - *Crosstalk*







40+ Gbps design paradigm must consider: (1) distance to GRVs, and (2) GRV patterns

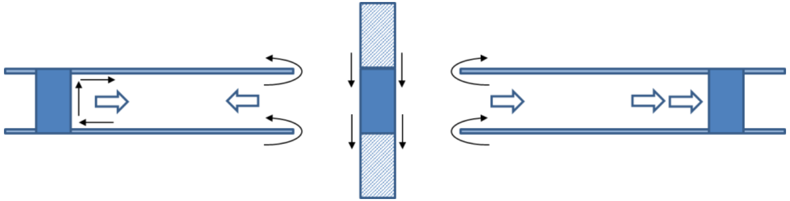
Differential Signal Vias & GRVs

- **Include their own return reference**
  - Less IL / TDR (loss / discontinuity) issues
- **However, crosstalk issues remain**
  - Waves propagating/reflecting on planes
  - GRVs do not shield, but instead reflect
- **GRVs can create a resonant cavity**
  - Based on pattern, dimensions, quantity
  - More is not always better
- **Acceptable crosstalk is changing**
  - Signals at 36 dB, hence SNR lowers "N"

This paper focuses on explaining and characterizing unexpected signal crosstalk as a function of surrounding GRV patterns.

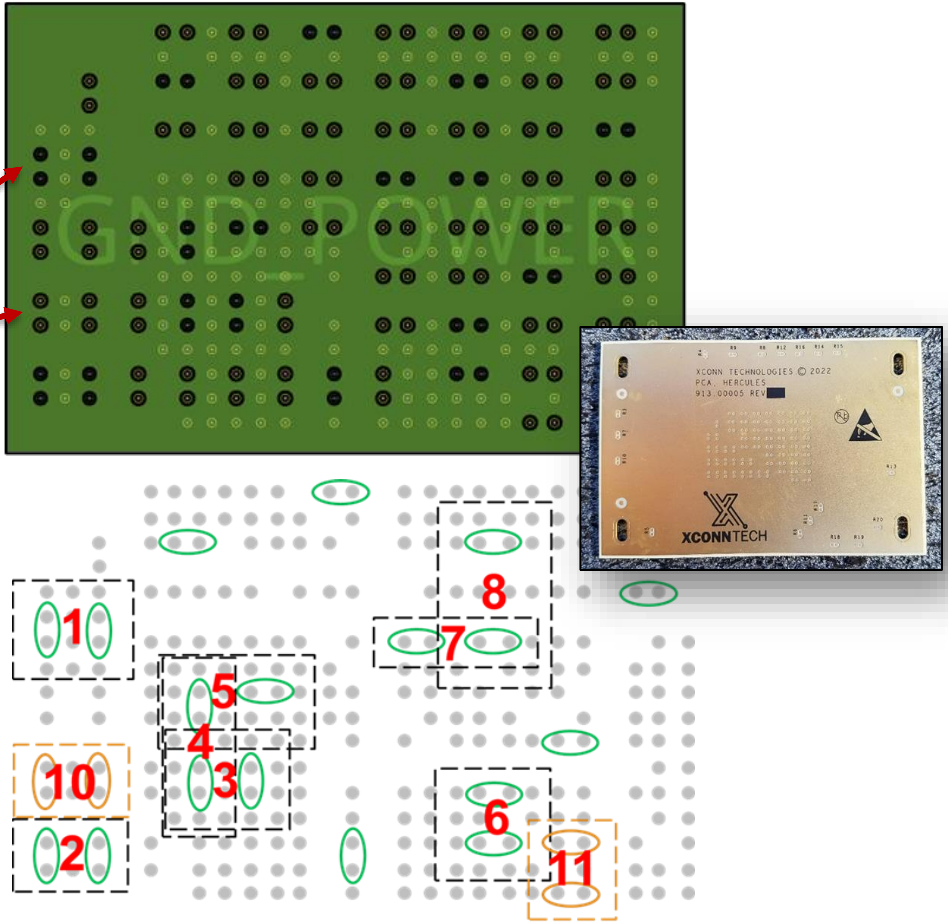
AGENDA: Managing Differential Via Crosstalk

- Introduction
- Test Structure
- Measurement
- Model vs. Measured Data
- Circuit Model
- Summary



