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Method of measurement of non-linearity in resistors

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This British Standard is the UK implementation of EN 60440:2012. It is identical to IEC 60440:2012. It supersedes BS 5694:1979 which is withdrawn.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 non-linearity in resistors
(IEC 60440:2012)

Méthode de mesure
de la non-linéarité des résistances
(CEI 60440:2012)

Verfahren zur Messung
der Nichtlinearität von Widerständen
(IEC 60440:2012)

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European Committee for Electrotechnical Standardization
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Foreword

The text of document 40/2155/FDIS, future edition 1 of IEC 60440, 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 60440:2012.

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)	2013-05-17
• latest date by which the national standards conflicting with the document have to be withdrawn	(dow)	2015-08-17

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The text of the International Standard IEC 60440:2012 was approved by CENELEC as a European Standard without any modification.

In the official version, for Bibliography, the following notes have to be added for the standards indicated:

IEC 60027 Series	NOTE	Harmonised as EN 60027 Series (not modified).
ISO 80000-1	NOTE	Harmonised as EN ISO 80000-1.

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 When an international publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

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

CONTENTS

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

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, *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.

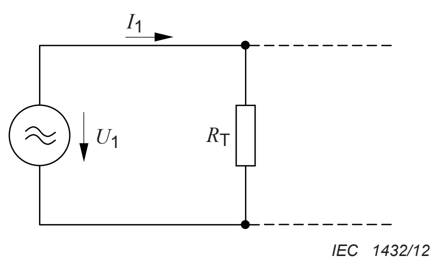
4 Method of measurement

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.



Key

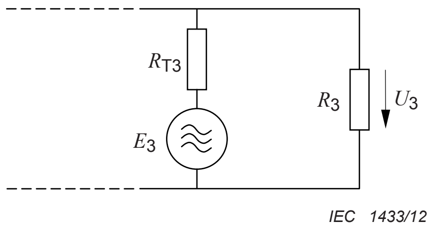
I_1 Sinusoidal current

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

$$U_3 = \frac{R_3}{R_3 + R_{T3}} \cdot E_3 \quad (1)$$

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

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

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

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

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

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

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.

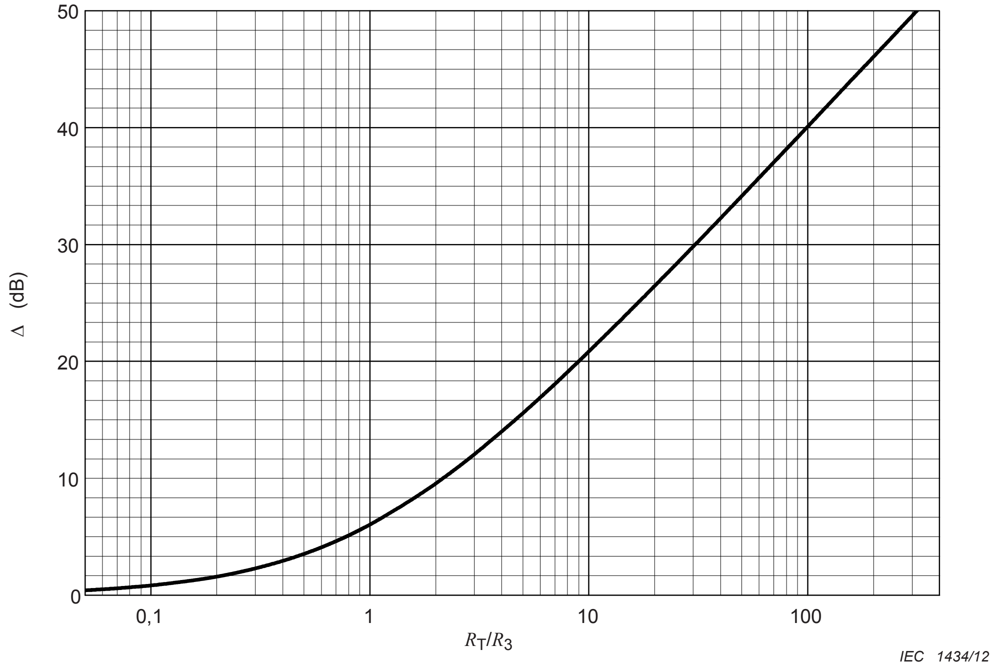


Figure 3 – Corrective term *Δ*

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.

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.

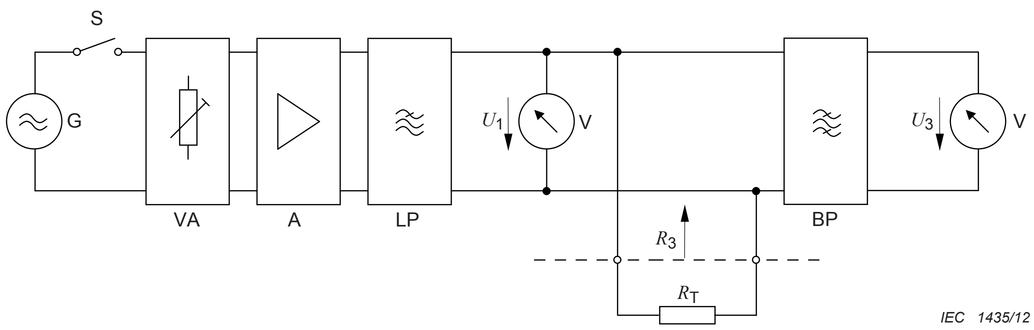
4.2 Measuring circuit

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.

