5G/ High Frequency Materials Characterization Challenges and Opportunities:

Optimizing Measurement accuracy and repeatability for high frequency measurements

Say Phommakesone	2021:04:14
Keysight Industry Application Engineer	

KEYSIGHT TECHNOLOGIES

Agenda

- Measurement setups & recommendations
- Experimental study using SPDR
  - How the shape of sample or finger oil effects the results
- Effect of sample thickness variation – BCDR vs SCR

SPDR

BCDR

SCR

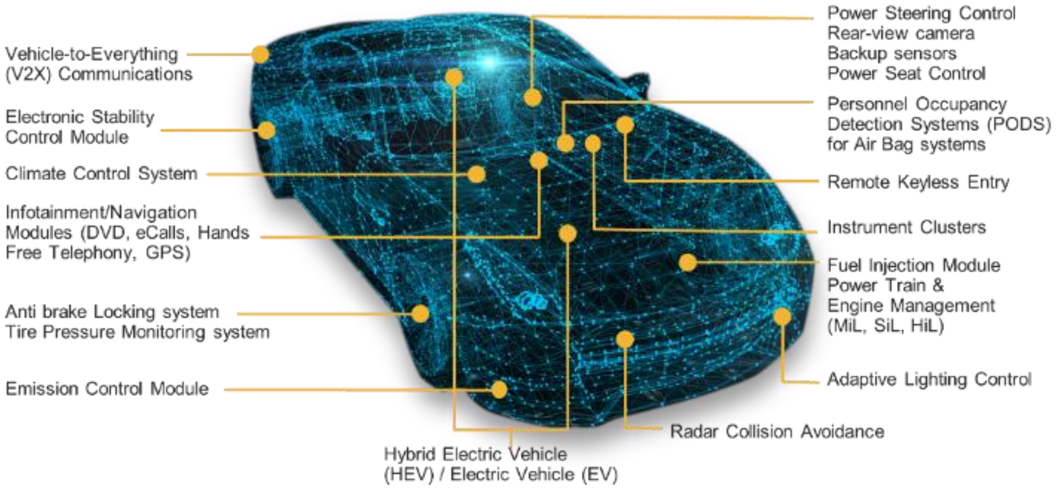
Industry Trends…

EMERGING NEW APPLICATIONS

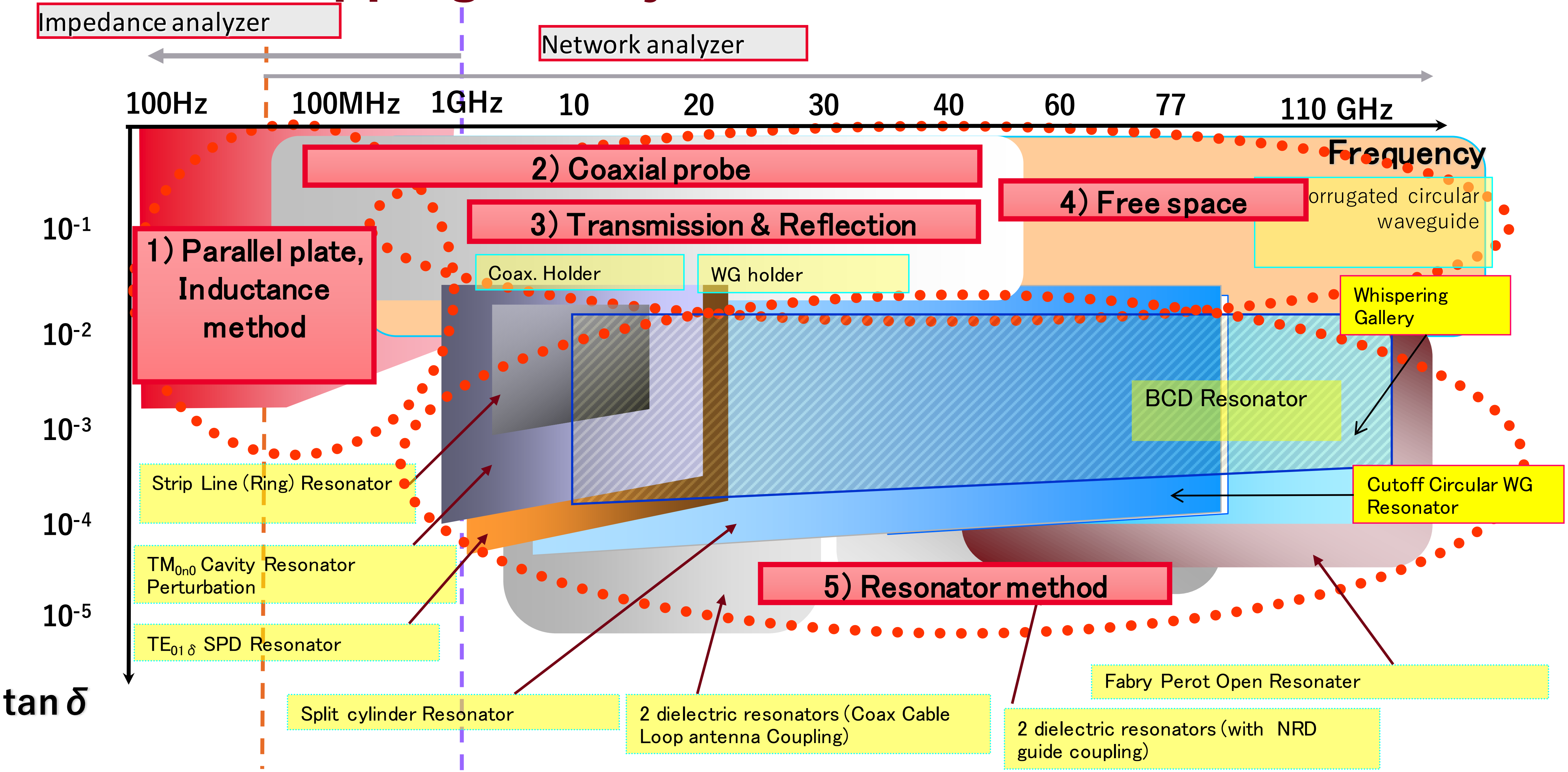
5G and Beyond

Advanced Radar & EW Solutions

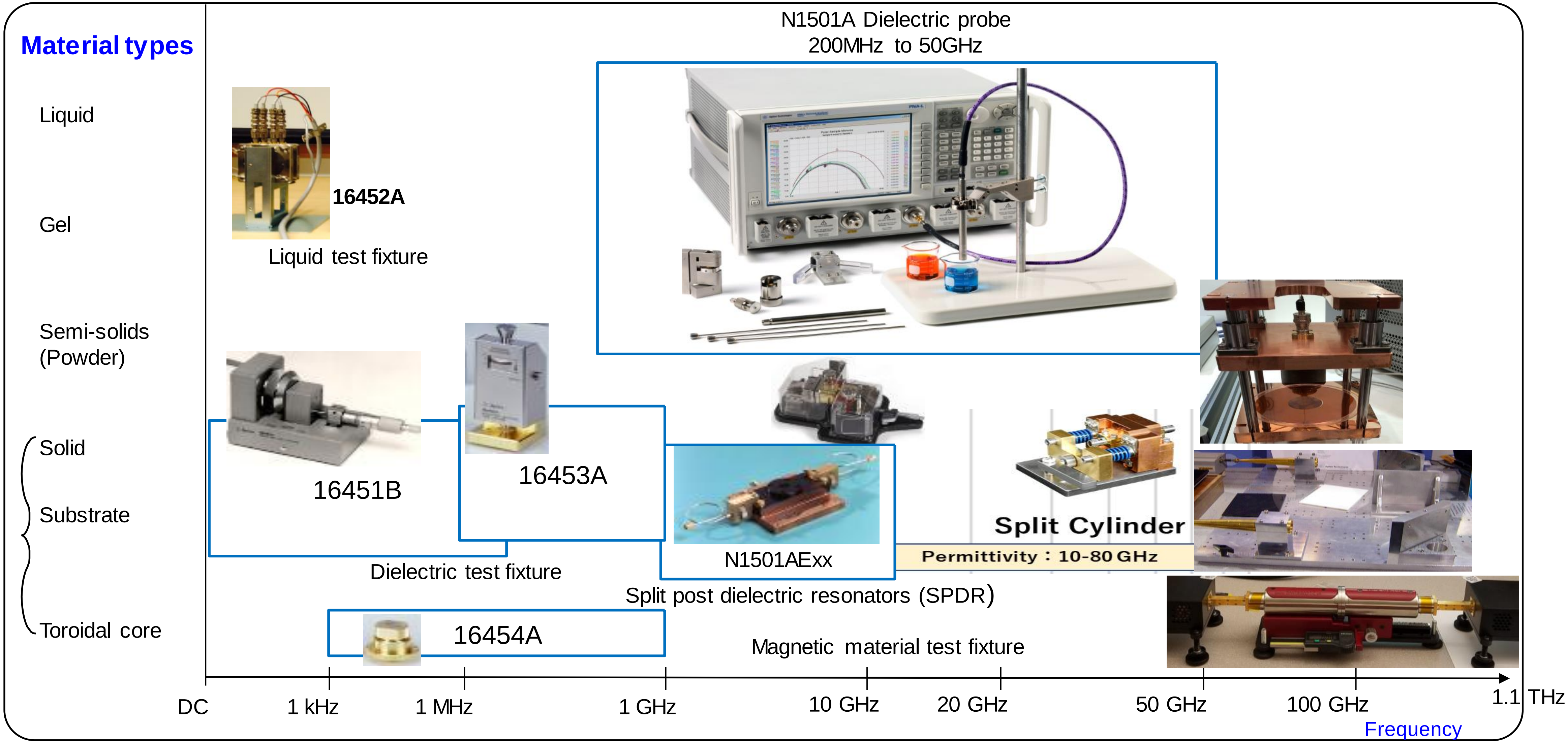
Automotive and Energy



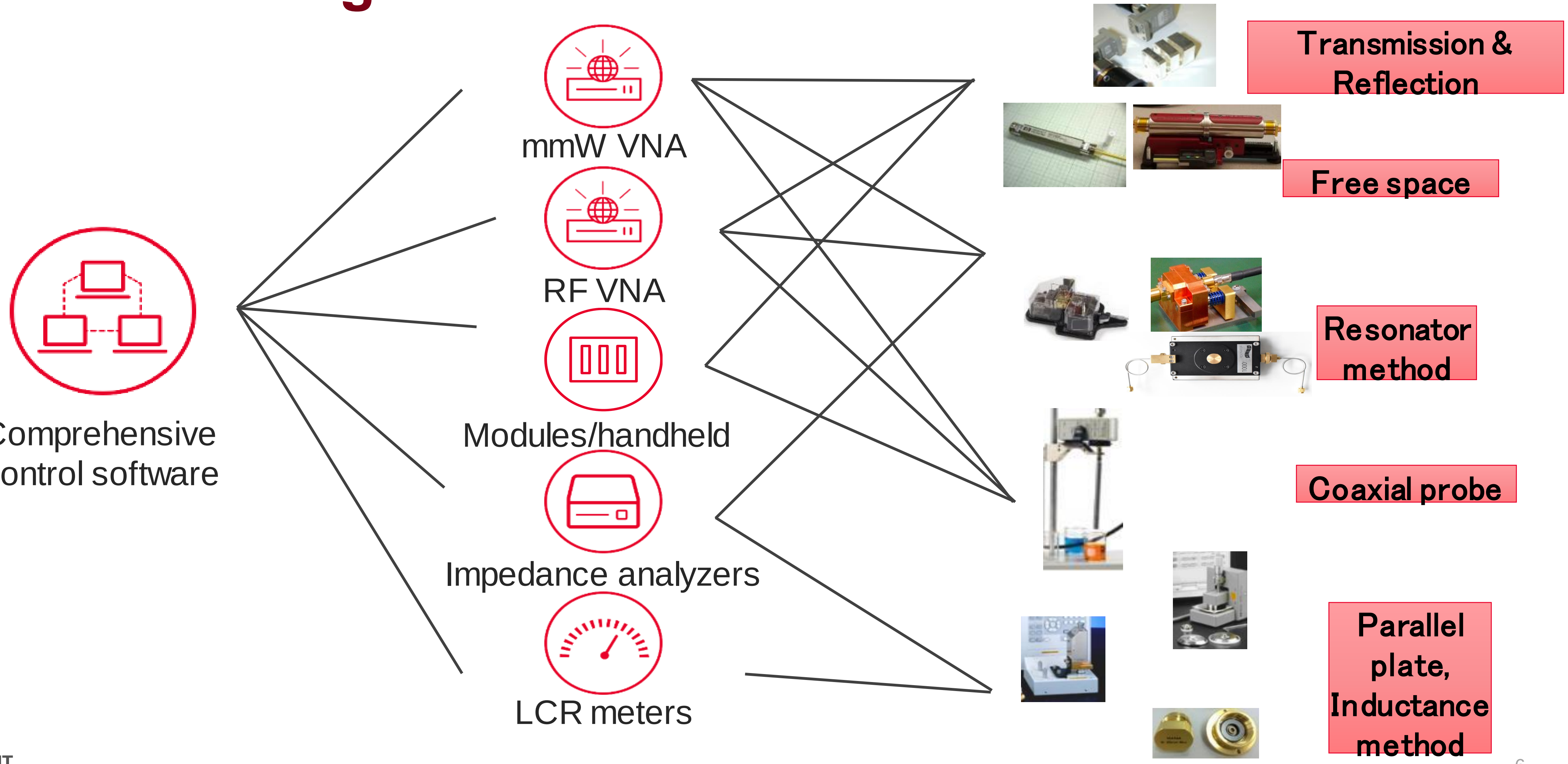
Solution Mapping: 5 major methods



Commercially Available Fixtures From Keysight…



Common Measurement Setup - Control from single interface



