

INTERNATIONAL STANDARD

NORME INTERNATIONALE

**Fixed capacitors for use in electronic equipment –
Part 1: Generic specification**

**Condensateurs fixes utilisés dans les équipements électroniques –
Partie 1: Spécification générique**



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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

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FIXED CAPACITORS FOR USE IN ELECTRONIC EQUIPMENT –**Part 1: Generic specification****FOREWORD**

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IEC 60384-1 has been prepared by IEC technical committee 40: Capacitors and resistors for electronic equipment. It is an International Standard.

This sixth edition cancels and replaces the fifth edition published in 2016. This edition constitutes a technical revision.

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

- a) The document has been completely restructured to comply with the ISO/IEC Directives, Part 2; a new technical categorization of test methods has been introduced and the test methods have been reorganized according to these new categories; tables, figures and references have been revised accordingly.
- b) Annex X has been added for comparison with the previous edition.

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

FDIS	Report on voting
40/2848/FDIS	40/2859/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 60384 series, published under the general title *Fixed capacitors for use in electronic equipment*, 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- withdrawn,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

The specification system for fixed capacitors for use in electronic equipment is structured in a hierarchical system consisting of the following specification types. See Figure 1.

Generic specification

The generic specification covers all subjects mainly common to the family of fixed capacitors for use in electronic equipment, such as terminology, methods of measurement and tests. Where the individual subjects require the conditions or parameters for provisions specific to the particular subfamily or type of fixed capacitor, such are required to be given by one of the subordinate specifications.

For the scope of fixed capacitors, the numeric reference to the generic specification is IEC 60384-1.

Sectional specification

Sectional specifications cover all subjects additional to those given in the generic specification, which are specific to a defined subgroup of fixed capacitors. These subjects normally are preferred values for dimensions and characteristics, additional test methods and relevant provisions for test methods given in the generic specification, requirements for sampling and for the preparation of specimen, recommended test severities and preferred acceptance criteria. The sectional specification also outlines the structure and scope of the test schedules which are to be applied in all subordinate detail specifications.

For the scope of fixed capacitors, the numeric references to the sectional specifications reach from IEC 60384-2 for polyester film capacitors to currently IEC 60384-26 for aluminum electrolytic capacitors with conductive polymer solid electrolyte. The variety of sectional specifications may be adapted to the portfolio of different technologies of fixed capacitors.

Detail specification

Detail specifications give directly, or by referring to other specifications, all information necessary to completely describe a given type and range of fixed capacitors, including requirements of all values for dimensions and characteristics. They also give all information required for the quality assessment of the covered type and range of fixed capacitors within a suitable quality assessment system, including requirements for all applied test severities and acceptance criteria, and the completed test schedules.

Detail specifications can be either specifications within the IEC system, another specification system linked to IEC, or specified by the manufacturer or user.

For the scope of fixed capacitors, the numeric references to detail specifications are for example IEC 60384-3-101, if related to the sectional specification IEC 60384-3 and to the ancillary blank detail specification IEC 60384-3-1.

Blank detail specification

The hierarchical system of specifications is supplemented by one or more blank detail specifications to a sectional specification, which are used to ensure a uniform presentation of detail specifications.

The blank detail specifications provide the specification writer with a template on the layout to be adopted and on the information to be given and with guidance for the preparation of detail specifications in line with the requirements of the superior generic or sectional specifications.

Blank detail specifications are not considered as relevant specifications since they do not themselves describe any particular component.

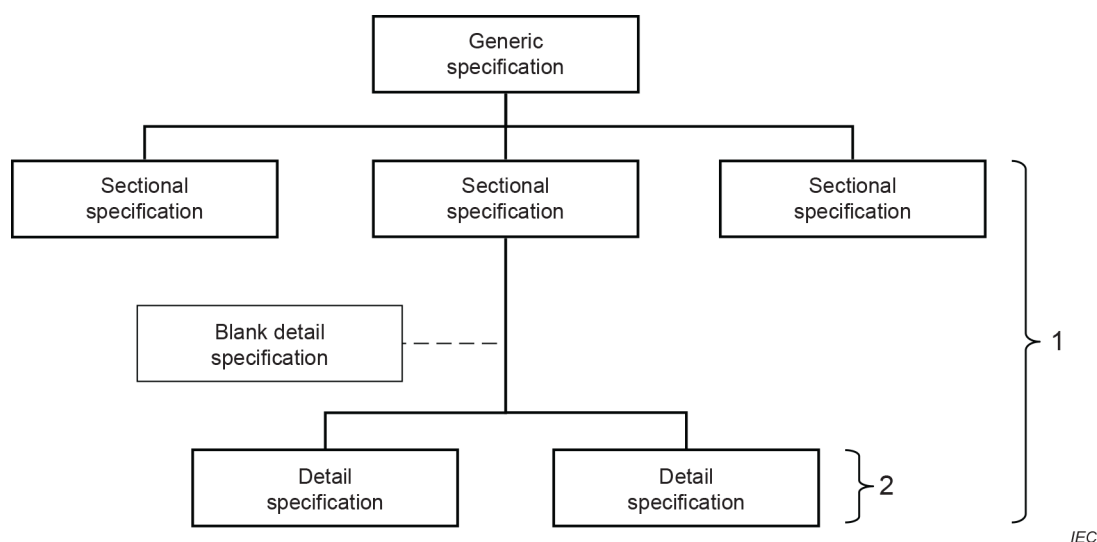
The presence of an established hierarchical specification system with blank detail specifications permits the preparation of detail specifications even outside of the relevant IEC technical committee.

For the scope of fixed capacitors, the numeric references to blank detail specifications are, for example, IEC 60384-3-1, if related to the sectional specification IEC 60384-3.

Relevant specification

In this system the term "relevant specification" addresses subordinate specifications containing specific requirements, where applicable.

Any generic or sectional specification may use abstract and universal references to subordinate specifications of either hierarchical level by use of the expression "relevant specification".



Key

- 1 Indicates the range of "*Relevant specifications*" to the superior generic specification, where applicable.
- 2 Indicates the range of "*Relevant specifications*" to the superior sectional specification, where applicable.

Figure 1 – Specification system for fixed capacitors

FIXED CAPACITORS FOR USE IN ELECTRONIC EQUIPMENT –

Part 1: Generic specification

1 Scope

This part of IEC 60384 is a generic specification and is applicable to fixed capacitors for use in electronic equipment.

It establishes standard terms, inspection procedures and methods of test for use in sectional and detail specifications of electronic components for quality assessment or any other purpose.

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 60062, *Marking codes for resistors and capacitors*

IEC 60063, *Preferred number series for resistors and capacitors*

IEC 60068-1:2013, *Environmental testing – Part 1: General and guidance*

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

IEC 60068-2-2:2007, *Environmental testing – Part 2-2: Tests – Tests B: Dry heat*

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

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

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

IEC 60068-2-17, *Basic environmental testing procedures – Part 2-17: Tests – Test Q: Sealing*

IEC 60068-2-20, *Environmental testing – Part 2-20: Tests – Test Ta and Tb: Test methods for solderability and resistance to soldering heat of devices with leads*

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

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

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

IEC 60068-2-45:1980, *Basic environmental testing procedures – Part 2-45: Tests – Test XA and guidance: Immersion in cleaning solvents*
IEC 60068-2-45:1980/AMD1:1993

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 60068-2-67, *Environmental testing – Part 2-67: Tests – Test Cy: Damp heat, steady state, accelerated test primarily intended for components*

IEC 60068-2-69, *Environmental testing – Part 2-69: Tests – Test Te/Tc: Solderability testing of electronic components and printed boards by the wetting balance (force measurement) method*

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

IEC 60068-2-82:2019, *Environmental testing – Part 2-82: Tests – Test Xw1: Whisker test methods for components and parts used in electronic assemblies*

IEC 60294, *Measurement of the dimensions of a cylindrical component with axial terminations*

IEC 60695-11-5, *Fire hazard testing – Part 11-5: Test flames – Needle-flame test method – Apparatus, confirmatory test arrangement and guidance*

IEC 60717, *Method for the determination of the space required by capacitors and resistors with unidirectional terminations*

IEC 61193-2, *Quality assessment systems – Part 2: Selection and use of sampling plans for inspection of electronic components and packages*

IEC 61249-2-7, *Materials for printed boards and other interconnecting structures – Part 2-7: Reinforced base materials clad and unclad – Epoxide woven E-glass laminated sheet of defined flammability (vertical burning test), copper-clad*

ISO 3, *Preferred numbers – Series of preferred numbers*

3 Terms and definitions

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

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

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

NOTE They have been listed in alphabetical order.

3.1

AC capacitor

capacitor designed essentially for application with alternating voltages

3.2**bipolar capacitor**

<electrolytic capacitor> capacitor designed to withstand an alternating voltage and/or reversal of the applied direct voltage

3.3**category of passive flammability**

category indicating the maximum burning time after a specified time of flame application

3.4**category temperature range**

ambient temperature range for which the capacitor has been designed to operate continuously

Note 1 to entry: The temperature range is limited by the lower and upper category temperature (see 3.10 and 3.41).

3.5**category voltage**

U_C

maximum voltage that can be applied continuously to a capacitor at its upper category temperature (3.41)

3.6**DC capacitor**

capacitor designed essentially for application with direct voltage

Note 1 to entry: It may not be suitable for use on AC supplies.

3.7**family**

<electronic components> group of components which predominantly displays a particular physical attribute and/or fulfils a defined function

3.8**grade**

additional general characteristic concerning the intended application of the component

3.9**insulated capacitor**

capacitor in which all terminations of a section may be raised to a potential different (but not less than the rated voltage) from that of any conducting surface with which the case is liable to come into contact in normal use

3.10**lower category temperature**

LCT

minimum ambient temperature for which a capacitor has been designed to operate continuously

Note 1 to entry: The lower category temperature in some tests is abbreviated as T_A .

3.11**maximum storage temperature**

maximum ambient temperature which the capacitor withstands in the non-operating condition without damage

3.12**maximum temperature**

<of a capacitor> temperature at the hottest point of its external surface

Note 1 to entry: The terminations are considered to be part of the external surface.

3.13

minimum storage temperature

minimum ambient temperature which the capacitor withstands in the non-operating condition without damage

3.14

minimum temperature

<of a capacitor> temperature at the coldest point of the external surface

Note 1 to entry: The terminations are considered to be part of the external surface.

3.15

nominal capacitance

C_N

designated capacitance value, usually indicated on the capacitor

3.16

passive flammability

ability of a capacitor to burn with a flame as a consequence of the application of an external source of heat

3.17

polar capacitor

<electrolytic capacitor> capacitor intended for use with a unidirectional voltage connected according to the polarity indication

3.18

pulse capacitor

capacitor for use with pulses of current or voltage

Note 1 to entry: The definitions of IEC 60469 apply.

3.19

pulse equivalent circuit

<of a capacitor> equivalent circuit consisting of an ideal capacitor in series with its residual inductance and the equivalent series resistance (ESR)

Note 1 to entry: For pulse operation the equivalent series resistance will be similar to, but not identical with, the ESR measured with a sinusoidal voltage. The pulse ESR depends on the series of harmonics in the pulse and the variation of the losses with frequency.

