Accurate PCB and Material Measurements for High-Speed SerDes Applications

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KEYSIGHT TECHNOLOGIES

Agenda

- Market trend mmWave radar and 5G communication
- Challenge of Dielectric parameter measurements
- New mmWave material solutions
    - Balanced Circular Disk Resonator (BCDR)
    - Split Cylinder Cavity Resonator (SCCR)

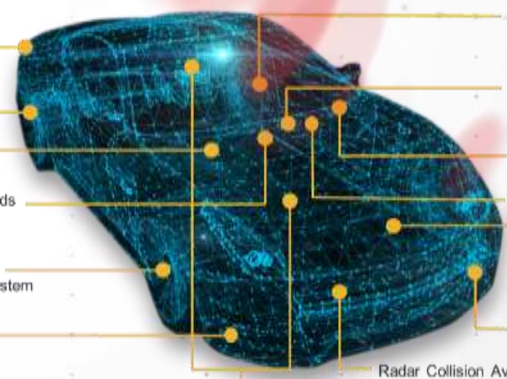
Market trends

EMERGING NEW APPLICATIONS

5G
chipset providers,
operators,
and NEMs

Advanced
Radar & EW
Solutions

Automotive and Energy

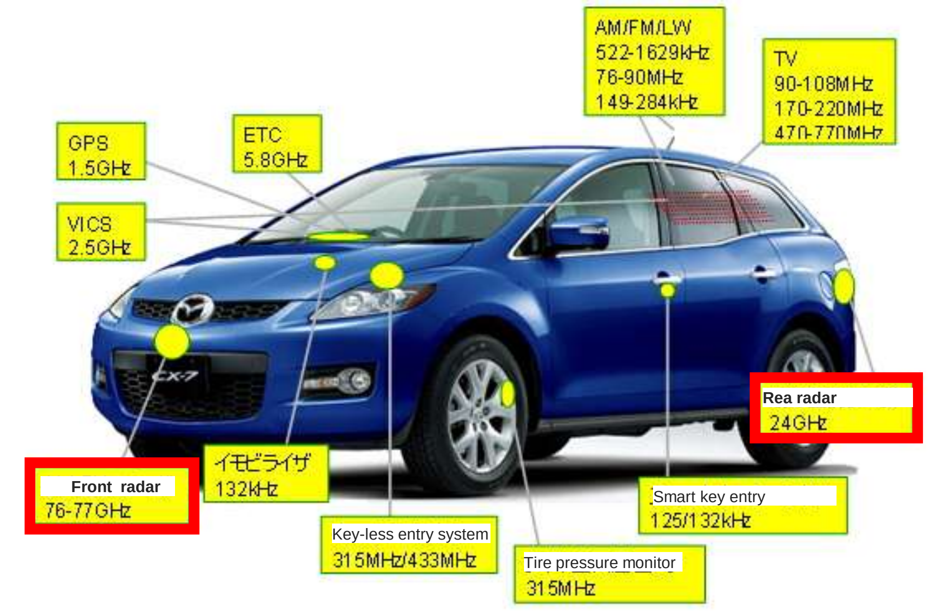


Biomedical

Food

Applications at millimeter frequencies

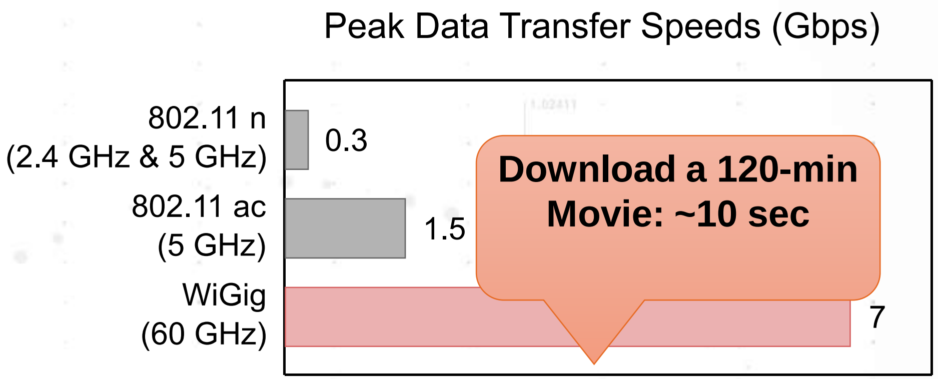
1. Automotive radars (76-77 GHz, 24 GHz,77-81GHz)



(from ESI Group HP)

- ✓ **Front long range radar: 76-77 ,77-81GHz**
- ✓ **Rear short range radar: 24 GHz**

2. Next-generation wireless communications (WiGig, 60 GHz band)



Demonstration experiment at Narita Int'l airport (Feb. 18-26, 2016)

KEYSIGHT WORLD 2017 AIST KATO and HORIBE

New Operating Bands In 5G NR – up to 40G by FR2

SUB-6GHZ AND MMWAVE

0.6 GHz | ISM | 2.5 GHz | 3.3-4.2 GHz | 4.4-5 GHz | ISM 5.7-5.8 | … | ISM 24 GHz | 24 GHz | 28 GHz | 39 GHz | … | 64-71GHz 71-76GHz

Frequency Range 1: 400 MHz to 6 GHz	Frequency Range 2: 24.25 to 52.6 GHz	
Adds 1.5 GHz of new spectrum in frequency bands	Adds 8.25 GHz of new spectrum in frequency bands	Frequencies up to 90 GHz are currently being investigated for future releases.
n77: 3.3–4.2 GHz n78: 3.3–3.8 GHz n79: 4.4–5 GHz	n257: 26.5-29.5 GHz n258: 24.25-27.5 GHz n260: 37–40 GHz	

Note :
3GPP band n258 refers to the range between 24.25-27.5 GHz and is commonly called 26 GHz. And 3GPP band n257 refers to 26.5-29.5 GHz. It is commonly called 28 GHz.

A lot of 5G commercial trial & initial deployment focus on:

- **3.6 to 3.8GHz band (part of n77 & n78)**
- **26 to 27.5GHz band (part of n257 & n258)**

Downlink 3.4 to 4.2GHz

Satellite Ground Station

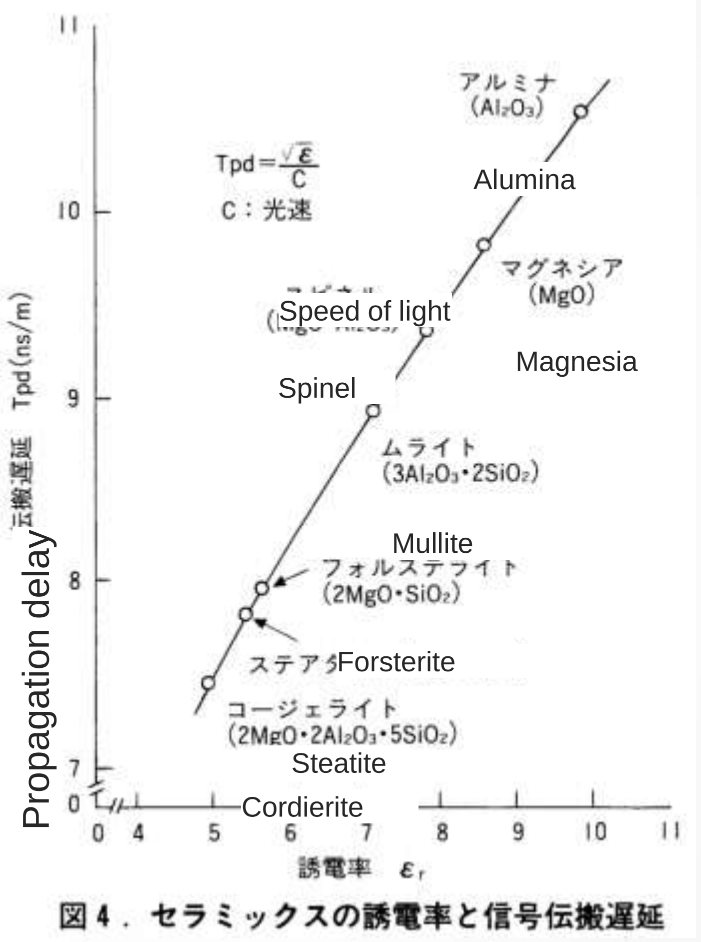
New bands	Supporting operators
Band n77 (3300-4200 MHz) Band n78 (3300-3800 MHz)	NTT DOCOMO, KDDI, Softbank Mobile, China Mobile, China Unicom, China Telecom, KT, SK Telecom, LG Uplus, Etisalat, Orange, Telecom Italia, British Telecom, Deutsche Telekom, Telstra
Band n257 (26.5-29.5 GHz) Band n258 (24.25-27.5 GHz)	NTT DOCOMO, KDDI, Softbank Mobile, China Mobile, KT, SK Telecom, LG Uplus, Etisalat, Orange, Verizon, T-mobile, Telecom Italia, British Telecom, Deutsche Telekom, Telstra

Source: Huawei

Material performance requested

LOW DK AND LOW DF

- Ideal performance is “air”
  - Designers have to use dielectric material to hold or to protect signal line, but they prefer “as same as nothing there”.
- 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
- Users’ request
  - Dk and Df at target frequency range = to cover 30GHz and 80GHz



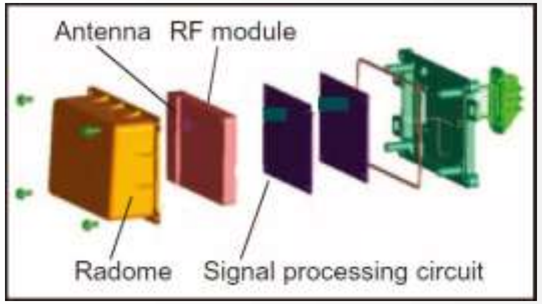
Permittivity

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

Desired performance for mmWave radar material

Product	mmWave radar		
Material	Bumper Emblem(徽) Paint	Radome (雷達罩)	Antenna & print circuit board
Requirement	Good transparency(透明度) for mmWave		Low cost, Small footprint, Avoid performance degrade at mmWave
Desired electric performance	Low refection and low loss =Low dk, less than 3.0 Low df to avoid loss in mmWave range		Low loss transmission line = low df, High conductivity. Accurate dk value & anisotropy understanding for good design



Ref. Denso Technical review vol.9 No.2

All application request low dk and low df material

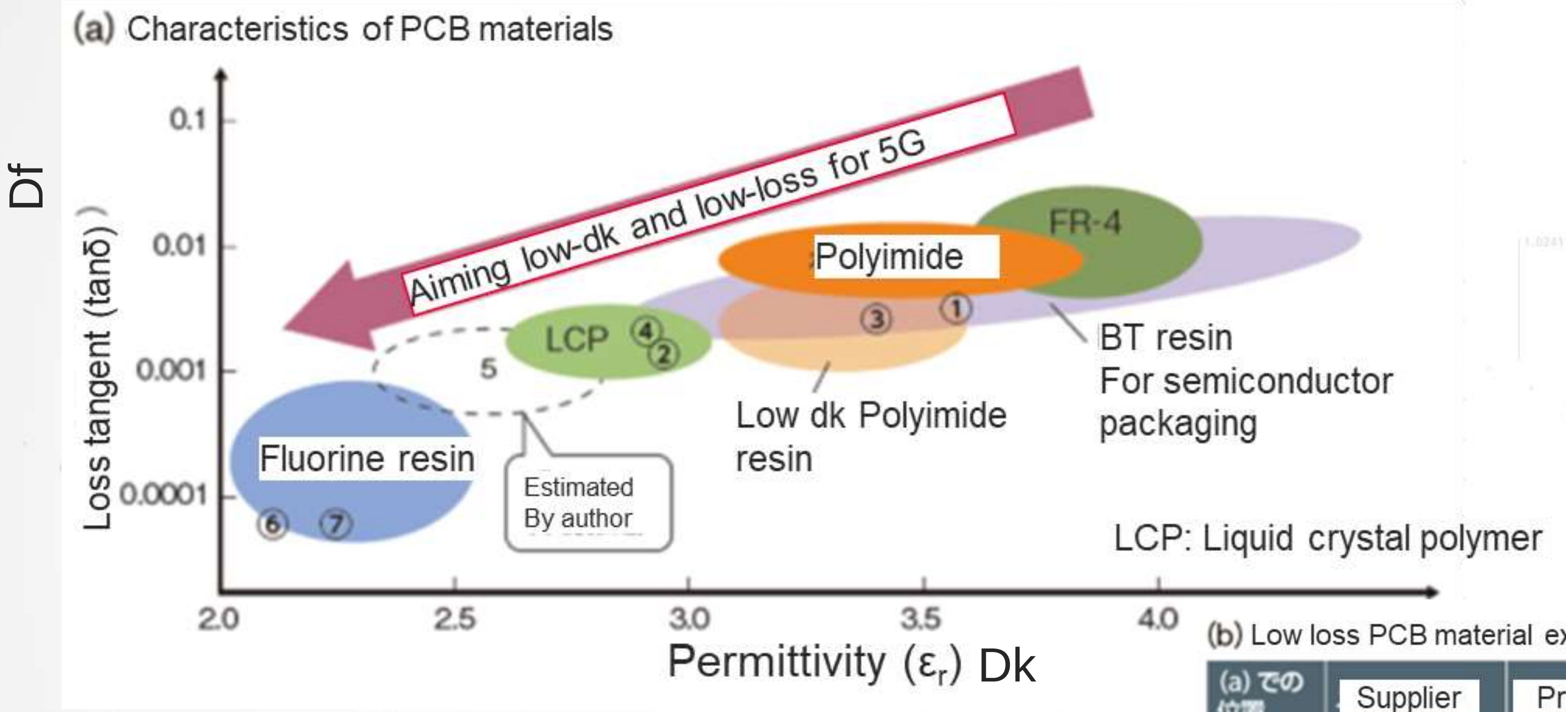
Expected performance for dielectric materials

Product	Rigid / Flexible print circuit board	IC / Semiconductor	Antenna protection, Mobile chassis	Others
Material	Resin Base material Composite Registration Adhesive(膠黏劑) Coverlay Copper Clad Laminate (CCL) Pre-preg	IC package Sealing material Adhesive Under fill	Resin Paint	Glass Transparent base Optical material Camera lens Anti-reflection film Connector form
Expected performance	Low dk, Low df, Low loss, Low transmission loss(Surface conductivity)	Low dk, Low df, User expects that filling space by resin doesn't change performance vs. air		

All application request low dk and low df material

KEYSIGHT TECHNOLOGIES

Typical PCB material Dk and Df



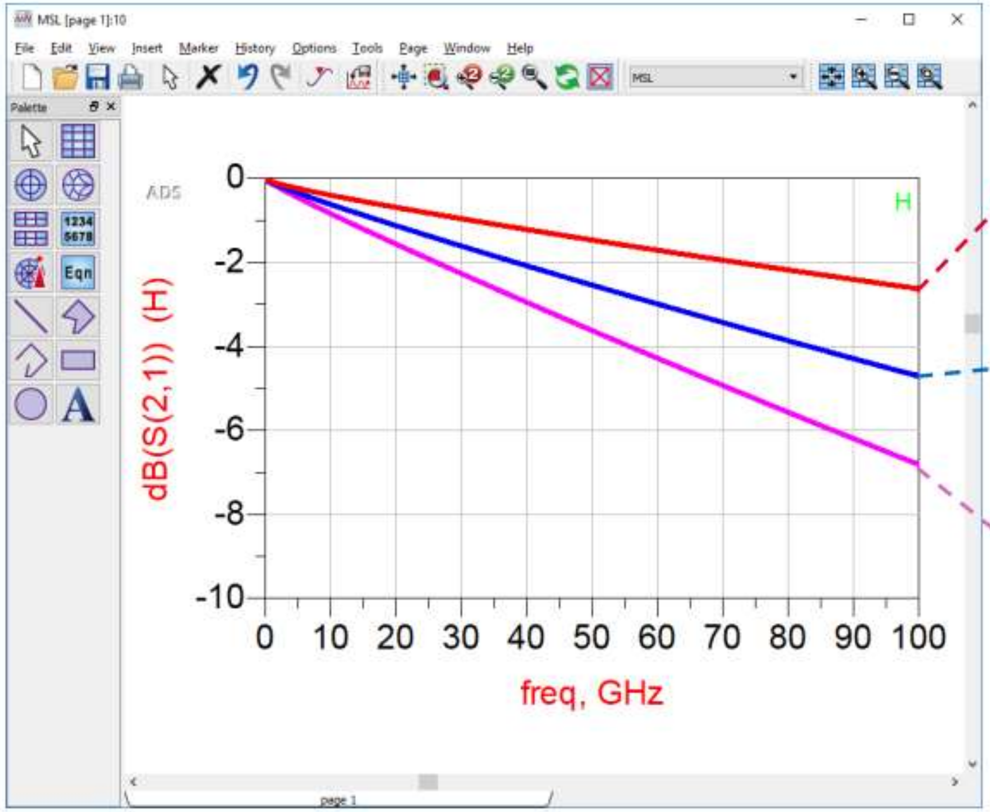
(b) Low loss PCB material examples

(a)での位置	Supplier	Product name	Material	Release schedule
①	Panasonic	R-5575	Thermosetting resin (details are hidden)	Released on June 2017
②	Panasonic	FELIOS LCPとR-BM17	Cpre as LCP	Prod. on Jan. 2017
③	MGC	HL972LF type LD	BT resin	Prod. on May 2017
④	DYCONEX社	Advanced LCP Subtrates	LCP	Early production
⑤	Murata	MetroCirc	LCP and Fluorine resin (estimation by nikkeibp)	Production. Released on Nov. 2016
⑥	Rogers社	CuClad	Fluorine resin (PTFE)	Production
⑦	Sumitomo Elec	未定	Fluorine resin	Under development

