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INTERNATIONAL STANDARD

NORME INTERNATIONALE

Method of measurement of current noise generated in fixed resistors

Méthode pour la mesure du bruit produit en charge par les résistances fixes

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INTERNATIONAL
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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- withdrawn,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

$$E_{\mathrm{c}}^{2} = \int_{f_1}^{f_2} [e(f)]^2 \mathrm{d}f$$

$$\sim \int_{f_1}^{f_2} \frac{I^2}{f} \mathrm{d}f$$

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

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:

$$A_1' = 20 \lg\left(\frac{E_{\mathrm{C}}'}{U_{\mathrm{T}}}\right) \mathrm{dB}$$

where

E_{c}' is the effective open circuit current-noise voltage in a frequency decade, given in 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,

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

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

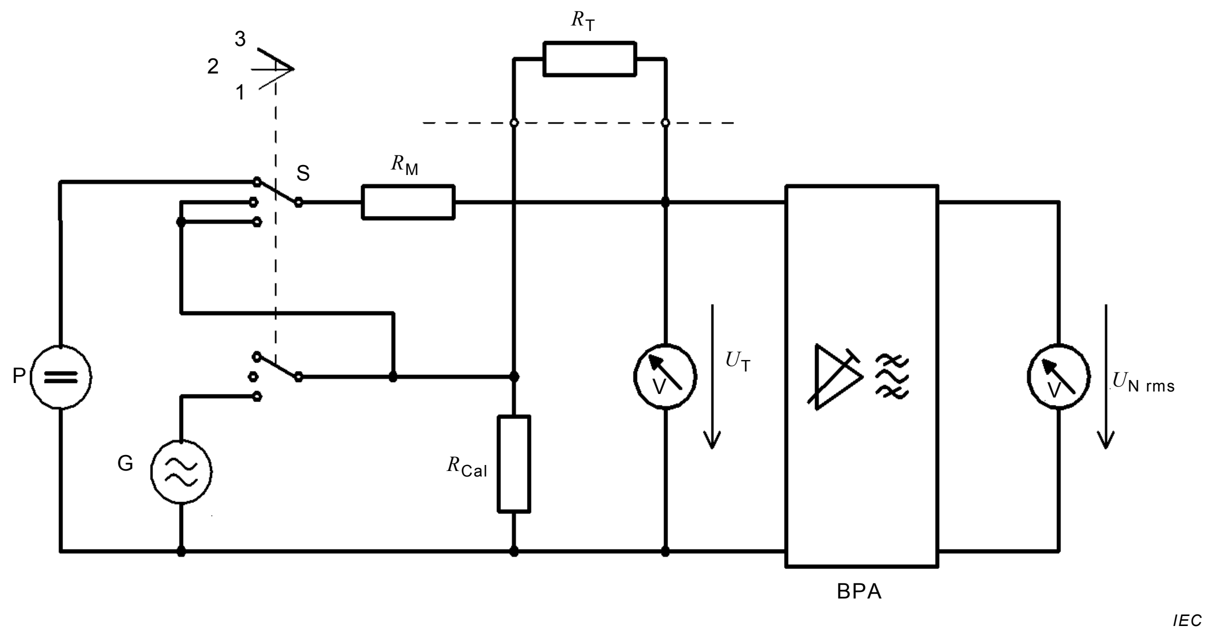
4.3.1 Proposal of a suitable measuring system

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

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

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:

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

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

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

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

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

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

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