L-2L De-embedding Method with Double-T-type PAD Model for Millimeter-wave Amplifier Design

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Outline

- Background, Motivation
- L-2L De-embedding
- Conventional PAD models
- Proposed 3 parameters PAD model
  - Transmission Line
  - 1-stage Amplifier
- Conclusion

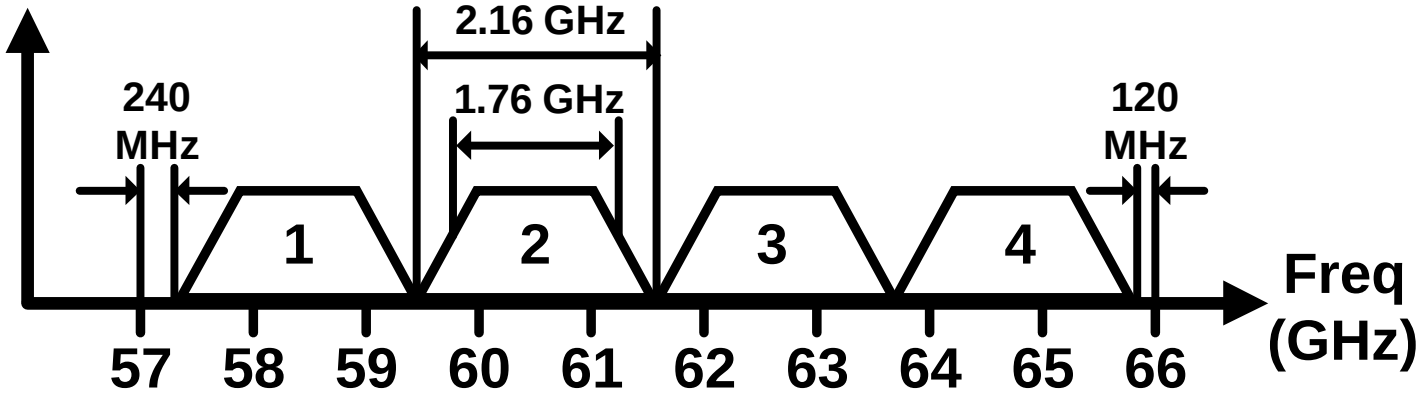
Motivation

60GHz Gbps wireless communication

IEEE 802.11ad specification

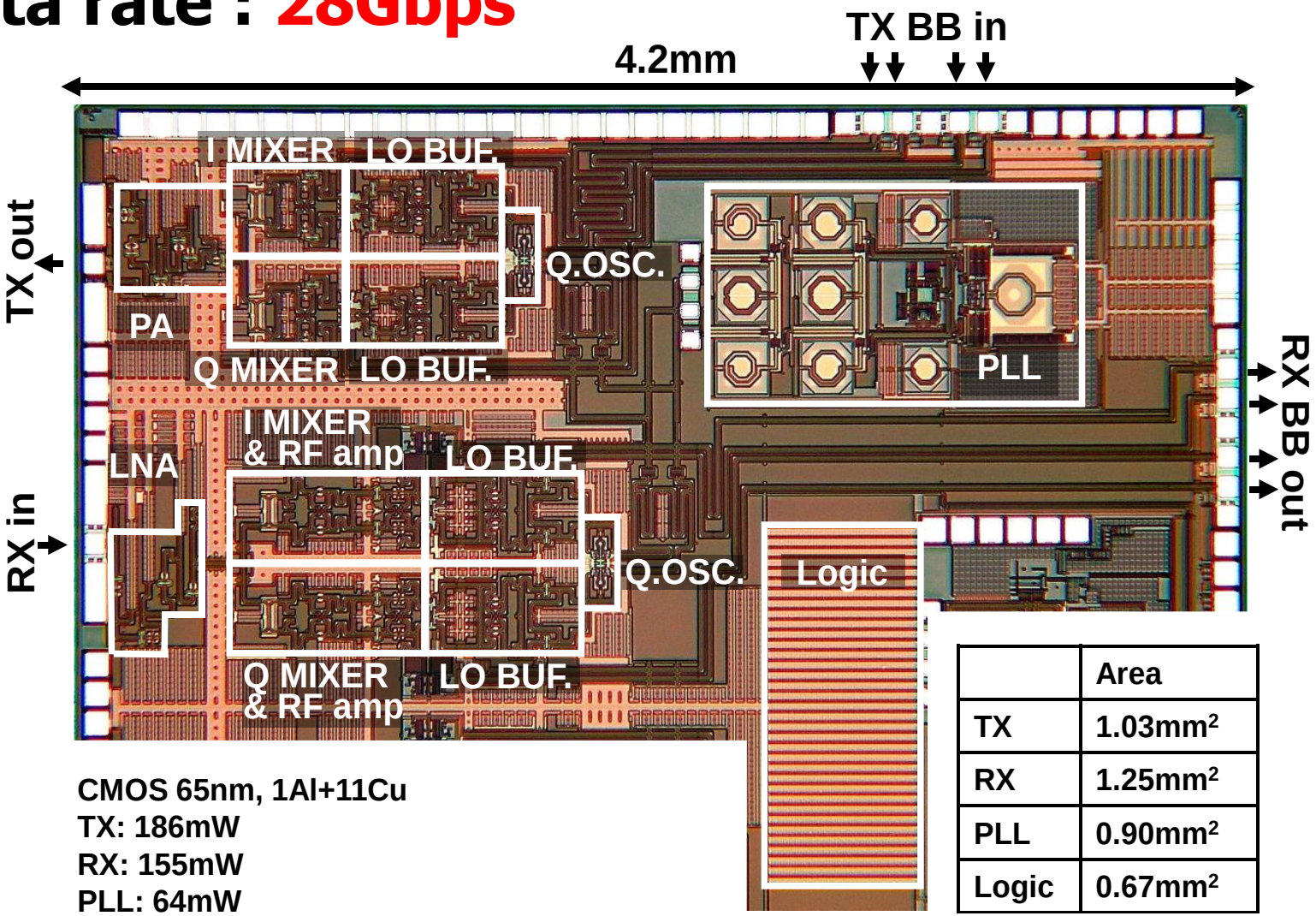
- 57.24GHz – 65.88 GHz
- 2.16GHz/ch x 4ch
- **10.56Gbps/ch** in 64QAM

