iNEMI Session @Imaps DPC March 2022
Track Session Title: “5G Electronics Challenges: High Frequency Materials Characterization "

Presented at Imaps Device Packaging Conference

Mar 2022

Advancing manufacturing technology

Industry Collaboration Brought Together by iNEMI

- This session will provide 4 presentations outlining the status of the benchmarking phase as shown in the paper titles below

	Title	Author(s)
Paper 1	Industry Challenges for Low loss measurements	Urmi Ray, iNEMI Urmi.ray@inemi.org Say Phommakesone, Keysight say_phommakesone@keysight.com
Paper 2	Key Highlights from iNEMI 5G project	Michael J. Hill, Intel michael.j.hill@intel.com
Paper 3	5G Electronics: Bridging the measurement challenges	Marzena Olszewska-Placha molszewska@qwed.com.pl Małgorzata Celuch, QWED mceluch@qwed.eu
Paper 4	mmWave Reference Material development at NIST	Lucas Enright, NIST Lucas.enright@nist.gov

Industry Challenges For Low Loss Measurements Presented at Imaps Device Packaging Conference

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Who's iNEMI

The International Electronics Manufacturing Initiative (iNEMI) is

- a not-for-profit,
- industry-led,
- highly efficient

R&D consortium of approximately 80 leading electronics manufacturers, suppliers, associations, government agencies and universities.

Forecast and Accelerate improvements in the Electronics Manufacturing Industry for a Sustainable Future via Collaborative Innovation

Roadmap	• Anticipate technology requirements • Identify gaps • Focus R&D priorities
Collaborative Projects	• Eliminate gaps • Deliver learning & critical data • Leverage efforts & participants' resources
Forums & Workshops	• Share solutions & best practices • Prioritize key challenges • Network with customers & suppliers

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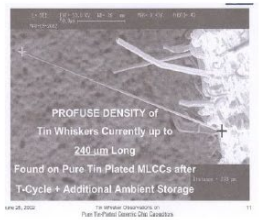
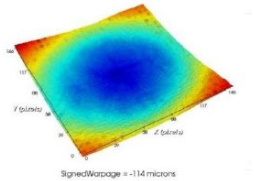
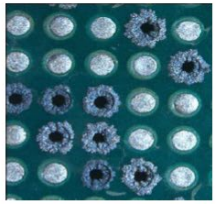


Tin Whisker Susceptibility



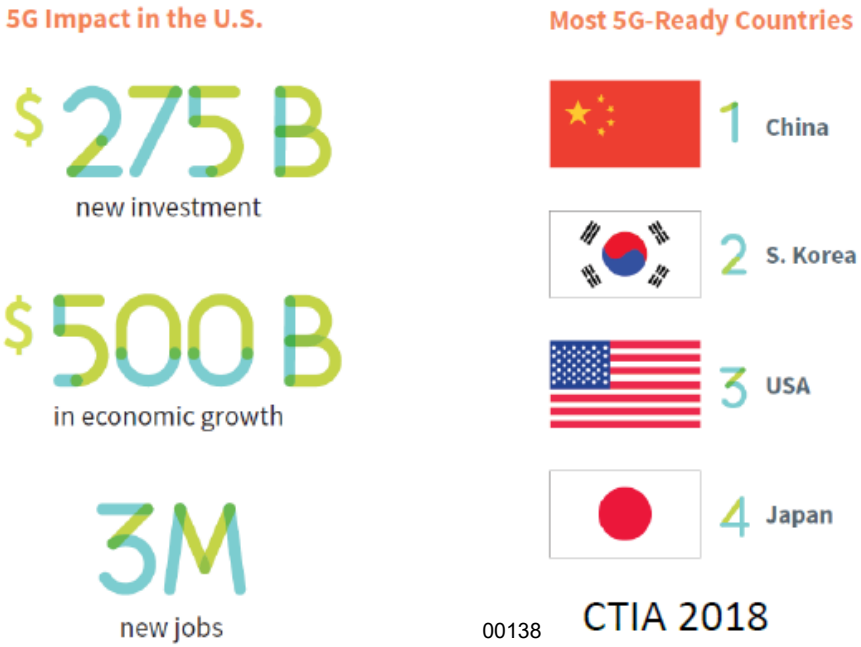
Warpage Characterization of Organic Packages



Creep Corrosion

5G: Disruptions Enabling next level of communication

- 5G is expected to enable **$12.3 trillion of global economic output** (almost as much as total US consumer spending in 2016).
- The global 5G value chain will generate **$3.5 trillion in output** and support **22M jobs** in 2035.
- The 5G value chain will invest an average of **$200 billion annually** in infrastructure (about half of the total US gov't spending on transportation infrastructure in 2014).



5G/mmWave- Critical Industry Initiative Needed

- 5G Semiconductor Challenges Summary

Challenge	Attractive Approaches
Need for Antenna in Package (AiP)	• Laminate-based solutions • eWLB (FO-WLP) solutions
High speed/ Ultra Low Loss materials	• Cost-effective materials at mmWave frequencies • Materials characterization and test methods
Heterogeneous Integration (SiP)	• Increases in # of components → Miniturization • Advanced molding technologies • Shielding
Test	• Contact vs OTA testing → still TBD • More sensitivities to process variations

5G solutions require complex packaging approaches and requires close collaboration.

Source: Heterogeneous Integration Roadmap: 2020

Industry Collaboration Brought Together by iNEMI

Problem Statement:

- Next-generation 5G communications solutions require ultra-low loss laminate materials and PCBs/substrates for efficient design and manufacturing.
- However, these materials pose challenges. For example, there is no consistent methodology for measuring transmission loss or Df/Dk, especially for higher frequencies (e.g., >30 GHz).
- Many different approaches are currently used, requiring different fixtures and test methods, sample preparation, and/or data analysis/extraction.

5G Materials Project: Industry Collaboration

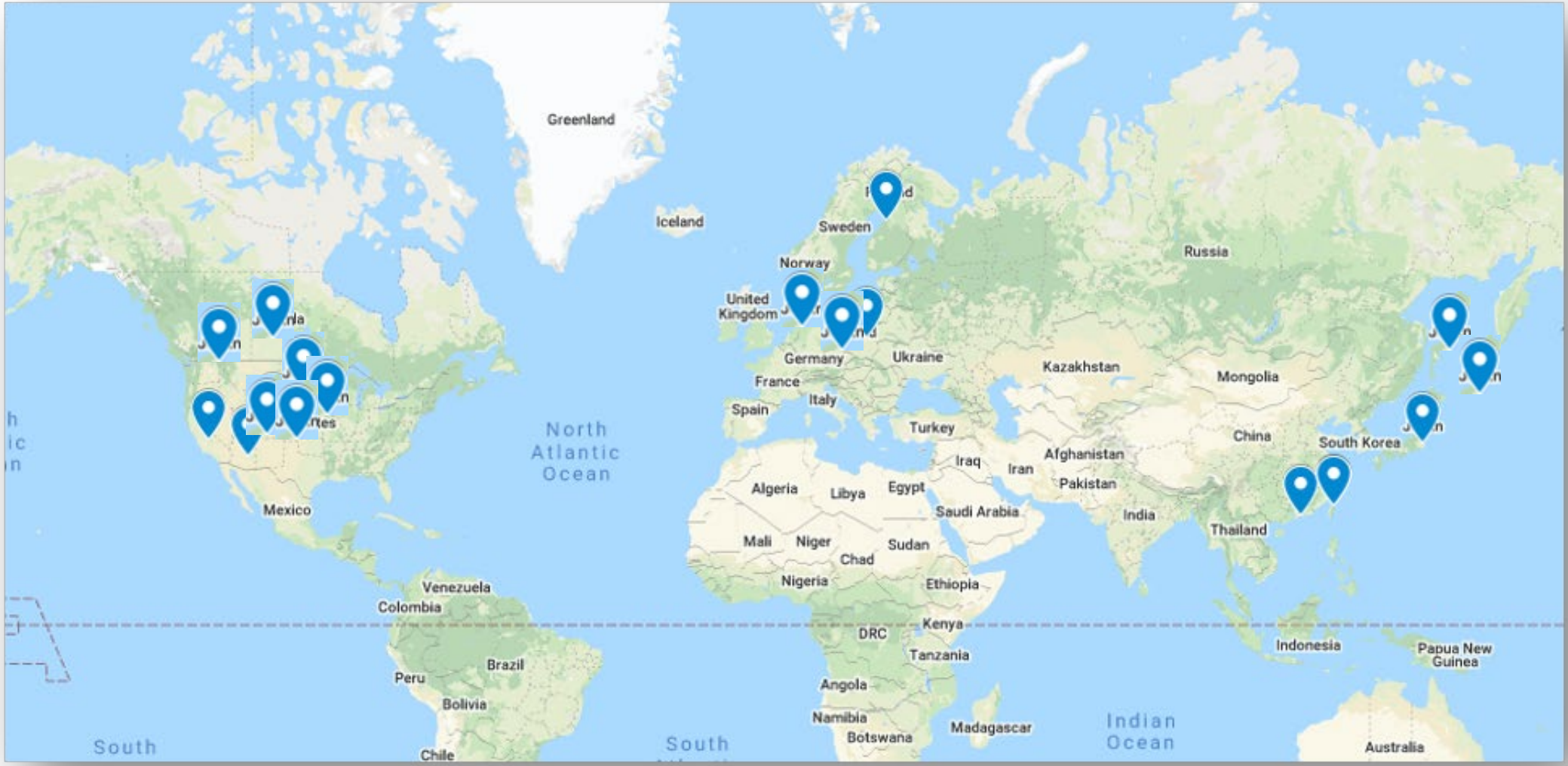
Approach for Solving Measurement Challenges @ High Frequencies:

