SW Test Workshop
Semiconductor Wafer Test Workshop
2-0-1-8

Probe Card Test Solution for 5th Generation Mobile Communications

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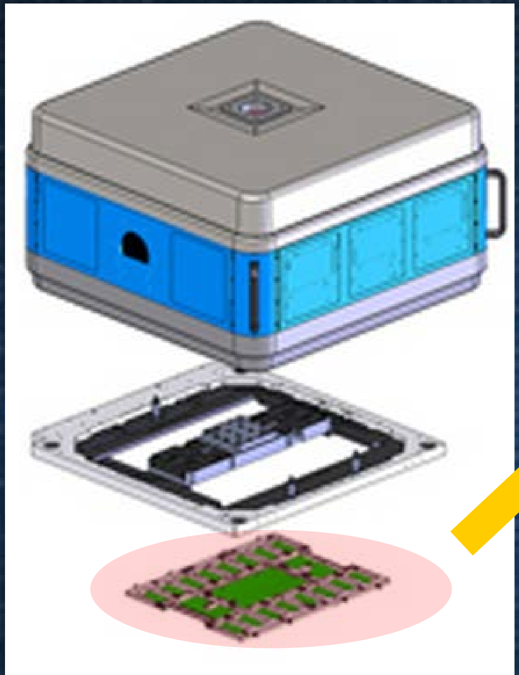
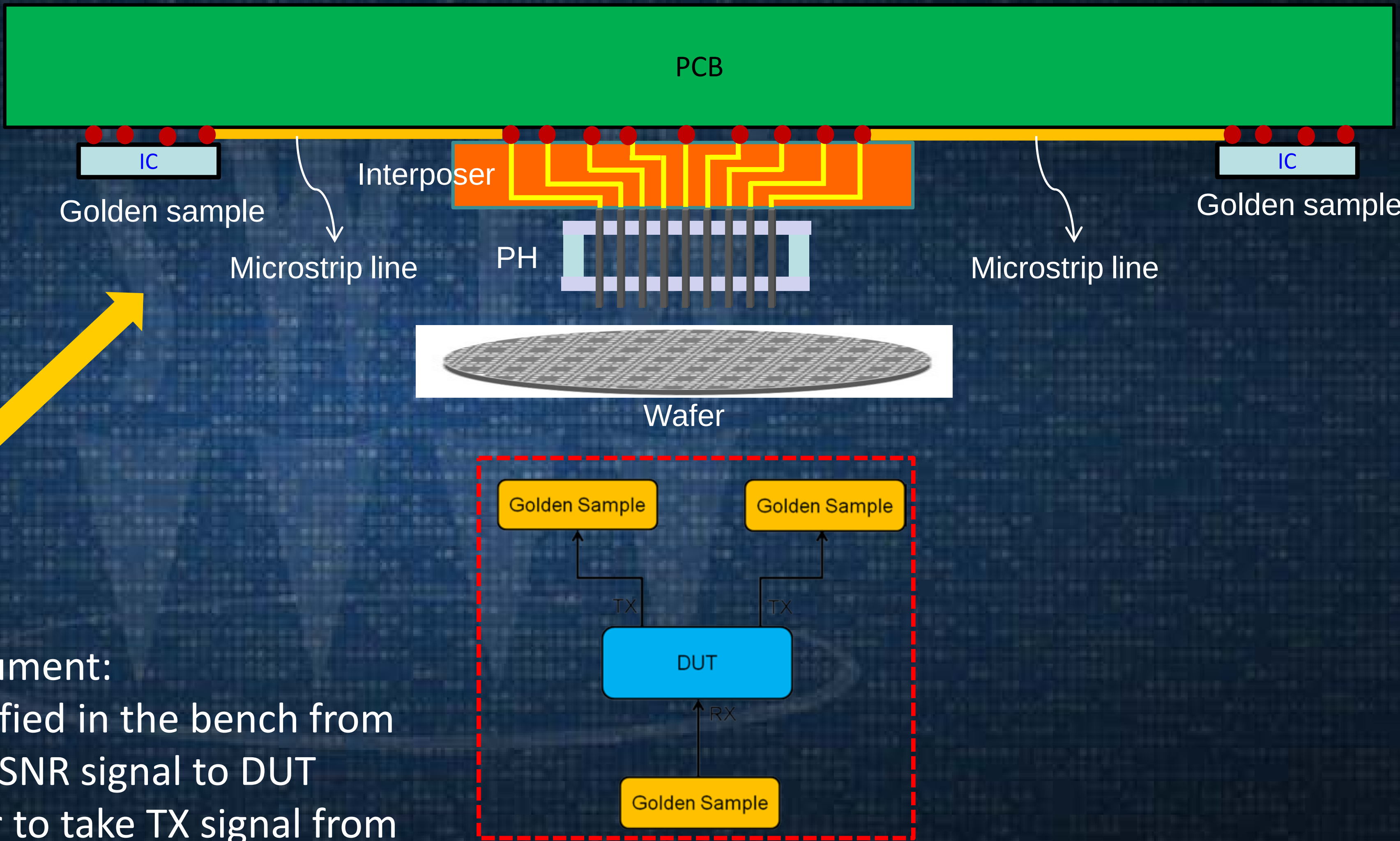
Outline

- Probe Card Test Solutions
- Pogo Pin Design for 28GHz Application
- The Loss Factors of T-Line & DK/DF Extraction
- Measurement and Simulation Correlation
- Conclusion

Probe Card Test Solution I





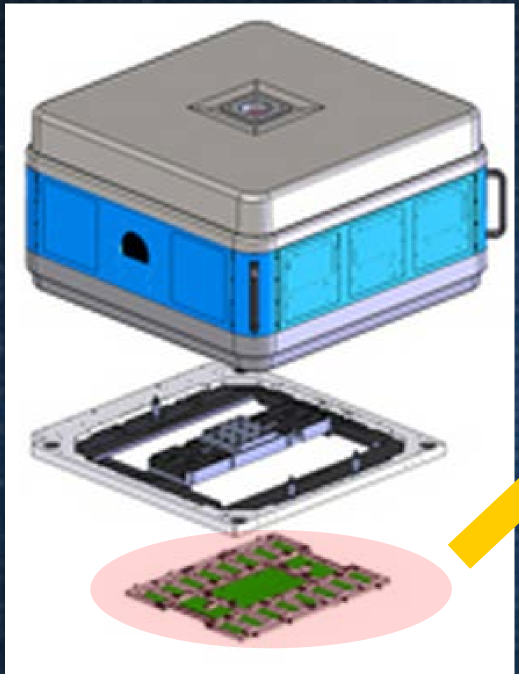
Golden Sample as an Ideal Instrument:
The best-performance chips verified in the bench from Socket which can transmit good SNR signal to DUT and also work as a good receiver to take TX signal from DUT.

