Microwave/mmWave
Material Measurements

EM labs

Product Catalog

Welcome note

Since the establishment, we have been providing high quality solutions around Electro-Magnetic applications, "permittivity(ε) and permeability(μ)" measurements in particular. Our mission is to provide measurement solutions to the customers who need to "accurately" characterize materials. Now the flowers of 5G communication and Automotive Radars are about to bloom, we believe accurate material measurement is absolutely necessary to grow "firm roots", which enable big flowers to flourish.

ε and μ are basic physical quantities essential for 5G/Radar components design. However, unfortunately, the "traditional" reality was that researchers and designers had to reluctantly accept measurement results with "unavoidable" large errors. We are breaking the "false tradition". With our right solutions, ε and μ can be measured accurately ,easily, and efficiently. We have already contributed to the Japanese customers significantly, and we consider this is time for us to take this responsibility to the world-wide customers. EM Labs promise to provide the most effective and the most reliable material measurement solutions to all who need it everywhere in the world.

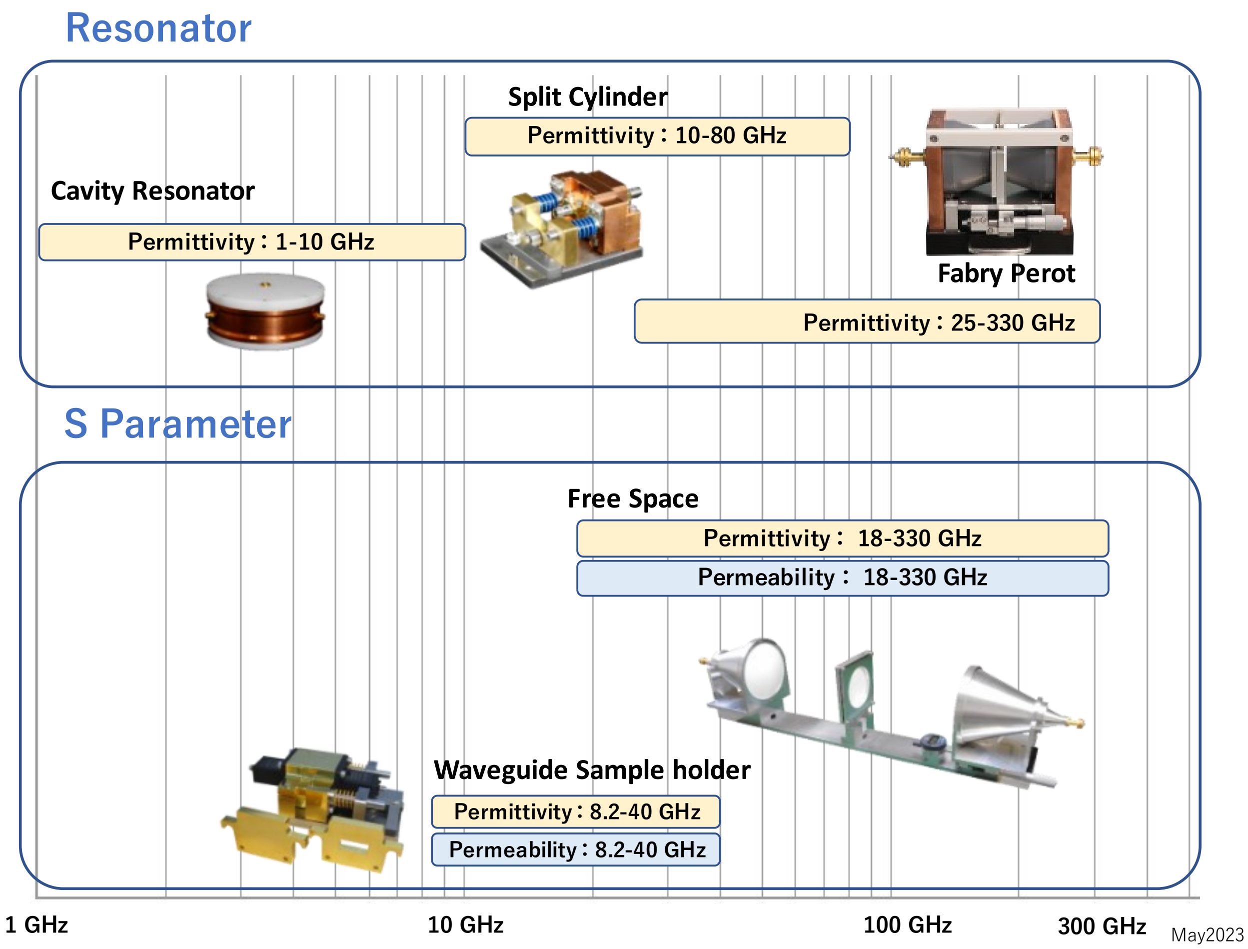
We are looking forward to helping your successful microwave measurements.

Yoshiyuki Yanagimoto CEO

Contents

Our solution for successful material measurements

In microwave material measurements, it is essential to select a right measurement method according to measurement objectives. We develop, manufacturer, sell, and support a wide variety of material test solutions for your successful material evaluation.



Emphasis on the Quality of our fixture and support

For accurate and repeatable material measurements, it is essential to use reliable fixtures. We provide high quality test fixtures by applying the know-how we have built up over 30 years of experience in every detail of design and manufacturing. The software has been developed with the aim of enabling reliable and efficient measurement by any operator. We also focus on technical support to ensure that our customers can perform correct measurements immediately after installation and for many years to come.

