IEC

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PUBLICLY AVAILABLE SPECIFICATION

PRE-STANDARD

Waveguide type dielectric resonators –
Part 1-5: General information and test conditions – Measurement method of conductivity at interface between conductor layer and dielectric substrate at microwave frequency

IEC/PAS 61338-1-5:2010(E)

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Part 1-5: General information and test conditions – Measurement method of conductivity at interface between conductor layer and dielectric substrate at microwave frequency

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A PAS is a technical specification not fulfilling the requirements for a standard, but made available to the public.

IEC/PAS 61338-1-5 has been processed by IEC technical committee 49: Piezoelectric and dielectric devices for frequency control and selection.

The text of this PAS is based on the following document:	This PAS was approved for publication by the P-members of the committee concerned as indicated in the following document
Draft PAS	**Report on voting**
49/873/PAS	49/902/RVD

Following publication of this PAS, which is a pre-standard publication, the technical committee or subcommittee concerned may transform it into an International Standard.

This PAS shall remain valid for an initial maximum period of 3 years starting from the publication date. The validity may be extended for a single period up to a maximum of 3 years, at the end of which it shall be published as another type of normative document, or shall be withdrawn.

A list of all parts of IEC 61338 series under the general title *Waveguide type dielectric resonators* can be found on the IEC website.

IEC 61338 consists of the following parts, under the general title *Waveguide type dielectric resonators*:

Part 1: Generic specification

Part 1-3: General information and test conditions - Measurement method of complex relative permittivity for dielectric resonator materials at microwave frequency

Part 1-4: General information and test conditions - Measurement method of complex relative permittivity for dielectric resonator materials at millimeter-wave frequency

Part 2: Guidelines for oscillator and filter applications

Part 4: Sectional specification

Part 4-1: Blank detail specification

INTRODUCTION

The International Electrotechnical Commission (IEC) draws attention to the fact that it is claimed that compliance with this PAS may involve the use of a patent concerning:

"Measurement method of conductivity at interface of conductor layer"

"Measurement method of conductivity of conductor layer"

IEC takes no position concerning the evidence, validity and scope of this patent right.

The holder of this patent right has assured the IEC that he/she is willing to negotiate licences under reasonable and non-discriminatory terms and conditions with applicants throughout the world. In this respect, the statement of the holder of this patent right is registered with IEC. Information may be obtained from:

KYOCERA Corporation

6 Takeda Tobadono-cho, Fushimiku, Kyoto 612-5801, Japan

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WAVEGUIDE TYPE DIELECTRIC RESONATORS –

Part 1-5: General information and test conditions – Measurement method of conductivity at interface between conductor layer and dielectric substrate at microwave frequency

1 Scope

Microwave circuits are popularly formed on multi-layered organic or non-organic substrates. In the microwave circuits, the attenuation of planar transmission lines such as striplines, microstrip lines, and coplanar lines are determined by their conductor loss, dielectric loss and radiation loss. Among them, the conductor loss is a major factor in the attenuation of the planar transmission lines. A new measurement method is needed to evaluate the conductivity of transmission line on or in the substrates such as the organic, ceramic and LTCC (low temperature co-fired ceramics) substrates.

The IEC 61338-1-3 described the measurement method for the surface resistance R_s and effective conductivity σ on the surface of the conductor. The term σ is designated as σ_s in this PAS, and is called surface conductivity (Figure 1). This PAS describes a measurement method for resistance and effective conductivity at the interface between conductor layer and dielectric substrate designated as R_i and σ_i respectively, and are called interface resistance and interface conductivity.

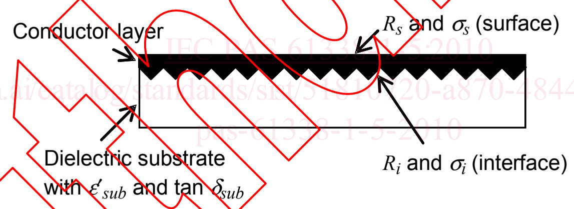

Figure 1 – Surface resistance R_s, surface conductivity σ_s, interface resistance R_i, and interface conductivity σ_i.

For the transmission line in the substrates, the electric current is concentrated at the interface between conductor layer and dielectric substrate, because the skin depth δ in the conductor is the order of μm in thickness at the microwave frequencies. In microstrip lines, the current is concentrated at the interface, rather than at the open face of the conductor. Furthermore, in copper-clad organic substrates, the interface side of the copper foil has rugged structure to hold the strong adhesive strength. In LTCC substrates, the interface between the conductor and ceramics has a rough structure, depending on the co-firing process and the material compositions. The interface conditions increase the conductor loss. Therefore, the evaluation of R_i and σ_i is important to design microwave circuit and to improve the conductor fabrication process.

