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# The Impact of Grounding on RF Performance

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# *Seminar Outline*

- 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 successful implementations
- Recommendations for optimizing grounding practices in diverse RF applications

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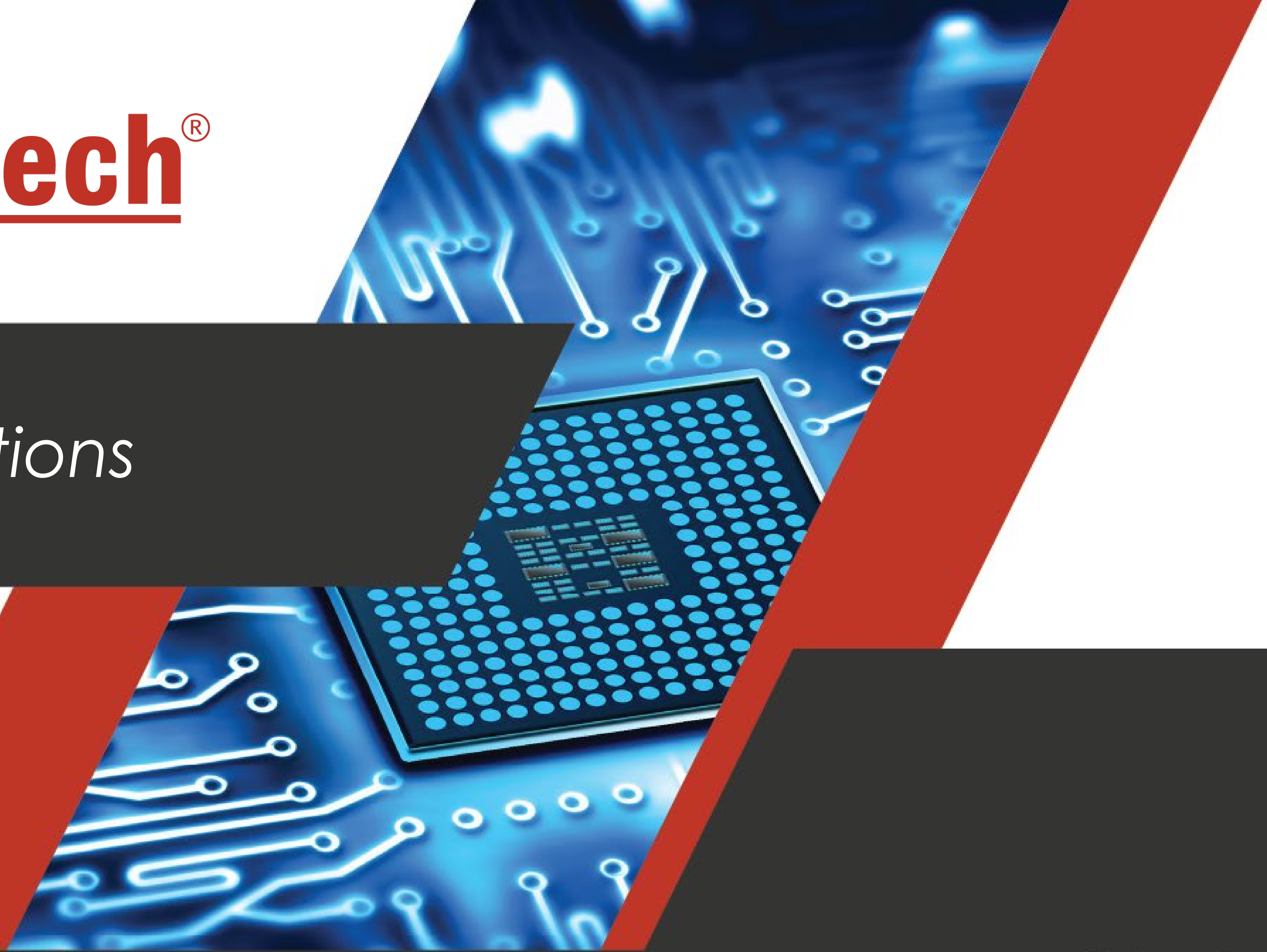
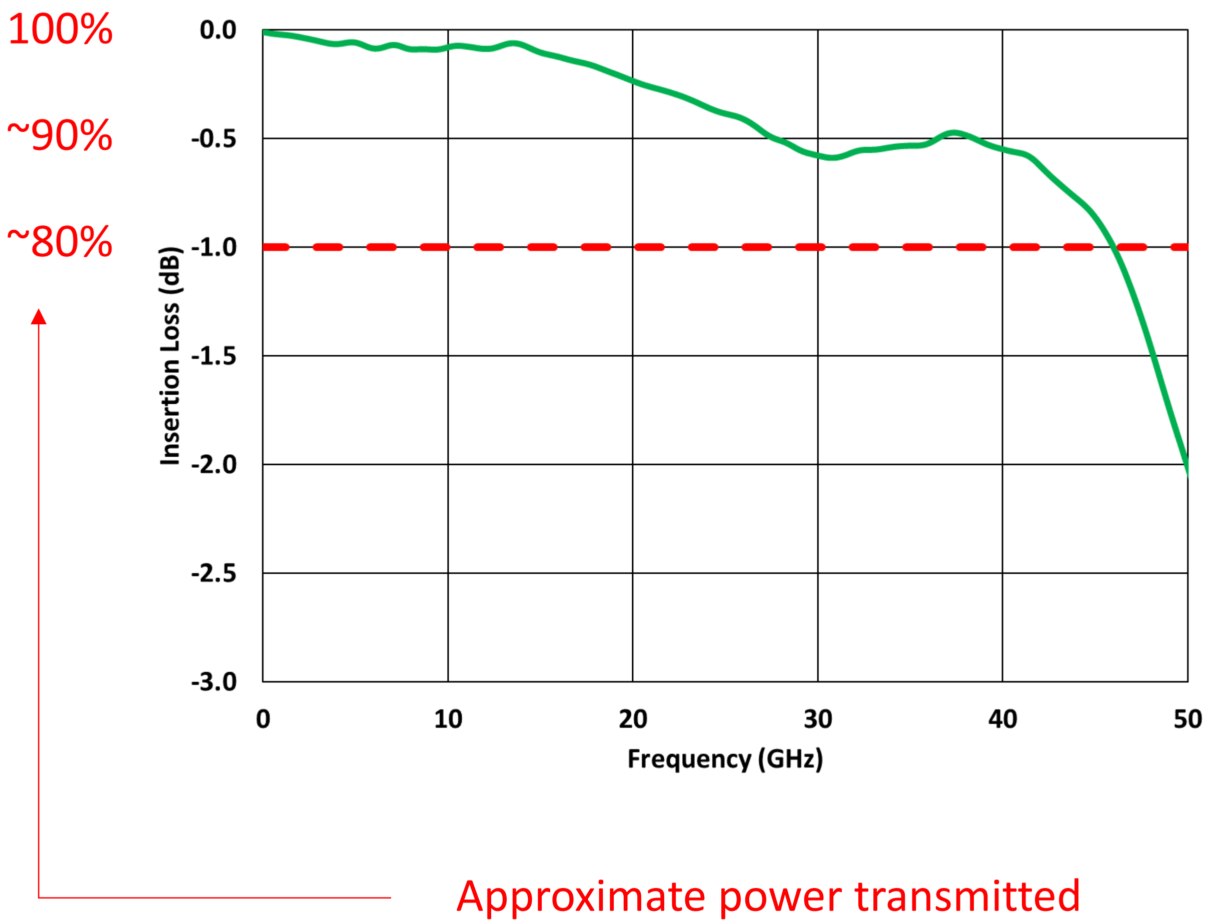
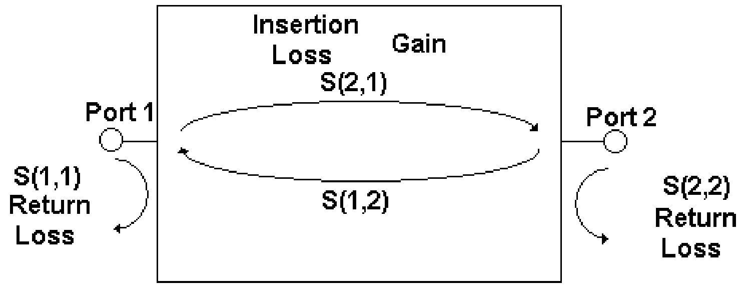


# *Definitions*

# Concepts: Insertion Loss




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




S(2,1) = S(1,2) For Ideal Passive Parts



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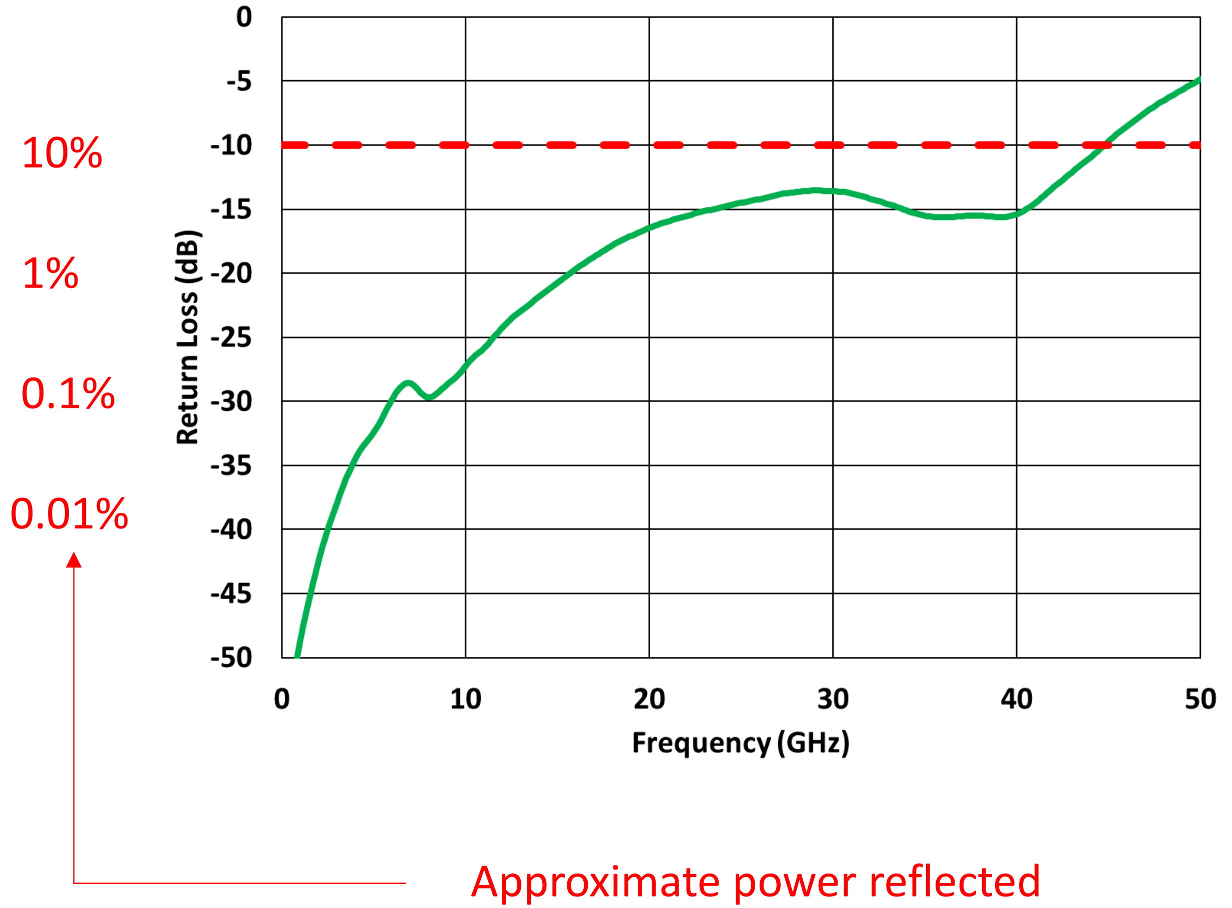
# Concepts: Return Loss



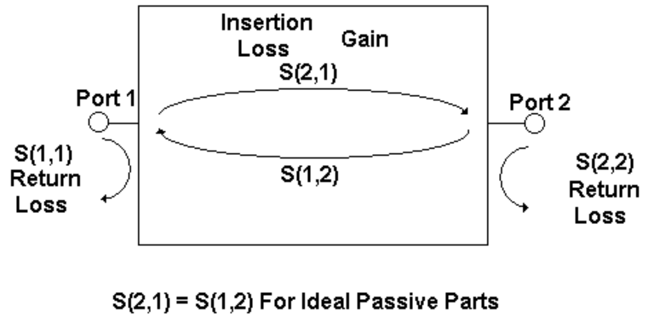

- Return Loss is the amount of power reflected back to a generator from a load due to impedance mismatch.
- $S_{11} = 10 * log_{10}(\left|\frac{P_{reflected}}{P_{incident}}\right|)$

or

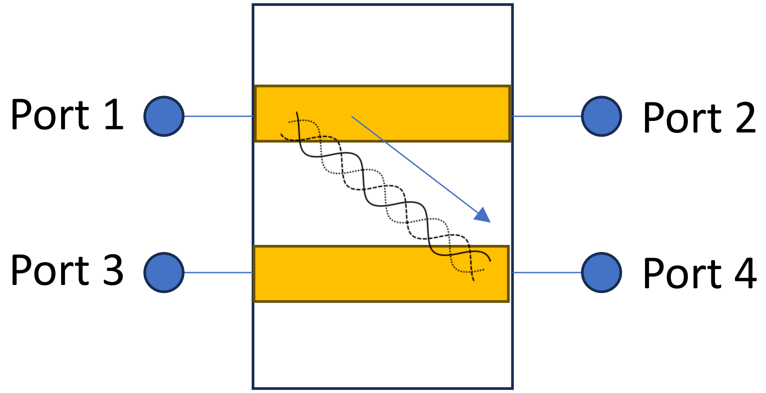
- $S_{11} = -20 * log_{10}(|\Gamma|)$

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



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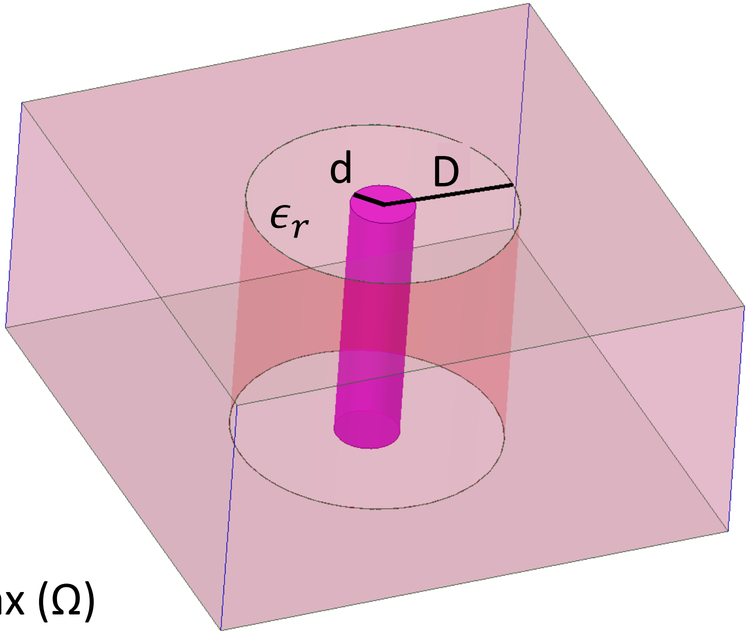
# RF Performance on Theoretical Coax

# Effects of Ground Location – Distance to Ground

Coaxial Impedance [1]

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




Where:

$Z_O$= characteristic impedance of the coax (Ω)

$\epsilon_r$ = relative permittivity (dielectric constant) of the insulator

D = inner diameter of the outer conductor (m)

d = outer diameter of the inner conductor (m)

| 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 |

Note: d= 0.24mm



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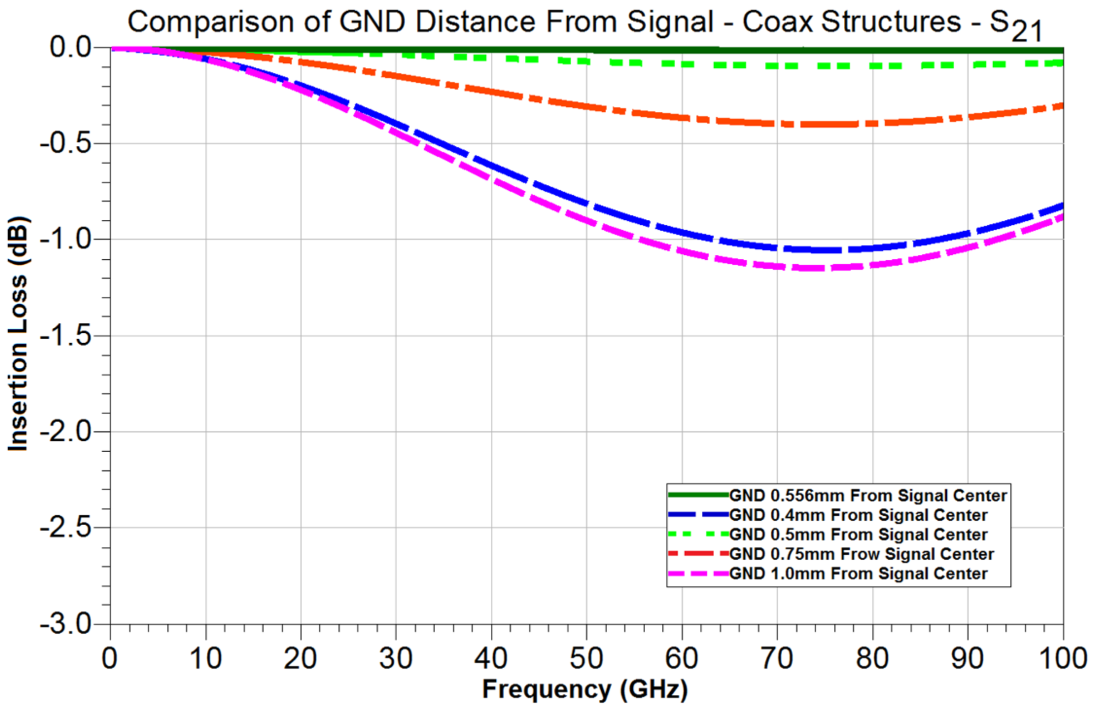
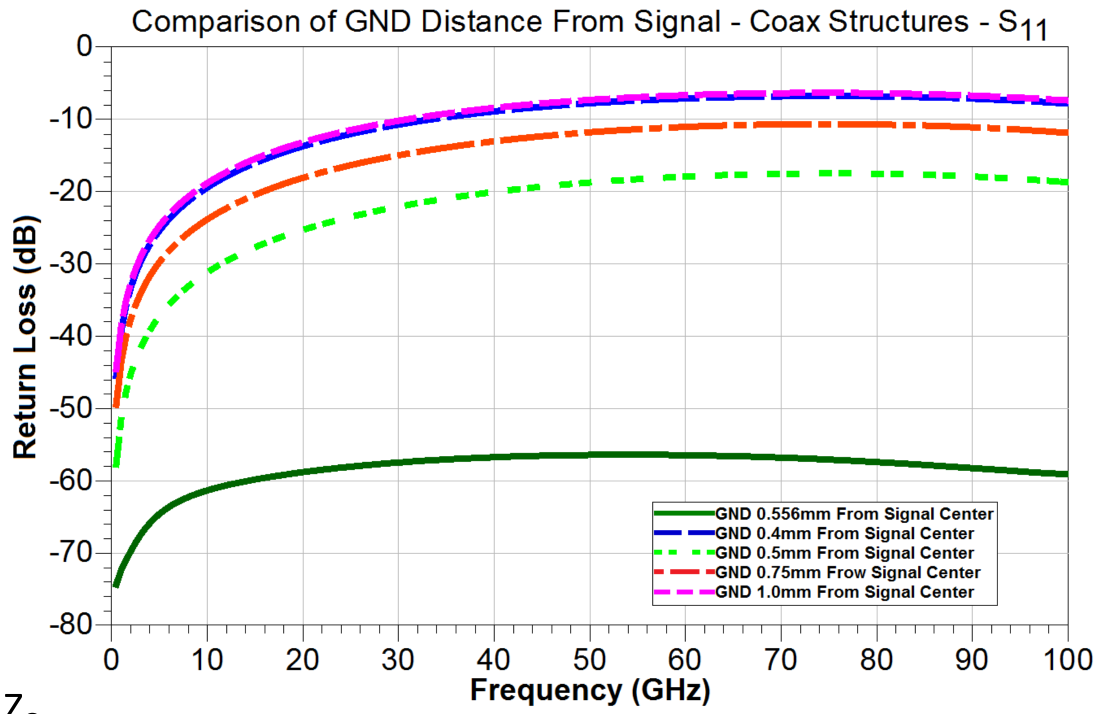
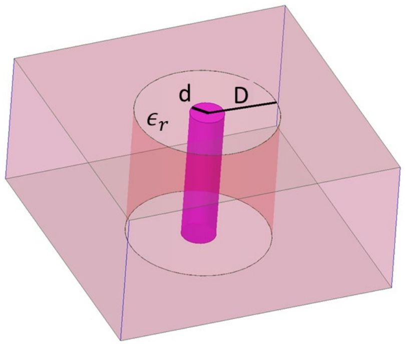
# Effects of Ground Location – Distance to Ground




| 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)



