Oshima Prototype engineering /Keysight Technologies Balanced Circular Disk Resonator Operation guide

For N5290/91A broadband connection

Ver.1.5.2 HF-110G

Revised 2020.10.06

Oshima Prototype Engineering

Keysight Technologies

CONTENT

1. Setup and Preparation

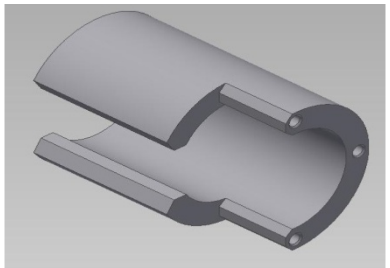
Installation procedure of Cavity, Measurement program

Preparing to measurement with useful accessories

BCDR Contents List

Contents in the box

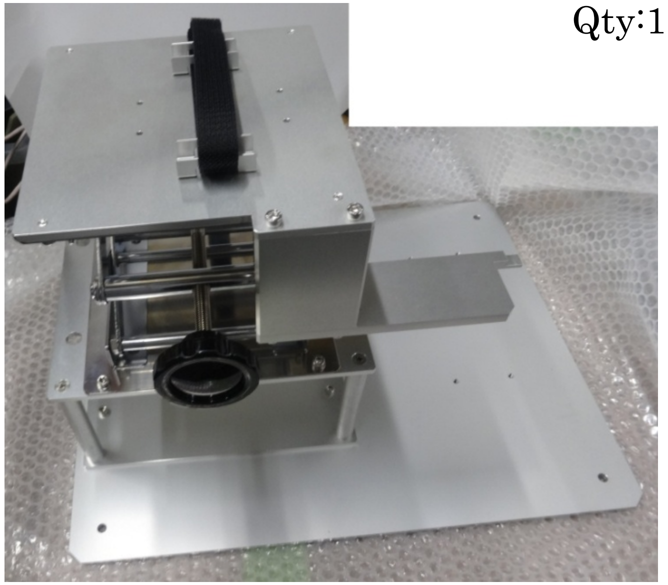
• BCDR 110G	Qty:1
• Φ12 Cu circular disk	Qty:5
• Φ12Shim centering sheet	Qty:5
• Φ15 Cu circular disk	Qty:5
• Φ15Shim centering sheet	Qty:5
• Φ18 Cu circular disk	Qty:5
• Φ18Shim centering sheet	Qty:5
• Sample MUT Φ50PTFE t=0.5	Set:1
• Sample MUT Φ50COP t=0.188	Set:1
• Sample MUT Φ50Polyimid t=0.5	Set:1
• Electrode cramp	Qty:1
• Pulley unit	Qty:1
• Weight	Qty:1
• Wire string	Qty:1
• Cable place	Qty:1
• M3 Flat head screw	Qty:4
• M4 Hex screw	Qty:4
• M5 Hex screw	Qty:4
• Software and help DVD	Qty:1
• Instruction manual	Qty:1
• Socket adapter	Qty:1



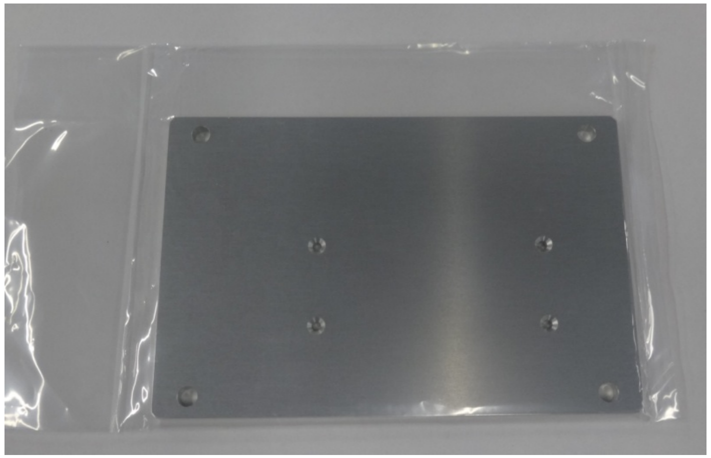
BCDR Contents List

Other contents list

・BCDR elevator unit Qty:1

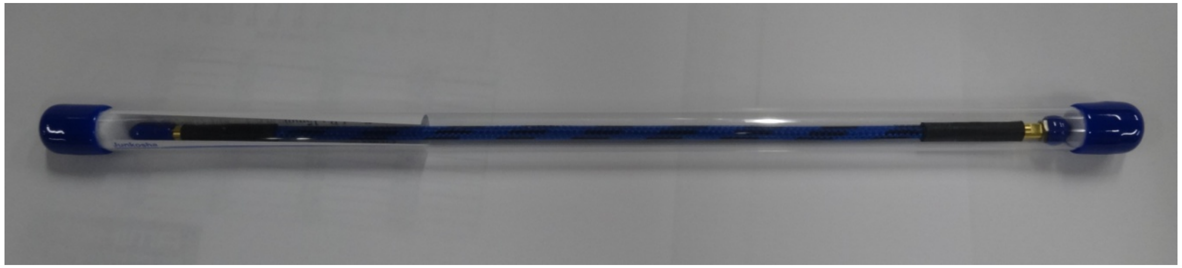


・Port 2 attach plate Qty:1



BCDR Contents List

- 1.00mm cable Qty:2



- USB-LAN adapter Qty:1

BCDR Contents List

・Torque driver Qty:1

・Hex 8mm bit Qty:1

KEYSIGHT TECHNOLOGIES

BCDR Contents List

・Hex bit set Qty:1

・Handy vacuum tweezers Qty:1

BCDR Contents List

- ・Stainless tweezers Qty:1

- Non-woven fabric BEMCOT M-3Ⅱ Qty:1

BCDR Contents List

・Blower Qty:1

・Anti-static finger cots latex Qty:1

BCDR Contents List

・Disposable natural rubber very thin gloves　　　　　　　Qty:1

・Mini slim wrench set　　　　　　　　　　　　　　　　　Qty:1

KEYSIGHT TECHNOLOGIES

BCDR Contents List

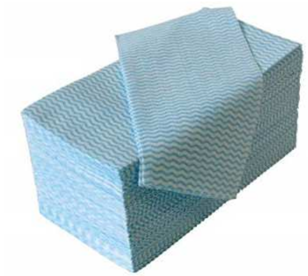
Recommended to prepare by users

- PC
- Anhydrous alcohol

DVD installed List

- BCDR+program_note_1.5.2_20200904.pdf
- Data+sheet+for+BCDR_200904.pdf
- N1501AE11_110GHz_BCDR_operation+guide_VER.1.5.pdf
- BCDR_setup_guide.pdf
- IOLibSuite_18_1_25310.exe
- BCDR_Program_US_withRuntime.exe
- Φ1X_No.XX(center electrode diameter/thickness data)
- Measurement result of excitation hole.pdf
- BCDR Measurement result PTFE.xlsx

Required Accessories 1



Equipped with the system (equivalent)

- Mini open wrench set (3.5 mm ~ 10 mm)
- Portable vacuum tweezers
- Plastic tweezers
- Torque screwdriver + hex wrench bit (8mm)
- Hex wrench bit set (2 mm ~ 6mm)
- Disposable antistatic finger sack and gloves
- Non-woven fabric cleaner
- Air blower

Recommended to prepare by users

- Coaxial torque wrench (included in VNA calibration kit)
- Coaxial 1.0mm torque wrench
- Anhydrous alcohol (99.55)
- Late gloves
- Micrometer

Required Accessories 2 / Cal. kit

Mechanical calibration kit

Ecal

- Calibration kit (mechanical or Ecal)
- Torque wrench / Box wrench / Adjustable wrench

For full two-port calibration at the end of test cable.
Calibration is necessary for accurate peak measurements on PNA network analyzer.

Preparation before installing the software

As of 2020 July:
・Keysight IO libraries Suite version 18.1 (available in the DVD disk)
https://www.keysight.com/main/software.jspx?ckey=2175637&lc=jpn&cc=JP&nid=-33330.977662&id=2175637&pageMode=CV

・BCDR_Program_US_withRuntime.exe (available in the DVD disk)
Matlab driver is included in the installer.

・Control PC
Win 10 64 bit professional OS

・N52xxA/B PNA series network analyzer, FW A.09.80.20 or later

【USB dongle key adapter (USB-LAN adapter shipped with BCDR)】
You have to plug in an USB dongle adapter to run and operate BCDR program. The BCDR software reads license information from the USB dongle, so you cannot run the program without the USB dongle. Plug-in the USB dongle (USB-LAN adapter) to be recognized by your PC before running the BCDR program. You can use standard driver in Win 10 PC.

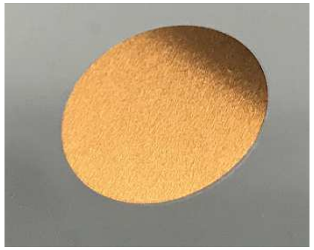
BCD Resonator Software installation

Note: The PC needs to be connected to LAN during the software installation

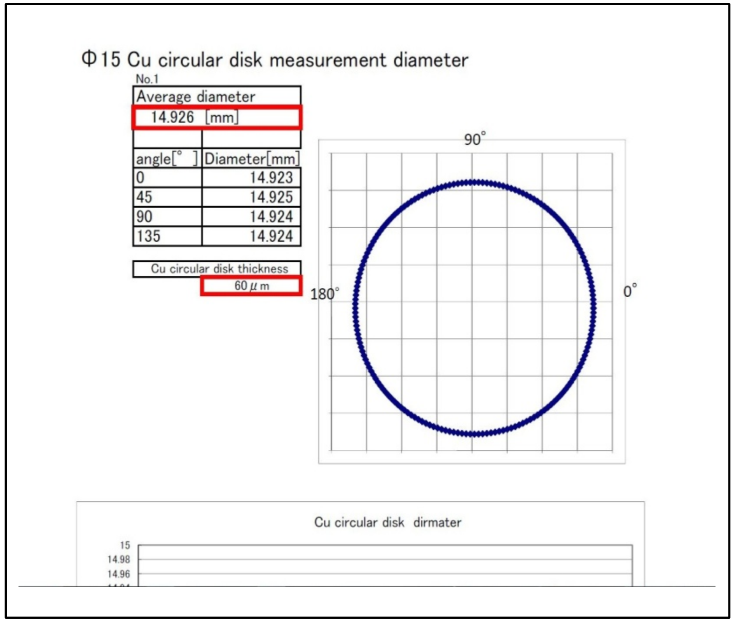
1. Install IO library SUITE 18.1: Download the IO library SUITE from DVD or Keysight web (need internet connection) and install it.
2. Plug-in USB-LAN module attached with BCD resonator. When module driver is not installed automatically, install standard driver in your Win10 PC.
3. Copy BCDR_Calc_Installer.exe from DVD to your desired directory and run it. Follow the procedure and answer yes for short-cut on desktop.
4. When running the BCD Resonator software, keep the USB-LAN module plugged-in to your computer, otherwise you fail to launch the program.

Change parameters > Editing initialentry.txt

1. Diameter of circular disk electrode 2. Excitation hole diameter



Input actual diameter of your using center electrode for accurate result



Φ15 Cu circular disk measurement diameter

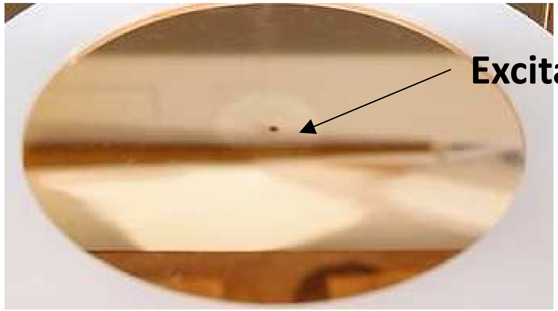
No.1

Average diameter
14.926 [mm]

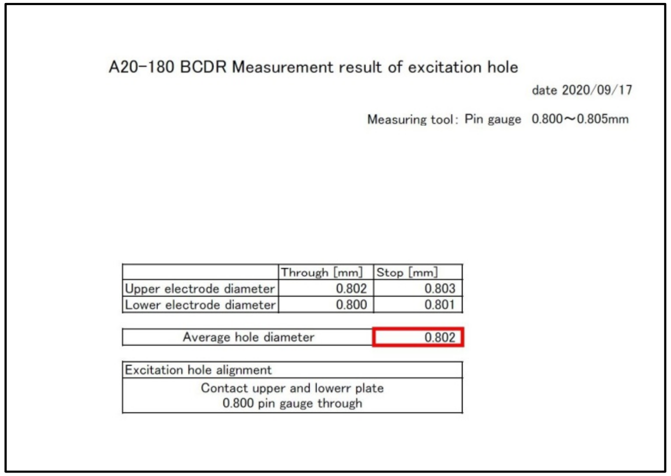
angle[°]	Diameter[mm]
0	14.923
45	14.925
90	14.924
135	14.924

Cu circular disk thickness
60 μm

Measured data is provided in DVD



Input excitation hole diameter. When your resonator’s upper and lower electrode are repaired, you have to input the diameter again.



A20−180 BCDR Measurement result of excitation hole

date 2020/09/17

Measuring tool: Pin gauge 0.800〜0.805mm

	Through [mm]	Stop [mm]
Upper electrode diameter	0.802	0.803
Lower electrode diameter	0.800	0.801
Average hole diameter		0.802

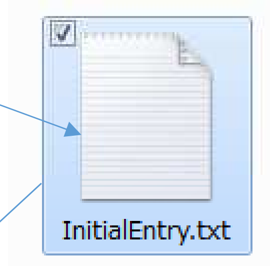
Excitation hole alignment
Contact upper and lowerr plate 0.800 pin gauge through

Measured data is provided in DVD

Change parameters >   Editing initialentry.txt

Initial setting file that BCDR software uses is stored at the below location.
You need to change the initial value by editing this file.
You can change electrode diameter on the GUI, but you can change the excitation hole diameter in this file only.

C:¥Users¥XXXXX¥Documents¥BCD_Resonator¥InitialEntry.exe



InitialEntry.txt - メモ帳

ファイル(F) 編集(E) 書式(O) 表示(V) ヘルプ(H)

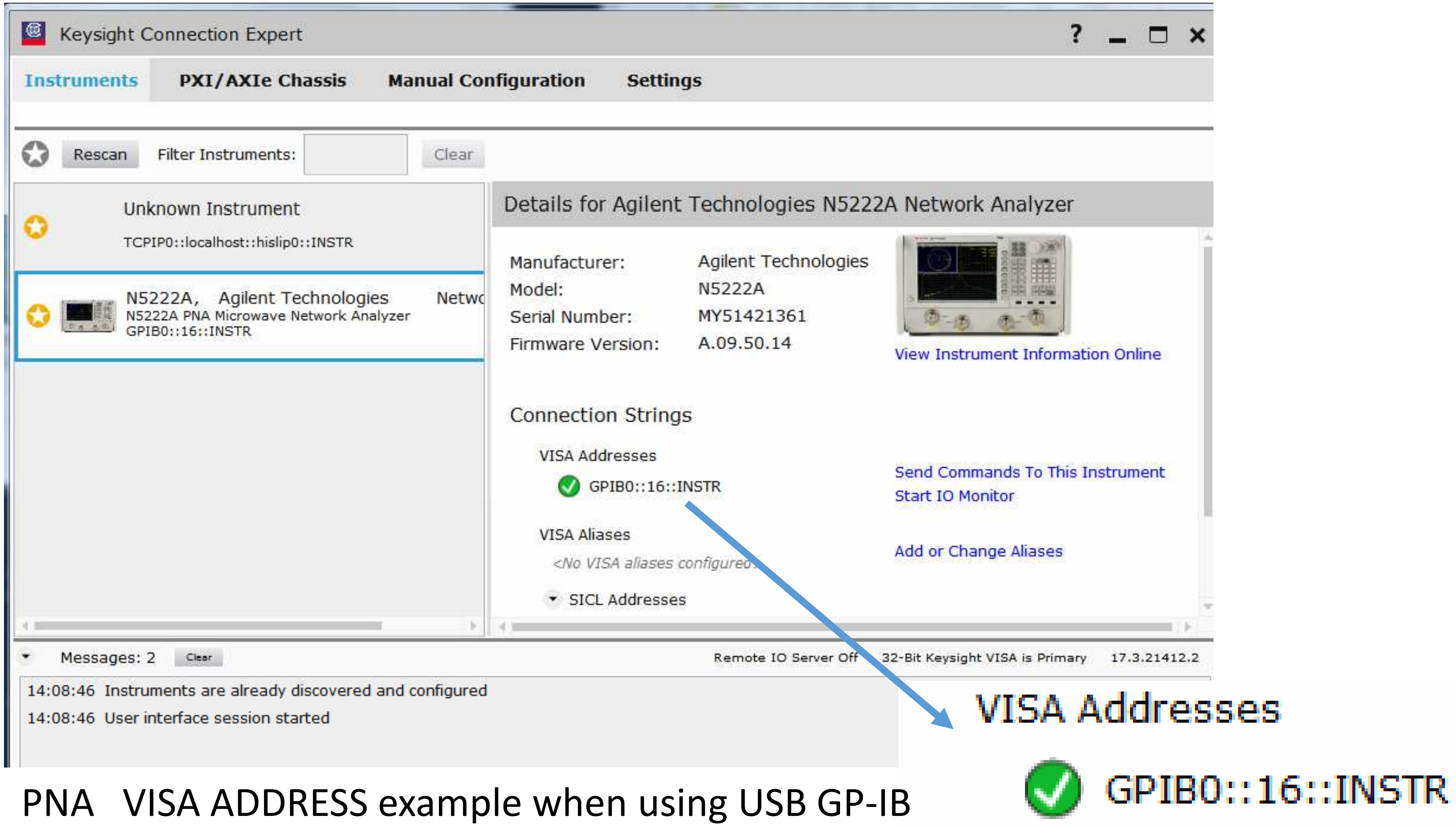
```
[VNA setp]
Start freq.: 5 GHz
Stop freq.: 70 GHz
Num. of freq.: 1001 points
IFBW: 300 Hz
Power: -5 dBm
Span per segment: 3 %
Points per segment: 1001 points
IFBW of segment: 100 Hz

[Sample & Resonator parameters]
Sample Thickness (t): 0.1 mm
Uncertainty of t: 0 mm
Disk Diameter (D): 18 mm
Uncertainty of D: 0.005 mm
Conductivity: 5.63 10^7 S/m
Uncertainty of Conductivity: 0.18 10^7 S/m
Disk Thickness (tc): 0.06 mm
Uncertainty of tc: 0.002 mm
Excitation Hole Diameter (A): 0.822 mm
Uncertainty of A: 0.04 mm
Excitation Hole Length (M): 2 mm

[Measurement setup]
File name prefix: mat1
Vendor: agilent
Visa address: GPIB0::16::INSTR
```

Setup Keysight Connection Expert's IO Config.

Keysight IO Library Suite (Keysight Connection Expert) setup example

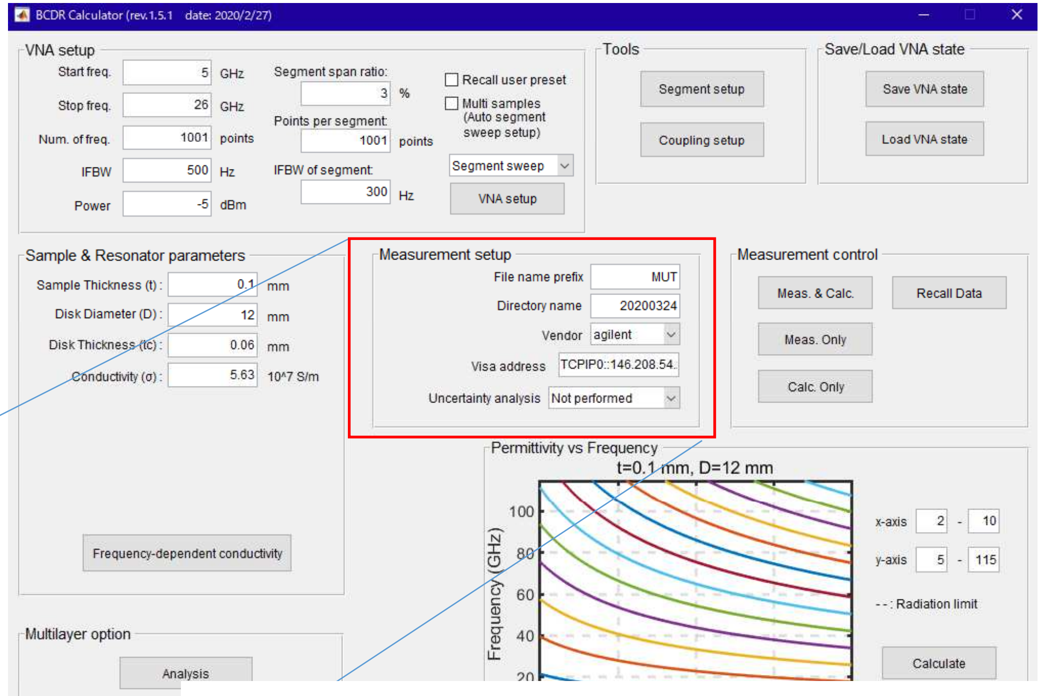


PNA VISA ADDRESS example when using USB GP-IB

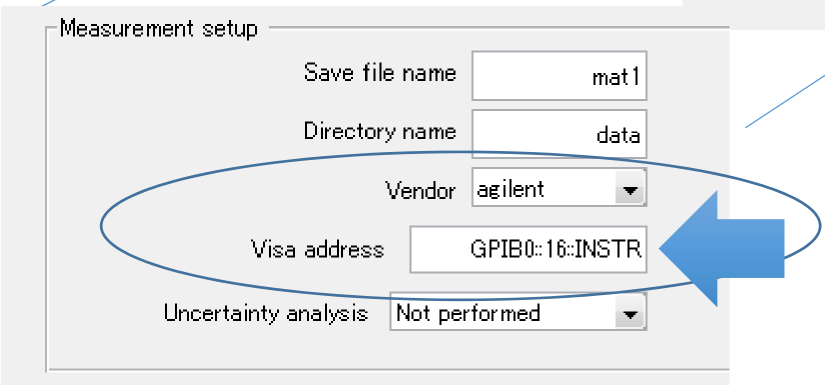
KEYSIGHT TECHNOLOGIES

Starting BCD Resonator Software

Run the program after connecting the PNA to your PC by USG-GPIB or USB cable.



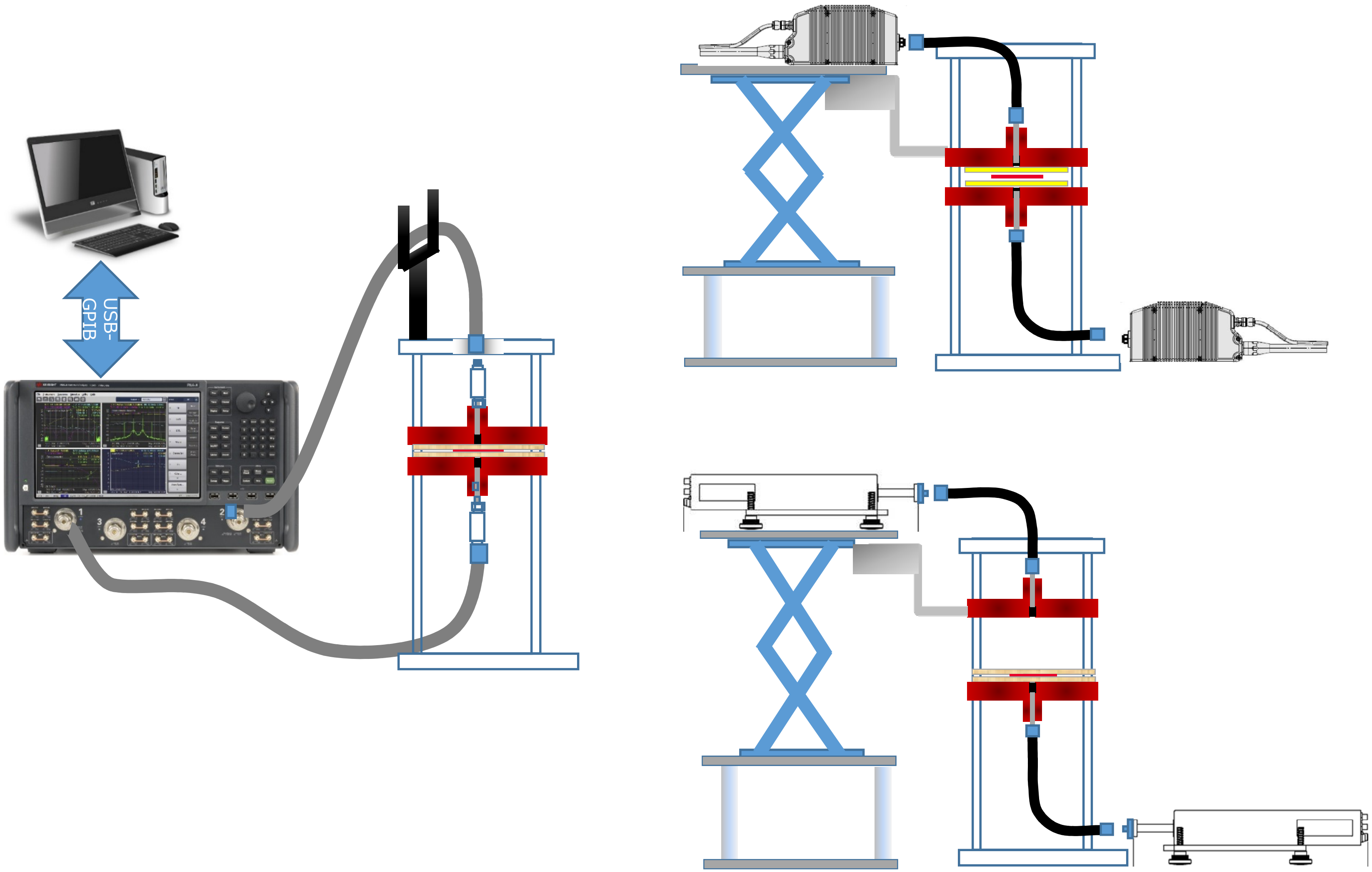
Note: Please select "agilent" as the vendor name, even you use Keysight IO library and PNA.



Set the IO information

1. Select IO-Library suite vendor as "agilent"
2. VISA address. You can check the VISA address on IO library suite (see the next page)

2. Connection and setup meas. condition



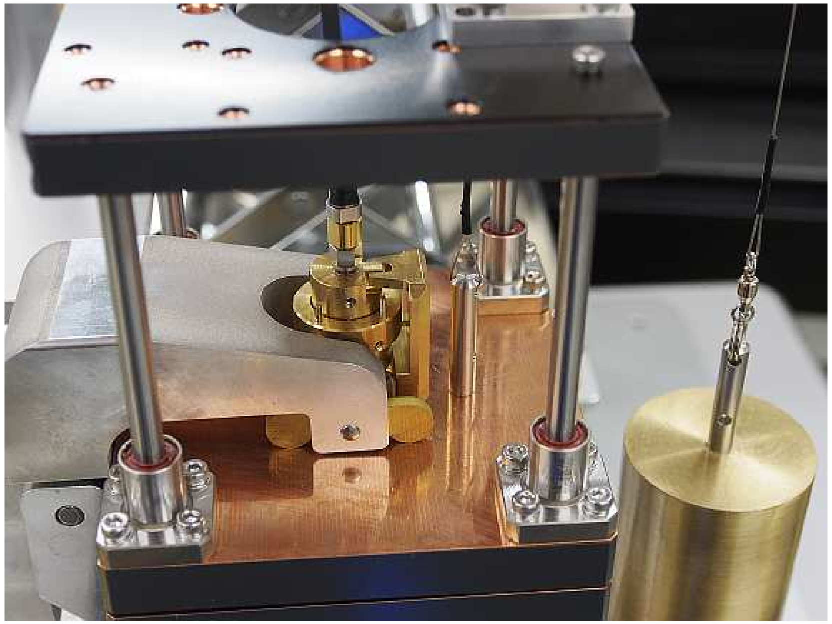
Daily operation – 15 steps

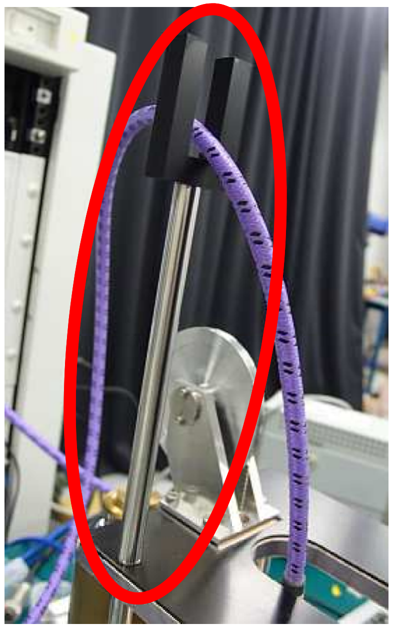
1. Run the BCDR software program on your PC
2. Confirm connection to the PNA thru USB or USB-GPIB
3. Insert your samples, center electrode, and shim-sheet in the BCDR
4. Close the BCDR and tighten by clamp with proper torque for pre-measurement
5. Connect PNA's test port cable to the BCDR
6. Set the VNA's sweep condition by using BCDR software by doing pre-measurement. You can search the multiple resonance, set segments and its condition.
7. Detach the test port cable from BCDR.
8. Conduct full two port calibration at the end of test port cable. Use PNA firmware function to do the cal.
9. Finish the calibration and save the state or calset.
10. Connect test port cable to the BCDR again
11. Adjust coupling so that peak levels are in the correct range
12. Conduct manual sweep and check the resonant slope and peak level
13. Start measurement by BCDR software program
14. Measurement value is displayed and saved
15. Finish the measurement

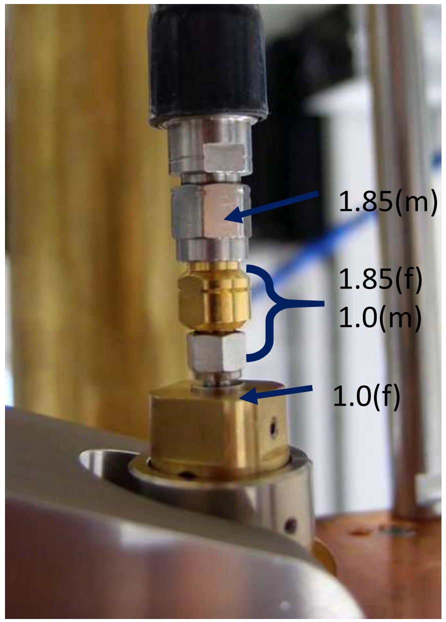
Setup the balanced weight and cable post

Balanced weight: Caution because it's heavy. Hold the bottom side of the weight by your hand when attaching/detaching it for safety operation.

Cable post: When using 1.85mm coax connector, use cable post for upper side test port cable to decrease mechanical stress to the connectors and adapters at upper electrode

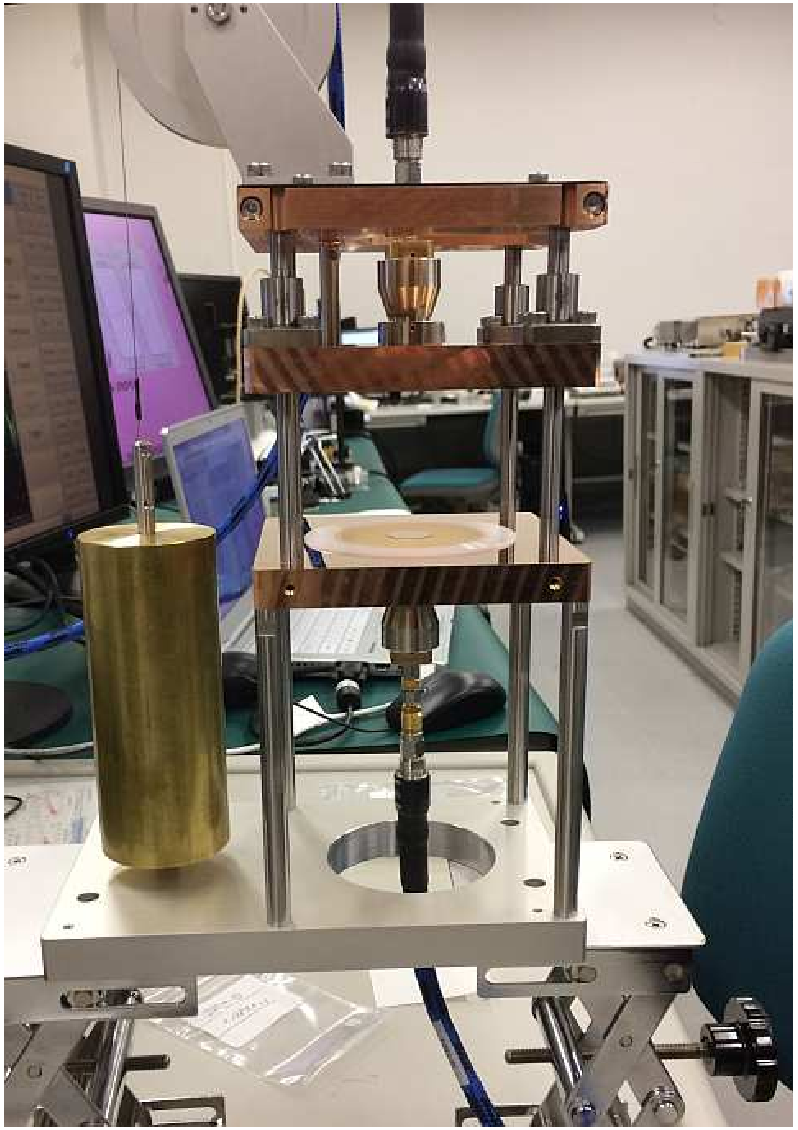






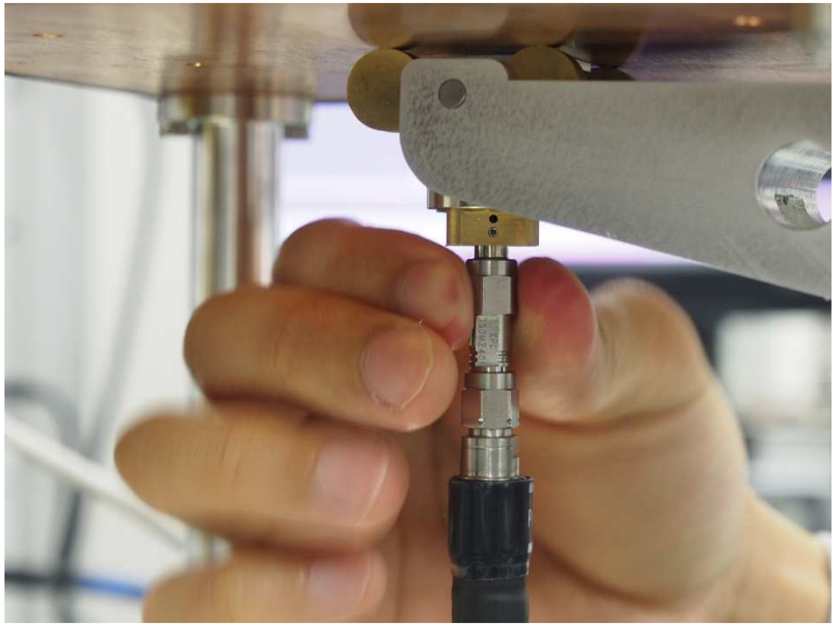
Test port cable connection(Before Cal.)

(COAX. BAND ~ 70 GHz)



Connect VNA test port cable to BCDR's upper and lower electrode connectors.

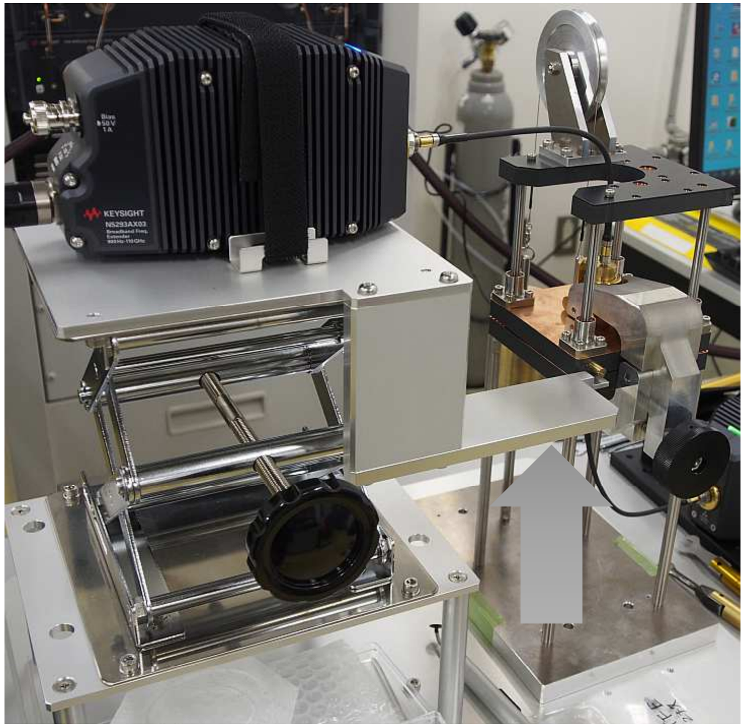
Caution: 1.0mm connectors are very fragile. Applying large torque damages the connector easily. Keep proper torque (45 N-cm (4 in-lb)) and DO NOT over it.

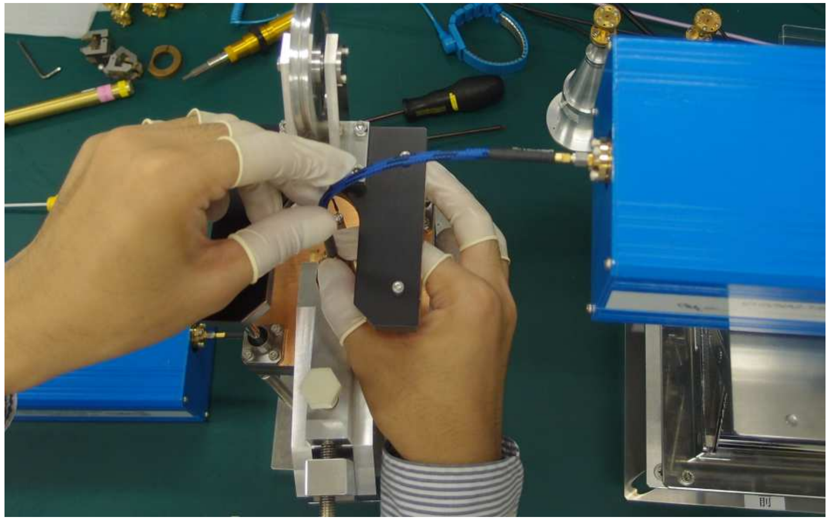


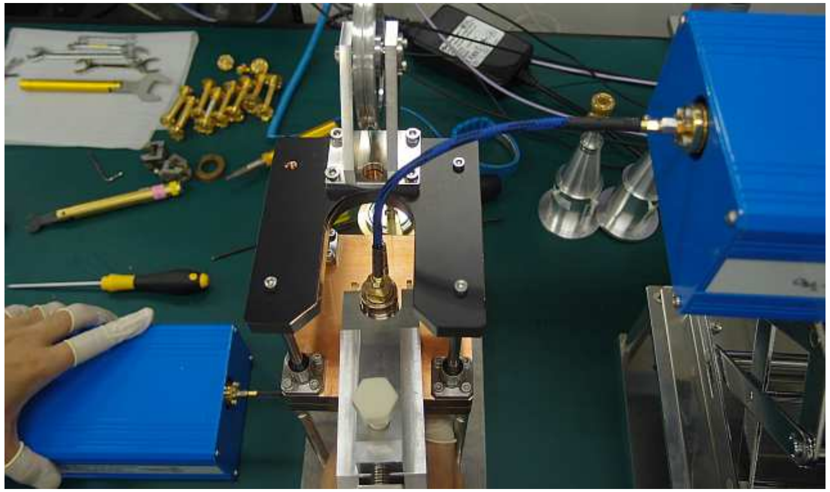
KEYSIGHT TECHNOLOGIES

Test port cable connection(before Cal.)

