IEC 60477-2

Edition 2.0 2022-03

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Laboratory resistors –
Part 2: Laboratory AC resistors

Résistances de laboratoire –
Partie 2: Résistances de laboratoire à courant alternatif

IEC 60477-2:2022-03(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

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Laboratory resistors – Part 2: Laboratory AC resistors

Résistances de laboratoire – Partie 2: Résistances de laboratoire à courant alternatif

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LABORATORY RESISTORS –

Part 2: Laboratory AC resistors

FOREWORD

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IEC 60477-2 has been prepared by IEC technical committee 85: Measuring equipment for electrical and electromagnetic quantities. It is an International Standard.

This second edition cancels and replaces the first edition published in 1979, and Amendment 1:1997. This edition constitutes a technical revision.

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

a) extended the AC resistor frequency range to 1 MHz;
b) updated the terms and definitions according to IEC 60050 series;
c) added the definition of AC/DC difference of an AC resistor;
d) added the resistor classification according to the AC resistance or AC/DC difference index;
e) updated the classification according to the AC resistor construction;
f) updated the safety symbols and requirements according to IEC 60477-1;
g) added the three-element equivalent circuits of an AC resistor in Annex C;

h) added the annex on constructions of AC resistors.

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

Draft	Report on voting
85/822/FDIS	85/825/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.

A list of all parts in the IEC 60477 series, published under the general title *Laboratory resistors*, can be found on the IEC website.

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.

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.

LABORATORY RESISTORS –

Part 2: Laboratory AC resistors

1 Scope

This part of IEC 60477 applies to resistors intended as laboratory AC resistors for use over a range of frequencies from DC up to a stated frequency which is not in excess of 1 MHz. Such resistors are hereinafter referred to as "AC resistors".

In addition to satisfying the requirements of IEC 60477-1, resistors satisfying the requirements of this document are designed to have a small variation of resistance and a small phase displacement over the stated frequency range.

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 60477-1, *Laboratory resistors – Part 1: Laboratory DC resistors*

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 http://www.iso.org/obp
- IEC Electropedia: available at http://www.electropedia.org/

3.1
equivalent electric circuit
circuit composed of ideal circuit elements which has, at the terminals or ports, a behaviour equivalent to that of a given electric or magnetic circuit or device

Note 1 to entry: Equivalent electric circuits can also be used to represent other kinds of devices or phenomena.

[SOURCE: IEC 60050-131:2002, 131-15-07]

3.2
circuit element
in electromagnetism, mathematical model of a device characterized by one or more relations between integral quantities

[SOURCE: IEC 60050-131:2002, 131-11-03]

3.3
equivalent circuit of an AC resistor
equivalent electric circuit of an AC resistor
electric circuit which has the same AC characteristics as a resistor, and which would have an impedance equal to the resistor under specified operating conditions

Note 1 to entry: Specified operating conditions should include working frequency and voltage.

3.4
two-element equivalent circuit of an AC resistor
equivalent circuit of an AC resistor with two elements under specified operating conditions

Note 1 to entry: A two-element equivalent circuit of an AC resistor is given by either an equivalent AC resistance, R_s in series with an equivalent inductance, L_s or an equivalent AC resistance, R_p in parallel with an equivalent capacitance, C_p (see Annex C).

3.5
three-element equivalent circuit of an AC resistor
equivalent electric circuit of an AC resistor with three elements under specified operating conditions

3.6
equivalent AC resistance of an AC resistor
AC resistance
value of resistance (R_s or R_p) which is the AC resistive component of the resistor

Note 1 to entry: The AC resistance is usually taken as the equivalent series resistance R_s, for resistors of Category A, and as the equivalent parallel resistance R_p, for resistors of Category C (see Annex B).

