Evaluation of Transmission Line Modeling Using Different De-embedding Methods

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Outline

- Background
- About de-embedding
- Different de-embedding methods
  - Open-short method
  - Thru-only method
  - L-2L method
- Comparison of measured transmission line data
- Performance comparison of the PAs using different TL models
- Conclusion

Background

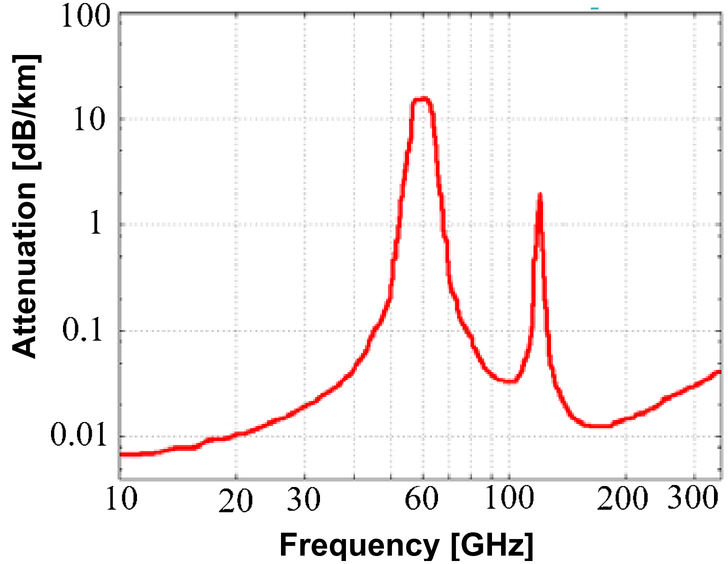
Advantage of 60GHz

- ☹ **Enable communication distance is short.**
- ☺ **Be resistant to interfere**

⇩

Suitable for short range wireless Communications

[1] Rec. ITU-R P.676-2, Feb. 1997



IEEE 802.15.3c

- **QPSK**

⇒ 3.5Gbps/ch

- **16QAM**

⇒ 7.0Gbps/ch

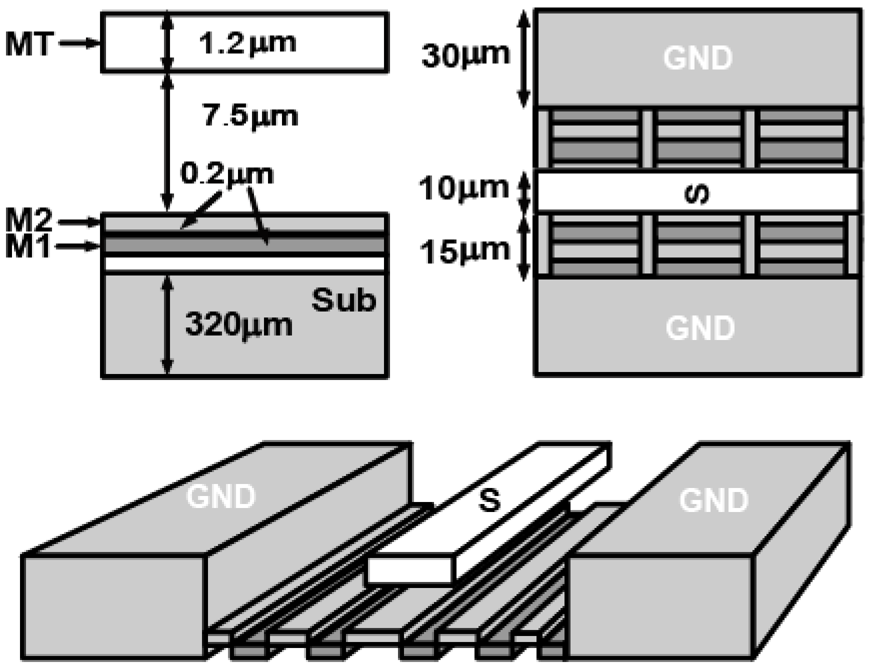
Gbps Wireless Communication

Transmission Line

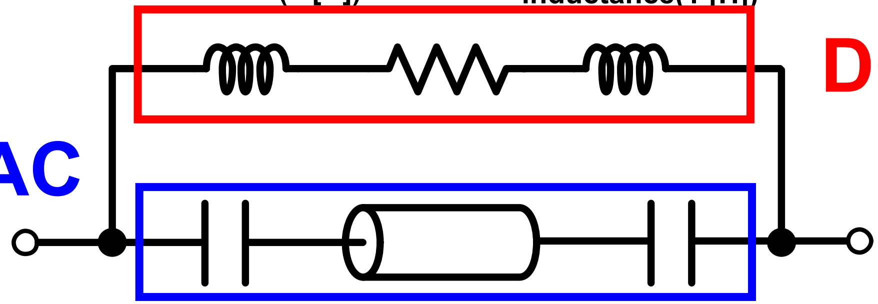
TL is used for considering the circuit by distributed constant.

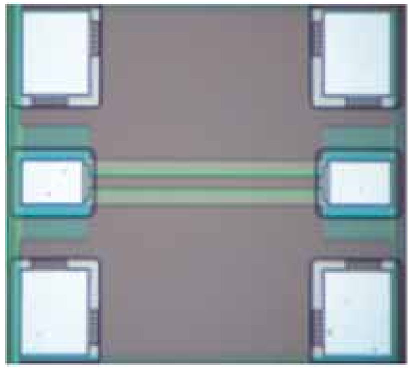
PDK are only guaranteed to 20 GHz.