(WAVEGUIDE BAND / Broad Band)





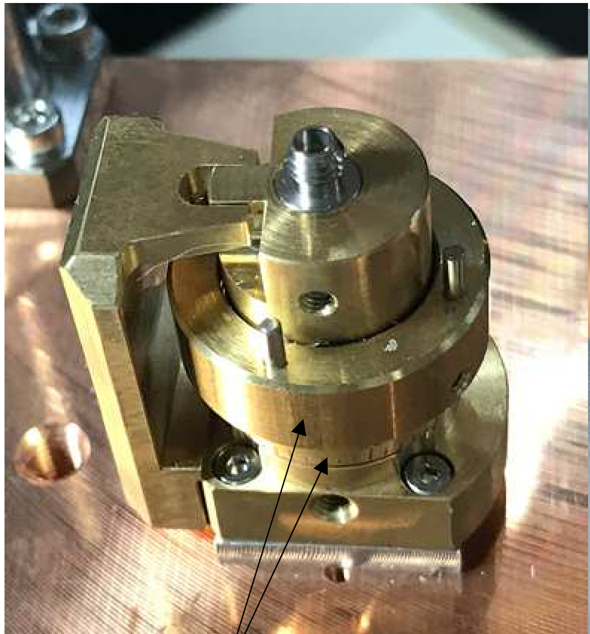


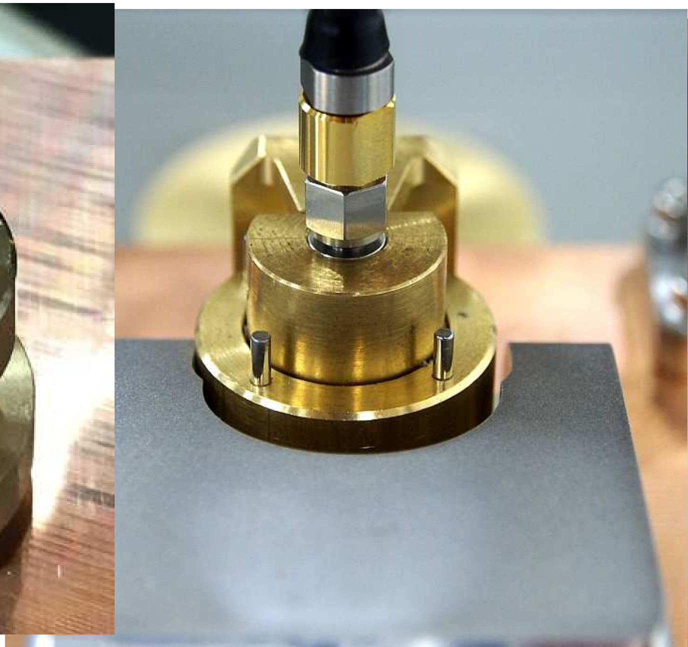
Upper electrode and mmWave head have to be synchronized when moving up/down to avoid cable position/bending change causing mismatch after calibration and deteriorating the accuracy.

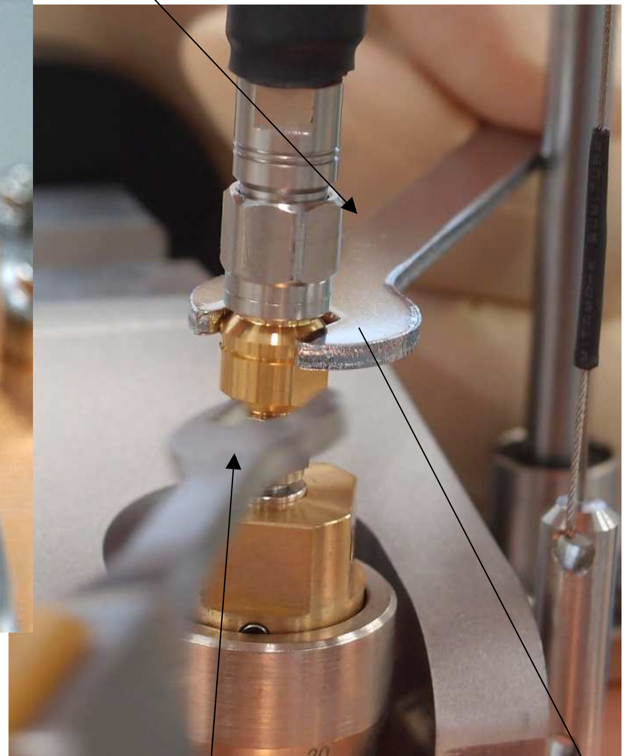
Test port cable connection using Torque wrench and Open wrench

Use a mini open wrench to hold the 1.0mm (m) – 1.85mm (f) adapter not to rotate when connecting 1.85 mm cable.

1.0 mm connector







Coupling adjustable knob:
Excitation line moves up and down
1mm by two rotations, 2 mm by 4 rotations.
When measuring a sample first time, be sure to rotate the knob clock-wise till the gage set to 0 to set maximum coupling

1.0mm torque wrench

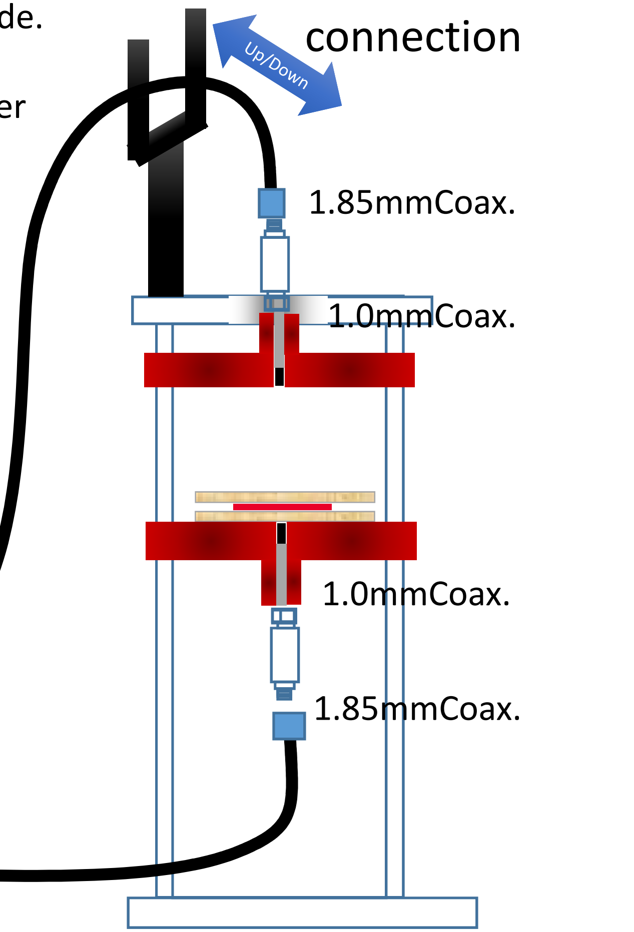
Lower the upper electrode gradually, and adhere - when using with standard PNA and cable (~67 GHz)

COAX. BAND

When setting or replacing samples

Take care not to stress test port cable when move up/down the upper electrode.

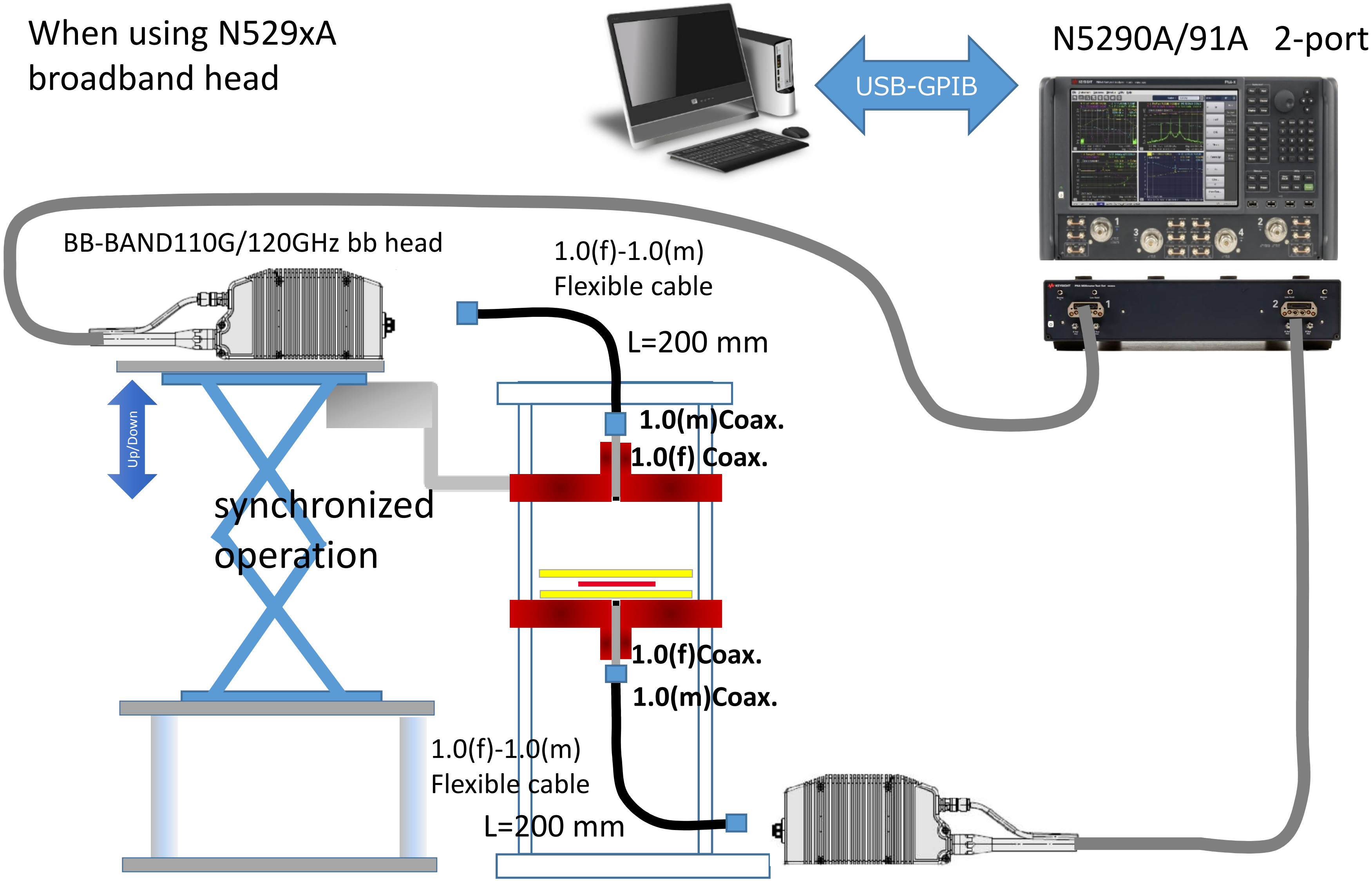
Changing cable position after full 2-port calibration deteriorates accuracy and causes mismatch error and ripples. Try not to change radius of the cable after calibration.



KEYSIGHT TECHNOLOGIES

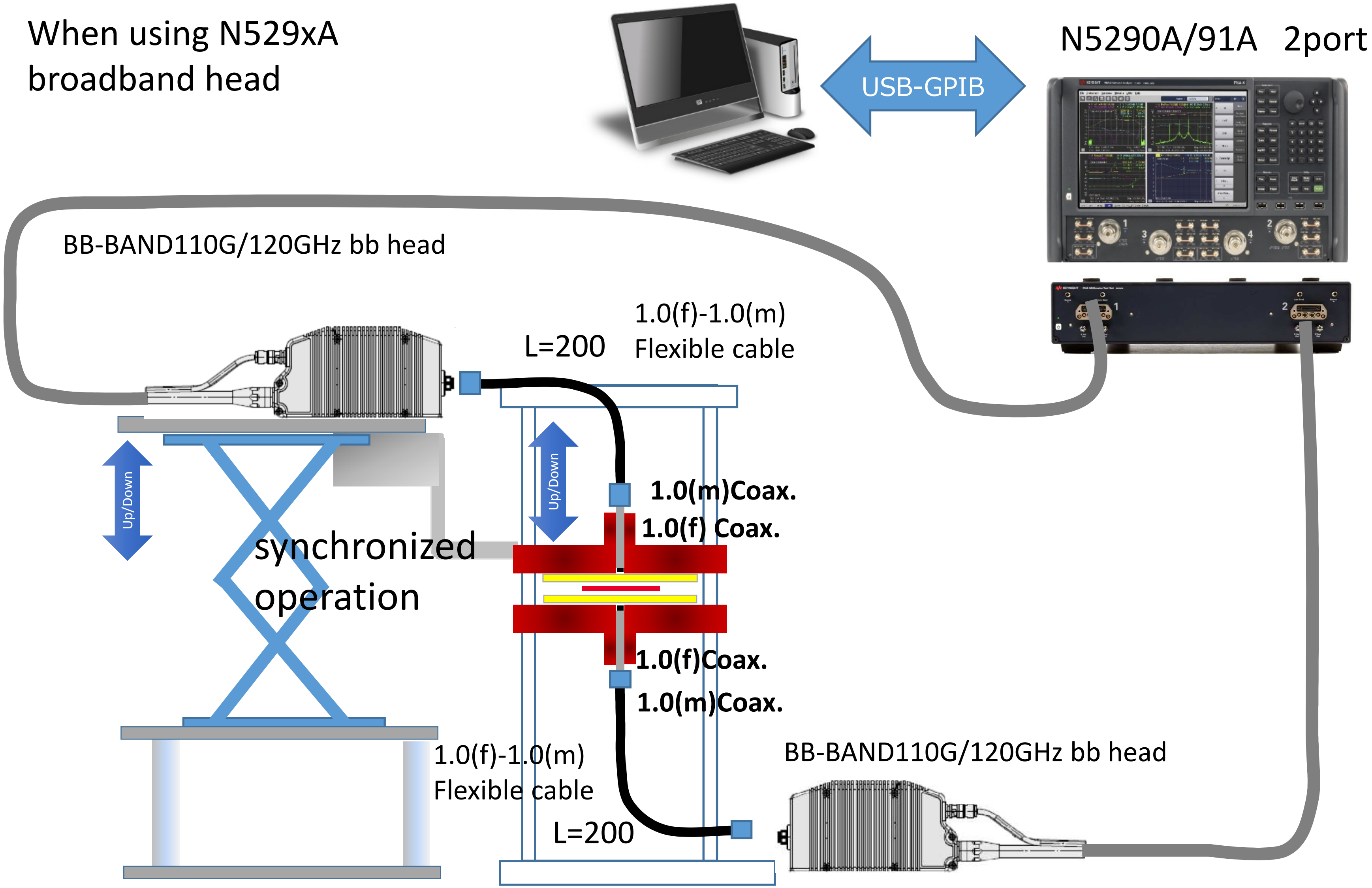
Lower the upper electrode gradually, and adhere - when using with the N529xA Broadband PNA

When using N529xA broadband head

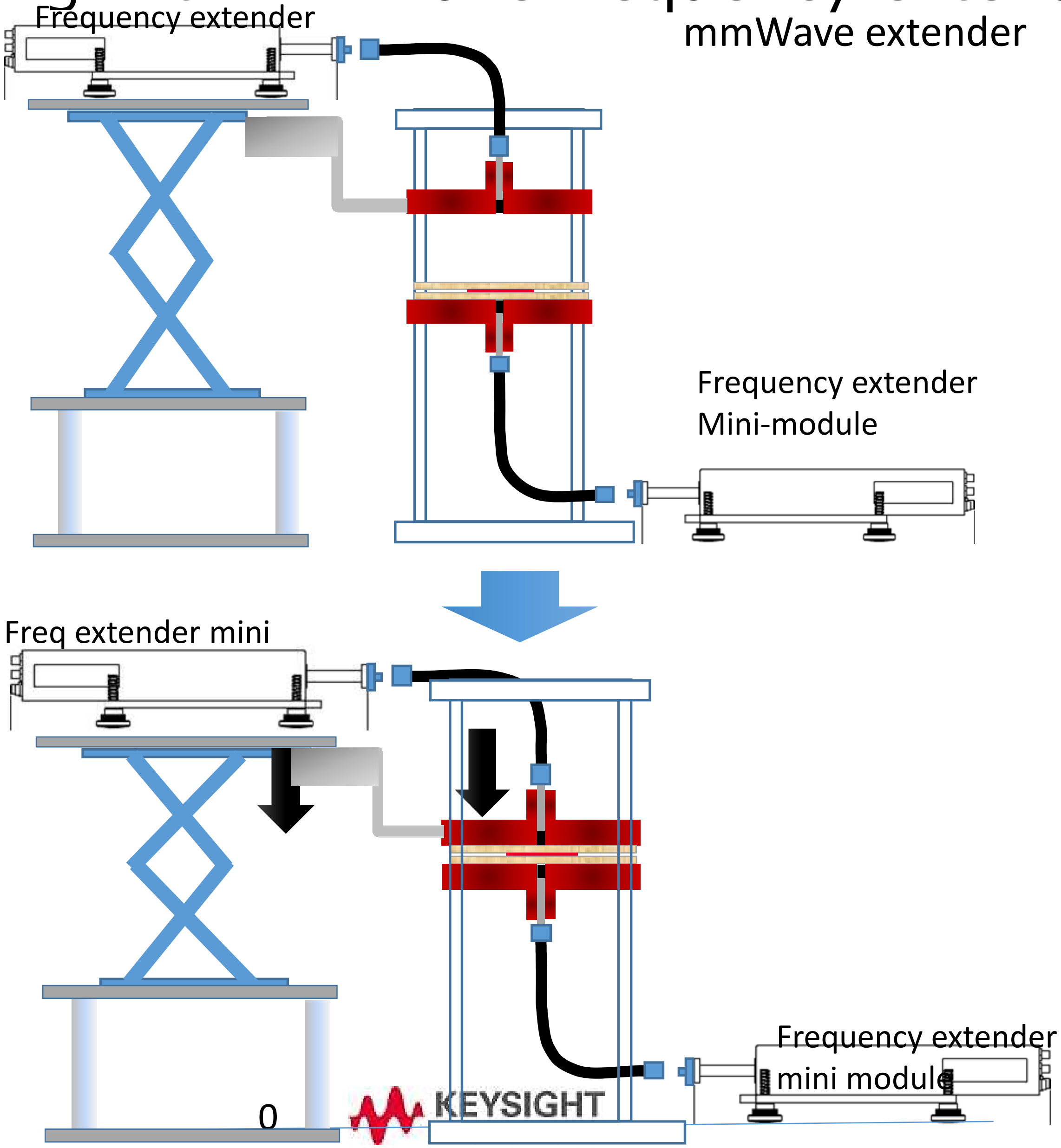


KEYSIGHT TECHNOLOGIES

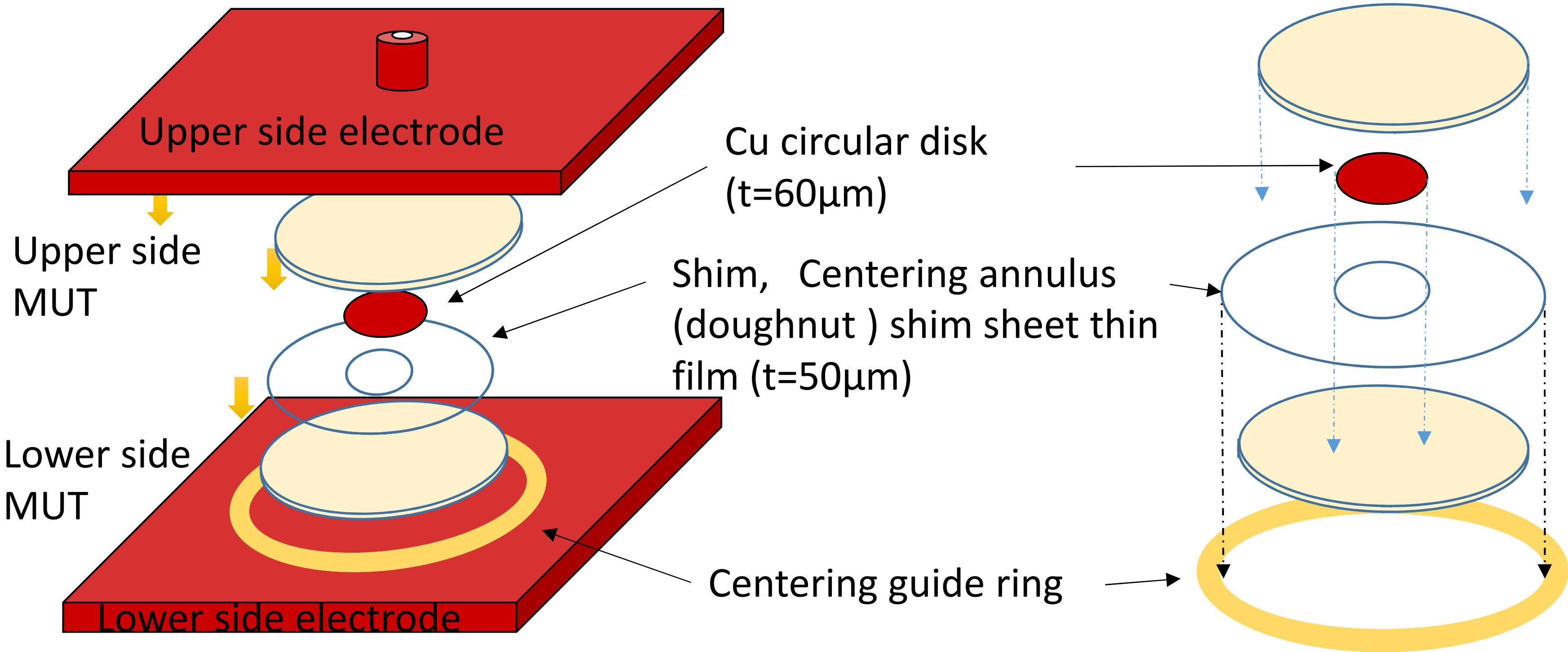
Lower the upper electrode gradually, and adhere - when using with the N529xA Broadband PNA



Lower the upper electrode gradually, and adhere - when using with mmWave frequency extender

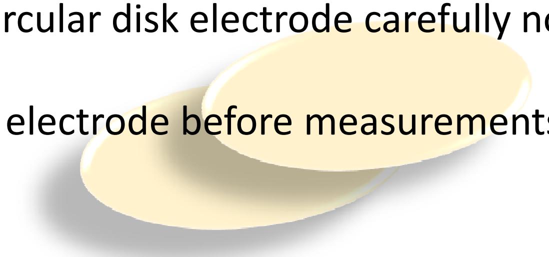


Setting electrode and MUT



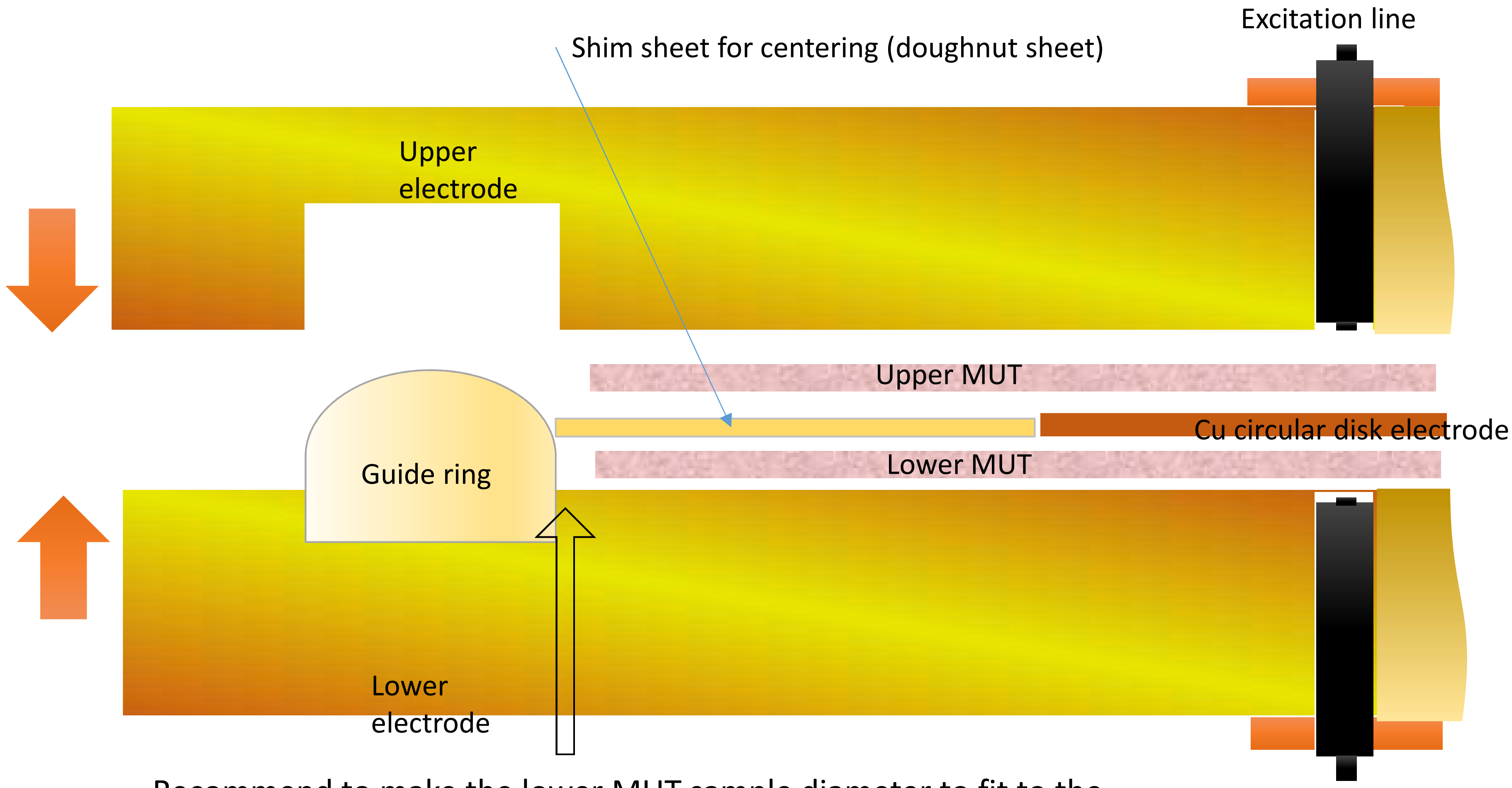
Shim centering sheet is used to set the position of Cu circular disk electrode, and keep this shim sheet in the resonator. during the measurement. Please set the center Cu circular disk electrode carefully not to overlap its edge to the shim sheet.

You can remove the shim sheet after setting up the Cu circular disk electrode before measurements, but you have to take care not to move the Cu circular disk electrode.



The center of Cu circular disk electrode has to be aligned to the center of excitation holes at both upper and lower side electrode.

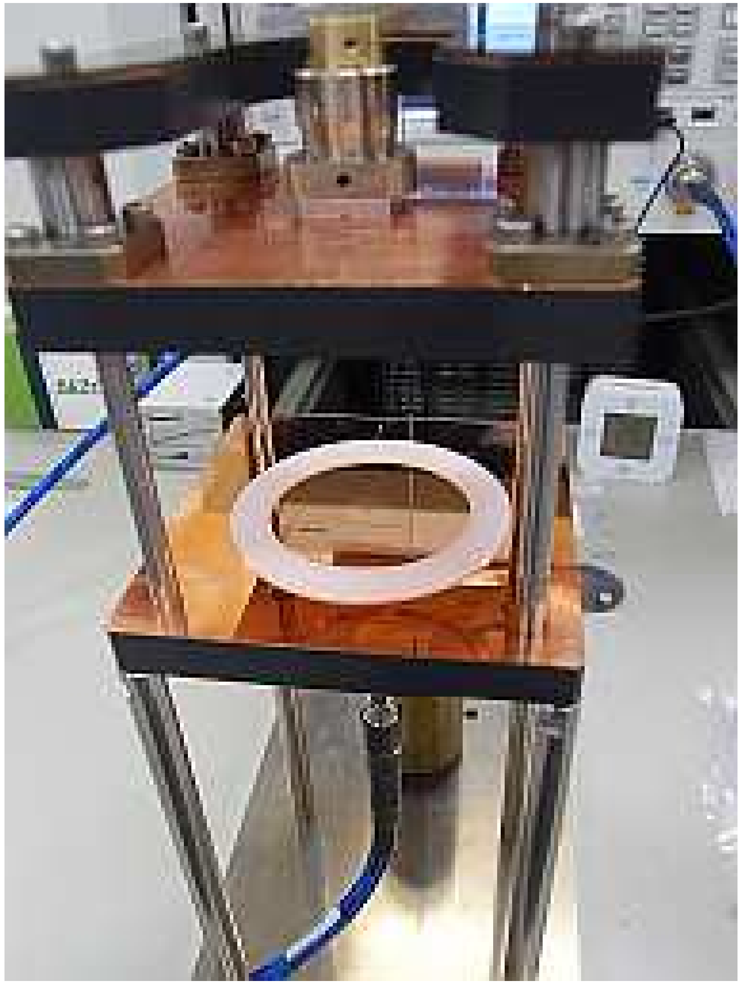
Upper and lower side electrode cross section

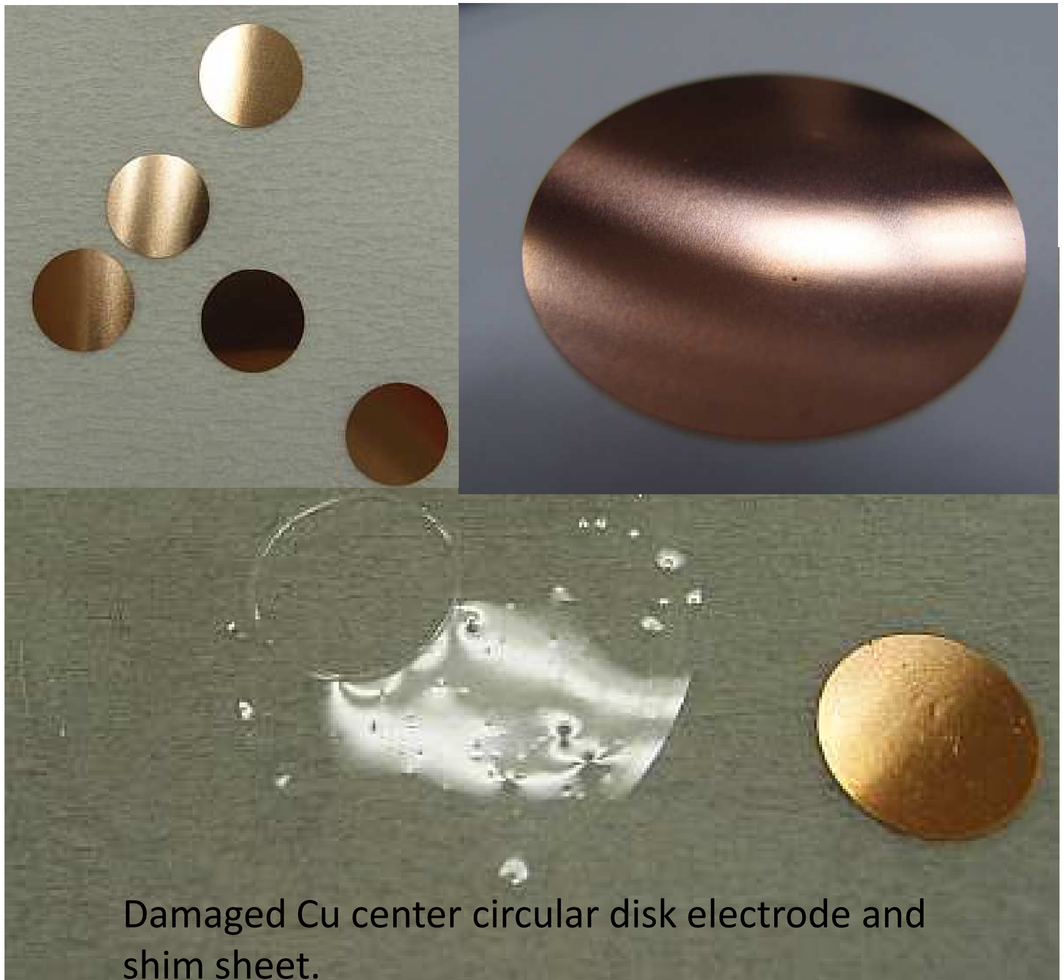


Recommend to make the lower MUT sample diameter to fit to the guide ring edge (~ 50mm diameter) to minimize the position shift for easy electrode setting.

Disposable centering sheet and circular disk

Make upper and lower electrode clean every time without dust. Cu Center circular disk electrode and shim sheet are consumable parts. Replace them when it’s damaged like the image below.



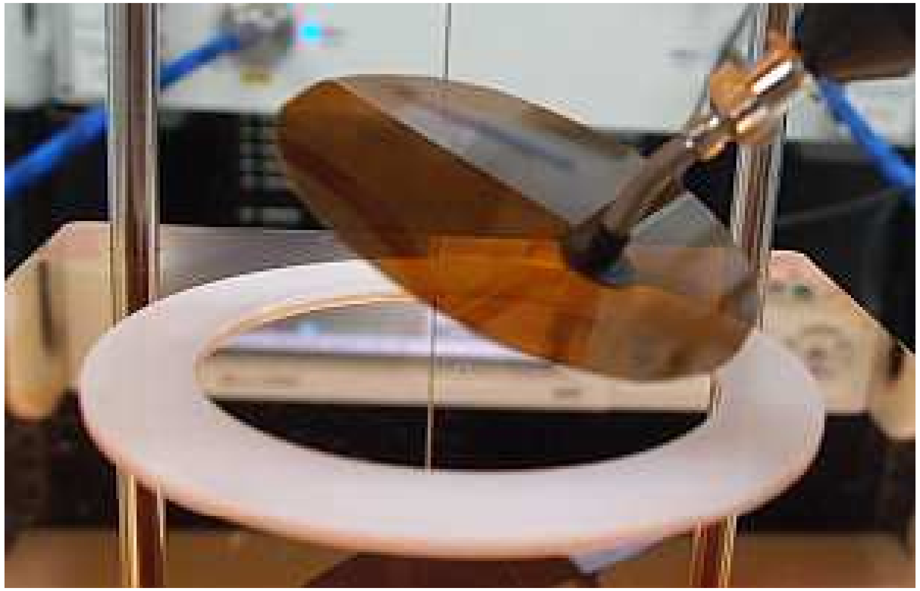


Damaged Cu center circular disk electrode and shim sheet.

Setting lower side MUT inside guide ring

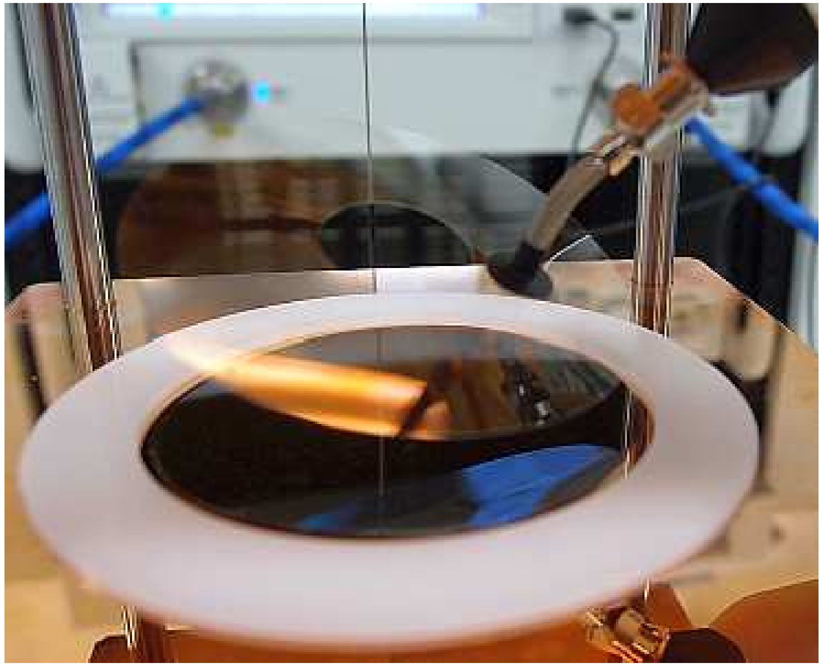
Set the lower side MUT.

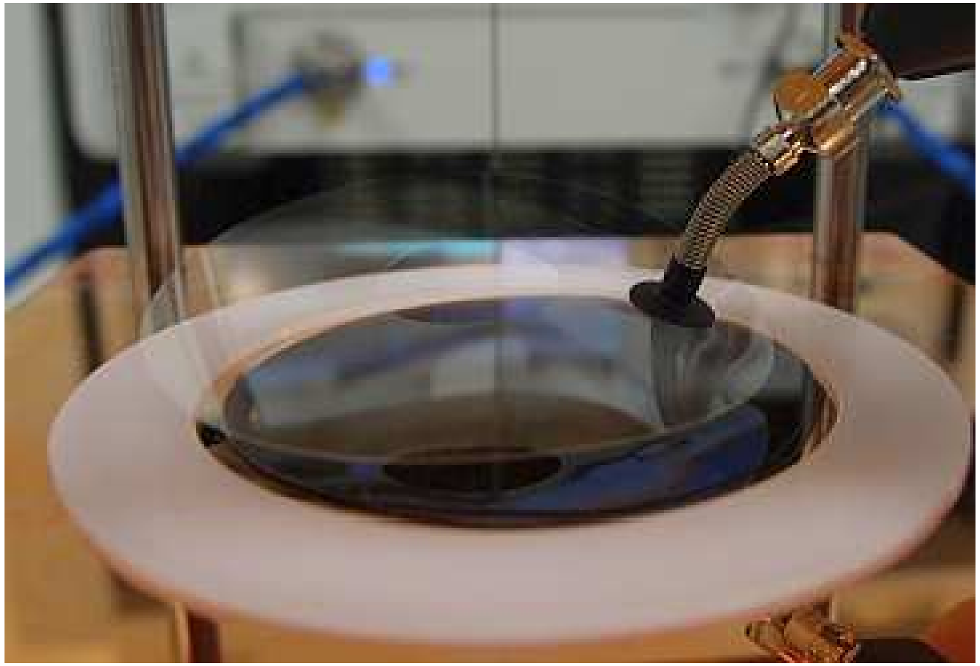
Recommend to set the lower side MUT not to move for easy setting afterwards. You can make the sample size to fit it to that of the guide ring size, or tape it by using small piece of adhesive tape to the guide ring. (The white guide ring is fixed to the lower electrode and don't move its position)



Set the centering shim sheet (doughnut shape sheet)

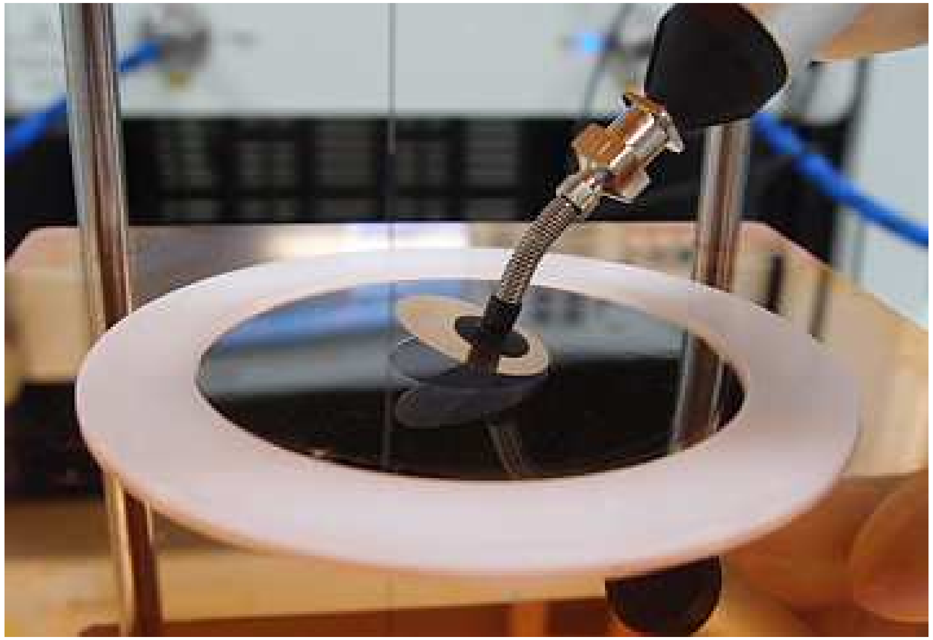
1. Use vacuum suction tweezers to hold and pull up the shim sheet
2. Put the shim sheet on the lower side sample carefully.
3. Rotate slightly to check the position of shim sheet, not to overlap to the edge of outer guide ring

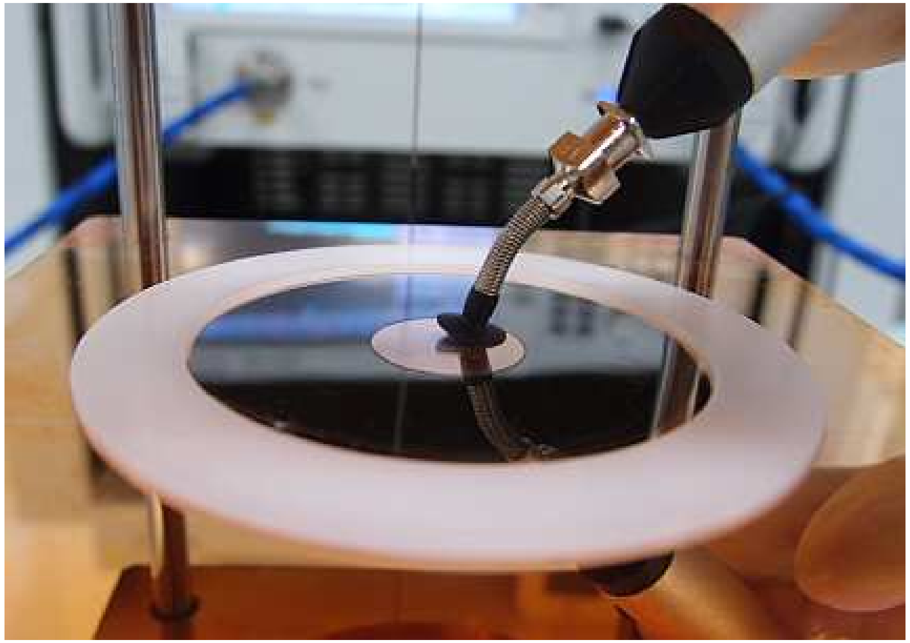




Setting the circular disk electrode

1. Use vacuum suction tweezers to hold and pull up the Cu center circular electrode carefully
2. Put the electrode to the center of shim sheet carefully
3. Adjust the position of the circular electrode not to overlap its edge to the shim sheet.