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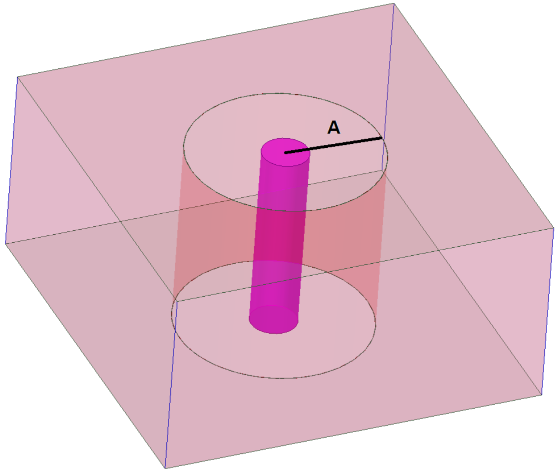
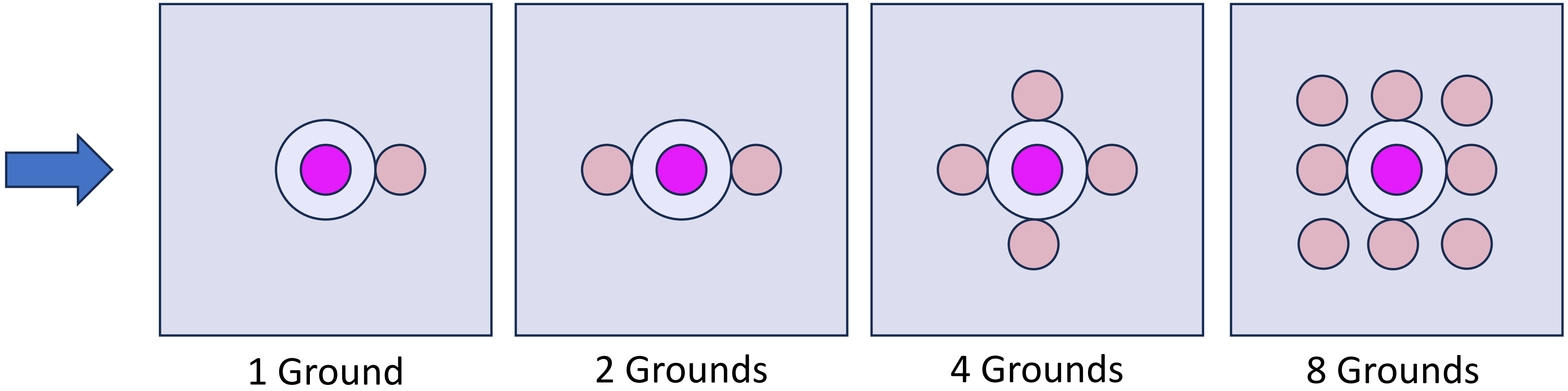
# *Effects of Ground Location – Number of Grounds*



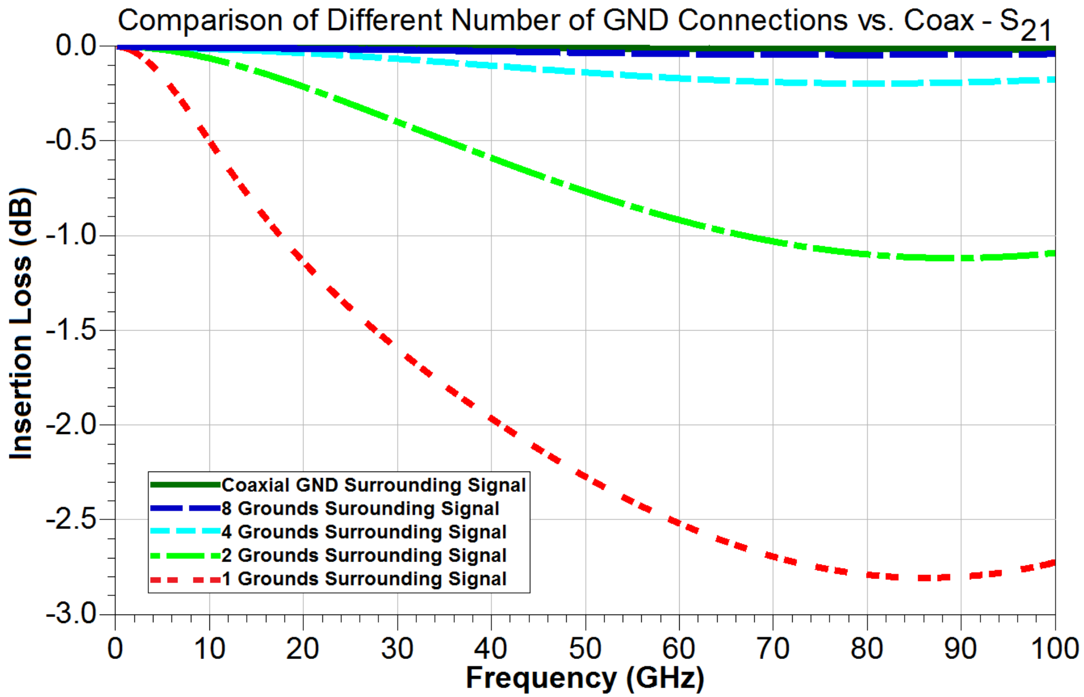

Coax

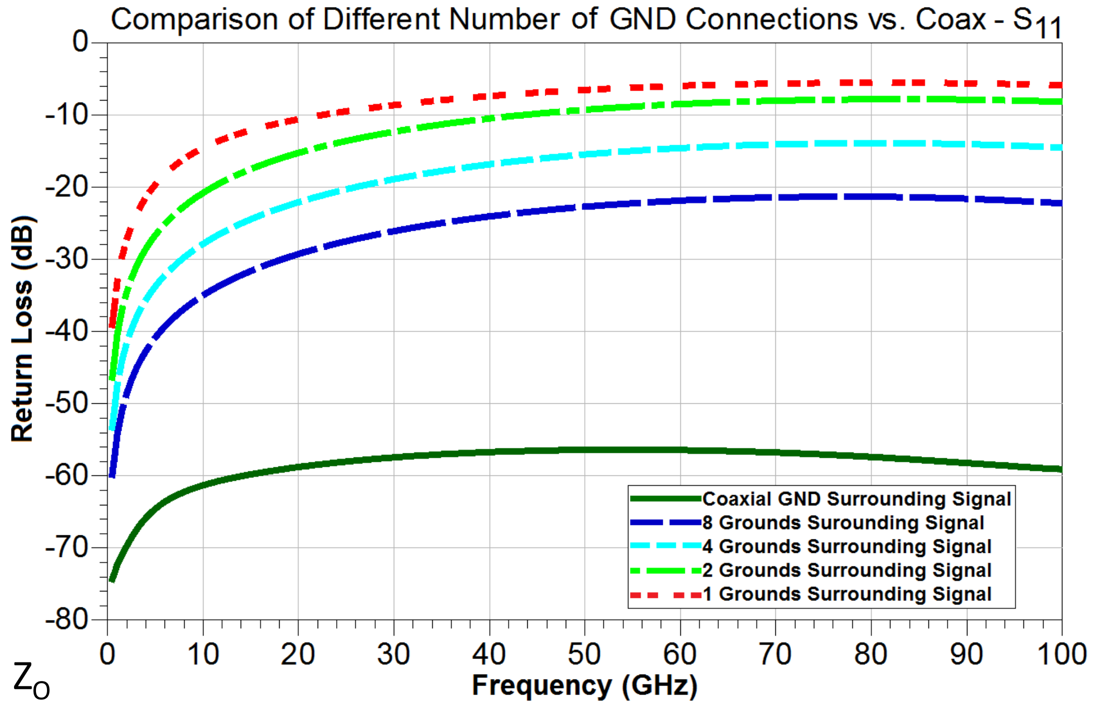



Continuous ground coax is ideal and when not possible, need to bring grounds very close.

How many are required?

# Effects of Ground Location – Number of Grounds

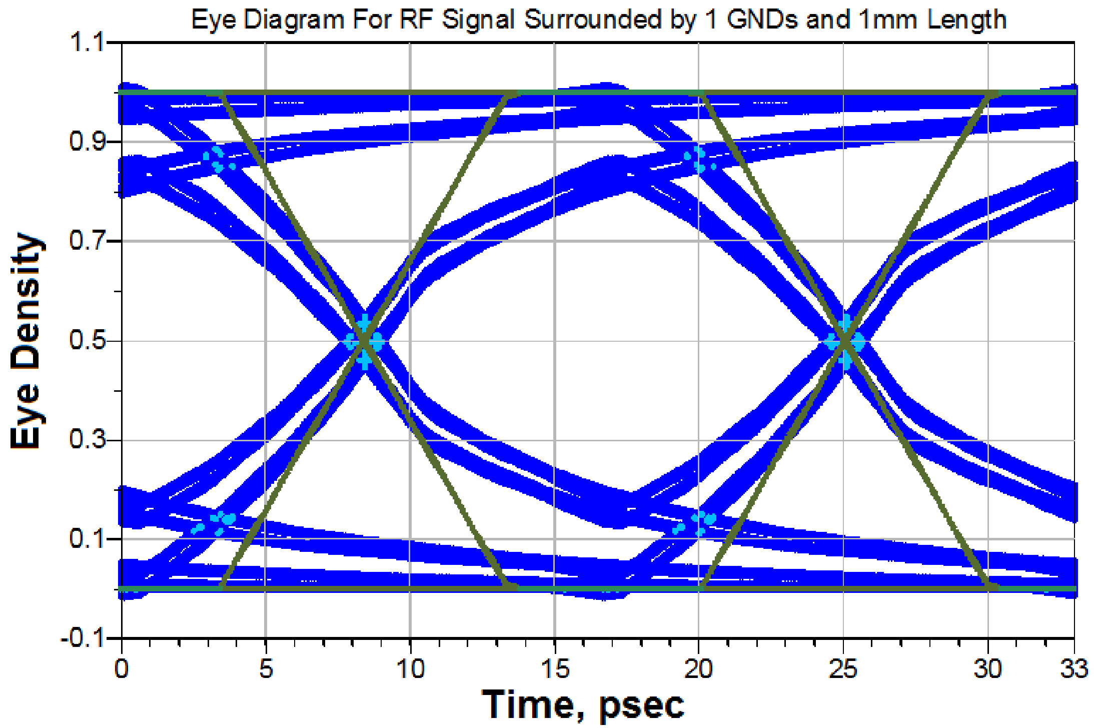


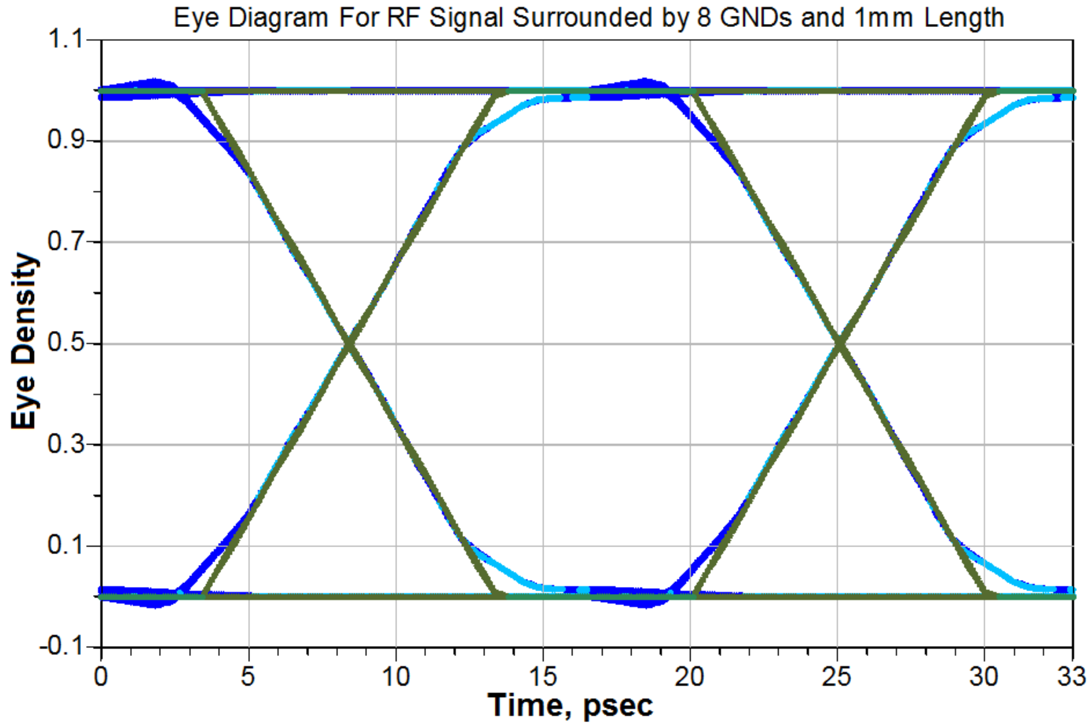



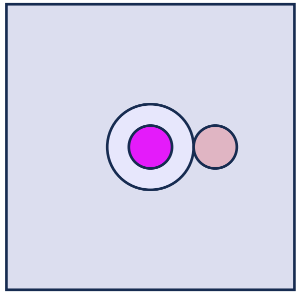

| Grounds | $Z_O$ |
|---|---|
| 1 | 81.8 Ω |
| 2 | 66.2 Ω |
| 4 | 56.9 Ω |
| 8 | 52.9 Ω |
| Coax | 50.2 Ω |

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

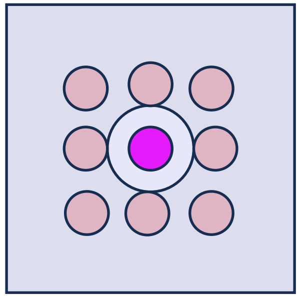
# *Effects of Ground Locations in the Time Domain*



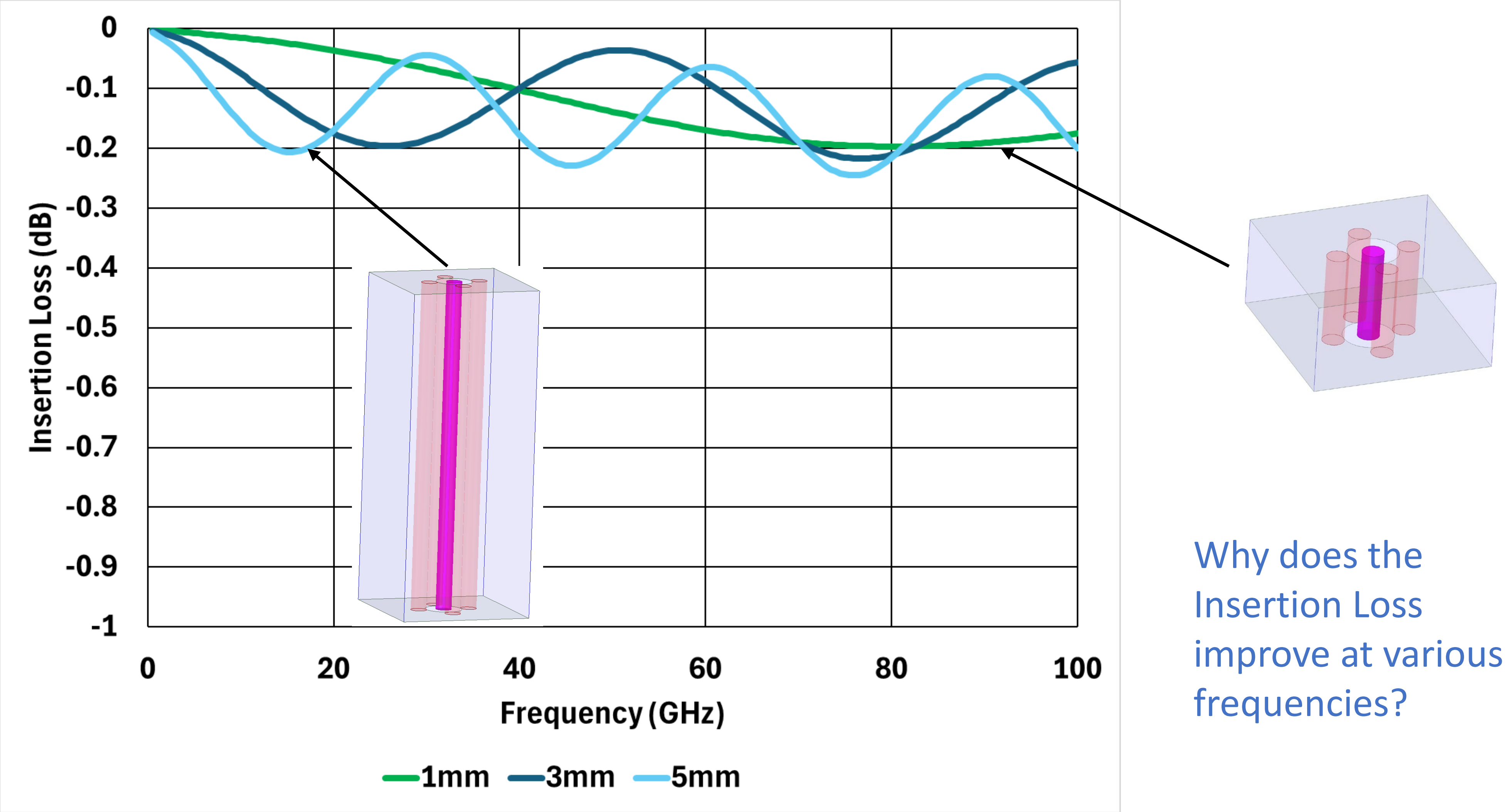



**Eye Diagram @ 60 Gbps**

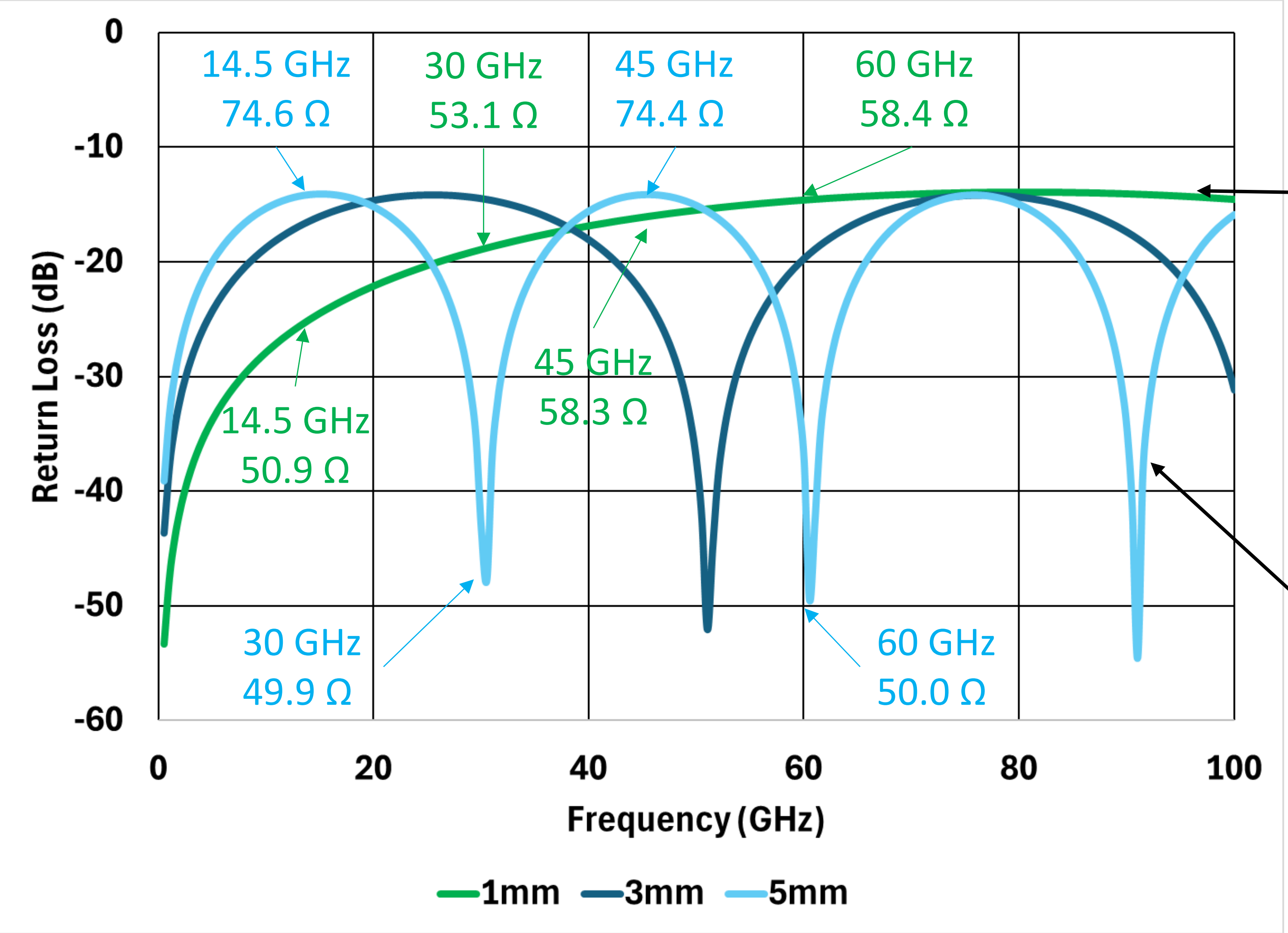


# Comparison of Different Contact Heights

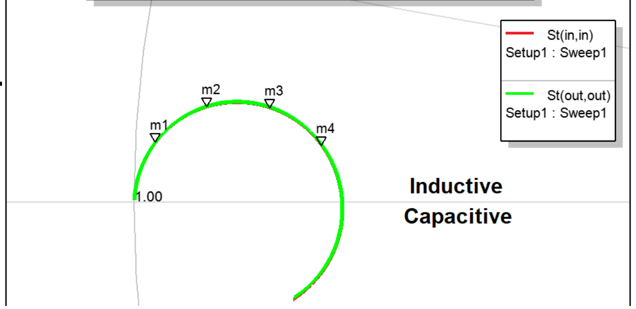


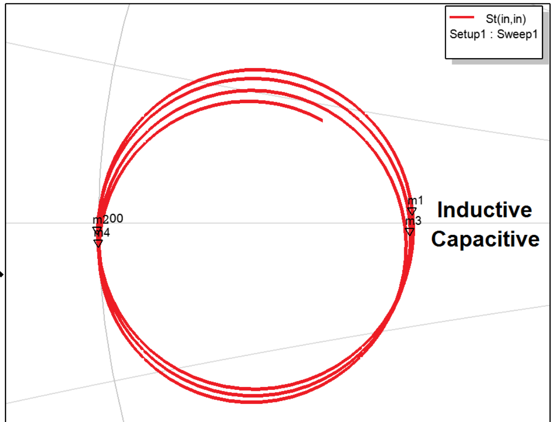

Why does the Insertion Loss improve at various frequencies?