64QAM x 4 channles x 8MIMO → 300Gbps



60GHz CMOS Transceiver

Data rate : 28Gbps

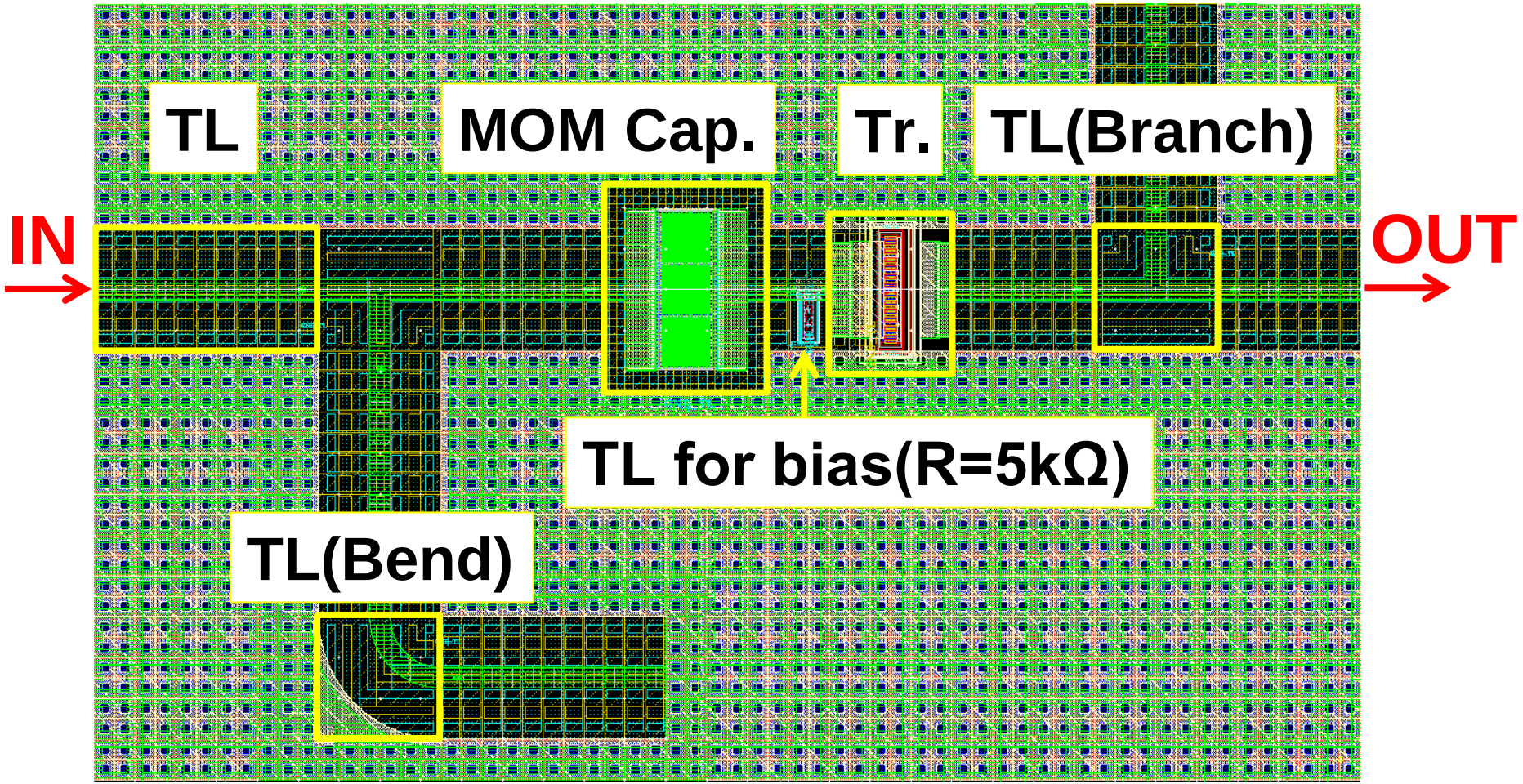


CMOS 65nm, 1Al+11Cu
TX: 186mW
RX: 155mW
PLL: 64mW

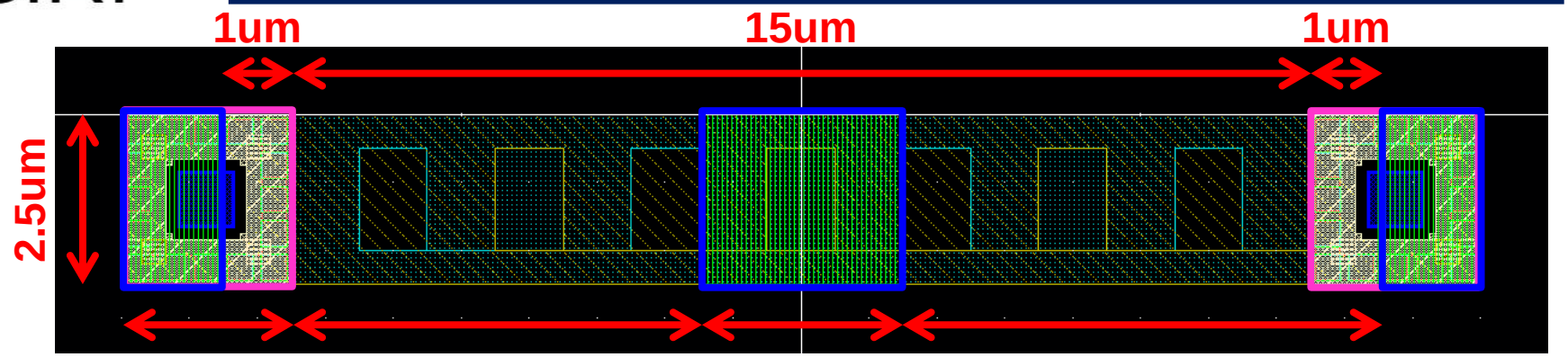
	Area
TX	1.03mm^2
RX	1.25mm^2
PLL	0.90mm^2
Logic	0.67mm^2