→ **The accurate models for 60 GHz are required.**



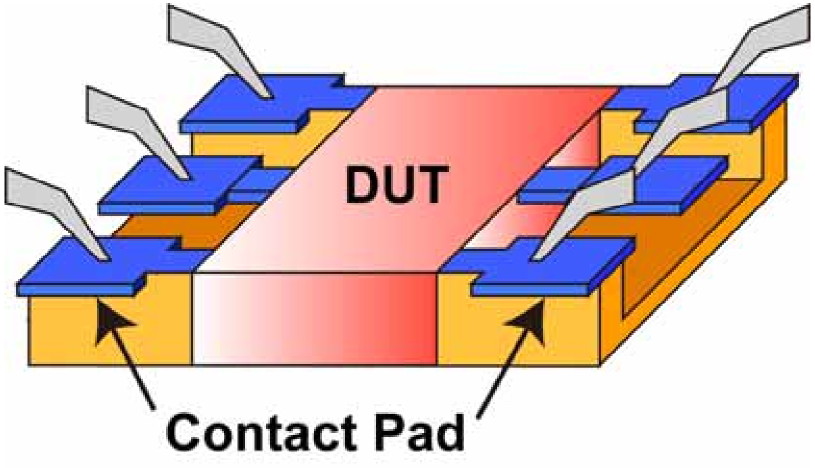
The structure of TL.

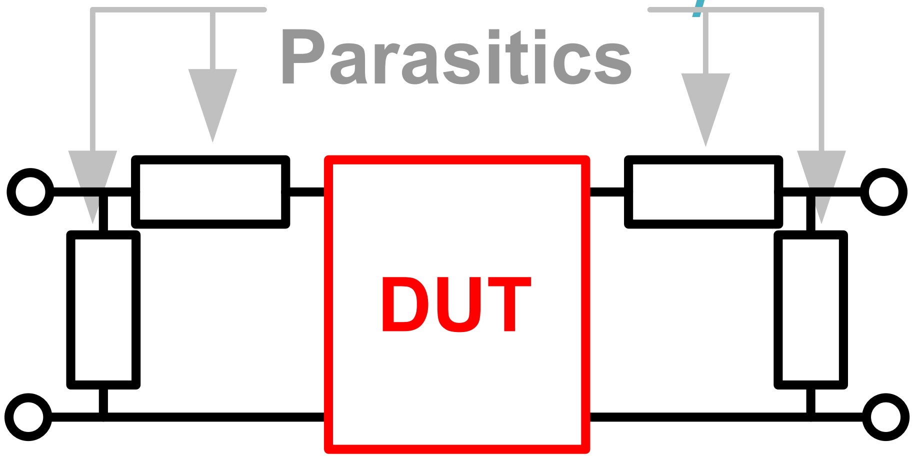




Model and photo.

What is De-Embedding?





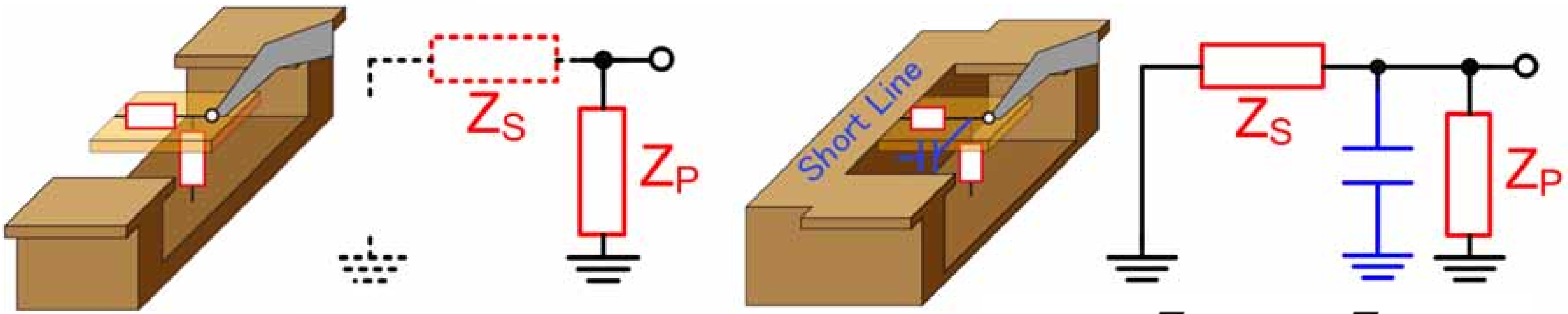
- **Measurement data include parasitic components.**
- **Parasitic components are not ignorable at 60GHz.**

⟶ These are required to be removed.