# Comparison of 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 |



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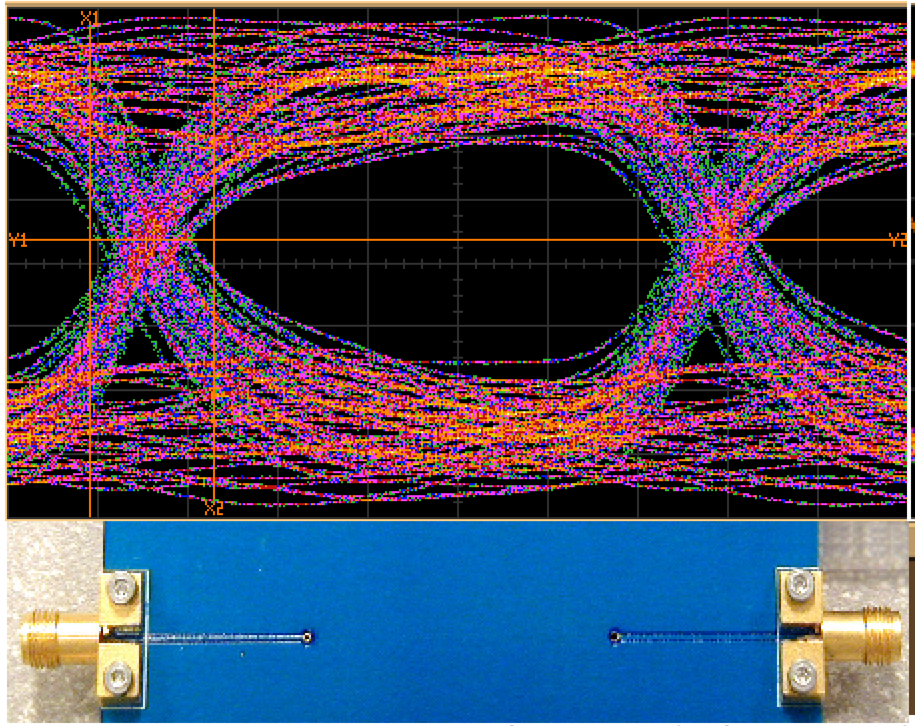
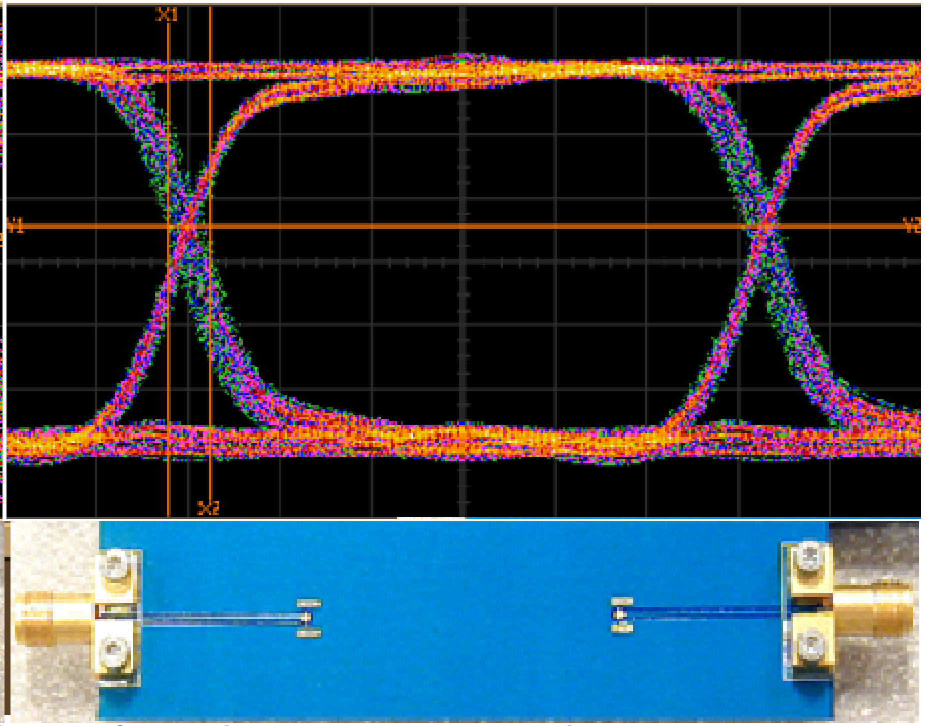
# *Proper grounding produces clean signals*

Vias not shielded by ground

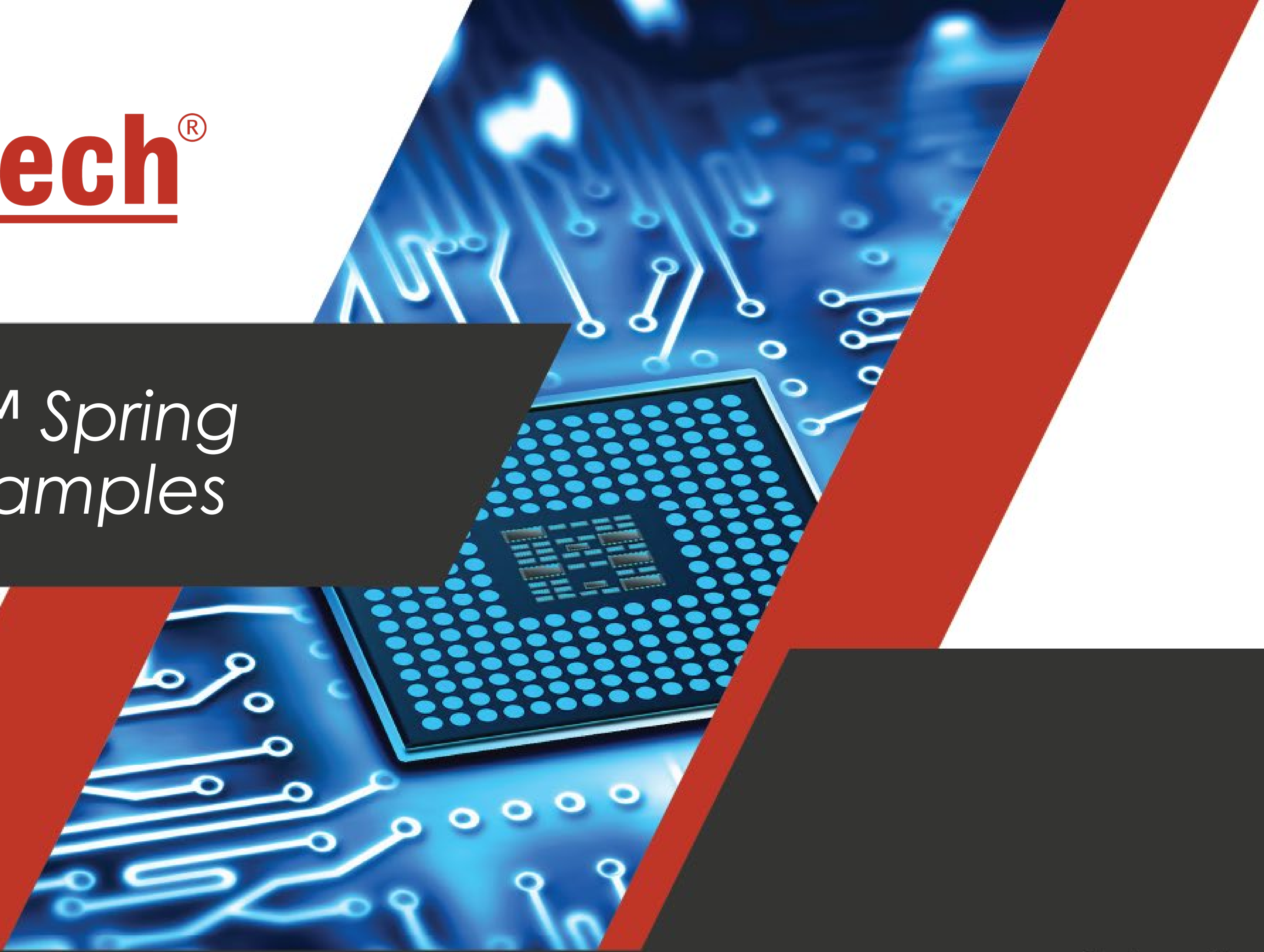


Vias surrounded by ground



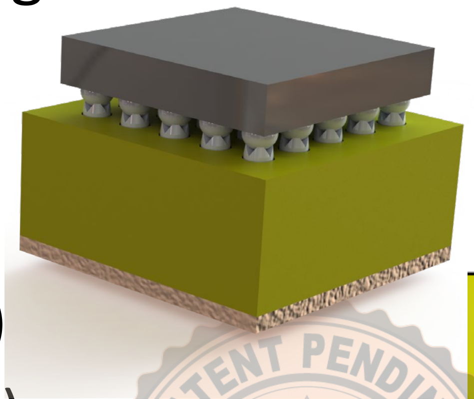
**Vias attach ground planes and significantly improves signal integrity**

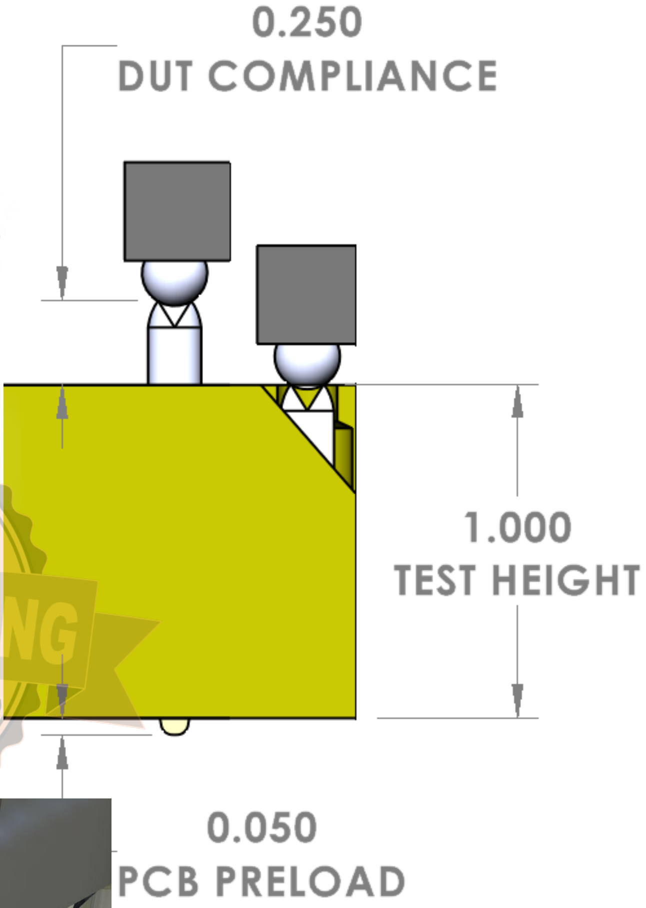
# HERØHF™ Spring Probe Examples



# HERØHF™ Spring Probe Attributes

- New Patented Single-ended probe architecture
- Robust homogeneous radial Pd-alloy DUT plunger
- Gold plated, stainless steel alloy spring
  - Temperature Rating: -65°C to 175°C
- Contact Resistance: 50 mΩ
- Inductance (GSG): 0.28nH (self), 0.49nH (loop)
- Current Carrying Capacity: 2.1A (20° T-Rise DC)
- Probe compressed test height: 1.000mm
- Probe free length: 1.3mm
- Force at test height: 23 g
- Reliability: Minimum 500,000 Cycles





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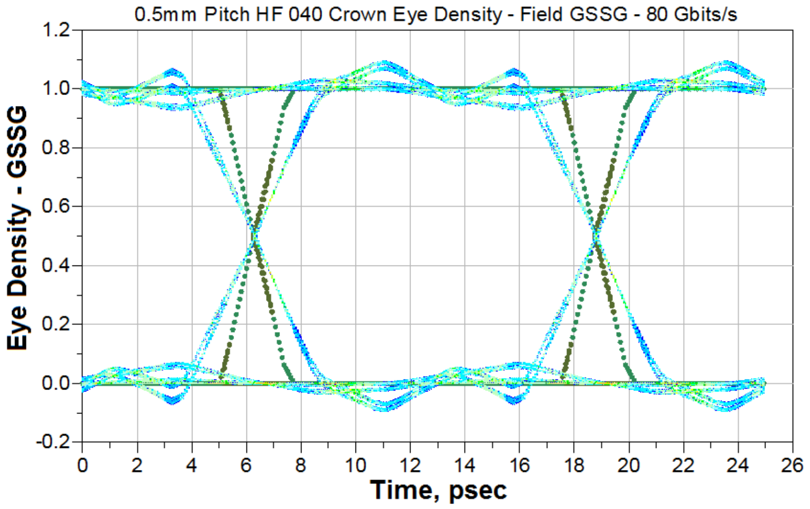
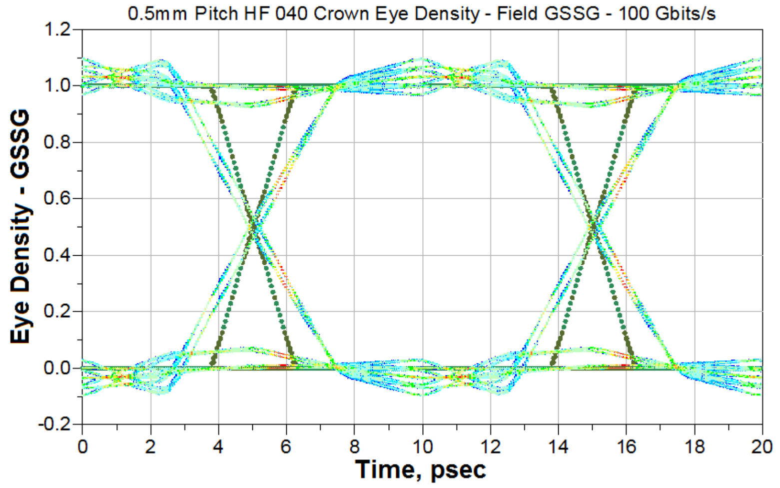
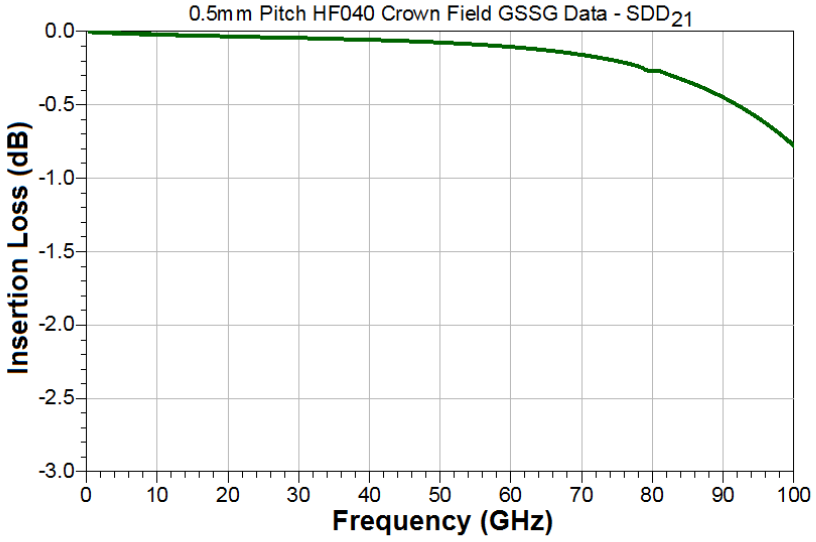
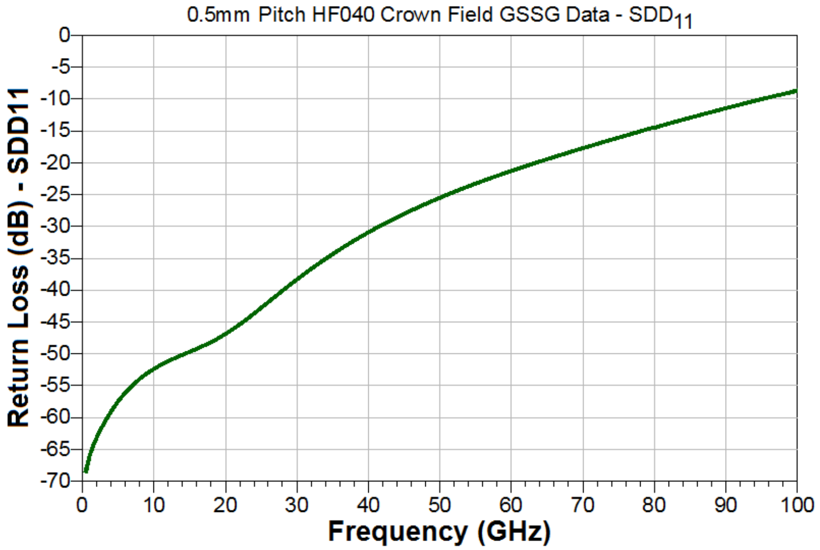
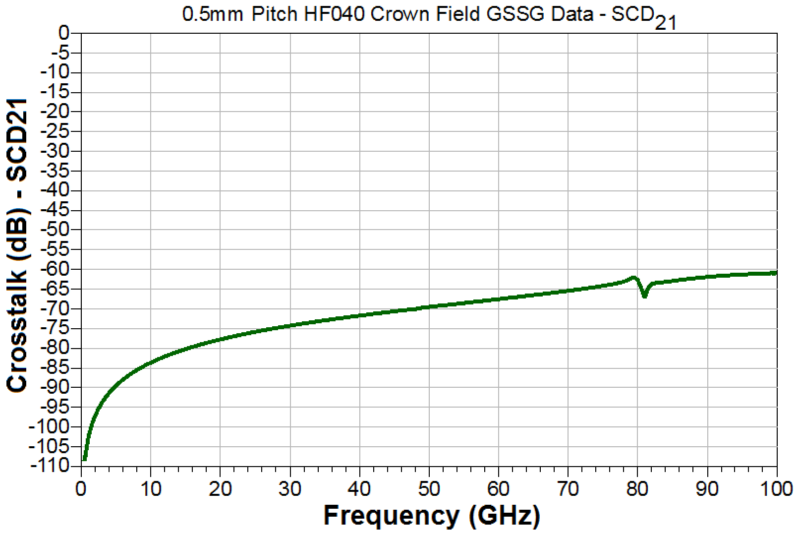
# HERØHF™
# Optimal Performance



