Package Considerations for 400GPL BGA-Side Feasibility Studies

A sensitivity study of package limitations and improvement paths

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Socionext

Scope and Terminology

Scope

- Investigate package sensitivity for future BGA-side signaling
- Identify dominant package limitations
- Explore package technology assumptions

Not in Scope

- Complete link feasibility
- COM validation
- Crosstalk optimization
- Reference package definition

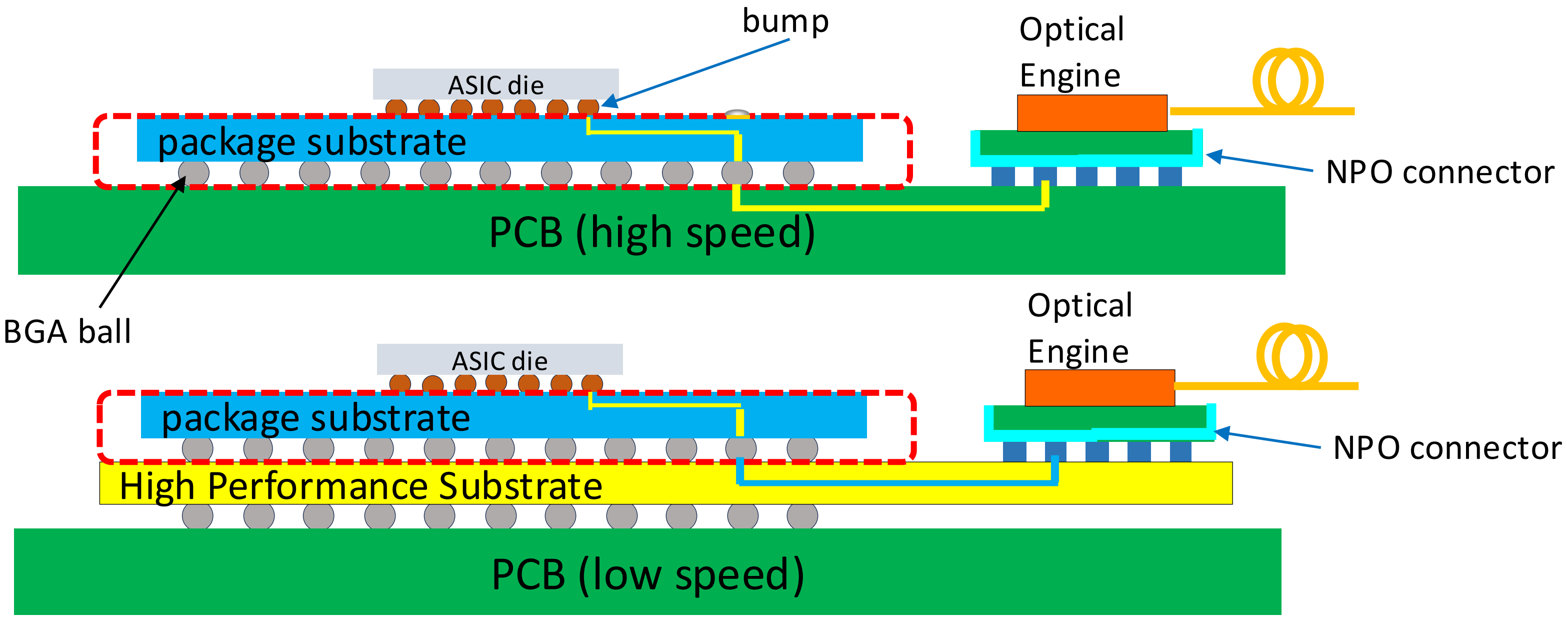
Rate Terminology

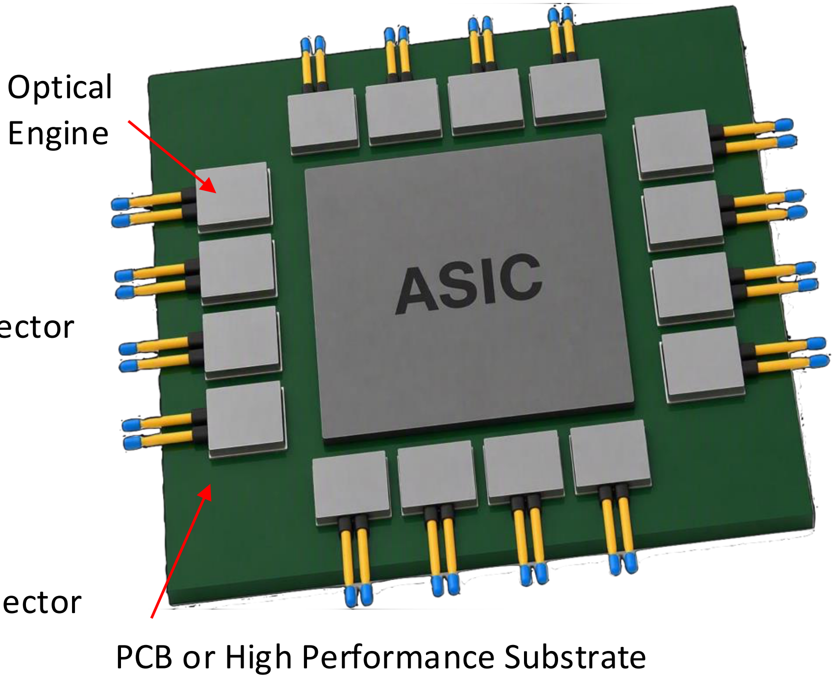
- 400GPL = IEEE Study Group scope
- 425G = illustrative gross-rate assumption
- 448G labels = frequency markers only
- PAM4/PAM6 = illustrative references, not proposals

1. Motivation

- This investigation was motivated by the recent NPO (Near Package Optics) activities in OIF EEI. The objective is to assess which package parameters dominate future BGA-side feasibility studies.

Example of NPO (Based on oif2026.211.06)





2. Background

Key Question

Can package technology assumptions significantly change the conclusion of future BGA-side feasibility studies?

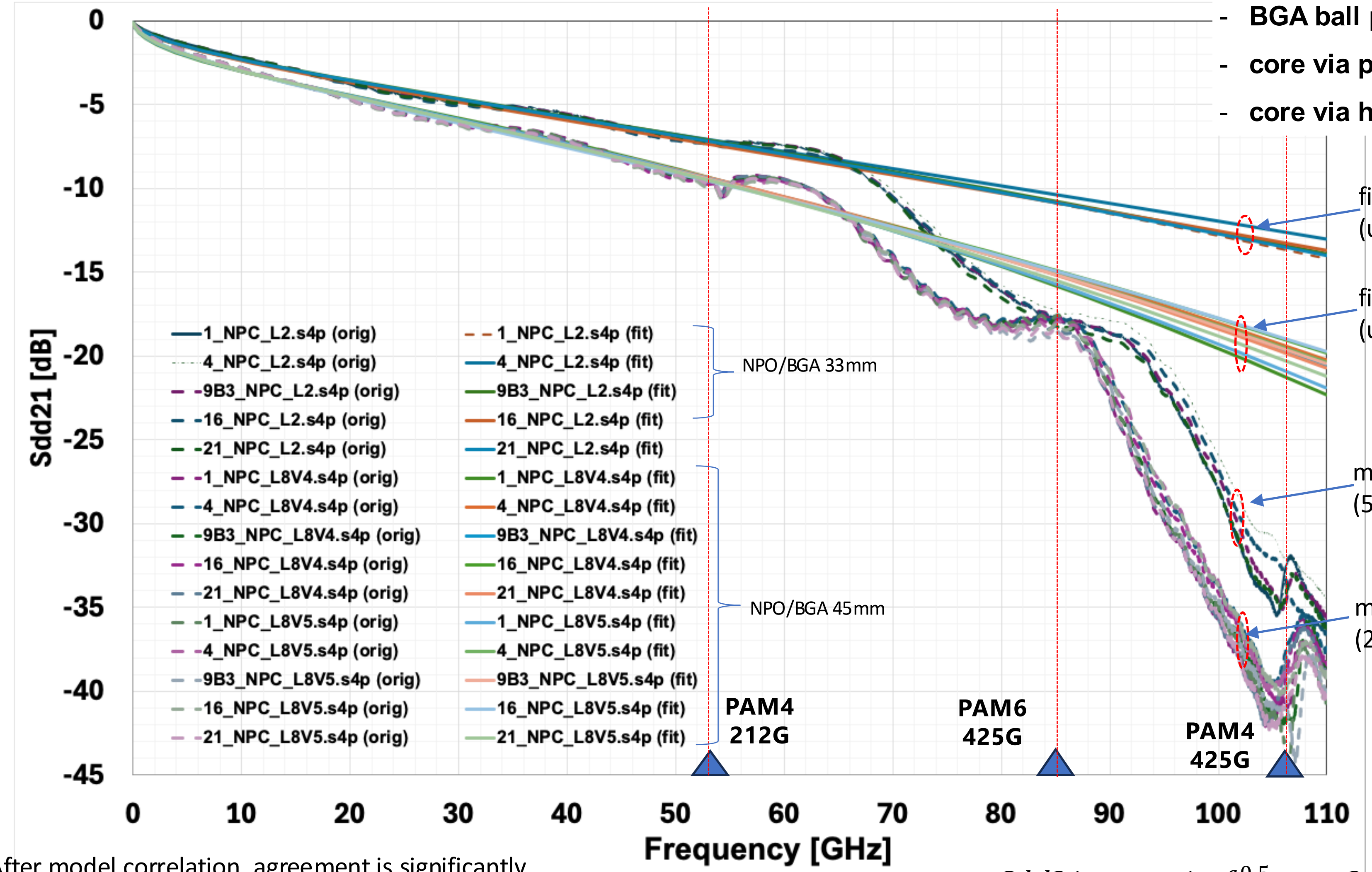
Working Hypothesis

Package limitations are dominated by:

- core-via electrical length
- resonance behavior
- impedance discontinuities
- return-path structure

3. Baseline Measurement

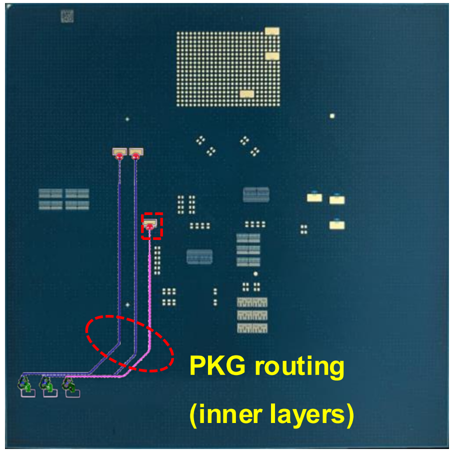
- BGA ball pitch: 0.80 mm
- core via pitch: 0.80mm
- core via height: 1.28mm



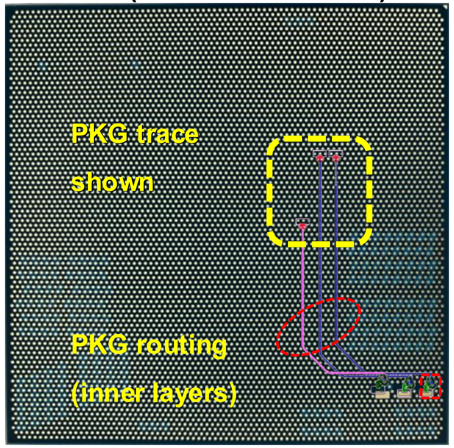
After model correlation, agreement is significantly improved and is used for comparative sensitivity analysis. (Appendix B.2)

$$Sdd21_{fit} = a1 \cdot f^{0.5} + a2 \cdot f + a3 \cdot f^{2}$$

top (PKG trace shown)



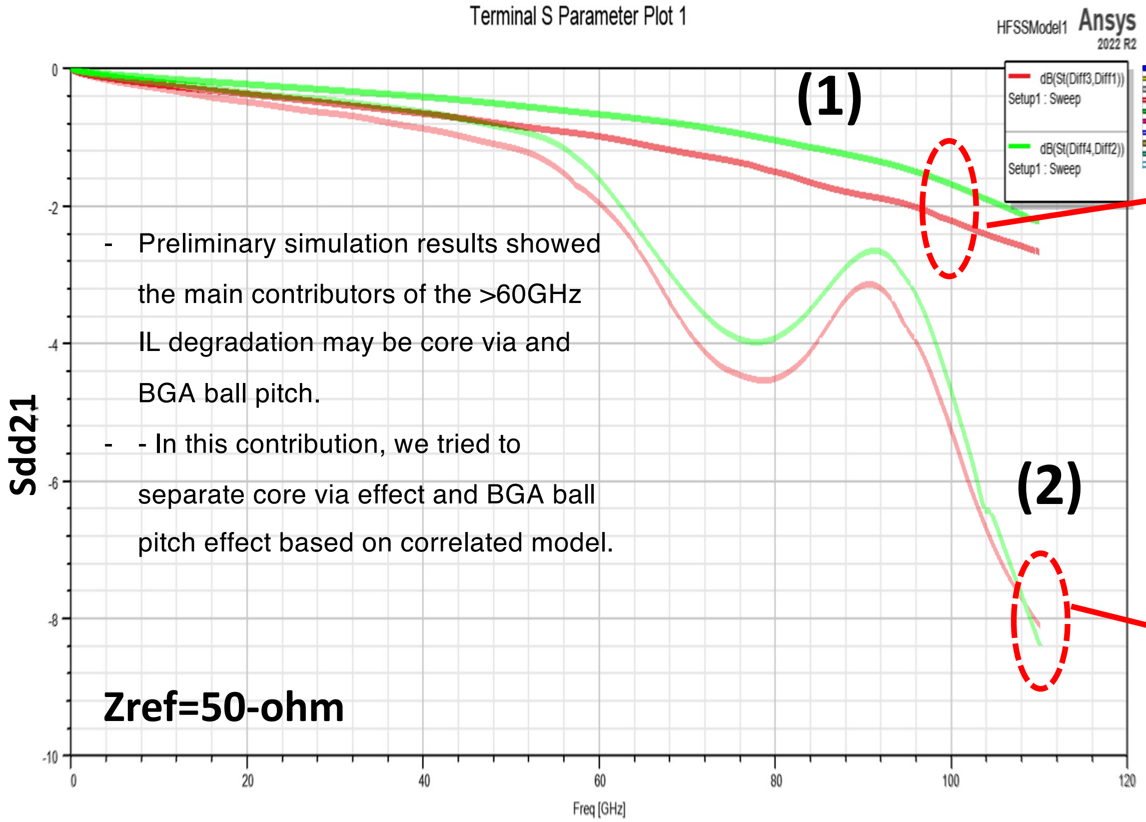
bottom (PKG trace shown)



Test PKG uses RF-probe structures in place of assembled BGA balls. Details are shown in Appendix A.2

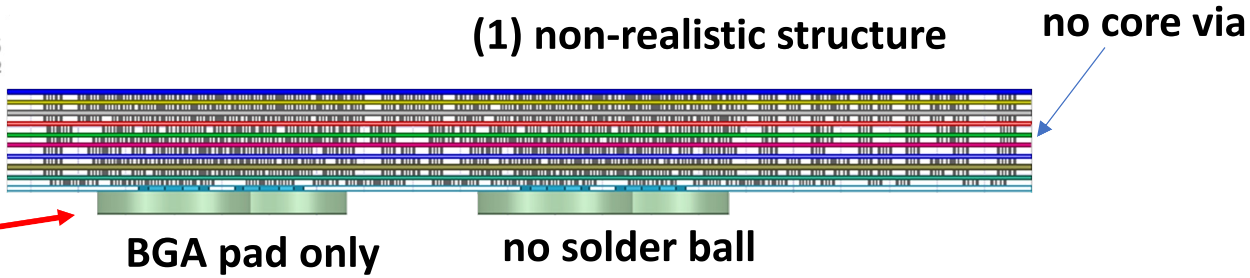
3.1 Baseline Observation

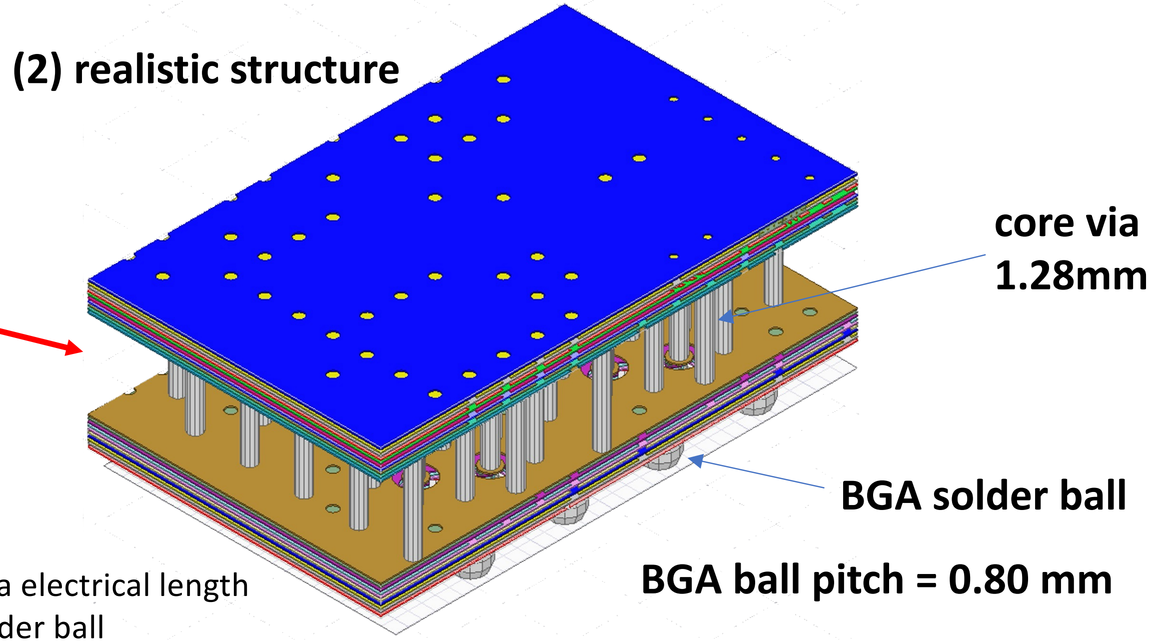
- Effect of core via and solder ball (from oif2025.484.02)



- Preliminary simulation results showed the main contributors of the >60GHz IL degradation may be core via and BGA ball pitch.
- - In this contribution, we tried to separate core via effect and BGA ball pitch effect based on correlated model.