- Bring together Cross-functional team spanning industry Value Chain
  - Develop a guideline/best practice for a standardized measurement and test methodology that can be shared with industry and relevant standards organizations

Project Team

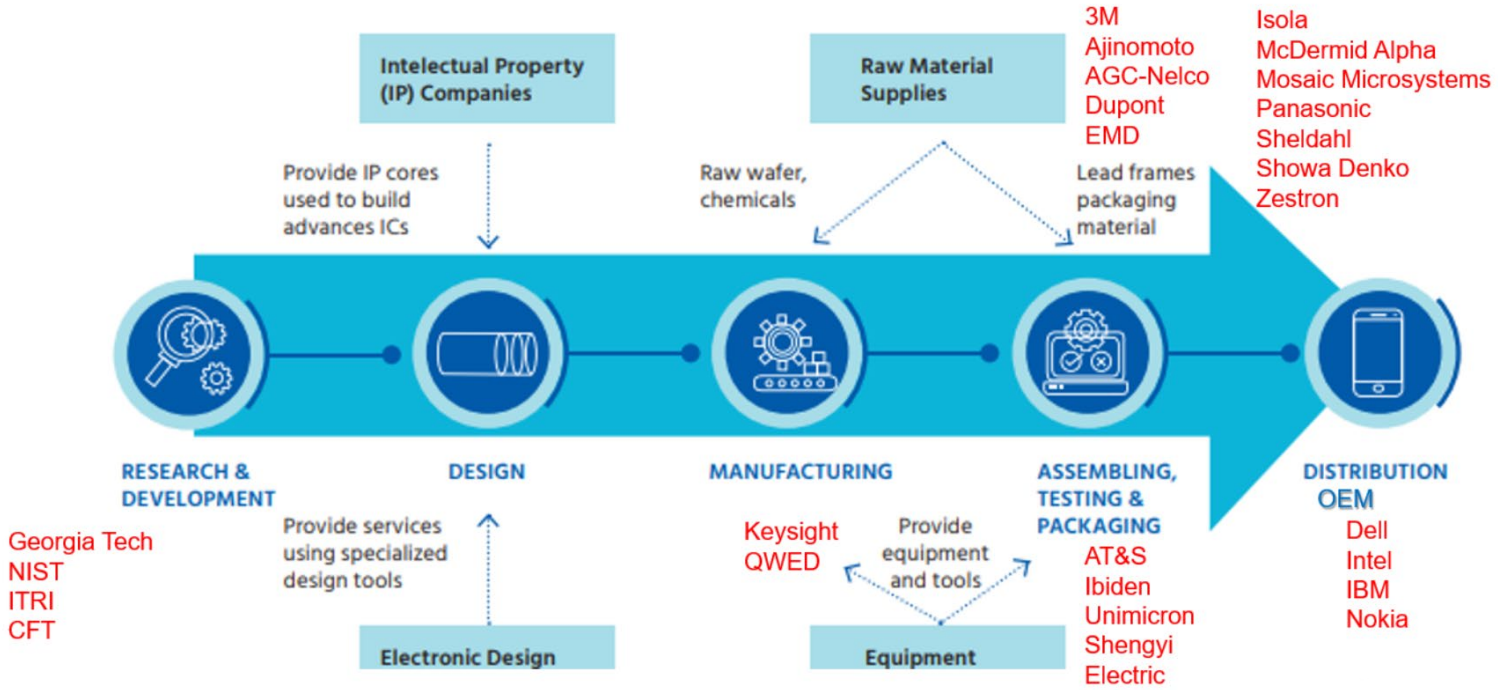
- 3M
- AGC-Nelco
- Ajinomoto USA
- AT&S
- Centro Ricerche FIAT-FCA
- Dell
- Dupont
- EMD Electronics (Co-Chair)
- Flex
- Georgia Tech
- IBIDEN Co Ltd
- IBM
- Intel
- Isola
- ITRI (Co-Chair)
- Keysight (Co-Chair)
- MacDermid-Alpha
- Mosaic Microsystems
- NIST
- Nokia
- Panasonic
- QWED
- Shengyi Technology Company
- Sheldahl
- Showa Denko Materials
- Unimicron Technology Corp
- Zestron

iNEMI 5G Materials GLOBAL Project Members



Project Tasks

- Task 1 – Benchmarking permittivity methods, potential reference materials ✓
- Task 2 – Emerging technologies / 100GHz & beyond ✓
- Task 3 – Multi Lab Round Robin Reference Experiment ✓
- Task 4 – Extension to advanced substrate materials



