The Impact of Grounding on RF Performance

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Johnstech International

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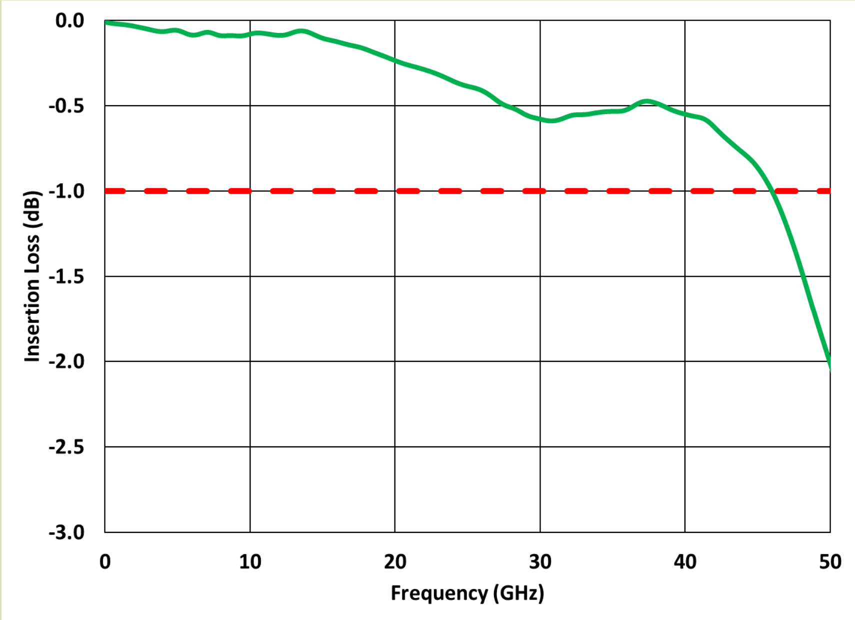
Agenda

- Theoretical background on grounding and its role in RF systems.
- Simulation setup and methodologies used to assess RF performance.
- Comparative analysis of various grounding locations and their impact on performance metrics.
- Case studies highlighting implementations

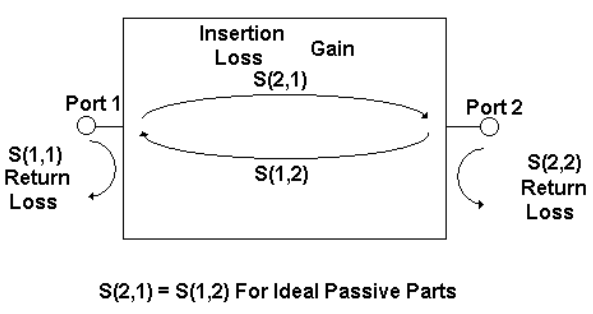
Concepts: Insertion Loss

100%
~90%
~80%

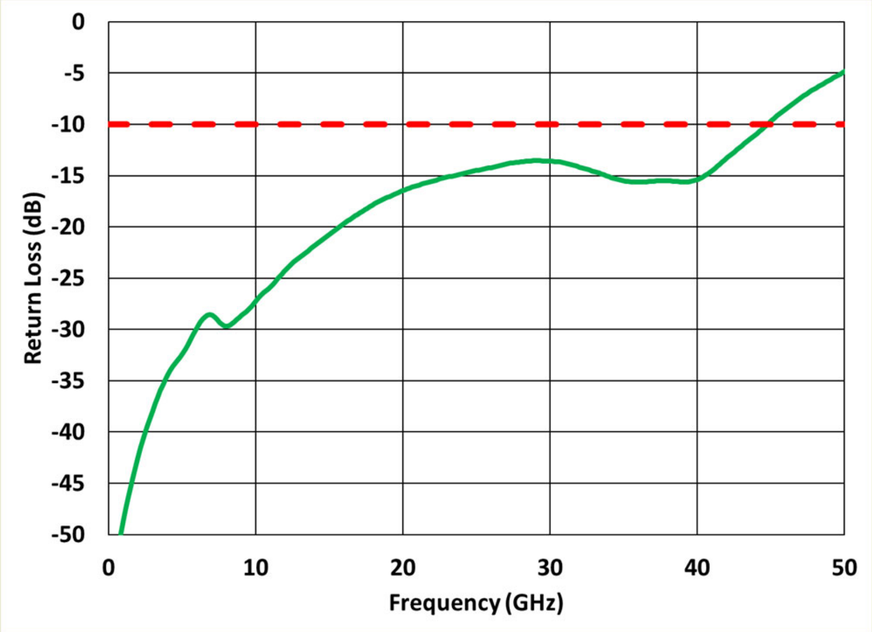


Approximate power transmitted

- Insertion Loss is the loss of signal power between two points in a circuit due to resistance, material absorption or impedance mismatch.
- $S_{21} = 10 * log_{10}(\frac{P_{in}}{P_{out}})$



Concepts: Return Loss



10%
1%
0.1%
0.01%

Approximate power reflected

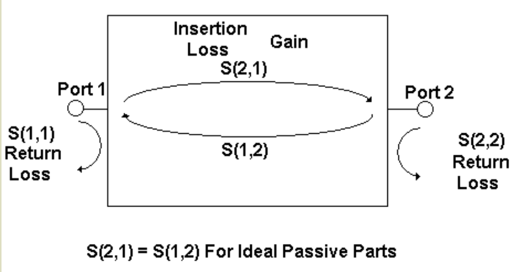
- Return Loss is the amount of power reflected back to a generator from a load due to impedance mismatch.
- $S_{11} = 10 * log_{10}\left(\left|\frac{P_{reflected}}{P_{incident}}\right|\right)$

or

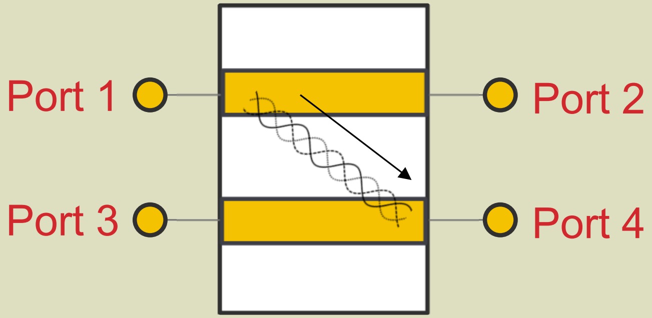
- $S_{11} = -20 * log_{10}(|\Gamma|)$

where

$$\Gamma = \frac{(Z_L - Z_0)}{(Z_L + Z_0)}$$



Concepts: Crosstalk

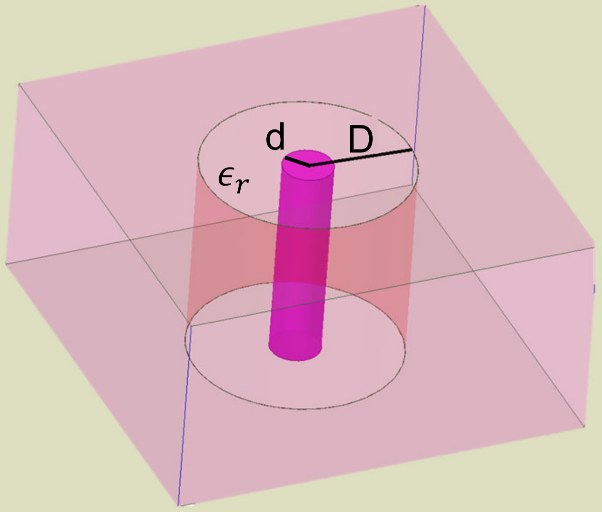


- Crosstalk is the coupling of undesired signals between lines.
- $S_{41} = 10 * log_{10} \left(\frac{P_4}{P_1}\right)$
  - P_1 is the input power at Port 1
  - P_4 is the power received at Port 4 from Port 1

Theoretical Coax: Effects of Ground Location – Distance to Ground

Coaxial Impedance

$$Z_O = \frac{138}{\sqrt{\epsilon_r}} log_{10}\left(\frac{D}{d}\right)$$



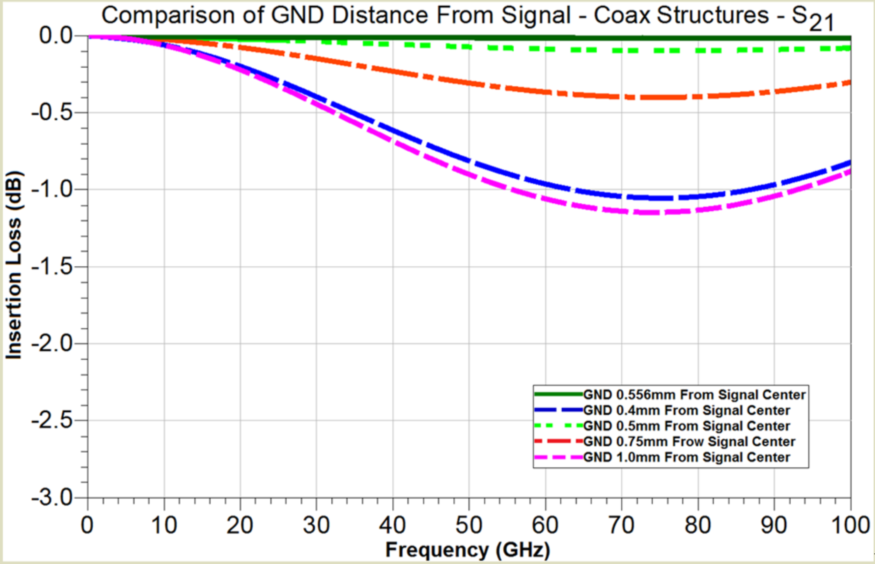
D	Z_O
1.000mm	85.2 Ω
0.750mm	68 Ω
0.556mm	50.2 Ω
0.500mm	43.9 Ω
0.400mm	30.5 Ω