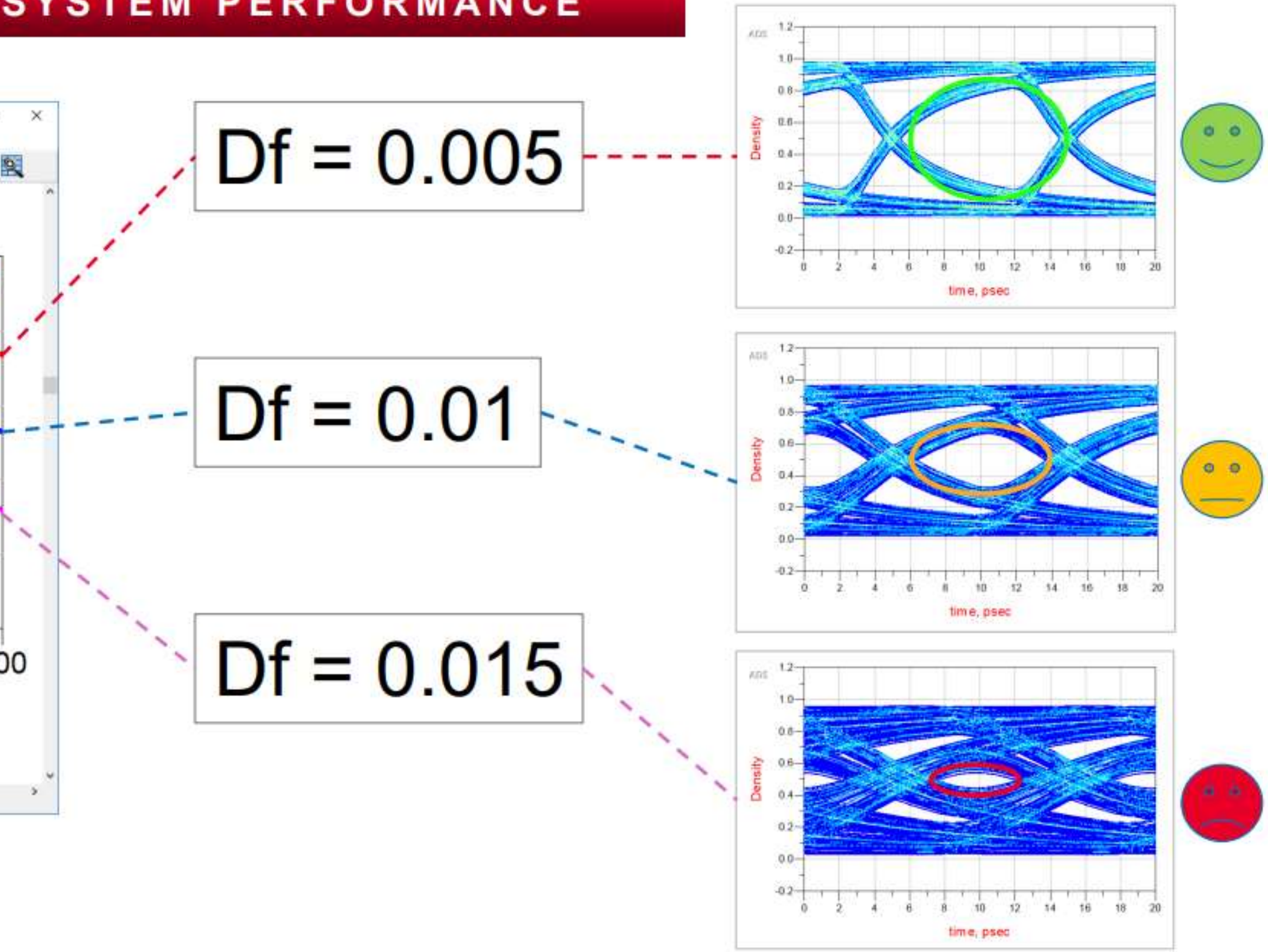
Ref; NikkeiBP 2017July
https://tech.nikkeibp.co.jp/dm/atcl/mag/15/398081/071100093/

How Df Affect Signal Quality at mmWave Frequencies

IMPACT OF LOSS TANGENT ON SYSTEM PERFORMANCE



Loss at 3 cm transmission line



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  - Balanced Circular Disk Resonator (BCDR)
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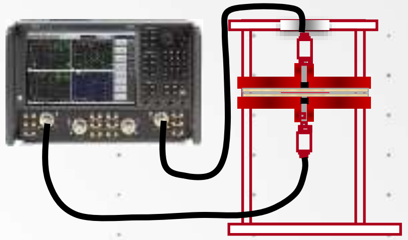
Result often differs from simulation…

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

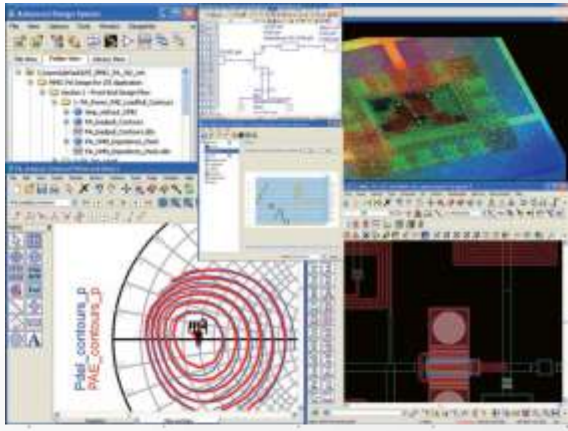
1. Design a circuit



2. getting ε_r tanδ from the data sheet

2+. Material 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

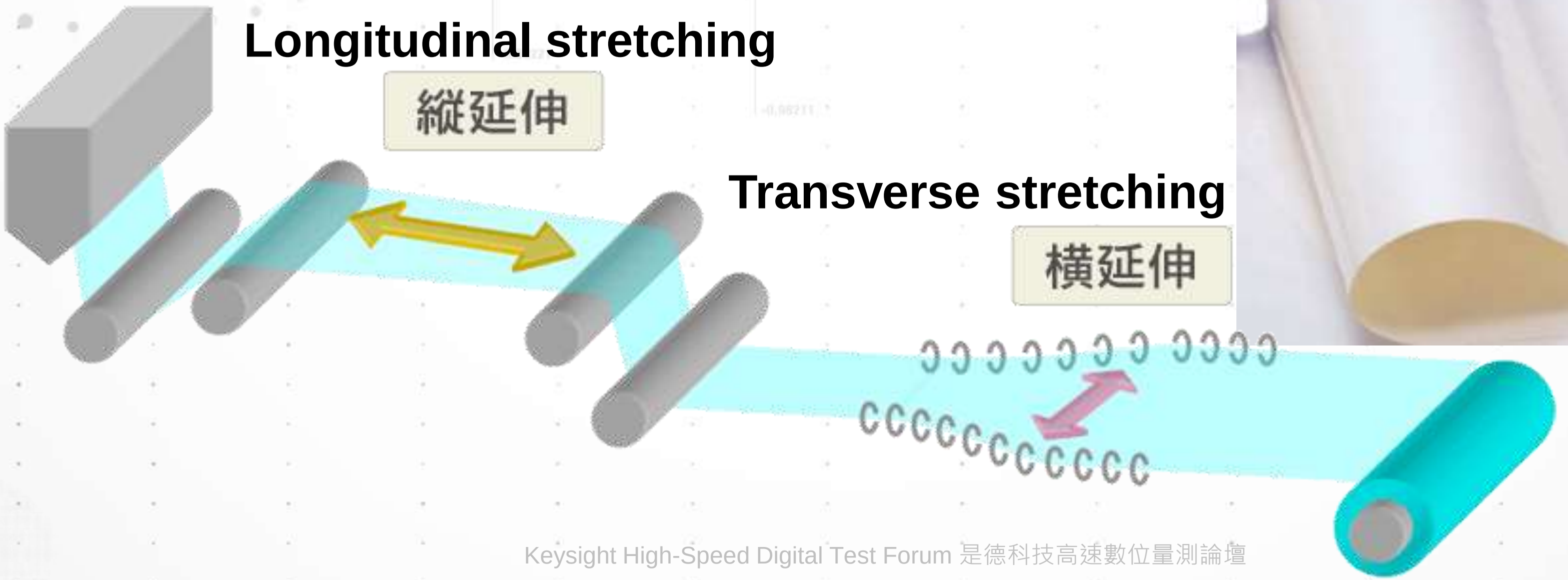
Dielectric constants in the in-plane X and Y directions may be different

Liquid crystal polymer (LCP film)

1. Low water absorption
2. Excellent high-frequency electrical characteristics (low permittivity, low dielectric loss)
3. High dimensional stability

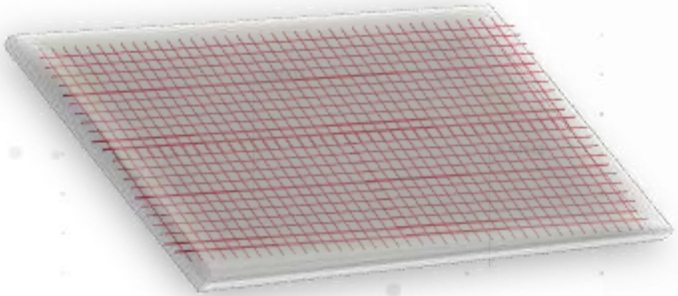
But, strong **anisotropy(各向異性)**

…In recent years, a method for controlling anisotropy has been developed



Case 2　glass epoxy substrate / FR-4

FR-4 is impregnated glass cloth（Dk = 6.3）with organic resin (Df =2 - 4)　, and then stacked many layers



Supplier A; Nominal value of Dk =4.4

Supplier B ; Nominal value of Dk = 4.2

Results are different depending on what measurement method is used

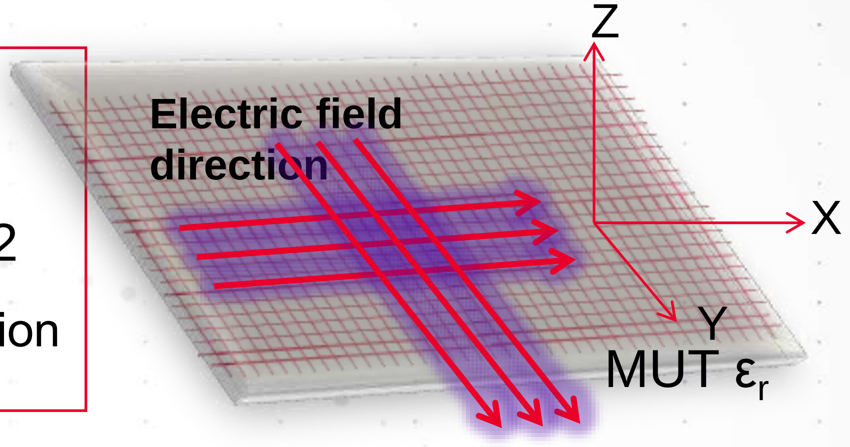
The glass epoxy substrate has its **anisotropy** due to its structure.

Actual meas. value of supplier A

permittivity in plane direction = 4.43

permittivity in thickness direction = 4.02

→ "Nominal value" means in plane direction

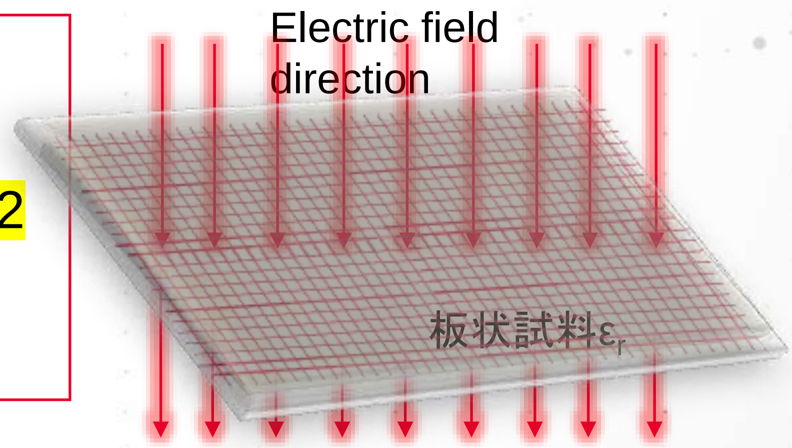


Actual meas. value of supplier B

permittivity in plane direction = 4.55

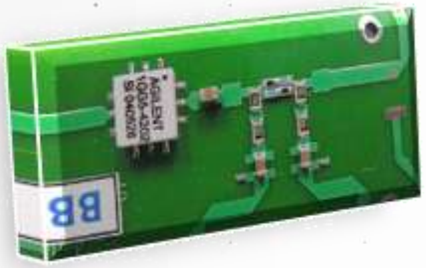
permittivity in thickness direction = 4.22

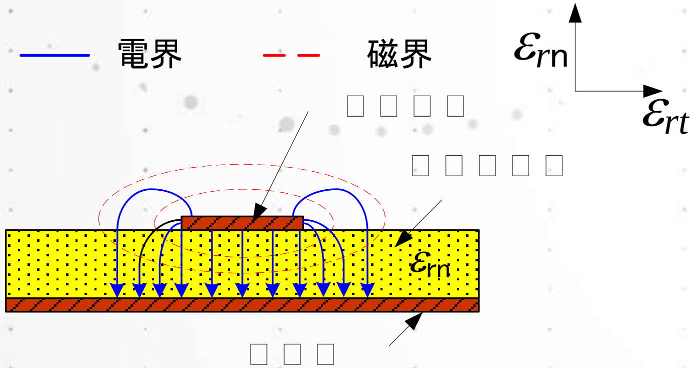
→ "Nominal value" means in thickness direction

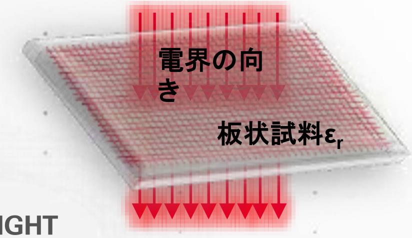


The electric field in the vertical (thickness) and horizontal (surface) direction

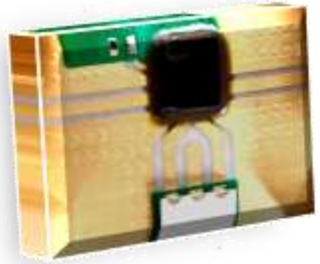
Strip line / Micro strip line

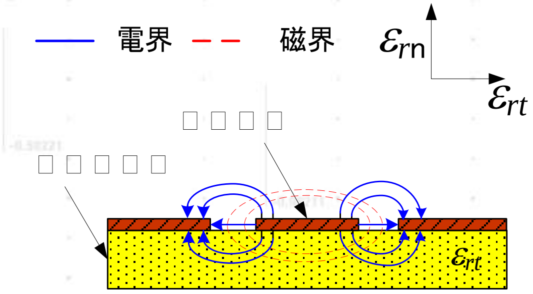


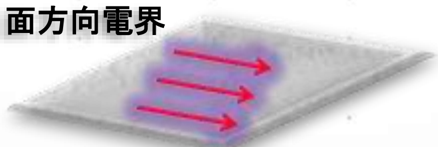




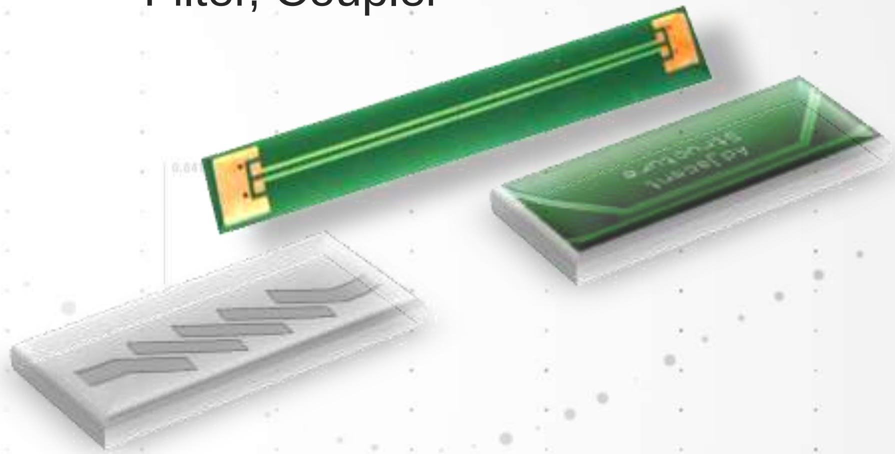
Coplanar line

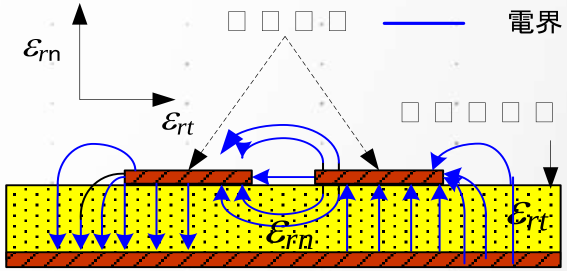






Differential transmission line, Filter, Coupler



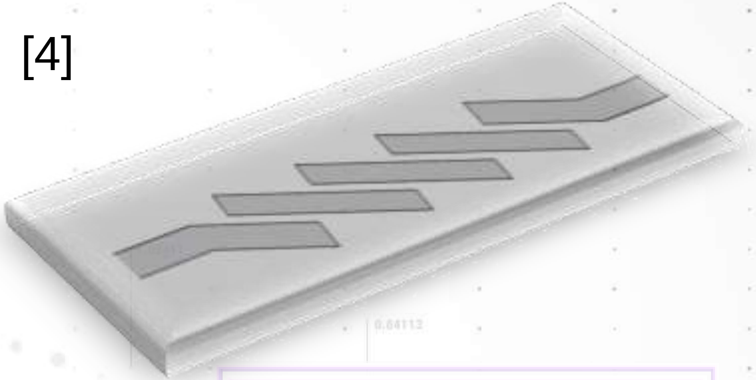


Not only surface direction, but also thickness direction measurement

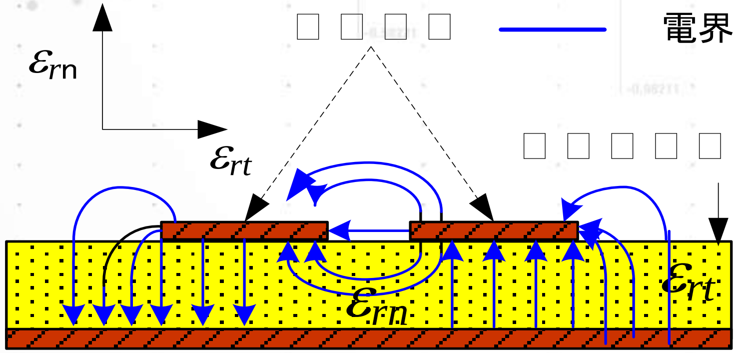
[3]

