



OPERATION MANUAL

CP Series cavity resonator

EM LABS INC.

Sep 12, 2020

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First Edition: April 6, 2020

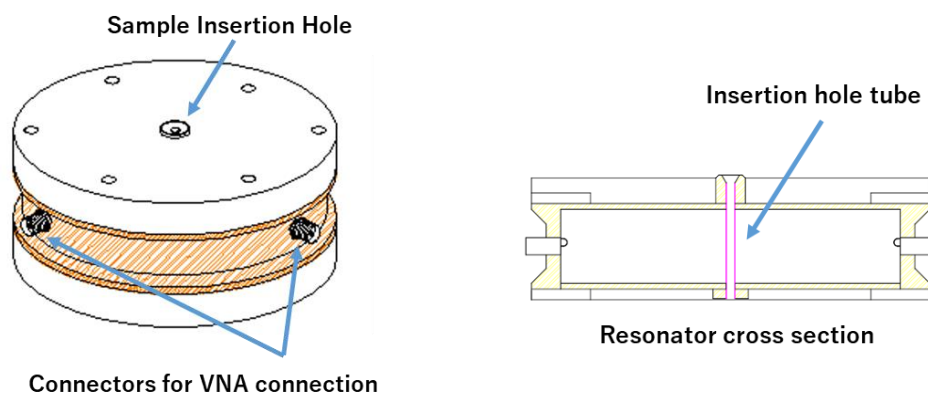
1. Product Overview

This section outlines the product.

CP series cavity resonators are designed to be used with a network analyzer and measure the complex relative permittivity, using the perturbation method. In order to accurately measure low loss materials, the loss of the resonator is designed and manufactured extremely small. In addition, since the sample can be easily inserted and removed, you can efficiently measure samples. Measurement can proceed according to the instructions of the permittivity measurement software.

Appearance and structure of the resonator

As shown in the figure below, the resonator has a cylindrical sample insertion hole in the center of the upper surface. There are two coaxial connectors on the side for connecting the network analyzer. The inside is empty except for the resin tube in the center for inserting the sample properly. The insertion hole penetrates through the lower surface of the resonator, as shown in the cross section view, so that a long sample can be measured at the specified part.



Product specifications

Model Number	Resonance characteristic			Sample insertion hole	VNA connector
	Frequency (MHz)	Un-loaded Q	Mode		
CP-001	1,000 ± 100	Over 10,000	TM010	φ 2.6mm	2.92mm (female)
CP-002	2,000 ± 150	Over 10,000	TM010		
CP-245	2,450 ± 150	Over 10,000	TM020		
CP-003	3,000 ± 200	Over 10,000	TM020		
CP-005	5,000 ± 300	Over 7,000	TM020		
CP-580	5,800 ± 300	Over 7,000	TM020		
CP-010	10,000 ± 700	6,000 or more	TM020		

Accessories

There is no accessory. The contents of the starter kit (CP-ST) are as follows.

Coaxial cable 2.92 mm (m)- (m) x 2
Quartz sample x 1

2. Measurement

This section mainly explains how to perform the measurement. In addition, as reference information, the measurement principle is outlined at the end of the chapter.

Sample preparation

It is necessary to prepare the sample into a rod shape with proper size according to the fixture to use. Since the size of the sample is used in the calculation of the permittivity, it is important to know the size accurately. In order to accurately determine the size, it is ideal that the cross-sectional area is uniform. It is the first step of accurate measurement to properly prepare the sample.

About sample size

Basically, it should be as thick as possible within the range that fits comfortably in the sample insertion hole. Due to the principle of the perturbation method, the larger the sample volume in the resonator, the smaller the measurement variation. The recommended sizes are as follows.