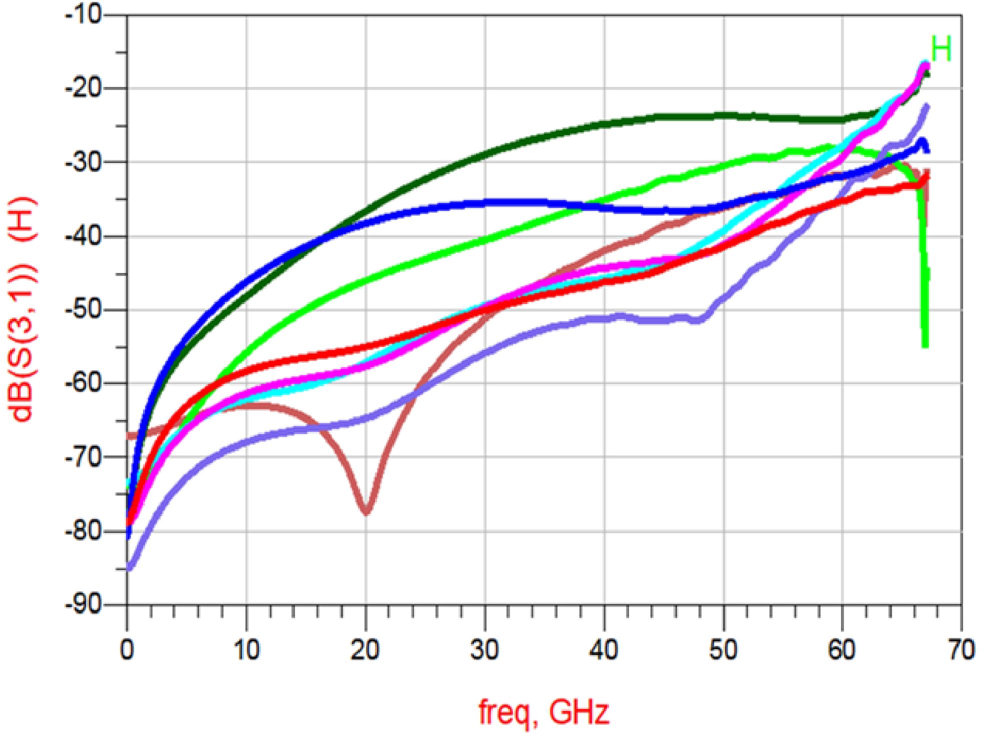
Test PCB

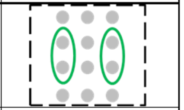
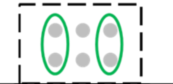
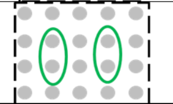
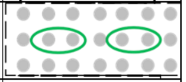
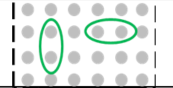
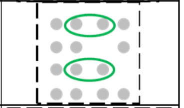
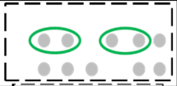
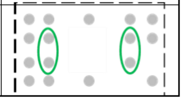
- **1 mm BGA, many diff-pairs**
  - Some with terminated routes
  - Some are diff vias only
- **GRV patterns vary**
  - GRVs are light green in image
- **10 crosstalk test sites chosen / analyzed**
  - Varying signal orientation, GRV pattern and density



Crosstalk Magnitude Varies with GRV Pattern

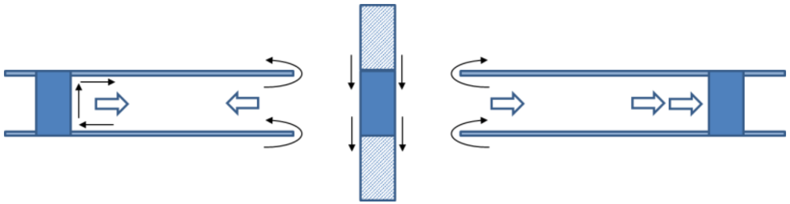
Measured Differential Crosstalk



Site #	40+ dB (GHz)	Structure
1	52	
2	17	
3	51	
4	49	
5	56	
6	31	
7	17	
8	43	

AGENDA: Managing Differential Via Crosstalk

- Introduction
- Test Structure
- Measurement
- Model vs. Measured Data
- Circuit Model
- Summary

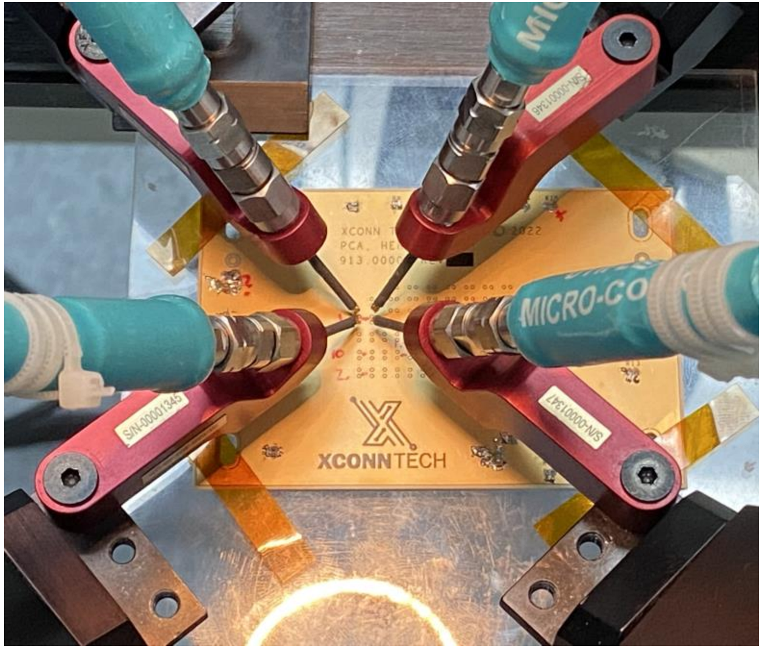


Measurement Considerations

- **Crosstalk to 67 GHz with probes challenging**
  - Isolation cal not valid so instrument isolation sets noise floor
  - Standard SOLT drift due to THRU loss model
  - Ground-signal (GS) probes tend to mode above 40 GHz
- **Proven approach**
  - Decrease IF bandwidth, add averaging
  - SOLR calibration for realistic THRU loss profile
  - Ground-signal-ground (GSG) to suppress moding