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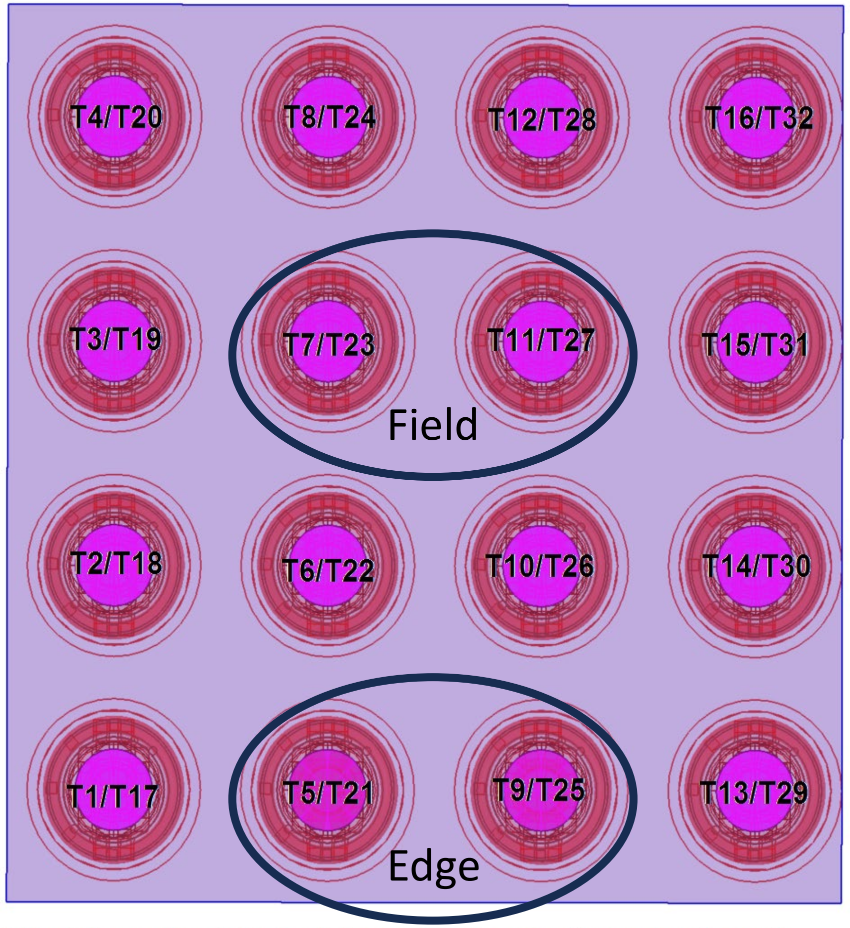
# 0.5mm Pitch HERØHF™ Different Ground Configurations

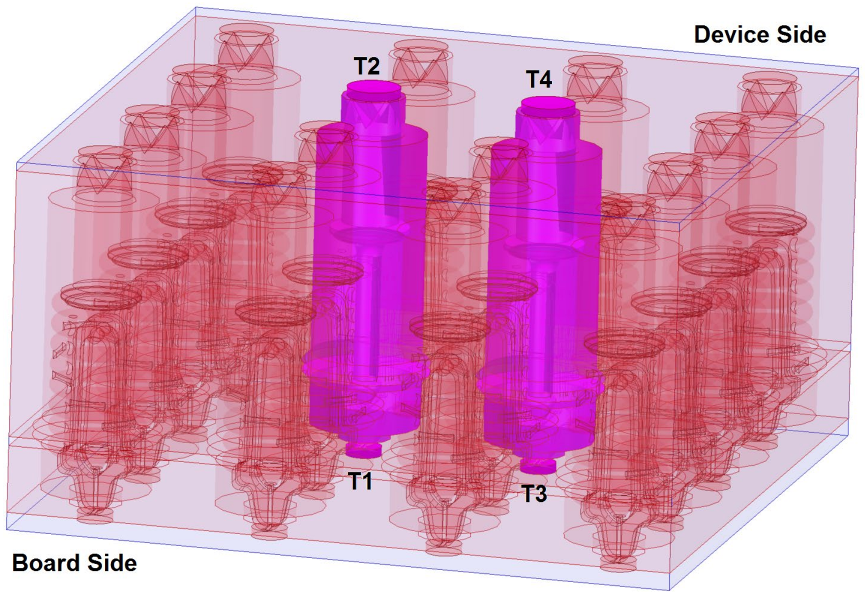
**Top View of Model**




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

Application: PAM4 112 Gbps high speed bus retimer

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



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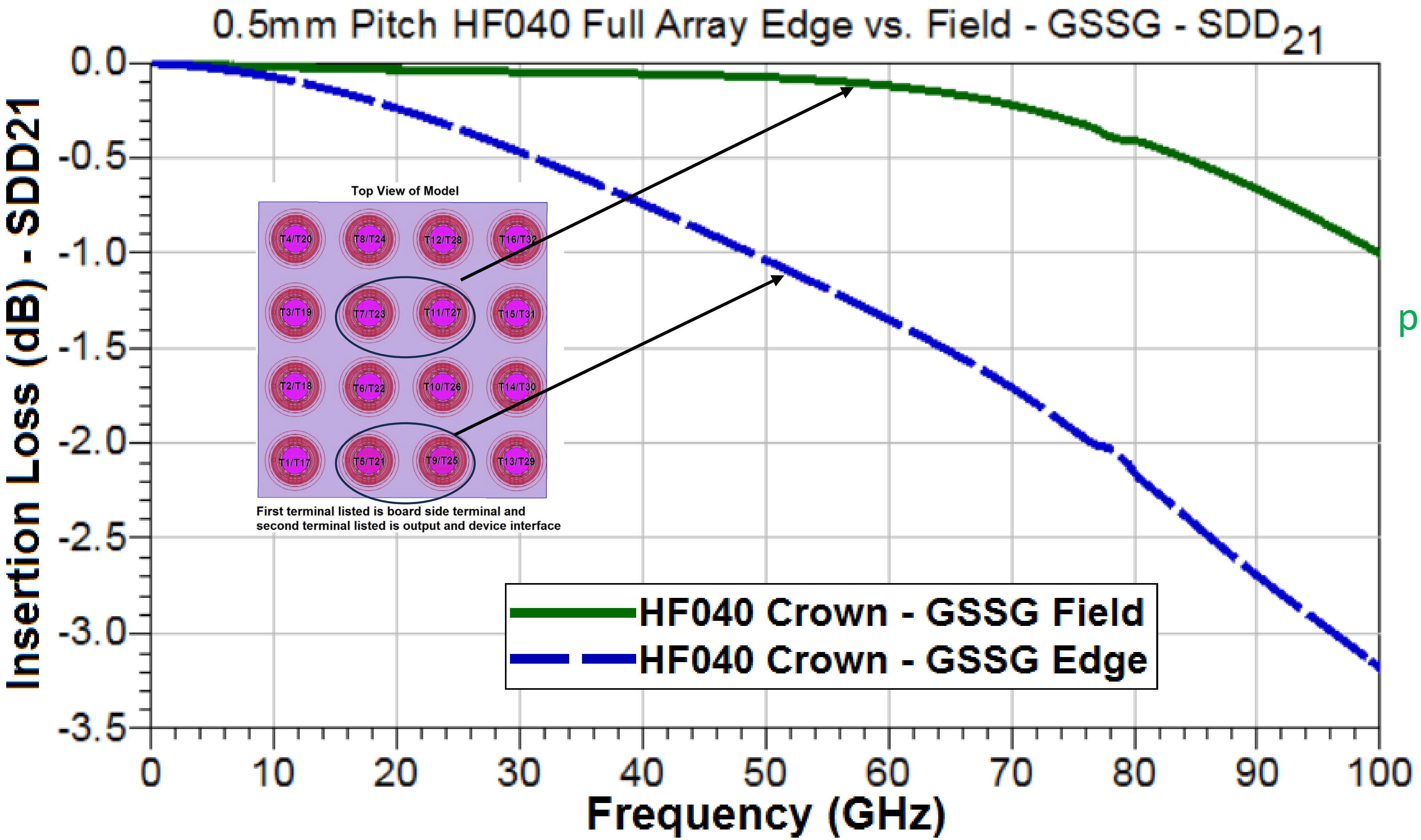
# 0.5mm Pitch HERØHF™
# Different Ground Configurations




Field configuration in differential mode performance up to 100 GHz.

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



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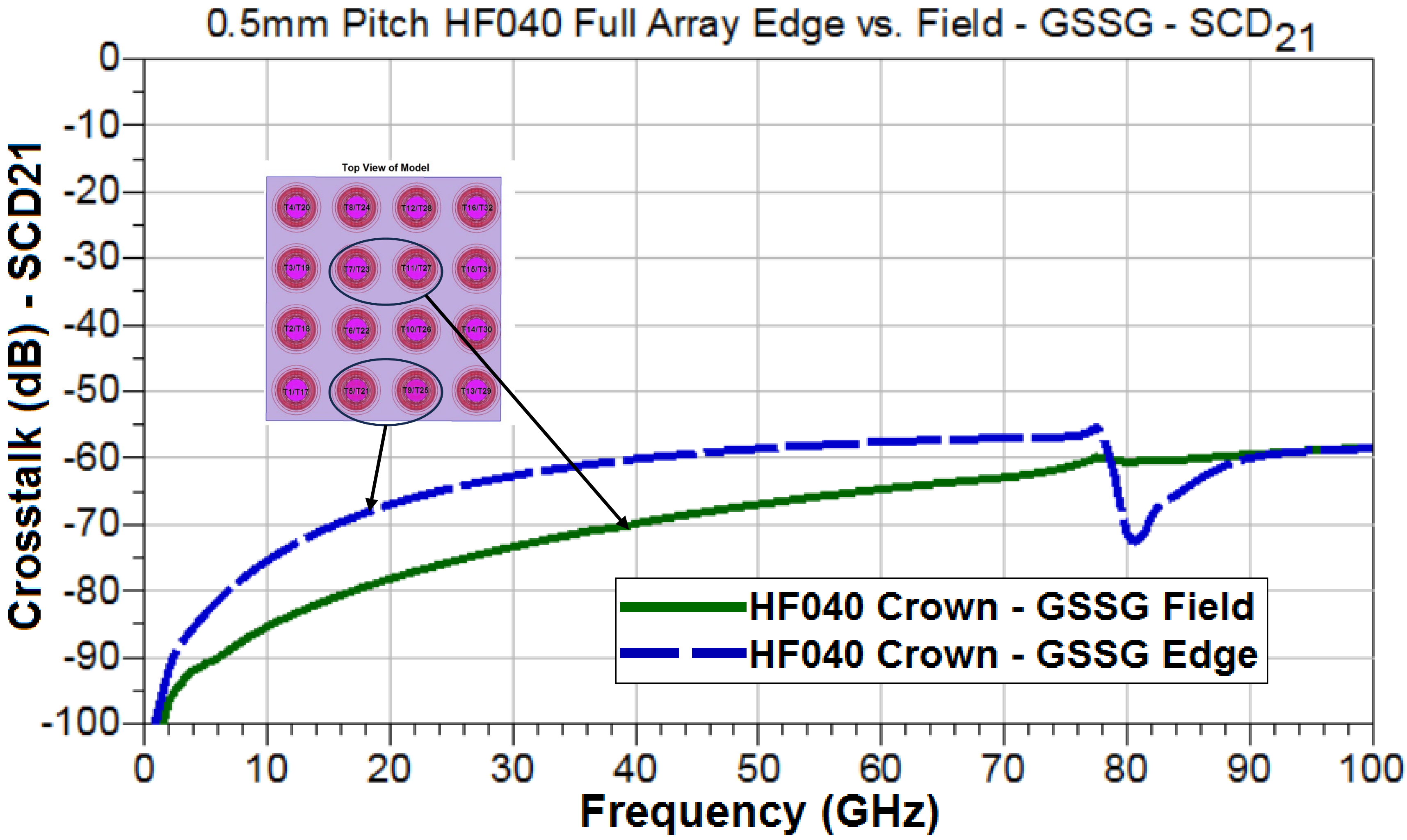
# 0.5mm Pitch HERØHF™ Different Ground Configurations

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 interference.



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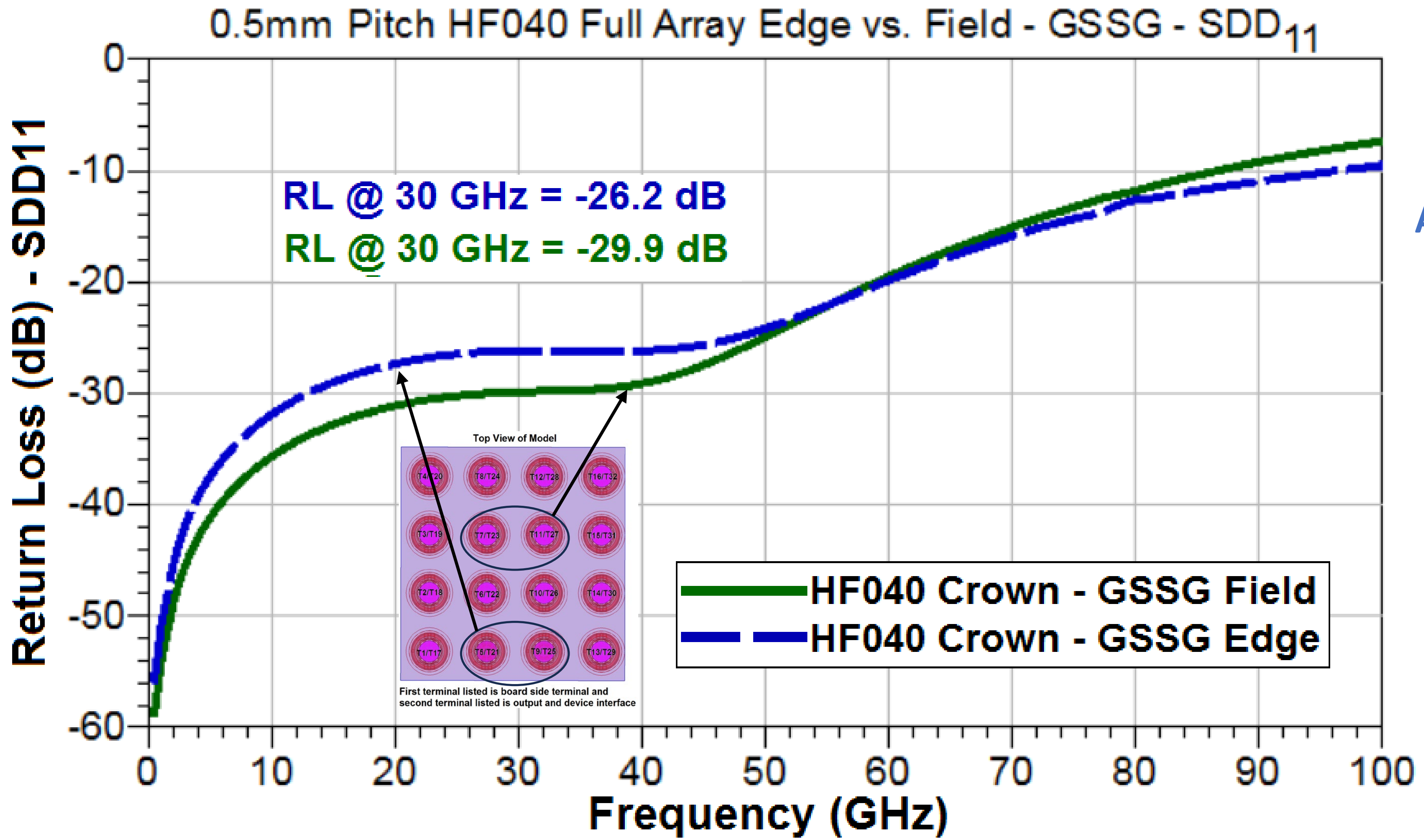
# 0.5mm Pitch HERØHF™ Different Ground Configurations




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

**Field**
0.1% power reflected

**Edge**
0.25% power reflected



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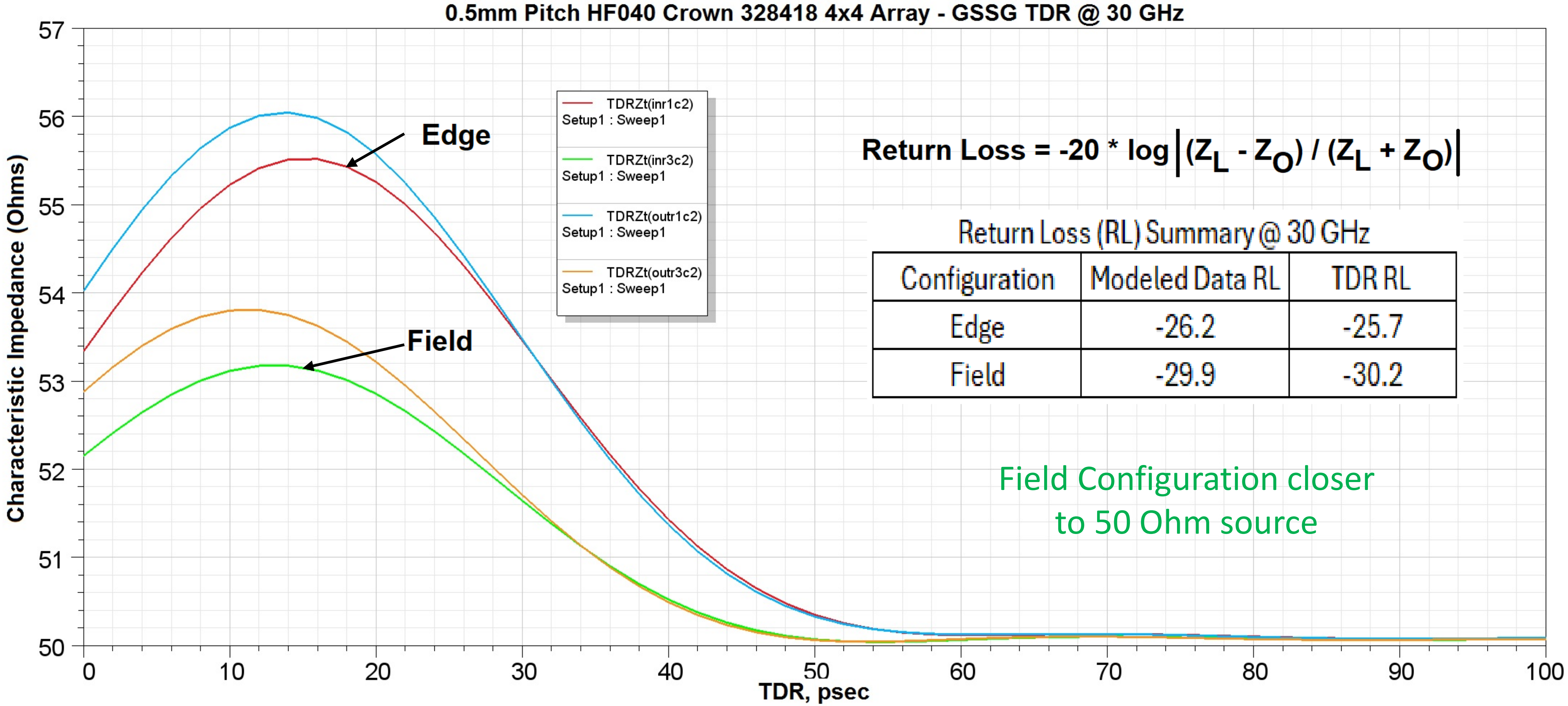
# *0.5mm Pitch HERØHF™ Different Ground Configurations*




**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



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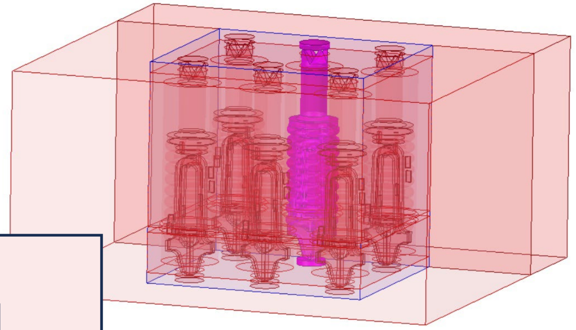
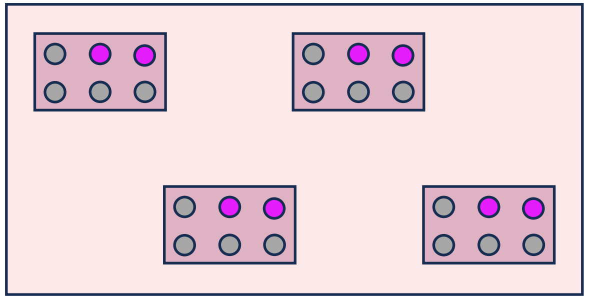
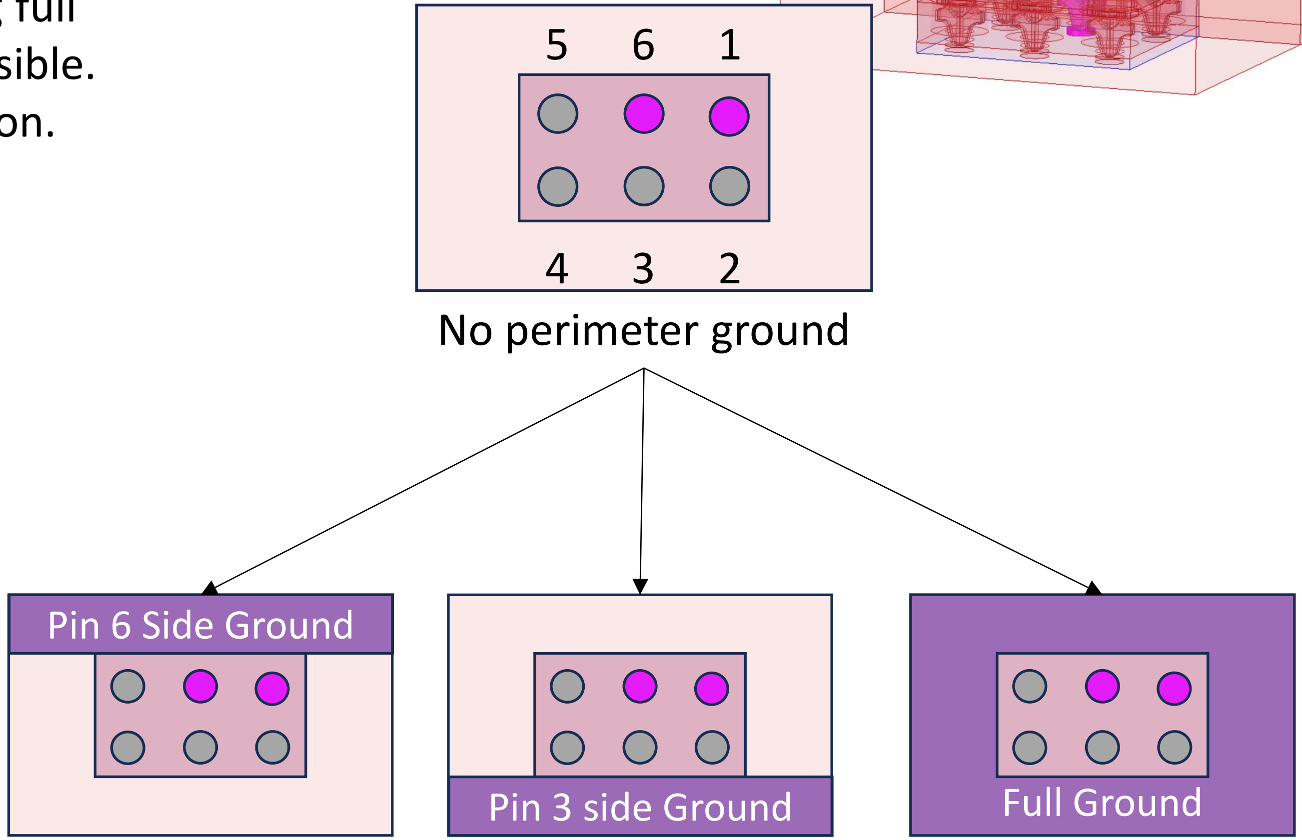
# HERØHF™ WLCSP Array
# Comparison Of Metal vs. Optimized Hsg