Resonator Type	Sample insertion hole	Cross section (mm)	Length (mm)
1 – 5.8 GHz	ϕ 2.6 mm	1.5x 1.5	80
10 GHz			60

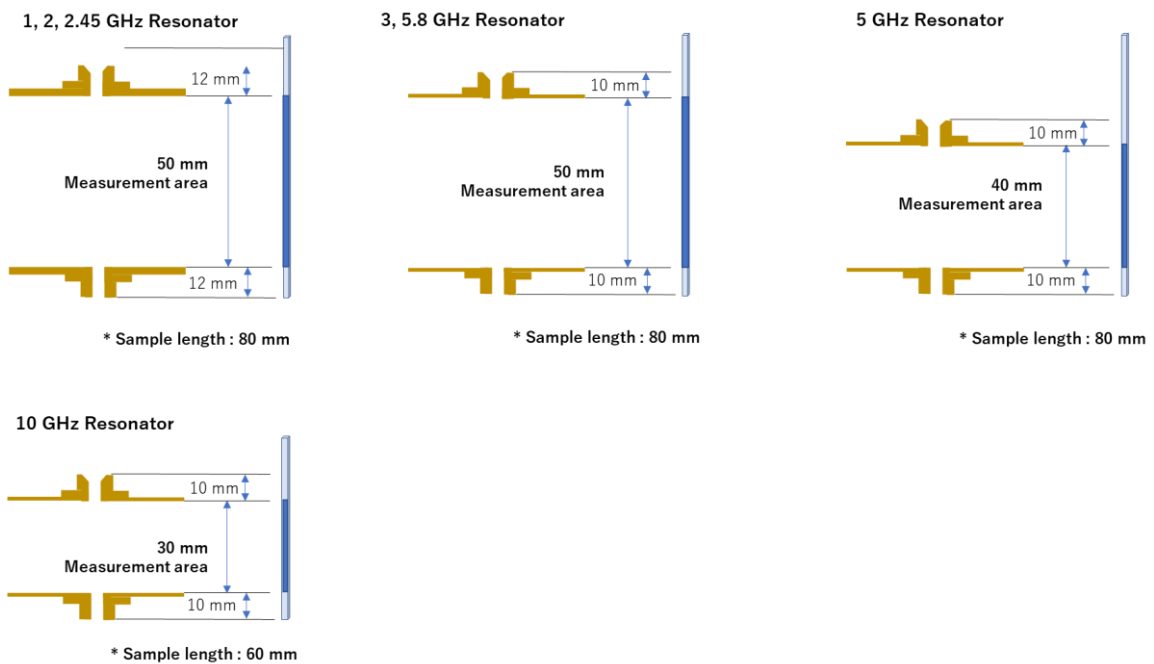
NOTE

If the sample is too thick, the tube of the sample insertion hole may be damaged. Process the sample so that it does not exceed the diameter of the insertion hole.

About size measurement

When actually measuring permittivity, enter the sample cross-section size as a rectangle (length and width) or a circle (diameter) according to the instructions of the measurement software. Therefore, it is necessary to measure the sample size in advance. Since the error of the input value causes the error of the permittivity measurement, accurate measurement is necessary.

Although it depends on the sample shape, it is generally recommended to measure 3 to 5 places with a micrometer and use the average value. In that case, it is important to measure the size of the part actually used for permittivity measurement. See the figure below for the specific locations of the parts used. The figure shows the cross section of the resonator and the corresponding sample. The red shaded area in the sample is the range that is used for measurement.



For thin film

If a thin-film sample is measured as it is, the sample volume is very small, and thus the measured results may vary significantly. If the variation cannot be tolerated, increase the volume using the following method:

- Cut a thin film into a suitable width and roll it into a bar for measurement: Effective when the sample is flexible
- Measuring multiple thin films together: Effective when the sample is hard

In any case, when entering the sample size in the measurement software, enter the value converted into a single square or round bar. In doing so, ignore the layer of air between the materials and calculate only the volume of the material.

Also, it may be difficult to insert the soft thin film into the insertion hole as it is. In most cases, this can be solved by adding a weight to the bottom of the sample. At that time, care must be taken so that the weight is not located in the measurement part. The insertion hole passes through the bottom of the resonator, so the weight can be located out of the resonator.

Measurement procedure

Start the permittivity measurement software and follow the instructions on the screen to perform the measurement. Please refer to the software manual for detailed procedure. This section focuses on cautions on handling the resonator and sample under test and explain what you need to know in order to measure correctly.