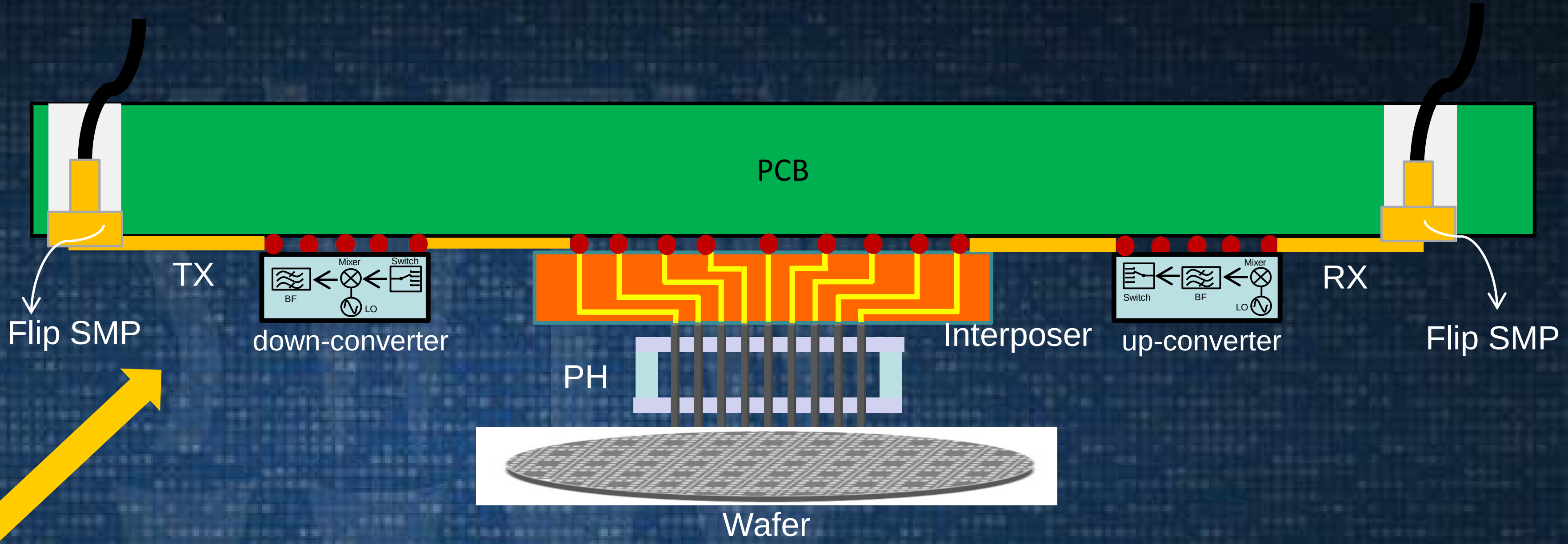
Probe Card Test Solution II

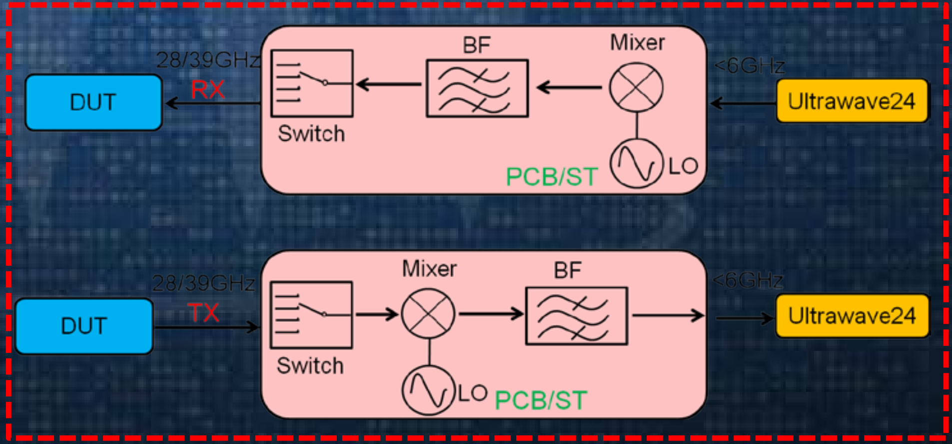
ATE

Bridge Beam

Probe Card





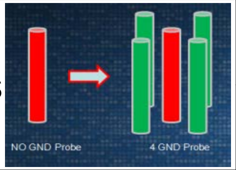
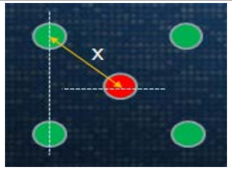
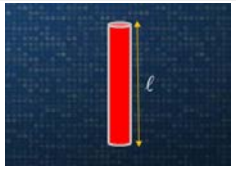
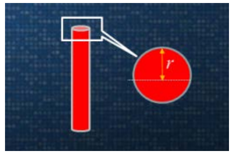


Up-Converter Components:
LPF → Mixer → Local Oscillator → BPF → Switch

Down-Converter Components:
Switch → LNA → BPF → Mixer → LPF

Impedance Control on Probe Pattern

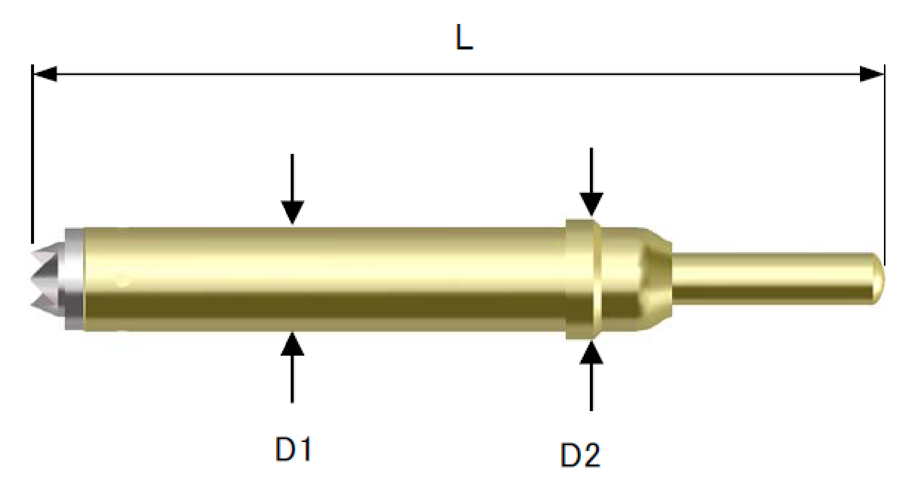
- DFT should take impedance continuity of probe pattern into consideration

Key Factors of Impedance Control	Variables of Probe Pattern		
	Bandwidth		
①GND Probe Quantities 	No GND Probe	2 GND Probe	4 GND Probe
	★	★★	★★★
②Probe Pitch 	X = 0.8mm	X = 0.5mm	X = 0.4mm
	★	★★	★★★
③Probe Length 	Length =3.5mm	Length = 3mm	Free Length = 2.4mm
	★	★★	★★★
④Probe Radius 	Type A(0.24mm)	Type B(0.26mm)	Type C(0.3mm)
	★	★★	★★★

Performance: ★ Bad ★★ Medium ★★★ Good

Refer to 2017 SWTW" Probe Pattern Design for Low-Cost and High-Speed Loopback Test"

28GHz Pogo Pin Specs

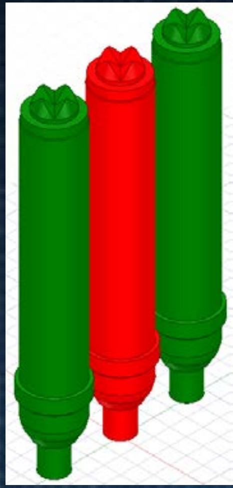


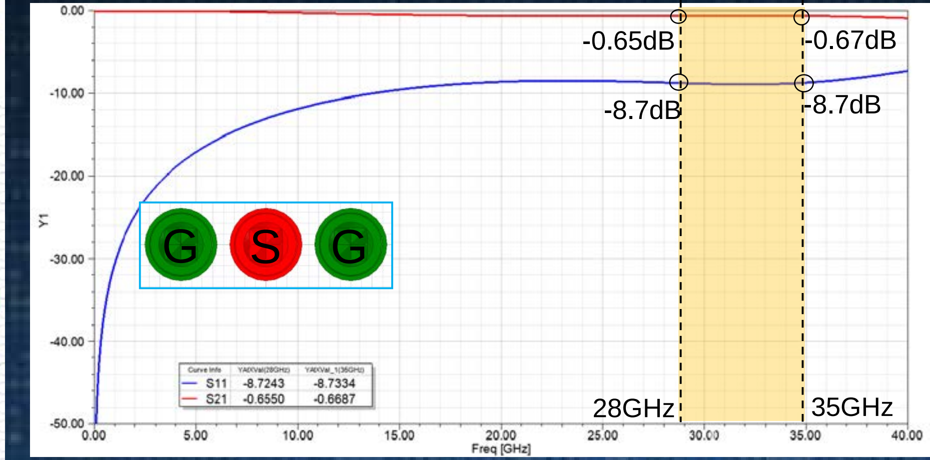
Mechanical Spec.	
Pitch	0.4 mm
Barrel Dia (D1/D2)	Φ0.3/0.34 mm
Free/Operating Length	2.4/2 mm
Operating Stroke	0.4 mm (0.25+0.15)
Spring Force	16±4 gf
Tip Style	Crown
Electrical Characteristics	
Resistance @ Initial	60mOhm(AVR)
Current Capacity	1.8A Max @ Room Temp.
Self-Inductance	0.31 nH

