L-2L De-embedding Techniques for Evaluation of Microstrip Die-Die Interconnect structure on the Interposer Technology

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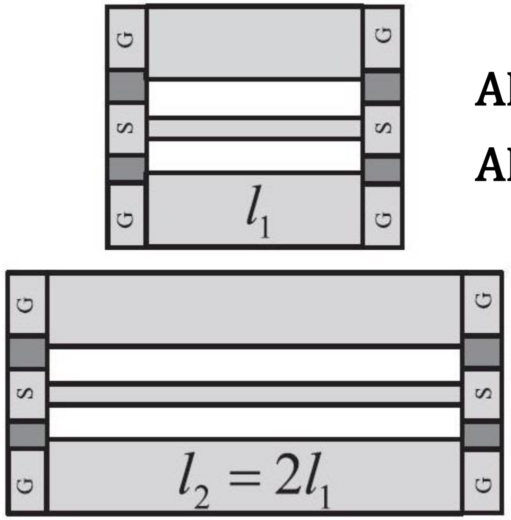
Outline

- Introduction of Theoretical L-2L de-embedding method:
  - Simple structure
  - **Microstrip line die-die interconnect**
- De-embedded results of Microstrip line die-die interconnect.
- Characteristics impedance de-embedded structure results.
- Weak points of L-2L de-embedding method.
- Conclusion.

Theoretical View of L-2L Method

- For the L-2L de-embedding method, the **measurement of two transmission lines is required**. The first transmission line is of **length L**, and the second transmission line is of **length 2L**. Additionally, probing pads are modeled as a shunt admittance, **Y=jωC**, followed by a series impedance, **Z=R+jωL**. **Pads are assumed to be symmetric**. Through use of network theory, the **ABCD matrix of a transmission line of length L, including probing pads, can be represented as the following cascade of ABCD matrices**:



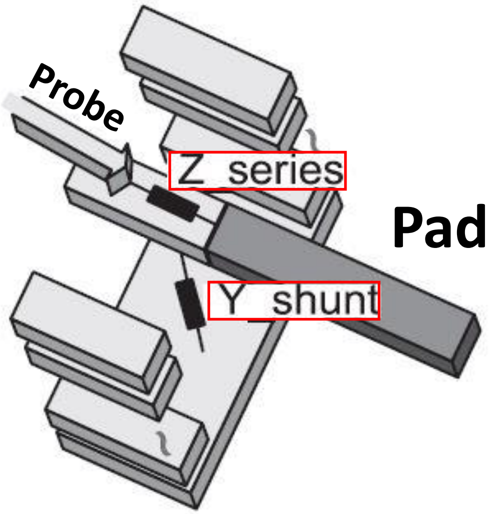
$$ABCD_{meas\_L} = ABCD_{LP} * ABCD_{L} * ABCD_{RP}$$
$$ABCD_{meas\_2L} = ABCD_{LP} * ABCD_{2L} * ABCD_{RP}$$

Where,

$ABCD_{LP}$: Represent the matrix of the left pad;

$ABCD_{L\&2L}$: Represent the matrix of the lines;

$ABCD_{RP}$: Represent the matrix of the left pad;



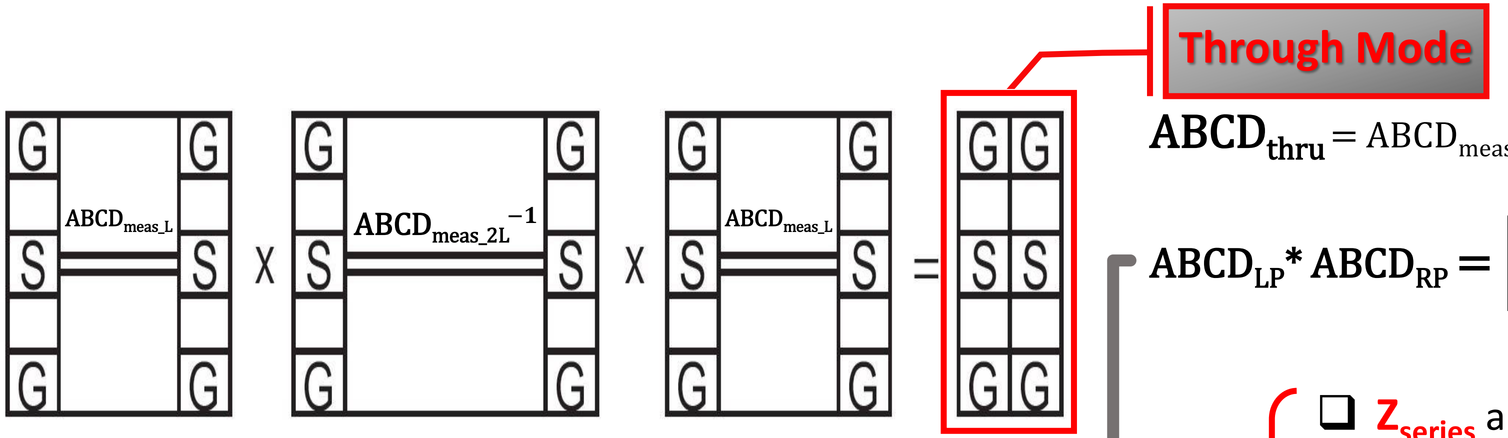
Pads:

$$ABCD_{RP} = ABCD_{Z\_series} * ABCD_{Y\_shunt}$$
$$ABCD_{LP} = ABCD_{Y\_shunt} * ABCD_{Z\_series}$$
$$ABCD_{Z\_series} = \begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix}$$
$$ABCD_{Y\_shunt} = \begin{bmatrix} 1 & 0 \\ Y & 1 \end{bmatrix}$$

Ref: De-embedding techniques for transmission lines: An exploration, review, and proposal, 2013

Ref: Evaluation of a Multi-Line De-embedding Technique up to 110GHz for Millimeter-Wave CMOS Circuit Design

Theoretical View of L-2L Method

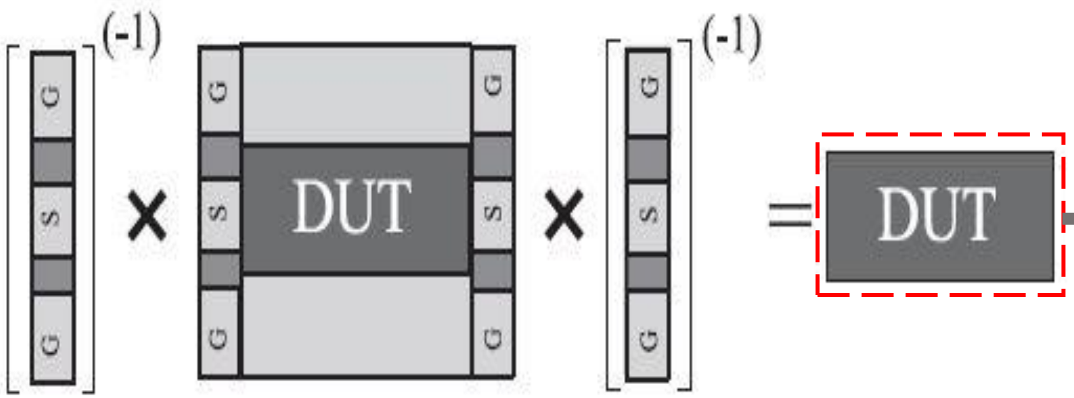


Ref: Evaluation of a Multi-line De-embedding Technique for Millimeter-Wave CMOS Circuit Design_ Proceeding of Asia-Pacific Microwave Conference

$$ABCD_{thru} = ABCD_{meas\_L}{}^{*}\, ABCD_{meas\_2L}{}^{-1*}\, ABCD_{meas\_L} = \boxed{ABCD_{LP}{}^{*}\, ABCD_{RP}}$$

$$ABCD_{LP}{}^{*}\, ABCD_{RP} = \begin{bmatrix} 2Y_{shunt}Z_{series}+1 & 2Z_{series} \\ 2Y_{shunt}(Y_{shunt}Z_{series}+1) & 2Y_{shunt}Z_{series}+1 \end{bmatrix}$$

- ❑ Z_{series} and Y_{shunt} are extracted from the **$ABCD_{thru}$** and placed in **$ABCD_{LP}$** and **$ABCD_{RP}$**
- ❑ $ABCD_{LP} = \begin{bmatrix} 1 & Z_{series} \\ Y_{shunt} & Y_{shunt}Z_{series}+1 \end{bmatrix}$
- ❑ $ABCD_{RP} = \begin{bmatrix} Y_{shunt}Z_{series}+1 & Z_{series} \\ Y_{shunt} & 1 \end{bmatrix}$



$$ABCD_{L} = ABCD_{LP}{}^{-1}\, {}^{*}ABCD_{meas\_L}{}^{*}\, ABCD_{RP}{}^{-1}$$

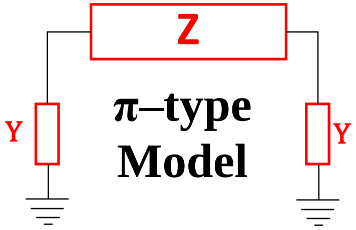
$$ABCD_{2L} = ABCD_{LP}{}^{-1}\, {}^{*}ABCD_{meas\_2L}{}^{*}\, ABCD_{RP}{}^{-1}$$

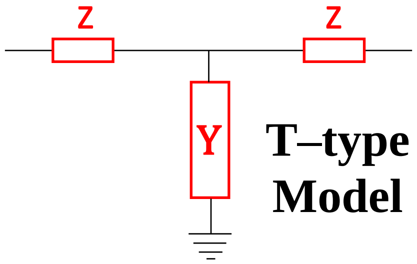
Ref: Evaluation of a Multi-Line De-embedding Technique up to 110GHz for Millimeter-Wave

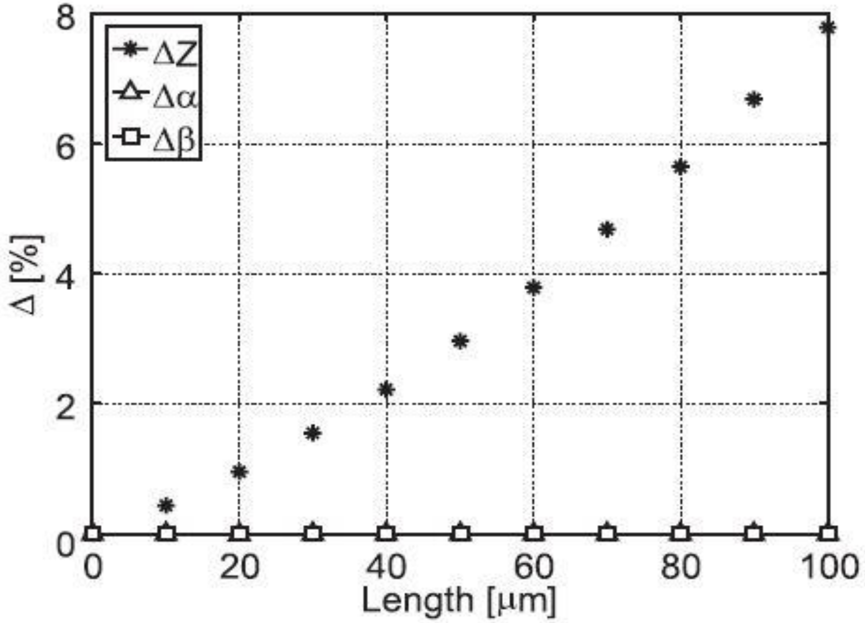
Theoretical View of L-2L Method

- By using the measured S-Parameter the parasites of the pad can be calculated which is modeled as a **π–type** **or** **T–type** lumped constant circuit. However, in **through-only** method, **the length of the through-line is required to be very short** to match with the π–type lumped model.

$$\Delta = \left| \frac{X^{L-2L} - X^{L}}{X^{L}} \right|$$





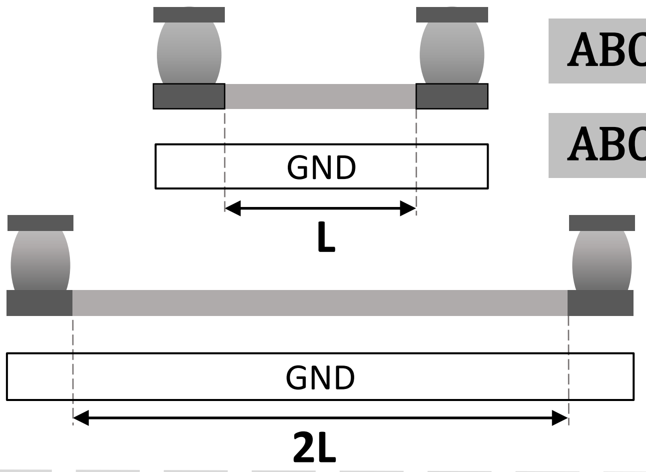


Ref: Ning Li," Evaluation of a Multi-Line De-Embedding Technique up to 110 GHz for Millimeter-Wave CMOS Circuit Design" , February 2010 IEICE Transactions

- **The parasitic contribution** of the extra grounded metal strip **cannot be ignored** **if the frequencies are high or if the device under test (DUT) structures are large**.

Ref: H. Cho, "A Novel Transmission-Line De-embedding Technique for RF Device Characterization," in IEEE Transactions on Electron Devices, vol, 2009

Theoretical View of L-2L Method (Microstripline)



$$ABCD_{meas\_L} = ABCD_{LS} * ABCD_{L} * ABCD_{RS}$$

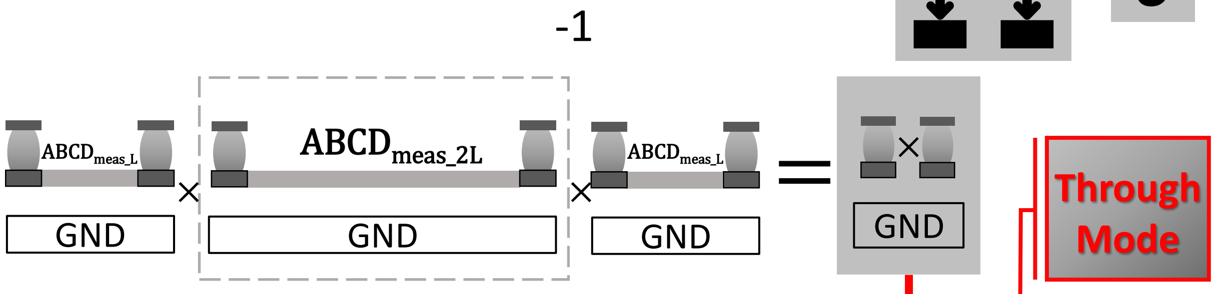
$$ABCD_{meas\_2L} = ABCD_{LS} * ABCD_{2L} * ABCD_{RS}$$

Where,

$ABCD_{LS}$: Represent the matrix of the left **Bump+Pads**;

$ABCD_{L\&2L}$: Represent the matrix of the **lines**;

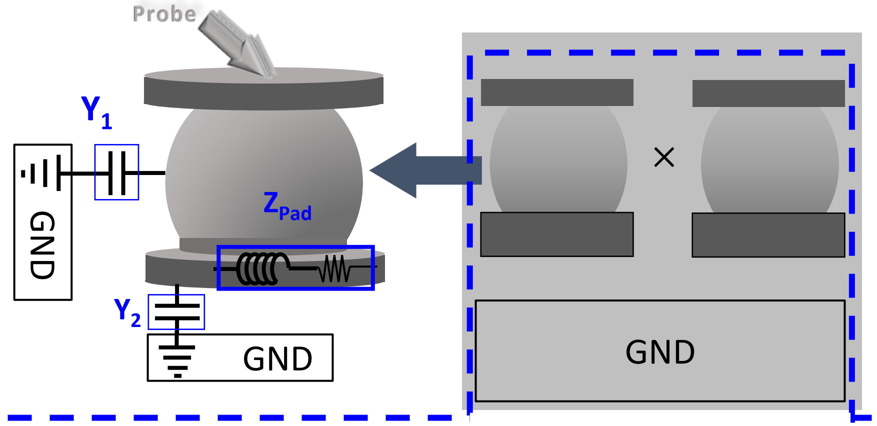
$ABCD_{RS}$: Represent the matrix of the right **Bump+Pads**;

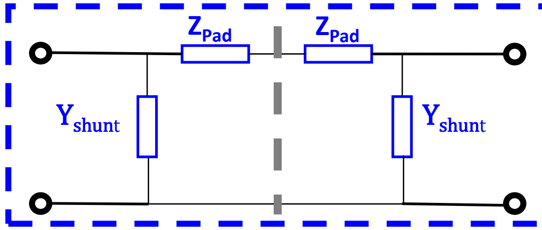


$$ABCD_{thru} = ABCD_{meas\_L} * ABCD_{meas\_2L}^{-1} * ABCD_{meas\_L} = ABCD_{LS} * ABCD_{RS}$$