Differential strip transmission line

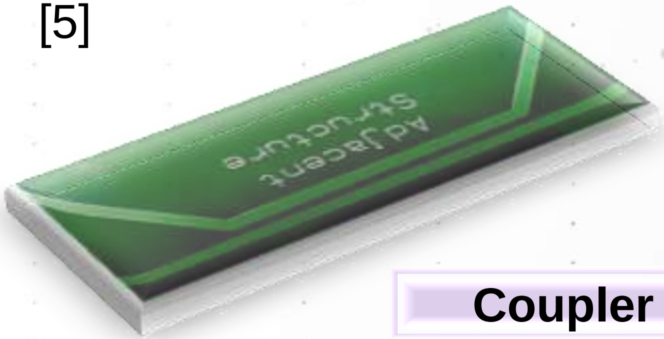
[4]



Band pass filter



[5]



Coupler

**Dominant direction is vertical and horizontal, both.

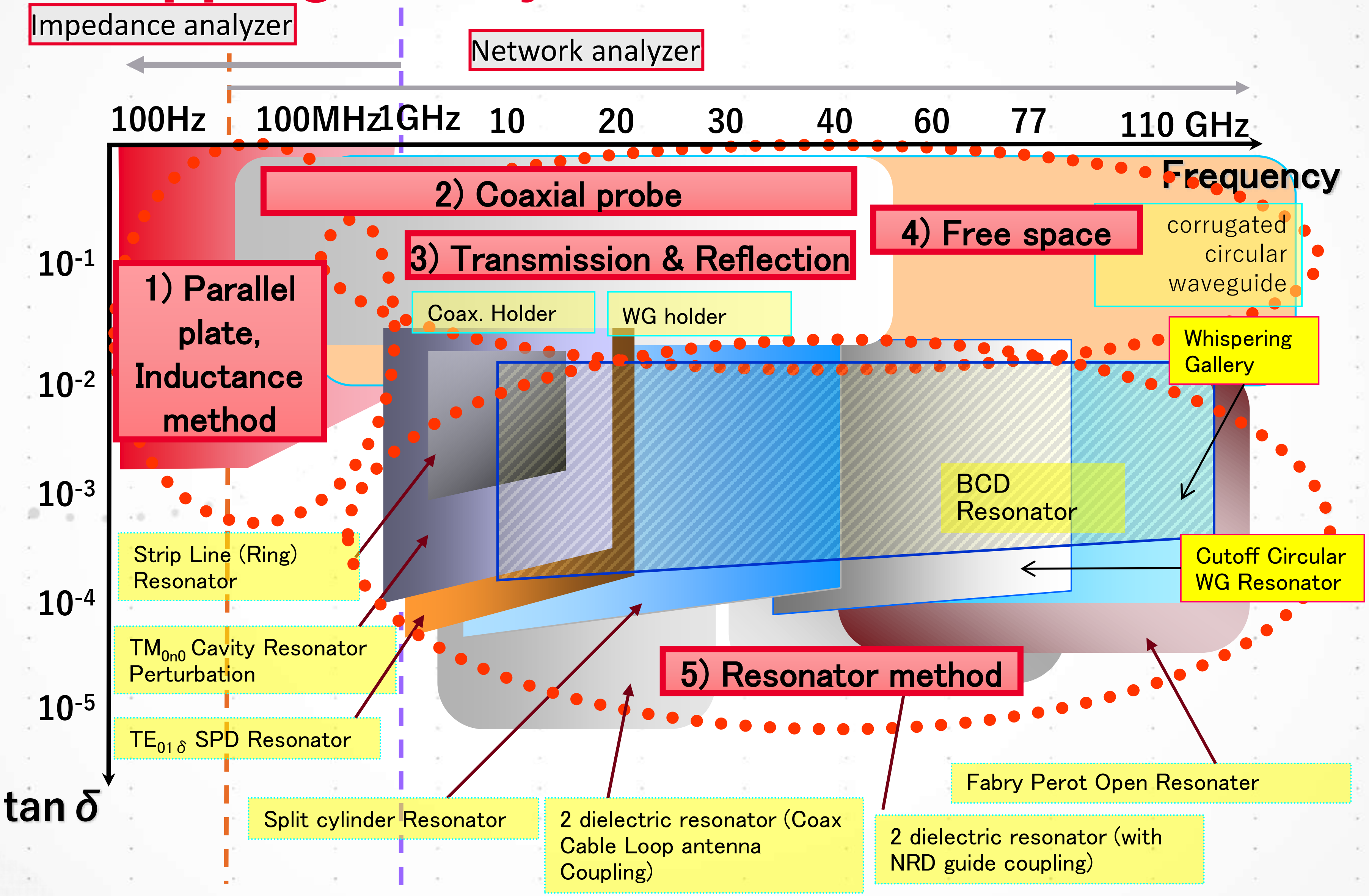
Materials Characterization Challenges

ACCURATE?

Which method should I use?

Improper fixture selection causes failure results

Solution Mapping: 5 major methods

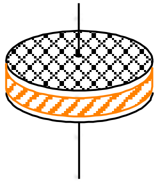


Select the most suitable method for your MUT

COMPROMISE IS NO LONGER REQUIRED

Parallel Plate & Inductance

ε_r and μ_r




Low Frequency below 1GHz

Best for thin flat sheets

Coaxial Probe

ε_r


Broadband

Best for liquids, semi-solids

Transmission Line

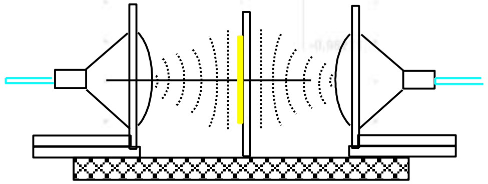
ε_r and μ_r

Broadband

Best for machine-able solids

Transmission Free Space

ε_r and μ_r



Broadband, mm-wave

Non-contacting

Resonant Cavity

ε_r


Single frequency

High accuracy, Best for low loss, or very thin samples

+

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Material measurement method for mmWave type 1

- Continuous frequency point measurements (For Dk or high loss)

Frequency axis: 100G, 50G, 10G, 1G

S-parameter method

Coaxial probe
10M - 50GHz
***N1501A**

Waveguide sample holder
2G - 50GHz
***max determined by MUT handling to modify**

Free space method (Horn antenna, Lens antenna)
5G – several hundreds GHz

Free space method
(Corrugated circular waveguide)
50GHz-1THz

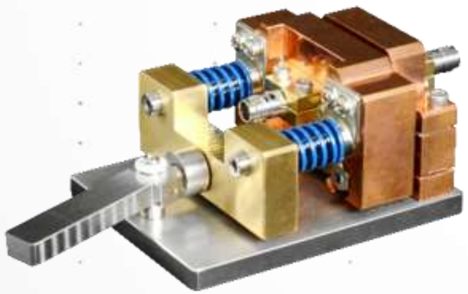
Material measurement method for mmWave type 2

- Best for low loss, plate or film type MUT

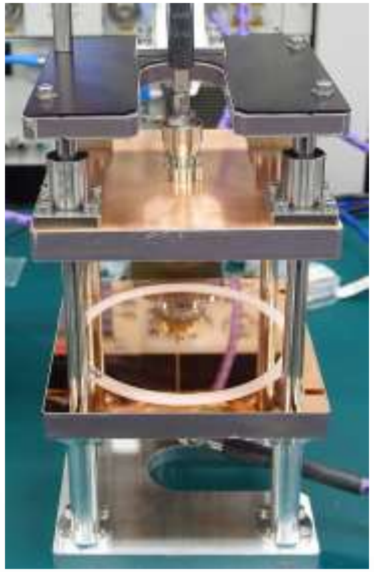
Resonator method

Frequency: 100G, 50G, 10G

TE mode
Split Cylinder Cavity Resonator
10 – 80GHz



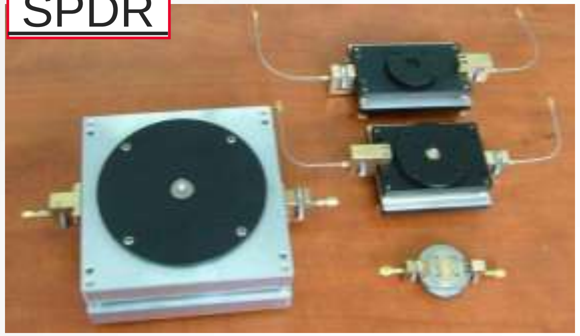
TM mode
Balanced type Circular Disk Resonator
10– 120 GHz



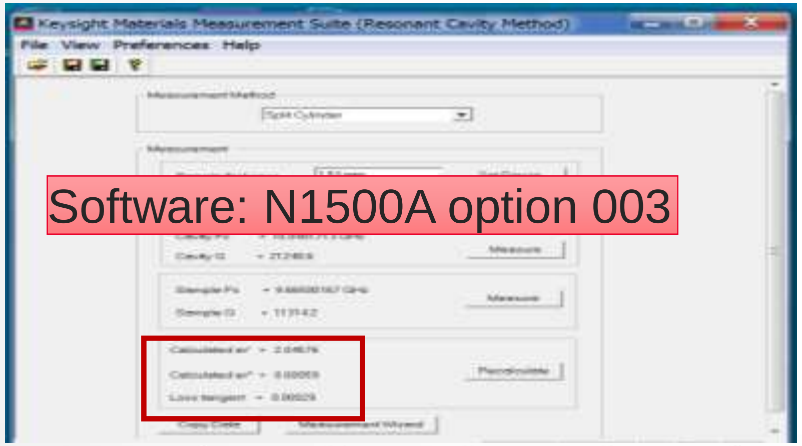
Fabry pelot open resonator (perturbation method)
18 – 140GHz
TEM_{00q} mode

Resonant Cavity Fixtures available thru Keysight

SPDR

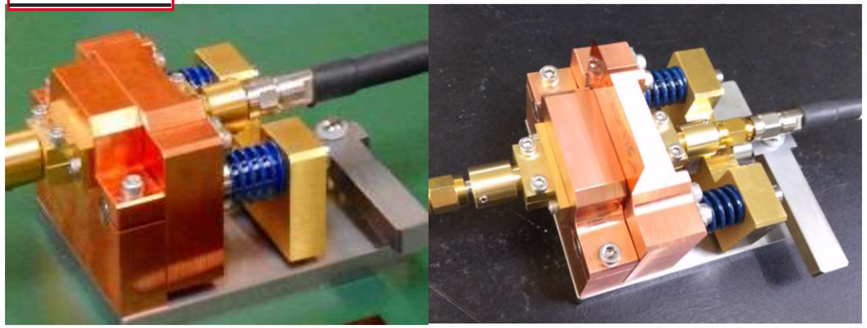


Model #	Description
N1501AE19	1.1 GHz, 3.5 mm (m) Split Post Dielectric Resonator
N1501AE03	2.5 GHz, 3.5 mm (m) Split Post Dielectric Resonator
N1501AE04	5.0 GHz, 3.5 mm (m) Split Post Dielectric Resonator
N1501AE10	10.0 GHz, 3.5 mm (m) Split Post Dielectric Resonator
N1501AE15	15 GHz, 3.5 mm (m) Split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

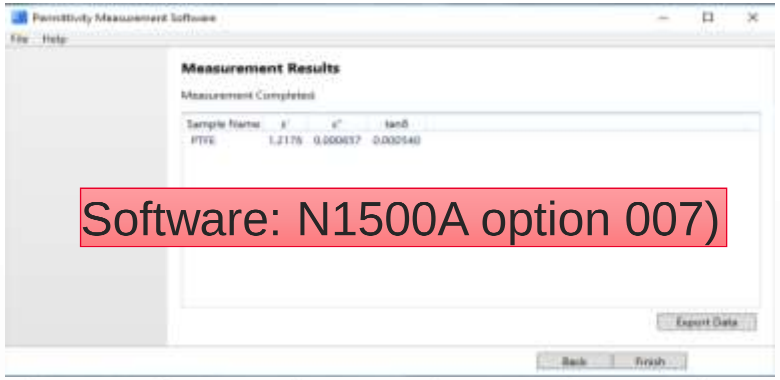


Software: N1500A option 003

SCCR

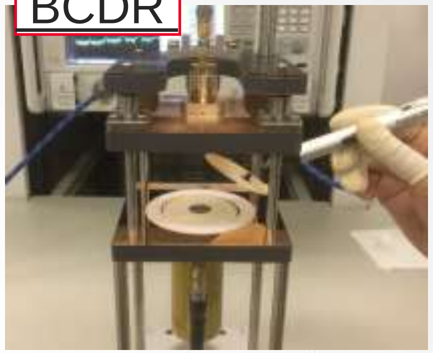


Model #	Description
N1501AKEAD-710	10 GHz, SMA (f) Split Cylinder Resonator
N1501AKEAD-720	20 GHz, 2.92 mm (f) Split Cylinder Resonator
N1501AKEAD-724	24 GHz, 2.92 mm (f) Split Cylinder Resonator
N1501AKEAD-728	28 GHz, 2.92 mm (f) Split Cylinder Resonator
N1501AKEAD-735	35 GHz, 2.92 mm (f) Split Cylinder 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
N1501AKEAD-ST1	Software Split Cylinder Resonator Starter Kit

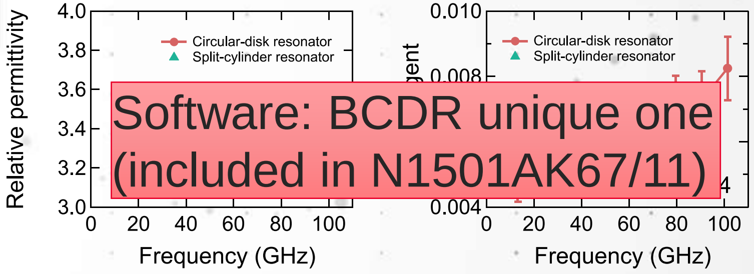


Software: N1500A option 007)

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

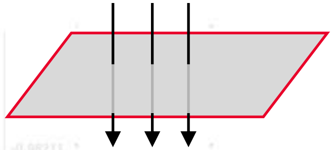
Low loss (<10^-2) solution mapping

E-Field direction Horizontal (X-Y)




Method	Original Supplier	Frequency	Standard	MUT thickness, size (Vary depends on er' & freq.)
TM0x0 perturbation cavity	KEAD, Keycom, etc.	1G to 10 GHz	JIS C2565, ASTMD2520	
TE01x Split Post Dielectric Resonator (SPDR)	QWED (N1501AExx)	1.1G to 15 GHz		0.7 mm, 15mm x 15mm @15G
TE011 Split Cylinder Cavity Resonator (SCCR)	Keysight (85072A), KEAD (N1501AKEAD)	Up to 80 GHz	IPC TM-650 2.5.5.13	20 um ~ 300 um (best for 100 um), 34mmx45mm > 20G
TEM00x Fabry-Perot Open Resonator	Keycom	Up to 140 GHz	JIS R 1660-2	10~20um, max 100um. 65mm x 65mm

E-Field direction Vertical (Z)





Method	Original Supplier	Frequency	Standard	MUT thickness, size (Vary depends on er' & freq.)
Parallel plate capacitor method	Keysight 16451B/453A	30M / 1 GHz	ASTM D150 / n/a	
Line/Ring resonator	Keycom, self-made, etc.	Up to 15 GHz	IPC TM-650 2.5.5.5.1	
TM0x0 Balanced Circular-Disk Resonator (BCDR)	Oshima (N1501AE67/11)	Up to 67/110 GHz	Plan to publish IEC IC in 2020 May	0.1 mm ~ 1mm, Best for 0.2~0.5mm, 50mmΦ x 2 ea.