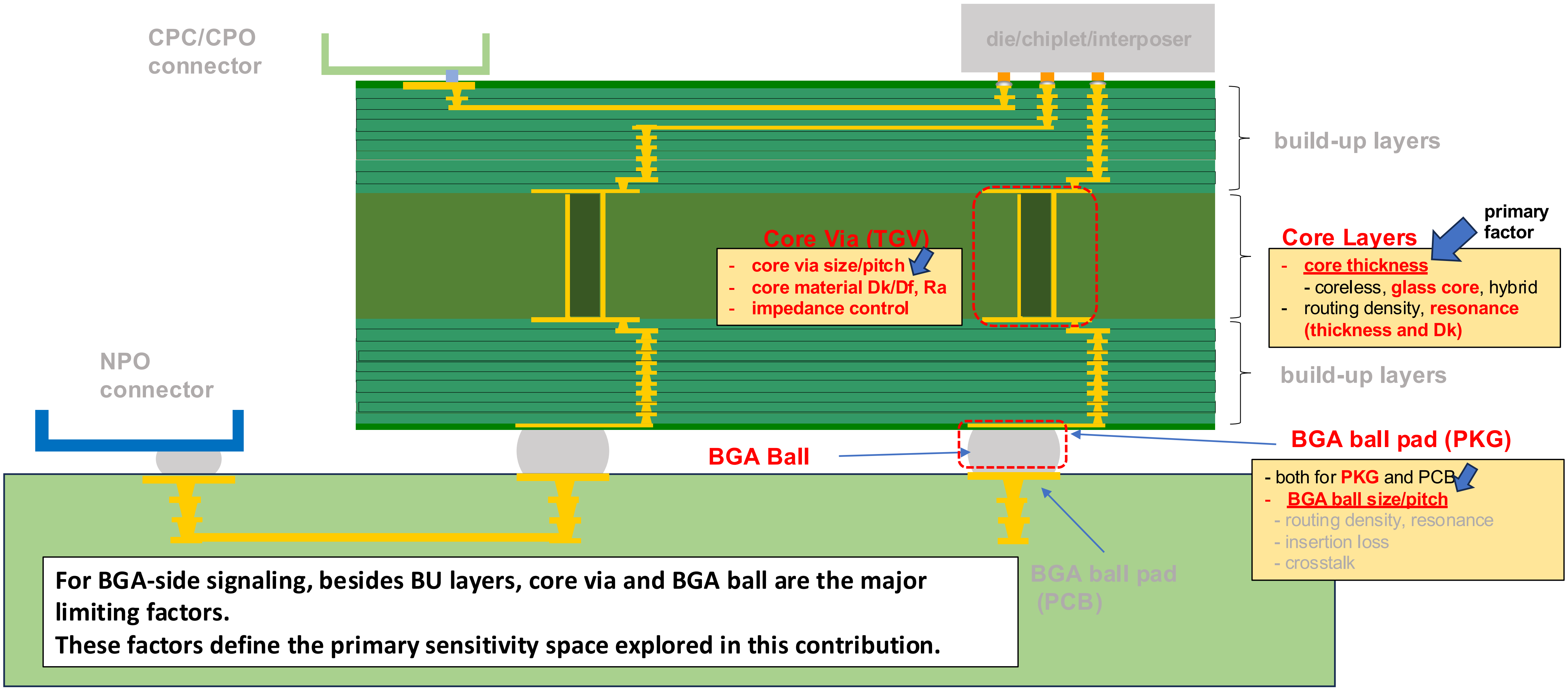
(1) non-realistic "ideal" structure characteristic is "similar" to CPC.





Possible measures:
A: Associated with core-via electrical length and resonance => Reduced core-via electrical length
B: Associated with BGA transition geometry => Narrower ball pitch, smaller solder ball
* These analyses are exploratory and for discussion purposes only; final feasibility will depend on material and manufacturing maturity.

4. What Limits BGA-side Signaling?



For BGA-side signaling, besides BU layers, core via and BGA ball are the major limiting factors.
These factors define the primary sensitivity space explored in this contribution.

5. Sensitivity Study Overview for 425G NPO/BGA-side Signaling

This contribution evaluates:
- core-via height
- TGV diameter
- TGV pitch
- TGV pad geometry
- material assumptions
- BGA geometry

Objective:
determine which package parameters most strongly influence high-frequency behavior

For the conditions and details, please refer to Appendix C.

Scope of this contribution
- Not a final optimized design
- Glass = preliminary what-if study
- RL/XT/COM = future work
- Glass-core correlation = future work

5.1 Why investigate glass core?

- Current organic substrates face increasing challenges beyond 70 - 100 GHz:
  - ✓ Core-via resonance
  - ✓ Via aspect ratio limitation
  - ✓ Surface roughness related loss
  - ✓ Mechanical challenges for large packages

- Potential advantages of glass-core substrates:
  - ✓ shorter TGV structures
  - ✓ finer via pitch
  - ✓ improved dimensional accuracy
  - ✓ lower skew variation
  - ✓ lower warpage for large packages

- For the large size PKG, may become mechanically challenging for large package sizes due to factors such as warpage, stiffness, and via-formation constraints.

This study investigates whether these package technology attributes significantly influence BGA-side signaling sensitivity.

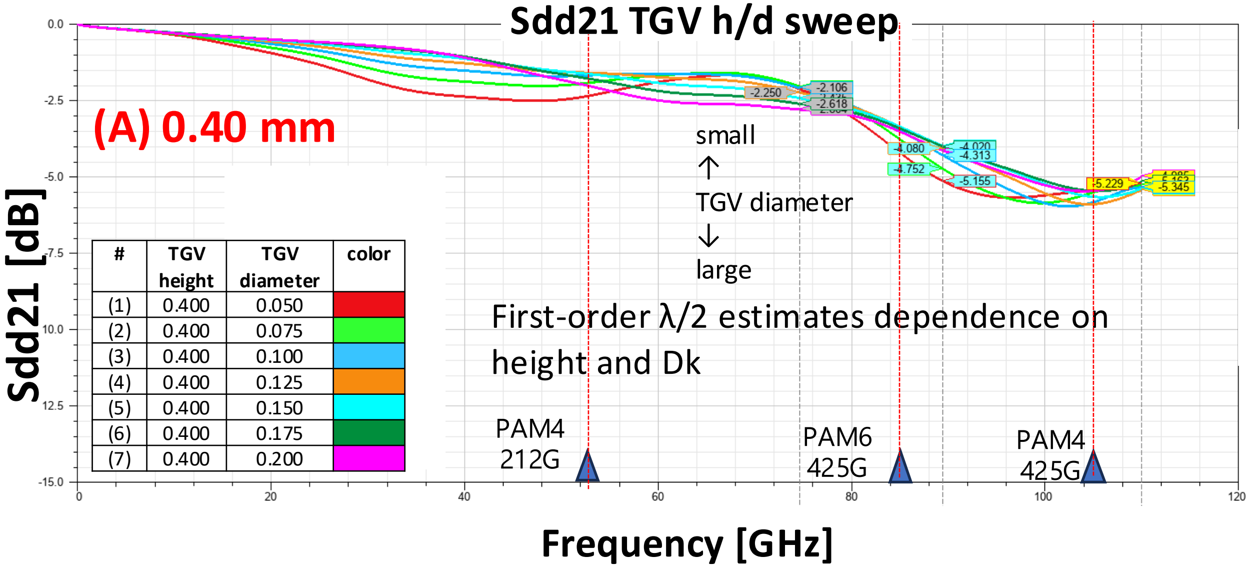
The optimum core thickness may differ between CPO/CPC-style large packages and NPO/BGA-side signaling applications.

5.2 TGV height and diameter

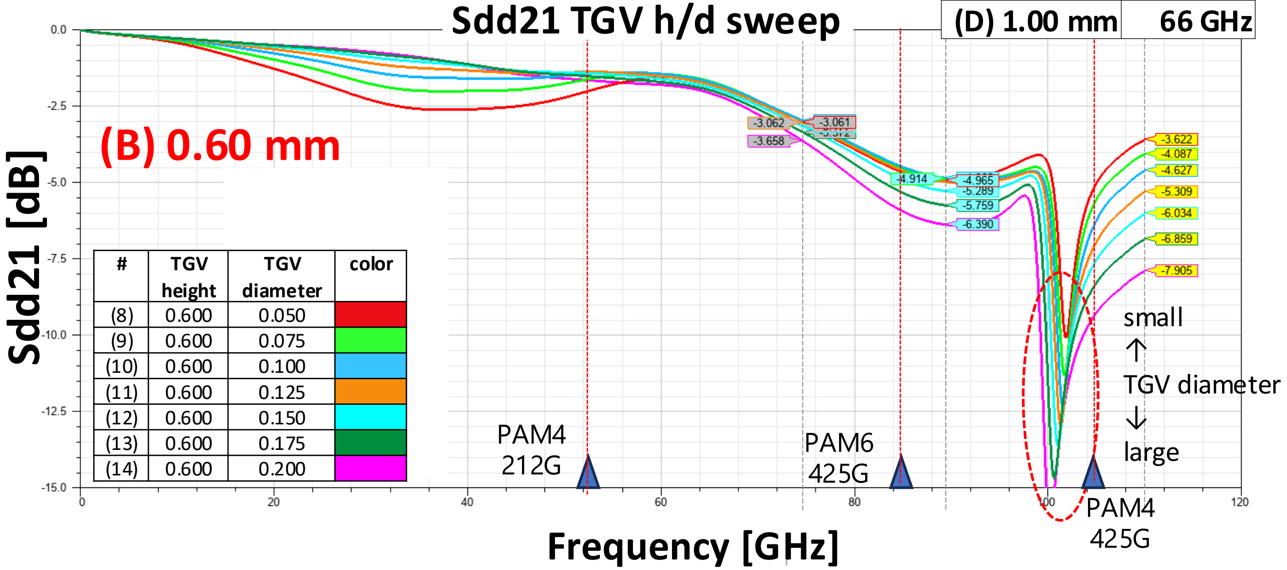
illustrative only

Dk = 5.10

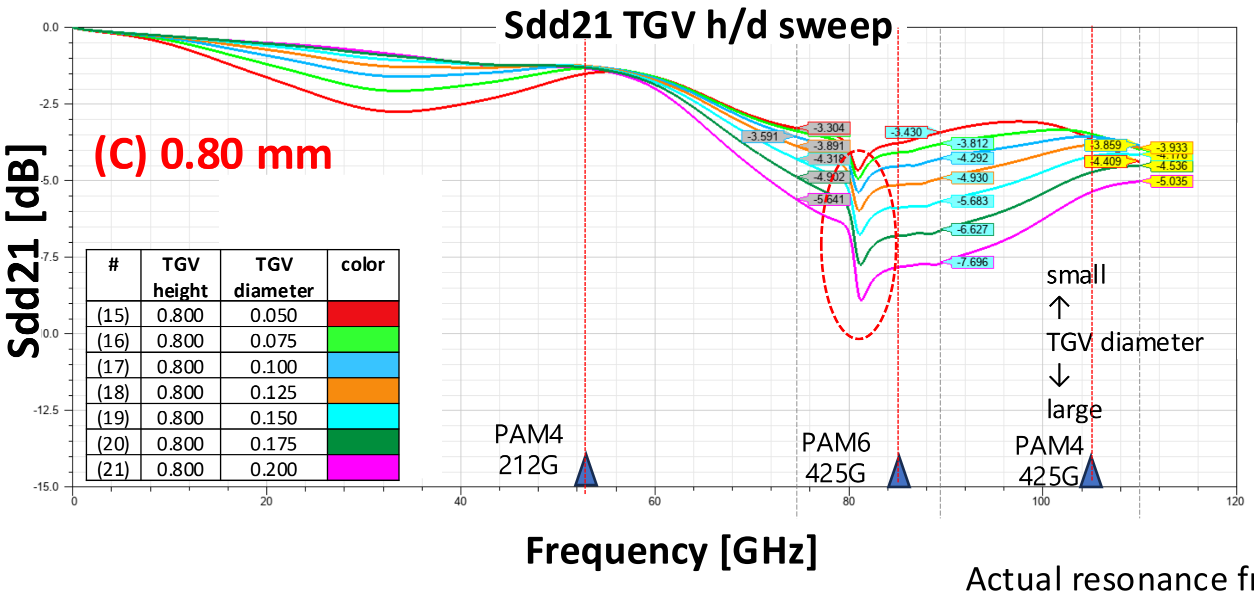
TGV height	λ/2@ *
(A) 0.40 mm	166 GHz
(B) 0.60 mm	111 GHz
(C) 0.80 mm	83 GHz
(D) 1.00 mm	66 GHz



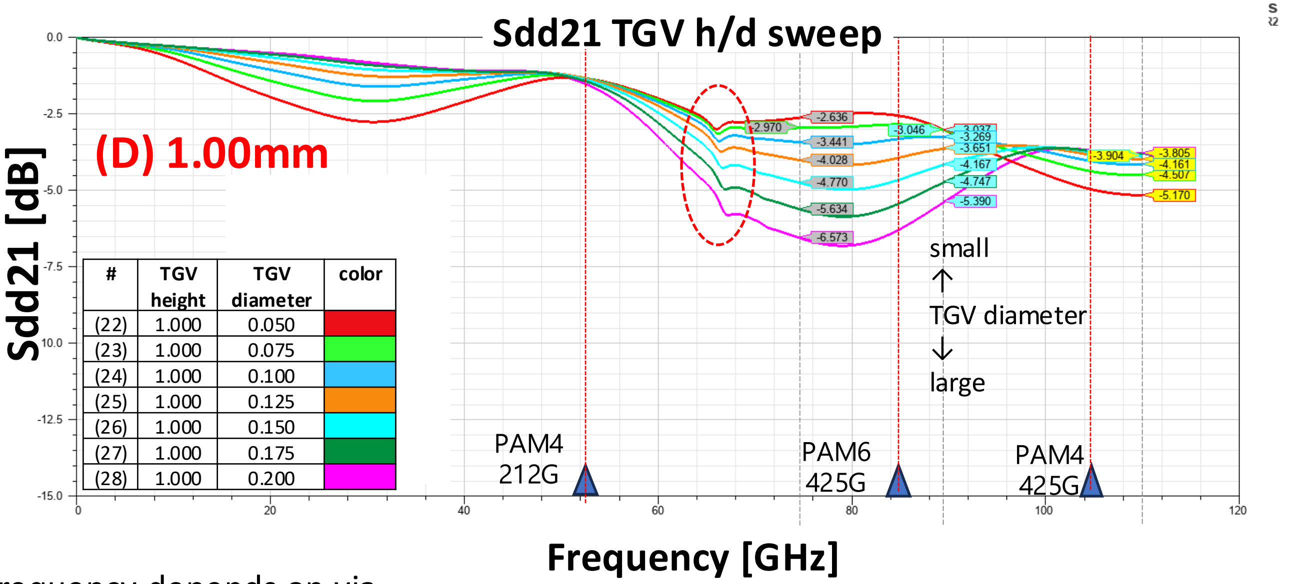
#	TGV height	TGV diameter	color
(1)	0.400	0.050	
(2)	0.400	0.075	
(3)	0.400	0.100	
(4)	0.400	0.125	
(5)	0.400	0.150	
(6)	0.400	0.175	
(7)	0.400	0.200	



#	TGV height	TGV diameter	color
(8)	0.600	0.050	
(9)	0.600	0.075	
(10)	0.600	0.100	
(11)	0.600	0.125	
(12)	0.600	0.150	
(13)	0.600	0.175	
(14)	0.600	0.200	



#	TGV height	TGV diameter	color
(15)	0.800	0.050	
(16)	0.800	0.075	
(17)	0.800	0.100	
(18)	0.800	0.125	
(19)	0.800	0.150	
(20)	0.800	0.175	
(21)	0.800	0.200	



#	TGV height	TGV diameter	color
(22)	1.000	0.050	
(23)	1.000	0.075	
(24)	1.000	0.100	
(25)	1.000	0.125	
(26)	1.000	0.150	
(27)	1.000	0.175	
(28)	1.000	0.200	

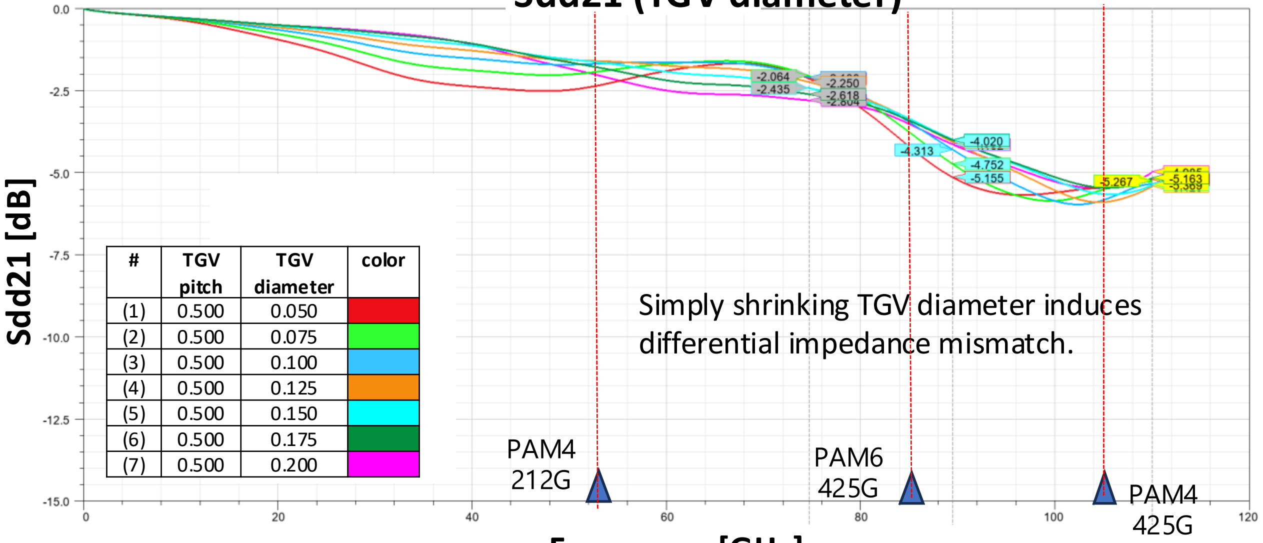
Actual resonance frequency depends on via, via pad, return-path, and transition effects.