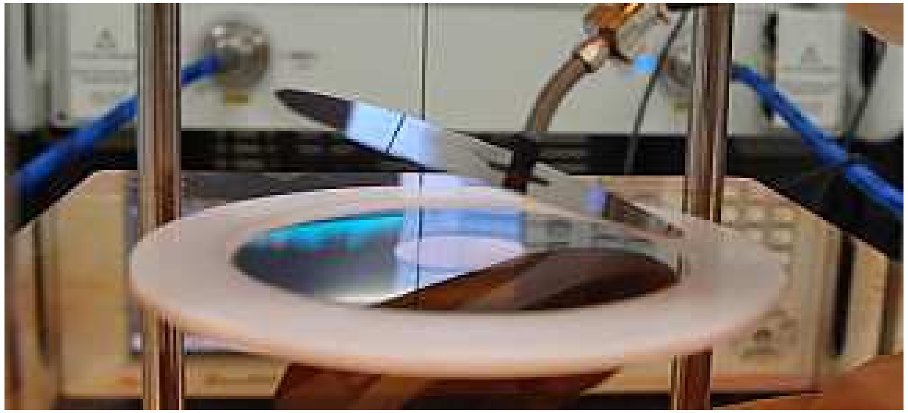


The position of center circular disk electrode has to be set at the center of the resonator for accurate measurements.

KEYSIGHT TECHNOLOGIES

Setting upper side MUT and fixed electrodes

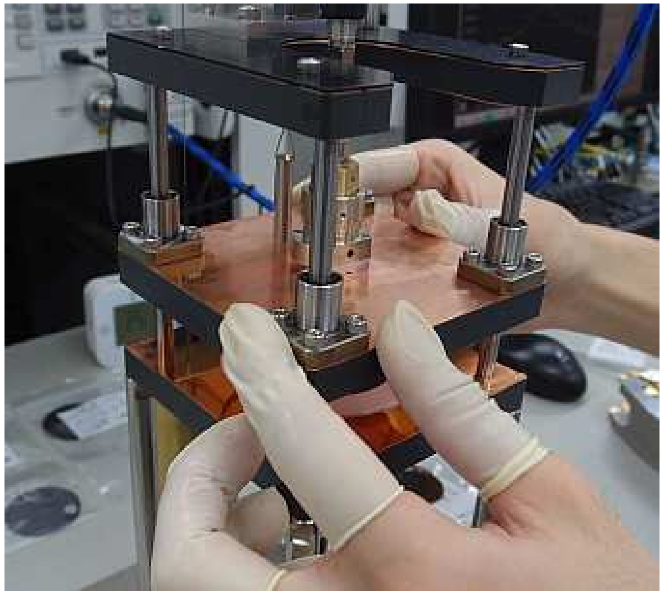
1. Set upper side sample slowly and carefully not to move the position of Cu circular disk electrode. Moving the position of Cu circular disk electrode causes un-wanted resonance and change the peak of TM0m0 resonance.



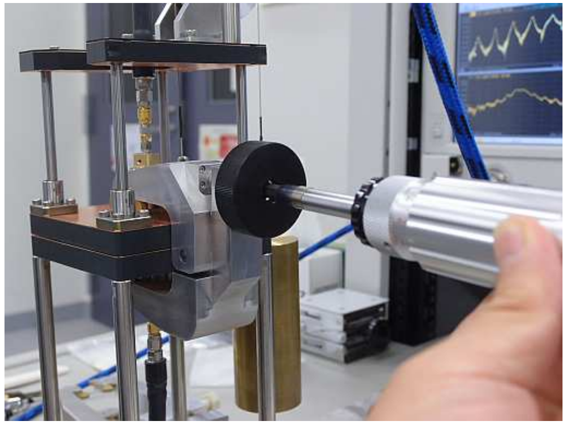
KEYSIGHT TECHNOLOGIES

Tighten firmly with a clamp and control tightening torque

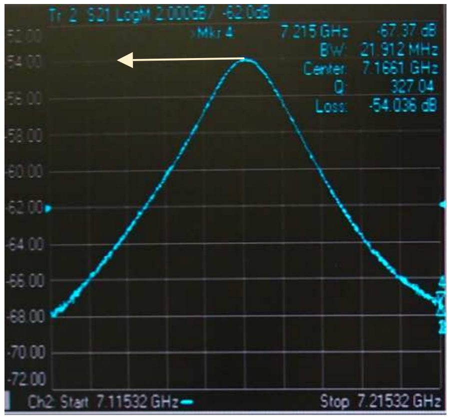
1. Close the resonator and clamp it
2. Tighten the clamp using torque wrench / torque driver.
3. Refer to the next page about deciding the proper torque for your sample. You need to check the response of resonant frequency.
4. Proper torque differs depending on how soft your sample is. You may need to measure the sample multiple times to find proper torque value



Be sure the air gap between MUT and electrodes

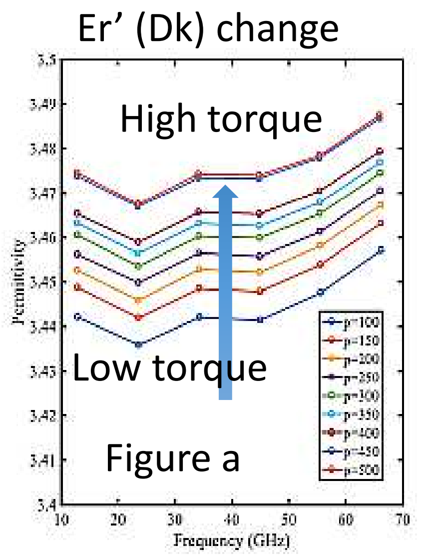


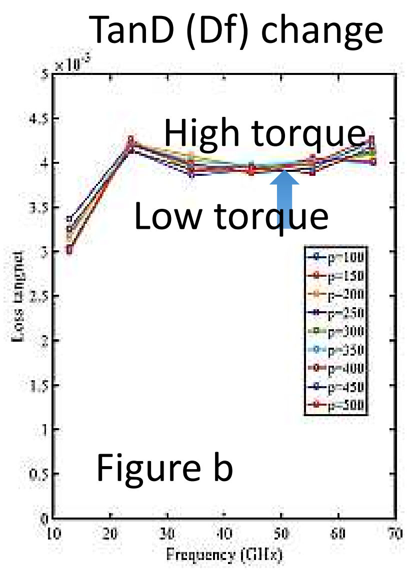
1. Enlarge the TM_{0m0} resonance peak trace to monitor the response
2. Set trigger to continuous mode
3. You can check the trace before calibration
4. Tighten the clamp by using a torque wrench / torque driver
5. When tighten the clamp, you can observe the peak frequency shifts to lower frequency because clamp push out the air between the electrode and sample
6. When the torque is enough, the peak position doesn't move anymore.
7. When the sample is warped, leave the resonator after tighten the clamp. Then resonant frequency goes down for a while and stop moving when the sample fit the resonator.

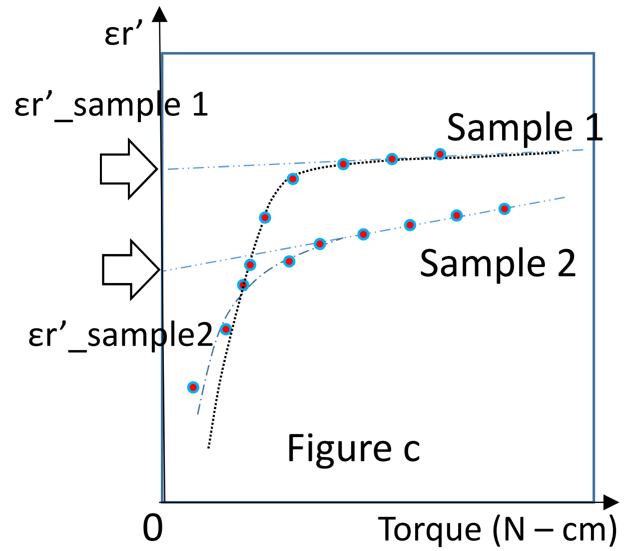


Reducing airgap shifts the resonant frequency to lower frequency side.

How to know the optimum torque







1. Set a value as a start torque to clamp, then measure samples by increasing the torque. Air gap layer becomes thinner when the torque becomes higher, so Er' (Dk) becomes higher like shown in figure a. When you increase the torque, air gap layer pushes out first, then the sample itself starts to be compressed. If the sample is a kind of soft material like polymer, the Er' (Dk) value keep changing when increasing the torque. 。
2. In this case, one suggestion is to plot the Dk value vs. torque at a specific frequency like figure c. The plot will have linear line part and curve line part. Crossing point of extrapolating the linear line and 0 torque line (y-axis) can be regarded as the Dk value of your sample.
3. Note that if you apply too much torque for the sample, the Cu center electrode will sink in to the sample. If you find clear mark of Cu center electrode on the sample after the measurement, the torque is possibly too high to measure for your sample. If you keep measuring the sample with this condition, measurement repeatability will be worse.

KEYSIGHT TECHNOLOGIES

Pre-checking the TM_{0m0} peaks

1. Confirm that you set the center Cu circular electrode properly at the center of the resonator.
2. Run the sweep and software detects TM0m0 mode from multiple peaks automatically.
3. When the Cu circular disk is not set at the center of the resonator, you can see large un-wanted resonant mode. Adjust the center electrode position to minimize the unwanted resonance.
4. If you cannot see enough peaks, confirm you set maximum coupling by rotating adjustable knob to clock-wise till it stops (page 27)

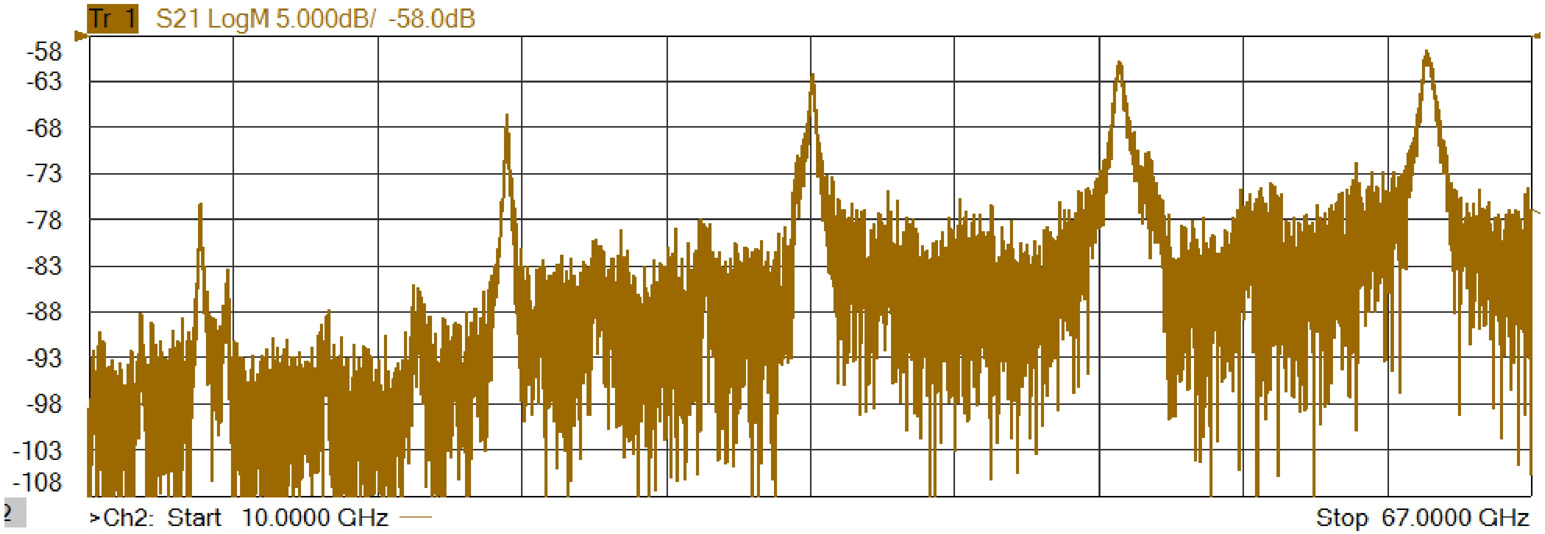
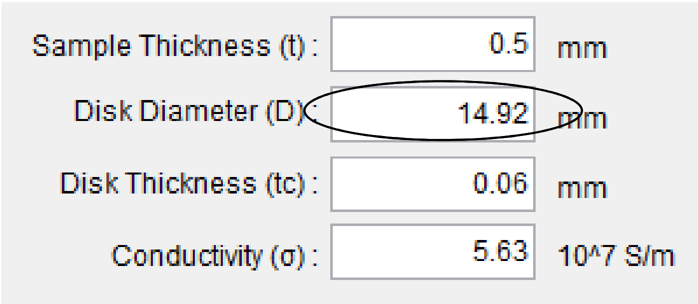


Image at ideal condition when S/N is good

Pre-checking TM_{0m0} Peak frequency

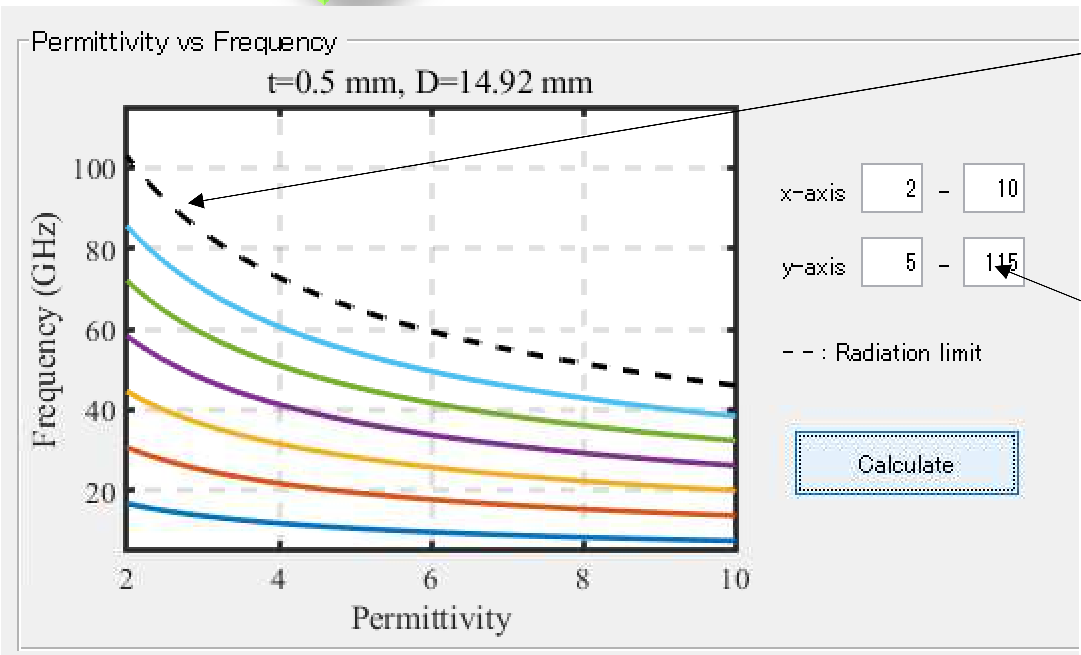


TM_{0m0} resonant frequency can be calculated rigorously.

The resonance changes according to

1. Diameter of the Cu center electrode (i.e. 15mm. The correspond value is in the attached DVD)
2. Permittivity (Dk) of the sample

Set the condition and press calculate button to show the result

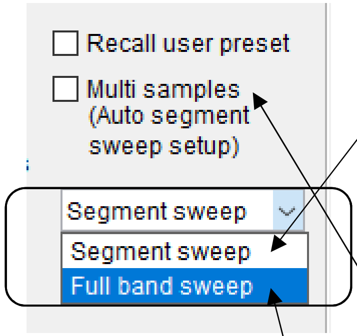


Note: This dotted line shows maximum measurable frequency determined by the sample thickness. Your sample cannot go higher than this line.

*Scale of the graph can be set here

KEYSIGHT TECHNOLOGIES

3 – Set sweep condition: Select sweep mode



1. Segment Sweep:　Standard.

Use segment sweep. Select this mode when using coaxial test port VNA

Setting option

☑**Multi Samples (Auto segment sweep setup)** :

Select this if you want to set segments to measure multiple different samples. By repeating the sample measurements, the software set segment sweep settings so that it can measure different peak samples. You can set the segment first, then take calibration after that to get the final result.

2. Full Band sweep:　**not using segment sweep**

1)When you do narrow band measurement or 2) when you use mmWave waveguide (banded) measurement. Not recommend to select this in standard or wideband measurement using coaxial VNA because too much points makes measurement very slow.

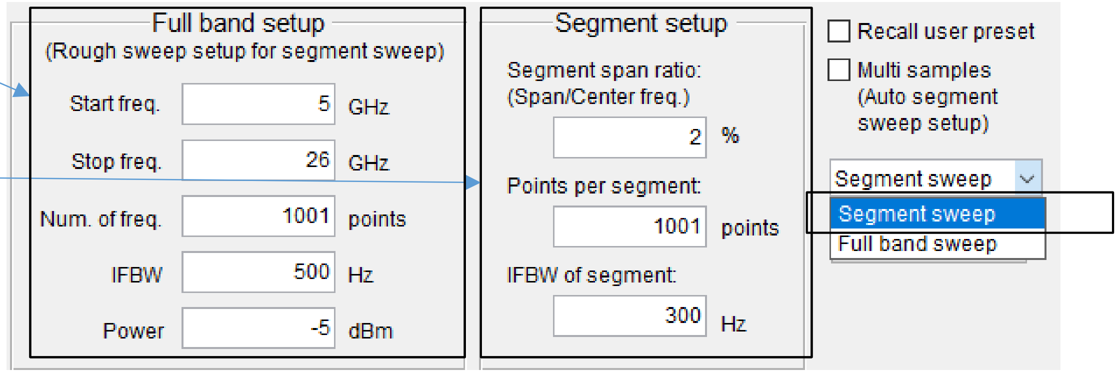
Set sweep condition

(1) Set full span measurement condition to grasp the overview of sample response

1. Sweep range
2. Number of point (Nop)
3. IFBW
4. power
5. Span of each segment
6. Nop of each segment
7. IFBW of each segment
8. Sample thickness (t)
9. Disk electrode diameter (D)
10. Disk electrode thickness (tc)
11. Conductivity of electrode (σ)
12. Uncertainty of sample thickness (t)
13. Uncertainty of D
14. Uncertainty of tc
15. Uncertainty of σ
16. Freq. dependency of σ

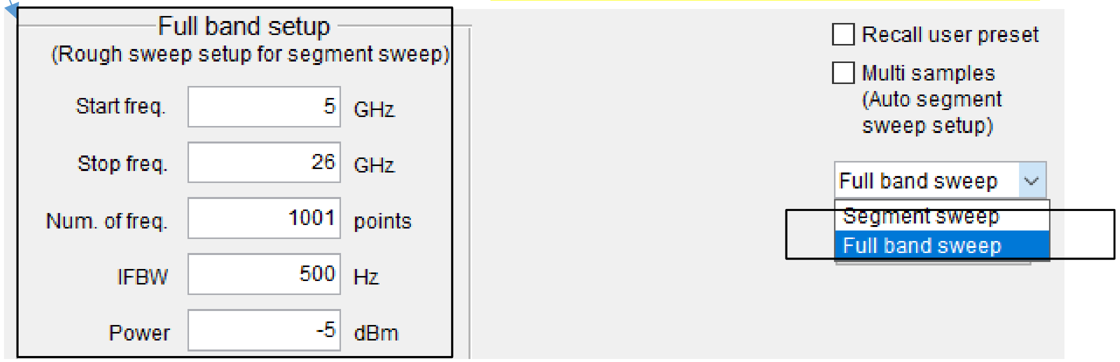
[Segment sweep] when applying segment sweep (standard)

Coarse setting for full band, but precise measurement at each segment



[Full band sweep] when not using segment like banded solution

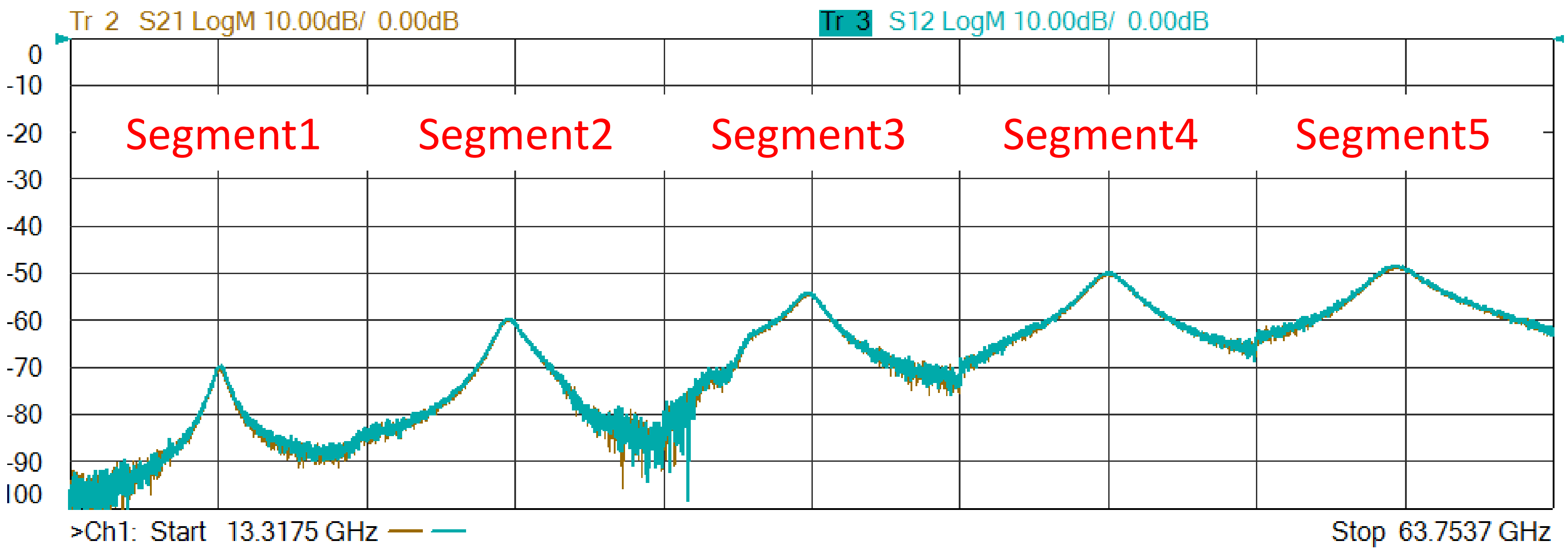
Set to measure precisely in full band



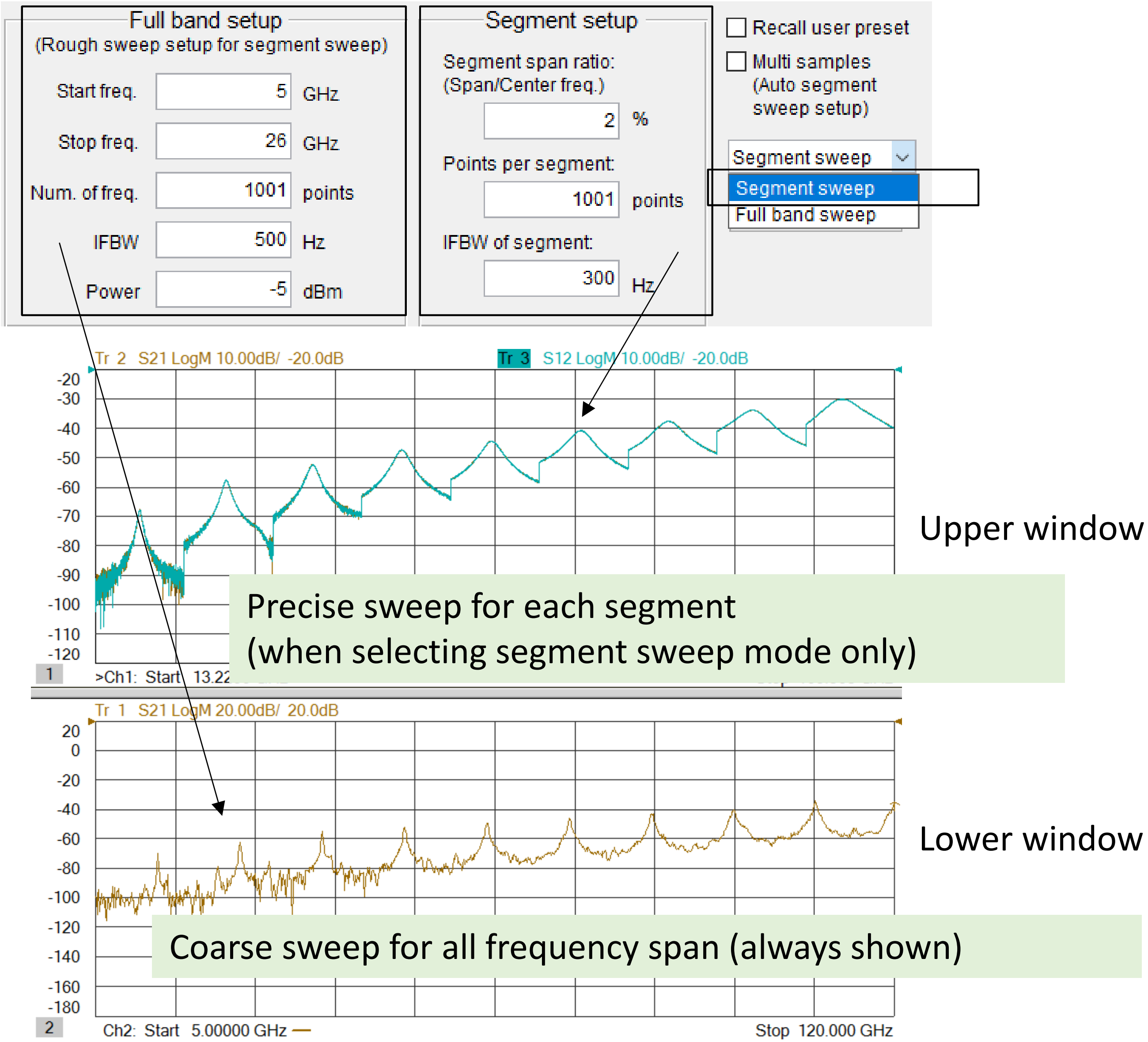
Setting of the segment sweep

Conduct multi-segment measurement like measuring TM_{010} by segment 1, TM_{020} by segment 2.. This approach can reduce total measurement time by measuring only the meaningful area.

Software sets segment only to the detected resonance peak. If the software cannot detect a resonance peak, you need to add it manually to measure, or that peak won't be measured.



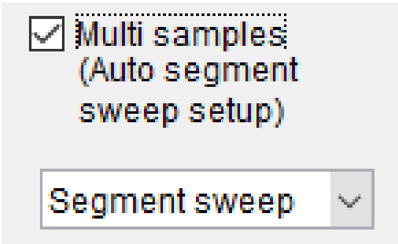
Setting Segment sweep



Auto segment span setting for multi Samples

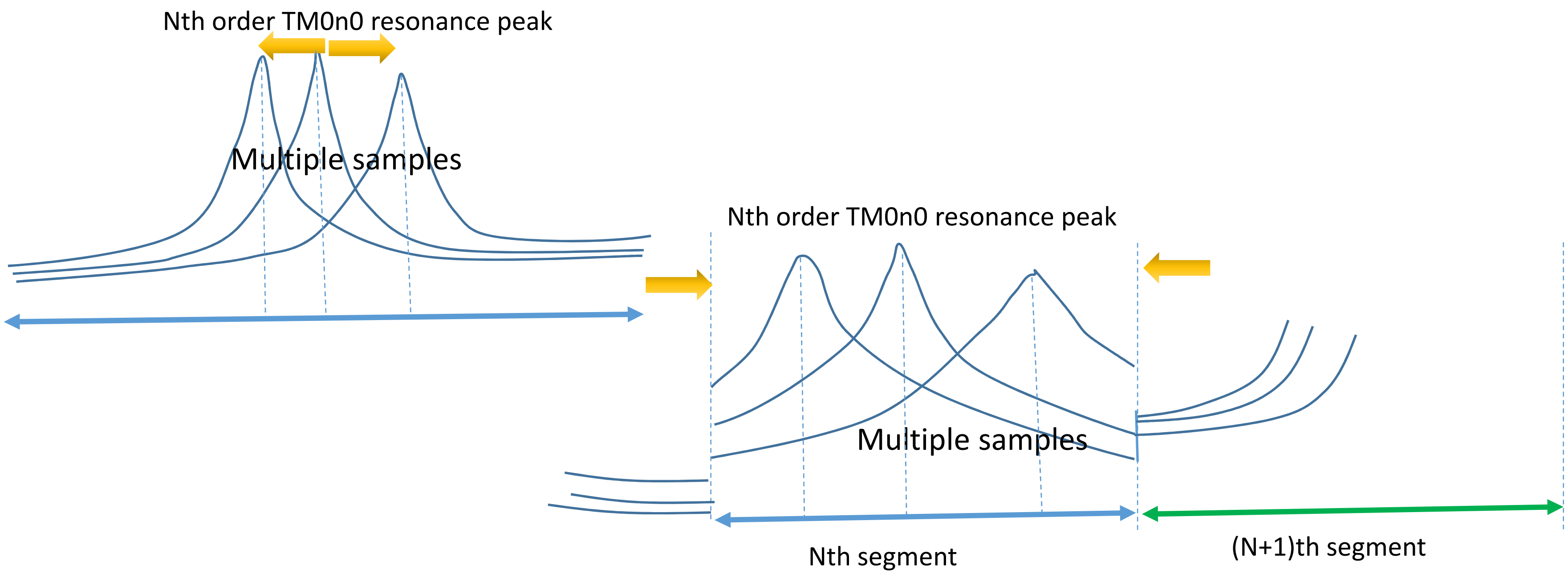
set segments automatically when measuring multiple samples

Purpose of this mode is to set proper segments to measure multiple samples which have different frequency shift and peak position before taking full two port calibration. (Otherwise, you have to take time taking calibration if one of the peak shifts out of the segment sweep range.)



STEP1 measure multiple samples in full span mode without setting segments and detect multiple peaks

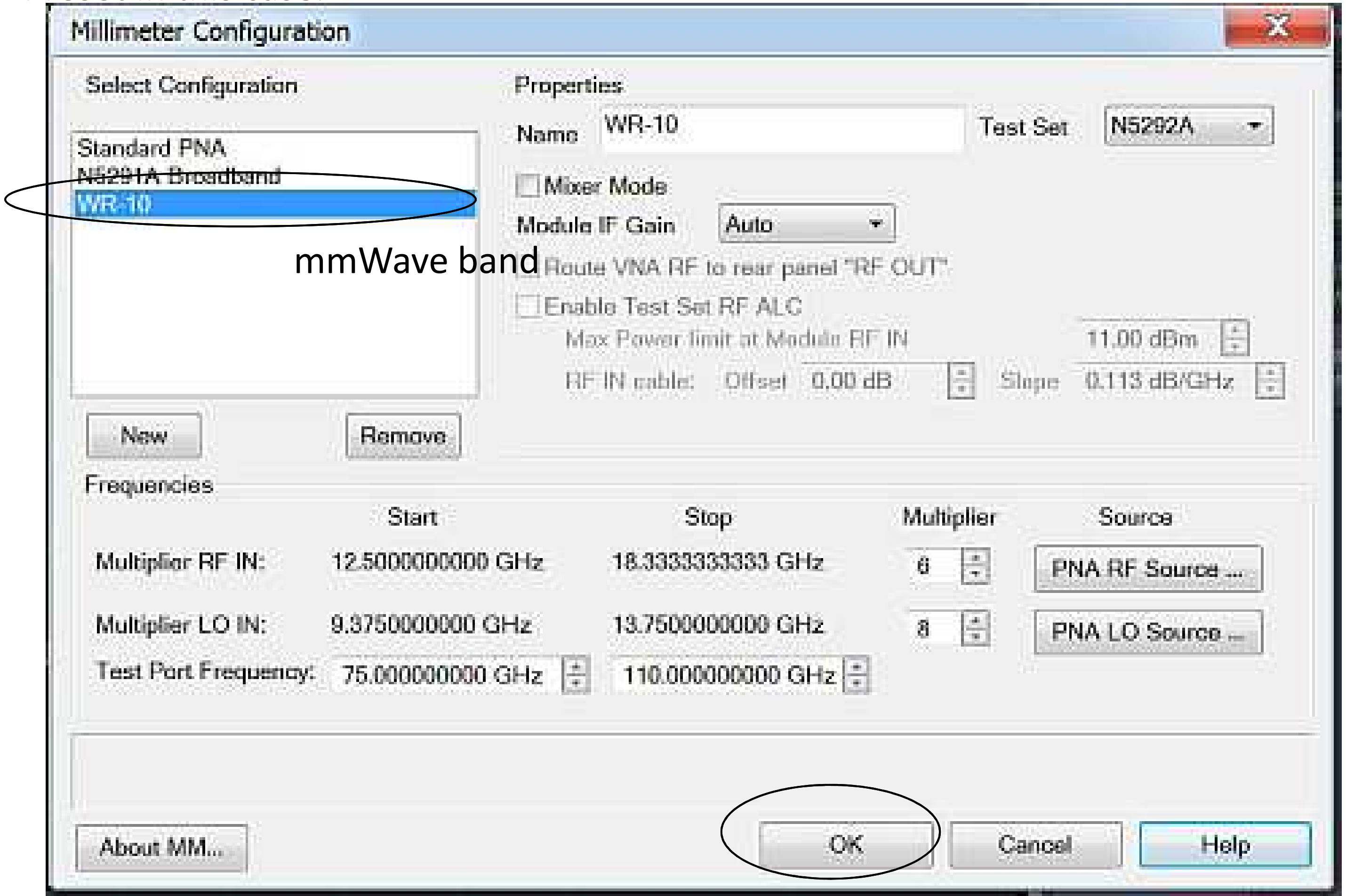
STEP2 Set and define multiple segments so that all peaks are located in these segments



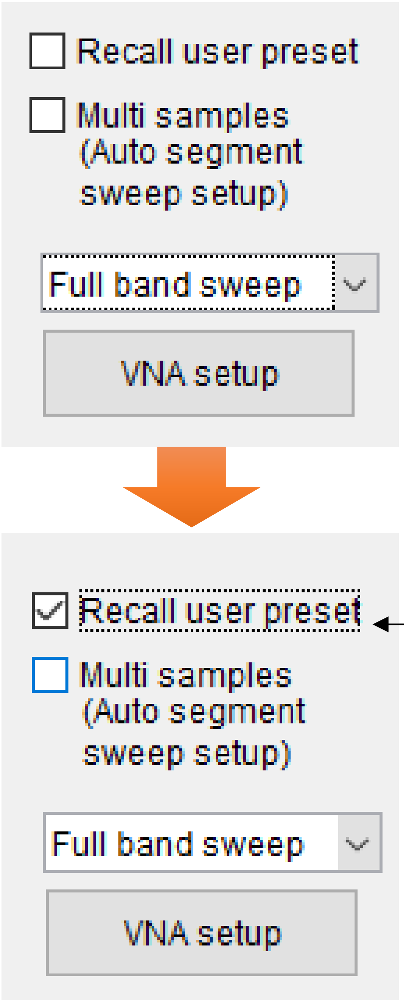
Coax. & Waveguide with testset controller

When using mmWave test set controller

If your system uses N5261A or N5292A test set controller, you can configure mmWave VNA system using Millimeter Configuration menu below. Once you set mmWave or Broadband mode, the PNA works as mmWave VNA after power on until you change the mode intentionally. You don't need to set User Preset in this case.



Direct connection condition



1. **Coaxial VNA mode:** No need to prepare/recall User preset. Factory preset is used when preset.

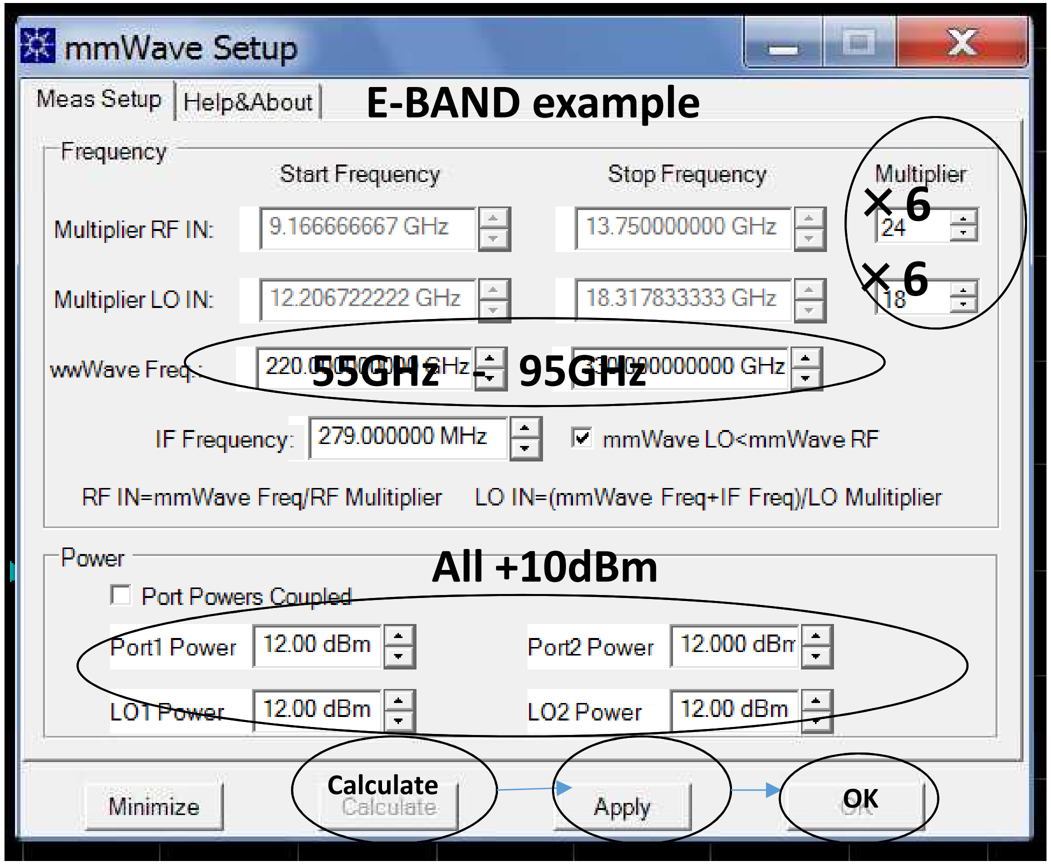
2. Using mmWave testset controller: NO need to prepare/recall User preset. You need to define/change the operation mode using mmWave configuration menu.

