IEC 61338-2

Edition 1.0 2004-05

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Waveguide type dielectric resonators –
Part 2: Guidelines for oscillator and filter applications

Résonateurs diélectriques à modes guidés –
Partie 2: Lignes directrices pour l'application aux filtres et aux oscillateurs

IEC 61338-2:2004-05(en-fr)

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

WAVEGUIDE TYPE DIELECTRIC RESONATORS –

Part 2: Guidelines for oscillator and filter applications

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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International Standard IEC 61338-2 has been prepared by IEC technical committee 49: Piezoelectric and dielectric devices for frequency control and selection.

This standard cancels and replaces IEC/PAS 61338-2 published in 2000. This first edition constitutes a technical revision.

This bilingual version (2014-02) corresponds to the monolingual English version, published in 2004-05.

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

FDIS	Report on voting
49/656/FDIS	49/674/RVD

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

The French version of this standard has not been voted upon.

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

The committee has decided that the contents of this publication will remain unchanged until 2008. At this date, the publication will be

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

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

Part 1:	Generic specification [1]
Part 1-1:	General information and test conditions – General information [2]
Part 1-2:	General information and test conditions – Test conditions [2]
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 [3]
Part 2:	Guidelines for oscillator and filter applications (the present standard)
Part 4:	Sectional specification [1]
Part 4-1:	Blank detail specification [1]

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[1] To be published.

[2] To be replaced by IEC 61338-1 in the near future.

[3] Under consideration.

INTRODUCTION

This part of IEC 61338 gives practical guidance on the use of waveguide type dielectric resonators that are used in telecommunications and radar systems (for general information, standard values, and test conditions, see the other parts of this series).

The features of these dielectric resonators are small size without degradation of quality factor, low mass, high reliability and high stability against temperature and ageing. The dielectric resonators are suitable for applications to miniaturized oscillators and filters with high performance.

This standard has been compiled in response to a generally expressed desire on the part of both users and manufacturers for guidelines for the use of dielectric resonators, so that the resonators may be used to their best advantage. For this purpose, general and fundamental characteristics have been explained in this standard.

WAVEGUIDE TYPE DIELECTRIC RESONATORS –

Part 2: Guidelines for oscillator and filter applications

1 Scope

This part of IEC 61338, which contains guidelines for use, is limited to the waveguide type dielectric resonators that are used for oscillator and filter applications. These types of resonators are now widely used in oscillators for direct broadcasting or communication satellite systems, oscillators for radio links, voltage-controlled oscillators for mobile communication systems and so on. In addition, these dielectric resonators are also used as an essential component of miniaturized filters for the same kind of applications.

It is not the aim of this standard either to explain theory or to attempt to cover all the eventualities that may arise in practical circumstances. This standard draws attention to some of the more fundamental questions, which should be considered by the user before he places an order for dielectric resonators for a new application. Such a procedure will be the user's insurance against unsatisfactory performance.

Standard specifications, such as those in the IEC 61338 series and national specifications or detail specifications issued by manufacturers, will define the available combinations of resonance frequency, the quality factor, the temperature coefficient of resonance frequency, etc. These specifications are compiled to include a wide range of dielectric resonators with standardized performances. It cannot be over-emphasized that the user should, wherever possible, select his dielectric resonators from these specifications, when available, even if it may lead to making small modifications to his circuit to enable standard resonators to be used. This applies particularly to the selection of the nominal frequency.

