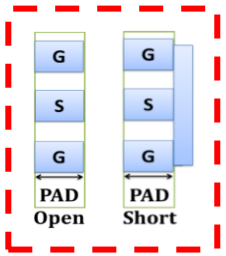
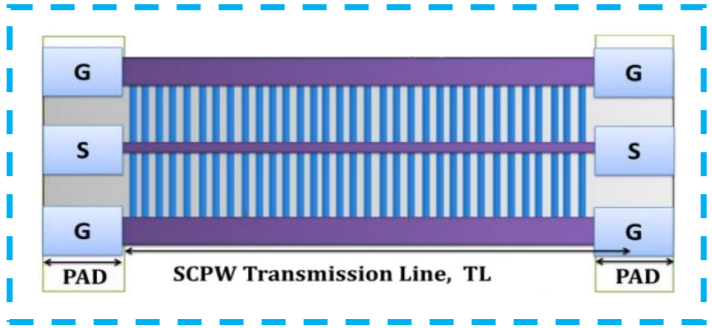
TRL Method

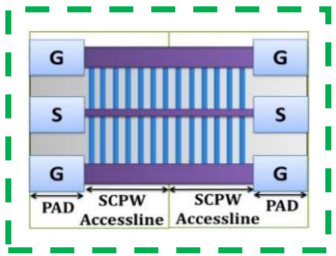
Calibration-kit



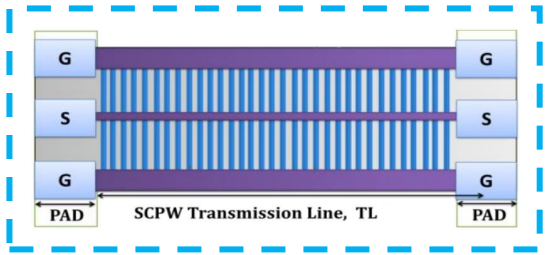
Reflect



Line1



Thru



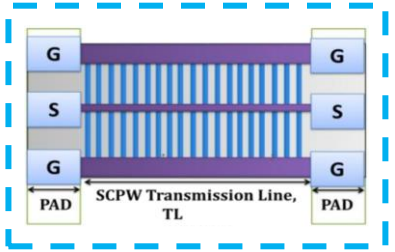
Line2

Line1 → $\frac{\pi}{1.125}\lambda$ → 160°

Line2 → $\frac{\pi}{2}\lambda$ → 90°

Line3 → $\frac{\pi}{9}\lambda$ → 20°

$$\lambda = \frac{C}{\varepsilon_{eff} \times f_{max}}$$



Line3

Ref: Errikson Lourandakis, On-wafer Microwave measurement and De-embedding,2016

Mathematical:

$$T_{11} = \frac{b_1}{a_1} = S_{11} + \frac{S_{11}S_{12}^2}{1 - S_{12}^2} \qquad T_{21} = T_{12}$$

$$T_{12} = \frac{b_1}{a_2} = \frac{S_{12}^2}{1 - S_{12}^2} \qquad T_{11} = T_{22}$$

$$R_{11} = \frac{b_1}{a_1} = S_{11} + \frac{S_{12}^2\Gamma_L}{1 - S_{22}\Gamma_L}$$

$$L_{11} = \frac{b_1}{a_1} = S_{11} + \frac{S_{22}S_{12}^2 e^{-2\iota\gamma}}{1 - S_{22}^2 e^{-2\iota\gamma}}$$

$$L_{11} = \frac{b_1}{a_1} = \frac{S_{12}^2 e^{-2\iota\gamma}}{1 - S_{22}^2 e^{-2\iota\gamma}}$$

$$Re\{\gamma\}, Im\{\gamma\} > 0$$

$$e^{-2\iota\gamma} = \frac{L_{12}^2 + T_{12}^2 - (T_{11} - L_{11}) \pm \sqrt{[L_{12}^2 + T_{12}^2 - (T_{11} - L_{11})^2]^2 - 4L_{12}^2T_{12}^2}}{2T_{12}L_{12}}$$