mmWave Fixtures and Measurement Methods

- **Best for low loss, plate or film type MUT**

Frequency

100G

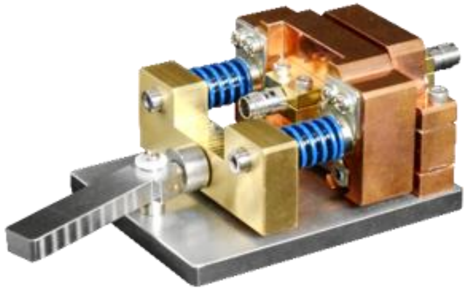
50G

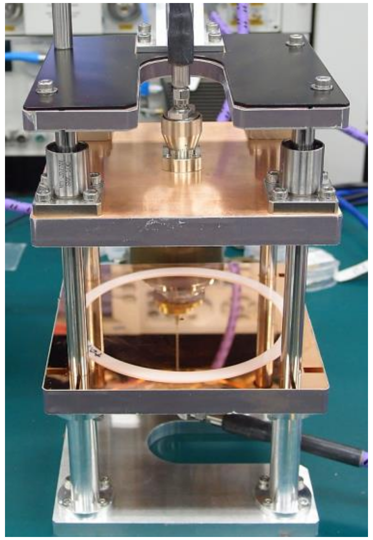
10G

TE mode
Split Cylinder Cavity Resonator
10 – 80GHz

TM mode
Balanced type Circular Disk Resonator
10– 120 GHz

Fabry Perot Open Resonator (perturbation method)
18 – 320 GHz
TEM_{00q} mode

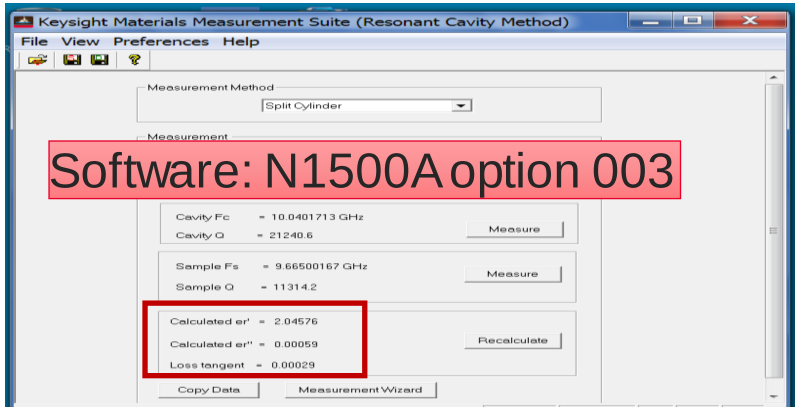




Resonant Cavity Fixtures Available through Keysight

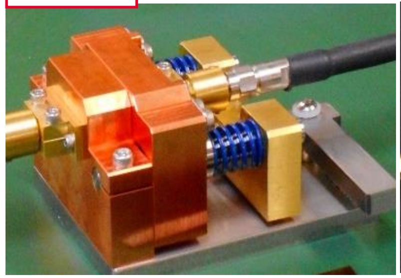
SPDR

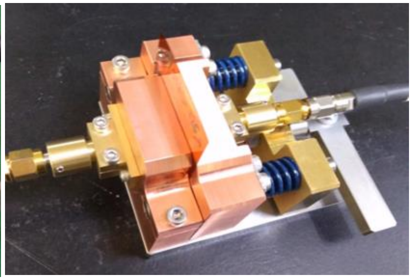
Model #	Description
N1501AE19	1.1 GHz, 3.5 mm (m) Split Post Dielectric Resonator
N1501AE03	2.5 GHz, 3.5 mm (m) Split Post Dielectric Resonator
N1501AE04	5.0 GHz, 3.5 mm (m) Split Post Dielectric Resonator
N1501AE10	10.0 GHz, 3.5 mm (m) Split Post Dielectric Resonator
N1501AE15	15 GHz, 3.5 mm (m) Split Post Dielectric Resonator



