INTERNATIONAL STANDARD

IEC 61338-2

First edition
2004-05

Waveguide type dielectric resonators –

Part 2: Guidelines for oscillator and filter applications

Reference number
IEC 61338-2:2004(E)

Publication numbering

As from 1 January 1997 all IEC publications are issued with a designation in the 60000 series. For example, IEC 34-1 is now referred to as IEC 60034-1.

Consolidated editions

The IEC is now publishing consolidated versions of its publications. For example, edition numbers 1.0, 1.1 and 1.2 refer, respectively, to the base publication, the base publication incorporating amendment 1 and the base publication incorporating amendments 1 and 2.

Further information on IEC publications

The technical content of IEC publications is kept under constant review by the IEC, thus ensuring that the content reflects current technology. Information relating to this publication, including its validity, is available in the IEC Catalogue of publications (see below) in addition to new editions, amendments and corrigenda. Information on the subjects under consideration and work in progress undertaken by the technical committee which has prepared this publication, as well as the list of publications issued, is also available from the following:

- **IEC Web Site (www.iec.ch)**

- **Catalogue of IEC publications**

  The on-line catalogue on the IEC web site (www.iec.ch/searchpub) enables you to search by a variety of criteria including text searches, technical committees and date of publication. On-line information is also available on recently issued publications, withdrawn and replaced publications, as well as corrigenda.

- **IEC Just Published**

  This summary of recently issued publications (www.iec.ch/online_news/ justpub) is also available by email. Please contact the Customer Service Centre (see below) for further information.

- **Customer Service Centre**

  If you have any questions regarding this publication or need further assistance, please contact the Customer Service Centre:

  Email: custserv@iec.ch
  Tel: +41 22 919 02 11
  Fax: +41 22 919 03 00

INTERNATIONAL STANDARD

IEC 61338-2

First edition
2004-05

Waveguide type dielectric resonators –

Part 2: Guidelines for oscillator and filter applications

International Electrotechnical Commission, 3, rue de Varembé, PO Box 131, CH-1211 Geneva 20, Switzerland
Telephone: +41 22 919 02 11 Telefax: +41 22 919 03 00 E-mail: inmail@iec.ch Web: www.iec.ch

Commission Electrotechnique Internationale
International Electrotechnical Commission
Международная Электротехническая Комиссия

PRICE CODE V

For price, see current catalogue

CONTENTS

FOREWORD 4
INTRODUCTION 5

1 Scope 7
2 Normative references
3 Technical overview 8
4 Fundamentals of waveguide type dielectric resonators 8
  4.1 Principle of operation 8
  4.2 Basic structure 9
5 Dielectric resonator characteristics 9
  5.1 Characteristics of dielectric resonator materials 9
  5.2 Characteristics of shielding conductor 10
  5.3 Characteristics of resonance modes 10
  5.4 Example of applications 16
6 Application guide for oscillators 17
  6.1 Practical remarks for oscillators 17
  6.2 Oscillator using $TE_{01\delta}$ mode resonator 18
  6.3 Oscillator using TEM mode resonator 19

Annex A (normative) 29

Bibliography 30

Figure 1 – Electromagnetic wave passing through a dielectric waveguide with relative permittivity ε' 20
Figure 2 – $TE_{01\delta}$ mode, TM_{010} mode, and quarter wavelength TEM mode dielectric resonators 20
Figure 3 – Equivalent circuits of dielectric resonator coupled to external circuit 21
Figure 4 – Cross-section of $TE_{01\delta}$ mode resonator with excitation terminal 21
Figure 5 – Dimension of $TE_{01\delta}$ mode resonator 22
Figure 6 – Mode chart for $TE_{01\delta}$ mode resonator 22
Figure 7 – Cross-section of TM_{010} mode resonator with excitation terminal 22
Figure 8 – Rectangular type λ/4 TEM mode resonator mounted on PWB 23
Figure 9 – TEM mode resonator with metal terminal moulded by resin 23
Figure 10 – Cylinder type and rectangular type λ/4 TEM mode resonators 23
Figure 11 – λ/4 TEM mode resonators with stepped inner diameter 23
Figure 12 – Microstripline resonator 24
Figure 13 – Stripline resonator 24
Figure 14 – Example of a frequency tuning mechanism of a dielectric resonator 24
Figure 15 – Example of a reflection-type oscillator 25
Figure 16 – Example of a feedback-type oscillator 25
Figure 17 – Simplified diagram of a reflection-type oscillator 25

Figure 18 – Example of a reflection-type voltage-controlled oscillator 26
Figure 19 – Example of a feedback-type voltage-controlled oscillator 26
Figure 20 – Configuration of VCO using a TEM mode resonator 26

Table 1 – Characteristics of available dielectric resonator materials 27
Table 2 – Characteristics of substrate materials 27
Table 3 – Comparison of size and unloaded Q of dielectric resonators with three resonance modes 27
Table 4 – Example of applications 28
Table A.1 – References to relevant publications 29

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.
2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
5) IEC provides no marking procedure to indicate its approval and cannot be rendered responsible for any equipment declared to be in conformity with an IEC Publication.
6) All users should ensure that they have the latest edition of this publication.
7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

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.

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.

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]

A bilingual version may be issued at a later date

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:

$$\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon'}} \qquad (1)$$

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 $TE_{01\delta}$ 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 $TE_{01\delta}$ 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:

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

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 ±1·10^{-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.

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

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 +6·10^{-6}/K to +12·10^{-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:

$$\frac{1}{Q_L} = \frac{1}{Q_u} + \frac{1}{Q_e} \text{ (for reflection and reaction type)} \tag{6}$$

$$\frac{1}{Q_L} = \frac{1}{Q_u} + \frac{1}{Q_{eg}} + \frac{1}{Q_{el}} \text{ (for transmission type)} \tag{7}$$

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 $\varepsilon' = 38$ and $Q_0 = 1/\tan\delta = 50\ 000$. The value $5{,}8 \times 10^7$ (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 $TE_{01\delta}$ 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 $TE_{01\delta}$ mode resonator. At the ratio of $D/L \approx \sqrt{5}$, the $TE_{01\delta}$ 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:

$$\frac{1}{Q_u} = \frac{1}{Q_d} + \frac{1}{Q_C} = \left(A_1 \tan\delta + A_2 \tan\delta_S + A_3 \tan\delta_a\right) + A_4 R_S \tag{11}$$

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:

$$R_S = \sqrt{\frac{\omega\mu_0}{2\sigma}} \tag{12}$$

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 $TE_{01\delta}$ 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.

b) Resonance frequency

The resonance frequency of the TM_{010} mode resonator is determined by the diameter of dielectric element. Under the conditions of ε' of 30 to 40 and $D/d = 1/3$, where D is the diameter of dielectric element and d is the inner diameter of shielding conductor, the resonance frequency of TM_{010} mode resonator is given by the following equation:

$$f_0 = \frac{c}{D}\sqrt{\frac{0{,}13}{\varepsilon'}} \tag{13}$$

c) Unloaded quality factor

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

$$\frac{1}{Q_u} = \frac{1}{Q_d} + \frac{1}{Q_C} = \left(A_1 \tan\delta + A_2 R_S\right) \tag{14}$$

where

$\tan\delta$ is the loss factor of the dielectric element; and

R_S is a surface resistance of the shielding conductor.