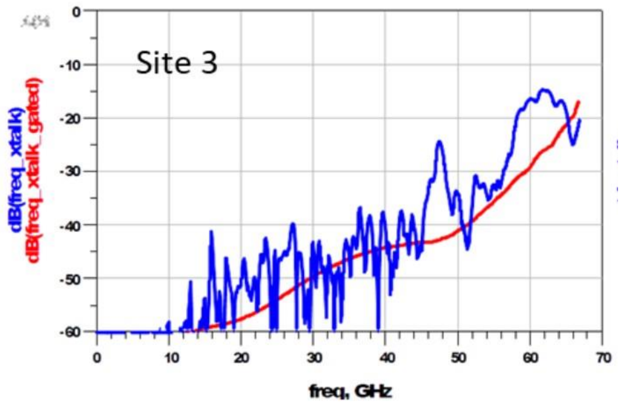
Measurement Setup

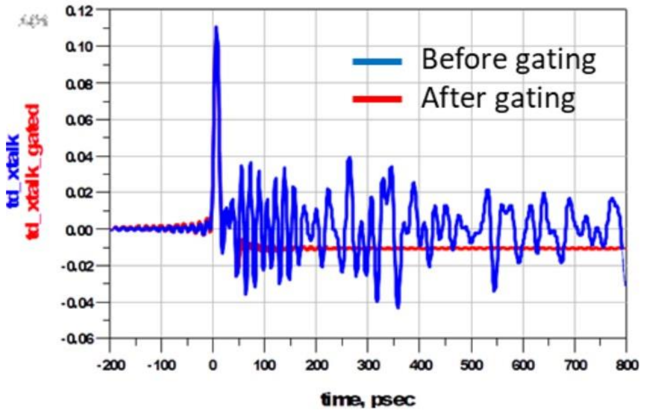
- **Board mounted on acrylic frame so sample mostly in air**
- **GTL-5050 probing platform to suspend sample**
- **Keysight PNA for SOLR**
- **GTL65 series probes**
- **GTL calibration substrate**



Measurement Results

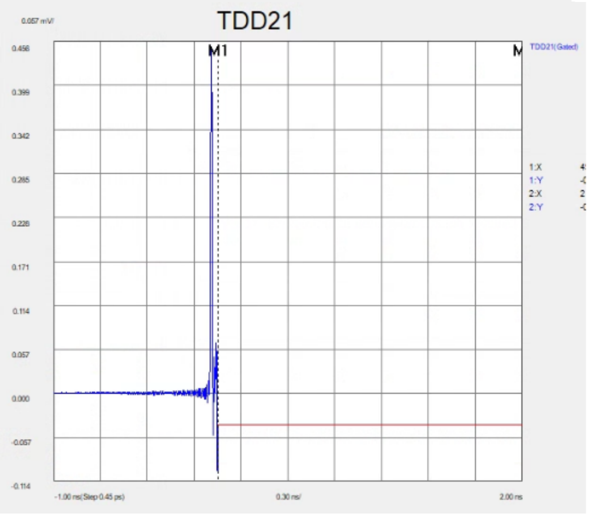
- Microstrips leading away to terminations generated their own crosstalk
- Surface-mount terminations generated reflections at higher frequencies
- Time-domain gating was used to suppress this noise





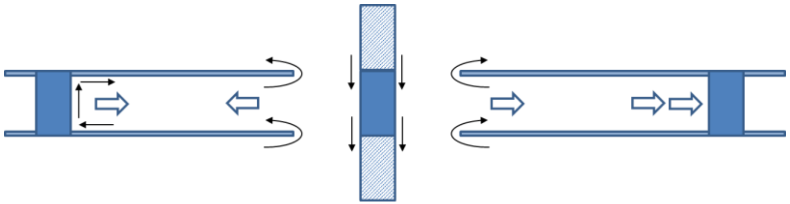
Gating Considerations

- Result depends on window start/stop
- Filtering effect at higher frequencies depending on window type
- DC offset affects low-frequency response

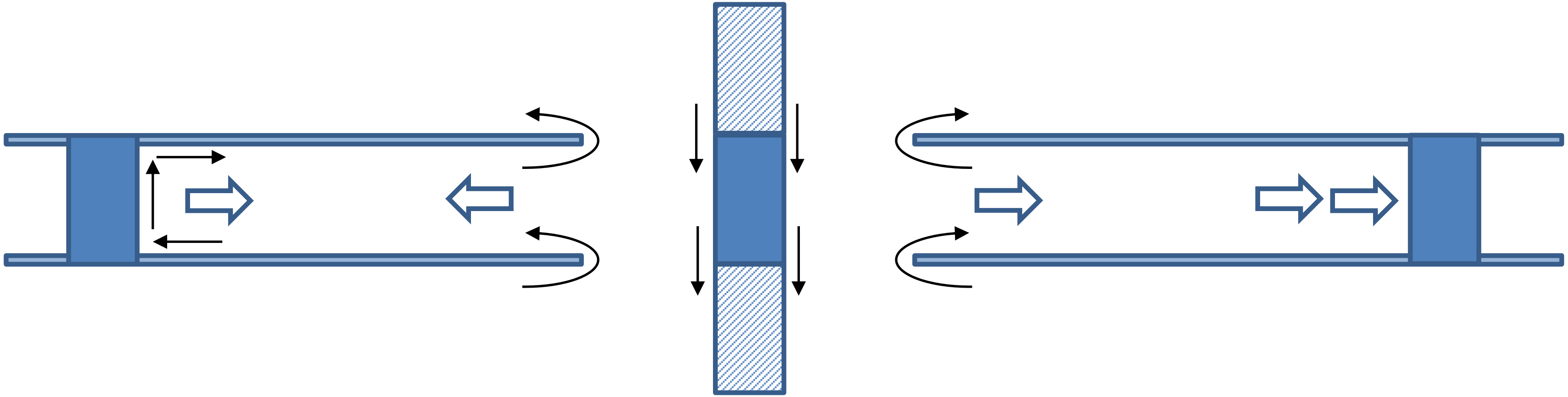


AGENDA: Managing Differential Via Crosstalk

- Introduction
- Test Structure
- Measurement
- Model vs. Measured Data
- Circuit Model
- Summary