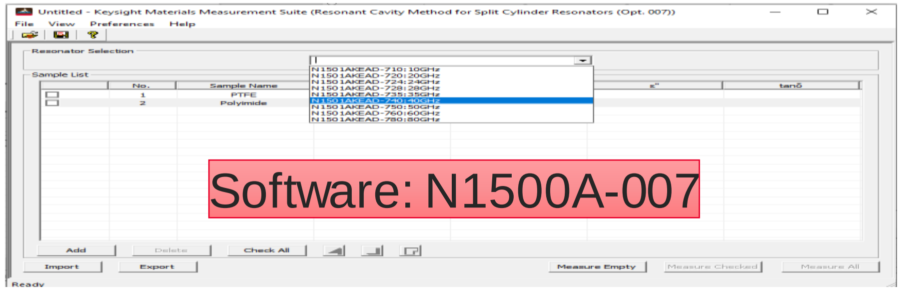
Software: N1500A option 003

SCR



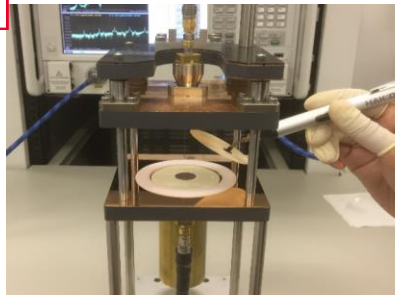


Model #	Description
N1501AKEAD-710	10 GHz, 2.9 mm (f) Split Cylinder Resonator
N1501AKEAD-720	20 GHz, 2.92 mm (f) Split Cylinder Resonator
N1501AKEAD-724	24 GHz, 2.92 mm (f) Split Cylinder Resonator
N1501AKEAD-728	28 GHz, 2.92 mm (f) Split Cylinder Resonator
N1501AKEAD-735	35 GHz, 2.92 mm (f) Split Cylinder Resonator
N1501AKEAD-740	40 GHz, 2.92 mm (f) Split Cylinder Resonator
N1501AKEAD-750	50 GHz, 2.4 mm (f) Split Cylinder Resonator
N1501AKEAD-760	60 GHz, 1.85 mm (f) Split Cylinder Resonator
N1501AKEAD-780	80 GHz, 1 mm (f) Split Cylinder Resonator
N1500A-007	Resonant Cavity Method for Split Cylinder Resonators

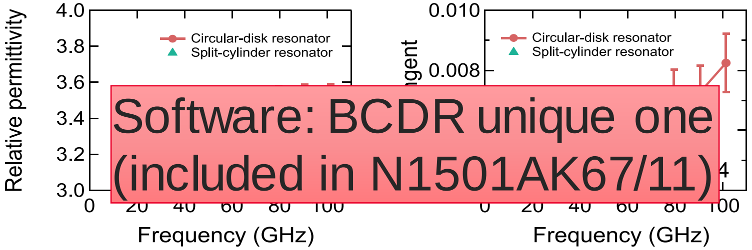


Software: N1500A-007

BCDR



Model #	Description
N1501AE67	67 GHz Balanced Circular Disk Resonator
N1501AE11	110 GHz Balanced Circular Disk Resonator



Software: BCDR unique one (included in N1501AK67/11)

SCCR

85072A 10 GHz Split Cylinder Resonator

Software: N1500A option 003

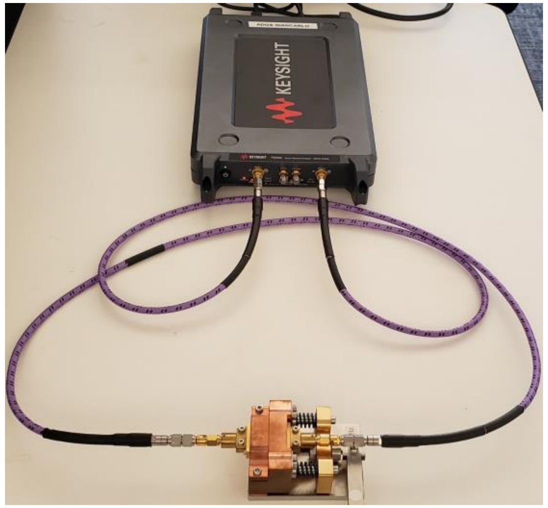
KEYSIGHT TECHNOLOGIES

Available Measurement Methods From Keysight

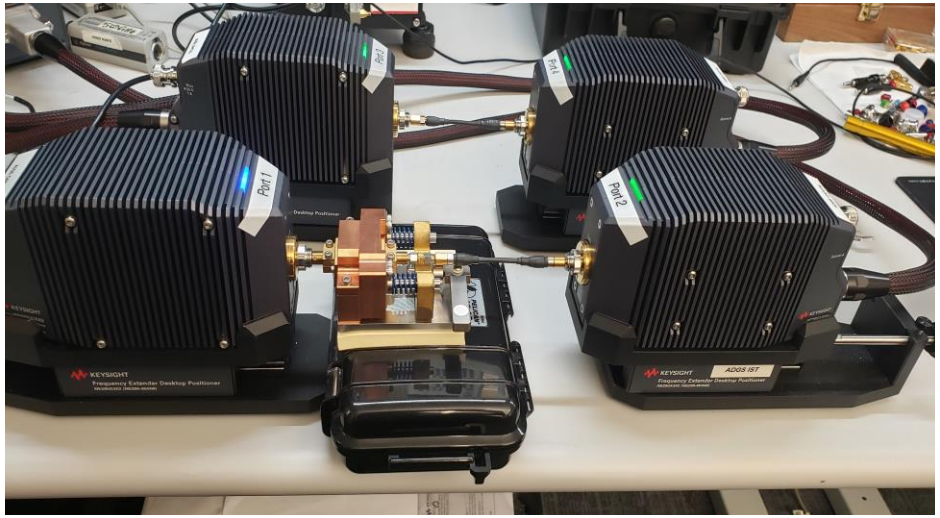
N1500A MATERIAL MEASUREMENT SUITE

Models	Description	Options and description	Comments
N1500A	Materials Measurement Software Suite	001: Transmission line and free space 002: Arch reflectivity 003: Resonant cavity 004: Coaxial probe 005: Parallel Plate/Inductance Method Up to 1.0 GHz 006: Parallel Plate/Inductance Method Up to 120 MHz 007: Resonant Cavity Method for Split Cylinder Resonators	• All licenses tied to USB dongle key, ordered N1500A-UL8

Typical Materials Measurement System



SCR



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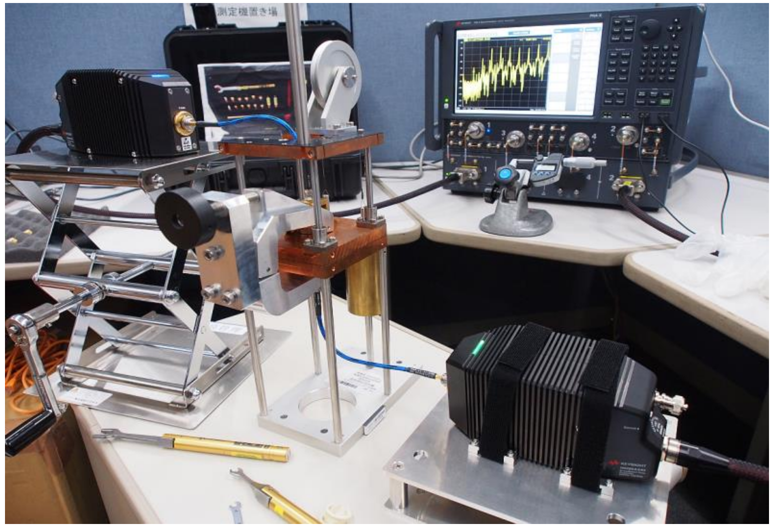
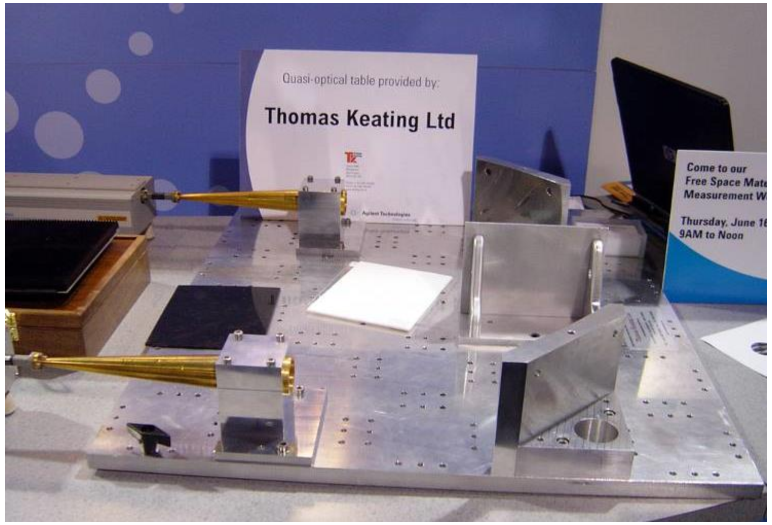


