IEC 62631-2-2

Edition 1.0 2022-04

INTERNATIONAL STANDARD

NORME INTERNATIONALE

**Dielectric and resistive properties of solid insulating materials –
Part 2-2: Relative permittivity and dissipation factor – High frequencies (1 MHz to 300 MHz) – AC methods**

**Propriétés diélectriques et résistives des matériaux isolants solides –
Partie 2-2: Permittivité relative et facteur de dissipation – Hautes fréquences (1 MHz à 300 MHz) – Méthodes en courant alternatif**

IEC 62631-2-2:2022-04(en-fr)

IEC Secretariat
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

About the IEC
The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

About IEC publications
The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigendum or an amendment might have been published.

IEC publications search - webstore.iec.ch/advsearchform
The advanced search enables to find IEC publications by a variety of criteria (reference number, text, technical committee, …). It also gives information on projects, replaced and withdrawn publications.

IEC Just Published - webstore.iec.ch/justpublished
Stay up to date on all new IEC publications. Just Published details all new publications released. Available online and once a month by email.

IEC Customer Service Centre - webstore.iec.ch/csc
If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: sales@iec.ch.

IEC Products & Services Portal - products.iec.ch
Discover our powerful search engine and read freely all the publications previews. With a subscription you will always have access to up to date content tailored to your needs.

Electropedia - www.electropedia.org
The world's leading online dictionary on electrotechnology, containing more than 22 300 terminological entries in English and French, with equivalent terms in 19 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

A propos de l'IEC
La Commission Electrotechnique Internationale (IEC) est la première organisation mondiale qui élabore et publie des Normes internationales pour tout ce qui a trait à l'électricité, à l'électronique et aux technologies apparentées.

A propos des publications IEC
Le contenu technique des publications IEC est constamment revu. Veuillez vous assurer que vous possédez l'édition la plus récente, un corrigendum ou amendement peut avoir été publié.

Recherche de publications IEC - webstore.iec.ch/advsearchform
La recherche avancée permet de trouver des publications IEC en utilisant différents critères (numéro de référence, texte, comité d'études, …). Elle donne aussi des informations sur les projets et les publications remplacées ou retirées.

IEC Just Published - webstore.iec.ch/justpublished
Restez informé sur les nouvelles publications IEC. Just Published détaille les nouvelles publications parues. Disponible en ligne et une fois par mois par email.

Service Clients - webstore.iec.ch/csc
Si vous désirez nous donner des commentaires sur cette publication ou si vous avez des questions contactez-nous: sales@iec.ch.

IEC Products & Services Portal - products.iec.ch
Découvrez notre puissant moteur de recherche et consultez gratuitement tous les aperçus des publications. Avec un abonnement, vous aurez toujours accès à un contenu à jour adapté à vos besoins.

Electropedia - www.electropedia.org
Le premier dictionnaire d'électrotechnologie en ligne au monde, avec plus de 22 300 articles terminologiques en anglais et en français, ainsi que les termes équivalents dans 19 langues additionnelles. Egalement appelé Vocabulaire Electrotechnique International (IEV) en ligne.

IEC 62631-2-2

Edition 1.0 2022-04

INTERNATIONAL STANDARD

NORME INTERNATIONALE

**Dielectric and resistive properties of solid insulating materials –
Part 2-2: Relative permittivity and dissipation factor – High frequencies
(1 MHz to 300 MHz) – AC methods**

**Propriétés diélectriques et résistives des matériaux isolants solides –
Partie 2-2: Permittivité relative et facteur de dissipation – Hautes fréquences
(1 MHz à 300 MHz) – Méthodes en courant alternatif**

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

COMMISSION
ELECTROTECHNIQUE
INTERNATIONALE

ICS 17.220.99; 29.035.01

ISBN 978-2-8322-1096-7

Warning! Make sure that you obtained this publication from an authorized distributor.
Attention! Veuillez vous assurer que vous avez obtenu cette publication via un distributeur agréé.