$$S_{22} = \frac{T_{11} - L_{11}}{T_{12} - L_{12}e^{-2\iota\gamma}}$$

$$S_{11} = T_{11} - S_{22}T_{12}$$

$$S_{12}^2 = T_{12}(1 - S_{22}^2)$$

T_{ii} & T_{ij} → S-parameters of the Thru Structure

L_{ii} & L_{ij} → S-parameters of the Line Structures

R_{ij} → S-parameters of the Reflect Structures

S_{ii} & S_{ij} → S-parameters of the pads

Ref: Pozar, Microwave Engineering

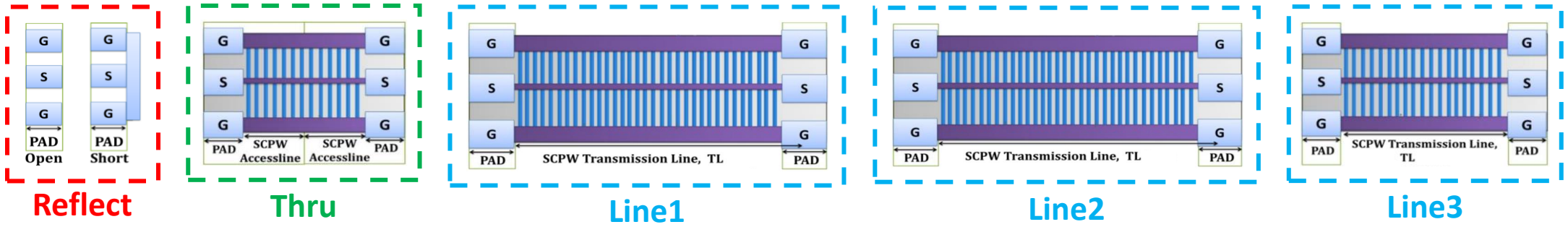
Weakness:

- ❑ **High cost due to the number of Cal-kit.**
- ❑ **The accuracy is decreased due to the number of Cal-kit during the measurement or manufacturing process.**
- ❑ **Unknown line impedance value, band limited; multiple lines required for wide band.**

Ref: G. F. Engen and C. A. Hoer, "Thru-Reflect-Line: An Improved Technique for Calibrating the Dual SixPort Automatic Network Analyzer," *IEEE Trans. Microw. Theory Tech.*, vol. 27, no. 12, pp. 987–993, Dec. 1979.

Multiline TRL Method Options

Frequency Band	Recommended Solution	Line Lengths (mm)	Thru Line Length (mm)	Accuracy
20 to 100 GHz	One Line	0.617331	0.15	
20 to 150 GHz	One Line	0.435763	0.15	
10 to 100 GHz	Two Lines	0.5628, 1.779	0.15	
10 to 200 GHz	Two Lines	0.30271, 1.3537	0.15	