* First-order electrical-length indicators only

5.3 TGV Scaling indicates the need for Impedance Co-Optimization

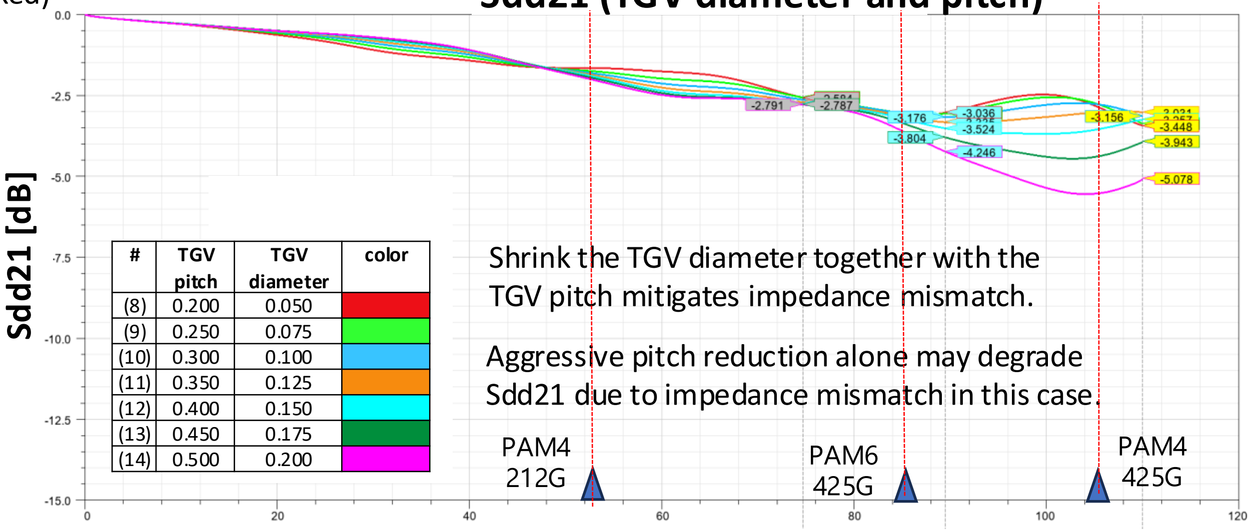
TGV height = 0.40 mm (fixed)

Sdd21 (TGV diameter)



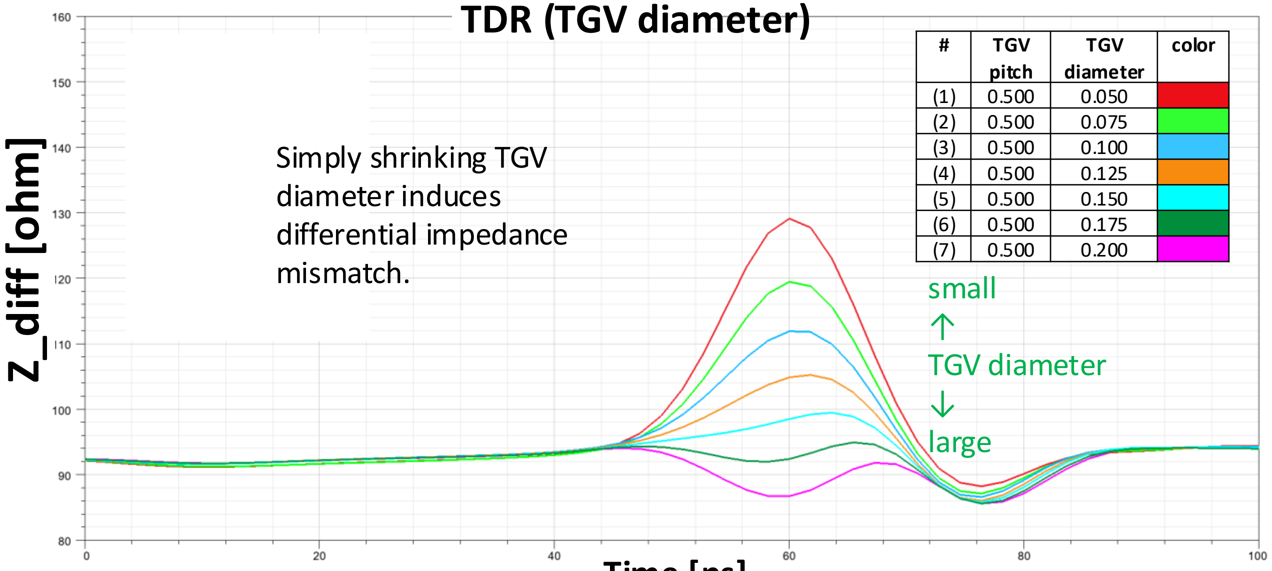
#	TGV pitch	TGV diameter	color
(1)	0.500	0.050	red
(2)	0.500	0.075	green
(3)	0.500	0.100	blue
(4)	0.500	0.125	orange
(5)	0.500	0.150	cyan
(6)	0.500	0.175	dark green
(7)	0.500	0.200	magenta

Sdd21 (TGV diameter and pitch)



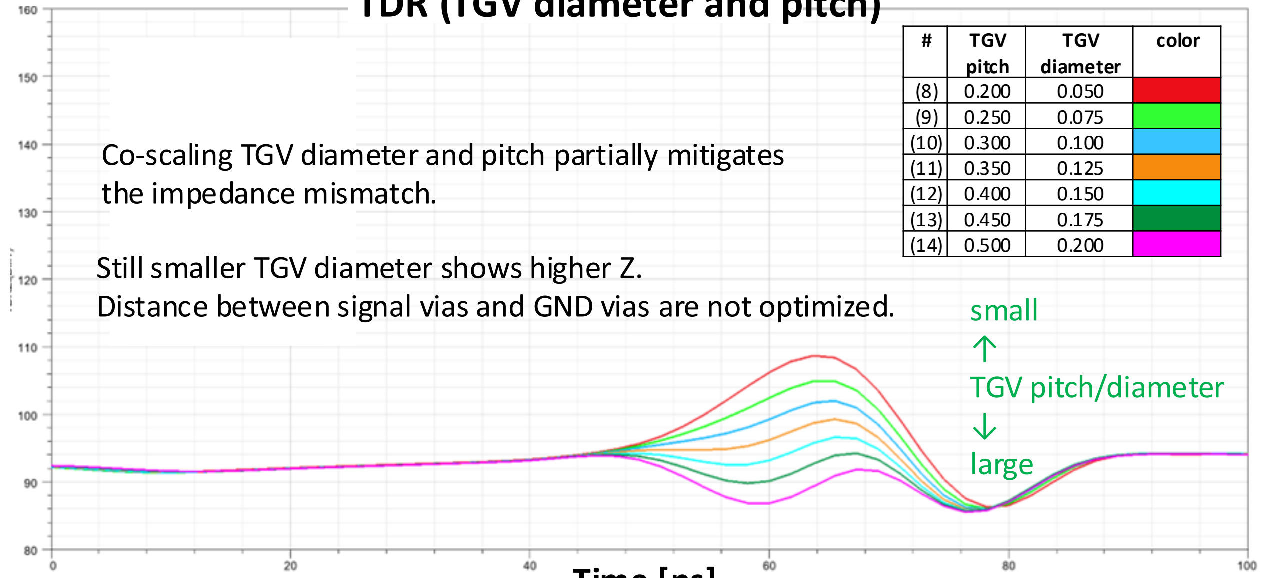
#	TGV pitch	TGV diameter	color
(8)	0.200	0.050	red
(9)	0.250	0.075	green
(10)	0.300	0.100	blue
(11)	0.350	0.125	orange
(12)	0.400	0.150	cyan
(13)	0.450	0.175	dark green
(14)	0.500	0.200	magenta

TDR (TGV diameter)



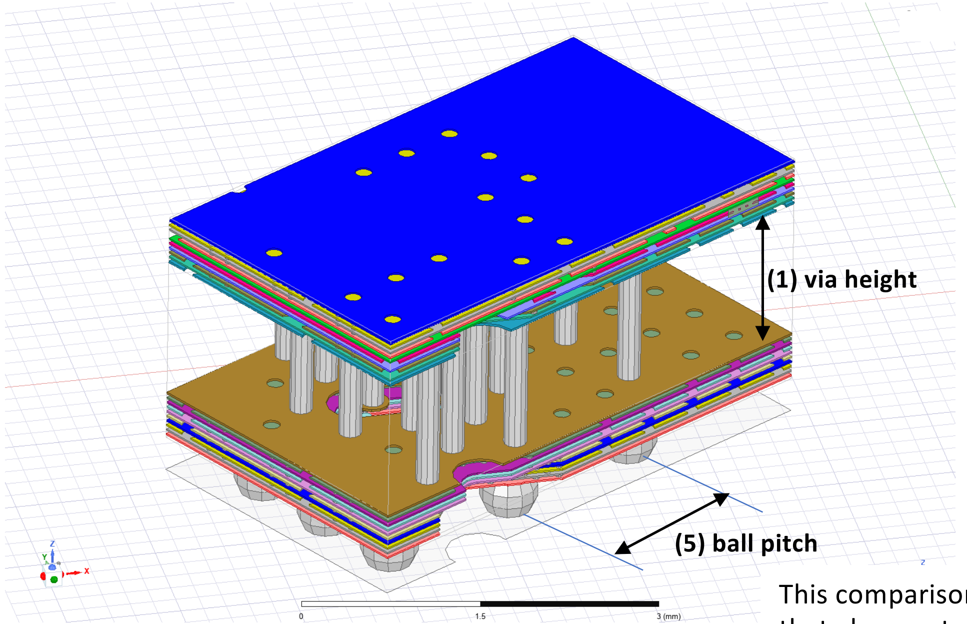
#	TGV pitch	TGV diameter	color
(1)	0.500	0.050	red
(2)	0.500	0.075	green
(3)	0.500	0.100	blue
(4)	0.500	0.125	orange
(5)	0.500	0.150	cyan
(6)	0.500	0.175	dark green
(7)	0.500	0.200	magenta

TDR (TGV diameter and pitch)



#	TGV pitch	TGV diameter	color
(8)	0.200	0.050	red
(9)	0.250	0.075	green
(10)	0.300	0.100	blue
(11)	0.350	0.125	orange
(12)	0.400	0.150	cyan
(13)	0.450	0.175	dark green
(14)	0.500	0.200	magenta

5.4 Material effect: Dk trade-off and importance of thinner core

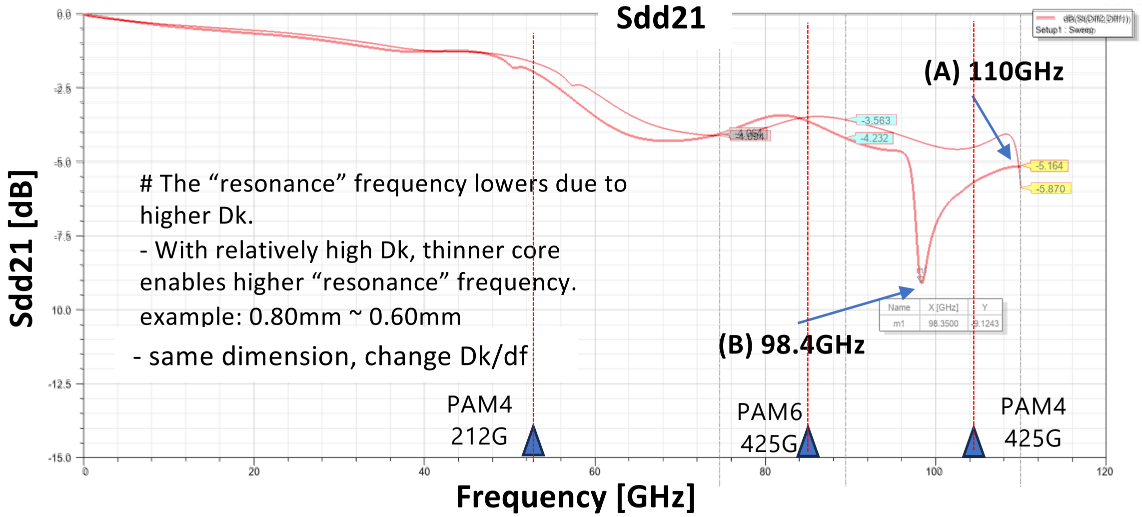


#	parameter	(A) organic	(B) glass
(1)	via height	1.28mm	1.28mm
(2)	via pitch	0.50mm	0.50mm
(3)	via diameter	0.20mm	0.20mm
(4)	via pad	0.30mm	0.30mm
(5)	ball pitch	0.80mm	0.80mm
(6)	material	organic (E795)	alkali-free glass
(7)	Dk*/Df*	3.96/8e-3	5.10/11e-3
(8)	shape	straight	straight

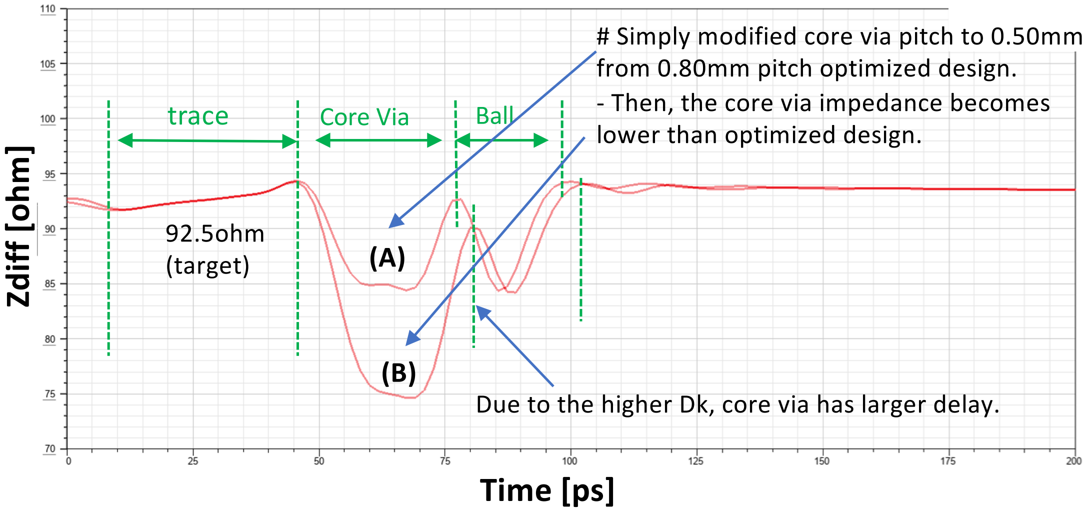
*: constant for 0~110GHz, just to see the trend.

This comparison does not demonstrate that glass material alone improves loss. The primary benefit evaluated is the potential to enable:
- thinner cores
- shorter vias
- finer dimensions

The glass Dk/Df values used here are conservative preliminary assumptions. (“E-glass”, @110GHz)
Lower-Dk/lower-Df glass options and thin-core composite structures will be evaluated in the next step.



TDR (same dimension, change Dk/df)



5.5 Preliminary observation

priority	resonance	Relative Sensitivity	Parameter	Improvement trend observed
1	major	Very High	TGV height	Reducing TGV height provides the most significant electrical benefit. - Resonance suppression needed. (height and Dk)
2	-	High	TGV diameter	Smaller diameter can reduce discontinuity but tends to increase Zdiff; co-optimization with pitch and GND vias is required.
2	-	High	TGV pitch	Excessively aggressive TGV pitch reduction increases mismatch Further optimization required
3	-	Moderate	TGV shape	Straight shape performs slightly better than hourglass
3	-	Low	TGV pad	Pad optimization is required together with TGV scaling.
4	-	Low	BGA ball pitch	Evaluated finer-pitch BGA geometry sets show improved insertion loss and return loss.

The correlated model suggests that advanced package assumptions can materially influence future package sensitivity studies.

Note: RL and XT are not fully covered in this contribution. They are planned as next-step evaluations after candidate structures are narrowed down.

6. Conclusions

Observations

- The baseline package shows significant degradation approaching the 400 Gb/s-per-lane frequency range.
- Core-via electrical length is the dominant sensitivity observed.
- Reduced via height provides the largest improvement.
- TGV geometry requires impedance co-optimization.
- BGA geometry provides a secondary improvement.

Boundaries

This contribution does not establish:

- Complete link feasibility
- COM compliance
- Crosstalk feasibility
- Manufacturing feasibility

Discussion

Should future package studies include

- Baseline organic-core packages
- Advanced thin-core package assumptions
- **Both, as sensitivity boundaries**

Thank you!

Questions?

contact: sakai.toshiaki@socionext.com

This document represents preliminary results for discussion within the 400GPL SG and does not imply consensus or endorsement by any members. The data and analysis are provided for reference and further technical collaboration.

Appendix follows.

Appendix

A. Test PKG Overview
- A.1 PKG Substrate (CPC)
  - A.1.1 Measured Sdd21 (CPC) Measurement
- A.2 Test Package Substrate (NPO/BGA)
  - A.2.1 PKG Substrate (NPO/BGA) Measurement
  - A.2.2 Measured Sdd21 (NPO/BGA)

B. Model correlation with measured data
- B.1 Simulation
- B.2 Correlated PKG Model: Agreement with Measurement

C. Detailed conditions, Simulation results
- C.0 Parameters Evaluated for Feasibility Improvement
- C.1 #1,#2: TGV height and diameter (condition) (TDR)
- C.2 #2,#3: TGV pitch and diameter (condition)
- C.3 #3: TGV pitch: optimization required, not simple scaling
- C.4 #4: TGV pad size
- C.5 #5: TGV shape (straight vs hourglass)
- C.6 #7: BGA ball pitch

D. References

E. Q/A (backup)

A. Test PKG Overview

	spec/target
PKG Size	65.0 mm x 65.0 mm
Trace Length: Bump Pad ~ BGA Ball	33.0 mm/45.0 mm
Trace Length: Bump Pad ~ CPC Pad	18.0 mm/26.6 mm
BGA Ball Pitch / Size	0.8 mm (hexagonal) / 0.50 mm (dia)
CPC Pad Pitch / Size	PN pair: 0.6 mm Tx-Tx/Rx-Rx: 1.2 mm (vert) Tx-Tx/Rx-Rx: 1.8 mm (horz) Tx-Rx: 1.8 mm (vert) / 0.43 mm (dia)
Differential Impedance	92.5 ohm

	spec/target
Layer Stackup	9-2-9 (20Layers)
Total Thickness	2176 um
Core Thickness (*2)	1280 um
Cu thickness	15 um
Dielectric Thickness	30 um
Trace Line/Space (designed)	15 um /15 um (min) 23 um/63 um (BGA/NPO) 20 um/49 um (CPC)
BU Material(*1)	GL107 equivalent, Dk 3.40/Df 0.0030
Core Material(*1)	E795G(LH) equivalent, Dk 3.96/Df 0.008
Surface Treatment(*4)	CZ8401 equivalent, Ra = 100 nm