3.20

rated AC load

maximum sinusoidal AC load which may be applied continuously to the terminations of a capacitor at any temperature between the lower category temperature (3.10) and the rated temperature (3.24)

3.21

rated pulse load

maximum pulse load which may be applied at a certain pulse repetition frequency to the terminations of a capacitor at any temperature between the lower category temperature (3.10) and the rated temperature (3.24)

3.22

rated ripple current

RMS value of the maximum allowable alternating current of a specified frequency, at which the capacitor can be operated continuously at a specified temperature

Note 1 to entry: As the ripple current will generate a ripple voltage across the capacitor, the sum of the direct voltage and the peak value of the alternating voltage applied to the capacitor should not exceed the rated voltage or temperature derated voltage, as applicable.

3.23

rated ripple voltage

RMS value of the maximum allowable alternating voltage at a specified frequency superimposed on the DC voltage at which the capacitor may be operated continuously at a specified temperature

Note 1 to entry: The sum of the direct voltage and the peak value of the alternating voltage applied to the capacitor should not exceed the rated voltage or temperature derated voltage, as applicable.

3.24

rated temperature

maximum ambient temperature at which the rated voltage may be continuously applied

3.25

rated voltage

U_R

3.25.1

rated DC voltage

maximum DC voltage which may be applied continuously to a capacitor at the rated temperature (3.24)

Note 1 to entry: The maximum DC voltage is the sum of the DC voltage and peak AC voltage or peak pulse voltage applied to the capacitor.

3.25.2

rated AC voltage

maximum RMS alternating voltage which may be applied continuously to a capacitor at the rated temperature (3.24) and at a given frequency

3.25.3

rated pulse voltage

peak value of the pulse voltage within a given pulse wave form which may be applied continuously to a capacitor at the rated temperature (3.24)

3.26

reverse voltage

<polar capacitor> voltage applied to the capacitor terminations in the reverse polarity direction

Note 1 to entry: Reverse voltage applies to polar capacitors only.

3.27

self-healing

process by which the electrical properties of the capacitor, after a local breakdown of the dielectric, are rapidly and essentially restored to the values before the breakdown

3.28

style

subdivision of a type (3.39), generally based on dimensional factors, which may include several variants, generally of a mechanical order

3.29

subfamily

<electronic components> group of components within a family (3.7) manufactured by similar technological methods

3.30

surface mount capacitor

fixed capacitor whose small dimensions and nature or shape of terminations make it suitable for use in hybrid circuits and on printed boards

3.31

surge voltage ratio

quotient of the maximum instantaneous voltage which can be applied to the terminations of the capacitor for a specified time at any temperature within the category temperature range (3.4) and the rated voltage (3.25) or the temperature derated voltage (3.36), as appropriate

3.32

tangent of loss angle

$\tan \delta$

power loss of the capacitor divided by the reactive power of the capacitor at a sinusoidal voltage at a specified frequency

3.33

temperature characteristics of capacitance

maximum variation of capacitance produced over a given temperature range within the category temperature range (3.4)

Note 1 to entry: The term characterizing this property applies mainly to capacitors of which the variations of capacitance as a function of temperature, linear or non-linear, cannot be expressed with precision and certainty.

Note 2 to entry: This characteristic is normally expressed as a percentage of the capacitance related to a reference temperature of 20 °C.

3.34

temperature coefficient of capacitance

α

rate of change of capacitance with temperature measured over a specified range of temperature

Note 1 to entry: The term characterizing this property applies to capacitors of which the variations of capacitance as a function of temperature are linear or approximately linear and can be expressed with a certain precision.

Note 2 to entry: This coefficient is normally expressed in parts per million per Kelvin ($10^{-6}/K$).

3.35

temperature cyclic drift of capacitance

maximum irreversible variation of capacitance observed at room temperature during or after the completion of a number of specified temperature cycles

Note 1 to entry: The term characterizing this property applies to capacitors of which the variations of capacitance as a function of temperature are linear or approximately linear and can be expressed with a certain precision.

Note 2 to entry: This drift is normally expressed as a percentage of the capacitance related to a reference temperature, usually 20 °C.

3.36

temperature derated voltage

maximum voltage that may be applied continuously to a capacitor, when it is at any temperature between the rated temperature (3.24) and the upper category temperature (3.41)

Note 1 to entry: Refer to 4.2.6.

3.37

temperature rise

rise in the temperature of the capacitor relative to the ambient temperature resulting from the losses in the capacitor due to operation under AC, pulse or charge/discharge conditions

3.38
time constant τ

product of the insulation resistance and the capacitance

Note 1 to entry: The time constant is normally expressed in seconds.

3.39**type**

group of components having similar design features and manufacturing techniques, enabling them to be considered together, either for qualification approval or for quality conformance inspection

Note 1 to entry: These components are generally covered by a single detail specification.

Note 2 to entry: Components described in several detail specifications, may, in some cases, be considered as belonging to the same type.

3.40**uninsulated capacitor**

capacitor in which one or more of the terminations of a section cannot be raised to a potential different (but not less than the rated voltage) from that of any conducting surface with which the case is liable to come into contact in normal use

3.41**upper category temperature****UCT**

maximum ambient temperature for which a capacitor has been designed to operate continuously

Note 1 to entry: The upper category temperature in some tests is abbreviated as T_B .

3.42**visible damage**

defect detected during visual inspection, which reduces the usability of the capacitor for its intended purpose

4 General requirements**4.1 Symbols, units and abbreviated terms****4.1.1 General**

Units, graphical symbols and letter symbols should, whenever possible, be taken from the following publications:

- IEC 60027 (all parts);
- IEC 60050 (all parts);
- IEC 60617;
- ISO 80000-1.

When further items are required, they should be derived in accordance with the principles of the publications listed above.

4.1.2 Letter symbols

For the purposes of this document and the subordinate specifications, the following letter symbols apply.

C_N	nominal capacitance
DA	dielectric absorption
du/dt	voltage slope of a pulse
f_r	self-resonant frequency
I_{leak}	leakage current
k_0	maximum permissible pulse characteristics
L	self-inductance
R_{INS}	insulation resistance
T_A	lower category temperature
$\tan \delta$	tangent of loss angle
T_B	upper category temperature
T_C	category temperature
T_{op}	operating temperature
T_R	rated temperature
U_C	category voltage
U_{op}	operating voltage
U_R	rated voltage
U_{RS}	surge voltage
Z	impedance
α	temperature coefficient of capacitance
τ	time constant ($= C_N \times R_{INS}$)

4.1.3 Abbreviated terms

For the purposes of this document and the subordinate specifications, the following abbreviated terms apply.

CA	capability approval
CB	certification body
CM	capability manual
CQC	capability qualifying component
CTR	certified test record
DMR	designated management representative
ESR	equivalent series resistance
FET	field effect transistor
IPA	isopropyl alcohol
LCT	lower category temperature
PCP	process control plan
QA	qualification approval
SMD	surface mount device

SPC	statistical process control
TA	technology approval
TADD	technology approval declaration document
TAS	technology approval schedule
UCT	upper category temperature

4.2 Preferred values and additional technical requirements

4.2.1 General

Each sectional specification shall specify the preferred values appropriate to the subfamily; for nominal capacitance, see also 4.2.2.

4.2.2 Preferred values of nominal capacitance

The preferred values of nominal capacitance shall be taken from the series specified in IEC 60063.

4.2.3 Preferred values of rated voltage

The preferred values of the rated voltage shall be taken from the R10 series of ISO 3, and are 1,0 – 1,25 – 1,6 – 2,0 – 2,5 – 3,15 – 4,0 – 5,0 – 6,3 – 8,0 and their decimal multiples ($\times 10^n$, n : integer).

4.2.4 Rated AC load

The rated AC load may be expressed:

- a) at low frequencies as a rated AC voltage;
- b) at high frequencies as a rated AC current;
- c) at intermediate frequencies as a rated reactive power (var).

The reactive power against frequency is shown in Figure 2.

For a particular type of capacitor, it may be necessary to specify one or more of the above characteristics.

Capacitors within the scope of this document are normally less than 500 var at 50 Hz to 60 Hz. Low frequencies may be 50 Hz to 60 Hz, 100 Hz to 120 Hz, or 400 Hz. RMS voltages may be up to 600 V at 50 Hz to 60 Hz. However, capacitors for filters, transmitter or converter circuits may be required to operate under power over a wide range of frequencies and up to 10 kvar at the higher frequencies with RMS voltages up to 1 000 V.

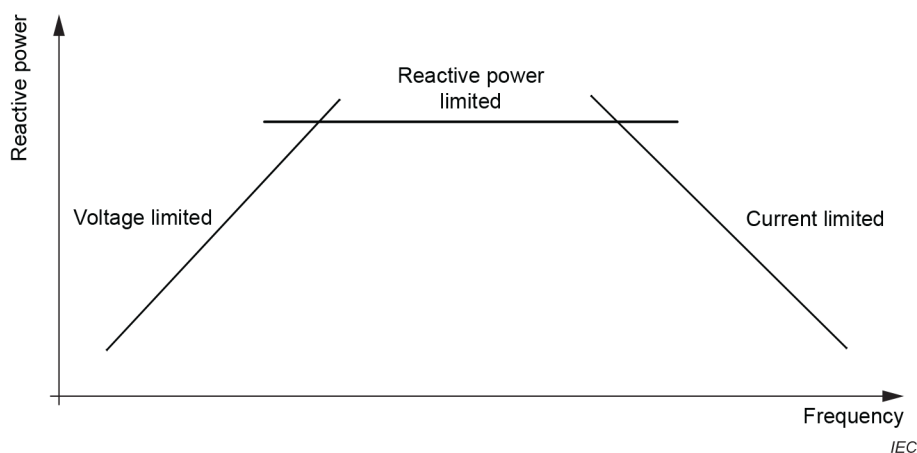


Figure 2 – Reactive power against frequency

4.2.5 Rated pulse load

The rated pulse load may be expressed as a) and b) and any of the remaining items:

- a) peak current per μF or du/dt ($\text{V}/\mu\text{s}$);
- b) relative duration of charge and discharge periods;
- c) current;
- d) peak voltage;
- e) peak reverse voltage;
- f) pulse repetition frequency;
- g) maximum active power.

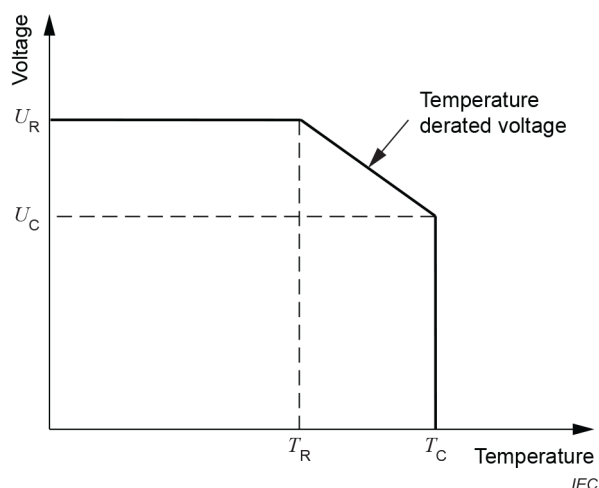
These parameters are fixed for periodic pulses.