3. Direct connection mmWave connection
Use mmWave setup macro (next page) to operate. You have to create user preset and check to Recall user preset on the BCDR program

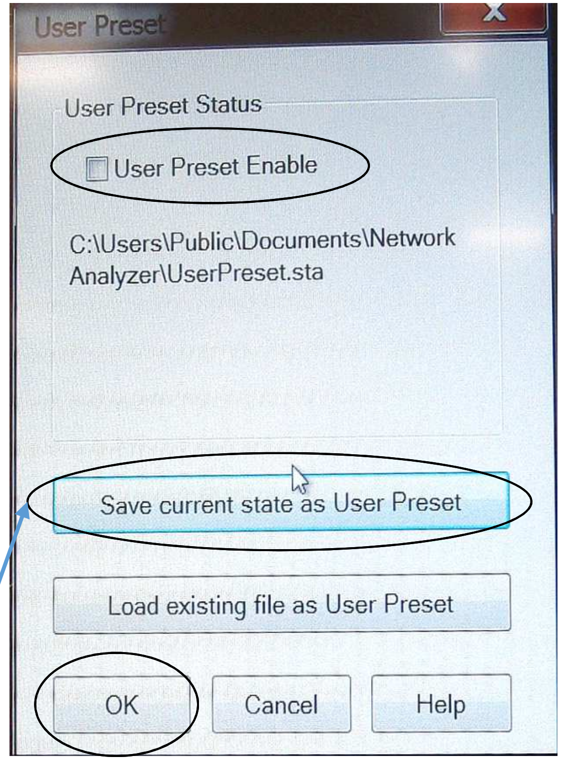
Refer to the PNA help for the detail operation

Direct connection mmWave band using "user preset" file on PNA

WAVEGUIDE BAND **Utility 〉 Macro 〉 [mmWave].**



Operate on the PNA firmware



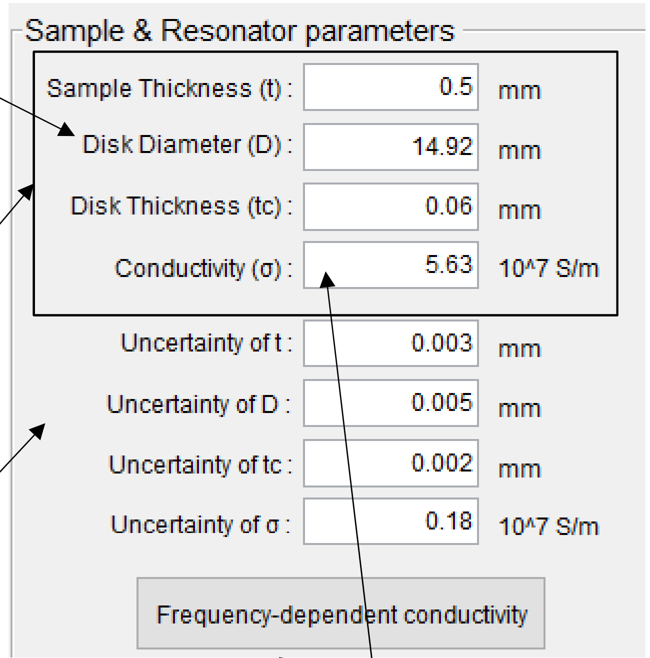
Some number may differ. Refer to your system's setup guide for detail. You have to create and save "User Preset" file.

Setting MUT and electrode condition (optional)

(2) You can input Uncertainty data to calculate the effect of dimension uncertainty

1. Sweep range
2. Number of point (Nop)
3. IFBW
4. power
5. Span of each segment
6. Nop of each segment
7. IFBW of each segment
8. Sample thickness (t)
9. Disk electrode diameter (D)
10. Disk electrode thickness (tc)
11. Conductivity of electrode (σ)
12. Uncertainty of sample thickness (t)
13. Uncertainty of D
14. Uncertainty of tc
15. Uncertainty of σ
16. Freq. dependency of σ

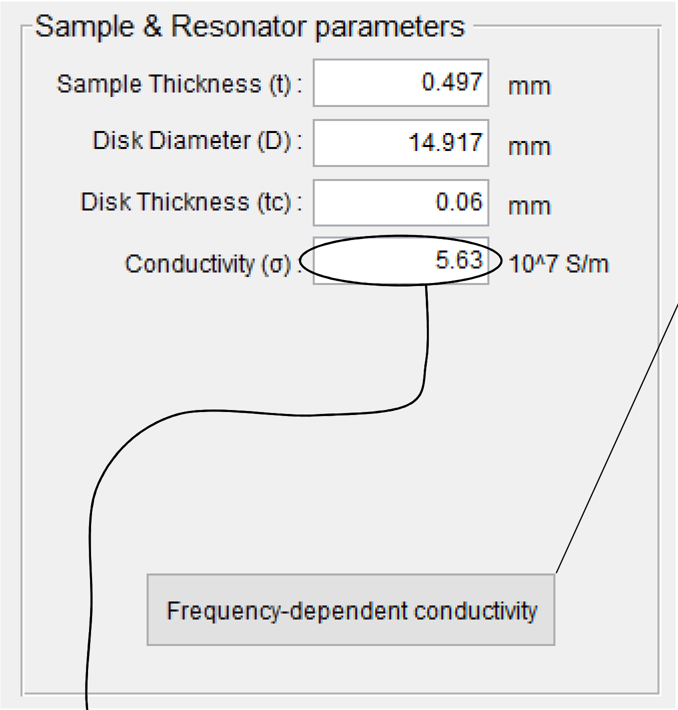
Disk Diameter:
Input the actual disk diameter (provided in DVD). Input range is from 11.5 mm to 18.5 mm. When you want to change the default value, change the value in “initialentry.txt” file (page 19)



σ: Input electrode surface conductivity, either international standard copper value or actual value. This value is used to compensate tanδ (Df) result

KEYSIGHT TECHNOLOGIES

File format for frequency-dependent conductivity



Designate prepared file when opening the file dialog.

Conductivity.csv (Arbitrary file name with csv format)

Frequency (GHz)	Conductivity (10^7 S/m)	Unc. of Cond. (10^7 S/m)
10	5.63	0.18
20	5.63	0.18
30	5.63	0.18
40	5.63	0.18
50	5.63	0.18
100	5.63	0.18
120	5.63	0.18

Shows N/A when recalling the frequency-dependent conductivity data

Format: CSV file

File structure: 1st line shows parameters, data starts from 2nd line

Parameters:

1st: Frequency (GHz), 2nd Conductivity (e7 S/m), uncertainty (10^7 S/m)

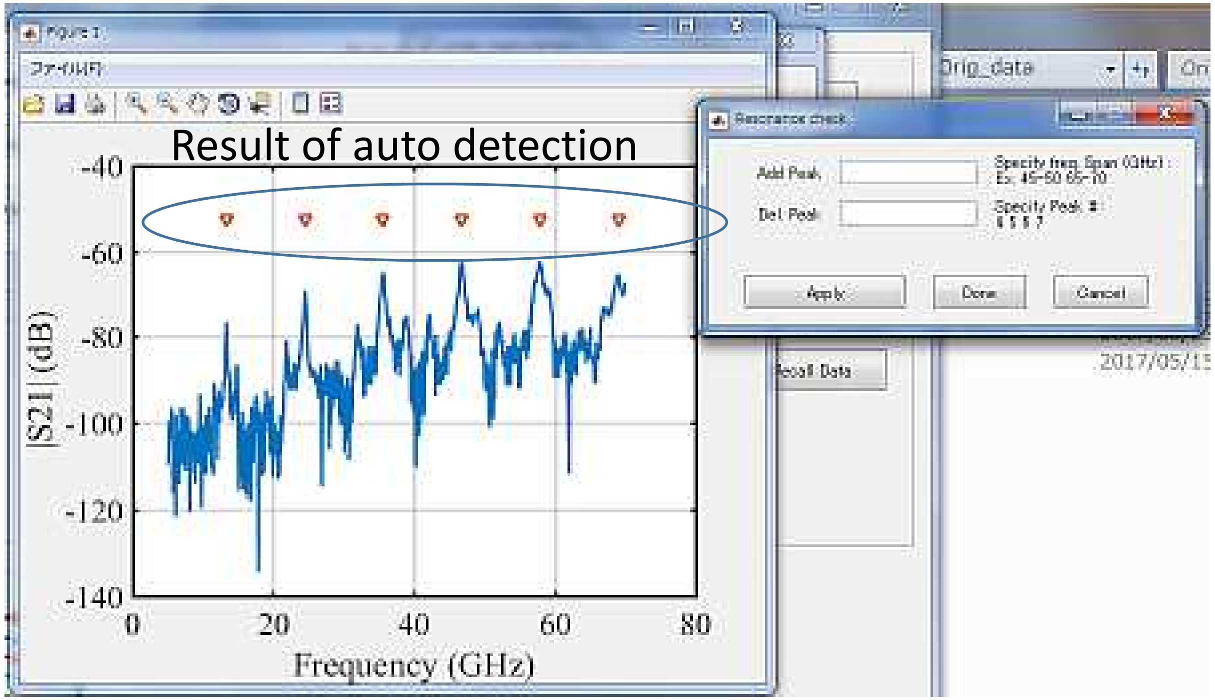
Number of point: Arbitrary

Data is interpolated between the frequency points

Automated TM_{0m0}mode Peak search

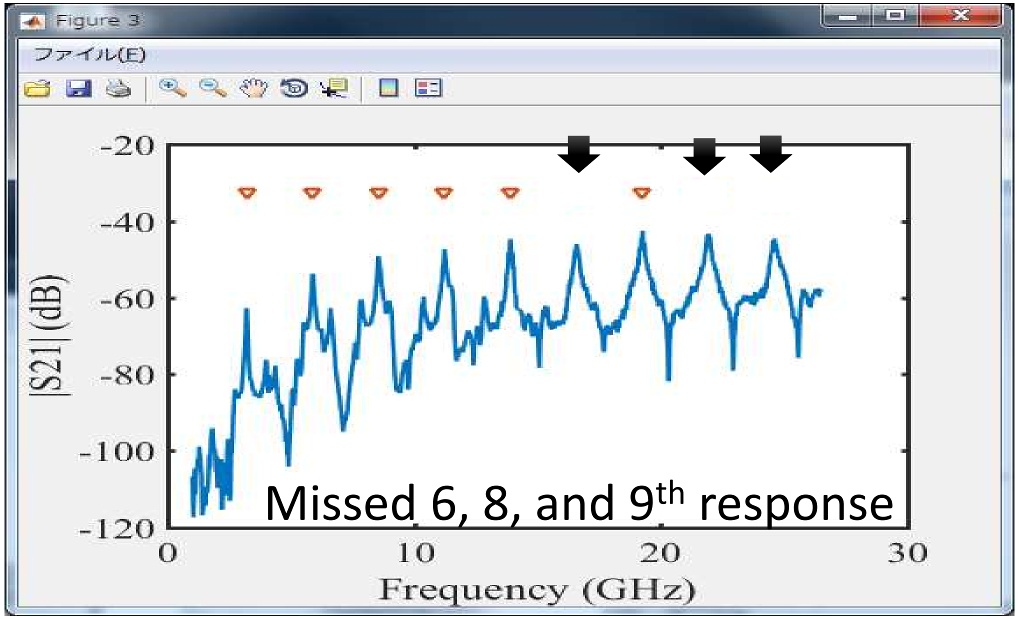
Press [VNA setup] to start pre-check measurement using Ch2 (full span mode). The program detects multiple TM0m0 response and show it on the display with marker. (This procedure takes a time. Please wait next actions till the results are shown correctly.)

If not all TM0m0 response is detected, you can add (or delete if you don't need it) resonant peaks manually by inputting frequency range.



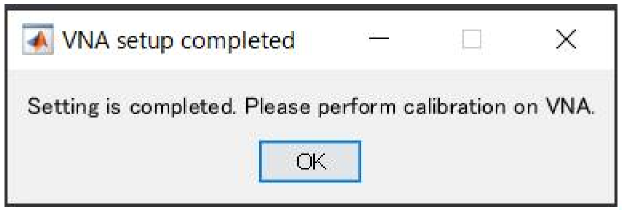
Example that program missed to detect TM_{0m0} resonance – when the peak is lower than other peaks

In case the program missed to detect some peaks, add or delete them



Add or delete peak and press apply

After finishing adjustment or you don't have any edits, press Done to finish.



KEYSIGHT TECHNOLOGIES

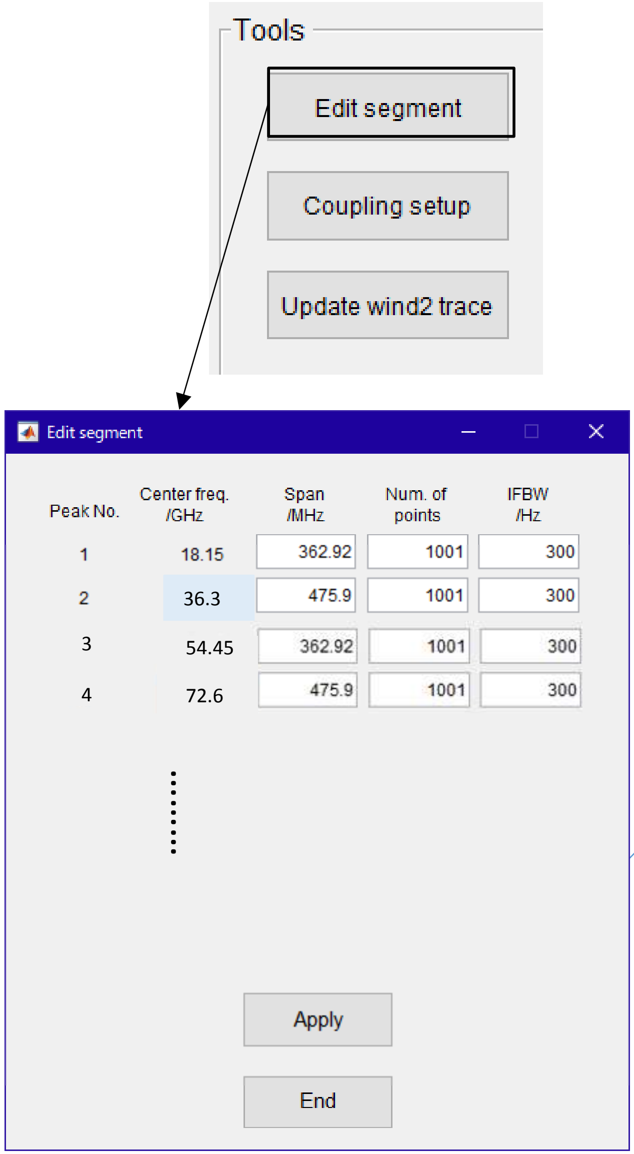
How many peaks you need to measure?

If your trace is in banded system and doesn't have TM_{010}, you can still get the measurement results.

When the trace has equal to or more than two resonant peaks, BCDR program can calculate the result without initial value, because the program can estimate it from the difference of the multiple peaks.

When the trace has only one resonant peak, users have to input initial value of dielectric parameter to calculate the result.

Edit sweep condition on each segment (optional)



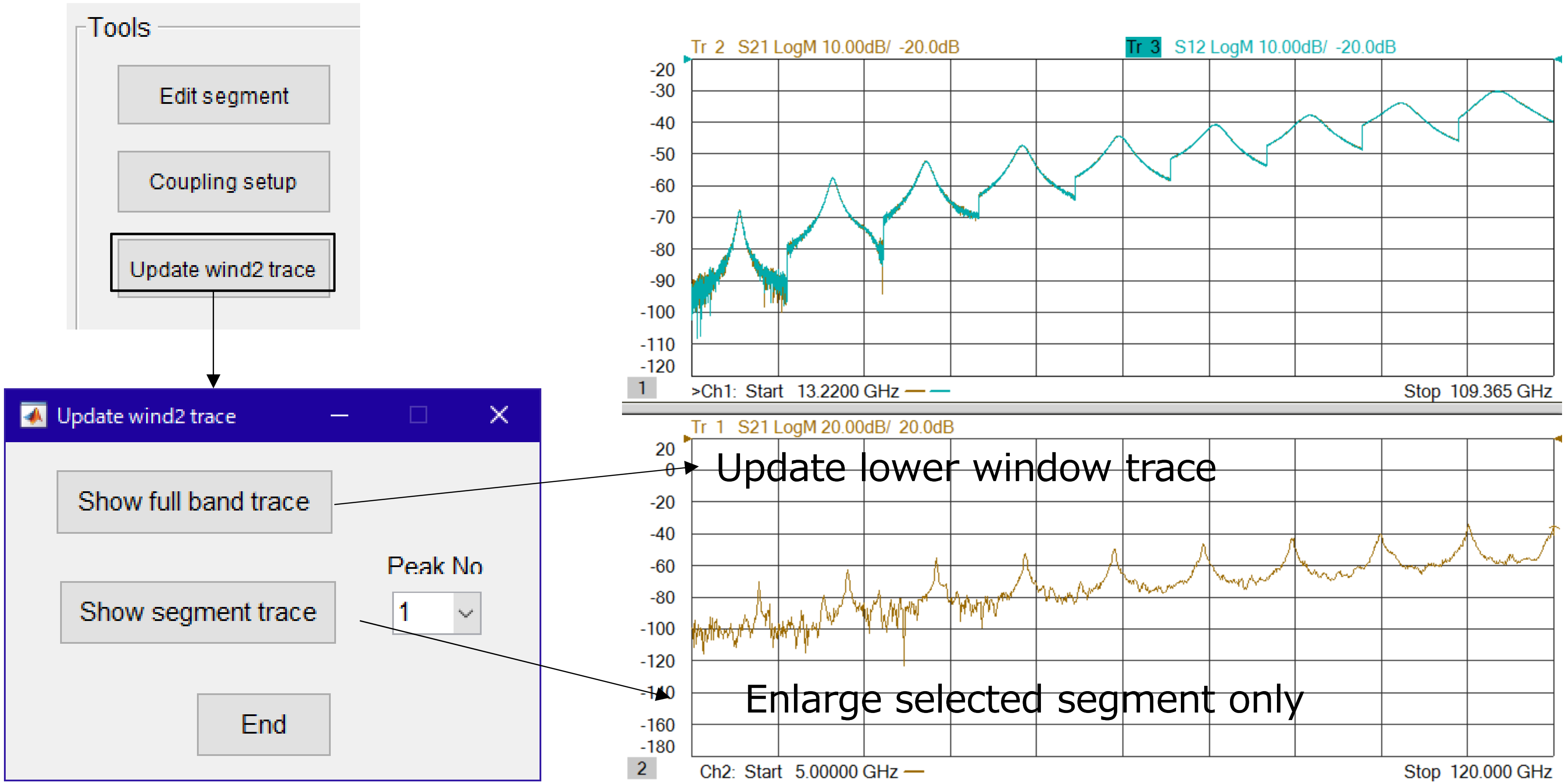
Press edit segment and select a segment to edit

Each resonant peak has different value.
You can set a particular segment to set

A. Narrow IFBW
B. Same NOP
C. Narrow frequency span

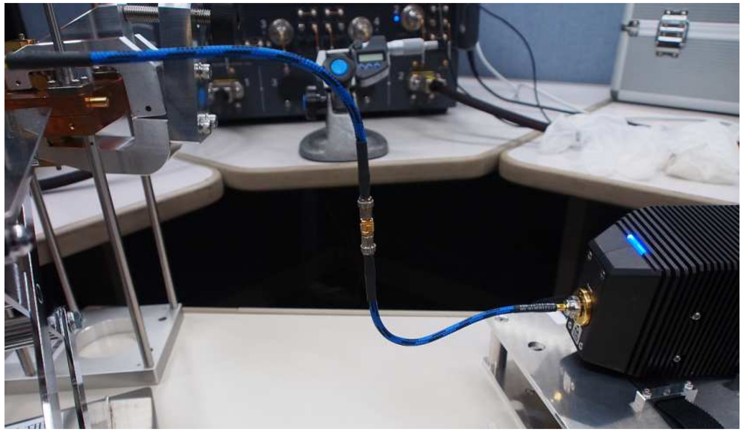
for example. Press Apply to reflect the setting.

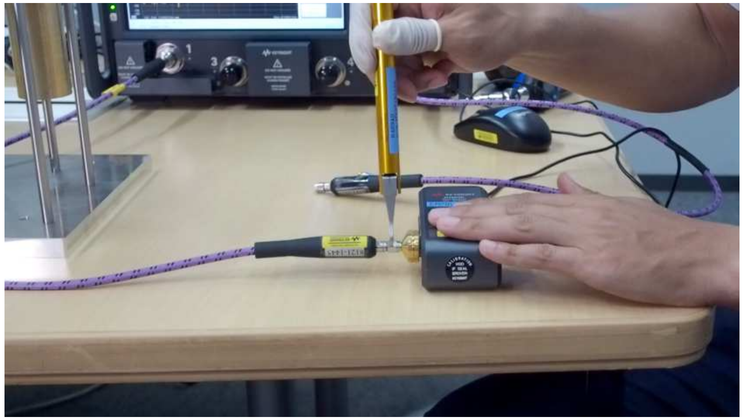
Update window2 trace

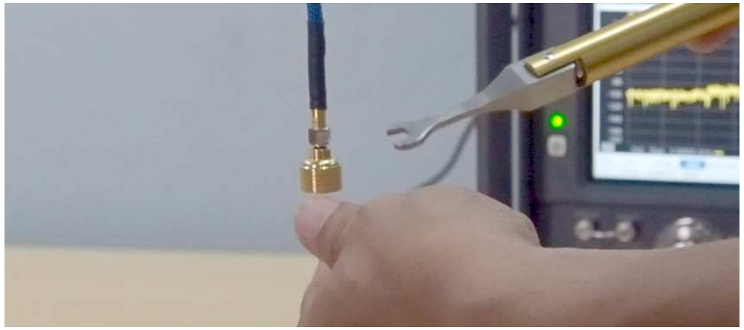


4. Calibration (manual operation)

Disconnect RF cables from the BCD resonator
and perform 2 Port Full Cal at Upper window trace (Window1/Channel 1).





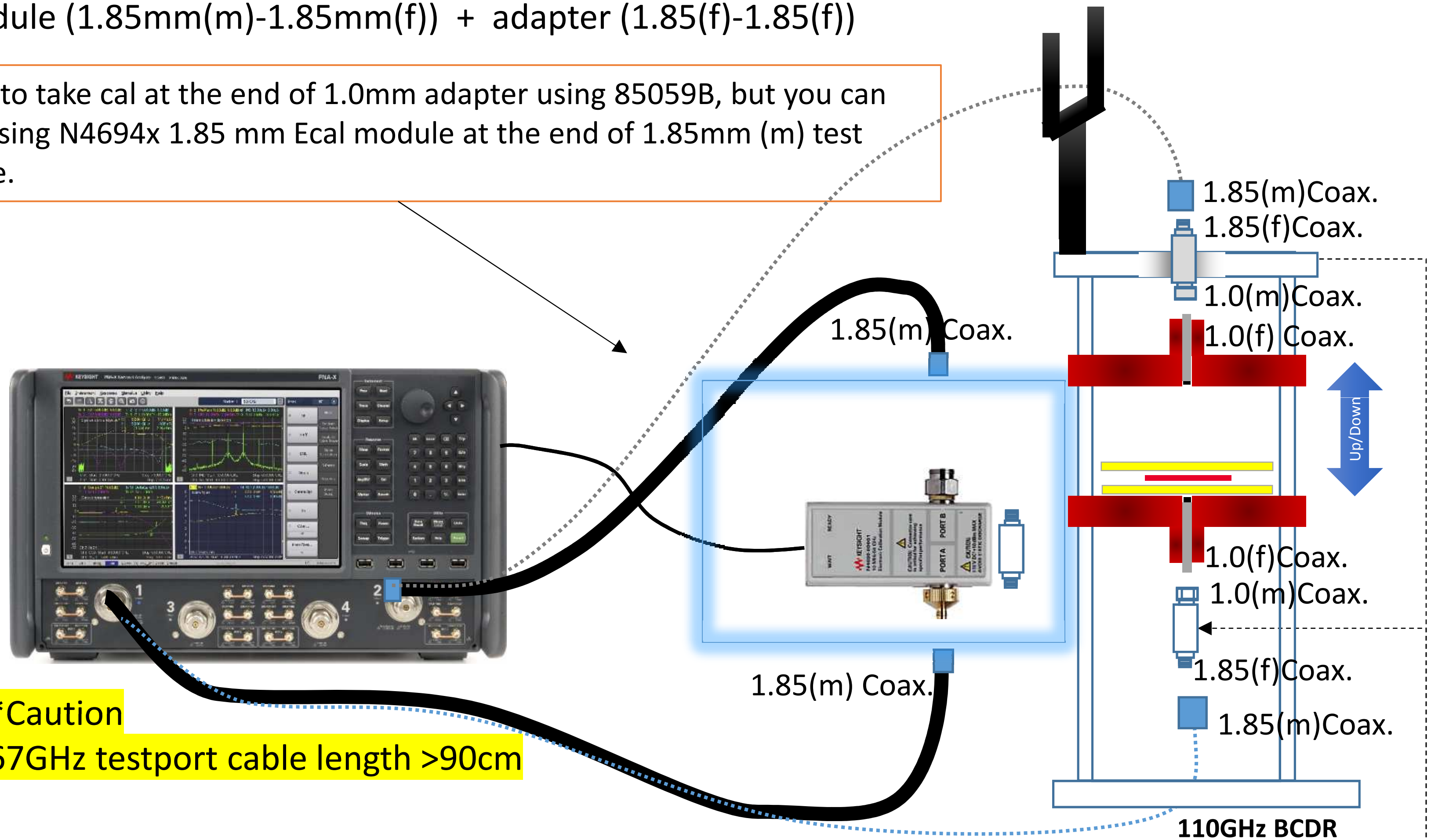


Calibration using an Ecal module

Example 1: 67GHz COAX.BAND

ECal Module (1.85mm(m)-1.85mm(f)) + adapter (1.85(f)-1.85(f))

*It's best to take cal at the end of 1.0mm adapter using 85059B, but you can take cal using N4694x 1.85 mm Ecal module at the end of 1.85mm (m) test port cable.



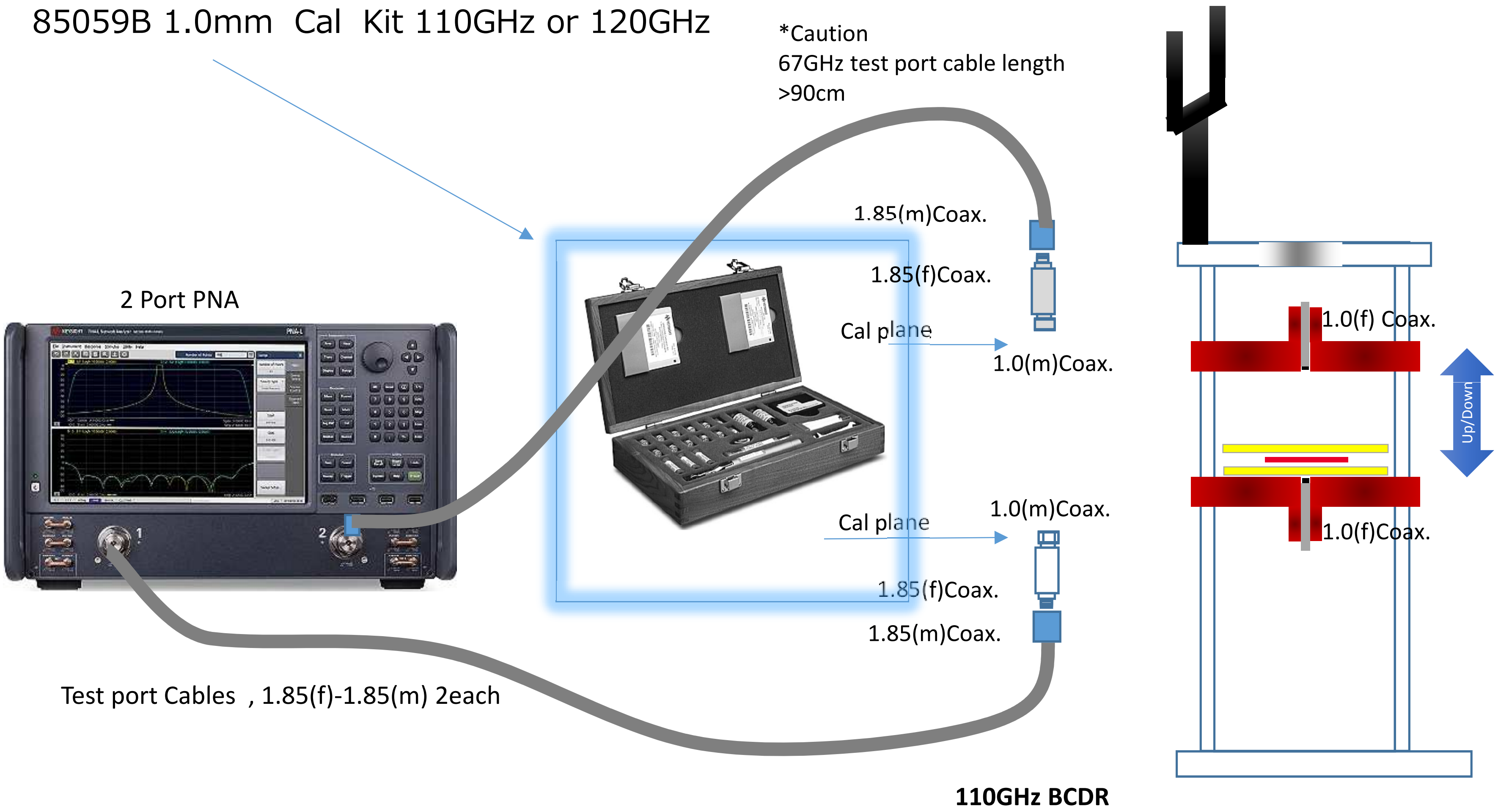
*Caution
67GHz testport cable length >90cm

11921G Coax. adapter
1 mm(m)—1.85 mm(f)

KEYSIGHT TECHNOLOGIES

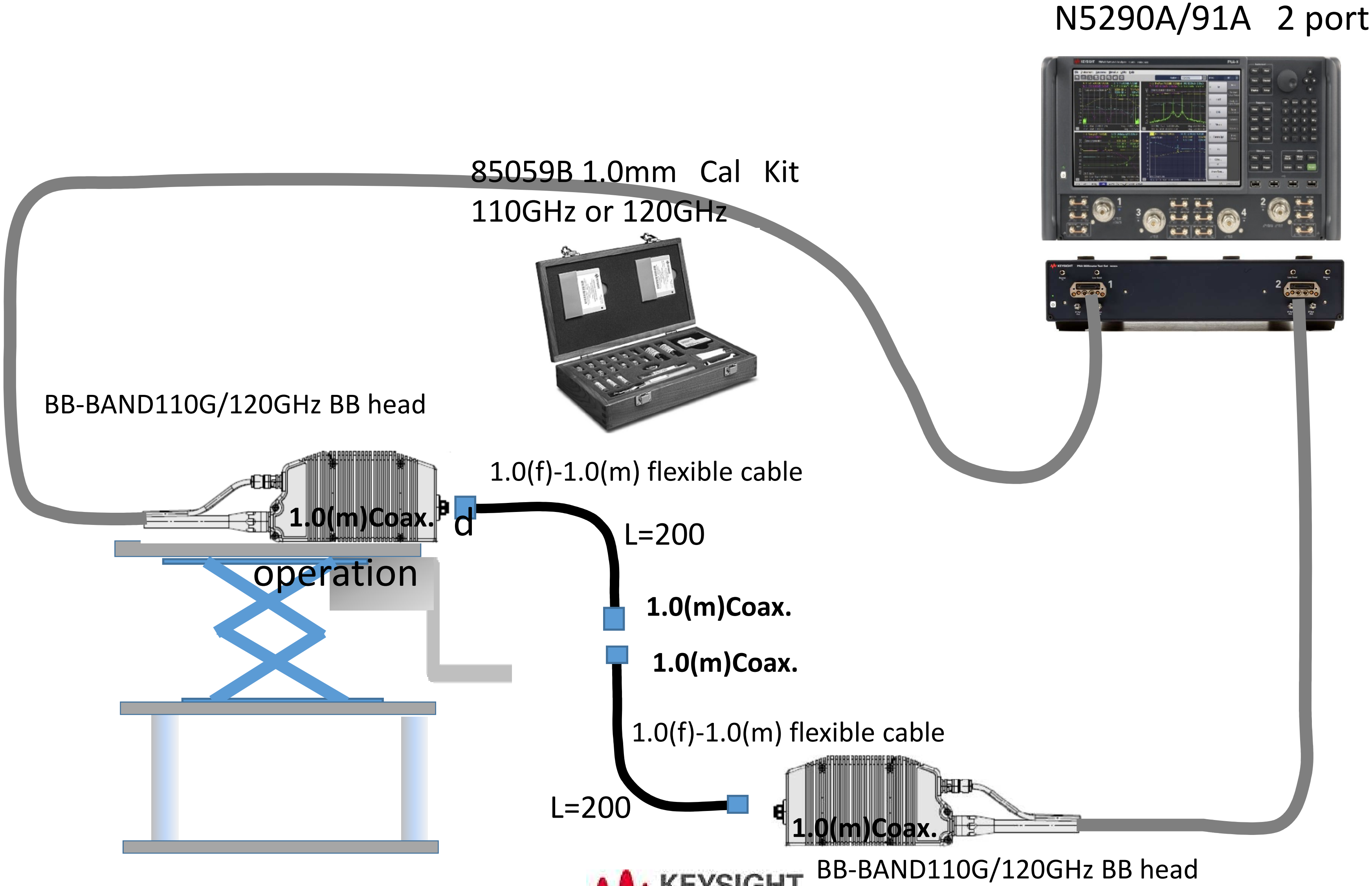
Calibration using the 85059B mechanical cal kit

Example 2: 67GHz COAX.BAND



Calibration using the 85059B mechanical cal kit

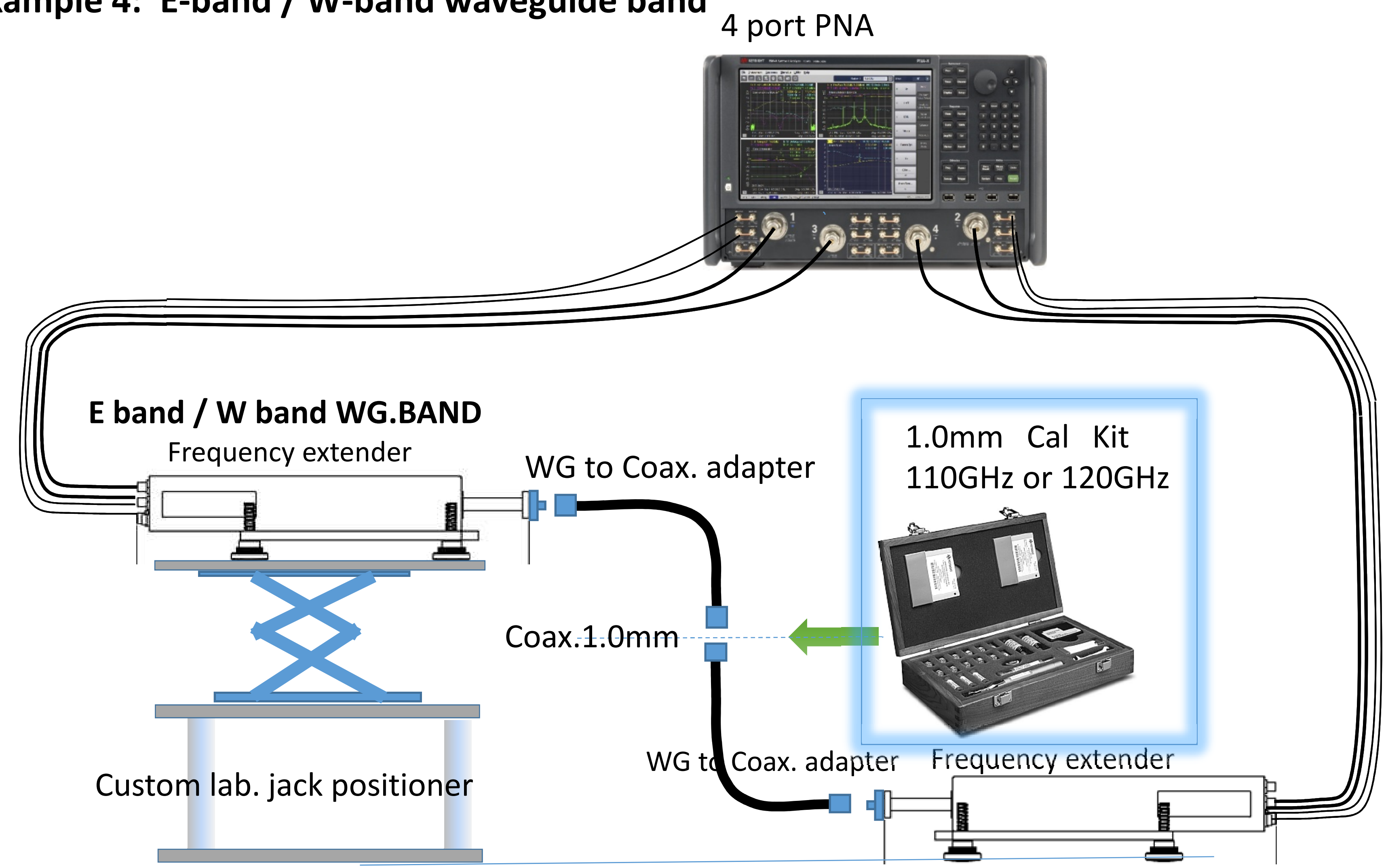
Example 3: 110GHz / 120GHz COAX.BAND



KEYSIGHT TECHNOLOGIES

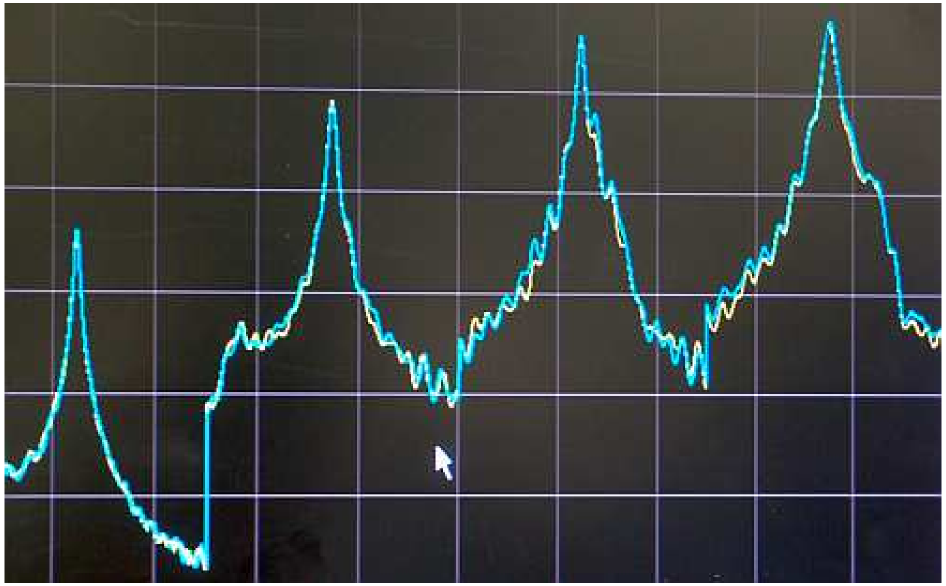
Calibration using the 85059B mechanical cal kit

Example 4: E-band / W-band waveguide band

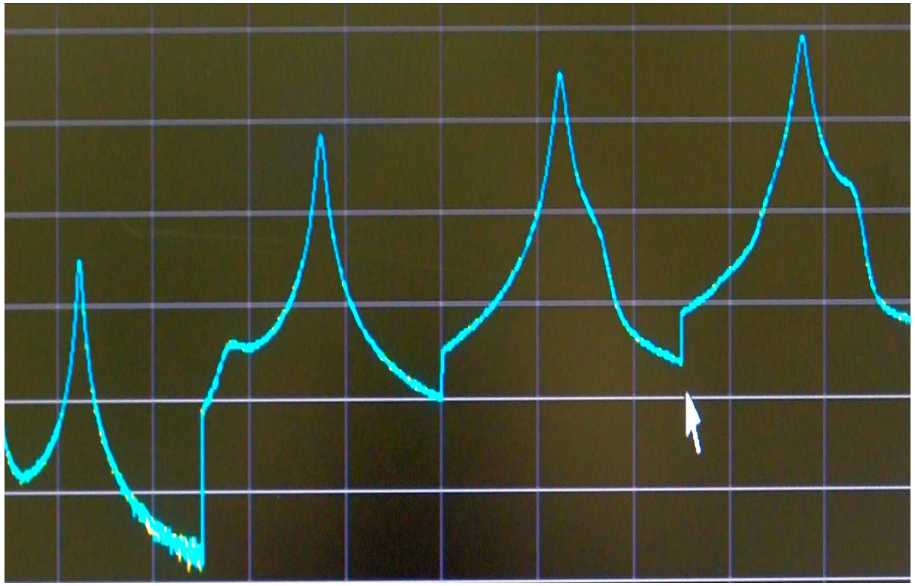


Why you need 2 port full calibration?

