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Method of measurement of current noise generated in fixed resistors

bsi.

National foreword

This British Standard is the UK implementation of EN 60195:2016. It is identical to IEC 60195:2016. It supersedes BS 4119:1967 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee EPL/40X, Capacitors and resistors for electronic equipment.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Method of measurement of current noise generated in fixed resistors (IEC 60195:2016)

Méthode pour la mesure du bruit produit en charge par les résistances fixes
(IEC 60195:2016)

Messverfahren für das Stromrauschen in Festwiderständen
(IEC 60195:2016)

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European foreword

The text of document 40/2431/FDIS, future edition 2 of IEC 60195, prepared by IEC/TC 40 “Capacitors and resistors for electronic equipment" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 60195:2016.

The following dates are fixed:

• latest date by which the document has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2017-02-12
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In the official version, for Bibliography, the following notes have to be added for the standards indicated:

IEC 60027 (series)	NOTE Harmonized as EN 60027 (series).

Annex ZA
(normative)
Normative references to international publications with their corresponding European publications

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

NOTE 1 When an International Publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

NOTE 2 Up-to-date information on the latest versions of the European Standards listed in this annex is available here: www.cenelec.eu.

Publication	Year	Title	EN/HD	Year
IEC 60068-1	2013	Environmental testing -- Part 1: General and guidance	EN 60068-1	2014

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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METHOD OF MEASUREMENT OF CURRENT NOISE GENERATED IN FIXED RESISTORS

FOREWORD

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International Standard IEC 60195 has been prepared by IEC technical committee 40: Capacitors and resistors for electronic equipment.

This second edition cancels and replaces the first edition published in 1965 and constitutes a technical revision.

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

- harmonization of the allocation of isolation resistors R_M in the recommended operating conditions given in Table 2;
- correction of erroneous numeric values of the contribution of system noise, $f(T - S)$ in Table 3;
- addition of advice on the prescription of requirements in a relevant component specification;
- addition of a set of recommended measuring conditions for specimens with a rated dissipation of less than 100 mW;

- complete editorial revision.

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

FDIS	Report on voting
40/2431/FDIS	40/2458/RVD

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

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

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

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

METHOD OF MEASUREMENT OF CURRENT NOISE GENERATED IN FIXED RESISTORS

1 Scope

This International Standard specifies a method of measurement and associated test conditions to assess the "noisiness", or magnitude of current noise, generated in fixed resistors of any given type. The method applies to all classes of fixed resistors. The aim is to provide comparable results for the determination of the suitability of resistors for use in electronic circuits having critical noise requirements.

The current noise in resistive materials reflects the granular structure of the resistive material. For some resistor technologies utilizing homogenous layers it is regarded as providing an indication of defects, which are considered as a root cause for abnormal ageing of the component under the influence of temperature and time.

The method described in this International Standard is not a general specification requirement and therefore is applied if prescribed by a relevant component specification, or, if agreed between a customer and a manufacturer.

2 Normative references

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

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

3 Terms and definitions

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

3.1
current-noise
combination of all random fluctuations of current flow in a resistor which are not attributed to thermal agitation of the charge carriers (thermal noise) and which depend on the applied direct current

3.2
current-noise index
A_1
logarithmic index of the ratio of the open circuit r.m.s. current-noise voltage in a frequency decade, in µV, over the d.c. voltage applied under test, in V, used to express the “noisiness” of an individual resistor

Note 1 to entry: The current-noise index is expressed in dB. The ratio between µV and V is not considered in this index, leading to its value being 120 dB less than the mathematical current-noise index A_1'. This practical index follows the history of prior revisions of this method.

3.3
mathematical current-noise index
A_1'
logarithmic index of the ratio of the open circuit r.m.s. current-noise voltage in a frequency decade over the d.c. voltage applied under test, established in consistent units and their multiples

Note 1 to entry: The mathematical current-noise index is expressed in dB. This index has been introduced for the mathematical derivation of the considered parameters.

3.4
current-noise voltage ratio
CNR_U
ratio of the open circuit r.m.s. current-noise voltage in a frequency decade over the d.c. voltage applied under test, established in μV/V, used to express the "noisiness" of an individual resistor

3.5
flicker noise
pink noise
random fluctuation present in most electronic devices and typically related to internal properties of the respective device, which depends on direct current and has a power spectral density inversely proportional to the frequency

3.6
noise
random fluctuation in an electrical signal having instantaneous amplitude values which, due to their distribution in a random manner, can only be predicted in terms of probability statements

3.7
shot noise
random fluctuation in electric current due to the flowing current consisting of discrete charges, which is independent of temperature and has nearly constant power spectral density throughout the frequency spectrum

3.8
thermal noise
random fluctuation generated by the thermal agitation of the charge carriers (usually the electrons) inside an electrical conductor at equilibrium, which is independent of any applied voltage and has nearly constant power spectral density throughout the frequency spectrum

Note 1 to entry: Thermal noise is also referred to as Johnson noise or as Nyquist noise.

4 Method of measurement

4.1 Noise basics

4.1.1 Noise

Noise appears as a spontaneous fluctuating voltage $e_n(t)$ with instantaneous amplitude values.

Noise voltage is a statistically independent random variable, where for most kinds of noise the frequency distribution of amplitudes follows a Gaussian distribution curve. Therefore noise voltage cannot be predicted except in terms of probability statements.

Usually the characteristic of principal interest is not the instantaneous amplitude value but the "time-averaged" value.

The measurement of amplitude commonly used and adopted for this International Standard is the effective (r.m.s.) voltage E_n observed in a particular frequency pass-band.

4.1.2 Thermal noise

The thermal noise of a resistor is a fluctuating voltage caused by the random motion of thermally agitated charges, which is present in all resistors. The root mean-square value of the fluctuating voltage appearing at the open-circuit terminals of a resistor, which would be indicated by the measuring system, may be calculated using Nyquist's equation:

$$E_{th} = \sqrt{\overline{e_{th}^2}} = \sqrt{4 \cdot k \cdot T \cdot R \cdot \Delta f}$$

where

E_{th} is the effective voltage (r.m.s. voltage) of the thermal noise in a given bandwidth;

e_{th} is the momentary voltage of the thermal noise in a given bandwidth;

k is the Boltzmann constant, $k \approx 1{,}38 \times 10^{-23}$ J/K;

T is the absolute temperature;

R is the resistance;

Δf is the bandwidth of the effective band-pass filter of the measuring system.

The presence of thermal noise cannot be ignored because the thermal noise of the resistor under test is frequently a major source of interference in the measurement.

4.1.3 Current noise

The presence of direct current in a fixed resistor causes an increase in the observed total noise above the level attributed to thermal noise. Regardless of its originating nature, this excess noise is referred to as current noise.

$$E_t^2 = E_{th}^2 + E_c^2$$

where

E_t is the effective voltage of the total noise in a given bandwidth;

E_{th} is the effective voltage of the thermal noise in a given bandwidth;

E_c is the effective voltage of the current noise in a given bandwidth.