In the case of intermittent pulses, the duty cycle should be specified. In the case of random pulses, the total number expected over a given time period should be stated.

The RMS pulse current should be calculated in accordance with IEC 60469:2013, 3.2.17.5. In the case of intermittent or random pulses, the time interval should be chosen to correspond to the maximum temperature rise.

4.2.6 Temperature derated voltage

Information on the relation between applied voltage and temperature at temperatures between the rated temperature and the upper category temperature should, if applicable, be given in the relevant specification (see Figure 3).

**Key**

U_R is the rated voltage

U_C is the category voltage

T_R is the rated temperature

T_C is the category temperature

Figure 3 – Relation between category temperature range and applied voltage

4.3 Marking

4.3.1 General

The sectional specification shall indicate the identification criteria and other information to be shown on the capacitor and/or packaging.

The order of priority for marking small capacitors shall be specified.

4.3.2 Coding

When coding is used for capacitance value, tolerance or date of manufacture, the method shall be selected from those given in IEC 60062.

5 General provisions for tests and measurement procedures

5.1 General

The sectional and/or blank detail specification shall indicate the tests to be made, which measurements are to be made before and after each test or subgroup of tests, and the sequence in which they shall be made. The stages of each test shall be carried out in the order written. The measuring conditions shall be the same for initial and final measurements.

If national specifications within any quality assessment system include methods other than those specified in the above specifications, they shall be fully described.

Limits given in all specifications are absolute limits. The principle to take measurement uncertainty into account shall be applied.

5.2 Standard atmospheric conditions

5.2.1 Standard atmospheric conditions for testing

Unless otherwise specified, all tests and measurements shall be carried out under standard atmospheric conditions for testing as given in IEC 60068-1:2013, 4.3:

- temperature: 15 °C to 35 °C;
- relative humidity: 25 % to 75 %;
- air pressure: 86 kPa to 106 kPa.

Before the measurements are made, the capacitor shall be stored at the measuring temperature for a time sufficient to allow the entire capacitor to reach this temperature. The period as specified for recovery at the end of a test is normally sufficient for this purpose.

When measurements are made at a temperature other than the specified temperature, the results shall, where necessary, be corrected to the specified temperature. The ambient temperature during the measurements shall be stated in the test report. In the event of a dispute, the measurements shall be repeated using one of the referee temperatures (as given in 5.2.3) and such other conditions as are specified in this document.

When tests are conducted in a sequence, the final measurements of one test may be taken as the initial measurements for the succeeding test.

During measurements, the capacitor shall not be exposed to draughts, direct sunlight or other influences likely to cause error.

5.2.2 Recovery conditions

Unless otherwise specified recovery shall take place under the standard atmospheric conditions for testing (5.2.1).

If recovery under closely controlled conditions is necessary, the controlled recovery conditions of IEC 60068-1:2013, 4.4.2, shall be used.

Unless otherwise specified in the relevant specification, a duration of 1 h to 2 h shall be used.

The definition of recovery is as given in IEC 60068-1:2013, 3.4, being further restricted for capacitors as follows:

When a recovery period is specified as, for example, 1 h to 2 h, this means that measurement (or other subsequent action) on a batch of capacitors may start after 1 h and shall be completed before 2 h from the beginning of the recovery period.

The preferred method of specifying a recovery period is in the form "x h to y h".

5.2.3 Referee conditions

For referee purposes, one of the standard atmospheric conditions for referee tests taken from IEC 60068-1:2013, 4.2, as given in Table 1, shall be selected.

Table 1 – Referee conditions

Temperature °C	Relative humidity %	Air pressure kPa
20 ± 1	63 to 67	86 to 106
23 ± 1	48 to 52	86 to 106
25 ± 1	48 to 52	86 to 106
27 ± 1	63 to 67	86 to 106

5.2.4 Reference conditions

For reference purposes, the standard atmospheric conditions for reference given in IEC 60068-1:2013, 4.1, apply:

- temperature: 20 °C;
- air pressure: 101,3 kPa.

5.3 Drying

Unless otherwise specified in the relevant specification, the capacitor shall be conditioned for 96 h ± 4 h by heating in a circulating air oven at a temperature of 55 °C ± 2 °C and a relative humidity not exceeding 20 %.

The capacitor shall then be allowed to cool in a desiccator using a suitable desiccant, such as activated alumina or silica gel, and shall be kept therein from the time of removal from the oven to the beginning of the specified tests.

5.4 Storage

5.4.1 Storage at high temperature

5.4.1.1 Initial measurement

The measurements specified in the relevant specification shall be made.

5.4.1.2 Test procedure

The capacitors shall be subjected to IEC 60068-2-2, Test Bb, using the following severities:

- temperature: upper category temperature;
- duration: 96 h ± 4 h.

The test specimens may be introduced into the test chamber at any temperature from laboratory temperature to the upper category temperature.

5.4.1.3 Final inspection, measurements and requirements

After recovery for at least 16 h, the measurements specified in the relevant specification shall be made.

5.4.2 Storage at low temperature

5.4.2.1 Initial measurement

The measurements specified in the relevant specification shall be made.

5.4.2.2 Test procedure

The capacitors shall be subjected to IEC 60068-2-1, Test Ab. The capacitors shall be stored at $-40\text{ }^{\circ}\text{C}$ for either a period of 4 h after thermal stability has been reached, or for 16 h, whichever is the shorter period.

The test specimens may be introduced into the test chamber at any temperature from laboratory temperature to $-40\text{ }^{\circ}\text{C}$.

5.4.2.3 Final inspection, measurements and requirements

After recovery for at least 16 h, the measurements specified in the relevant specification shall be made.

5.5 Mounting (for surface mount capacitors only)

5.5.1 Substrate

Surface mount capacitors shall be mounted on a suitable substrate, the method of mounting being dependent on the capacitor construction. The substrate material shall normally be an epoxide woven glass fabric laminated printed board (as defined in IEC 61249-2-7) with a thickness of $1,6\text{ mm} \pm 0,20\text{ mm}$ or $0,8\text{ mm} \pm 0,10\text{ mm}$, or a 90 % to 98 % alumina substrate having a thickness of $0,635\text{ mm} \pm 0,05\text{ mm}$ or more, and shall not affect the result of any test or measurement. The detail specification shall indicate which material shall be used for the electrical measurements.

The substrate shall have metallized land areas of proper spacing to permit mounting of surface mount capacitors and shall provide electrical connection to the surface mount capacitor terminals. The details shall be specified in the detail specification.

Examples of test substrates for mechanical and electrical tests are shown in Figure 4 and Figure 5, respectively.

If another method of mounting applies, the method should be clearly described in the detail specification.

5.5.2 Wave soldering

When the detail specification specifies wave soldering, a suitable glue, details of which may be specified in the detail specification, shall be used to fasten the component to the substrate before soldering is performed.

Small dots of the glue shall be applied between the conductors of the substrate by means of a suitable device securing repeatable results.

The surface mount capacitors shall be placed on the dots using tweezers. To ensure that no glue is applied to the conductors, the surface mount capacitors shall not be moved about.

The substrate with the surface mount capacitors shall be heat-treated in an oven at $100\text{ }^{\circ}\text{C}$ for 15 min.

The substrate shall be soldered in a wave soldering apparatus. The apparatus shall be adjusted to have a pre-heating temperature of $80\text{ }^{\circ}\text{C}$ to $100\text{ }^{\circ}\text{C}$, a solder bath at $260\text{ }^{\circ}\text{C} \pm 5\text{ }^{\circ}\text{C}$ and a soldering time of $5\text{ s} \pm 0,5\text{ s}$.

The substrate shall be cleaned for 3 min in a suitable solvent (see IEC 60068-2-45:1980/AMD1:1993, 3.1.2).

5.5.3 Reflow soldering

When the detail specification specifies reflow soldering, the following mounting procedure applies.

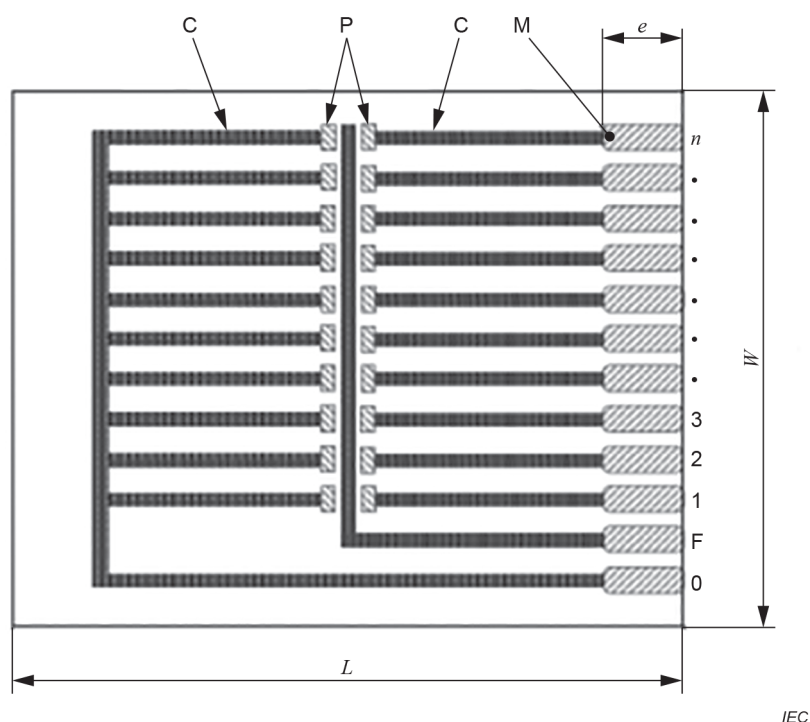
- a) The solder used in preform or paste form shall be silver bearing (2 % minimum) eutectic Sn/Pb solder together with a flux as stated in IEC 60068-2-20. Alternative solders such as 60/40 or 63/37 may be used on the surface mount capacitors whose construction includes solder leach barriers. Pb-free solder used in preform or paste form shall be Sn96,5Ag3,0Cu0,5 or derivative solder together with a flux as stated in IEC 60068-2-58, or as defined in the relevant specification.
- b) The surface mount capacitor shall then be placed across the metallized land areas of the test substrate so as to make contact between the surface mount and substrate land areas.
- c) The substrate shall then be placed in or on a suitable heating system (molten solder, hot plate, tunnel oven, etc.). The temperature of the unit shall be maintained between 215 °C and 260 °C, until the solder melts and reflows forming a homogeneous solder bond, but for not longer than 10 s.

The flux should be removed by a suitable solvent (see IEC 60068-2-45:1980/AMD1:1993, 3.1.2). All subsequent handling should be such as to avoid contamination. Ensure that cleanliness in test chambers and during post test measurements is maintained.

The detail specification may require a more restricted temperature range.

If vapour phase soldering is applied, the same method may be used with the temperatures adapted.