The constants A_1 and A_2 are determined by the ε' of the dielectric element and the dimensions of the resonator. The effect of R_S on Q_u for the TM_{010} mode resonator is comparatively larger than that for the $TE_{01\delta}$ mode resonator. A longer dielectric element gives a higher unloaded Q.

d) Temperature coefficient of resonance frequency

The air gap between a dielectric element and a shielding conductor shifts the resonance frequency drastically. Therefore, the thermal expansion of these two materials must be coincided to prevent the creation of an air gap.

5.3.4 TEM mode resonator

a) Structure

Figure 8 shows a rectangular type λ/4 TEM mode resonator mounted on a PWB by reflow soldering. For coupling with a transmission line, a metal terminal is connected to the inner wall of the resonator. In the case where a capacitance is needed on the resonator side, a resin is inserted between a metal terminal and an inner wall of the resonator (Figure 9).

b) Resonance frequency

Figure 10 shows the dimensions of a cylinder type and a rectangular type λ/4 TEM mode resonators. The outer wall, inner wall and one end of the resonator are metallized by silver or copper.

The resonance frequency of this mode is determined by the length of the resonator:

$$f_0 = \frac{c}{4L\sqrt{\varepsilon'}} \tag{15}$$

The next higher mode response appears at 3 f_0. A different higher mode appears at the frequency given by the following equation:

$$\frac{c}{f} = \lambda = 2\pi\left(\frac{a+b}{2}\right) \tag{16}$$

Figure 11 shows a λ/4 TEM mode resonator with a step in the inner diameter. This step shortens the length by 10 % to 20 % compared with the straight inner diameter resonator but degrades the unloaded quality factor according to the shorter length.

c) Unloaded quality factor

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

$$\frac{1}{Q_u} = \frac{1}{Q_d} + \frac{1}{Q_C} \tag{17}$$

where $Q_d = 1/\tan\delta$ and Q_c is given by the following equation for a cylinder type λ/4 TEM mode resonator:

$$Q_C = \sqrt{2\sigma\omega\mu_0 \frac{\ln(b/a)}{1/a + 1/b + (2/L)\ln(b/a)}} \tag{18}$$

For a rectangular type resonator, the transformation of $4W = 2\pi b$ is acceptable. The dimensional condition of b/a = 3,6 gives the maximum Q_c value.

d) Temperature coefficient of resonance frequency

The temperature coefficient of the resonance frequency of this mode coincides approximately with the TCF of a dielectric element.

5.3.5 Microstripline resonator

a) Structure

Figure 12 shows a microstripline resonator. This operates as a λ/4 resonator when one end of the microstripline is shorted and as a λ/2 resonator when both ends of the microstripline are open- or short-circuited.

b) Resonance frequency

Resonance frequency is given by the following equation for a λ/4 microstripline resonator:

$$f_0 = \frac{c}{4L\sqrt{\varepsilon_{eff}}} \tag{19}$$

where ε_{eff} is the effective permittivity of the microstripline resonator. ε_{eff} is given by the following equation using a width w of microstripline and a thickness h of substrate:

$$\varepsilon_{eff} = \frac{\varepsilon' + 1}{2} + \frac{\varepsilon' - 1}{2} \frac{1}{\sqrt{1 + 10h/w}} \tag{20}$$

c) Unloaded quality factor

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

$$\frac{1}{Q_\mathrm{u}} = \frac{1}{Q_\mathrm{d}} + \frac{1}{Q_\mathrm{C}} = \left(A_1 \tan\delta + A_2 R_\mathrm{S1} + A_3 R_\mathrm{S2}\right) \tag{21}$$

where

$\tan\delta$ is the loss factor of dielectric substrate; and

R_S1 and R_S2 are the surface resistances of the microstripline and the ground-plane electrode, respectively.

This type of resonator is usually set in a shielding conductor to avoid electromagnetic radiation loss.

d) Temperature coefficient of resonance frequency

The temperature coefficient of resonance frequency of this mode coincides approximately with the TCF of dielectric substrate.

5.3.6 Stripline resonator

a) Structure

Figure 13 shows a stripline resonator. This operates as a λ/4 resonator when one end of the stripline is shorted and as a λ/2 resonator when both ends of the stripline are open- or short-circuited.

b) Resonance frequency

This resonator has a similar structure to the TEM mode resonator. Resonance frequency is given by the following equation for a λ/4 stripline resonator:

$$f_0 = \frac{c}{4L\sqrt{\varepsilon'}} \tag{22}$$

c) Unloaded quality factor

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

$$\frac{1}{Q_\mathrm{u}} = \frac{1}{Q_\mathrm{d}} + \frac{1}{Q_\mathrm{C}} = \left(A_1 \tan\delta + A_2 R_\mathrm{S1} + A_3 R_\mathrm{S2}\right) \tag{23}$$

where

$\tan\delta$ is the loss factor of dielectric substrate; and

R_S1 and R_S2 are the surface resistances of the microstripline and the ground-plane electrode, respectively.

The ratio of W/w is recommended to be greater than 3 to prevent the deterioration of unloaded Q caused by the interference at the edge of the stripline.

d) Temperature coefficient of resonance frequency

The temperature coefficient of resonance frequency of this mode coincides approximately with the TCF of dielectric substrate.

5.4 Example of applications

Table 4 shows the application of dielectric resonators in microwave filters and oscillators. For the filters of mobile communication systems at 900 MHz, the $BaO-Nd_2O_3-TiO_2$ based materials with a ε' higher than 90 are popularly used. The λ/4 TEM resonance mode is utilized for this application to obtain the greatest size-reduction effect.