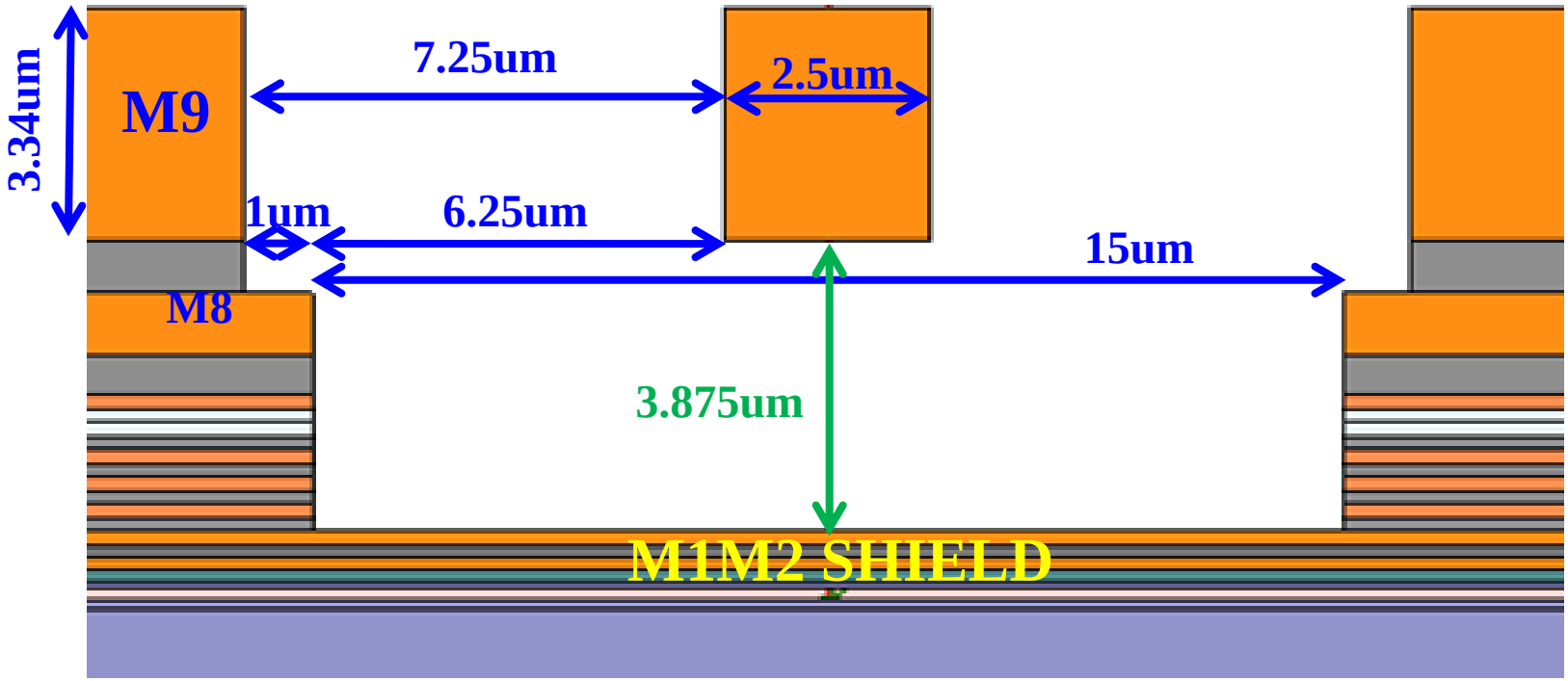
[1] K. Okada, *et al.*, ISSCC2014

Circuit Components in mmW

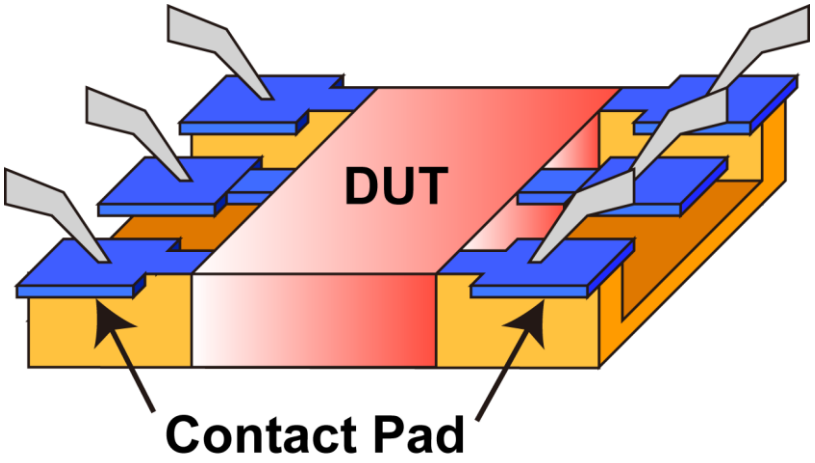


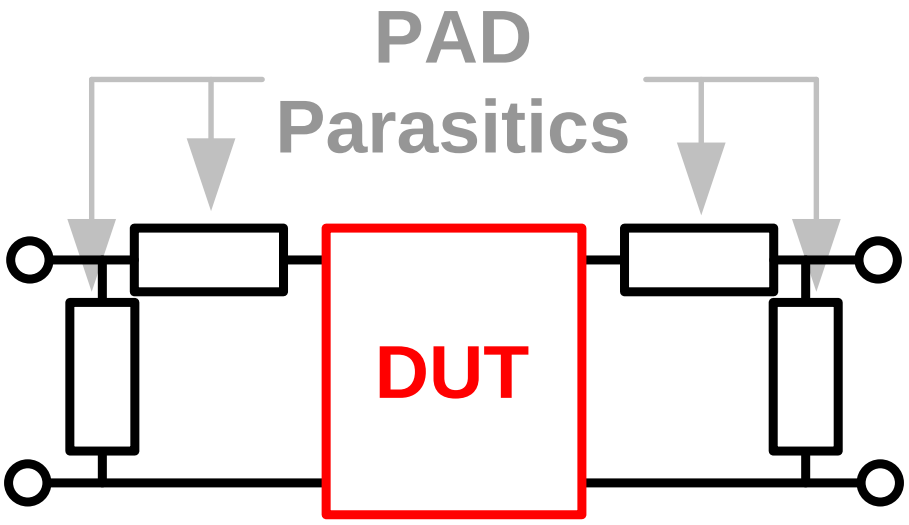
TL Structure





De-embedding





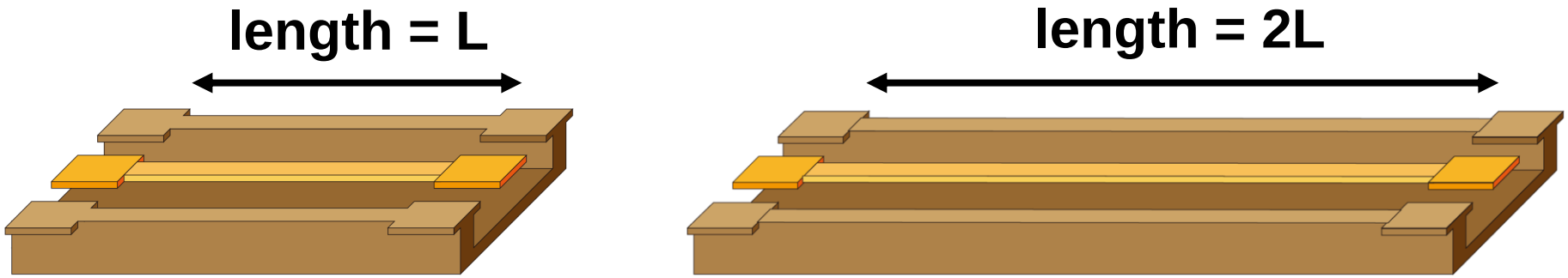
- **Measurement results include PAD, TL.**

➔These components should be removed.

- **De-embedding is the first step.**

➔Affect to modeling of all components.

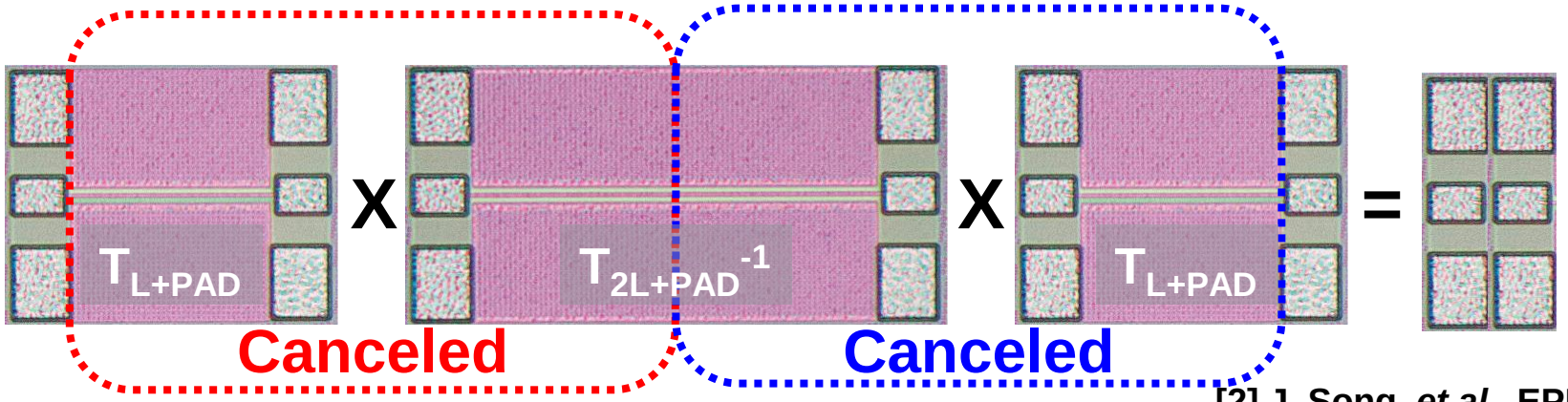
L-2L Method