Through mode:

***π*-Type**



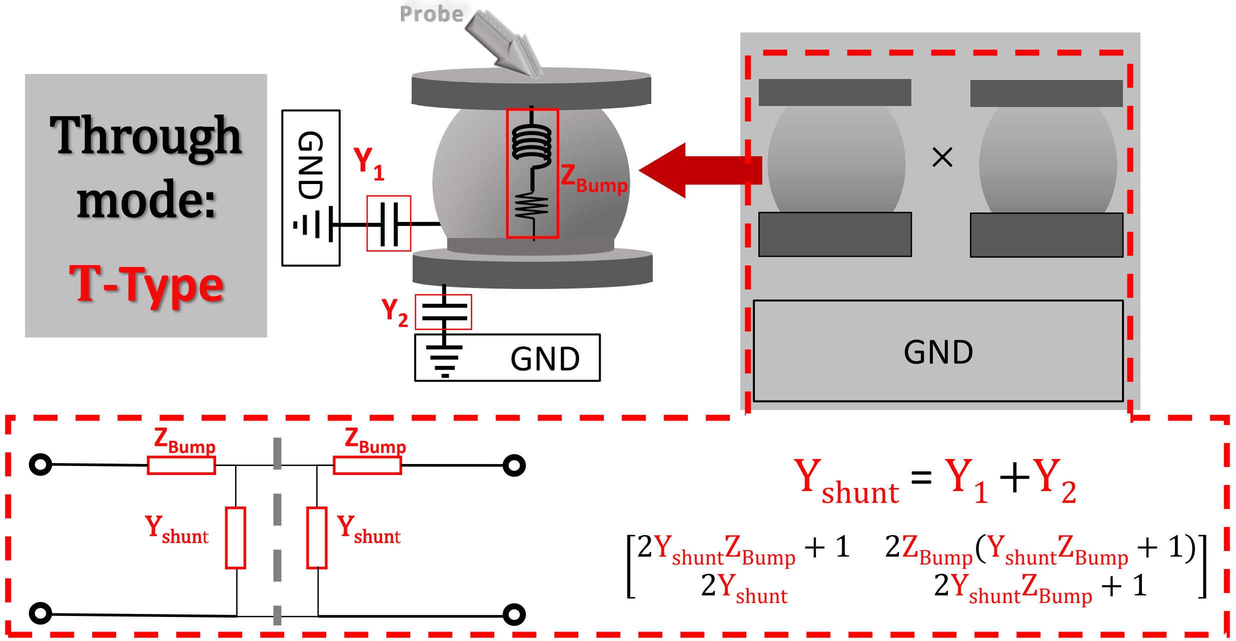


$$Y_{shunt} = Y_1 + Y_2$$

$$\begin{bmatrix} 2Y_{shunt}Z_{Pad} + 1 & 2Z_{Pad} \\ 2Y_{shunt}(Y_{shunt}Z_{Pad} + 1) & 2Y_{shunt}Z_{Pad} + 1 \end{bmatrix}$$

Through mode:

T-Type

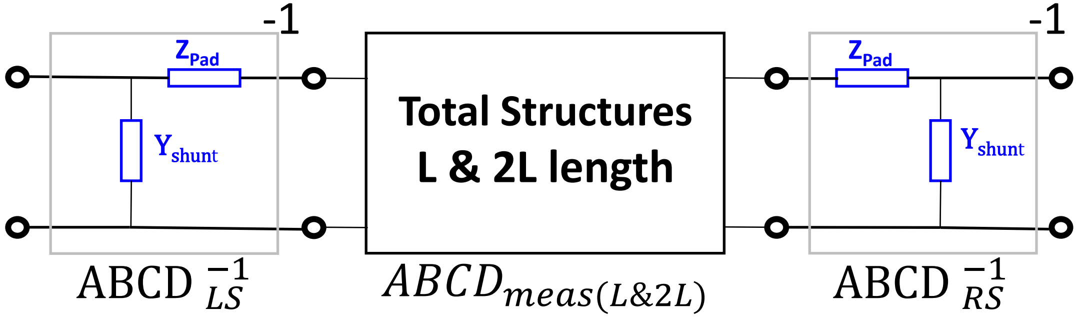


$$Y_{shunt} = Y_1 + Y_2$$

$$\begin{bmatrix} 2Y_{shunt}Z_{Bump} + 1 & 2Z_{Bump}(Y_{shunt}Z_{Bump} + 1) \\ 2Y_{shunt} & 2Y_{shunt}Z_{Bump} + 1 \end{bmatrix}$$

L-2L De-embedding Results(Microstripline)

π-Type

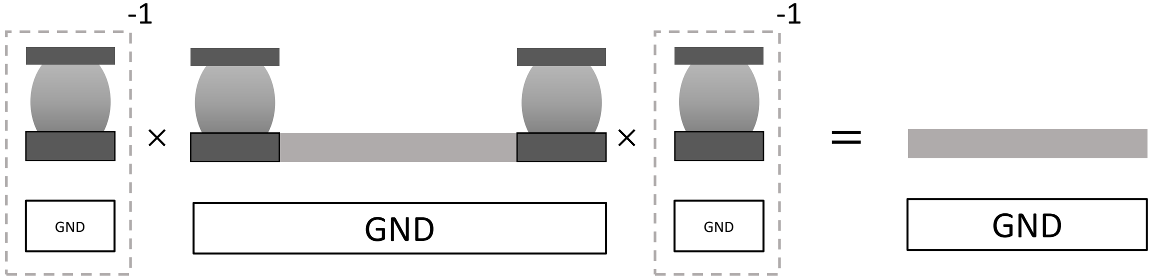


$$= \begin{bmatrix} \cosh\gamma\ell & Z_0\sinh\gamma\ell \\ \dfrac{\sinh\gamma\ell}{Z_0} & \cosh\gamma\ell \end{bmatrix}$$

$ABCD_{L\&2L}$

$$ABCD_{LS} = \begin{bmatrix} 1 & Z_{Pad} \\ Y_{shunt} & Y_{shunt}Z_{Pad}+1 \end{bmatrix}$$

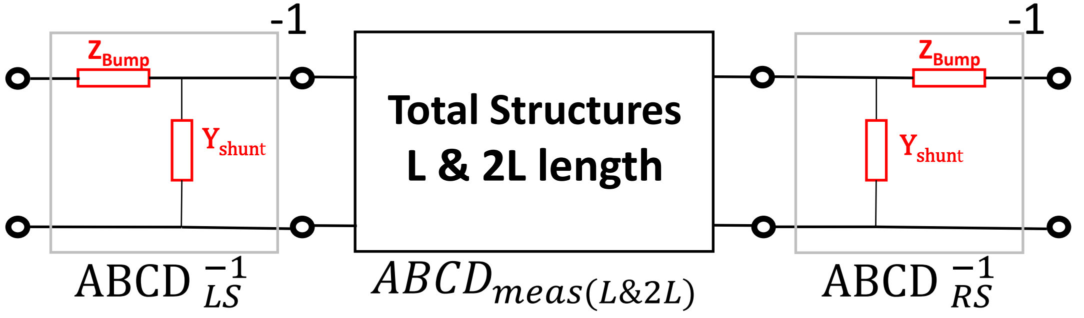
$$ABCD_{RS} = \begin{bmatrix} Y_{shunt}Z_{Pad}+1 & Z_{Pad} \\ Y_{shunt} & 1 \end{bmatrix}$$



$$\mathbf{ABCD_L} = ABCD_{LS}^{-1} * ABCD_{meas\_L} * ABCD_{RS}^{-1}$$

$$\mathbf{ABCD_{2L}} = ABCD_{LS}^{-1} * ABCD_{meas\_2L} * ABCD_{RS}^{-1}$$

T-Type

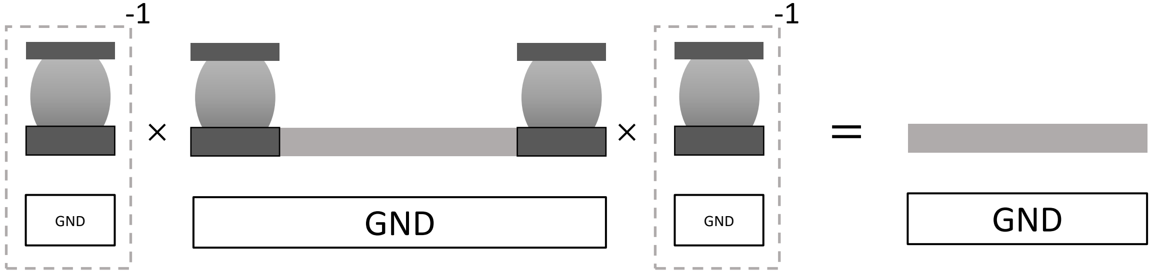


$$= \begin{bmatrix} \cosh\gamma\ell & Z_0\sinh\gamma\ell \\ \dfrac{\sinh\gamma\ell}{Z_0} & \cosh\gamma\ell \end{bmatrix}$$

$ABCD_{L\&2L}$

$$ABCD_{LS} = \begin{bmatrix} Y_{shunt}Z_{Bump}+1 & Z_{Bump} \\ Y_{shunt} & 1 \end{bmatrix}$$

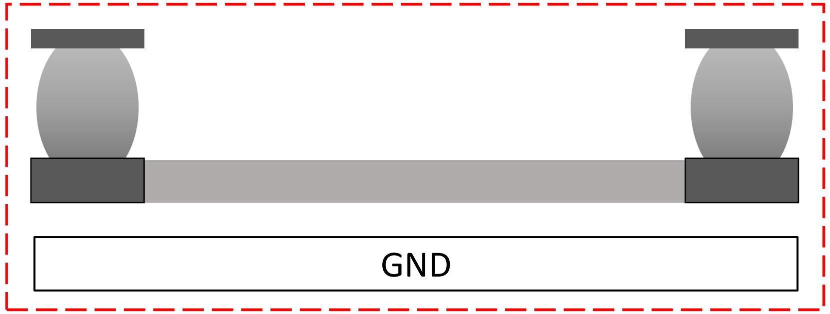
$$ABCD_{RS} = \begin{bmatrix} 1 & Z_{Bump} \\ Y_{shunt} & Y_{shunt}Z_{Bump}+1 \end{bmatrix}$$



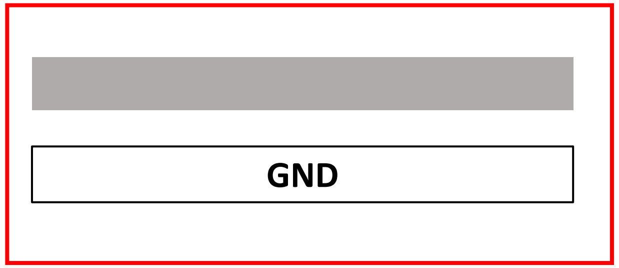
$$\mathbf{ABCD_L} = ABCD_{LS}^{-1} * ABCD_{meas\_L} * ABCD_{RS}^{-1}$$

$$\mathbf{ABCD_{2L}} = ABCD_{LS}^{-1} * ABCD_{meas\_2L} * ABCD_{RS}^{-1}$$

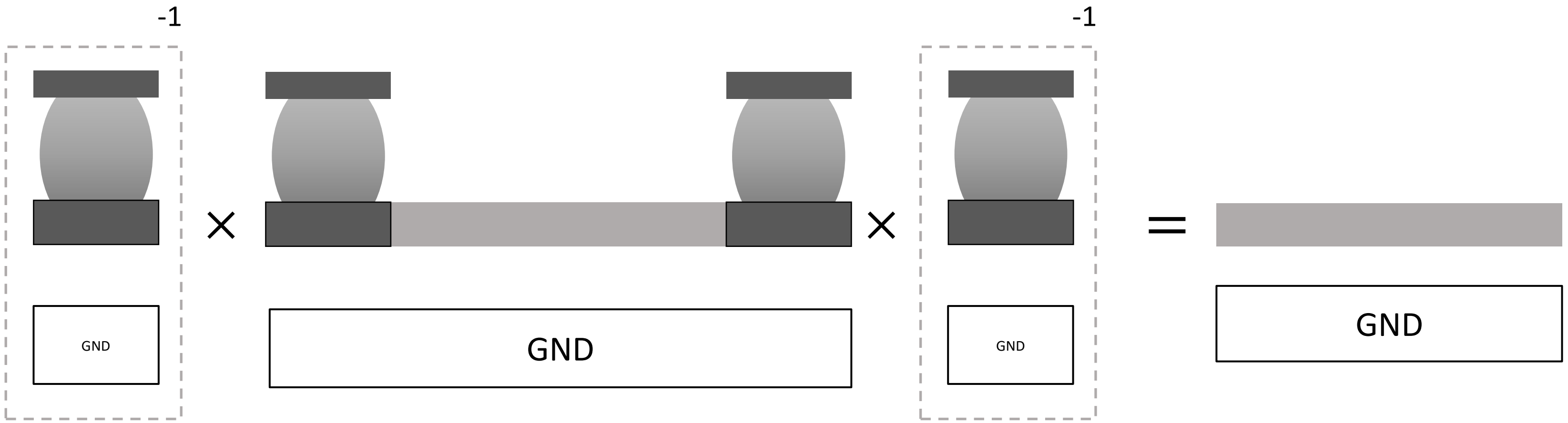
L-2L De-embedding Results(Microstripline)



