IEC 60440

Edition 1.0 2012-07

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Method of measurement of non-linearity in resistors

Méthode de mesure de la non-linéarité des résistances

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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

COMMISSION
ELECTROTECHNIQUE
INTERNATIONALE

PRICE CODE
CODE PRIX Q

ICS 31.040

ISBN 978-2-83220-228-9

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METHOD OF MEASUREMENT OF NON-LINEARITY IN RESISTORS

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International Standard IEC 60440 has been prepared by committee 40: Capacitors and resistors for electronic equipment.

This International Standard cancels and replaces the Technical Report IEC/TR 60440, published in 1973.

The major changes with regard to the Technical Report are:

– change of the principle parameter's term from "third harmonic attenuation" to "third harmonic ratio";
– addition of advice on the prescription of requirements in a relevant component specification;
– addition of a set of recommended measuring conditions for a specimen with a rated dissipation of less than 100 mW;
– a complete editorial revision.

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

FDIS	Report on voting
40/2155/FDIS	40/2167/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 web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

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METHOD OF MEASUREMENT OF NON-LINEARITY IN RESISTORS

1 Scope

Non-linearity testing is a method to evaluate the integrity of a resistive element. It may be applied as an effective inline screening method suitable to detect and eliminate potential infant mortality failures in passive components. The method is fairly rapid, convenient, and the associated equipment is relatively inexpensive.

Typical effects causing non-linearity on resistors are e.g. inhomogeneous spots within a resistive film, traces of film left in the spiraling grooves, or contact instability between a connecting lead or termination and the resistive element.

This International Standard specifies a method of measurement and associated test conditions to assess the magnitude of non-linear distortion generated in a resistor. This method is applied if prescribed by a relevant component specification, or if agreed between a customer and a manufacturer.

2 Normative references

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

3 Terms and definitions

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

3.1
electromotive force
e.m.f.
difference in potential that tends to give rise to an electric current

3.2
non-linearity
deviation of a component’s impedance from Ohm’s law, resulting in voltage of harmonic frequencies when subjected to sinusoidal current

3.3
third harmonic ratio
A_3
ratio of the fundamental voltage over the e.m.f. of the third harmonic

Note 1 to entry: The third harmonic ratio is expressed in dB.

Note 2 to entry: The third harmonic ratio has been addressed before as third harmonic attenuation. This historic convention is misleading as it wrongly suggests harmonic frequencies originating from the test equipment being attenuated or filtered by the components under test. The misleading term should therefore be avoided.

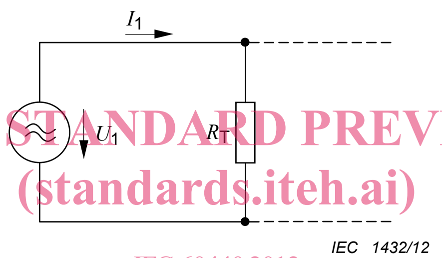
4 Method of measurement

4.1 Measurement principle

A pure sinusoidal current is passed through the component under test. If the impedance of the component is not perfectly linear, the voltage across the component will be distorted and contain harmonics. One or more of these harmonics can be measured and the magnitude of these distortions is a measure of the non-linearity in the component. It is recommended to measure the third harmonic, as it is the dominant one.

The third harmonic voltage appearing across a component needs to be separated from the fundamental voltage and from any other harmonic voltage for the measurement. This is accomplished by a filter circuit letting the harmonic voltage pass through while featuring very high impedance at the fundamental frequency. Also, the generator of the fundamental frequency needs to feature very high impedance at the third harmonic frequency so as not to act as a load to the generated distortions.

Hence, the equivalent circuit of the generator part operating at the fundamental frequency is quite simple, as shown in Figure 1.



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Key

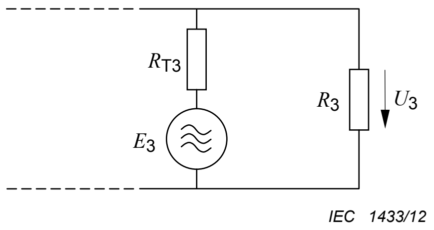
I_1 Sinusoidal current

U_1 Fundamental voltage across the resistor under test

R_T Impedance of the resistor under test at the fundamental frequency

Figure 1 – Equivalent circuit at the fundamental frequency

The equivalent circuit for the third harmonic frequency is built around the test specimen represented by a linear impedance with a zero-impedance harmonic generator in series. This signal source loads the measuring system represented by its impedance as seen from the test terminals, see Figure 2.