Chip Stackup

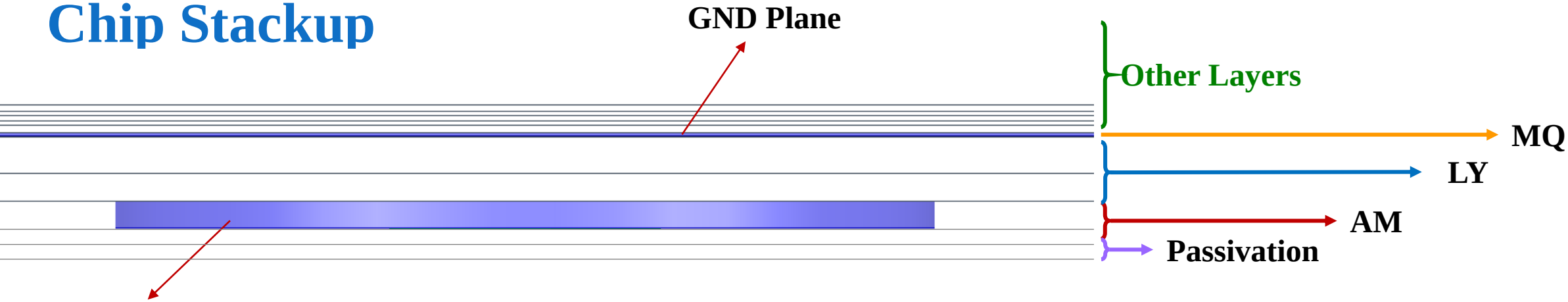
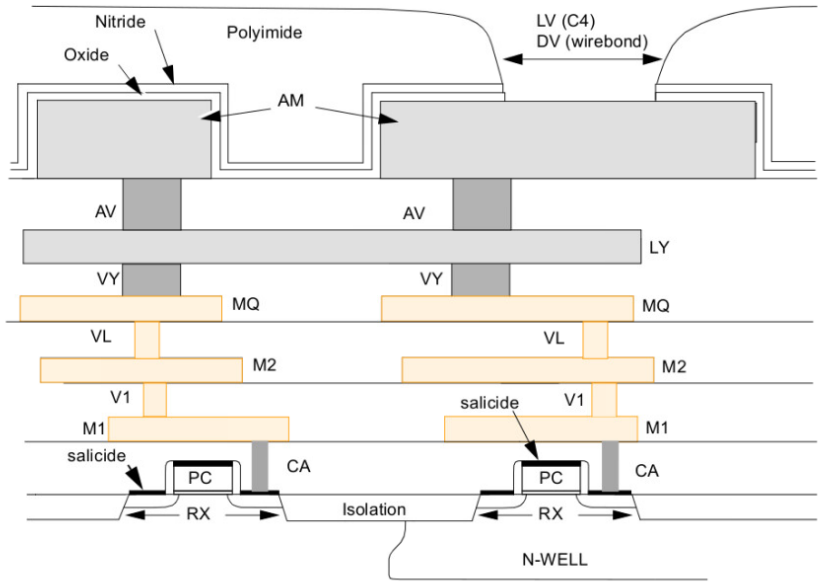
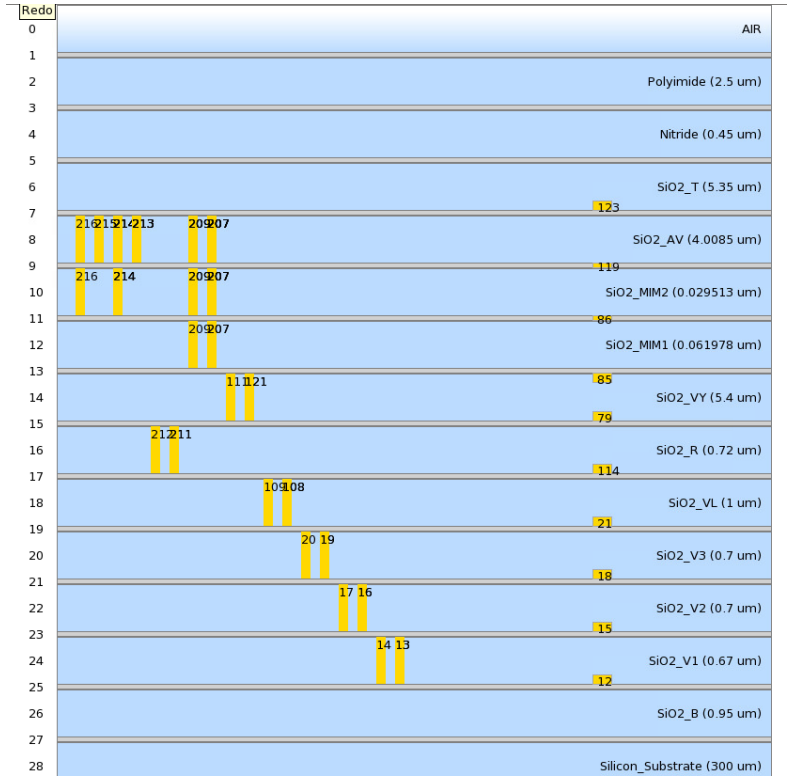


Figure 1-1. Cross Section of the 5 Level of Metal BEOL Option (2 Thin Mx; x=1,2 and 1 Thick = MQ and Analog Metal = LY, AM) with either DV or LV Final Passivation (not drawn to scale.))