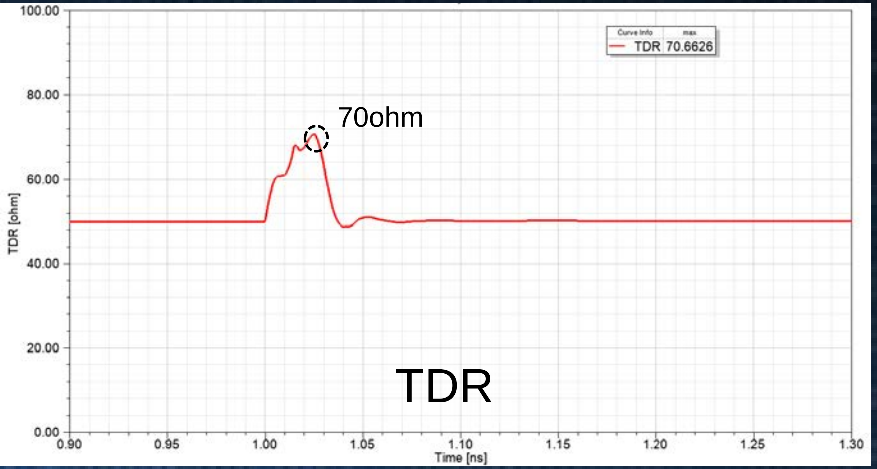
28GHz Pogo Pin Simulation

Pitch:0.4mm

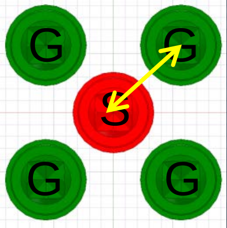
Length:2 mm
(After Preload)

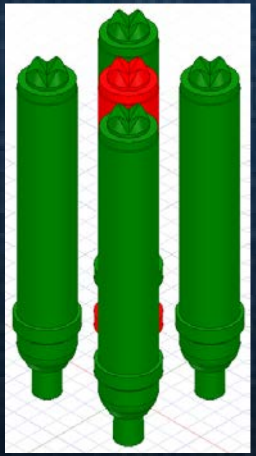


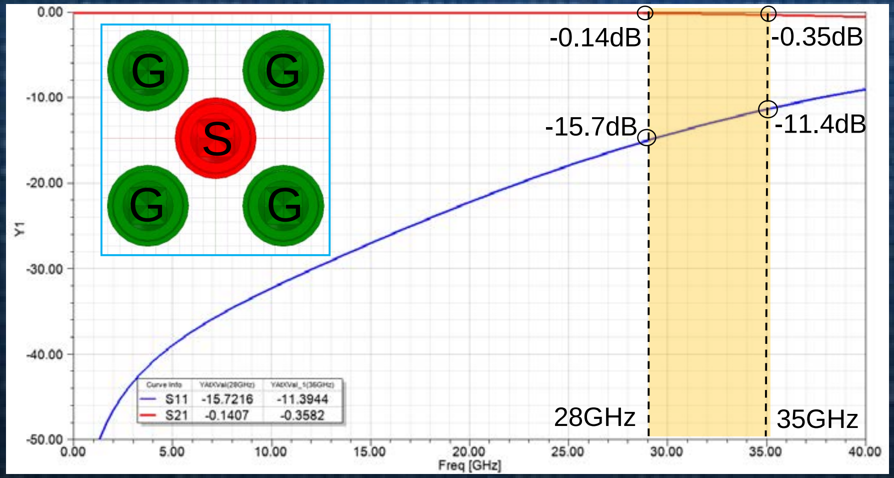


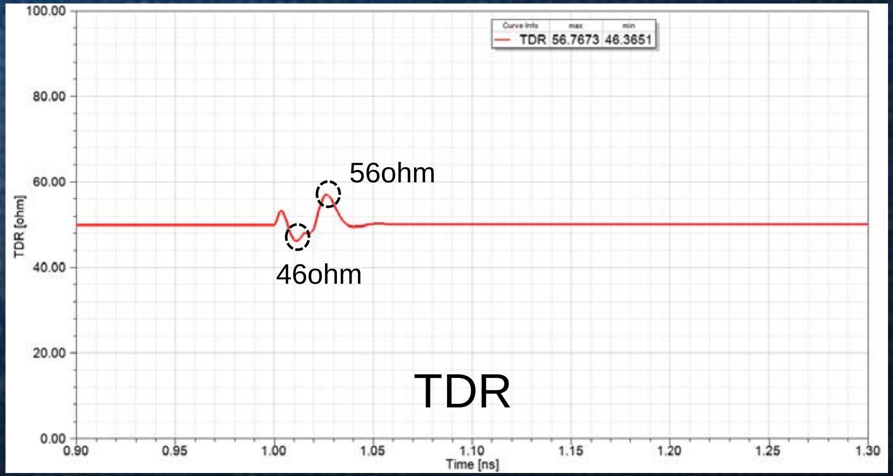


Pitch:0.4mm









The Loss Factors of the Transmission Line

T-Line Loss : $\alpha_{dB} = A_1\sqrt{f} + A_2 f \quad (dB/in)$

Conductive loss(α_c)

Dielectric loss(α_d)

- Conductor loss refers to the T-Line series Resistance.
- T-Line Resistance is proportional to $\sqrt{f}$
- T-Line Resistance is inversely proportional to trace width.
- Metal Surface Roughness is also crucial.

- Dielectric loss refers to the T-Line shunt Conductance.
- Dielectric loss is proportional to f_{req} & $\sqrt{\varepsilon_r}$ & $\tan\delta$.

$$\alpha_d = \frac{\pi \times f \times \tan\delta \times \sqrt{\varepsilon_r}}{3\times10^8}$$

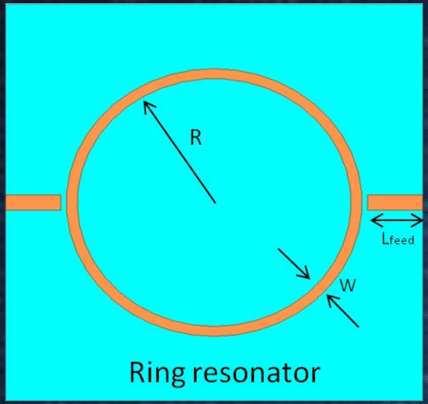
For 5G, we need low and flat DK/DF vs. Freq. due to 2 reasons:

1. 28GHz is a very high Freq., a big weighting in this loss formula.
2. DK/DF are Freq. dependent & 850 MHz Channel BW in 5G.

➔ Keep channel power flatness & Avoid wideband signal dispersion due to different Vp.

PCB DK/DF Extraction

- M-Line Ring Resonator: Two-port gap-coupled Ring method to extract the PCB material's DK and DF.