CONTENTS

FOREWORD ... 4
INTRODUCTION ... 6
1 Scope ... 7
2 Normative references ... 7
3 Terms and definitions ... 7
4 Methods of test ... 8
4.1 Basic theory ... 8
4.2 Distinctive factors for the measurement in high frequency range ... 12
4.3 Power supply ... 13
4.4 Equipment ... 13
4.4.1 Accuracy ... 13
4.4.2 Distinctive feature of equipment for measurement in high frequency range ... 14
4.4.3 Choice of measurement methods ... 15
4.5 Calibration ... 16
4.6 Test specimen ... 16
4.6.1 General ... 16
4.6.2 Recommended dimensions of test specimen and electrode arrangements ... 16
4.6.3 Number of test specimens ... 16
4.6.4 Conditioning and pre-treatment of test specimen ... 16
4.7 Procedures for specific materials ... 17
5 Test procedure ... 17
5.1 General ... 17
5.2 Calculation of permittivity and relative permittivity ... 17
5.2.1 Relative permittivity ... 17
5.2.2 Dielectric dissipation factor tan δ ... 17
6 Report ... 17
7 Repeatability and reproducibility ... 18
Annex A (informative) Compensation method using a series circuit ... 19
Annex B (informative) Parallel electrodes with shield ring ... 20
Annex C (informative) Apparatus ... 21
C.1 Parallel T network bridge ... 21
C.2 Resonance method ... 22
C.3 I-V method designed for high frequencies ... 24
C.4 Auto-balancing bridge method ... 24
Annex D (informative) Non-contacting electrode method with micrometer-controlled parallel electrodes in air ... 26
Bibliography ... 28

Figure 1 – Dielectric dissipation factor ... 10
Figure 2 – Equivalent circuit diagrams with capacitive test specimen ... 11
Figure 3 – Equivalent parallel circuit for test fixture with sample and leads to equipment ... 12
Figure 4 – Existence of residual impedance and stray capacitance in directly connected system ... 15

Figure A.1 – Compensation method using a series circuit 19
Figure B.1 – Configuration of parallel electrode with shield ring 20
Figure C.1 – Parallel T network, principal circuit diagram 21
Figure C.2 – Parallel T network, practical circuit diagram 21
Figure C.3 – Principle of resonance method, circuit diagram (originally from Q meter) 23
Figure C.4 – Auto-balancing circuit 25
Figure D.1 – Non-contacting electrode method 27

Table 1 – Applicable frequency range in effective apparatus 16

INTERNATIONAL ELECTROTECHNICAL COMMISSION

____

DIELECTRIC AND RESISTIVE PROPERTIES OF SOLID INSULATING MATERIALS –

Part 2-2: Relative permittivity and dissipation factor – High frequencies (1 MHz to 300 MHz) – AC methods

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 itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
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.

IEC 62631-2-2 has been prepared by of IEC technical committee 112: Evaluation and qualification of electrical insulating materials and systems. It is an International Standard.

The text of this International Standard is based on the following documents:

Draft	Report on voting
112/562/FDIS	112/565/RVD

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

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

A list of all parts in the IEC 62631 series, published under the general title *Dielectric and resistive properties of solid insulating materials*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

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

INTRODUCTION

Permittivity and dissipation factor (tan δ) are basic parameters for the quality of insulating materials. The dissipation factor depends on several parameters, such as environmental factors, moisture, temperature, applied voltage, and highly depends on frequency, the accuracy of measuring apparatus and other parameters applied to the measured specimen.

The frequency range measurable for permittivity and dissipation factor is highly limited by the design of the electrode system, dimension of the sample and impedance of the wiring lead. Special consideration should be given to the measurement in the high frequency range. This document focuses on the method for measurements of permittivity and dissipation factor in the high frequency range from 1 MHz to 300 MHz.

DIELECTRIC AND RESISTIVE PROPERTIES OF SOLID INSULATING MATERIALS –

Part 2-2: Relative permittivity and dissipation factor – High frequencies (1 MHz to 300 MHz) – AC methods

1 Scope

This part of IEC 62631 specifies test methods for the determination of permittivity and dissipation factor properties of solid insulating materials in a high frequency range from 1 MHz to 300 MHz.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 60212, *Standard conditions for use prior to and during the testing of solid electrical insulating materials*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at https://www.iso.org/obp
- IEC Electropedia: available at http://www.electropedia.org/

3.1
solid electrical insulating material
solid with negligibly low electric conductivity, used to separate conducting parts at different electrical potentials

Note 1 to entry: The term "electrical insulating material" is sometimes used in a broader sense to designate also insulating liquids and gases. Insulating liquids are covered by IEC 60247 [1].