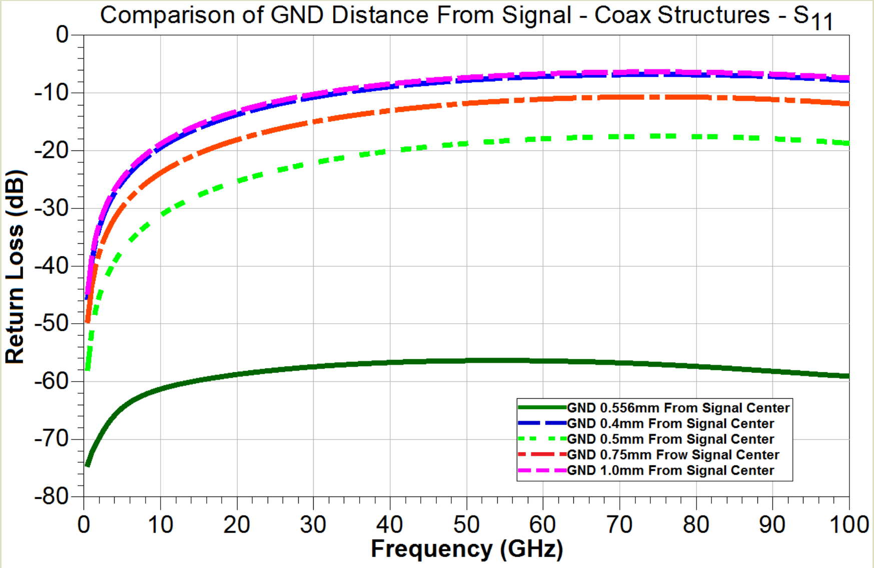
Where:

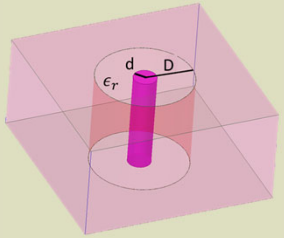
Z_O= characteristic impedance of the coax (Ω)
ϵ_r = relative permittivity (dielectric constant) of the insulator
D = inner diameter of the outer conductor (m)
d = outer diameter of the inner conductor (m)

Note: d= 0.24mm

Theoretical Coax: Effects of Ground Location – Distance to Ground



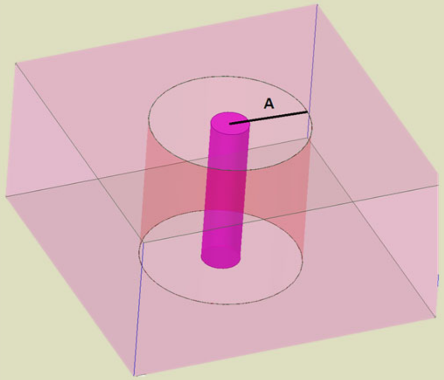




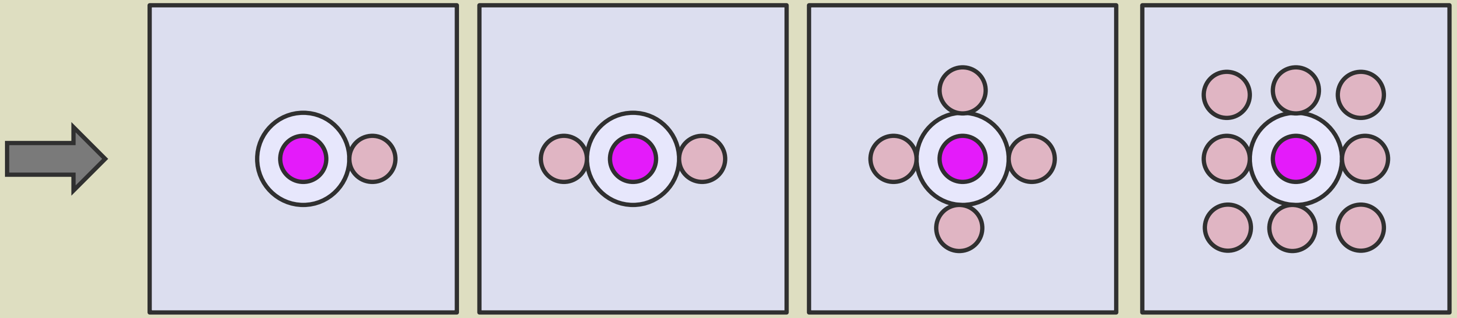
D	Z_O
1.000mm	85.2 Ω
0.750mm	68 Ω
0.556mm	50.2 Ω
0.500mm	43.9 Ω
0.400mm	30.5 Ω

Deviation from 50 Ohms leads to lower return loss (more reflections)

Theoretical Coax: Effects of Ground Location
Number of Grounds



Coax

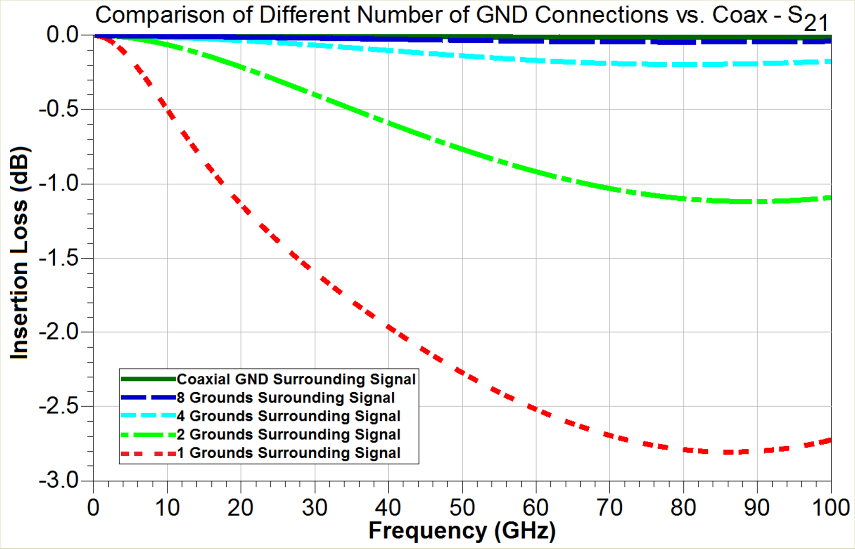


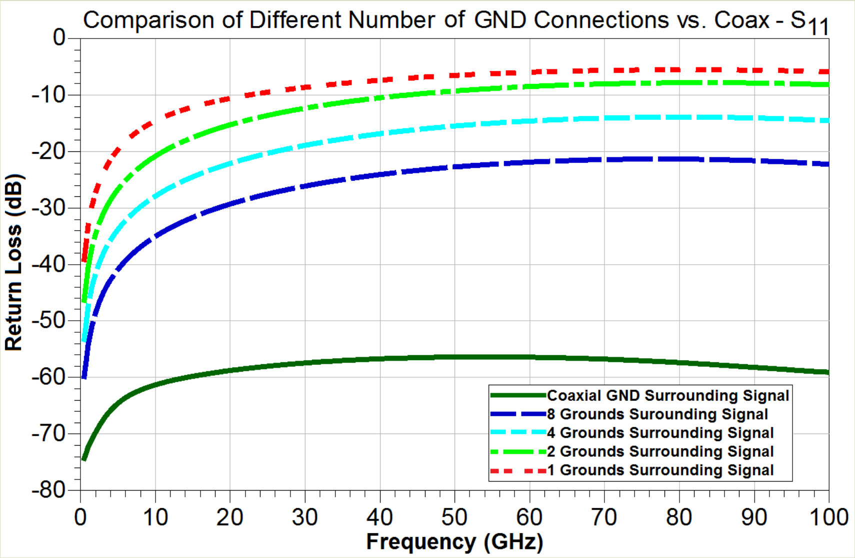
1 Ground 2 Grounds 4 Grounds 8 Grounds

Continuous ground coax is ideal and when not possible, need to bring grounds very close.

How many are required?