The applicable frequency range of $(Zr,Sn)TiO_4$ and $Ba_2Ti_9O_{20}$ materials is as wide as 0,2 GHz to 10 GHz. They have a high ε' of 38 and a high Q_0 value and are used for the filters of cellular base stations, for the filters of many kinds of communication systems and for the oscillators of direct broadcasting satellite TV. The $TE_{01\delta}$ resonance mode is used when an application needs the high unloaded quality factor. For high-power applications such as cellular base stations, the TM_{010} resonance mode has the advantage of aiding the release of heat from the dielectric element to the shielding conductors. Designers of high-power applications should take care to avoid the electric discharge that rises around a dielectric element at low air pressure. The low third harmonic distortion level is another subject to be considered to avoid the crosstalk between signals. $(Zr,Sn)TiO_4$ material has a low third harmonic distortion level.

The complex perovskite materials such as $Ba(Zn,Ta)O_3$ and $Ba(Mg,Ta)O_3$ have an extremely high Q_0 value. They are used at higher frequencies from 10 GHz to 80 GHz. The $TE_{01\delta}$ resonance mode is mainly used to obtain a higher unloaded quality factor.

6 Application guide for oscillators

6.1 Practical remarks for oscillators

Dielectric resonators are used for stabilizing the oscillation frequency and reducing the phase noise of microwave oscillators. A TEM mode dielectric resonator is generally used for oscillators with oscillation frequencies from 0,3 GHz to 3,0 GHz, and a $TE_{01\delta}$ mode resonator is used for those with frequencies higher than 3,0 GHz.

An Si bipolar transistor or a GaAs FET is used for active elements. The former can be used at frequencies lower than 10 GHz and the latter can be used at frequencies higher than 10 GHz. However, because the phase noise in the 1/f area of GaAs FET oscillators is 20 dB higher than that of Si bipolar transistor oscillators, a dielectric resonator with high unloaded Q is often utilized to stabilize the oscillation frequency of GaAs FET oscillators.

Figure 14 shows an example of a mechanical tuning system for a resonance frequency of a $TE_{01\delta}$ mode dielectric resonator. A metal screw above the dielectric element usually tunes the oscillation frequency by about 5 %. The oscillation frequency of an oscillator is mainly determined by the resonance frequency of the dielectric resonator and affected by the parameters of transistors and circuits. In the case of VCO (Voltage Controlled Oscillator), it is also affected by the capacitance of the varactor diode.

The temperature stability of the oscillator frequency is mainly determined by the temperature coefficient of the resonance frequency of the dielectric resonator (TCF) and affected by the thermal expansion coefficient of the metal case. The effect of the thermal expansion coefficient of the metal case is a function of the distance between the dielectric element and the metal case. To get a stable oscillation frequency, the TCF of the dielectric resonator is selected so that it compensates for the thermal expansion coefficient of the metal case.

Dielectric resonator materials such as $(Zr,Sn)TiO_4$, $Ba(Zn,Ta)O_3$ and $Ba(Mg,Ta)O_3$ have linear temperature dependence of resonance frequency that enables the frequency stability to be within $\pm 100 \cdot 10^{-6}$ from –50 °C to 100 °C. The automatic phase control system (phase-lock loop system) is sometimes adopted to obtain the higher frequency stability.

The phase noise $L(f_{osc})$ is another important parameter for evaluating oscillators. $L(f_{osc})$ is given by the following equation:

$$L(f_m) \approx 10 \log \left[\alpha \left(\frac{f_{osc}}{2Q_{osc}} \right)^2 \frac{1}{f_m^3} + \frac{FkT}{P_{FET}} \left\{ \left(\frac{f_{osc}}{2Q_{osc}} \right)^2 \frac{1}{f_m^2} + 1 \right\} \right] \quad \text{(dB/Hz)} \qquad (24)$$

where

f_{osc} is the oscillation frequency;

f_m is the offset frequency from carrier frequency;

Q_{osc} is the loaded quality factor of the oscillator excluding the negative resistance of the FET;

P_{FET} is the output power of the oscillator transistor;

α is the flicker noise coefficient;

F is the noise figure of the FET;

k is the Boltzman constant; and

T is the temperature of the FET.

In order to get a lower phase noise with minimal output power in the transistor, a higher Q_{osc} value is needed. A higher Q_{osc} value is obtained by using a $TE_{01\delta}$ mode dielectric resonator.

6.2 Oscillator using $TE_{01}\delta$ mode resonator

A $TE_{01\delta}$ mode, high Q dielectric resonator is used to stabilize the oscillation frequency and to reduce the FM noise. There are two types of oscillators: reflection-type and feedback-type. Figure 15 shows a reflection-type oscillator where a dielectric resonator is utilized as a narrowband-rejection filter. Figure 16 shows a feedback type oscillator where a dielectric resonator is utilized as a narrowband-pass filter. Due to easiness of design, the reflection-type oscillator is commonly used.

Figure 17 is a simplified diagram for analysing the oscillation condition of a reflection type oscillator. The oscillation condition is given by the following equations.

$$|\Gamma_{in}| \cdot |\Gamma_r'| > 1 \qquad (25)$$

$$\arg(\Gamma_{in}) + \arg(\Gamma_r') = 2n\pi \; (n : \text{integer}) \qquad (26)$$

where

Γ_{in} is the input reflection coefficient of the FET gate terminal; and

Γ_r' is the reflection coefficient seen from the FET gate terminal to the direction of the dielectric resonator.

Γ_{in} is given as follows:

$$\Gamma_{in} = \frac{Z_{in} - Z_0}{Z_{in} + Z_0} \qquad (27)$$

where Z_{in} is the input impedance of the FET. Under the condition that the input reflection coefficient Γ_{in} is greater than 1, $|\Gamma_{in}| > 1$, the input impedance Z_{in} is expressed as follows.

$$Z_{in} = -R_{in} + jX_{in} \tag{28}$$

where $-R_{in}$ and X_{in} are the negative input resistance and the input reactance of the FET respectively. The feedback reactance of Figure 17 is adjusted to obtain an appropriate ratio of gain-to-reflection coefficient Γ_{in} over a desired frequency range, while the reflection coefficient Γ_r' is expressed as follows:

$$\Gamma_r' = \Gamma_r \ e^{-j\theta} \tag{29}$$

where

Γ_r is the reflection coefficient of a band-stop filter;

θ is the phase angle of a transmission line; and

Γ_r is a function of coupling coefficient β that is determined by the distance between a dielectric resonator and a microstripline.