Total Structure: From Simulation



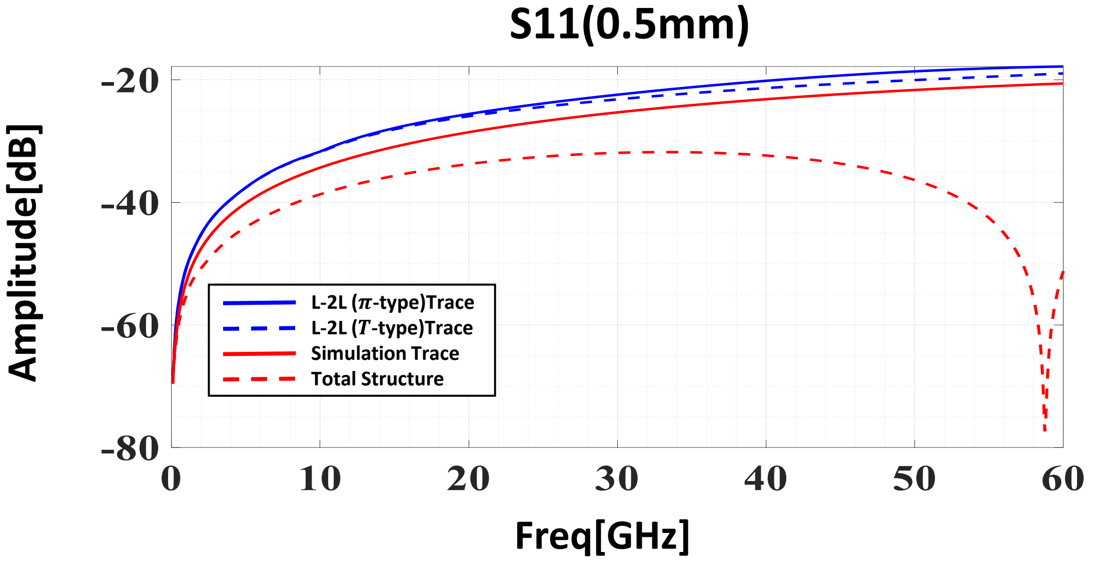
Trace: From Simulation

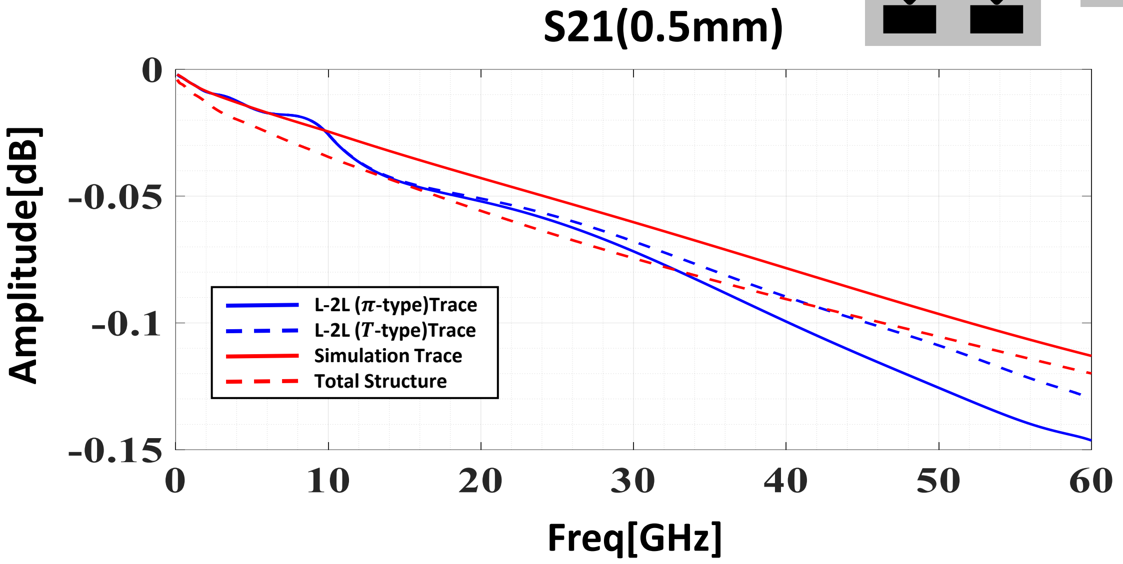


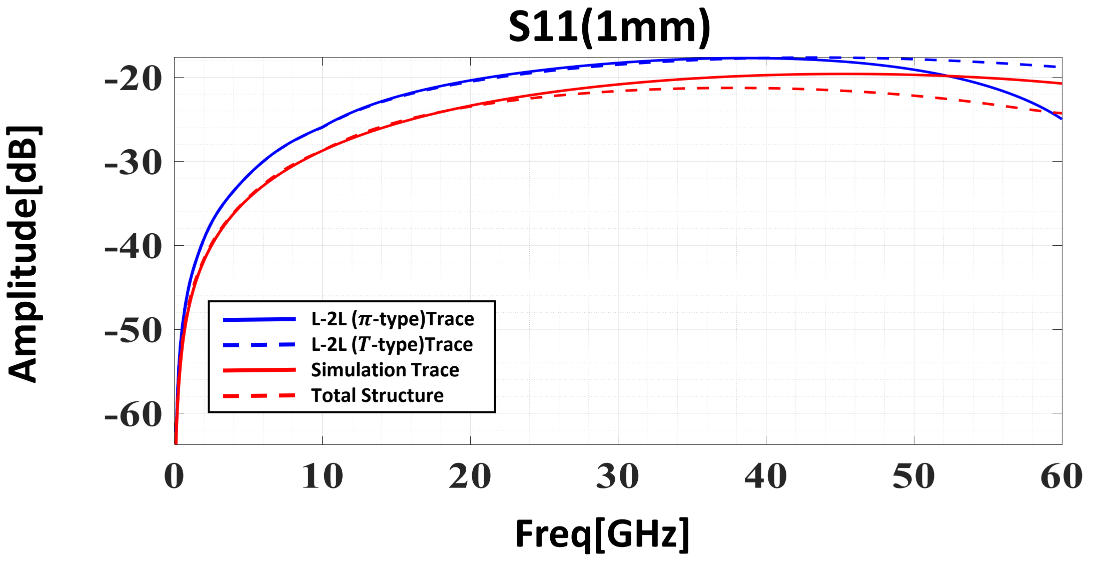
Trace: From L-2L De-embedding (T- Type)

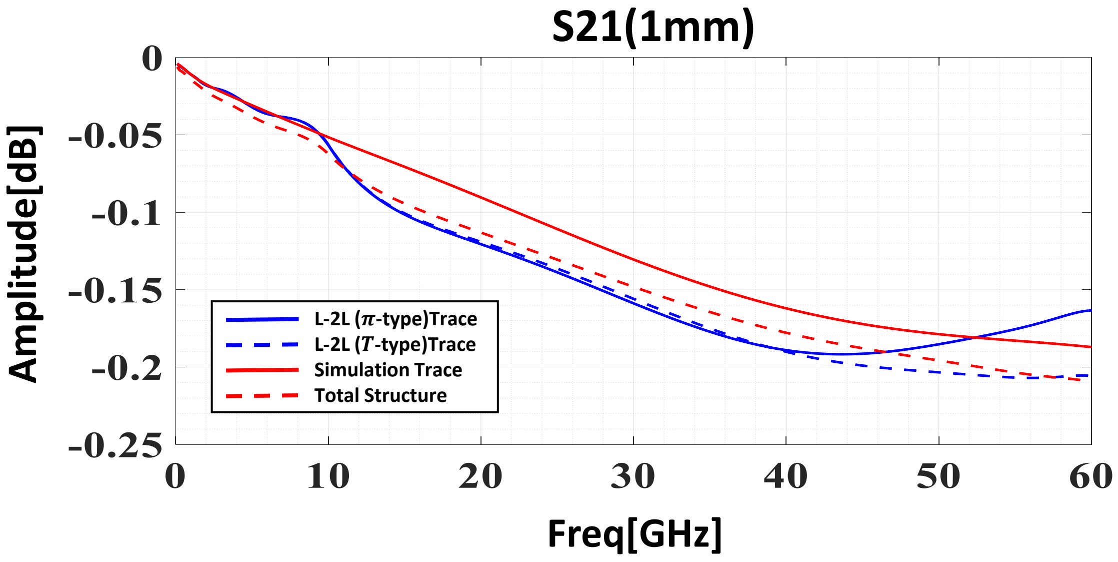
Trace: From L-2L De-embedding (π- Type)

L-2L De-embedding Results(Microstripline)

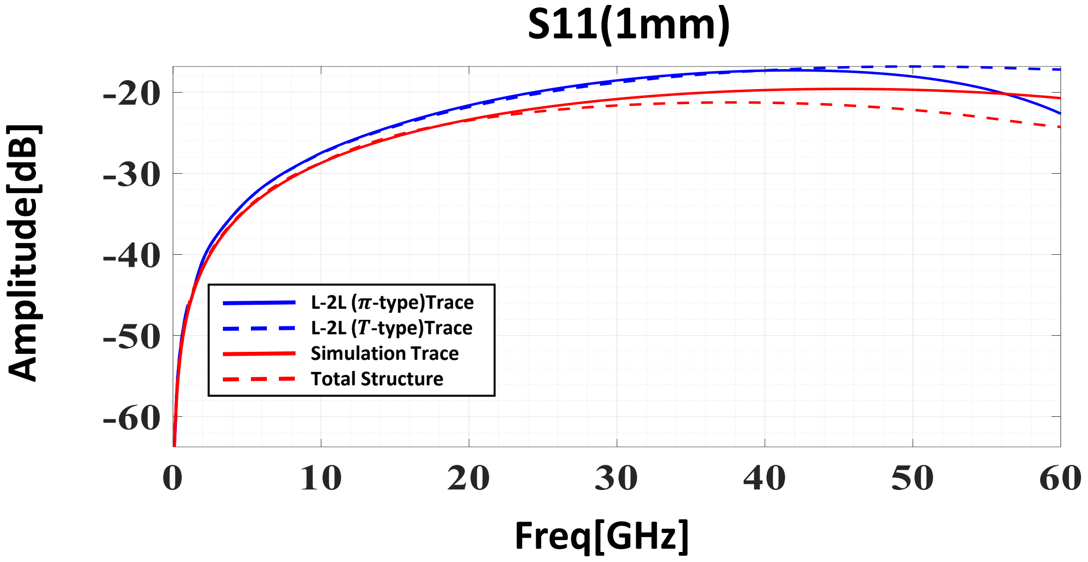


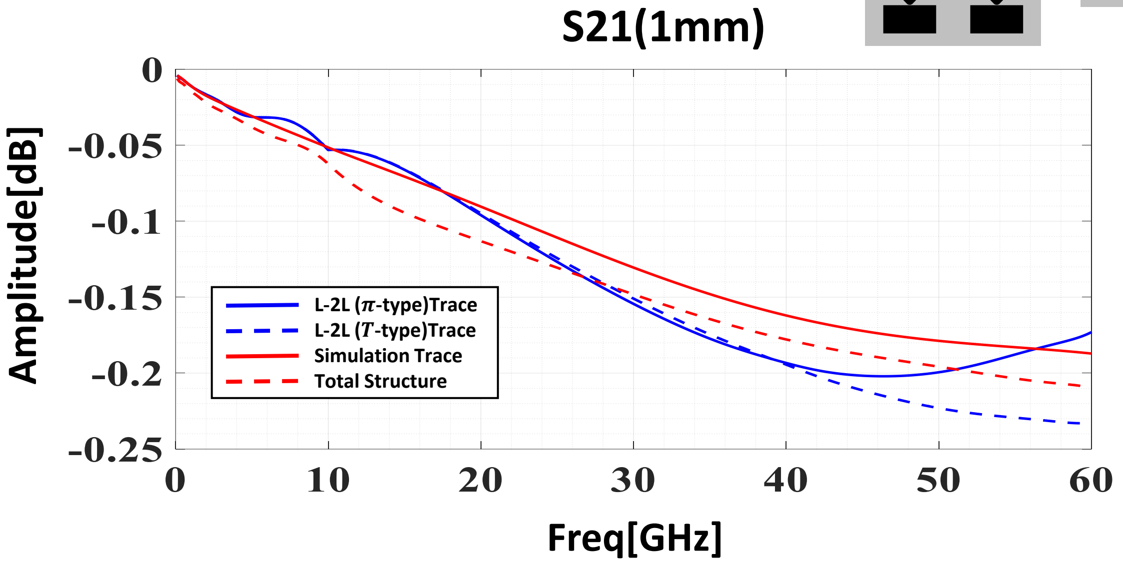


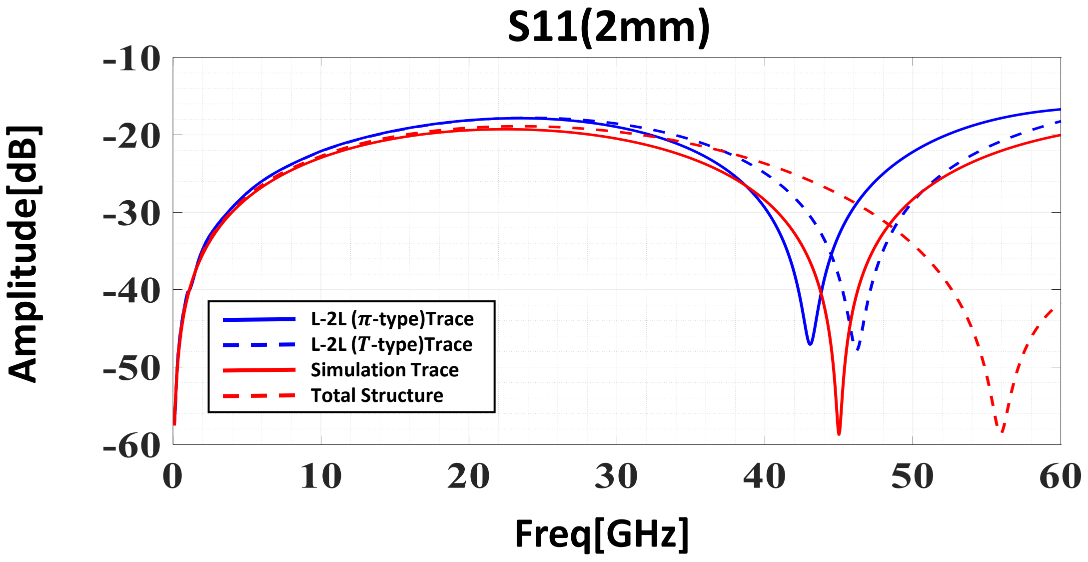


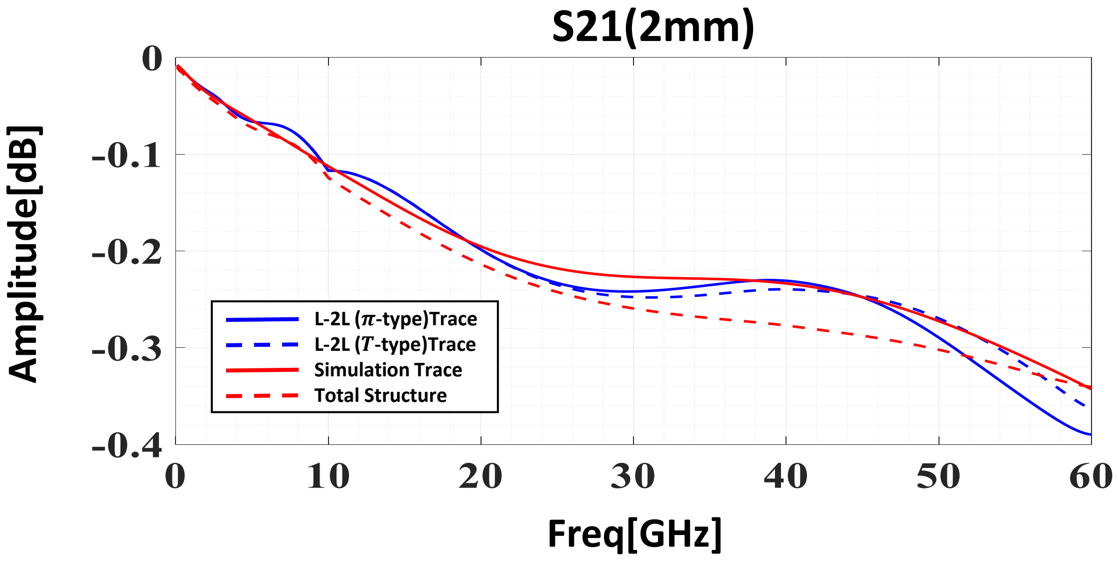


L-2L De-embedding Results(Microstripline)