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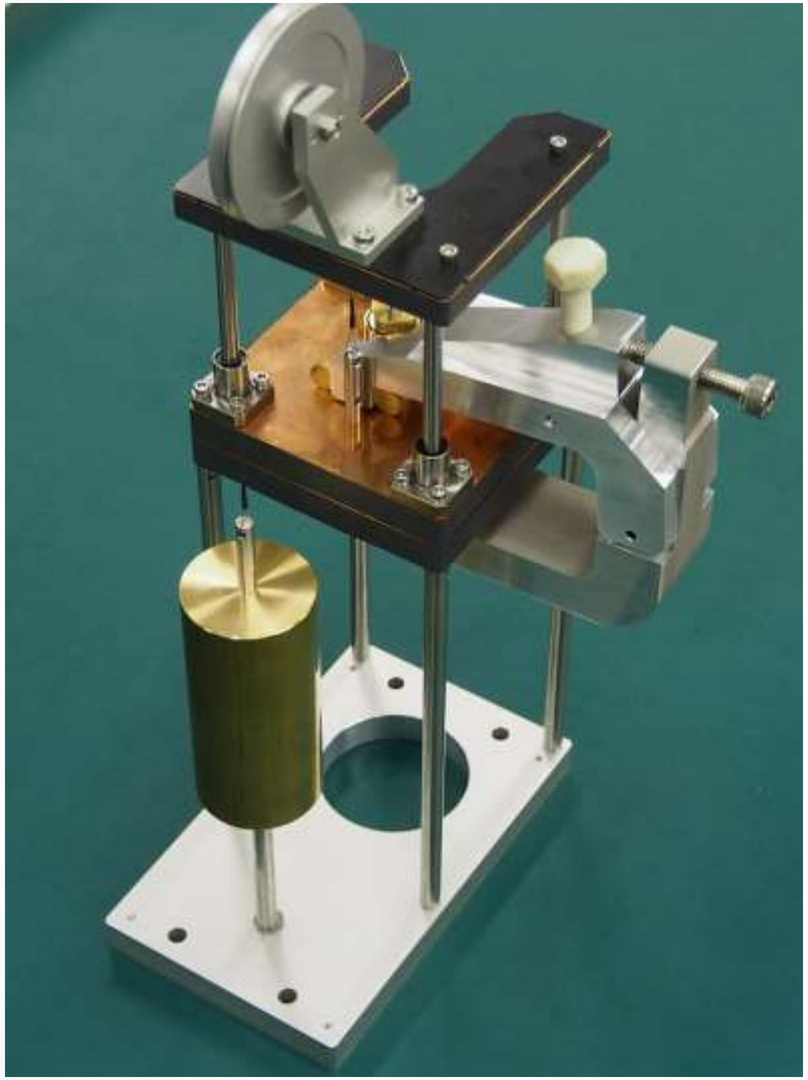
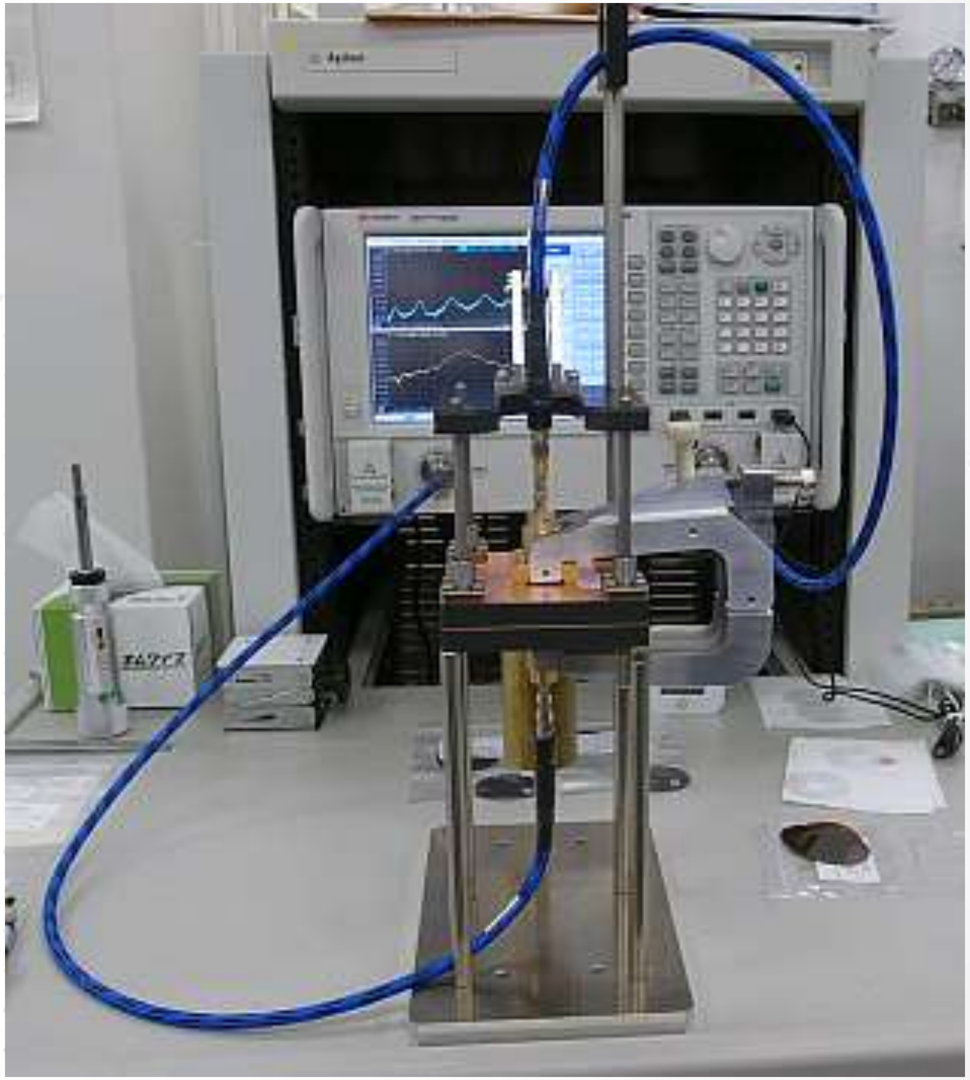
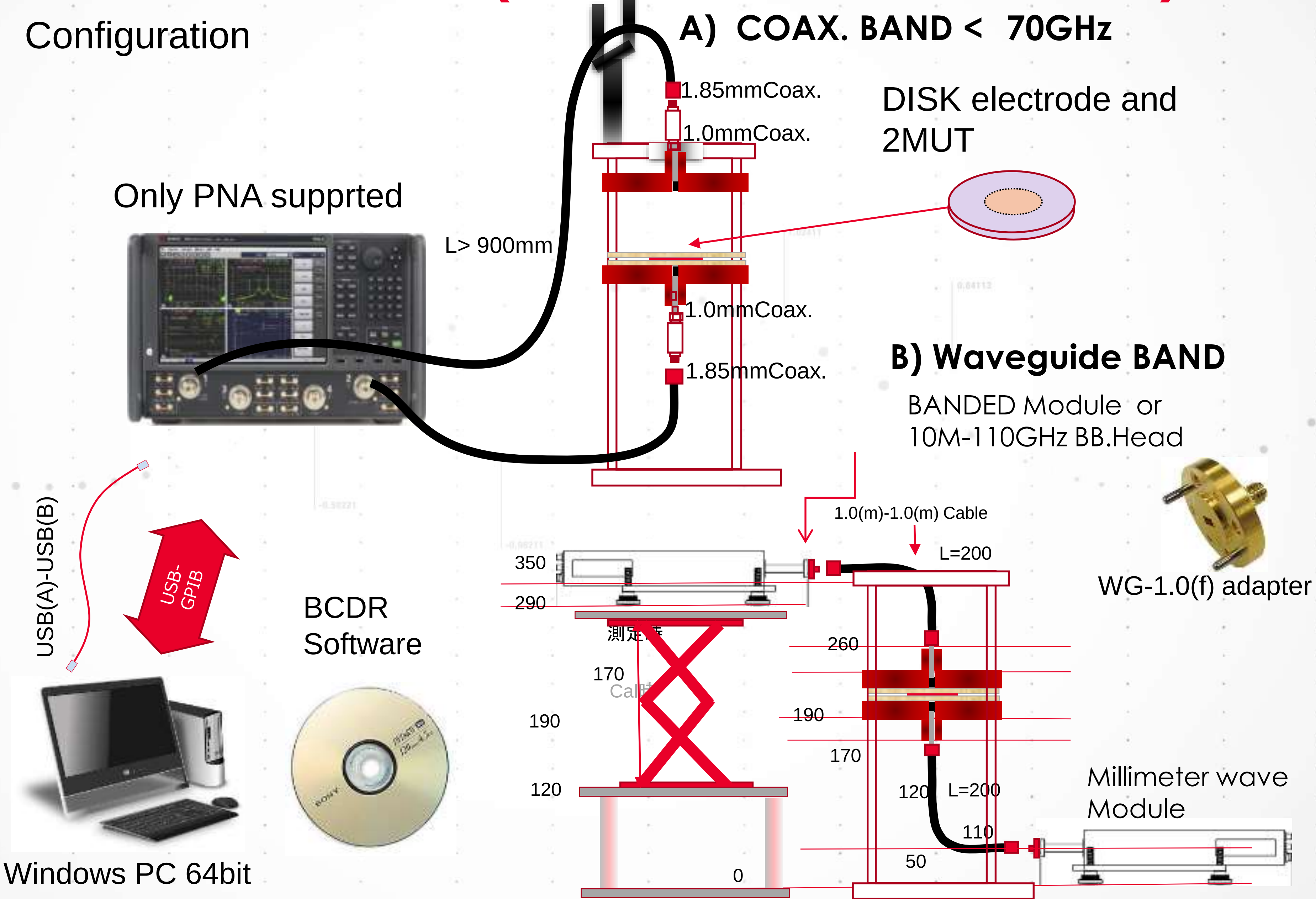
Exterior Photo of BCD Resonator

BALANCED TYPE CIRCULAR DISK RESONATOR

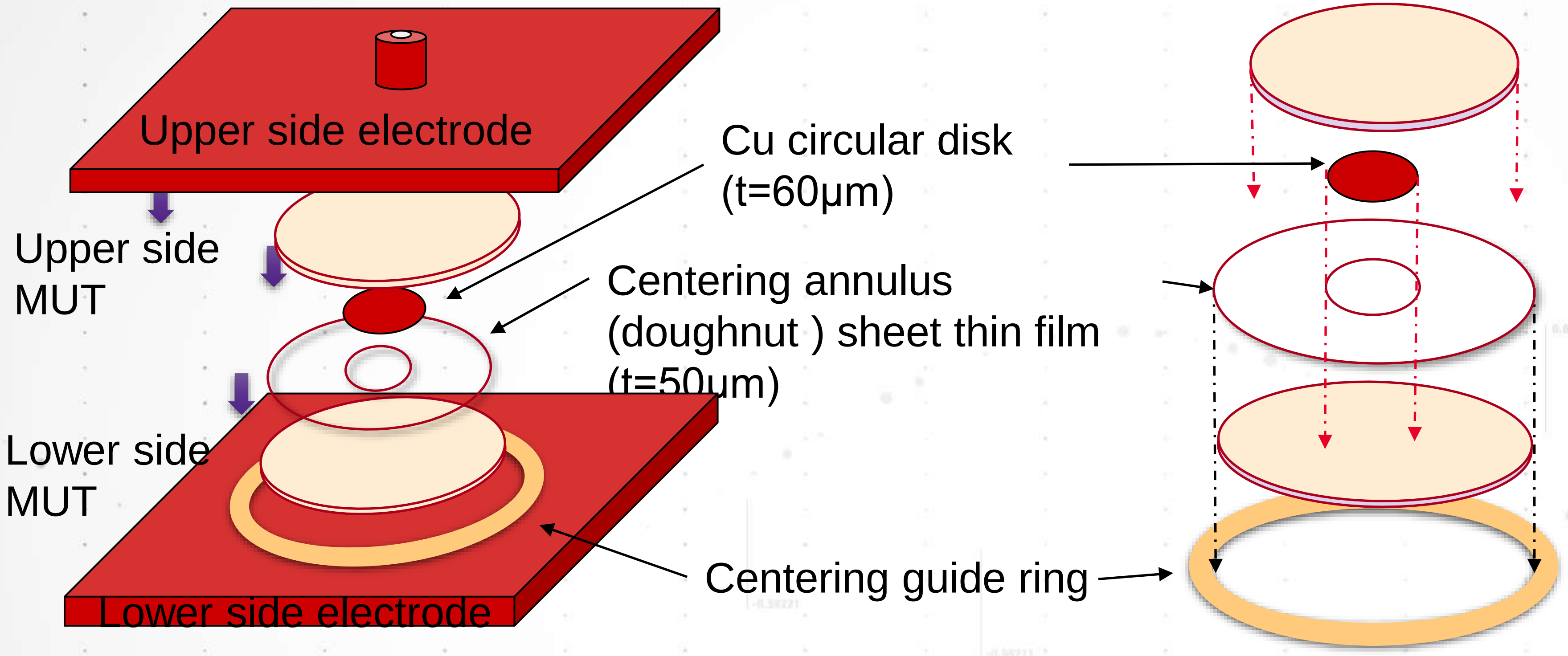


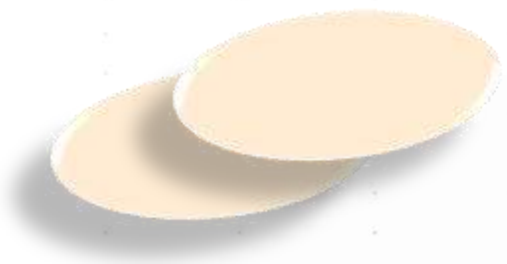


BCD Resonator and PNA (Coax. and WG Banded)



Setting electrode and MUT inside Cavity

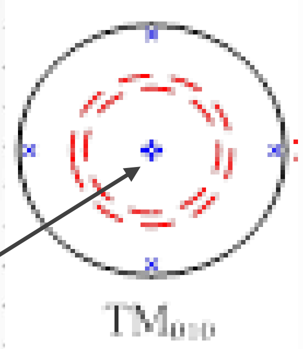




Set up the MUT and electrode

Resonant Frequency (Approximation formula)

TM_{0M0} RESONANT FREQUENCY APPROXIMATE EXPRESSION



$$f_{0m0} = \frac{c}{2\pi R\sqrt{\varepsilon_{rn}}} x'_{0m0}$$

$$f'_{010} = 3.8317$$
$$f'_{020} = 7.0155$$
$$f'_{030} = \ldots$$
....