$$T_{L+PAD} = T_{LPAD}\, T_L\, T_{RPAD} \qquad T_{2L+PAD} = T_{LPAD}\, T_{2L}\, T_{RPAD}$$

$$(T_{2L} = T_L^2)$$

$$T_{L+PAD}\, T_{2L+PAD}^{-1}\, T_{L+PAD} = T_{LPAD}\, T_{RPAD}$$



[2] J. Song, *et al.*, EPEP2014

Problems

T_{LPAD} T_{RPAD} is symmetric because TL is symmetric.

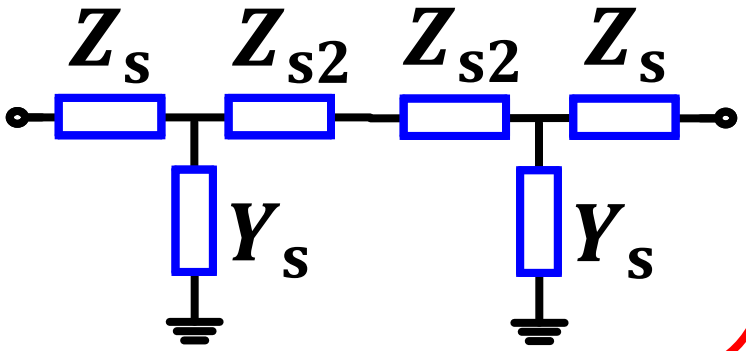
➔ $T_{11}=T_{22}$, $T_{12}=T_{21}$

➔ Only 2 parameters can be obtained.

T_{LPAD} , T_{RPAD} are not symmetric.
3 parameter model should be needed.