3.2
dielectric properties
comprehensive behaviour of an insulating material measured with an alternating current comprising the capacitance, absolute permittivity, relative permittivity, relative complex permittivity, dielectric dissipation factor

3.3
absolute permittivity
ε
electric flux density divided by the electric field strength

3.4
vacuum permittivity
ε_0
permittivity of a vacuum, which is related to the magnetic constant $\varepsilon_0\mu_0$ and to the speed of light in vacuum c_0 by the relation $\varepsilon_0\mu_0 c_0^2 = 1$

3.5
relative permittivity
ε_r
ratio of the absolute permittivity to the permittivity of a vacuum ε_0

3.6
relative complex permittivity
$\underline{\varepsilon}_r$
permittivity in a complex number representation, under steady sinusoidal field conditions

3.7
dielectric dissipation factor tan δ (loss tangent)
numerical value of the ratio of the imaginary to the real part of the complex permittivity

3.8
capacitance
C
property of an arrangement of conductors and dielectrics which permits the storage of electrical charge when a potential difference exists between the conductors

3.9
voltage application
application of a voltage between electrodes

Note 1 to entry: Voltage application is sometimes referred to as electrification.

3.10
measuring electrodes
conductors applied to, or embedded in, a material to make contact with it to measure its dielectric or resistive properties

Note 1 to entry: The design of the measuring electrodes depends on the specimen and the purpose of the test.

4 Methods of test

4.1 Basic theory

Capacitance C is the property of an arrangement of conductors and dielectrics which permits the storage of electrical charge when a potential difference exists between the conductors.

C is the ratio of a quantity q of charge to a potential difference U. A capacitance value is always positive. The unit is farad when the charge is expressed in coulomb and the potential in volts.

$$C = \frac{q}{U} \tag{1}$$

The measured permittivity (formerly known as dielectric constant) ε of an insulating material is the product of its relative permittivity ε_r and the permittivity of a vacuum ε_0:

$$\varepsilon = \varepsilon_0 \cdot \varepsilon_r \tag{2}$$

This general method describes common values for general measurements. If a method for a specific type of material is described in this document, the specific method shall be used.

The permittivity is expressed in farad per metre (F/m); the permittivity of vacuum ε_0 has the following value:

$$\varepsilon_0 = 8{,}854187817 \times 10^{-12} \tag{3}$$

Relative permittivity is the ratio of the absolute permittivity to the permittivity of a vacuum ε_0.

In the case of constant fields and alternating fields of sufficiently low frequency, the relative permittivity of an isotropic or quasi-isotropic dielectric is equal to the ratio of the capacitance of a capacitor, in which the space between and around the electrodes is entirely and exclusively filled with the dielectric, to the capacitance of the same configuration of electrodes in vacuum.

$$\varepsilon_r = \frac{C_x}{C_0} \tag{4}$$

The relative permittivity ε_r of dry air, at normal atmospheric pressure, equals 1,000 59, so that in practice, the capacitances C_a of the configuration of electrodes in air can normally be used instead of C_0 to determine the relative permittivity ε_r with sufficient accuracy.

Relative complex permittivity is permittivity in a complex number representation under steady sinusoidal field conditions expressed as

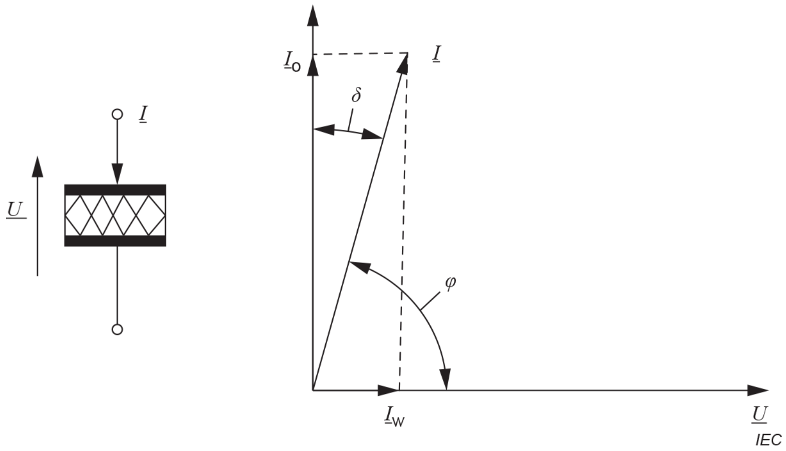
$$\underline{\varepsilon_r} = \varepsilon_r' - j\varepsilon_r'' = |\varepsilon_r| e^{-j\delta} \tag{5}$$

where ε_r' and ε_r'' have positive values.