Ring resonator

DK Extraction

$$\lambda_o = \frac{c}{fr} \quad (1)$$

$$\lambda_g = \frac{\lambda_o}{\sqrt{\varepsilon_{eff}}} \quad (2)$$

$$\ell_F = n\lambda_g \quad (3)$$

From (1),(2), and (3)

$$\varepsilon_{eff} = \left(\frac{nc}{\ell_F \, fr}\right)^2$$

λ_o : Wavelength of the wave with fr in free space

λ_g : Wavelength of the wave with fr in straight line

fr : Resonant frequency

n : Order of the resonant frequency

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2\sqrt{\left(\frac{1 + 12h}{w}\right)}}$$

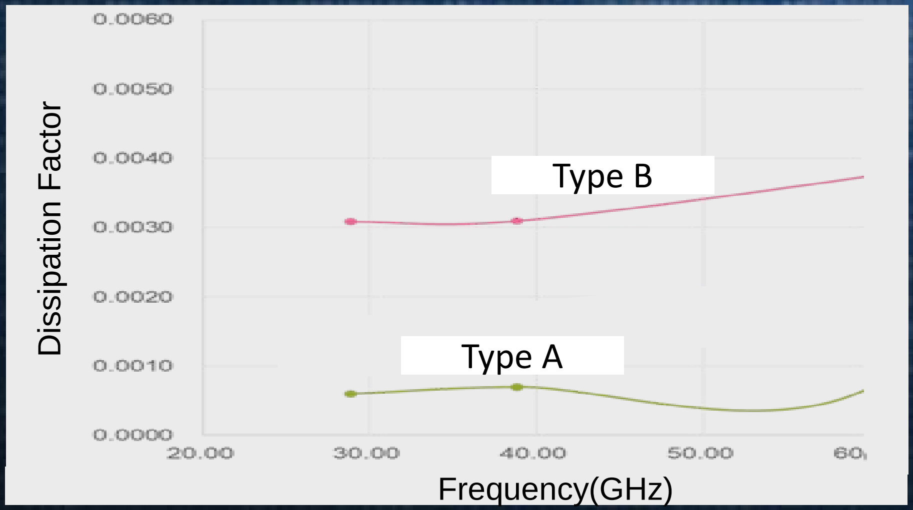
DF Extraction

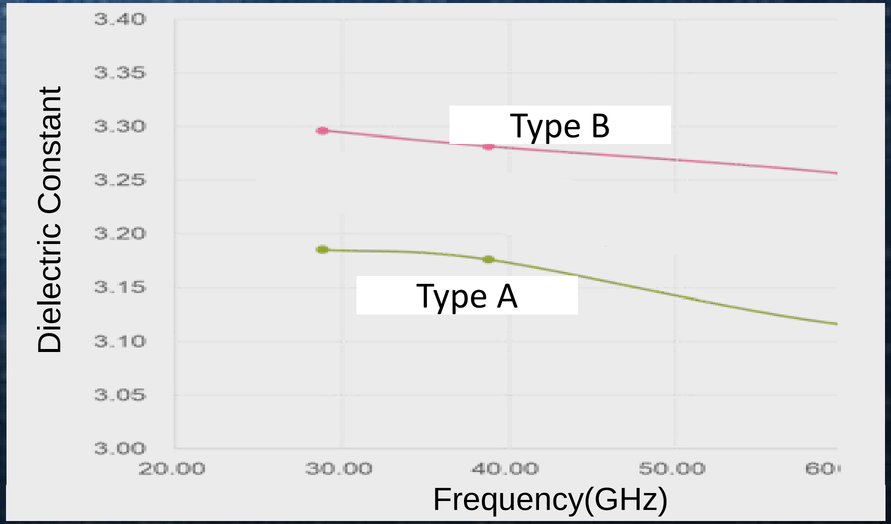
$$Q = \omega \frac{Stored \;\; energy}{Disspated \;\; power} = \frac{f_r}{BW_{3dB}} = \frac{f_r}{f_2 - f_1}$$

$$\frac{1}{Q} = \frac{1}{Q_c} + \frac{1}{Q_d}$$

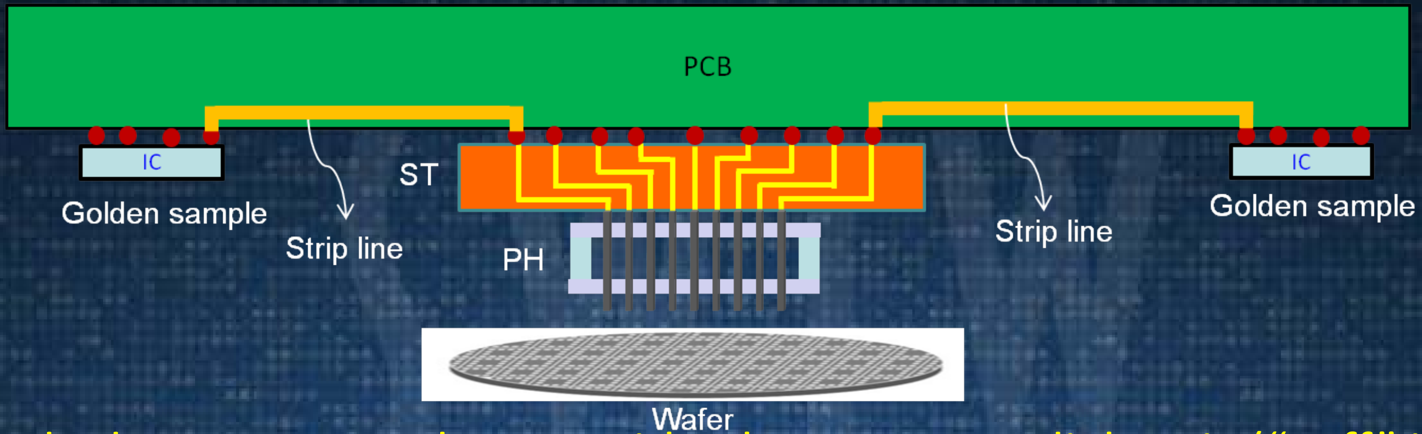
Dissipation factor(DF)