How Return Current Gets from Here to There



$$E_Z = AH_0^{(2)}(kr)$$

$$H_\phi = \frac{j}{\eta} AH_1^{(2)}(kr)$$

$$V = -E_z d$$

$$I = 2\pi r H_\phi$$

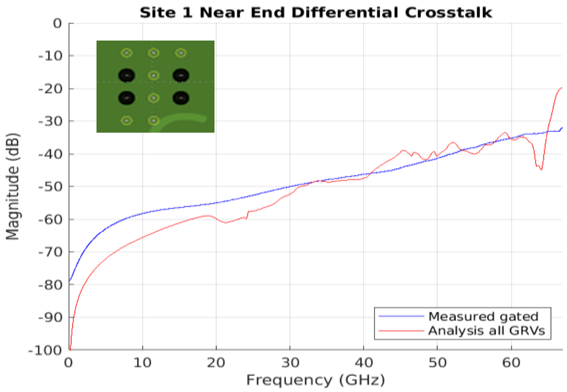
$$Z = \frac{jd\eta}{2\pi r} \frac{H_0^{(2)}(kr_a)}{H_1^{(2)}(kr_a)}$$

$$P(j,k) = \frac{H_0^{(2)}(kR_{jk})}{H_0^{(2)}(kr_k)} \quad j \neq k,$$
$$= 0 \ otherwise$$

$$\Gamma(j,j) = -1 \quad j > n,$$
$$= 0 \ otherwise$$

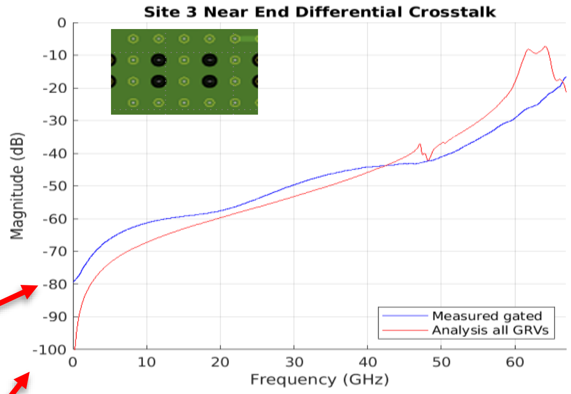
$$\mathcal{V}_{return} = (I + P)(I - \Gamma P)^{-1} Z \mathcal{I} \equiv Z_{return} \mathcal{I}$$

