IEC 61338-1-5

Edition 1.0 2015-06

INTERNATIONAL STANDARD

NORME INTERNATIONALE

**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**

**Résonateurs diélectriques à modes guidés –
Partie 1-5: Informations générales et conditions d'essais – Méthode de mesure de la conductivité au niveau de l'interface entre une couche conductrice et un substrat diélectrique fonctionnant aux hyperfréquences**

IEC 61338-1-5:2015-06(en-fr)

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ICS 31.140 ISBN 978-2-8322-2721-3

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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FOREWORD

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International Standard IEC 61338-1-5 has been prepared by IEC technical committee 49: Piezoelectric, dielectric and electrostatic devices and associated materials for frequency control, selection and detection.

This first edition cancels and replaces IEC PAS 61338-1-5 published in 2010.

This edition includes the following significant technical changes with respect to the previous edition:

a) description of technical content related to patents (Japanese patent numbers JP3634966, JP3735501) in the Introduction;
b) changes to normative references;
c) addition to bibliography.

The text of this standard is based on the following documents:

CDV	Report on voting
49/1089/CDV	49/1103/RVC

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

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

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

INTRODUCTION

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

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

– The use of a $TE_{01\delta}$ mode dielectric rod resonator for the interface resistance and the interface conductivity measurement, given in Clause 4;
– The use of a substrate/conductor/substrate layer structure, where a conductor is formed between two dielectric substrates, for the interface resistance and interface conductivity measurement, given in Clause 5.

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 612-8501, Japan

Attention is drawn to the possibility that some of the elements of this standard may be the subject of patent rights other than those identified above. IEC shall not be held responsible for identifying any or all such patent rights.

ISO (www.iso.org/patents) and IEC (http://patents.iec.ch) maintain on-line data bases of patents relevant to their standards. Users are encouraged to consult the data bases for the most up to date information concerning patents.

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 standardized in this document 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. This standard describes a measurement method for resistance and effective conductivity at the interface between conductor layer and dielectric substrate, which are called interface resistance and interface conductivity.

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 $TE_{01\delta}$ 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 documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. 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 62562: *Cavity resonator method to measure the complex permittivity of low-loss dielectric plates*

3 Measurement and related parameters

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 standard, and is called surface conductivity (Figure 1). This standard 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.

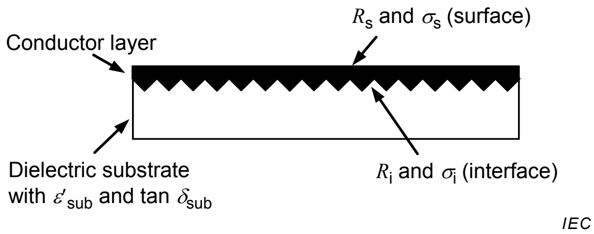


Figure 1 – Surface resistance R_s, surface conductivity σ_s, interface resistance R_i, and interface conductivity σ_i.

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 δin 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 conductor loss depends on the interface conditions. Therefore, the evaluation of R_i and σ_i is important to design microwave circuit and to improve the conductor fabrication process.

The relationship between R_s and σ_s is given by

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

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 (μ_0 = 4π × 10^{-7} H/m) for nonmagnetic conductors such as copper and silver.

The relationship between R_i and σ_i is given by

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

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 relative interface conductivity 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 because of the reference dielectric rods used in this standard.

4 Calculation equations for R_i and σ_i

Figure 2 shows the structure of a $TE_{01\delta}$ 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.

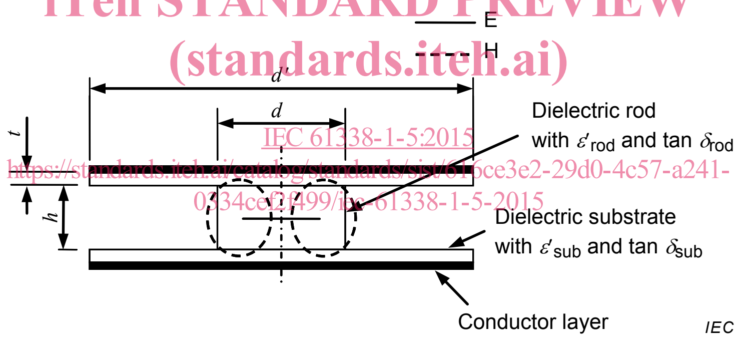


Figure 2 – $TE_{01\delta}$ mode dielectric rod resonator to measure σ_i.

In this structure, the conductive loss of the $TE_{01\delta}$ 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 $\tan\delta_{sub}$:

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

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.

The equation for R_i is derived from Equation (4):

$$R_i = g\left(\frac{1}{Q_u} - P_{rod} \tan\delta_{rod} - P_{sub} \tan\delta_{sub}\right) \tag{5}$$

The value σ_i is calculated from this R_i value by Equation (2).