2 Normative references

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

IEC 60068-1, *Environmental testing – Part 1: General and guidance*

IEC 60068-2-1, *Environmental testing – Part 2: Tests – Test A: Cold*

IEC 60068-2-2, *Environmental testing – Part 2: Tests – Tests B: Dry heat*

IEC 60068-2-6, *Environmental testing – Part 2: Tests – Test Fc: Vibration (sinusoidal)*

IEC 60068-2-7, *Environmental testing – Part 2: Tests – Test Ga: Acceleration, steady state*

IEC 60068-2-13, *Environmental testing – Part 2: Tests – Test M: Low air pressure*

IEC 60068-2-14, *Environmental testing – Part 2: Tests – Test N: Change of temperature*

IEC 60068-2-20, *Environmental testing – Part 2: Tests – Test T: Soldering*

IEC 60068-2-21, *Environmental testing – Part 2-21: Tests – Test U: Robustness of terminations*

IEC 60068-2-27, *Environmental testing – Part 2: Tests – Test Ea and guidance: Shock*

IEC 60068-2-29, *Environmental testing – Part 2: Tests – Test Eb and guidance: Bump*

IEC 60068-2-30, *Environmental testing – Part 2: Tests – Test Db and guidance: Damp heat, cyclic (12 + 12-hour cycle)*

IEC 60068-2-58, *Environmental testing – Part 2-58: Tests – Test Td: Test methods for solderability, resistance to dissolution of metallization and to soldering heat of surface mounting devices (SMD)*

IEC 60068-2-78, *Environmental testing – Part 2-78: Tests – Test Cab: Damp heat, steady state*

IEC 61338-1-1, *Waveguide type dielectric resonators – Part 1-1: General information and test conditions – General information*

IEC 61338-1-2, *Waveguide type dielectric resonators – Part 1-2: General information and test conditions – Test conditions*

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*

3 Technical overview

It is of prime interest to a user that the resonator characteristics should satisfy particular specifications. The selection of oscillating circuits and dielectric resonators to meet that specification should be a matter of agreement between user and manufacturer.

Resonator characteristics are usually expressed in terms of resonance frequency, quality factor, etc. These characteristics are related to the dielectric characteristics in 5.3.

The specifications shall be satisfied between the lowest and highest temperatures of the specified operating temperature range and before and after environmental tests.

4 Fundamentals of waveguide type dielectric resonators

4.1 Principle of operation

When an electromagnetic wave passes through a dielectric waveguide with a relative permittivity of ε', the interface between air and a dielectric will be a perfect reflector if the angle of incidence is greater than the critical angle θ, $\theta = \arcsin\ (1/\sqrt{\varepsilon'})$, as shown in Figure 1.

In a very rough approximation, the air/dielectric interface can be considered to work as a magnetic wall (open-circuit), on which a normal component of the electric field and a tangential component of a magnetic field vanish. Thus, a dielectric rod with finite length functions as a resonator due to internal reflections of electromagnetic waves at the air/dielectric interface.

The size of a dielectric resonator can be considerably smaller than an empty resonant cavity at the same frequency. This is because the resonance frequency is determined when the resonator dimensions are of the order of half a wavelength of the electromagnetic wave, and because the wavelength is shortened in the dielectric according to the following equation:

$$\lambda_{\mathrm{g}} = \frac{\lambda_0}{\sqrt{\varepsilon'}} \tag{1}$$

where λ_{g} and λ_0 are the wavelengths in a dielectric with relative permittivity ε' and in vacuum. This size-reduction effect on microwave components is the biggest advantage in using the dielectric resonator.

4.2 Basic structure

The shape of a dielectric resonator is usually a disc or a cylinder which is a dielectric rod waveguide with finite length. Although the air/dielectric interface is considered to work roughly as a magnetic wall, some of the field actually leaks out (radiates) especially at the end faces, where the angle of incidences is less than the critical angle. In order to prevent such radiation losses, the resonator must be inside some form of shielding conductor.

As in a conventional metal wall cavity, there are various types of dielectric resonator structure and a number of modes can exist in each structure. Among these modes, the one with the lowest resonance frequency for certain diameter/length ratio is designated as the dominant mode. Figure 2 shows the three most commonly utilized dominant modes for dielectric resonators.