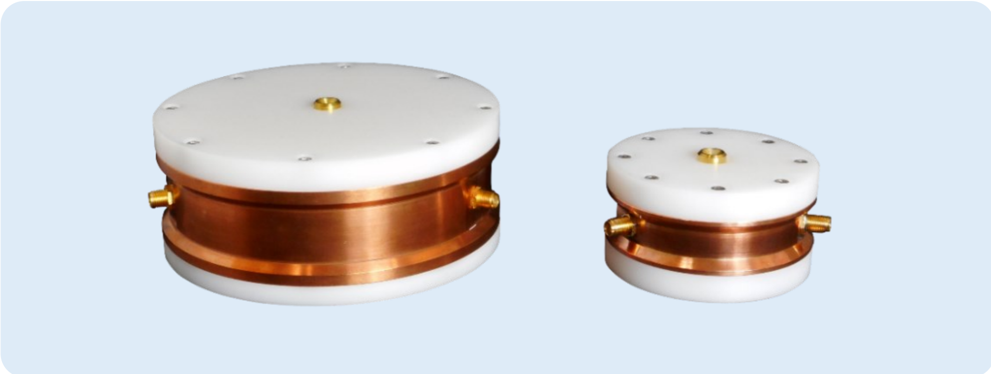
1 GHz - 10 GHz

Resonator method

Cavity resonator for permittivity measurement

Industry-proven low loss dielectric test solution

- **Ideal for evaluating low loss dielectric materials with tan δ 0.01 or less.**
- **Easy operation: simply inserting a rod-shaped sample into the insertion hole**
- **Efficient and reliable measurement with permittivity measurement software**
- **Robust hardware provides reproducible measurements over the years**



The cavity resonator is a highly reliable solution that has been used extensively by many companies and research institutions for over a quarter of a century since our company began selling for the first time in Japan. With the extremely high Q value (over 10,000, typical) of the resonator itself, it is possible to accurately evaluate low loss materials with tan δ of 0.01 or less.
Furthermore, since the measurement procedure is simple, you can efficiently measure materials with high repeatability. You can simply insert the rod-shaped sample into the sample insertion hole in the upper part of the resonator, and just click "measure". The measurement software guides you through the measurement with step-by-step explanation, with which you can obtain the correct measurement result from the beginning.

System Configuration Example

- Keysight Streamline Series USB Network Analyzer — P9373B (14 GHz)
- Permittivity measurement software for cavity resonators — CP-MA
- Cavity resonator starter kit — CP-ST
- Cavity Resonator 1 GHz — CP-001
- Windows PC

Product Line-up

<table>
<tr><th>Model</th><th>Description</th><th>Res Mode</th><th>Q factor</th><th>Sample Hole</th><th>Connectors</th></tr>
<tr><td>CP-001</td><td>Cavity Resonator 1 GHz</td><td rowspan="2">TM010</td><td rowspan="4">>10,000</td><td rowspan="7">ϕ2.6 mm</td><td rowspan="7">2.92 mm (f)</td></tr>
<tr><td>CP-002</td><td>Cavity Resonator 2 GHz</td></tr>
<tr><td>CP-245</td><td>Cavity Resonator 2.45 GHz</td><td rowspan="5">TM020</td></tr>
<tr><td>CP-003</td><td>Cavity Resonator 3 GHz</td></tr>
<tr><td>CP-005</td><td>Cavity Resonator 5 GHz</td><td rowspan="2">>7,000</td></tr>
<tr><td>CP-580</td><td>Cavity Resonator 5.8 GHz</td></tr>
<tr><td>CP-010</td><td>Cavity Resonator 10 GHz</td><td>>6,000</td></tr>
</table>

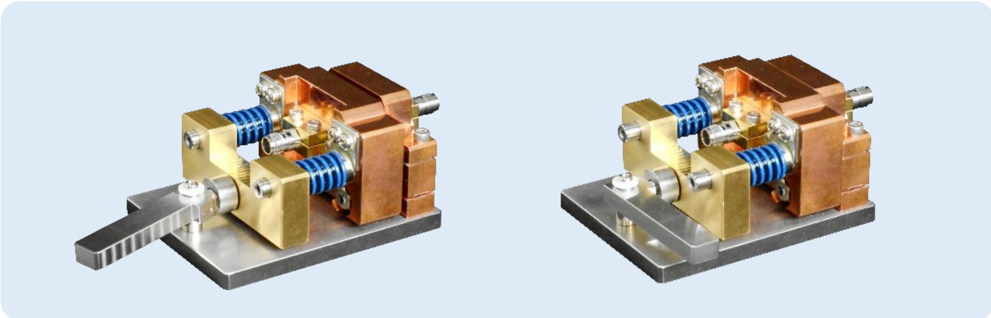
Resonator method

10 GHz - 80 GHz

Split cylinder resonator for permittivity measurement

Easy to use mm wave low loss dielectric test

- **Ideal for evaluating low loss dielectric materials with tan δ 0.01 or less**
- **Easy and reproducible dielectric material measurement in millimeter wave band with excellent fixture design**
- **Resonator design optimization extends the upper limit frequency to 80 GHz**



The millimeter wave material market is changing drastically by 5G and automotive radar. A measurement system that can evaluate leading edge materials accurately is needed to succeed in the market.
The 80 GHz split-cylinder resonator responds to this market demand and provides easy-to-use and accurate dielectric material measurements. Our split cylinder has been very well established up to 50 GHz, and the resonator design has been optimized according to the latest machining technology to extend the upper frequency towards 80 GHz. As a result, it has become possible to accurately and easily measure low loss dielectric materials in a wide frequency range from 10 GHz to 80 GHz using a flat plate sample.