A suitable substrate for mechanical tests is shown in Figure 4. Note that this substrate may not be suitable for impedance measurements. A suitable substrate for electrical tests is shown in Figure 5.



Key

C conductor tracks, typically covered with solder resist

P solder pads, dimensions as specified by the relevant specification

M mating area for a card edge connector, or for attachment of individual test wires

F optional conductor track

L length of the substrate, $L \geq 100$ mm

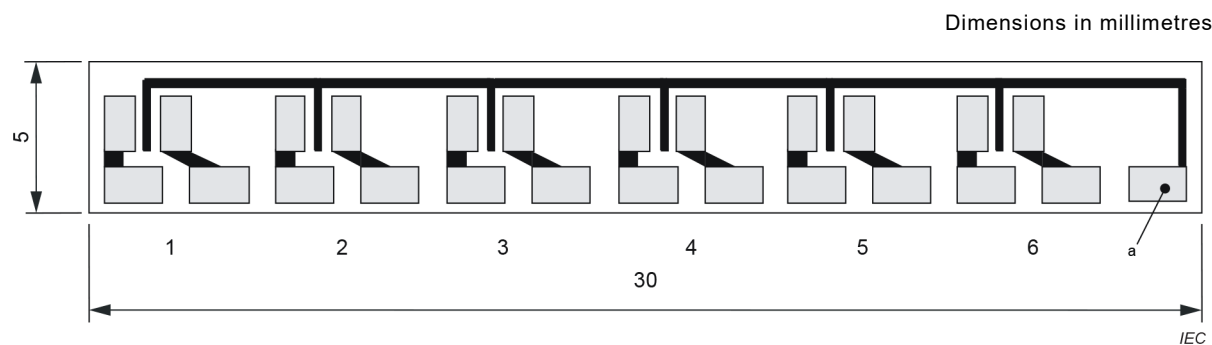
W width of the substrate, depending on the design of the test equipment and on the intended number n of specimens to be tested in parallel

e length of the connector pads, e.g. 15 mm

n specimen number

The relevant specification shall specify a minimum spacing of the specimens, which shall be applied if $n > 1$

Figure 4 – Suitable substrate for mechanical tests

**Key**

- Solderable areas
- Non-solderable areas (covered with non-solderable lacquer)

All dimensions are in millimetres. Tolerances: medium.

Material: 90 % to 98 % alumina substrate

Thickness: 0,635 mm ± 0,05 mm, or more

Dimensions not given should be chosen according to the design and size of the specimens to be tested.

^a This conductor may be omitted or used as a guard electrode.

Figure 5 – Suitable substrate for electrical tests

6 Electrical tests and measurements

6.1 Insulation resistance

6.1.1 Preconditioning

Before this measurement is made, the capacitors shall be fully discharged.

6.1.2 Measuring conditions

Unless otherwise specified in the relevant specification, the insulation resistance shall be measured at the voltage specified in Table 2.

The insulation resistance shall be measured after the voltage has been applied for 60 s ± 5 s, unless otherwise specified in the detail specification.

Table 2 – Measuring voltage of insulation resistance

Voltage rating of capacitor V	Measuring voltage V
U_R or $U_C < 10$	U_R or $U_C \pm 10\%$
$10 \leq U_R$ or $U_C < 100$	10 ± 1^a
$100 \leq U_R$ or $U_C < 500$	100 ± 15
$500 \leq U_R$ or U_C	500 ± 50
^a When it can be demonstrated that the voltage has no influence on the measuring result, or that a known relationship exists, measurements can be performed at voltages up to the rated or category voltage. In case of dispute, 10 V shall be used, unless otherwise specified in the sectional specification.	

U_R is the rated voltage used for defining the measuring voltage to be used under standard atmospheric conditions for testing.

U_C is the category voltage used for defining the measuring voltage to be used at the upper category temperature.

6.1.3 Test points

The insulation resistance shall be measured between the measuring points defined in Table 3, specified in the relevant specification.

Test A, between terminations, applies to all capacitors, whether insulated or not.

Test B, internal insulation, applies to insulated capacitors in uninsulated metal cases and to insulated and uninsulated multiple section capacitors.

Test C, external insulation, applies to insulated capacitors in non-metallic cases or in insulated metal cases. For this test, the measuring voltage shall be applied using one of the three following methods as specified in the relevant specification:

6.1.4 Test methods

6.1.4.1 Foil method

A metal foil shall be closely wrapped around the body of the capacitor.

For capacitors with axial terminations, this foil shall extend beyond each end by not less than 5 mm, provided that a minimum distance of 1 mm can be maintained between the foil and the terminations. If this minimum distance cannot be maintained, the extension of the foil shall be reduced by as much as is necessary to establish the distance of 1 mm.

For capacitors with unidirectional terminations, a minimum distance of 1 mm shall be maintained between the edge of the foil and each termination.

6.1.4.2 Method for capacitors with mounting devices

The capacitor shall be mounted in its normal manner on a metal plate, which extends at least 12,7 mm in all directions beyond the mounting face of the capacitor.

6.1.4.3 V-block method

The capacitor shall be clamped in the trough of a 90° metallic V-block of such size that the capacitor body does not extend beyond the extremities of the block.

The clamping force shall be such as to guarantee adequate contact between the capacitor and the block.

The capacitor shall be positioned in accordance with the following:

- a) for cylindrical capacitors: the capacitor shall be positioned in the block so that the termination furthest from the axis of the capacitor is nearest to one of the faces of the block;
- b) for rectangular capacitors: the capacitor shall be positioned in the block so that the termination nearest the edge of the capacitor is nearest to one of the faces of the block.

For cylindrical and rectangular capacitors having axial terminations any out-of-centre positioning of the terminations at their emergence from the capacitor body shall be ignored.

6.1.5 Temperature compensation

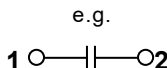
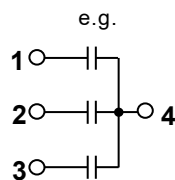
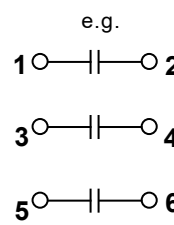
When specified in the detail specification, the temperature at which the measurement is made shall be noted. If this temperature differs from 20 °C, a correction shall be made to the measured value by multiplying the value by the appropriate correction factor specified in the sectional specification.

6.1.6 Conditions to be specified in the relevant specification

The relevant specification shall specify:

- a) the measuring points and the measuring voltage corresponding to each of these test points;
- b) the method of applying the voltage (one of the methods described in 6.1.4);
- c) time of electrification if other than 1 min;
- d) any special precautions to be taken during measurements;
- e) any correction factors required for measurement over the range of temperatures covered by the standard atmospheric conditions for testing;
- f) the temperature of measurement if other than the standard atmospheric conditions for testing;
- g) the minimum value of insulation resistance for the various measuring points (see Table 3).

Table 3 – Measuring points

Test	Applicable to:	1: Single-section capacitors e.g. 	2: Multiple-section capacitors having common termination for all sections e.g. 	3: Multiple-section capacitors having no common termination e.g. 
A. Between terminations ^a	All capacitors	1a: Between terminations (1–2)	2a: Between each of the terminations and the common termination (1-4, 2-4, 3-4)	3a: Between terminations of each section (1-2, 3-4, 5-6)
B. Internal insulation	Insulated single- and multiple-section capacitors in uninsulated metal cases (1b, 2b, 3b)	1b: Between terminations connected together and the case [(1 to 2)- case]	2b: Between all terminations connected together and the case [(1 to 4)- case]	3b: Between all terminations connected together and the case [(1 to 6)- case]
	Insulated and uninsulated multiple-section capacitors (2c and 3c)		2c: Between the non-common termination of each section and all the other terminations connected together e.g. [2-(1, 3, 4)]	3c: Between the terminations of separate sections, the two terminations of each section being connected together e.g. [(1 to 2)-(3 to 6)]
C. External insulation	Insulated capacitors in non-metallic cases or in insulated metal cases	1c: Between the two terminations connected together and, as appropriate, the metal foil, the metal plate or the metal V-block [(1 to 2)-metal jig]	2d: [(1 to 4)-metal jig]	3d: [(1 to 6)-metal jig]
			Between all terminations connected together and, as appropriate: the metal foil, the metal plate or the metal V-block	
^a Where a capacitor has more than two terminations, the measuring points are the two terminations which are insulated from one another by the capacitor's element dielectric. For example, for a coaxial lead-through capacitor, the measuring points should be one of the terminations connected to the central conductor and the coaxial metal case or mounting face.				

6.2 Voltage proof

6.2.1 General

The test specified in 6.2.3 is a DC test. When an AC test is applied, the test circuit shall be specified in the relevant specification.

6.2.2 Test circuit (for the test between terminations)

The test circuit elements shall be selected in such a way as to ensure that the conditions relating to the charging and discharging currents and the time constant for charging, specified in the relevant specification, are maintained.

Figure 6 specifies the characteristics of a suitable test circuit.

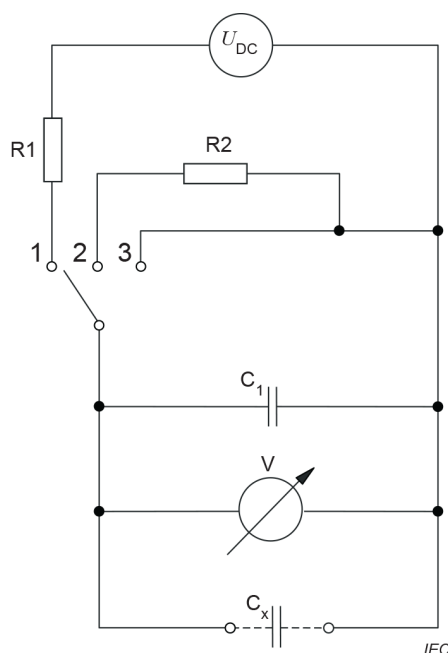
The resistance of the voltmeter shall be not less than 10 000 Ω/V .

The resistor R_1 includes the internal resistance of the voltage source.

The resistors R_1 and R_2 shall have a value sufficient to limit the charging and discharging current to the value specified in the relevant specification.

The capacitance of capacitor C_1 shall be not less than 10 times the capacitance of the capacitor under test.

If applicable, the time constant $R_1 \times (C_X + C_1)$ shall be less than, or equal to, the value specified in the relevant specification.



Key

1, 2 and 3	switching terminations
C_x	Test specimen
C_1	capacitance of C_1 to be not less than 10 times the capacitance of test specimen
U_{DC}	test voltage
R_1 and R_2	resistors
A	ammeter
V	voltmeter

Figure 6 – Voltage-proof test circuit

The capacitor C_1 may be omitted for the testing of certain types of capacitors. This should be stated in the sectional specification.

6.2.3 Test

6.2.3.1 General

Depending on the case, the test comprises one or more parts in accordance with Table 3 and the requirements of the relevant specification.

Repeated application of the voltage proof test may cause permanent damage to the capacitor and should be avoided as far as possible.