Industry Challenges for Low loss measurements

Say Phommakesone

Keysight Application Engineer

2022.03.08

iNEMI®
Advancing manufacturing technology

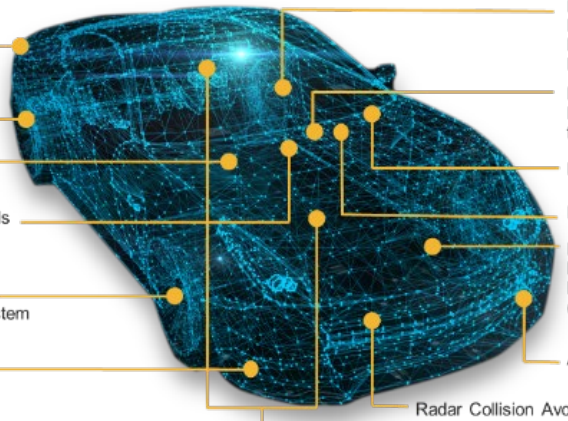
Market Trends

5 & 6G

chipset providers, operators, and NEMs

Advanced **Radar & EW** Solutions

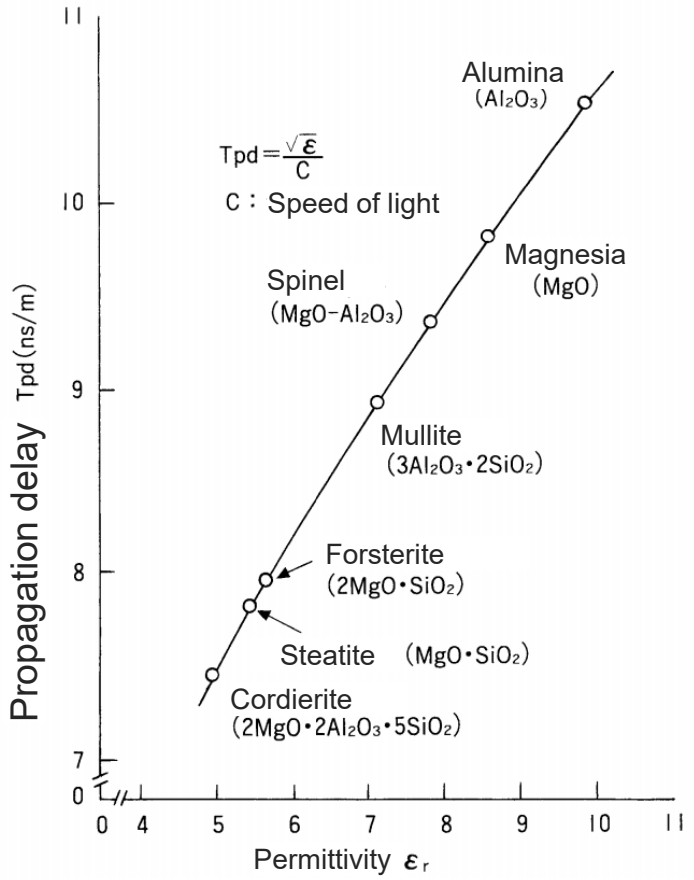
Automotive and Energy



Dielectric Constant and Loss Tangent

MATERIAL IMPACTS PERFORMANCE

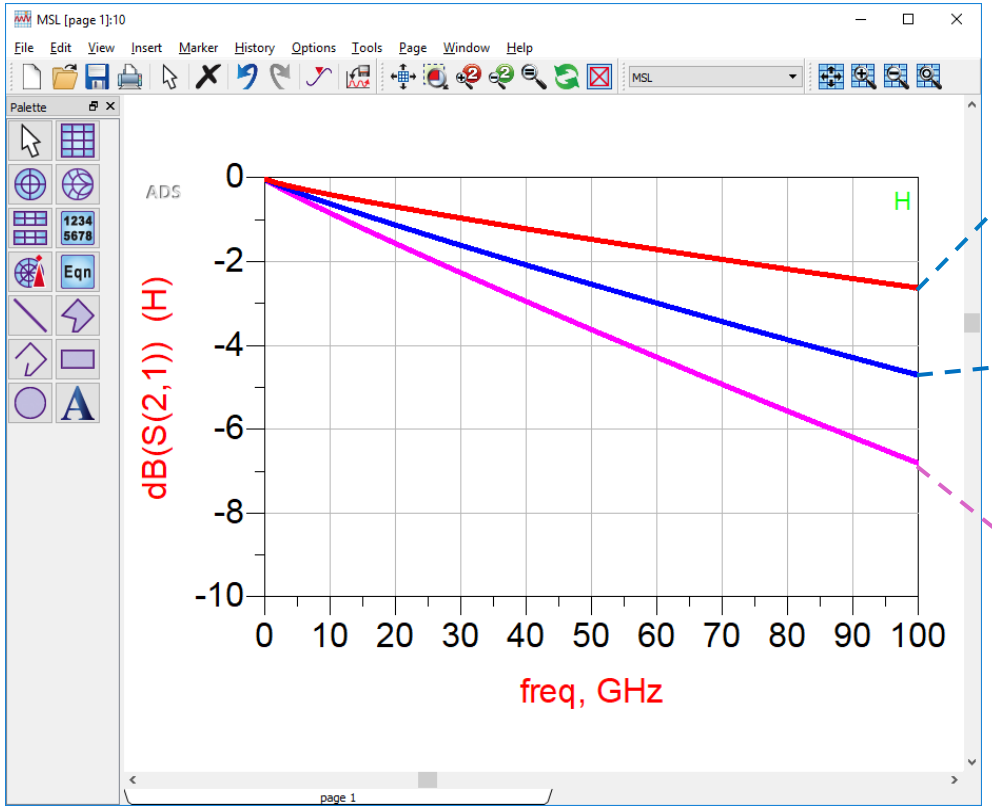
- Ideal performance is “air”
- Lower Dk & Low Df
  - Lower Dk（ ε_r'）： To achieve lower latency/delay signal
  - Lower Df (tanδ): To avoid signal loss at high-speed signal



Propagation Delay vs. Dk of ceramics

Figure modified based on https://www.jstage.jst.go.jp/article/ieejfms1990/113/7/113_7_495/_pdf/-char/ja

Impact of Loss Tangent On System Performance

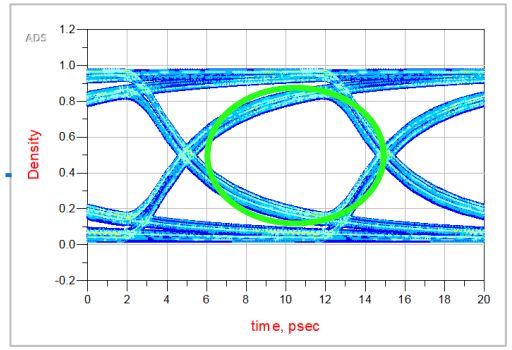


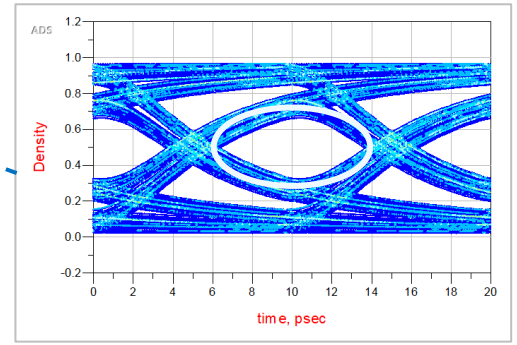
Loss at 3 cm transmission line

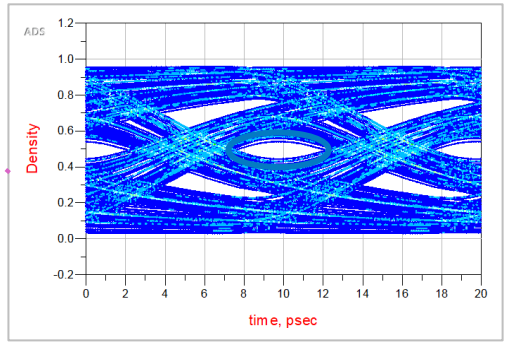
Df = 0.005

Df = 0.01

Df = 0.015





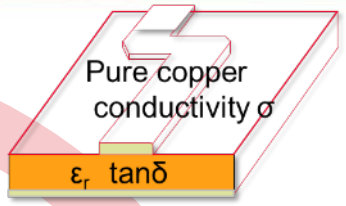


10 cm transmission line @ 50 GHz = 100Gbps

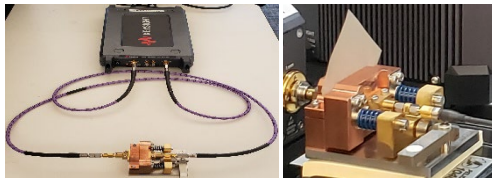
Result Often Differs from Simulation…

- Another 8 to 12 weeks to run the 2nd round
- Cost thousands of $

1. Design a circuit

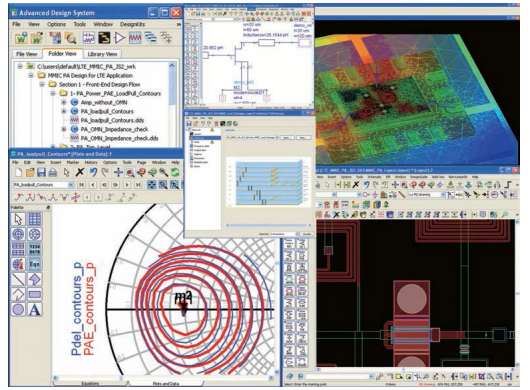


2. Getting ε_r tanδ from the data sheet



2+. Materials Test

3. Circuit simulation



4. Design the final circuit

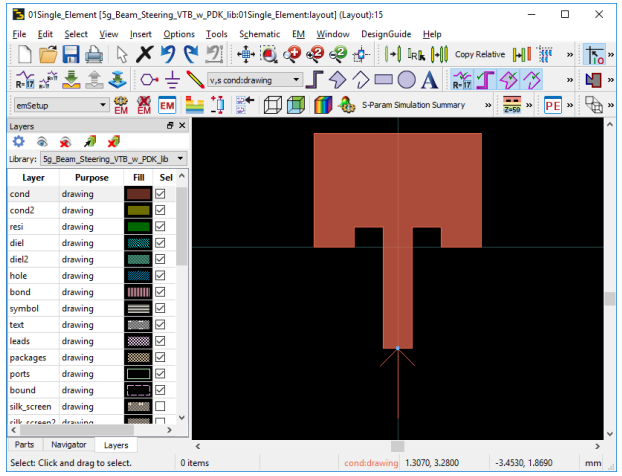
5. Make an actual circuit

4-6 weeks

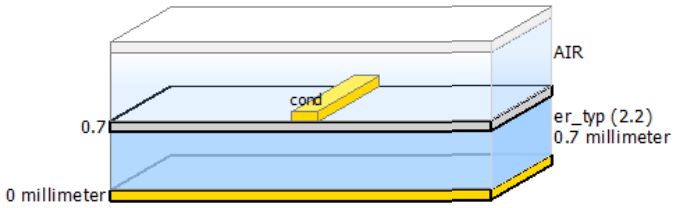
6. Evaluate the circuit and find difference!