R= radius of center electrode

ε_{rn}= permittivity (Dk) of thickness direction

diameter

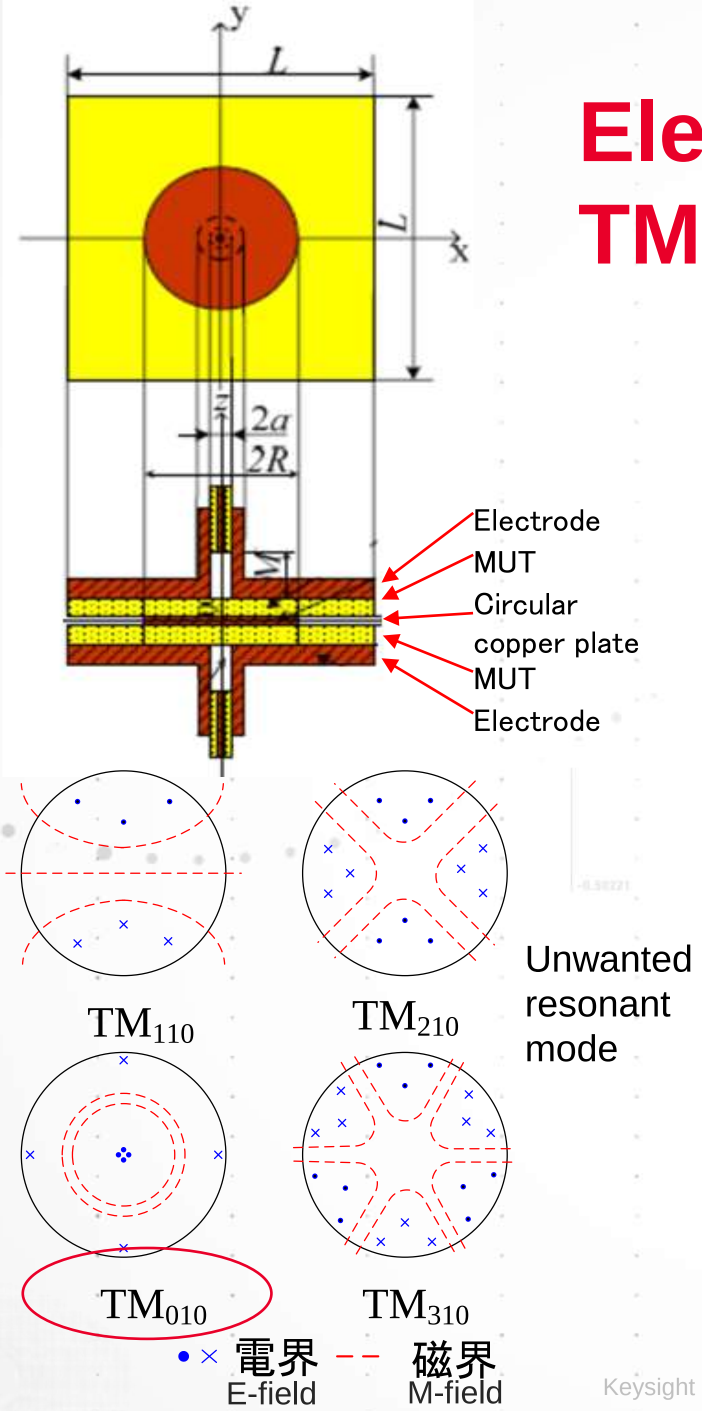
PTFE(εr=2.04) disc Φ15mm f_{010}≒17.07GHz

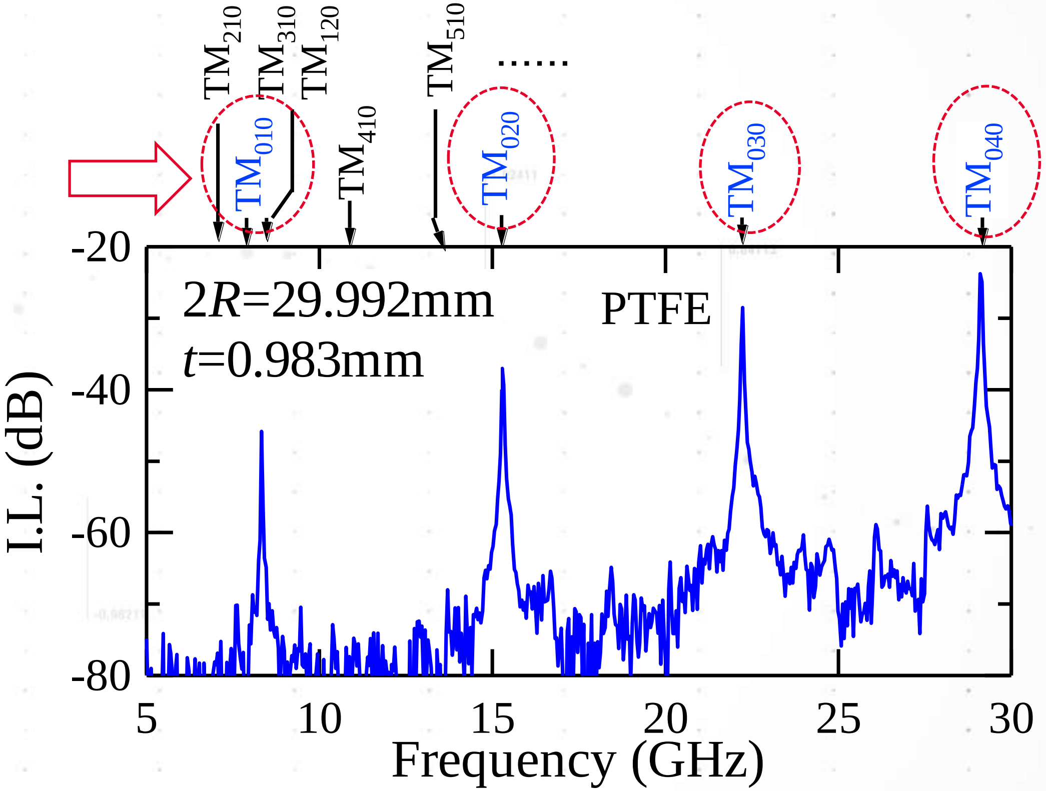
FR4 (εr=4) disk Φ15mm f_{010}≒ 11.89GHz

PTFE(εr=2.04), disk Φ18mm f_{010}≒ 14.22GHz

FR4(εr=4) , disk Φ18mm f_{010}≒ 9.9GHz

Electromagnetic field distribution in TM_{0m0} resonance mode





Dielectric measurement in microwave – IEICE, vol. J89-C, no.12, pp.1039-1046, Dec. 2006, Hasuike, Kawabata, Kobayashi

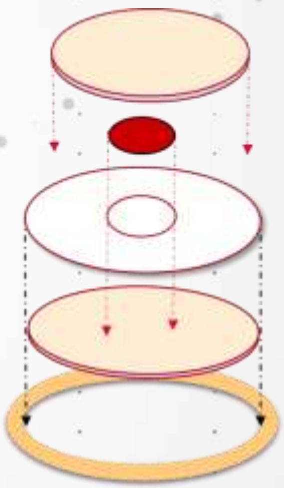
TM_{0m0} Resonant Frequency (Approximation)

CALCULATED FROM RESONATOR DIAMETER AND DIELECTRIC CONSTANT

TM0m0 BCDR, Electrode diameter vs. Permittivity vs. Resonant frequency (GHz)

		Electrode diameter (mm)				Electrode diameter (mm)				Electrode diameter (mm)		
		12	6.00E-03			15	7.50E-03			18	9.00E-03	
		Permittivity				Permittivity				Permittivity		
X'_{0m0} value	Mode	2.04	4.2	6.5	Mode	2.04	4.2	6.5	Mode	2.04	[illegible]	[illegible]
3.8317	TM010	**21.33**	**14.87**	**11.95**	TM010	**17.07**	**11.89**	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7.0155	TM020	**39.06**	**27.22**	**21.88**	TM020	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10.1743	TM030	**56.65**	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
13.3237	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	**34.47**	**27.71**
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	**41.10**	TM050	**61.14**	**42.61**	**34.25**
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	**87.37**	**60.89**	**48.95**	TM060	**72.81**	**50.74**	**40.79**
[illegible]	[illegible]	[illegible]	**88.32**	**70.99**	TM070	**101.38**	**70.65**	**56.79**	TM070	**84.48**	**58.88**	**47.33**
[illegible]	TM080	144.22	**100.51**	**80.80**	TM080	**115.38**	**80.41**	**64.64**	TM080	**96.15**	**67.01**	**53.86**
29.0468	TM090	161.72	**112.71**	**90.60**	TM090	129.38	**90.17**	**72.48**	TM090	**107.82**	**75.14**	**60.40**
32.1897	TM0100	179.22	124.91	**100.40**	TM0100	143.38	**99.92**	**80.32**	TM0100	**119.48**	**83.27**	**66.94**

Resonant frequency in each mode (TM_{0m0} (m=1~n) is determined by sample's Dk and circular disk electrode diameter



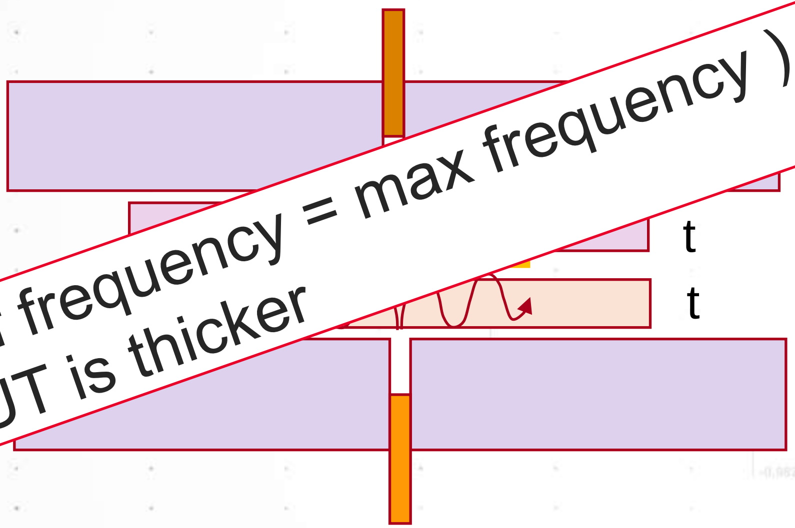
※Maximum measure-able frequency is determined by thickness and permittivity. See next page.

Factors that determine the Max. Frequency

Approximate expression for calculating the cutoff frequency of radial radiation

$$f_c = \frac{c}{2\pi R\sqrt{\varepsilon_{rn}}} X_{0m0}(S_c) = \frac{c}{2\pi R\sqrt{\varepsilon_{r}}}\frac{\pi}{2} S = \ldots$$ [illegible]

Fc (cut off frequency = max frequency) becomes lower when MUT is thicker



T=MUT thickness
C=Speed of light

Example of maximum frequency calculation

a) T=1mm εr=2 ≒ 52.85GHz

b) T=1mm εr=4 ≒ 37.37GHz

c) T=1mm εr=9 ≒ 24.91GHz

When the thickness of the specimen is increased, the unloaded Q increases. But at the same time, the cutoff frequency regarded as a waveguide consists of center electrode and upper/lower electrode is decreases , and the electromagnetic energy has a radius propagating in the direction toward the outside of the resonator. This radiation causes a limit of measurement frequency.

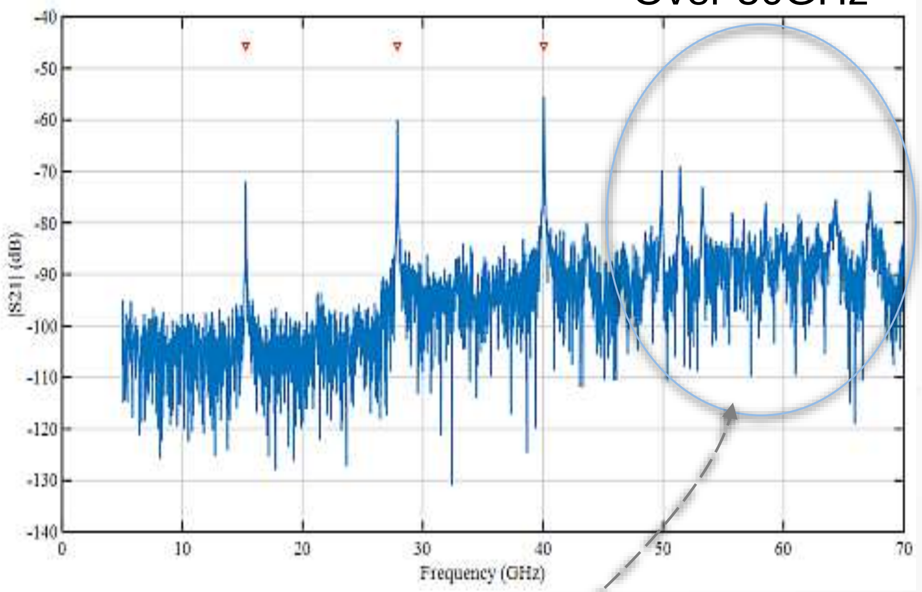
Max. Frequency(Max. GHz) determined by thickness and permittivity er

Max frequency becomes lower when MUT is thicker

TM_{0m0} permittivity VS. Max. frequency(GHz)			
※can measure at TM_{0m0} under Max. freq.			
Permittivity	2.04	4.2	6.5
Thickness mm	Max.GHz	Max.GHZ	Max.GHz
1.0	52.5	36.6	29.4
0.9	58.3	40.6	32.7
0.8	65.6	45.7	36.7
0.7	75.0	52.2	42.0
0.6	87.5	61.0	49.0
0.5	104.9	73.1	58.8
0.4	131.2	91.4	73.5
0.3	174.9	121.9	98.0
0.2	262.4	182.9	147.0
0.1	524.7	365.7	294.0