This resonator has low impedance matching by its exciting method, so you will observe ripple effect by multiple reflection. This is more obvious when the sample has relatively higher loss.
Full two port calibration reduces the error coursed by this mismatch and can take more accurate result.



Response before calibration



Response after calibration

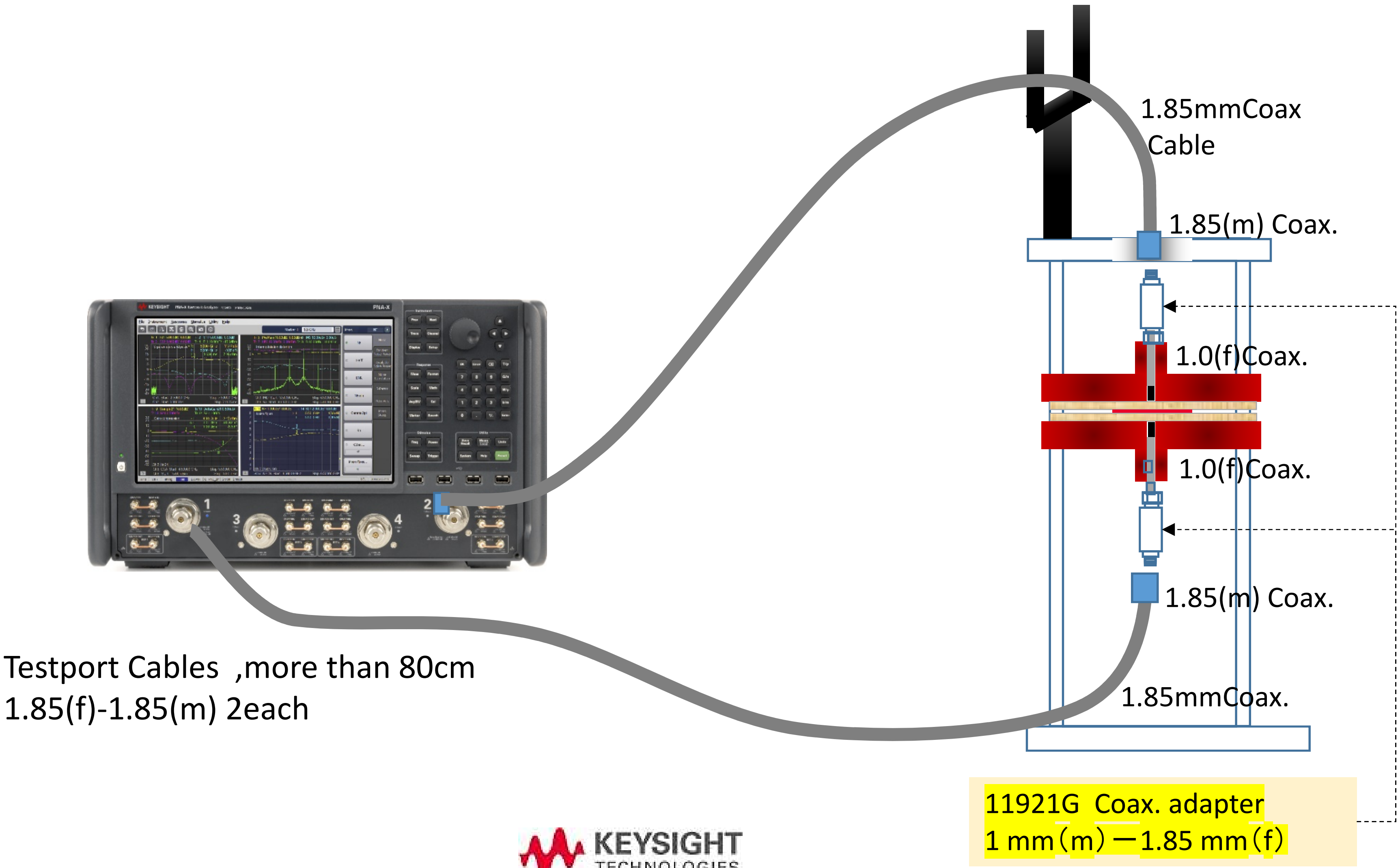
Note for accurate and stable operation;

- Do not touch test port cables after calibration
- Maintain the environment temperature as stable as possible
- Save setup file with calibration data using PNA menu > File > Save state as.. Menu before making measurement

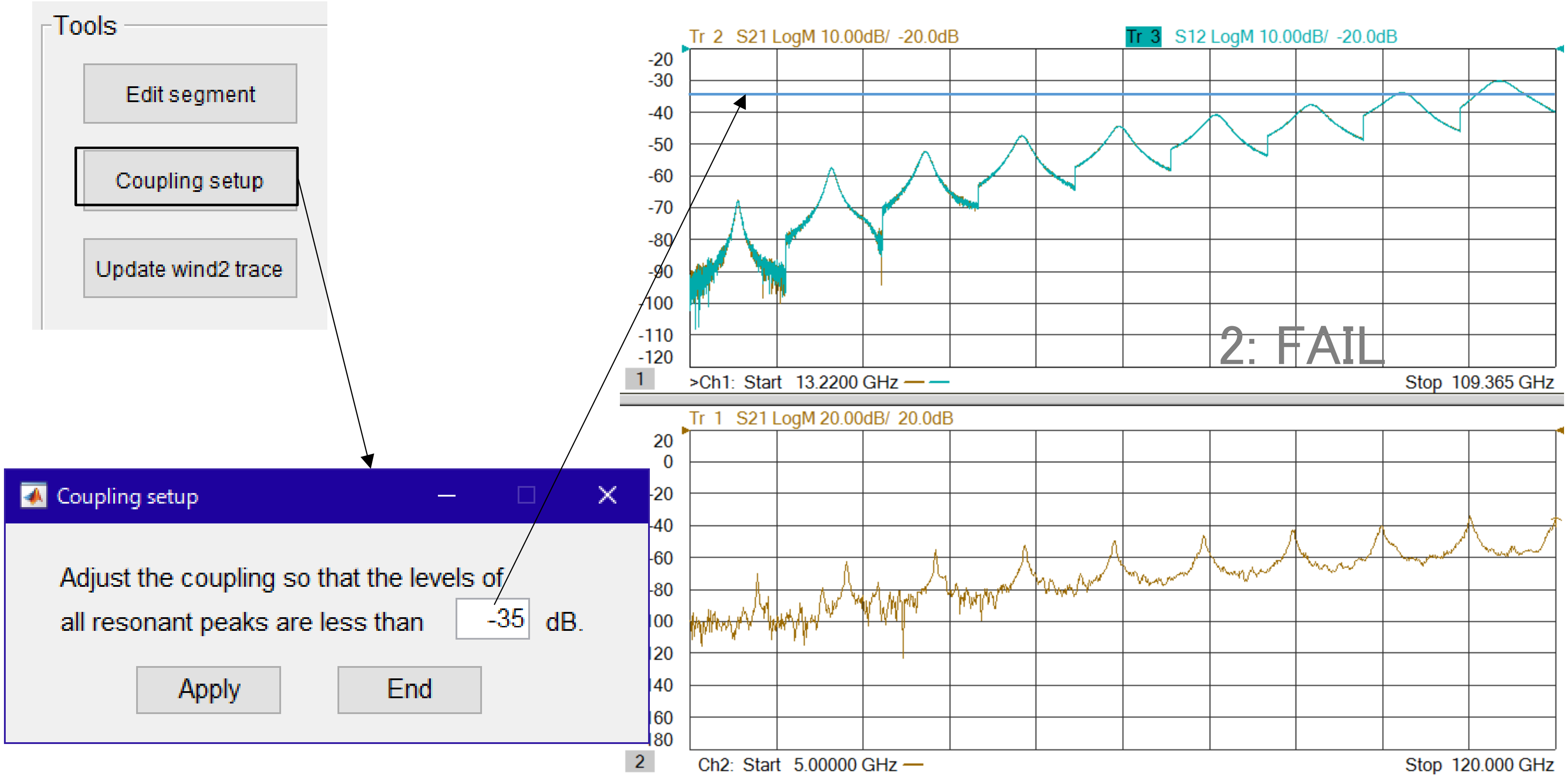
KEYSIGHT TECHNOLOGIES

Reconnect cables to fixture after calibration

In case of COAX. BAND



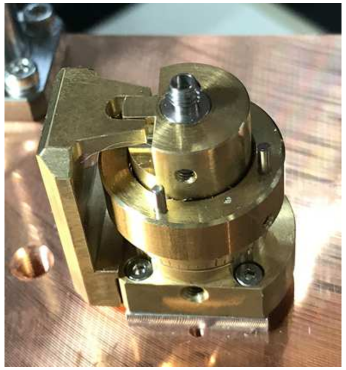
5. Coupling setup after calibration



Before the measurement, check that all resonant peaks don't' exceed -35 dB (recommended level)

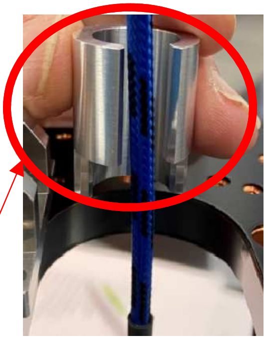
Adjusting coupling

Note: This procedure is only when you need to adjust the coupling level, and you don't need to do this adjustment every time. The coupling part has precise and fine structure, so take dare NOT TO OVER-ROTATE to avoid damage

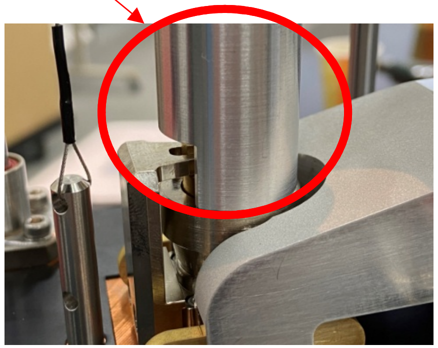


- Adjusting resonator coupling so that the peak value falls between -70 dB to -35 dB

1. You can find adjust knob at the connector part of upper and lower resonator electrode
2. Turn CCW the upper and lower know slowly to check the peak value and adjust it. (Max 4 rotation / 2mm)
3. **Turn both upper and lower knob approx. same amount**
4. Again, do not cause over rotation, or the resonator may be damaged. Turn the knob slowly and carefully.

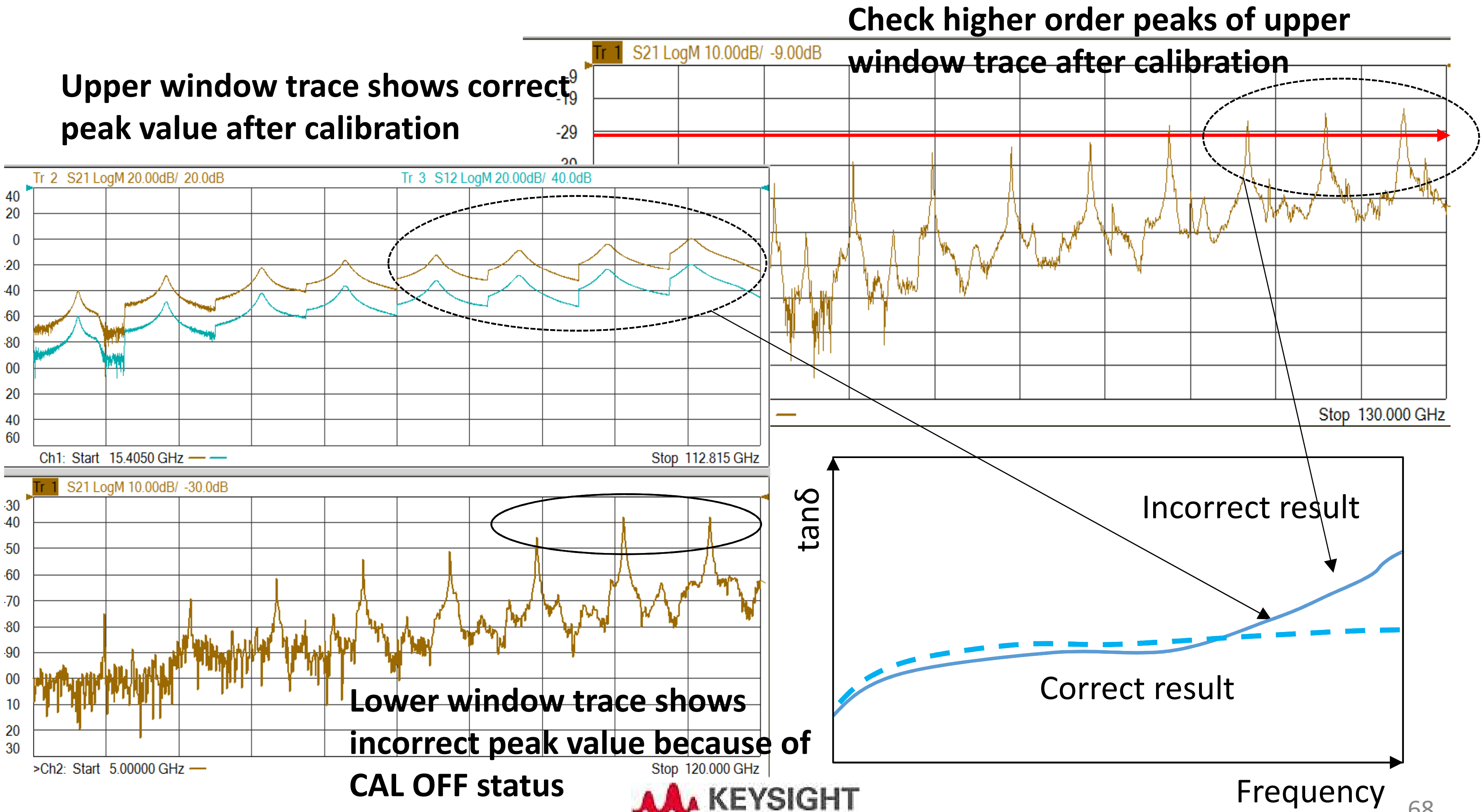


Use a socket adapter to rotate the knob with clamp closed



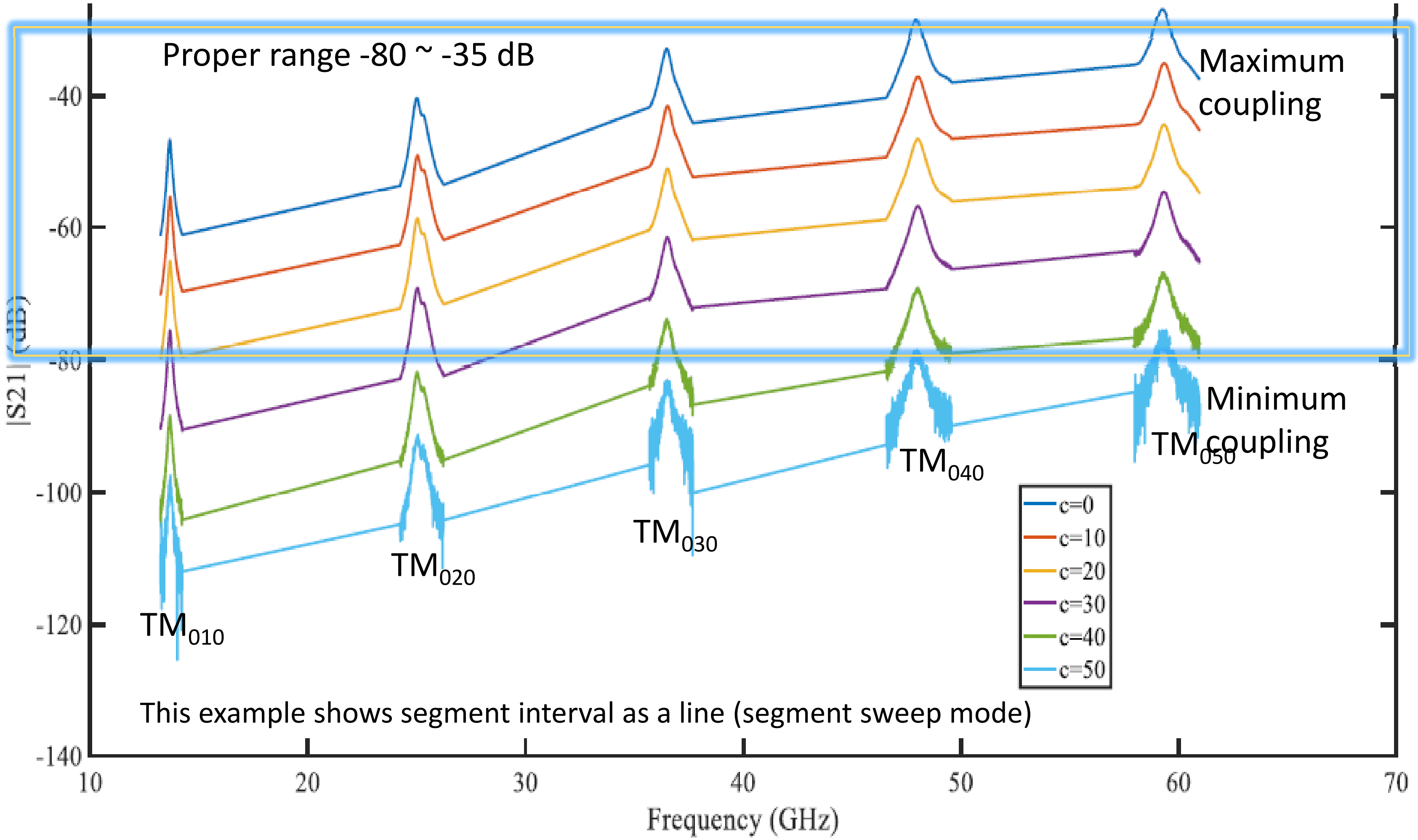
Adjust coupling – When the peak is too high after cal

Adjust the resonator coupling so that the maximum peak value is less than -35. Failing the adjustment causes incorrect result of tanδ (becomes higher loss) because Q-value becomes worse, especially for low-loss samples.



Adjusting coupling – guideline -

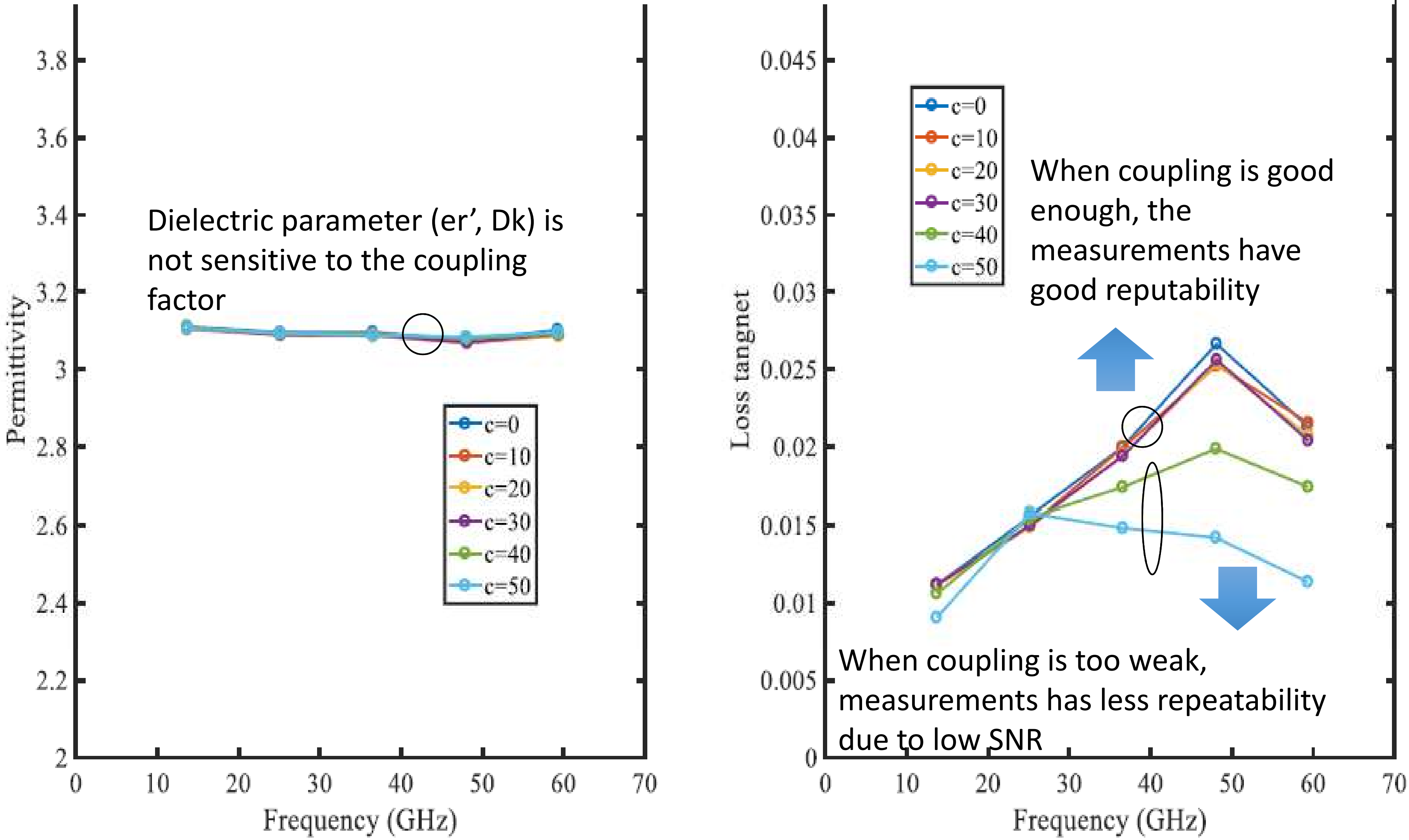
Calibration removes test cable loss, so the trace level rises up.
You need to take care and adjust the coupling so that the highest mode peak has less than – 35 dB.
You need to check the peak level after the calibration again.



KEYSIGHT TECHNOLOGIES

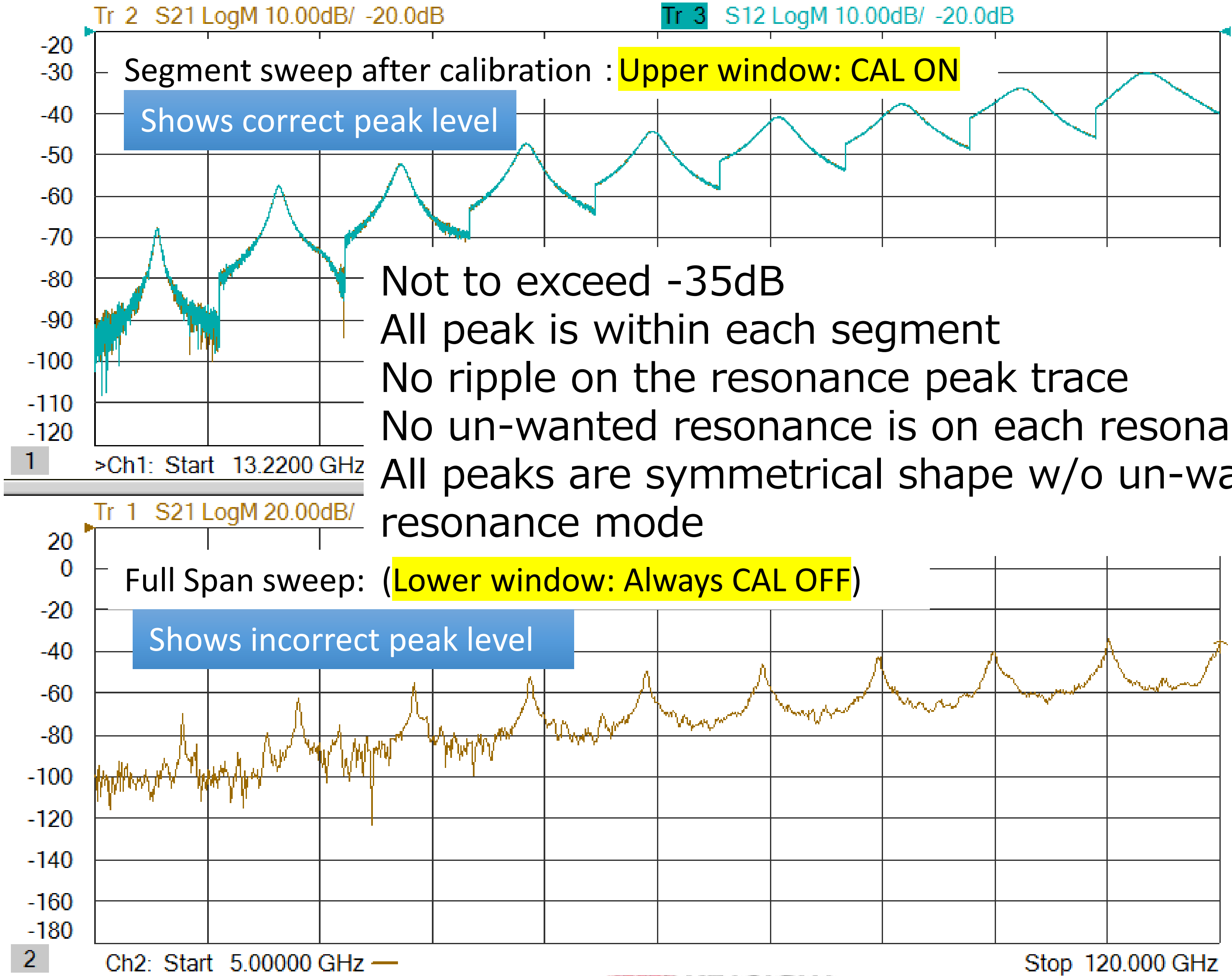
Adjusting coupling – when coupling is too weak -

In case the coupling is too weak and S/N ratio is not enough, you will see poor repeatability. Check that you have proper coupling value.



KEYSIGHT TECHNOLOGIES

Check the peak value after calibration



Not to exceed -35dB
All peak is within each segment
No ripple on the resonance peak trace
No un-wanted resonance is on each resonance trace
All peaks are symmetrical shape w/o un-wanted resonance mode

When you want to re-use stored cal set data

1. Save setup file (*.csa) with cal before hand after calibration VNA
   File > Save state as… > xxx.csa

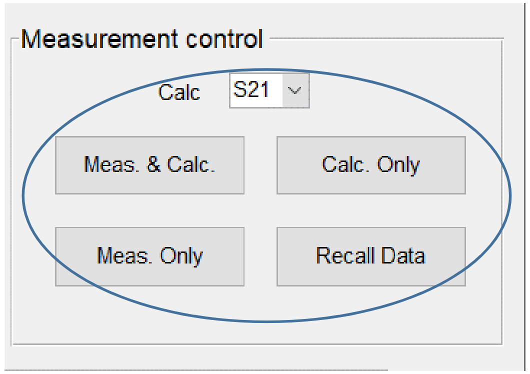
2. The state file (*.csa) has sweep, segment, and calset information

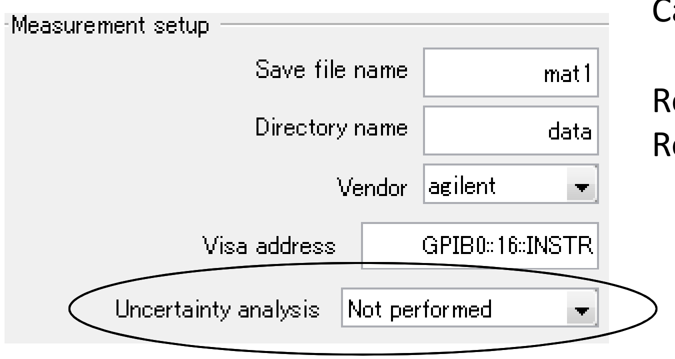
3. After recalling *.csa file, you can start measurement without setup or calibration when you measure the same group samples.

4. You have to judge whether the calibration is valid for your measurement or not by checking the resonance pea trace and ripples on it.

5. If ripple is small and calculated tanδ at each frequency shows natural trend, you can judge that the recalled calibration is valid. If you observe large frequency characteristics on tanδ , you have to re-take the calibration.
6. When you re-take calibration, you don't need to press VNA setup button

6. Starting meas. and Calculation





Calc:
Select S21 or S12 trace to calculate the result. (Normally it's identical if the system has good SN ratio and applied calibration.)

Meas. & Calc. :
Conduct measurement and calculation

Meas. Only :
Measurement only and no dielectric parameter calculation. Measure data is saved automatically.

Calc. Only :
Conduct dielectric parameter calculation using saved S-parameter data. Calculated result is saved automatically.

Recall Data :
Read and show the saved measurement data or calculation data

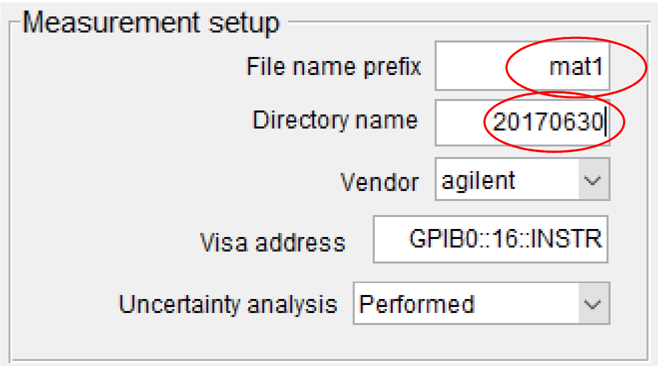
Uncertainty analysis: If you set this as "Performed", the software conducts uncertainty calculation. It take twice time compared to standard measurement.

Measurements of the BCDR using PNA take time because it has precipice setting for accuracy.
Wait until the PNA finishes the sweep for the next action.

Starting meas. or Calculation

Four files are created

Example when creating arbitrary folder under default directory > date name folder (20170630) with prefix as "mat1"



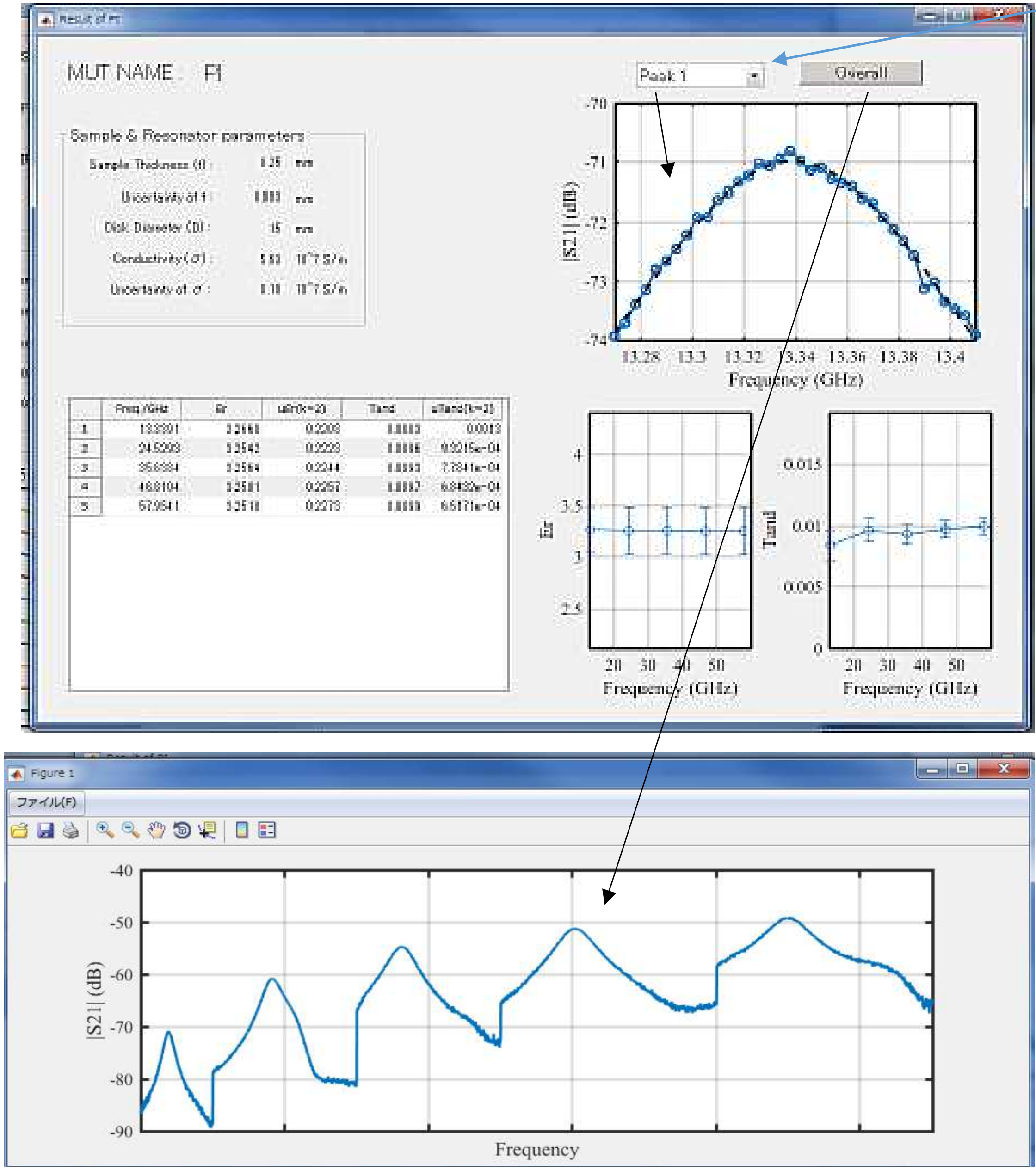
Document ▸ BCD Resonator ▸ 20170630 ▸ Polymide_No_Cal_1

mat1-ertand.dat	Calculated result for er' (Dk) and tanδ (Df)
mat1-ertand-detail.dat	Calculated result for er' (Dk) and tanδ (Df)
mat1-frQ.dat	Resonant frequency and un-load Q measurement result
mat1-sij.dat	S-parameters obtained by sweep

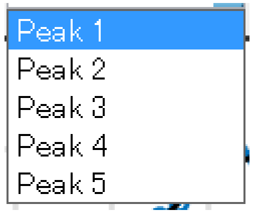
*.dat is the original measurement data. You can re-calculate using this file at Calc. only menu.

KEYSIGHT TECHNOLOGIES

Result of [Meas. & Calc.] or [Calc. Only]



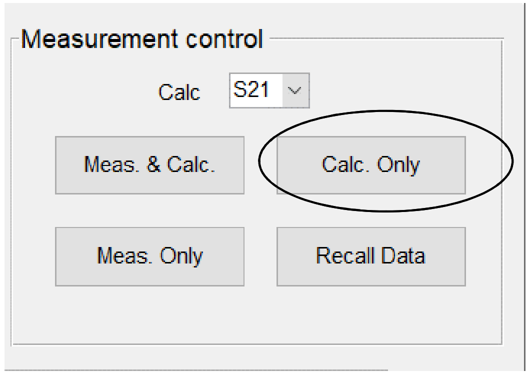
Pull-down menu

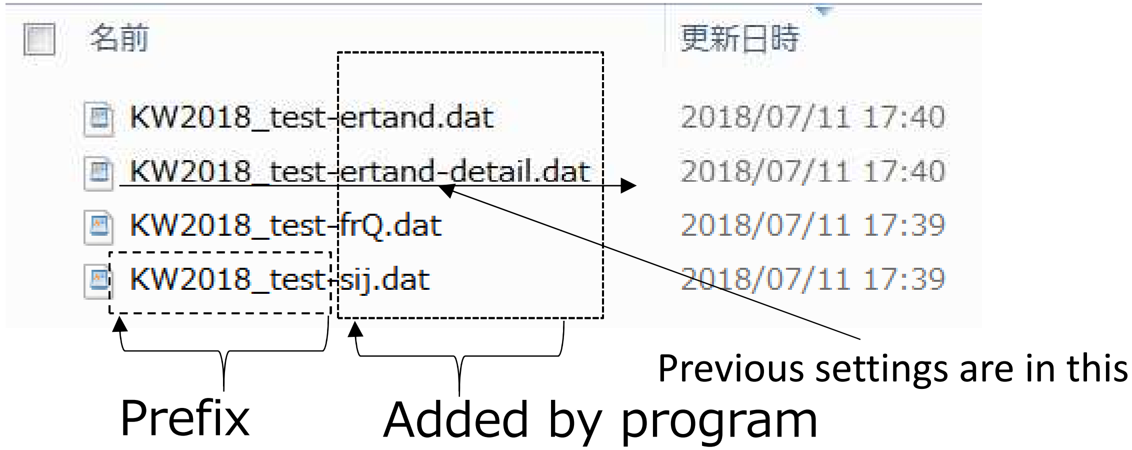


You can select each peak from pull down menu to show the trace and fitting line

Overall button opens a new window showing all peak data. You can zoom in/out to check overview and detail data.

Re-calculation function



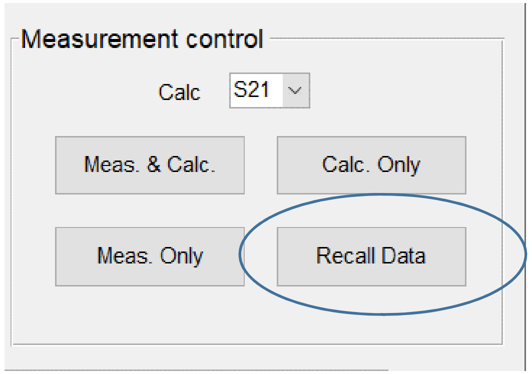


Once you do Meas. & Calc., you will see the four files above under the directory
Recall Data can work only when these four data are available.

Operation example to do re-calculation after changing some parameters;

1. **Input re-measured sample thickness into GUI's thickness menu**
2. **Check diameter of electrode and input it if necessary**
3. **Copy the original data file"KW2018_test-sij.dat" , paste it and rename like "KW2018_RECALC-sij.dat"**
4. **Press "Calc Only" and select the new "KW2018_RECALC-sij.dat".**
5. **You can get new calculation result and three new data with prefix "KW2018_RECALC"**

Recall Data / result of the previous meas.



When you want to show previous measured data

1 set of data

mat1-ertand.dat	2017/06/30 10:52	DAT ファ...	1 KB
mat1-ertand-detail.dat	2017/06/30 10:52	DAT ファ...	3 KB
mat1-frQ.dat	2017/06/30 10:52	DAT ファ...	1 KB
mat1-sij.dat	2017/06/30 10:52	DAT ファ...	951 KB

When you have all four data taken at previous measurements, you can show the data again using Recall Data function.

Displayed data is the same to that is Calc. Only or Meas. & Calc.

Four files have to have the same Prefix information.