3.7
terminal pair
port consisting of two terminals such that the electric current directed from an external circuit or device to one terminal is identical with the current directed from the other terminal to the external circuit or device

[SOURCE: IEC 60050-131:2002, 131-12-63]

3.8
time constant
τ
time τ in the expression $F(t) = A + Be^{-t/\tau}$ of a quantity F growing or decaying exponentially towards a constant value A with increasing time t, or in the expression $F(t) = A + f(t)e^{-t/\tau}$ of an exponentially damped oscillation, where f is a periodic function of time

Note 1 to entry: The time constant of an exponentially varying quantity is the duration of a time interval at the end of which the absolute value of the difference between the quantity and the limit has decreased to 1/e of the absolute value of this difference at the beginning of the time interval, where e is the base of natural logarithms.

Note 2 to entry: For a resistor, at any particular frequency, the time constant is defined as either: L_s/R_s, or R_pC_p whichever yields a positive value (see Annex C). For determining the time constant, the DC resistance may be used instead of the equivalent AC resistance.

Note 3 to entry: For a resistor using the three-element equivalent circuit expressed, the time constant is approximately equal to: $\frac{L}{R} - CR$, or $CR - \frac{L}{R}$ (see Annex C).

Note 4 to entry: The phase displacement of the current flowing through the resistor from the voltage appearing across it with a time constant L_s/R_s or $\frac{L}{R} - CR$ is such that the current is lagging, and that with a time constant R_pC_p or $CR - \frac{L}{R}$ is leading when L_s and C_p, have positive values, L_s and L being expressed in henrys, R_s, R_p and R in ohms and C_p and C in farads.

[SOURCE: IEC 60050-103:2009, 103-05-26, modified – The existing Note 2 has been deleted and a new Note 2, Note 3 and Note 4 to entry have been added to adapt to usage in AC resistor technology.]

3.9
time constant index
conventional designation of a time constant by a number or symbol

Note 1 to entry: In this document, the time constant index is expressed in seconds using the appropriate SI prefix.

3.10
AC/DC difference
<of an AC resistor> difference between the equivalent AC resistance at a stated frequency and the DC resistance, expressed as a percentage (%) of the DC resistance

3.11
AC/DC difference index
number which designates the limit of the AC/DC difference in nominal range of use for frequency, expressed in %

3.12
frequency index
number which designates the upper limit of the nominal range of use for frequency, expressed in hertz using the appropriate SI prefix

3.13
skin effect
for an alternating electric current in a conductor, phenomenon in which the current density is greater near the surface than in the interior of the conductor

Note 1 to entry: The skin effect increases the resistance and decreases the inductance of a conductor with the frequency of the electric current.

Note 2 to entry: The skin effect occurs also in the more general case of any time-varying current.

[SOURCE: IEC 60050-121:1998, 121-13-18]

3.14
residual inductance
inductance value between the points of connection of a multiple or multi-dial AC resistor having switching devices with a zero position, when all switching elements are set to the zero position

4 Resistor characterization and construction

4.1 Resistor characterization

AC resistors satisfying the requirements of this document are characterized:

a) by classes related to their DC accuracy as specified in IEC 60477-1,

b) by classes related to their equivalent AC resistance as specified in 5.1 or AC/DC difference indices as specified in 5.1, and

c) by time constant indices as specified in 5.1, and

d) by frequency indices as specified in Clause 6.

4.2 Resistor construction

Because of the uncertainties in AC properties which can result from stray inductances, stray capacitances, eddy currents, dielectric absorption effects and skin effects, the AC resistors to which this document applies are classified according to their construction (see Annex D), as follows:

a) two-terminal resistor, each terminal being able to be used both for current or potential;
b) three-terminal resistor which has one more shield terminal (can also be called a guard terminal) connected to the electric screen than the two-terminal resistor to reduce the stray capacitances effect;
c) four-terminal resistor which has independent current terminals and potential terminals to reduce the stray inductances and contact resistances;
d) five-terminal resistor which has one more shield terminal than the four-terminal resistor;
e) four-terminal coaxial resistor which has two terminal-pairs with the outer shield conductors working as the low terminal of current or potential;
f) two-terminal-pair resistor which has two terminal-pairs with the outer shield conductors working as the return path for the signal current (not grounded);
g) four-terminal-pair resistor which has four terminal-pairs with the outer shield conductors working as the return path for the signal current (not grounded) to eliminate the effect of mutual coupling between the current and potential leads.