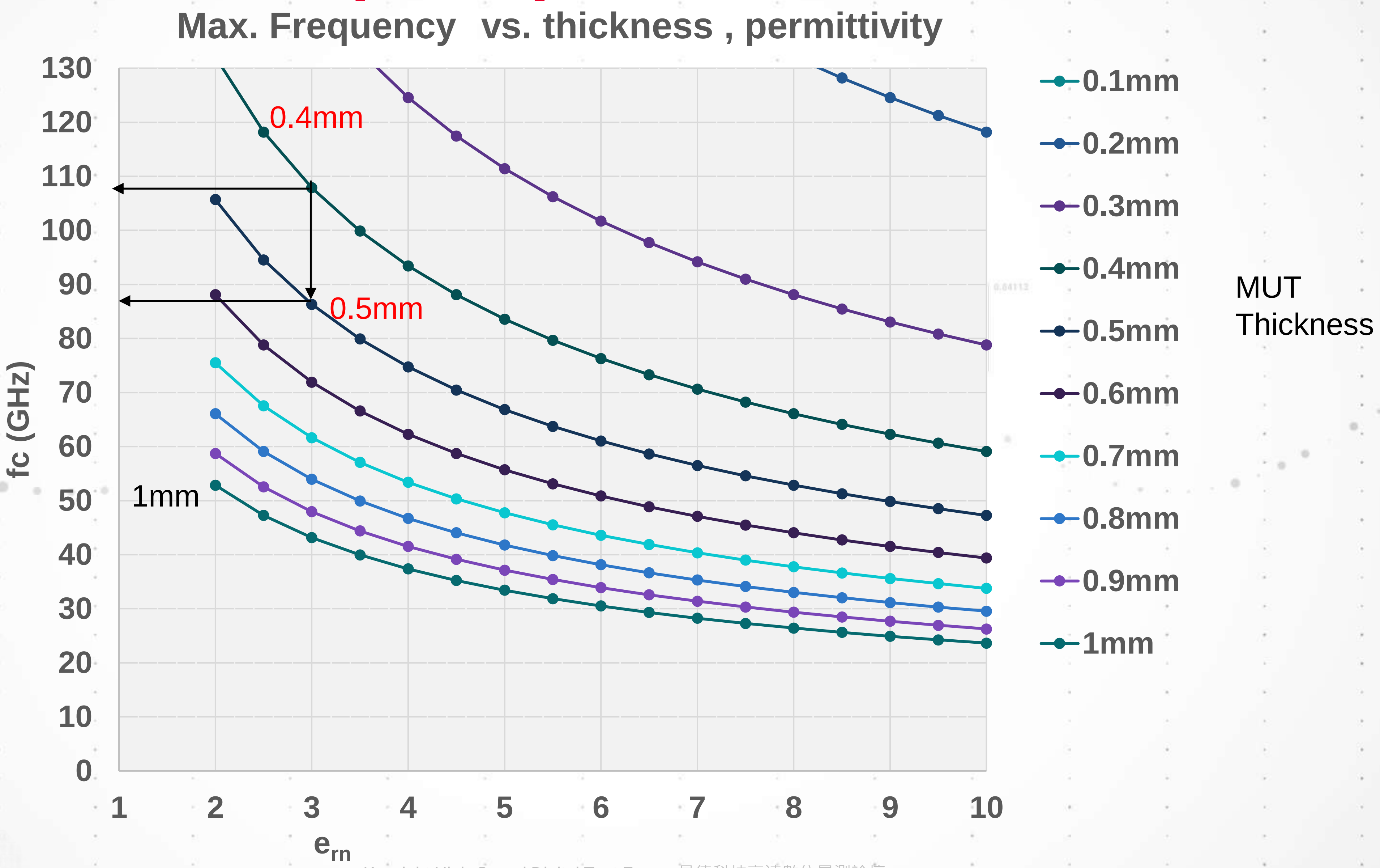
MUT : PP 1mm

Over 50GHz**

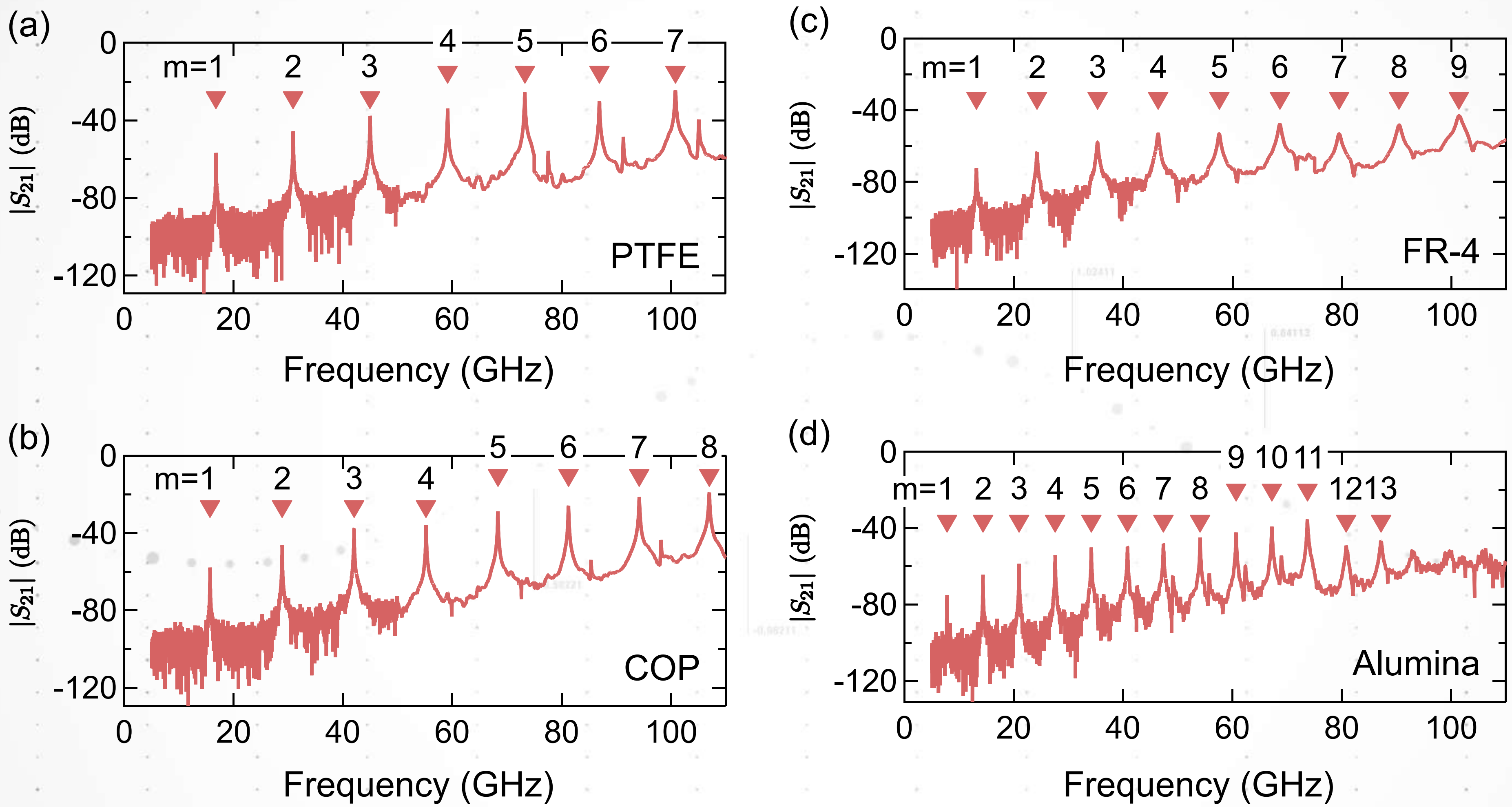


**The resonance peak waveform disappeared due to the influence of energy leakage, making measurement impossible

Max available frequency vs. thickness & Dk



BCD RESONATOR Resonant traces

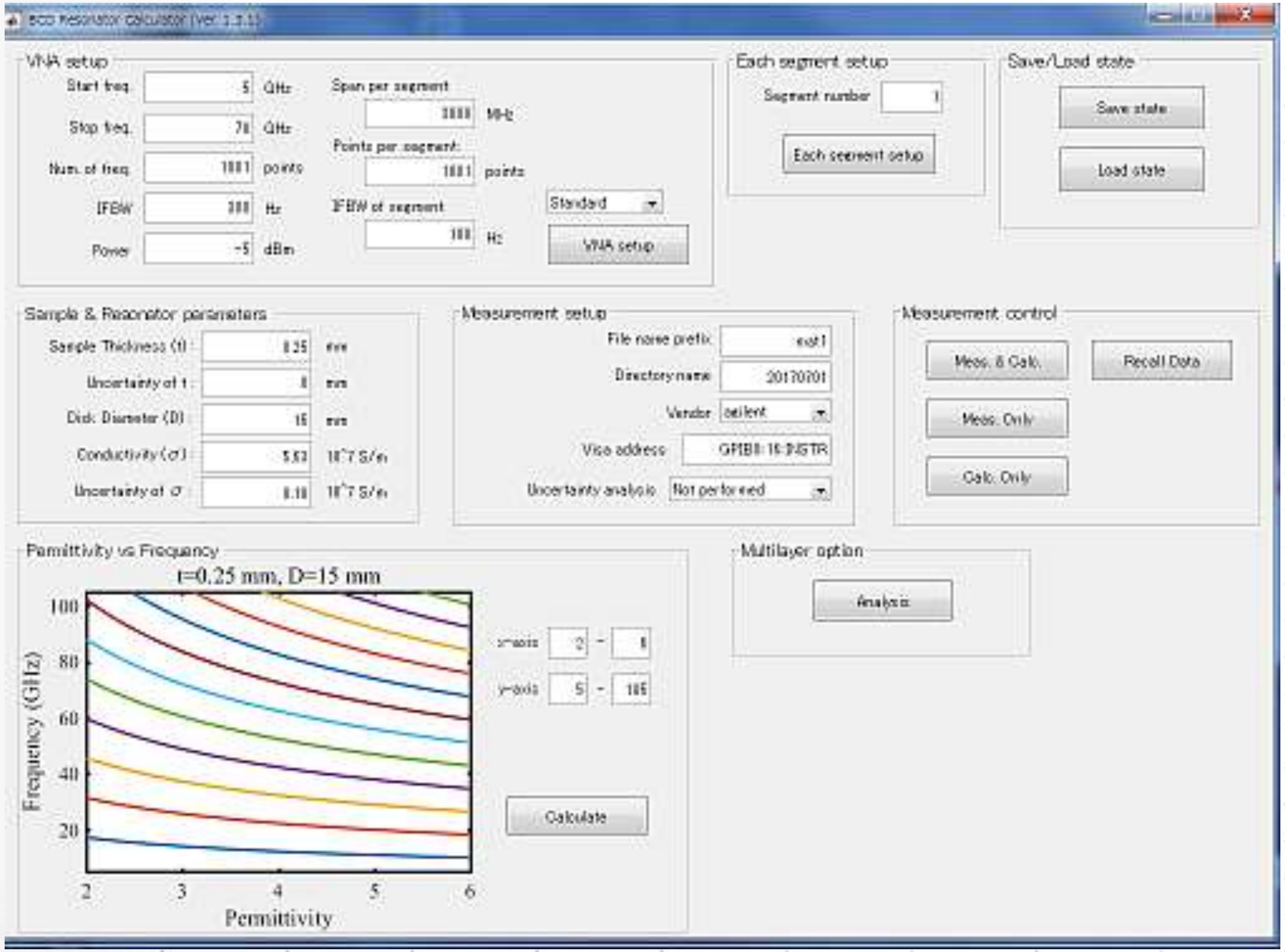


Only TM_{0m0} modes are observed up to **110 GHz** except alumina (radiation error)

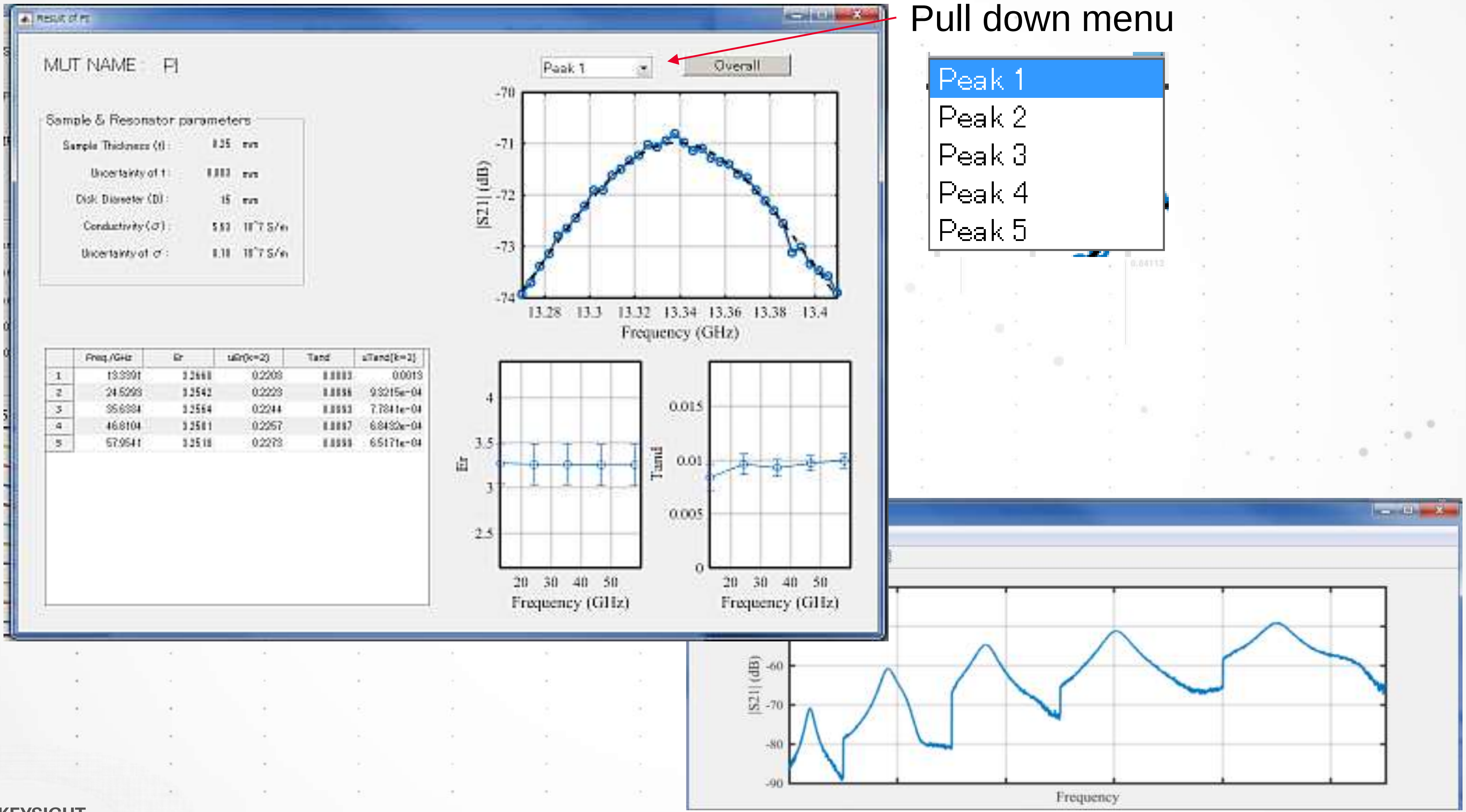
(PTFE: polytetrafluoroethylene, COP: cyclic olefin polymer, FR-4: flame-retardant type 4)

BCD Resonator Software

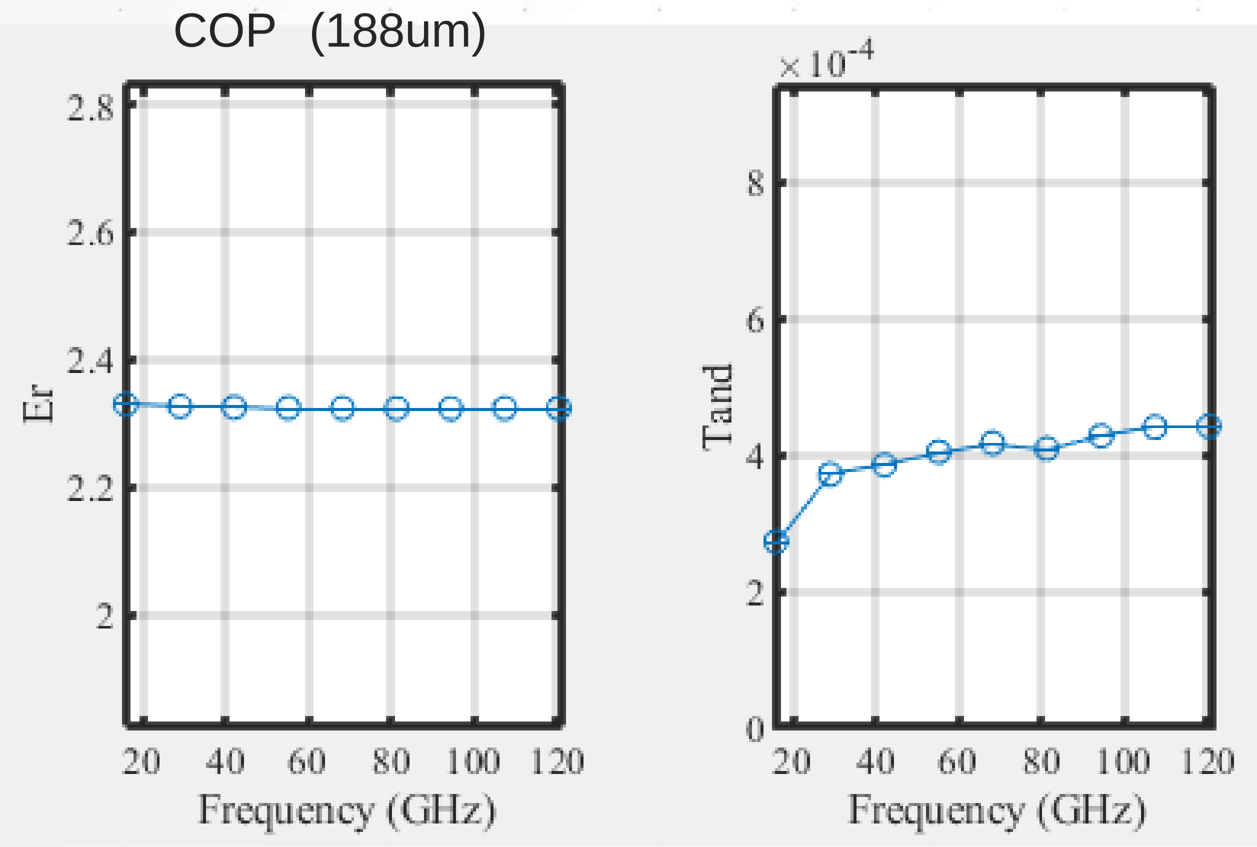
MATLAB base Software on Windows (64bit) PC

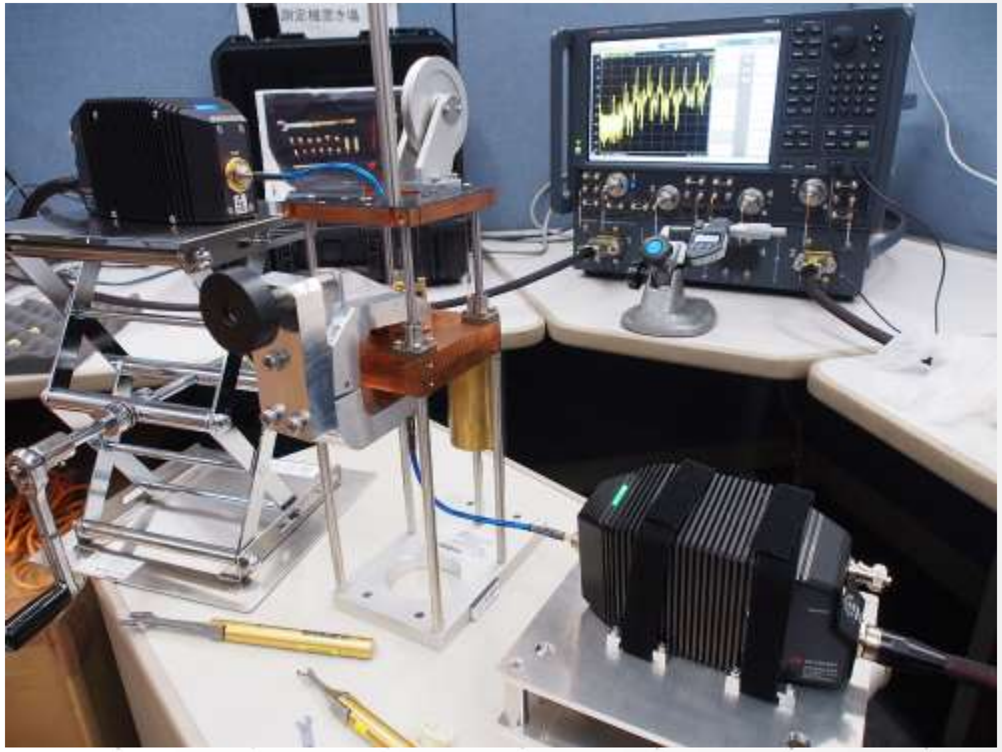


Measurement result



Measurement result example (COP 188 um)