Hence, the current noise is the geometric difference between the total noise and the thermal noise

$$E_c^2 = E_t^2 - E_{th}^2$$

The effective current-noise voltage per 1 Hz bandwidth is substantially inversely proportional to frequency

$$[e(f)]^2 \sim \frac{I^2}{f}$$

where

$e(f)$ is the momentary voltage of the current noise as a function of frequency;

I is the d.c. current passing through the resistor;

f is the frequency for which the current noise voltage is considered.

The effective current noise voltage for a given bandwidth is calculated by integrating the current noise voltage over the frequency band

$$E_c{}^2 = \int_{f_1}^{f_2} [e(f)]^2 \mathrm{d}f$$
$$\sim \int_{f_1}^{f_2} \frac{I^2}{f} \mathrm{d}f$$
$$\sim I^2 \ln\left(\frac{f_2}{f_1}\right)$$

where

E_c is the effective voltage of the current noise in a given bandwidth;

f_1 is the lower cut-off frequency of the ideal band-pass;

f_2 is the upper cut-off frequency of the ideal band-pass.

If the mean-square voltage is inversely proportional to frequency, then ideal rectangular pass-bands having equal ratios of upper to lower band-pass limits transmit equal amounts of noise voltage from a given noise source.

A resistor exhibiting current noise may be represented as a noise source having a zero-impedance current-noise voltage generator connected in series with an independent thermal-noise voltage generator and with a noise-free resistor.

4.2 Measurement principle

The current noise voltage E_c is, in general, closely proportional to the applied d.c. test voltage U_T. It is recommended, however, to apply a harmonized set of operating conditions in order to ensure the most comparable measurements for all resistors.

Table 2 gives a set of operating conditions recommended for the testing of resistors with resistances in the range of 100 Ω to 22 MΩ. The values given therein also avoid overloading the specimen and the input circuit.

The frequency dependence of noise voltages requires the prescription of a frequency pass-band to be used in this measurement, which is an ideal rectangular pass-band of one frequency decade, geometrically centered at 1 000 Hz.

The measurement results in the mathematical current noise index in a frequency decade, A_1', as follows:

$$A_1' = 20 \lg\left(\frac{E_c{}'}{U_T}\right) \text{dB}$$

where

E_c' is the effective open circuit current-noise voltage in a frequency decade, given in V;

U_T is the d.c. voltage applied to the resistor under test, given in V.

The typical magnitude of the current-noise voltage being in the microvolt range rather than in a volt range is reflected in the prevalent current noise index in a frequency decade, A_1,

$$A_1 = 20 \lg\left(\frac{E_\mathrm{c}}{U_\mathrm{T}}\right) \mathrm{dB}$$

where

E_c is the effective open circuit current-noise voltage in a frequency decade, given in μV;

U_T is the d.c. voltage applied to the resistor under test, given in V.

The ratio between μV and V, which results in an offset of 120 dB, is neglected in the traditional definition of the current noise index A_1, hence the following relationship applies:

$$A_1 = A_1' - 120 \text{ dB} .$$

Since the current-noise power spectrum approximates to a $1/f$ frequency characteristic, the index and the ratio provides an estimate of current noise in any frequency decade.

4.3 Measurement system

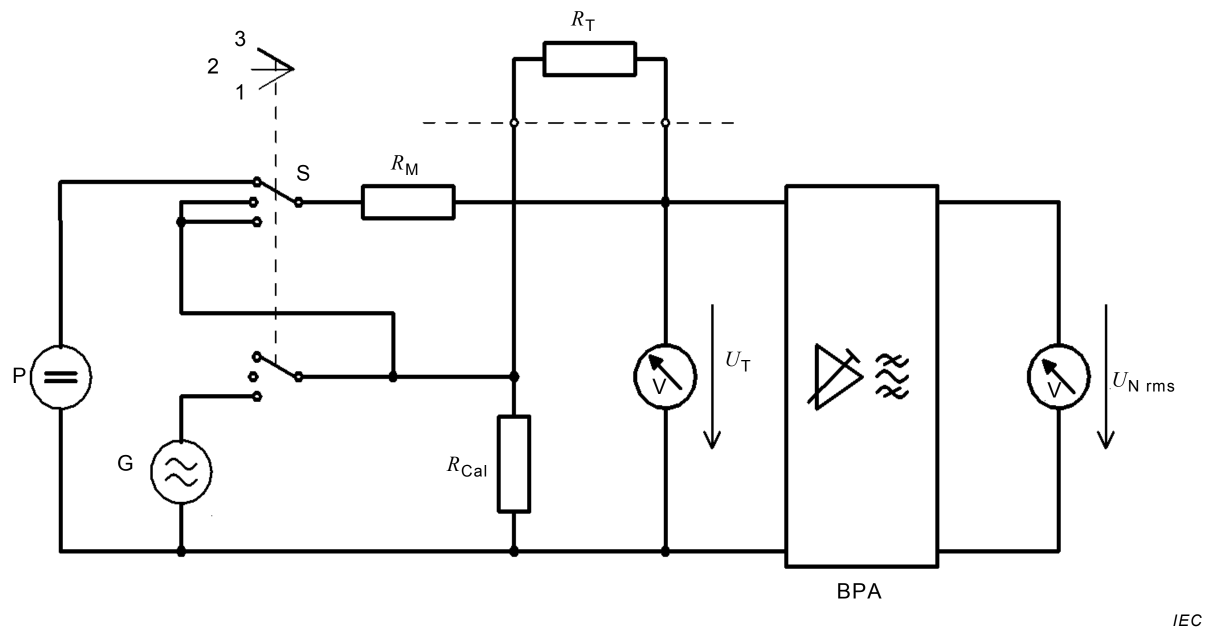
4.3.1 Proposal of a suitable measuring system

Figure 1 shows a block schematic of a suitable measuring system.

A three-position switch may be used to access any of the three modes of operation normally followed in the measurement procedure:

- calibration;
- measurement of system noise;
- measurement of total noise.

The input circuit consists of the resistor under test R_T, the isolation resistor R_M and the calibration resistor R_Cal, where the isolation resistor R_M is required to reduce the shunting effect of the d.c. supply system on the noise generated in the resistor under test.



Key

P	DC voltage source		
G	Calibration source, f = 1 kHz		
S	Three position switch	Position 1:	Calibration
		Position 2:	System noise
		Position 3:	Total noise
R_M	Isolation resistor		
R_{Cal}	Calibration resistor, R_{Cal} = 1 Ω		
R_T	Resistor under test		
U_T	Test voltage, d.c.		
BPA	Band-pass amplifier with adjustable gain		
$U_{N\ rms}$	Noise voltage, a.c. r.m.s.		

Figure 1 – Block schematic of a suitable measuring system

The following content of this International Standard refers to this suitable measuring system, unless otherwise specified.

4.3.2 Alternative measuring systems

The proposal of a measuring system in 4.3.1 intends to unify the test and measurement procedures used for the assessment of the current noise generated in fixed resistors. This system, however, is not necessarily the only system which can be used, except when specifically designated as referee or reference methods.