6.2.3.2 Test A – Between terminations

6.2.3.2.1 Test points

The test voltage is applied to 1a, 2a, 3a of Table 3 in accordance with the requirements of the relevant specification.

6.2.3.2.2 Procedure

With the switch in position 2, connect the two terminals in Figure 6 to a variable DC supply of sufficient power adjusted to the required test voltage.

Connect the capacitor to be tested (C_X) to the test circuit as indicated in Figure 6.

Move the switch to position 1 so as to charge capacitors C_1 and C_X via R_1 .

The switch remains in this position for the time specified after the test voltage has been reached.

Discharge the capacitors C_1 and C_X through R_2 by moving the switch to position 2. As soon as the voltmeter reading has fallen to zero, short-circuit the capacitors by moving the switch to position 3 and disconnect the capacitor C_X .

6.2.3.3 Test B – Internal insulation

6.2.3.3.1 Test points

The test voltage is applied to 1b, 2b, 2c, 3b, 3c of Table 3 in accordance with the requirements of the relevant specification.

6.2.3.3.2 Procedure

The specified test voltage is applied instantaneously via the internal resistance of the power supply for the time specified in the relevant specification. For point 2c use the test circuit and the procedure indicated for the test between terminations (6.2.2 and 6.2.3.2).

6.2.3.4 Test C – External insulation (applicable only to insulated capacitors in a non-metallic case or in an insulated metal case)

6.2.3.4.1 Test points

The test voltage is applied to 1c, 2d or 3d of Table 3, using one of the three following methods for the application of the voltage, in accordance with the requirements of the relevant specification.

6.2.3.4.2 Foil method

A metal foil shall be closely wrapped around the body of the capacitor.

For capacitors with axial terminations this foil shall extend beyond each end by not less than 5 mm, provided that a minimum distance of 1 mm/kV can be maintained between the foil and the terminations. If this minimum cannot be maintained, the extension of the foil shall be reduced by as much as is necessary to establish the distance of 1 mm/kV of test voltage.

For capacitors with unidirectional terminations, a minimum distance of 1 mm/kV shall be maintained between the edge of the foil and each termination.

In no case shall the distance between the foil and the terminations be less than 1 mm.

6.2.3.4.3 Method for capacitors with mounting devices

The capacitor shall be mounted in its normal manner on a metal plate which extends by not less than 12,7 mm in all directions beyond the mounting face of the capacitor.

6.2.3.4.4 V-block method

The capacitor shall be clamped in the trough of a 90° metallic V-block of such a size that the capacitor body does not extend beyond the extremities of the block.

The clamping force shall be such as to guarantee adequate contact between the capacitor and the block.

The capacitor shall be positioned as follows:

- a) for cylindrical capacitors: the capacitor shall be positioned in the block so that the termination furthest from the axis of the capacitor is nearest to one of the faces of the block;
- b) for rectangular capacitors: the capacitor shall be positioned in the block so that the termination nearest the edge of the capacitor is nearest to one of the faces of the block.

For cylindrical and rectangular capacitors having axial terminations any out-of-centre positioning of the termination at its emergence from the capacitor body shall be ignored.

6.2.3.4.5 Procedure

The specified test voltage is applied instantaneously through the internal resistance of the power source for the time specified in the relevant specification.

6.2.4 Requirements

For each of the specified test points there shall be no sign of breakdown or flashover during the test period.

6.2.5 Conditions to be specified in the relevant specification

The relevant specification shall specify:

- a) the test points (see Table 3) and the test voltage corresponding to each of these points;
- b) for the external insulation test (test C), the method of applying the test voltage (one of the methods described in 6.2.3.4);
- c) the time for which the voltage is applied;
- d) the maximum charging and discharging currents;
- e) when applicable, the maximum value of the time constant for charging ($R_1 \times (C_1 + C_X)$).

6.3 Capacitance

6.3.1 Measuring frequency and measuring voltage

The capacitance shall be measured at one of the following frequencies, unless otherwise specified in the relevant specification:

- electrolytic capacitors: 100 Hz or 120 Hz;
- other capacitors: $C_N \leq 1 \text{ nF}$: 100 kHz, 1 MHz or 10 MHz
(1 MHz shall be the reference);
 $1 \text{ nF} < C_N \leq 10 \text{ }\mu\text{F}$: 1 kHz or 10 kHz
(1 kHz shall be the reference);
 $C_N > 10 \text{ }\mu\text{F}$: 50 Hz (60 Hz) or 100 Hz (120 Hz).

The tolerance on all frequencies for measuring purposes shall not exceed $\pm 20 \%$.

The measuring voltage shall not exceed 3 % of U_R or 5 V, whichever is the smaller, unless otherwise specified in the relevant specification.

6.3.2 Measuring equipment

The accuracy of the measuring equipment shall be such that the error does not exceed:

- a) for absolute capacitance measurements: 10 % of the capacitance tolerance or 2 % absolute, whichever is the smaller;
- b) for measurement of variation of capacitance: 10 % of the specified maximum change of capacitance.

In neither case a) nor case b) need the accuracy be better than the minimum absolute measurement error (for example 0,5 pF) specified in the relevant specification.

6.3.3 Conditions to be specified in the relevant specification

The relevant specification shall specify:

- a) the measurement temperature if other than the standard atmospheric conditions for testing;
- b) the frequencies for measurement and the capacitance range over which they apply, if different from those specified in 6.3.1;
- c) the absolute measurement error, when applicable (for example 0,5 pF);
- d) the measuring voltage if different from the one specified in 6.3.1;
- e) the applied polarizing voltage, when applicable.

6.4 Tangent of loss angle and equivalent series resistance (ESR)

6.4.1 Tangent of loss angle

6.4.1.1 Measuring frequency

The tangent of loss angle shall be measured under the same conditions as those given for the measurement of capacitance at one or more frequencies taken from the list in 6.3.1, as specified in the relevant specification.

6.4.1.2 Measuring accuracy

Unless otherwise specified in the sectional specification, the measuring method shall be such that the error does not exceed 10 % of the specified value or 0,000 3, whichever is the greater.

6.4.2 Equivalent series resistance (ESR)

6.4.2.1 Measuring frequency

The ESR shall be measured at one of the following frequencies, unless otherwise specified in the relevant specification:

50 Hz, 60 Hz, 100 Hz, 120 Hz, 1 kHz, 10 kHz, 100 kHz, 1 MHz and 10 MHz.

6.4.2.2 Measuring accuracy

The accuracy of the measuring equipment shall be such that the error does not exceed 10 % of the requirement, unless otherwise specified in the relevant specification.

6.4.2.3 Conditions to be specified in the relevant specification

The relevant specification shall specify

- a) the frequency of measurement;
- b) the absolute error measurement;
- c) the measuring voltage, if different from that specified in 6.3.1;
- d) the applied polarizing voltage, where applicable;
- e) the temperature at which measurements shall be made, if other than the standard atmospheric conditions for testing.

6.5 Leakage current

6.5.1 Preconditioning

Before this measurement is made, the capacitors shall be fully discharged.

6.5.2 Test method

The leakage current shall be measured, unless otherwise specified in the relevant specification, using the direct voltage (U_R or U_C) appropriate to the test temperature, after a maximum electrification period of 5 min. The full 5 min electrification need not be applied if the specified leakage current limit is reached in a shorter time.

6.5.3 Power source

For the object of test, a steady source of power such as a regulated power supply shall be used.

6.5.4 Measuring accuracy

The measurement error shall not exceed ± 5 % or 0,1 μA , whichever is the greater.

6.5.5 Test circuit

When not specified in the relevant specification, the protective resistor shall be 1 000 Ω with a tolerance of ± 10 %.

6.5.6 Conditions to be specified in the relevant specification

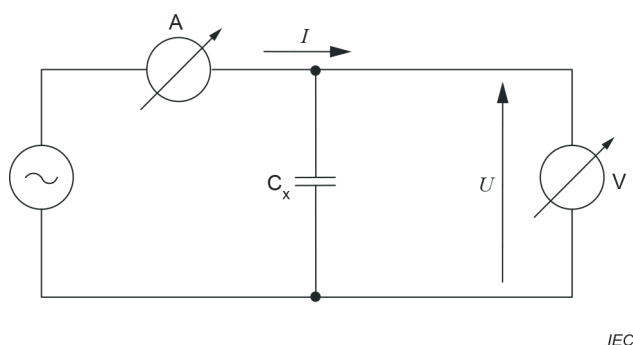
The relevant specification shall specify:

- a) the leakage current limit at a reference temperature of 20 °C, and at other specified temperatures;

- b) when necessary, the correction factor, if the measurements are made at a temperature other than 20 °C, but within the range of temperatures covered by the standard atmospheric conditions for testing;
- c) the electrification time, if different from 5 min;
- d) whether or not a protective resistor shall be placed in series with the capacitor to limit the charging current as defined in 6.5.5, and its nominal values, if it is other than 1 000 Ω.

6.6 Impedance

Impedance shall be measured by the voltmeter-ammeter method according to the circuit of Figure 7, or equivalent.



Key

- C_x test specimen
- U measuring voltage
- I measuring current
- A ammeter
- V voltmeter

Figure 7 – Schematic diagram of the impedance measuring circuit

The impedance Z_X of the capacitor C_X is given by $Z_X = \frac{U}{I}$.

The frequency of the measuring voltage should, preferably, be chosen from the following values:

50 Hz, 60 Hz, 100 Hz, 120 Hz, 1 kHz, 10 kHz, 100 kHz, 1 MHz and 10 MHz.

The accuracy of the measuring equipment shall be such that the error does not exceed 10 % of the requirement, unless otherwise specified in the relevant specification.

At frequencies above 120 Hz, precautions are necessary to avoid errors arising from stray currents. The current flowing through the capacitor should be limited so that the measuring result is not significantly affected by the rise of the temperature of the capacitor.

The relevant specification shall specify:

- a) the frequency of measurement;
- b) the temperature(s) at which measurements shall be made;
- c) the limits of impedance, or ratio of impedances measured at different temperatures.

6.7 Self-resonant frequency and inductance

6.7.1 Self-resonant frequency (f_r)

6.7.1.1 General

For this measurement three methods are described. The first method is for general application; the other methods may be particularly suitable for measuring certain types of capacitors having low capacitance.

The accuracy of the measuring equipment shall be such that the error does not exceed 10 % of the requirement, unless otherwise specified in the relevant specification.

6.7.1.2 Method 1

Using the impedance measuring method of 6.6 and a variable frequency source, the lowest frequency shall be determined at which the impedance passes through a minimum. This is the self-resonant frequency.

When it is difficult to determine precisely the frequency at which the impedance is at a minimum, then use may be made of a phase-meter to compare the phase of the voltage across the capacitor with the phase of the voltage across a low-inductance resistor connected in series with the capacitor. The resonant frequency is then the frequency when there is no phase difference. A Q-meter may be used for this purpose.

6.7.1.3 Method 2

6.7.1.3.1 General

For this measuring method, use shall be made of an absorption oscillator-wavemeter (grid dip meter).