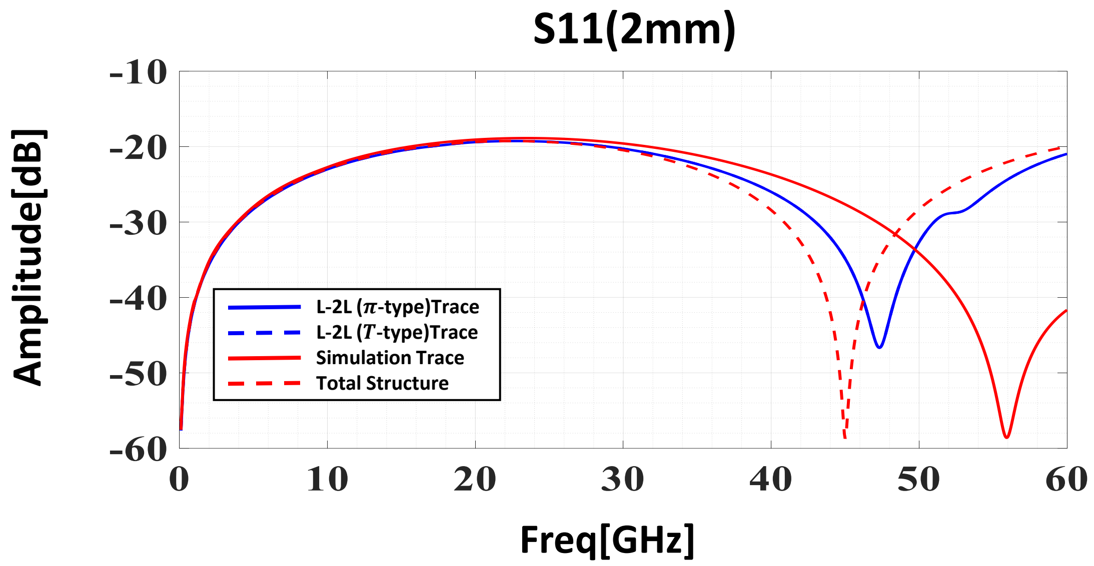


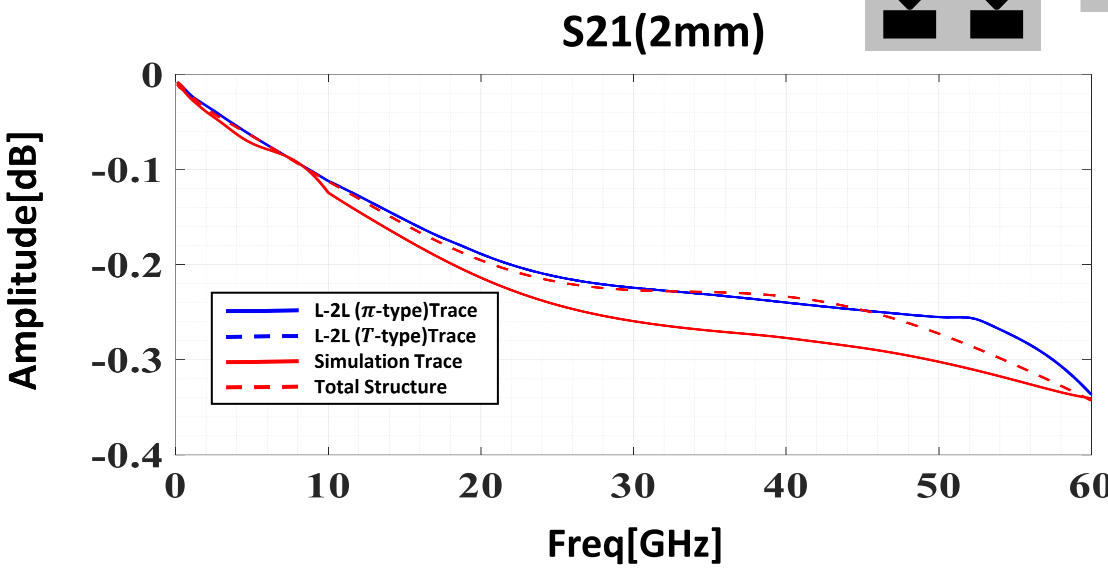


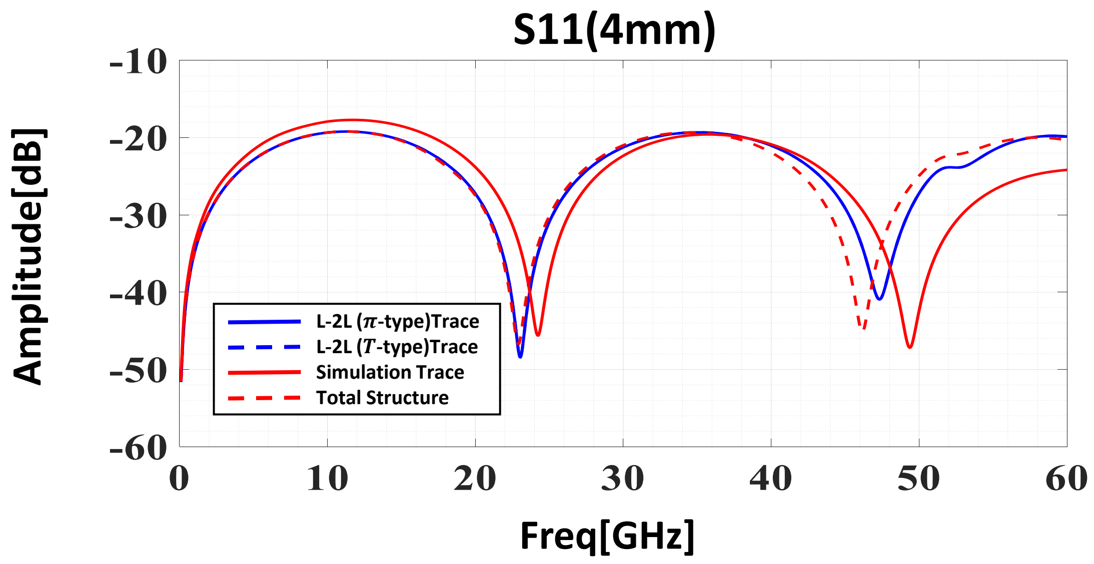


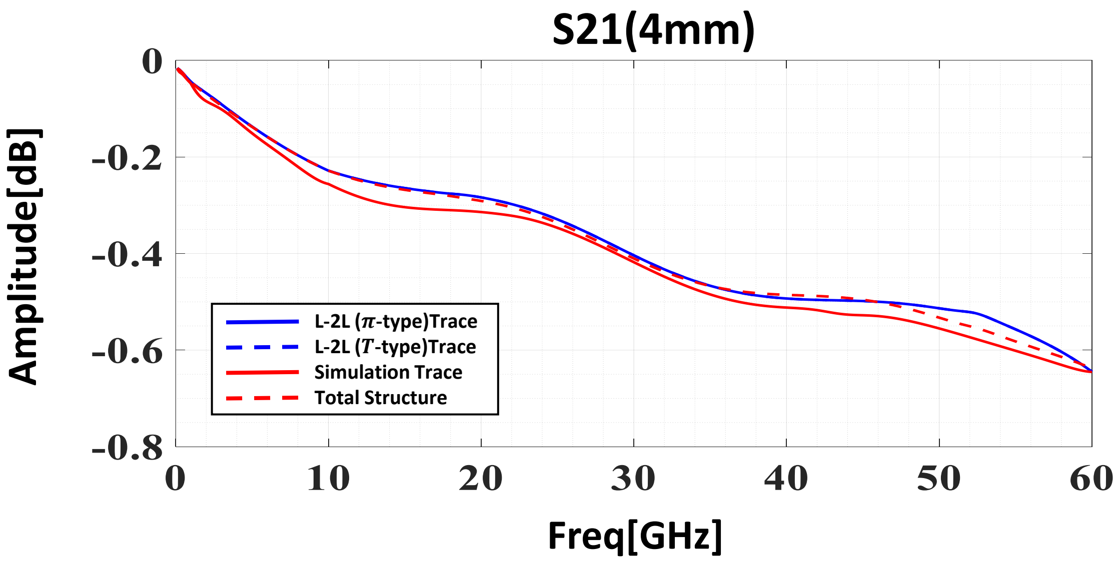


L-2L De-embedding Results(Microstripline)

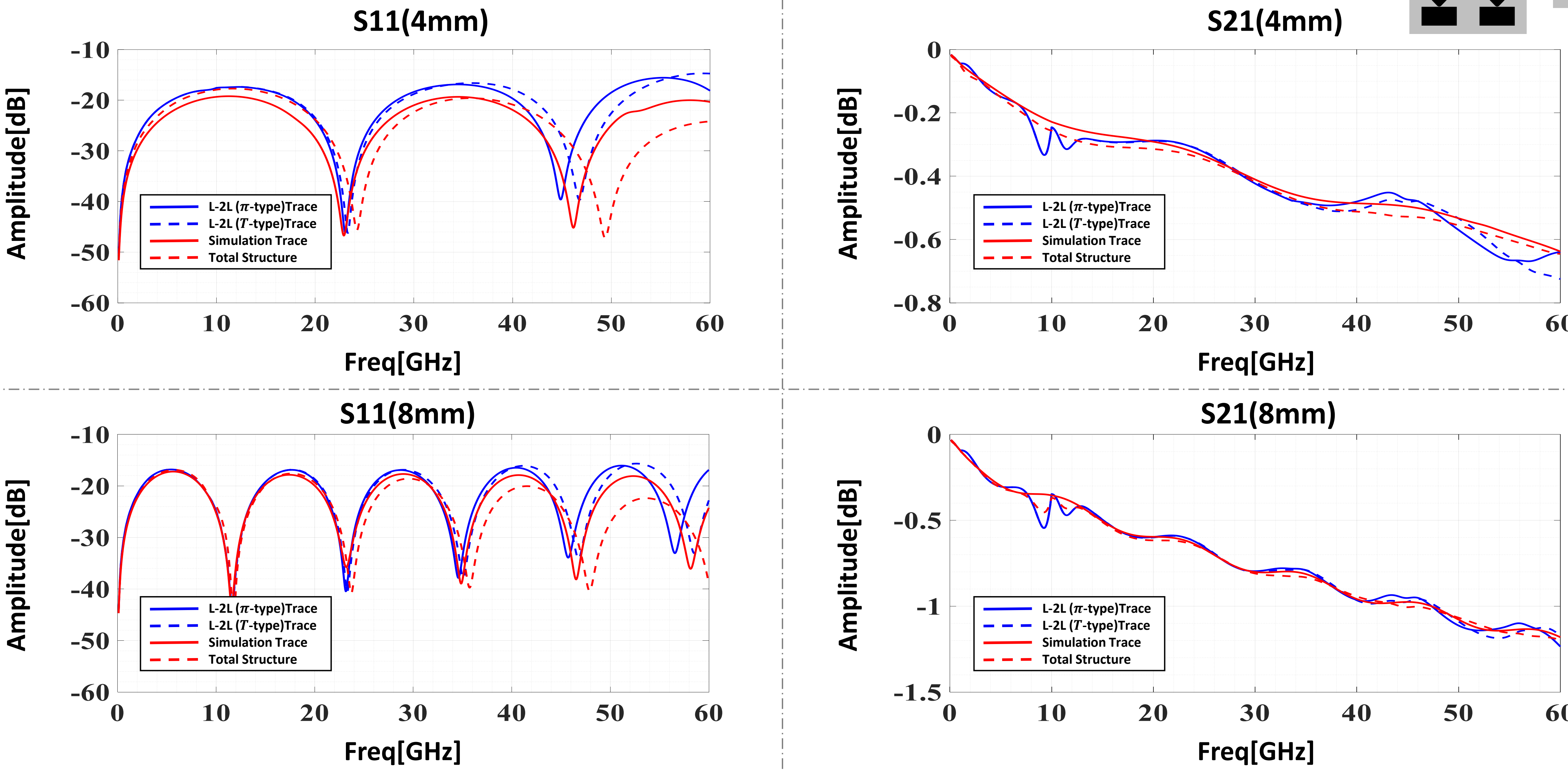




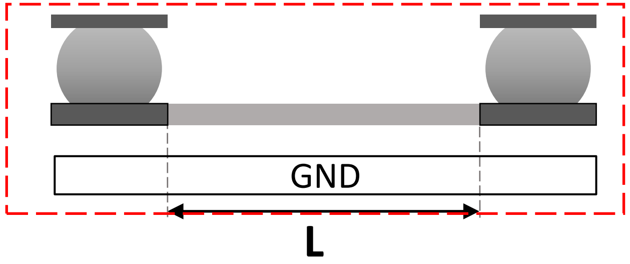




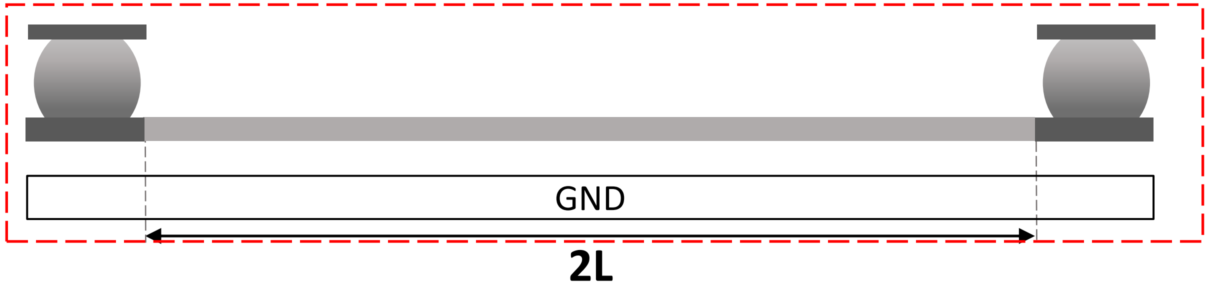
L-2L De-embedding Results(Microstripline)

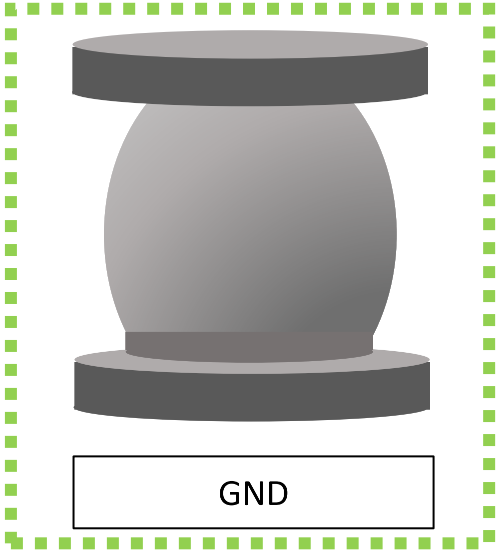


L-2L De-embedding π-Type Results (Microstripline)

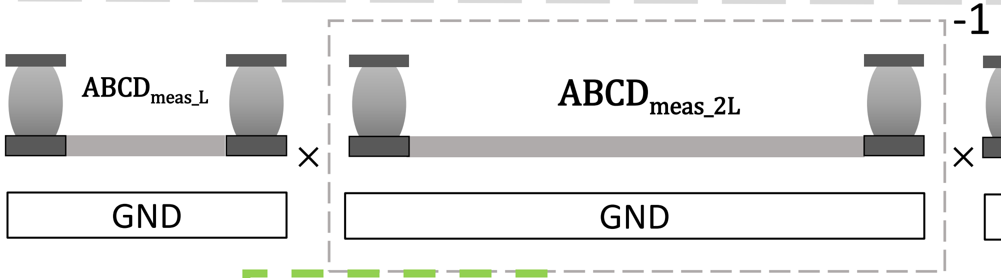


Total Structure:
From Simulation





Single Bump:
From L-2L
De-embedding



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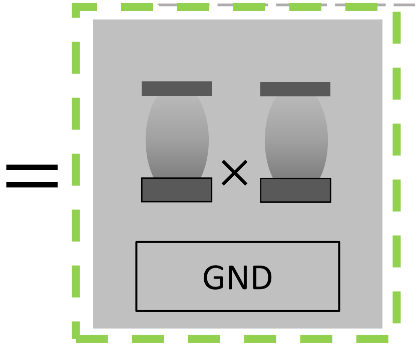
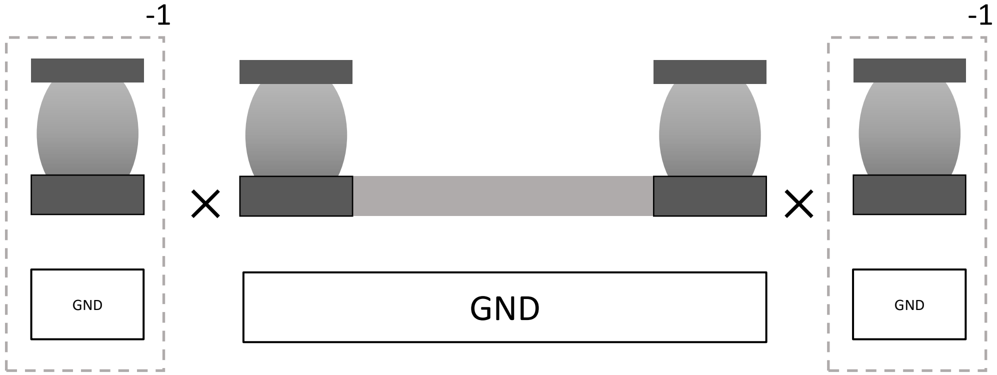