Saved meas. data 4 files

❶ Prefix-frQ.dat

% Freq/Hz & S parameter (real/imag)
% Freq S11 S21 S12 S22

4 S-parameters with frequency

Prefix-ertand-detail.dat ❹

% Sample & Resonator parameters
% Sample Thickness (t):0.25 mm, Unc. of t:0.003 mm, Disk Diameter:15 mm
% Conductivity:5.63e7 S/m, Unc. of Conductivity:0.18e7 S/m
% Permittivity & Loss tangent
% Freq./GHz Er uEr(k=2) tand utand(k=2)
% Unc.: ufr, uQ, ut, uD, ua, uM, usigma, uN, utotal

1.3339052012e+01	3.2660269534e+00	6.9433698635e-04	1.86703[illegible]	[illegible]	[illegible]	[illegible]
2.4529347921e+01	3.2541962127e+00	6.5287949977e-04	3.2593937577e-04	5.7604212602e-04	5.5284895852e-02	5.0468864601e-03
3.5638364723e+01	3.2564263038e+00	3.4587078538e-04	1.1513009668e-05	4.4623032380e-04	5.5621634766e-02	6.5282684165e-03
4.6810358591e+01	3.2500773531e+00	3.0595502622e-04	1.4109697600e-04	5.9067962047e-04	5.5729944678e-02	7.9978258513e-03
5.7954076085e+01	3.2510405114e+00	2.6232160720e-04	2.4065555399e-05	6.3477326013e-04	5.5929558557e-02	9.0658687632e-03

Prefix-ertand.dat ❸

Calculation conditions are saved here

% Sample & Resonator parameters
% Sample Thickness (t):0.25 mm, Unc. of t:0.003 mm, Disk Diameter:15 mm
% Conductivity:5.63e7 S/m, Unc. of Conductivity:0.18e7 S/m
% Permittivity & Loss tangent
% Freq./GHz Er uEr(k=2) tand utand(k=2)

1.3339052012e+01	3.2660269534e+00	1.1042471696e-01	8.3332653140e-03	6.2753751195e-04
2.4529347921e+01	3.2541962127e+00	1.1112887753e-01	9.5748219828e-03	4.6607449776e-04
3.5638364723e+01	3.2564263038e+00	1.1218062055e-01	9.2537450403e-03	3.8920421386e-04
4.6810358591e+01	3.2500773531e+00	1.1284035274e-01	9.6612833067e-03	3.4215944463e-04
5.7954076085e+01	3.2510405114e+00	1.1363519510e-01	9.8990554705e-03	3.2585662878e-04

Prefix-frQ.dat ❷

% Resonant Freq & Q-factor
% Analysis: Lorenzian fitting method, Range: 3 dB
% Res.Freq uRes.Freq(k=2) Q-fac uQ-fac(k=2)

1.3339052012e+10	2.8575051670e+06	9.3841208870e+01	5.4606417806e+00
2.4529347921e+10	3.3302360761e+06	8.8590907366e+01	3.6166333905e+00
3.5638364723e+10	3.6569348719e+06	9.3677905717e+01	3.3777194126e+00
4.6810358591e+10	3.9743055189e+06	9.1732682035e+01	2.8480940458e+00
5.7954076085e+10	4.4764165555e+06	9.0798469523e+01	2.6606099176e+00

Contiguous measurements

[Conduct next measurement (or repeat measurement) without re-calibration]

You can measure the next sample without calibration when

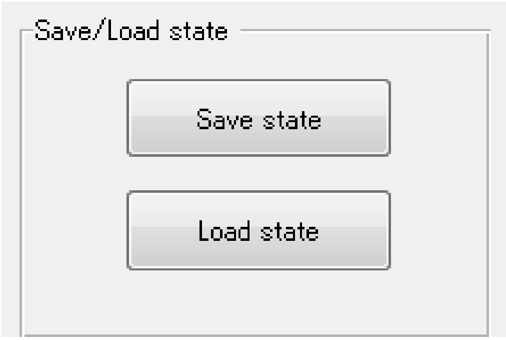
1. All TM0m0 mode has correct peak traces
2. NOP and IFBW are proper one for the sample
3. Full two-port calibration is done and ON

are all met.

[Not using “VNA setup” but recall the *.csa or Cal set file to setup and measure]

1. Save proper VNA setup condition to state file manually by File >> Save state as … >> State and Cal Set data (*.csa) with unique name
2. Recall the saved State and Calset data file (*.csa) to start measurements
3. You need to input actual sample thickness and electrode diameter in GUI before measurements

Save state, Load state, VNA Instrument states



- Save VNA’s sweep conditions into your specified file
- Sweep conditions like segment table setting and full-span sweep setting are saved.
- Load the VNA’s setting from the file

Information like sample thickness, electrode diameter, conductivity, and interface information is not saved.
You can modify “Initialentry.txt file” to modify these information.

SAVE measurement condition

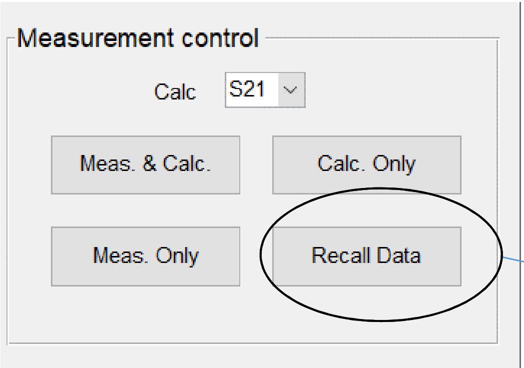
You can find “Initialentry.txt” file under
¥Documents¥BCD_Resonator¥ folder.

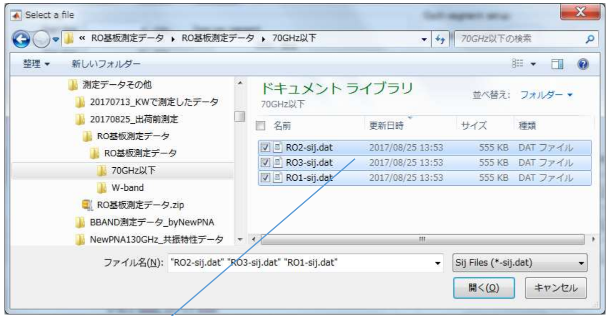
Parameters used in calculation except sweep conditions and frequency settings are saved in this file and overwritten when closing the BCDR software program.

You can modify the “Initialently.txt” manually by using text editor like memo Pad app. Open, edit, and save the info before running the BCDR program.

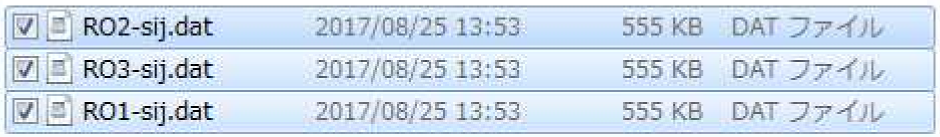
Verified the dispersion using multiple meas. result

By recalling multiple saved S-parameter file (*.dat file), measurement dispersion is displayed to analyze.



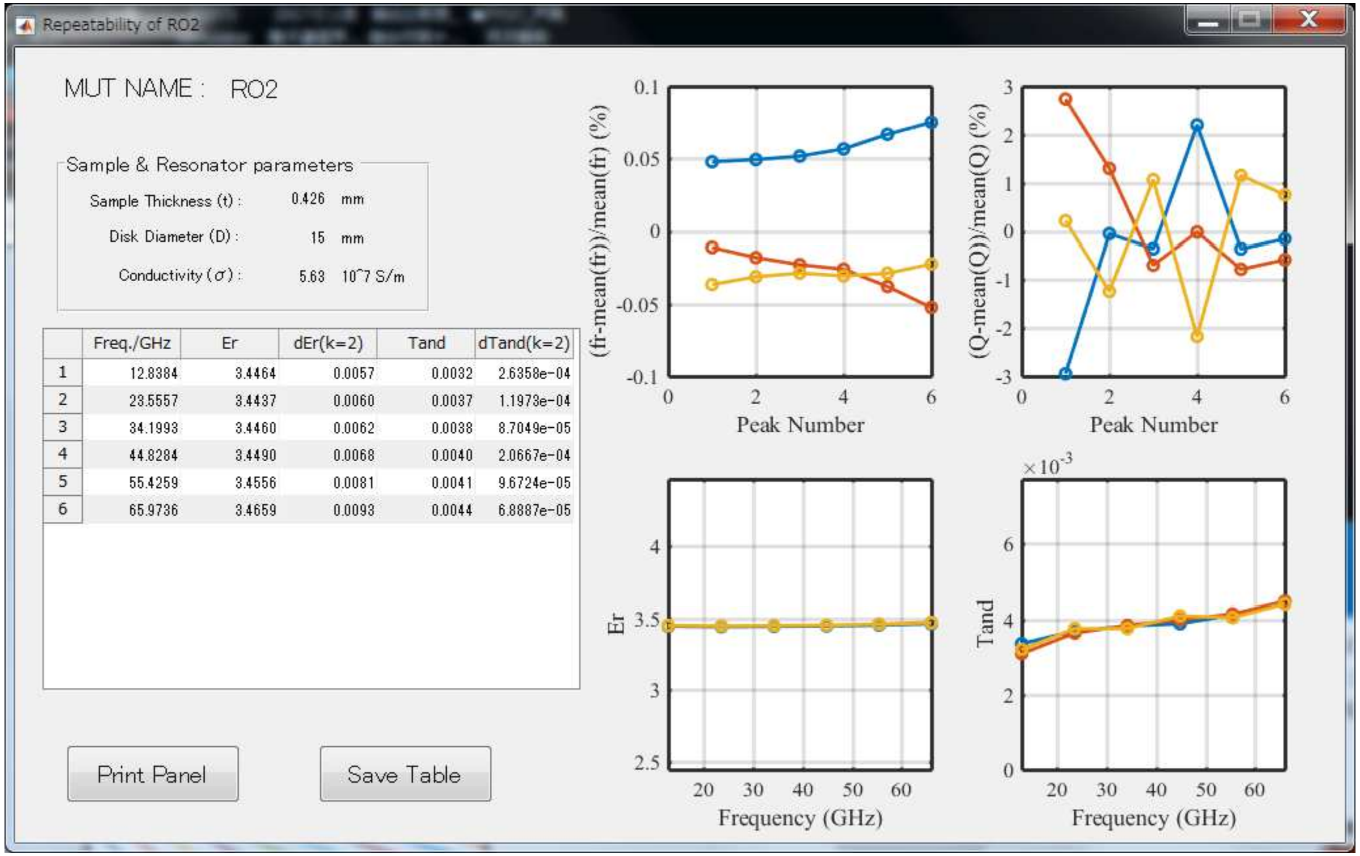


Select multiple *.dat files



Verified the dispersion using multiple meas. result

Upper two graphs shows resonant frequency dispersion and Q-factor dispersion in % format. Lower two graphs overlays Er’ and tanD values. You can analyze how much dispersion occurs in multiple measurements.

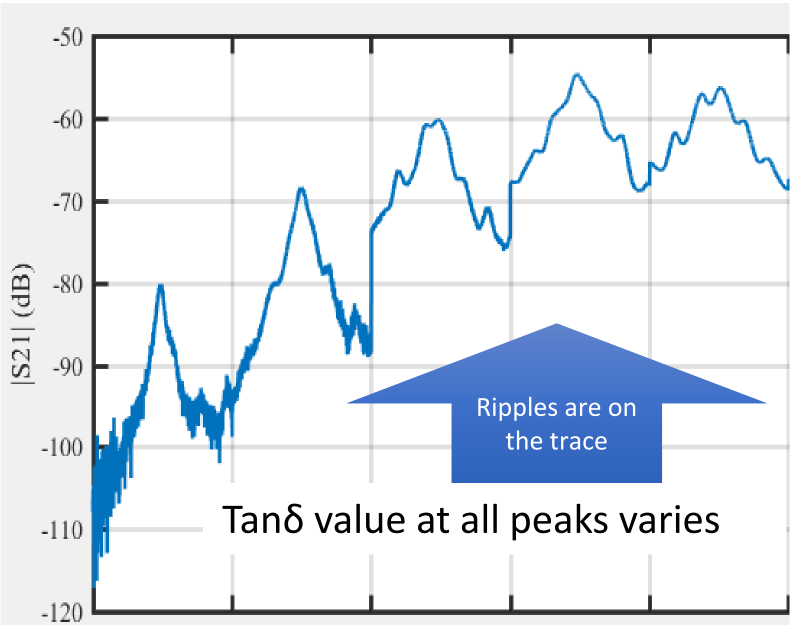


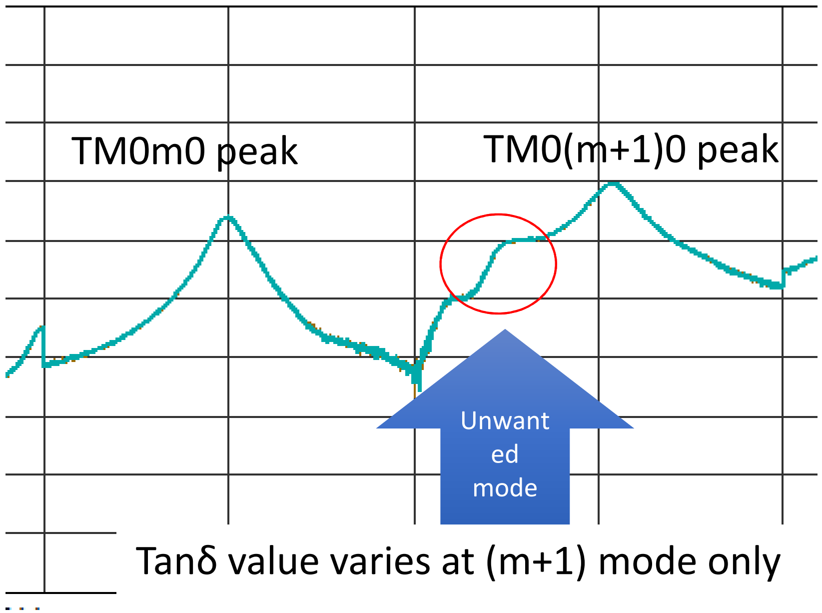
	Freq./GHz	Er	dEr(k=2)	Tand	dTand(k=2)
1	12.8384	3.4464	0.0057	0.0032	2.6358e-04
2	23.5557	3.4437	0.0060	0.0037	1.1973e-04
3	34.1993	3.4460	0.0062	0.0038	8.7049e-05
4	44.8284	3.4490	0.0068	0.0040	2.0667e-04
5	55.4259	3.4556	0.0081	0.0041	9.6724e-05
6	65.9736	3.4659	0.0093	0.0044	6.8887e-05

KEYSIGHT TECHNOLOGIES

When distortion occurs on the resonant shapes

When you observe distortions or irregular shapes on the resonant trace, you cannot get accurate results from the measurement. You need to measure the sample again so that resonant traces becomes as ideal as possible by taking calibration again or adjusting position of the center electrode.
You may not get ideal Lorentz distribution shape in all peaks by various reasons.





Using attenuators instead of full 2-port Cal (optional)

This BCDR's TM0m0 mode has relatively lower Q value, so traces tend to have small ripples due to multi reflection.

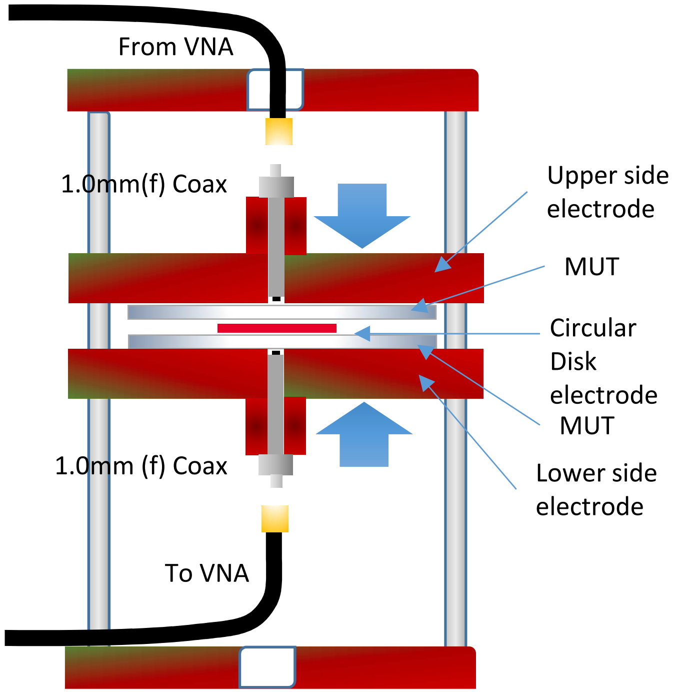
The ways to remove the ripples are;
- Applying full 2-port calibration
- Adding 3 dB or 6 dB pads (attenuators) at the BCDR's connectors

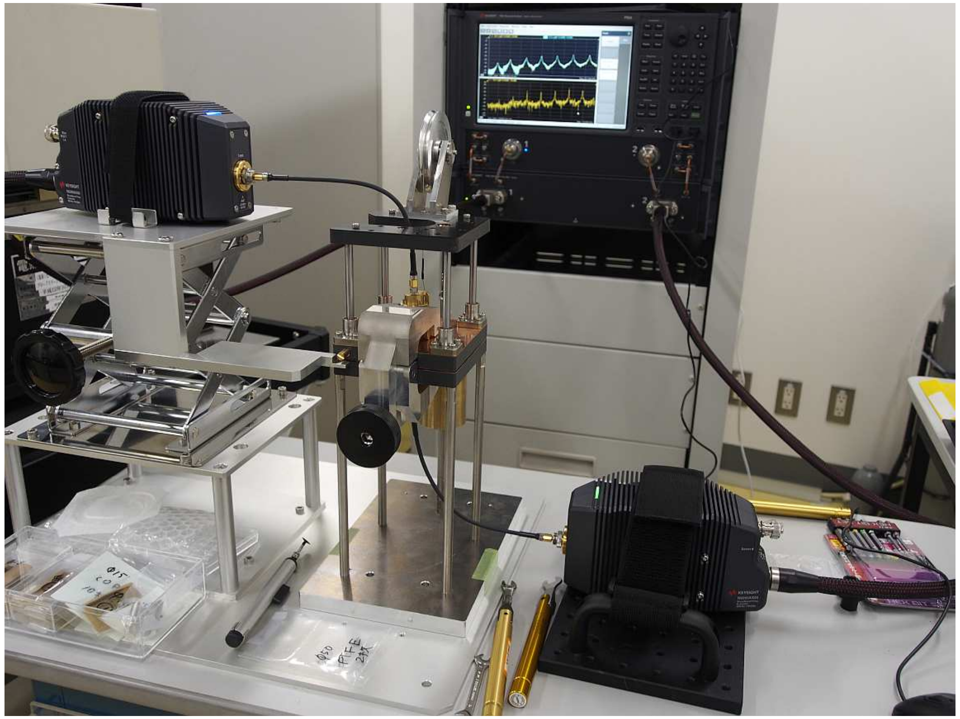
You can also combine full 2-port and attenuators.

Adding attenuators degrades VNA's dynamic range. This makes SNR of lower resonant mode measurement worse and may make the measurements difficult. You need to increase input power or narrower IFBW at that segment.

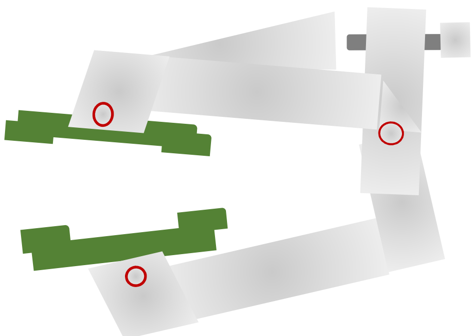
When you conducts full 2-port cal with attenuators, connect the attenuators at both side of BCDR connector, and take full 2-port cal at the end of the test port without attenuator.

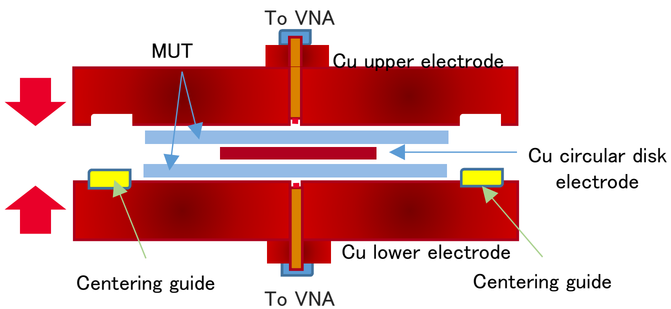
7. BCDR General Information (N1501AE11)





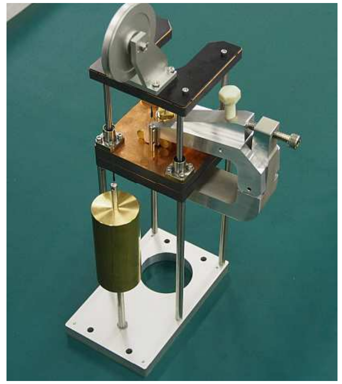
Clamping tool with torque driver





KEYSIGHT TECHNOLOGIES

handling notice



- Do not touch resonator body by bare hands
  especially surface of upper/lower/circular disk electrodes.
- Always use something like lubber groves
- Do not use bended, folded, dented the Cu circular disk electrode (replace it when damaged)
- Do not use warped centering shim sheet (replace it when damaged)
- Use torque wrench and open wrench when connecting cables
- 1 mm (female) connectors on resonator is precise and fragile parts. Hold the connector with open wrench not to rotate the female connector.
- A balancing weight for upper electrode is heavy. Take care not to drop it when removing
- Store the resonator with closing upper and lower electrode by clamp
- Wipe BCDR’s body and electrode surface by using anhydrous alcohol during and after using.

- scope of application -

Frequency f : 6.5G- 67/110GHz, 70120GHz (typ.)
Circular electrode disk size : ø12mm ,ø15mm , 18mm

Permittivity $\varepsilon_{r\,n}$: 1.1 - 10
Accuracy :±1% (@ε_{rn}=2, t:>0.2mm)
Loss tangent $\tan\delta_n$: 10^{-2} - 10^{-4}
Accuracy :
±0.0001(@$\tan\delta_n$=0.0002, $\varepsilon_{r\,n=}$2, t:>0.4mm)
±0.0004(@$\tan\delta_n$=0.002, $\varepsilon_{r\,n=}$2, t:>0.2mm)
±0.002(@$\tan\delta_n$=0.02, $\varepsilon_{r\,n=}$2, t:>0.2mm

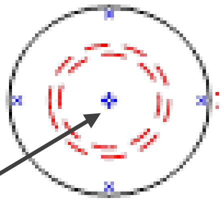
Size of Dielectric sheet (MUT)

MUT Thickness(t) : 0.1 - 1mm
0.2-0.5mm(to reach to 80 GHz or higher)
MUT SIZE min. ø 23mm – max. ø 49mm Not limited to circular shape
Min. 1.5 times of circular disk electrode diameter

Fixture Dimension about W104 X D172 X H329.5 mm
Weight about 5kg

Resonant Frequency (Approximation Formula)

TM_{0M0} RESONANT FREQUENCY APPROXIMATE EXPRESSION



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

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

R= radius of center electrode

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

Resonant frequency is determined by
- Circular disk electrode radius (=fixed)
- Dk of sample (=target value)

-> Free from sample thickness accuracy

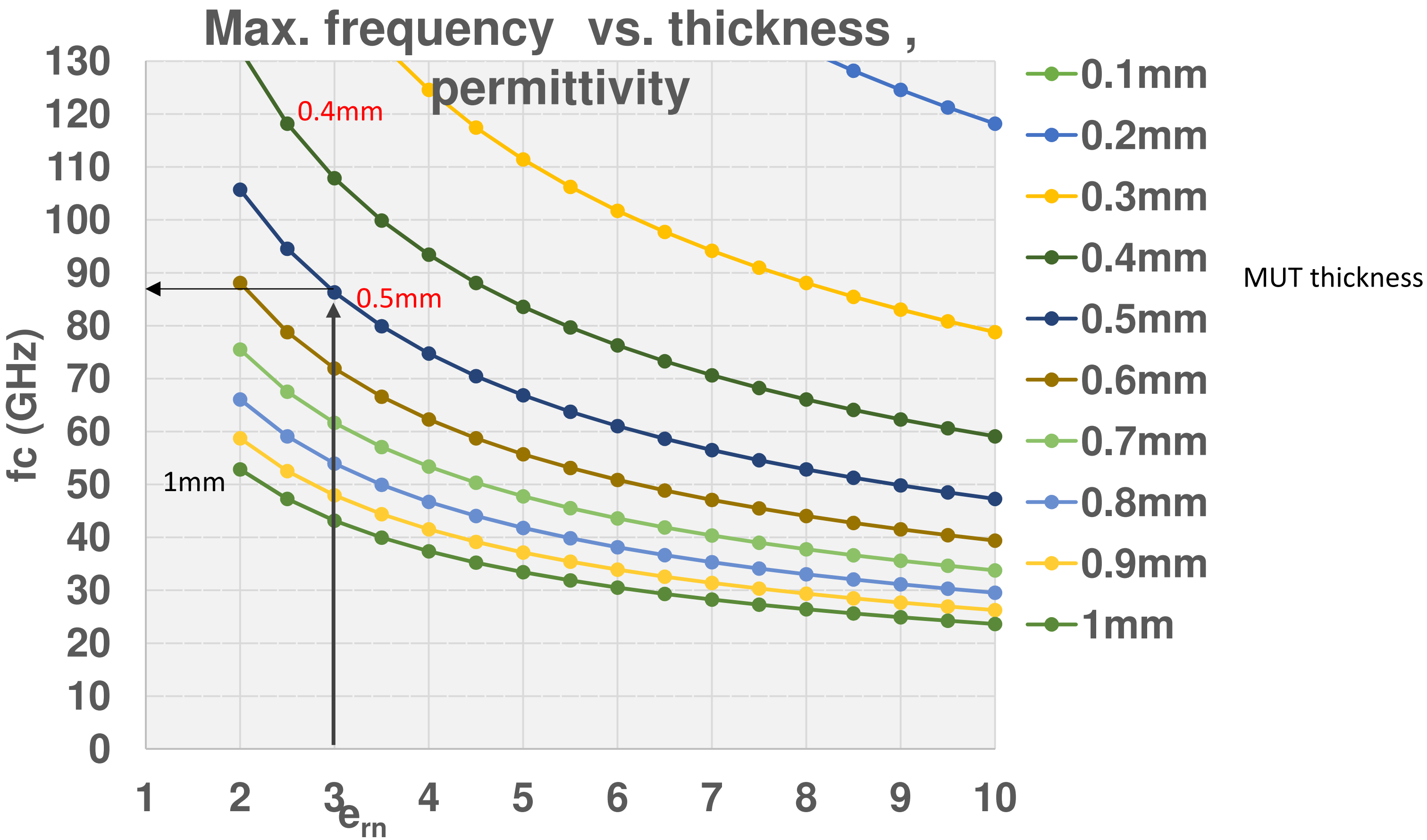
PTFE(εr=2.04) disc Φ15mm f_{010}≒17.07GHz

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

Max Available Frequency Versus Thickness and Dk



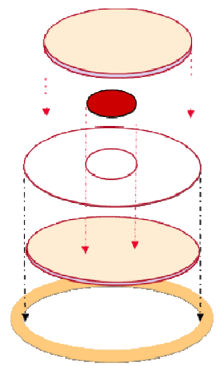
KEYSIGHT TECHNOLOGIES

TM_{0m0} Resonant Frequency Examples

CALCULATED FROM RESONATOR DIAMETER AND DIELECTRIC CONSTANT

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

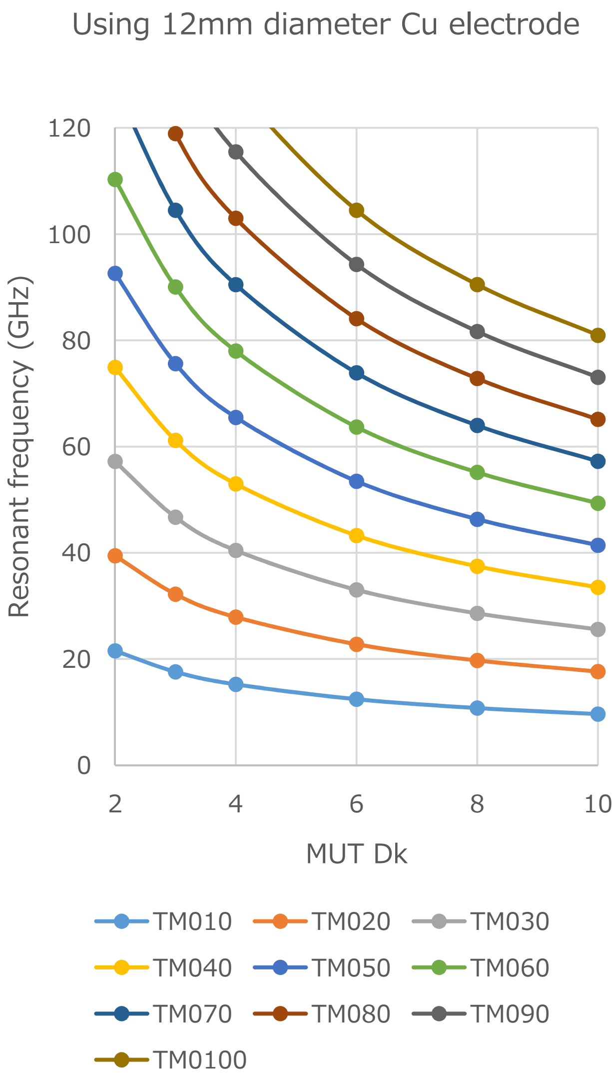
		Electrode diameter (mm)				Electrode diameter (mm)				Electrode diameter (mm)		
		12	6.00E-03			15	7.50E-03			18	9.00E-03	
		Permittivity				Permittivity				Permittivity		
X'_{0m0} value	Mode	2.04	4.2	6.5	Mode	2.04	4.2	6.5	Mode	2.04	4.2	6.5
3.8317	TM010	**21.33**	**14.87**	**11.95**	TM010	**17.07**	**11.89**	**9.56**	TM010	**14.22**	**9.91**	**7.97**
7.0155	TM020	**39.06**	**27.22**	**21.88**	TM020	**31.25**	**21.78**	**17.51**	TM020	**26.04**	**18.15**	**14.59**
10.1743	TM030	**56.65**	**39.48**	**31.73**	TM030	**45.32**	**31.58**	**25.39**	TM030	**37.76**	**26.32**	**21.16**
13.3237	TM040	**74.18**	**51.70**	**41.56**	TM040	**59.35**	**41.36**	**33.25**	TM040	**49.45**	**34.47**	**27.71**
16.4706	TM050	**91.70**	**63.91**	**51.37**	TM050	**73.36**	**51.13**	**41.10**	TM050	**61.14**	**42.61**	**34.25**
19.6159	TM060	**109.22**	**76.12**	**61.18**	TM060	**87.37**	**60.89**	**48.95**	TM060	**72.81**	**50.74**	**40.79**
22.7601	TM070	126.72	**88.32**	**70.99**	TM070	**101.38**	**70.65**	**56.79**	TM070	**84.48**	**58.88**	**47.33**
25.9037	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**

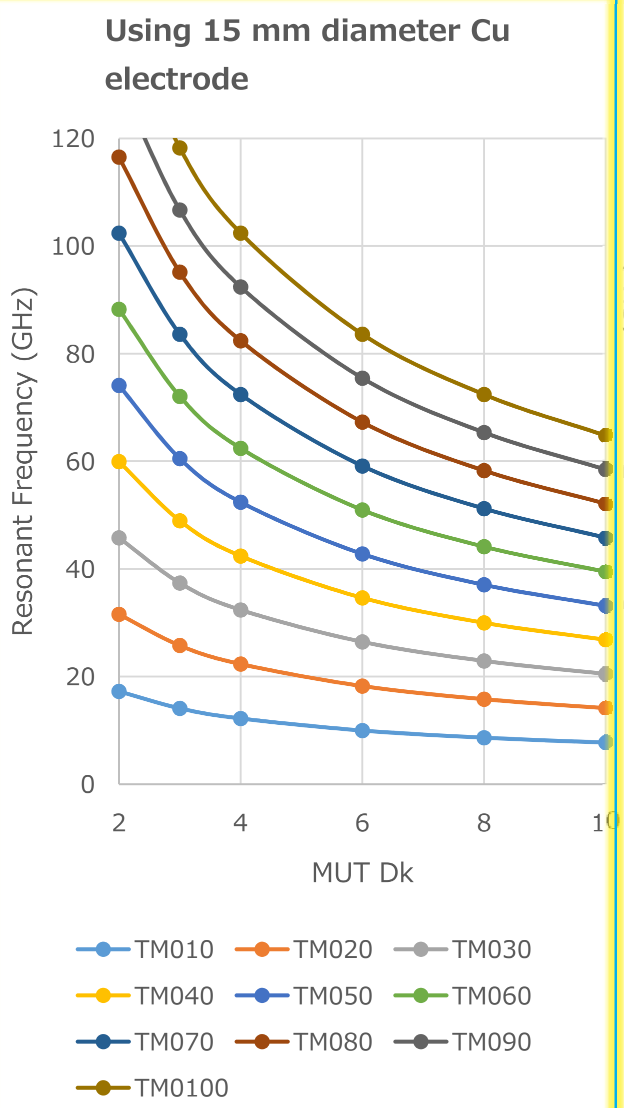


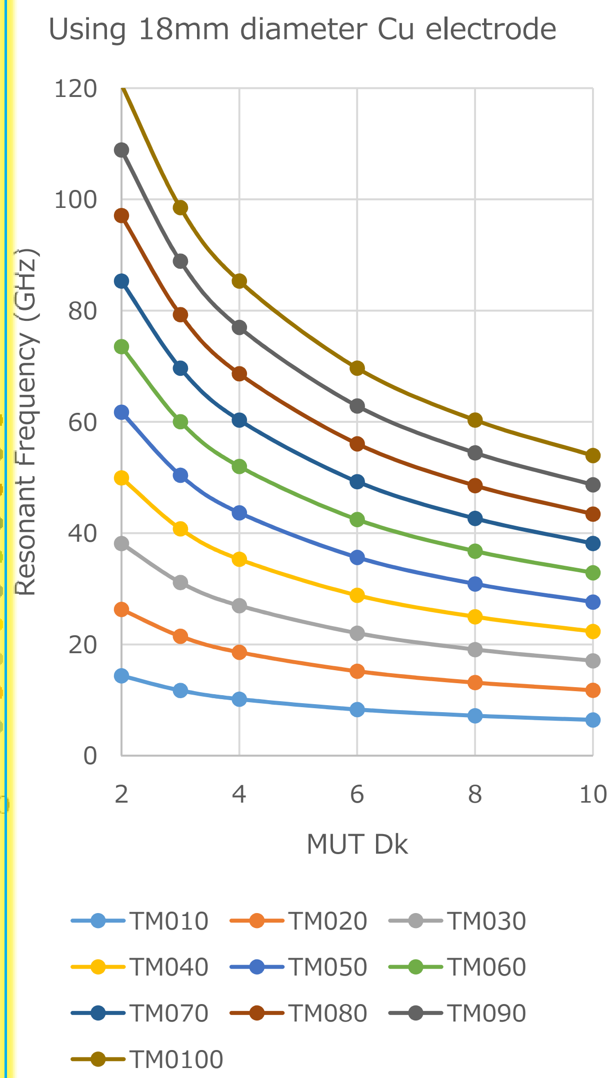
Maximum measure-able frequency is determined by thickness and permittivity. See next page.

TM_{0m0} Resonant Freq.(Approximation)

Resonant frequency vs. MUT's Permittivity (Dk), Cu center electrode diameter







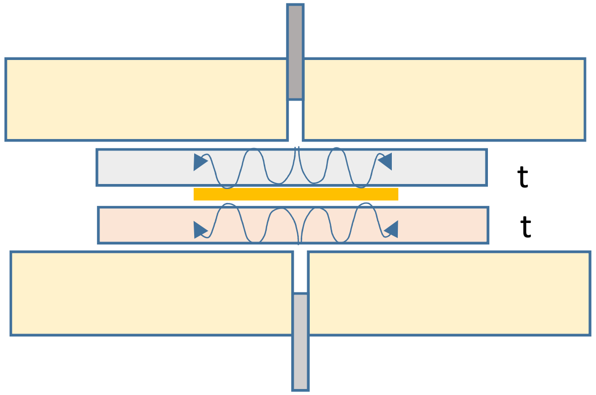
KEYSIGHT TECHNOLOGIES

Factors that determine the Max. Frequency

Approximate expression for calculating the cutoff frequency of radial radiation

$$f_c = \frac{c}{2\pi R\sqrt{\varepsilon_{rn}}} X_{0m0}(S_c) = \frac{c}{2\pi R\sqrt{\varepsilon_{rn}}}\frac{\pi}{2}S = \frac{c}{4t\sqrt{\varepsilon_{rn}}}$$

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.