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

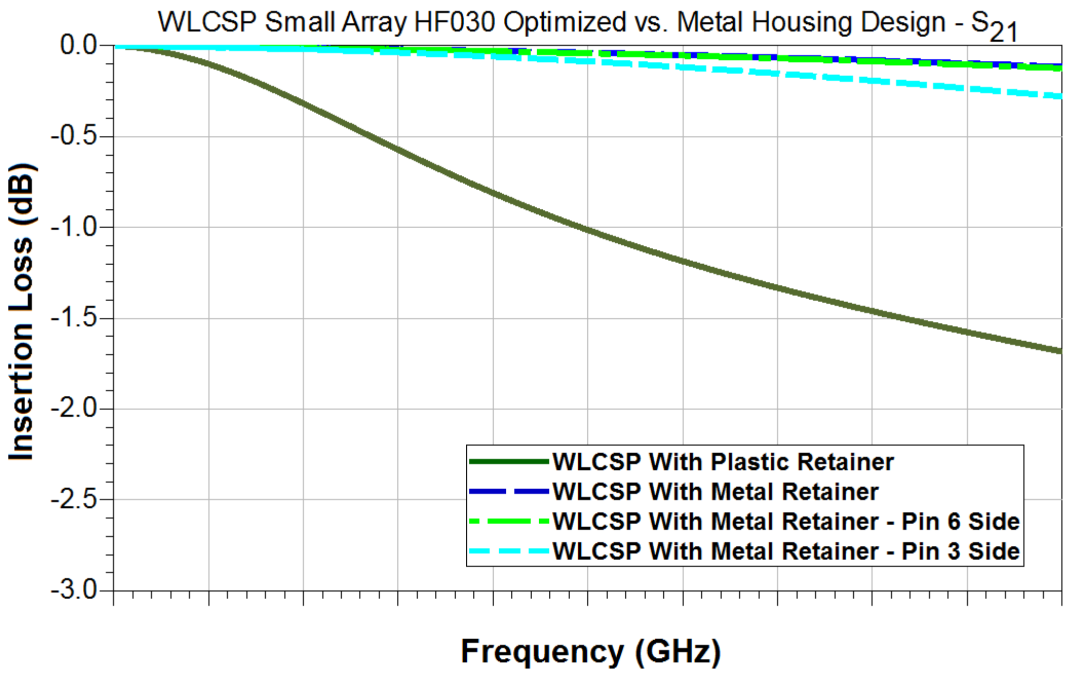
Challenge: Due to geometry constraints, providing full ground surrounding each test site may not be possible. Need to determine how grounding impacts isolation.



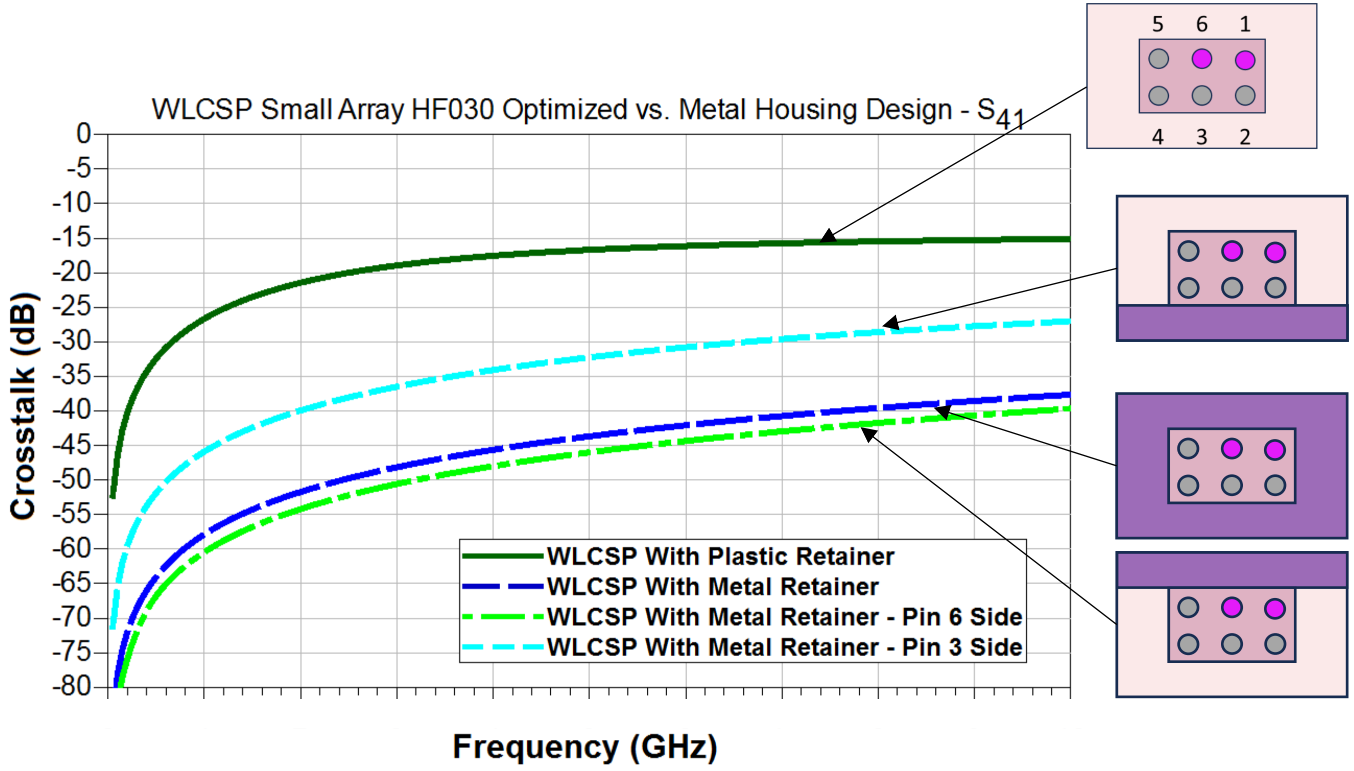





# HERØHF™ WLCSP Array
# Comparison Of Metal vs. Optimized Hsg




The addition of any ground improves Insertion Loss




Improved isolation with grounding in proximity to signal pins



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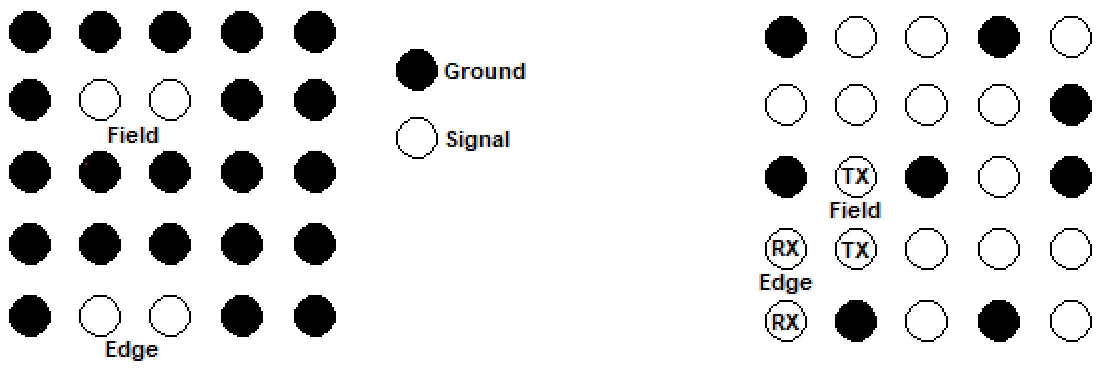
# HERØHF™ 0.80mm Pitch

Application: 26 Gbps 0.80mm pitch

Challenge: Larger pitches and less ground are unavoidable. Both tend to increase characteristic impedance.




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

# HERØHF™ *Family Solution*

- Contactor construction
  - Standard CNC machined housing components for quick fabrication – no special tooling required
  - BGA / LGA / QFN – any configuration

PATENT PENDING

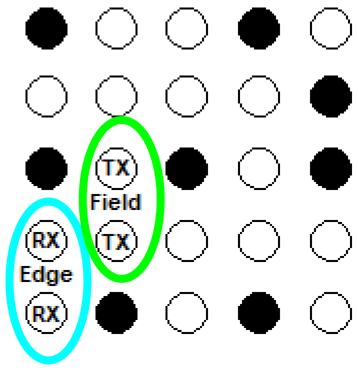
0.3 mm 0.4 mm 0.5 mm 0.8 mm

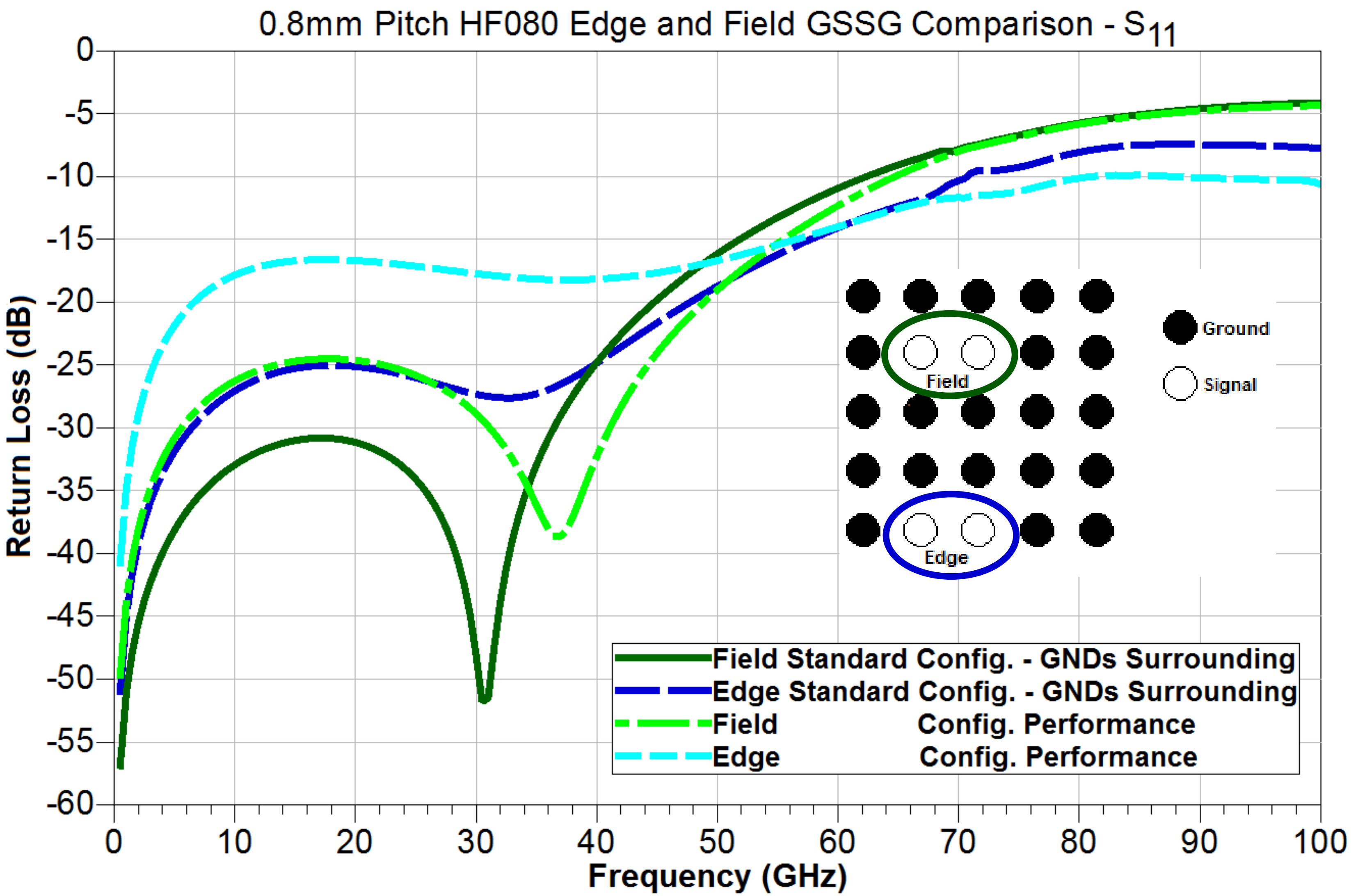
- True configurability
  - Socket design improved with optimal probe size for application – *J-tuned*™
    - Optimize for RF performance (match impedance)
    - Optimize for signal isolation

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

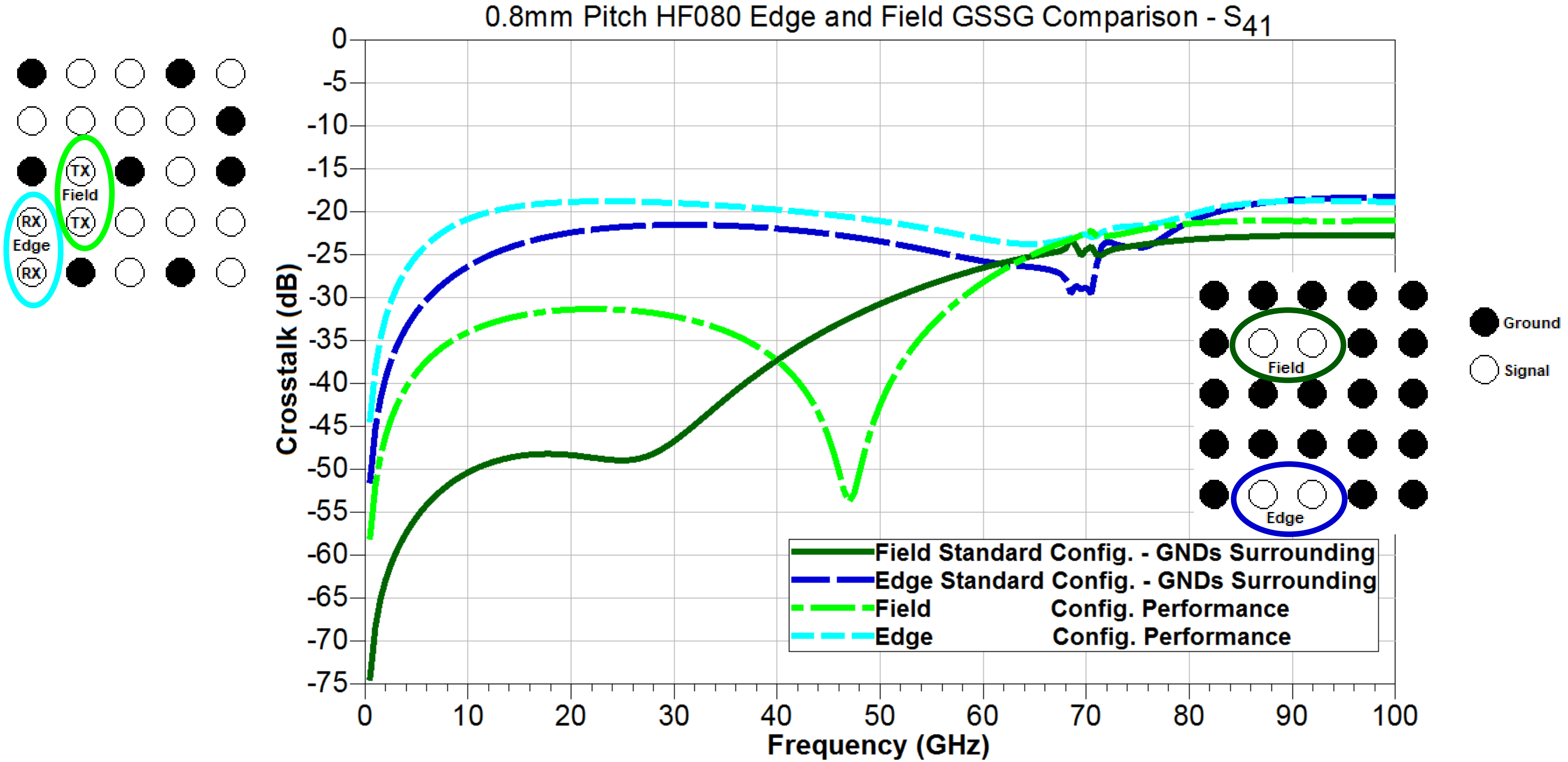
J-TUNED™ PERFORMANCE OPTIMIZATION

# HERØHF™ 0.80mm Pitch



# HERØHF™ 0.80mm Pitch



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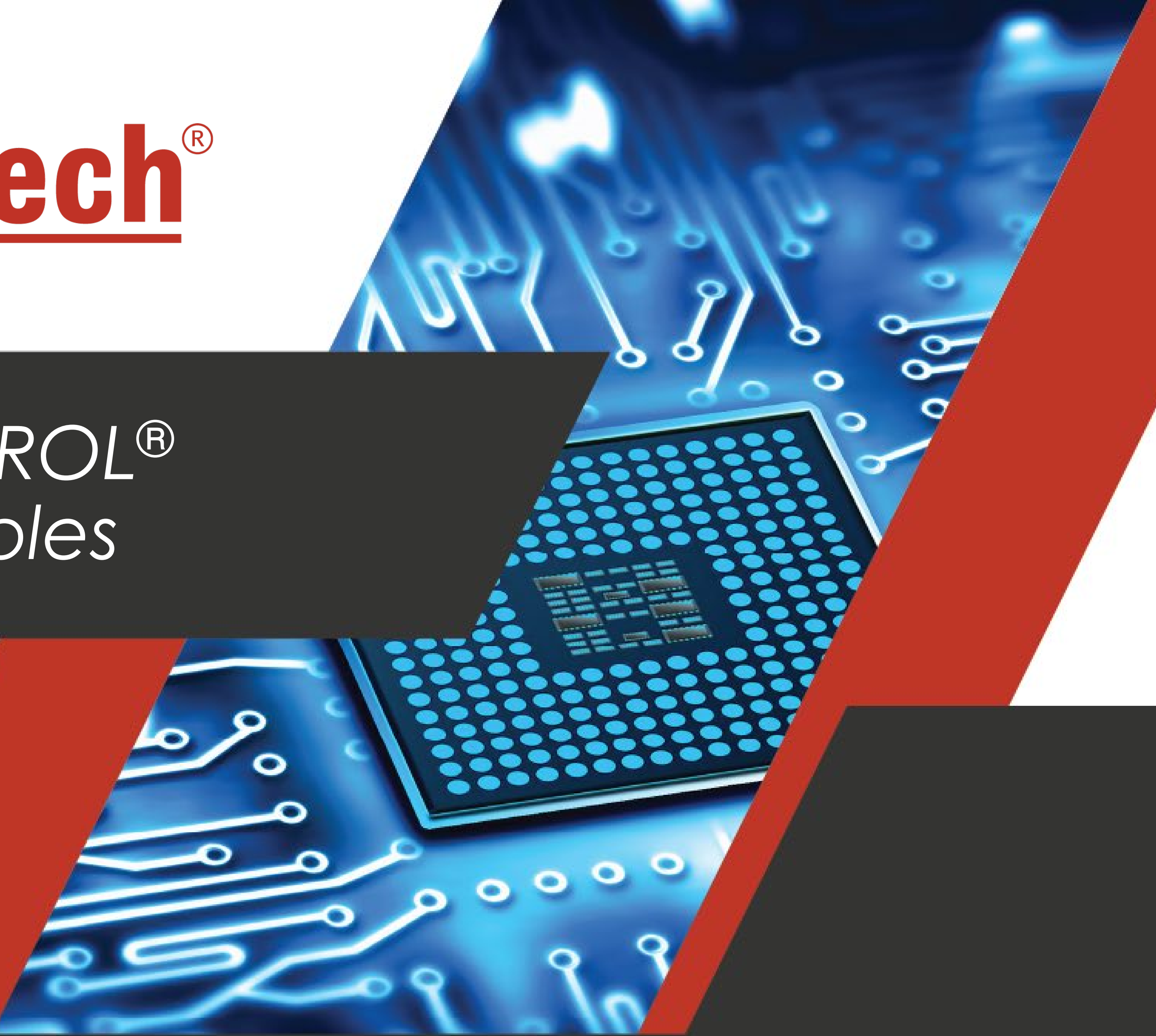

# ROL®/VROL® Examples

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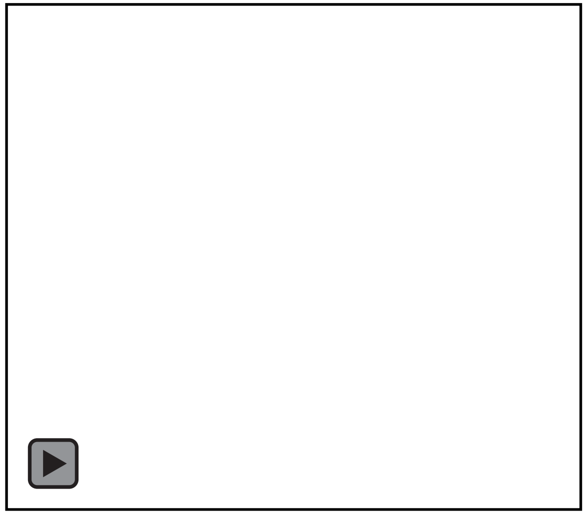
# VROL® Specifications

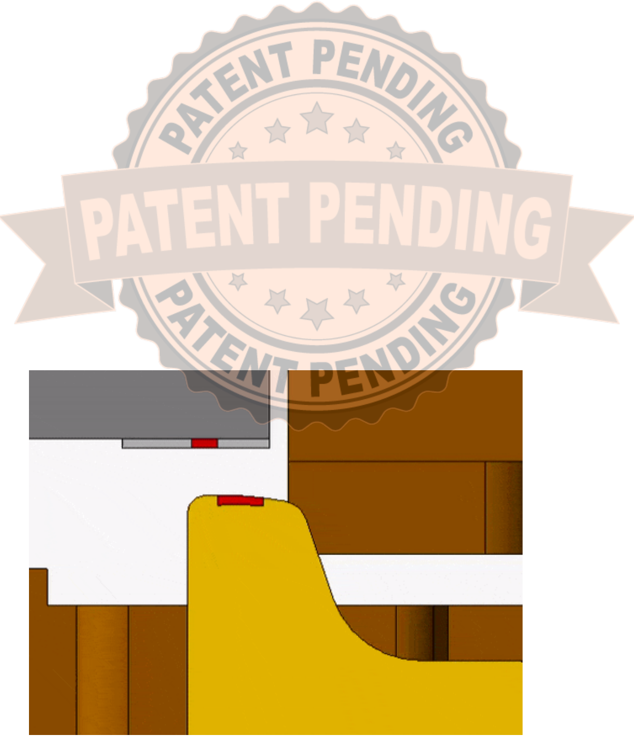
## Product Summary:

- A solid contact featuring a self-cleaning wipe motion. VROL products have the industry's best Cres performance and are ideal for RF products.