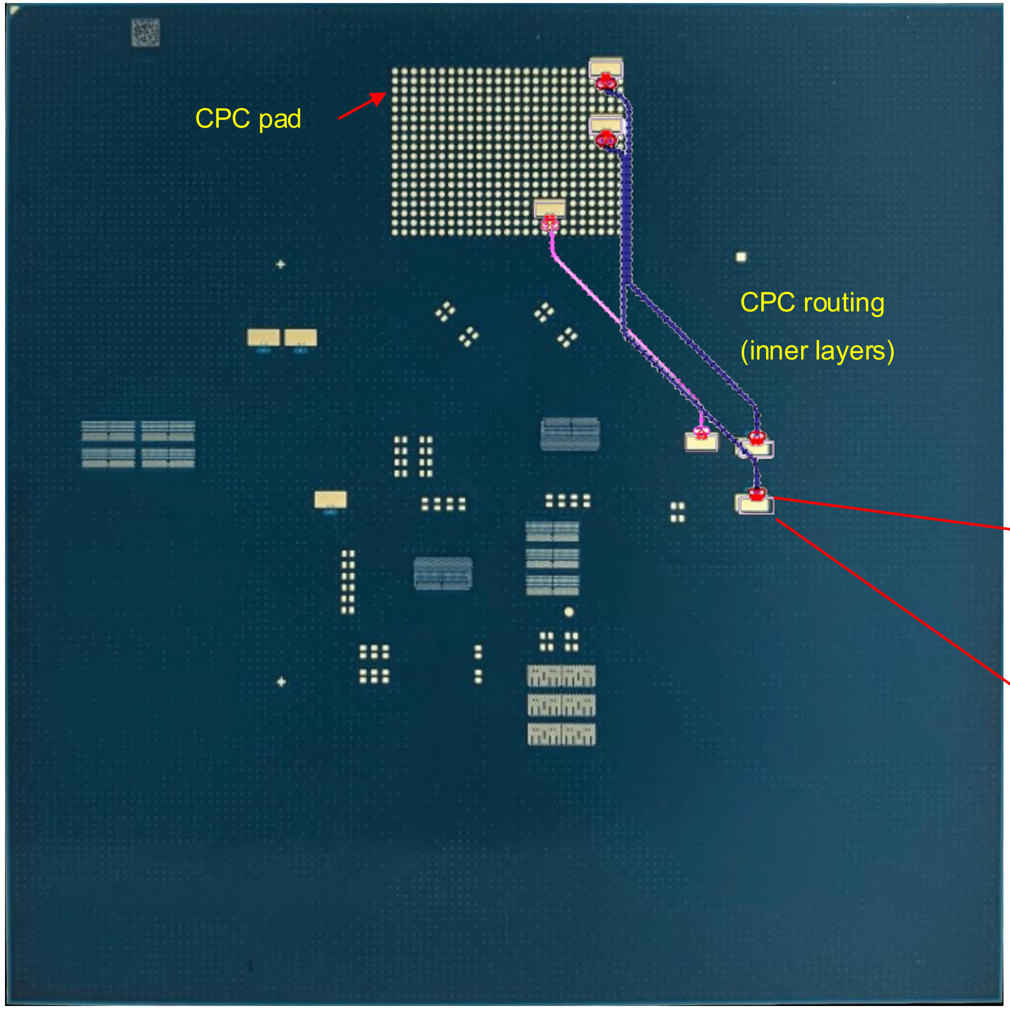
- Assuming "class B(*3)" equivalent usage.
  - high radix/lane count
  - high density
  - no skip layers

CPC: Co-Packaged Copper
NPO: Near Package Optics
(Using BGA ball and PCB connection
- In this case electrical connection to NPO module)
BU: Build Up

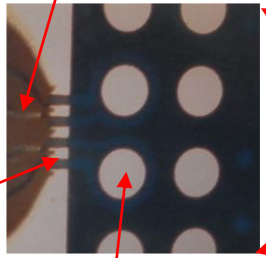
(*1): at Room Temp. @60 GHz
- material vendor's "table value"
(*2): Assuming large PKG size ~120 mm-sq,
 - Also to mitigate PKG warpage. Especially Organic core cases. This can be mitigated using glass core.
(*3): Please refer to IEEE P802.3dj draft.
(*4): Vendor's "catalog value"

A.1 PKG Substrate (CPC) Measurement

top view (bump/CPC side)



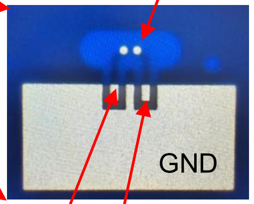
RF probe



RF probe pad
0.15mm pitch
0.08mm W

CPC pad
0.60 mm pitch
0.43mm dia

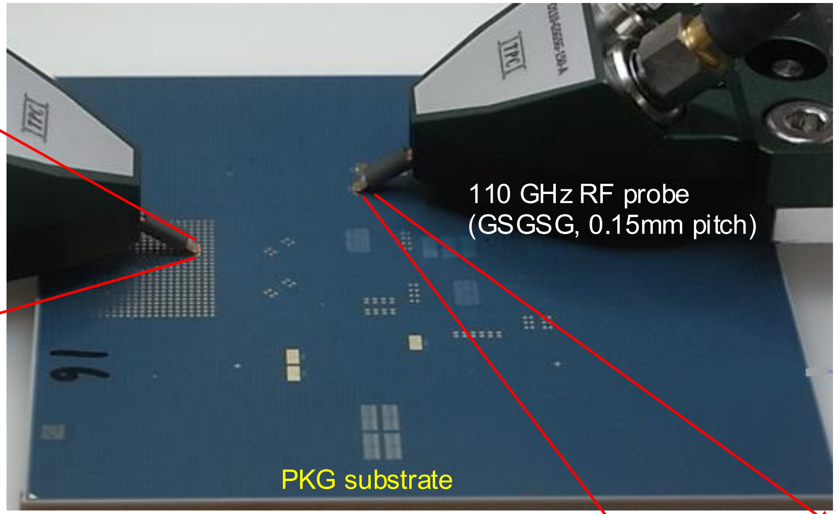
bump pad



signal

RF probe pad

Both bump pads and CPC pads are with RF probe pads for measurement.



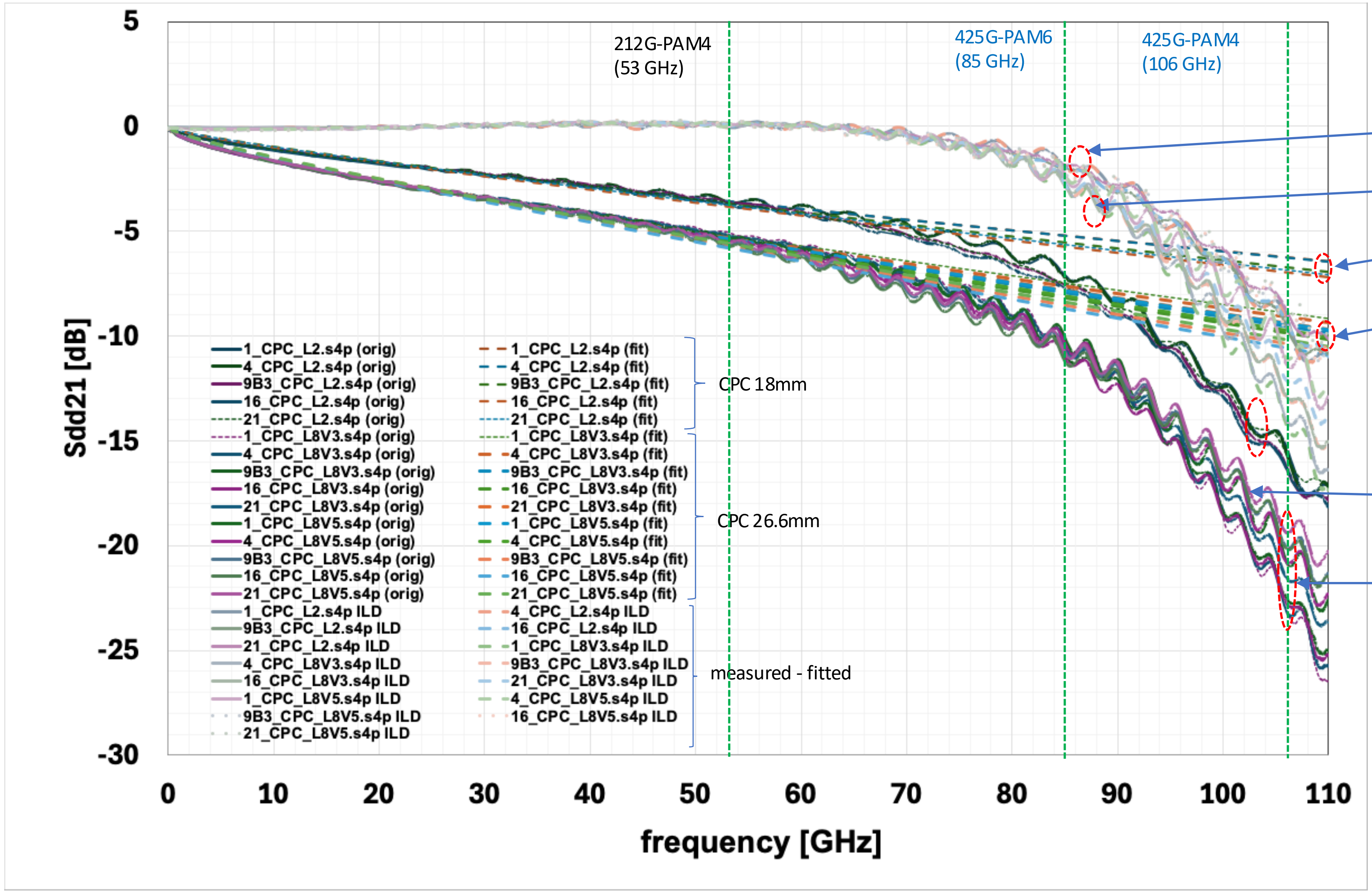
RF probe

reference plane
at RF probe tip
(calibration is done here)

- To measure up to 110 GHz, 0.15mm pitch GSGSG RF probe was used.
- To absorb the different pitch (CPC pad, bump pad), additional PKG routing was required to the RF probe pads.

- We understand this may introduce artificial effects in measurement. By taking correlation and measurement, we can build the correlated model and eliminate these effect in simulation.

A.1.1 Measured Sdd21 (CPC)



fitting function

$$Sdd21_{fit} = \underbrace{a1 \cdot f^{0.5}}_{\text{conductor}} + \underbrace{a2 \cdot f}_{\text{dielectric}}$$

measured - fitted_18mm

measured - fitted_26.6mm

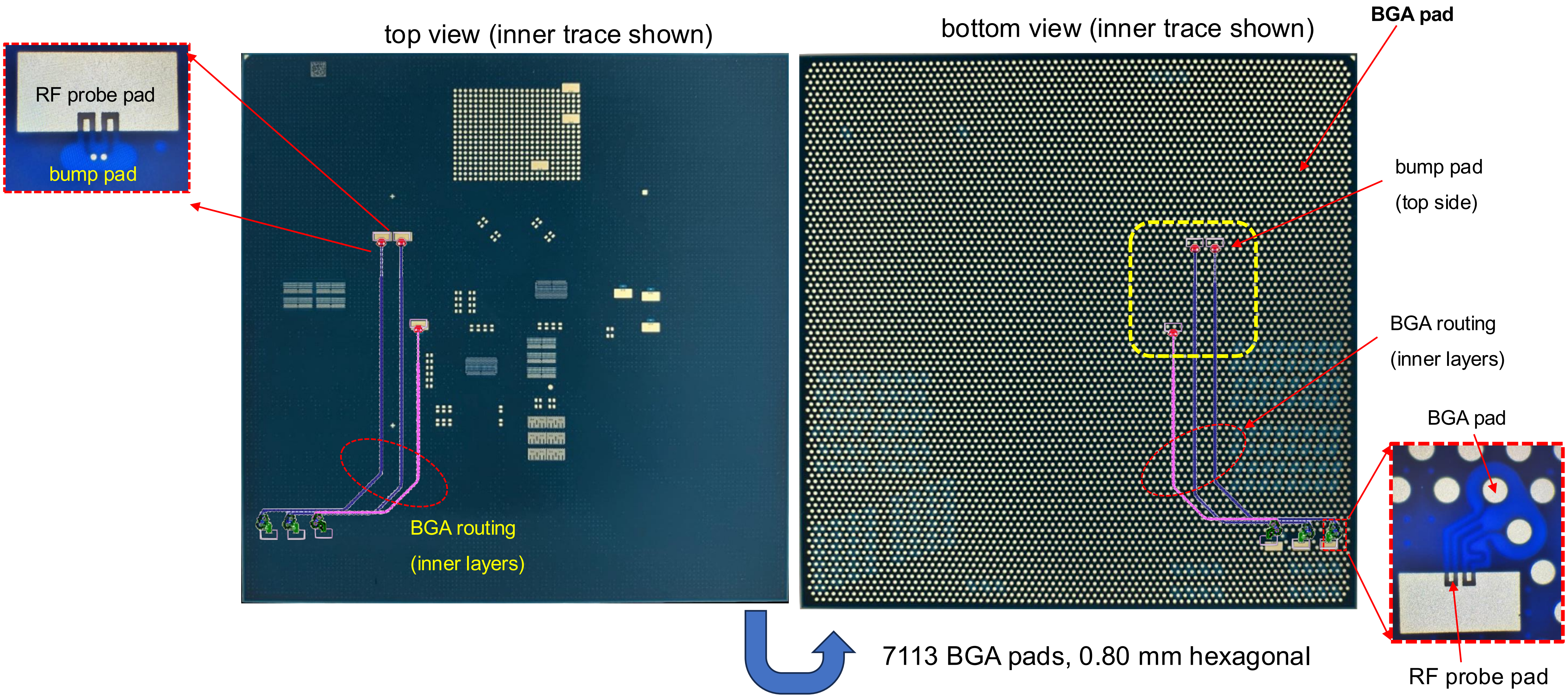
fitted_18mm(up to 70 GHz)

fitted_26.6mm(up to 70 GHz)

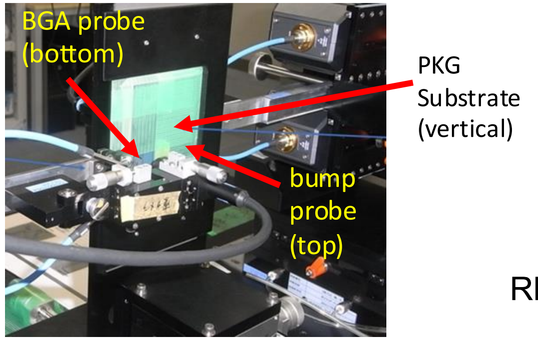
measured_18mm (5-samples)

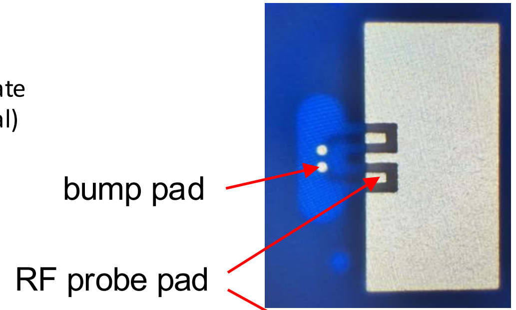
measured_26.6mm (2-type x 5-samples)

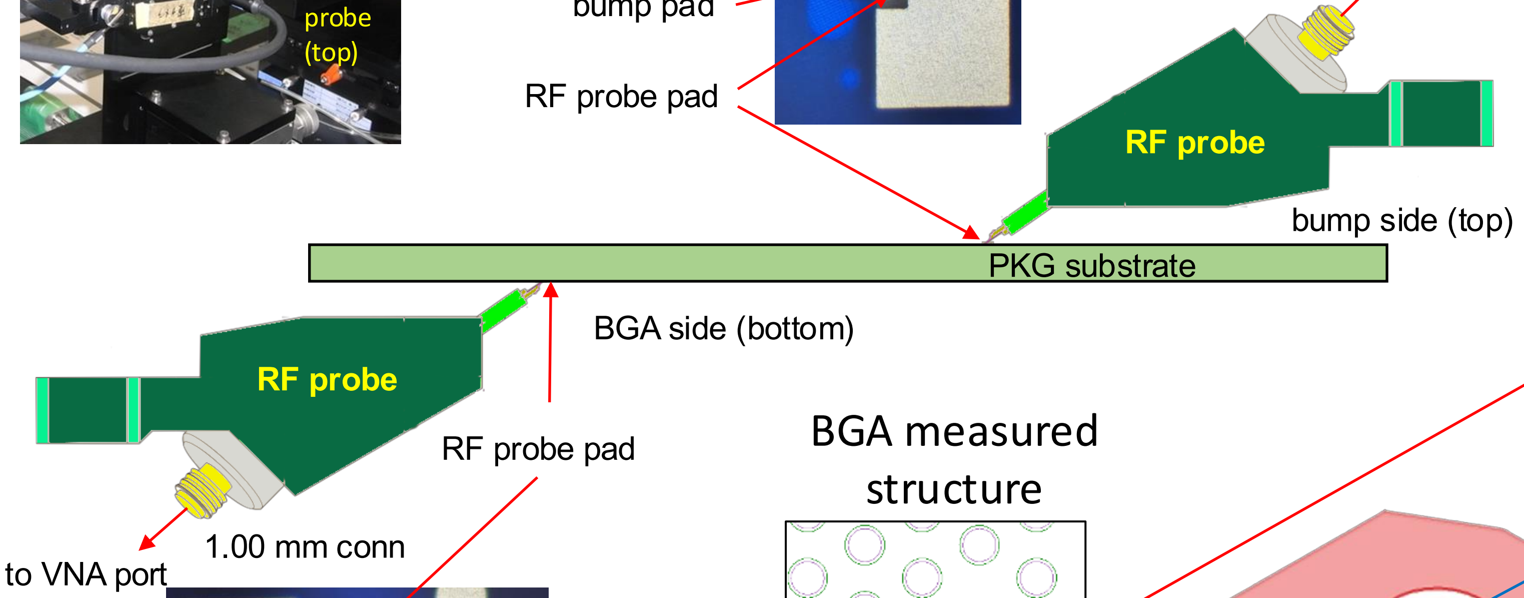
A.2 Test Package Substrate (NPO/BGA)

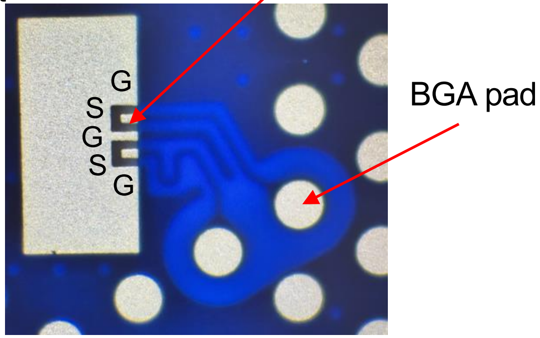


A.2.1 PKG Substrate (NPO/BGA) Measurement





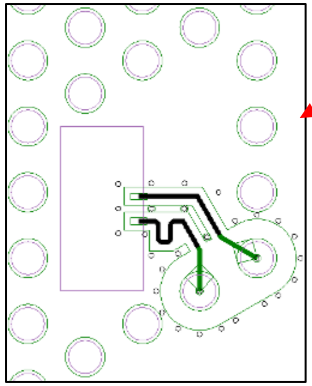


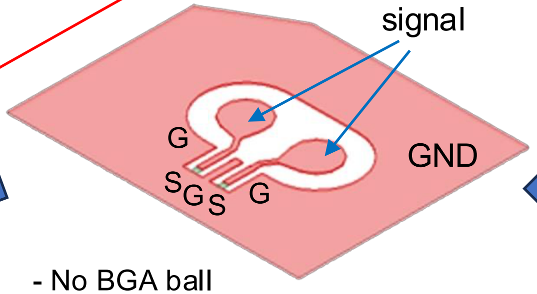


- We also understand this may introduce artificial effects in measurement. By taking correlation and measurement, we can build the correlated model and eliminate these effect in simulation.