The values Γ_{in} and Γ_r' are measured by a vector network analyser. The coupling coefficient, phase angle, and feedback reactance are designed to satisfy equations (25) and (26).

The coupling coefficient is adjusted to satisfy equation (25) at a desired frequency, and the phase angle is adjusted to satisfy equation (26). The stronger coupling gives a stable oscillation and a wider frequency tuning range but the excess coupling gives a low loaded-quality factor of the resonator and an inferior oscillation performance. On the other hand, the weaker coupling results in a lower FM noise characteristic. The strength of β must be determined by considering the situation described above.

Figures 18 and 19 show examples of a reflection-type voltage controlled oscillator (VCO) and a feedback-type VCO. A highly stabilized oscillation frequency is obtained by using a $TE_{01\delta}$ mode, high Q dielectric resonator. Low FM noise in the low frequency range is obtained by using a PLL technique. These VCO can be constructed by coupling a varactor diode to the resonator.

6.3 Oscillator using TEM mode resonator

Figure 20 shows an example of a voltage-controlled oscillator (VCO) with an oscillation frequency of 900 MHz where V_{ctrl} denotes a control voltage, V_{cc} is the bias voltage of the transistor, and RF_{out} is the output signal. A TEM mode dielectric resonator is used for stabilizing the oscillation frequency.

This VCO constitutes the common base-type oscillation circuit with a λ/4 TEM mode dielectric resonator, having a ε' of 90 and a Q_u value of 400 at 900 MHz. The common base-type oscillation circuit realizes a low phase noise and the varactor diode gives a wide tunable frequency range. A portable phone for 900 MHz band is the representative application of this VCO.

For a VCO with an oscillation frequency higher than 1,5 GHz, the length of a TEM mode resonator with ε' of 90 is too short and it degrades the Q values. Thus, the dielectric resonators with ε' from 20 to 40 are often used for high-frequency oscillators.

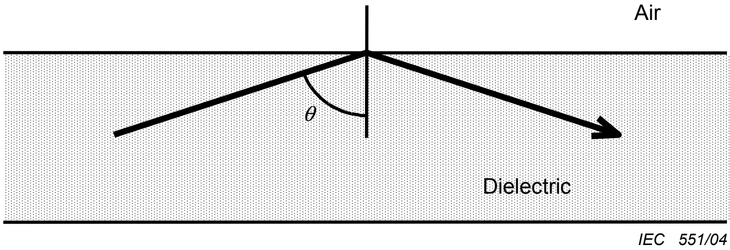
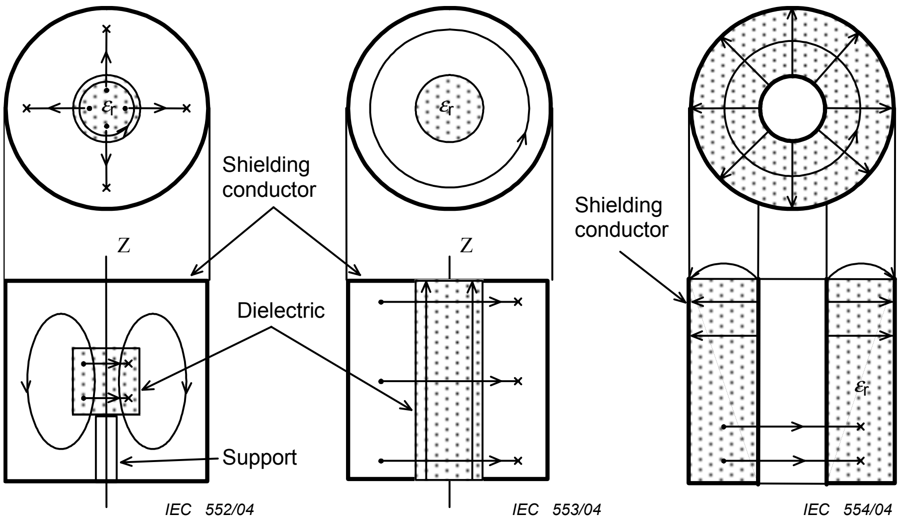


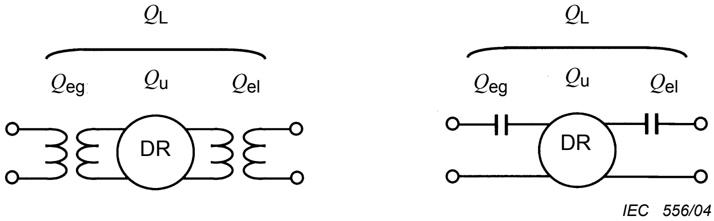
Figure 1 – Electromagnetic wave passing through a dielectric waveguide with relative permittivity ε'



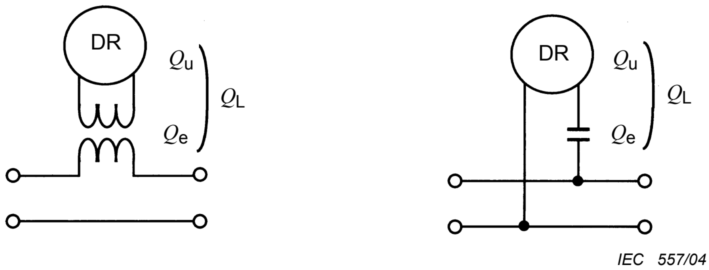
2a) – $TE_{01\delta}$ mode **2b) – TM_{010} mode** **2c) – λ/4 TEM mode**

Figure 2 – $TE_{01\delta}$ mode, TM_{010} mode, and quarter wavelength TEM mode dielectric resonators

3a – Reflection type resonator



3b – Transmission type resonator



3c – Reaction type resonator

Figure 3 – Equivalent circuits of dielectric resonator coupled to external circuit

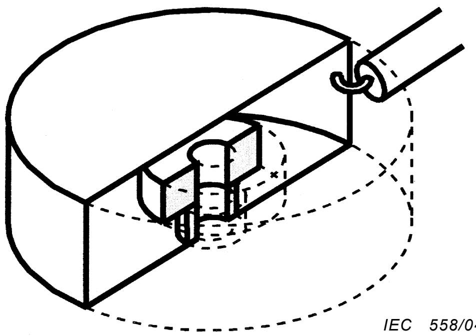


Figure 4 – Cross-section of $TE_{01\delta}$ mode resonator with excitation terminal