The provider and user of any alternative measuring system shall demonstrate that such system will give results equivalent to those obtained by the proposed system.

4.4 Measurement system requirements

4.4.1 Input circuit

The input impedance of the measurement system is influenced by the impedance of the d.c. electronic voltmeter, which is in parallel with the isolation resistor R_M and also with the resistor under test, and thereby attenuates the noise signal generated in the specimen.

The input impedance of the d.c. electronic voltmeter shall meet the impedance requirement given in 4.4.4 in order to avoid any detrimental influence on the measurement.

4.4.2 Isolation resistor R_M

A number of current noise free isolation resistors R_M will be needed to cover the range of resistance values of the specimen, which may be switched into the circuit as required. The isolation resistor shall be current noise-free (for example, good quality wirewound resistors). Each isolation resistor shall have a rated dissipation of at least 1 W and the resistance tolerance shall be ±1 %.

At least four isolation resistors R_M are required if the range of specimen resistance extends from 100 Ω to 22 MΩ. Examples for suitable values of R_M are 1 kΩ; 10 kΩ; 100 kΩ and 1 MΩ. These values are used for establishing the test conditions in Table 2.

4.4.3 DC voltage source

The d.c. voltage source shall be capable of supplying a suitable range of voltages, which depends on the specimen resistance R_T, on the required test voltage U_T, and on the isolation resistor R_M. The adjusted d.c. test voltage shall be maintained sufficiently stable throughout a measurement.

Table 2 provides recommended operating conditions for the specimen resistance R_T in the range from 100 Ω to 22 MΩ, leading to test voltages U_T in the range from 2,2 V to 250 V. In order to achieve this, the d.c. voltage source is required to provide a voltage adjustable in the range of 14 V through 500 V.

There may be some hum and noise interference introduced by the d.c. voltage source when it drives a current through the resistor under test. The influence of this on the observed noise index shall not exceed 0,5 dB, when the connected test resistor is known not to generate any current noise itself (e.g. a good quality wirewound or metal foil resistor).

4.4.4 DC electronic voltmeter

The voltmeter used for measuring the d.c. test voltage U_T shall have a constant impedance of at least 4 MΩ in the frequency range from 0 Hz to 1 600 Hz.

The meter, in conjunction with a step attenuator, shall be capable of indicating the required d.c. test voltages with an accuracy of ±3 %. The time constant shall be less than 0,5 s.

The meter shall support the reading of the d.c. test voltage U_T in volt, and the reading of the d.c. test voltage index D in dB, which is determined by

$$D = 20 \lg\left(\frac{U_T}{1\,\text{V}}\right) \text{dB}$$

There may be some interference introduced by the voltmeter when it is connected to the input circuit. The influence of this on the observed noise index shall not exceed 0,2 dB.

4.4.5 Calibration resistor R_{Cal}

The calibration resistor R_{Cal} shall meet the following specification details:

$$R_{Cal} = 1{,}00\ \Omega$$

$$P_r \geq 0{,}5\ \text{W}$$

The calibration resistor shall be selected for the lowest possible generation of current noise (e.g. a good quality wirewound or metal foil resistor).

4.4.6 Calibration source

The calibration source shall be a stable sine-wave generator with a fixed frequency within the range of 980 Hz to 1 020 Hz. Its output shall supply a voltage across the calibration resistor R_{Cal}, which is adjustable within a range from 0,6 mV to 0,7 mV, where the actual required calibration voltage is determined in 4.4.7. The stability of the adjusted calibration voltage shall be better than ±2 %.

The calibration source is connected to the measuring system only in calibration mode.

4.4.7 Determination of the calibration voltage

The calibration voltage U_{Cal} is determined to produce a noise meter reading equal to that produced by a current-noise voltage having an r.m.s. value of 1 mV in a frequency decade.

In 4.1.3 it has been shown that the effective current noise voltage depends of the d.c. current and of the cut-off frequencies of the ideal band-pass like

$$E_{\mathrm{c}}{}^2 \sim I^2 \ln\left(\frac{f_2}{f_1}\right)$$

where

E_{c} is the effective voltage of the current noise in a given bandwidth;

I is the d.c. current passing through the resistor;

f_1 is the lower cut-off frequency of the ideal band-pass;

f_2 is the upper cut-off frequency of the ideal band-pass.

For a frequency decade and an ideal band-pass the relationship of the two cut-off frequencies is

$$f_2 = 10\,f_1$$

For the considered reference condition with

$$E_{\mathrm{c}} = 1 \text{ mV}$$

the above relationship is

$$(1 \text{ mV})^2 \sim I^2 \ln(10)$$

where

I is the d.c. current passing through the resistor.

For this method an ideal band-pass filter of 1 kHz bandwidth, geometrically centered at 1 kHz shall be used, with a lower cut-off frequency f_1 = 618 Hz and an upper cut-off frequency f_2 = 1 618 Hz, see 4.4.8.

For this condition applies

$$E_c = U_{Cal}$$

and hence the above relationship is

$$(U_{Cal})^2 \sim I^2 \ln\left(\frac{f_2}{f_1}\right)$$

where

U_{Cal} is the calibration voltage required to achieve a 1 mV per frequency decade reading;

I is the d.c. current passing through the resistor;

f_1 is the lower cut-off frequency of the ideal band-pass;

f_2 is the upper cut-off frequency of the ideal band-pass.

Dividing $(U_{Cal})^2$ by $(1\ mV)^2$ results in

$$\frac{(U_{Cal})^2}{(1\,mV)^2} = \frac{\ln\left(\frac{f_2}{f_1}\right)}{\ln(10)}$$

and finally in the determination of the calibration voltage as

$$U_{Cal} = \sqrt{\frac{\ln\left(\frac{f_2}{f_1}\right)}{\ln(10)}} \times 1\,mV$$

For practical use this equation may be simplified to

$$U_{Cal} = \sqrt{A} \cdot 0{,}659\ mV$$

where

A is a non-dimensional value representing the area under the pass-band curve

$$A = \ln\frac{f_2}{f_1}$$

where

f_1 is the lower cut-off frequency of the ideal band-pass;

f_2 is the upper cut-off frequency of the ideal band-pass.

For the prescribed ideal band-pass filter of 1 kHz bandwidth, geometrically centered at 1 kHz, the calculation results in A_i = 0,962.

Hence, for this case the required calibration voltage is

$$U_{Cal} = \sqrt{0{,}962} \times 0{,}659\ mV = 0{,}646\ mV$$

For any particular non-ideal band-pass filter, value A can be computed as follows.

a) The voltage gain is measured throughout the pass-band of the system versus frequency, where the voltage gain is the ratio of the output voltage, as indicated by the output meter, to the input voltage, applied across the terminals of the calibration resistor.
b) The power gain is calculated by squaring of the voltage gain for each frequency.
c) Each power gain value is divided by its respective frequency and plotted against frequency in a linear diagram.
d) The area under the resulting curve is planimetrically measured to give the value A for the respective non-ideal band-pass filter, where the accuracy of this determination shall be within ±2,5 % of the result.