6.7.1.3.2 Mounting of capacitors with terminations for general use

Four capacitors of nearly equal value and configuration shall be soldered in series at right angles to form a closed loop. The wires shall be of the specified length and no additional wiring or connections shall be employed (see Figure 8). This loop shall be coupled as loosely as possible to an absorption oscillator-wavemeter and the resonant frequency shall then be determined.

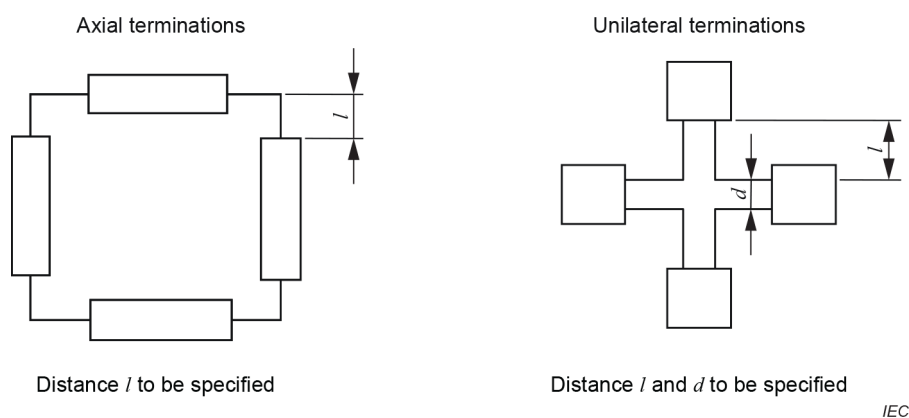


Figure 8 – Capacitor mounting arrangement for general use

6.7.1.3.3 Mounting of capacitors with terminations for printed circuit use

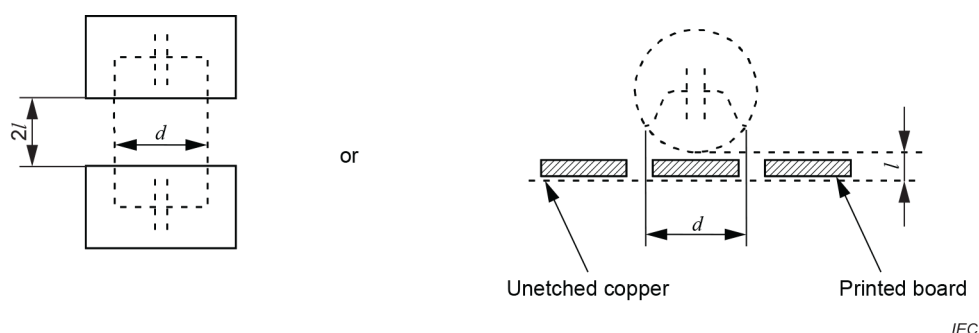
To determine the resonant frequency under the conditions of the capacitor being mounted on a printed circuit board and where the configuration of the case and/or the terminations does not permit a four capacitor loop to be formed correctly, the loop shall be formed by two (nearly) identical capacitors with straight terminations of specified length (see Figure 9).

The second capacitor may be substituted by its mirror image on a conductive plane in the following way.

A copper-clad, unetched sheet of printed circuit base material, whose edges are at least three times as long as the maximum dimension of the capacitor is drilled in its centre to accommodate the capacitor in its normal way.

The relevant specification shall specify the details of mounting. The capacitor is soldered in place with the capacitor being short-circuited by the copper laminate. Then the capacitor is coupled to the search coil and measured as in 6.7.1.3.5.

Metal-cased capacitors may necessitate special arrangements for coupling, which should be specified in the relevant specification.



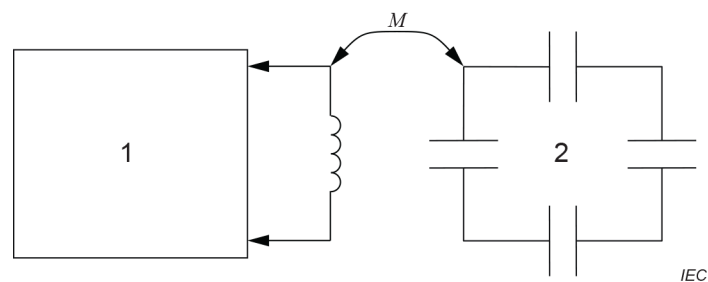
Distances l and d to be specified, where l shall be measured from the seating plane.

Figure 9 – Capacitor mounting arrangement for printed circuit use

6.7.1.3.4 Description of the method

The absorption oscillator-wavemeter is a variable frequency L-C oscillator with the inductor formed as an external search coil. When the search coil is coupled into another resonant circuit, power is absorbed causing a change in the mean grid (gate on FETs (field effect transistor)) voltage. This is monitored and hence "dips" at the resonant frequency of the coupled circuit. This coupled circuit consists of four capacitors mounted as described in 6.7.1.3.2 and connected in series to minimize the mutual inductance.

A typical diagram showing the use of an absorption oscillator-wavemeter is given in Figure 10.

**Key**

1 absorption oscillator-wavemeter (grid-dip meter)

2 coupled resonant circuit

 M coupling factor**Figure 10 – Typical diagram of an absorption oscillator-wavemeter****6.7.1.3.5 Use of the absorption oscillator-wavemeter**

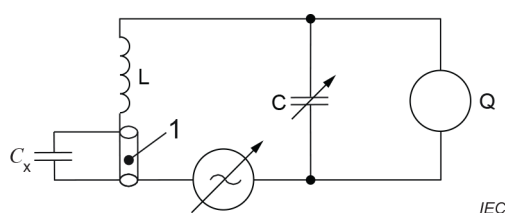
With the search coil of the wavemeter close to the capacitors under investigation, the resonant frequency is approached from a lower frequency. Dips should be checked by moving the wavemeter away from the capacitors (reducing the absorbed power) to make sure the dip is not due to internal effects of the wavemeter. The resonant frequency should be measured with as loose a coupling as is practical to avoid pulling the oscillator.

6.7.1.3.6 Requirements

The resonant frequency shall not exceed the limits specified in the relevant specification.

6.7.1.4 Method 3

This method is particularly suitable for capacitors of low capacitance and with a self-resonant frequency within the Q-meter operating range. Using a Q-meter and the circuit shown in Figure 11, the lowest frequency shall be determined at which the same resonant frequency is obtained, whether the capacitor shorting strap is in place or not. This frequency can be shown to be equal to the self-resonant frequency of the capacitor.

**Key**

1 shorting strap

 C_x capacitance of the capacitor under test C variable capacitor L inductor Q Q-meter**Figure 11 – Schematic diagram of the measuring circuit**

6.7.2 Inductance

The series inductance L_X of a capacitor is calculated from the measured self-resonant frequency f_r of the capacitor using the formula given below:

$$L_X = \frac{1}{4\pi^2 \times f_r^2 \times C_X}$$

where C_X is the capacitance of the capacitor measured in accordance with 6.3 and the requirements of the relevant sectional specification.

6.7.3 Conditions to be specified in the relevant specification

The relevant specification shall specify:

- a) which test method is preferred;
- b) the lead length of the capacitor to be employed in the measurement;
- c) any special mounting arrangement;
- d) the limits of series inductance or self-resonant frequency.

6.8 Variation of capacitance with temperature

6.8.1 Static method

6.8.1.1 Initial measurement

Measurements of capacitance shall be made under the conditions specified in the relevant specification.

6.8.1.2 Test procedure

The capacitor shall be maintained at each of the following temperatures in turn:

- a) 20 °C ± 2 °C;
- b) lower category temperature (LCT) ± 3 °C;
- c) intermediate temperatures, if required in the detail specification;
- d) 20 °C ± 2 °C;
- e) intermediate temperatures, if required in the detail specification;
- f) upper category temperature (UCT) ± 2 °C;
- g) 20 °C ± 2 °C.

If required for a particular type of capacitor, the relevant specification shall specify whether thermal shock shall be avoided or whether a maximum rate of change of temperature shall be specified.

When this test is referenced, the relevant specification shall specify:

- the soak time at each temperature,
- at which time the capacitance value shall be measured,
- the number of cycles to be performed.

6.8.1.3 Measuring method

Capacitance measurements shall be made at each of the temperatures specified above, after the capacitor has reached thermal stability.

The condition of thermal stability is judged as having been reached when two readings of capacitance taken at an interval of not less than 5 min do not differ by an amount greater than that which can be attributed to the measuring apparatus.

The measurement of the actual temperature shall be made with a precision compatible with the requirements of the detail specification.

During measurements, ensure that there is no condensation or frost on the surface of the capacitors.

6.8.1.4 Reduced procedure

For the lot-by-lot quality conformance testing, the detail specification may specify a reduced procedure, for example, measurements d), f) and g) in 6.8.1.2 covering the temperature range from 20 °C to the upper category temperature.

6.8.2 Dynamic method

As an alternative to the static method of 6.8.1, a dynamic plotting method may be employed. The capacitors shall be subjected to a slowly varying temperature.

A temperature-sensing device shall be embedded in a dummy capacitor to be included with the capacitor under test in a manner that will ensure that the measured temperature is the same as that occurring in the capacitor under test. The capacitance shall be measured using a self-balancing bridge or comparator.

The output of the bridge or comparator shall be coupled to the "Y" axis of a plotting table.

The output of the temperature sensing device shall be coupled to the "X" axis of a plotting table.

The temperature shall be varied slowly enough to produce a uniform curve with no loop at the lower or upper category temperature. The temperature shall be varied subsequently from 20 °C to the lower category temperature (LCT), then to the upper category temperature (UCT) and back to 20 °C. Two cycles shall be carried out.

This method may be employed only when it can be demonstrated that the results are the same as for the method employing stabilized temperatures.

In case of dispute, the static method shall be used.

6.8.3 Methods of calculation

6.8.3.1 General

The following applies:

C_0 is the capacitance measured at point d) of 6.8.1.2;

T_0 is the temperature measured at point d) of 6.8.1.2;

C_i is the capacitance measured at the test temperature, other than at points a), d) and g) of 6.8.1.2;

T_i is the temperature measured on test.

6.8.3.2 Temperature characteristics of capacitance

The variation of capacitance as a function of temperature shall be calculated for all the values of C_i as follows:

$$\frac{\Delta C}{C_0} = \frac{C_i - C_0}{C_0}$$

The variation of capacitance is normally expressed in per cent.

6.8.3.3 Temperature coefficient of capacitance and temperature cyclic drift of capacitance

Temperature coefficient of capacitance and temperature cyclic drift of capacitance shall be calculated as follows:

a) Temperature coefficient of capacitance (α)

Temperature coefficient of capacitance (α) shall be calculated for all the values of C_i as follows:

$$\alpha_i = \frac{C_i - C_0}{C_0(T_i - T_0)} \times 10^6$$

The temperature coefficient is normally expressed in parts per million per Kelvin ($10^{-6}/K$).

b) Temperature cyclic drift of capacitance

The temperature cyclic drift of capacitance shall be calculated for the points of measurement of 6.8.1.2 a), d) and g) in the following manner as required in the relevant specification.

$$\delta_{da} = \frac{C_0 - C_a}{C_0}$$

$$\delta_{gd} = \frac{C_g - C_0}{C_0}$$

$$\delta_{ga} = \frac{C_g - C_a}{C_0}$$

where

δ_{da} is the temperature cyclic drift of capacitance between a) and d) of 6.8.1.2;

δ_{gd} is the temperature cyclic drift of capacitance between g) and d) of 6.8.1.2;

δ_{ga} is the temperature cyclic drift of capacitance between a) and g) of 6.8.1.2.