Excellent repeatability

Data from AIST,

MUT: COP (Er' 2.3x, tanD ~4E-4)
Thickness: 0.2509 mm
# of meas: 7
Freq ~ 130G

Dk = ~2.3
Df = 4 x 10E-4

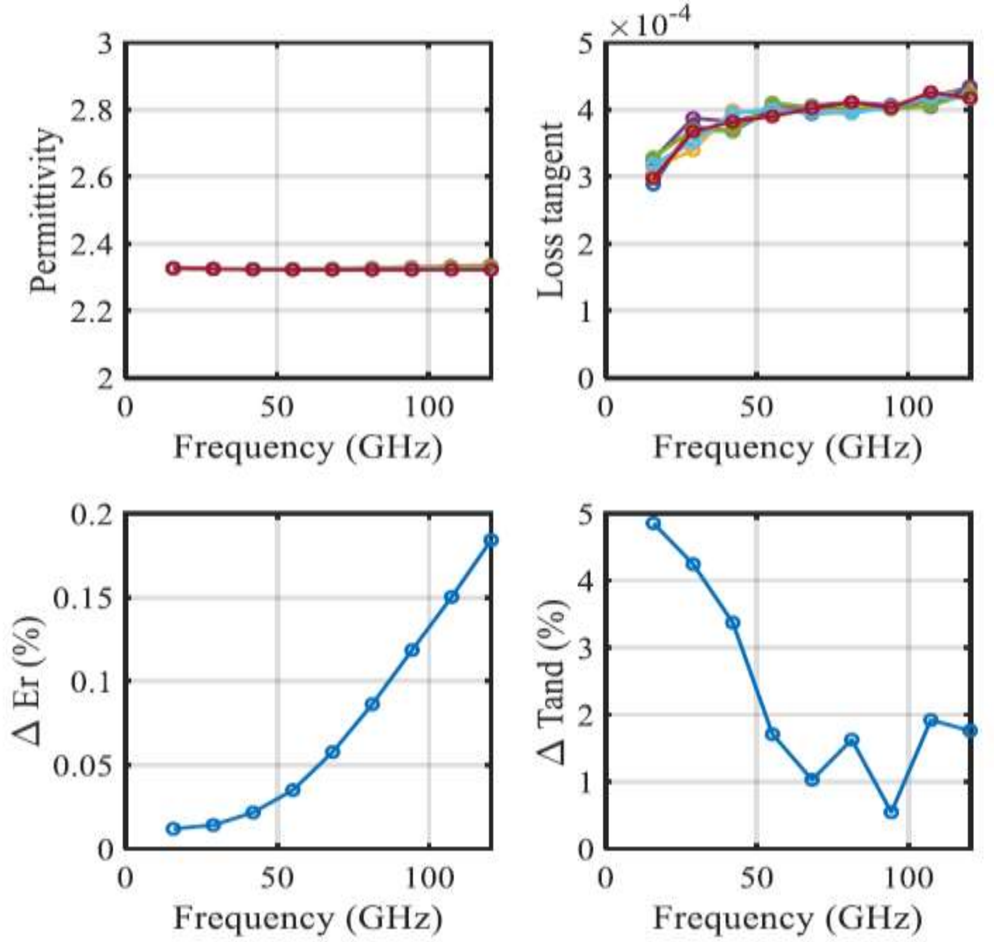
Repeatability
Dk: < 0.2%
Df: < 5%

- 材料: COP
  (cyclic olefin polymer)
- 試料厚: 0. 2509 mm
- 測定回数: 7回
- 周波数: ～130 GHz

$$Repeatability \equiv \frac{Std.}{Average}$$

✓ 誘電率 < 0.2%

✓ 誘電正接 < 5%



BCD Resonator specification

Typical performance

Frequency f : about 10GHz - 110GH
Circular disk size : ø15mm, ø12mm, ø 18mm

Permittivity ε_{rn} **:** 1.1 – 10 **Accuracy :** ±(1- 5)%
Loss tangent tanδ_n **:** 10^{-2} - 10^{-4} **Accuracy :** ±(10 - 30)%

Size of Dielectric sheet (Sample = Material Under Test)

MUT Thickness(t) : 0.1 - 1mm 0.5mm(better)
MUT SIZE ø 30mm - ø 50mm >2 times of circular disk electrode diameter
Fixture Dimension about W104 X D172 X H329.5 mm
Weight about 5kg

Connector type

N1501AE11: 1.0 mm(f) Coax.(Max.110GHz)
N1501AE67: 1.85 mm(f) Coax.(Max.67GHz)

Measurement sample (MUT)

Required number of MUT

1 pair (same permittivity, same thickness)

Suitable sample

Plastic plate-shaped dielectric substrate, sheet dielectric substrate

Not suitable for measurement

Roughness on the surface and having protrusions

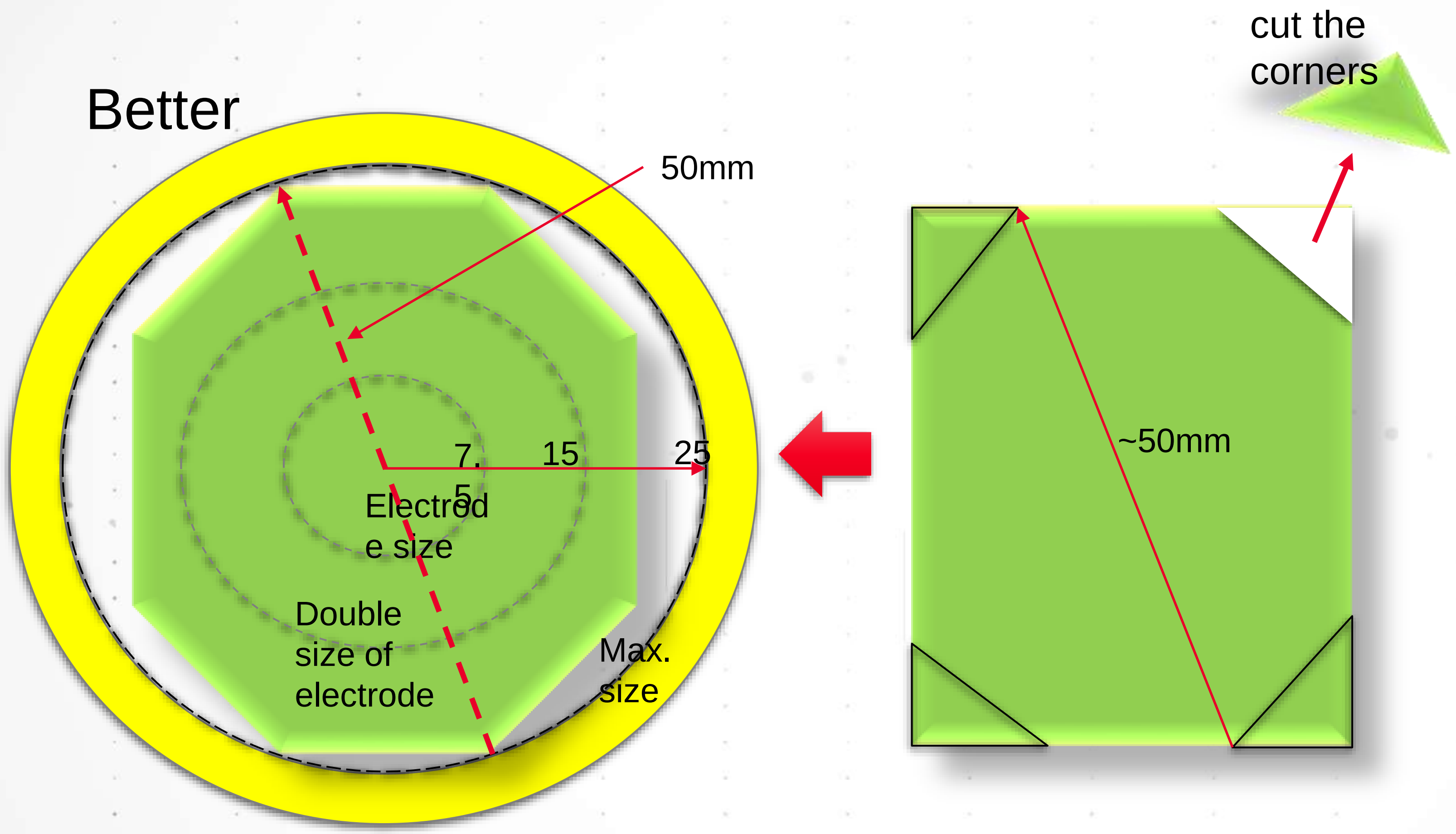
(Surface roughness: preferably 30 μm or less)

hard and easily broken (thin vitreous, thin ceramic substrates, etc.)

Warping with a hard substrate

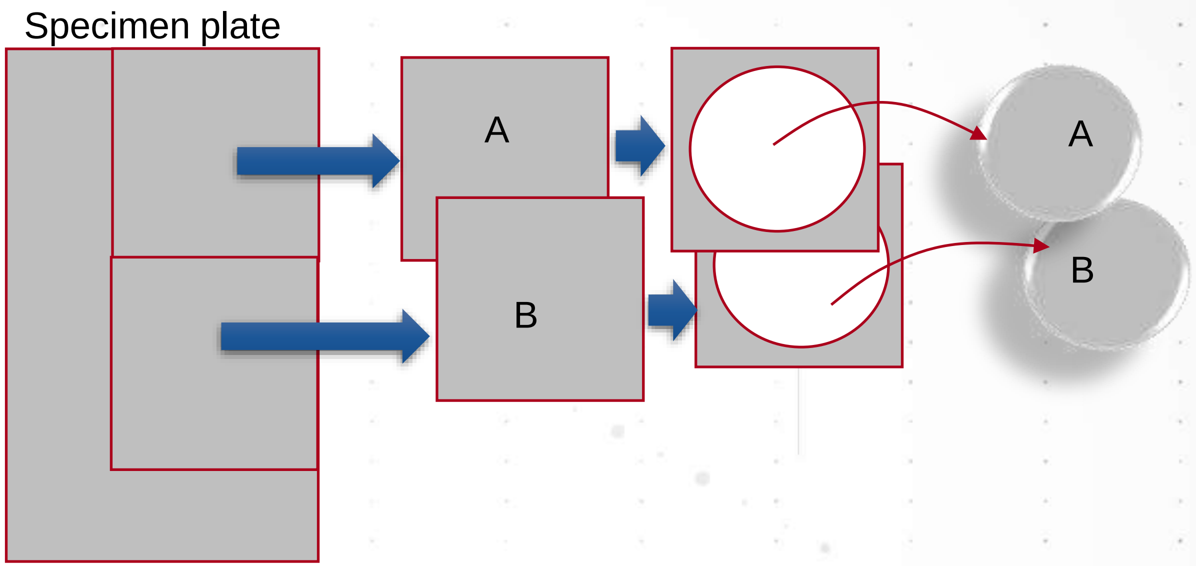
Copper-clad board or substrate with copper electrode left

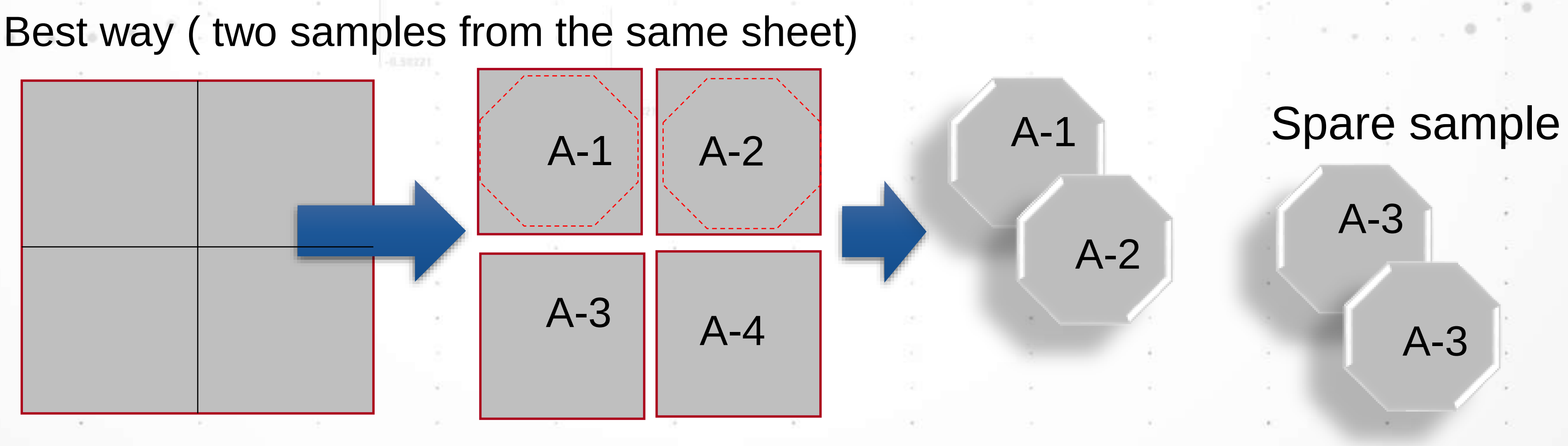
How to set in the cavity for square sheet



MUT Positioning guide ring

Sample preparation





Summary

I. Wide frequency range, 10 GHz to 67G or 110 GHz

II. Multi frequency-points measurement by using multiple higher modes, such as $TM_{010,020,0n0}$…

III. Good for low loss material, tanδ range from 0.01 to 0.0001.

IV. Measure permittivity with E-field of thickness direction

V. Do not need to know MUT thickness accurately. (Disk electrode diameter accuracy and its position is much important.)

VI. Remote control and calculation software are bundled. Complete measurement package for the lower loss materials

VII. Thickness: 0.1mm to 1.0mm

VIII. Not easy to measure the “hard” and “thin” materials . it means the fragile materials like glass, because of using strong clumping fixture. Very sensitive to the roughness of surface.

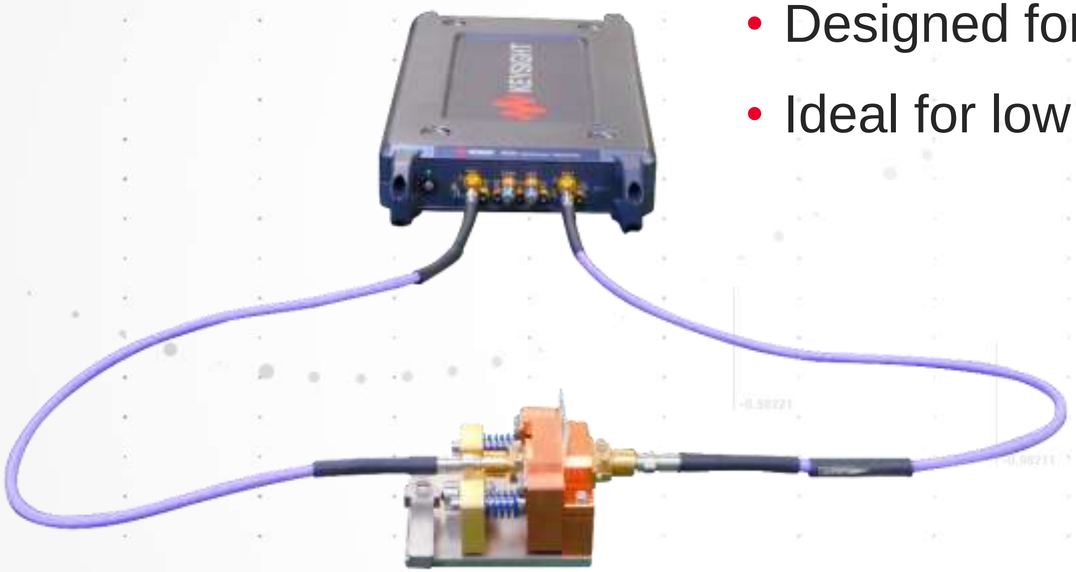
Agenda

- Market trend mmWave radar and 5G communication
- Challenge of Dielectric parameter measurements
- mmWave material solutions
  - Balanced Circular Disk Resonator (BCDR)
  - Split Cylinder Cavity Resonator (SCCR)

Split Cylinder Cavity Resonator for Dk/Df test

5G &
Automotive radar
AD – Satellite

Easy to use low Dk/Df test **up to 80 GHz!**



- Designed for easy operation and high repeatability.
- Ideal for low loss materials (0.0001< tanδ < 0.01 typical)