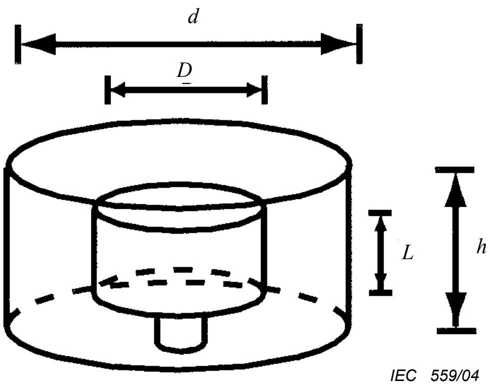


Figure 5 – Dimension of $TE_{01\delta}$ mode resonator

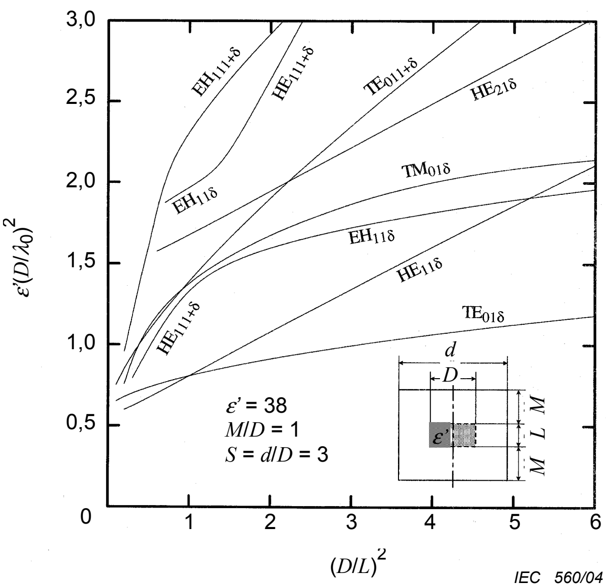


Figure 6 – Mode chart for $TE_{01\delta}$ mode resonator

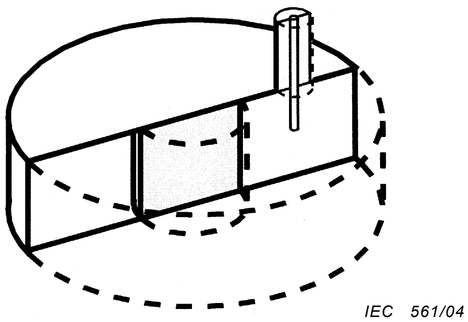


Figure 7 – Cross-section of TM_{010} mode resonator with excitation terminal

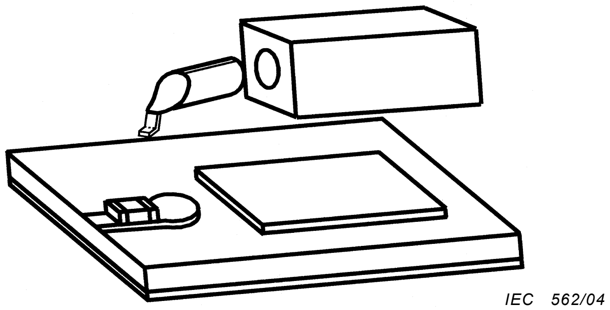


Figure 8 – Rectangular type λ/4 TEM mode resonator mounted on PWB

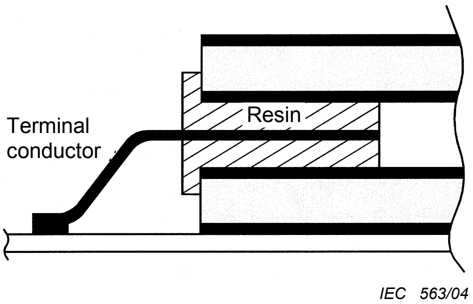


Figure 9 – TEM mode resonator with metal terminal moulded by resin

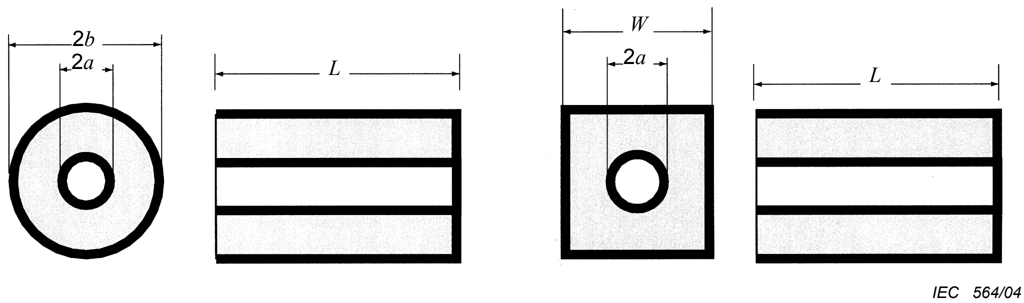


Figure 10 – Cylinder type and rectangular type λ/4 TEM mode resonators

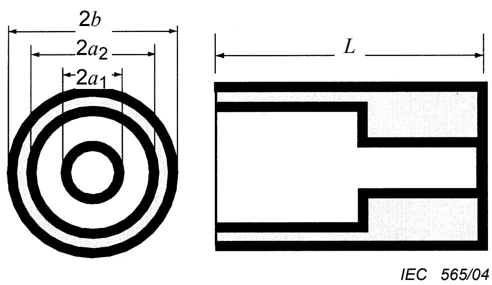


Figure 11 – λ/4 TEM mode resonators with stepped inner diameter

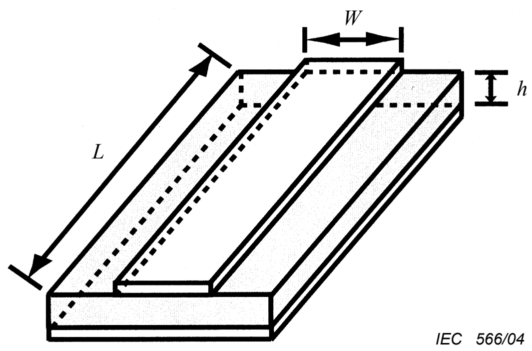


Figure 12 – Microstripline resonator

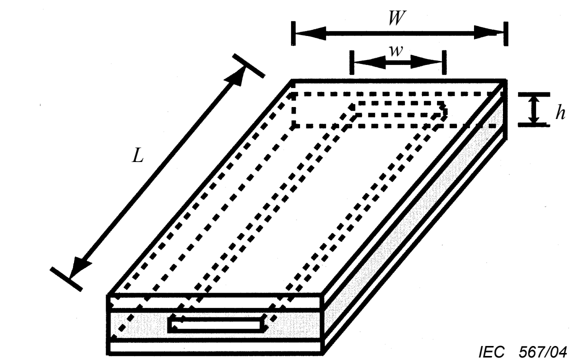


Figure 13 – Stripline resonator

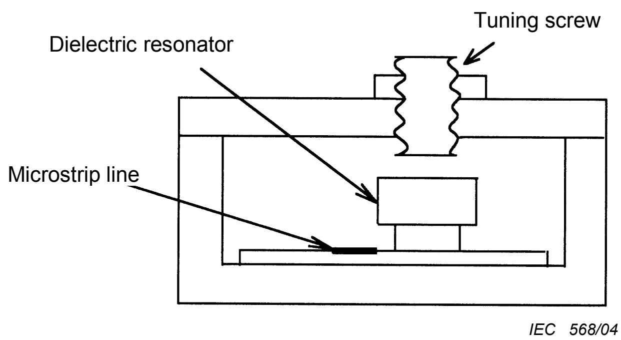


Figure 14 – Example of a frequency tuning mechanism of a dielectric resonator

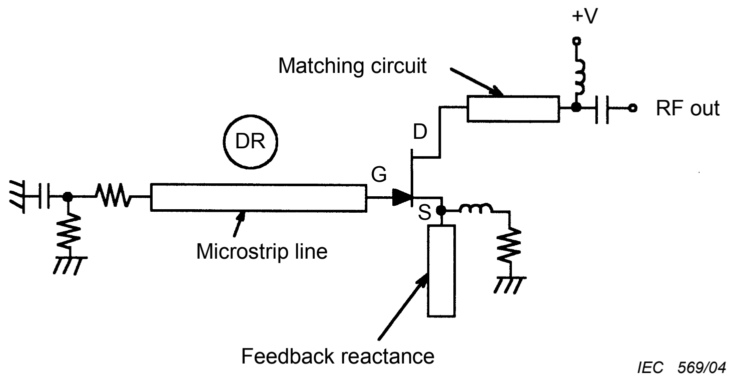


Figure 15 – Example of a reflection-type oscillator

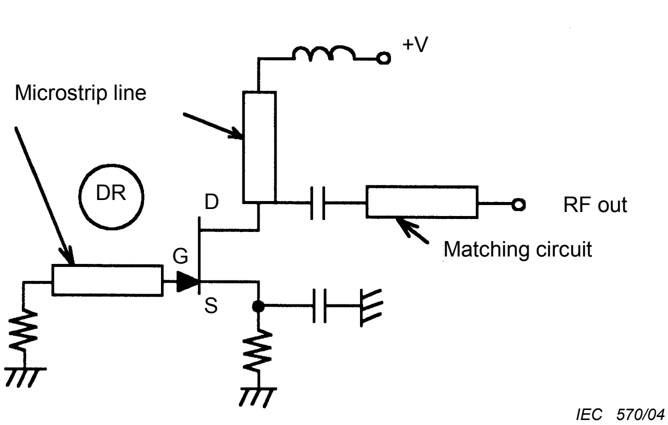


Figure 16 – Example of a feedback-type oscillator

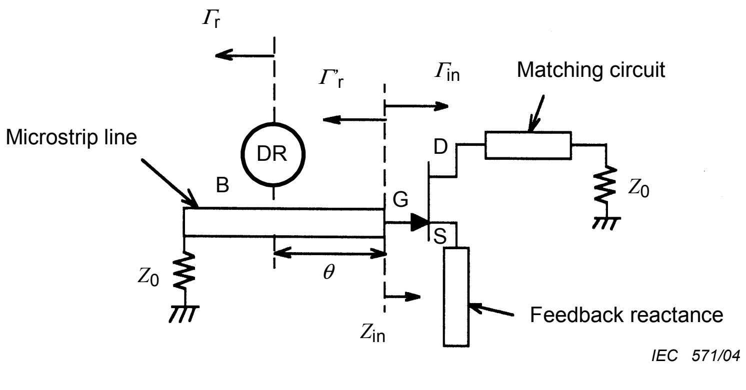


Figure 17 – Simplified diagram of a reflection-type oscillator

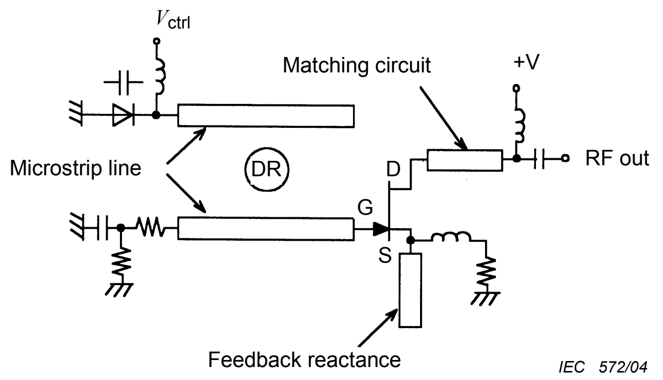


Figure 18 – Example of a reflection-type voltage controlled oscillator

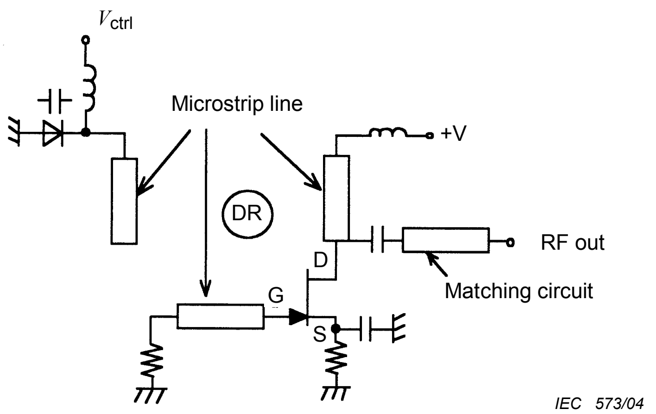


Figure 19 – Example of a feedback-type voltage-controlled oscillator

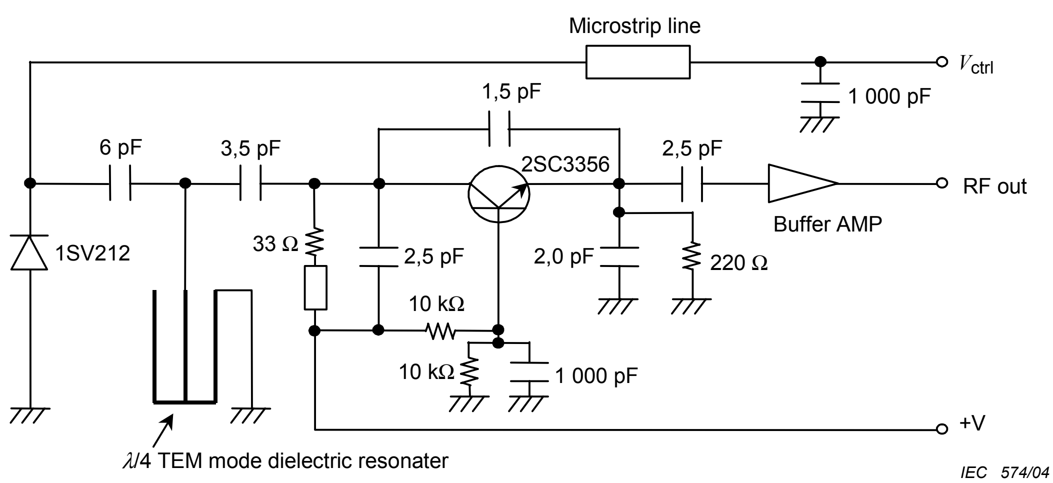


Figure 20 – Configuration of VCO using a TEM mode resonator

Table 1 – Characteristics of available dielectric resonator materials

Materials	ε'	$Q_0 f$ product GHz	TCF 10^{-6}/K