Where there is the result of a numerical simulation available of the gain over frequency of a designed band-pass filter, with the gain typically given in dB, the procedure described above can be executed numerically, e.g. using a calculation spreadsheet.

The resulting value A should be close to the result for an ideal band-pass, A_i = 0,962.

NOTE The numerical determination of the area under the pass-band shown in Figure 2 results in a value A = 0,959, which leads to a required calibration voltage U_{Cal} = 0,645 mV.

The calibration source shall be adjusted to provide the r.m.s. voltage U_{Cal} at the terminals of the calibration resistor R_{Cal} with a relative accuracy of better than ±2 %.

4.4.8 AC band-pass amplifier

The amplifier gain shall be sufficient to measure circuit noise with the input terminals shorted and with the adjustable gain control, described below, set near its minimum gain position.

In a verification with $R_M \geq$ 100 kΩ and no d.c. current present, the circuit noise shall be no greater than that equivalent to the thermal noise of a 6,2 kΩ resistor. Therefore, the increase in the output reading when the short is replaced by a resistor of 6,2 kΩ with a relative tolerance of ±5 % shall be at least 3 dB with the gain control setting kept unchanged.

The amplifier shall be capable of measuring input signals up to 650 μV. This signal amplitude gives a scale reading of approximately 60 dB when the system is calibrated.

A continuously adjustable gain control shall be provided for maintaining a fixed overall system gain which would otherwise vary with input conditions listed in Table 2. The necessary gain control range is approximately 33 dB.

The pass-band shall be flat, shall have a fixed half-power pass-band of approximately 1 000 Hz within the limits ±50 Hz and shall be geometrically centered at 1 000 Hz ± 50 Hz. Ripple in the flat top of the pass-band shall not exceed ±0,2 dB. Figure 2 shows the transfer function of a band-pass meeting these requirements.

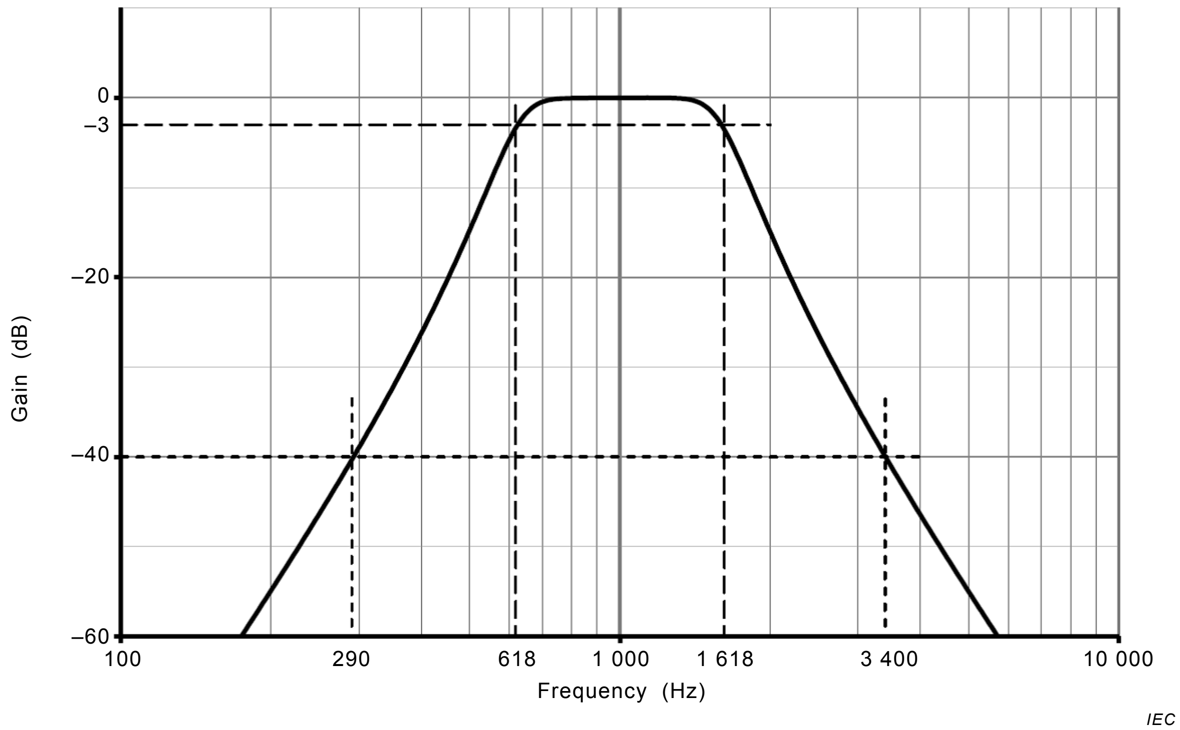


Figure 2 – Typical transfer function of the band-pass amplifier

These requirements shall be satisfied for all measurement conditions listed in Table 2. Neither the area under the pass-band, A, as determined in 4.4.7, nor the half-power pass-band shall vary with respect to measurement condition by more than ±4 % for any recommended measurement condition. Compliance at 100 Ω and at 22 MΩ is considered sufficient.

The a.c. amplifier shall respond to noise signals without introducing a significant error due to clipping. This requires the dynamic range to extend at least 10 dB beyond the indicated a.c. r.m.s. value.

4.4.9 AC r.m.s. meter

The a.c. measuring system shall be calibrated in dB from −20 dB to at least +60 dB with 0 dB being 1 μV in a frequency decade. The accuracy of the a.c. r.m.s. meter shall be ±0,4 dB. The time constant shall be in the range of 0,8 s to 1,5 s.

4.4.10 Test fixture

The test fixture for the resistor under test, R_T, shall be capable of providing a safe electrical connection and sufficient shielding from any external fields.

The lead-to-lead and lead-to-ground capacitances of the resistor under test in its test fixture and of the leads to the input of the band-pass amplifier shall be minimized, e.g. by the use of short leads, adequate spacing and careful mounting.

Good shielding practice shall be adopted in the construction of the measurement system. The input circuit operates at extremely low signal levels, which makes it necessary that all parts and leads in the input circuit be very well shielded. Components carrying large signals should not be located near the input circuit.

4.5 Verification of the measuring system

4.5.1 Performance check by measurement of instrument and thermal noise

It is recommended to verify the performance of the measurement system by checking the level of system noise, including thermal noise, without involving any specimen.

For a measurement system as proposed in 4.3, the following procedure should be applied:

a) turn the function switch to “calibration” and short-circuit the terminals for the specimen R_T;

b) adjust the gain of the band-pass amplifier to the calibrate line on the a.c. r.m.s. meter;

NOTE The calibration line typically is a line centred on the a.c. r.m.s. meter scale. With the measuring system set in calibration mode the meter is connected without an attenuator network.

c) turn the function switch to “system noise” and read the noise index S_k;

d) remove the short circuit from the terminals for the specimen R_T;

e) read the noise index S_o for each isolation resistor R_M.