The largest of these values is the "temperature cyclic drift of capacitance".

The capacitance drift is normally expressed in per cent.

6.9 Surge

6.9.1 Initial measurement

The measurements specified in the relevant specification shall be made.

6.9.2 Test procedure

Suitable test circuits are shown in Figure 12 and Figure 13.

NOTE The thyristor circuit has the advantage of high repetition rates and is free from troubles associated with dirty contacts and contact bounce.

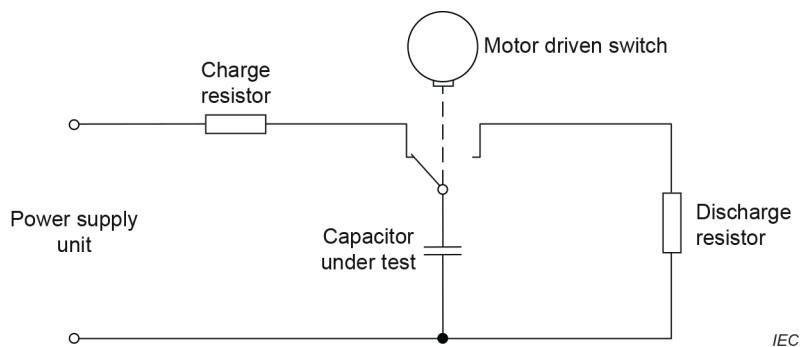


Figure 12 – Relay circuit

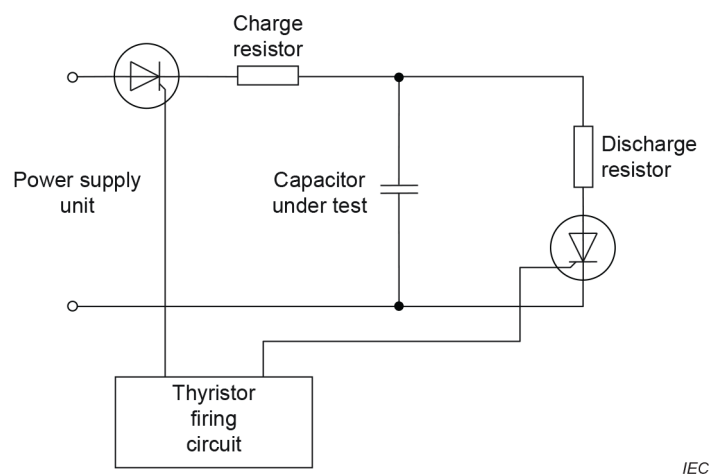
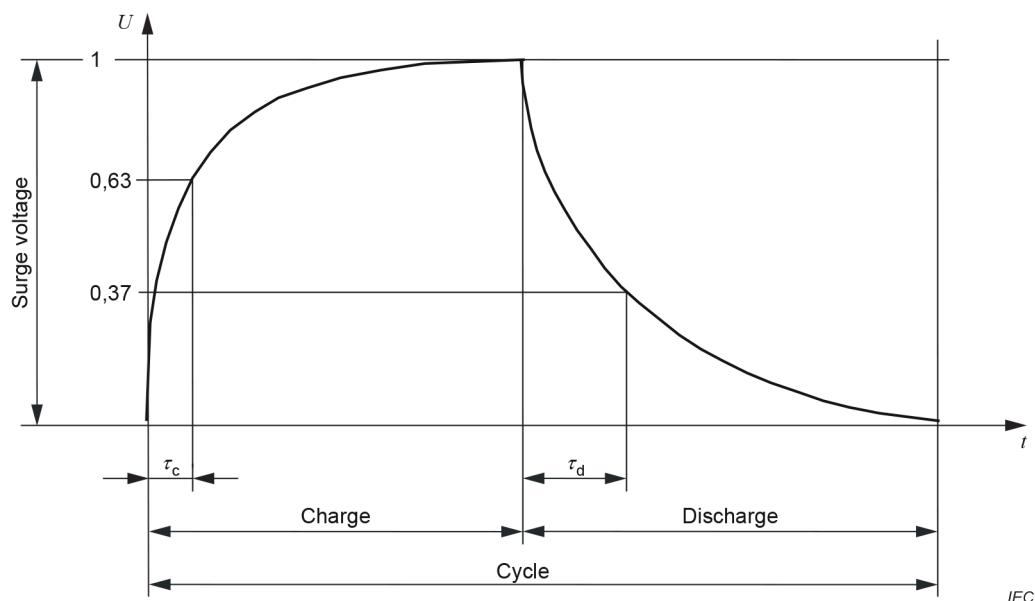


Figure 13 – Thyristor circuit

The voltage waveform across the capacitor under test shall be approximately as shown in Figure 14.



Key

τ_c charge time constant

τ_d discharge time constant

Figure 14 – Voltage waveform across capacitor

6.9.3 Final inspection, measurements and requirements

The measurements specified in the relevant specification shall be made.

6.9.4 Information to be given in the relevant detail specification

The following information shall be given in the relevant specification:

- the charge time constant arising from the internal resistance of the power supply and the resistance of the charge circuit and the capacitance of the capacitor under test;
- the discharge time constant arising from the resistance of the discharge circuit and the capacitance of the capacitor under test;
- the ratio of the surge voltage to rated or category voltage (as appropriate);
The number of times per hour that this voltage may be applied should be specified.
- the number of cycles of test;
- the duration of the charge period;
- the duration of the discharge period;
- the repetition rate (cycles per second);
- the temperature, if different from standard atmospheric conditions for testing.

6.10 High surge current test

6.10.1 Initial measurements

Not required.

6.10.2 Test procedure

The test shall be carried out at a temperature of $(23 \pm 3) ^\circ\text{C}$.

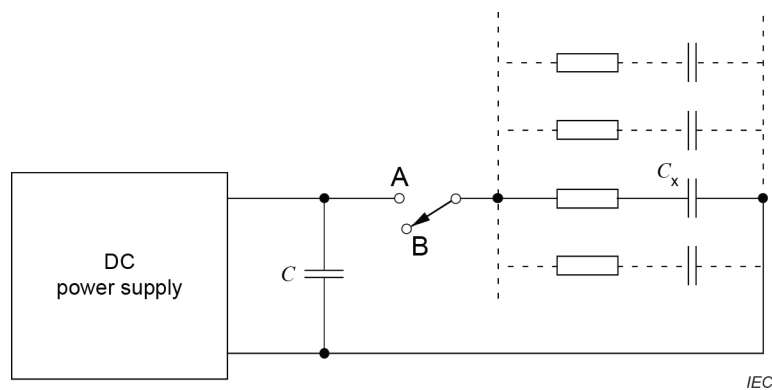
The test circuit is shown in Figure 15. The switch may be mechanical or electronic but is preferably electronic. With the switch in position A, the capacitor under test is charged for 1 s from a low-impedance electrolytic capacitor of capacitance at least 20 000 μF (capacitor bank) to the rated voltage of the capacitor under test (U_R with a tolerance of $\pm 2\%$) from a regulated power supply capable of delivering 10 A. The impedance of the circuit through which the capacitor under test is charged shall meet the requirements of 6.10.3. After 1 s charging time the capacitor under test shall be discharged for 1 s with the switch in position B through a circuit whose resistance is greater than 0,05 Ω , but less than 0,2 Ω .

The voltage across the capacitor under test shall be monitored. Four further chargings and dischargings of the capacitor under test shall be carried out under the same conditions.

Capacitors may be tested in parallel provided that

- a) their total capacitance is less than 2 % of the capacitance of the capacitor bank, and
- b) all the conditions specified above are met for each capacitor under test.

The fuse may be a wire fuse designed to blow between 0,5 A and 2,0 A or an electronic circuit designed to trip in the same current range.



Key

- C_x capacitance of capacitor under test
- C capacitance of low-impedance electrolytic capacitor of at least 20 000 μF (capacitor bank)
- A, B switching positions

Figure 15 – High surge current test

6.10.3 Requirements for the charging circuit

The test procedure of 6.10.2 shall be carried out with a capacitor of 47 μF with a tolerance of $\pm 10\%$ and a rated voltage of 35 V in the test position, or in every one of the test positions if provision is made for testing capacitors in parallel. The monitoring of the voltage across the capacitor under test shall demonstrate that the peak voltage across the capacitor during charging is U_R with a tolerance of $^{+5}_{-2}\%$, and that 90 % of the measured peak voltage is achieved within 60 μs from the time of closure of the switch and without unwanted transients due to switch bounce or circuit inductance. Where there is provision for testing capacitors in parallel, this requirement shall be verified for each capacitor under test.

It is unlikely that this requirement will be met unless the DC resistance of the charging circuit including wiring, fuse, fixtures, and the series resistance of the capacitor bank is less than 0,5 Ω .

6.10.4 Nonconforming items

A capacitor shall be considered a nonconforming item if the fuse blows or the electronic circuit trips at any single charging or discharging of the capacitor.

6.11 Charge and discharge tests and inrush current test

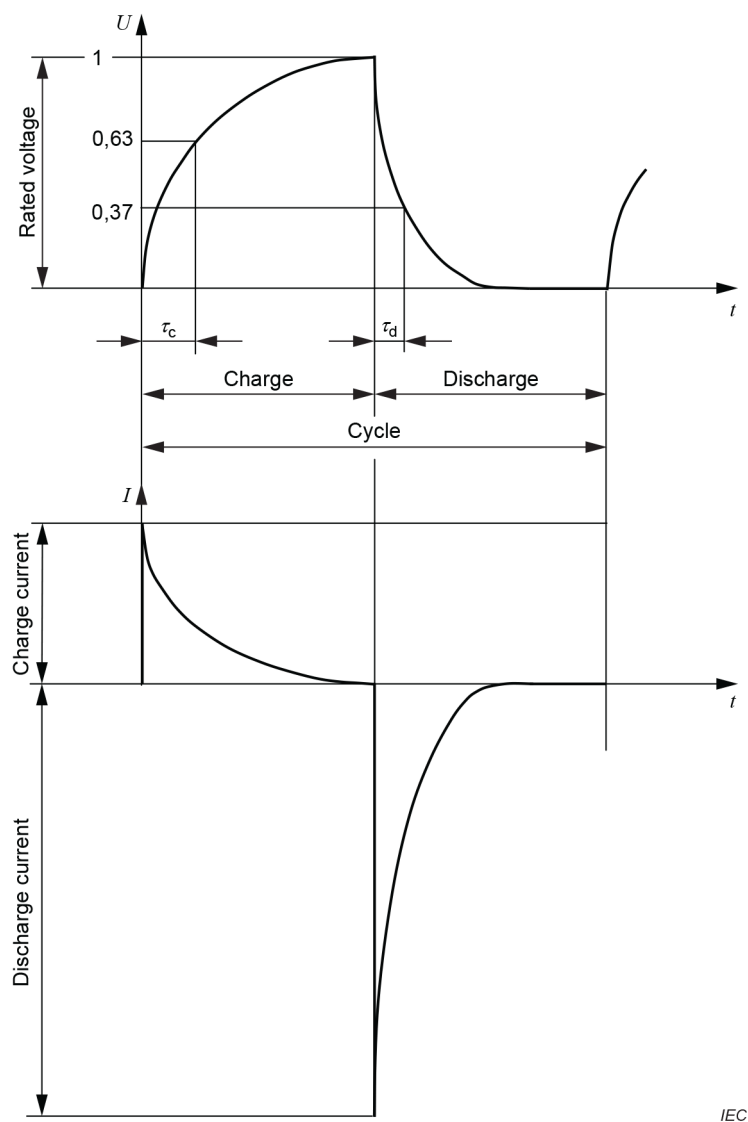
6.11.1 Initial measurement

The measurements specified in the relevant specification shall be made.