Theoretical Coax: Effects of Ground Location Number of Grounds

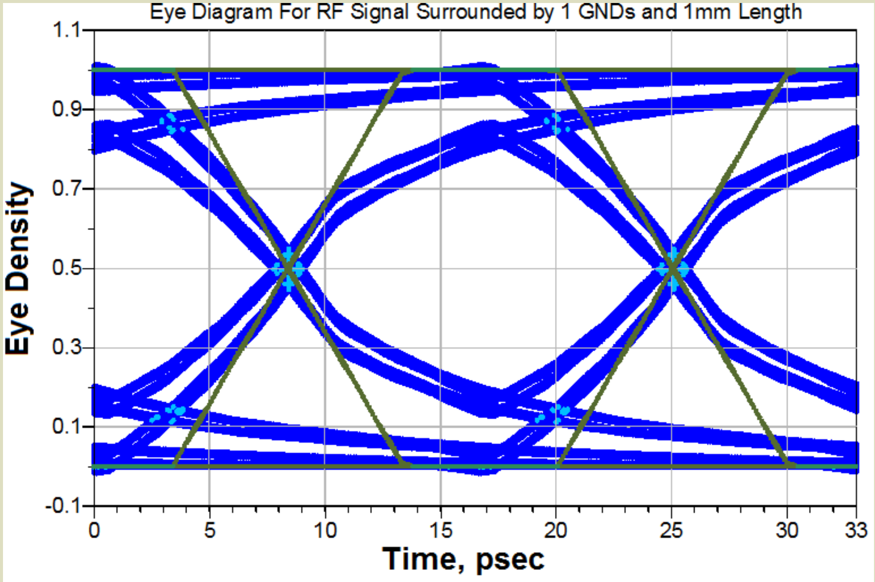


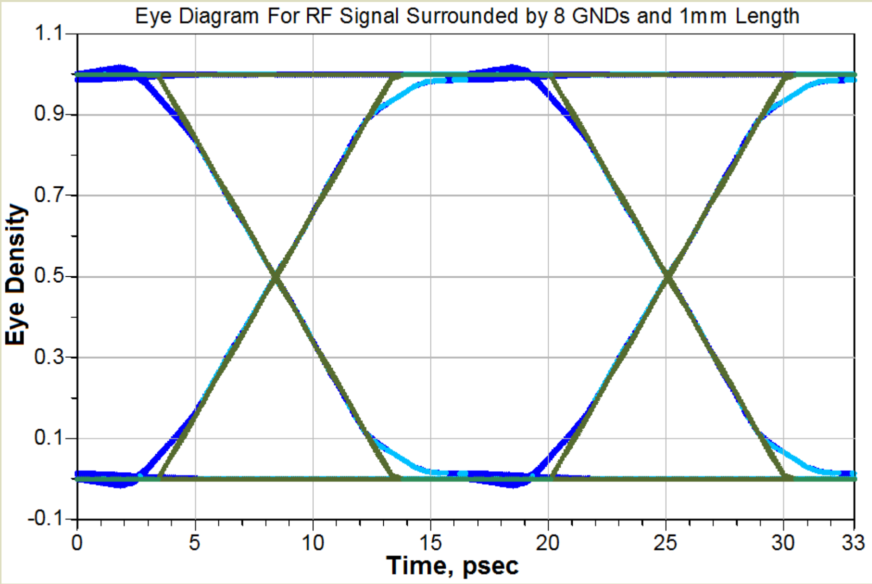


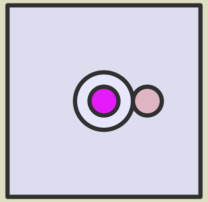
Grounds	Z_O
1	81.8 Ω
2	66.2 Ω
4	56.9 Ω
8	52.9 Ω
Coax	50.2 Ω

Addition of grounds brings the system closer to ideal coax of 50 Ohms

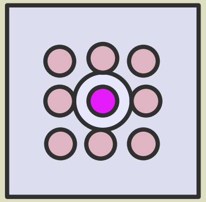
Theoretical Coax: Effects of Ground Locations
Time Domain