5 General requirements

5.1 DC resistance, AC resistance and time constant

The DC characteristics of an AC resistor shall be as specified in IEC 60477-1.

The equivalent AC resistance of an AC resistor characterized by class related to the AC resistance shall comply with the limits of relative uncertainty as specified for their AC resistance class index in Table 1 at initial calibration.

Table 1 – Limits of the AC resistance relative uncertainty

AC resistance class index	0,000 01	0,000 02	0,000 05	…	2	5	10
Limits of relative uncertainty for AC resistance	0,000 01 %	0,000 02 %	0,000 05 %	…	2 %	5 %	10 %

NOTE The value of the AC resistance of a given resistor is somewhat dependent on the frequency at which it is measured. However, as the purpose here is to classify AC resistors, measurements at 1 kHz (or lower) are generally adequate.

The AC/DC difference of an AC resistor characterized by AC/DC difference index shall comply with the limits of AC/DC difference specified for its AC/DC difference index in Table 2 at initial calibration.

Table 2 – Limits of the AC/DC difference

AC/DC difference index	0,000 001	0,000 002	0,000 005	…	0,2	0,5	1
Limits of the AC/DC difference	±0,000 001 %	±0,000 002 %	±0,000 005 %	…	±0,2 %	±0,5 %	±1 %
NOTE Measurements at 1 kHz (or lower) are here generally adequate.							

An AC resistor shall choose either an AC resistance class index or an AC/DC difference index to show the AC resistance character.

The time constant of an AC resistor shall not exceed the appropriate value of the time constant index selected from the sequence:

- 1 ns, 2 ns, 5 ns, 10 ns, …100 µs.

NOTE The value of the time constant of a given resistor is also somewhat dependent on the frequency at which it is measured. Measurements at 1 kHz (or lower) are here generally adequate as with the measurements of AC resistance.

5.2 Multiple resistors

Multiple resistors, excluding multi-dial resistors, may have a different AC resistance class or AC/DC difference and time constant index for each selectable value.

For a multiple resistor in which the lowest selectable resistance value is nominally zero, the manufacturer shall state the value of the residual inductance under this condition.

5.3 Multi-dial resistors

Multi-dial resistors shall have a single AC resistance class index or AC/DC difference index and a single time constant index for all selectable values on any dial used alone. The several dials may each have a different AC resistance class index or AC/DC difference index and a different time constant index.

The AC resistance class index or AC/DC difference index of a given dial shall also apply at any setting of the dial when that dial is used in conjunction with any setting of any dial(s) inferior to it in value.

The time constant index of a given dial shall also apply at any setting of the dial when that dial is used in conjunction with any setting of any dial(s) inferior to it in value.

5.4 Connecting leads

Separate current and potential connections shall be made to a resistor having a pair of terminals for each port of connection, unless other conditions are stated by the manufacturer. The mutual inductances between the current and potential leads and between each of these leads and the resistor shall be minimized.

The leads making connection to a resistor having a single terminal for each port of connection shall be arranged so as to minimize their inductance.

NOTE 1 This arrangement is particularly important for resistors of values of 10 Ω and lower.

The leads making connection to a resistor shall not alter significantly the equivalent parallel capacitance, if necessary, by the provision of a screen for each lead and by the use of an appropriate measuring circuit.

NOTE 2 The magnitude of capacitance that will cause a significant alteration will depend upon the value of the resistance and the time constant.

5.5 Conditions for the determination of DC and AC characteristics

All tests of DC characteristics shall be carried out as specified in IEC 60477-1.

NOTE At low frequencies, the uncertainty of an AC resistor is essentially the same as its uncertainty at DC.

At higher frequencies, an additional variation as specified in Clause 6 is permitted.

All tests of AC characteristics shall be carried out under the reference conditions specified in IEC 60477-1.

The AC resistance of an AC resistor shall be measured at a frequency of 1 kHz or at the frequency corresponding to its frequency index if the latter is lower (see Clause 6).

The time constant of an AC resistor shall be measured at a frequency of 1 kHz or at the frequency corresponding to its frequency index if the latter is lower (see Clause 6).