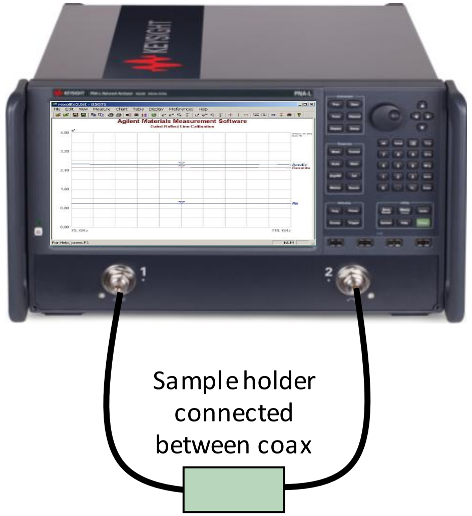
BCDR

Free space



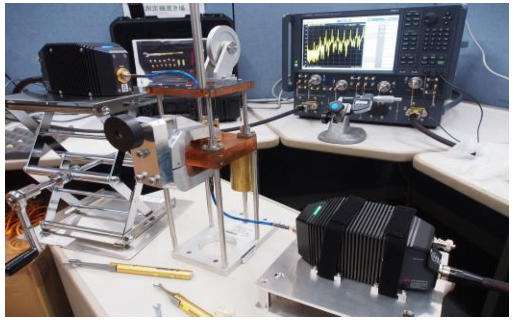
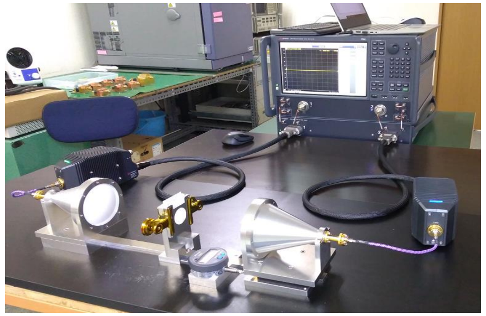
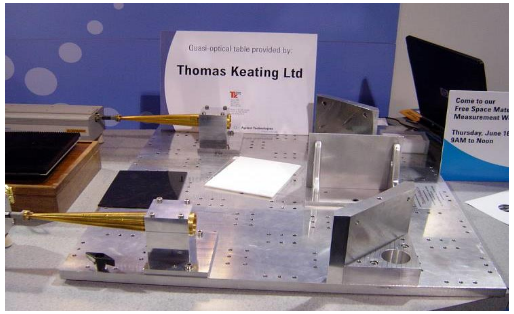
Free space

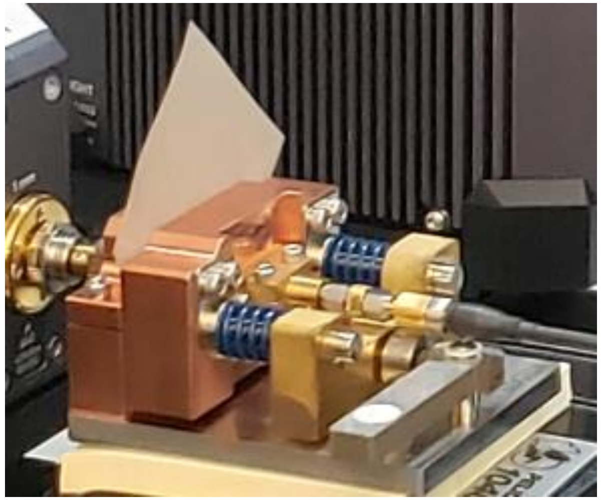
Network Analyzer



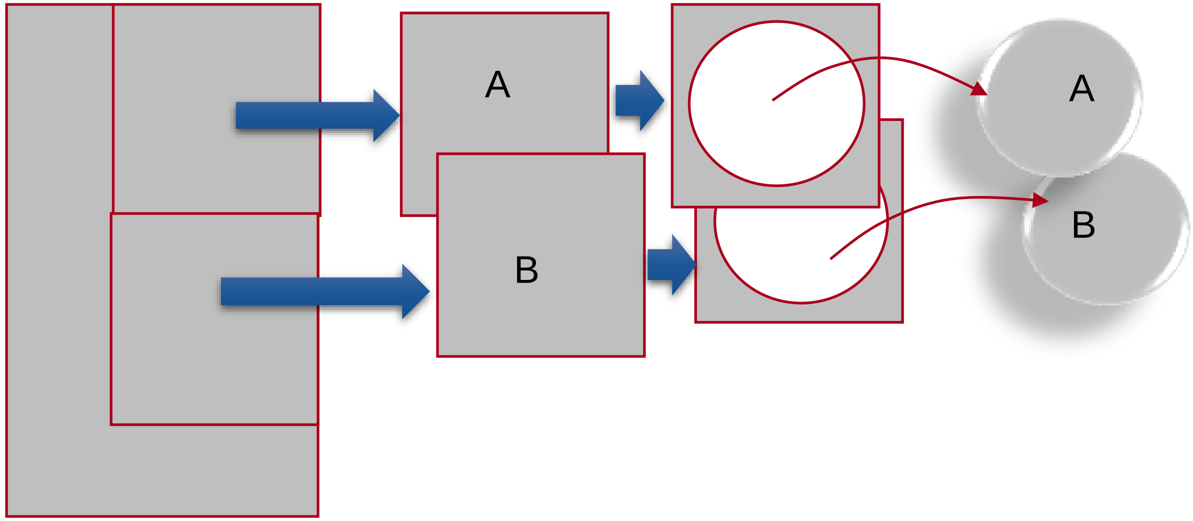
Transmission line

Sample Fabrication / Preparation…

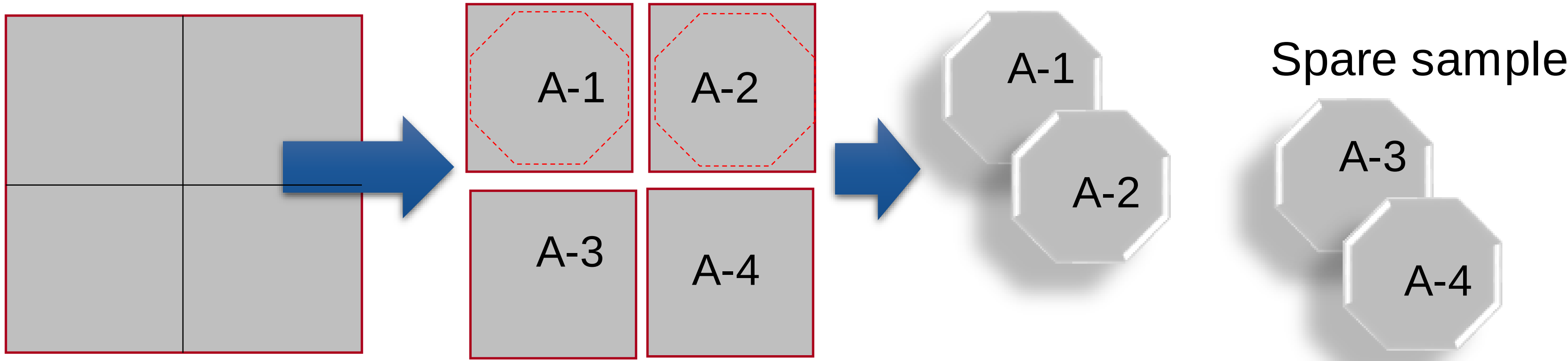







Specimen plate

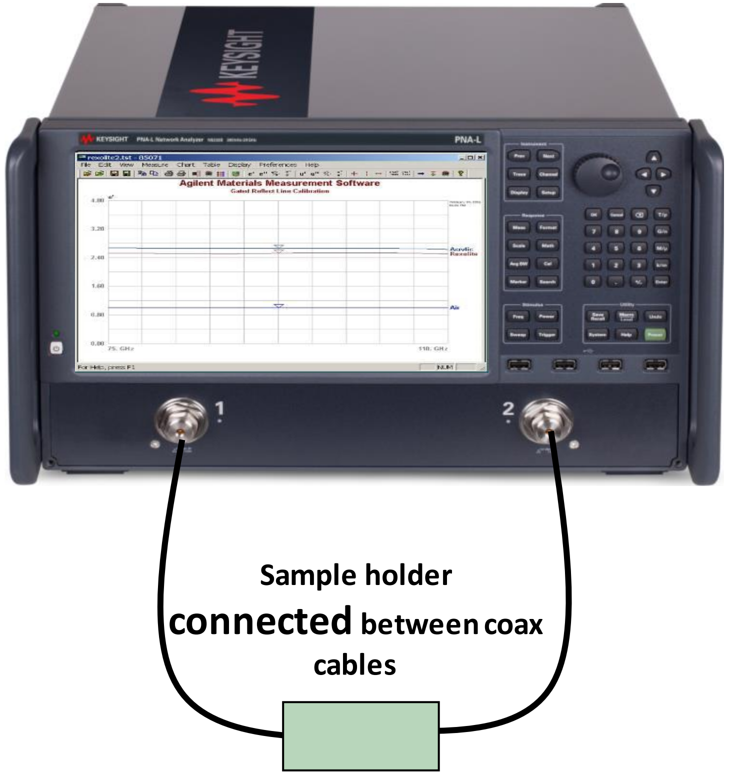


Best way (two samples from the same sheet)