$$DF = \tan\delta = \frac{1}{Q_d} = \frac{1}{Q} - \frac{1}{Q_c}$$

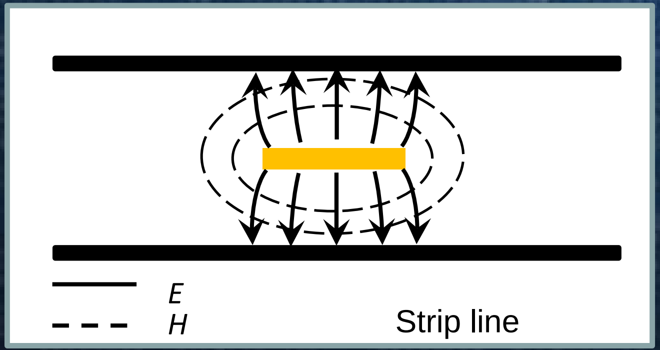


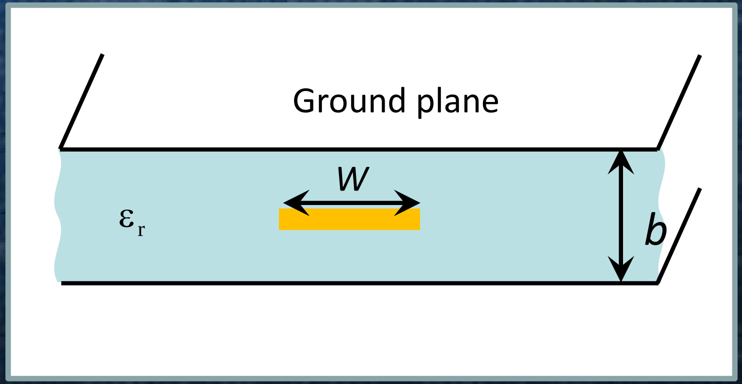


Transmission Line Structure-Strip line

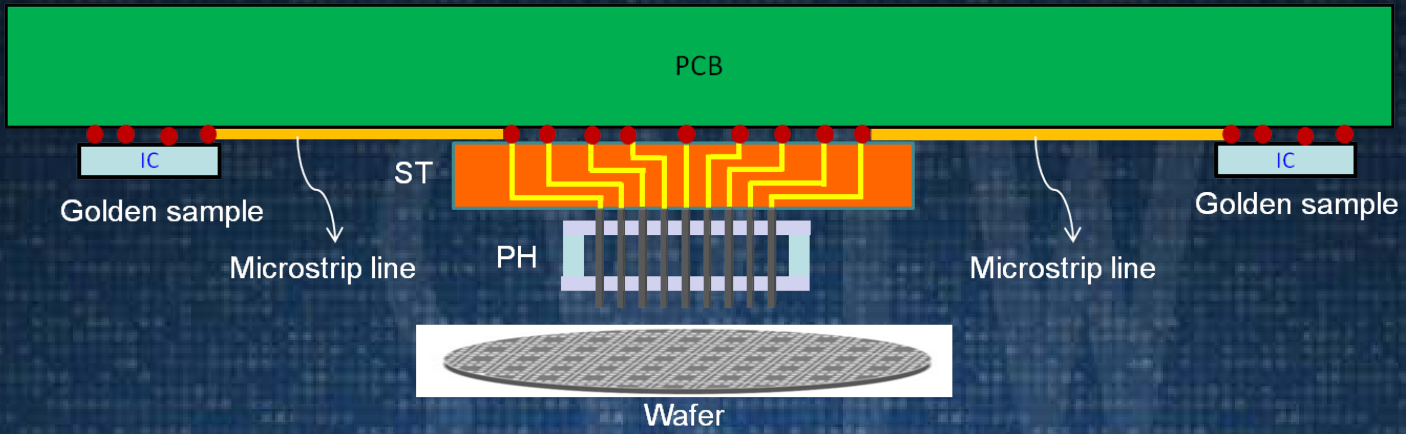


- Usual Mode: TEM mode due to two conductors with a homogenous dielectric ("Keff" is equal to εr.).
- High Order TE/TM Modes: Asymmetry is introduced between two GND planes, particularly in mmWave Freq.
- GND Stitch Via: Used to eliminate high order mode, an over-moded phenomenon.

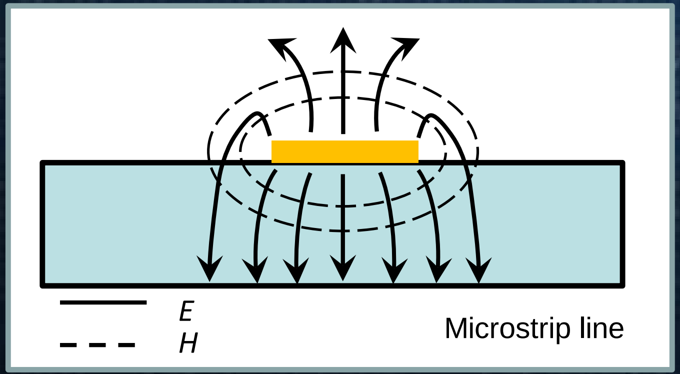


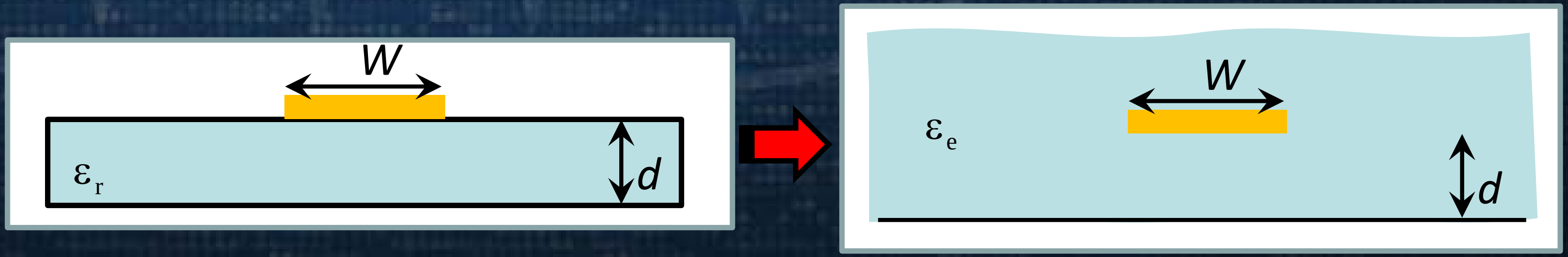


Transmission Line Structure-Microstrip line



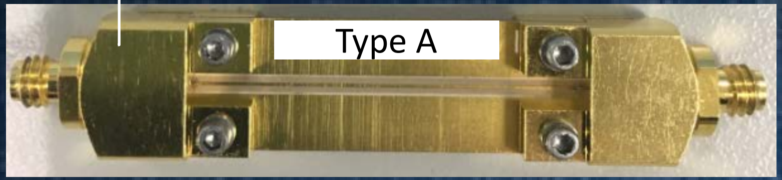
- Usual Mode: Complicated interface results in different Vp in the air and inside the dielectric.
  Quasi-TEM mode due to very thin dielectric, just like static case.
- Above the signal is air, effective dielectric constant :1<εe< εr.
- High Order Mode: Eliminate it by avoiding trace transverse discontinuity (bends, junction 、 return path and step trace width change).



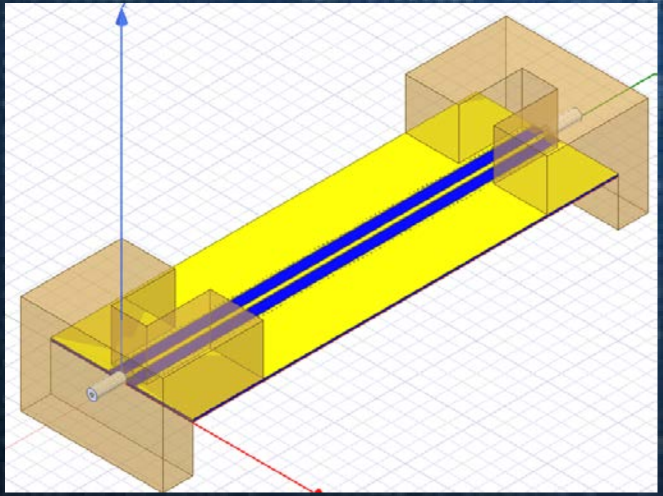


MS Line Simulation and Measurement (Type A)