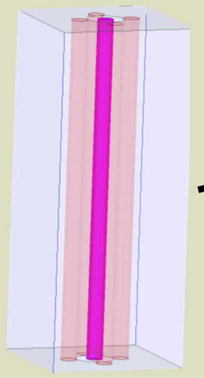




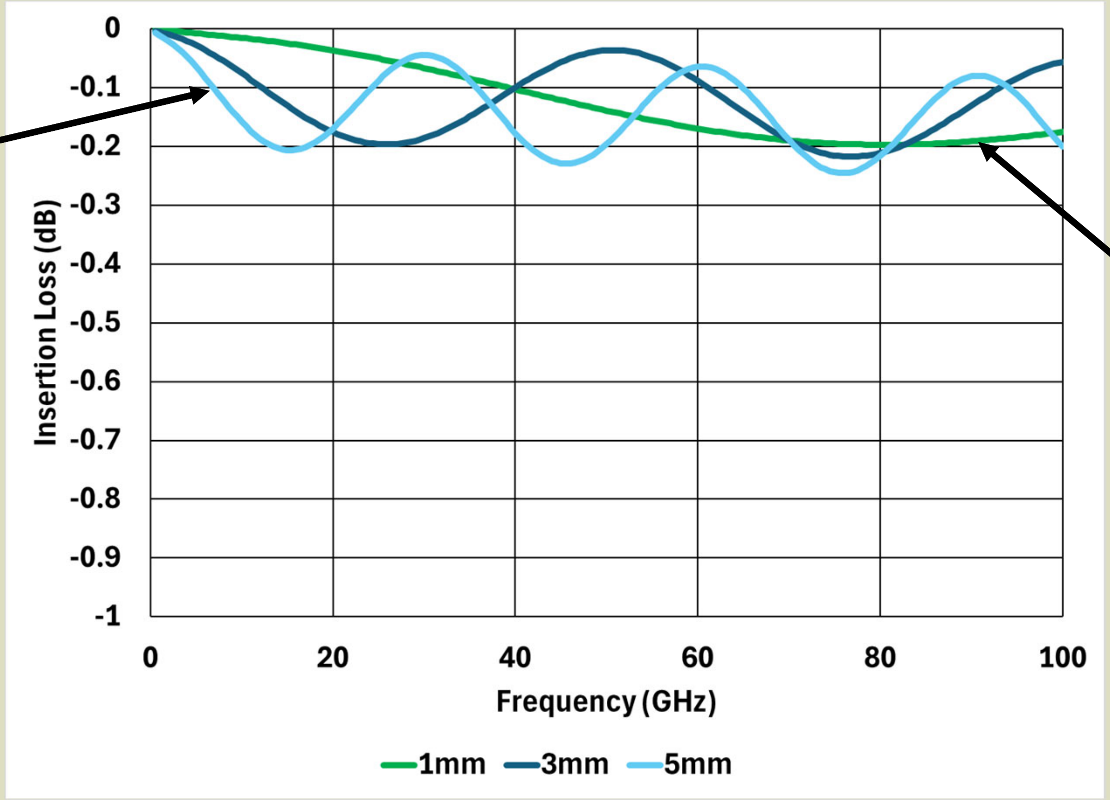
Eye Diagram @ 60 Gbps

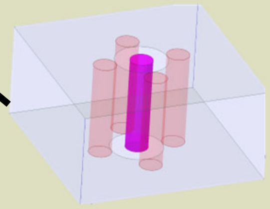


Theoretical Coax: Different Contact Heights



5 mm

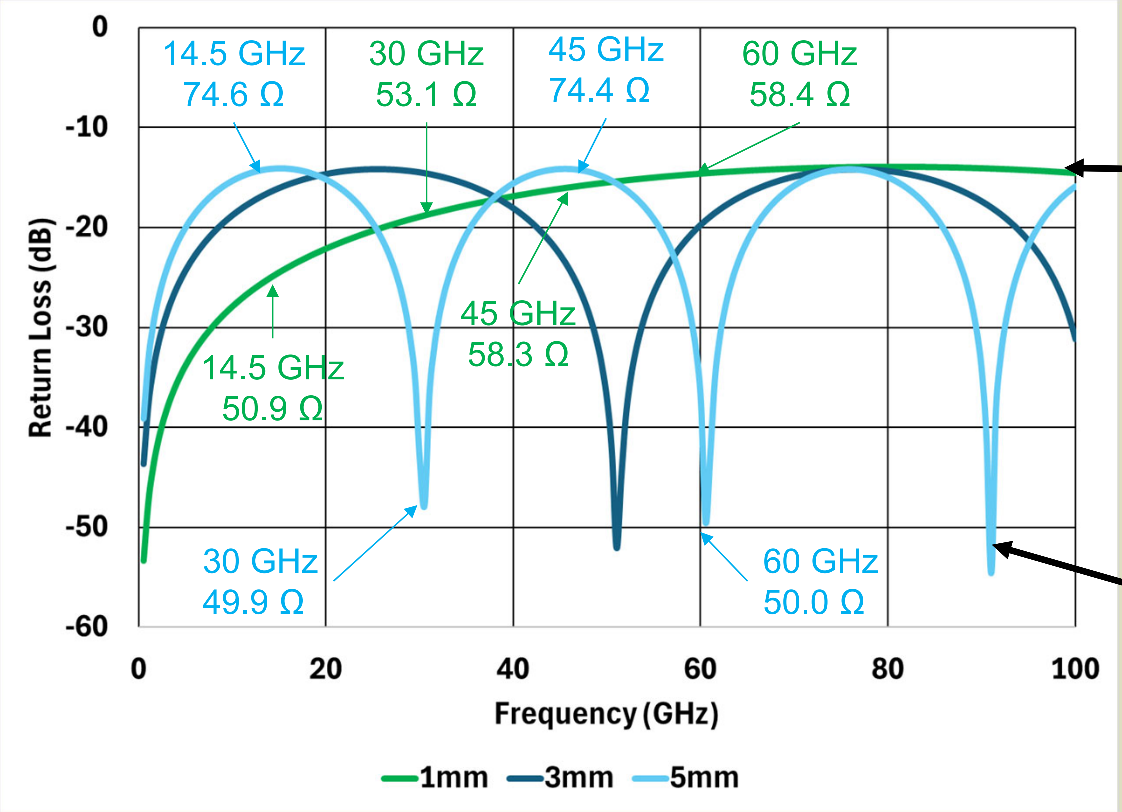


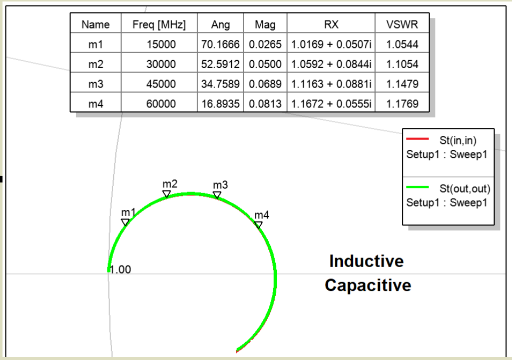


1 mm

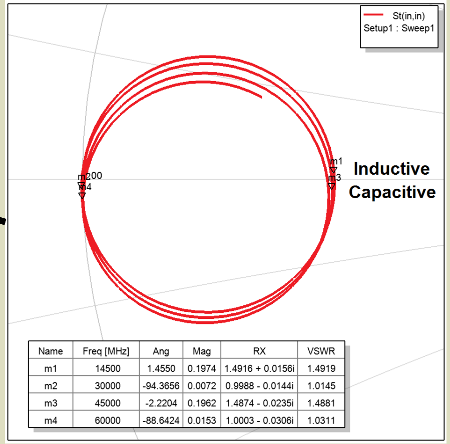
Why does the Insertion Loss improve at various frequencies?

Theoretical Coax: Different Contact Heights





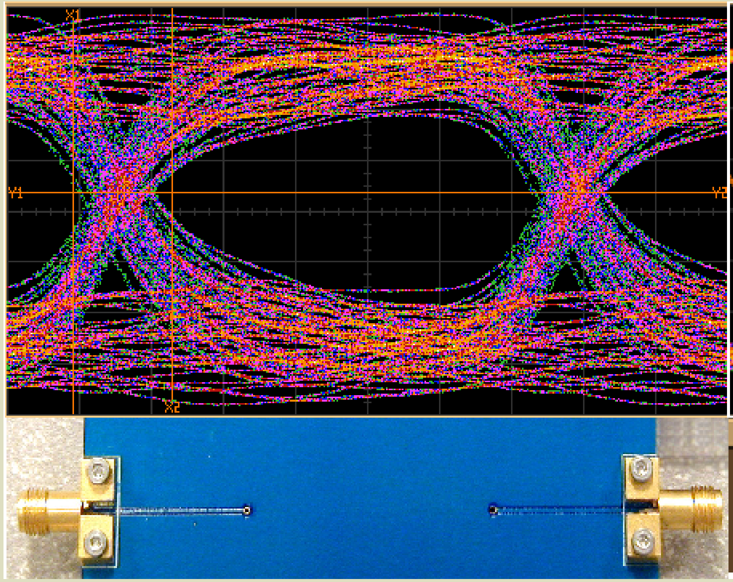
Name	Freq [MHz]	Ang	Mag	RX	VSWR
m1	15000	70.1666	0.0265	1.0169 + 0.0507i	1.0544
m2	30000	52.5912	0.0500	1.0592 + 0.0844i	1.1054
m3	45000	34.7589	0.0689	1.1163 + 0.0881i	1.1479
m4	60000	16.8935	0.0813	1.1672 + 0.0555i	1.1769



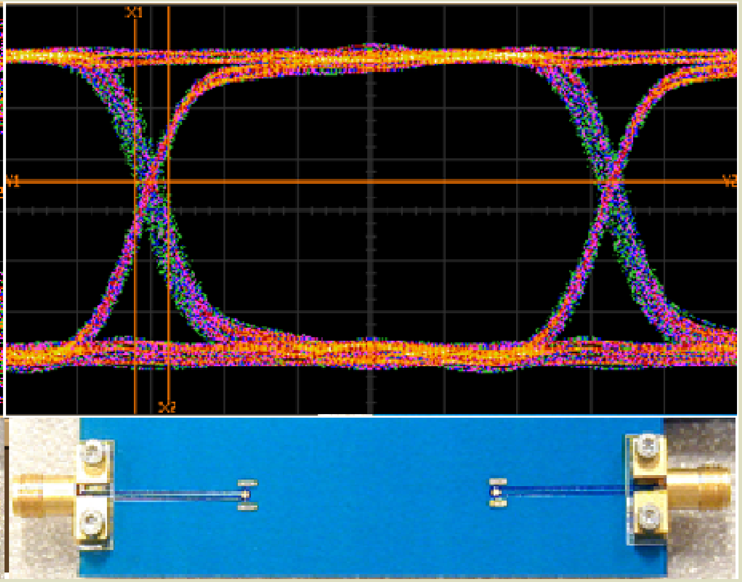
Name	Freq [MHz]	Ang	Mag	RX	VSWR
m1	14500	1.4550	0.1974	1.4916 + 0.0156i	1.4919
m2	30000	-94.3656	0.0072	0.9988 - 0.0144i	1.0145
m3	45000	-2.2204	0.1962	1.4874 - 0.0235i	1.4881
m4	60000	-88.6424	0.0153	1.0003 - 0.0306i	1.0311

Proper grounding produces clean signals

Vias not shielded by ground

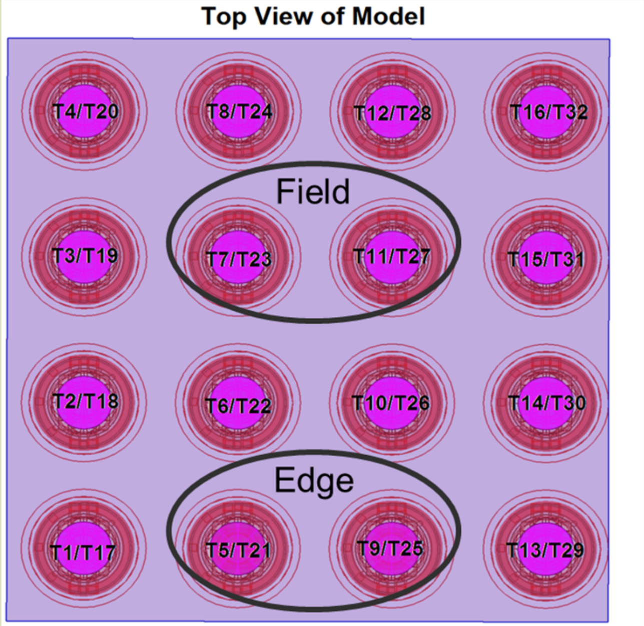


Vias surrounded by ground



Vias attach ground planes and significantly improves signal integrity

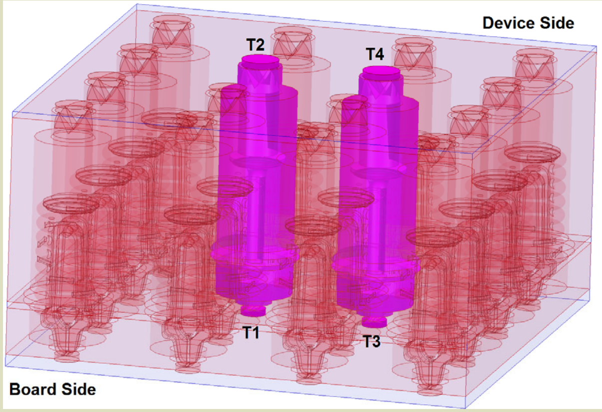
Example: 1 mm Probe* @ 0.5 mm Pitch
Different Ground Configurations



First terminal listed is board side terminal and second terminal listed is output and device interface