The derivation of Equation (4) is given in Annex A, together with definitions of the parameters g, P_{rod} and P_{sub}. These parameters for the $TE_{01\delta}$ mode resonator can be calculated by using the FEM or the mode matching method. However, the calculation requires complicated and tedious works. To make the treatment simple and easy, this standard recommends to use the graphical charts that are prepared for the parameters of reference dielectric rod resonators; a sapphire single crystal and a $(Zr,Sn)TiO_4$ ceramic (Table 1). The axis of sapphire rod should be parallel to the c-axis within 0,3 degree. The $(Zr,Sn)TiO_4$ ceramic rod is provided from the Japan fine ceramics center. The parameters f_0, g, P_{rod} and P_{sub} for the reference rods were calculated by an FEM analyzed in cylindrical coordinate and are shown in Figures 3 and 4 graphically. The calculation uncertainty on the parameters is shown in Annex B.

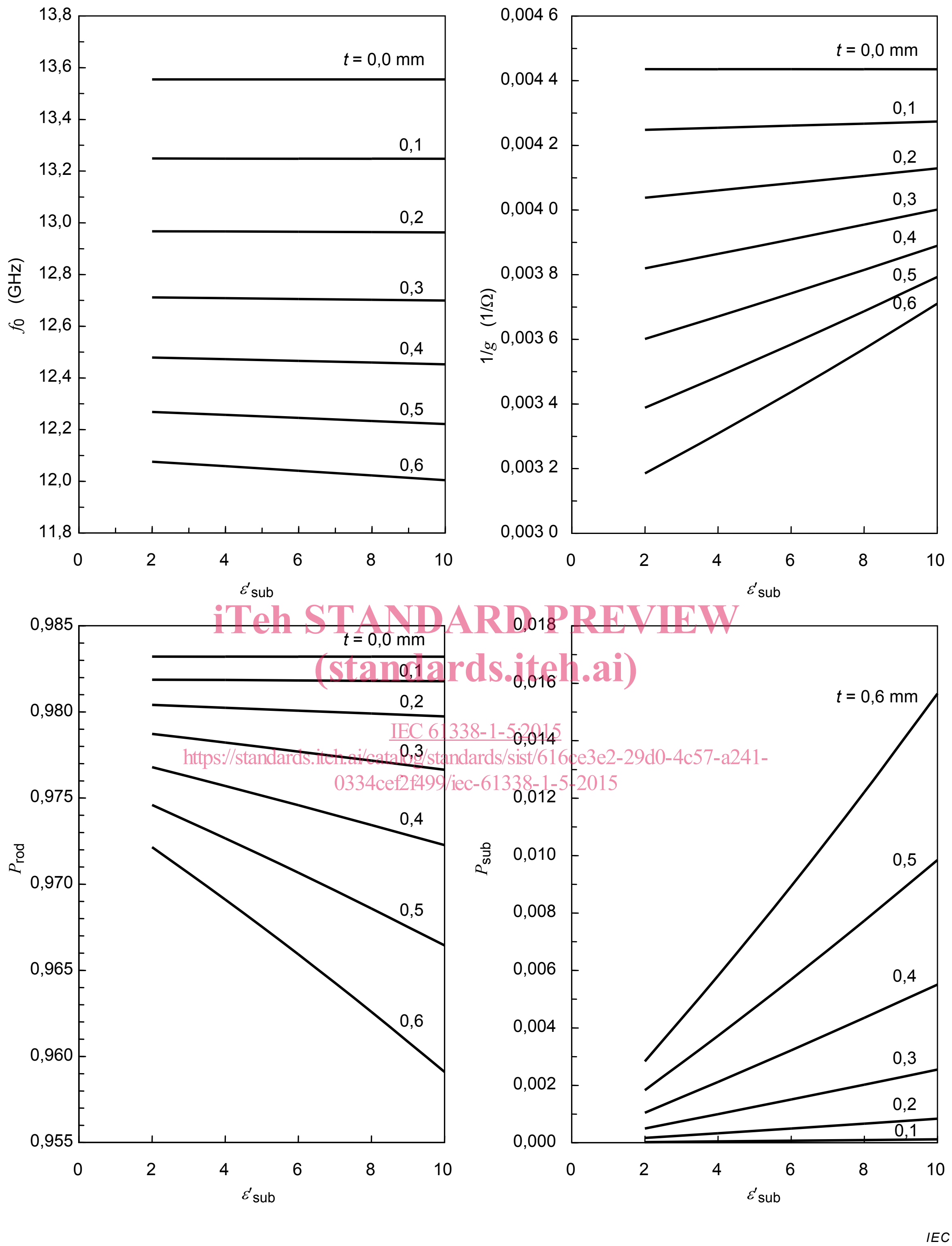
To calculate the R_i in Equation (5), the complex permittivity values of the dielectric rod and the substrate are necessary to be given in advance. IEC 61338-1-3 shall be used to measure the values of ε'_{rod} and $\tan\delta_{rod}$. IEC 62562 shall be used to measure the values of ε'_{sub} and $\tan\delta_{sub}$.

