AET, Inc. presents

Dielectric Measurement Solution

Microwave Dielectrometer
The industrial market for high frequency dielectric measurement

The various conventional measuring methods
  Particularly about resonator methodology

Problems with the current measurement method in achieving the desired measurement method

Introduction of AET’s dielectric measurement system (Microwave Dielectrometer)
  Explanation of the open coaxial resonator type and the resonant cavity type

AET’s dielectric measurement service

Information of AET’s dielectric measurement in our web site
Concerns about high frequency material characteristics is growing with the progress in electronics and communications industries. Furthermore, the need for measuring these characteristics will increase not only in the electronics industry but also in the medical and food industries where electromagnetic waves are used as well.

**The measuring objects**

- Printed circuit board material for high-speed digital / microwave circuits
- Dielectric antenna for communication, and Filter
- Thin film material
- Ceramics
- High dielectric constant material
- Resin material
- Semiconductor products
- Plasma devices
- Medical electric device
- Chemicals
- Environmental process
- Waste treatment
- Food (moisture content)
Various measurement methods in high frequency

Various methods in measuring dielectric properties using high frequencies have been invented. The reasons why:
1. Various materials must be measured
2. The measuring frequency covers a wide range

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
<th>Frequency Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parallel Plate (capacitance) method</td>
<td>The method which builds up capacitance. This may not be suitable for measurements in the high GHz frequencies.</td>
<td>Up to several MHz</td>
</tr>
<tr>
<td>Transmission (reflection and penetration) method</td>
<td>The method which measures the reflection and penetration by setting a sample on the whole or in part of the transmission line such as a strip line or a coaxial line. It is necessary to treat the error factors generated in the terminal area of the transmission line.</td>
<td>Up to several 10GHz</td>
</tr>
<tr>
<td>Free space method</td>
<td>The method which measures reflection by discharging an electric wave to a sample placed in free space. It's an effective high frequency measurement method that utilizes short wavelengths (millimeter wave) though it seems to be only available in large-scale equipments.</td>
<td>10GHz - 100GHz</td>
</tr>
<tr>
<td>Resonant Cavity method</td>
<td>The method which uses a resonator such as a cavity and measures from the changed resonance of a small sample. The specialized knowledge and skills for the treatment of a sample and the resonator, are needed. This method is adopted in AET microwave dielectrometer.</td>
<td>1GHz - 100GHz</td>
</tr>
<tr>
<td>Near-field method</td>
<td>The method which uses a probe, an open resonator or a transmission line and measures from the changed resonance of a sample. Non-destructive measurement in a local point of a sample is possible. It is necessary to treat distribution in near-field with accuracy. This method is adopted in AET microwave dielectrometer.</td>
<td>1GHz - 100GHz (available to optical domain)</td>
</tr>
</tbody>
</table>
About the resonator methodology

The dielectric measurement techniques in high frequency are divided roughly into the techniques using reflection/penetration, and a resonance phenomenon.

The transmission line method using reflection/penetration

This method has the advantage which can measure the continuous dielectric properties in a broadband. The disadvantage is it gets influenced by the noise from measurement equipments. (remarkable in high frequency region).

The Resonant cavity method using the changed resonance

This method measures the dielectric properties in a single frequency. It is measured by relative changes of resonance conditions. Therefore, it has very little influence from noise, and high-precision measurement is possible.

The relation between resonance and dielectric constant

When a dielectric material is inserted into an identical space, the wavelength of electromagnetic wave will be shortened with the dielectric constant of the material and the effective spatial size which is conversed in a vacuum unit will increase, furthermore the resonance frequency of a structure will decline. Dielectric properties are calculated by measuring how many resonance frequency is changed before and after inserting the dielectric material.
Problem with the current measurement method in achieving the desired measurement method

The obstacles to the dielectric measurement

- Destructive measurement (sample cutting)
- Difficulty in obtaining a stable measurement
- Expensive measuring instruments (Ex. network analyzer)
- Technical knowledge about high frequency is needed

The desired measurement method

- Non-destructive measurement
- Stable measurement
- No need for expensive instrument
- Simple measurement without technical knowledge

The near-field method by AET's Microwave Dielectrometer meets the above requirements.
Two types of AET’s Microwave Dielectrometer