- Measurement of the NPO/BGA substrate required simultaneous probing from both top and bottom sides to capture through-path characteristics.
- This caused “fixed” RF probe direction for stable measurement.
- As the BGA balls are hexagonally placed, it is necessary to route from BGA ball pad to RF probe pad with “non-straight” routing lines.

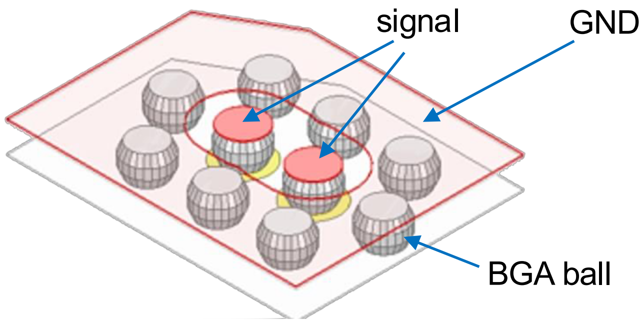
BGA measured structure





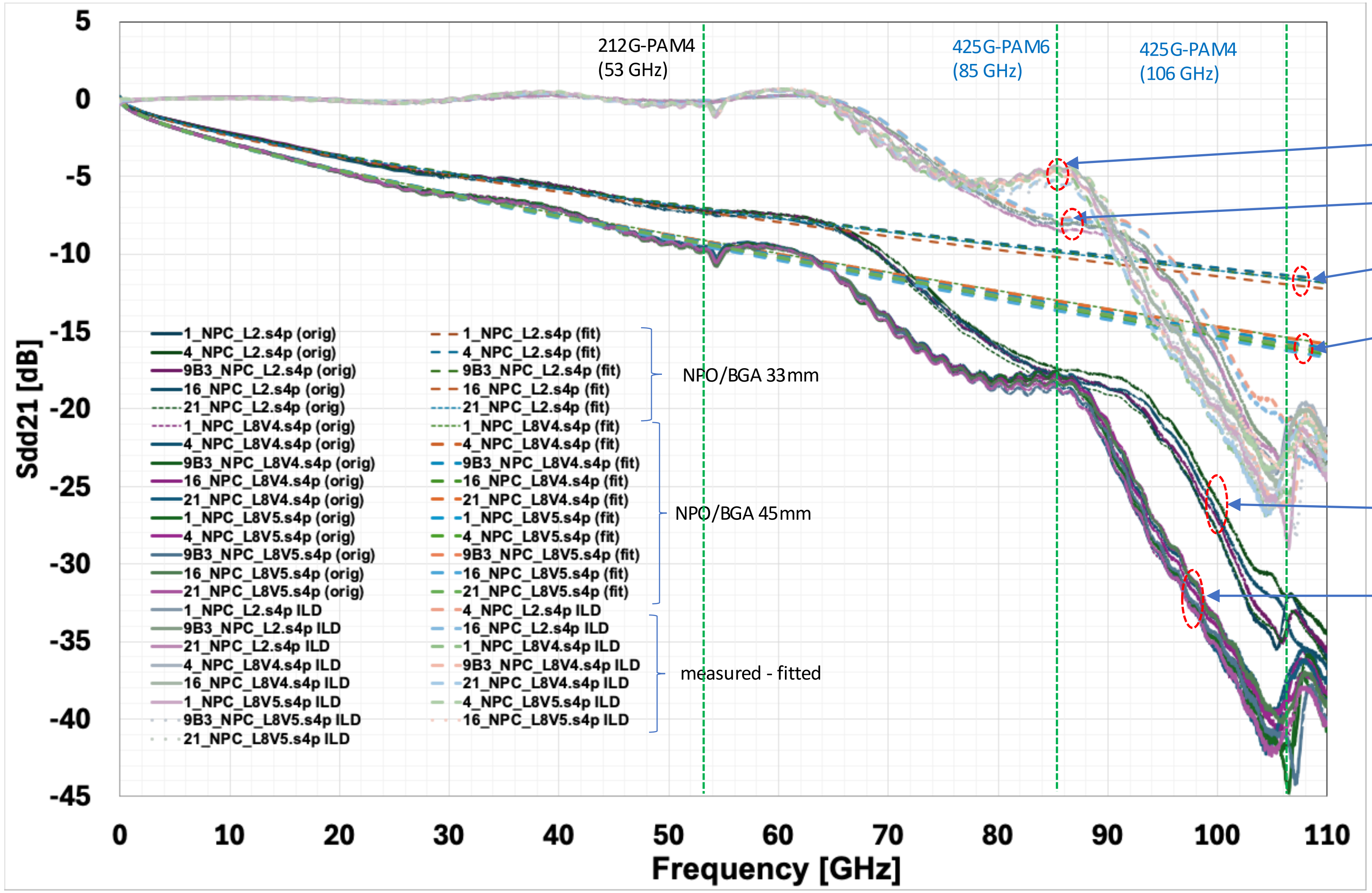
- No BGA ball
- 150um RF probe pitch
- GSGSG

BGA actual structure



- RF probe cannot probe directly, due to pad pitch (0.8mm).
- Need “GSGSG” structure for 110 GHz measurement.

A.2.2 Measured Sdd21 (NPO/BGA)



fitting function

$$Sdd21_{fit} = \underbrace{a1 \cdot f^{0.5}}_{\text{conductor}} + \underbrace{a2 \cdot f}_{\text{dielectric}}$$

measured - fitted_45mm

measured - fitted_33mm

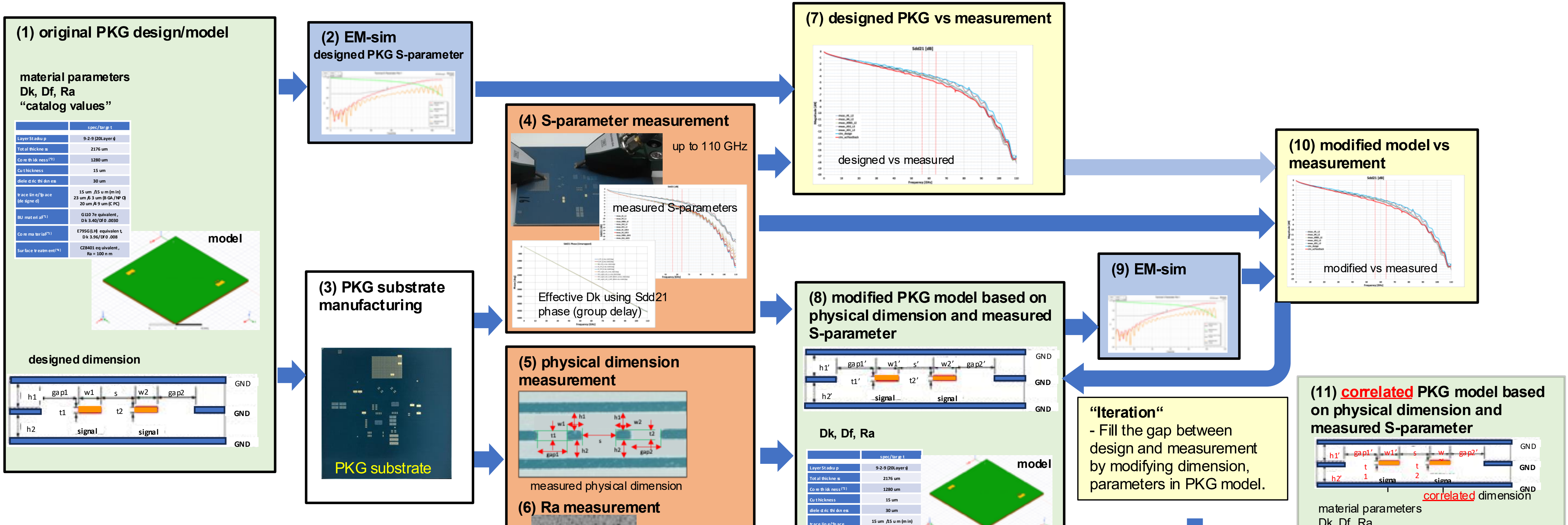
fitted_33mm(up to 70 GHz)

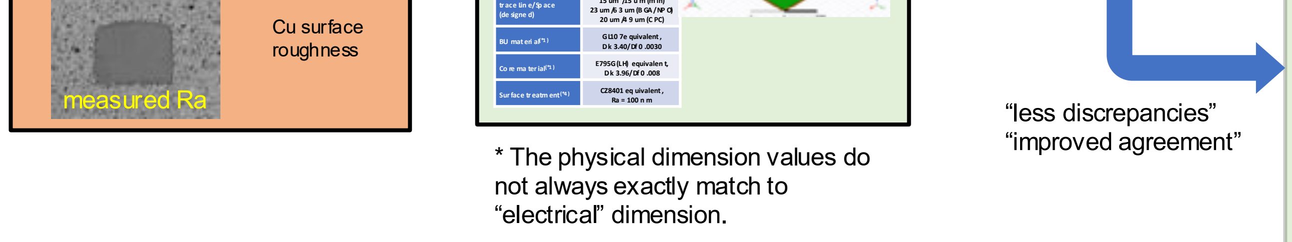
fitted_45mm(up to 70 GHz)

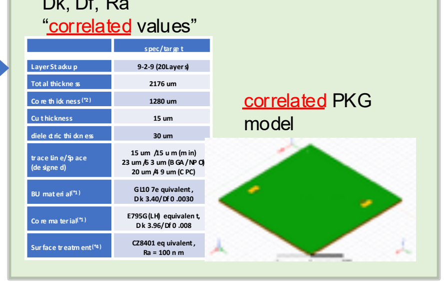
measured_33mm (5-samples)

measured_45mm (2-types x 5-samples)

B. Model correlation with measured data







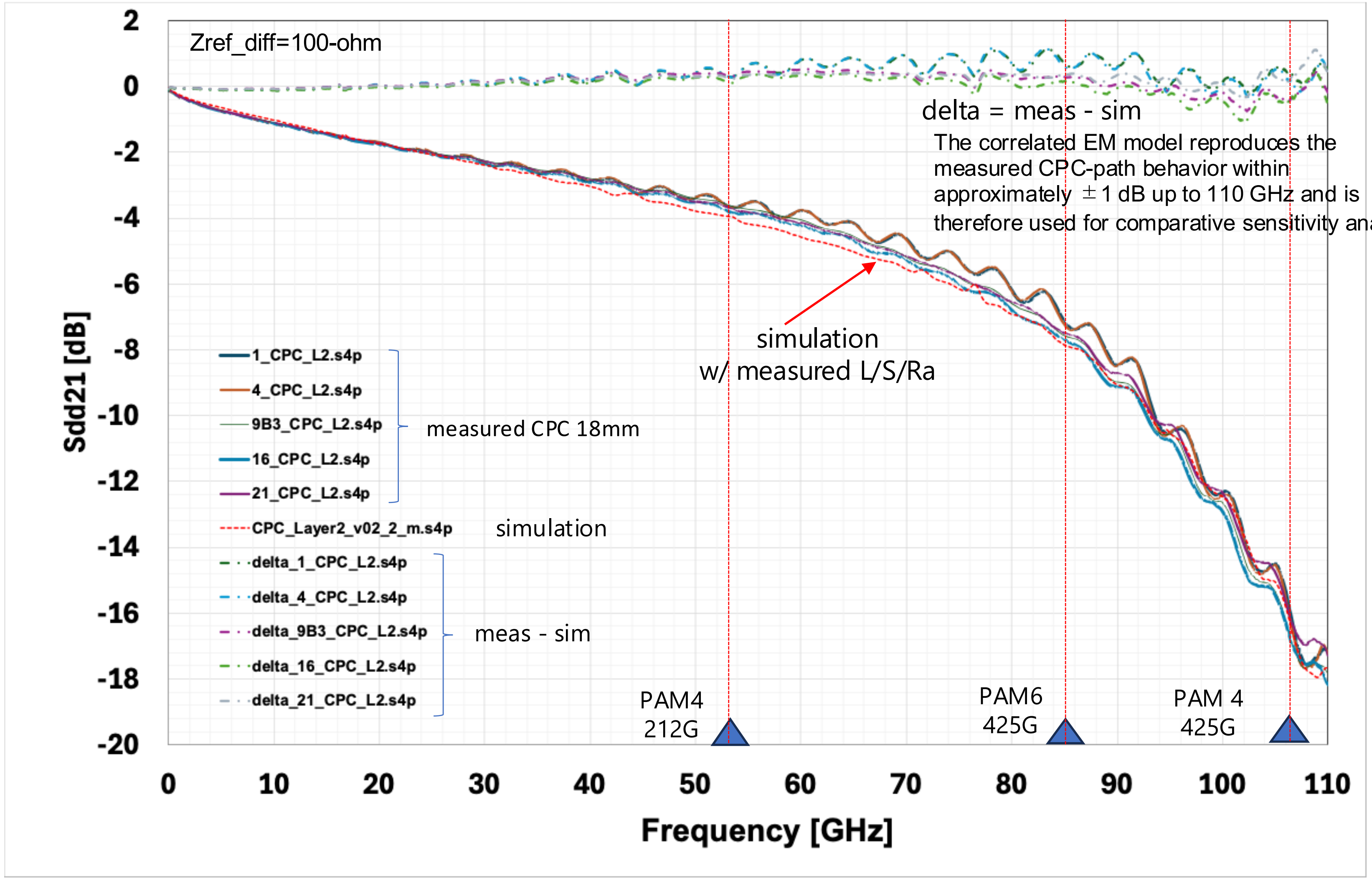
(1) dimension: trace width, space, dielectric thickness,
- material parameters: Dk, Df, Ra, conductivity
- "catalog" values, material vendor parameters (raw material measured)
- The model includes structures for measurement. (RF probe pad and trace) And also bump pad and BGA pad.

(8) dimension: measured values from cross sectional measurement (L/S,h/t, Ra) (5) (6)
(4) Dk_eff: fitting to measured Sdd21 phase (group delay)

B.1 Simulation

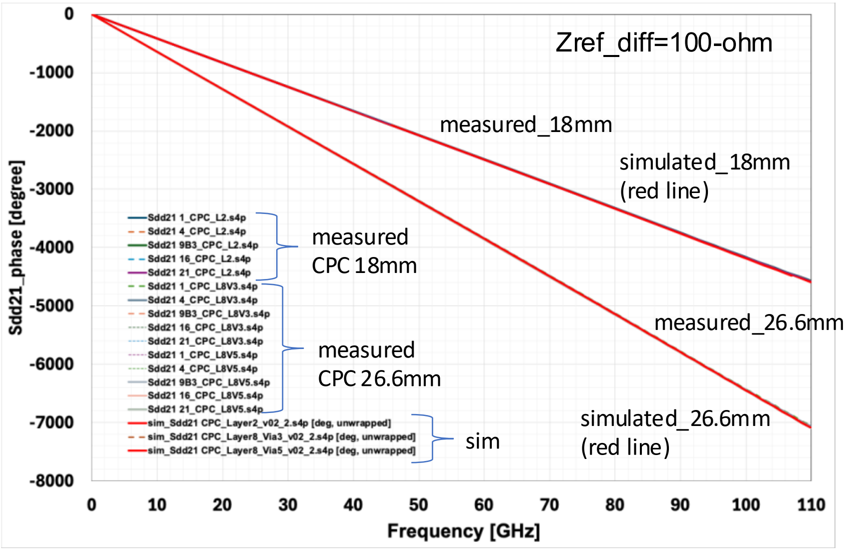
- 1st step: (sakai_400GPL_01_2605, oif2025.331.02)
  - dimension: trace width, space, dielectric thickness,
  - material parameters: Dk, Df, Ra, conductivity
    - "catalog" values, material vendor parameters (raw material measured)
- 2nd step: (sakai_400GPL_01_2605, oif2025.331.02, oif2025.484.02, oif2026.054.02, oif2026.252.03)
  - dimension: measured values from in-line measurement (L/S, Ra)
  - material parameters: fitting to measured S-parameter values
  - Exclude CPC pad and RF probe pad effects by simulation model modification.
  - Update COM PKG model using updated CPC PKG trace model (tentative TP0p/TP5p)
- 3rd step (This contribution): Explore dimensions, structures, and material assumptions relevant to future package technologies.

B.2 Correlated PKG Model: Agreement with Measurement



The measured results correlate well with the simulated results of the PKG trace with the RF probe pad.

- Both bump pads and CPC pads are with RF probe pads for measurement.



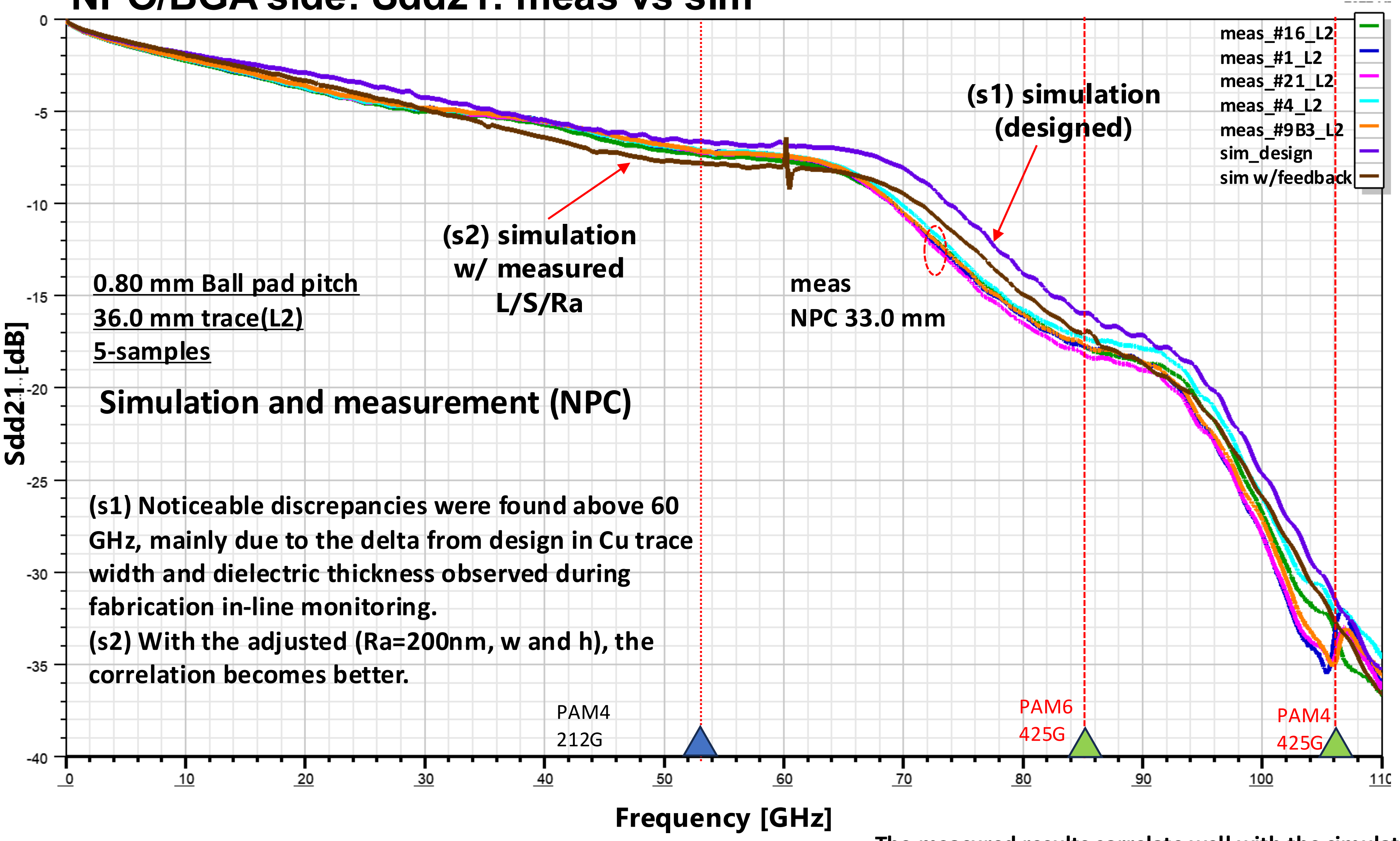
- Also, simulated Sdd21 phase correlates well with measured results. (Dk_eff was derived from group delay fitting to ensure phase accuracy.)