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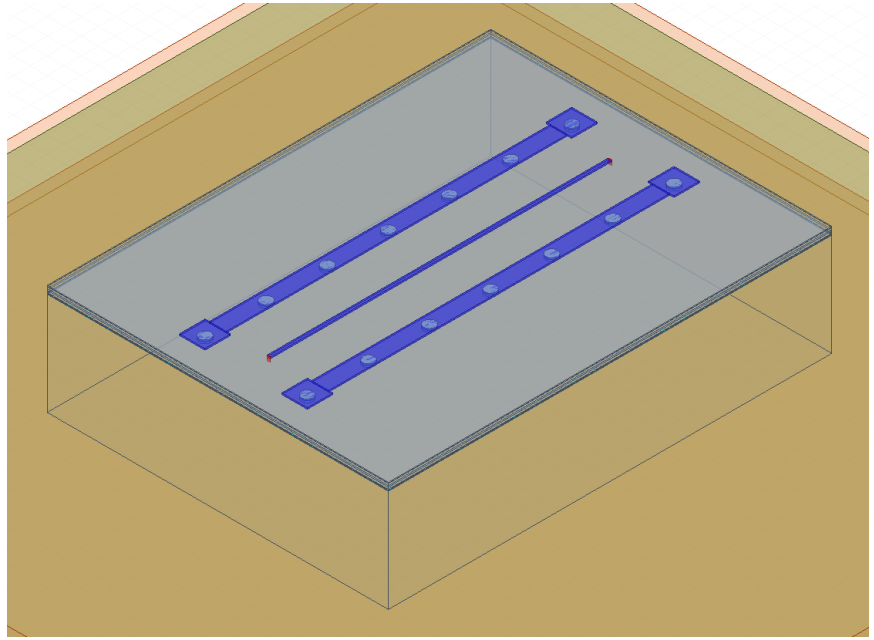
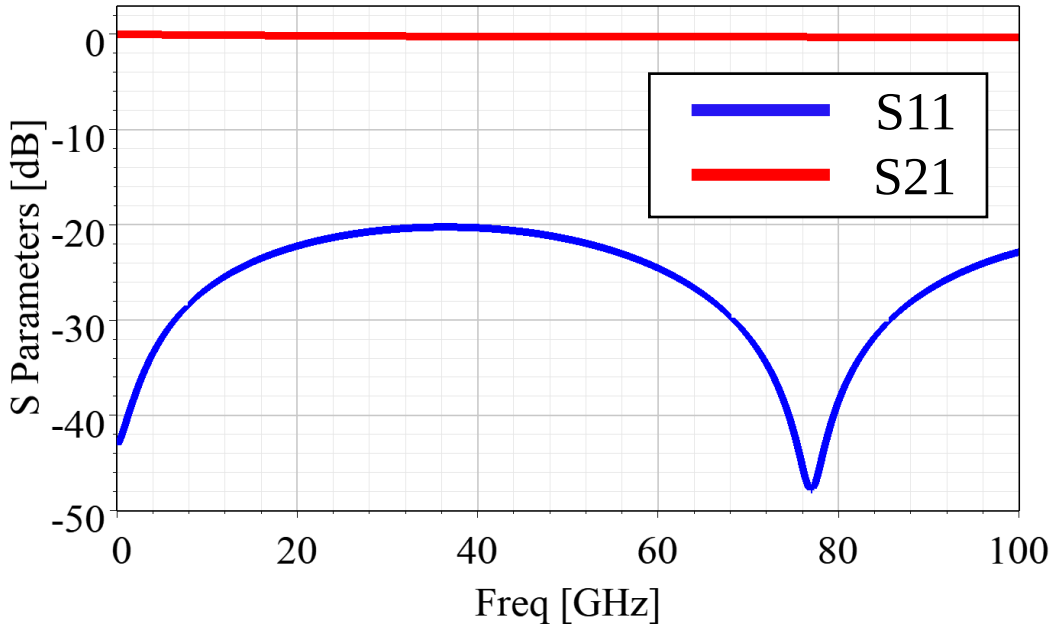
Trace (W=10um, L=1mm)