Table 1 – Specifications of reference rods

Reference rod	f_0 GHz	ε'_{rod}	$\tan\delta_{rod}$	diameter d mm	height h mm
Sapphire single crystal	13	9,4 ± 0.1	13×10^{-6}	10,00 ± 0,05	5,00 ± 0,05
$(Zr,Sn)TiO_4$ ceramics	5	39 ± 1	$<10 \times 10^{-4}$	14,00 ± 0,05	6,46 ± 0,05

NOTE 1 The reference dielectric rod of $(Zr,Sn)TiO_4$ is provided by JFCC (Japan fine ceramics center[1]) as ER-ZST.

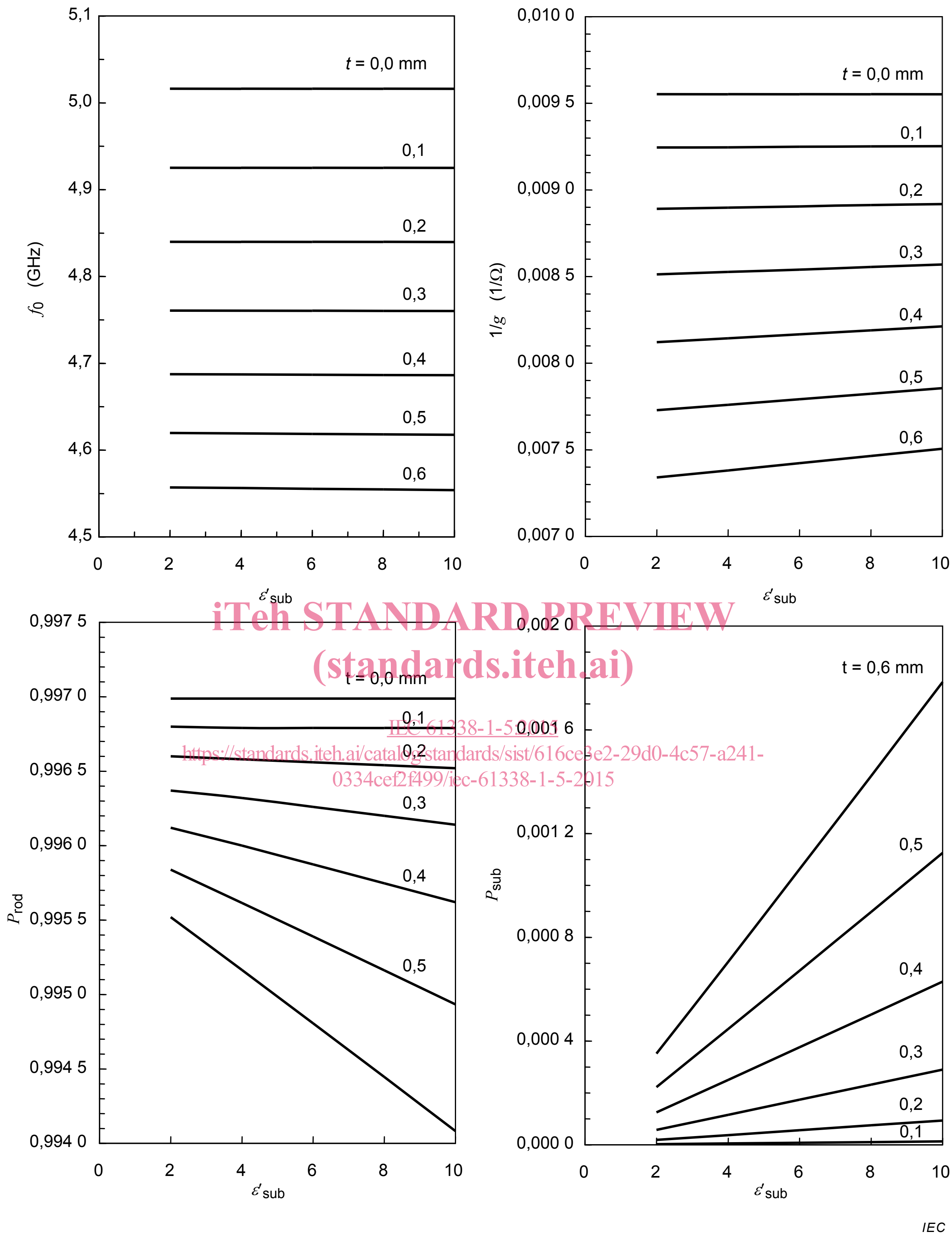
[1] Japan fine ceramics center is an example of a suitable commercial supplier. This information is given for the convenience of users of this document and does not constitute an endorsement by IEC of this supplier.



The calculation conditions are the following:

ε'_{rod} = 9,4, d = 10,00 mm and h = 5,00 mm.

Figure 3 – Parameters chart of f_0, g, P_{rod} and P_{sub} for reference sapphire rod



The calculation conditions are the following:

ε'_{rod} = 39, d = 14,00 mm and h = 6,46 mm.

Figure 4 – Parameters chart of f_0, g, P_{rod} and P_{sub} for reference $(Zr,Sn)TiO_4$ rod