$MgTiO_3$-$CaTiO_3$ system	21	50 000	–10 to 10
$Ba(Mg,Ta)O_3$ system	24	300 000	0 to 10
$Ba(Zn,Ta)O_3$ system	30	150 000	–10 to 10
$Ba(Zn,Nb)O_3$ system	34	85 000	0 to 10
$(Zr,Sn)TiO_4$ system	38	50 000	–10 to 10
$Ba_2Ti_9O_{20}$ system	38	40 000	4 to 10
BaO-PbO-Bi_2O_3-Nd_2O_3-TiO_2 system	90	5 000	–20 to 20
NOTE Measured at 7 GHz by the TE_{011} mode.			

Table 2 – Characteristics of substrate materials

Materials	ε'	$\tan\delta$ at 1 GHz (*at 1 MHz)	TCF 10^{-6}/K
PTFE	1,9 to 2,8	0,0002 to 0,0025	
Epoxy	2,5	0,01 to 0,02	
Glass-PTFE	2,7	0,002	
BT resin	3,4	0,003	
Glass-epoxy	2,6 to 4,2	0,01	
Polyimid	2,7 to 3,2	*0,005 to 0,008	
Glass-polyimid	4,0 to 4,4	*0,006 to 0,012	
Al_2O_3	9,8	<0,00001	–55
NOTE PTFE = Polytetrafluoro ethylene, BT = Bismaleimide-Triazine.			

Table 3 – Comparison of size and unloaded Q of dielectric resonators with three resonance modes

Resonance mode	Inner size of shielding conductor	Size of dielectric element	Q_d	Q_C	Q_u
			at 1 GHz		
$TE_{01\delta}$ mode	163 mmφ × 65 mm	54 mmφ × 22 mm	51 000	180 000	40 000
TM_{010} mode	64 mmφ × 52 mm	17 mmφ × 52 mm	52 000	16 000	12 000
λ/4 TEM mode	10 mmφ × 12 mm	10 mmφ × 12 mm	50 000	1 030	1 010
NOTE φ denotes diameter. A λ/4 TEM mode resonator has an inner diameter of 4 mm.					

Table 4 – Example of applications

Frequency range	Resonance modes	Materials	Example of applications
0,2 GHz to 3 GHz	λ/4 TEM TM_{010} $TE_{01\delta}$	BaO-Nd_2O_3-TiO_2 system $MgTiO_3$-$CaTiO_3$ system (Zr,Sn)TiO_4 system $Ba_2Ti_9O_{20}$ system	Mobile communication service Mobile satellite communication service
3 GHz to 30 GHz	λ/4 TEM $TE_{01\delta}$ $EH_{11\delta}$	(Zr,Sn)TiO_4 system $Ba_2Ti_9O_{20}$ system Ba(Zn,Nb)O_3 system Ba(Zn,Ta)O_3 system	Microwave terrestrial communication service Fixed satellite communication service Broadcasting service Broadcasting satellite service