Coupling Bumps:
From L-2L
De-embedding



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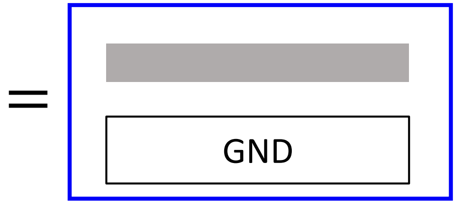
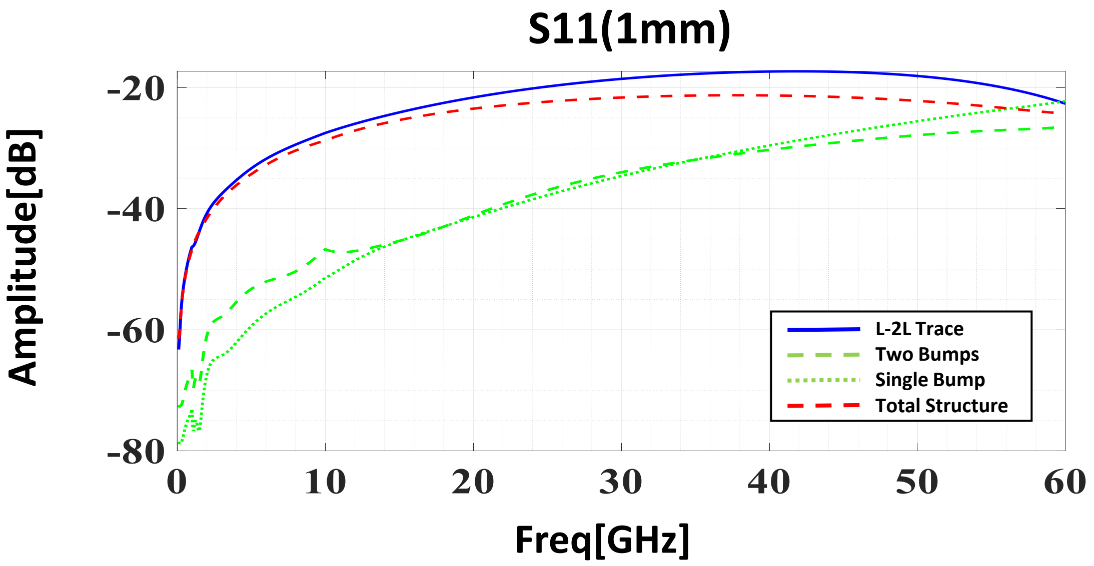
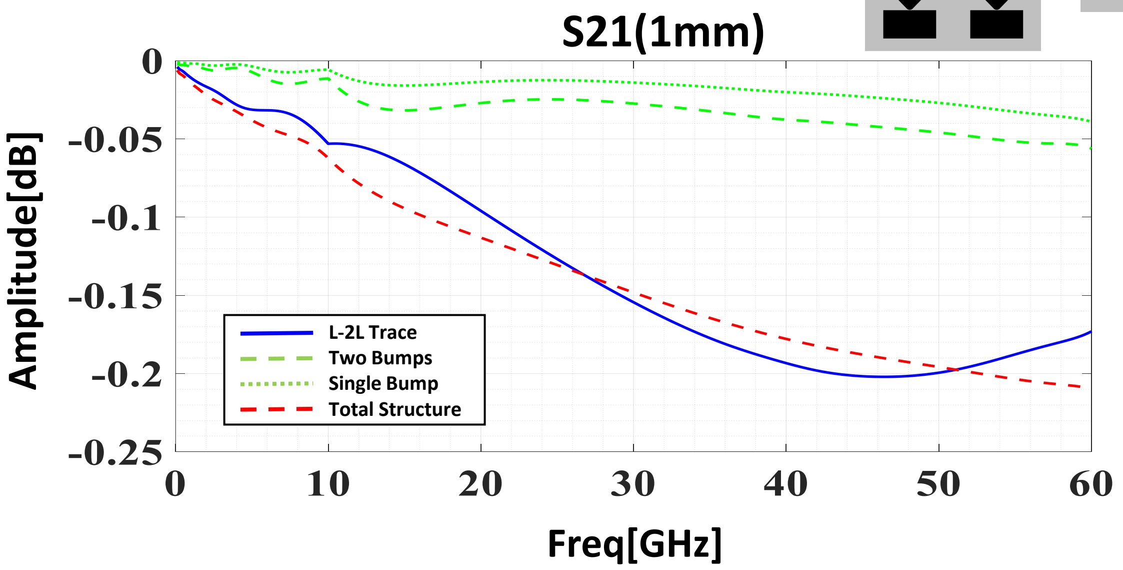
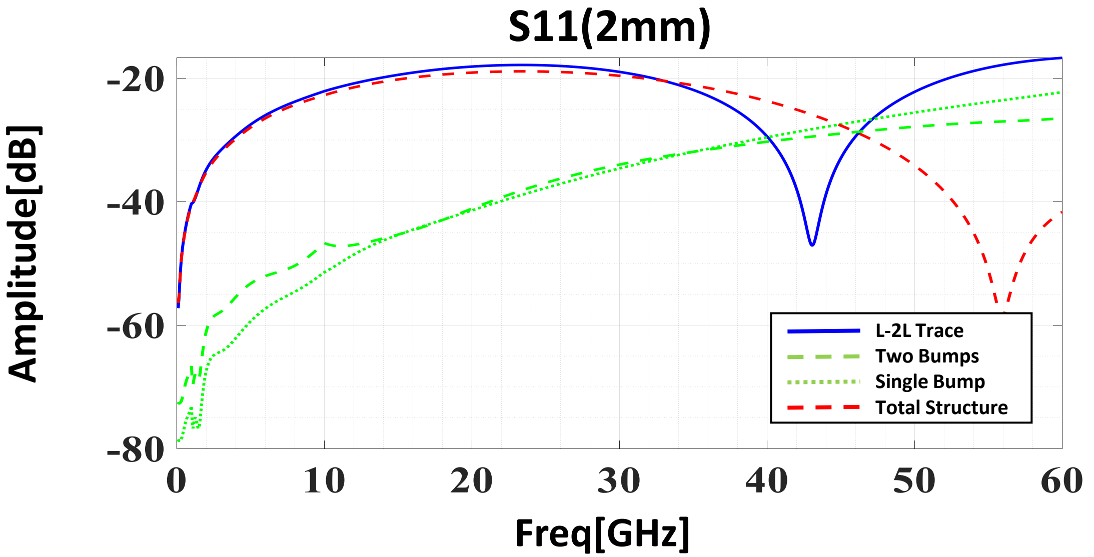


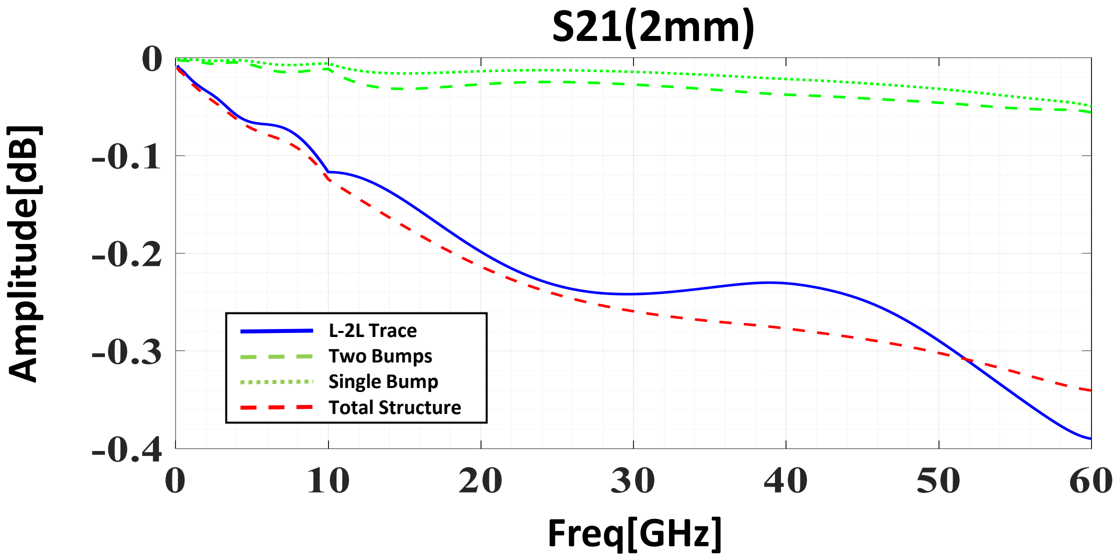
Trace: From L-2L
De-embedding

L-2L De-embedding π-Type Results(Microstripline)

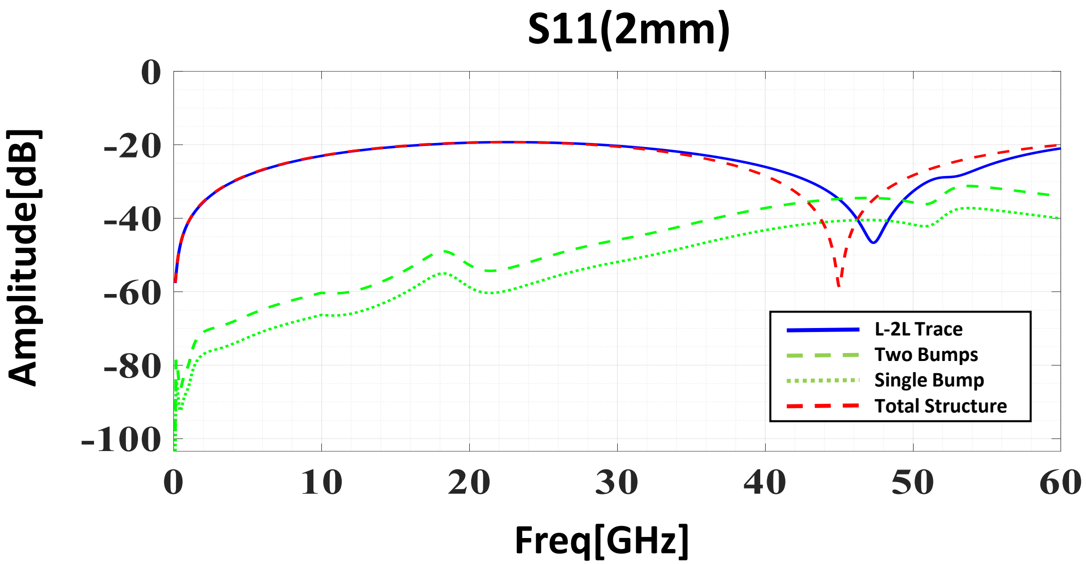


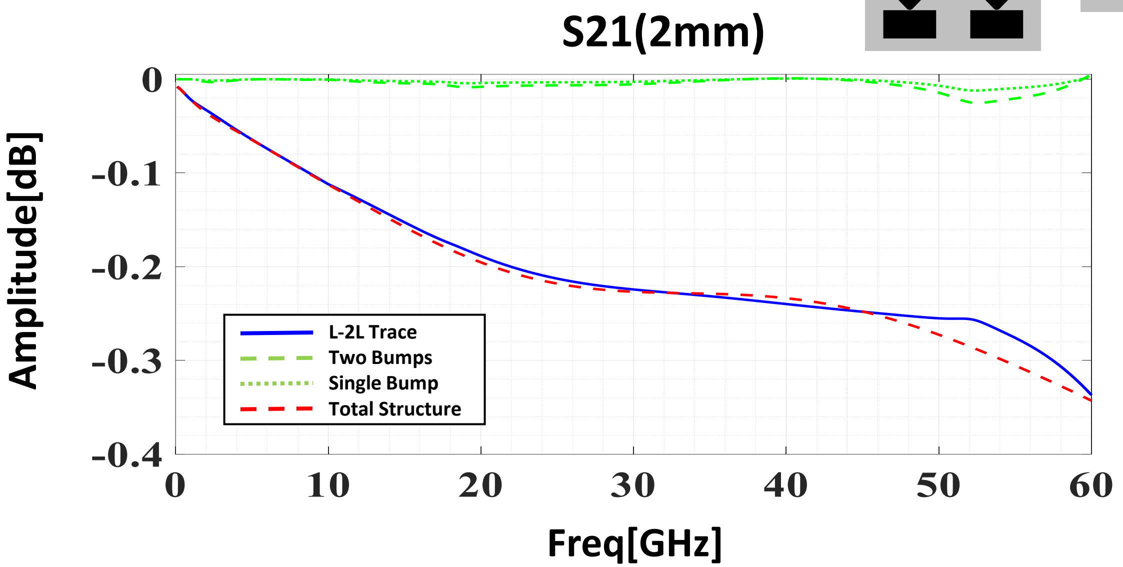


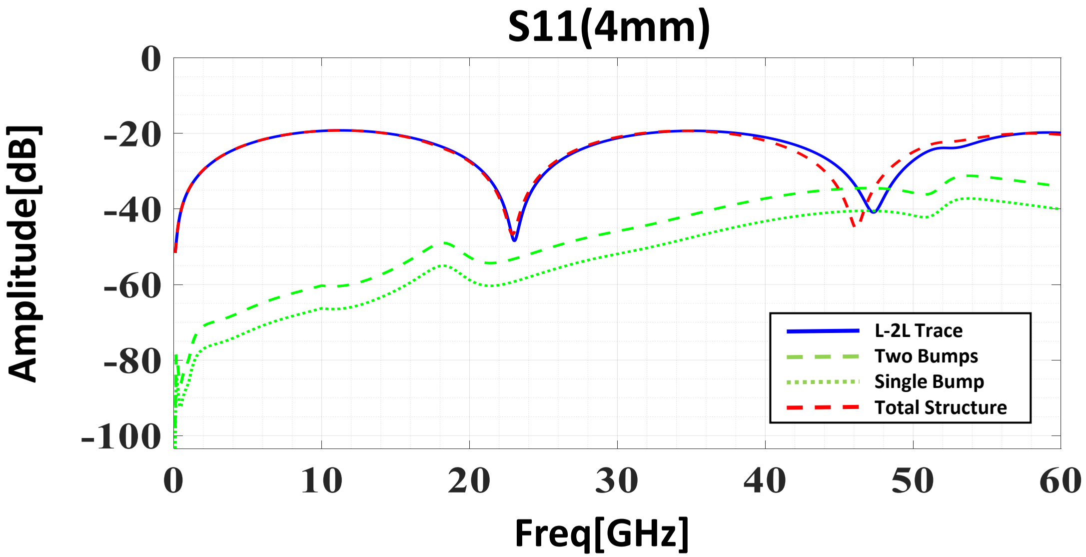


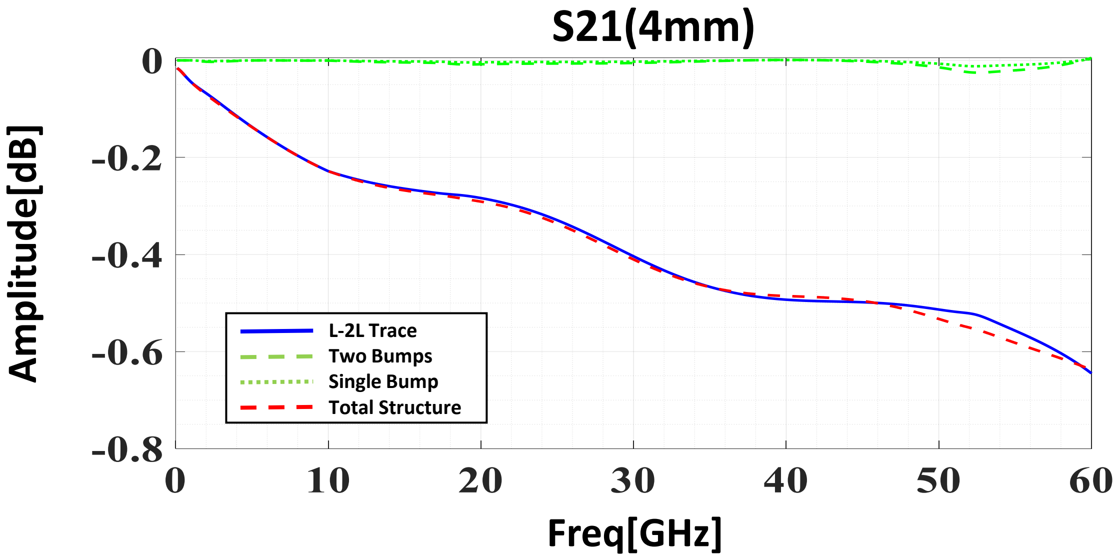


L-2L De-embedding π-Type Results(Microstripline)