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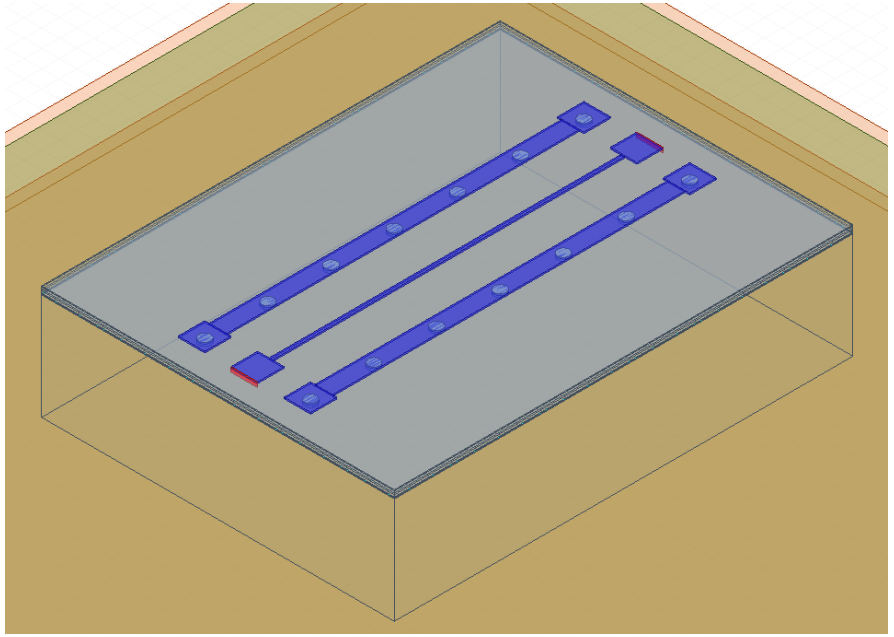
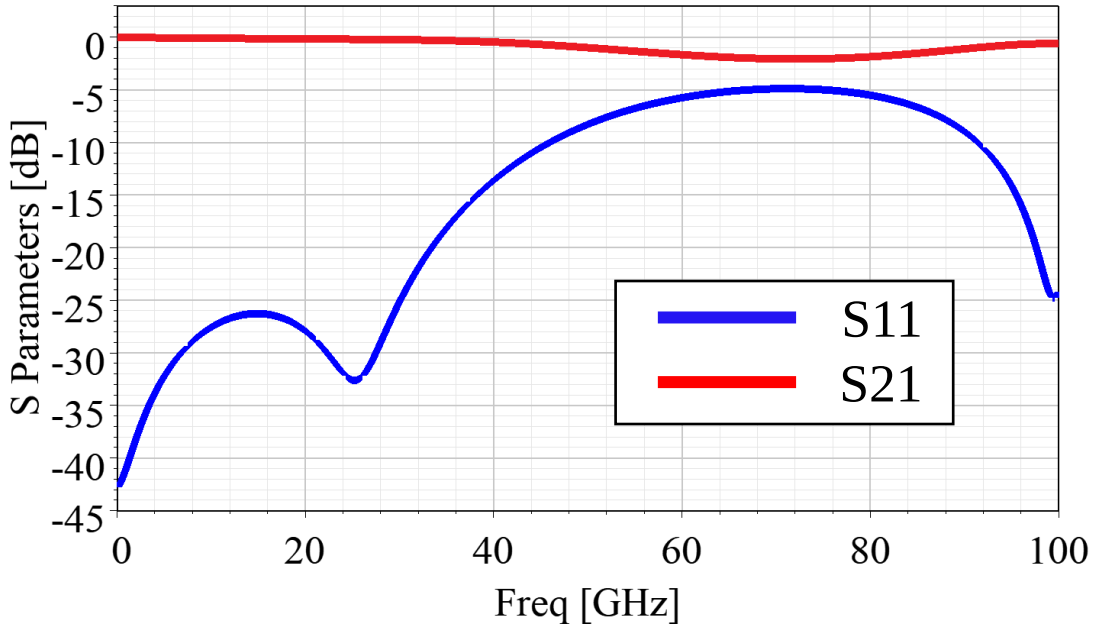
Trace (W=10um, L=1mm) + Pad (W=75um, L= 75um)





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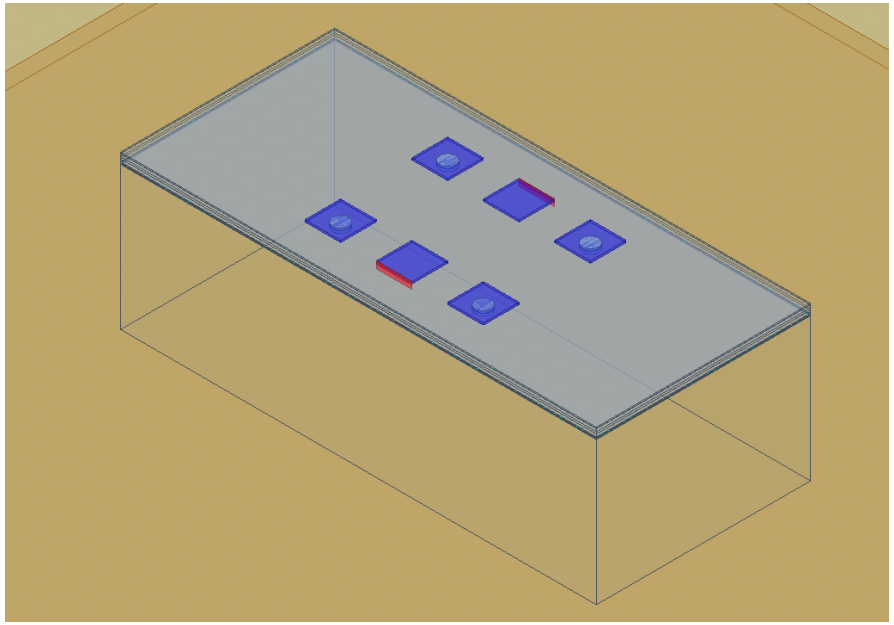
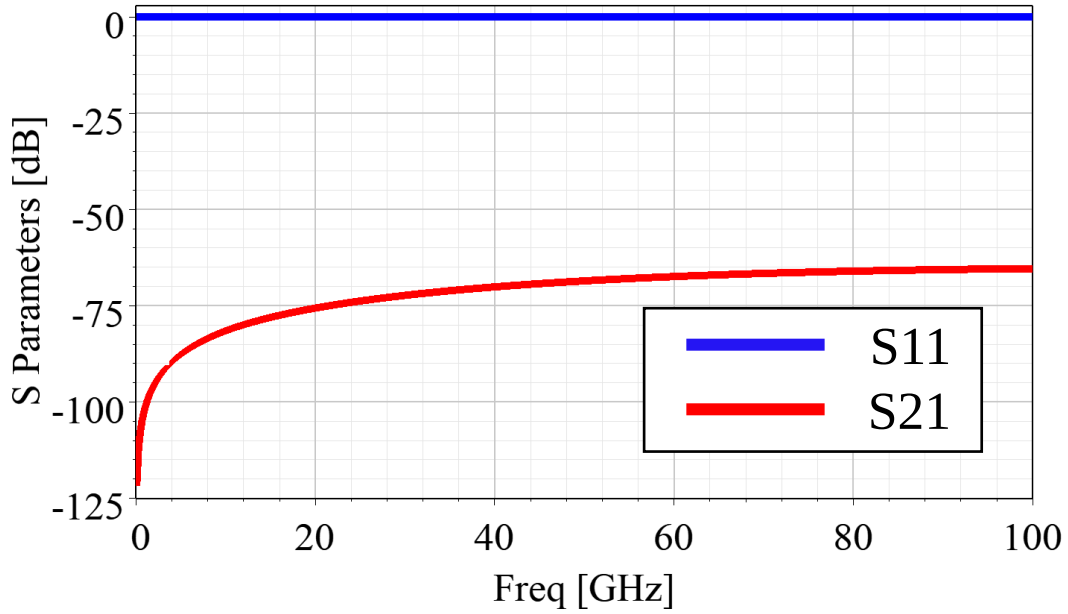
Open