System Configuration Example

- Keysight Streamline Series USB Network Analyzer — P5007B (44 GHz)
- Permittivity measurement software for split cylinder — CR-MA
- 2.92 mm test cables
- Split Cylinder Resonator 40 GHz — CR-740
- Windows PC

*** Split Cylinder Resonators are available from Keysight Technologies**

Product Line-up

<table>
<tr><th>Model</th><th>Description</th><th>Res Mode</th><th>Q factor</th><th>Connectors</th></tr>
<tr><td>CR-710</td><td>Split Cylinder Resonator 10 GHz</td><td rowspan="9">TE011</td><td>>20,000</td><td rowspan="6">2.92 mm (f)</td></tr>
<tr><td>CR-720</td><td>Split Cylinder Resonator 20 GHz</td><td rowspan="3">>14,000</td></tr>
<tr><td>CR-724</td><td>Split Cylinder Resonator 24 GHz</td></tr>
<tr><td>CR-728</td><td>Split Cylinder Resonator 28 GHz</td></tr>
<tr><td>CR-735</td><td>Split Cylinder Resonator 35 GHz</td><td rowspan="2">>10,000</td></tr>
<tr><td>CR-740</td><td>Split Cylinder Resonator 40 GHz</td></tr>
<tr><td>CR-750</td><td>Split Cylinder Resonator 50 GHz</td><td>>7,000</td><td>2.4 mm (f)</td></tr>
<tr><td>CR-760</td><td>Split Cylinder Resonator 60 GHz</td><td rowspan="2">>6,000</td><td>1.85 mm (f)</td></tr>
<tr><td>CR-780</td><td>Split Cylinder Resonator 80 GHz</td><td>1 mm (f)</td></tr>
</table>

Resonator method

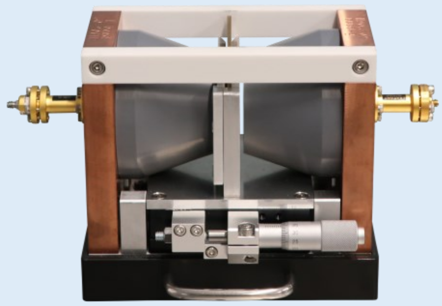
25 GHz - 330 GHz

Fabry-Perot resonator for permittivity measurement

Remarkably easy and repeatable measurements even at 330 GHz

- **Ideal for evaluation of low-loss dielectric materials with tan δ of 0.01 or less.**
- **Automatic measurement in about 5 minutes to obtain the frequency characteristics in the frequency band.**
- **Fast measurement of only 4 seconds per point.**
- **Easy installation: Normal laboratory environment is sufficient.**

FP-BB 25-110 GHz



FP-E/W/D/G/J
60-330 GHz

The Fabry-Perot resonator method is ideal for the evaluation of low-loss dielectric materials at high frequencies up to 330 GHz, which cannot be covered by split-cylinder resonators. Traditionally the Fabry-Perot resonator was thought of as a specialized instrument for a few specialists, but EM Labs has developed a solution that defies conventional wisdom by focusing on ease of use and repeatability in real-world applications. Even at a high frequency of 330 GHz, highly reproducible measurement results can be obtained regardless of the operator skills or installation environment.

System Configuration Example

- Keysight PNA MM-Wave Test System (110 GHz) P5290A
- Permittivity measurement software for Fabry-Perot Resonator FP-MA
- Fabry-Perot Resonator Broad-band (25 – 110 GHz) FP-BB
- 1 mm test cables
- Windows PC

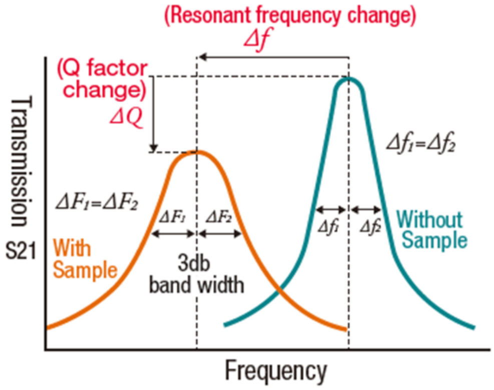
Product Line-up

<table>
<tr><th>Model</th><th>Description</th><th>Res Mode</th><th>Q factor</th><th>Connectors</th></tr>
<tr><td>FP-BB</td><td>Fabry-Perot Resonator broad band (25-110 GHz)</td><td rowspan="6">TEM</td><td rowspan="6">>100,000</td><td>1mm(f)</td></tr>
<tr><td>FP-E</td><td>Fabry-Perot Resonator E-band (60-90 GHz)</td><td>WR12</td></tr>
<tr><td>FP-W</td><td>Fabry-Perot Resonator W-band (75-110 GHz)</td><td>WR10</td></tr>
<tr><td>FP-D</td><td>Fabry-Perot Resonator D-band (110-170 GHz)</td><td>WR 6.5</td></tr>
<tr><td>FP-G</td><td>Fabry-Perot Resonator G-band (140-220 GHz)</td><td>WR 5.1</td></tr>
<tr><td>FP-J</td><td>Fabry-Perot Resonator J-band (220-330 GHz)</td><td>WR 3.4</td></tr>
</table>