The residual inductance of an AC resistor (see 5.2) shall be measured with the resistor connected as in normal use and at a frequency of 1 kHz or at the frequency corresponding to its frequency index if the latter is lower (see Clause 6).

A resistor with a shield terminal (see items b) and d) of 4.2 shall be tested with the screen connected as specified by the manufacturer.

A resistor without a shield terminal (see items a) and c) of 4.2 shall be tested within an earthed conductive enclosure as specified by the manufacturer. If this enclosure is not specified, the resistor shall be tested within an earthed conductive enclosure separated from the surface of the resistor by between 10 mm and 20 mm at all places.

A resistor with terminal pairs (see items e), f) and g) of 4.2 shall be tested with the terminal pair connected as specified by the manufacturer.

Any other necessary conditions shall be stated by the manufacturer.

When necessary, details of the testing method shall be agreed between the manufacturer and the user.

6 Permissible variations

Changes in influence quantities over the nominal ranges of use specified in IEC 60477-1 will cause no significant effect on the AC characteristics of the resistor. Requirements relating to variations of AC characteristics other than those due to frequency are therefore not included in this document.

The upper limit of the nominal range of use for frequency shall be designated using the appropriate frequency index selected from Table 3.

Table 3 – Upper limit of the nominal range of use for frequency

Frequency index	1 M	500 k	200 k	…	500	200	100	50
Upper limit of the nominal range of use for frequency	1 MHz	500 kHz	200 kHz	…	500 Hz	200 Hz	100 Hz	50 Hz

When the AC resistor is under reference conditions as specified in IEC 60477-1, the AC resistance relative uncertainty for any frequency within its nominal range of use shall not exceed the permissible AC resistance relative uncertainty (see 5.1), or the AC/DC difference for any frequency within its nominal range of use shall not exceed the permissible AC/DC difference (see 5.1).

Multiple resistors, excluding multi-dial resistors, may have a different frequency index for each selectable value.

Multi-dial resistors shall have a single frequency index for all selectable values on any dial used alone. The several dials may each have a different frequency index. The frequency index of a given dial shall also apply when that dial is used in conjunction with any dial(s) inferior to it in value.

Conditions for the determination of the variation due to frequency:

- connecting leads shall be arranged as specified in 5.4.
- when necessary, details of the testing method shall be agreed between the manufacturer and the user.

7 Further electrical and mechanical requirements

AC resistors shall comply with the further electrical and mechanical requirements specified in IEC 60477-1.

The manufacturer shall specify the method(s) of connection of the screen, if any.

The manufacturer shall state whether the characteristics are given relating to the equivalent series model or the equivalent parallel model (see 3.4) as relevant (see note to 3.6).

8 Information, markings and symbols

8.1 Information

In addition to the markings required by IEC 60477-1 (except for those mentioned in 8.2 of this document), AC resistors shall also carry markings to show the AC resistance class index or AC/DC difference index, time constant index and the frequency index.

The AC resistance class index or AC/DC difference index shall be marked using the appropriate value selected from the set of values given in Table 1 or Table 2 (see 5.1) and shall follow "AC resistance" or "AC/DC difference".

The time constant index shall be marked using the appropriate value selected from the set of values given in 5.1 and followed by "s".

The frequency index shall be marked using the appropriate value selected from Table 3 and followed by "Hz".

For a multiple resistor in which the lowest selectable resistance value is nominally zero, the value of residual inductance under this condition (see 5.2) shall be marked.

8.2 Markings and symbols

The markings (see Annex A) of AC resistance class index or AC/DC difference index, time constant index and frequency index specified in 8.1 shall be given on a nameplate or on the enclosure and shall follow the marking for DC accuracy class (as specified in IEC 60477-1) on the same line or on successive lines and in the order stated in 8.1.

The marking of residual inductance specified in 8.1 shall be given on a nameplate or on the enclosure and shall follow the marking of the value of the residual resistance (as specified in IEC 60477-1).

Instead of the marking "Laboratory DC resistor" (see 9.2 of IEC 60477-1:2022), AC resistors shall be marked "Laboratory DC / AC resistor". This term may be marked in any other language.