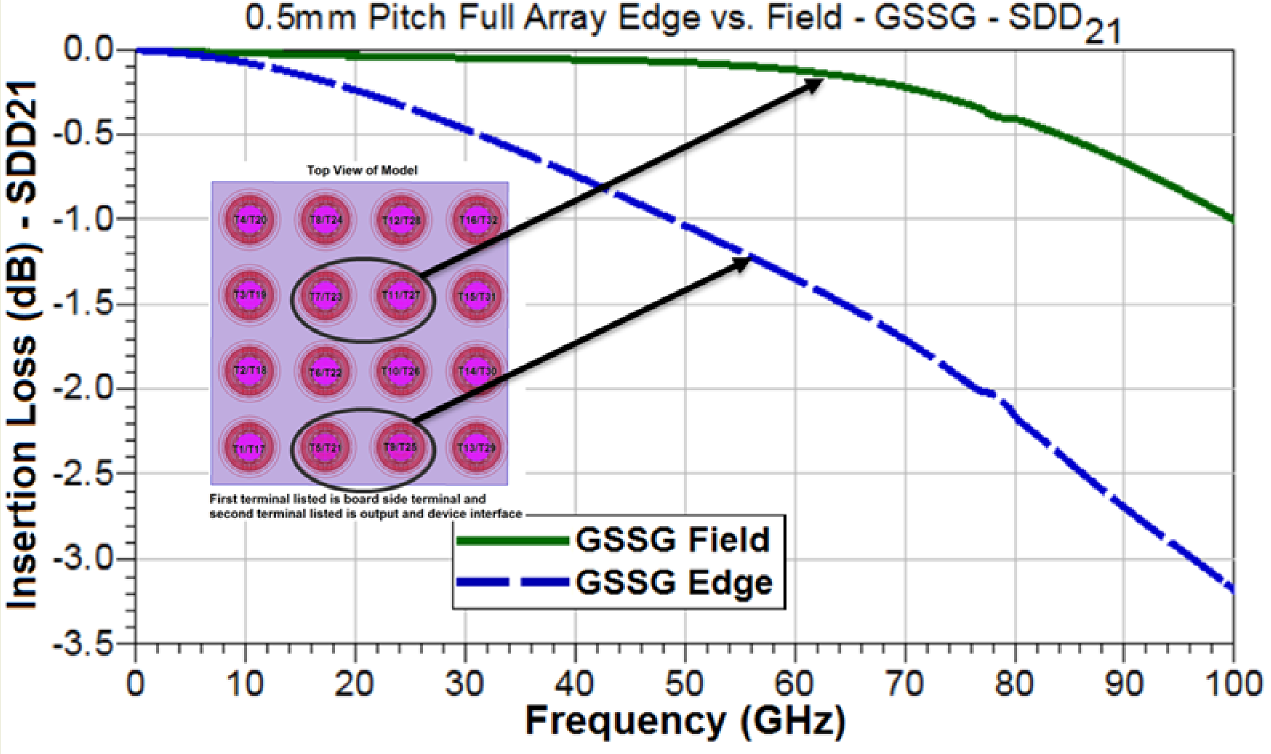
Application: PAM4 112 Gbps high speed bus.

Challenge: Multiple configurations within the device needed to be evaluated to ensure high speed performance.



* Probe test height = 1 mm

Example: 1 mm Probe @ 0.5 mm Pitch Different Ground Configurations



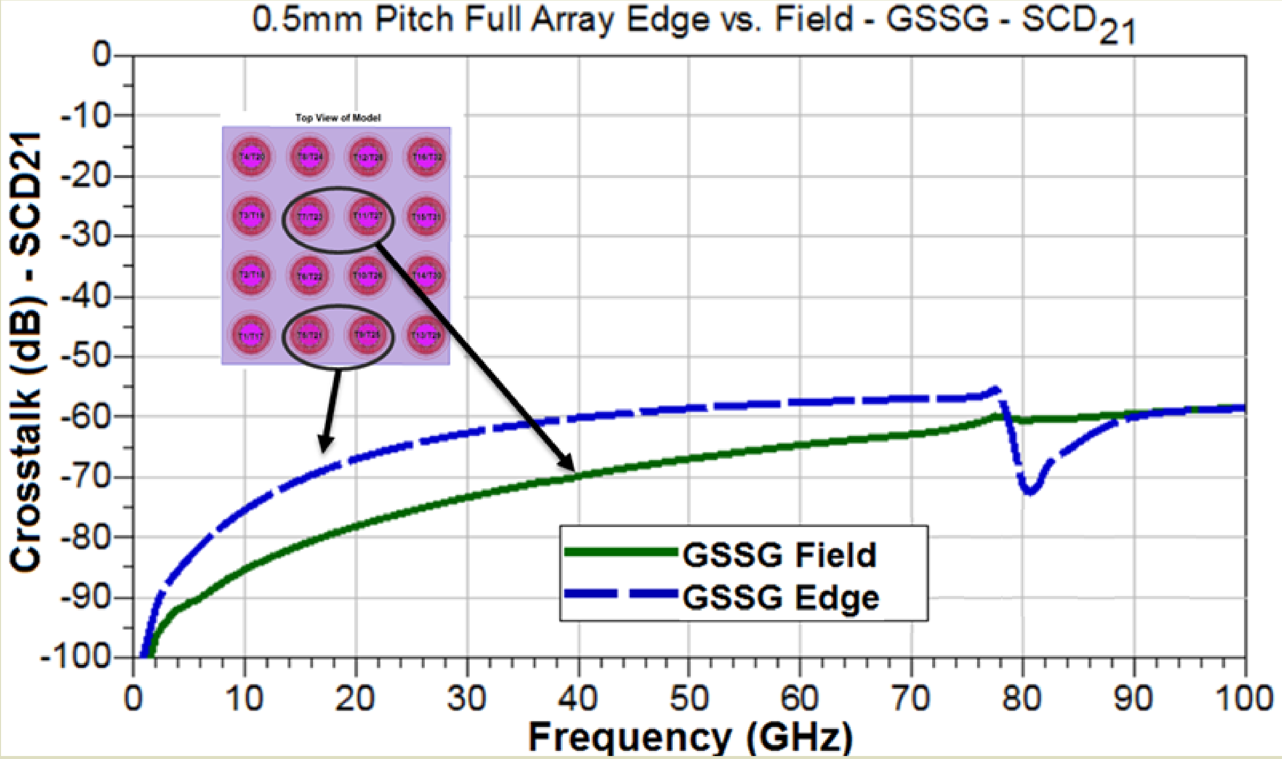
Field configuration in differential mode performance up to 100 GHz.

Short probe technology allows for 50 GHz performance in edge configuration.

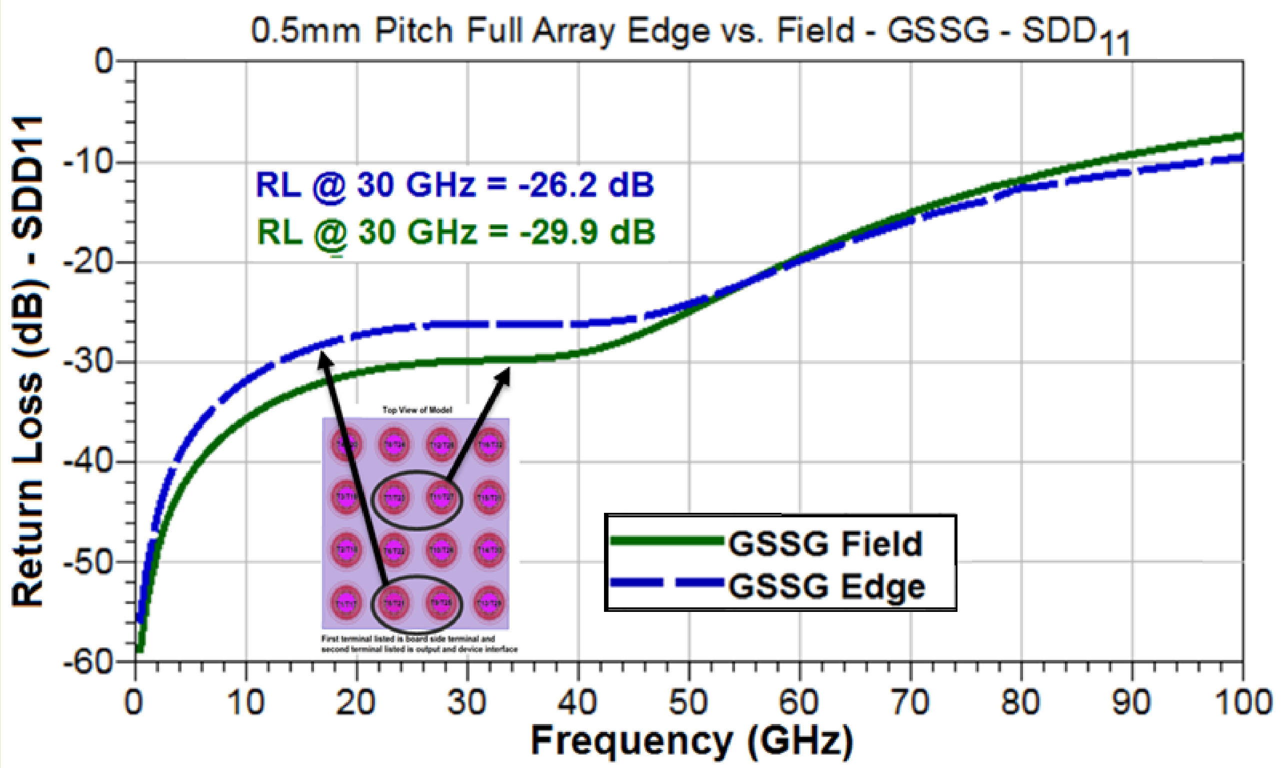
Example: 1 mm Probe @ 0.5 mm Pitch Different Ground Configurations

Excellent isolation performance in either field or edge configuration.

The addition of grounding minimizes the noise on the differential pairs, reducing the signal loss associated with crosstalk.