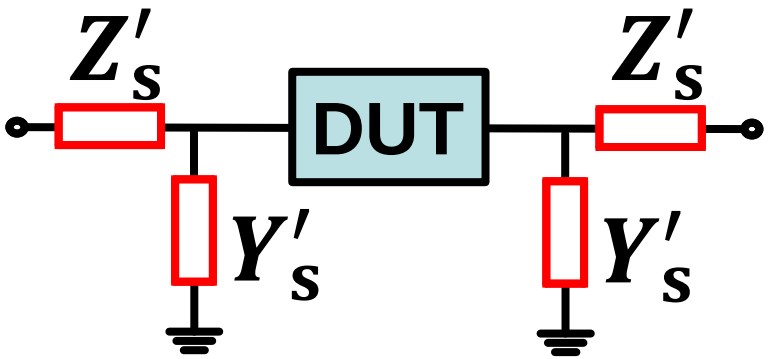
Ideal model

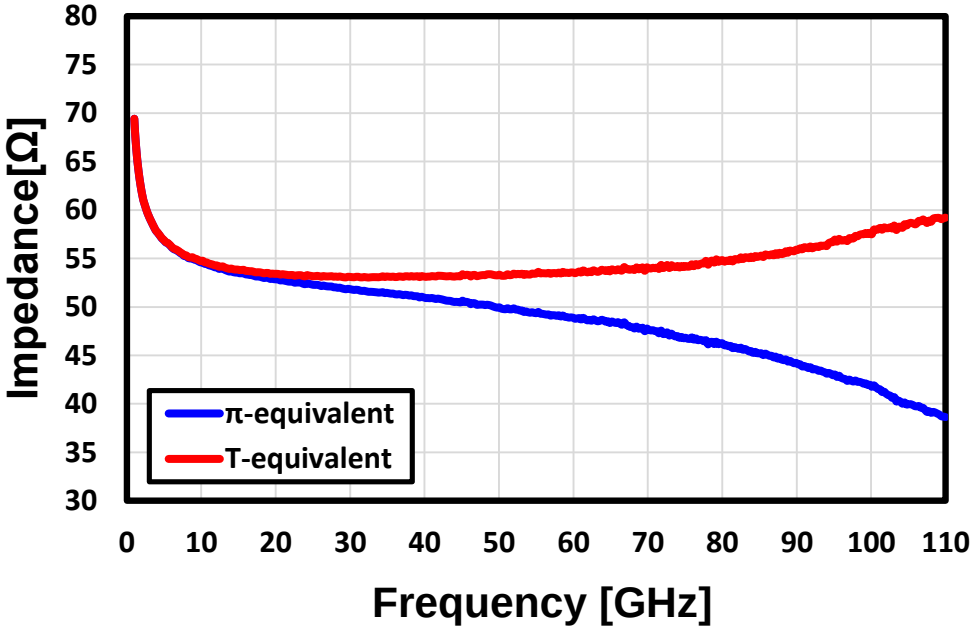
T_{LPAD} T_{RPAD}



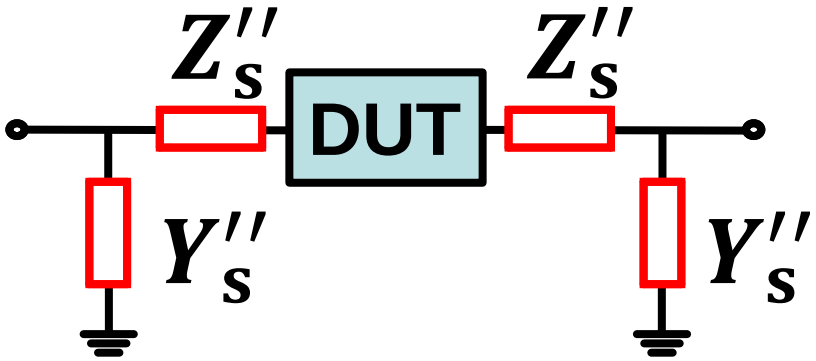
Problems

T-type





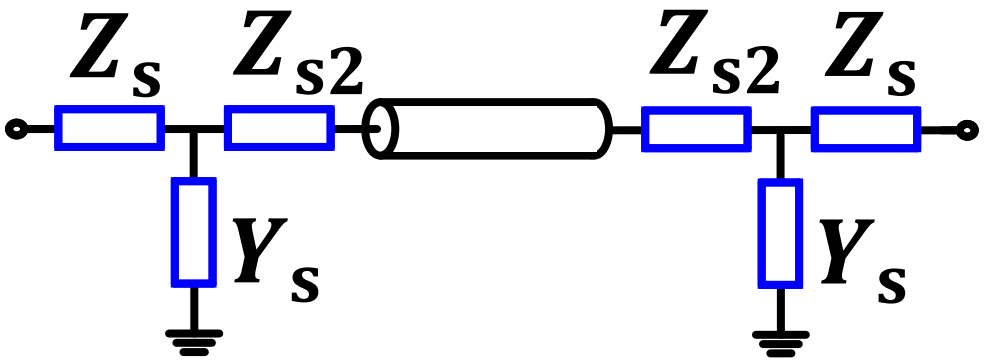
π-type

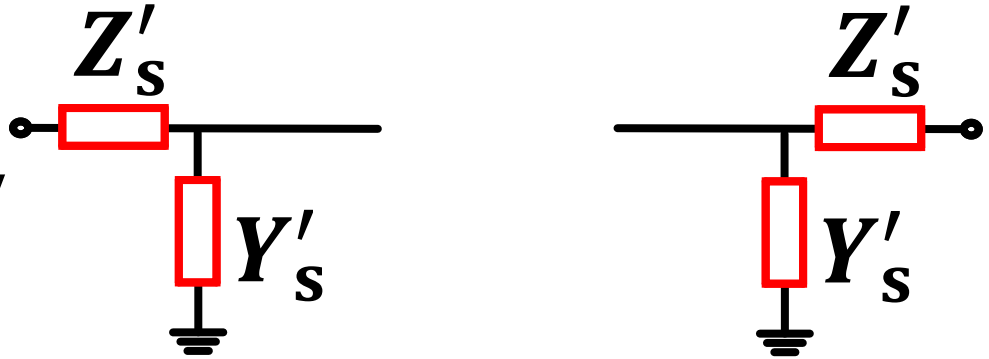


$$Z_0 = \sqrt{\frac{R + j\omega L}{G + j\omega C}} \approx \sqrt{\frac{L}{C}}$$

$$(\omega L \gg R, \omega C \gg G)$$

Problems

When  is

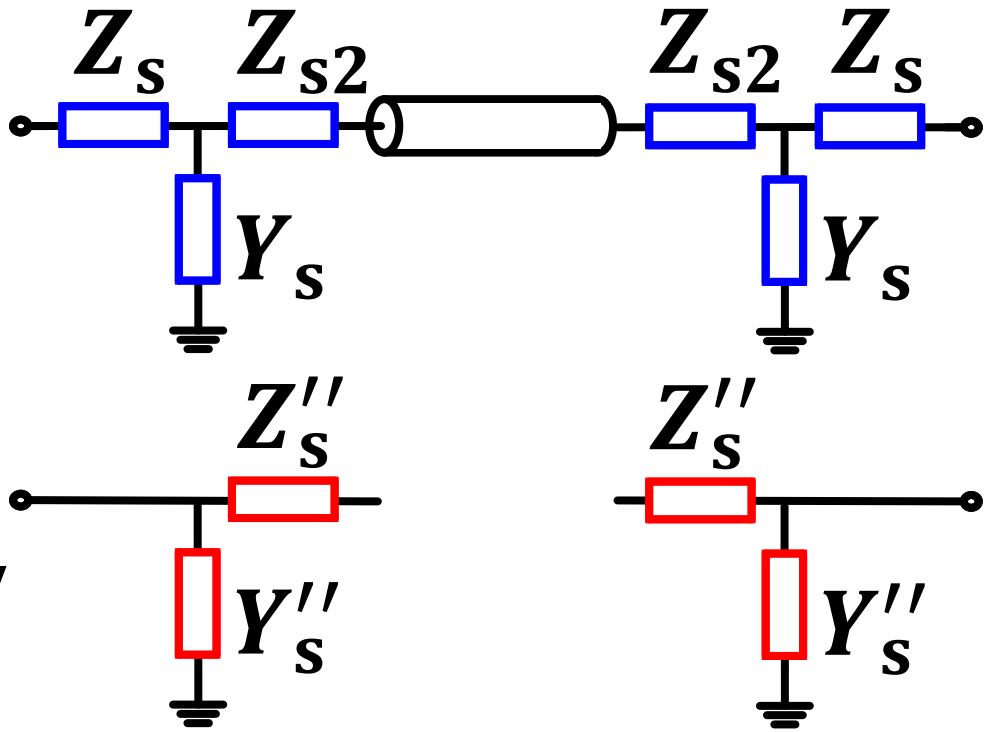


de-embedded by

$$F'_{TL} = \begin{pmatrix} \cosh\gamma\ell & \frac{Z_0}{(Y_S Z_{S2}+1)^2}\sinh\gamma\ell \\ \frac{(Y_S Z_{S2}+1)^2}{Z_0}\sinh\gamma\ell & \cosh\gamma\ell \end{pmatrix}$$