## Applications:

- Power amplifiers
- RF Front-end modules
- Transceivers
- LNAs
- High speed digital IC's
- Switches



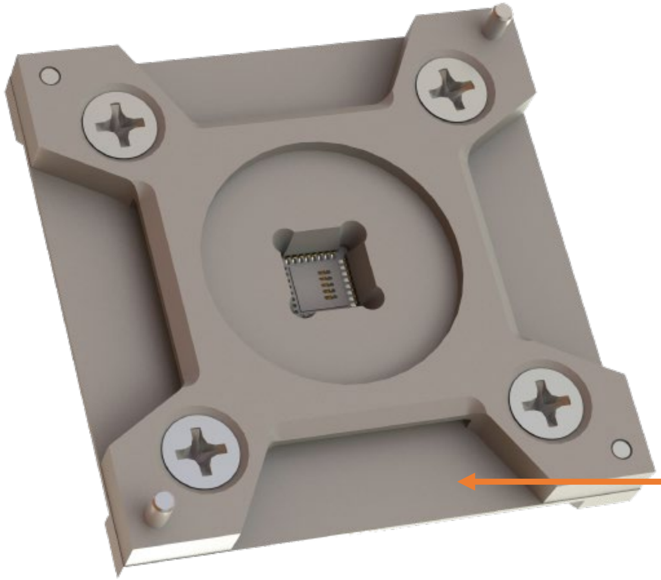



| Electrical Specs | Pad VROL200 | VROL100 |
|---|---|---|
| Device Pitch | ≥0.3mm | ≥0.3mm |
| Insertion loss | < -1.0 dB up to 45 GHz | < -1.0 dB up to 55 GHz |
| Return loss | > -10 dB up to 45 GHz | > -10 dB up to 52 GHz |
| Cres | 30mΩ | 30mΩ |
| CCC | 100% up to 4.3A<br>1% up 43A (RMS) | 100% up to 2.8A<br>1% up 28A (RMS) |
| **Mechanical Specs** | **Pad VROL200** | **VROL100** |
| Device Pitch | ≥0.3mm | ≥0.3mm |
| Compressed Height | 1.40mm | 0.75mm |
| Contact Compliance | 0.20mm | 0.175mm |
| Contact Force | Up to 50gm | Up to 40gm |
| Temperature | -65°C to 175°C | -65°C to 175°C |

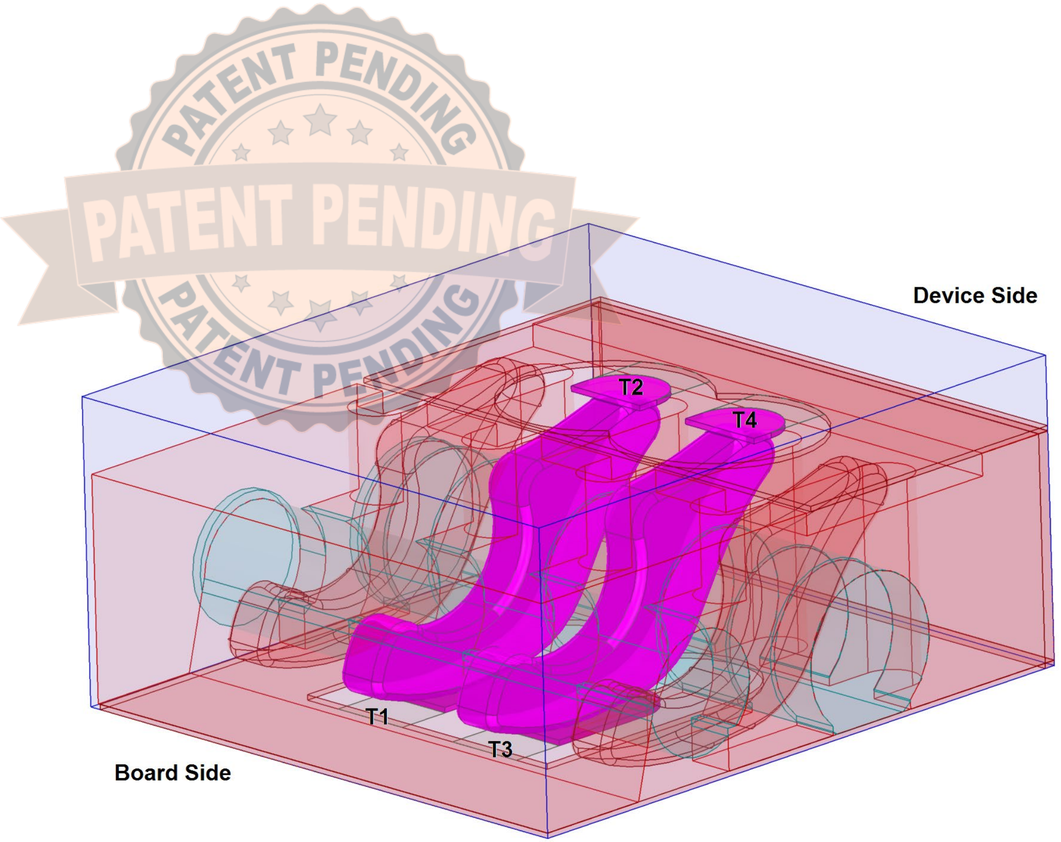
# Impact of ES-P™ on VROL® Performance

Application: ESD-sensitive devices

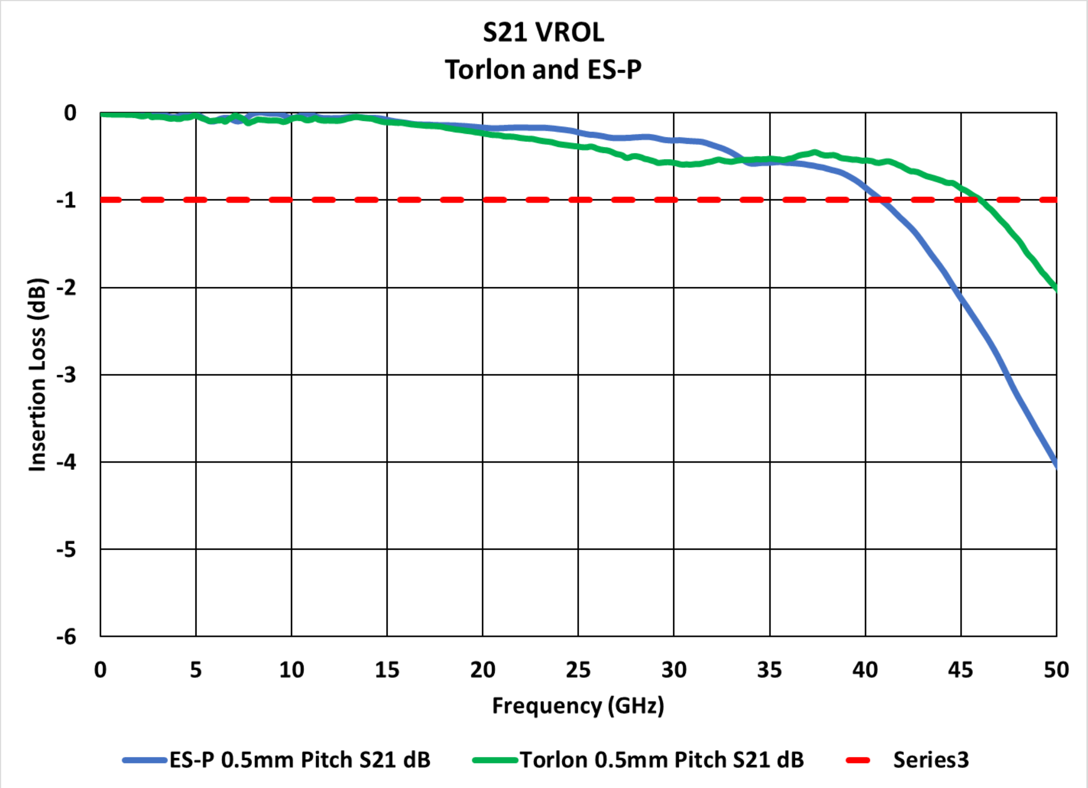
Challenge: Developed ROL/VROL with standard materials. Customers requesting static dissipative materials that limit triboelectric charging to <100V. Need to determine the impact of performance over frequency.

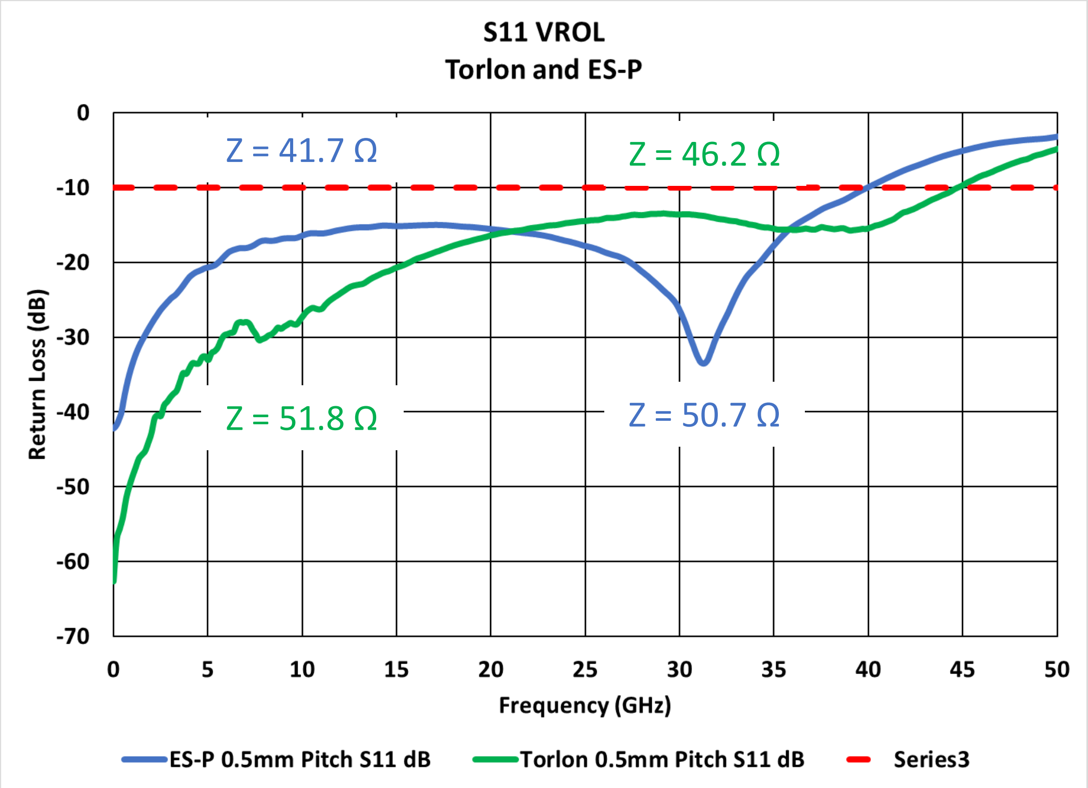


$$Z_O \propto \frac{1}{\sqrt{\epsilon_r}}$$



# Impact of Dielectric on VROL® Performance




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

VROL100/VROL200 designed to be optimized to 50 Ohms with standard materials

ES-P material has a higher dielectric, which lowers the impedance from 50 Ohms, but can still operate as a 40 GHz contactor.



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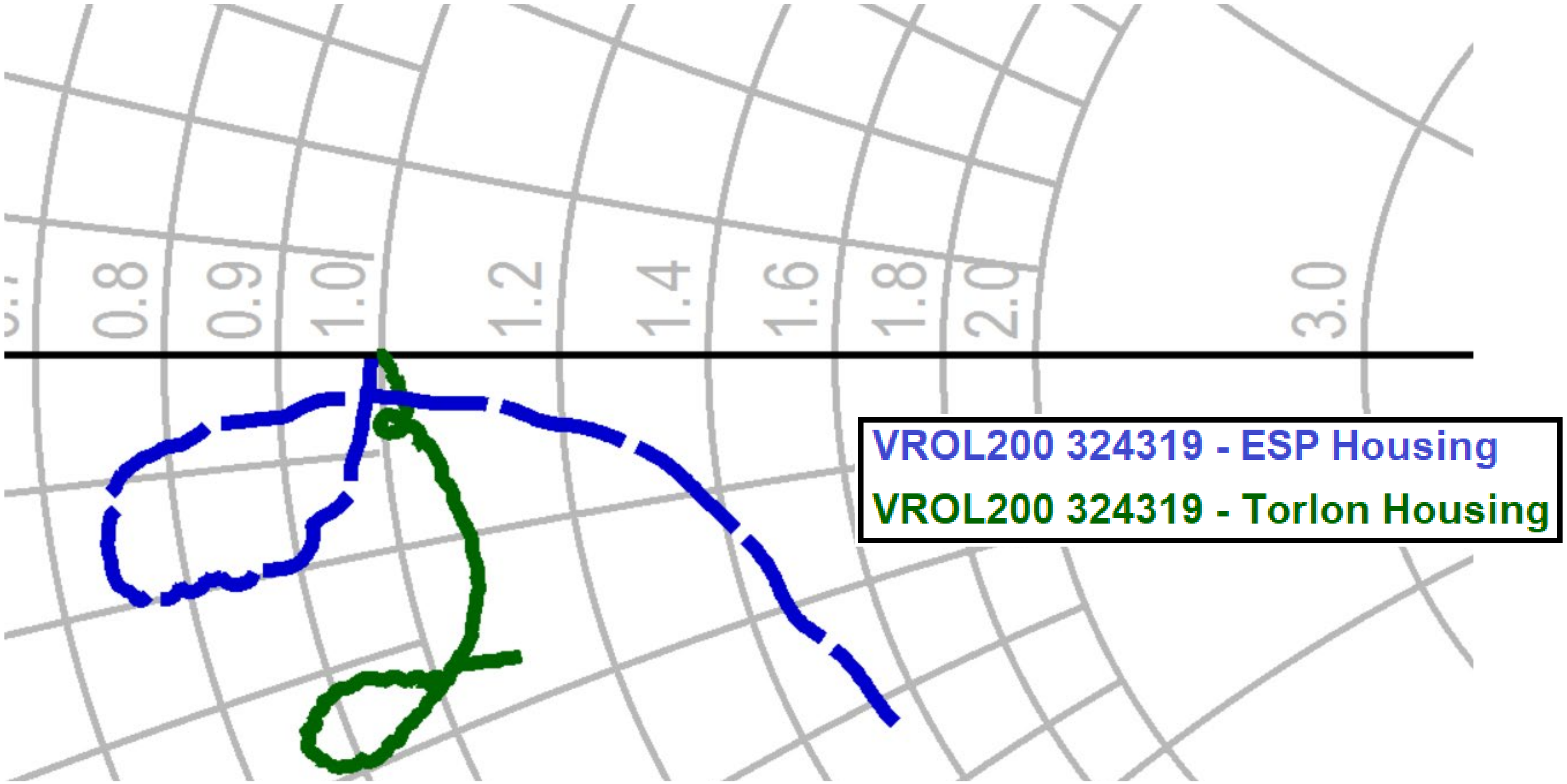
# 0.5mm Pitch VROL200 324319 Contact in Torlon vs. Esp Housing Material – Smith Chart




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



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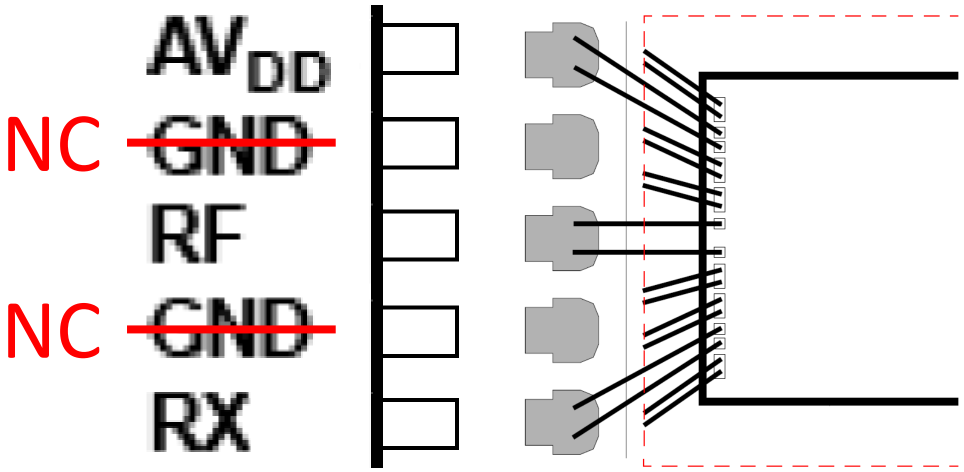
# 0.5mm Pitch Customer Package and Layout

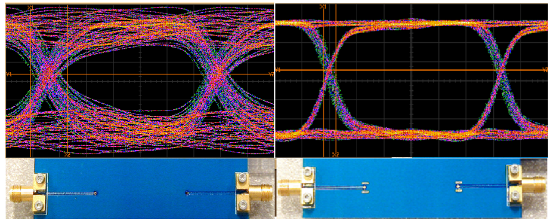



Application: RF Amplifier

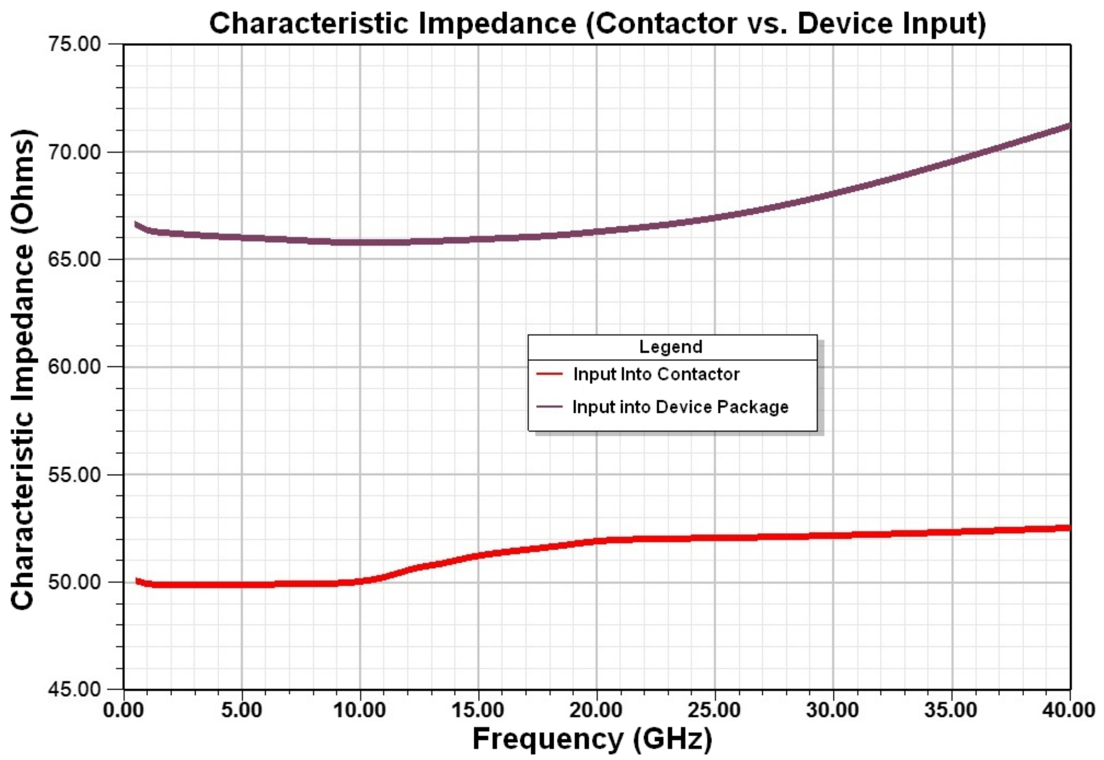
Challenge: Customer was experiencing performance degradation not typical or ROL performance.