- Open-short method
- Thru-only method
- L-2L method

Open-short and thru-only method

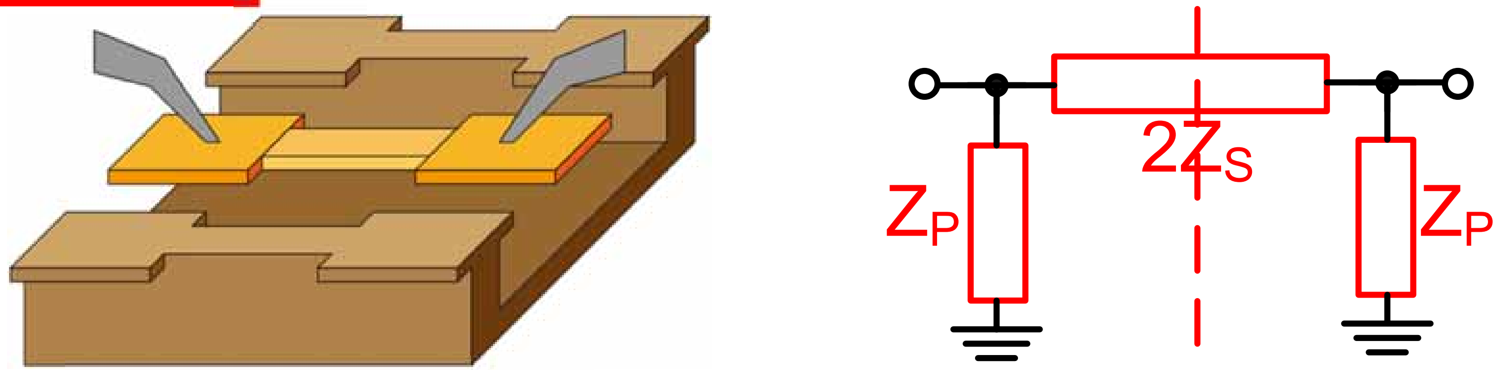
Open-short ☹ **Ideal short pattern cannot be achieved.**



$$Z_p = Z_{open}$$

$$Z_s = \frac{Z_{open} * Z_{short}}{Z_{open} - Z_{short}}$$

Thru-only ☹ **Affected by the thru length and probe coupling.**

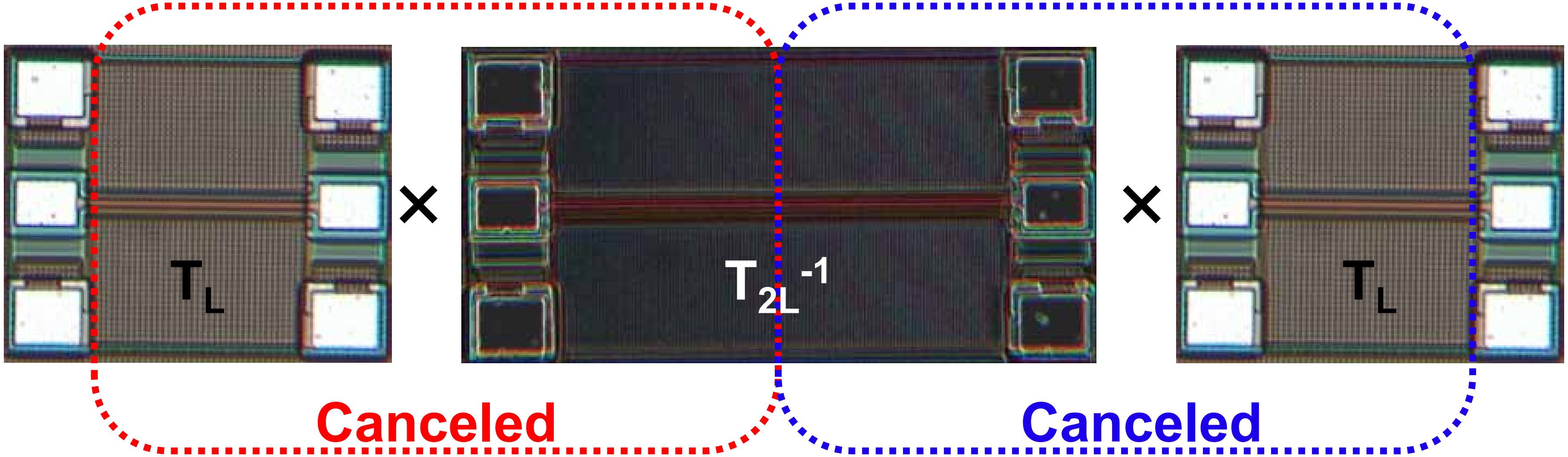


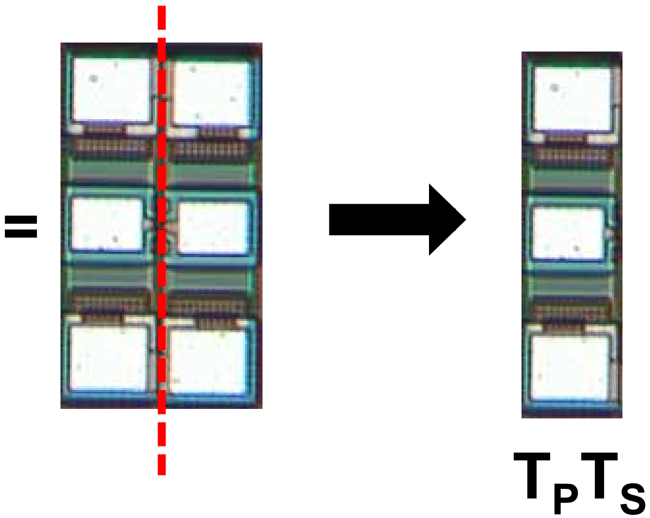
$$Z_p = \frac{1}{Y_{11} + Y_{12}}$$

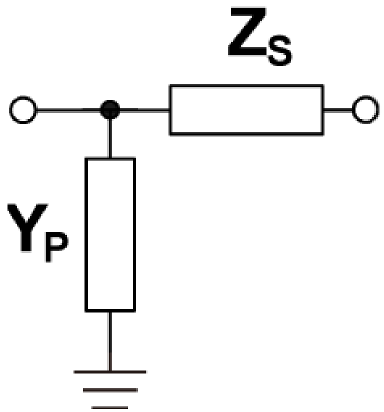
$$Z_s = -\frac{1}{2Y_{12}}$$

[2] H. Ito, et al, IMS 2008.