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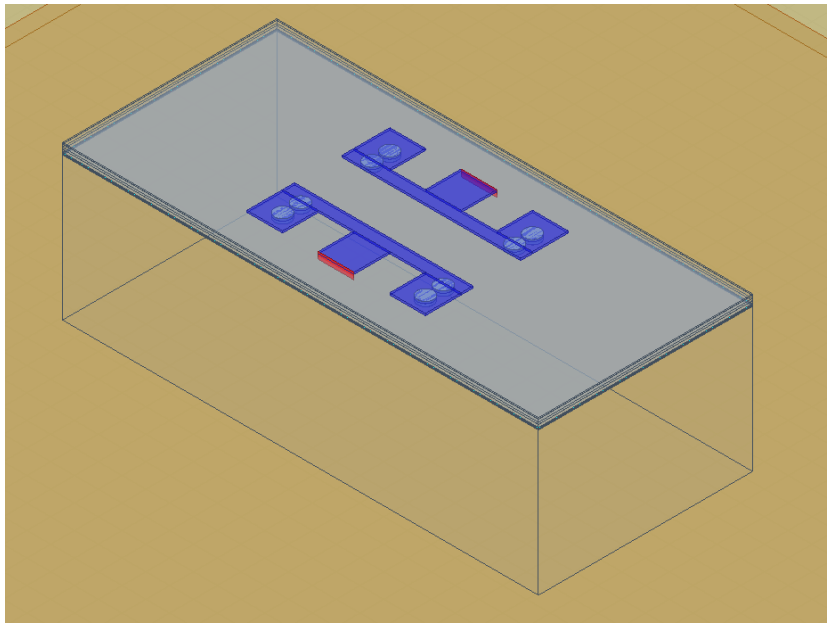
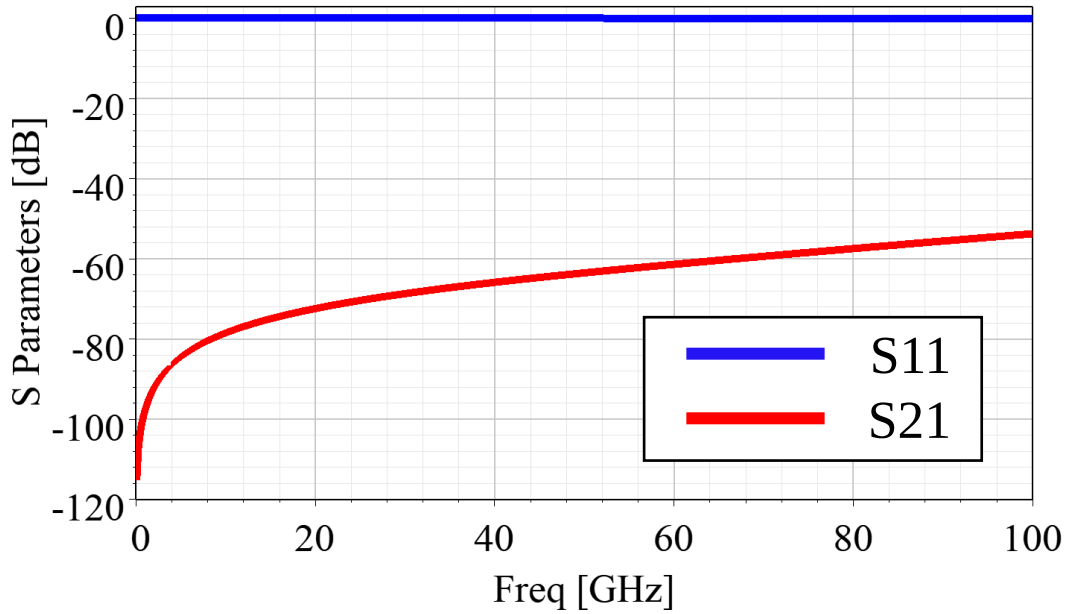
Short