The readings of the noise index should fall within the limits given in Table 1, unless other recommendations are given for a specific measuring system.

Table 1 – Permissible limits of system noise

R_M	R_T	Permissible limits of system noise reading dB
Any	Short circuit	$S_k \leq -5$ dB
1 kΩ	None, terminals open	-9 dB $\leq S_o \leq -4{,}5$ dB
10 kΩ	None, terminals open	-5 dB $\leq S_o \leq -2$ dB
100 kΩ	None, terminals open	5 dB $\leq S_o \leq 7{,}5$ dB
1 MΩ	None, terminals open	14 dB $\leq S_o \leq 18$ dB
The first two readings are essentially measurements of the noise in the amplifier, while the last two readings are essentially measurements of thermal noise of R_M in the pass-band of the instrument. The third reading is influenced by both factors.		

There may be different performance check procedures and permissible limits prescribed for practical realizations of the measurement system proposed in 4.3.1, or for alternative measuring systems as suggested in 4.3.2.

4.5.2 Performance check by comparison of repeated measurements

It is recommended to verify the performance of the measurement system by checking the current noise of specific resistor specimens after repeated measurements.

A practical means of monitoring the stability of the measurement system is to keep a record of the measurements made on a set of specific control resistors, where it is desirable for the set of control resistors to consist of different types of resistors and to represent a large range of resistance and current-noise values.

Plotting the data against time in the form of a control chart for each specimen is suggested as a simple and effective means for detecting any irregularity within the measurement system.

5 Measurement procedure

5.1 Ambient conditions

The measurement shall preferably be made under standard atmophere for referee measurements and test as given in IEC 60068-1:2013, 4.2.

– Temperature: 23 °C ± 2 °C
– Relative humidity: 45 % to 55 %
– Air pressure: 86 kPa to 106 kPa

A relevant specification may prescribe other ambient conditions for this measurement.

NOTE The generally applied standard atmospheric conditions for testing with their wider permissible temperature range are not recommendable for this test due to the influence of temperature on the measurement, e.g. by means of thermal noise.

5.2 Preparation of specimen

The specimen shall be stored at the ambient conditions prescribed in 5.1 for at least 24 h before a measurement is made.

5.3 Procedure

5.3.1 General

The measurement system shall be stored at the ambient conditions prescribed in 5.1 for at least 24 h before a measurement is made.

The complete operation consists of three consecutive steps:

a) calibration;
b) measurement of system noise;
c) simultaneous measurement of total noise and of the d.c. voltage across the specimen.

Considerable saving of time can be achieved when groups of similar resistors are to be measured by taking advantage of the stability of the particular test equipment. The intervals with which the calibration and system noise measurements shall be repeated will be dependent on the stability of the equipment and on the accuracy required.

5.3.2 Calibration

The resistor to be tested, R_{T}, shall be inserted into the test fixture, and the appropriate isolation resistor R_{M} shall be switched into the circuit. The allocation given in Table 2 shall apply, unless other provisions are made by the relevant specification.

With the measuring system set into configuration for calibration, the isolation resistor R_{M} is connected to ground instead of to the d.c. voltage source, and the 1 000 Hz calibration voltage is connected to the calibration resistor R_{Cal}.

The gain control of the band-pass amplifier shall be adjusted so that the noise voltage meter indicates +60 dB, or its equivalent 1 mV, in a frequency decade.

5.3.3 Measurement of system noise S

The connection of the specimen R_{T} and of the isolation resistor R_{M} shall remain as set in 5.3.2.

With the measuring system configured to measure system noise, the isolation resistor R_M is connected to ground instead of to the d.c. voltage source, and the calibration resistor R_{Cal} is disconnected from the calibration voltage.

The system noise index S is read on the noise voltage meter after a minimum delay of 5 s, allowing the meter to reach a representative mean value.

5.3.4 Measurement of total noise T

The connection of the specimen R_T and of the isolation resistor R_M shall remain as set in 5.3.2.

With the measuring system configured to measure total noise, the isolation resistor R_M is connected to the d.c. voltage source in order to pass a current through the resistor under test, R_T. The calibration resistor R_{Cal} is disconnected from the calibration voltage.

The d.c. voltage U_T shall be set according to the prescription given in Table 2, unless other provisions are made by the relevant specification, e.g. in consideration of the dissipation rating of a particular style of resistors. For values of R_T not contained in Table 2, it is suitable to apply the parameters for the next lower given value.

The d.c. test voltage index D, is read on the d.c. voltmeter, and the total noise index T is read on the noise voltage meter after a minimum delay of 5 s, allowing the meter to reach a representative mean value.

Table 2 – Recommended operating conditions *(1 of 2)*

R_T	R_M	P_r ≥ 0,5 W			0,5 W > P_r ≥ 0,1 W			0,1 W > P_r		
		U_T V	D dB	P_T mW	U_T V	D dB	P_T mW	U_T V	D dB	P_T mW
100 Ω	1,0 kΩ	3,2	10,0	100	3,2	10,0	100	2,2	7,0	50
120 Ω	1,0 kΩ	3,8	11,6	120	3,5	10,8	100	2,4	7,8	50
150 Ω	1,0 kΩ	4,7	13,5	150	3,9	11,8	100	2,7	8,8	50
180 Ω	1,0 kΩ	5,7	15,1	180	4,2	12,6	100	3,0	9,5	50
220 Ω	1,0 kΩ	7,0	16,8	220	4,7	13,4	100	3,3	10,4	50
270 Ω	1,0 kΩ	8,2	18,3	250	5,2	14,3	100	3,7	11,3	50
330 Ω	1,0 kΩ	9,1	19,2	250	5,7	15,2	100	4,1	12,2	50
390 Ω	1,0 kΩ	9,9	19,9	250	6,2	15,9	100	4,4	12,9	50
470 Ω	1,0 kΩ	10,8	20,7	250	6,9	16,7	100	4,8	13,7	50
560 Ω	1,0 kΩ	11,8	21,5	250	7,5	17,5	100	5,3	14,5	50
680 Ω	1,0 kΩ	13,0	22,3	250	8,2	18,3	100	5,8	15,3	50
820 Ω	1,0 kΩ	14,3	23,1	250	9,1	19,1	100	6,4	16,1	50
1,0 kΩ	1,0 kΩ	15,8	24,0	250	10,0	20,0	100	7,1	17,0	50
1,2 kΩ	1,0 kΩ	17,3	24,8	250	11,0	20,8	100	7,7	17,8	50
1,5 kΩ	1,0 kΩ	19,4	25,7	250	12,2	21,8	100	8,7	18,8	50
1,8 kΩ	1,0 kΩ	21,2	26,5	250	13,4	22,6	100	9,5	19,5	50
2,2 kΩ	1,0 kΩ	23,5	27,4	250	14,8	23,4	100	10,5	20,4	50
2,7 kΩ	10 kΩ	26,0	28,3	250	16,4	24,3	100	11,6	21,3	50
3,3 kΩ	10 kΩ	28,7	29,2	250	18,2	25,2	100	12,8	22,2	50
3,9 kΩ	10 kΩ	31,2	29,9	250	19,7	25,9	100	14,0	22,9	50
4,7 kΩ	10 kΩ	34,3	30,7	250	21,7	26,7	100	15,3	23,7	50
5,6 kΩ	10 kΩ	37,4	31,5	250	23,7	27,5	100	16,7	24,5	50
6,8 kΩ	10 kΩ	41,2	32,3	250	26,1	28,3	100	18,4	25,3	50
8,2 kΩ	10 kΩ	45,3	33,1	250	28,6	29,1	100	20,2	26,1	50
10 kΩ	10 kΩ	50,0	34,0	250	31,6	30,0	100	22,4	27,0	50
12 kΩ	10 kΩ	54,8	34,8	250	34,6	30,8	100	24,5	27,8	50
15 kΩ	10 kΩ	61,2	35,7	250	38,7	31,8	100	27,4	28,8	50
18 kΩ	10 kΩ	67,1	36,5	250	42,4	32,6	100	30,0	29,5	50
22 kΩ	10 kΩ	74,2	37,4	250	46,9	33,4	100	33,2	30,4	50
27 kΩ	100 kΩ	82,2	38,3	250	52,0	34,3	100	36,7	31,3	50
33 kΩ	100 kΩ	90,8	39,2	250	57,4	35,2	100	40,6	32,2	50
39 kΩ	100 kΩ	98,7	39,9	250	62,4	35,9	100	44,2	32,9	50
47 kΩ	100 kΩ	108	40,7	250	68,6	36,7	100	48,5	33,7	50
56 kΩ	100 kΩ	118	41,5	250	74,8	37,5	100	52,9	34,5	50
68 kΩ	100 kΩ	130	42,3	250	82,5	38,3	100	58,3	35,3	50
82 kΩ	100 kΩ	143	43,1	250	90,6	39,1	100	64,0	36,1	50