The model is not intended to establish complete link feasibility.

Similar agreement trends were observed for the measured NPO/BGA structures. See oif2025.484.02 (p12) [B].

B.2.1 Correlated PKG Model: Agreement with Measurement

NPO/BGA side: Sdd21: meas vs sim

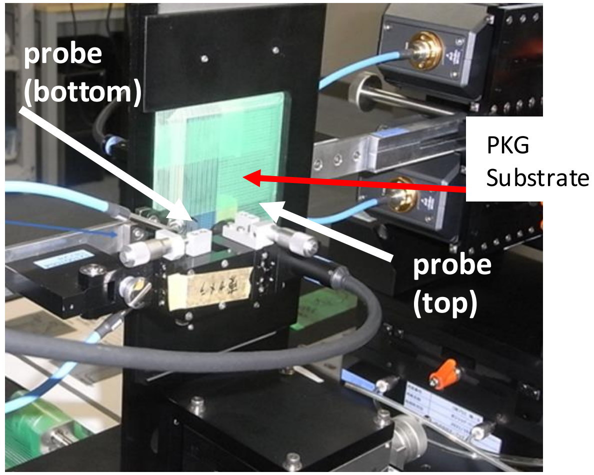


The measured results correlate well with the simulated results of the PKG trace with the RF probe pad.

bump pad (RF probe pad)

~ PKG ball pad (RF probe pad)

Both bump pads and Ball pads are with RF probe pads for measurement.



The measured results correlate well with the simulated results of the PKG trace with the RF probe pad.

C.0 Parameters Evaluated for Feasibility Improvement

#	Item	Parameter	Improvement trend observed
1	Glass Core	TGV height	Reduced height minimizes insertion loss
2	Glass Core	TGV diameter	Smaller diameter elevates differential impedance Z_diff
3	Glass Core	TGV pitch	Optimization required
4	Glass Core	TGV pad size	Smaller pad may reduce IL, but requires impedance co-optimization
5	Glass Core	TGV shape	Straight shape shows slightly better
6	Glass Core	Core layer material Dk	Lower Dk increase resonance frequency
7	BGA Ball	BGA ball pitch, pad size, ball size	Finer pitch may reduce IL, but requires impedance co-optimization

TGV: Through Glass Via. - Used as core via in glass core package substrate.

- ❖ Observed in this study
  - ✓ reduced via-height resonance
  - ✓ controllable impedance
  - ✓ finer pitch possibility
- ❖ Potential benefits reported by industry
  - ✓ dimensional accuracy
  - ✓ skew control
  - ✓ warpage improvement

*: Besides these, glass core also has mechanical benefit like lower warpage in large sized packages, like >120mm-sq, or lower CTE.

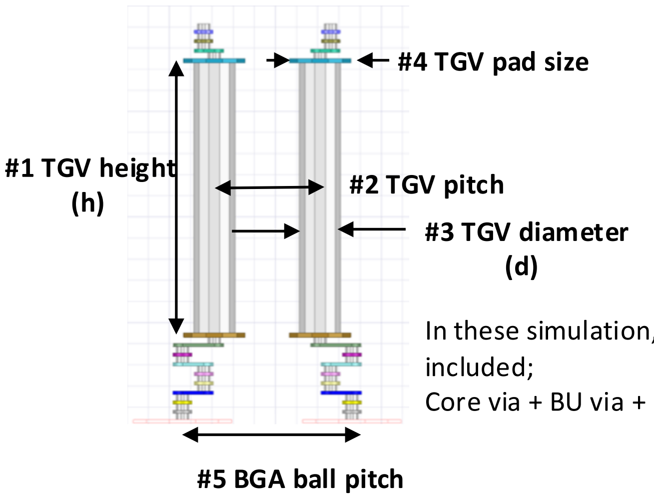
The correlated model indicates that reducing core-via electrical length and optimizing TGV structures can materially influence package sensitivity.
Thin-core technologies, including glass-core approaches, are therefore of interest for future study.

C.1 #1,#2: TGV height and diameter (condition)

#	parameter	(A)	(B)	(C)	(D)	unit	comment
1	TGV height	0.40	0.60	0.80	1.00	mm	0.20 mm step
2	TGV pitch	0.50				mm	
3	TGV diameter	0.050:0.200:0.025				mm	min:max:step
4	TGV pad size	TGV diameter + 0.100				mm	
5	BGA ball pitch	0.80				mm	
6	material	alkali-free glass					
7	Dk/Df	5.10/11e-3					const 0~110GHz
8	shape	hourglass					

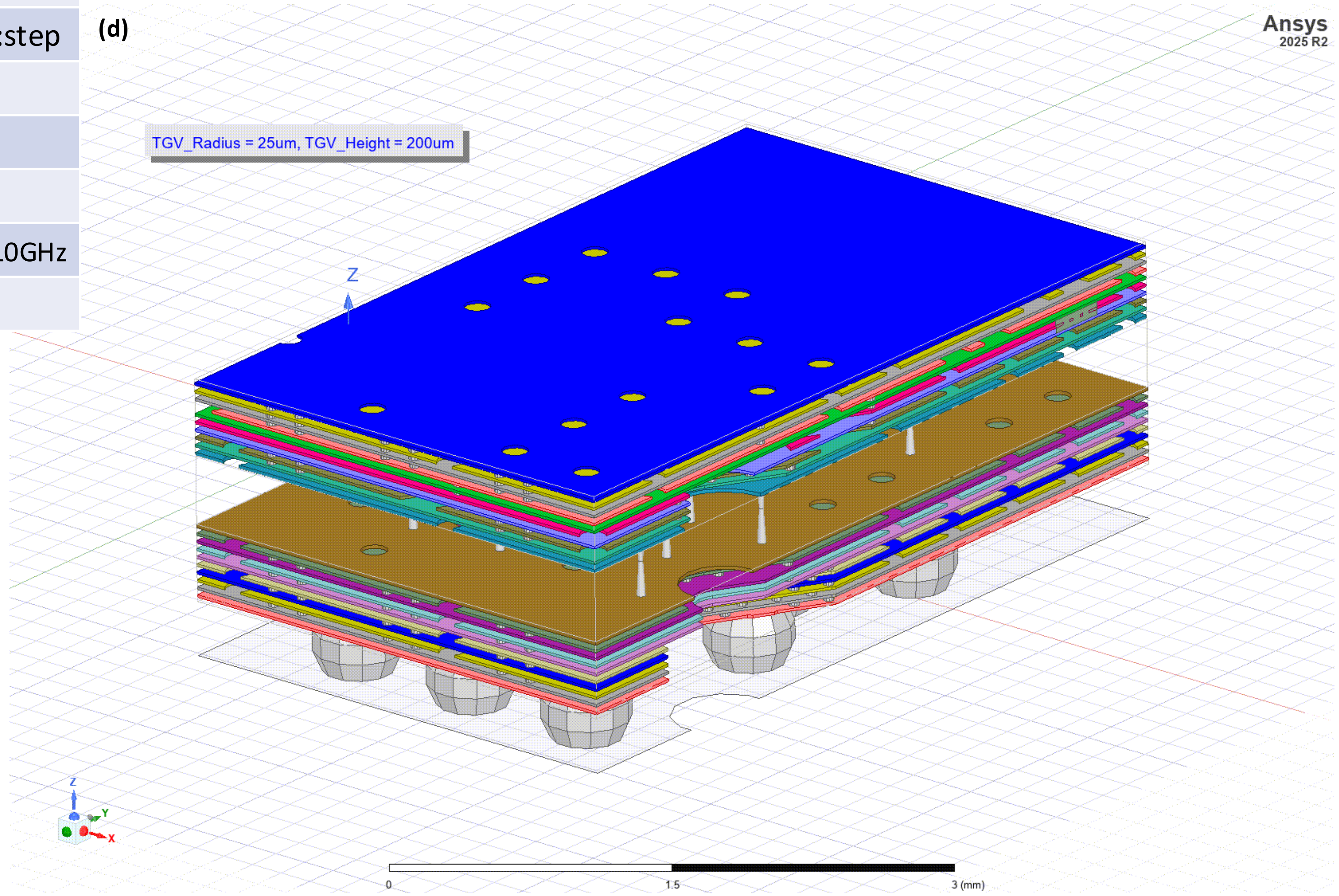
(h)

(d)



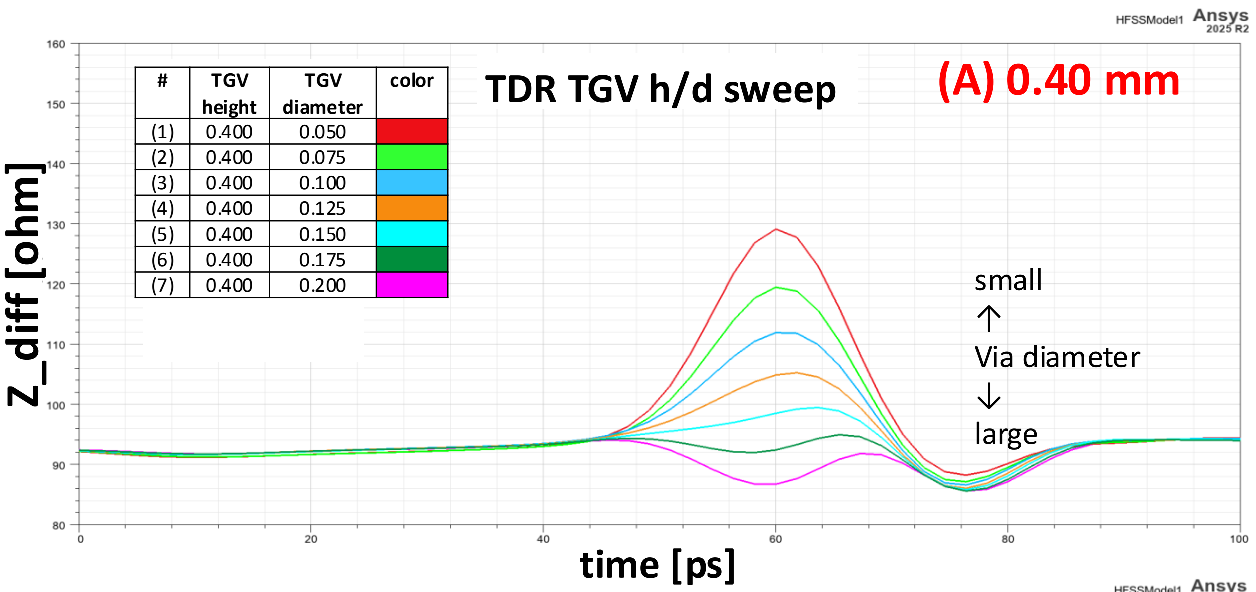
In these simulation, followings are included;
Core via + BU via + BGA pad/ball

■ Animation: sweep via height only

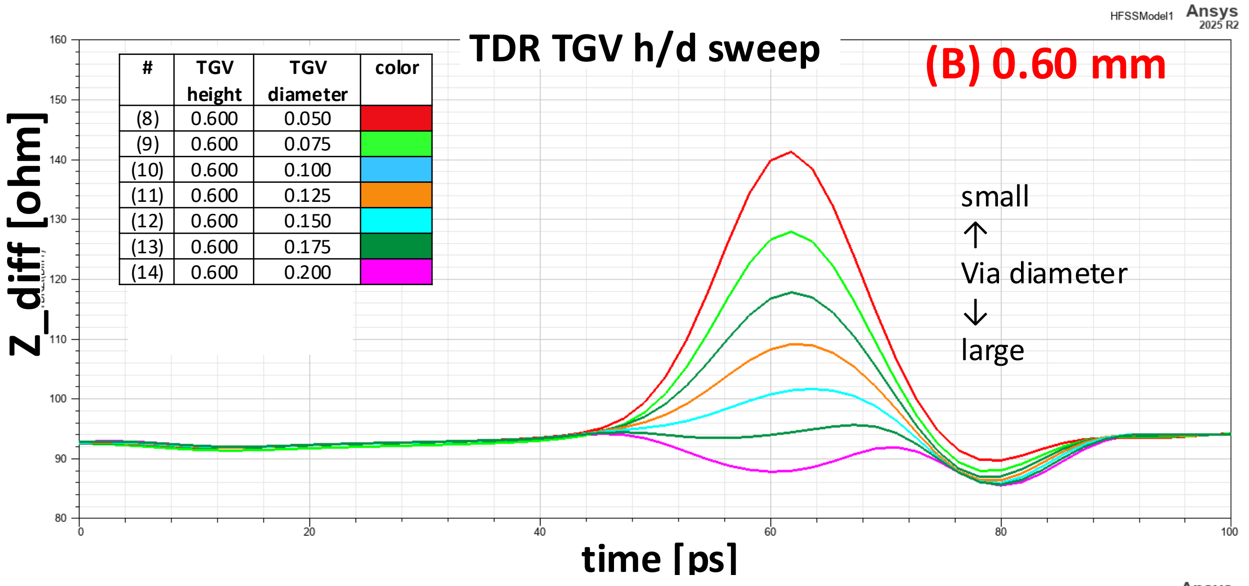


C.1 #1,#2: TGV height and diameter (TDR)

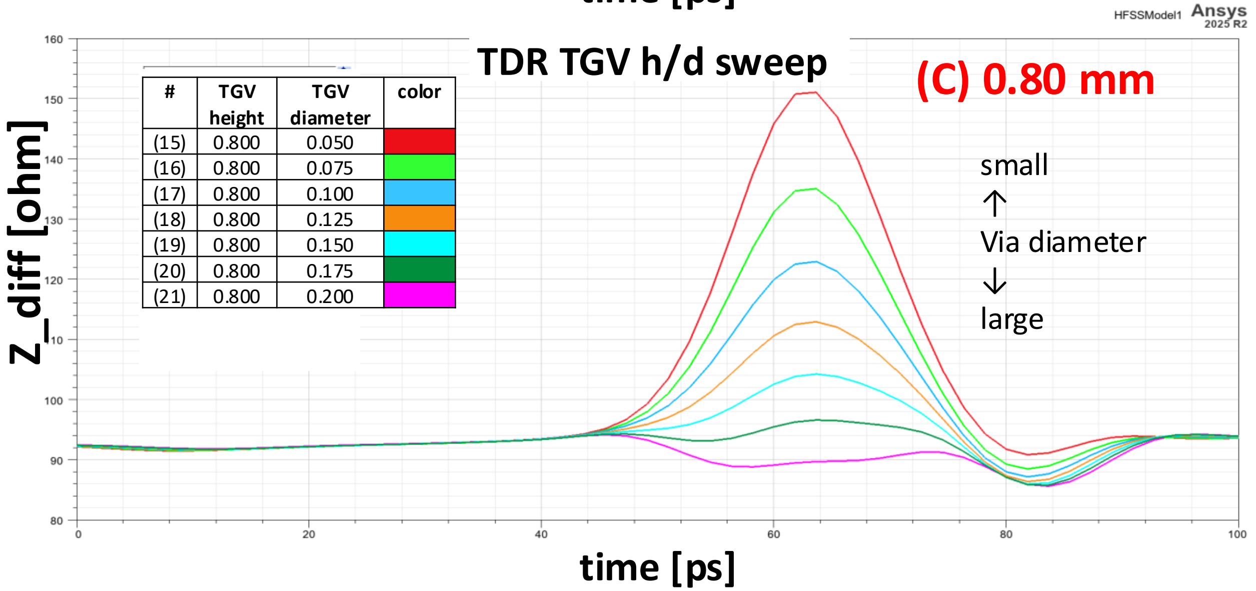
- Smaller via diameter: larger Zdiff
No clearance optimization is done.