Example: 1 mm Probe @ 0.5 mm Pitch Different Ground Configurations

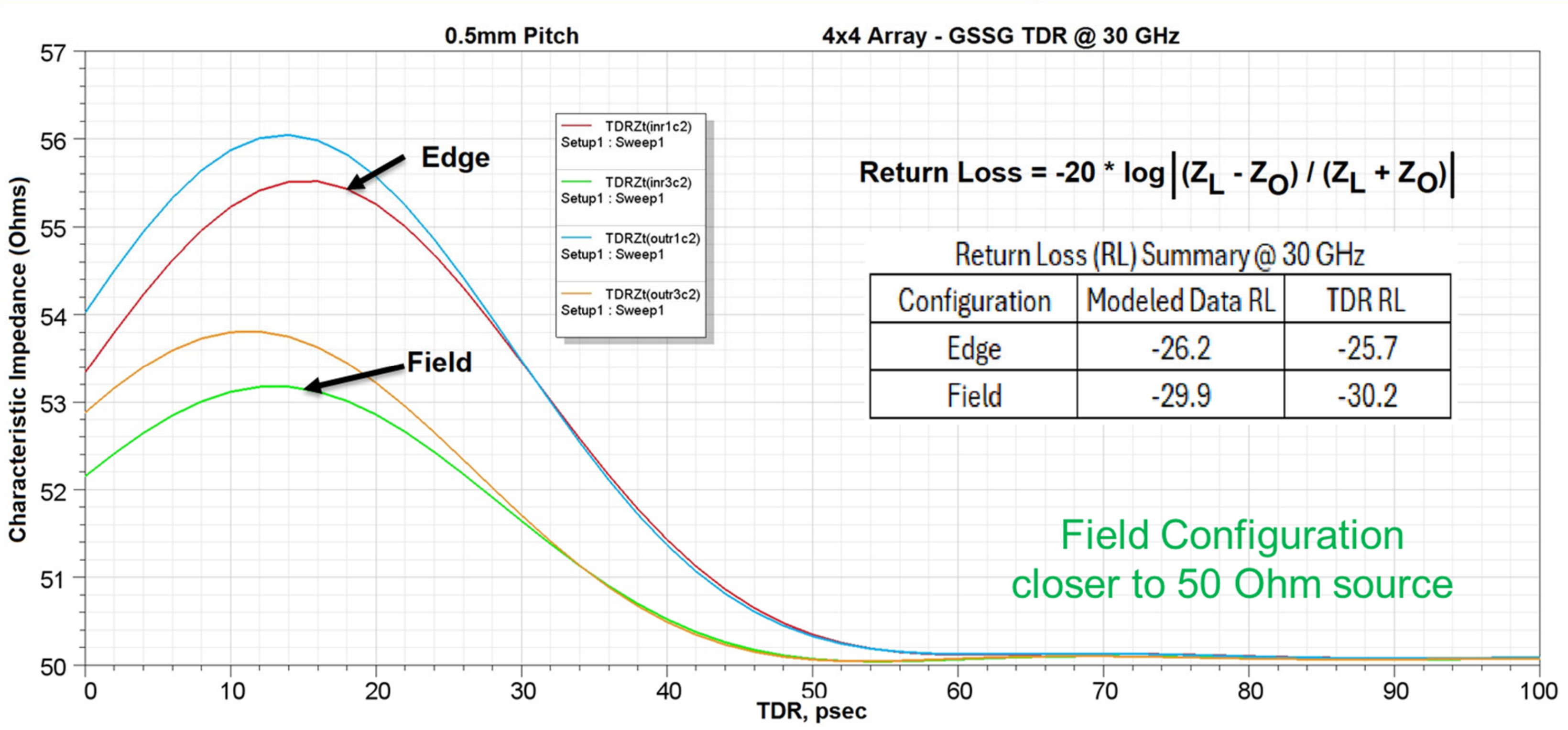


At 30 GHz, what accounts to additional reflected power in the Edge configuration?

<u>Field</u>
0.1% power reflected

<u>Edge</u>
0.25% power reflected

Example: 1 mm Probe @ 0.5 mm Pitch Different Ground Configurations



$$\text{Return Loss} = -20 * \log\left|(Z_L - Z_O) / (Z_L + Z_O)\right|$$

Return Loss (RL) Summary @ 30 GHz

Configuration	Modeled Data RL	TDR RL
Edge	-26.2	-25.7
Field	-29.9	-30.2

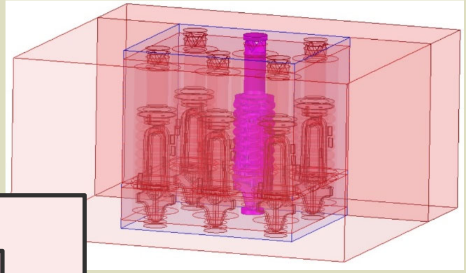
Field Configuration closer to 50 Ohm source

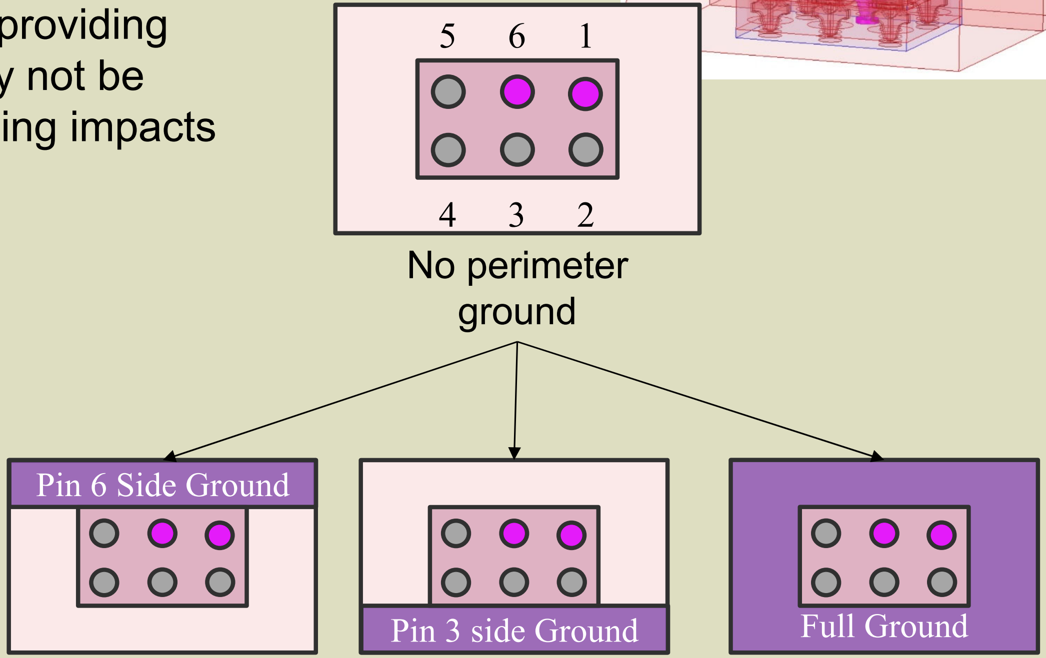
Example: 1 mm Probe WLCSP Array

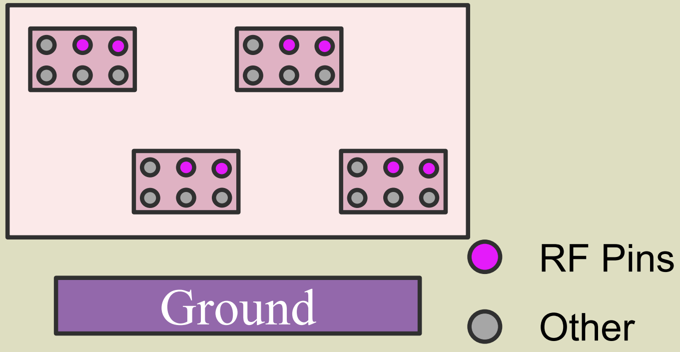
Comparison Of Metal vs. Optimized Housing

Application: High power RF switch requiring excellent isolation (very low crosstalk on pins 6 to 1)

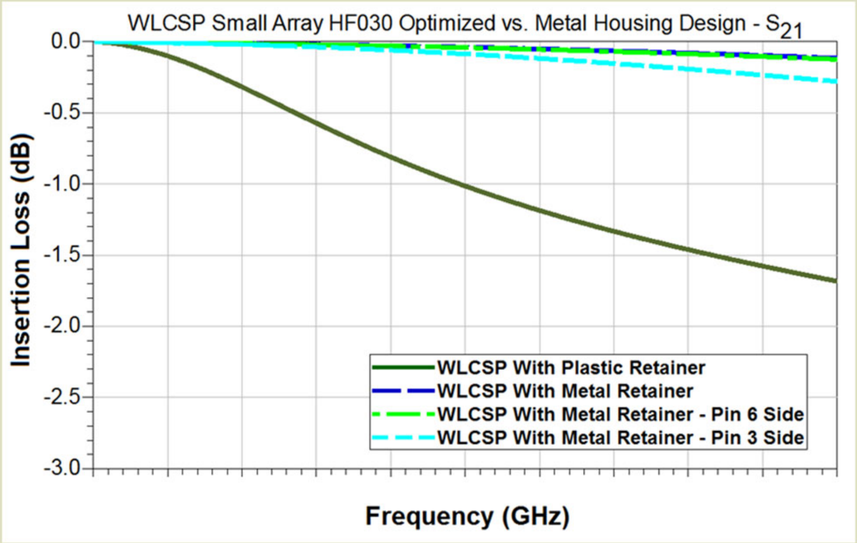
Challenge: Due to geometry constraints, providing full ground surrounding each test site may not be possible. Need to determine how grounding impacts isolation.