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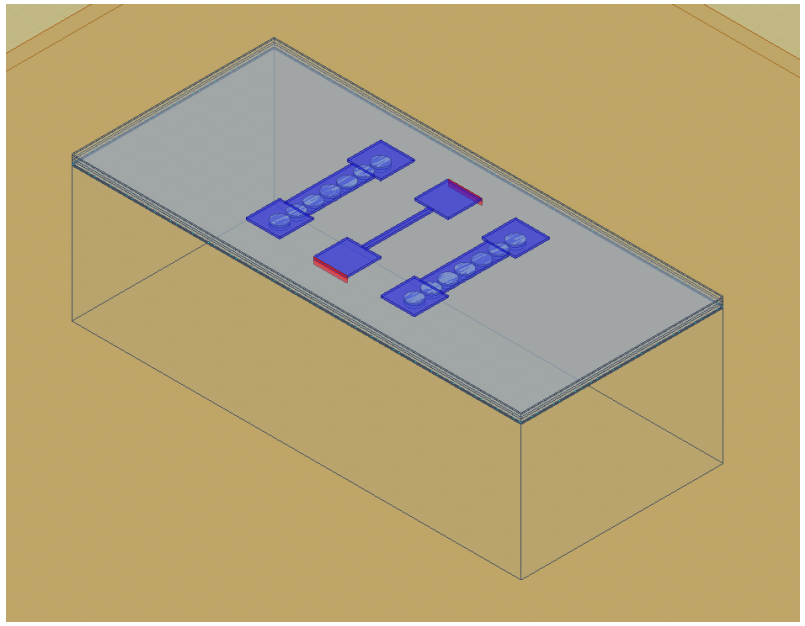
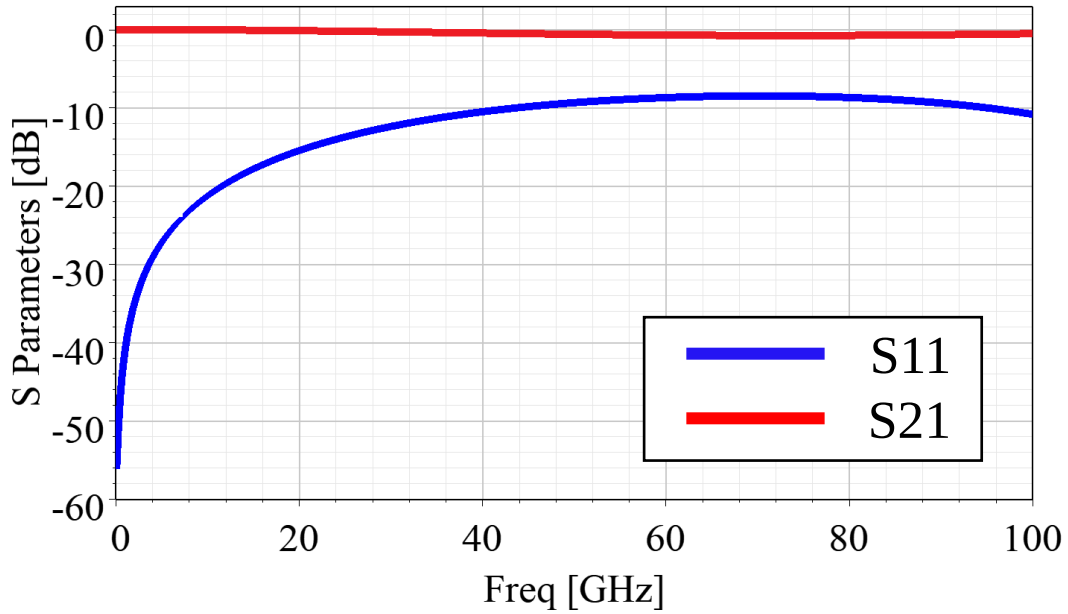
Thru