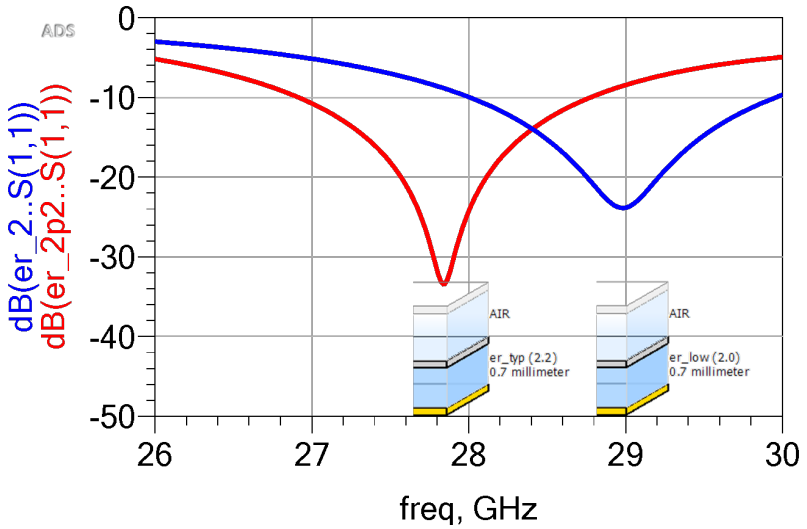
4~ weeks

Accurate Measurement Is Key to High Quality Design



28GHz patch antenna





Dk = 2.2

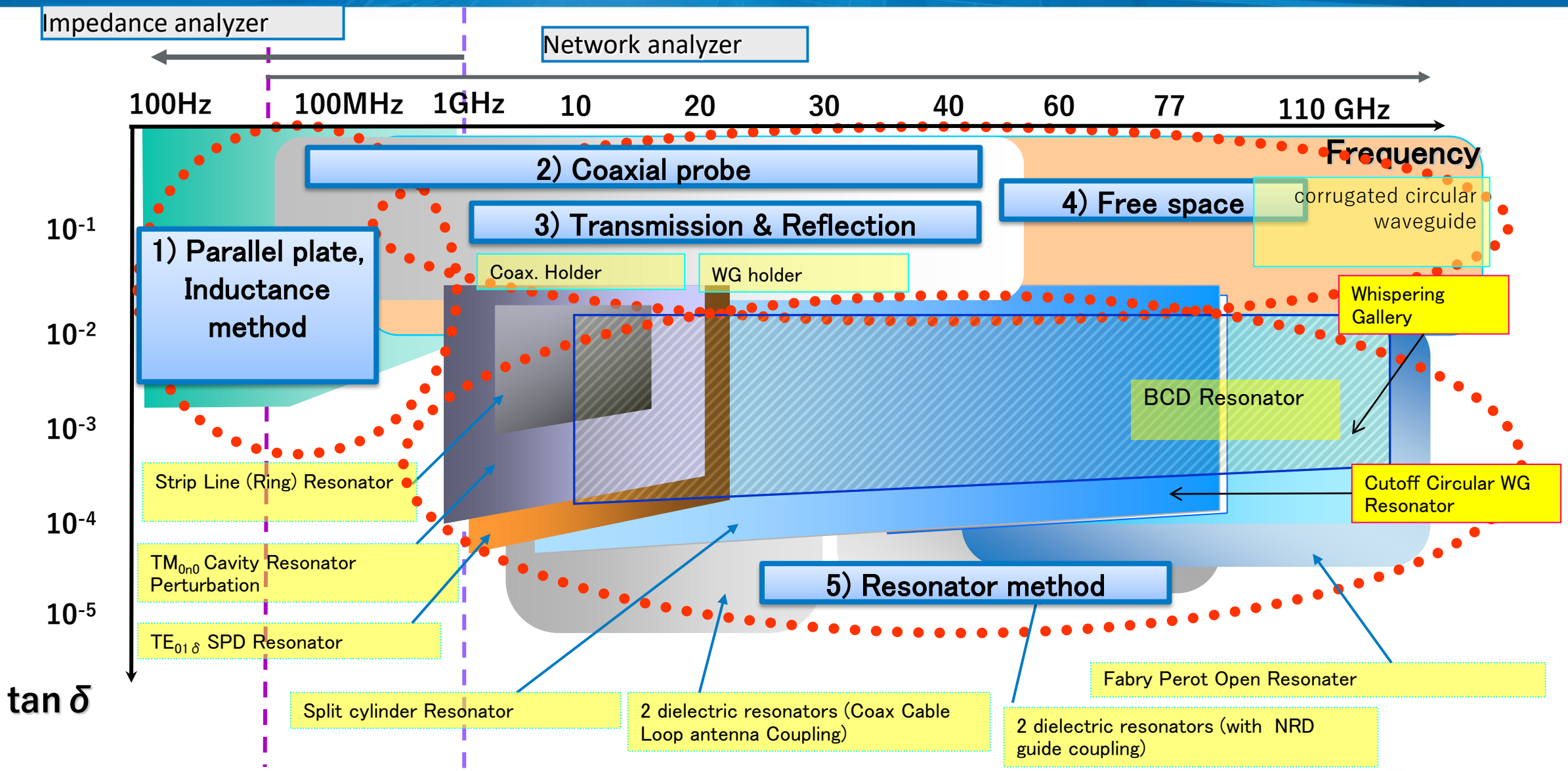
Dk = 2.0

Dk changes -
10%

Antenna's sensitivity peak shifts
+1GHz

Performance degrade at target frequency

Solution Mapping: 5 major methods



Results Differ Depending on Measurement Methods

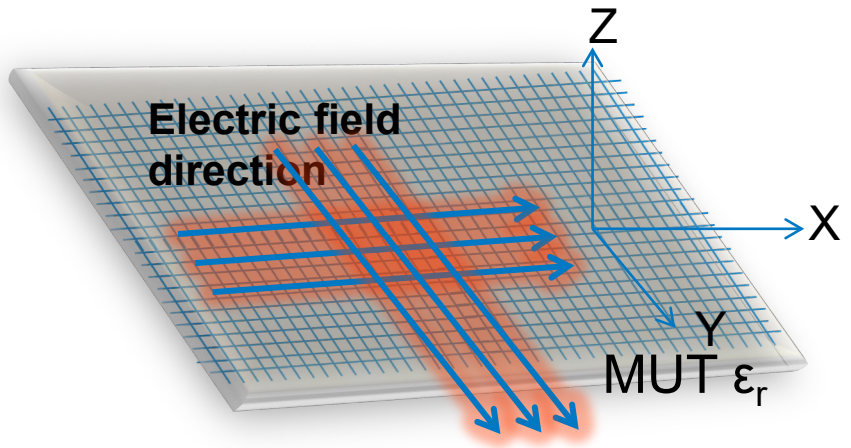
The glass epoxy substrate has its **anisotropy** due to its structure.