Tightly Shielded Sites

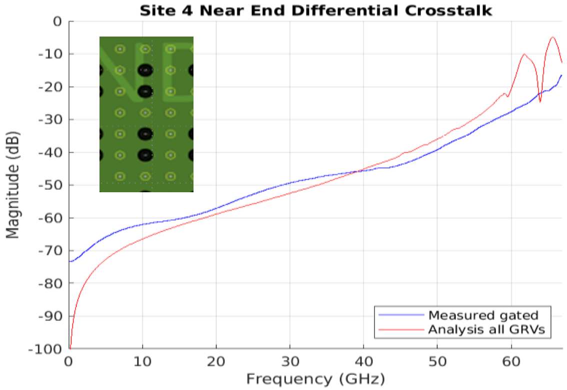


Isolation vs. frequency
< 20GHz Good
< 40GHz Decent
> 40GHz Unacceptable

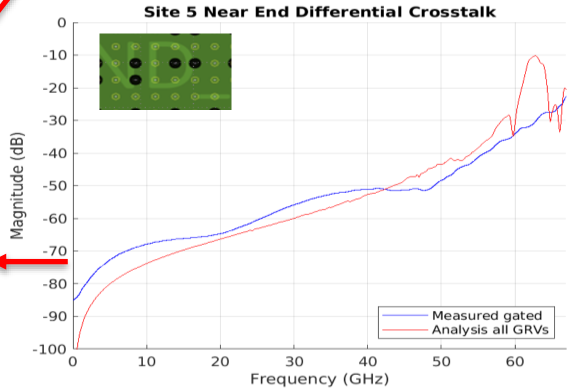
Resonance above 60GHz



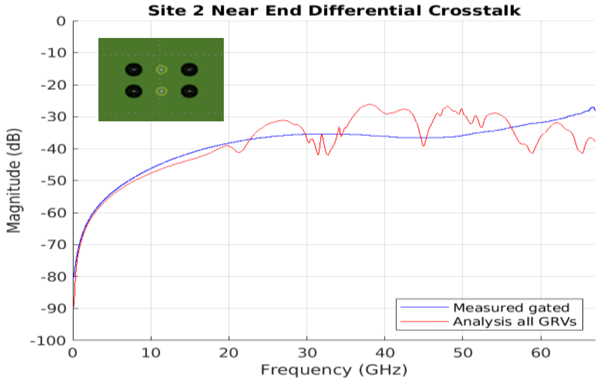
Nearly identical isolation

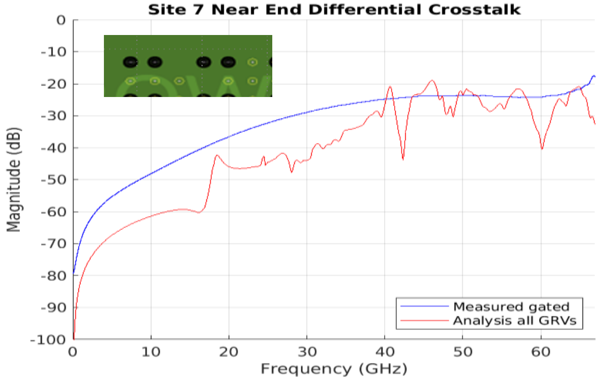


10dB better isolation than either



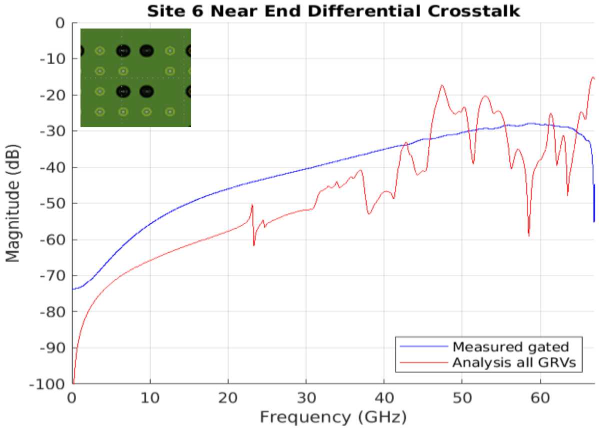
Loosely Shielded Sites

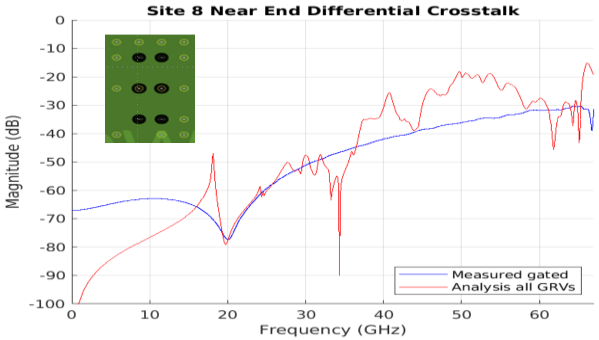




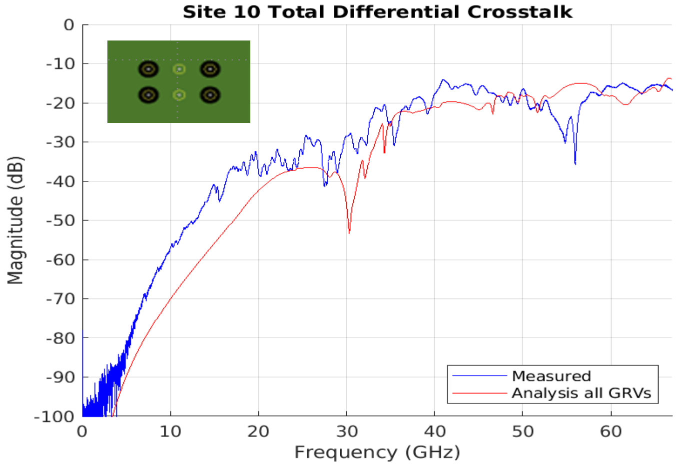
Compared to tightly shielded sites:

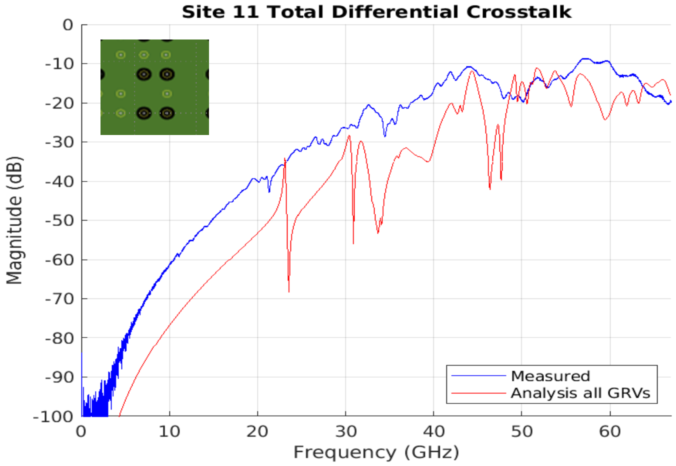
- Less isolation at lower frequencies but more isolation at higher frequencies.
- Model shows more rapid variation with frequency. (Longer distances in crosstalk path?)





Unterminated Sites (no gating)



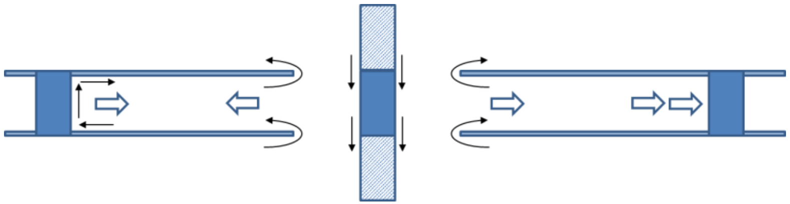


Less frequency variation than ungated results from terminated sites.
Near end and far end crosstalk cancel at low frequencies.