Problems

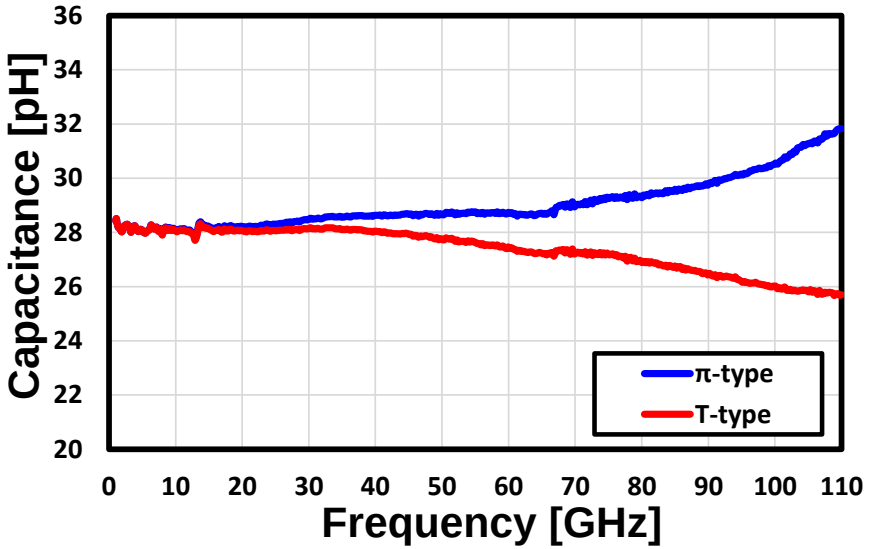
When



is de-embedded by

$$F''_{TL} = \begin{pmatrix} \cosh \gamma \ell & Z_0 (Y_S Z_S + 1)^2 \sinh \gamma \ell \\ \dfrac{1}{Z_0 (Y_S Z_S + 1)^2} \sinh \gamma \ell & \cosh \gamma \ell \end{pmatrix}$$

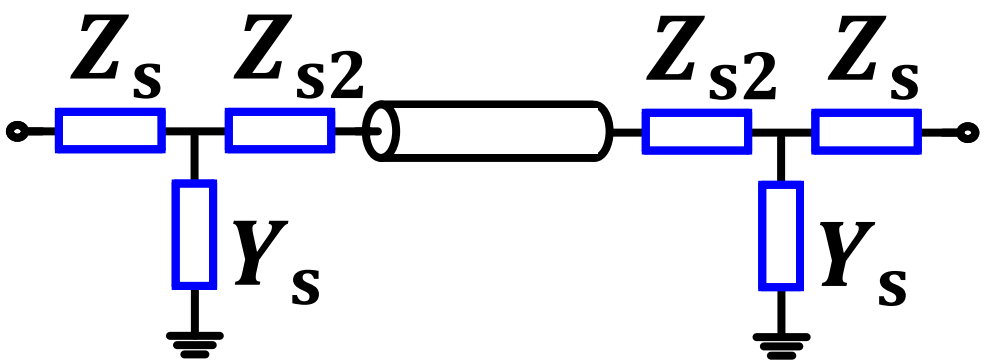
Problems

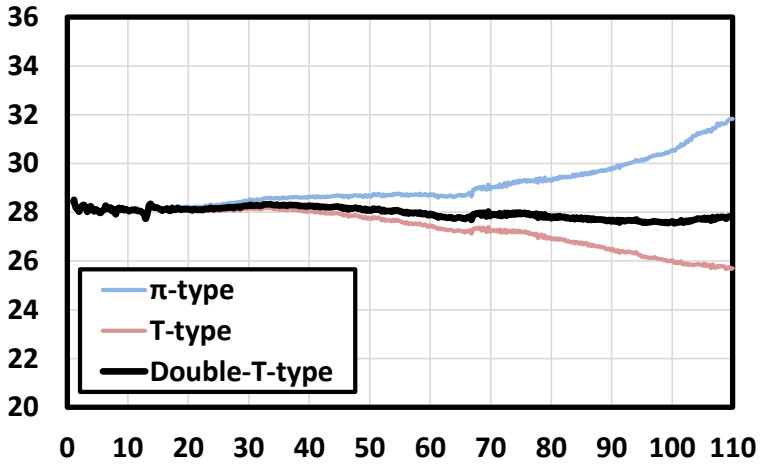


- **Capacitance of PAD affects to impedance.**
- **Capacitance is because of top-metal to ground.**

➔ It should be constant in high frequency.