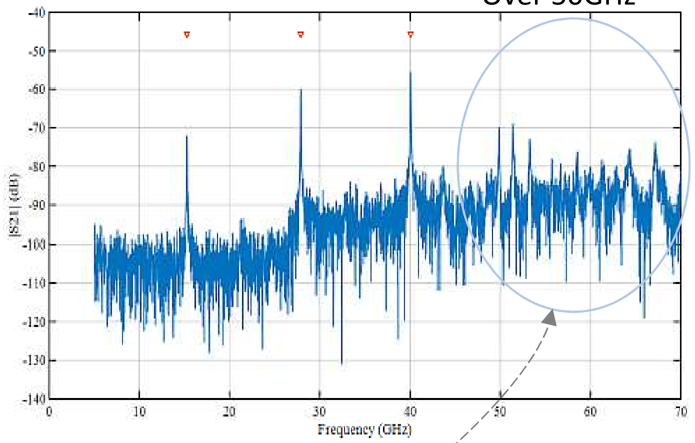
Fc (cut off frequency = max frequency) becomes lower when MUT is thicker

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

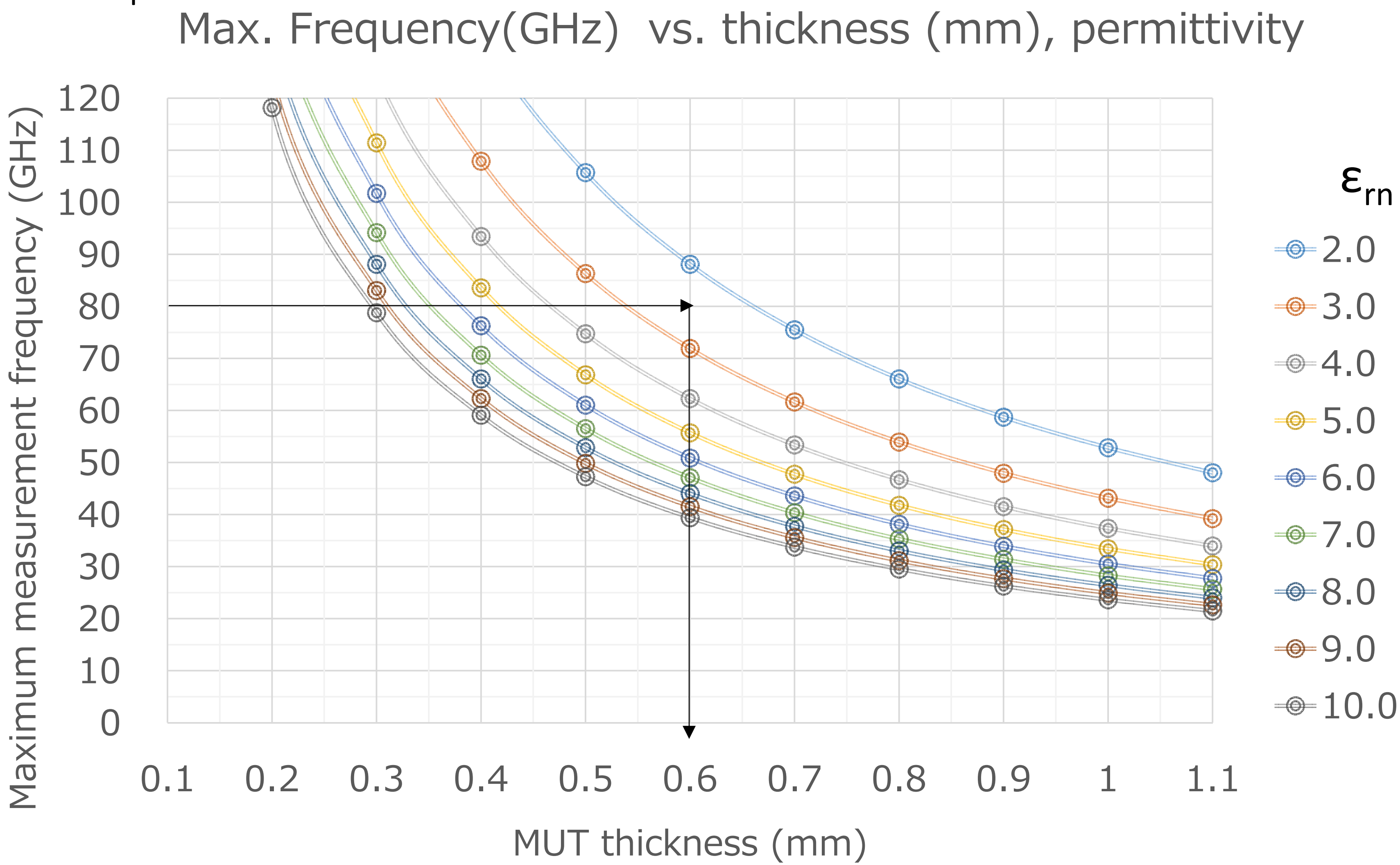
MUT : PP 1mm



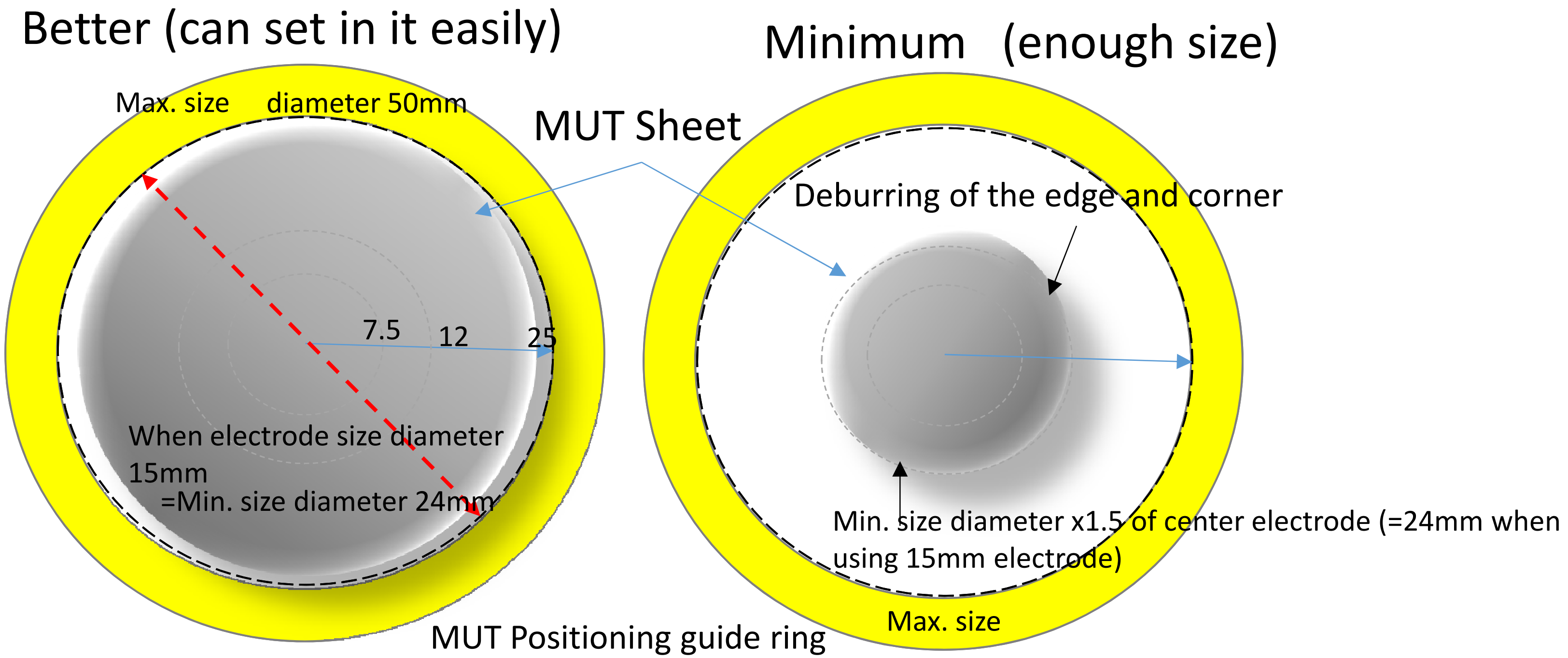
**The resonance peak waveform disappeared due to the influence of energy leakage, making measurement impossible

Max. limit Freq.(GHz) vs. t_{mut} and e_{rn}

Example: Sample thickness has to be less than 0.6mm when the sample Dk is 2.5 and you want to measure up to 80 GHz



Size of MUT sheet/when machine in disk shape

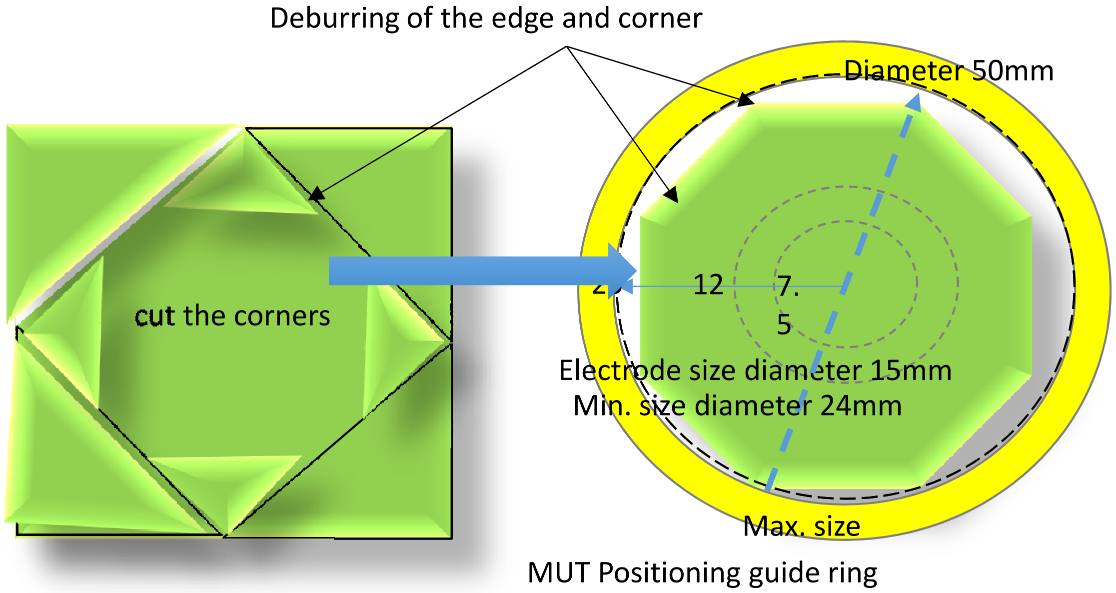


Sample size: 50mm diameter max. > x1.5 of the center Cu electrode size. Larger sample makes it easy to put the electrode because the shim sheet doesn't float up

Cu center disk electrode size: Φ12, 15, 18 mm
Sample thickness: approx. 0.1 mm ~ 1 mm. When the sample size becomes thick, max available frequency becomes low.
Optimum thickness: approx. 0.2 mm to 0.4 mm
Need two samples as a pair

Note about edge treatment: Sample edge has to be processed properly to protect Shim sheet from damage. Especially when the sample is thick, you need deburring or make the edge flat. See the next page for detail.

How to cut out sample from square sheet



Tips:

Make the sample as large as possible but within 50 mm diameter circle for stable measurement. When the sample size is small, the shim sheet is easy to float up and it's hard to set the Cu center disk electrode at the center position of the resonator. This is the same when the sample is warped or wrinkled.

Not suitable for measurement

Roughness on the surface and having protrusions

(Surface roughness: preferably 30 μm or less)

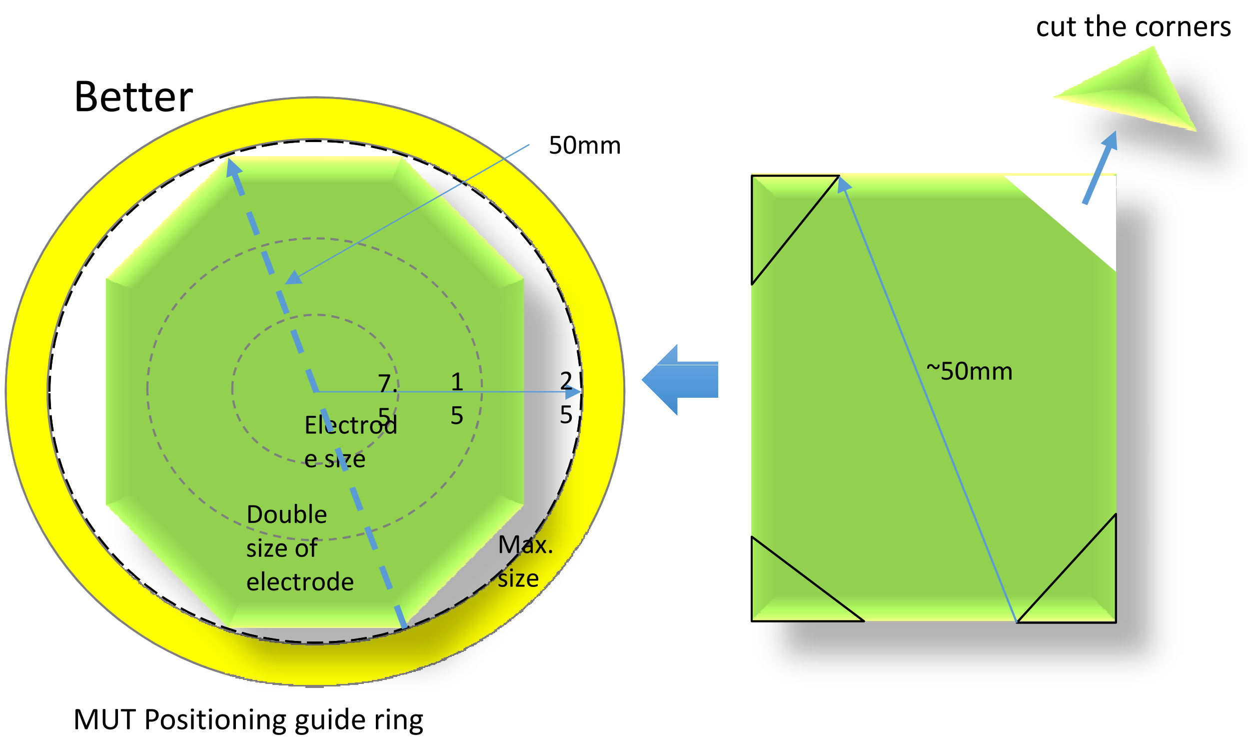
hard and fragile (thin glass, thin ceramic substrates, etc.)

Warping with a hard substrate

Copper-clad board or substrate with copper electrode left

KEYSIGHT TECHNOLOGIES

How to cut and set square sheet in the cavity



Measurement Materials Sample Under Test (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

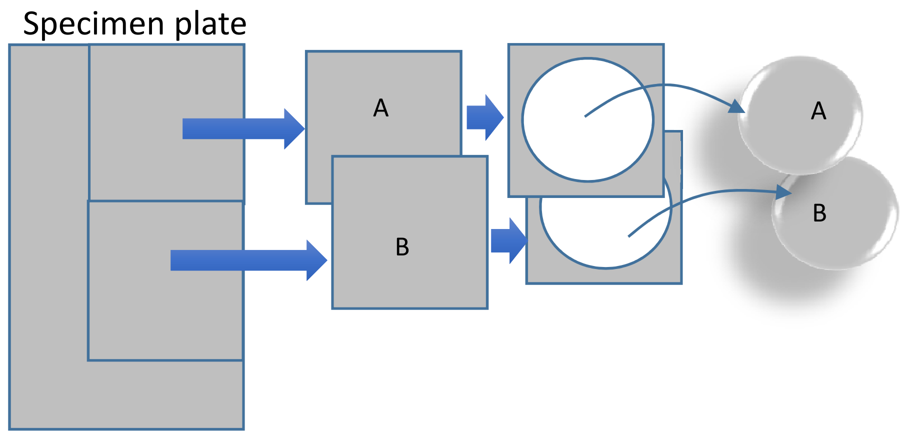
Roughness on the surface and having protrusions

(Surface roughness: preferably 30 µm or less)

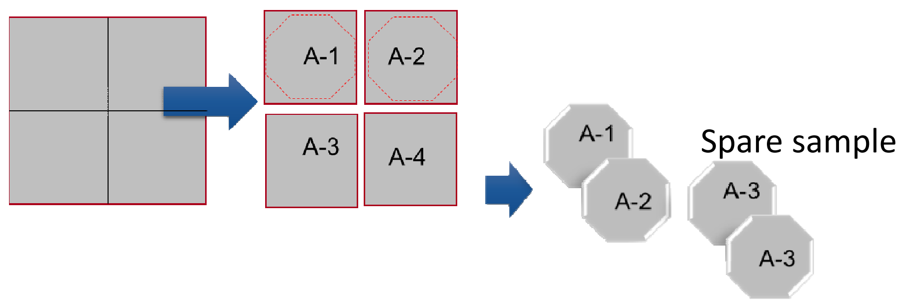
hard and fragile (thin glass, thin ceramic substrates, etc.)

Warping with a hard substrate

Copper-clad board or substrate with copper electrode left

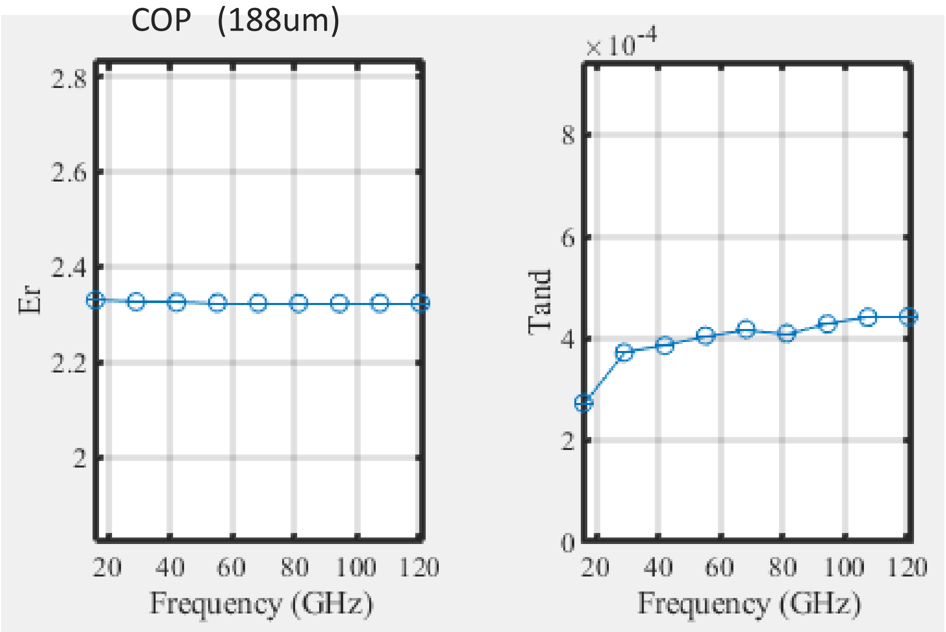


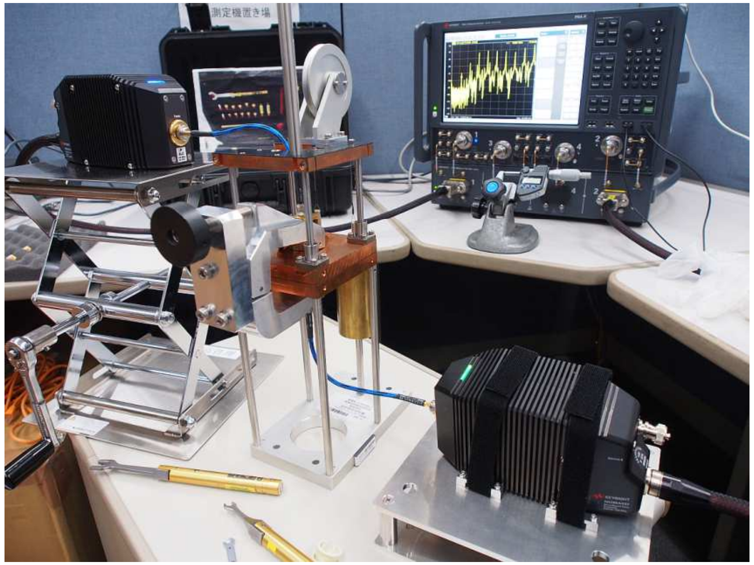
Best way (two samples from the same sheet)



KEYSIGHT TECHNOLOGIES

Measurement Result Example (COP 188 um)





BCD Resonator Typical Performance

Measurable frequency: 10 GHz – 67G / 110 GHz (typ. 120GHz)
Circular disk electrode size : Ø15 mm, Ø12 mm, Ø18 mm
Permittivity εr n : 1.1 – 10 Accuracy :±1% (@εrn=2, t:>0.2mm)
Loss tangent tanδn : 1x 10^{-2} - 10^{-4} Accuracy :

±0.0001(@tanδn=0.0002, εr n=2, t:>0.4mm)

±0.0004(@tanδn=0.002, εr n=2, t:>0.2mm)

±0.002(@tanδn=0.02, εr n=2, t:>0.2mm)
Sample thickness(t) : 0.1 – 1 mm (0.2 ~ 0.5mm is optimum but depends on sample's Dk/Df)
Sample size: Ø 24mm - Ø 49mm, >2 times of circular disk electrode diameter

Fixture dimension: approx. W104 X D172 X H329.5 mm
Weight: ~ 5kg

Connector type
N1501AE11: 1.0 mm(f) Coax.(Max.110GHz, typ. 120 GHz)
N1501AE67: 1.85 mm(f) Coax.(Max.67GHz, typ. 70 GHz)

KEYSIGHT TECHNOLOGIES

8. Points of Multi-layer meas. (thin film with support substrate/ optional)

1. Note when measuring multi-layer samples

The sample has to be flat so that air gap layer becomes as minimum as possible. You need to prepare one pair of the multi-layer sample to measure.

2. Sample thickness estimation and uncertainty

Actual sample thickness information is VERY important for this multi-layer measurement method. When the sample thickness is less than 0.1mm, you need to have 1 um order thickness accuracy for accurate measurement.

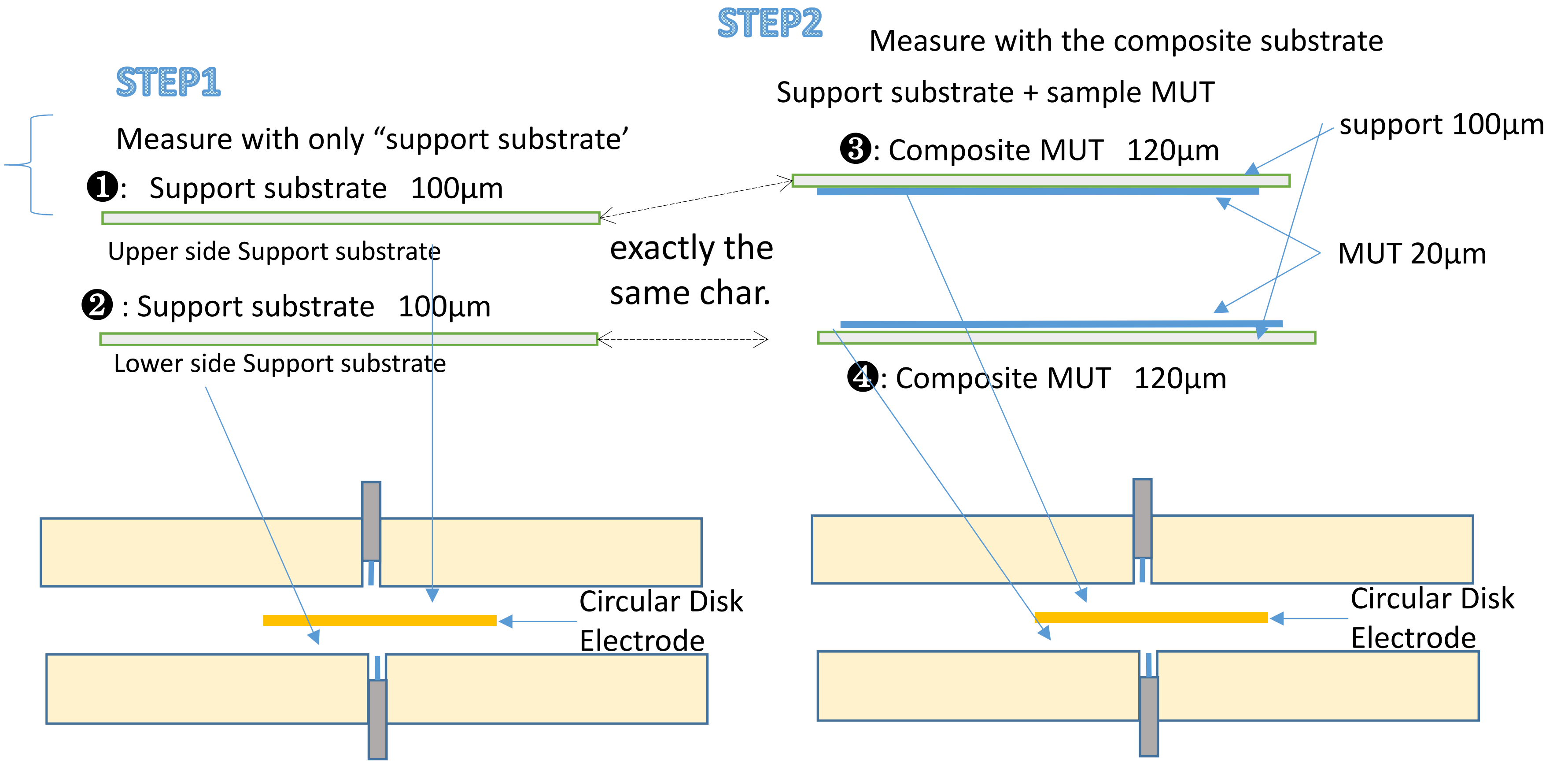
3. Tips to keep uncertainty in reasonable range

Support substrates have to be the same thickness, the same dielectric parameter. When the sample is thin, the fluctuation of support substrate affects a lot to the measurement result. The support substrates needs to be low Dk and low loss material. It's better that the support substrates doesn't change its thickness much even applying the pressure to clamp.

You need to take care to maintain the VNA system drift as small as possible. Not to change the temperature or bend the cable during and after the calibration.

Preparation for Multi-layer MUT (2 times meas. needed)

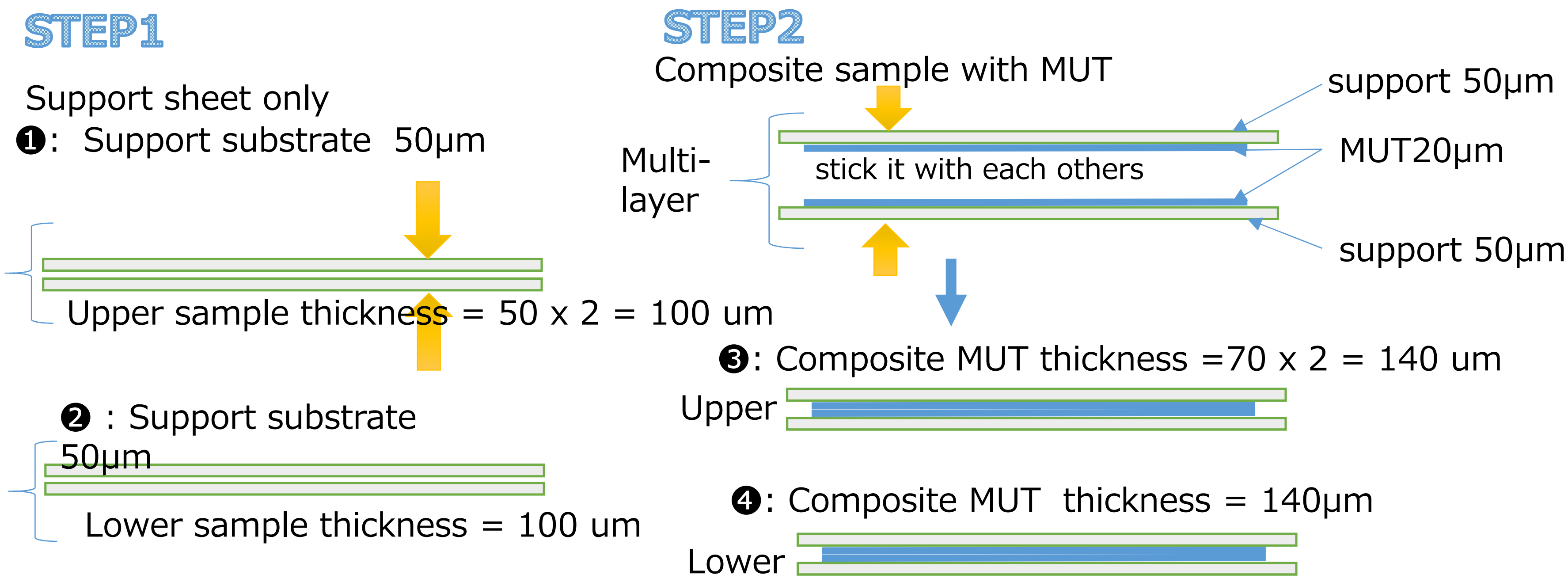
When your sample thickness is less than 0.1mm, you can stack the sample to make it thick and/or can calculate the sample Dk/Df using multi-layer method (2 step method, “support substrate”, and “support substrate + sample”)
<u>When you stack many samples, the possibility of air gap error becomes large. So it’s better to maintain the number of stack small when possible. Support substrate is better to have robust, low dk and low df, and thin but at least 0.1 mm as its property. Example　COP100µm)</u>



(Case 2) Preparation for Multi-layer MUT

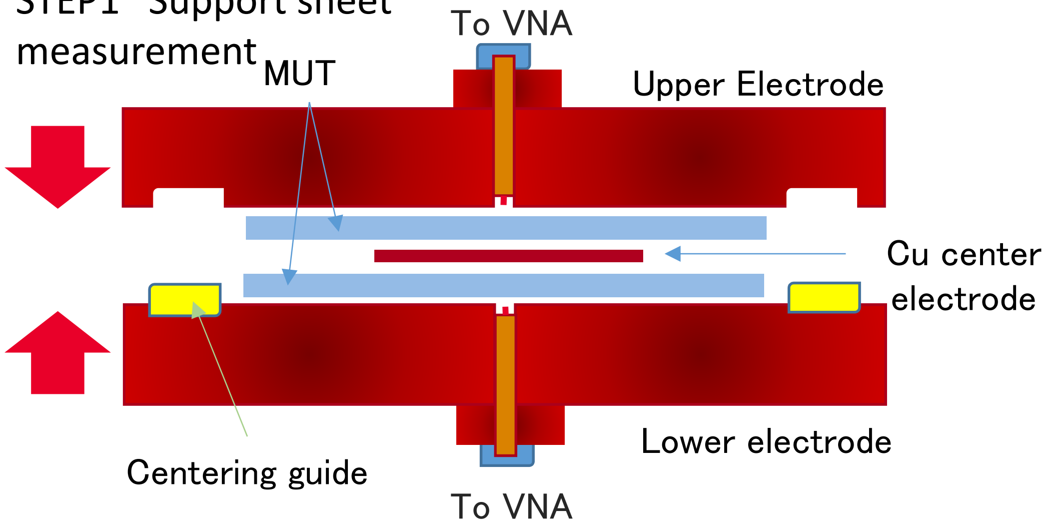
When the MUT thickness is less than 0.1mm or sticky samples, you can make measurement by preparing one pair of support sheet x 2 AND one pair of “support sheet + sample + sample + support sheet” as below.

The composite sample has to be flat. Take care to remove air gap as much as possible



Preparation for Multi-layer MUT (2 times meas. needed)

STEP1 Support sheet measurement



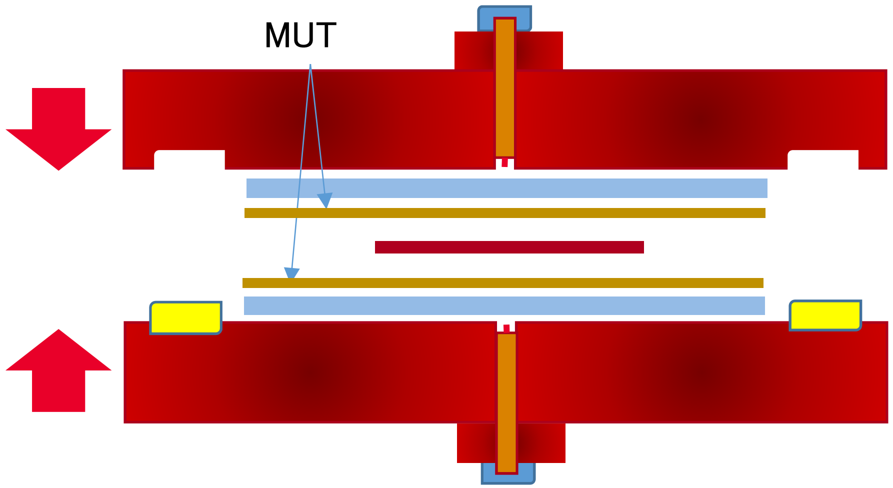
Required condition

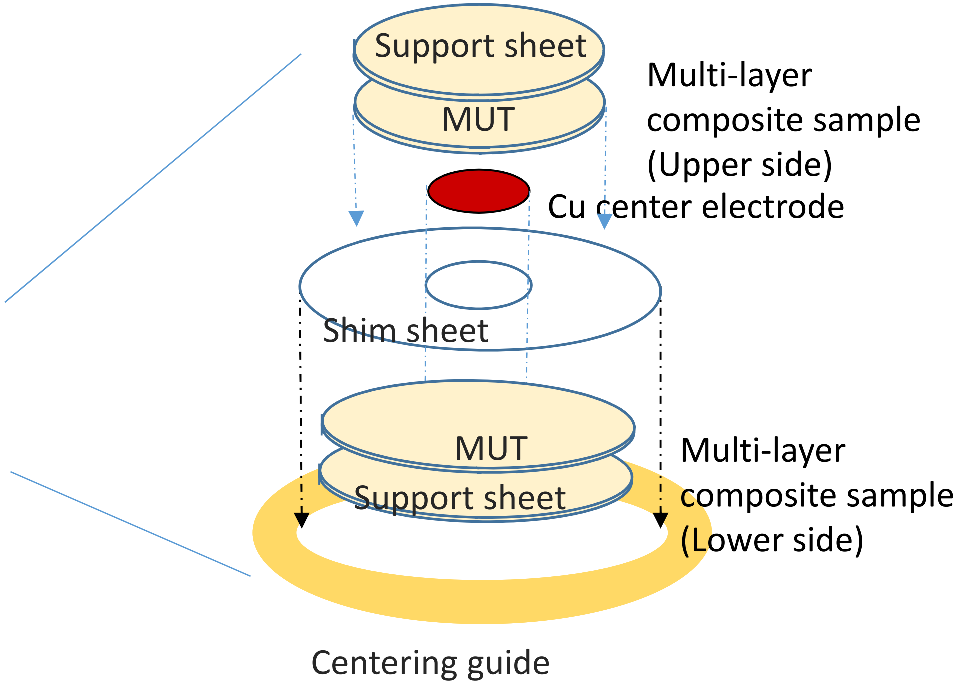
1. Upper and lower sample have to be the same total thickness

2 Upper and lower sample have to have the same dielectric parameter

3.No air gap in the composite sample

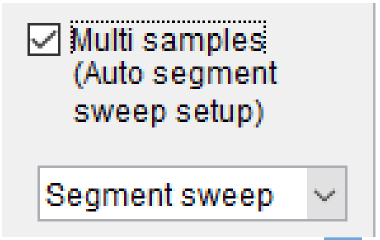
STEP2 Support + MUT measurement



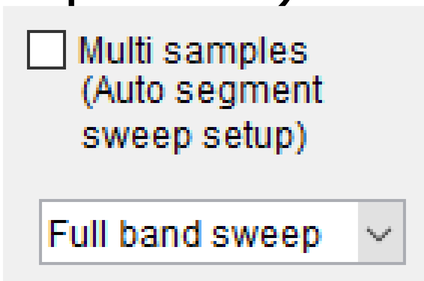


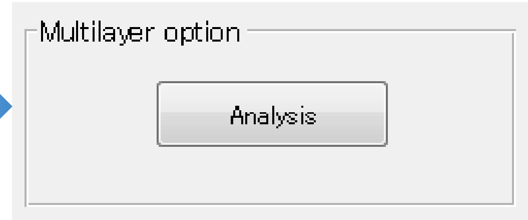
Meas. procedure of multi-layer MUT (2 times meas. for each) (thin film, optional)

A



B



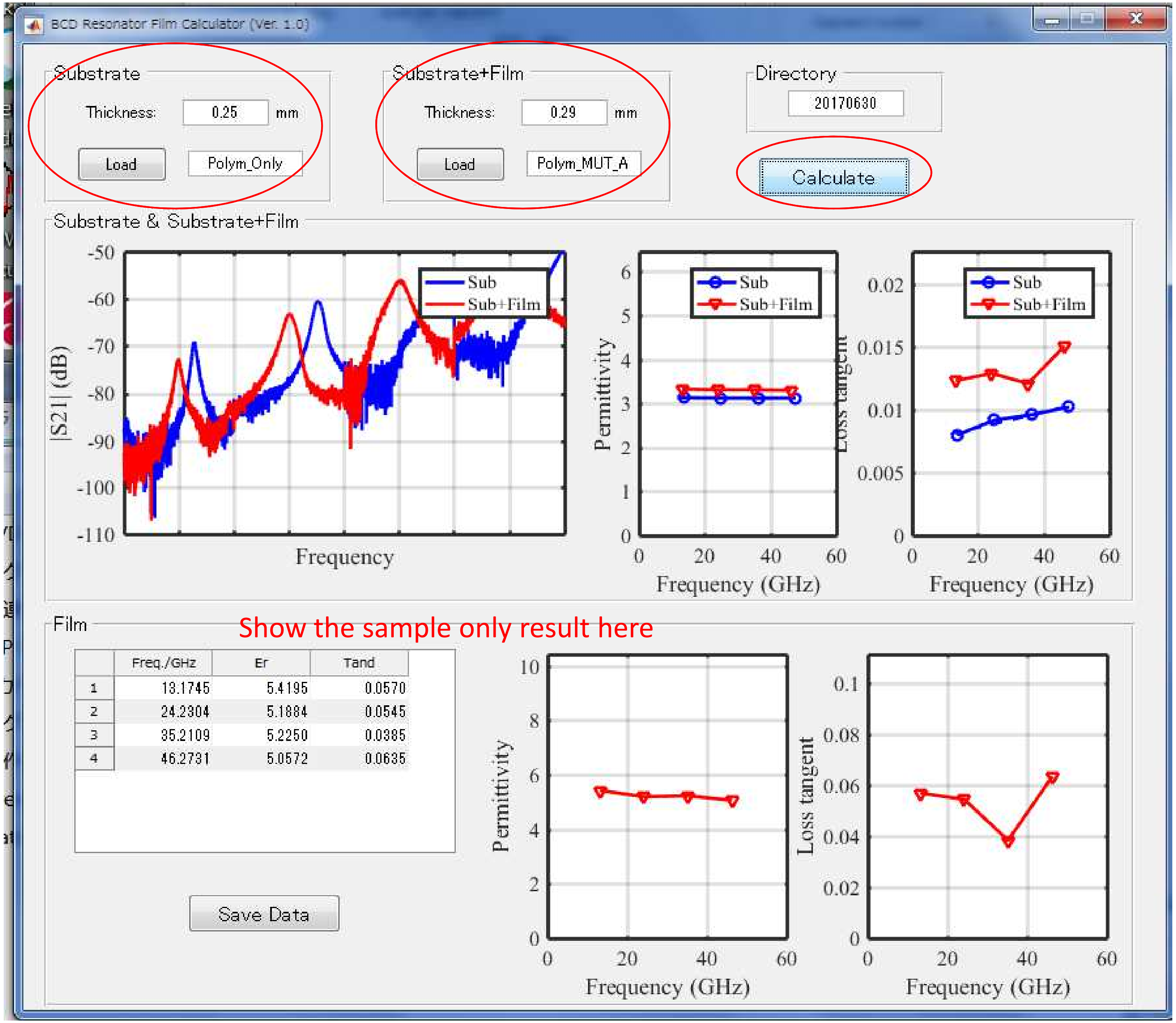


When you don’t use segment sweep but use full-span measurement, skip step 2 and 3

Step outline

1. Check “Multi samples..” and run VNA setup
2. Follow the instruction and set “support substrate only” and measure. Check the peak and set the segment frequency.
3. Follow the instruction and set “support substrate and sample”. Measure and check the frequency shift. The segment settings are automatically adjusted to include the frequency shift.
4. Take VNA calibration at the end of test port manually. Turn on the CAL.
5. Measure “support substrate and sample”, and calculate the result. Use proper file name like “support + sampleA” etc. to recall later.
6. Set “support substrate only”, then measure and calculate. Save the result into the different file.
7. Run “Analysis” under Multilayer Option.
8. Recall the calculation result file of step 4 and 5 and enter parameters. Calculate shows the sample only results.