30 GHz to 80 GHz	$TE_{01\delta}$	Ba(Mg,Ta)O_3 system	Intelligent transport system Wireless LAN

Annex A
(normative)

Checklist of dielectric resonator specification

The following checklist provides guidance for the manufacturer to complete specifications for a particular dielectric resonator, including parameters and operating environmental characteristics. It will also be useful for operating the resonator and for drawing up specifications. The prospective user is then able to evaluate more accurately the applicability of the resonator to his intended use. The list also assists the user when he finds it necessary to specify a new dielectric resonator for a particular application, by alerting him to the various operating conditions and performance characteristics which need definition.

When the requirements can be met by a standard item, it will be sufficient to specify the corresponding specifications. When the requirements cannot be wholly met by the existing detailed specifications, the specifications should be referred to, together with a list of known differences.

In rare cases where the differences are such that it is not reasonable to quote the existing detailed specifications, new specifications are to be prepared in a format similar to those already used for standard detailed specifications.

Clearly, it is not necessary to specify all of the parameters listed for every application. Only those which are of importance in a particular case should be imposed. Specifications regarding non-critical parameters, as well as the imposition of unnecessarily close tolerances, would result in excessive costs.

In Table A.1, references are made to the relevant subclauses of IEC 61338-1-1, IEC 61338-1-2, IEC 61338-1-3, IEC 60068-1 and IEC 60068-2.