L-2L De-embedding method







$$T_S = \begin{pmatrix} 1 & Z_S \\ 0 & 1 \end{pmatrix}$$

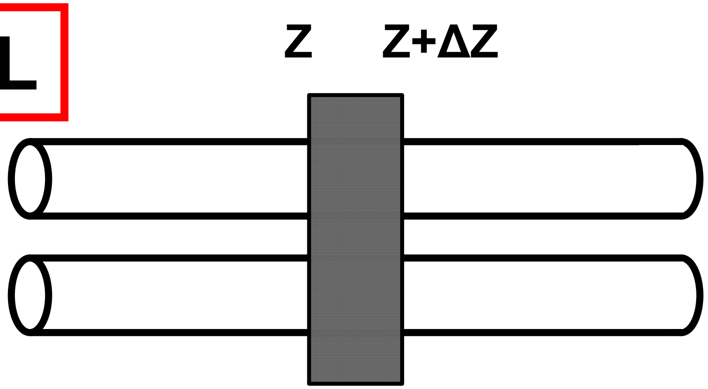
$$T_P = \begin{pmatrix} 1 & 0 \\ Y_P & 1 \end{pmatrix}$$

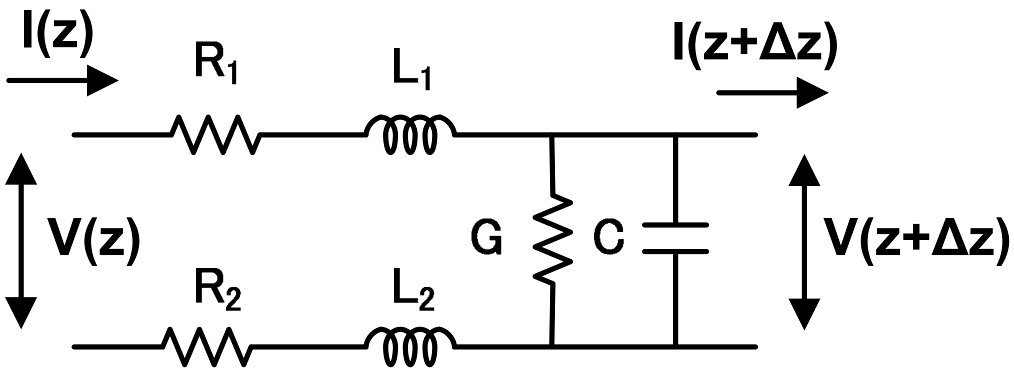
- ☺ **Realize ideal thru pattern.**
- ☺ **Good isolation between probes.**

[3] N. Li, et al, IEICE TRANS 2010.

Parameters of TL (α, β, Q, Z_0)

TL





Equivalent circuit

$$-\frac{dV(z)}{dz} = (R + j\omega L)I(z)$$
$$-\frac{dI(z)}{dz} = (G + j\omega C)V(z)$$

$$\frac{d^2V(z)}{dz^2} - \gamma^2 V(z) = 0$$
$$\frac{d^2I(z)}{dz^2} - \gamma^2 I(z) = 0$$

Wave equation

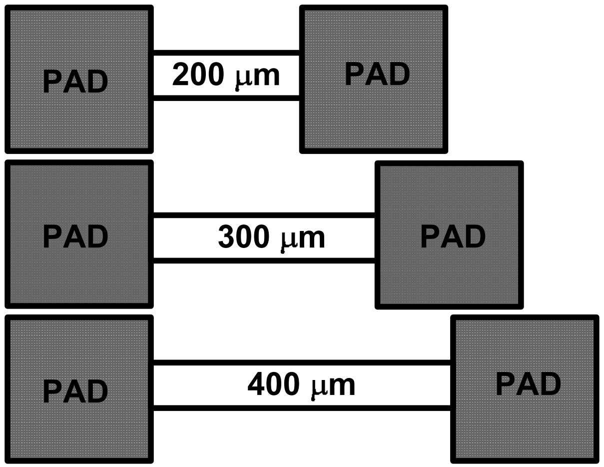
$$\gamma = \sqrt{(R + j\omega L)(G + j\omega C)} = \alpha + j\beta$$
$$\alpha \approx \frac{1}{2}\left(\frac{R}{Z_0} + GZ_0\right)$$
$$\beta \approx \omega\sqrt{LC}$$

$$Q = \frac{\beta}{2\alpha}$$
$$Z_0 = \sqrt{\frac{R + j\omega L}{G + j\omega C}}$$

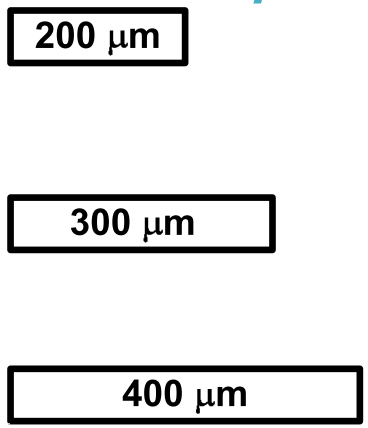
α:attenuation constant **Q:quality factor**