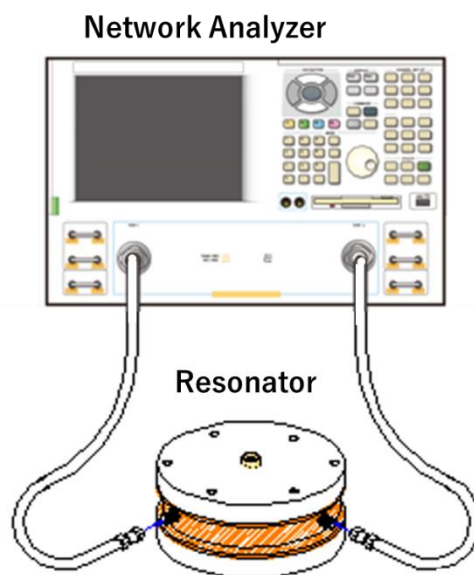
Before starting measurement

Before starting the permittivity measurement software and starting the actual measurement, please make sure that the following preparation has been completed.

- The temperature of the resonator is stable. It is recommended to start measurement at least 30 minutes after setting the fixture in the actual measurement environment.
- The network analyzer has been warmed up. (Follow the recommended warm-up time of the network analyzer)
- The size of the samples has been measured and recorded.
- A torque wrench and spanner for connector connection must be prepared. Tweezers and gloves for handling samples are prepared, if necessary.

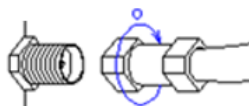
Instrument connection

Connect the cavity resonator to the network analyzer to measure permittivity by using two RF cables.



NOTE

It is important to use a torque wrench to apply proper torque when tightening the connector. Excessive torque can damage the connector. Torque shortage causes measurement errors and rotation of the center conductor, which can damage the connector. Also, be careful to rotate only the nut of the male connector. Rotating the center conductor leads to wear and damage of the connector.



For accurate measurement

The cavity resonator perturbation method is a method that can measure dielectric constant with high accuracy. There are some key points in order to make full use of its performance.

About temperature

Since the resonance characteristics of the cavity resonator change with temperature, it is necessary to avoid large temperature change during measurement. Here are the key points to note:

- Do not touch the resonator: Be careful not to touch the resonator during measurement. Temperature changes due to body temperature can cause large errors. Be careful not to touch the resonator when inserting or removing the sample.
- Pay attention to the air conditioning outlet: Make sure that the air conditioning does not directly blow the resonator. Changes in air conditioning can cause measurement errors.
- Allow the resonator to adapt to the measurement environment: If the storage location is different from the measurement location, it is recommended to place the resonator 30 minutes before measurement.

About cables

Minimize the cable movement during measurement. Also, minimize the movement of the resonator.

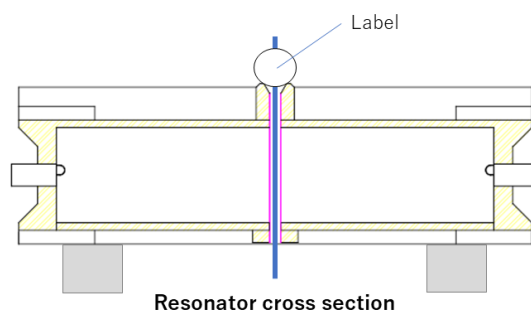
About vibration

For the lower frequency models (1 GHz, 2.45GHz, and 3 GHz), care must be taken not to apply mechanical vibration to the resonator during measurement. Avoid as much vibration as you can feel. It is also necessary to pay attention to the vibration transmitted from the desk on which the resonator is placed. As a guide, the measured waveform of the network analyzer doesn't move by mechanical vibration.