Supplier A (Dk = 4.4 in data sheet)

permittivity in plane direction = 4.43

permittivity in thickness direction = 4.02

→ "Nominal value" means in plane direction

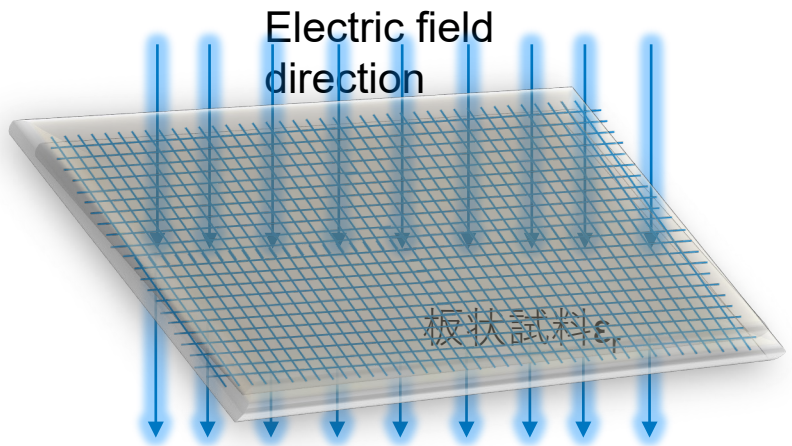


Supplier B (Dk = 4.2 in data sheet)

permittivity in plane direction = 4.55

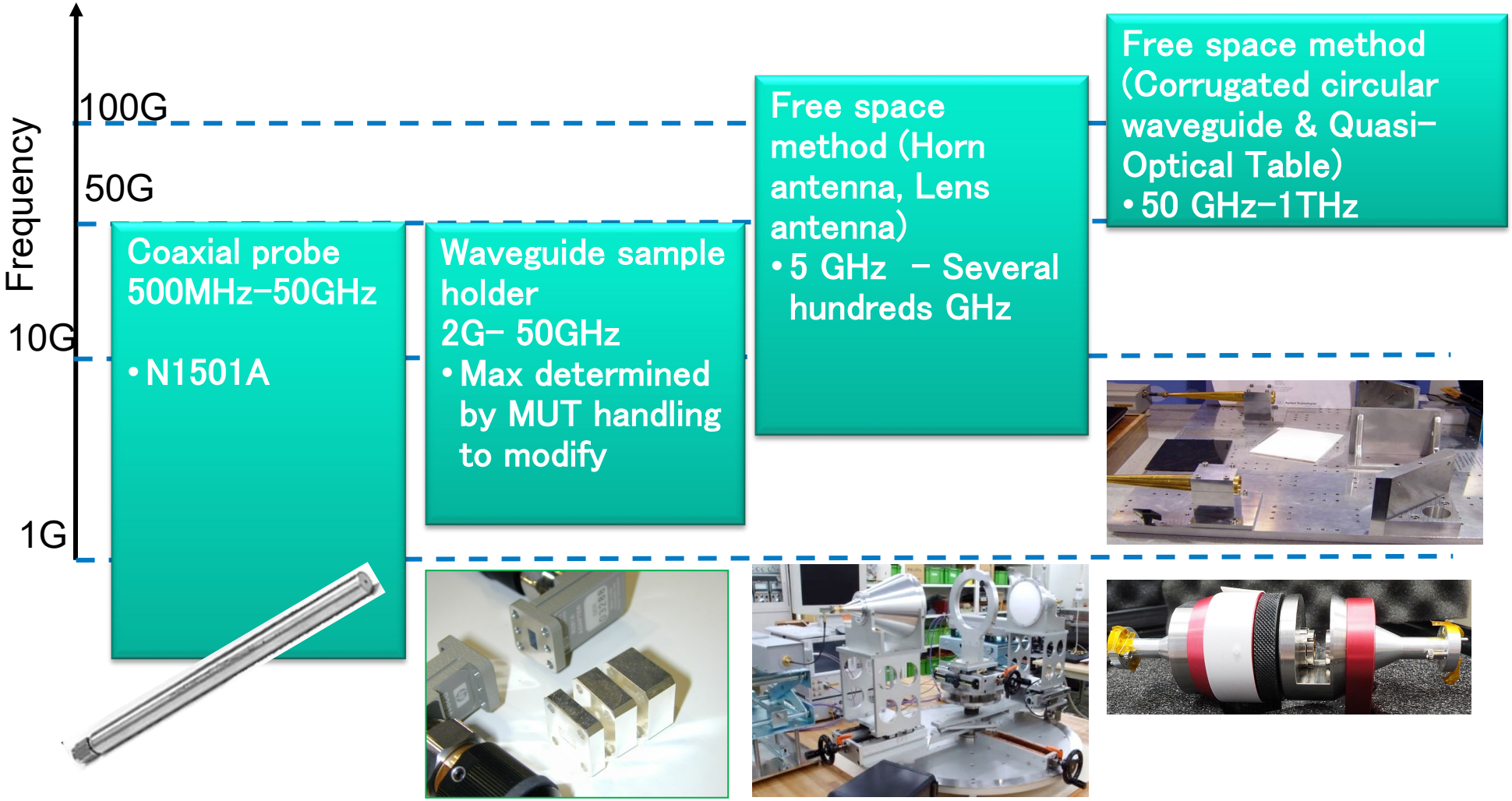
permittivity in thickness direction = 4.22

→ "Nominal value" means in thickness direction (out-of-plane)



High Loss Material Measurement for mmWave

- Multiple frequency points measurement (For high loss materials, Df > 0.01)



Low Loss Materials Measurement for mmWave

- Single freq. point measurement
  (For low loss materials, Df < 0.01)

Frequency

100G

50G

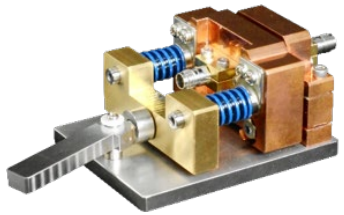
10G

in-plane

TE mode
Split Post Dielectric
Resonator (SPDR)
1 – 15 GHz

TE mode
Split Cylinder
Resonator (SCR)
10 – 80GHz

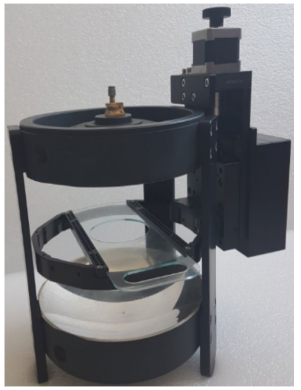
in-plane

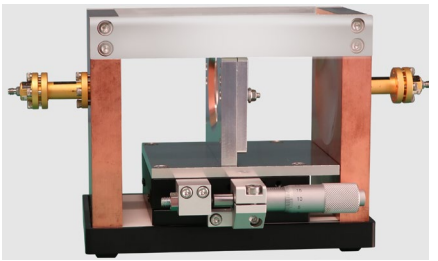


- Multiple freq. points measurement
  (For low loss materials, Df < 0.01)

Fabry Perot Open
Resonator (FPOR)
(perturbation method)
18 – 330GHz
TEM_{00q} mode

in-plane





TM mode
Balanced type
Circular Disk
Resonator (BCDR)
10 – 110 GHz

Out-of-plane

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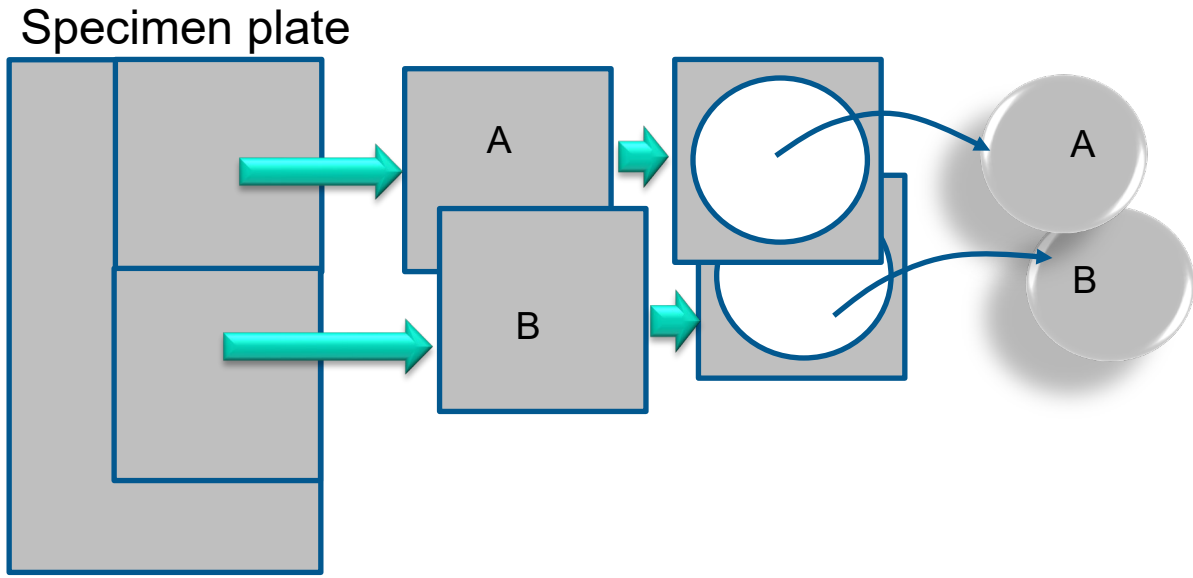
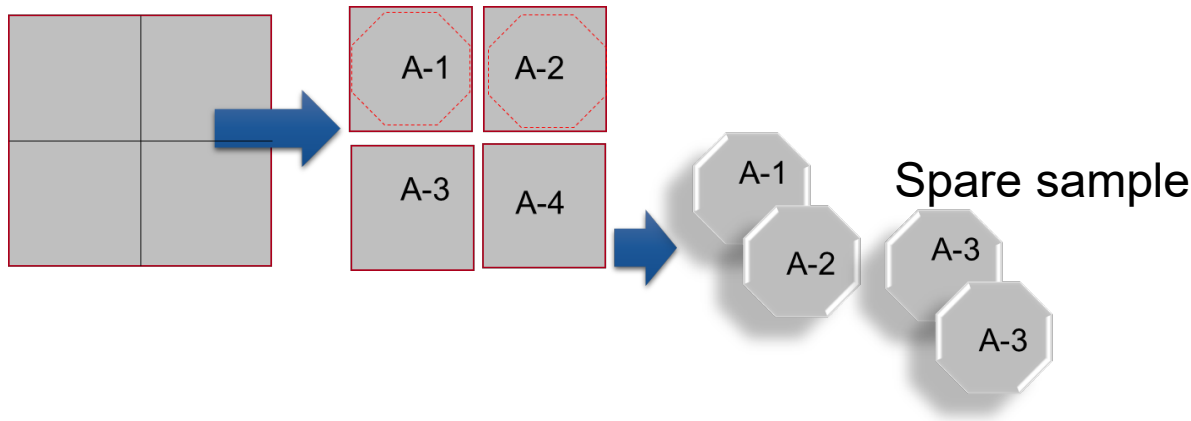
Measurement Materials Sample Under Test (MUT)