β:phase constant **Z_0:characteristic impedance**

Evaluation



- open-short
- thru-only
- L-2L



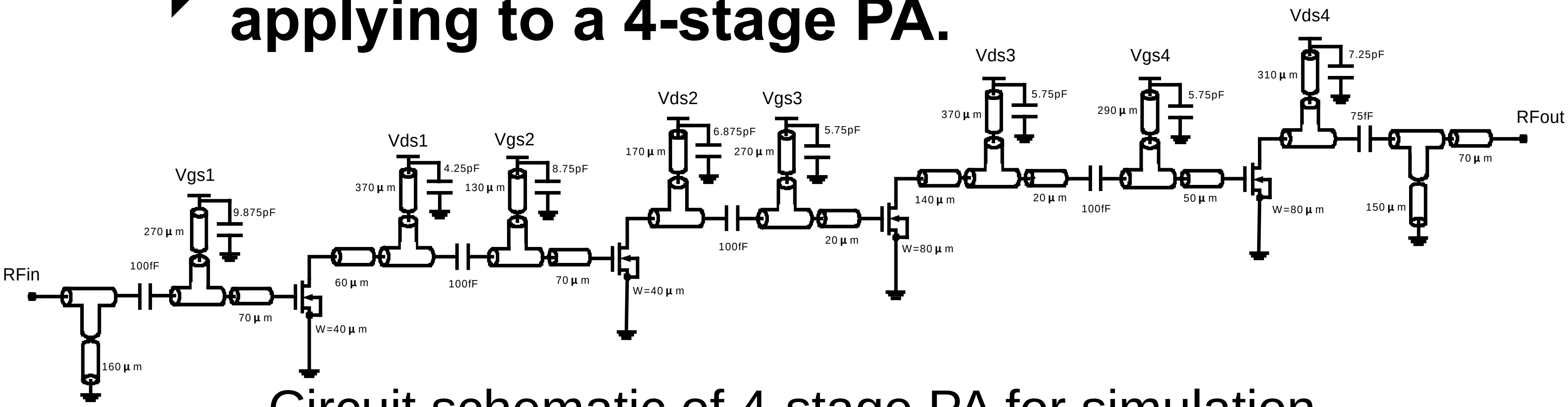
Compare the parameter $\alpha, \beta, Q,$ and Z_0 per unit length.

These parameters must be the same regardless of the length of TLs.

Make the models of TL using measurement result of different de-embedding methods.

Evaluation, cont.

→ **Simulate the effect of different models by applying to a 4-stage PA.**

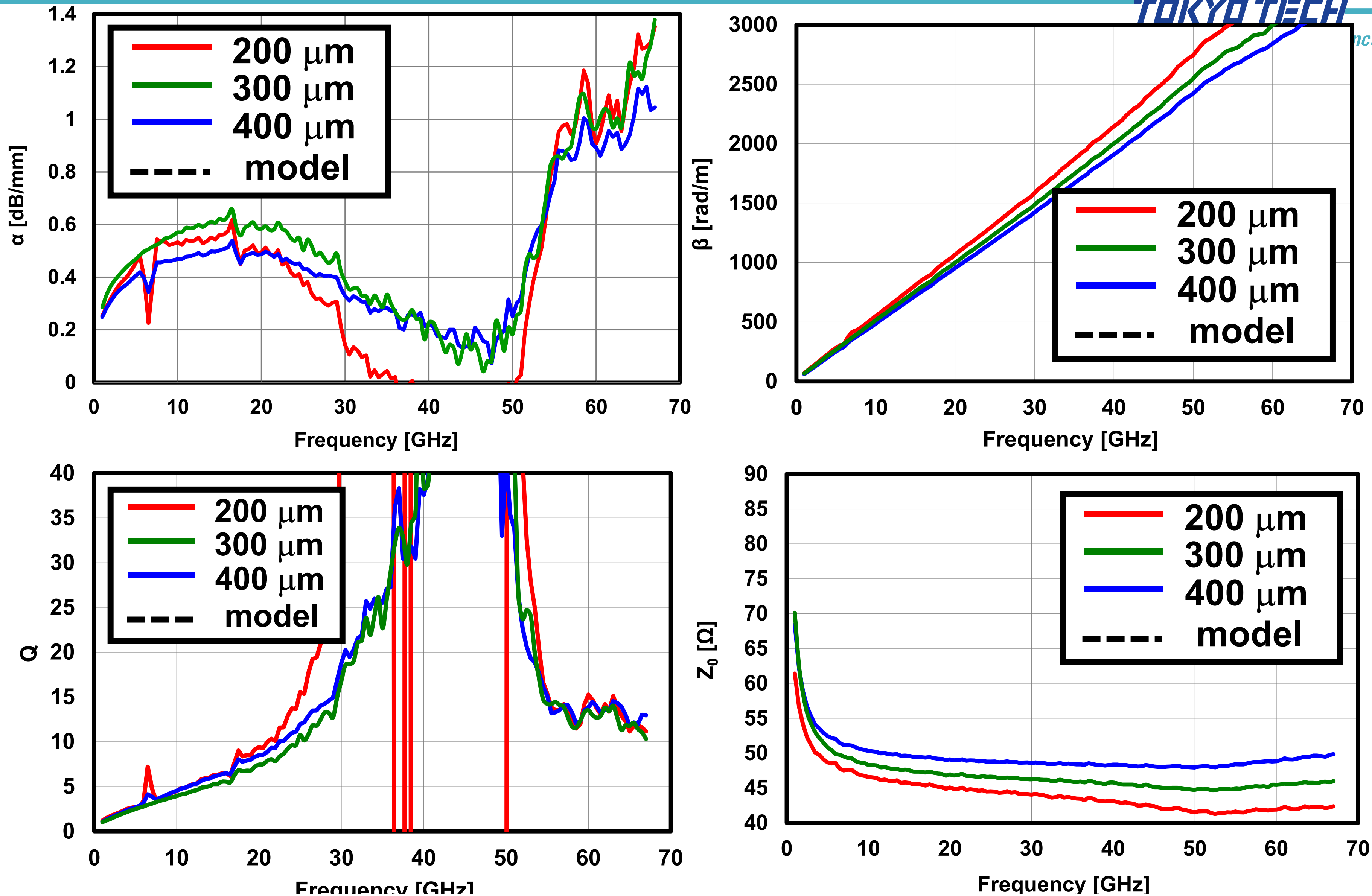


Circuit schematic of 4-stage PA for simulation

- **common source topology**
- **MIM capacitor is used for decoupling**
- **1.2V supply, 65nm CMOS**