This measurement method has the following characteristics:

– the interface resistance R_i is obtained by measuring the resonant frequency f_0 and unloaded quality factor Q_u of a $\mathrm{TE}_{01\delta}$ mode dielectric rod resonator shown in Figure 2;

– the interface conductivity σ_i and the relative interface conductivity $\sigma_{ri} = \sigma_i / \sigma_0$ are calculated from the measured R_i value, where $\sigma_0 = 5{,}8 \times 10^7$ S/m is the conductivity of standard copper;

– the measurement uncertainty of σ_{ri} ($\Delta\sigma_{ri}$) is less than 5%.

2 Normative references

The following referenced documents are indispensable for the application of this PAS. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 61338-1-3: *Waveguide type dielectric resonators - Part 1-3: General information and test conditions – Measurement method of complex relative permittivity for dielectric resonator materials at microwave frequency*

IEC 61338-1-4: *Waveguide type dielectric resonators - Part 1-4: General information and test conditions – Measurement method of complex relative permittivity for dielectric resonator materials at millimetre-wave frequency*

3 Measurement and related parameters

The relationship between R_s and σ_s is given by

$$R_s = \sqrt{\frac{\pi f_0 \mu}{\sigma_s}} \quad , \quad \sigma_s = \sigma_{rs}\sigma_0 \tag{1}$$

where

R_s is the surface resistance;
f_0 is the resonance frequency;
μ is the permeability of the conductor;
σ_s is the surface conductivity;
σ_{rs} is the relative surface conductivity.

Particularly, μ equals μ_0 ($\mu_0 = 4\pi \times 10^{-7}$ H/m) for nonmagnetic conductors such as copper and silver.

The relationship between R_i and σ_i is given by

$$R_i = \sqrt{\frac{\pi f_0 \mu}{\sigma_i}} \quad , \quad \sigma_i = \sigma_{ri}\sigma_0 \tag{2}$$

where

R_i is the interface resistance;
σ_i is the interface conductivity;
σ_{ri} is the relative interface conductivity.

The skin depth δ is given by

$$\delta = \sqrt{\frac{1}{\pi f \mu \sigma}} \tag{3}$$

where

f is the frequency;

σ is the conductivity of the conductor.

To obtain high accuracy in this measurement method, the σ_{ri} of the conductor is preferable to be higher than 5%, and the thickness of conductor to be three times greater than skin depth δ. The measurement frequencies are limited to be 5 GHz and 13 GHz in this PAS because of the reference dielectric rods used in this PAS.

4 Calculation equations for R_i and σ_i

Figure 2 shows the structure of a $\mathrm{TE}_{01\delta}$ mode dielectric rod resonator for the R_i measurement. The resonator consists of a dielectric rod and a pair of dielectric substrates with a conductor layer at one side. The dielectric rod has diameter *d*, height *h*, relative permittivity ε'_{rod}, and loss tangent $\tan\delta_{rod}$. The pair of dielectric substrates have the same values of diameter *d'*, thickness *t*, relative permittivity ε'_{sub}, and loss tangent $\tan\delta_{sub}$. To suppress the radiation loss, the diameter *d'* shall be three times greater than *d*. The conductor layers on each dielectric substrate are supposed to have the same value of R_i.

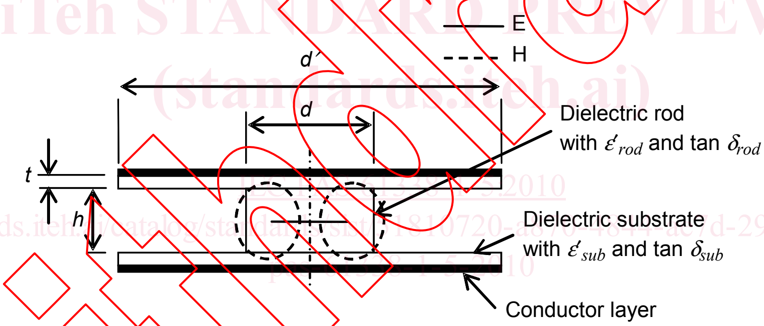

Figure 2 – The $\mathrm{TE}_{01\delta}$ mode dielectric rod resonator to measure σ_i.

In this structure, the conductive loss of the $\mathrm{TE}_{01\delta}$ mode resonator is caused by the interface resistance R_i. The value of $1/Q_u$ is given by a sum of power losses due to R_i, $\tan\delta_{rod}$ and $\tan\delta_{sub}$:

$$\frac{1}{Q_u} = \frac{R_i}{g} + P_{rod}\tan\delta_{rod} + P_{sub}\tan\delta_{sub} \quad , \tag{4}$$

where

g is the geometric factor of the resonator (Ω);

P_{rod} is the partial electric energy filling factor of the dielectric rod;

P_{sub} is the partial electric energy filling factor of the dielectric substrate.