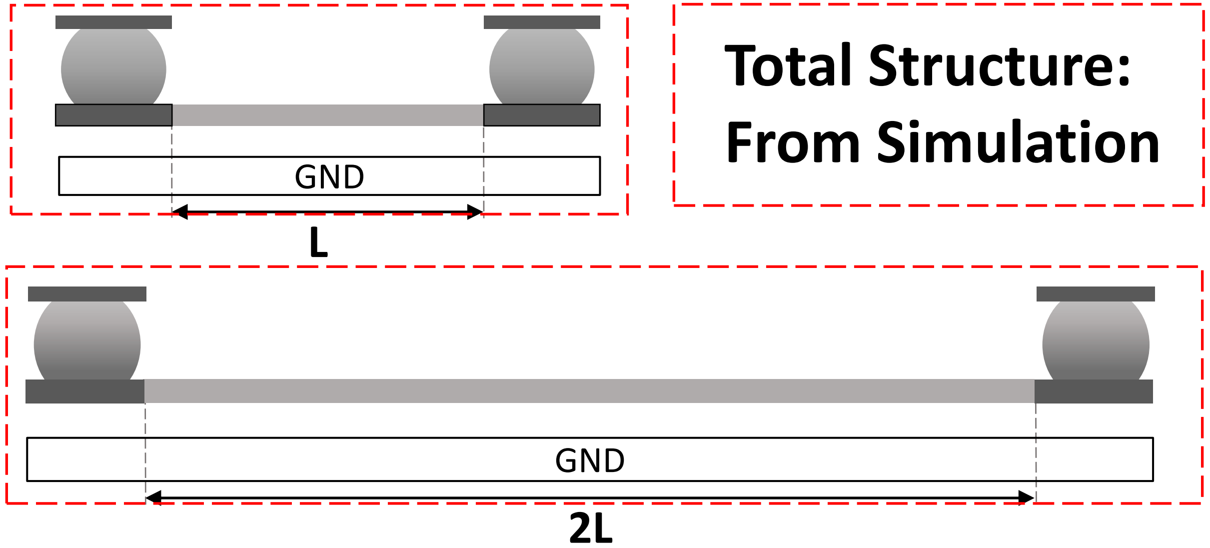




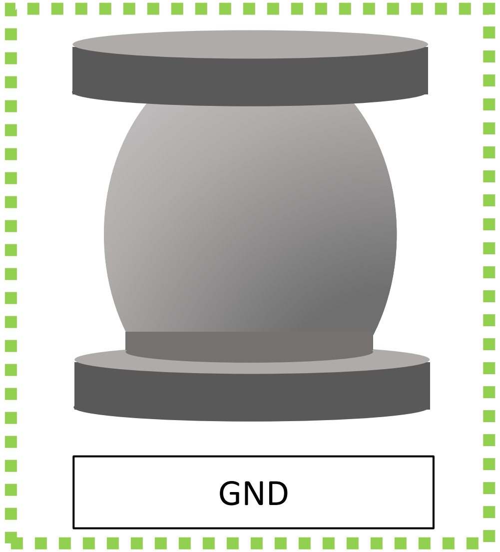




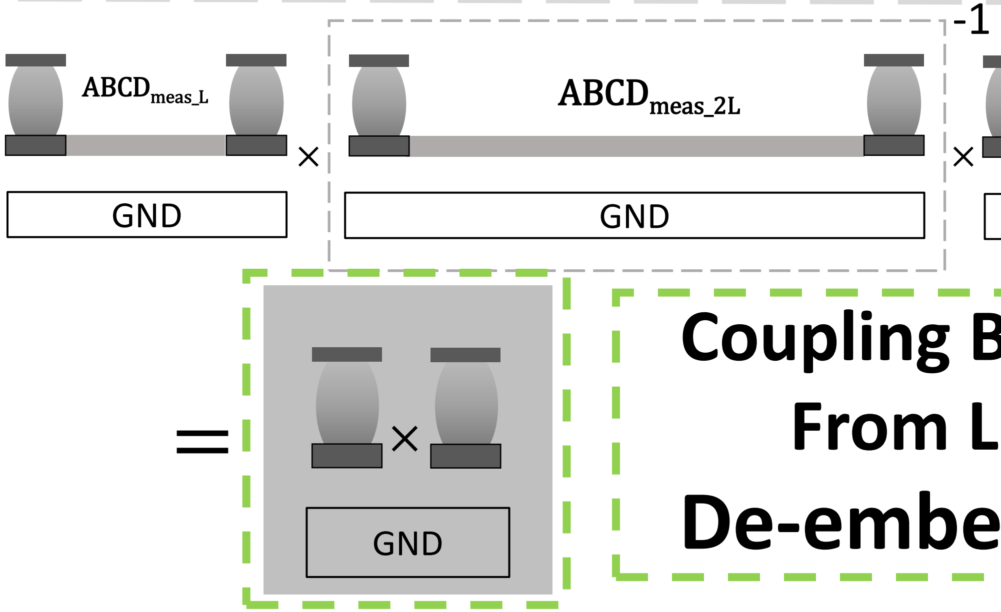
L-2L De-embedding T-Type Results(Microstripline)



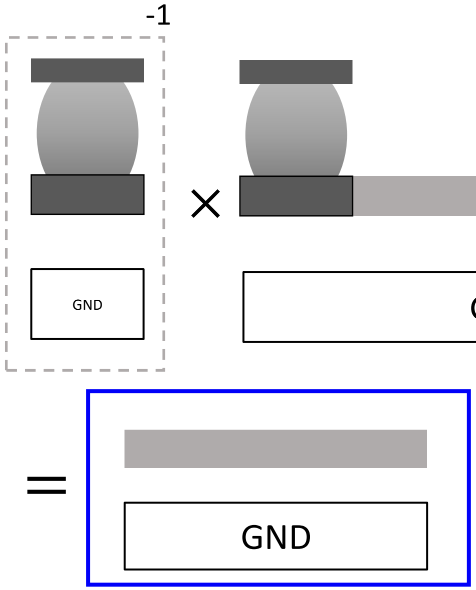
Total Structure:
From Simulation



Single Bump:
From L-2L
De-embedding



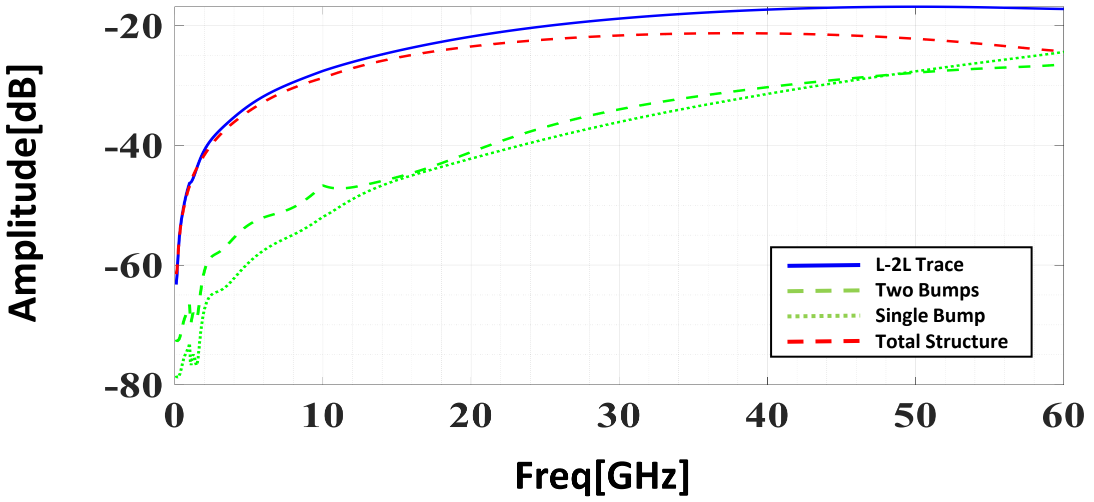
Coupling Bumps:
From L-2L
De-embedding



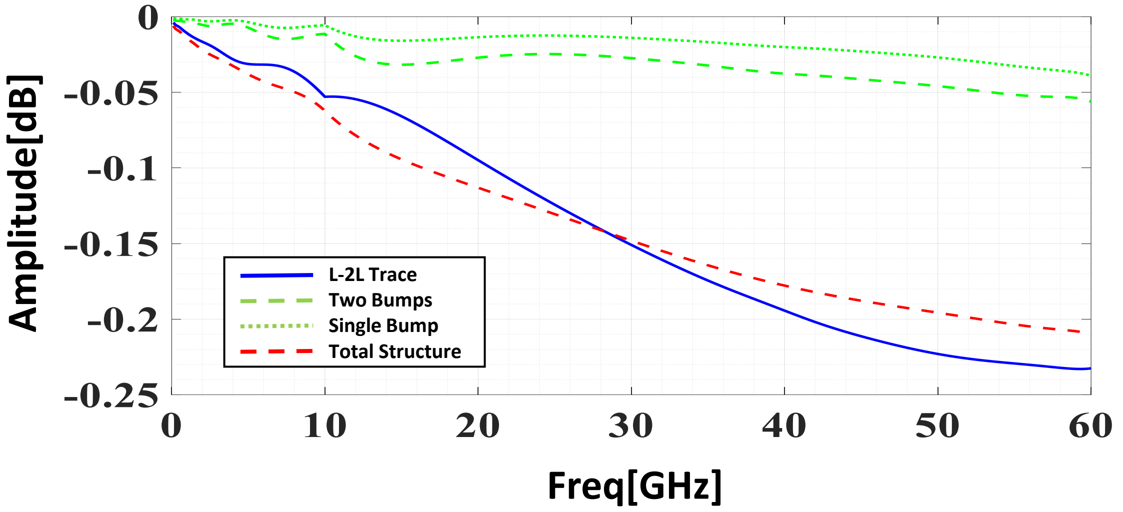
Trace: From L-2L
De-embedding

L-2L De-embedding T-Type Results(Microstripline)

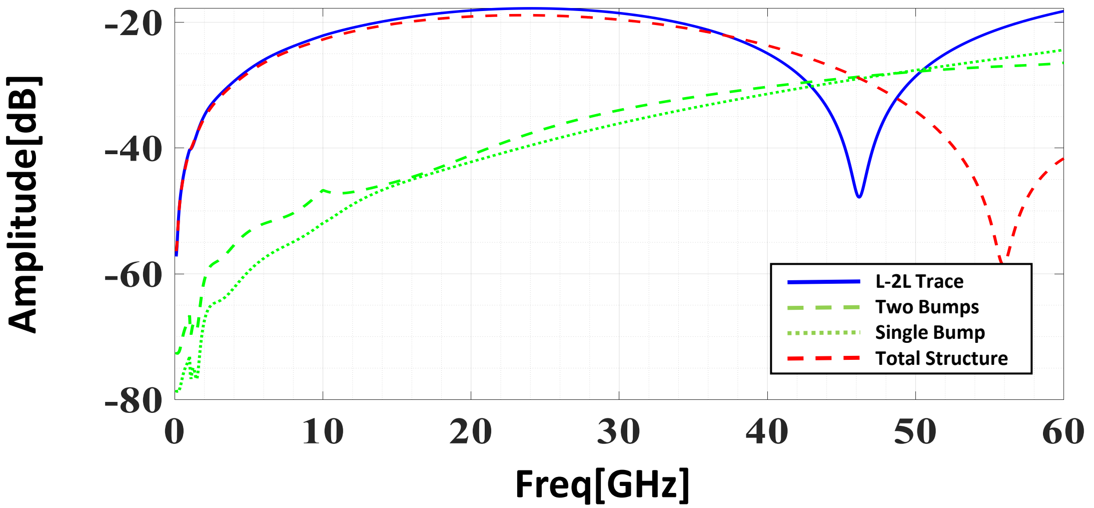
S11(1mm)



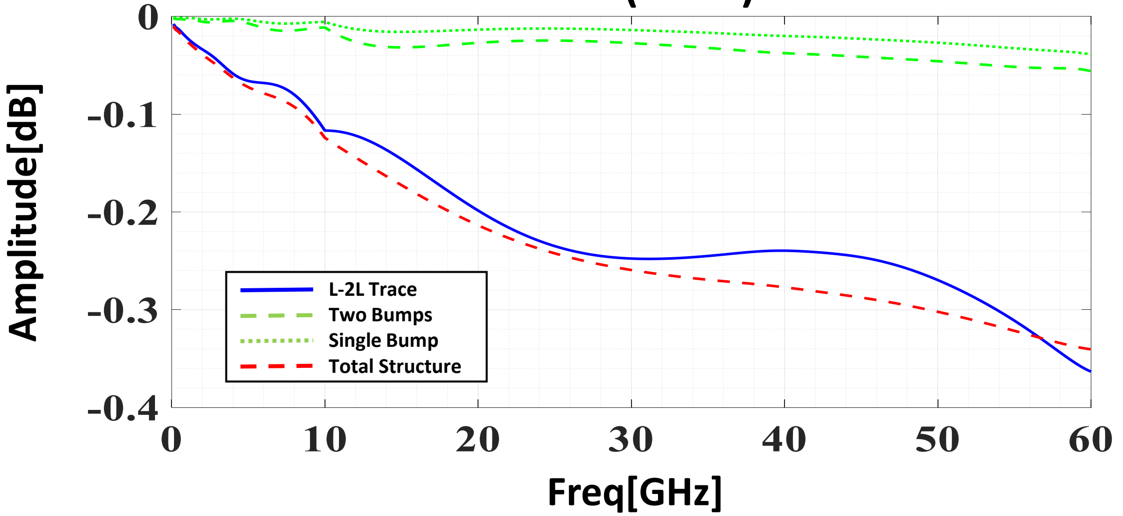
S21(1mm)



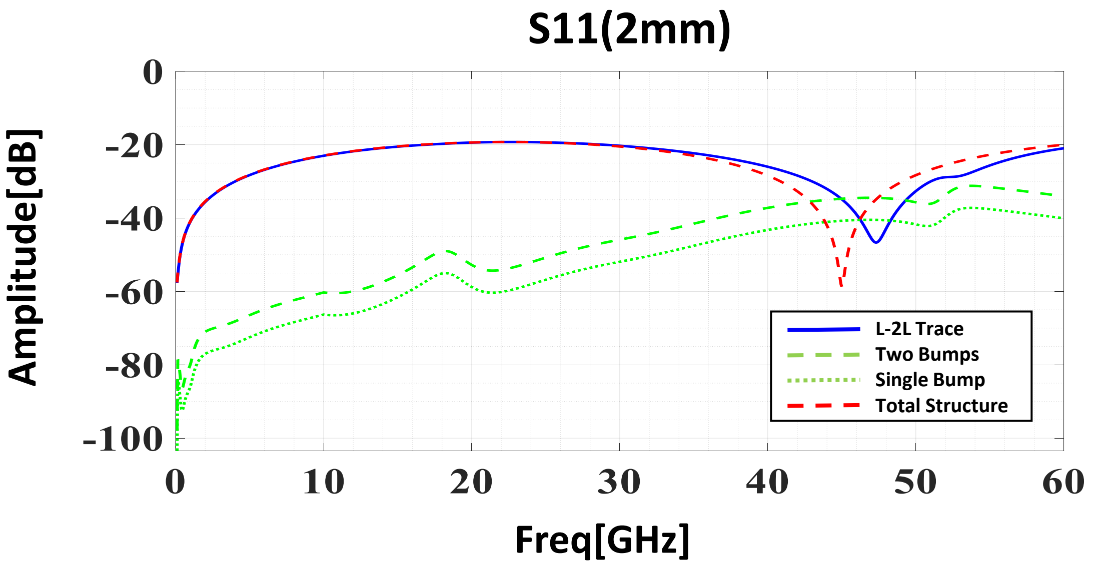
S11(2mm)

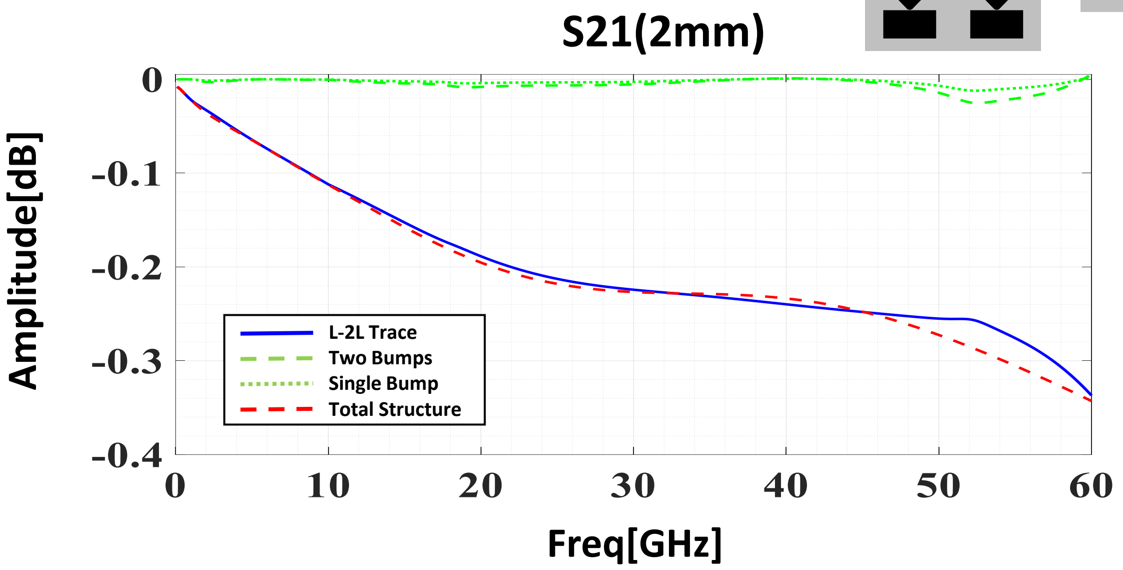


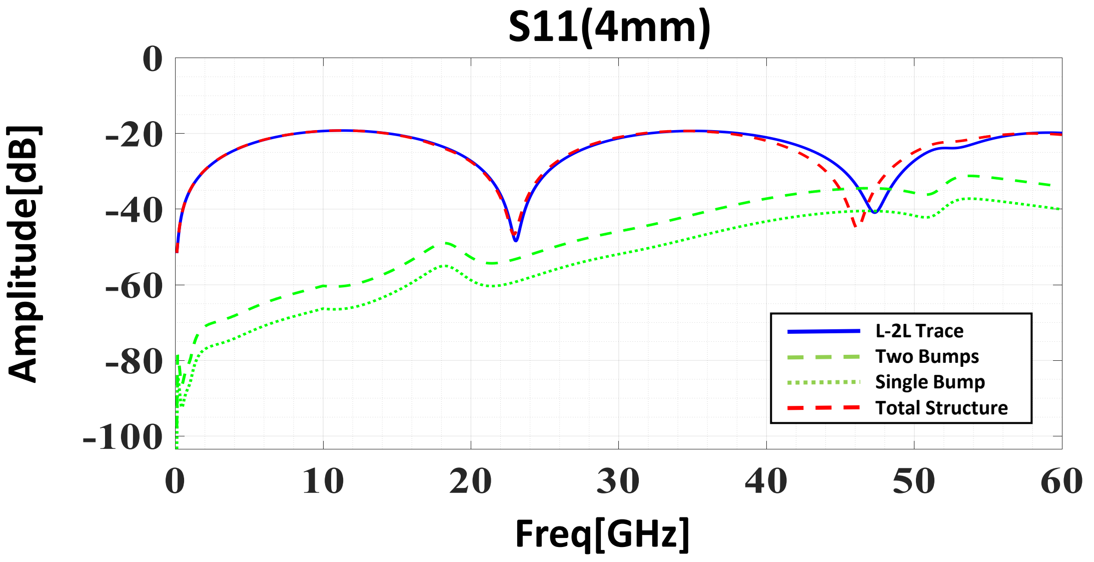
S21(2mm)