Key

E_3 e.m.f. of the third harmonic

R_{T3} Impedance of the resistor under test at the third harmonic frequency

R_3 Impedance of the measuring circuit at the third harmonic frequency, seen from the test terminals

U_3 Third harmonic voltage

Figure 2 – Equivalent circuit at the third harmonic frequency

In this circuit the e.m.f. of the third harmonic E_3 is divided into the measurable third harmonic voltage U_3

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$$U_3 = \frac{R_3}{R_3 + R_{T3}} \cdot E_3 \tag{1}$$

Hence, the e.m.f. of the third harmonic E_3 in the component can be determined by

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$$E_3 = \left(1 + \frac{R_{T3}}{R_3}\right) \cdot U_3 \tag{2}$$

The corrective term Δ for the reduction of U_3 to the origin E_3 is

$$\Delta = 20 \cdot \log_{10}\left(1 + \frac{R_{T3}}{R_3}\right) \tag{3}$$

In many cases it can be shown for a range of resistors under test that the impedance R_{T3} at the third harmonic frequency is equal or very close to the impedance R_T at the fundamental frequency. Then the corrective term Δ in decibels is

$$\Delta = 20 \cdot \log_{10}\left(1 + \frac{R_T}{R_3}\right) \tag{4}$$

NOTE 1 For fixed film resistors this equality of R_{T3} and R_T can generally be assumed with sufficient accuracy.

Numeric values for the corrective term Δ can be obtained from Figure 3 or for specific sets of impedance R_3 and specimen resistance R_T from Table 1.

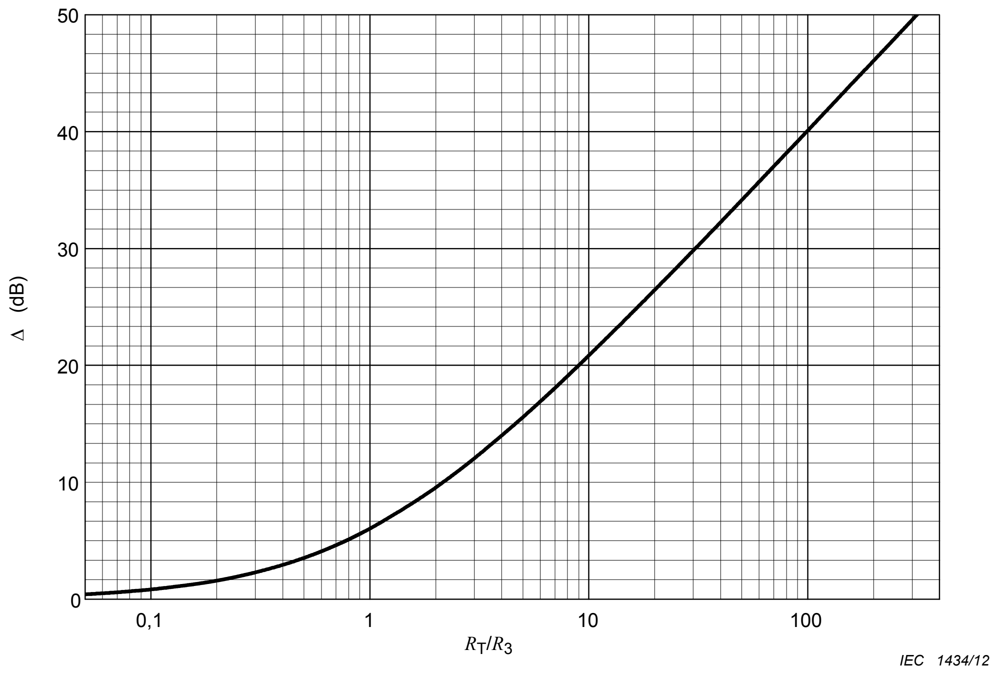

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Figure 3 – Corrective term Δ

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A suitable range for the fundamental frequency f_1 for measurements on resistors is between 10 kHz and 40 kHz. This frequency range enables the test circuit to be set up without too much difficulty.

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NOTE 2 Another method is using a bridge which is balanced at the fundamental frequency, where the harmonics appear across the bridge diagonal. This method requires individual balancing of the bridge for each specimen, which may be suitable for occasional use in a laboratory environment.

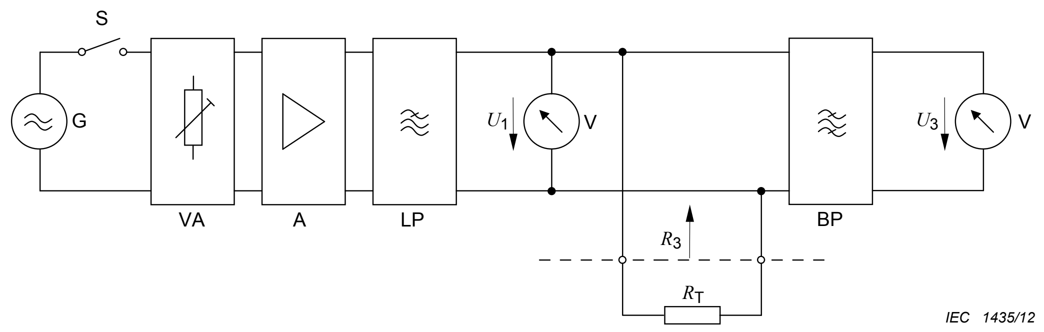
4.2 Measuring circuit

Figure 4 shows a block schematic of a suitable measuring circuit.