MUT (sample) requirement:

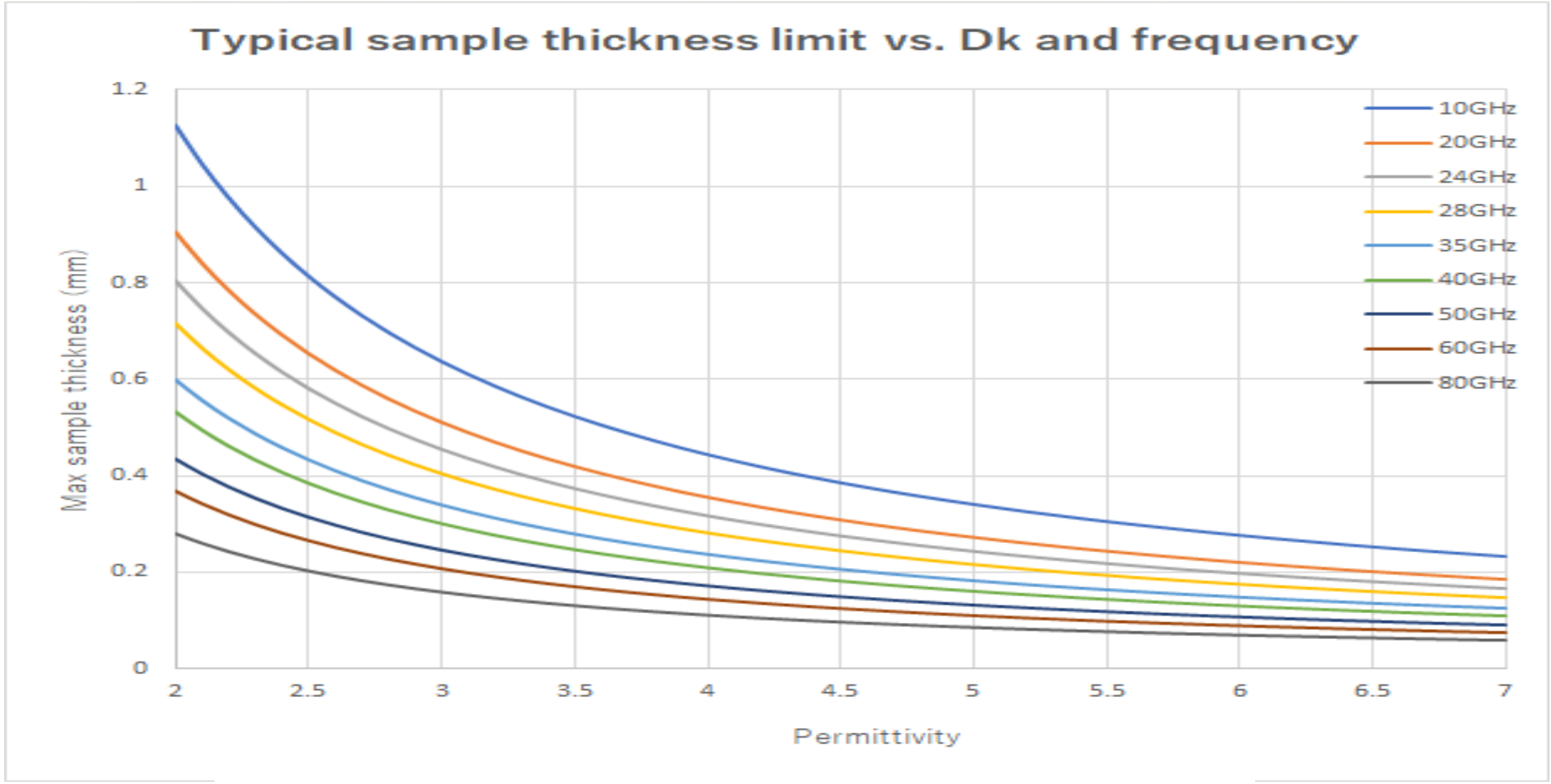
- One sample (Two for BCDR)
- Appropriate thickness
- Smooth surface (roughness < 30 μm)
- Flat (no warping)
- Square / Rectangle (round for BCDR)
- No finger oil on sample



Best way (two samples from the same sheet)