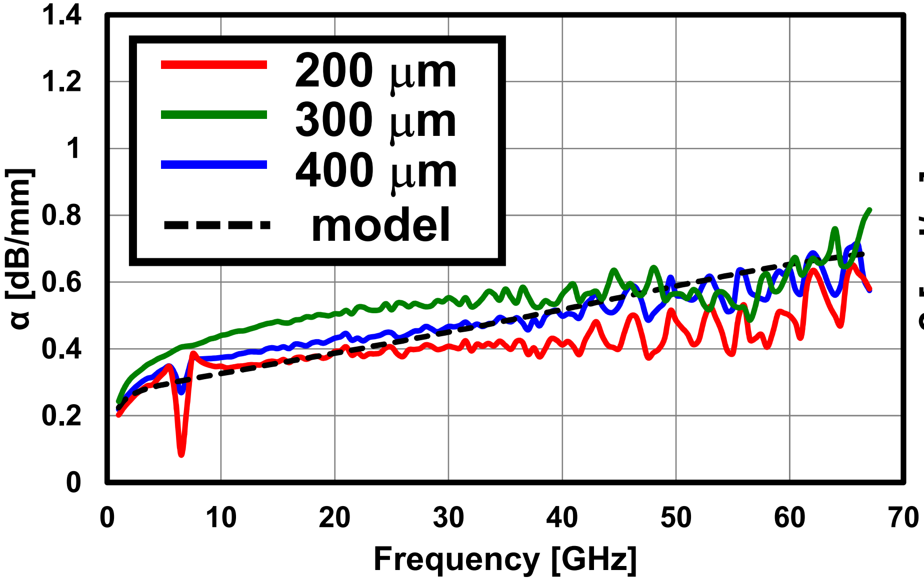
The evaluation is focused on the accuracy of transmission line models, so the same models are used for transistor, MIM capacitor, etc.

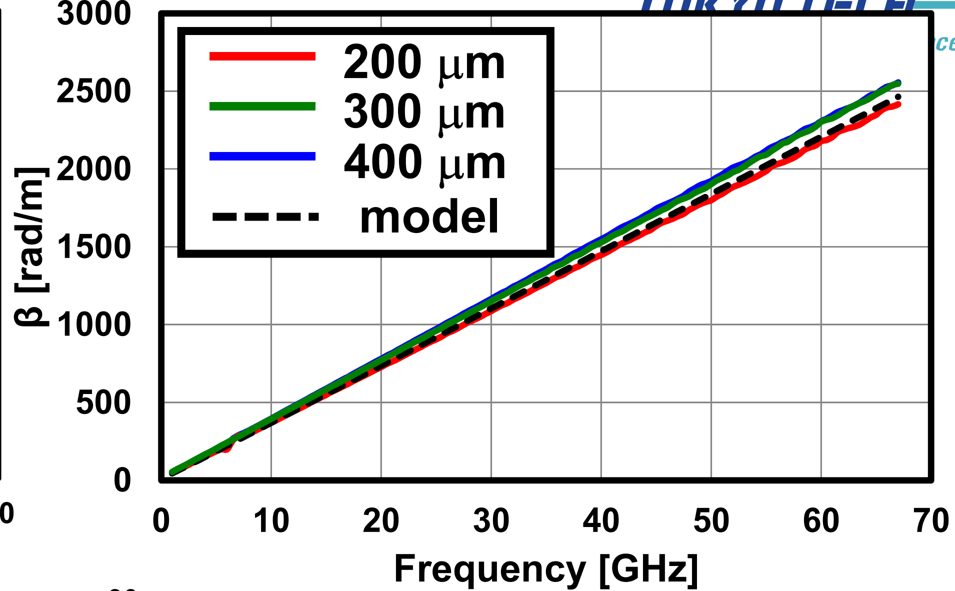
Measurement results using open-short method