A distortion-free impedance matching device may be used to switch R_3 in order to achieve good matching to the test specimen R_T. Examples of suitable values of R_3 are 10 Ω; 100 Ω; 1 kΩ; 10 kΩ and 100 kΩ; these values are used for specifying the test conditions in Table 1.

The suitability of the measuring circuit for measurements on resistors with resistance values covering a wide range depends on the lowest and highest available impedance R_3 of the circuit. The range of values for R_3 proposed above grants suitability for measurements on specimen R_T with their resistance being in the range of 1 Ω to at least 10 MΩ.

However, there is an overriding influence of the correcting term Δ depending on the ratio of resistance under test R_T over impedance R_3, see Table 1 and Figure 3.



Key

G Oscillator, at the fundamental frequency f_1

S Switch for applying the test signal to the test specimen

VA Variable attenuator

A Power amplifier

LP Low-pass filter

U_1 r.m.s. voltage at the fundamental frequency f_1

BP Band-pass filter

U_3 r.m.s. voltage at the third harmonic frequency f_3

R_T Resistor under test

R_3 Impedance of the measuring circuit at the third harmonic frequency f_3, seen from the test terminals.

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Figure 4 – Block schematic of a suitable measuring system

4.3 Measurement system requirements

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4.3.1 Measuring frequency

The fundamental frequency f_1 shall be 10 kHz and thus the third harmonic frequency f_3 shall be 30 kHz, unless otherwise specified in the relevant component specification.

4.3.2 Noise level of the measuring system

The noise level referred to the test terminals shall not be higher than 0,2 μV at R_3 = 1 kΩ.

4.3.3 Third harmonic ratio of the measuring system

The third harmonic ratio $20 \cdot \log_{10}(U_1/E_3)$ shall be higher than 140 dB for most of the impedance range when the required dissipation P is applied to a virtually linear component.

The required dissipation is 0,25 VA, as given in Table 1, or a value prescribed by the relevant component specification, e.g with reference to the rated dissipation.

4.3.4 Power amplifier

The power amplifier shall be capable of delivering an apparent power of four times the required dissipation into a resistive component under test, in order to ensure sufficient linearity.

Hence, the power amplifier shall be capable of delivering an apparent power of 1 VA if the required dissipation is 0,25 VA as given in Table 1.

4.3.5 Voltmeter

The error of the voltmeter for measurement of the voltage U_1 at the fundamental frequency shall be less than 5 % of its full scale deflection.

The error of the voltmeter for measurement of the voltage U_3 at the third harmonic frequency shall be less than 10 % of its full scale deflection.

4.3.6 Filter

The cut-off frequency of the low-pass filter shall be immediately above the fundamental freuqency f_1.

The band-pass filter shall permit the third-harmonic frequency f_3 to pass through, while it shall provide very high attenuation at the fundamental frequency f_1.

Precautions shall be taken to avoid non-linear distortion from the components near the test specimen in the low-pass and band-pass filters. The filter inductors for instance shall not contain cores of magnetic material.

4.3.7 Test fixture

The test fixture for the specimen R_T shall be capable of providing safe electrical connection.

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4.4 Verification of the measuring system

Reference resistors with known non-linearity shall be used to verify the integrity of the measuring system.

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5 Measurement procedure

5.1 Environmental conditions

Unless otherwise specified, all tests shall be carried out under standard atmospheric conditions for measurement and tests as specified in IEC 60068-1.

5.2 Preparation of specimen

The specimen shall be kept for at least 2 h in the environmental conditions prescribed in 5.1.

5.3 Measurement conditions

The choice of system impedances R_3 is determined by the properties of the actual measurement system. Table 1 is based on examples of suitable values for R_3.

The fundamental test voltage U_1 shall be chosen from Table 1, unless otherwise specified in the relevant component specification, e.g. relative to the rated dissipation.

Analysis shows that the third harmonic ratio depends significantly on the choice of the fundamental voltage as the readings of the third harmonic voltage U_3 show an exponential relationship over the ratio of applied fundamental voltages. Comparison of the non-linearity of different products should therefore always be based on identical prescriptions for dissipation and voltage limitation in order to define an identical fundamental voltage for each resistance value.

The application of the fundamental voltage results in a dissipation, and thus in a temperature rise within the specimen. Depending on its temperature coefficient of resistance (TCR), the