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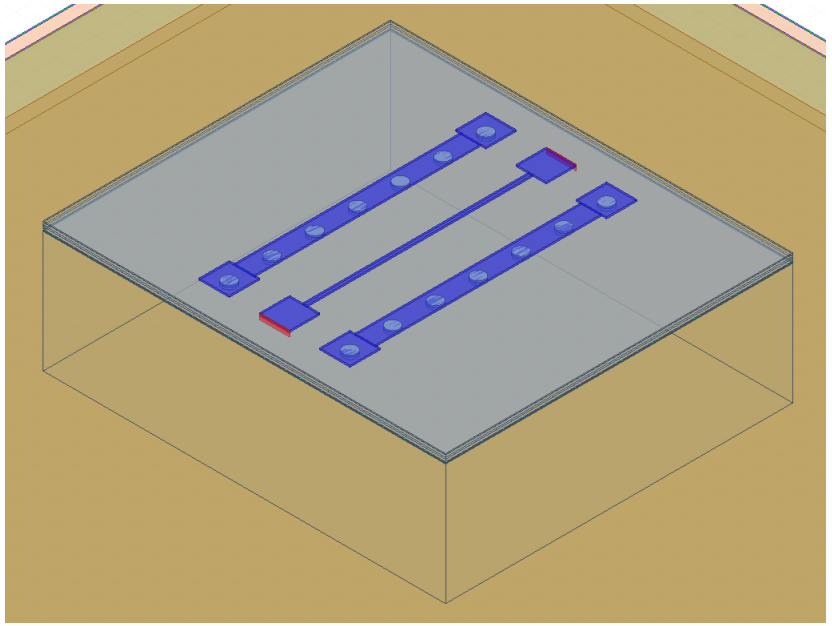
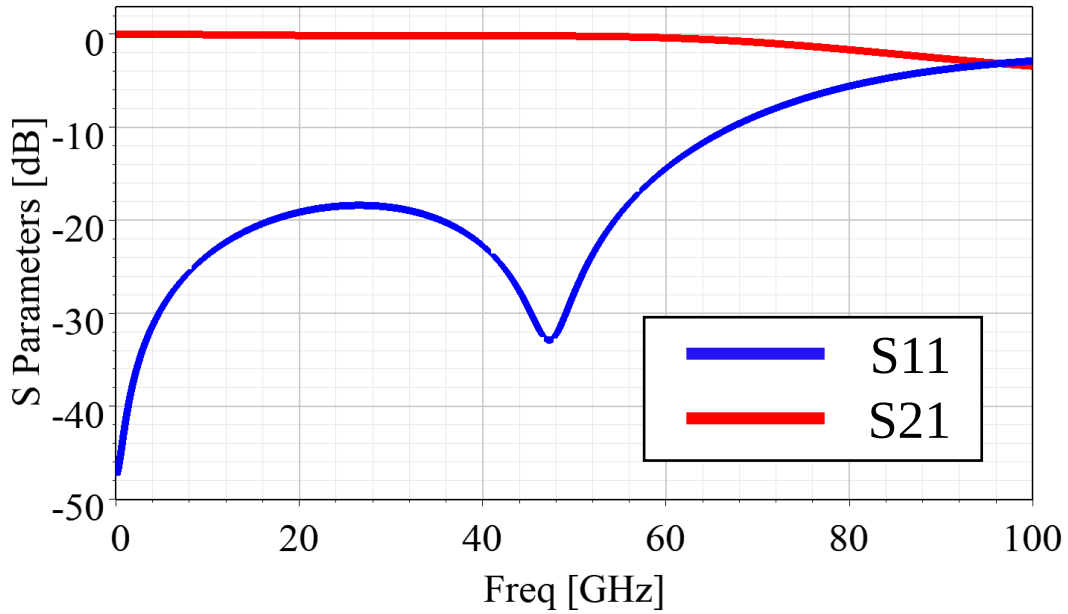
Line 1 = 0.5628 mm





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Line 2 = 1.779 mm