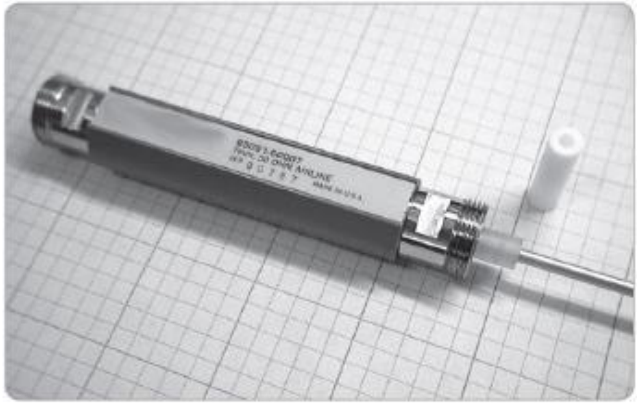
Transmission Line System – Require 2-port Calibration

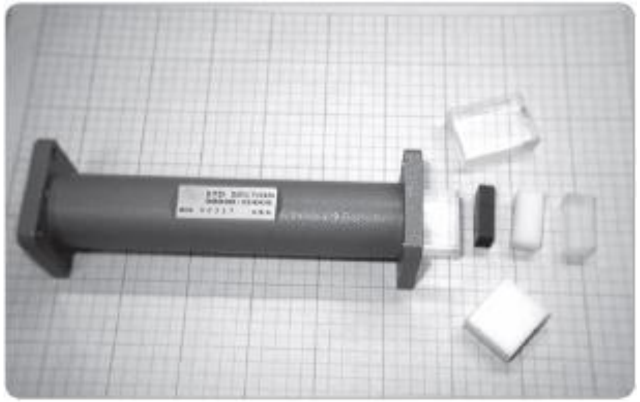
Network Analyzer



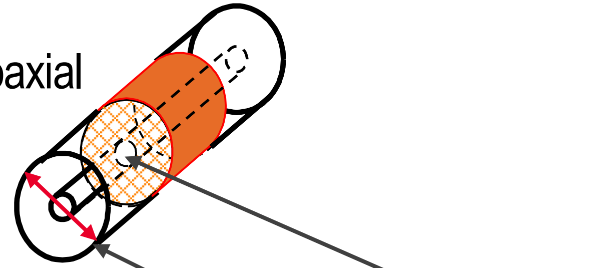
Calibration Type:

- SOLT (Short, Open, Load, Thru)
- **TRL** (Thru, Reflect, Line)
- ECal (Electronic Calibration Module)





Coaxial



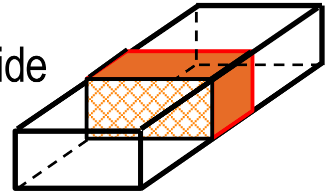
APC7 & Type N Dimension:

- Inner outer diameter (center hole of sample) = 3.034 +/- 0.003 mm
- Out inner diameter (sample diameter) = 7.000 +/- 0.005 mm

3.5mmm Airline:

- ID of outer = 3.5mm
- OD of center = 1.52mm

Waveguide



Waveguide Band	W (mm)	H (mm)	R (mm)	Thickness (mm)
WR90	22.86 ±0.01	10.16 ±0.01	0.13 max	9.78 ±0.02
WR62	15.80 ±0.01	7.90 ±0.01		6.50 ±0.02
WR42 000310	10.671 ±0.08	4.318 ±0.008		4.5 ±0.02

KEYSIGHT TECHNOLOGIES

Measurement Setup Recommendations

Measurement method at mmWave frequency:

- If Df or Loss Tangent or Tan Delta > 0.01 use Free space or Transmission line (Corrugated wave guide) method
- 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:

Select appropriate fixture per measurement method and Freq of interest

- SCR or BCDR for Cavity method
- Coaxial or Wave guide section for Transmission line method
- Free space fixture or Quasi optical table for Free space method

RF instrument:

- Warm up per manufacturer recommendation, typically 30 to 60 minutes
- Set maximum leveled port power, refer to instrument datasheet
- Set IFBW to 100Hz for mmWave frequency (typical = 300Hz). This help reduce trace noise and improve measurement accuracy
- Use TRL calibration when possible. TRL is the best compared to SOLT or Electronic Calibration module

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, BCDR 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

Agenda

- Measurement setup & recommendations
- Experimental study using SPDR
  - – How the shape of sample or finger oil effects the results
- Effect of sample thickness variation – BCDR vs SCR