NOTE 1 The complex permittivity $\underline{\varepsilon_r}$ is customarily quoted either in terms of ε_r' and ε_r'', or in terms of ε_r and tan δ.

NOTE 2 ε_r'' is termed loss index.

The dielectric dissipation factor tan δ (loss tangent) is the numerical value of the ratio of the imaginary to the real part of the complex permittivity.



Key

$\underline{U}$ applied voltage

$\underline{I}$ current

$\underline{I}_w$ real part of current

$\underline{I}_o$ imaginary part of current

φ phase difference between applied voltage and current

δ subtracted angle of φ from $\frac{\pi}{2}$

Figure 1 – Dielectric dissipation factor

$$\tan\delta = \frac{\varepsilon_r''}{\varepsilon_r'} \quad (6)$$

Thus, the dielectric dissipation factor tan δ of an insulating material is the tangent of the angle δ by which the phase difference φ between the applied voltage and the resulting current deviates from π/2 rad when the solid insulating material is exclusively used as dielectric in a capacitive test specimen (capacitor), compared with Figure 1. The dielectric dissipation factor can also be expressed by an equivalent circuit diagram using an ideal capacitor with a resistor in series or parallel connection (see Figure 2).

$$\tan\delta = \omega C_s \times R_s = \frac{1}{\omega C_p \times R_p} \quad (7)$$

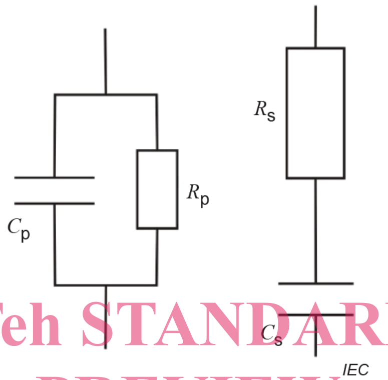
with

$$\frac{C_p}{C_s} = \frac{1}{1 + \tan^2\delta} \quad (8)$$

and

$$\frac{R_p}{R_s} = 1 + \frac{1}{\tan^2 \delta} \qquad (9)$$

NOTE 3 R_s and R_p respectively are not directly related to but affected by the volume and the surface resistance of an insulating material. Therefore, the dielectric dissipation factor can also be affected by these resistive materials properties.

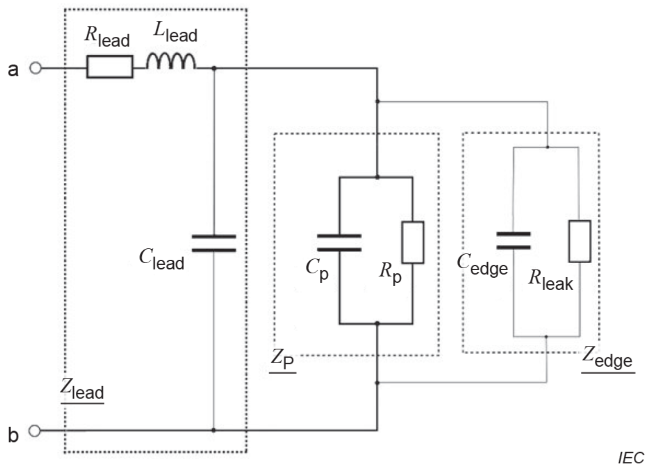


Key

C_p and R_p	capacitance and resistance for equivalent parallel circuit, respectively
C_s and R_s	capacitance and resistance for equivalent series circuit, respectively

Figure 2 – Equivalent circuit diagrams with capacitive test specimen

This general method describes common values for general measurements. If a method for a specific type of material is described in this document, the specific method shall be used.