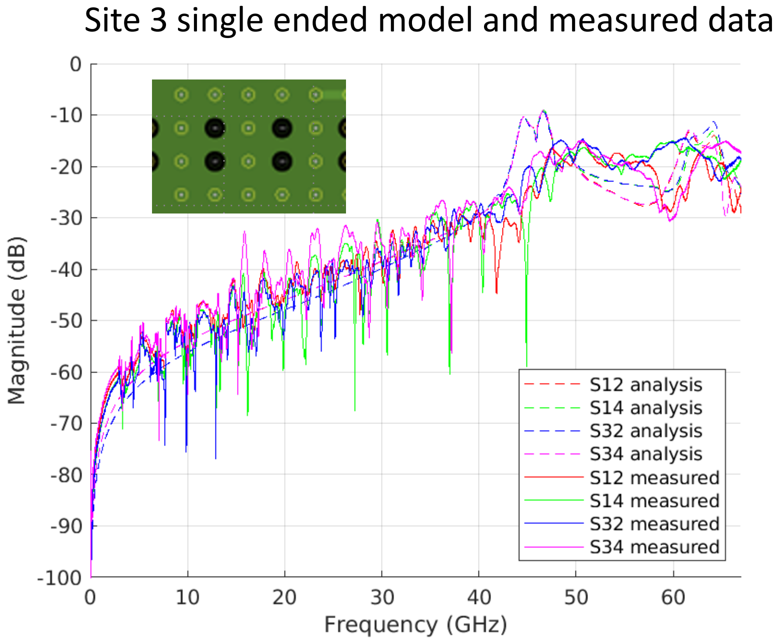
Overall: Generally less than 10dB difference between model and measured data.

AGENDA: Managing Differential Via Crosstalk

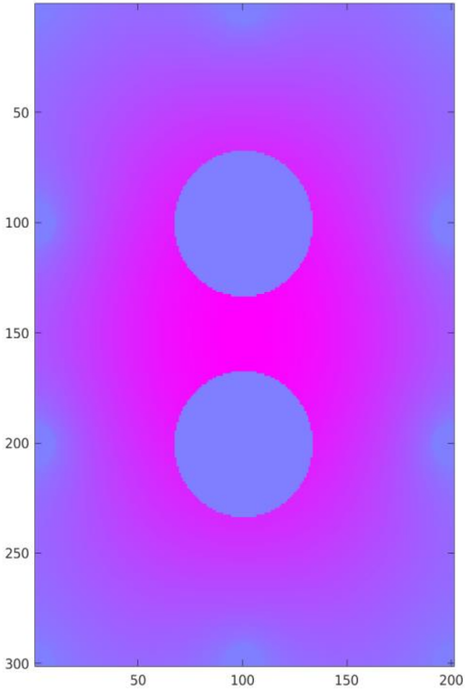
- Introduction
- Test Structure
- Measurement
- Model vs. Measured Data
- Circuit Model
- Summary