The $\mathrm{TE}_{01\delta}$ mode dielectric resonator is characterized by a dominant TE (transverse electric) mode field distribution, the field of which leaks in the direction of wave propagation. This kind of mode resonator consists of a disc or a cylindrical-shaped dielectric resonator, a low ε' dielectric support, and a shielding conductor made of high-conductivity metals such as copper and silver. A high unloaded quality factor can be achieved using this mode.

The TM_{010} mode dielectric resonator is characterized by a TM (transverse magnetic) mode field distribution. This mode resonator has the middle levels of unloaded Q and size reduction effect between $\mathrm{TE}_{01\delta}$ and TEM mode resonators. The TM_{010} mode resonator is often used for high-power applications such as filters for cellular base stations because of its construction which aids in the release of heat.

The TEM (transverse electromagnetic) mode dielectric resonator is characterized by a guided mode field distribution of a TEM mode with standing wave of a quarter wavelength. The inside, outside and one end of walls of a cylindrical dielectric resonator are fired or plated with a high-conductivity metal such as copper and silver. This mode dielectric resonator causes a significant size-reduction effect.

5 Dielectric resonator characteristics

5.1 Characteristics of dielectric resonator materials

The materials used to produce dielectric resonators should have a high relative permittivity (ε'), a low loss factor ($\tan\delta$) and a minimal temperature coefficient of resonance frequency (TCF). Table 1 shows the composition of several resonator materials with their dielectric properties at microwave frequencies.

Table 2 shows the dielectric properties of substrate materials. Dielectric resonators are mounted on these boards.

5.1.1 Relative permittivity (ε')

Relative permittivity of dielectric resonator materials is independent of frequency (i.e. constant) over the practical microwave frequency range, because the materials are made of para-electric ceramics. Materials with ε' from 20 to 100 are now typically used for dielectric resonators.

5.1.2 Loss factor ($\tan\delta$)

The quality factor of a material (Q_0) is defined as the reciprocal of loss factor:

$$Q_0 = 1/\tan\delta \tag{2}$$

As $\tan\delta$ increases proportionately with frequency for the ionic crystals, the product of Q_0 and frequency is approximately constant at microwave frequencies. So, the $Q_0 f$ product is often used as a figure of merit for each material. The materials with lower ε' generally have the lower $\tan\delta$.

5.1.3 Temperature coefficient of resonance frequency (TCF)

The TCF is given by the following equation as a material constant:

$$TCF = -\frac{1}{2} TC\varepsilon - \alpha \tag{3}$$

where

$TC\varepsilon$ is the temperature coefficient of relative permittivity, and

α is the coefficient of thermal expansion of the dielectric resonator.

The TCF is obtained by the following equation:

$$TCF = \frac{f_\mathrm{T} - f_\mathrm{ref}}{f_\mathrm{ref}\,(T - T_\mathrm{ref})} \times 10^6 \tag{4}$$

where

f_T is the resonance frequency at temperature T, and

f_ref is the resonance frequency at reference temperature T_ref.

The TCF of dielectric resonator material can be selected with a precision of $\pm 1 \cdot 10^{-6}$/K.

In the case where a material has a significant non-linear dependency on temperature, the following second-order temperature coefficient of resonance frequency TCF'' is used.

$$\frac{f_\mathrm{T} - f_\mathrm{ref}}{f_\mathrm{ref}} = TCF'(T - T_\mathrm{ref}) + TCF''(T - T_\mathrm{ref})^2 \tag{5}$$

5.1.4 Insulation breakdown voltage

The breakdown voltage of dielectric resonator materials is usually higher than 10 kV/mm. For high-power applications such as filters for cellular base stations, precautions should be taken to ensure good heat dissipation from dielectric resonators, so as to prevent the decrease of breakdown voltage.

5.1.5 Coefficient of linear thermal expansion (α)

Dielectric resonators have a coefficient of linear thermal expansion from $+6 \cdot 10^{-6}$/K to $+12 \cdot 10^{-6}$/K. When the resonator is soldered direct on a printed wired board (PWB), care must be taken to avoid the cracking of the ceramic body caused by the difference of coefficient of linear thermal expansion between the dielectric resonator and the PWB.