Open Coaxial Resonator Type

Features
- Non-destructive measurement
- AET original measuring method
- 5 point measurement mode
- Calibration with 2 reference materials

Applications
- Various solid shapes
  - Various resin
  - Rubber
  - Liquid crystal polymer
- Plastic
- Connector
- Glass

Resonant Cavity Type

Features
- Measuring method of JIS C2565
- Sample shape: Strip and Flat plate
- Available measurement for a thin film (several 10μm thickness), a high dielectric material and an ultra low loss material

Applications
- Thin film and multilayer structure shapes
  - Various films
  - Multilayer structure PCB
  - Liquid
- Various resin
- Connector
- Ceramics
- Glass
- Powder

Easy measurement by the self-developed measurement software
Features of the coaxial resonator probe developed by AET

① Measurement by the open coaxial resonator probe
  - Unique shape resonator
  - 5 point simultaneous measurement mode or single measurement mode can be chosen

② Simple, accurate and non-destructive measurement
  - Easy placement of a sample
  - Fast and accurate measurement

③ Stable measurement
  A firm contact between a sample and a probe with a vacuum attachment

④ Measurement within a local area
  Measurement is done in a small opening on the tip of the probe

Patent No. 3691812

This measurement system was developed as a project authorized by Kawasaki-city, Japan, by cooperation of the Maeda laboratory of the university of Tokyo.
A resonance electrical field (evanescent wave) penetrates into a sample.

The electromagnetic wave leaks from a small opening of the probe tip.

When electromagnetic wave propagates into the empty cavity.

Outline view of the coaxial resonator

Sample

Small opening
The measurement principle of the coaxial resonator probe

The coaxial resonator probe (length L) resonates at the frequency with the wavelength \( \lambda \).

\[
L \approx \frac{2n - 1}{4} \cdot \lambda
\]

If a sample material is placed on the probe, the evanescent electrical field leaks from the probe tip into the material. The electrical field changes with the dielectric properties of the material, which in turn changes the resonant frequency and the Q factor of the whole resonator. The dielectric properties are then calculated from the changed resonance.
The resonance mode of a resonator and the electromagnetic distribution is analyzed by 3D electromagnetic analysis software. The obtained result is applied to the calculation method of the conventional dielectric constant. Hence, the software for the measurement theory was developed.

1. Set a non-destructive sample on the probe.

2. Click the button of the software. The dielectric constant and dielectric loss are measured accurately.

Measurement result by software
A composite material such as PCB consists of some materials with different dielectric properties. Therefore, a dielectric constant on the surface and inside of the sample may be different. Moreover, a ceramic PCB may have different dielectric constants locally with the sintering condition. In such cases, we recommend the measurement by the resonant cavity type.
How to measure the dielectric characteristics:

1. Insert a cut sample into a cavity.
2. Input the dimensions of the sample and click the button by following the software wizard.
3. The dielectric constant and dielectric loss are measured.

**The resonant cavity is suitable for the measurement of a multilayer structure and a thin film.**

- Able to measure the average dielectric constant of a sample.
- Able to measure a 50μm thick sample.
- Able to measure a 0.0001-0.1 dielectric loss sample.
System components of Microwave Dielectrometer

A network analyzer type
(Incl. fixture, software & accessories)

Use any of the network analyzers listed below:
- Agilent technology PNA series, ENA series, 872x series, ANRITSU 37000 and Rohde & Schwarz network analyzers

Synthesized sweep oscillator Type
(Incl. oscillator, fixture, software & accessories)

(Network analyzer is unnecessary)
The dedicated device composed of microwave signal generator, a detector and a voltage monitor works as a network analyzer.