6.11.2 Test procedure

Suitable test circuits are given in 6.9.2, Figure 12 and Figure 13.

The voltage and current waveforms across and through the capacitor under test are approximately as shown in Figure 16.



IEC

Key

τ_c charge time constant

τ_d discharge time constant

Figure 16 – Voltage and current waveform

6.11.3 Charge and discharge

The following information shall be given in the relevant specification:

- a) the charge time constant arising from the internal resistance of power supply and the resistance of the charge circuit and the capacitance of the capacitor under test;
- b) the discharge time constant arising from the resistance of the discharge circuit and the capacitance of the capacitor under test;
- c) the voltage to be applied during the charge period, if different from the rated voltage;
- d) the number of cycles of test;
- e) the duration of the charge period;
- f) the duration of the discharge period;
- g) the repetition rate (cycles per second);
- h) the temperature, if different from standard atmospheric conditions for testing.

6.11.4 Inrush current

The following information shall be given in the relevant specification:

- a) the peak charge current;
- b) the voltage to be applied during the charge period if different from the rated voltage;
- c) the number of cycles of test;
- d) the duration of the charge period in milliseconds;
- e) the duration of the discharge period;
- f) the repetition rate;
- g) the temperature if different from standard atmospheric conditions for testing.

6.11.5 Final inspection, measurements and requirements

The measurements specified in the relevant specification shall be made.

6.12 Dielectric absorption

6.12.1 Test procedure

The capacitor under test shall be placed in a screened enclosure to reduce the effect of electric fields. The test circuit is shown in Figure 17.

For the measurement of the voltage an electrometer or other suitable instrument having an input resistance of minimum 10 000 M Ω shall be used.

The resistance of any jigs, switches etc. used shall not affect the input resistance of the measuring system.

The capacitor shall then be charged at the rated DC voltage for 60 min $\pm$ 1 min. The initial surge current in charging shall not exceed 50 mA.

At the end of this period the capacitor shall be disconnected from the power source and shall be discharged through a resistor of 5 Ω with a tolerance of ± 5 % for 10 s $\pm$ 1 s, unless the specified du/dt value is exceeded.

The discharge resistor shall be disconnected from the capacitor at the end of the 10 s discharge period. The voltage remaining or regained on the capacitor (recovery voltage) shall be measured.

NOTE The recovery voltage is the maximum voltage occurring across the capacitor terminations within a 15 min period.

The dielectric absorption shall be calculated from the following formula:

$$DA = \frac{U_1}{U_2} \times 100 \times \frac{C_X + C_0}{C_X}$$

where

DA is the per cent dielectric absorption;

U_1 is the recovery voltage;

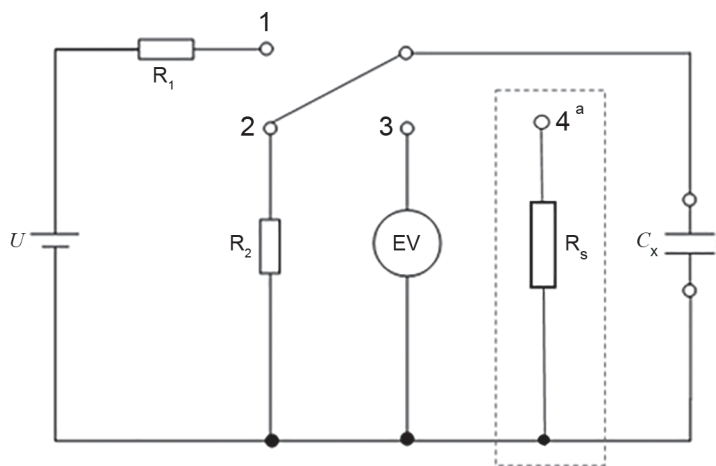
U_2 is the charging voltage;

C_X is the capacitance of the capacitor under test;

C_0 is the input capacitance of the measuring system.

If C_0 is less than 10 % of C_X , the above formula can be simplified to:

$$DA = \frac{U_1}{U_2} \times 100$$



IEC

Key

1, 2, 3 and 4 switching terminations

C_X capacitance of capacitor under test

S switch

U DC voltage source

R_1 protective resistor

R_2 discharge resistor

R_s discharge resistor (if required)

EV electronic voltmeter

^a For high voltage capacitors or the like, a discharge circuit may be added to prevent an electric shock accident.

Figure 17 – Dielectric absorption test circuit

6.12.2 Requirement

The dielectric absorption calculated shall not exceed the limit specified in the detail specification.

6.13 Voltage transient overload (for aluminum electrolytic capacitors with non-solid electrolyte)

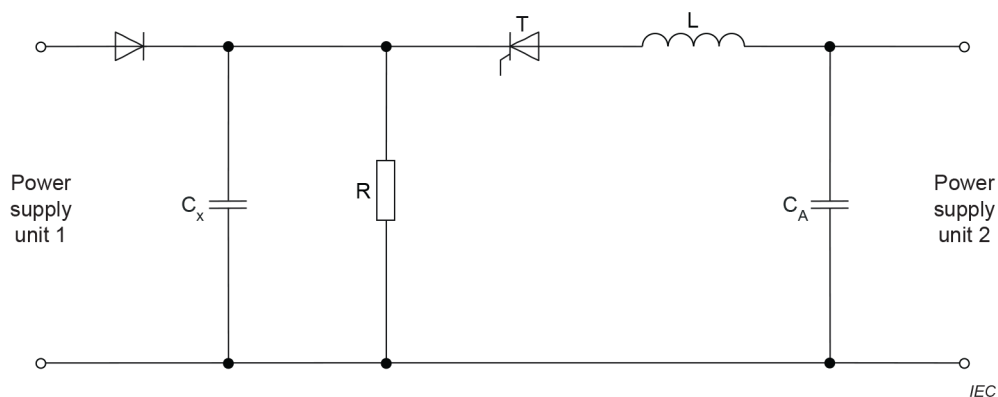
6.13.1 Initial measurement

The measurements specified in the detail specification shall be made.

6.13.2 Test procedure

The capacitor(s) shall then be conditioned at the test temperature by having U_R with a tolerance of $\pm 1\%$ applied from a regulated power supply. At the end of this period, the test may commence but not later than 48 h after conditioning.

An example of a test circuit is shown in Figure 18.



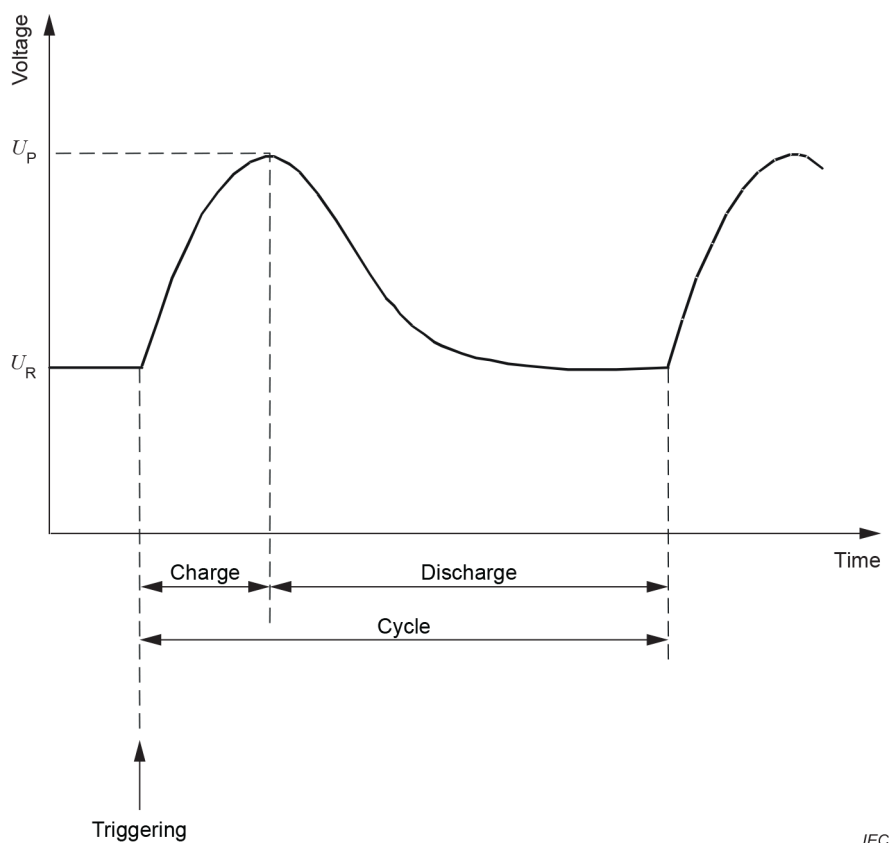
Key

- C_X capacitor under test
- C_A capacitor bank to give a maximum charge time
- R resistor to give a maximum charge time
- L inductor to give a maximum charge time
- T thyristor

Figure 18 – Voltage transient overload test circuit

The capacitor under test C_X is charged from the power supply unit 1, and the auxiliary capacitor bank C_A is charged to a voltage higher than the test voltage U_P from the power supply unit 2. On triggering the thyristor T, the capacitor bank C_A is discharged through the inductor L charging the test capacitor C_X to U_P . On turning the thyristor off, the test capacitor C_X is discharged through the resistor R from U_P down to U_R .

The voltage waveform across the capacitor under test shall be approximately as shown in Figure 19.



Key

U_P transient peak voltage

U_R rated voltage

Figure 19 – Voltage waveform

6.13.3 Final inspection, measurements and requirements

The measurements specified in the relevant specification shall be made.

6.13.4 Conditions to be specified in the relevant specification

The relevant specification shall specify:

- the duration of the conditioning period;
- the value of the transient peak voltage U_P ;
- the value of C_A , L and R to give a maximum charge time of 15 ms;
- the duration of each test cycle;
- the number of test cycles;
- the temperature if different from standard atmospheric conditions of testing.

7 Mechanical tests and measurements

7.1 Visual examination and check of dimensions

7.1.1 Visual examination

The condition, workmanship and finish shall be satisfactory, as checked by visual examination (see 3.42).