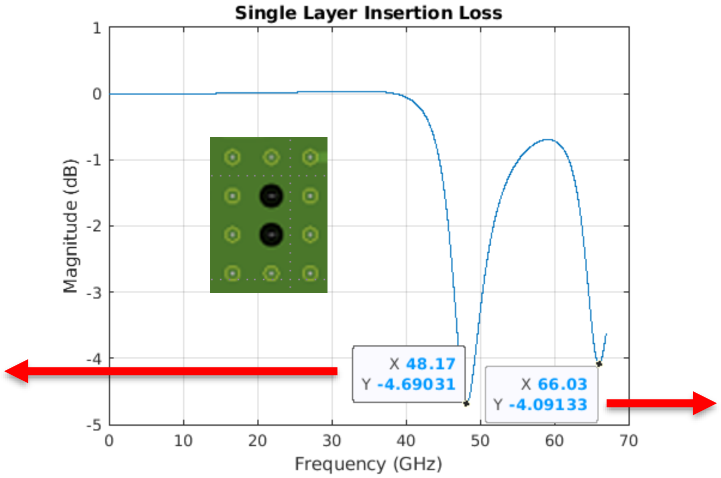


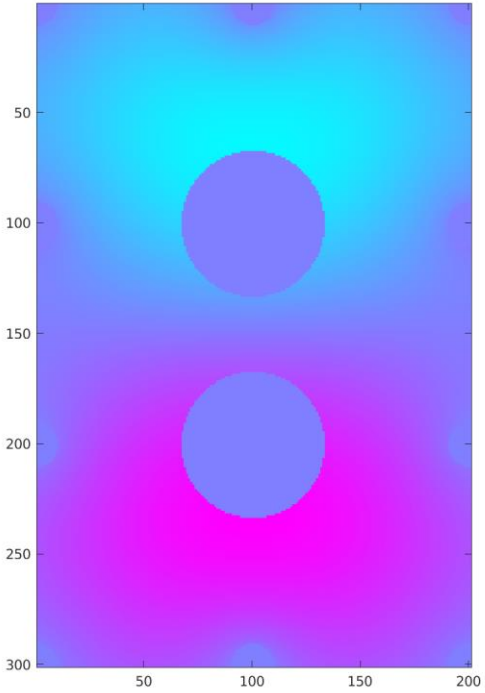
Single Ended Model vs. Measured Data



Two Resonant Modes



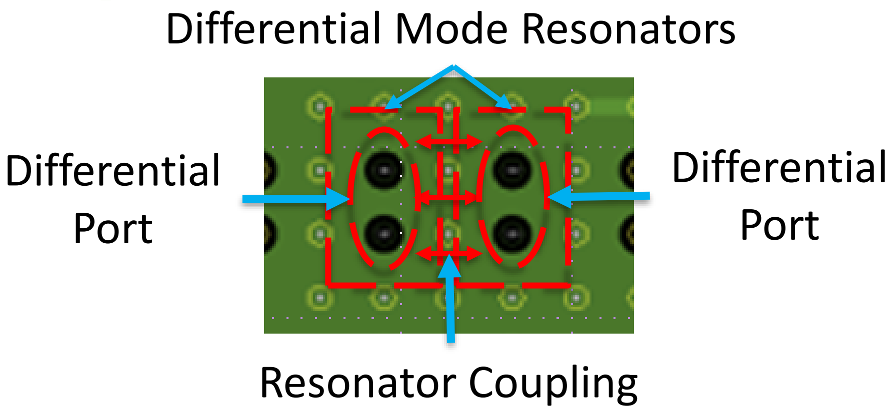


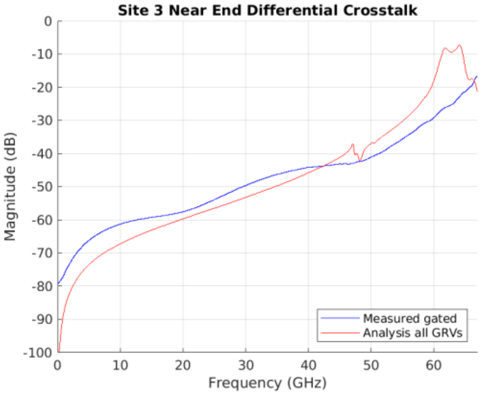


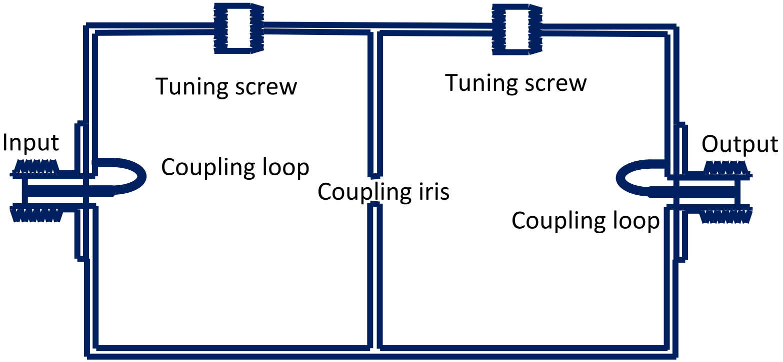
Common Mode
48.17GHz

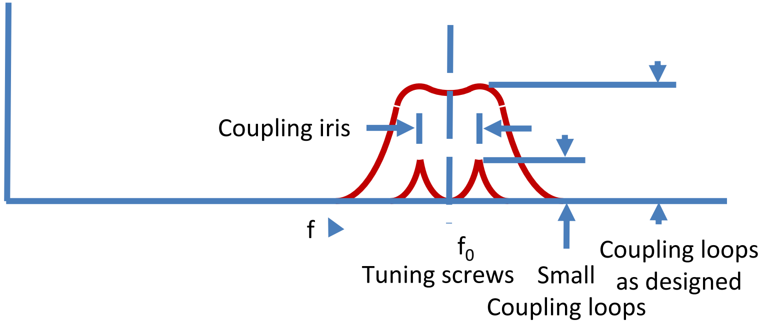
Differential Mode
66.04GHz

Coupled Resonators Make Bandpass Filters.