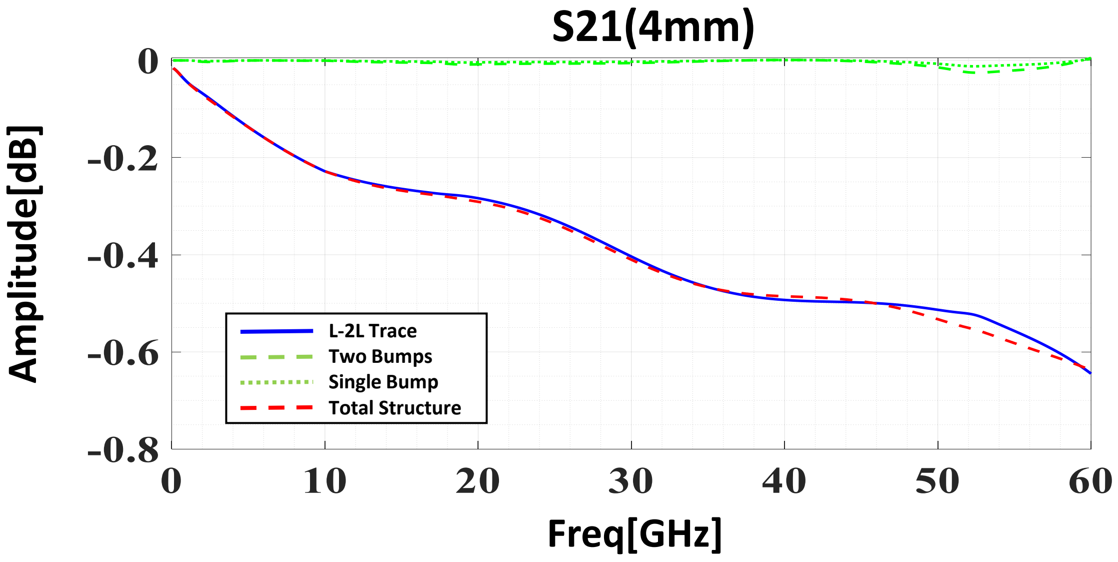


L-2L De-embedding T-Type Results(Microstripline)

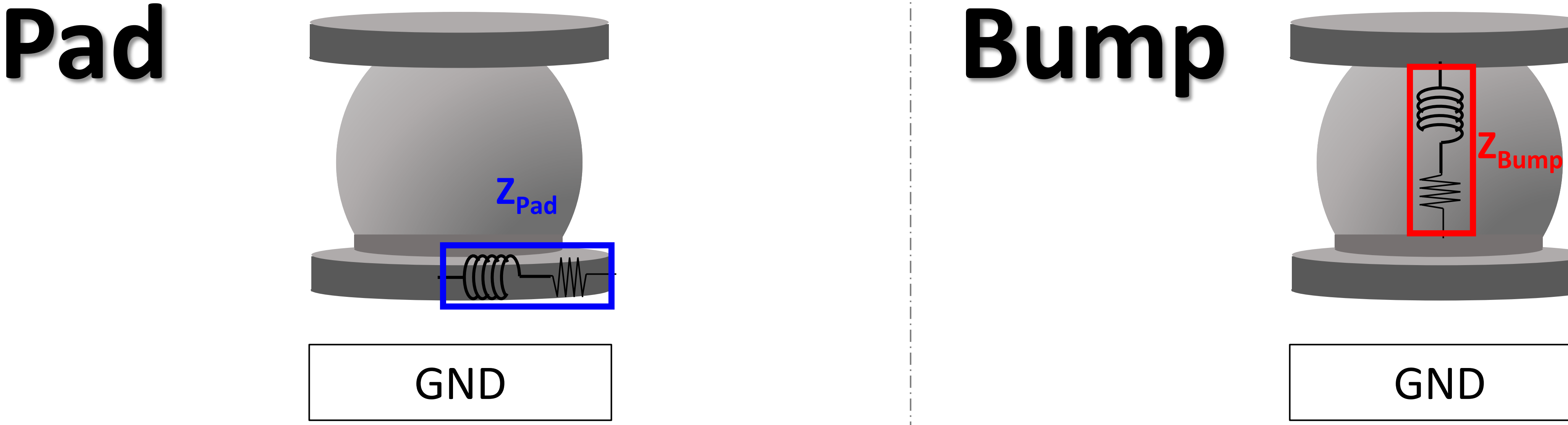


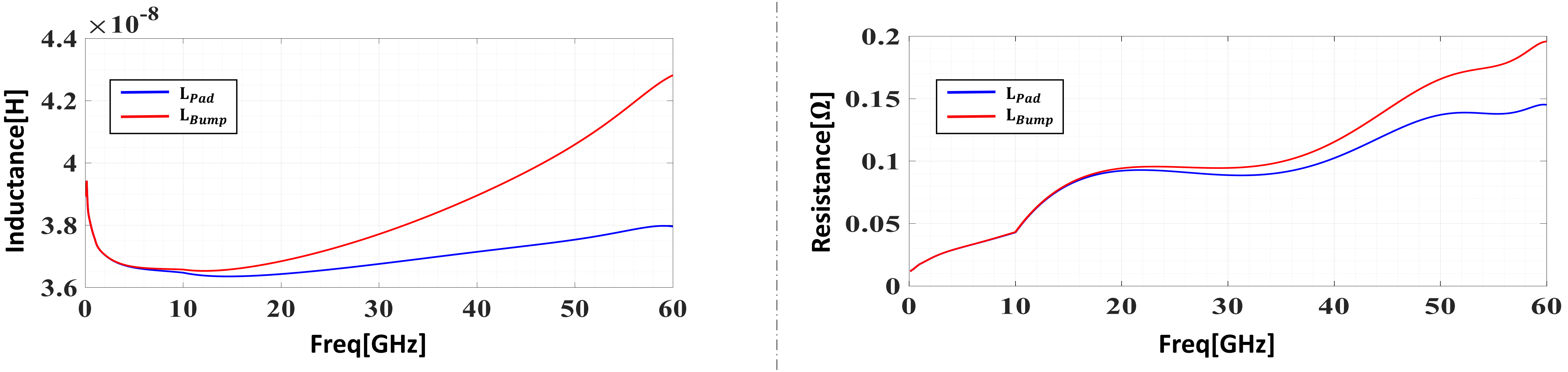




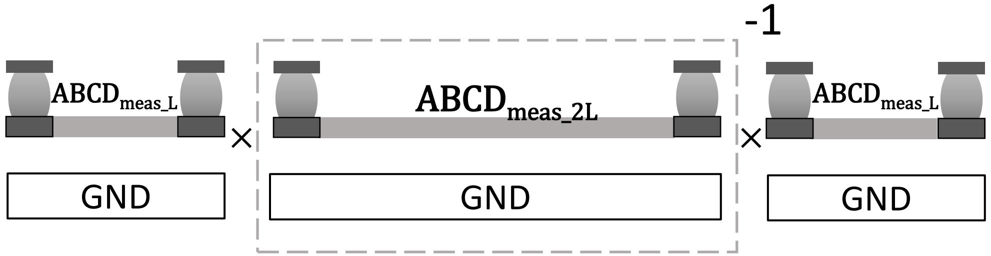


Comparing of Impedance of the Pad and Bump(Microstripline)





Characteristic Impedance Results(Bump)



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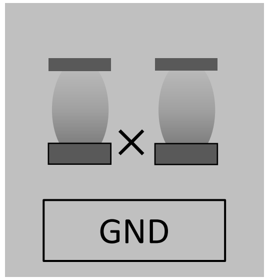
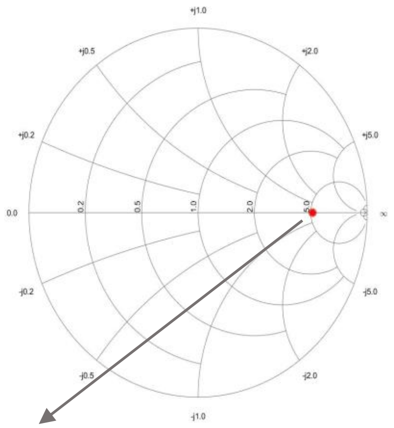


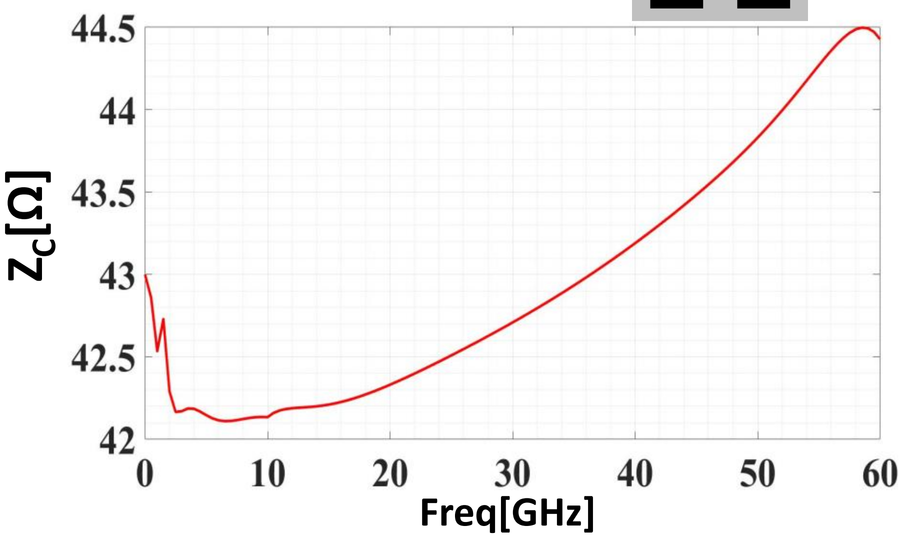
$$Z_C = Z_0 \left[\frac{(1+S_{11})^2 - S_{21}^2}{(1-S_{11})^2 - S_{21}^2}\right]^{\frac{1}{2}}$$

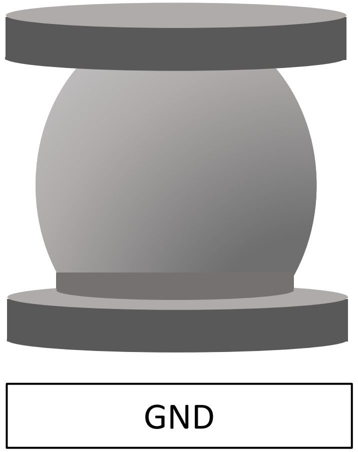
$$Z_0 = 50\ \Omega$$

$$\Gamma = \alpha + \beta i = \frac{Z_C - Z_0}{Z_C + Z_0}$$



$\Gamma = 615$

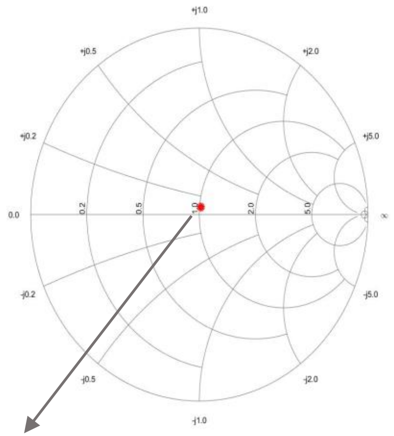




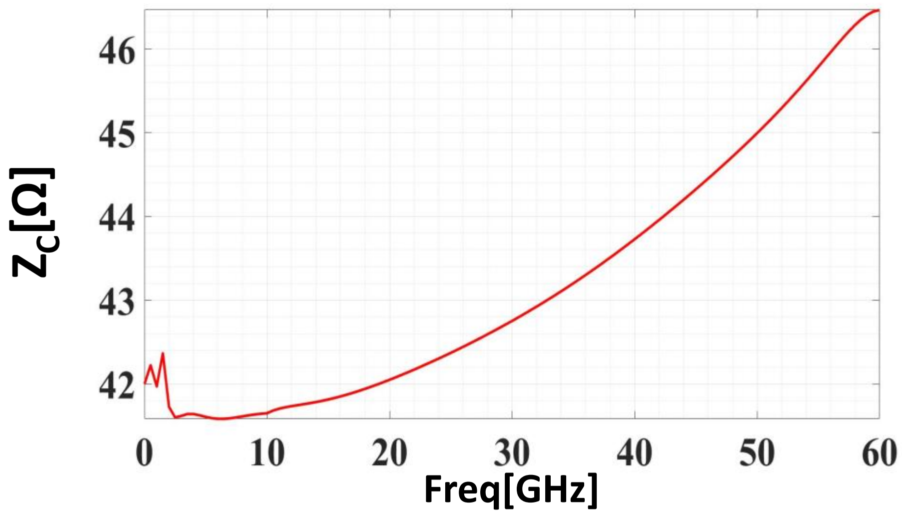
$$Z_C = Z_0 \left[\frac{(1+S_{11})^2 - S_{21}^2}{(1-S_{11})^2 - S_{21}^2}\right]^{\frac{1}{2}}$$

$$Z_0 = 50\ \Omega$$

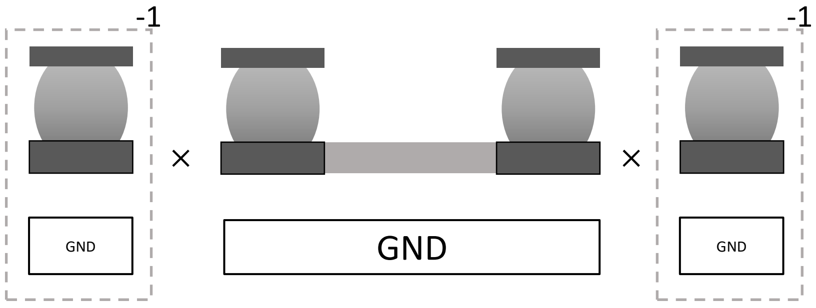
$$\Gamma = \alpha + \beta i = \frac{Z_C - Z_0}{Z_C + Z_0}$$



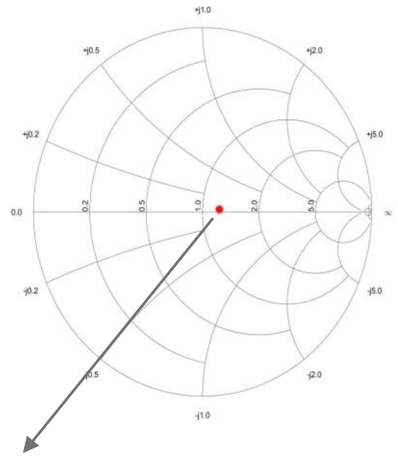
$\Gamma = 111 + 10i$



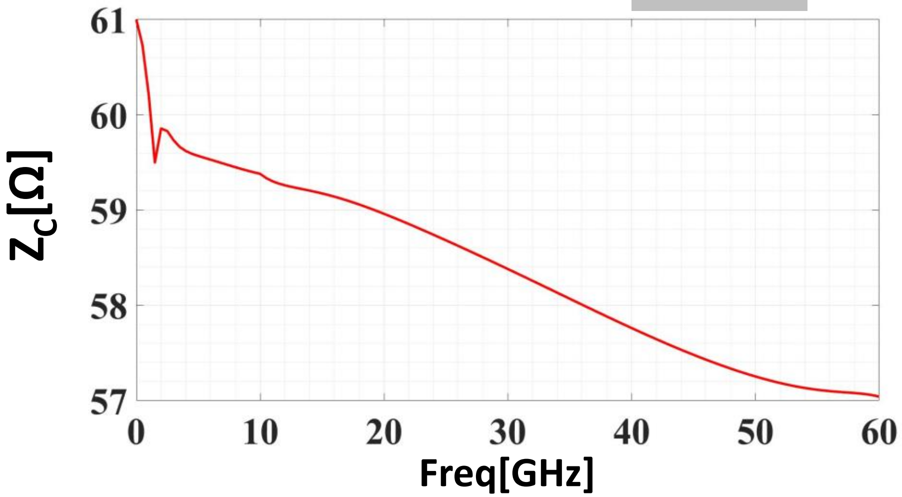
Characteristic Impedance Results(Microstripline)