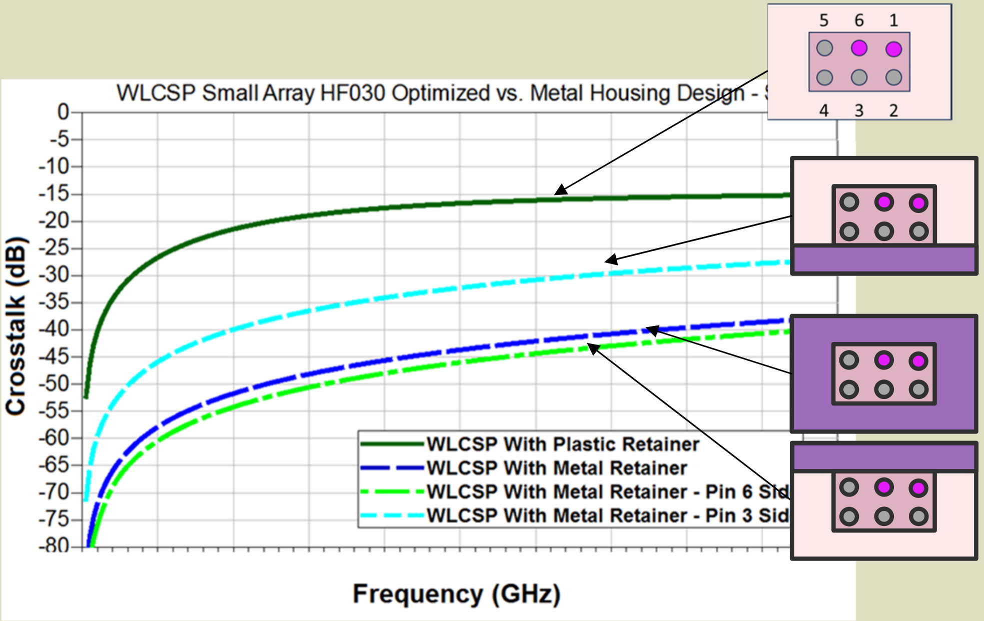




Example: 1mm Probe WLCSP Array Comparison Of Metal vs. Optimized Housing



The addition of any ground improves Insertion Loss



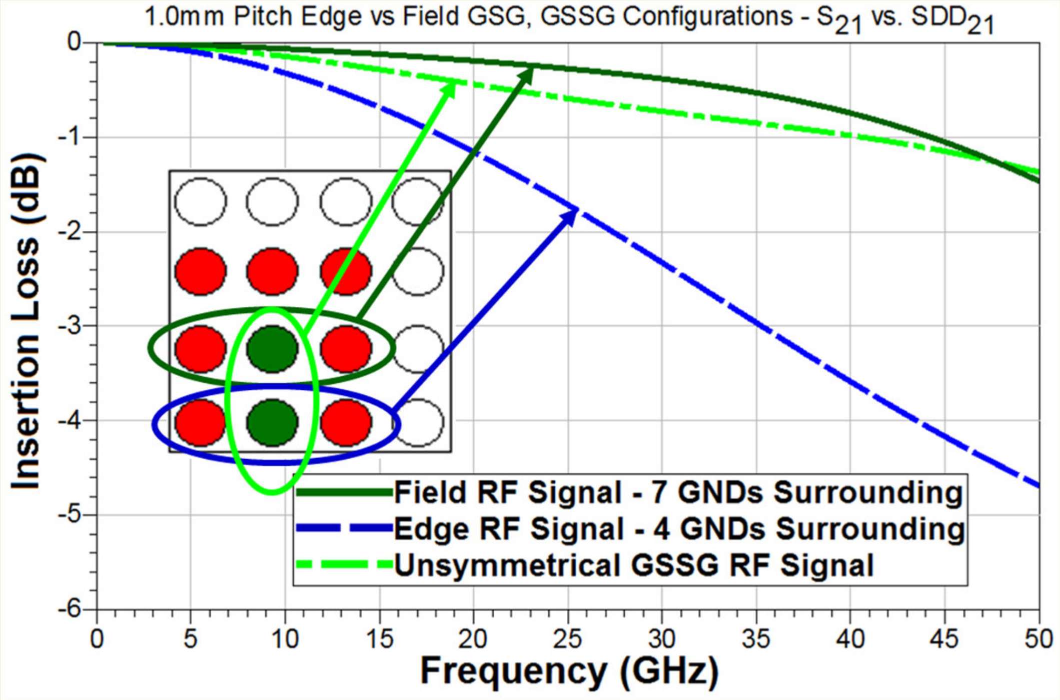
Improved isolation with grounding in proximity to signal pins

Example: 1 mm Probe @ 1.0 mm Pitch Crosstalk and Symmetry

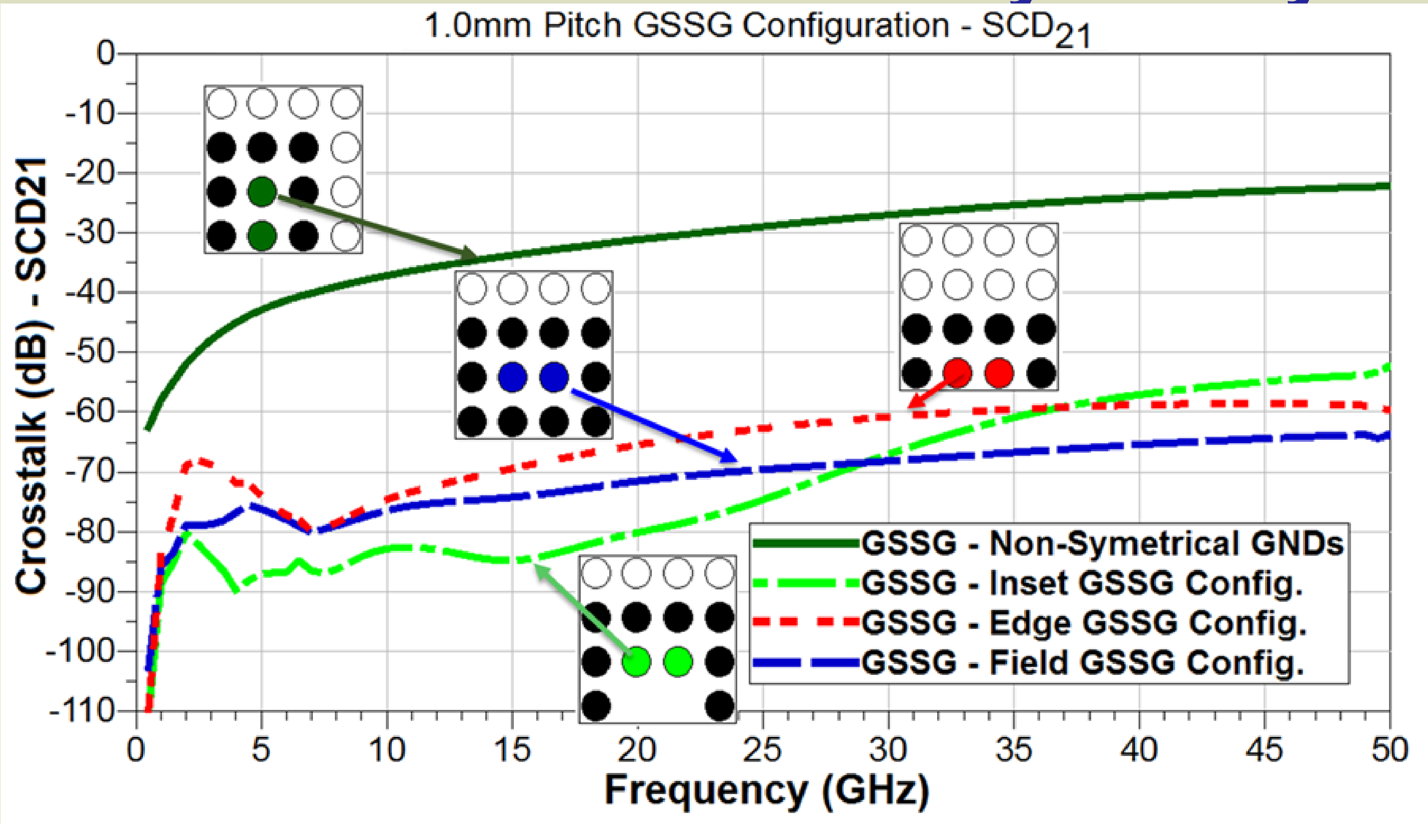
Challenge: Larger pitches have grounds farther away which tends to increase characteristic impedance. Additionally, non-symmetrical configurations impact crosstalk.