Microwave Dielectrometer has two system types. If you don’t have a network analyzer, select a synthesized sweep oscillator type, and if you have a network analyzer, select a network analyzer type.
<table>
<thead>
<tr>
<th>Measurement tool</th>
<th>Open coaxial resonator</th>
<th>Resonant cavity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>0.8GHz to 18GHz</td>
<td>1GHz~18GHz</td>
</tr>
<tr>
<td>Measurement range</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dielectric constant</td>
<td>$\varepsilon_r = 1 \sim 15$</td>
<td>$\varepsilon_r = 1 \sim 30$</td>
</tr>
<tr>
<td></td>
<td>Accuracy +/-1%</td>
<td>Accuracy +/-1%</td>
</tr>
<tr>
<td>Tanδ</td>
<td>$\tan\delta = 0.001 \sim 0.1$</td>
<td>$\tan\delta = 0.0001 \sim 0.1$</td>
</tr>
<tr>
<td></td>
<td>Accuracy +/-5%</td>
<td>Accuracy +/-5%</td>
</tr>
<tr>
<td>Frequency point</td>
<td>5 discrete frequency points or 1 point can be chosen</td>
<td>1 point per resonator</td>
</tr>
<tr>
<td></td>
<td>Type A: 0.8 / 2.45 / 4.2 / 5.8 / 7.6GHz</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Type B: 1 / 3 / 5 / 7 / 9 GHz</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Type C: 2 / 6 / 10 / 14 / 18 GHz</td>
<td></td>
</tr>
<tr>
<td>Sample shape</td>
<td>Arbitrary if there is a flat surface (A dimension of more than 10mmx10mmx0.5mm)</td>
<td>Strip (more than 80mm(L) $\times$ less than 3mm (W) $\times$ 0.05mm - 1mm (thickness))</td>
</tr>
<tr>
<td>Main factors of measurement error</td>
<td>• Roughness of a sample</td>
<td>The width and thickness of a sample cutting is not uniform.</td>
</tr>
<tr>
<td></td>
<td>• A heterogeneous sample</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Contact condition between a sample and a probe</td>
<td></td>
</tr>
<tr>
<td>Measuring method</td>
<td>AET self-developed method (patent acquisition)</td>
<td>The method known widely (compliant with JIS C2565 standard)</td>
</tr>
</tbody>
</table>
## Dielectric measurement service provided by AET

<table>
<thead>
<tr>
<th>Measuring methods</th>
<th>Material shapes</th>
<th>Materials</th>
<th>Frequency</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Open Coaxial Resonator</strong></td>
<td>Free</td>
<td>Solid</td>
<td>800MHz - 18GHz</td>
<td>Non-destructive measurement of the dielectric properties in microwave range.</td>
</tr>
<tr>
<td><strong>Resonant Cavity</strong></td>
<td>• Strip</td>
<td>• Solid</td>
<td>1GHz - 50GHz</td>
<td>• Accurate but destructive measurement in the microwave and millimeter wave range.</td>
</tr>
<tr>
<td></td>
<td>• Small-size cylinder/prism,</td>
<td>• Liquid</td>
<td>※Ask about more than10GHz</td>
<td>• Compliant with JIS C2565 standard</td>
</tr>
<tr>
<td></td>
<td>• Thin film</td>
<td>• Particle</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Stripline Resonator</strong></td>
<td>• Plate</td>
<td>Solid</td>
<td>1GHz - 18GHz</td>
<td>Measurement of the material of a printed circuit board while in use.</td>
</tr>
<tr>
<td></td>
<td>• Thin film</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Coaxial Reflection</strong></td>
<td>Free</td>
<td>Liquid, etc.</td>
<td>200MHz - 40GHz</td>
<td>Measurement of continuous dielectric properties in broad band.</td>
</tr>
<tr>
<td><strong>Capacitance</strong></td>
<td>Plate</td>
<td>Solid</td>
<td>10MHz - 1GHz</td>
<td>Measurement of continuous dielectric properties in broad band.</td>
</tr>
<tr>
<td><strong>Dielectric Resonator</strong></td>
<td>• Cylinder</td>
<td>Low dielectric loss and high dielectric constant</td>
<td>Less than 20GHz</td>
<td>• Dielectric loss (DF) of materials is about 0.001 or less.</td>
</tr>
<tr>
<td></td>
<td>• Toroidal</td>
<td></td>
<td></td>
<td>• Compliant with JIS R1627 standard</td>
</tr>
</tbody>
</table>
If you are interested to learn more about the dielectric measurement system and the measurement service please visit our web site at:


The animation explains AET’s dielectric measuring method.

You can experience the real measurement by the movie 4 “Actual measurement“.