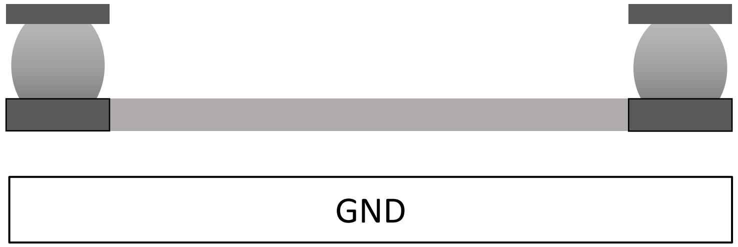


The line with 0.5mm long

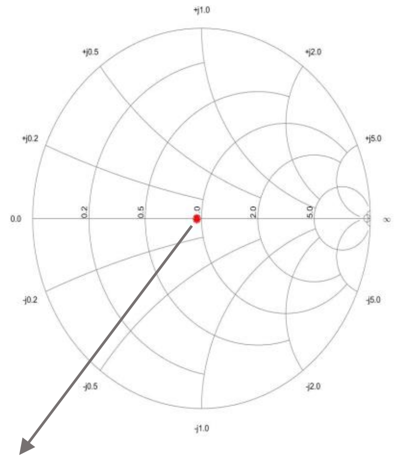


$\Gamma = 131 + 5i$

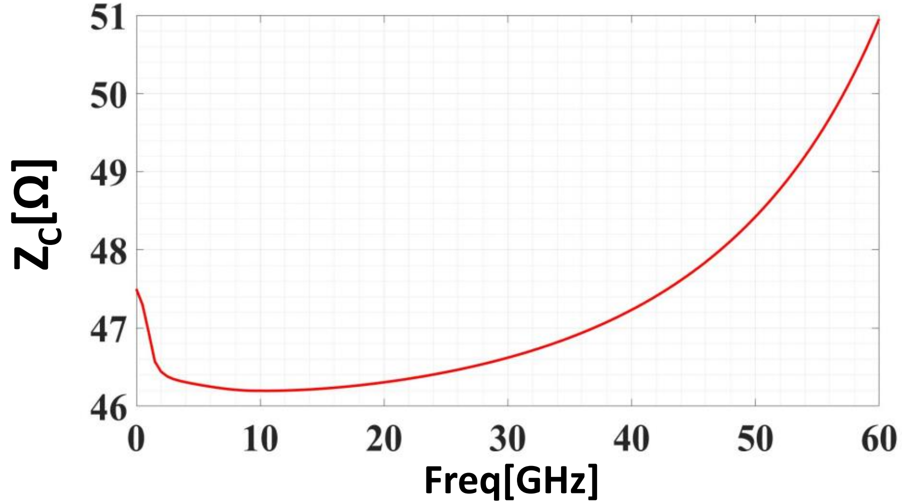




Total structure with 0.5mm long

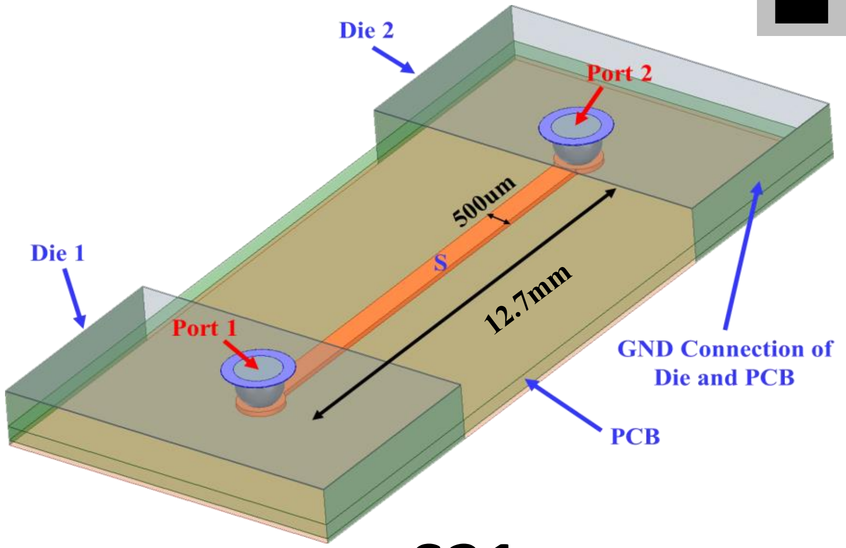


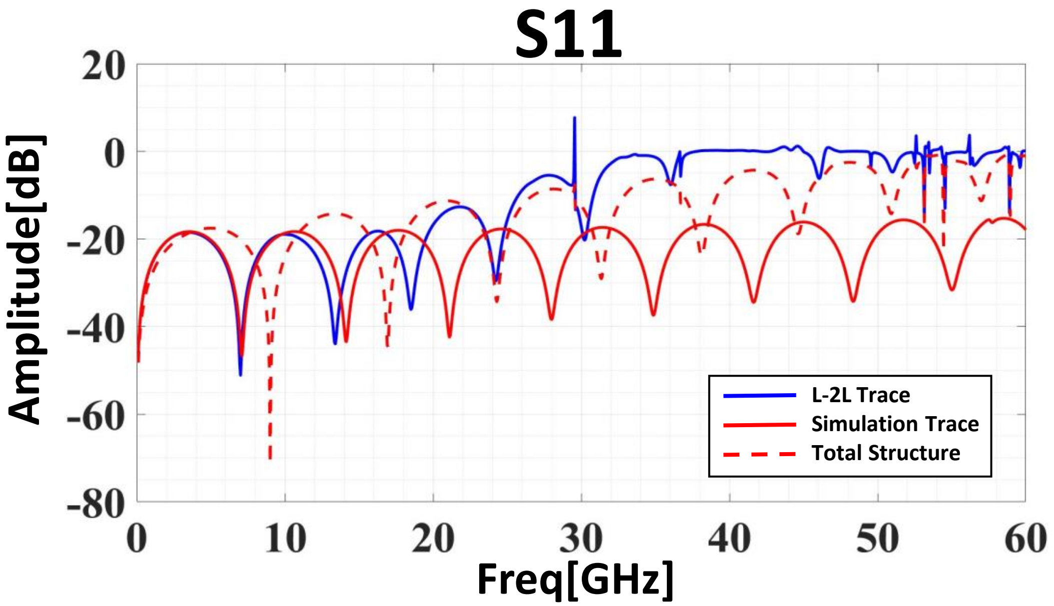
$\Gamma = 80$

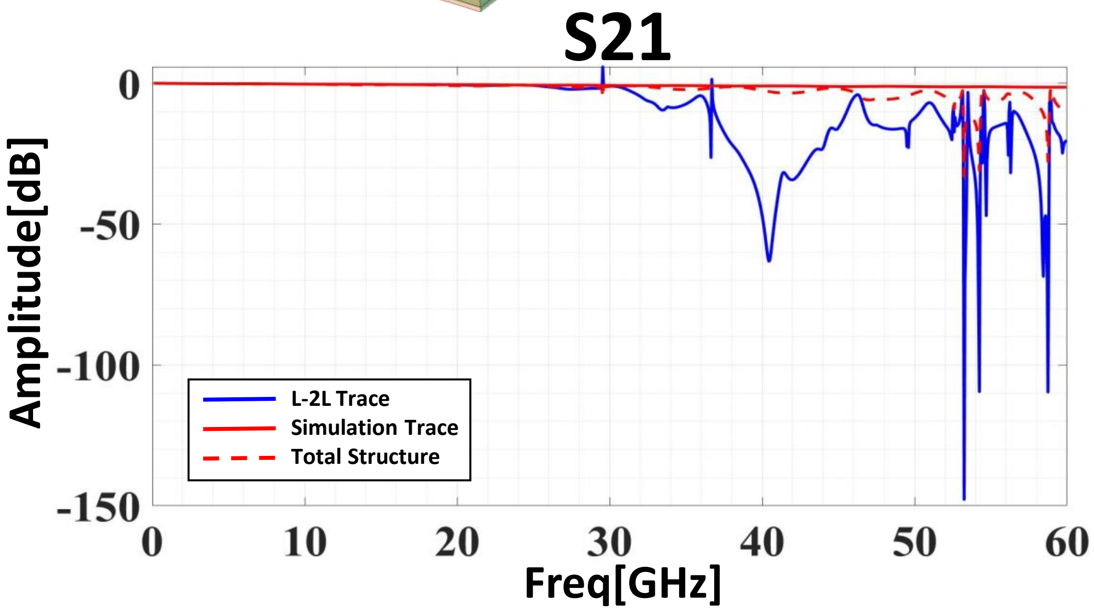


Weak points of L-2L De-embedding (Large Fixture)

- **The parasitic contribution** of the extra grounded metal strip **cannot be ignored if the frequencies are high or if the DUT structures are large**.

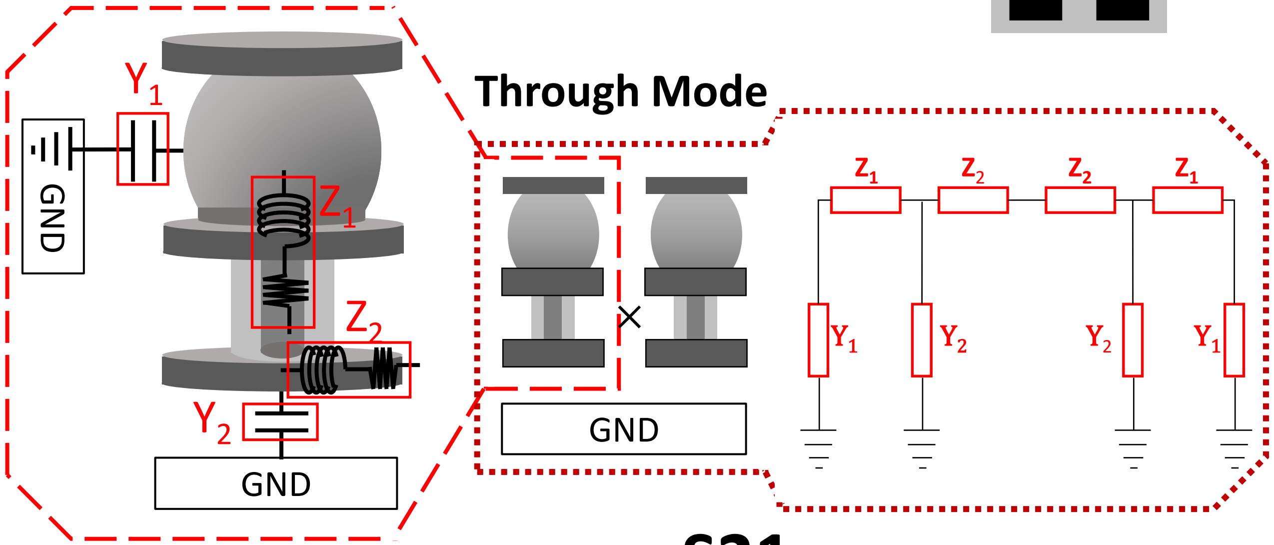


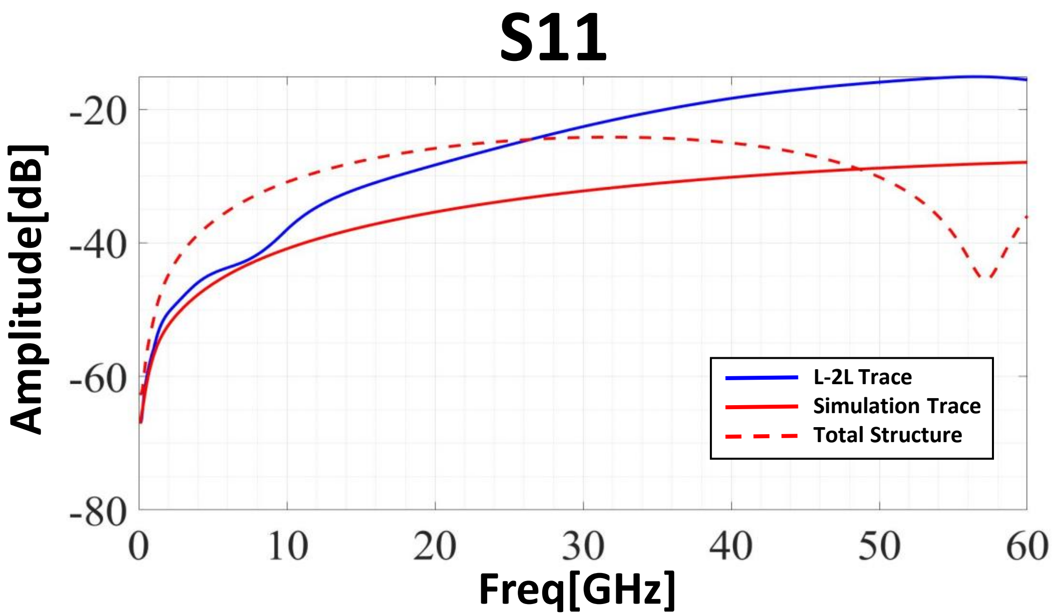


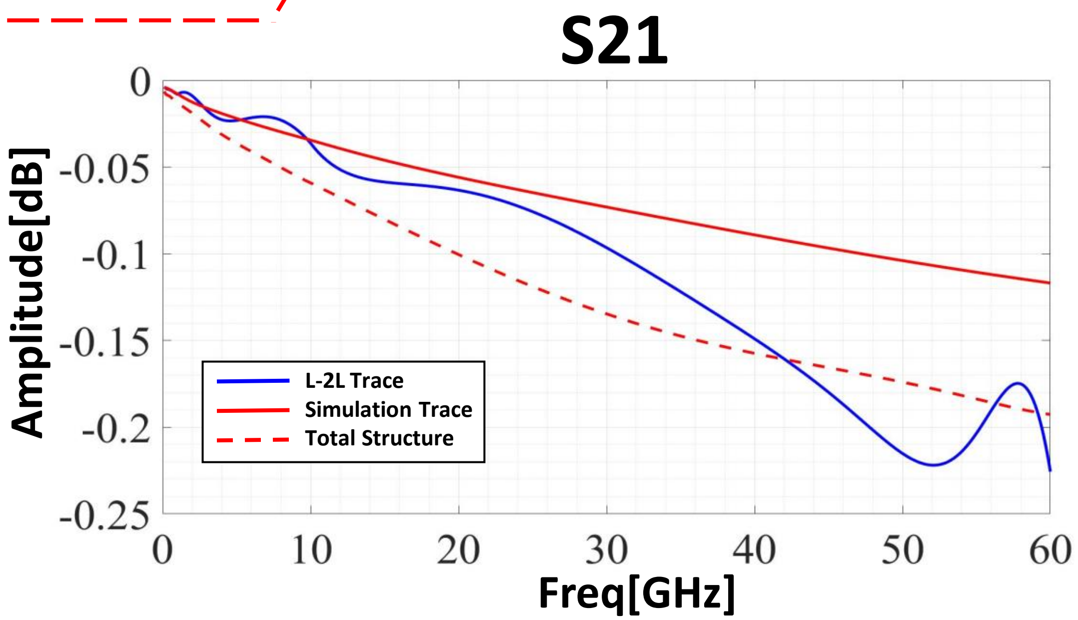


Weak points of L-2L De-embedding (Stripline)

- The **circuit model of Stripline** in **through mode cannot be π–type or T–type** model, then the method is not accurate for **Stripline interconnect.**







Conclusion

- For **microstrip,** L-2L De-embedding method is accurate enough.
- The value of parasites in the **single ended structures** could be calculated if the **Through Mode** could be modeled as a **π–type lumped constant circuit**. **Otherwise the method can not be accurate and workable**.
- The method is **not applicable** for **large structures**.
- The method is **not applicable** for **Stripline** interconnect

Future Works

- **Addressing the mentioned problems of L-2L De-embedding using Fixture removal Algorithm. In other words, Combination of methods 2X Thru and L-2L will be used to solve the problems of L-2L De-embedding method.**

- **Designing a GUI program (tool) for L-2L method using Python.**

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