$$Z_O \propto \log_{10}\left(\frac{D}{d}\right)$$

D → pitch
d → probe Ø



Example: 1 mm Probe @ 1.0 mm Pitch Crosstalk and Symmetry



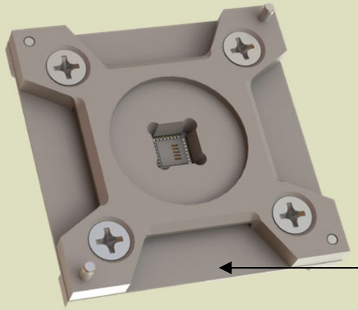
Non-symmetric

Symmetric

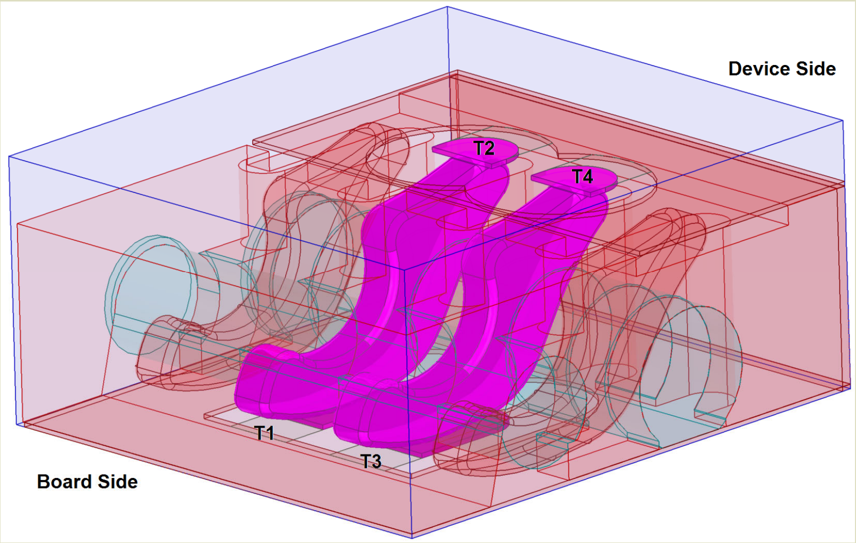
Ground Symmetry is impactful

Example: Solid Contact Technology
Impact of Dielectric on RF Performance

- Application: ESD-sensitive devices
- Challenge: Developed solid contact technology with standard materials. Customers requesting static dissipative materials that limit triboelectric charging to <100V. Need to determine the impact of performance over frequency.

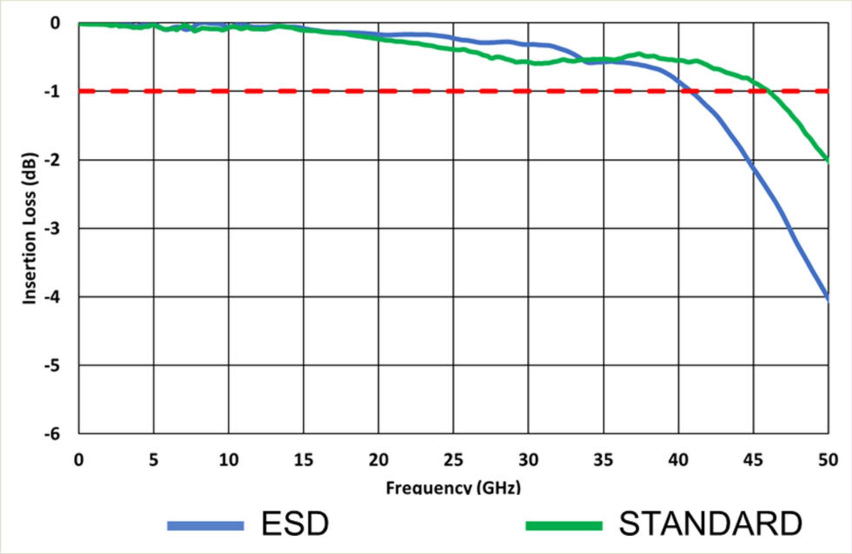


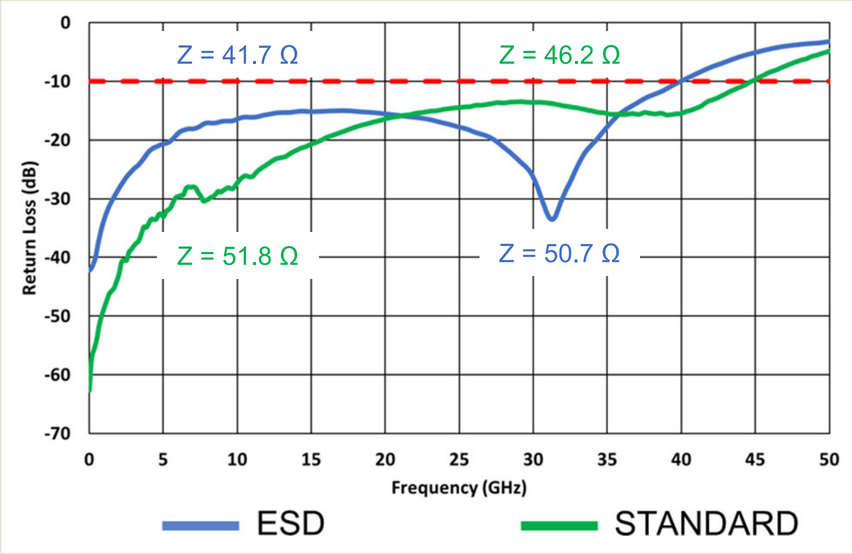
$$Z_O \propto \frac{1}{\sqrt{\epsilon_r}}$$



Example: Solid Contact Technology Impact of Dielectric on RF Performance

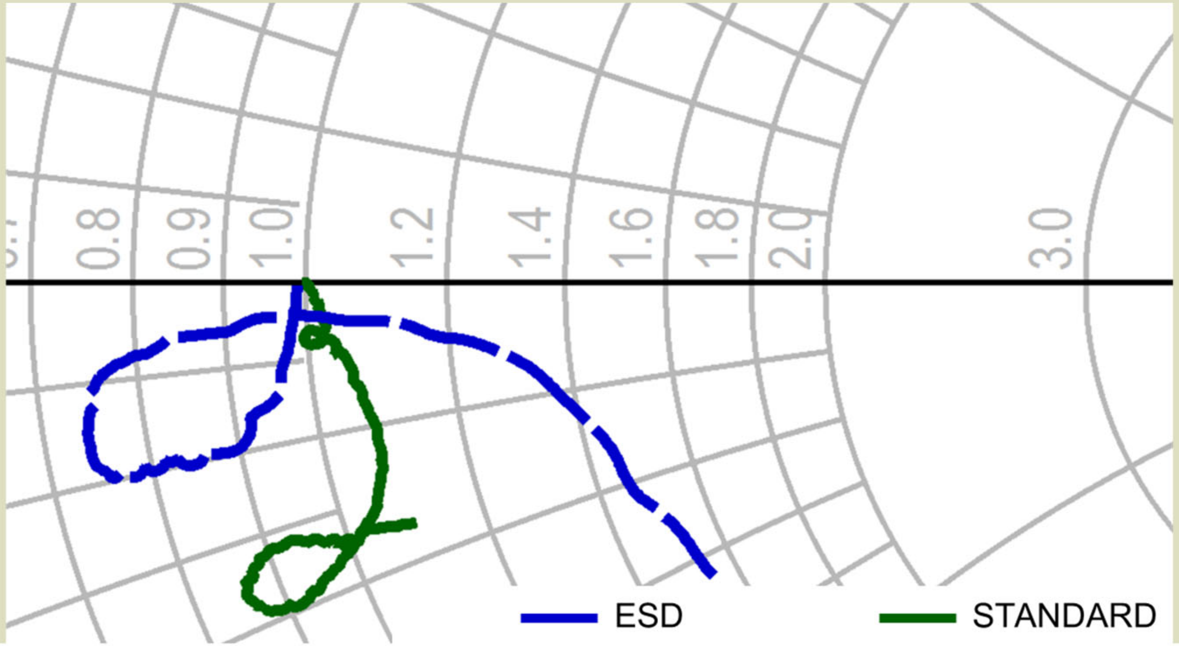
$$Z_0 \propto \frac{1}{\sqrt{\epsilon_r}}$$





ESD material has a higher dielectric, which lowers the impedance from 50 Ohms

Example: Solid Contact Technology
Impact of Dielectric on RF Performance



Housing Material	10 GHz Imp.	20 GHz Imp.	33 GHz Imp.	10 GHz RL	20 GHz RL	33 GHz RL
Standard	51.8 - j4	52.4 - j15.5	43.8 - j16.7	-27.3	-16.4	-14.5
ESD	40.5 - j9.9	37.2 - j7.1	55.8 - j2.8	-16.4	-15.5	-24.4

In Summary

- Many variables in socket design impact signal integrity
  - Signal/grounding configuration, material, contact design
- Impact can be seen when comparing simulations of
  - Insertion loss, return loss, impedance, crosstalk
- The quality of the ground has a major influence on signal integrity
  - Number of grounds
  - Proximity to grounds
  - Symmetry of grounds
  - Signal configuration (GSG, GSSG)
- Impacts of above variables are application specific and must be considered for each unique package layout

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