To further improve reproducibility

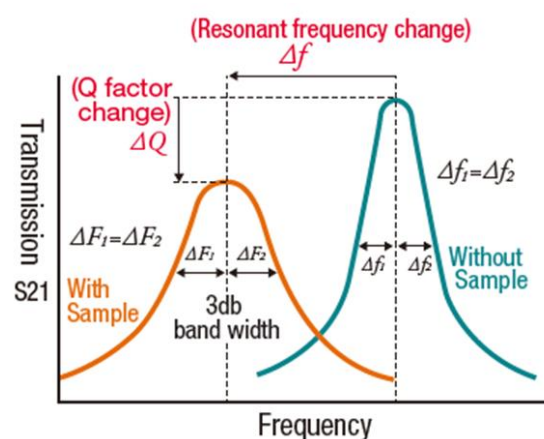
For normal measurements, you do not need to worry about the position of the sample in the insertion hole. If it is necessary to further improve the reproducibility after giving due consideration to the above precautions (temperature, cable, vibration), the position of the sample may need to be considered. Depending on the measurement conditions, it is worth considering the position of the sample when aiming for variations within the permittivity of 0.1% and $\tan \delta$ of 0.00001. Please note that sample positioning does not guarantee such high reproducibility.

A practical method for accurate positioning is as follows: As shown below, a round disk-shaped label is attached to the sample, and the sample is automatically positioned at the center of the insertion hole by hanging the sample from the insertion hole. Use a stand below the resonator if necessary.



Measurement principle

This section outlines the principle of permittivity measurement by the cavity resonator perturbation method. In this measurement method, the complex relative permittivity is measured from the change in the resonance (ie, perturbation) caused by inserting the dielectric material to be measured into the cavity. As the dielectric material enters, the resonator size increases equivalently and thus the resonance frequency decreases. From this change the permittivity of the sample can be obtained. In addition, the loss of the dielectric material increases the loss of the resonator and thus the Q value decreases. From this change the dielectric loss of the sample can be obtained. (See the figure below)



Specifically, the real part (ϵ') and the imaginary part (ϵ'') of the relative permittivity are given by the following perturbation formula.

$$\varepsilon' = 1 + \frac{S_c}{\alpha \cdot S_s} \cdot \frac{Fr_0 - Fr_s}{Fr_0}, \quad \varepsilon'' = \frac{S_c}{2\alpha \cdot S_s} \cdot \left(\frac{1}{Q_s} - \frac{1}{Q_0} \right)$$

$$\tan \delta = \frac{\varepsilon''}{\varepsilon'}$$

Fr_0, Q_0 : resonance frequency and un-loaded Q without sample

Fr_s, Q_s : Resonant frequency and un-loaded Q when sample is inserted

S_c : cross section of resonator

S_s : cross section of sample

α : Constant determined by resonance mode

Both the resonance frequency (F) and the Q value can be obtained from the measurement result of the transmission characteristic (S_{21}) by the network analyzer. These equations show that the larger the cross-sectional area of the sample, the more the resonance frequency and Q value change. In other words, the larger the cross section of the material, the easier it will be to measure. It is also evident that sample size measurement errors have a significant effect on permittivity measurements.

3. Maintenance and Repairs

This section explains daily maintenance and simple troubleshooting.

Health check with stable samples

It is recommended to periodically measure samples with stable characteristics and check the measurement system. The quartz sample from the Starter Kit (CP-ST) is suitable for this application.

Daily cleaning

Some of the sample may adhere to the tube in the sample insertion hole. Depending on the material, the characteristics of the resonator may be degraded and the measurement may be affected. If the Q value decreases, clean the tube according to the following procedure.

The resonator body is made of copper, so keep it clean so that it will not corrode due to dirt. In addition, the surface of the main unit changes to dark brown due to oxidation due to aging, but this does not hinder measurement.

Insertion tube cleaning procedure

Cut the non-woven fabric to a suitable size and make it into a shape that can smoothly pass through the tube. Apply a small amount of alcohol, and then clean from the top of the insertion hole. Be sure to clean from top to bottom. If you move the fabric upwards, it can remove the tube from the resonator.

Simple troubleshooting

This section explains what to do when an error occurs in the measured value.

The Q value of the resonator has decreased

If the Q value is lower than when the product was shipped, the tube in the sample insertion hole may be dirty. "Refer to "Daily Cleaning" to perform cleaning.

Large variation in measured dielectric constant

Review the measurement method by referring to "For accurate measurement" in this manual. For thin film samples, also refer to "Thin film".

Repair

If repair is necessary, contact us directly from our website.

<https://www.emlabs.jp>