Table 2 *(2 of 2)*

R_T	R_M	$P_r \geq$ 0,5 W			0,5 W > $P_r \geq$ 0,1 W			0,1 W > P_r		
		U_T V	D dB	P_T mW	U_T V	D dB	P_T mW	U_T V	D dB	P_T mW
100 kΩ	100 kΩ	158	44,0	250	100	40,0	100	70,7	37,0	50
120 kΩ	100 kΩ	173	44,8	250	110	40,8	100	77,5	37,8	50
150 kΩ	100 kΩ	194	45,7	250	122	41,8	100	86,6	38,8	50
180 kΩ	100 kΩ	212	46,5	250	134	42,6	100	94,9	39,5	50
220 kΩ	100 kΩ	235	47,4	250	148	43,4	100	105	40,4	50
270 kΩ	100 kΩ	250	48,0	231	164	44,3	100	116	41,3	50
330 kΩ	100 kΩ	250	48,0	189	182	45,2	100	129	42,2	50
390 kΩ	100 kΩ	250	48,0	160	197	45,9	100	140	42,9	50
470 kΩ	100 kΩ	250	48,0	133	217	46,7	100	153	43,7	50
560 kΩ	100 kΩ	250	48,0	112	237	47,5	100	167	44,5	50
680 kΩ	100 kΩ	250	48,0	92	250	48,0	92	184	45,3	50
820 kΩ	100 kΩ	250	48,0	76	250	48,0	76	202	46,1	50
1,0 MΩ	100 kΩ	250	48,0	63	250	48,0	63	224	47,0	50
1,2 MΩ	100 kΩ	250	48,0	52	250	48,0	52	245	47,8	50
1,5 MΩ	100 kΩ	250	48,0	42	250	48,0	42	250	48,0	42
1,8 MΩ	1,0 MΩ	250	48,0	35	250	48,0	35	250	48,0	35
2,2 MΩ	1,0 MΩ	250	48,0	28	250	48,0	28	250	48,0	28
2,7 MΩ	1,0 MΩ	250	48,0	23	250	48,0	23	250	48,0	23
3,3 MΩ	1,0 MΩ	250	48,0	19	250	48,0	19	250	48,0	19
3,9 MΩ	1,0 MΩ	250	48,0	16	250	48,0	16	250	48,0	16
4,7 MΩ	1,0 MΩ	250	48,0	13	250	48,0	13	250	48,0	13
5,6 MΩ	1,0 MΩ	250	48,0	11	250	48,0	11	250	48,0	11
6,8 MΩ	1,0 MΩ	250	48,0	9,2	250	48,0	9,2	250	48,0	9,2
8,2 MΩ	1,0 MΩ	250	48,0	7,6	250	48,0	7,6	250	48,0	7,6
10 MΩ	1,0 MΩ	250	48,0	6,3	250	48,0	6,3	250	48,0	6,3
12 MΩ	1,0 MΩ	250	48,0	5,2	250	48,0	5,2	250	48,0	5,2
15 MΩ	1,0 MΩ	250	48,0	4,2	250	48,0	4,2	250	48,0	4,2
18 MΩ	1,0 MΩ	250	48,0	3,5	250	48,0	3,5	250	48,0	3,5
22 MΩ	1,0 MΩ	250	48,0	2,8	250	48,0	2,8	250	48,0	2,8

The values for this table are established under the following prerequisites:

– The voltage to be provided by the internal d.c. voltage source shall not exceed 400 V.
– The voltage U_T at the resistor specimen shall not exceed 250 V.
– The dissipation on the isolation resistor R_M shall not exceed 1 W.
– The allocation of isolation resistors R_M to specimen resistance R_T shall apply to all specimen styles.

Key

P_r is the rated dissipation of the resistor specimen under test

R_T is the resistance of the resistor specimen under test

R_M is the isolation resistor

U_T is the d.c. voltage applied to the specimen

D is the d.c. test voltage index, D = 20 lg (U_T/ 1 V) dB

P_T is the power dissipated in the specimen

5.4 Precautions

Reasonable precautions such as are commonly associated with sensitive measurements should be followed when operating the test set. The operating location should be free of strong magnetic and electric fields and of sources of electro-magnetic radiation. Ordinarily, it need not be operated in a screened room. The location should be free from strong mechanical vibrations and from sources of loud sound. These precautions are mentioned to serve as a guide in selecting suitable locations. The suitability of a location can be determined by comparing test set performance in the selected location with that obtained in a "quiet" location. Usually, sources of interference are readily identifiable.

6 Evaluation of measurement results

6.1 Term for the contribution of system noise

The total noise voltage is the geometric sum of the system noise voltage and the current-noise voltage of the resistor under test

$$E_t^2 = E_s^2 + E_c^2$$

where

E_t is the effective total noise voltage in a given bandwidth;

E_s is the effective system noise voltage in a given bandwidth;

E_c is the effective current noise voltage in a given bandwidth.

NOTE For practical reasons, these noise voltages are generally given in μV.