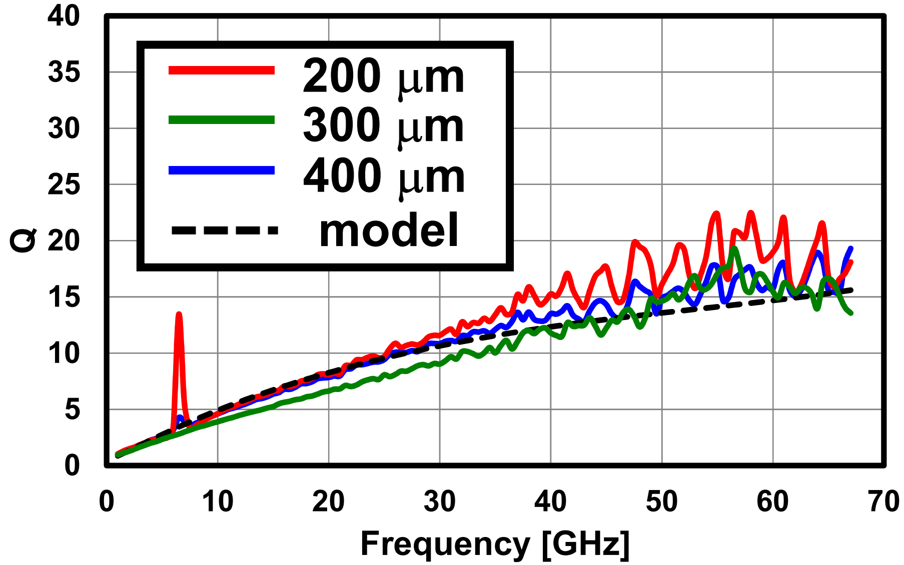


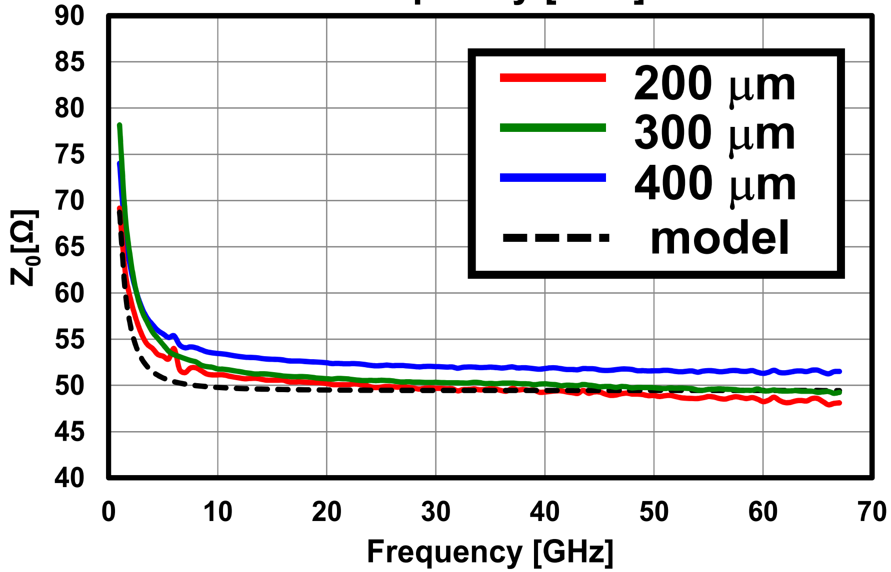
Open-short method cannot be used for modeling.