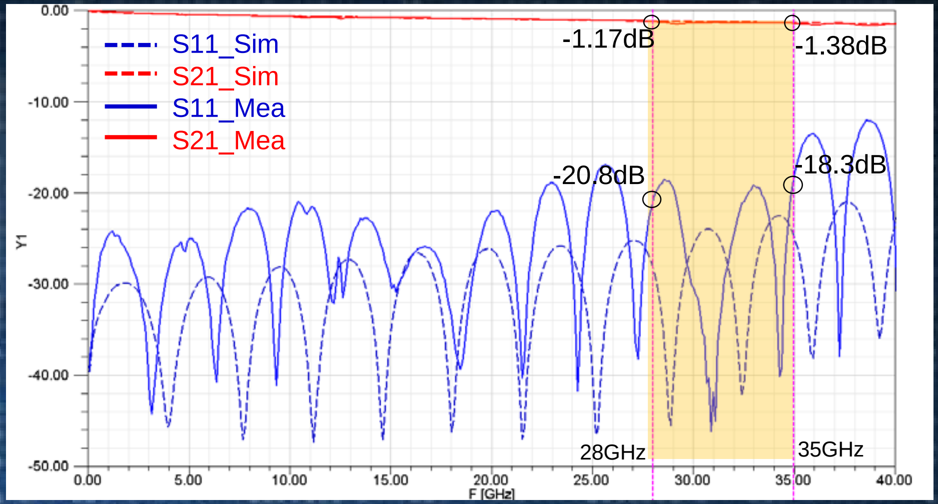
End Launch connector

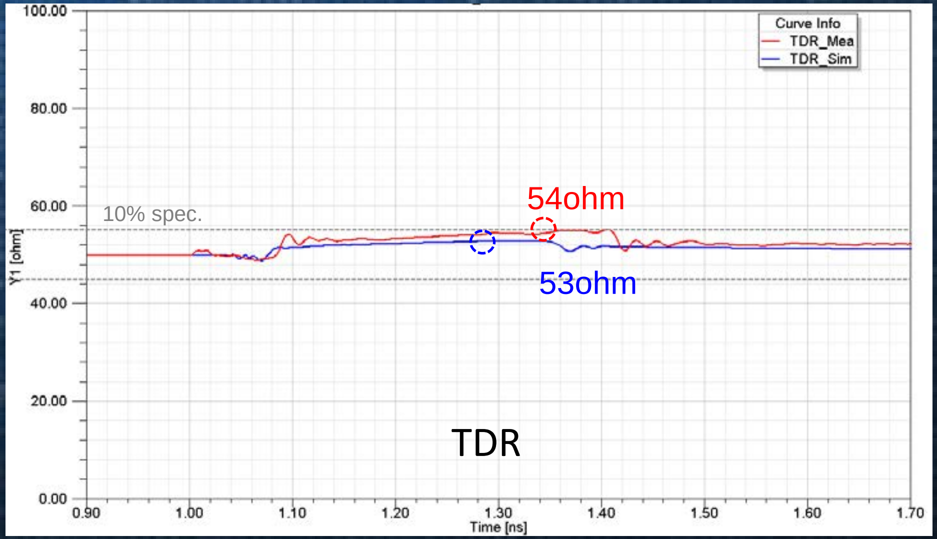


30mm, Type A microstrip line with 5mil CORE
Stitch via spacing:8mil



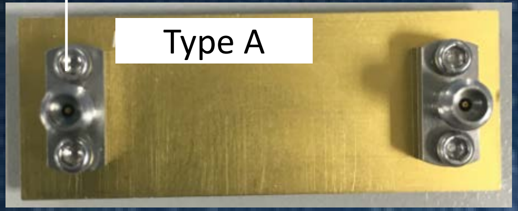
HFSS simulation



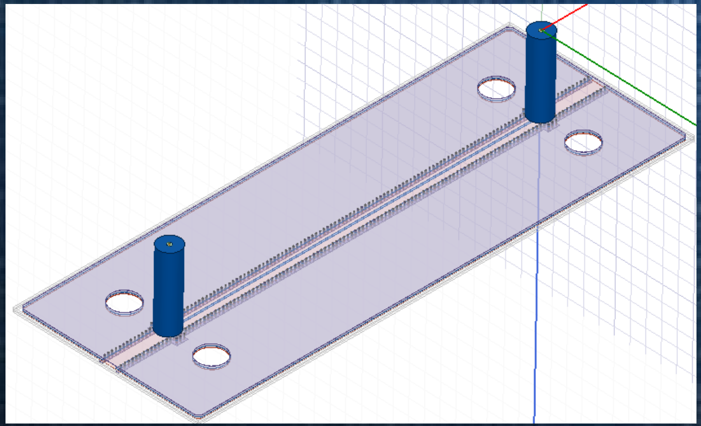


Strip line Simulation and Measurement (Type A)

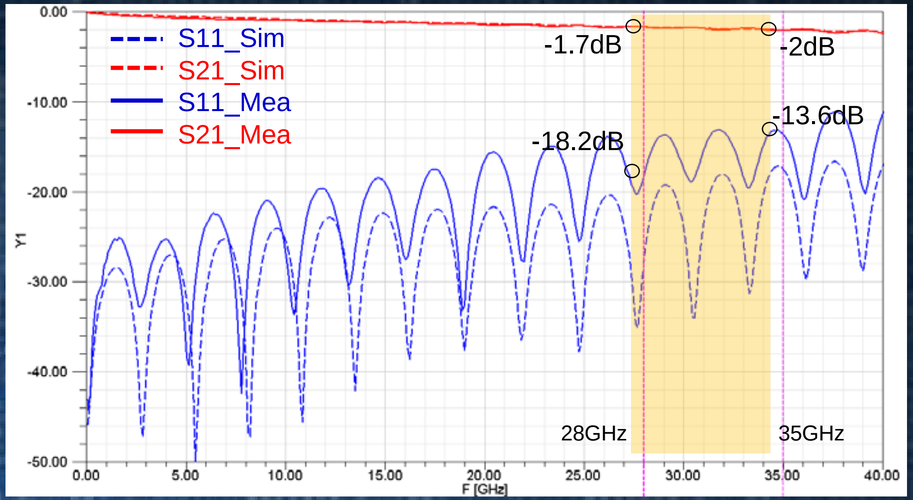
Vertical connector

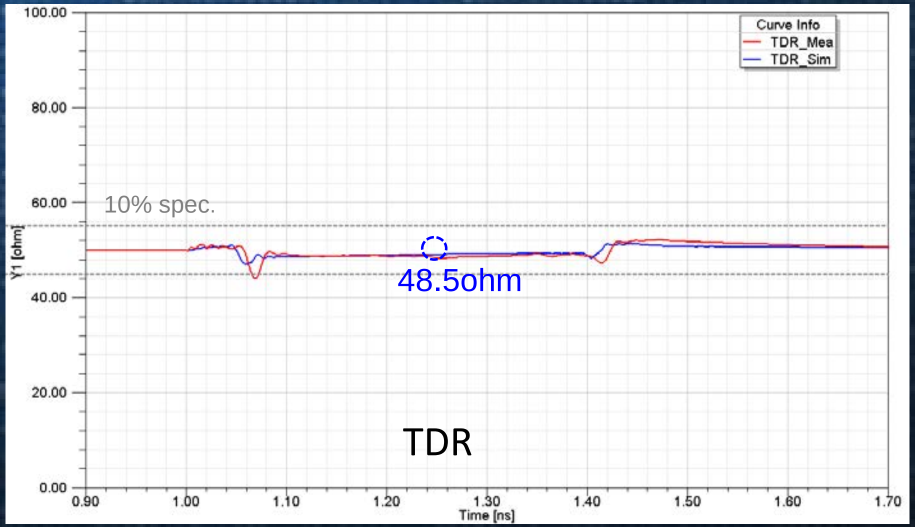


30mm, Type A strip line with 5mil CORE & 5mil PP
Stitch via spacing:8mil



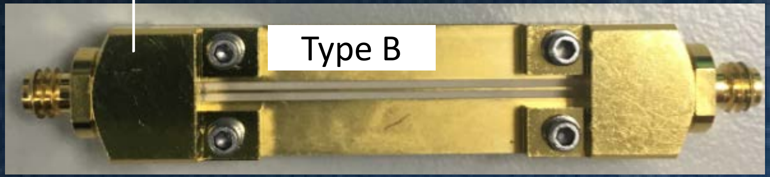
HFSS simulation



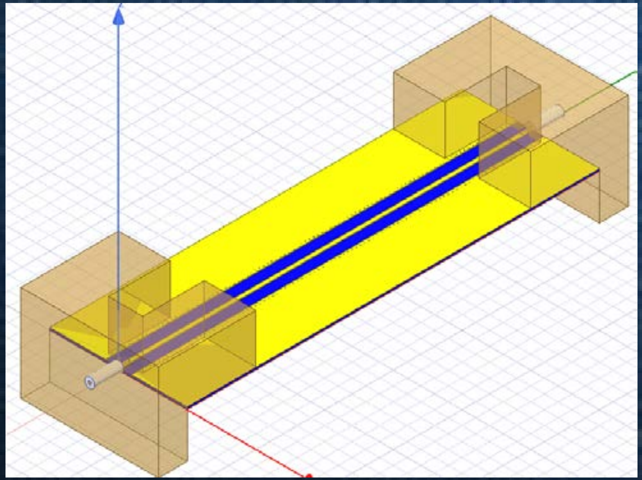


MS Line Simulation and Measurement (Type B)