SPDR

BCDR

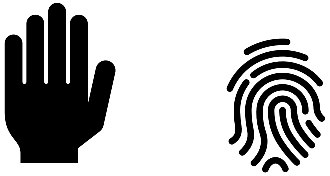
SCR

Experimental repeatability study when using SPDR

- Measure three different thickness samples by the same 9 GHz SPDR

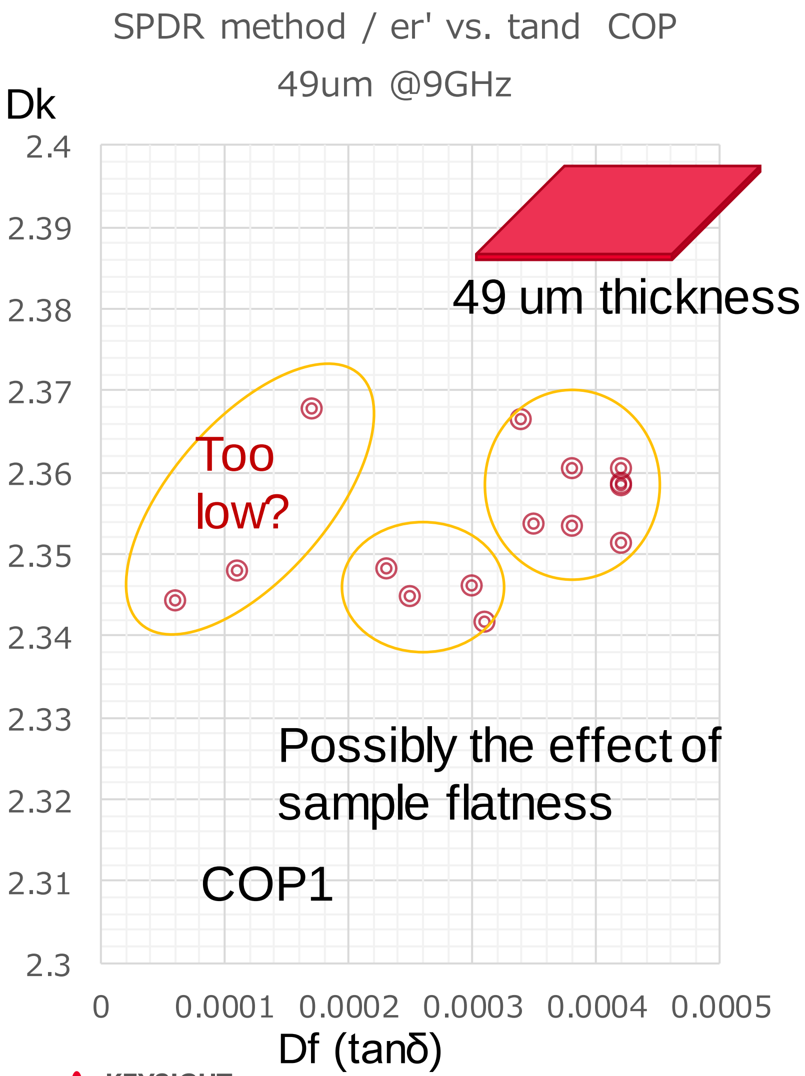
- Measure a sample with warpage

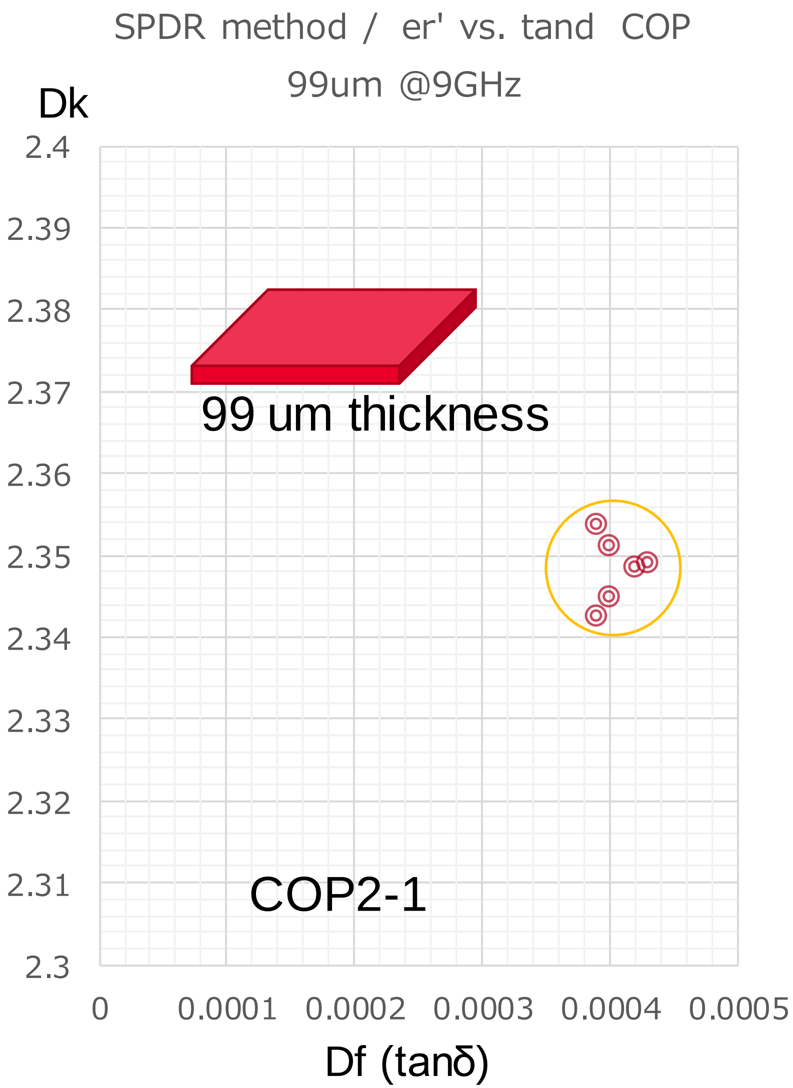
- Measure samples with and without touching by bare hand