Resonator method Technical overview

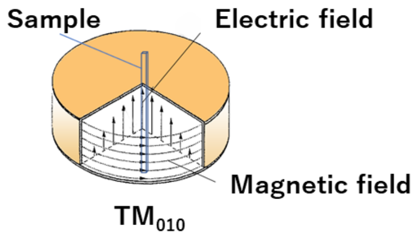
In the resonator permittivity measurement method, the material parameters are obtained from the change in resonance caused by placing the measurement sample in the resonator. The permittivity is obtained from the change in frequency, and the dielectric loss is obtained from the change in Q value. Since even a small change in loss due to the insertion of a low-loss sample can result in a large change in Q-value, low-loss can be measured accurately, which is the major advantage of this method.

The resonator method can be further classified into several techniques depending on the measurement frequency. The following is a description of the key technologies that characterize the various resonators we provide.



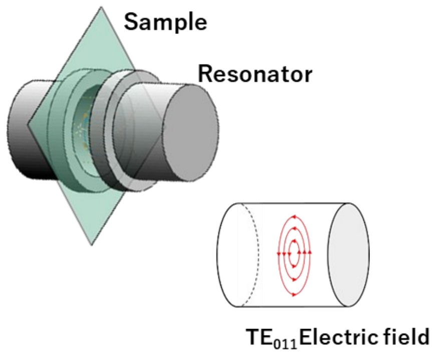
Cavity resonators for 1 GHz measurements

The CP series measures the permittivity from 1 GHz to 10 GHz using the TM010/020 mode resonance that occurs in a cavity resonator. In this resonance, the center of the cylinder is the area where the electric field is greatest, and by inserting a rod-shaped sample into this area, the permittivity is measured using the electric flux along the sample. It is possible to evaluate anisotropy by changing the direction in which the sample is cut out.



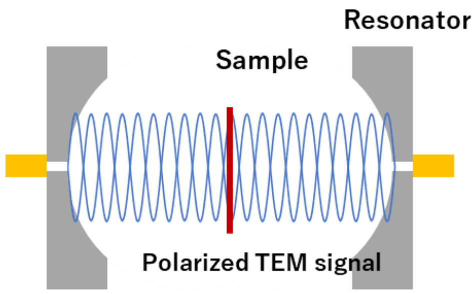
Split cylinder for measurements up to 80 GHz

In the split-cylinder resonator method, the resonator is split in the middle and a plate sample is placed between the two. In the case of the CP series resonators, imperfections at both ends of the flux in the sample can cause measurement errors. This effect is more pronounced at higher frequencies where the sample is shorter. The split cylinder uses the TE011 mode of resonance, where the electric flux circulates in the sample plane, eliminating the negative effects of "ends" and allowing accurate measurements up to high frequencies.



Fabry-Perot resonator for frequency multipoint measurements up to 330 GHz

The FP series uses polarized TEM modes signal generated in an open-type resonator, and its primary advantage is that even high frequencies such as 330 GHz can be realized with a practical-sized test fixture. (To achieve this frequency as an extension of the split cylinder, a resonator with a diameter of less than 1 mm must be made with impractical precision.) Another important feature is that multiple resonances suitable for permittivity measurement can be generated in a wide frequency range. By making good use of this, it is possible to evaluate the frequency characteristics of the permittivity with a single fixture. In addition, since polarized signal is used, anisotropy can be evaluated by rotating the sample.



S-parameter method

18 GHz - 330 GHz

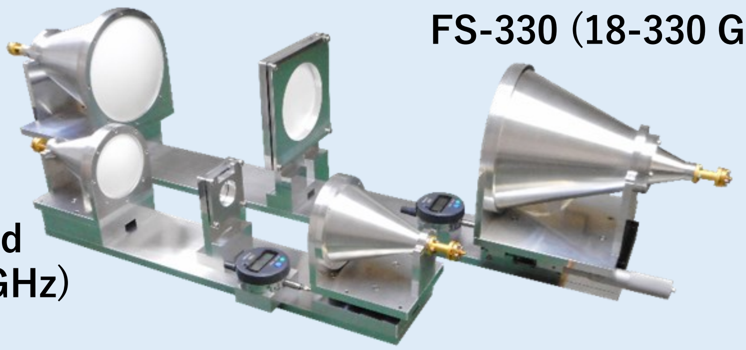
Free space method test fixture

Versatile solution with high reproducibility

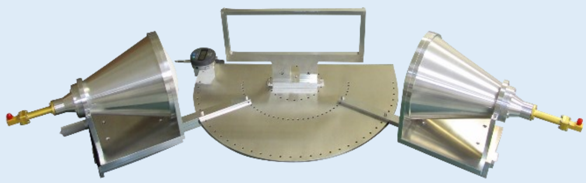
- **No need for anechoic chambers or absorbers, unlike traditional solutions**
- **Easy to move and install lightweight design**
- **1 μm precision antenna positioner that enables accurate measurement**

FS-330 (18-330 GHz)

FS-Eband (60-90 GHz)

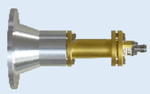


FS-330 (Oblique incidence configuration)

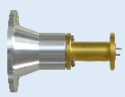


Adapters for connection

Coaxial: FS-330-xCF



Waveguide: FS-330-xWG



The free space method is indispensable to material evaluation in microwave, which can flexibly deal with a wide range of applications such as permittivity/permeability measurement and oblique incident reflection measurement. Our solution is revolutionary in that it enables accurate evaluation without anechoic chamber and radio wave absorber.