Proposed PAD Model





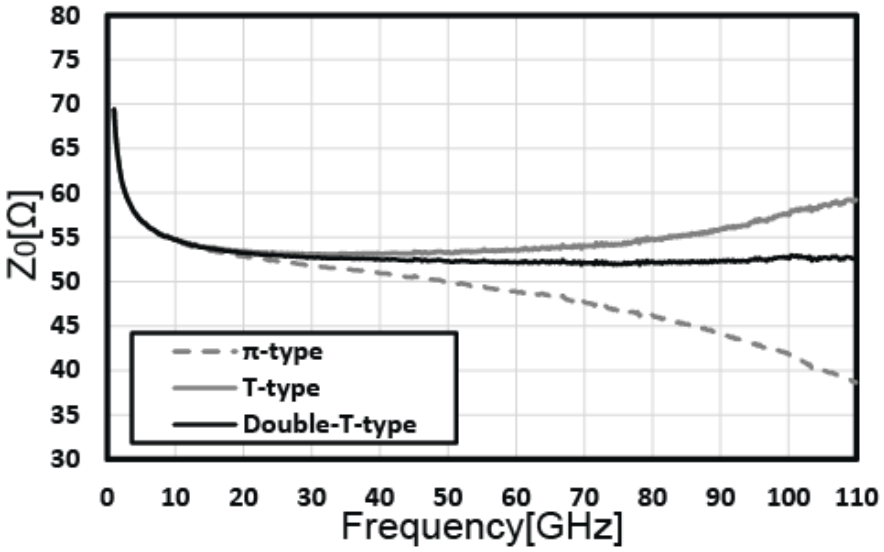
It is impossible to get 3 parameter from L-2L.

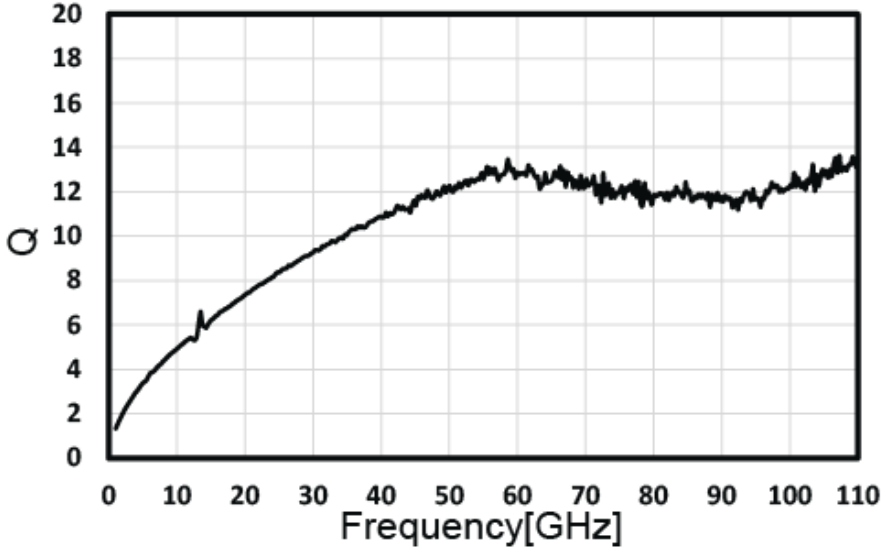
Assumption: $Z_{S2} = k \times Z_S (0 \leq k \leq 1)$

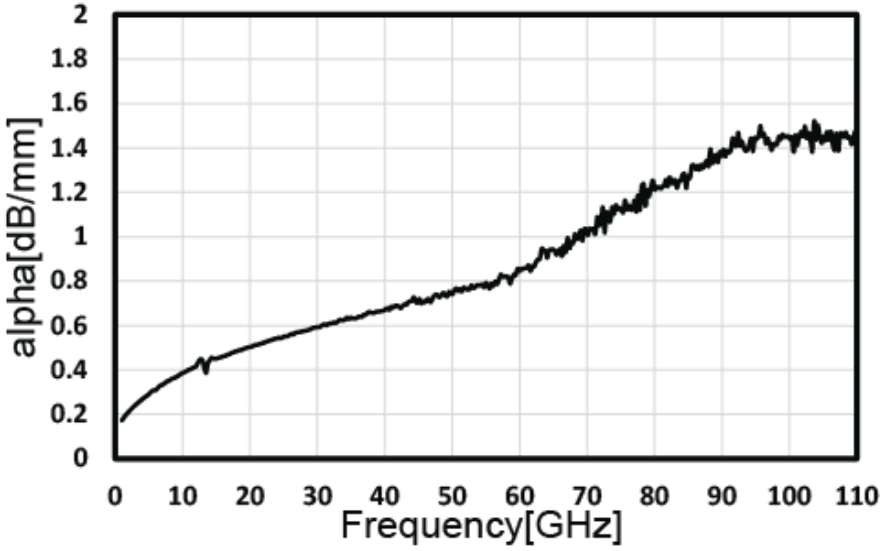
Set "k" to be the PAD capacitance constant.

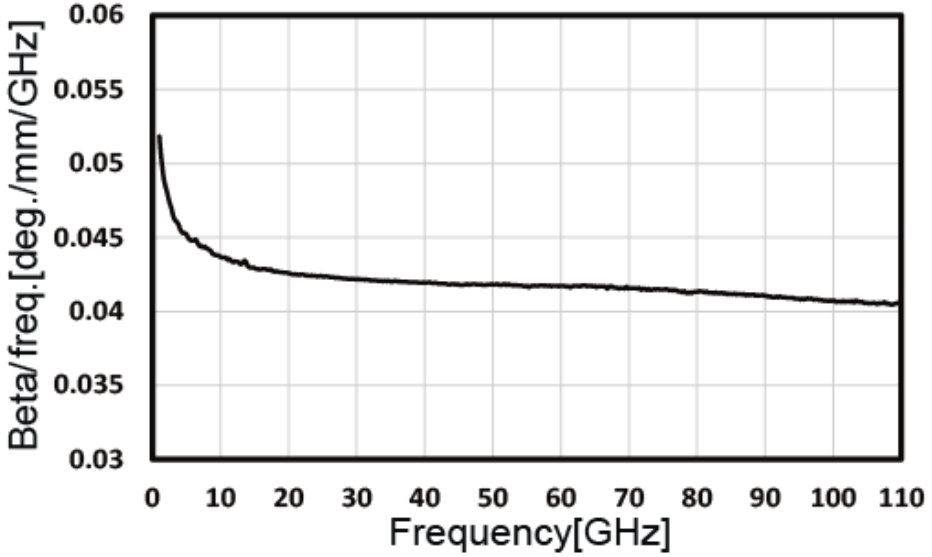
(In this time, k=0.4)