Table A.1 – References to relevant publications

	Relevant publications, clauses and subclauses
Dielectric characteristics	
Relative permittivity (ε')	IEC 61338-1-1, 3.1.4
Loss factor ($\tan\delta$)	IEC 61338-1-1, 3.1.6, IEC 61338-1-3
Quality factor of material (Q_0)	IEC 61338-1-1, 3.1.7, IEC 61338-1-3
Temperature coefficient of permittivity ($TC\varepsilon$)	IEC 61338-1-1, 3.1.8, IEC 61338-1-3
Coefficient of linear thermal expansion (α)	IEC 61338-1-1, 3.1.9, IEC 61338-1-3
Electrical characteristics	
Quality factor (Q)	IEC 61338-1-1, 3.3.1
Unloaded quality factor (Q_u)	IEC 61338-1-1, 3.3.2, IEC 61338-1-2, 5.2
External quality factor (Q_e)	IEC 61338-1-1, 3.3.3
Loaded quality factor (Q_L)	IEC 61338-1-1, 3.3.4, IEC 61338-1-2, 5.2
Resonance frequency (f_0)	IEC 61338-1-1, 3.3.5, IEC 61338-1-2, 5.2
Temperature coefficient of resonance frequency (TCF)	IEC 61338-1-1, 3.3.6, IEC 61338-1-2, 5.2

	Relevant publications, clauses and subclauses
Environmental characteristics	
Storage test	IEC 61338-1-2, Clause 6
High temperature ageing	IEC 61338-1-2, Clause 7
Rapid change of temperature	IEC 61338-1-2, Clause 10, IEC 60068-2-14
Bump	IEC 61338-1-2, Clause 11, IEC 60068-2-29
Vibration	IEC 61338-1-2, Clause 12, IEC 60068-2-6
Shock	IEC 61338-1-2, Clause 13, IEC 60068-2-27
Acceleration, steady state	IEC 61338-1-2, Clause 14, IEC 60068-2-7
Climatic test	IEC 61338-1-2, Clause 15, IEC 60068-1
Dry heat	IEC 61338-1-2, 15.1, IEC 60068-2-2
Damp heat, cyclic	IEC 61338-1-2, 15.2, IEC 60068-2-30
Cold	IEC 61338-1-2, 15.3, IEC 60068-2-1
Damp heat, steady state	IEC 61338-1-2, Clause 16, IEC 60068-2-78
Low air pressure	IEC 61338-1-2, Clause 17, IEC 60068-2-13
Other factors	
Physical characteristics	
Strength of terminations	IEC 61338-1-2, Clause 8, IEC 60068-2-21
Resistance to soldering heat and to dissolution of metallization	IEC 61338-1-2, 9.1, IEC 60068-2-58
Solderability of terminations	IEC 61338-1-2, 9.2, IEC 60068-2-20
Adhesion strength of metallized electrode	IEC 61338-1-2, 9.3
Marking	IEC 61338-1-1, Clause 4
Other factors	
Inspection requirements	
Applicable documents (related specifications)	
Inspection authority	
Type test	
Type test procedure	IEC 61338-1-2, Annex A
Acceptable quality level	IEC 61338-1-2, Annex A
Other factors	

Bibliography

[1] KAJFEZ, D. and GUILLON, P. eds*, Dielectric Resonators*, Artech House Inc., Dedham, MA, 1986.

[2] KONISHI, Y. *Microwave Integrated Circuits*, Marcel Dekker Inc., New York, Basel, Hong Kong, 1991.

[3] KOBAYASHI, Y. and NAKAYAMA, S. *Design Chart for Shielded Dielectric Rod and Ring Resonator*, IEEE MTT-S Digest, p. 241-244, 1986.

[4] SOARES, R., GRAFFEUIL J. and OBREGON, J. *Applications of GaAs MESFETs*, Artech House Inc., Ch.6, 1983.

[5] LESSON, DB. *Simple Model of Feedback Oscillator Noise Spectrum*, Proc. Letters IEEE, p.329-330, 1966.

Standards Survey

The IEC would like to offer you the best quality standards possible. To make sure that we continue to meet your needs, your feedback is essential. Would you please take a minute to answer the questions overleaf and fax them to us at +41 22 919 03 00 or mail them to the address below. Thank you!

Customer Service Centre (CSC)

International Electrotechnical Commission
3, rue de Varembé
1211 Genève 20
Switzerland

or

Fax to: **IEC**/CSC at +41 22 919 03 00

Thank you for your contribution to the standards-making process.

Nicht frankieren
Ne pas affranchir

Non affrancare
No stamp required

A Prioritaire

RÉPONSE PAYÉE

SUISSE

Customer Service Centre (CSC)
International Electrotechnical Commission
3, rue de Varembé
1211 GENEVA 20
Switzerland

Q1 Please report on **ONE STANDARD** and **ONE STANDARD ONLY**. Enter the exact number of the standard: *(e.g. 60601-1-1)*

....

Q2 Please tell us in what capacity(ies) you bought the standard *(tick all that apply)*. I am the/a:

- purchasing agent ❑
- librarian ❑
- researcher ❑
- design engineer ❑
- safety engineer ❑
- testing engineer ❑
- marketing specialist ❑
- other...

Q3 I work for/in/as a: *(tick all that apply)*

- manufacturing ❑
- consultant ❑
- government ❑
- test/certification facility ❑
- public utility ❑
- education ❑
- military ❑
- other...

Q4 This standard will be used for: *(tick all that apply)*

- general reference ❑
- product research ❑
- product design/development ❑
- specifications ❑
- tenders ❑
- quality assessment ❑
- certification ❑
- technical documentation ❑
- thesis ❑
- manufacturing ❑
- other...

Q5 This standard meets my needs: *(tick one)*

- not at all ❑
- nearly ❑
- fairly well ❑
- exactly ❑

Q6 If you ticked NOT AT ALL in Question 5 the reason is: *(tick all that apply)*

- standard is out of date ❑
- standard is incomplete ❑
- standard is too academic ❑
- standard is too superficial ❑
- title is misleading ❑
- I made the wrong choice ❑
- other ....

Q7 Please assess the standard in the following categories, using the numbers:
(1) unacceptable,
(2) below average,
(3) average,
(4) above average,
(5) exceptional,
(6) not applicable

- timeliness ....
- quality of writing....................................
- technical contents.................................
- logic of arrangement of contents ....
- tables, charts, graphs, figures...............
- other ....

Q8 I read/use the: *(tick one)*

- French text only ❑
- English text only ❑
- both English and French texts ❑

Q9 Please share any comment on any aspect of the IEC that you would like us to know:

....
....
....
....
....
....
....
....
....
....
....
....

ISBN 2-8318-7518-8

9 782831 875187

ICS 31.140

Typeset and printed by the IEC Central Office
GENEVA, SWITZERLAND