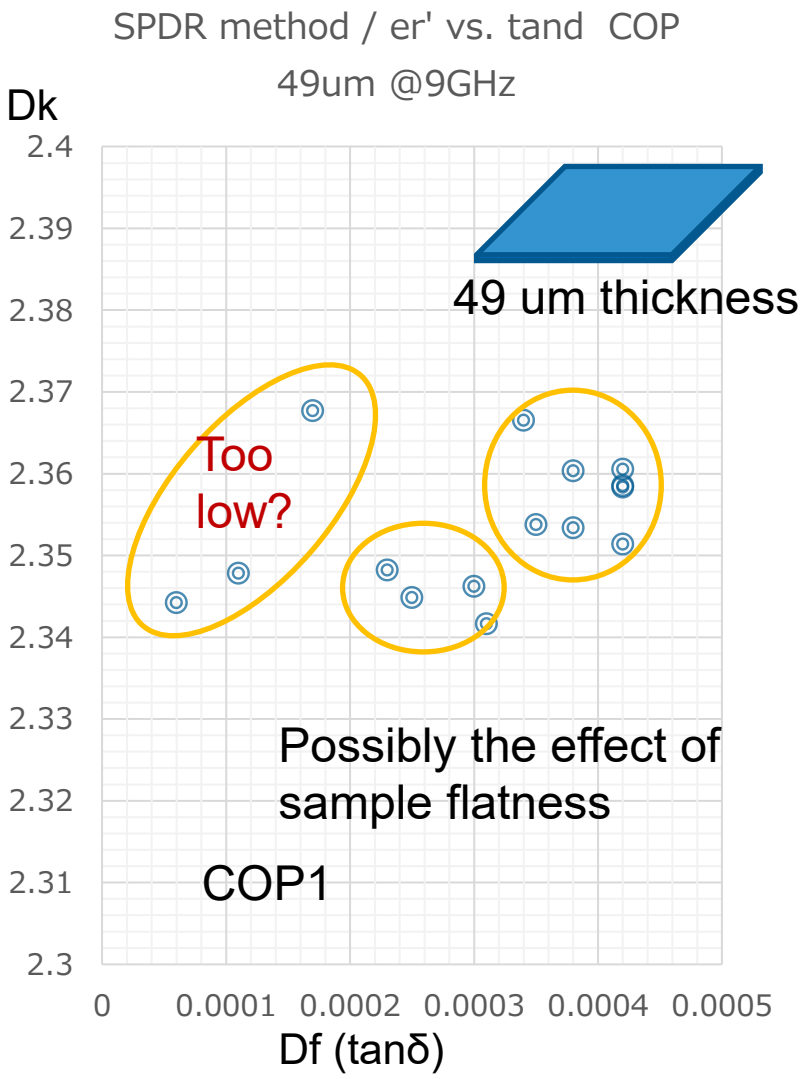
Sample Thickness - SCR

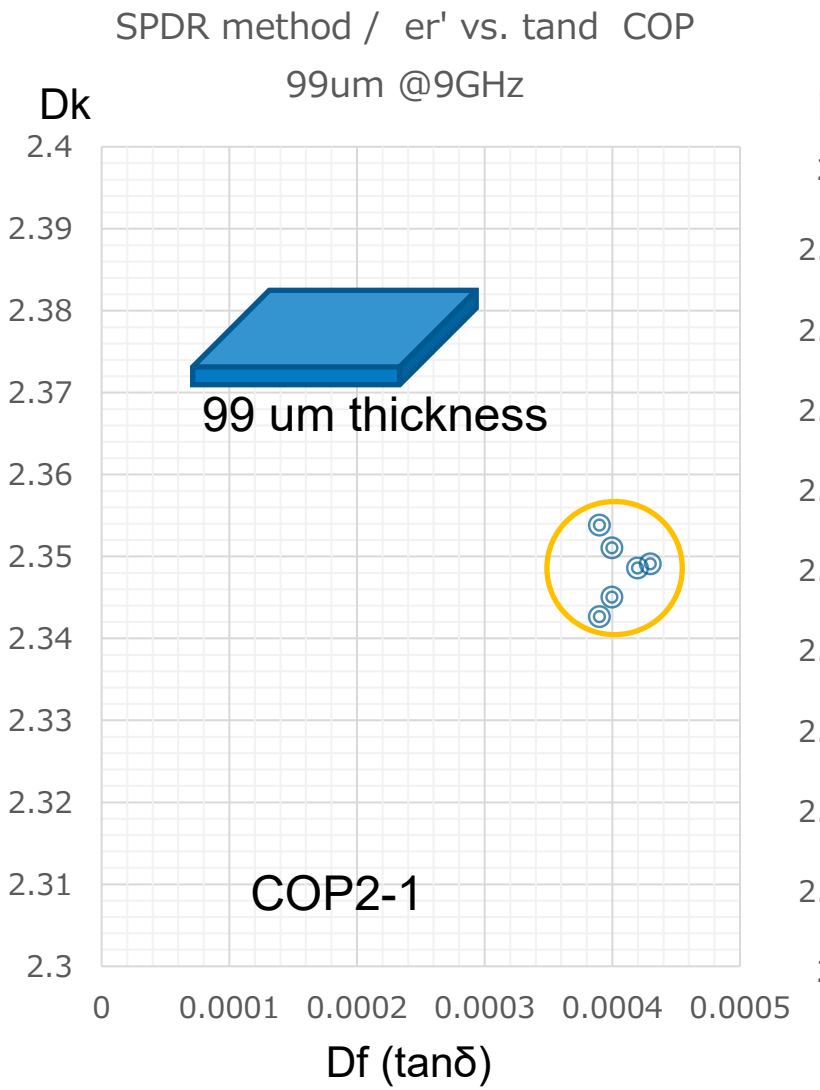


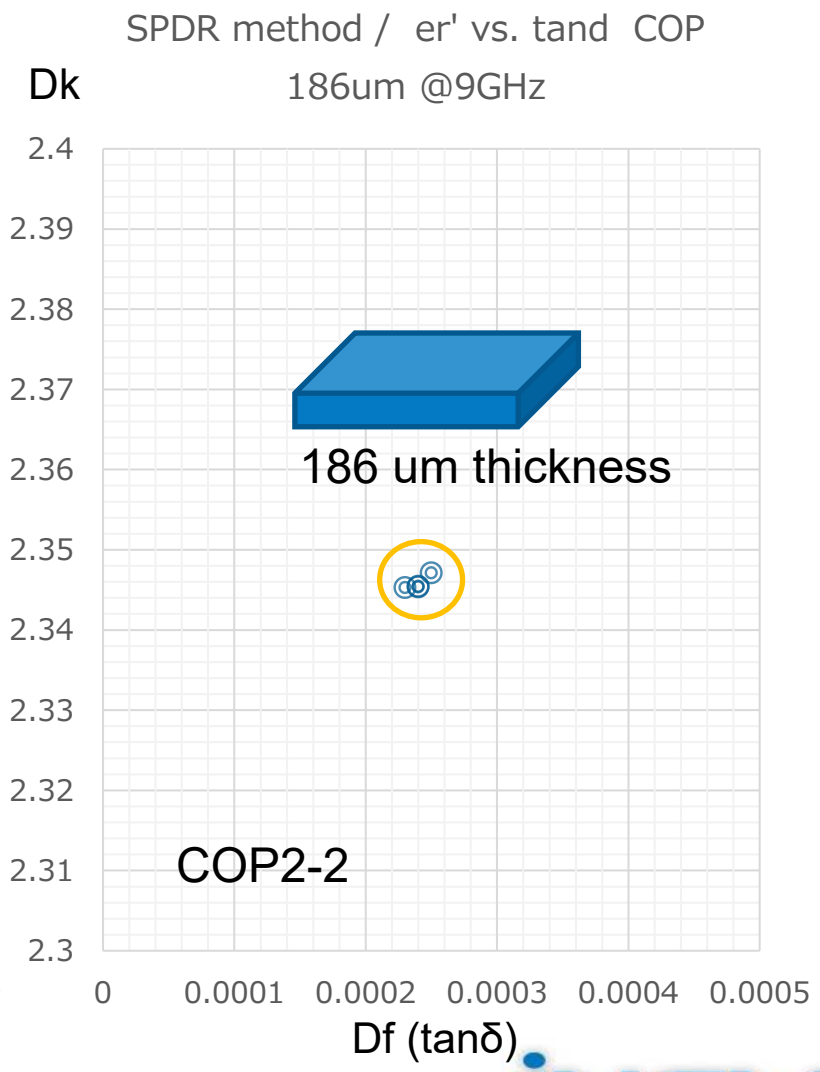
Size: Recommendation for accurate measurement and easy handling:
10 GHz: 62 mm x 75 mm, Others: 34 x 45 mm