De-embedding Results of TL

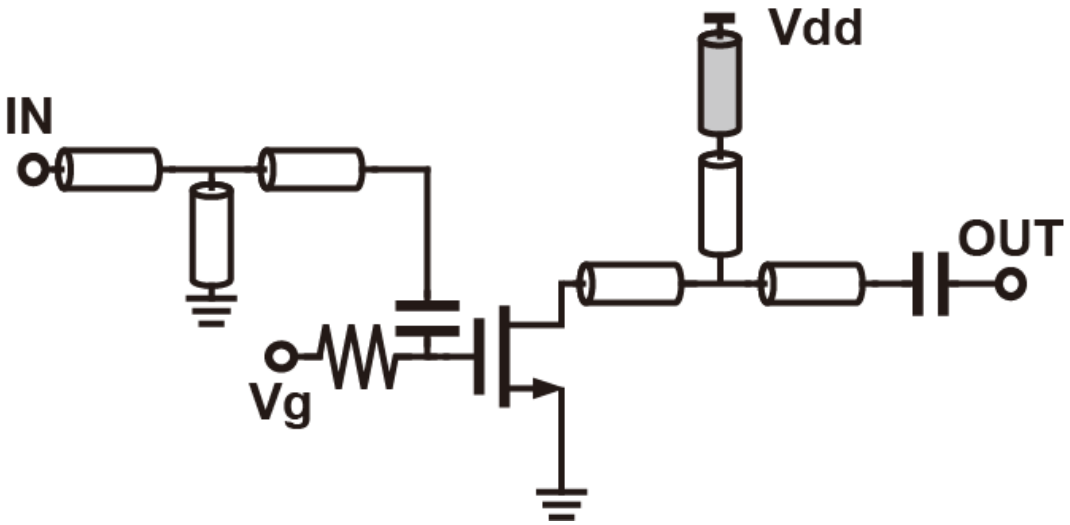


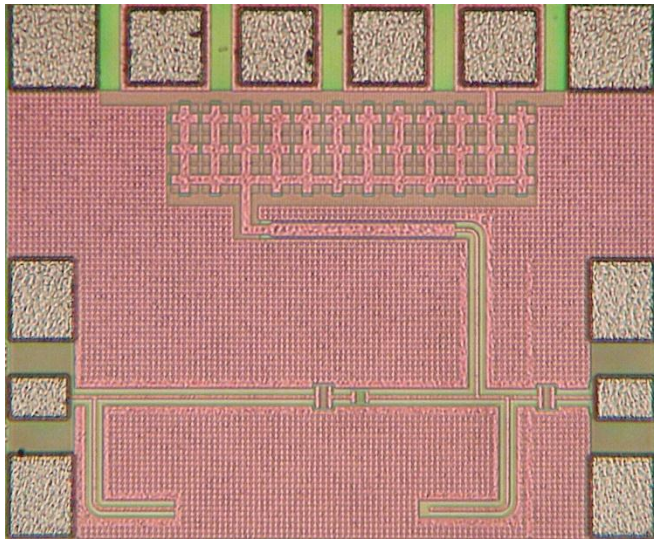


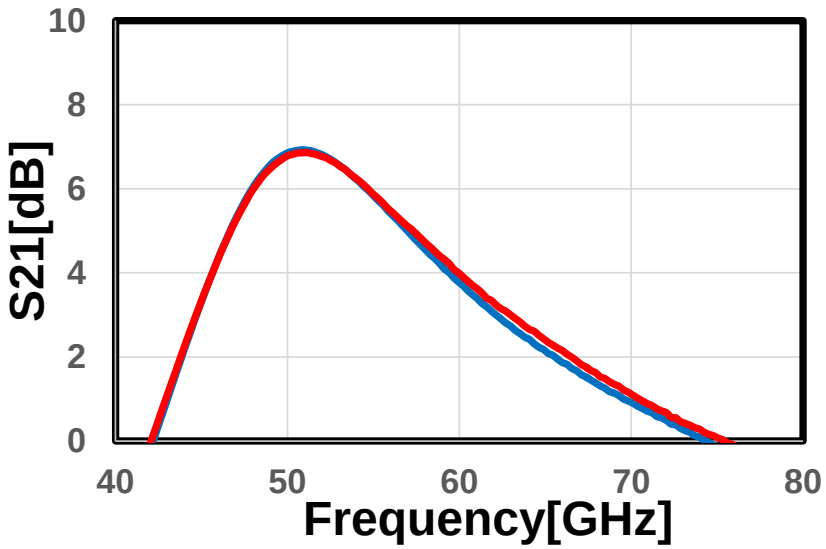


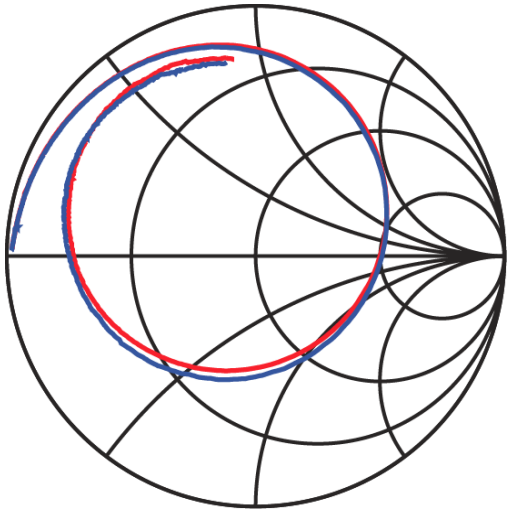


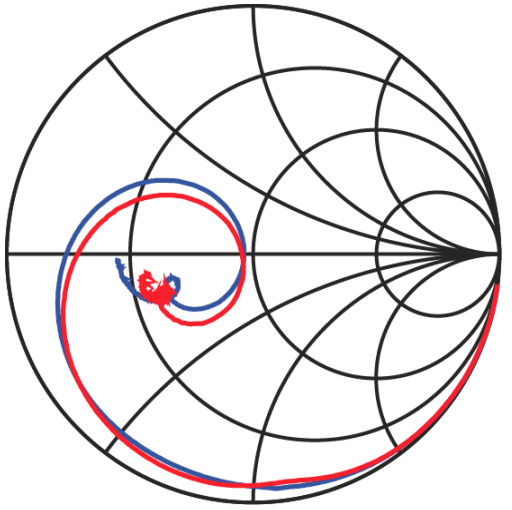
Simulation Comparison











Conclusion

- **L-2L de-embedding based on 3-parameter PAD model is proposed.**
- **According to the characteristic impedance of TL, the TL is de-embedded correctly.**
- **Simulation and measurement results are matched well.**

→An accurate model in mm-W is realized.

Thank you for your attention!