We have also simplified the mechanics significantly for easy operation while improving measurement accuracy and reducing the weight of the fixture. The simple structure improves the positioning accuracy of the antenna and makes it possible to perform TRL calibration, which is indispensable for permittivity/permeability measurements, more accurately.

Combine with Keysight Materials Measurement Suite N1500A for efficient and reliable materials measurements.

System Configuration Example

• Keysight PNA Millimeter Wave Test System	N5290A (110 GHz)
• Keysight Materials Measurement Suite	N1500A
• 1 mm test cable	
• Free Space 330 GHz	FS-330
• W band 1 mm (f) Connection	FS-330-WCF
• Windows PC	

Product Line-up

Model	Description	Frequency	Beam size (3dB width)	Beam side lobe	Focus point
FS-110	Free Space 110 GHz	18-110 GHz	3 λ	-30 dB	280 mm
FS-Eband	Free Space 60-90 GHz	60-90 GHz	3 λ	-30 dB	150 mm

FS-330 Main Options and Accessories

- FS-330-OR Oblique incidence
- Connector options

Freq band	Coaxial type	Waveguide type
K-band (18-26.5GHz)	FS-330-KCF 2.4 mm (f)	FS-330-KWG WR42
R-band (26.5-40GHz)	FS-330-RCF 2.4 mm (f)	FS-330-RWG WR28
Q-band (33-50GHz)	FS-330-QCF 2.4 mm (f)	FS-330-QWG WR22
U-band (40-60GHz)	FS-330-UCF 1.85 mm (f)	FS-330-UWG WR19
V-band (50-75GHz)	FS-330-VCF 1 mm (f)	FS-330-VWG WR15

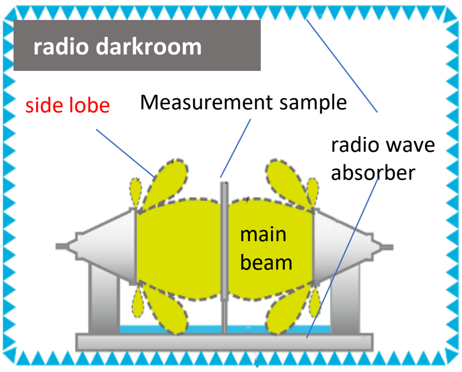
Freq band	Coaxial type	Waveguide type
E-band (60-90GHz)	FS-330-ECF 1 mm (f)	FS-330-EWG WR12
W-band (75-110GHz)	FS-330-WCF 1 mm (f)	FS-330-WWG WR10
D-band (110-170GHz)	——	FS-330-DWG WR6
G-band (140-220GHz)	——	FS-330-GWG WR5
J-band (220-330GHz)	——	FS-330-JWG WR3

Advantages of dielectric lens antennas

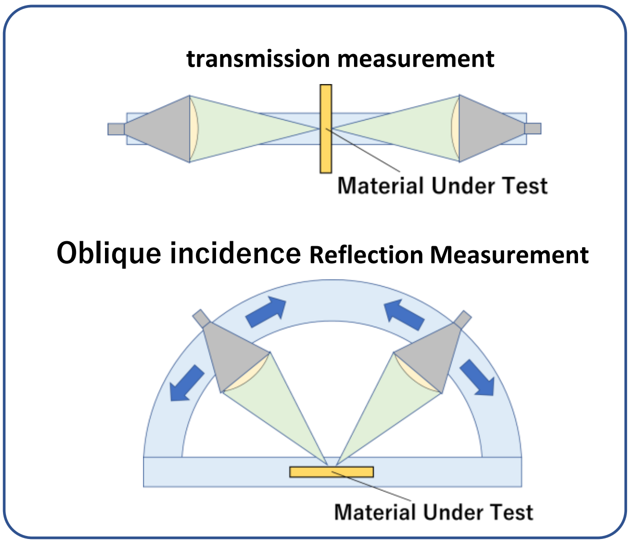
A proprietary dielectric antenna focuses the signal into the diameter of about 3 wavelengths on the material surface and suppresses the side lobe to less than -30dB. Since unnecessary reflection of electromagnetic waves hardly occurs, you can concentrate on material measurement without worrying about the surrounding electromagnetic environment. As there is no need for an anechoic chamber or radio wave absorber as in the past, it leads to significant cost reduction.
In addition, since the signal is focused, a small sample can be used for measurements.