5.1.6 Mechanical strength

Dielectric resonators have practical robustness for usual application usage, the bending strength of which is approximately 80 MPa to 200 MPa. When the dielectric resonators are mounted on a PWB, precautions are needed to ensure that the mechanical stress caused by the bending of the PWB does not break the dielectric resonators.

5.1.7 Resistance to soldering heat

In the case of large-size TEM mode resonators, abrupt temperature elevation by soldering might cause cracking in the body. Preheating in advance of soldering is recommended. Users should follow the soldering conditions issued by suppliers.

5.1.8 Long-term stability

The relative permittivity and loss factor of dielectric resonator materials have good long-term stability. However, the resonator element should be handled in a dry atmosphere to avoid the deterioration of unloaded Q value due to the existence of moisture and the oxidation of shielding conductor. Handling with bare hands should also be avoided to protect the conductor from being sulfurized, chloridized or stained.

5.1.9 Available frequency range

Dielectric resonators currently available in the market are used at the frequencies from 200 MHz to 60 GHz.

5.2 Characteristics of shielding conductors

5.2.1 Shielding conductors for TE$_{01\delta}$ mode dielectric resonator

Silver-plated brass and copper are usually selected because of their high electrical conductivity and preferable mechanical properties. Aluminum is occasionally selected according to its low cost.

5.2.2 Shielding conductors for TEM and TM$_{010}$ mode dielectric resonators

Electrodes are directly formed on the dielectric surface of TEM and TM$_{010}$ mode resonators by using silver or copper. The electrode layer is usually electroplated with an appropriate top layer to improve solderability.

5.3 Characteristics of resonance modes

5.3.1 Quality factors

In practice, dielectric resonators are excited by external circuits. Figure 3 shows the equivalent circuits of dielectric resonators coupled to external circuits. Most of the TE$_{01\delta}$ and TM$_{010}$ mode resonators are coupled magnetically and electrically to the external circuits, respectively. The TEM mode resonators are generally coupled electrically to the external circuits.

In Figure 3, Q_L indicates the loaded quality factor, which is the total quality factor for the resonator system including energy losses both in the resonator and in the external circuit. Q_L is given by the following equations:

$$\frac{1}{Q_\mathrm{L}} = \frac{1}{Q_\mathrm{u}} + \frac{1}{Q_\mathrm{e}} \text{(for reflection and reaction type)} \qquad (6)$$

$$\frac{1}{Q_\mathrm{L}} = \frac{1}{Q_\mathrm{u}} + \frac{1}{Q_\mathrm{eg}} + \frac{1}{Q_\mathrm{el}} \text{ (for transmission type)} \qquad (7)$$

where

Q_e, Q_{eg} and Q_{el} indicate the external quality factors determined by the coupling coefficient between the resonator and the external circuits;

Q_{eg} is the Q_e on the generator side and Q_{el} is that on the load side;

Q_u indicates the unloaded quality factor of a dielectric resonator with shielding conductor.

The unloaded quality factor is mainly determined by the loss factor of a dielectric resonator material and the conduction loss on surfaces of a shielding conductor. Q_u is given by the following equation:

$$\frac{1}{Q_u} = \frac{1}{Q_d} + \frac{1}{Q_c} \tag{8}$$

where

Q_d is the quality factor due to the $\tan\delta$ of a material; and

Q_c is the quality factor due to the conduction loss of a shielding conductor.

The quality factor of a material is defined as $Q_0 = 1/\tan\delta$. Using Q_0, Q_d is given by the following equation:

$$Q_d = (1 + A) \cdot Q_0 \tag{9}$$

where

A is the geometrical factor determined by the structure of the dielectric resonator and given by $A = W_O / W_I$, where W_O and W_I are the electric energy stored outside and inside of the dielectric element, respectively. The value A equals zero when all the electric field energy is concentrated inside the dielectric element.