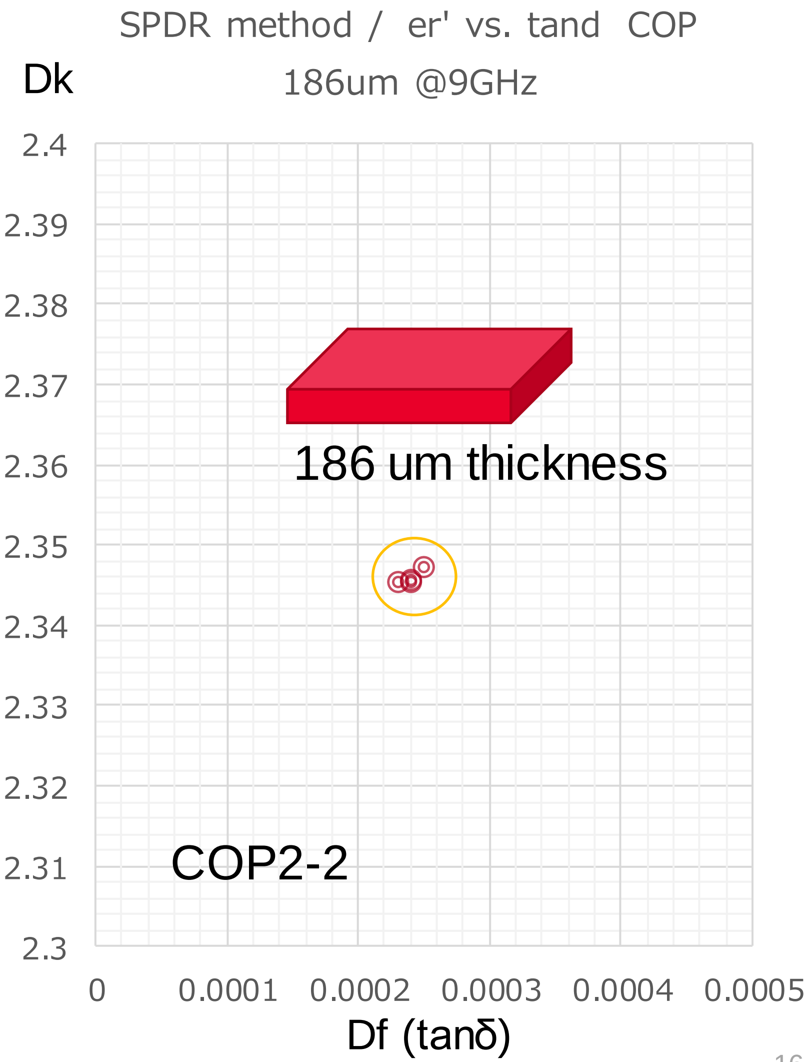


Measurement repeatability SPDR 9GHz COP – 3 different thickness

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







Possible factor to increase uncertainty w/SPDR

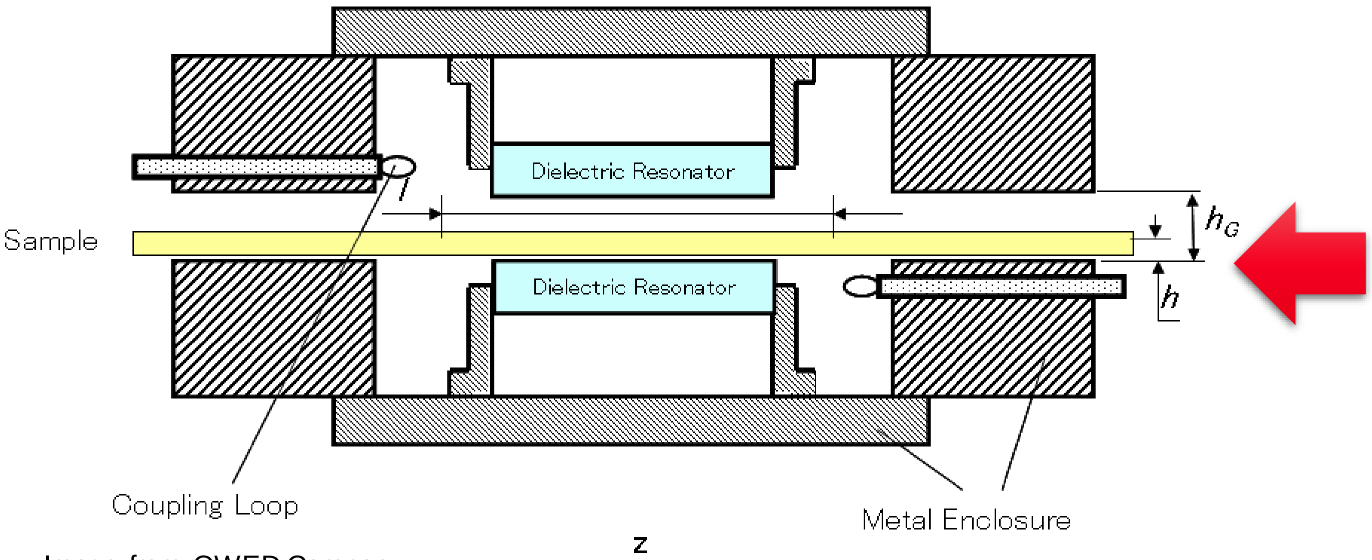
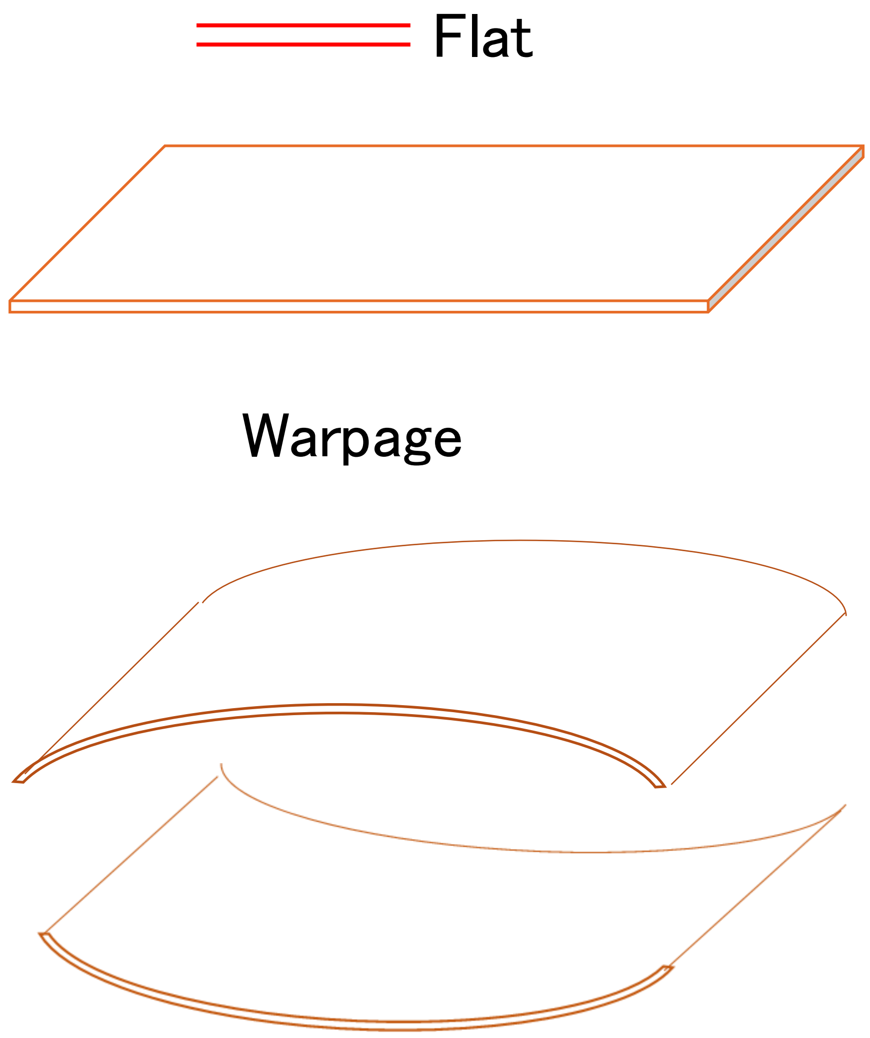
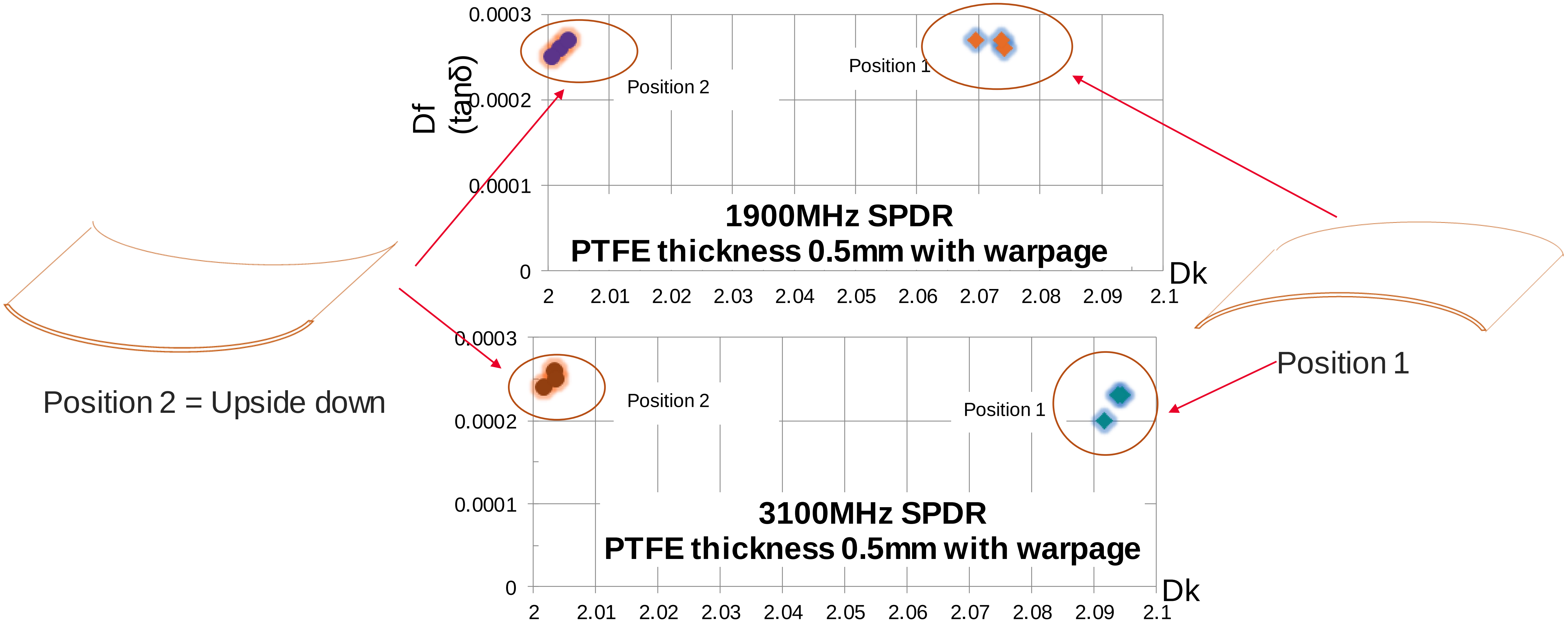


Image from QWED Company



Warpage increases uncertainty

Repeat measurements by flipping upside down the same sample

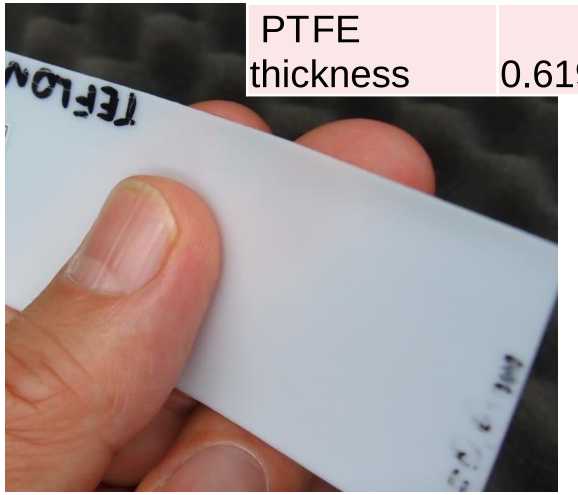


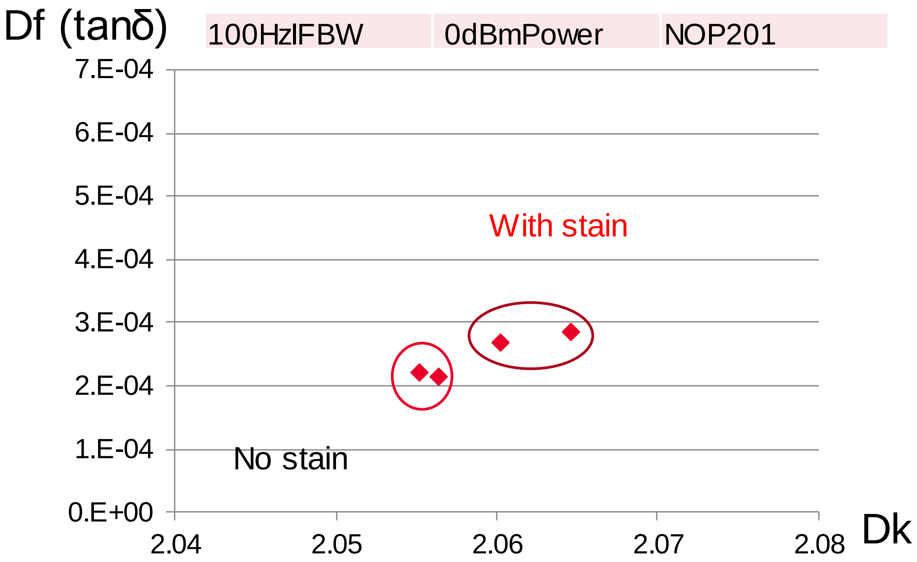
The results change according to the position

Caution when measuring thin sheet, do not touch low loss samples by your finger

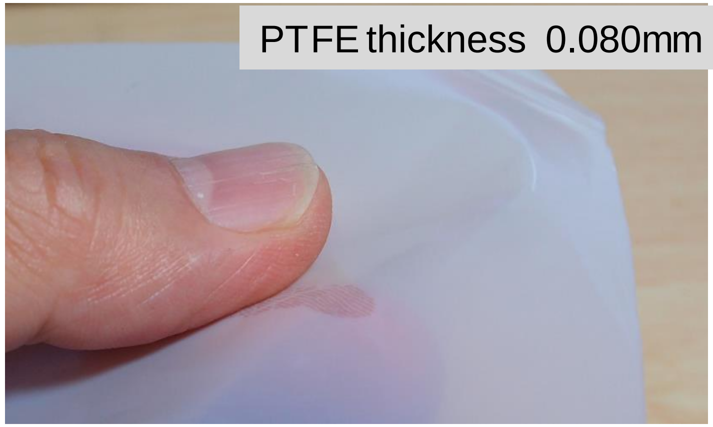
Sebum stain / finger oil increase the loss

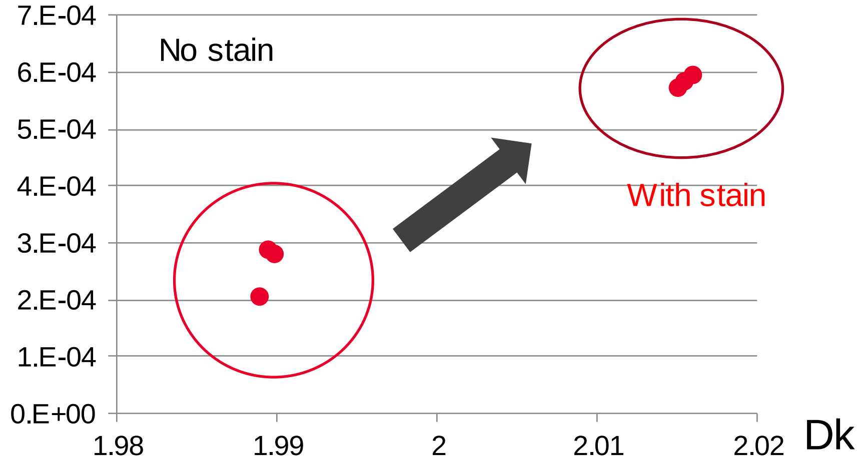
PTFE thickness	0.619mm





PTFE thickness 0.080mm





Thinner the sample, more influence

KEYSIGHT TECHNOLOGIES

Effect of thickness variation – BCDR vs SCR

Measure a 188 um COP sheet by BCDR and SCR.