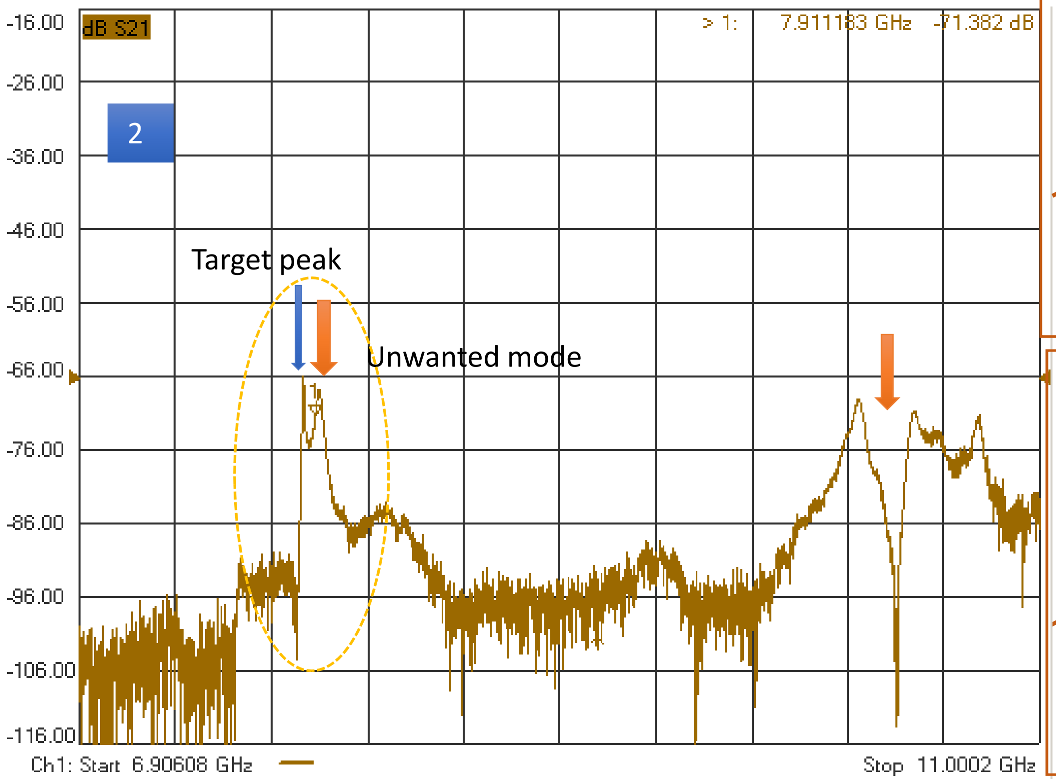
Meas. result of multi-layer MUT (2 times meas.) (thin film, optional)

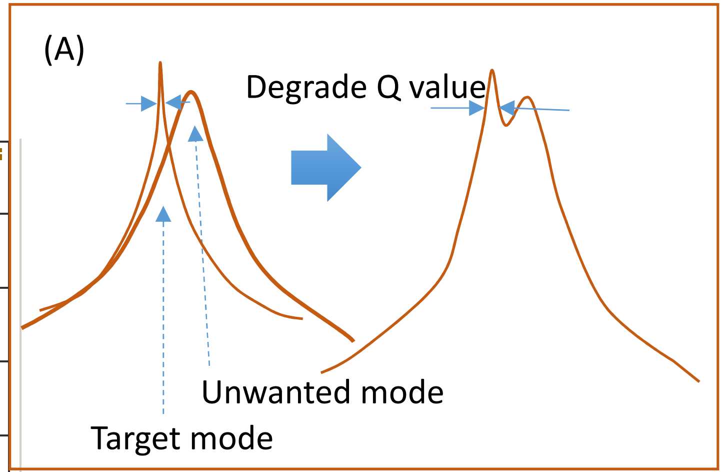


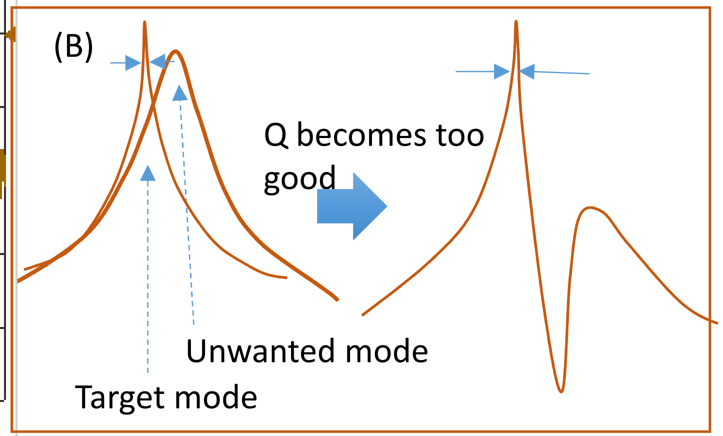
	Freq./GHz	Er	Tand
1	13.1745	5.4195	0.0570
2	24.2304	5.1884	0.0545
3	35.2109	5.2250	0.0385
4	46.2731	5.0572	0.0635

9. Summary of measurement uncertainty

Overlapping un-wanted resonance mode – Why it degrade tanδ? -

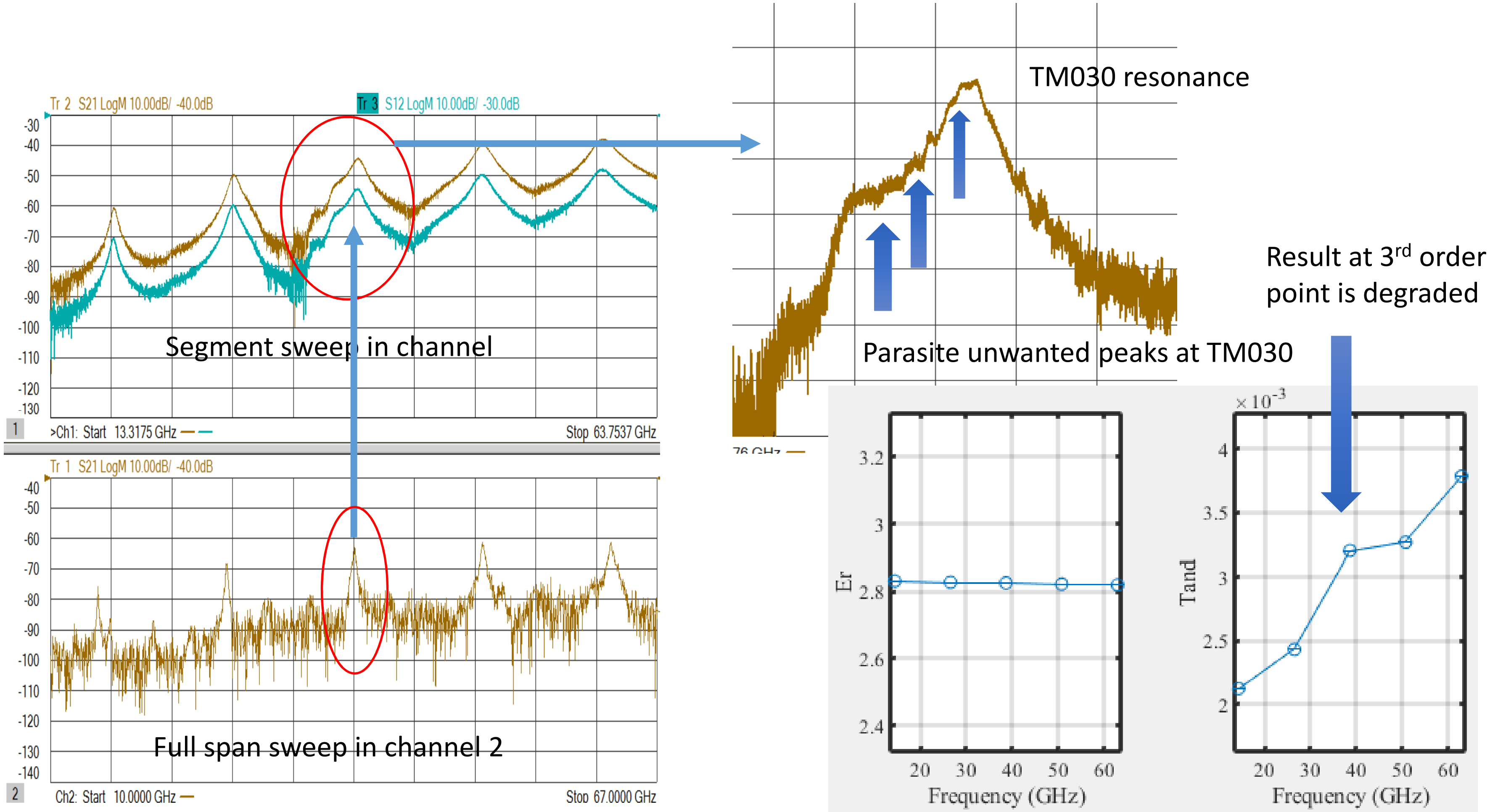






When two peaks are located in close distance, each phase difference causes response dip or multiple peaks. This makes tanδ calculation inaccurate.

Overlapping un-wanted resonance mode
- Cont. -



Factors to effect resonant frequency (= permittivity value)

Uncertainty of Cu center electrode diameter “2R” ⇒ Uncertainty factor for permittivity value

1. It’s recommended to measure the actual diameter within 0.01 mm uncertainty
2. Use precise measurement system to measure like microscope and um resolution stage or image sensor.
3. When the diameter has fluctuation, change the angle to measure and get average value

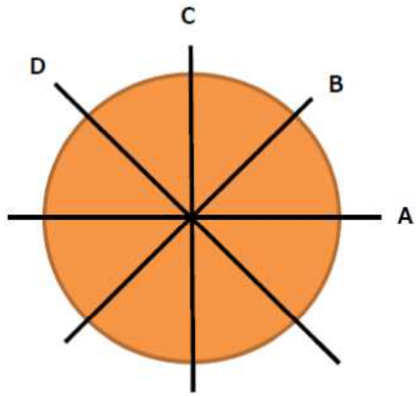
Diameter 14.925±0.015mm (measured)

(diameter fluctuation ±0.005 measurement uncertainty 0.010mm)

Measured: $\varepsilon r'$: 2.330 → $\varepsilon r'$ =2.325～2.335 with uncertainty

Δ R=±0.015mm ⇒ $\Delta\varepsilon r'$ =∓0.005

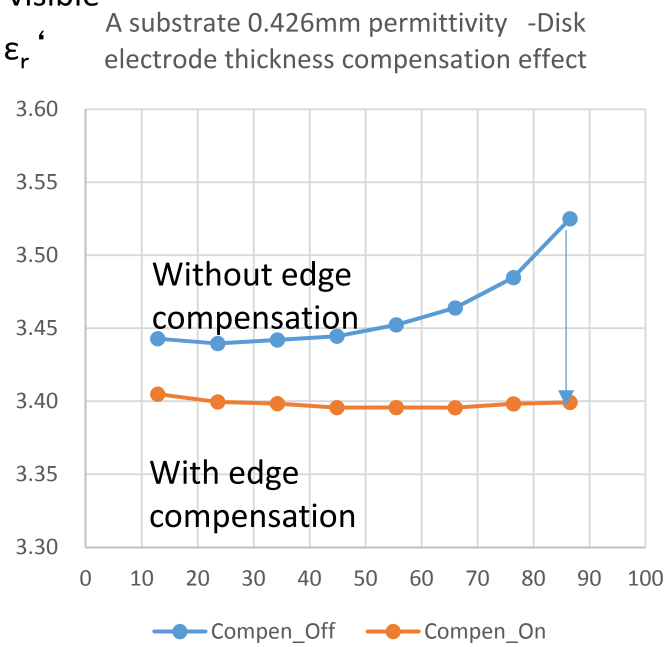
(Δ R=±0.1% ⇒ $\Delta\varepsilon r'$ =∓0.2%)



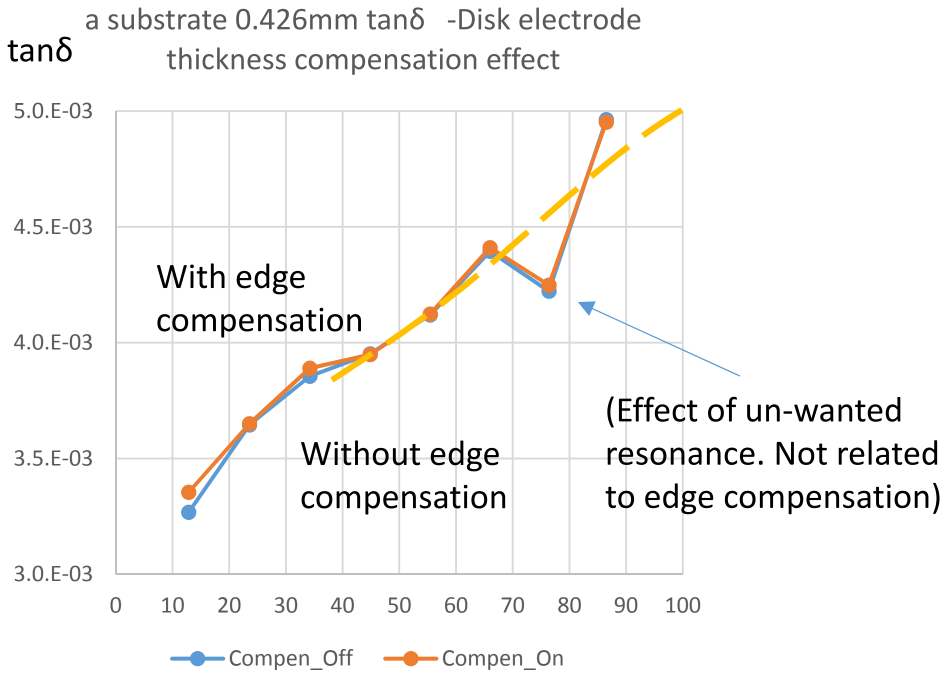
銅板測定箇所

Correction to compensate Cu electrode thickness (avoid the effect of edge) - Included BCDR 1.5.2 -

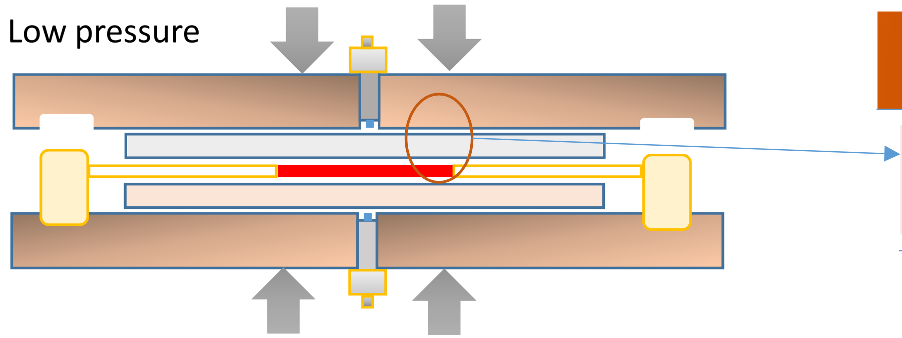
Dk value: effect of edge compensation is visible

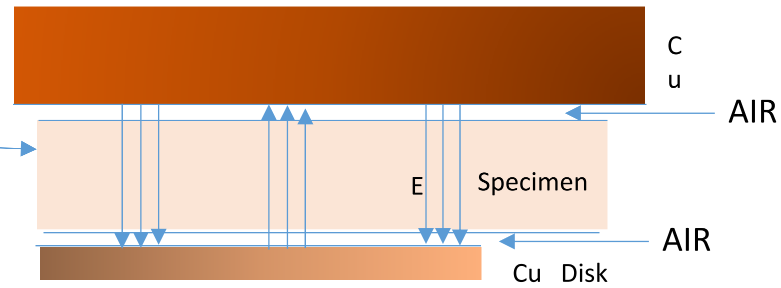


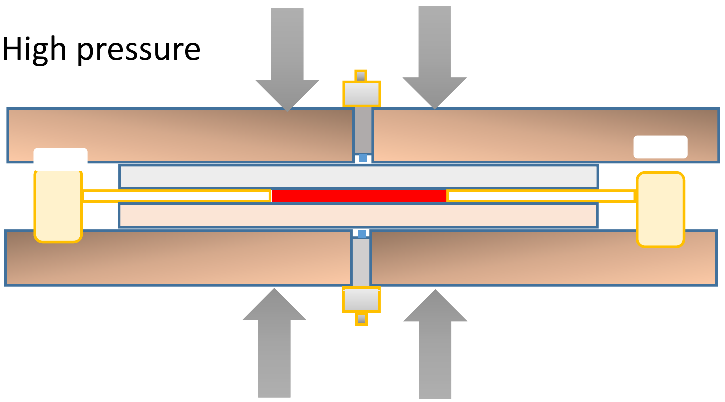
TanD: Effect of edge compensation is negligible

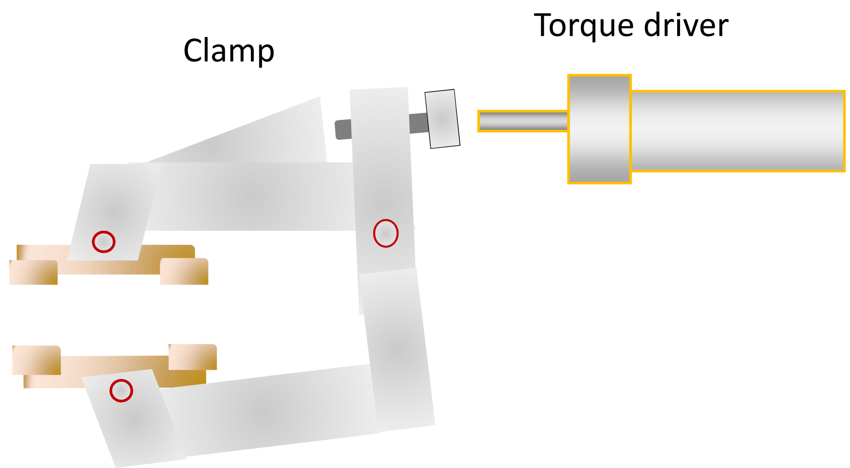


Effect of air gap: Lower Dk value



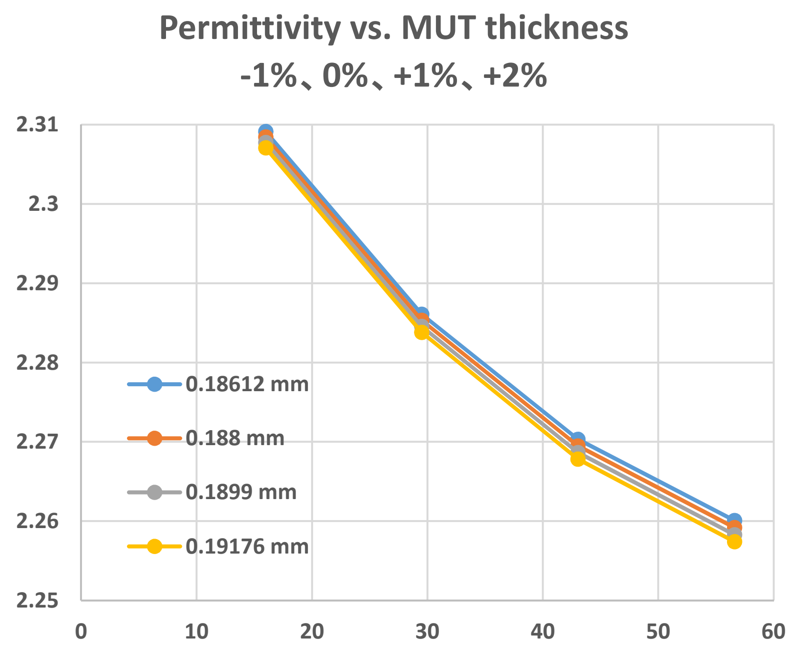


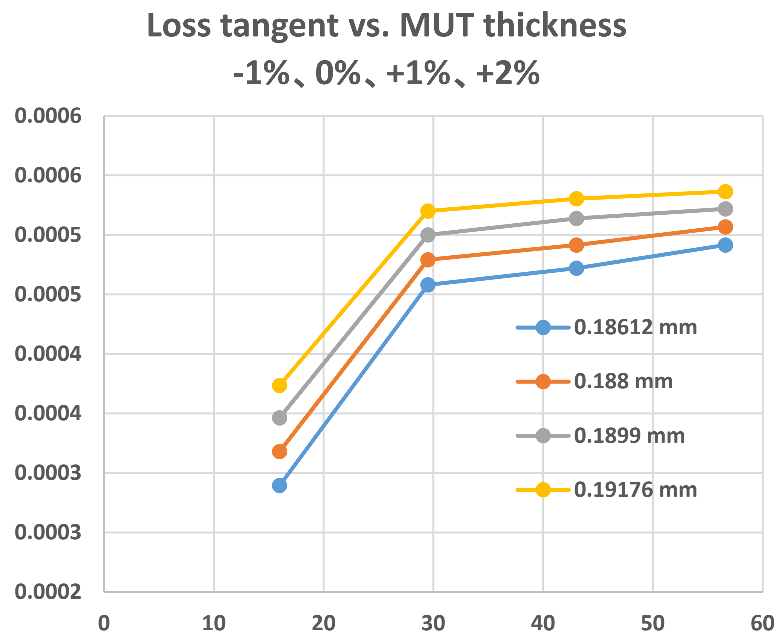




Effect of thickness error
– when t = 0.188mm & low loss sample -

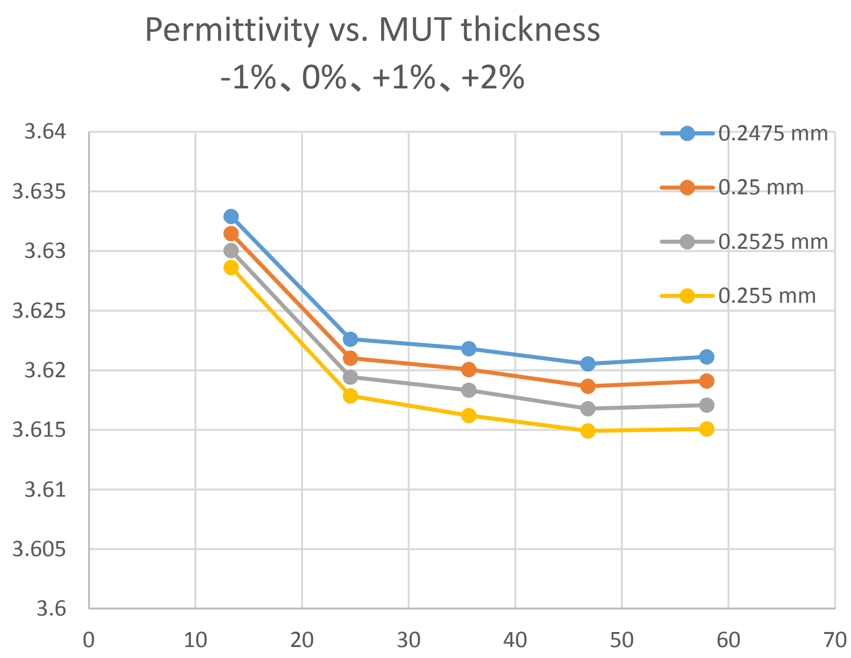
Simulate result when actual t = 0.188mm, and change the input result to -1%,0%,+1%,+2%
For tanδ=10^{-4} order samples, the effect is relatively visible
For Dk, the result is very limited and almost negligible.

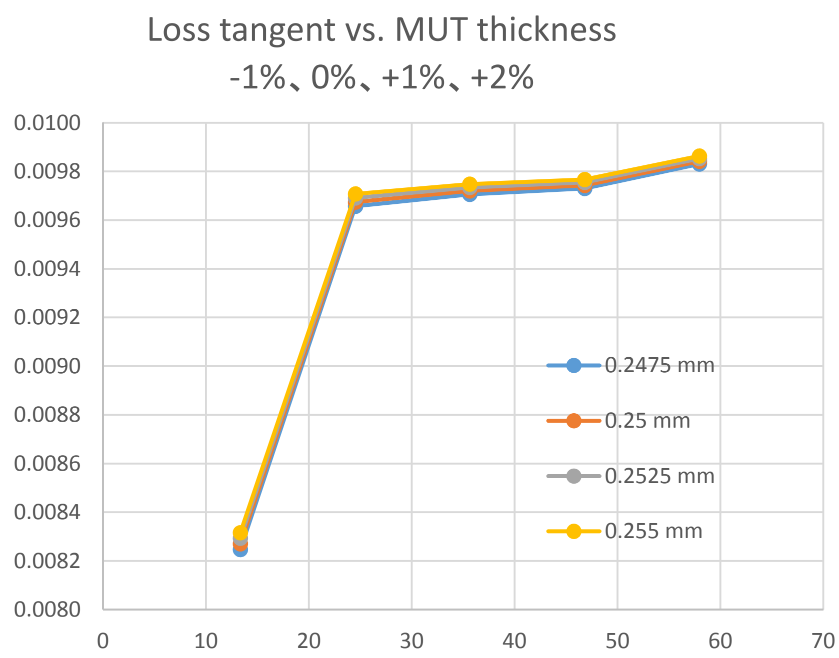




Effect of thickness error
- When t = 0.25mm and higher loss sample -

Simulate result when actual t=0.25mm and change he input value to
-1%,0%,+1%,+2%
For tanδ=10^{-2} order samples, the effect is very limited and negligible
For Dk, the result is relatively visible (~0.1 %)

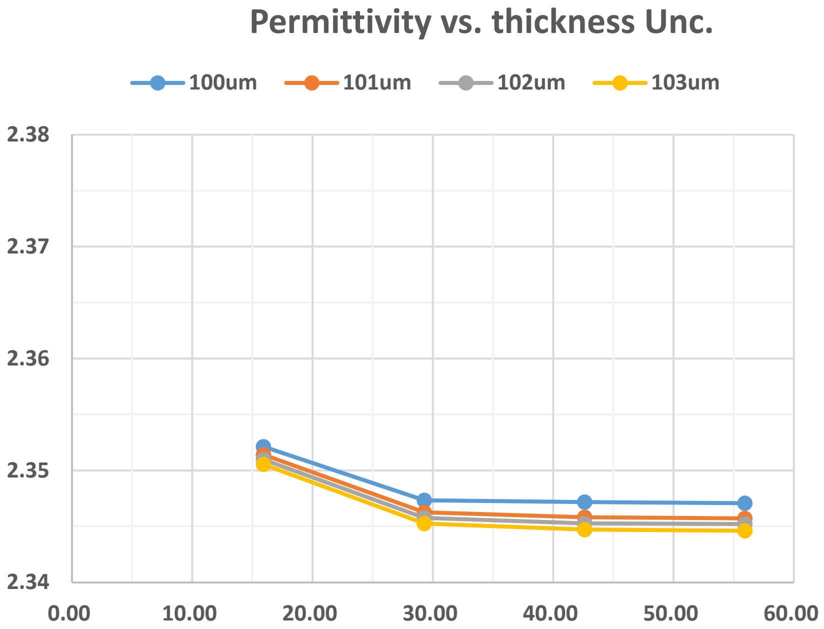


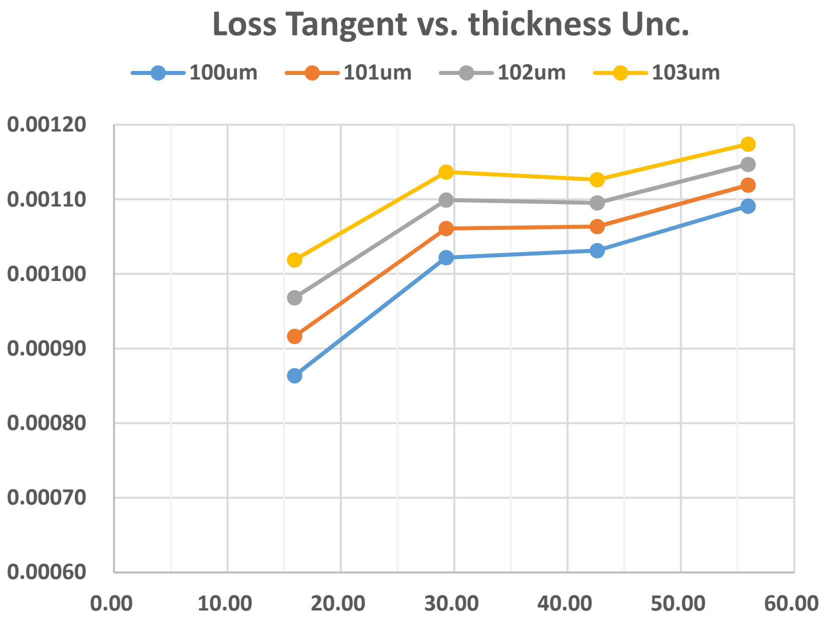


KEYSIGHT TECHNOLOGIES

Effect of thickness error
- When t = 100 um and lower loss sample -

Simulate result when actual t = 100 um and change the input value to 103 um (+3%)
For Tanδ, the effect is relatively large
For Dk, the effect is limited



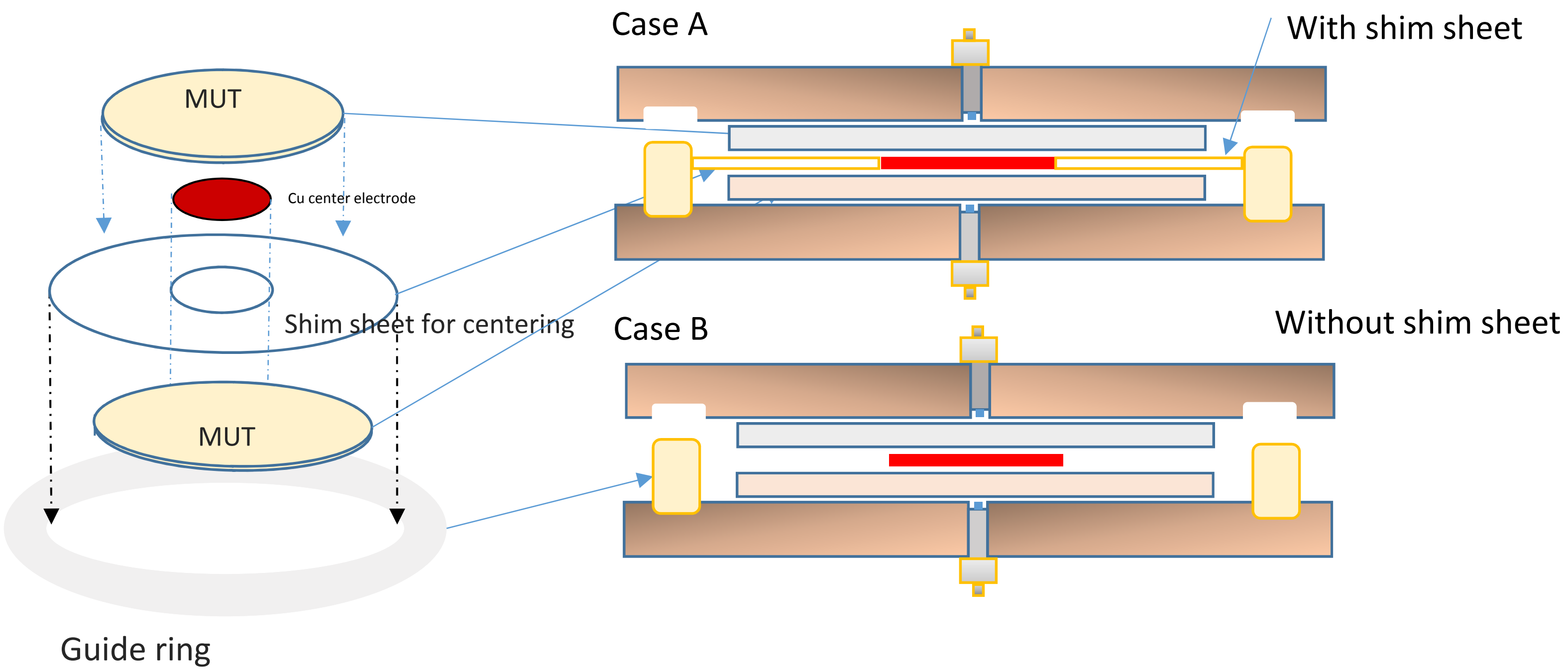


Frequency trend (slope angle) of tanD also changes

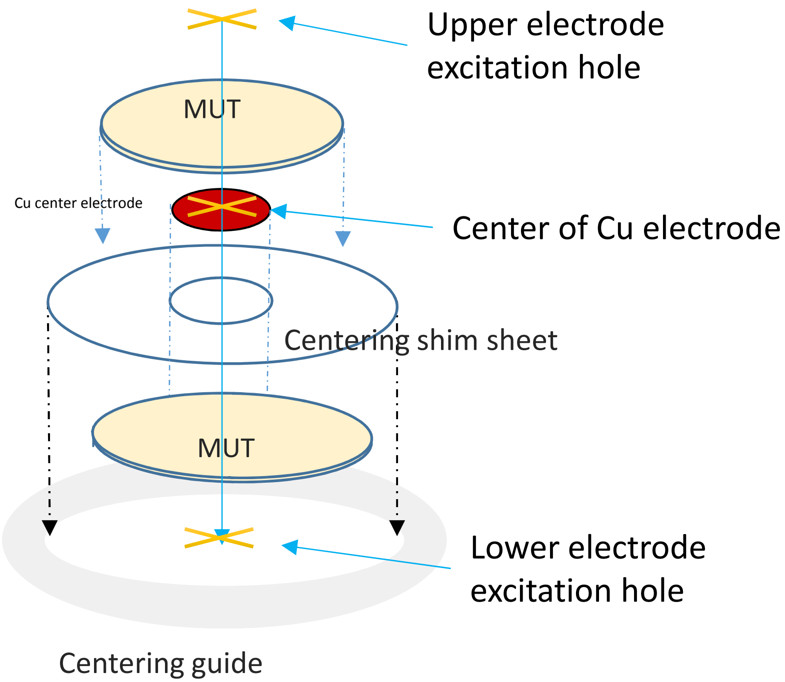
Effect of centering shim sheet

The shim sheet is required to be thin, low-loss and low-Dk material. This BCDR system uses Cyclo Olefin Polymer (COP)

Users can remove the shim sheet after setting the center Cu electrode, but we recommend to keep the shim sheet during the measurement to avoid possible electrode misalignment when removing the shim sheet, because it causes measurement error. The effect keep remaining the shim sheet during the measurement is negligible per a report from AIST.



Effect of Cu electrode centering position



Effect of the difference between the center of Cu disk electrode and center of upper/lower excitation hole is simulated as below;

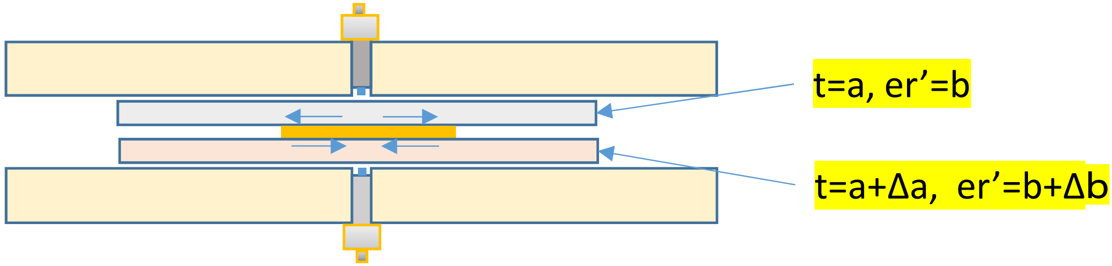
1) Less than 100 μm difference is negligible for both Dk and Df

2) Center position difference causes non TM_{0m0} mode resonance. However the effect is also negligible if enough S/N ratio is secured for the TM0m0 resonance

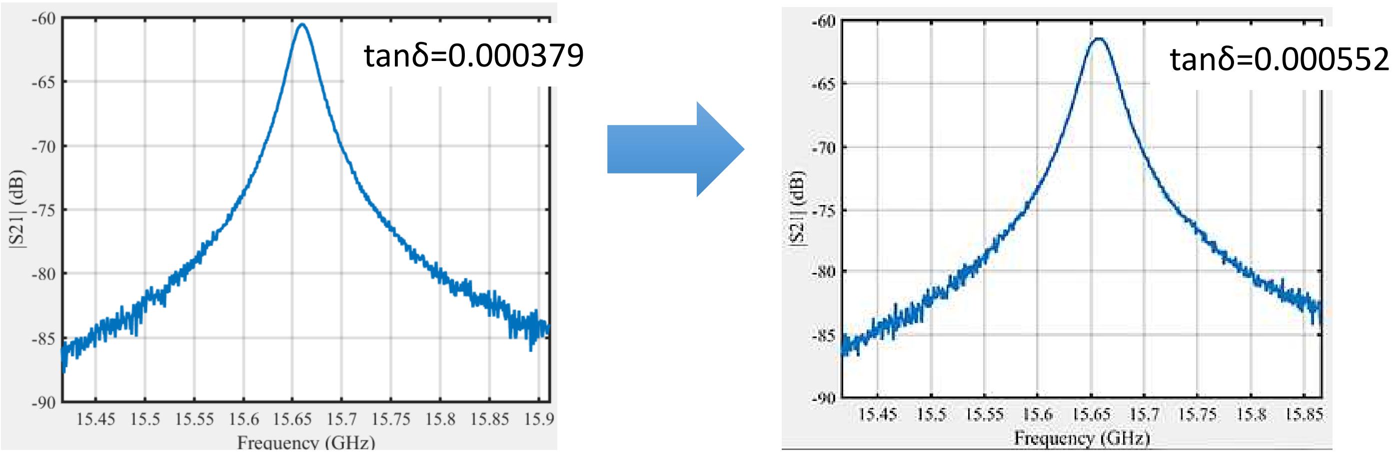
3) Larger than 100 μm difference makes non-TM0m0 mode resonance and deteriorate / distort the TM0m0 shape. It will enlarge the fluctuation of tan δ measurement result.

Effect of upper and lower sample in-balance (thickness or dielectric parameter difference)

The BCDR needs to have balanced upper and lower sample to operate correctly and keep the energy in the resonator.



If there is an unbalance factor like dielectric characteristics or thickness difference, the BCDR cannot keep the balanced status and exciting energy leaks out of the resonator. This makes Q-value lower and tanδ to be worse.



Effect of upper and lower sample's in-balance – Cont. -

Simulated result for acceptable in–balance condition when the thickness t = 0.4 mm

1. **When the Dk value is not the same between the upper and lower samples**

Dk: Results close to the average value of upper and lower sample's Dk value

tan δ: When the Dk value difference from the average value is less than 0.2%, then the effect is negligible. Otherwise, tan δ becomes degraded

2. **When the tan δ (Df) value is not the same between upper and lower samples**

Dk: no obvious effect

tan δ: Results close to the average value of upper and lower sample's tan δ value

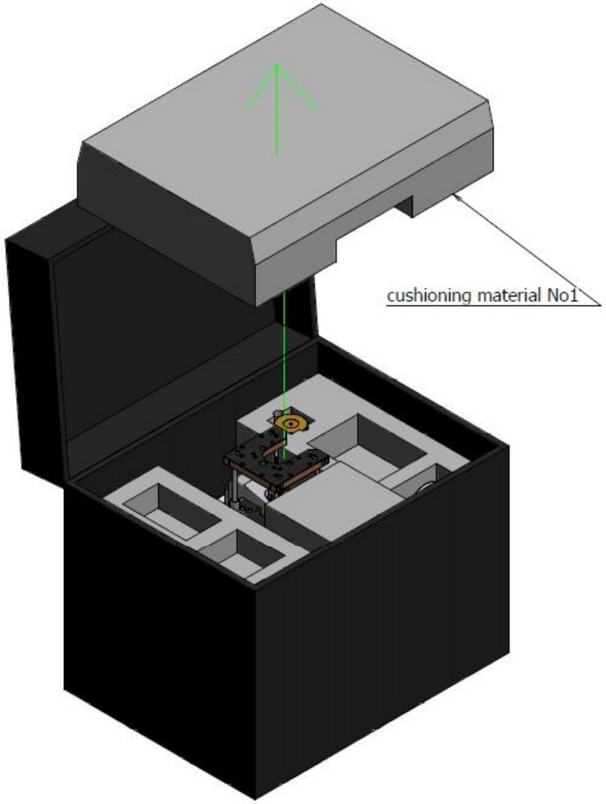
3. **When the thickness differs between upper and lower samples**

When Dk value is less than 6: The effect to Dk/Df is negligible if the thickness difference/fluctuation is less than 1% of its average value.

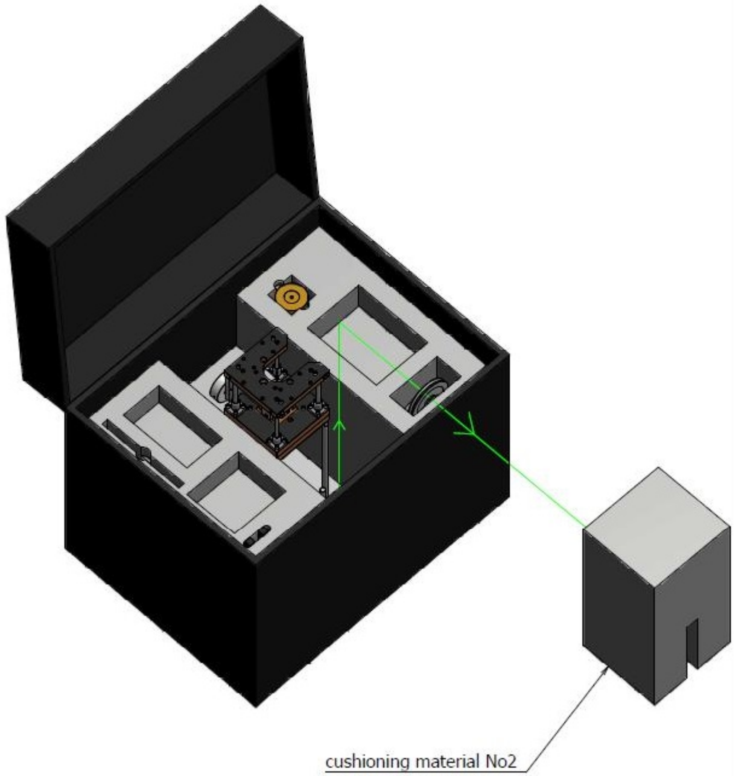
When Dk is 9, Dk/Df will change even the thickness difference is +/– 0.5%

Housing to Hard carrying case

① Lift the cushioning material No1 up.

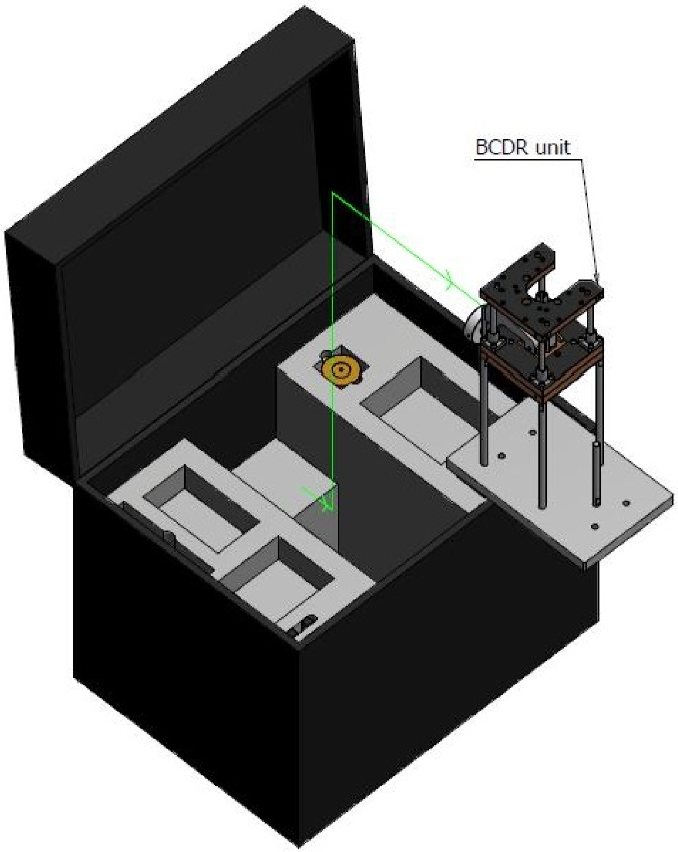


② Lift the cushioning material No2 up.



Housing to Hard carrying case

③Pull the BCDR toward you and then lift it up.



④Pull up each part weight , pulley and cable place.