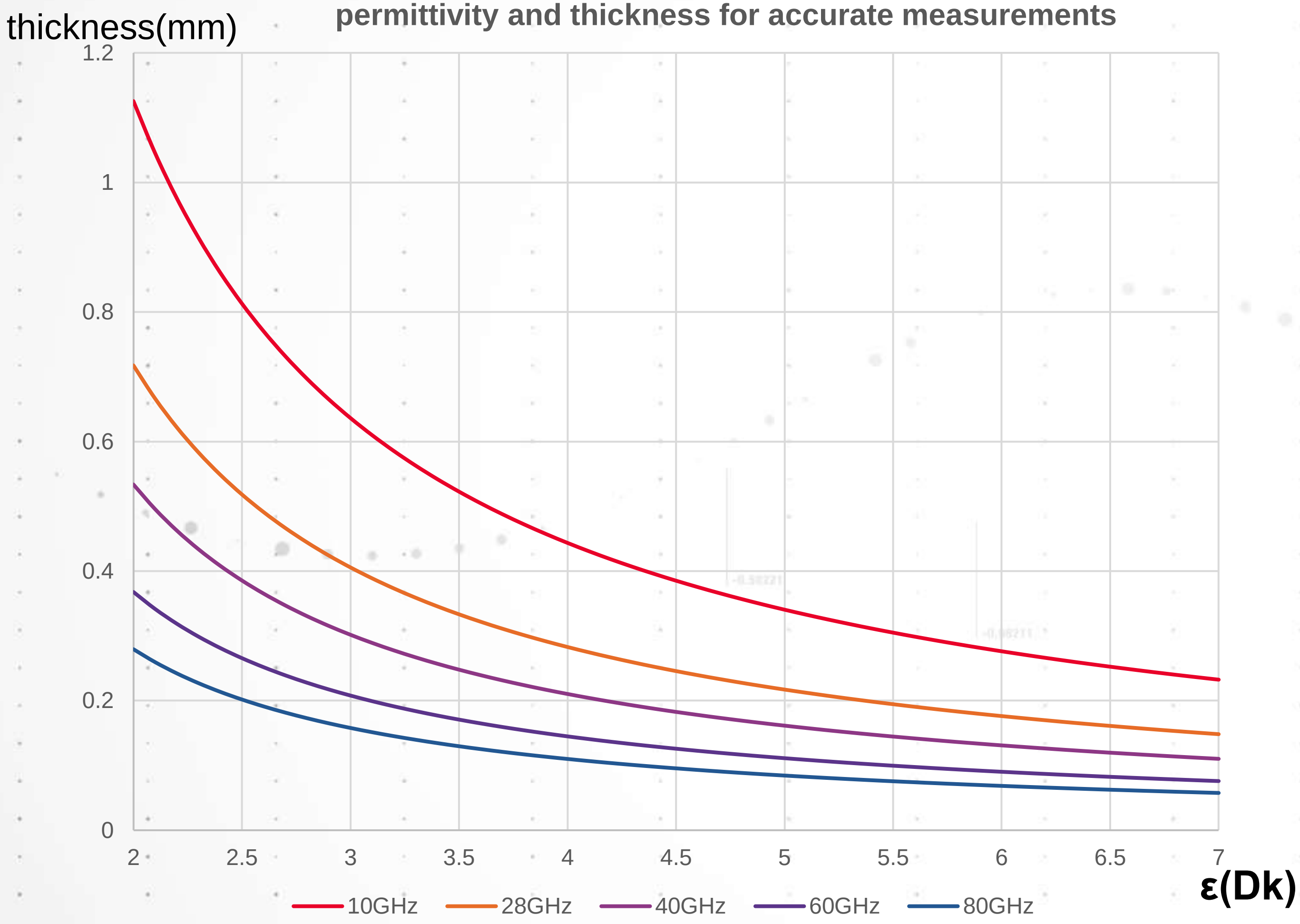
Model #	Description
N1501AKEAD-710	10 GHz, SMA (f) Split Cylinder Resonator
N1501AKEAD-720	20 GHz, 2.92 mm (f) Split Cylinder Resonator
N1501AKEAD-724	24 GHz, 2.92 mm (f) Split Cylinder Resonator
N1501AKEAD-728	28 GHz, 2.92 mm (f) Split Cylinder Resonator
N1501AKEAD-735	35 GHz, 2.92 mm (f) Split Cylinder 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
N1501AKEAD-ST1	Software Split Cylinder Resonator Starter Kit

Excellent Repeatability up to 80 GHz!

Repeat 8 measurements: removing/inserting the sample every time

	ε			tanδ		
	28GHz	40GHz	80GHz	28GHz	40GHz	80GHz
1	3.5513135	3.5461616	3.5316448	0.0014638	0.0014985	0.0026641
2	3.5573029	3.5513652	3.5259343	0.0014652	0.0015015	0.0027728
3	3.5373529	3.5454758	3.5286601	0.0014661	0.0015031	0.0027724
4	3.5475343	3.5451975	3.5406693	0.0014636	0.0015016	0.0026712
5	3.5462314	3.5571790	3.5343098	0.0014635	0.0015048	0.0027275
6	3.5546762	3.5534020	3.5418378	0.0014570	0.0015082	0.0026762
7	3.5535140	3.5450251	3.5301140	0.0014585	0.0015111	0.0027662
8	3.5463382	3.5533046	3.5460484	0.0014584	0.0015120	0.0026603
Avg	3.5492829	3.5496389	3.5349023	0.0014620	0.0015051	0.0027138
S. Dev	0.0063110	0.0047489	0.0071602	0.0000035	0.0000049	0.0000513

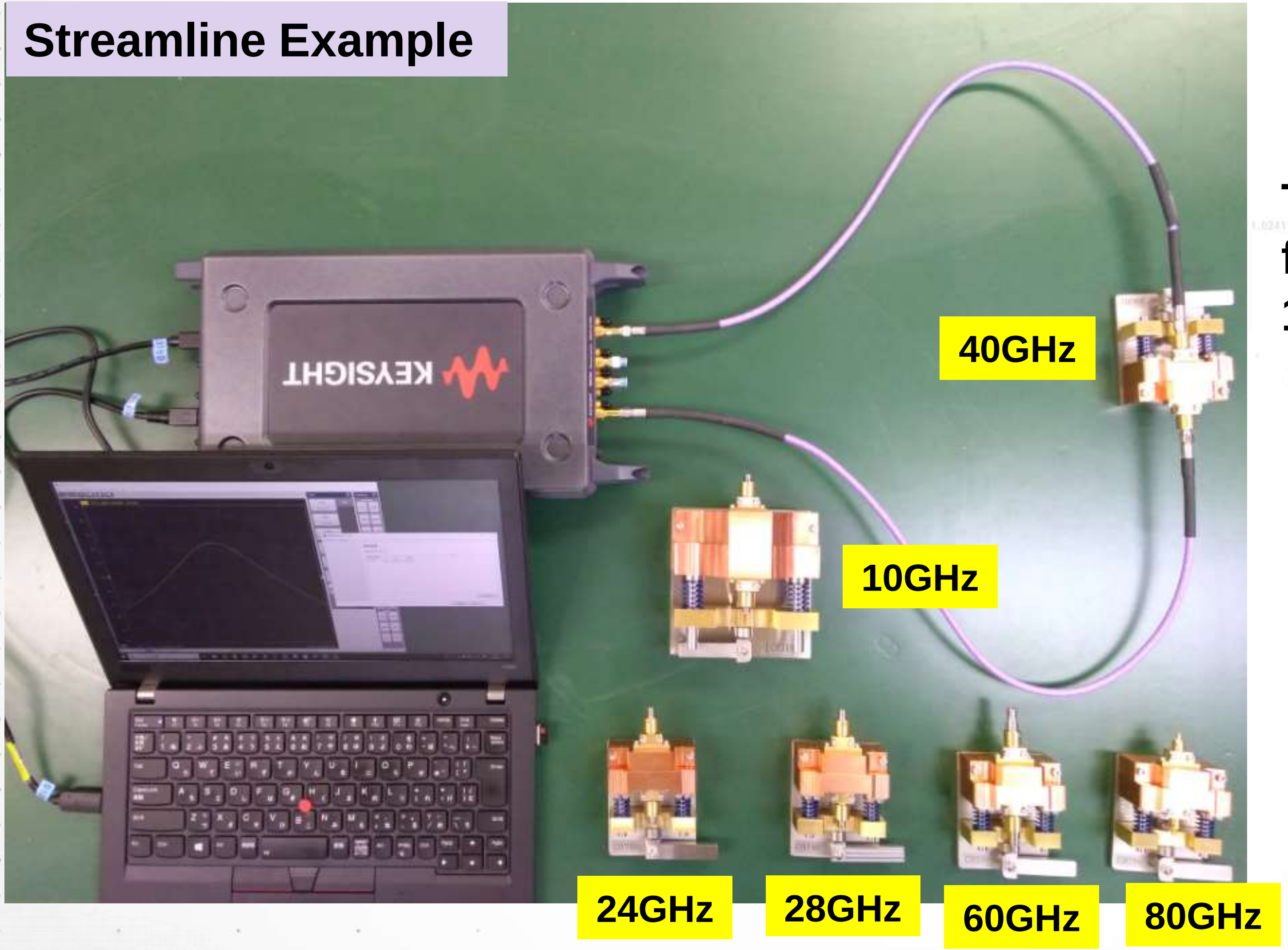
Sample size limitation



left graph is a guideline for material size and permittivity

tanδ guideline is hard to set clearly but tanδ ＜ 0.01 is a rough guideline

Split Cylinder Configuration: PNA/ENA/Streamline supported

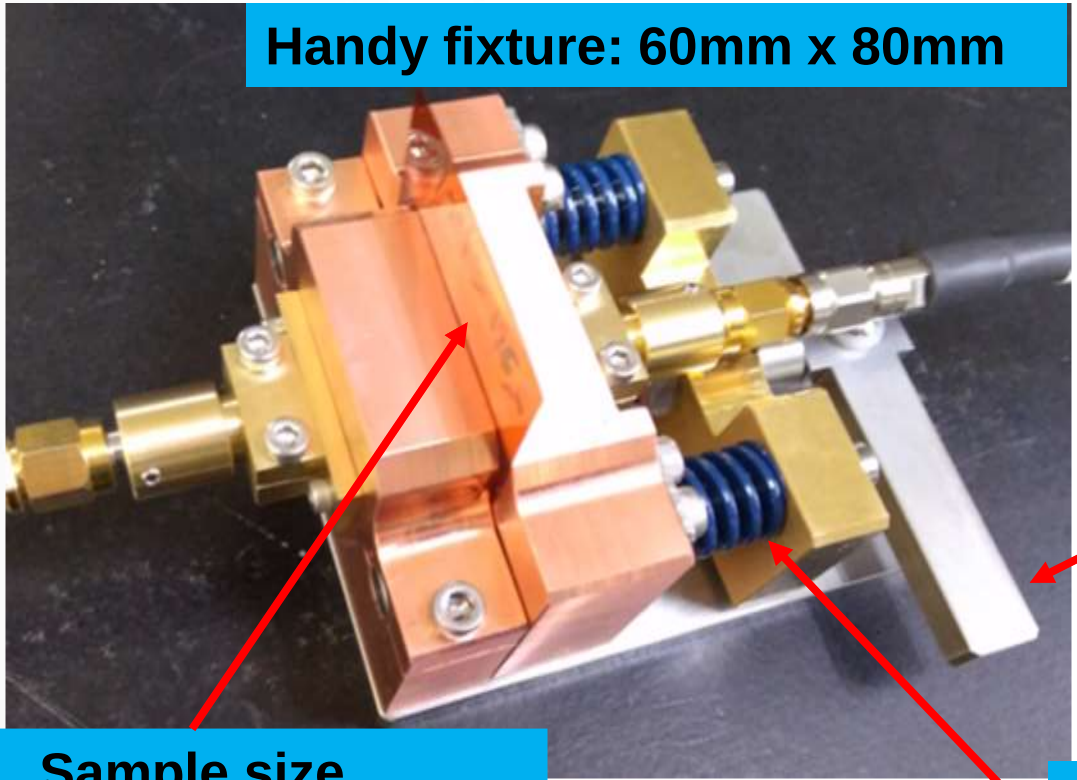


The same design concept for all frequencies: 10/20/24/28/35/40/50/60/80GHz

Split Cylinder Key Design Features

Designed for easy operation and high repeatability

Handy fixture: 60mm x 80mm



Test software with step by step instruction ensures right measurements from the beginning.

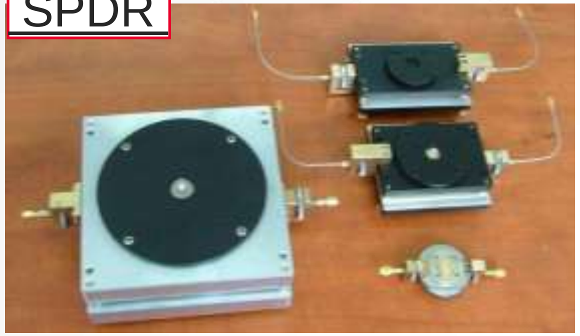
Lever for easy operation

Two springs fix a sample properly: A key to repeatable measurements

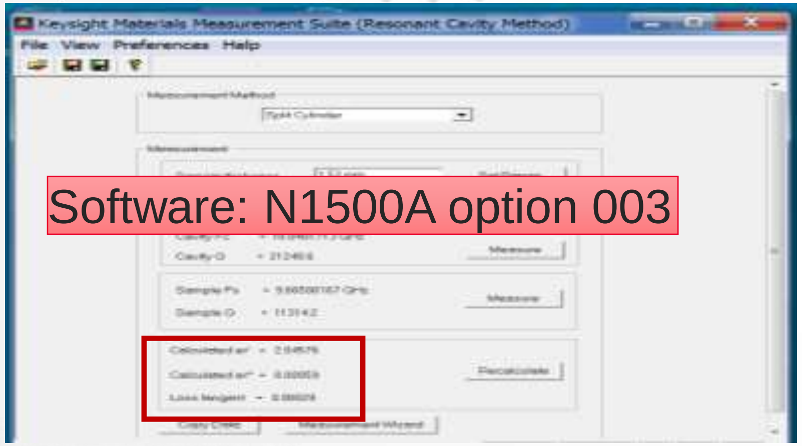
Sample size
35mm x 50mm
Thickness 20um ~ 300um

Resonant Cavity Fixtures available thru Keysight

SPDR

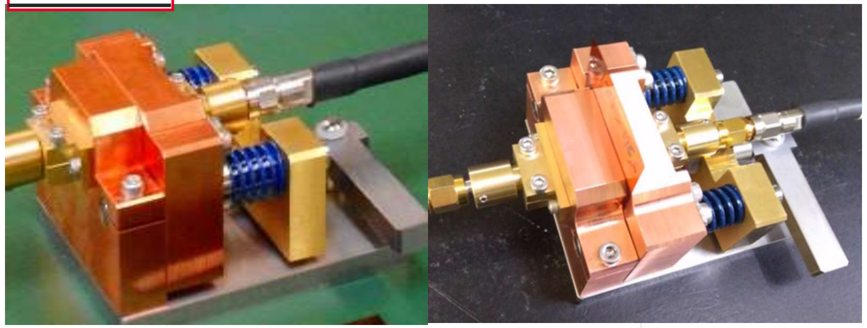


Model #	Description
N1501AE19	1.1 GHz, 3.5 mm (m) Split Post Dielectric Resonator
N1501AE03	2.5 GHz, 3.5 mm (m) Split Post Dielectric Resonator
N1501AE04	5.0 GHz, 3.5 mm (m) Split Post Dielectric Resonator
N1501AE10	10.0 GHz, 3.5 mm (m) Split Post Dielectric Resonator
N1501AE15	15 GHz, 3.5 mm (m) Split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

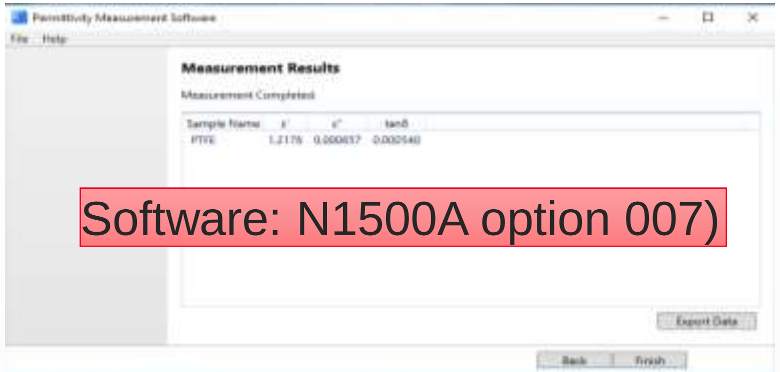


Software: N1500A option 003

SCCR

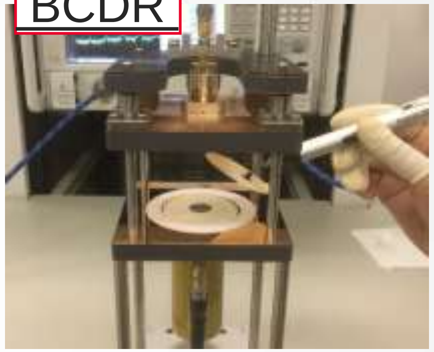


Model #	Description
N1501AKEAD-710	10 GHz, SMA (f) Split Cylinder Resonator
N1501AKEAD-720	20 GHz, 2.92 mm (f) Split Cylinder Resonator
N1501AKEAD-724	24 GHz, 2.92 mm (f) Split Cylinder Resonator
N1501AKEAD-728	28 GHz, 2.92 mm (f) Split Cylinder Resonator
N1501AKEAD-735	35 GHz, 2.92 mm (f) Split Cylinder 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
N1501AKEAD-ST1	Software Split Cylinder Resonator Starter Kit

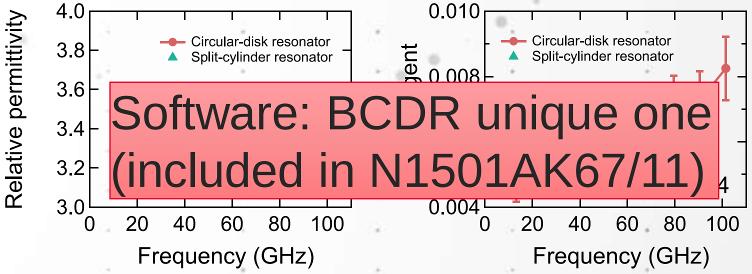


Software: N1500A option 007)

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

Question?