Check how the calculated Dk/Df change according to the defined thickness

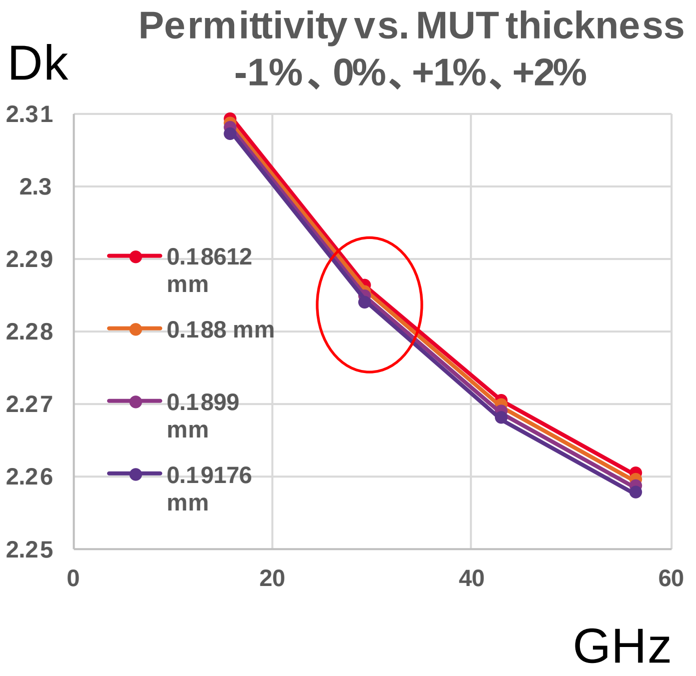
BCDR

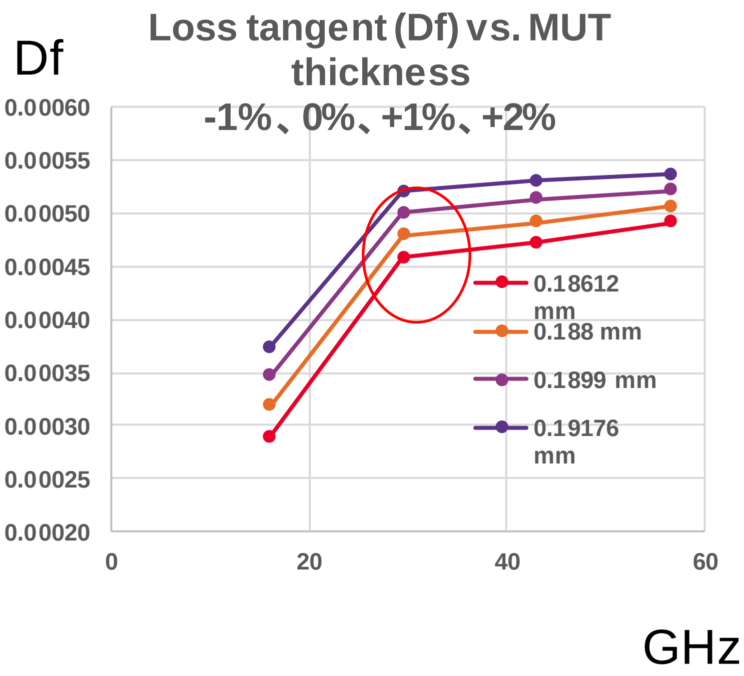
SCR

BCDR: Effect of thickness error – when t = 0.188mm thickness low-loss sample (DK ~2.28 , Df 0.00048 @29G)

Simulate results when actual t = 0.188mm, and change the thickness to calculate as -1%, +1%,+2% (1% = 1.8 um).

- Dk changes approx. by 0.03% per 1 % thickness change
- Df (Tanδ) changes in the order of 10^{-5}



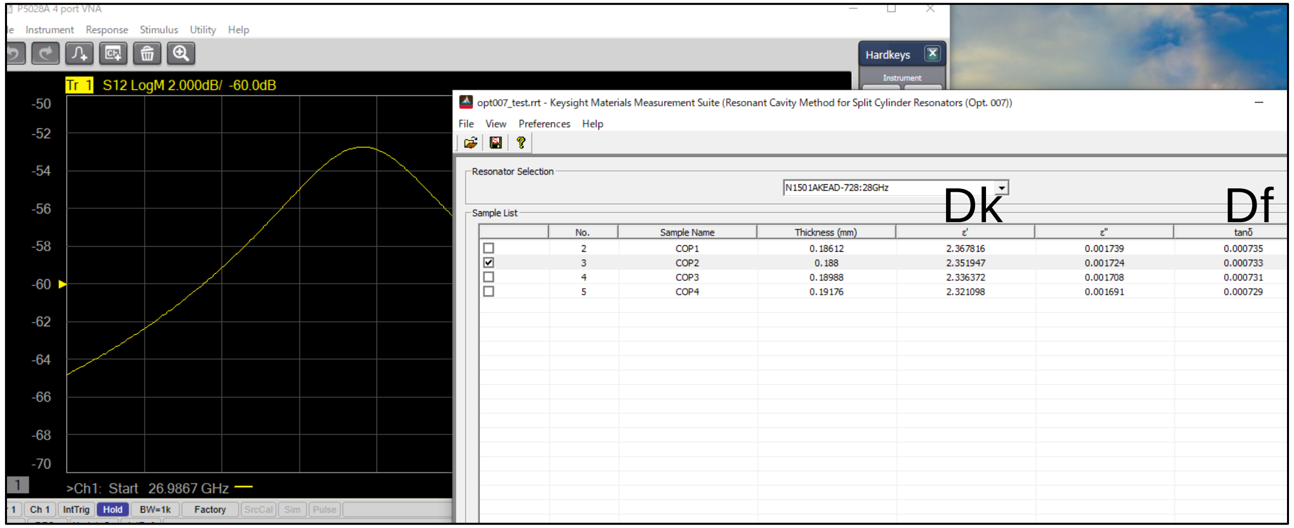


Thickness	Dk @29G	Df @29G
-1 %	2.2861 (+0.03%)	0.000458 (-2E-5)
0.188 mm **(ref.)**	2.2853 (ref.)	0.000479 (ref.)
+1 %	2.2845 (-0.03%)	0.00050 (+2E-5)
+2 %	2.2838 (-0.07%)	0.00052 (+4E-5)

SCR: Effect of thickness error
- when t = 0.188mm thickness low-loss sample (DK ~2.35 , Df 0.00074 @28G)

Use a sample with actual t = 0.188 mm, repeat the measurement by changing the thickness to calculate as 0.188 mm -1% to +2%
(1% = 1.8 um)

- Dk changes approx. by 0.7% per 1% thickness change
- Df (Tanδ) changes in the order of 10^{-6}



Thickness	Dk @28G	Df @28G
-1 %	2.369602 (+0.68%)	0.00074 (+3E-6)
0.188 mm **(ref.)**	2.353693 (ref.)	0.000737 (ref.)
+1 %	2.338098 (-0.66%)	0.000735 (-2E-6)
+2 %	2.322808 (-1.31%)	0.000733 (-4E-6)

Summary

- When measuring materials at mmWave frequency range, the instrument warmup time including stimulus condition, cable quality and movement, and sample fabrication should be taken into consideration to obtain highest measurement accuracy and repeatability.

- When measuring thinner sample, you need to take care the followings for better repeatability;
  - **Thickness equality and accuracy**
    - ➢ Sensitiveness differs per the resonator method, but thickness flatness and accuracy effects to the measurement result
  - **Shape and position of the sample**
    - ➢ It's important to set the sample to the same position and orientation.
    - ➢ Take care the warpage/winkles and flatness
  - **Not to touch the sample by finger**
    - ➢ Finger oil (sebum) will add extra loss

Question & Answer

KEYSIGHT
TECHNOLOGIES