From this graphic you can see that the GND labeled on the device pinout are in fact not ground, but not connected.

This is similar to having a coaxial cable with a shield, but having the shield broken or not connected to outer shield on connector on one end.



# Source of the Issue – Impedance Mismatch



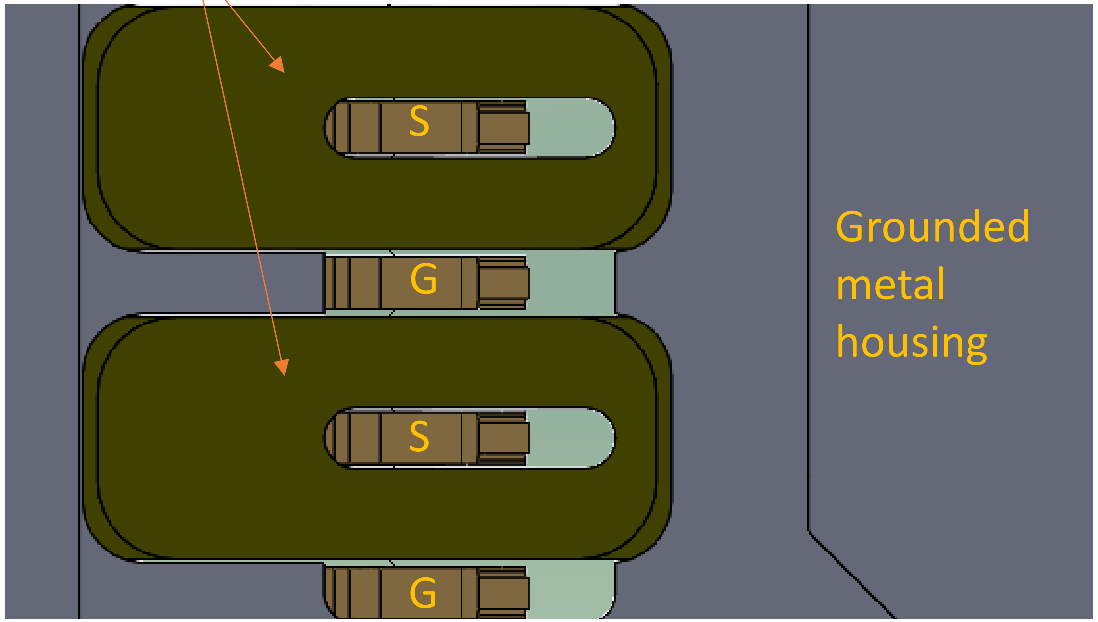

The lack of wire bonds (grounds), the signal into the device package has an increased impedance from 50 Ohms.

The closest ground is in the center paddle, which places the ground farther away and yields a higher impedance.

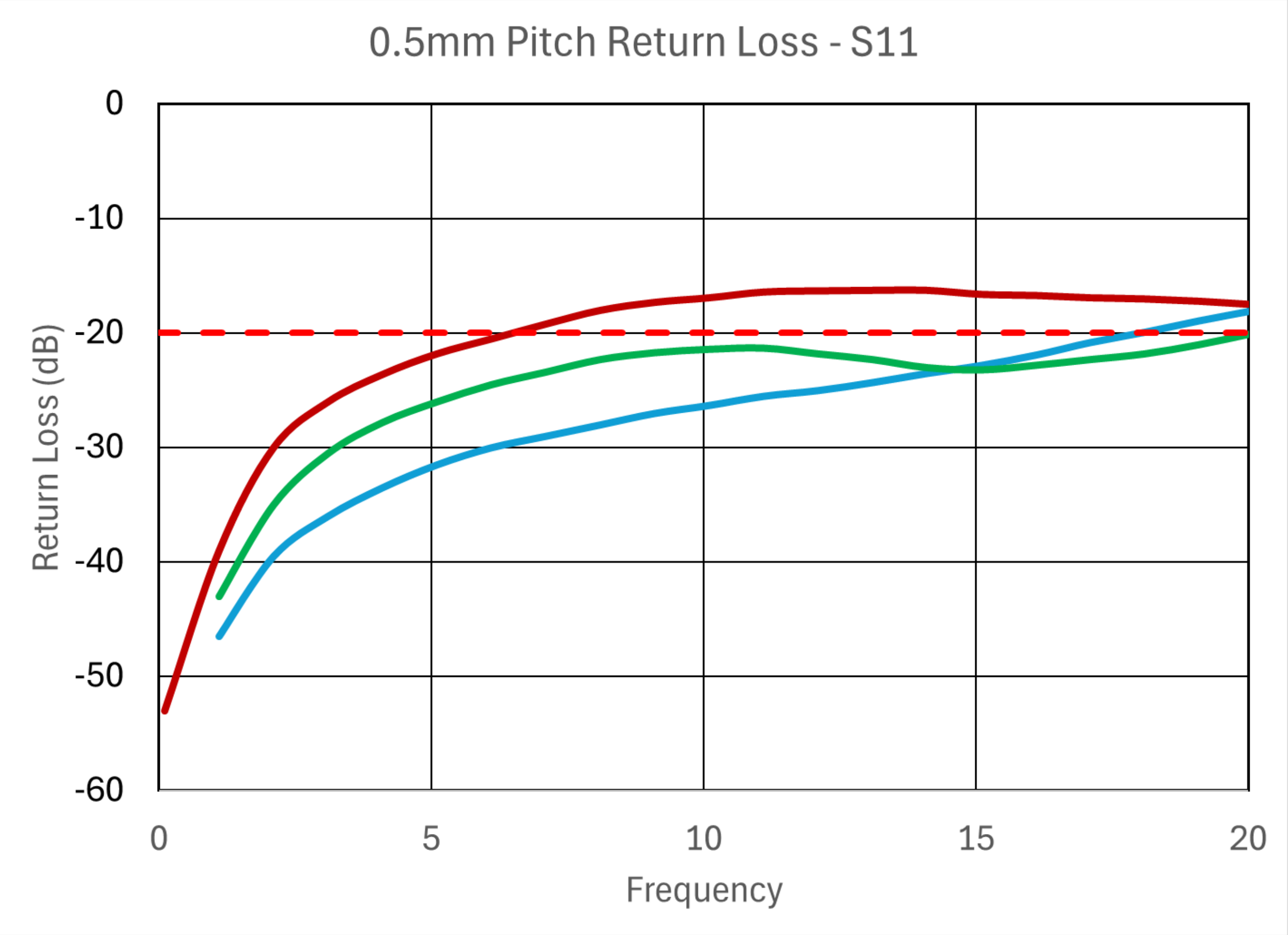
Loadboard characteristic impedance close to 50 Ohms.

# Solution – Bring the Ground to the Device

Coax-like
plastic inserts



# Solution – Bring the ground to the device




S12 - Original Contactor
S12 - Solder to Board
S12 - Performance Plus

Grounded metal housing creates "solder-to-board" environment.



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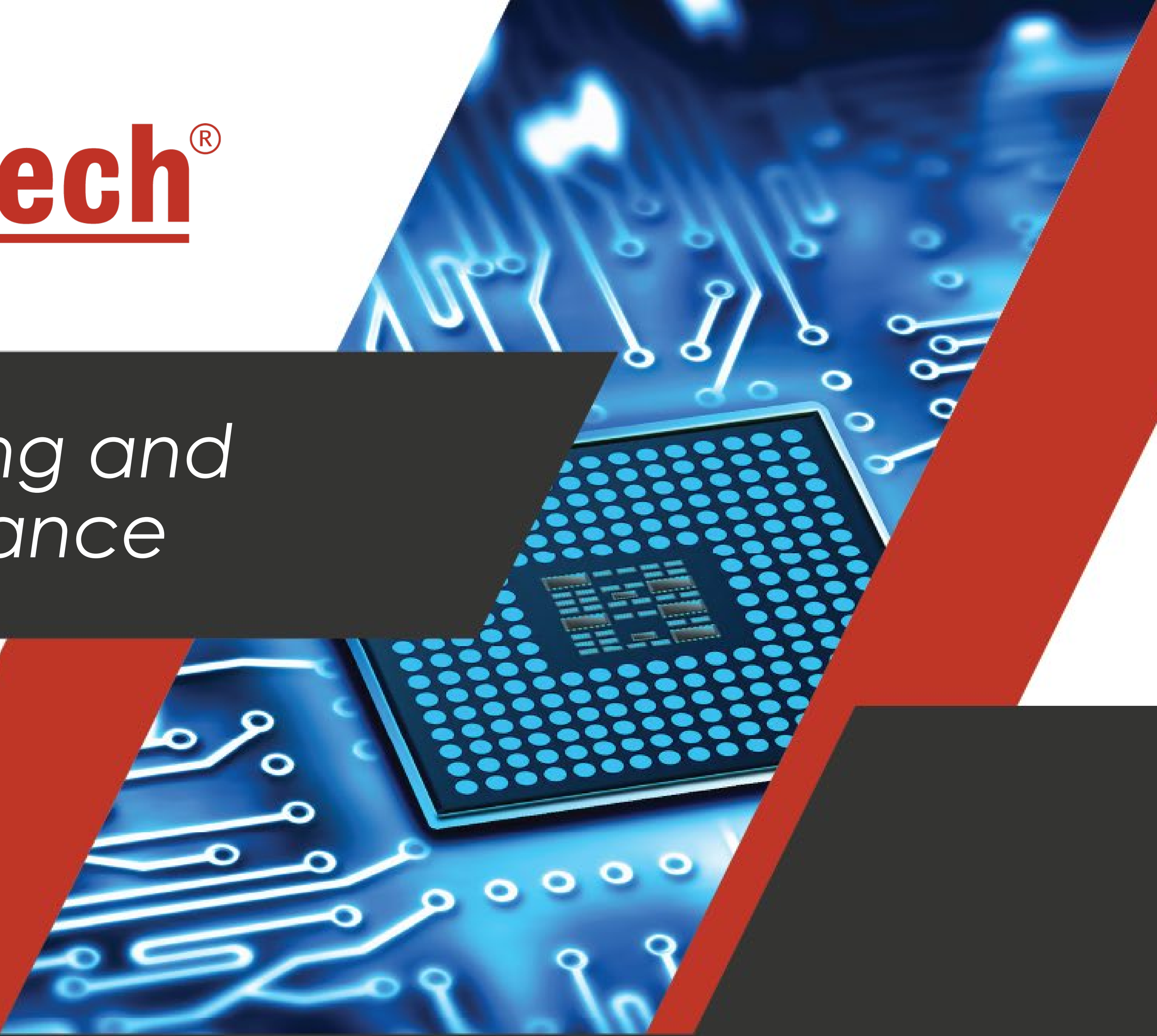
# Grounding and Inductance

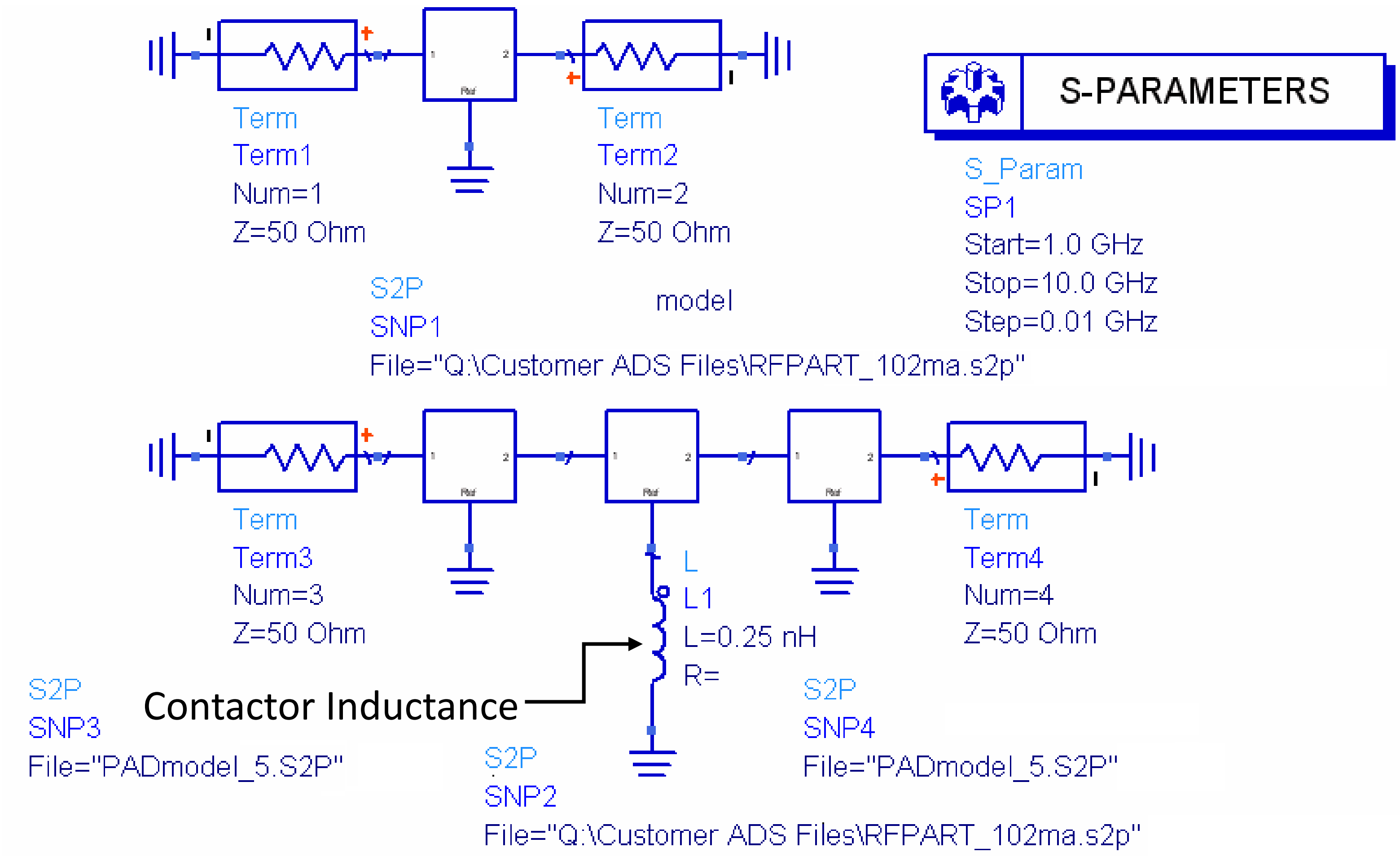


# Ground Inductance

Ground Inductance is Critical on:

- High frequency designs – above 3 GHz
- High speed digital designs – above 6 Gbits/sec
- High gain devices (above 20 dB)
- Voltage sensitive devices – i.e. high BIT DACs and ADCs (voltage per BIT small)

# Effects of Amplifier Ground Inductance Paths

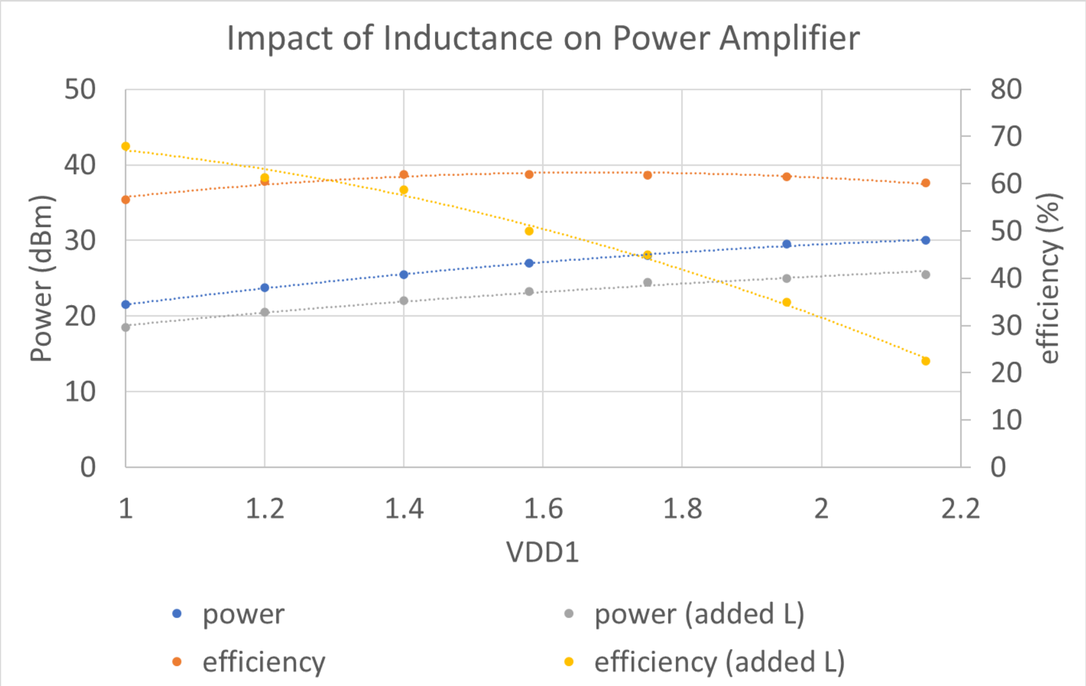


# Effect of Inductance on Power Amplifiers

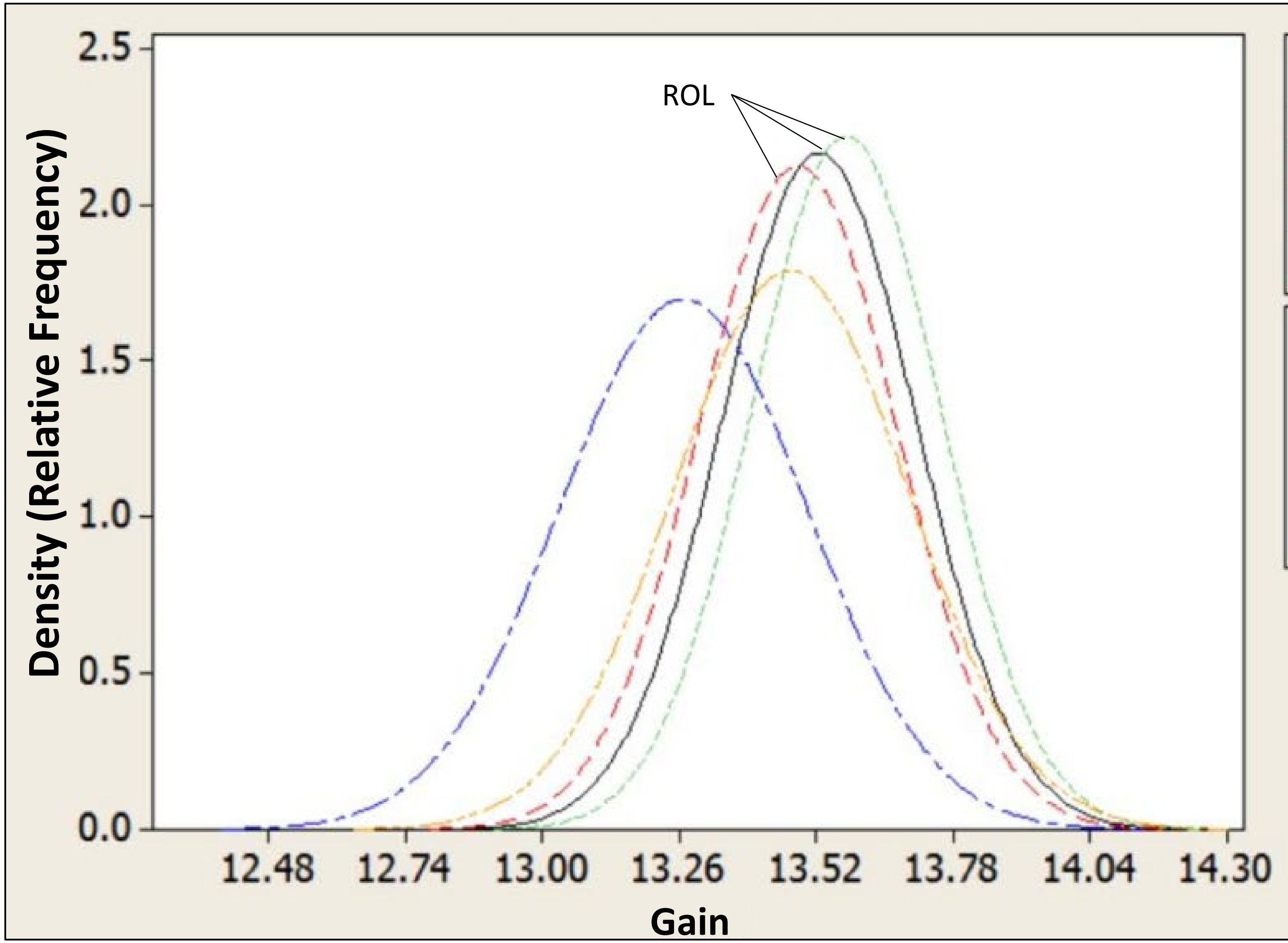
For Power Amplifiers, additional inductance leads to ground bounce, introducing voltage noise in the high inductance return path.