This equation can be rearranged for E_c

$$E_c^2 = E_t^2 - E_s^2$$

Each noise voltage can be replaced by a term based on its logarithmic index,

$$C = 20\lg\left(\frac{E_c}{1\,\mu\text{V}}\right)\text{dB} \qquad \text{hence} \qquad E_c = 10^{\left(\frac{C}{20\,\text{dB}}\right)} \times 1\,\mu\text{V}$$

$$T = 20\lg\left(\frac{E_t}{1\,\mu\text{V}}\right)\text{dB} \qquad \text{hence} \qquad E_t = 10^{\left(\frac{T}{20\,\text{dB}}\right)} \times 1\,\mu\text{V}$$

$$S = 20\lg\left(\frac{E_s}{1\,\mu\text{V}}\right)\text{dB} \qquad \text{hence} \qquad E_s = 10^{\left(\frac{S}{20\,\text{dB}}\right)} \times 1\,\mu\text{V}$$

where

C is the logarithmic index of the current noise voltage, scaled at 0 dB = 1 μV;

T is the logarithmic index of the total noise voltage, scaled at 0 dB = 1 μV;

S is the logarithmic index of the system noise voltage, scaled at 0 dB = 1 μV.

This leads to the equation

$$\left(10^{\frac{C}{20\text{ dB}}}\right)^2 = \left(10^{\frac{T}{20\text{ dB}}}\right)^2 - \left(10^{\frac{S}{20\text{ dB}}}\right)^2$$

Solving this equation for C and isolating T results in the following expression,

$$C = T + 10\lg\left(1 - 10^{-\left[\frac{T-S}{10\text{ dB}}\right]}\right)\text{dB}$$

which permits to isolate a term for the contribution of system noise in relationship to the total noise, $f(T\text{-}S)$

$$C = T - f(T - S)\,.$$

This function of the difference between total noise and system noise itself hence is defined as

$$f(T - S) = -10\lg\left(1 - 10^{-\left[\frac{T-S}{10\text{ dB}}\right]}\right)\text{dB}$$

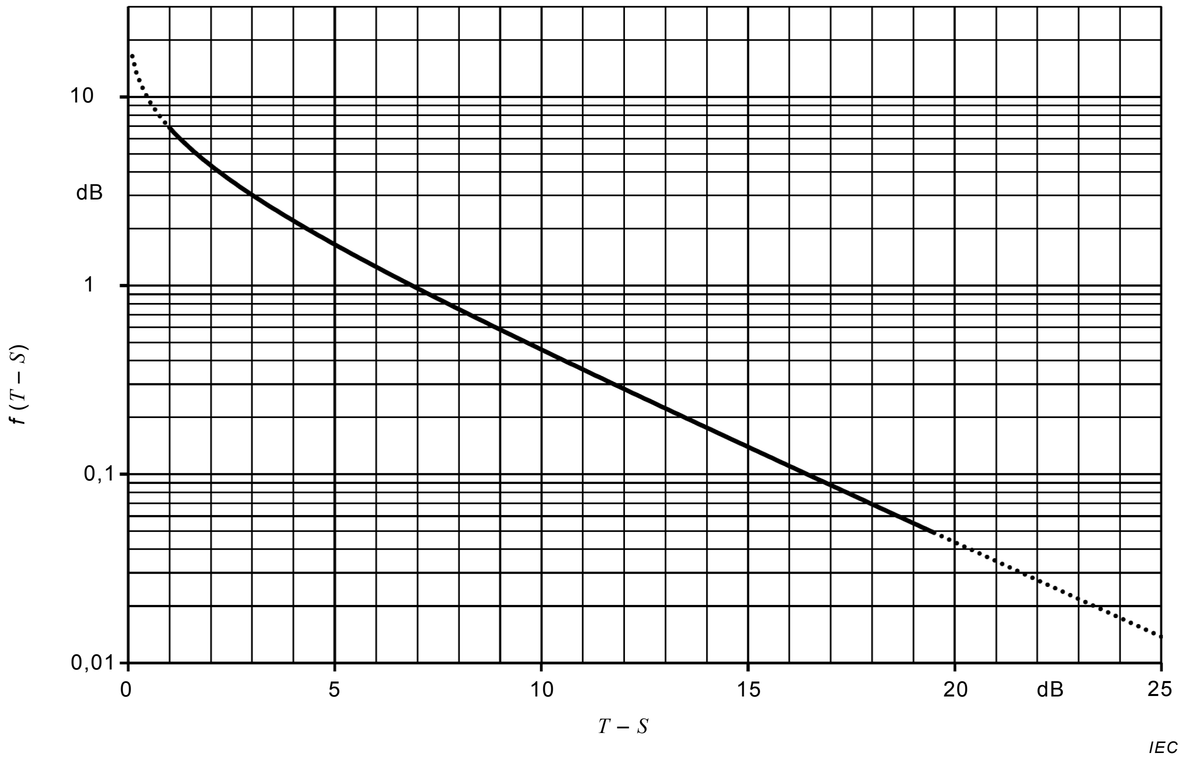


Figure 3 – Contribution of system noise, $f(T - S)$

Figure 3 shows the result of $f(T - S)$ plotted over $(T - S)$ and illustrates the special considerations discussed below.

– The accuracy of the determination of the current-noise deteriorates if the total noise approaches the system noise, which is the case for $(T - S) < 1{,}0$ dB. For such a case the reporting of seemingly accurate values for the current-noise index A_1.is no longer appropriate.

– The contribution of the system noise may be ignored if $f(T - S)$ does not provide a result which, rounded to one decimal, is at least 0,1 dB. This is the case for $(T - S) > 19{,}5$ dB.

For the reader's convenience, Table 3 provides numerical values of the contribution of system noise, rounded to one decimal.

Table 3 – Numeric values of the contribution of system noise, $f(T - S)$

$T - S$ dB	$f(T - S)$ dB	$T - S$ dB	$f(T - S)$ dB	$T - S$ dB	$f(T - S)$ dB
<1,0	7,0 [a]	2,9	3,1	5,0	1,7
		3,0	3,0	5,1	1,6
1,0	6,9	3,1	2,9	5,2	1,6
1,1	6,5	3,2	2,8	5,3	1,5
1,2	6,2	3,3	2,7	5,4	1,5
1,3	5,9	3,4	2,7	5,5 to 5,7	1,4
1,4	5,6	3,5	2,6	5,8 to 6,0	1,3
1,5	5,3	3,6	2,5	6,1 to 6,3	1,2
1,6	5,1	3,7	2,4	6,4 to 6,6	1,1
1,7	4,9	3,8	2,3	6,7 to 7,0	1,0
1,8	4,7	3,9	2,3	7,1 to 7,5	0,9
1,9	4,5	4,0	2,2	7,6 to 7,9	0,8
2,0	4,3	4,1	2,1	8,0 to 8,5	0,7
2,1	4,2	4,2	2,1	8,6 to 9,2	0,6
2,2	4,0	4,3	2,0	9,3 to 10,0	0,5
2,3	3,9	4,4	2,0	10,1 to 11,1	0,4
2,4	3,7	4,5	1,9	11,2 to 12,5	0,3
2,5	3,6	4,6	1,8	12,6 to 14,6	0,2
2,6	3,5	4,7	1,8	14,7 to 19,4	0,1
2,7	3,3	4,8	1,7	≥19,5	0
2,8	3,2	4,9	1,7		

[a] The value $f(T - S) = 7$ dB given for $(T - S) < 1{,}0$ dB should be applied only for the determination of a maximum current noise index $A_{1\,max}$.