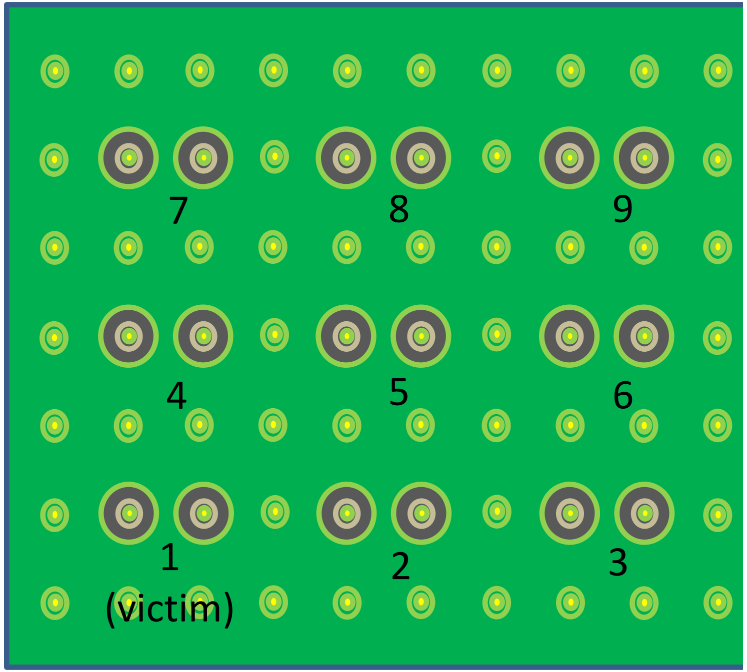




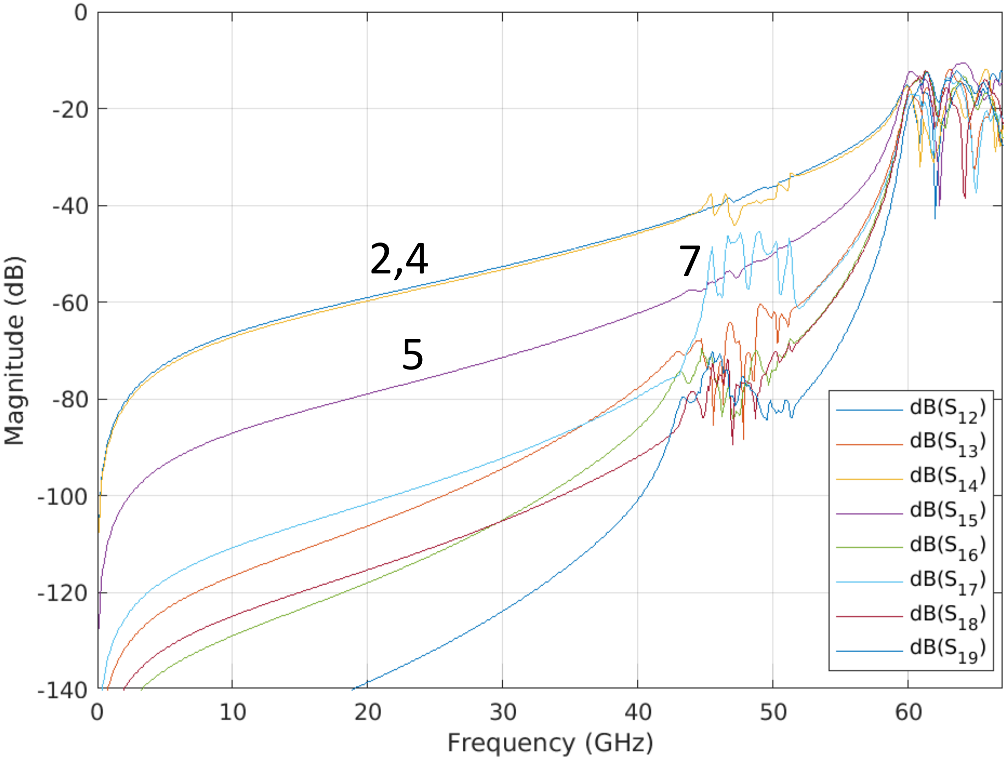




Coupling from Non-Adjacent Sites

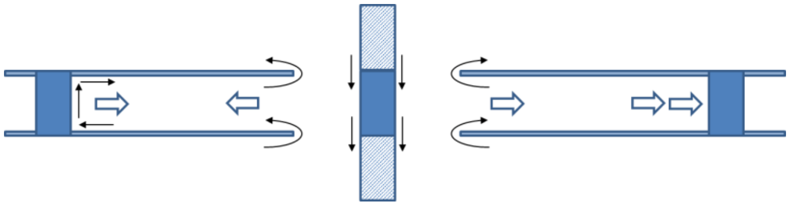


Non-Adjacent Coupling Model Configuration
(Additional GRV grid below and to the left.)



AGENDA: Managing Differential Via Crosstalk

- Introduction
- Test Structure
- Measurement
- Model vs. Measured Data
- Circuit Model
- Summary



Summary & Conclusions

- **Differential signaling is robust, 6 generations of data rate doubling**
  - However, crosstalk mechanism is the same for differential and single-ended vias
- **Measurement and computation deployed to quantify crosstalk**
- **Crosstalk levels become significant in 20 to 40 GHz range**
- **Above 40 GHz GRV resonant cavities must be considered**
  - Can be advantageous to remove GRVs to reduce crosstalk
- **Via crosstalk levels can rise to 20 to 10 dB around 60 GHz**
  - Use mathematical models provided to assess GRV patterns

MORE INFORMATION

- Much more in Paper
- MathWorks.com, SiGuys.com
- References at right →
- msteinb@mathworks.com
  telian@siguys.com
  orlando@gigatest.com
  kevin.rowett@xconn-tech.com

References

1. Steinberger, Telian, Tsuk, Iyer, Yanamadala, "Proper Ground Return Via Placement for 40+ Gbps Signaling", technical paper, DesignCon 2022 best paper, April 2022.
2. Tucker, Sankararaman, and Ellis, "PCB Stack-up and Launch Optimization in High Speed Designs", DesignCon 2022, April 2022.
3. PCI-SIG, "PCI Express® Base Specification Revision 5.0" Version 1.0, 22 May 2019.
4. Ding, Gopinath, Scearce, Steinberger and White, "A Simple Via Experiment", technical paper, DesignCon 2009, February 2009.
5. Matthei, Young and Jones, Microwave Filters, Impedance-Matching Networks, and Coupling Structures, Chapter 8, McGraw-Hill, 1964.
6. Telian, Rowett, Teplitsky, "PCIe Gen5 Signal Integrity Implementation, Issues & Solutions," technical paper, DesignCon 2023, February 2023.
7. Donald Telian, "Signal Integrity, In Practice – A Practical Handbook for Hardware, SI, FPGA & Layout Engineers" – book published in 2022 and available at Amazon.

Thank you!

QUESTIONS?

Join us again for Advanced Manufacturing Minneapolis

October 10-11, 2023