The inductance will affect the efficiency and gain of the power amplifier.

- Efficiency decreases as output power increases
- Output power is reduced



# Example 1: ROL® 200 Contact vs. Competitor Customer Data




| Mean | StDev | N | |
|---|---|---|---|
| 13.53 | 0.1843 | 39163 | ROL |
| 13.49 | 0.1879 | 39173 | ROL |
| 13.58 | 0.1798 | 38943 | ROL |
| 13.27 | 0.2353 | 19398 | Competitor |
| 13.47 | 0.2231 | 21965 | Competitor |

Higher and more repeatable gain with Johnstech solid-contact technology



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# Example 1: ROL® 200 Contact vs. Competitor Customer Data

Return Loss Performance

| | Mean | Stdev | N |
|---|---|---|---|
| ROL | -26.08 | 0.9766 | 39163 |
| | -26.20 | 0.9862 | 39173 |
| | -25.91 | 1.152 | 38943 |
| Competitor | -24.09 | 1.964 | 19398 |
| | -24.30 | 1.514 | 21965 |

ROL provided better matched impedance and more repeatable performance.



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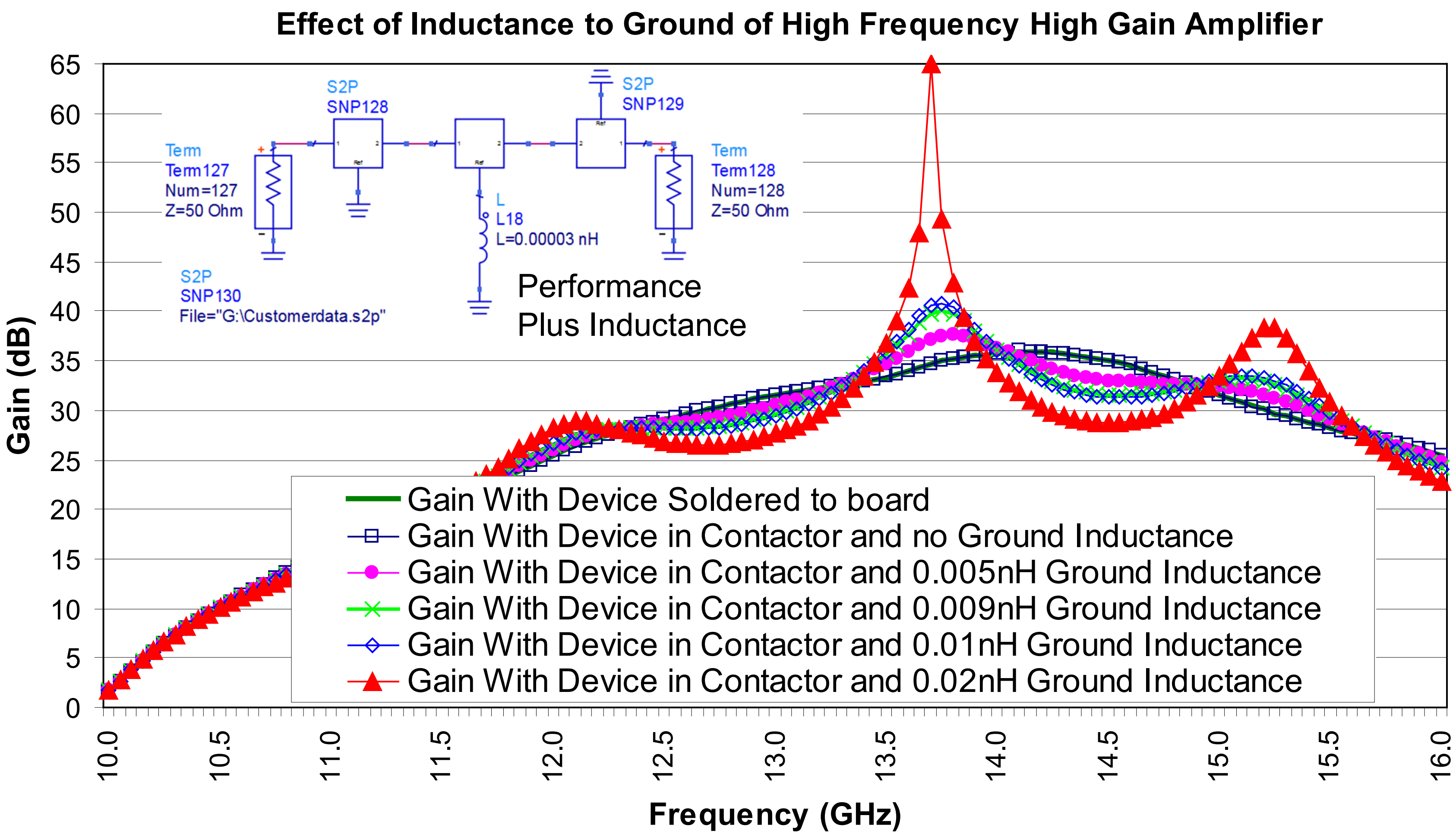
# Example 2: Ground Inductance Effect on Gain Oscillations




When inductive reactance is high, resonance can occur more easily at lower frequencies, driving the amplifier into oscillation.

Solution: Ultra-low impedance to ground with Performance Plus prevents oscillations.



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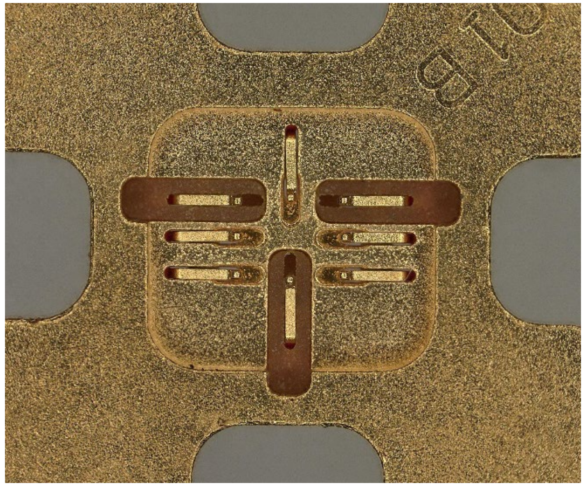
# Ultra Low Inductance Solution – Performance Plus

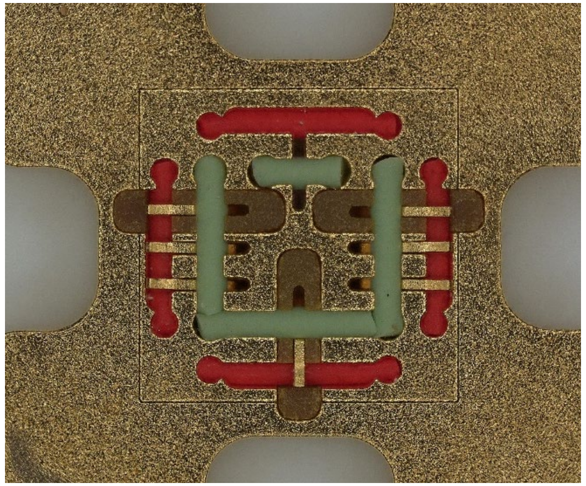
## Summary

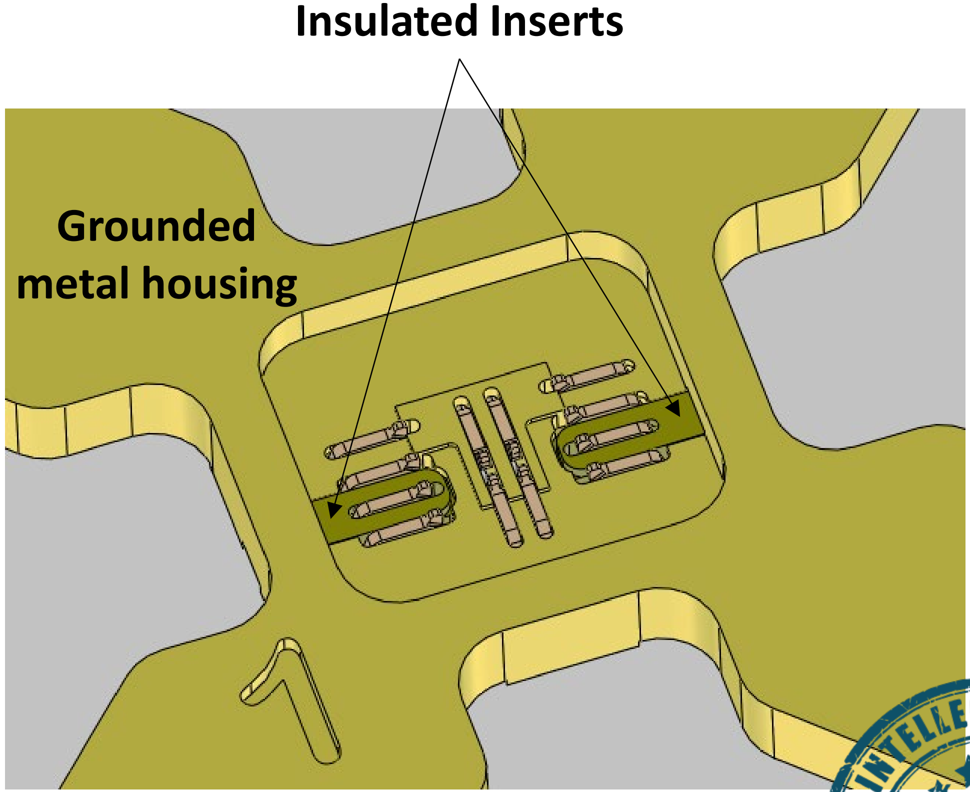
- Available with insulated inserts, conductive housings, or insulative metal coated housings

## Details

- Insertion loss:  < -1.0 dB to ≈ 62 GHz & < -1.5dB to 78 GHz
- Return loss: > -20 dB to ≈ 70 GHz
- Ground Inductance :  <0.0003 to 0.002nH (Application Specific)







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# How to Improve Package Grounding

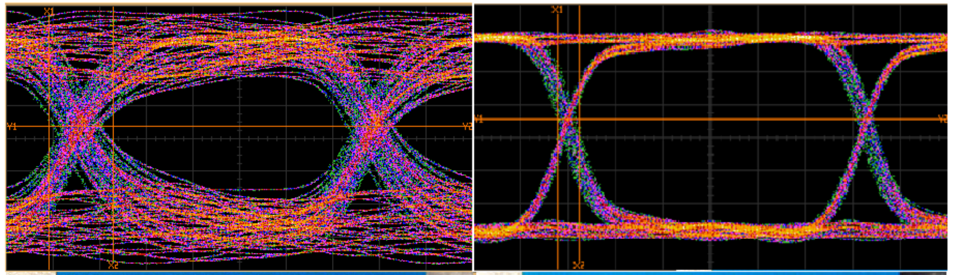
- More wire bonds to ground plane
- Shorter ground paths
- Flip chip to reduce path lengths
- Thin substrates with vias to ground pad
- More ground on peripheral, especially around high frequency or clock signals
- Differential signals (GND-SIG-SIG-GND) vs. single ended (GND-SIG-GND)

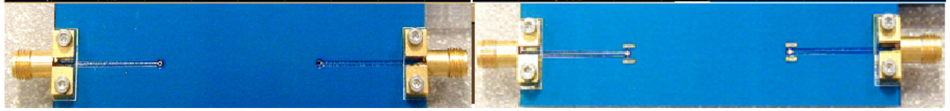
# *How to Improve Contactor Grounding*

- More ground paths to lower inductance
- Lower housing height reduces inductance
- Provide various probe sizes to match impedance at different pitches
- Creating ground planes in the contactor with metal housing
- Make contact to device where package ground connections are to reduce path to board ground plane

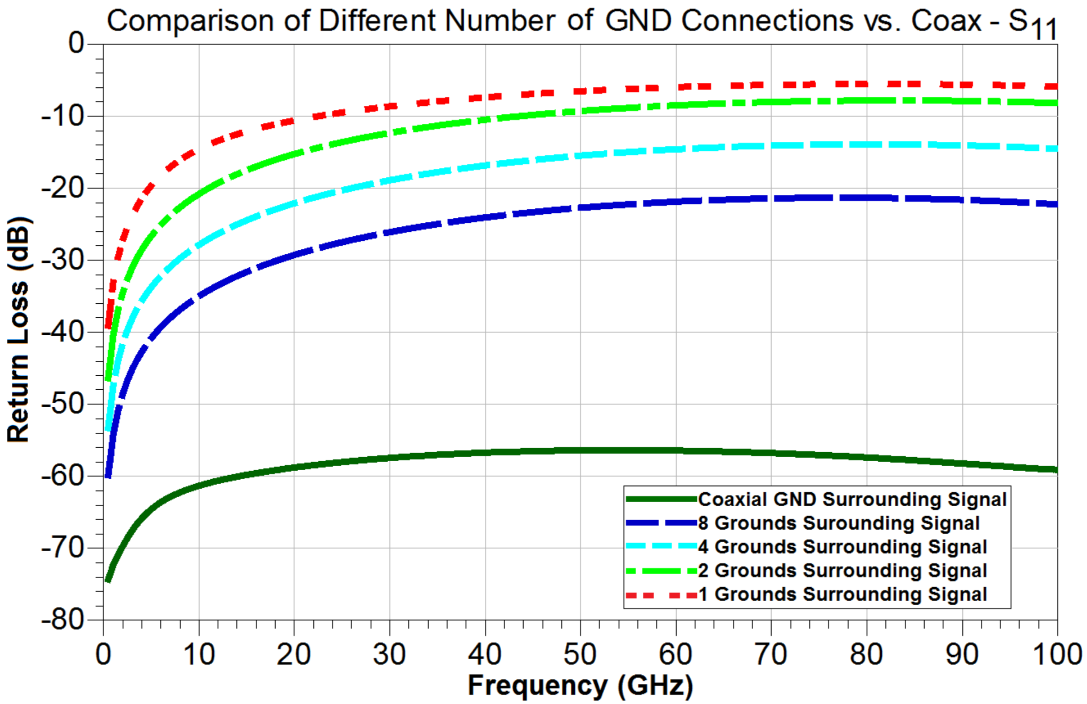
# In Summary

- A properly grounded system improves return loss by ensuring that signals reflect less back into the system from mismatched components.



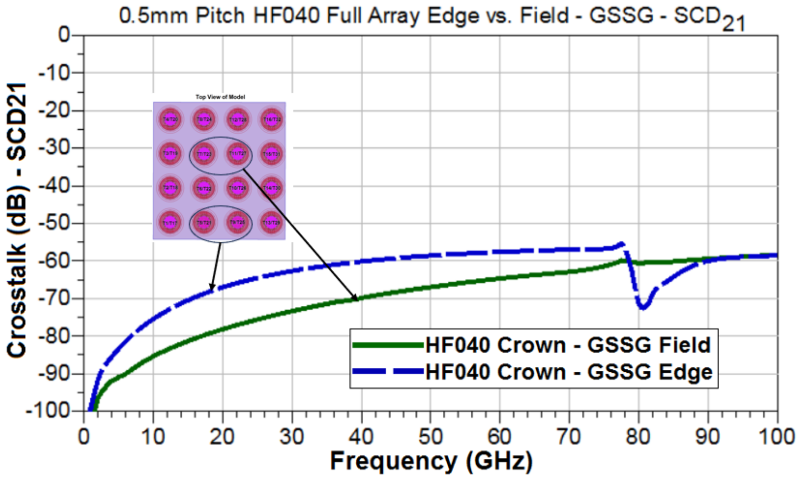


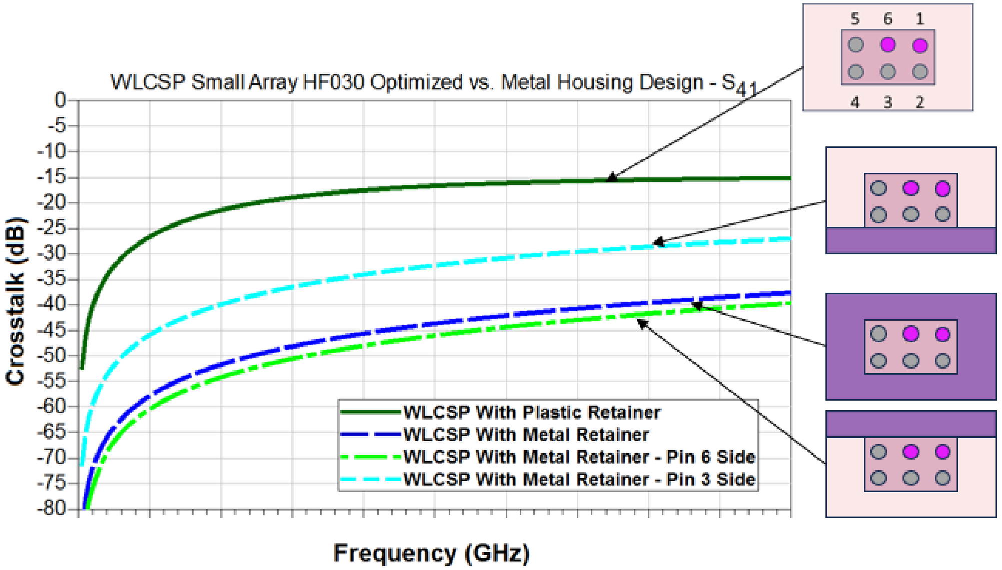
50 Ω



# In Summary

- Grounding provides a reference point for the signal and the system, reducing the risk of unintended coupling between RF circuits. Without proper grounding, stray RF signals can leak into sensitive parts of the system, leading to crosstalk or interference.



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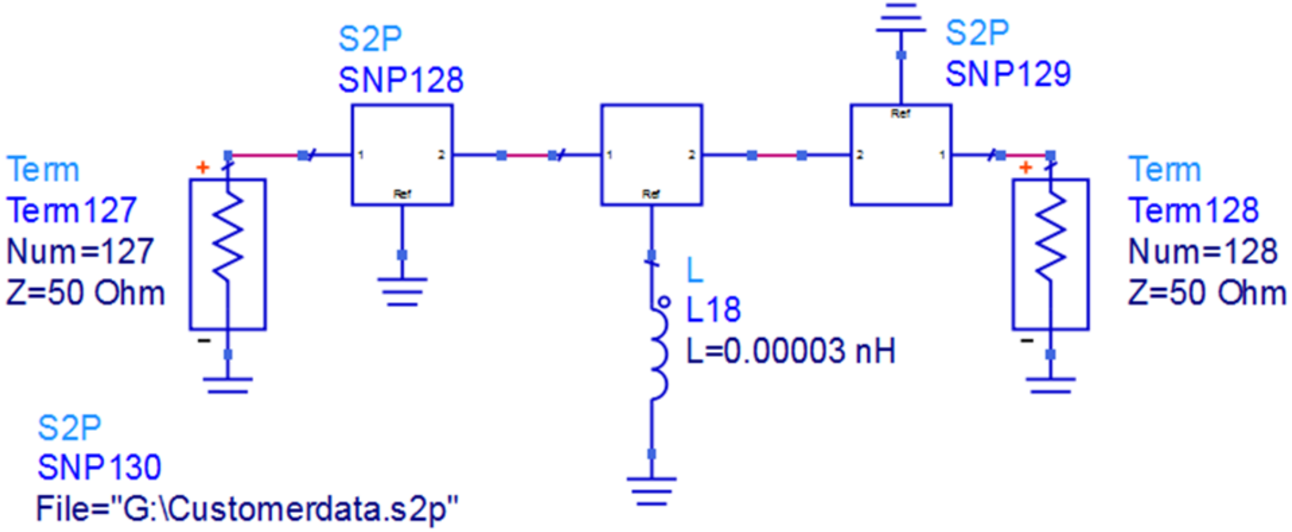
# In Summary

- A properly grounded system offers a low-impedance path for return currents, especially at higher frequencies. This is important because inductive reactance increases with frequency, and a high inductance will result in signal loss or interference. Proper grounding helps reduce this impedance, lowering inductance and maintaining signal strength and integrity.



*Thank you for attending!*

Q&A