The value Q_c is strongly dependent on the resonance mode and the dimension of the dielectric resonator.

Table 3 shows an example of the Q_d, Q_c and Q_u for three kinds of dielectric resonators with different resonance modes. The values Q_d and Q_c were calculated under the conditions that a dielectric resonator material has the property of the ε'= 38 and $Q_0 = 1/\tan\delta =$ 50 000. The value 5,8 × 10^7 (S/m) was used as the conductivity of a shielding conductor for Cu. The size of each resonator was determined so that each one has the same resonance frequency of 1 GHz.

As shown in Table 3, the value Q_u is determined by Q_d for the $TE_{01\delta}$ mode resonator and by Q_c for the TEM mode resonator (these being the lower value between Q_d and Q_c in each case).

5.3.2 $TE_{01\delta}$ mode resonator

a) Structure

Figure 4 shows a cross-section of a $TE_{01\delta}$ mode resonator with an excitation terminal. The dielectric element with the shape of a disc or a ring is fixed at the centre of a shielding conductor by using a low ε' support that is usually made of forstelite, alumina or quartz.

b) Resonance frequency

Figure 5 shows the dimensions of the $\mathrm{TE}_{01\delta}$ mode resonator. The height of the shielding conductor h should be less than $\lambda_0/2$, where λ_0 is the wavelength in vacuum at the resonance frequency.

Under the condition of $d \approx 2D$ to $3D$, $h \approx 2L$ to $3L$, the resonance frequency is given by

$$f_0 = 1{,}1 \frac{c}{D\sqrt{\varepsilon'}} \tag{10}$$

where c is the velocity of light in vacuum.

Figure 6 shows a mode chart for a $\mathrm{TE}_{01\delta}$ mode resonator. At the ratio of $D/L \approx \sqrt{5}$, the $\mathrm{TE}_{01\delta}$ dominant mode is mostly separated from the adjacent higher mode. It is, therefore, recommended to use this ratio to obtain the desirable spurious response. A ring-shaped dielectric element gives a more improved spurious response.

c) Quality factor

The unloaded Q of this mode is given by the following equation:

$$\frac{1}{Q_\mathrm{u}} = \frac{1}{Q_\mathrm{d}} + \frac{1}{Q_\mathrm{c}} = \left(A_1 \tan\delta + A_2 \tan\delta_\mathrm{S} + A_3 \tan\delta_\mathrm{a}\right) + A_4 R_\mathrm{S} \tag{11}$$

where $\tan\delta$, $\tan\delta_S$ and $\tan\delta_a$ are the loss factors for a dielectric element, a dielectric support and adhesive glue, respectively. R_S is the surface resistance of a shielding conductor that is given by the following equation:

$$R_\mathrm{S} = \sqrt{\frac{\omega\mu_0}{2\sigma}} \tag{12}$$

where

ω is the angular resonance frequency;

μ_0 is the permeability in vacuum; and

σ is the conductivity of the shielding conductor.

The constants A_1 to A_4 are determined by ε' of a dielectric element and by dimensions of the resonator.

d) Temperature coefficient of resonance frequency

The temperature coefficient of resonance frequency TCF of a material is selected so that it compensates the effect of thermal expansion of a shielding conductor on a resonator's temperature coefficient of resonance frequency. The value $TCF \approx 3$ is recommended for the $\mathrm{TE}_{01\delta}$ mode resonator with dimensions of $d \approx 2D$ to $3D$, $h \approx 2L$ to $3L$.

5.3.3 TM_{010} mode resonators

a) Structure

Figure 7 shows a cross-section of the TM_{010} mode resonator with an excitation terminal. A rod type dielectric element is set at the centre of a shielding conductor. Both ends of it are electrically contacted to the upper and the lower conductor.