This high-quality antenna system benefits oblique incidence reflection measurement as well: very small side lobe minimizes unwanted reflection, which results in highly reproducible measurements.

conventional technology



new technology



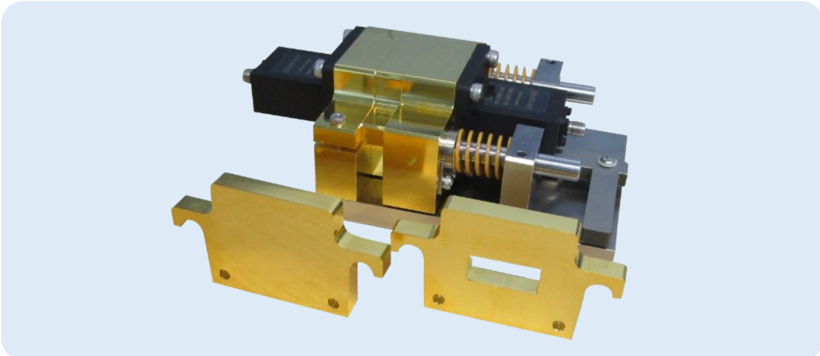
S-parameter method

Waveguide sample holder fixture

8.2 GHz - 40 GHz

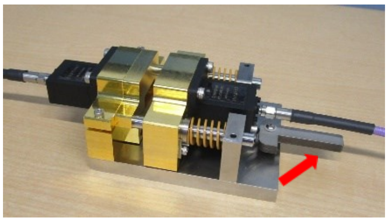
Ease of use and high precision that breaks through the norm!

- **Both permittivity and permeability measurements in a wide frequency range with a small investment**
- **One-touch fixing of the holder minimizes operational errors.**

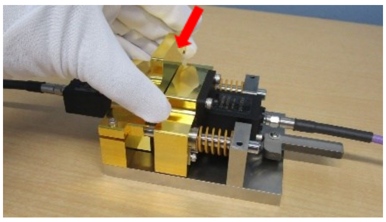


With the waveguide sample holder fixture, the coaxial connector moves less than 1 cm during the entire TRL calibration and sample mounting process. This provides unprecedented reproducibility. In addition, the holder and SHORT plate can be fixed with a single lever operation, which is efficient and eliminates variation in measurement values from operator to operator.

Release the lever



Insert the holder



Tighten the lever to secure

System configuration example

- Keysight Streamline Series USB Network Analyzer — P5007A (44 GHz)
- Keysight Material Measurement Suite — N1500A (opt.001)
- R-band Waveguide Sample holder Fixture (26.5 – 40 GHz) — WSF-R
- RF cable 2.92 mm
- Windows PC

Product Lineup

Model Number	WSF-X	WSF-P	WSF-K	WSF-R
Frequency (GHz)	8.2-12.4	12.4-18	18-26.5	26.5-40
Waveguide Standard	WR90	WR62	WR42	WR28
Holder inner dimensions (mm)	22.86 x 10.16	15.80 x 7.90	10.67 x 4.32	7.11 x 3.56
Holder length (mm)	7.5	5	3.5	2.5
Connectors	2.92 mm (f)			

S-parameter method technology overview

The permittivity/permeability can be obtained based on the S-parameters of the material to be measured. S-parameter method can be roughly classified into two: the free space method and the sample holder method. In the free space method, the material is placed in a free space for measurement. In the sample holder method, the material is inserted into a closed space such as a coaxial line or waveguide for measurement. Both methods are ideal for evaluating the frequency characteristics of materials. They are also effective for measuring samples with relatively large losses or samples that are difficult to process into film form.

On the other hand, the accuracy of the loss measurement is directly dependent on the measurement accuracy of the network analyzer, which limits the evaluation of low-loss materials: Tan δ 0.01 is the approximate measurement limit. (For low-loss materials, resonator methods are recommended for accurate measurements.)

When combined with Keysight Materials Measurement Suite N1500A, efficient and reliable material measurement can be achieved. The N1500A supports a variety of algorithms, among which representative ones are listed below.

N1500A	Model	measurement S parameter	material paramete r	Summary
Reflection/ Transmission Mu and Epsilon	Nicholson-Ross-Weir (NRW)	S11, S21, S12, S22	ε_r μ_r	It was developed by Nicholson and Ross and later applied by Weir to network analyzers to calculate permittivity/permeability from S-parameters. Discontinuities can occur in low-loss samples with thicknesses greater than half a wavelength. It is ideal for evaluating magnetic materials such as ferrites and radio wave absorbers.
Reflection/ Transmission Epsilon Precision	NIST Precision	S11, S21, S22	ε_r	Developed by NIST to calculate permittivity from S-parameters. It is ideal for relatively thick low-loss dielectric material samples.
Transmission Epsilon Fast	Fast Transmission	S21, S12	ε_r	The permittivity is predicted and then the minimization of the difference between the predicted S parameters and the measured values is repeated into predefined value. It is best suited for relatively thick, low-loss dielectric materials and where reflection measurements include significant errors. .