Thickness Impacts Measurement Repeatability: COP – 3 different thickness

Factor1: Position in the resonator, Factor 2: flatness/distribution of thickness







Avoid Sample Warpage Shape – Flat Sample

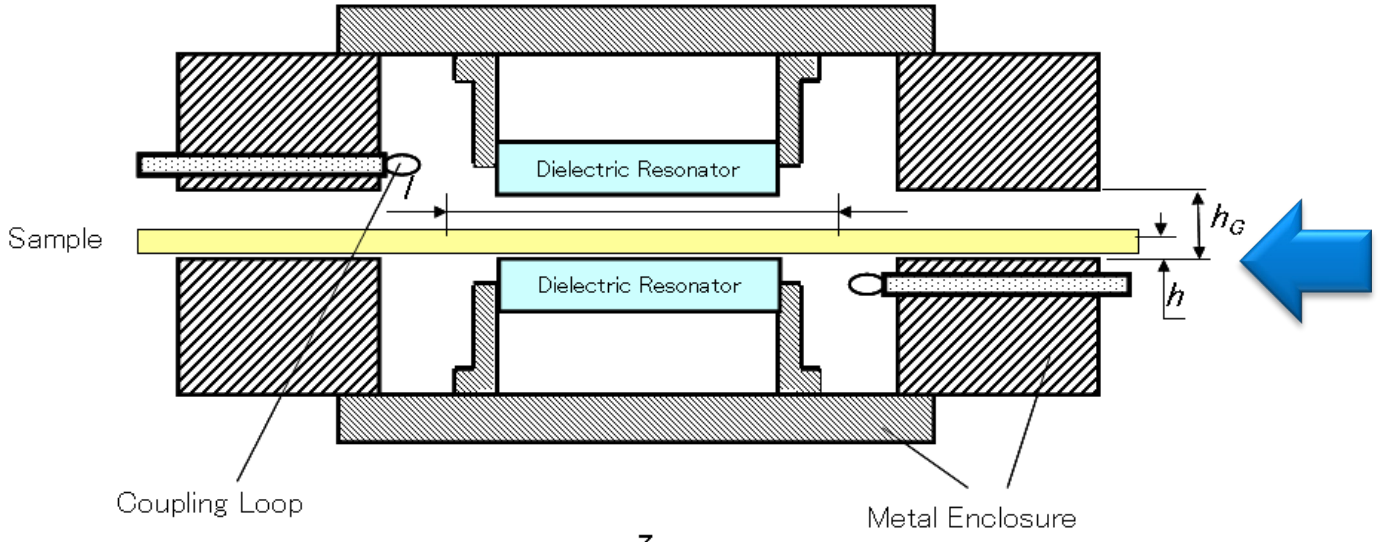
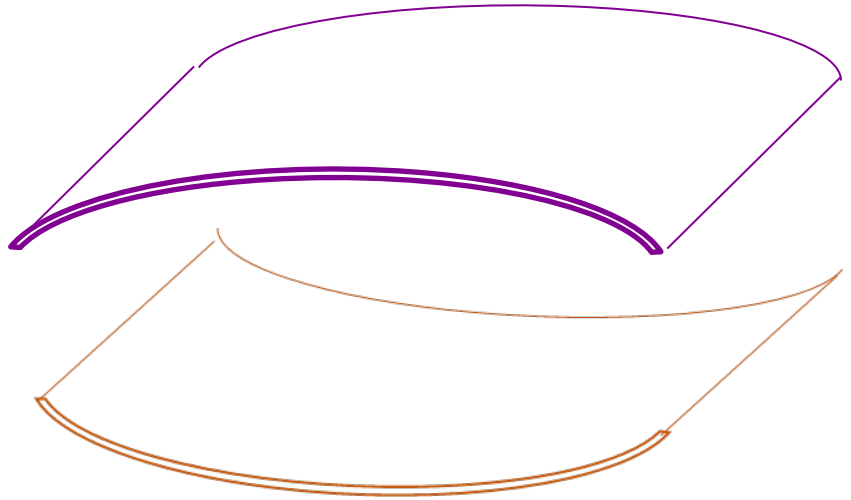


Image from QWED Company

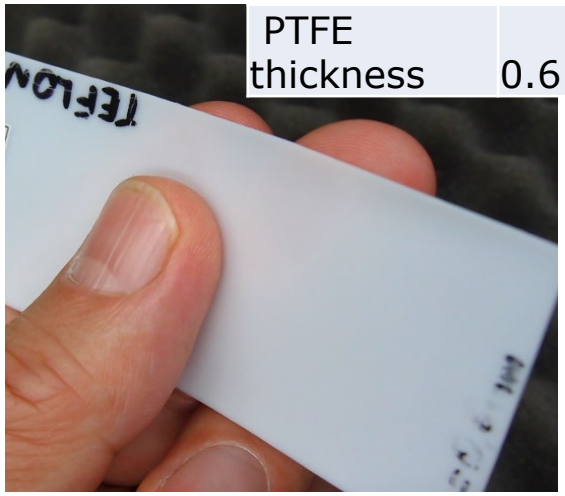
Flat

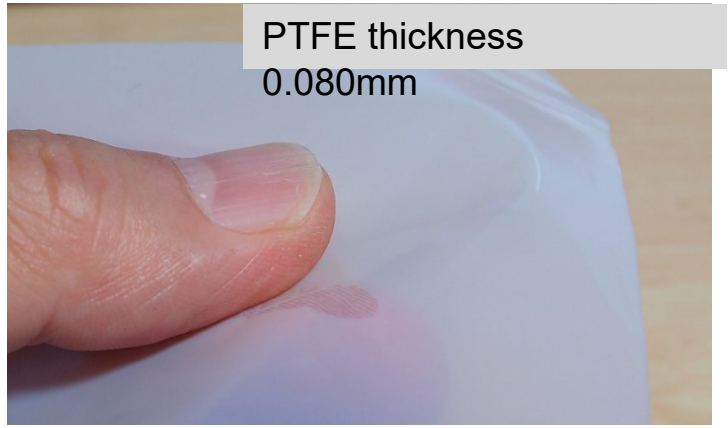
Warpage



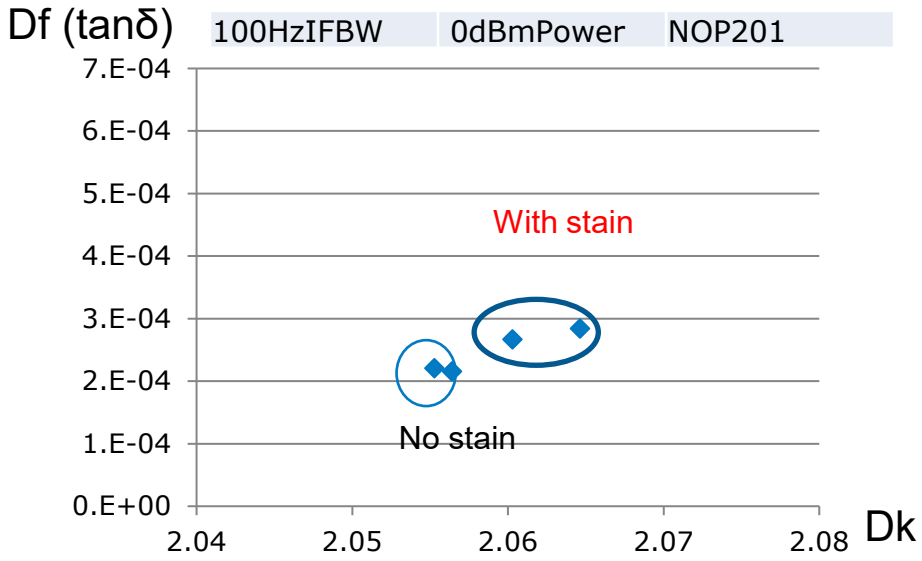
Finger Oil Changes Measurement Result (do not touch low loss samples with bare finger)

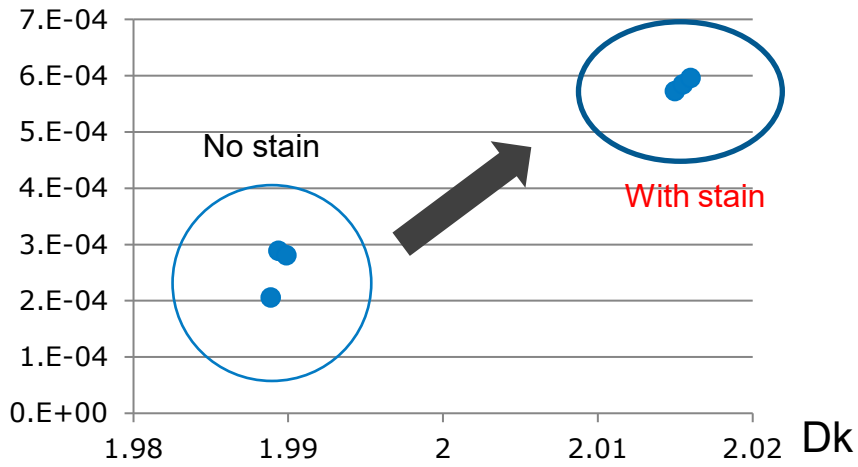
Sebum stain / finger oil increase the loss





Thinner the sample, more influence





Measurement Setup Recommendations

Measurement method for low loss:

- If Df or Loss Tangent or Tan Delta < 0.01 use Resonant cavity method
  - Resonant cavity method provides the highest measurement resolution compared to all other methods

Fixture:

- Split Post Dielectric Resonator (SPDR)
- Split Cylinder Resonator (SCR)
- Balance Circular Disk Resonator (BCDR)
- Febry-Perot Open Resonator (FPOR)

RF instrument:

- Warm up per manufacturer recommendation, typically 30 to 60 minutes
- Set maximum leveled port power, refer to instrument datasheet
- Reduce IFBW to 100Hz for mmWave frequency (typical = 300Hz). This help reduce trace noise and improve measurement accuracy

Cable:

- Good quality cable (low loss and stable)
- Connect cables and let them settle before making measurement (wait time ~1min)
  - Minimize the movement during calibration and measurement

Sample or MUT:

- Accurate sample thickness – this is critical parameter for SPDR, SCR and Transmission line/Free space method
  - Measure multiple spots and take the average helps reduce thickness uncertainty
- Flat and smooth (avoid warpage if possible)
- No finger oil – use tweezer or hand glove

Question & Answer