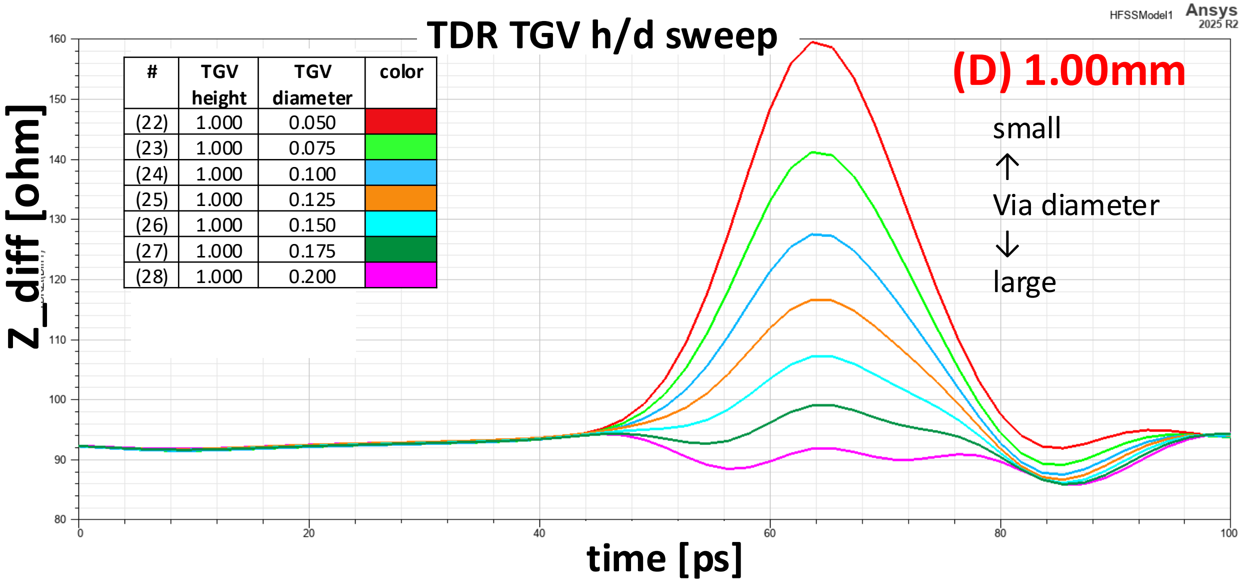
#	TGV height	TGV diameter	color
(1)	0.400	0.050	
(2)	0.400	0.075	
(3)	0.400	0.100	
(4)	0.400	0.125	
(5)	0.400	0.150	
(6)	0.400	0.175	
(7)	0.400	0.200	



#	TGV height	TGV diameter	color
(8)	0.600	0.050	
(9)	0.600	0.075	
(10)	0.600	0.100	
(11)	0.600	0.125	
(12)	0.600	0.150	
(13)	0.600	0.175	
(14)	0.600	0.200	



#	TGV height	TGV diameter	color
(15)	0.800	0.050	
(16)	0.800	0.075	
(17)	0.800	0.100	
(18)	0.800	0.125	
(19)	0.800	0.150	
(20)	0.800	0.175	
(21)	0.800	0.200	



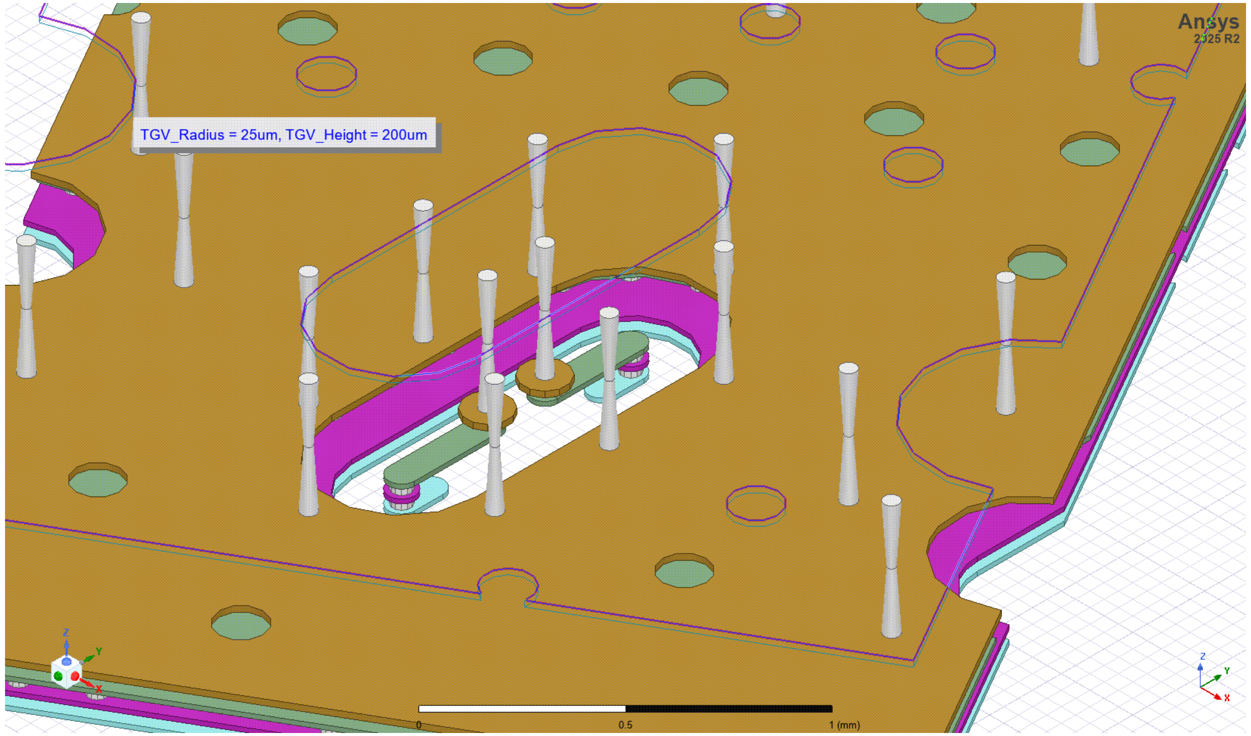
#	TGV height	TGV diameter	color
(22)	1.000	0.050	
(23)	1.000	0.075	
(24)	1.000	0.100	
(25)	1.000	0.125	
(26)	1.000	0.150	
(27)	1.000	0.175	
(28)	1.000	0.200	

C.2 #2,#3: TGV pitch and diameter (condition)

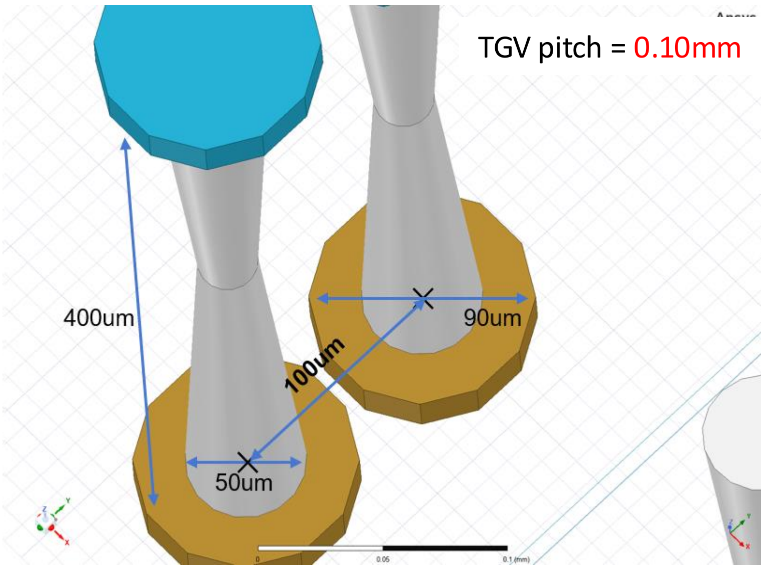
#	parameter	(1)	(2)	(3)	(4)	(5)	(6)	(7)	unit
(1)	TGV height	0.40							mm
(2)	TGV pitch	0.50							mm
(3)	TGV diameter	0.050	0.075	0.100	0.125	0.150	0.175	0.200	mm
(4)	TGV pad diam.	0.150	0.175	0.200	0.225	0.250	0.275	0.300	mm
(5)	ball pitch	0.80							mm
(6)	material	alkali-free glass							
(7)	Dk/Df	5.10 / 11e-3							
(8)	TGV shape	hourglass							

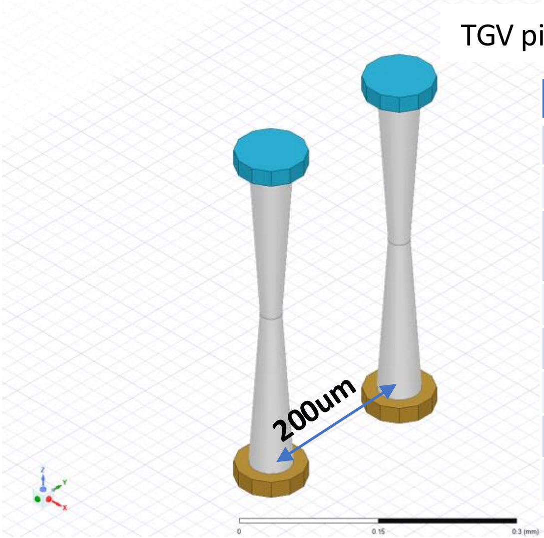
#	parameter	(8)	(9)	(10)	(11)	(12)	(13)	(14)	unit
(1)	TGV height	0.40							mm
(2)	TGV pitch	0.20	0.25	0.30	0.35	0.40	0.45	0.50	mm
(3)	TGV diameter	0.050	0.075	0.100	0.125	0.150	0.175	0.200	mm
(4)	TGV pad diam.	0.150	0.175	0.200	0.225	0.250	0.275	0.300	mm
(5)	ball pitch	0.80							mm
(6)	material	alkali-free glass							
(7)	Dk/Df	5.10 / 11e-3							
(8)	TGV shape	hourglass							

■ Animation: sweep via pitch and diameter

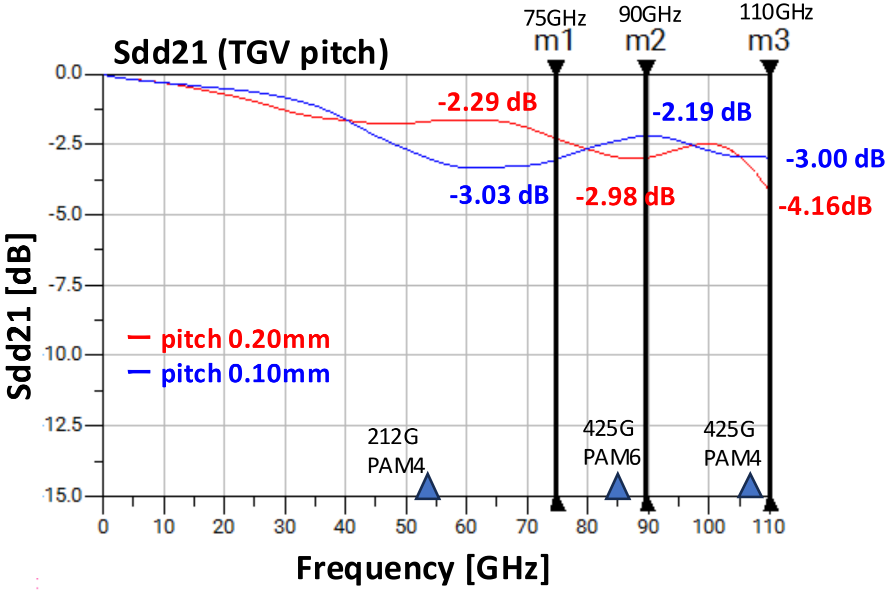


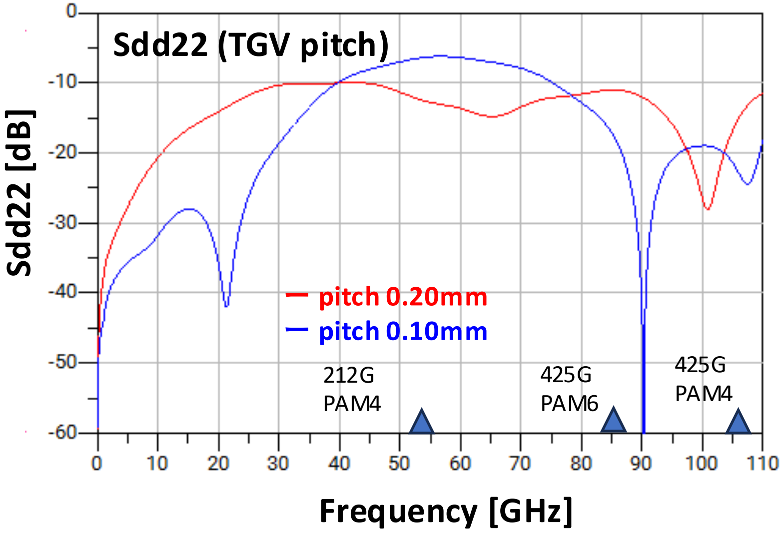
C.3 #3: TGV pitch: optimization required, not simple scaling

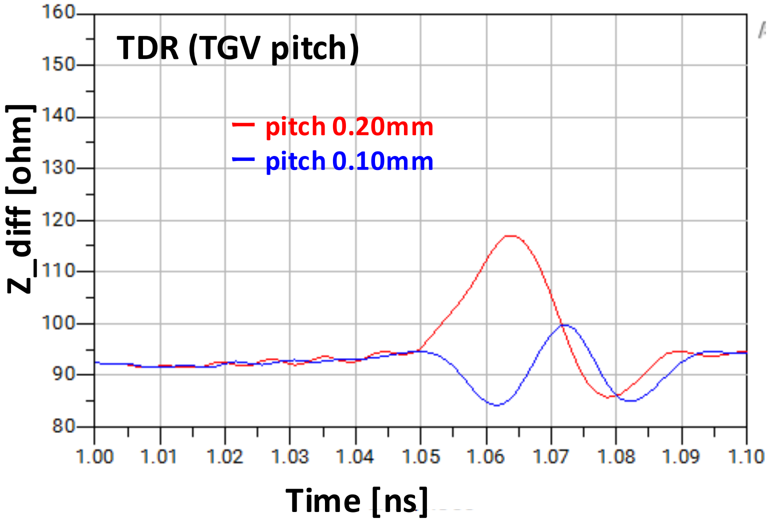




#	parameter	
(1)	TGV height	0.40 mm
(2)	TGV pitch	sweep
(3)	TGV diameter	0.05 mm
(4)	TGV pad	0.09 mm
(5)	ball pitch	0.80 mm
(6)	material	alkali-free glass
(7)	Dk/Df	5.10/11e-3
(8)	shape	hourglass



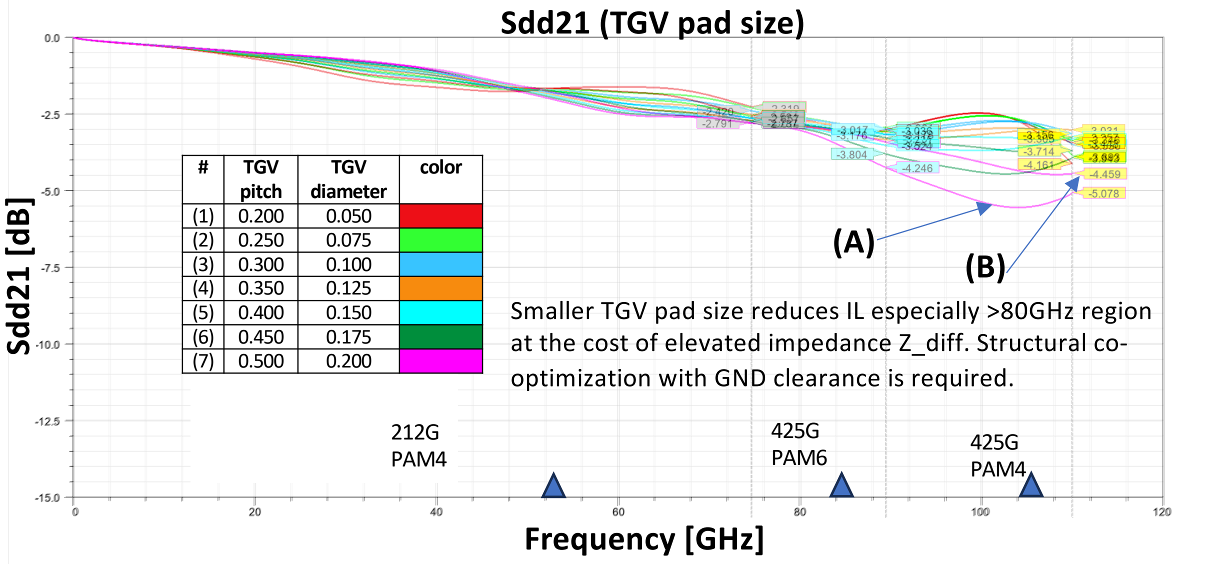


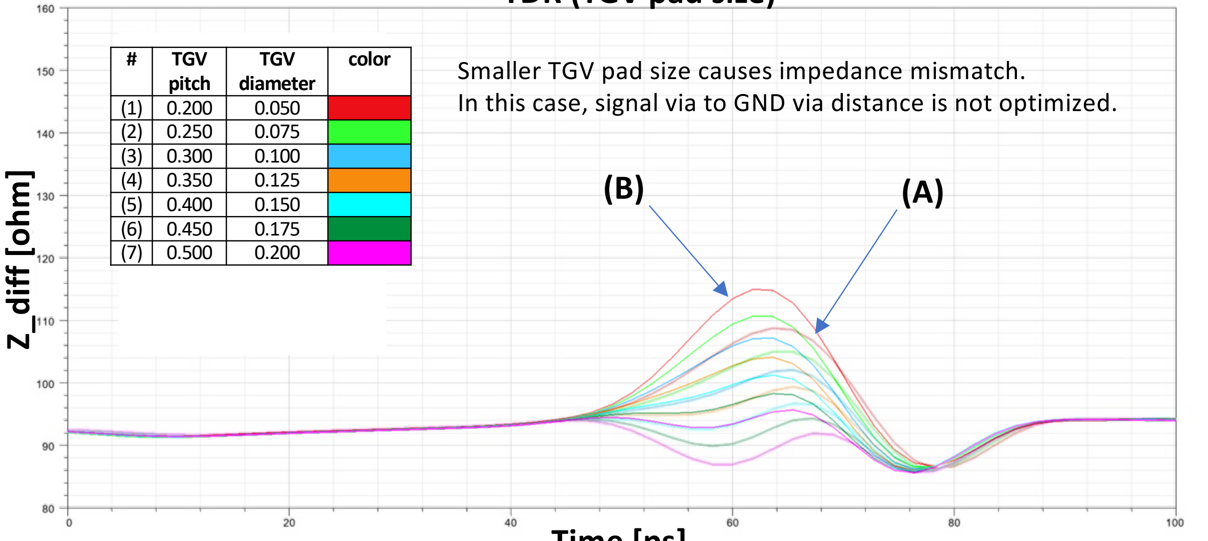


- Aggressive TGV pitch reduction alone introduces high ILD (Insertion Loss Deviation) due to multiple reflections caused by differential impedance mismatch (~85 ohm to ~100 ohm shift as shown in TDR).

- These results indicate that coplanar or surrounding GND via shielding optimization will likely be required. Optimized GND via arrangements will be evaluated in the next step.