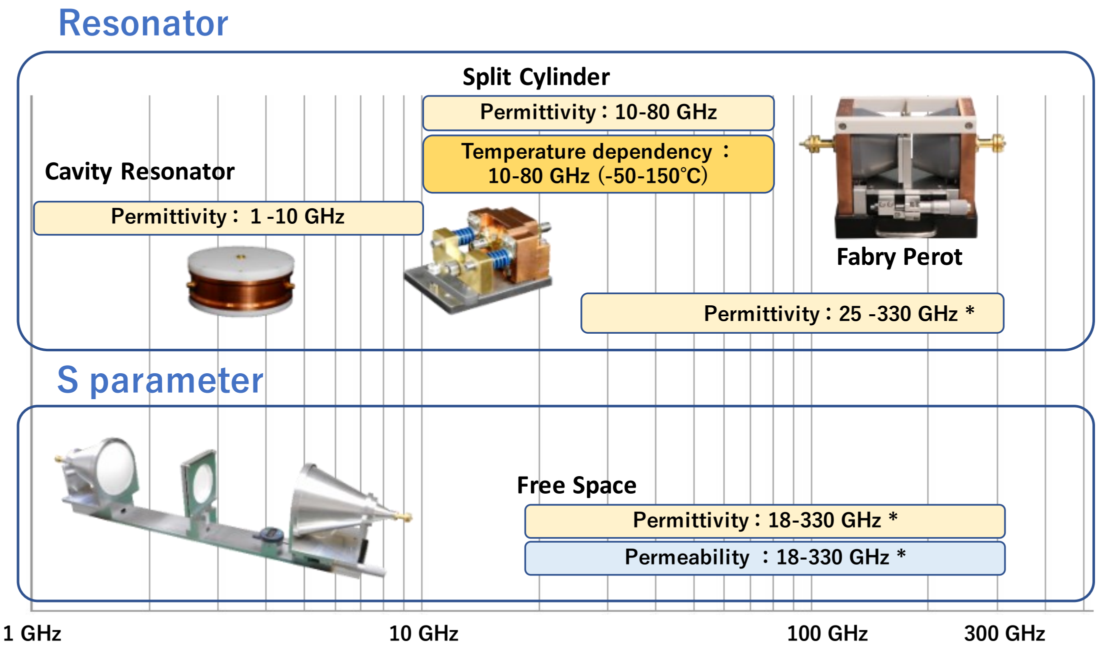
Professional Measurement Service

- Up to 330 GHz
- Suggest the best method for your test needs
- Reliable measurements from experts

Contact
mail：mido@emlabs.jp

Service Lineup

All of the resonator methods (Cavity Resonator, Split Cylinder, and Fabry Perot) as well as S-parameter methods (Waveguide Sample Holder and Free Space) are available for professional measurement service. In addition to dielectric constant and magnetic permittivity, reflection and transmission characteristics are available on the S-parameter method.



* Except 170-220 GHz May2023

Resonator Method test frequencies (GHz)	**Cavity :** 1, 2, 2.45, 3, 5, 5.8, 10 **Split Cylinder :** 10, 20, 24, 28, 35, 40, 50, 60, 80 **Fabry-Perot :** Broadband (25-110), Eband(60-90), Wband(75-110), Dband(110-170), Jband(220-330)

10-80 GHz DkDf Temperature/humidity dependency test

Temperature dependency of dielectric constant is getting more and more important with growth of the application area of mmW devices.

DkDf temperature dependency test conditions

Freq： 10, 20, 24, 28, 35, 40, 50, 60, 80 GHz
Temp： -50℃~150℃

DkDf temp/humidity dependency test conditions

Freq： 10, 28, 40 GHz
Temp：Refer to our web site

For more information, visit the measurement service page on our web site.

Importance of Sample Preparation

It is the first step to accurate measurements.

Both methods, the resonator method and the S-parameter method, require the sample to be machined to fit the fixture. Since the size of the sample is used to calculate the permittivity and permeability, measurement errors in the sample size directly affect the measured values of permittivity and permeability. Therefore, in order to evaluate material properties accurately, it is necessary to know the size accurately. Ideally, the cross-sectional area of a rod-shaped sample should be uniform, and the thickness of a plate-shaped sample should be uniform.

Material preparation for cavity resonators

It is basic to machine the sample into a rod shape. The recommended size is shown below. In the case of anisotropic samples, the difference in permittivity due to anisotropy can be evaluated by changing the direction of sample extraction.

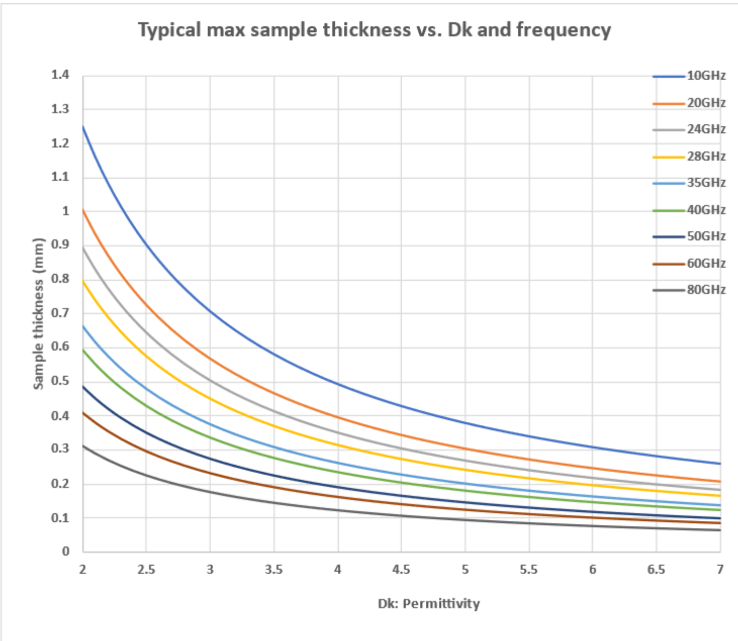
Size recommendation: Cavity

Resonator	WxD (mm)	L (mm)
1- 5.8 GHz	1.5 x 1.5	80
10 GHz		60

Material preparation overview for Split Cylinder

The sample needs to be processed into a plate. The characteristics of the material and the measurement frequency determine the appropriate thickness and size.