Measurement results using thru-only method



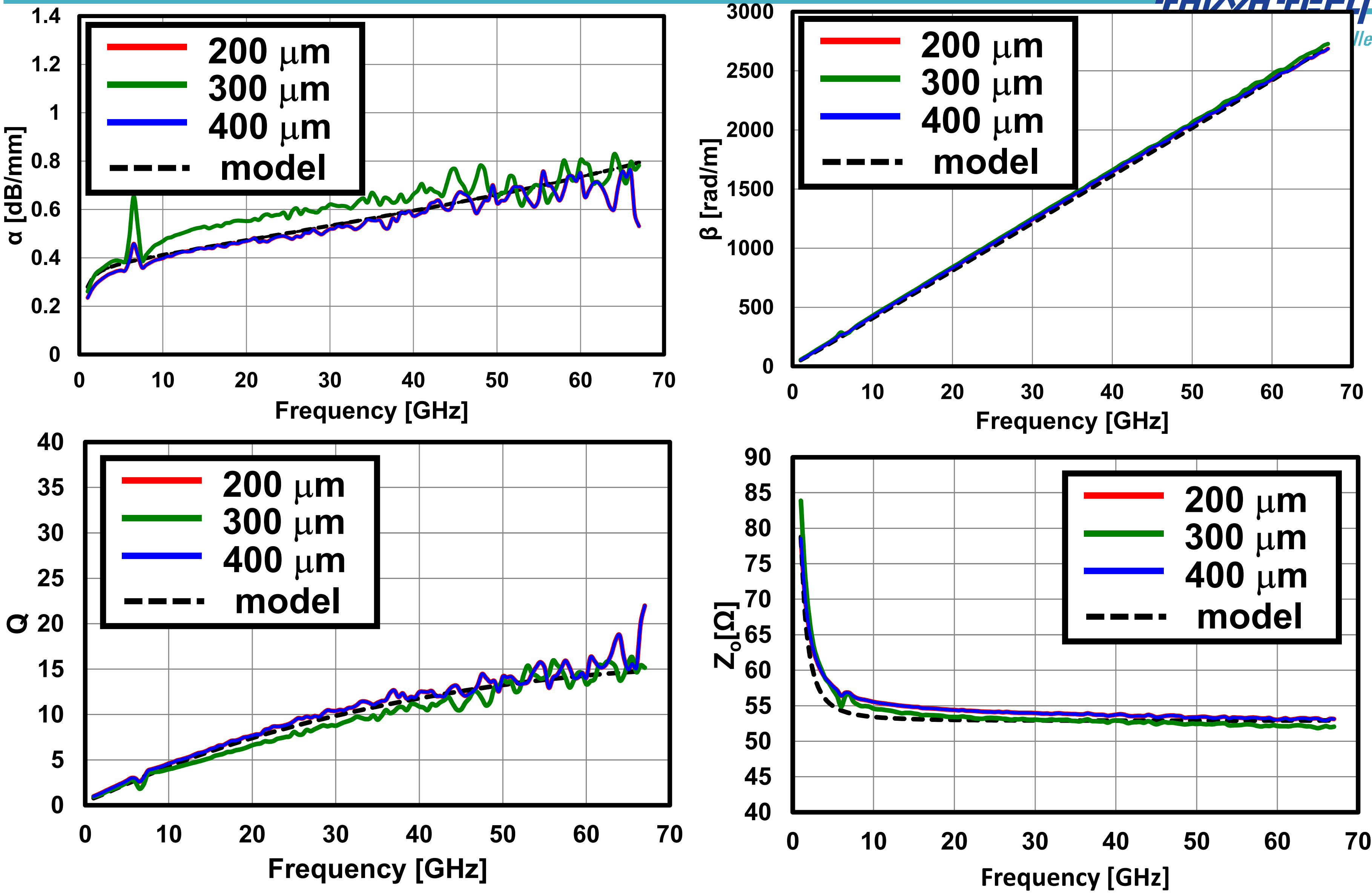






Z_0 has 3 Ω difference at 60 GHz.

Measurement results using L-2L method



Z_0 has 0.9 Ω difference at 60 GHz.

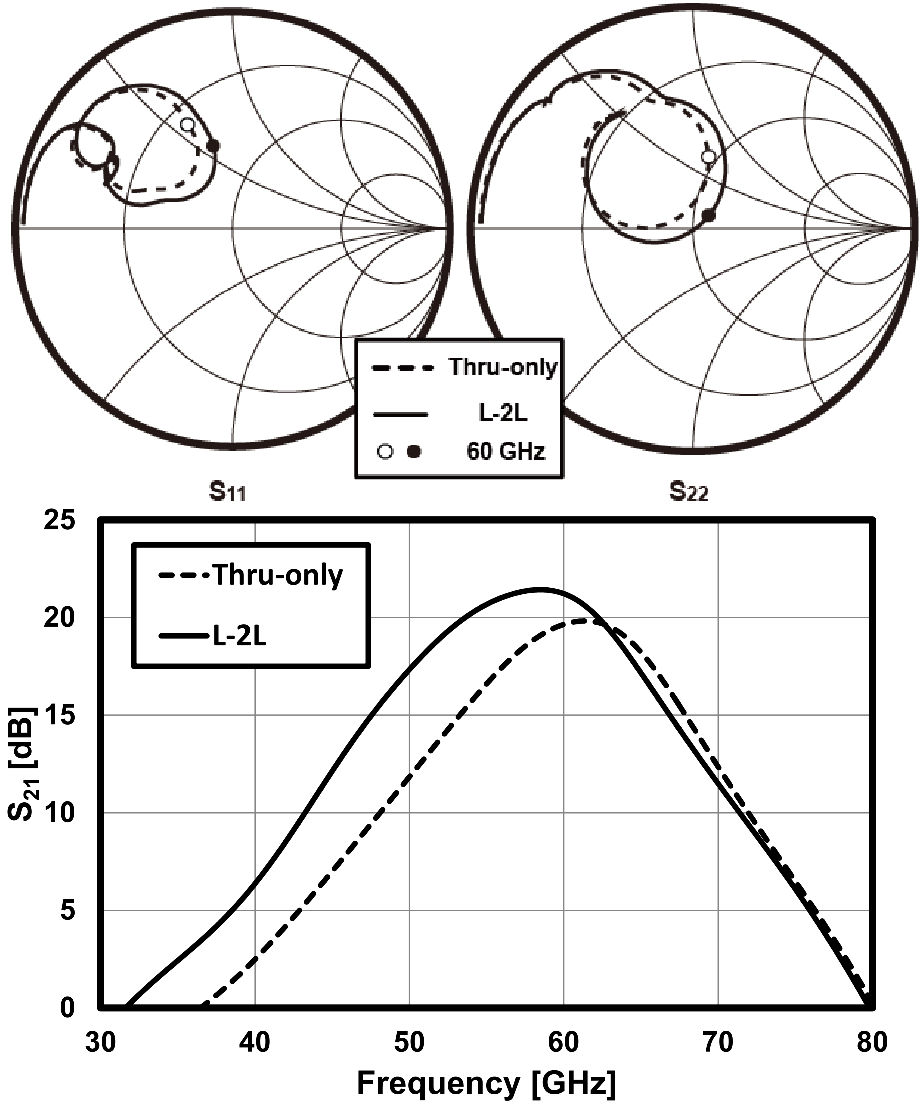
De-embedding error at 60GHz

This table shows the difference of transmission line parameters between different length of TLs.

	Open-short	Thru-only	L-2L
Δ α [%]		20.4	2.6
Δ β [%]	32.7	5.7	0.1
Δ Q [%]		21	1.5
Δ Z_0 [%]	15.3	6.1	1.7

L-2L method can obtain the smallest error of transmission line parameters.

The effect of different de-embedding method



Simulation result

	Thru-only	L-2L
Freq. [GHz]	61.4	58.8
Gain [dB]	19.8	21.3
P_{1dB} [dBm]	7.41	8.78
P_{sat} [dBm]	11.0	11.4
Peak PAE [%]	6.51	7.45
Power [mW]	169	170

There are 1.5-dB gain error and 2.6-GHz frequency shift.

Sim. error heavily depends on the de-embedding method.

Conclusion

- This presentation shows an evaluation of de-embedding methods for mmW transceiver design.
- The L-2L de-embedding method is the most accurate for transmission-line characterization.
- The frequency shift with 4-stage PA using different de-embedding methods is 2.6 GHz which is over a channel of IEEE802.15.3c.
- The effect of different de-embedding method cannot be negligible.