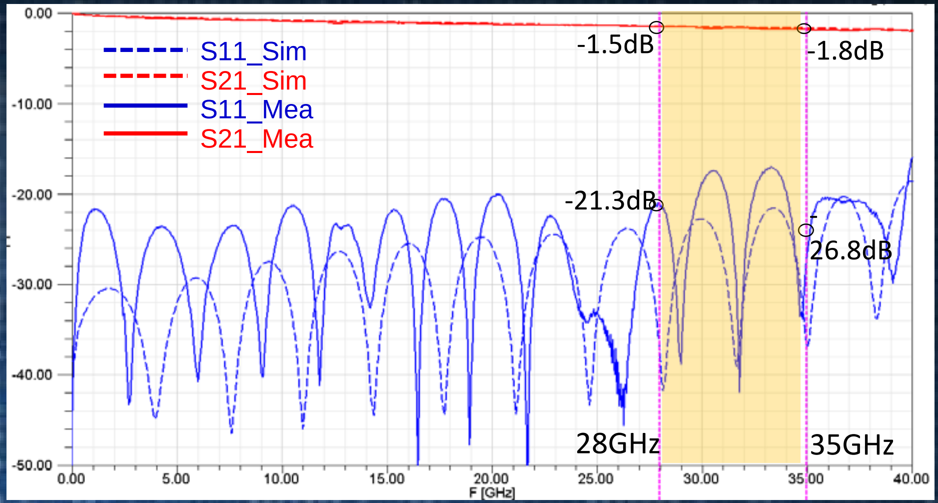
End launch connector

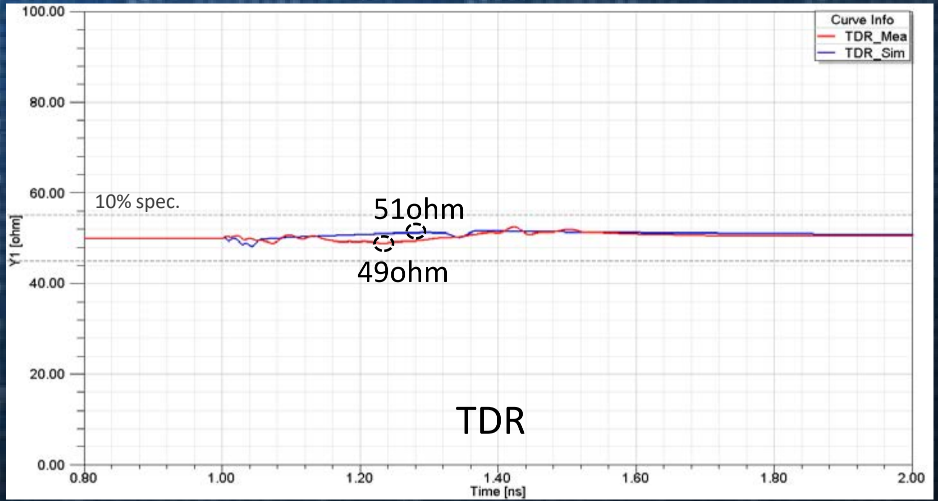


30mm, Type B microstrip line with 4mil CORE
Stitch via spacing:8mil



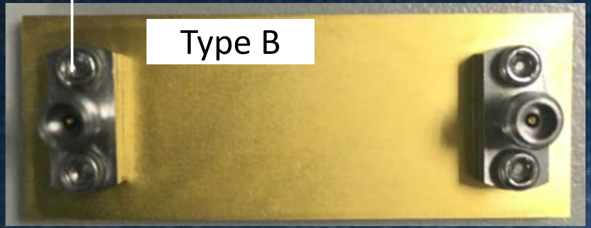
HFSS simulation



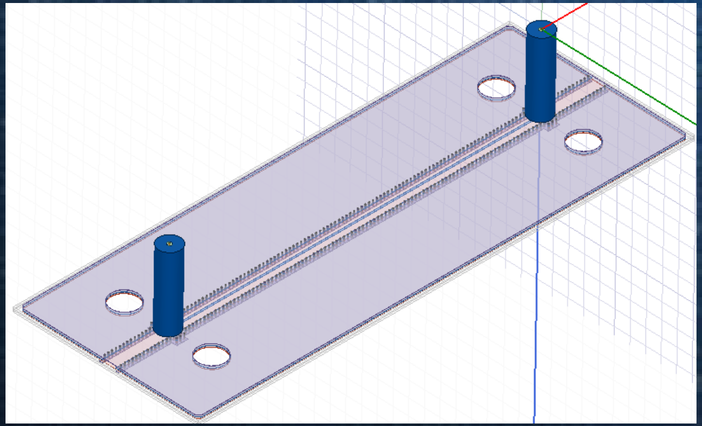


MS Line Simulation and Measurement (Type B)