Thickness :
We recommend about 100µm. The graph shows the approximate maximum thickness that can be measured with the split cylinder resonators. The larger the permittivity and the higher the frequency, the thinner the sample needs to be. If the loss is more than about 0.01, a thinner sample may be required. On the other hand, it should be noted that the thinner the sample (e.g. 10µm), the more noticeable the error in thickness measurement becomes, and consequently the larger the error in permittivity measurement becomes. For details, please contact us.



Size:

Recommended size for split cylinder

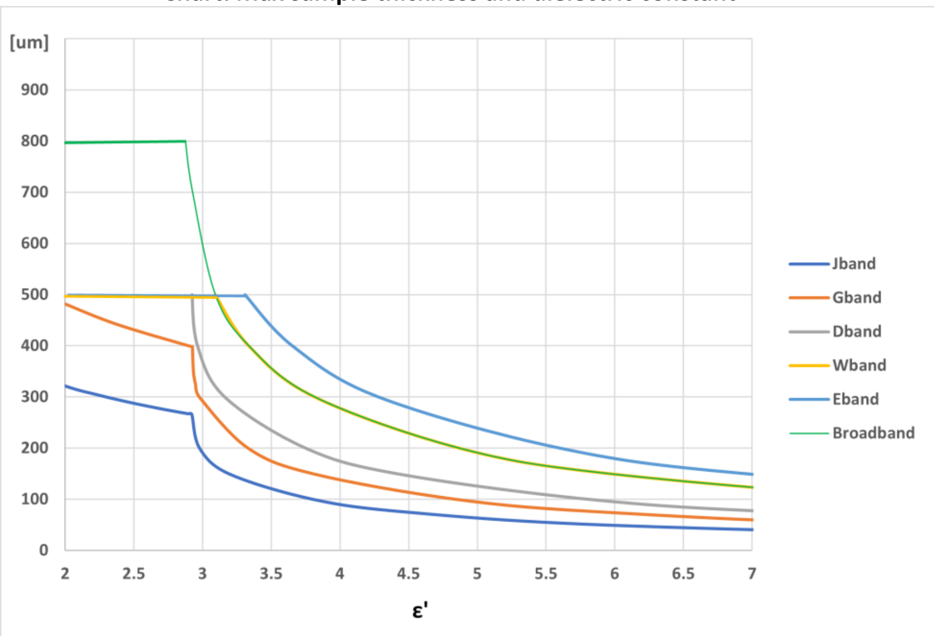
Resonator	Short side (mm)	Long side (mm)
10 GHz	62	75
20-80 GHz	34	45

Material Preparation Overview for Fabry-Perot Resonator

The sample needs to be processed into a squere plate. The characteristics of the material and the measurement frequency determine the appropriate thickness and size.

Thickness: The appropriate thickness depends on the dielectric properties and the resonator used, but 100 µm is a good rule of thumb. The higher the frequency and the higher the dielectric constant, the thinner the sample needs to be. The relationship between the sample thickness, dielectric constant, and frequency band is shown in the chart. The maximum sample thickness that can be measured correctly throughout the entire measurement frequency band of each device is shown in the chart. Please contact us for measurement of thicker samples. Note that a sample with high loss (tan δ >0.01 is a rough guide) requires an even thinner sample.

Chart: Max sample thickness and dielectric constant



Size:

Recommended size for Fabry-Perot

Resonator	Square (mm)
E/W/D/G/Jband	50
Broadband	65

Material preparation overview for free space method

It is necessary to process the sample into a flat plate shape. The recommended size varies depending on the measurement frequency and the permittivity/permeability of the material.

Thickness: For permittivity measurements, a half wavelength is optimal. For permeability, a quarter wavelength is optimal. The thicker the sample, the more significant the error due to multiple reflections within it. This is especially noticeable in magnetic permeability measurement. (In both cases, it is necessary to take into account the wavelength shortening in the sample*.)

* wavelength shortening $= \frac{1}{\sqrt{\varepsilon' \mu'}}$ (ε ': relative permittivity, μ ': relative permeability)

Size: A diameter of 6 wavelengths or more is recommended. A diameter of 60 mm or more makes it easier to fix to the fixture.

Company name	EM Labs Inc.
Location	1-4-13 Mizukasadori, Nagata, Kobe Hyogo 653-0842 Japan TEL +81-50-5370-0262 Mail: info@emlabs.jp Web site: www.emlabs.jp
CEO	Yoshiyuki Yanagimoto
Establishment	March 1, 1982
Business areas	Microwave measurement: fixture/system development, measurement service, and consulting ・Dielectric/Magnetic material test solutions ・Test fixtures for network analyzers ・Test fixtures for impedance analyzers
Owned Equipment	Network Analyzers (Keysight Technologies) N5290A (10 MHz - 110 GHz) P5007A (100 kHz - 44 GHz) N5262BW06 (Frequency Extender 110-170 GHz) N5262BW03 (Frequency Extender 220-330 GHz)

KEYSIGHT TECHNOLOGIES

Nov 2023