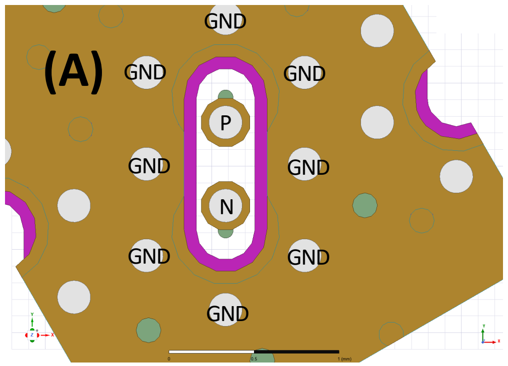
C.4 #4: TGV pad size



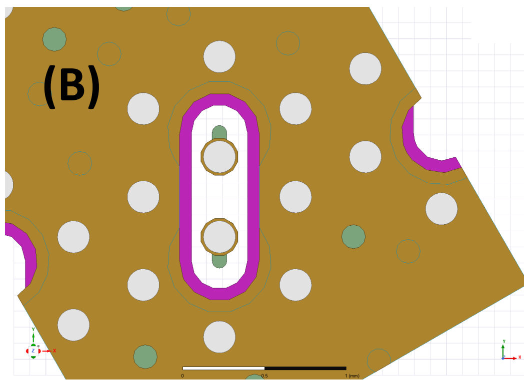


sakai_400GPL_01_2609

pad_dia = TGV_dia + 0.10mm



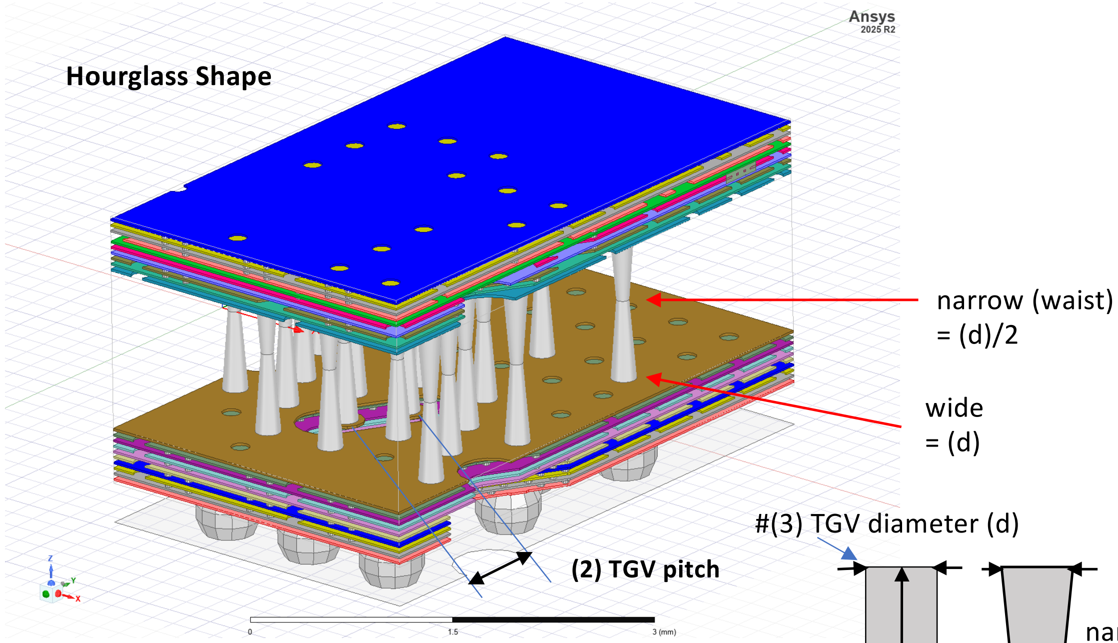
pad_dia = TGV_dia + 0.04mm



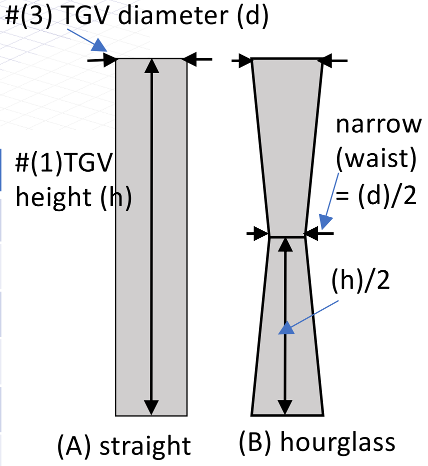
#	parameter	(1)	(2)	(3)	(4)	(5)	(6)	(7)	unit
(1)	TGV height	0.40							mm
(2)	TGV pitch	0.20	0.25	0.30	0.35	0.40	0.45	0.50	mm
(3)	TGV diameter	0.050	0.075	0.100	0.125	0.150	0.175	0.200	mm
(4-A)	pad diameter	0.150	0.175	0.200	0.225	0.250	0.275	0.300	mm
(4-B)	pad diameter	0.090	0.115	0.140	0.165	0.190	0.215	0.240	mm
(5)	ball pitch	0.80							mm
(6)	material	alkali-free glass							
(7)	Dk/Df	5.10/11e-3							
(8)	TGV shape	hourglass							

C.5 #5: TGV shape (straight vs hourglass)

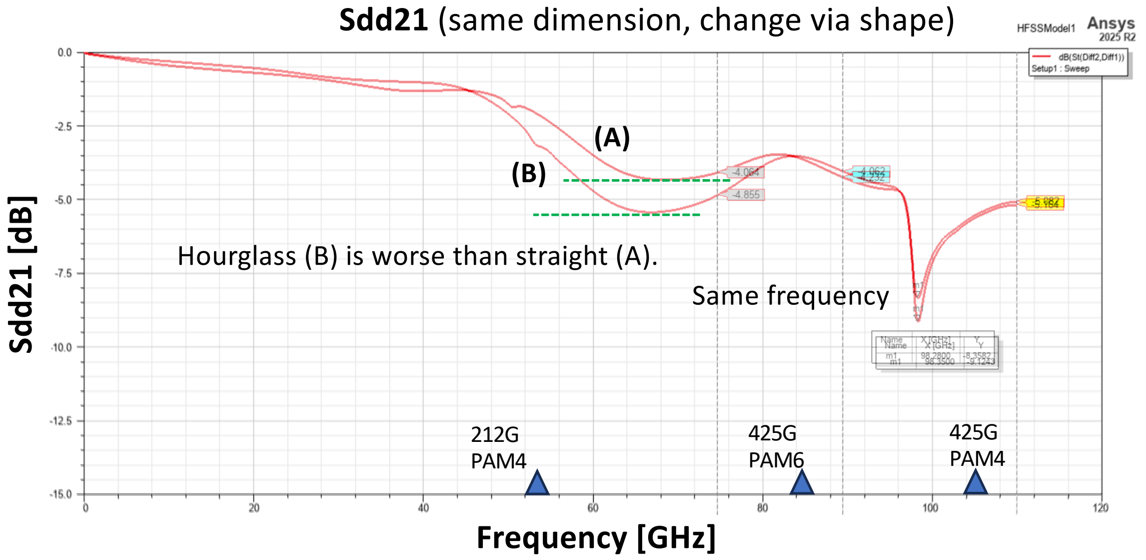
Minor benefit was observed for the straight TGV shape in this study.

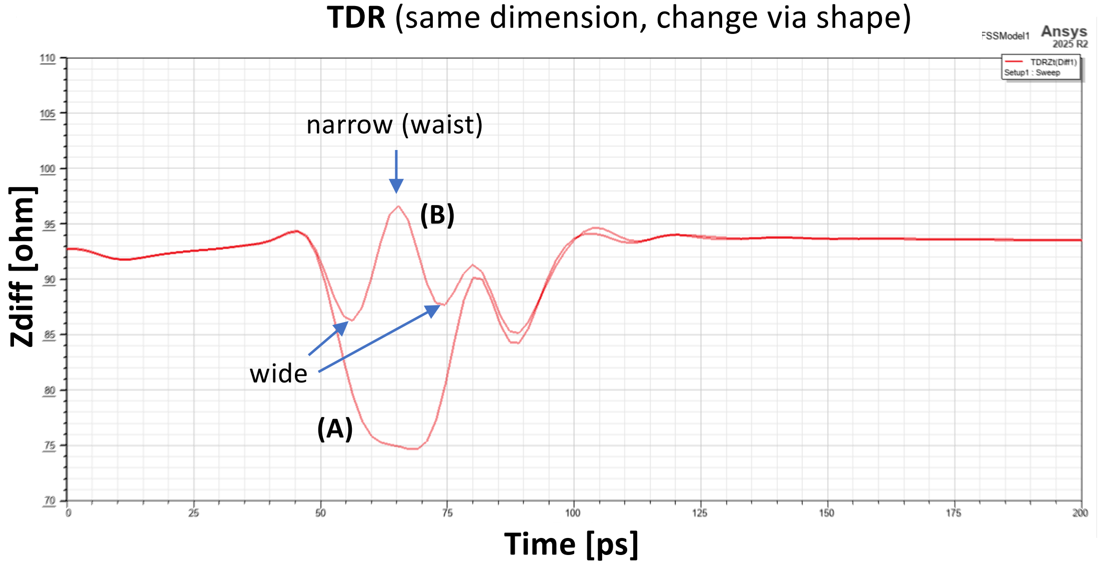


#	parameter	(A) straight	(B) hourglass
(1)	TGV height	1.28 mm	1.28 mm
(2)	TGV pitch	0.50 mm	0.50 mm
(3)	TGV diameter	0.20 mm	0.20 mm
(4)	TGV pad	0.30 mm	0.30 mm
(5)	ball pitch	0.80 mm	0.80 mm
(6)	material	alkali-free glass	alkali-free glass
(7)	Dk/Df*	5.10/11e-3	5.10/11e-3
(8)	shape	straight	hourglass



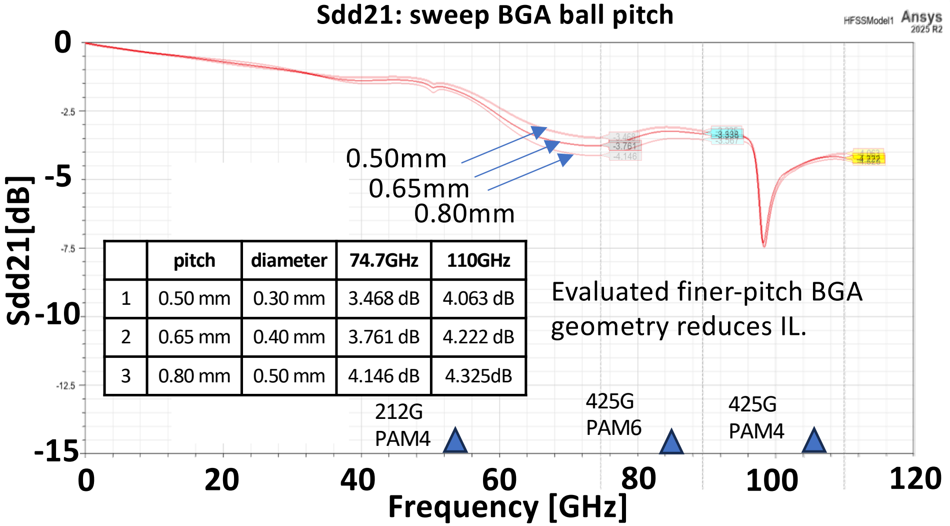
*: constant for 0~110GHz, just to see the trend.





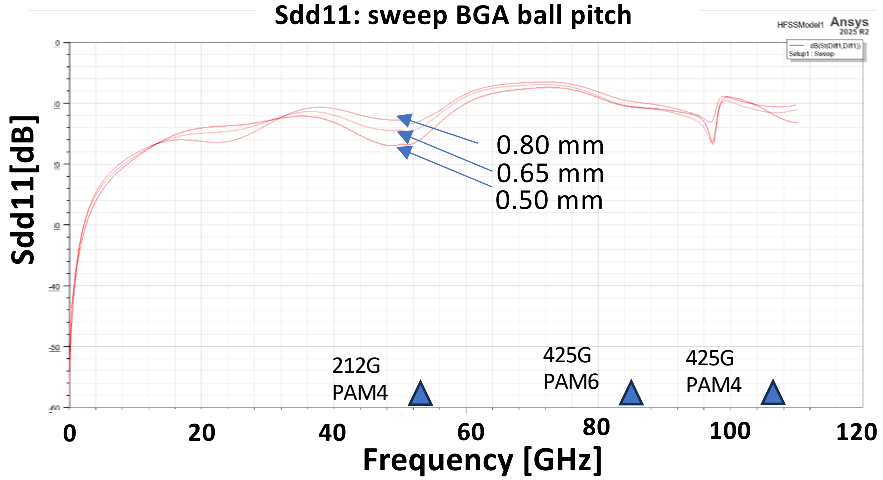
C.6 #7: BGA pitch-family

- BGA pitch optimization provides additional improvement, but it is secondary compared with TGV height and resonance control.



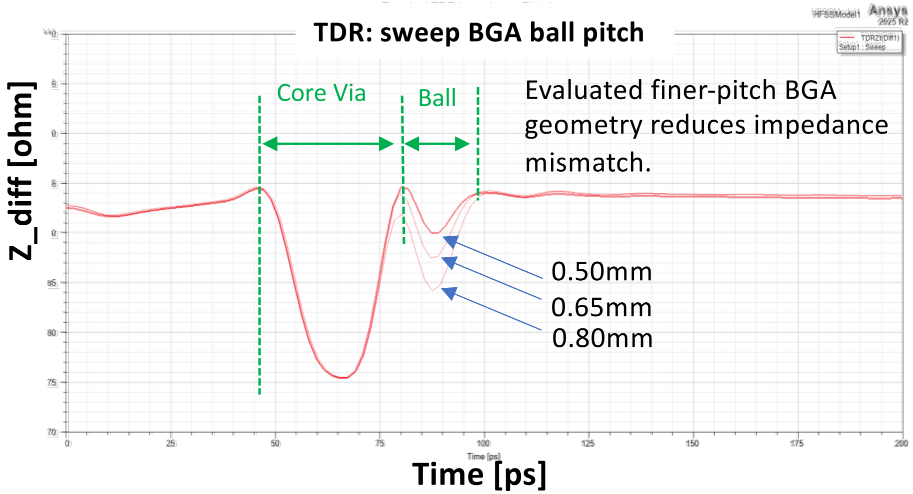
	pitch	diameter	74.7GHz	110GHz
1	0.50 mm	0.30 mm	3.468 dB	4.063 dB
2	0.65 mm	0.40 mm	3.761 dB	4.222 dB
3	0.80 mm	0.50 mm	4.146 dB	4.325dB

Evaluated finer-pitch BGA geometry reduces IL.



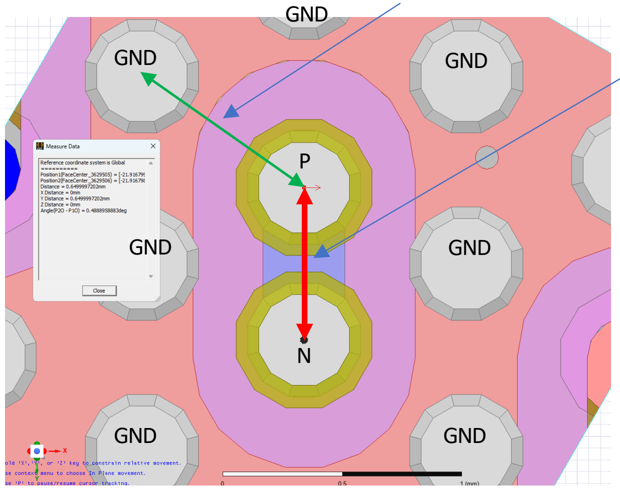
#	parameter	(A) straight
(1)	TGV height	1.28 mm
(2)	TGV pitch	0.50 mm
(3)	TGV diameter	0.20 mm
(4)	TGV pad	0.30mm
(5)	ball pitch	see table below
(6)	material	alkali-free glass
(7)	Dk/Df	5.10/11e-3
(8)	shape	straight

unit [mm]



Evaluated finer-pitch BGA geometry reduces impedance mismatch.

0.80 mm (when P/N is 0.80mm)



Sweep P/N pair BGA ball pitch and associated parameters. (See table below.)

#	BGA pitch	ball diameter	BGA pad	BGA SRO	ball stand off
1.	0.50	0.30	0.375	0.275	0.20
2.	0.65	0.40	0.450	0.350	0.30
3.	0.80	0.50	0.500	0.400	0.40

- Ball diameter, pad size, SRO (solder resist opening) and ball stand off are also swept.

- GND balls are not moved.

The evaluated finer-pitch BGA geometry set shows lower insertion loss, and lower return loss.

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E. Q/A (backup)

Q1: Why glass?
A1: Glass itself is not the benefit. The benefit comes from
- **thinner core**
- **finer TGV**
- **dimensional control**
- **lower skew**

Q2: How much improvement is needed for 425G?
A2: This work focuses on identifying dominant package limitations and technology directions.
Full link feasibility remains future work

Q3: Why BGA-side instead of direct attach from surface-side (CPC like)?
A3: Because some of current NPO activities assume BGA-side interfaces.
This study evaluates whether future package technologies can extend that architecture.

Q4: Why not a thinner organic core?
A4: Glass is only one candidate. The key observation is that shorter core-via height improves resonance behavior.
A thinner organic core may become mechanically challenging for large package sizes, depending on package size, stack-up, and warpage requirements.
Glass-core is one candidate because industry reports suggest it may enable thinner core structures, finer via pitch, and better dimensional control.

E. Q/A (backup)

Q5: Why is glass considered?
A5: Glass itself is not the key conclusion.
This study indicates that shorter core-via structures provide significant benefit.
Glass-core technology is one possible enabler.

Q6: Does this contribution claim 425G feasibility?
A6: No. This contribution identifies dominant package sensitivities and potential technology directions.
Complete link feasibility remains future work.

Q7: Why use a correlated model rather than measurement only?
A7: Measurement establishes the baseline organic core package behavior.
The correlated model is used to explore parameter sensitivities beyond the measured structures and materials.

Q8: Why does this work use 425G rather than 400Gb/s?
A8: The exact rate is not the conclusion of this contribution. The study focuses on package sensitivity trends in the >80GHz frequency region.

Q9: Is glass required?
A9: No. The key observation is the benefit of reduced core-via electrical length. Glass-core is one possible enabler.

Q10: How much of the model is measurement-correlated?
A10: The organic based package trace, dimensions, material assumptions and measured structures were correlated.
Additional advanced package structures and materials are exploratory extrapolations from the correlated baseline model.

E. Q/A (backup)

Q11: Why wasn't COM evaluated?
A11: This contribution focuses on identifying dominant package sensitivities.
COM evaluation requires candidate package structures to be selected first.

Q12: Why not evaluate thinner organic cores?
A12: Thinner organic cores may become mechanically challenging for large package sizes depending on stack-up, package size, and warpage requirements.
This work focuses on understanding the sensitivity to reduced core-via electrical length rather than promoting a specific material.

Q13: Are you proposing that glass-core substrates should be assumed for the 400GPL COM reference package?
A13: The objective of this contribution is not to specify a particular substrate material for standardization, but rather to demonstrate the sensitivity of channel feasibility to physical parameters such as 'thinner core' and 'finer via density'. We would like to discuss whether future studies should consider advanced packaging technologies (e.g., thin-core / glass structures) as sensitivity boundaries, alongside the legacy organic baseline."

Q14: The improvement from reducing the BGA ball pitch (0.8 mm -> 0.5 mm) appears to be relatively small. What is your perspective on this?
A14: In this model, the GND via arrangement on the PCB side is intentionally kept fixed (non-optimized) to isolate the sensitivity of the BGA transition itself. In practical implementations, finer BGA pitch scaling enables package size reduction—which may enable package size reduction, which can potentially reduce routing loss (shorter routing) and higher radix/lane density—offering substantially greater overall channel benefits.

End