6.2 Determination of the current-noise index A_1

The current noise index in a frequency decade, A_1, is determined by the quotient of the current-noise voltage in a frequency decade, E_c, over the applied d.c. voltage U_T.

The mathematical index A_1' is based on dividing the current noise voltage and d.c. voltage with proper consideration of the multiples of their unit volt, which with their logarithmic indexes C' and D is presented as

$$A_1' = C' - D$$

where

C' is the logarithmic index of the current noise voltage, scaled at 0 dB = 1 V;

D is the logarithmic index of the d.c. voltage U_T applied to the specimen, scaled at 0 dB = 1 V.

The practical index A_1 is based on dividing the current noise voltage and d.c. voltage in their individual units and multiples, which with their logarithmic indexes C and D is presented as

$$A_1 = C - D$$

where

C is the logarithmic index of the current noise voltage, scaled at 0 dB = 1 μV.

The difference of 120 dB between the two indexes A_1' and A_1

$$A_1 = A_1' - 120 \text{ dB} .$$

is generally neglected.

Applying the definition of $f(T - S)$ from above (see 6.1), leads to the following standard equation for the determination of the current noise index A_1

$$A_1 = T - f(T - S) - D$$

The readings of the total noise index T, the system noise index S, both scaled at 0 dB = 1 μV, and the index D of the applied d.c. voltage U_T, scaled at 0 dB = 1 V, shall be used to calculate the current noise index A_1.

The following special consideration applies.

If the measured total noise approaches the measured system noise, hence if

$$(T - S) < 1{,}0 \text{ dB}$$

and thus the accuracy of the determination deteriorates, it is not recommended to use this method for the determination of a current-noise index A_1 with a pretended accuracy.

In such case the current-noise should only be reported as being less than a maximum current-noise index $A_{1\ max}$, which is determined by

$$A_{1\ max} = T - 7 \text{ dB} - D$$

6.3 Determination of the current-noise voltage ratio CNR_U

The current-noise voltage ratio in a frequency decade CNR_U

$$CNR_U = \frac{E_c}{U_T}$$

is derived from an established current-noise index A_1 by calculating

$$CNR_U = 10^{\frac{A_1}{20\ \text{dB}}} \cdot \frac{\mu\text{V}}{\text{V}}$$

6.4 Accuracy

The accuracy of the noise voltage measurement shall be ±0,75 dB. The accuracy of determinations of the current-noise index shall be ±1 dB when the current noise is large compared to the system noise, i.e. ($T - S$) is greater than 15 dB.

It is not uncommon for certain resistors to exhibit noise measurement variations greater than 0,75 dB. It should therefore be recognized that lack of agreement of repeated measurements on such resistors does not necessarily reflect a loss of accuracy of the measuring system, but is an indication of a noise property of the resistor.

6.5 Requirements

Acceptance criteria for the current noise of tested products shall be given with reference to a required maximum current-noise index A_1 in the relevant component specification.

Such acceptance criteria should be stated through a fixed maximum value, typically given as function of the specimen resistance.

7 Information to be given in the relevant component specification

When this test is included in a relevant component specification, the following details shall be given as far as they are required or applicable:

	Subclause
The environmental conditions for this measurement	5.1
The dissipation to be provided through the applied d.c. voltage	5.3.4, Table 2
A limitation to the applied d.c. voltage, if applicable	5.3.4, Table 2

The relevant component specification shall specify for its own purpose:

	Subclause
Acceptance criteria to the current noise index A_1	6.5

Annex A
(informative)

Letter symbols and abbreviations

A.1 Letter symbols

A	Non-dimensional figure representing the area of a pass-band in a gain-over-frequency diagram	1
A_1	Current-noise index in a frequency decade (see 3.2)	dB
C	Logarithmic index of the current noise voltage	dB
D	Logarithmic index of the d.c. bias voltage	dB
$e(f)$	Momentary current noise voltage as a function of frequency	μV
e_{th}	Momentary thermal noise voltage	μV
E_c	Effective (r.m.s) current noise voltage	μV
E_s	Effective (r.m.s) system noise voltage	μV
E_t	Effective (r.m.s) total noise voltage	μV
E_{th}	Effective (r.m.s) thermal noise voltage	μV
f	Frequency	Hz
f_1	Lower cut-off frequency of a band-pass filter	Hz
f_2	Upper cut-off frequency of a band-pass filter	Hz
f_c	Centre frequency of a band-pass filter	Hz
Δf	Pass-band of a band-pass filter	Hz
I	Current	A
k	Boltzmann constant, $k \approx 1{,}38 \times 10^{-23}$ J/K	J/K
R	Resistance	Ω
R_{Cal}	Resistance of the calibration resistor	Ω
R_M	Resistance of the isolation resistor	Ω
R_T	Resistance of the specimen	Ω
S	Logarithmic index of the system noise voltage	dB
S_k	Logarithmic index of the system noise voltage with shorted test terminals	dB
S_o	Logarithmic index of the system noise voltage with open test terminals	dB
T	Logarithmic index of the total noise voltage	dB
T	Absolute temperature	K
U_{Cal}	Calibration voltage	V
$U_{N\ rms}$	AC r.m.s. noise voltage	μV
U_T	DC test voltage applied to the specimen	V

A.2 Abbreviations

BPA	Band-pass amplifier
G	Calibration source, a.c. generator
P	DC power supply
S	Switch

Annex X
(informative)

Cross-reference for references to the prior revision of this standard

The revision of this standard has resulted in a new clause numbering. Table X.1 provides cross-references between the clause numbering of this edition compared to the first edition of this standard.

Table X.1 – Cross reference for references to the 1st edition of this standard

IEC 60195:1965 1st edition Clause	**IEC 60195:2016 2nd edition** Clause	**Notes**
1	1	Object and scope are merged into one new clause.
2		
3	3 4.1	–
4	4.3 4.4	–
4.1	4.4.1 4.4.2	–
4.2	4.2 4.4.3 4.4.4	–
4.3	4.4.6 4.4.8 4.4.9	–
4.4	4.3.1	–
5	4.4.6	–
6	5	–
6.1	5.3.2	–
6.2	5.3.3	–
6.3	5.3.4	–
6.4	6	–
7	6.3	–
8	–	The content of the prior Clause 8 is spread into new subclauses, see below.
8.1	4.4	–
8.2	5.4	–
8.3	4.5	–
Table I	Table 2	Table 2 is modified for a harmonized allocation of the suggested R_M to the indicated values of R_T. Table 2 is amended with a new set of recommended operating conditions for specimen with $P_r < 0,1$ W.
Table II	Figure 3 Table 3	Table 3 is re-calculated based on the given equation.

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