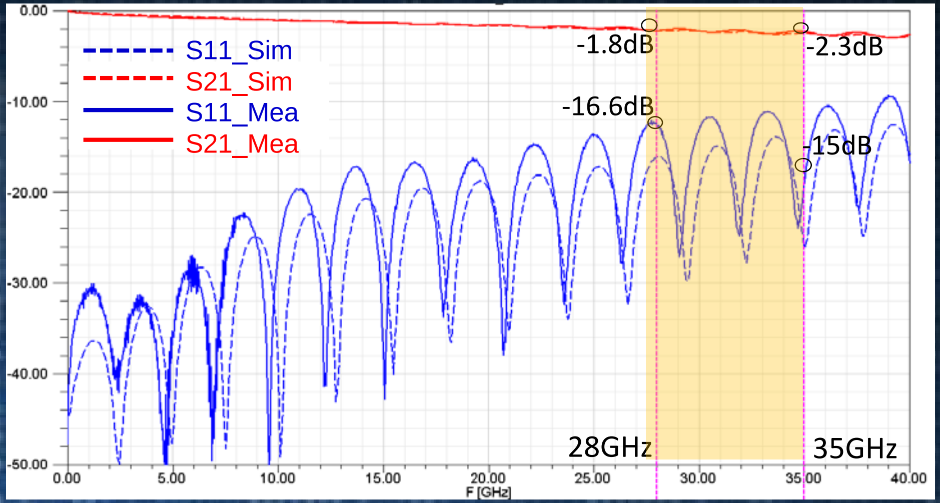
→Vertical connector

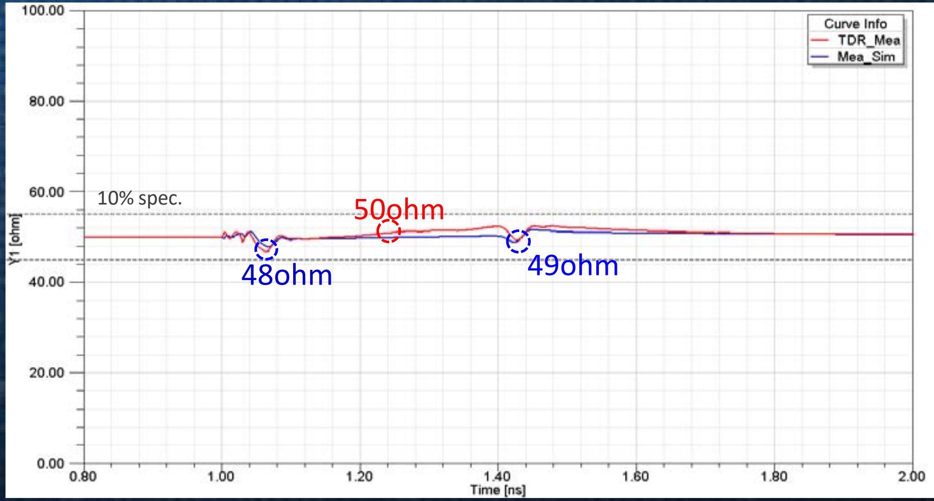


30mm, Type B strip line with 4mil CORE & 3.5mil PP
Stitch via spacing:8mil



HFSS simulation





Correlation Summary

Structure	MS Line (30mm)		Strip Line (30mm)	
Material	TypeA	TypeB	TypeA	TypeB
S21@ 28GHz	-1.2dB	-1.5dB	-1.7dB	-2.2dB
S11@ 28GHz	-20.8dB	-21.3dB	-18.2dB	-16.6dB
Performance	★★	★	★★	★

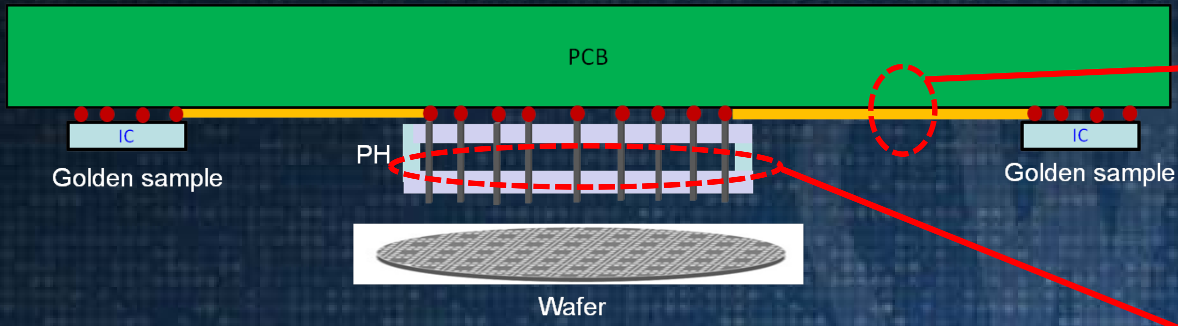
- For the same material, Microstrip line has lower loss than Stripline:

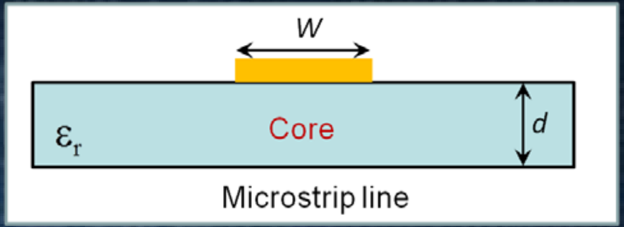
① At 28GHz, dielectric loss dominates the total power loss.

② Microstrip line has part of the electromagnetic field line in the air with lower loss.

- Same transmission line structure in different materials:
  Low DF indeed has lower power loss.

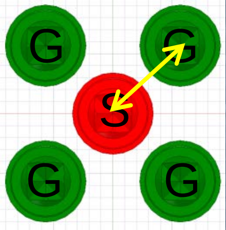
28GHz Probe with PCB simulation



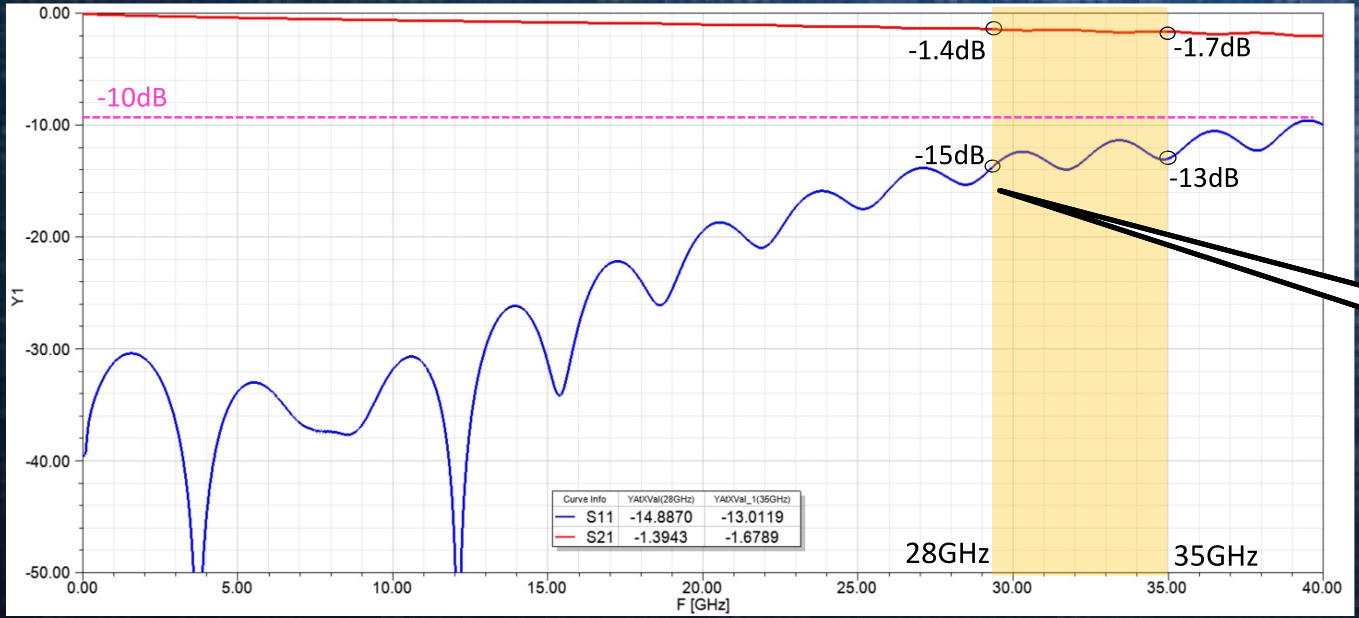


30mm, Type A Microstrip line with 4mil CORE

Pitch:0.4mm



Length:2mm



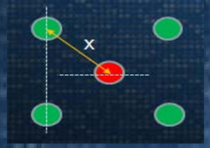
The loss is only -1.4dB at 28GHz and the return loss is below -15dB.

Conclusion

- Probe Design

— For 28GHz probe design, there are 4 key factors to optimize the probe pattern for high performance, and we proposed a best design for 28GHz.

①GND Probe Quantities ②Probe Pitch ③Probe Length ④Probe Diameter



- PCB T-Line Correlation

— After we put extracted DK/DF back to simulation, the correlation results are very close for both Microstrip line and Stripline.

— For the same material, Microstrip line has lower loss than Stripline.

— For the same trace structure on different material, low DF has lower power loss.

- 28GHz Probe Card Solution

— After the performance optimization and carefully correlation, we provide the best Probe Card Test Solution of the cascaded Pogo pin + Microstrip Line + Type A lower DK/DF material.