Key

a and b	terminals
C_p R_p and $\underline{Z_P}$	capacitance, resistance and impedance for equivalent parallel circuit with sample P, respectively
R_{lead}, L_{lead}, C_{lead} and $\underline{Z_{lead}}$	$\underline{Z_{lead}}$ is the impedance due to the residual resistance R_{lead} and residual inductance L_{lead} existing with leads from the equipment to the test fixture. The stray capacitor, C_{lead} is the stray capacitor involved in $\underline{Z_{lead}}$
C_{edge}, R_{leak} and $\underline{Z_{edge}}$	$\underline{Z_{edge}}$ is the impedance due to the edge capacitance of the electrode and leakage resistance on sample and insulators of the electrode fixture

Figure 3 – Equivalent parallel circuit for test fixture with sample and leads to equipment

The measurement of permittivity and dielectric dissipation factor shall be made taking into consideration the electric properties of the measuring circuit as well as the specific electric properties of the material. To carry out the test, in most cases, the use of high voltage is necessary. Care should be taken to prevent any electric shock.

The basic principles of apparatus and methods are not described here. Some references to the literature are given in the bibliography of IEC 62631-2-1 [2][1].

4.2 Distinctive factors for the measurement in high frequency range

Figure 3 shows an equivalent parallel circuit comprising an electrode system with a sample and wiring leads from terminals a and b.

The impedance of C_p, $\frac{1}{j\omega C_p}$, decreases when the frequency is increased, which causes the increase in current through C_p in the high frequency range. When the frequency is increased from 100 kHz to 100 MHz, the current through C_p increases 1 000 times more than that at 100 kHz. This causes a decrease of accuracy in the obtained results.

[1] Numbers in square brackets refer to the bibliography.

The impedances due to the inductance of leads (L_{lead}), and the stray capacitance (C_{lead}) also depend on the frequency. That kind of impedance can be ignored in the measurements in the low frequency range. In the high frequency range, on the other hand, the effect of the impedance of $\underline{Z_{edge}}$ on the measured values cannot be ignored and causes errors in the measured results.

The impedance due to $\underline{Z_{edge}}$ is also a significant factor in the high frequency range. R_{leak} which is independent of the frequency could be negligible, because the leakage current on the sample surface is much smaller than the current through the edge capacitance in the high frequency range.

In the low frequency range, as described in IEC 62631-2-1, effective guarding and shielding should be applied to avoid measurement errors resulting from the stray capacitance and the residual impedance. In the frequency range higher than 100 kHz, however, the current through the guard and shielding are significant in comparison with the current through the specimen in the lower frequency range. Furthermore, care should be taken to prevent any electromagnetic interference (EMI) during measurements in the radio frequency range.

NOTE 1 Since the impedance of a capacitor is inversely proportional to frequency, at high frequencies it is essentially acting as a wire.

NOTE 2 The stray capacitance is the additional capacitance which exists in parallel with the capacitance of the test specimen. The stray capacitance also exists between the ground and a lead line connecting a terminal of an equipment to an electrode.

NOTE 3 The residual impedance is the impedance existing in series with the impedance of the test specimen. The residual impedance includes an impedance of the electrode produced on the surface of the specimen (e.g. by evaporation), and a lead line for the connection between a terminal of an instrument and an electrode.

4.3 Power supply

The power source shall provide a stable sinusoidal voltage. For the measuring duration the measured value of the supplied voltage shall be maintained within ±5 %.

The voltage wave shape shall approximate to a sinusoid with the difference between the magnitudes of the positive and negative peak values being less than 2 %.

The deviation from the sinusoidal shape (the ratio of peak to RMS values equals $\sqrt{2}$) shall be within ±5 %.

Preferred voltages are 0,1 V; 0,5 V; 10 V; 100 V; 500 V; 1 000 V; 2 000 V. Other voltage levels shall be documented in the report.

NOTE 1 Higher voltages can be applicable in order to perform tests at operating field strength.

NOTE 2 Partial discharge can lead to erroneous measurements when a specific inception voltage is exceeded. In air, below 340 V, no partial discharges will occur at atmospheric pressure.

4.4 Equipment

4.4.1 Accuracy

The measuring device should be capable of determining the unknown permittivity and dielectric dissipation factor in accordance with the expected material properties. The accuracy of the measuring system shall be documented in the report.

NOTE The user can choose the measuring system accuracy according to the requirements of the measuring results.