Figure 4 – Block schematic of a suitable measuring system

4.3 Measurement system requirements

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.

4.4 Verification of the measuring system

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

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 specimen resistance will change, which will change the actual applied fundamental voltage. Depending on the respective temperature rise and TCR, this effect may be insignificant or not. Limiting the duration of the application of the fundamental voltage may be a suitable way out of this problem, if set below the thermal time constant of the specimen.

The relevant component specification shall state respective requirements, if applicable.

5.4 Procedure

The specimen shall be inserted into the test fixture and properly connected to the test terminals.

The system impedance R_3 shall be selected in order to achieve the best possible impedance matching.

The fundamental voltage shall be applied, e.g. by closing the switch S in a system according to Figure 4, and adjusted to the prescribed value.

The third harmonic voltage U_3 shall be read.

The application of the fundamental voltage shall not exceed the prescribed duration, if applicable.

5.5 Precautions

Ferromagnetic materials give rise to harmonic distortion and care shall be taken to avoid influence from e.g. iron in the immediate vicinity of the component which can mask component non-linearities especially at high currents.

6 Evaluation of measurement results

6.1 Evaluation

The reading of the third harmonic voltage U_3 shall be used to calculate the third harmonic ratio.

The third harmonic ratio A_3 in decibels is

$$\begin{aligned} A_3 &= 20 \cdot \log_{10} \frac{U_1}{E_3} \\ &= 20 \cdot \log_{10} \frac{U_1}{U_{\text{ref}}} - 20 \cdot \log_{10} \frac{E_3}{U_{\text{ref}}} \\ &= 20 \cdot \log_{10} \frac{U_1}{U_{\text{ref}}} - 20 \cdot \log_{10} \frac{U_3}{U_{\text{ref}}} - 20 \cdot \log_{10} \left(1 + \frac{R_{\text{T3}}}{R_3}\right) \end{aligned} \tag{5}$$

where

U_1 is the fundamental voltage across the resistor under test

U_{ref} is the basis for voltage ratios, arbitrarily set

E_3 is the e.m.f. of the third harmonic in the component

U_3 is the measured third harmonic voltage

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

R_3 is the impedance of the measuring circuit at the third harmonic frequency, seen from the test terminals (source impedance)

In Equation (5), the logarithmic term describing the fundamental voltage may be abbreviated as D with

$$D = 20 \cdot \log_{10} \frac{U_1}{U_{\text{ref}}} \tag{6}$$

NOTE The calculation of the third harmonic ratio requires a common U_{ref} for all used logarithms of voltage ratios; throughout this standard, U_{ref} = 1 V is used for the 0 dB reference level.

The abbreviation of a logarithmic expression $20 \cdot \log_{10}(U/U_{\text{ref}})$ to $20 \cdot \log_{10} U$ is mathematically incorrect and particularly bears the risk of confusion when the used reference voltage is no longer considered. Hence the abbreviated form is not an appropriate expression.

With the above definitions of D in Equation (6) and of Δ in 4.1, Equation (5) can be simplified to

$$A_3 = D - 20 \cdot \log_{10} \frac{U_3}{U_{\text{ref}}} - \Delta \tag{7}$$

6.2 Requirements

Acceptance criteria for non-linearity of tested products shall be given with reference to a required minimum third harmonic ratio A_3 in the relevant component specification.

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

Superior selectivity of non-linearity screening is achievable through the use of a dynamic minimum value relative to the statistical distribution of non-linearity within an analyzed batch in addition to a fixed minimum value. Such dynamic requirement should be referenced to a batch's mean value and a multiple of its standard deviation, e.g. like $\geq \overline{A}_3 - 3\sigma$.

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 applicable:

	Subclause
a) the fundamental frequency	4.2
b) the environmental condition for this measurement	5.1
c) the dissipation to be provided through the fundamental voltage	5.3, Table 1
d) a limitation to the fundamental voltage, if applicable	5.3, Table 1
e) a limitation to the duration of application of the fundamental voltage, if applicable	5.3

The relevant component specification shall specify for its own purpose:

	Subclause
f) acceptance criteria to the third harmonic ratio A_3	6.2

Table 1 gives the values for the recommended impedance of the measuring circuit R_3, for the corresponding corrective term Δ and for the fundamental voltage U_1 of the recommended measuring conditions for specimen R_T with a resistance in the range of 1 Ω to 22 MΩ.

Table 1 – Recommended measuring conditions (1 of 2)

R_3 Ω	R_T [a] Ω	Δ [b] dB	Specimen's rated dissipation P_r: $P_r \geq$ 0,25 W			0,25 W $> P_r \geq$ 0,1 W			0,1 W $> P_r$		
			U_1 [c] V	D [d] dB	P mW	U_1 [c] V	D [d] dB	P mW	U_1 [c] V	D [d] dB	P mW
10	1,0	0,8	0,50	−6,0	250	0,32	−10,0	100	0,22	−13,0	50
	1,2	1,0	0,55	−5,2	250	0,35	−9,2	100	0,24	−12,2	50
	1,5	1,2	0,61	−4,3	250	0,39	−8,2	100	0,27	−11,2	50
	1,8	1,4	0,67	−3,5	250	0,42	−7,4	100	0,30	−10,5	50
	2,2	1,7	0,74	−2,6	250	0,47	−6,6	100	0,33	−9,6	50
	2,7	2,1	0,82	−1,7	250	0,52	−5,7	100	0,37	−8,7	50
	3,3	2,5	0,91	−0,8	250	0,57	−4,8	100	0,41	−7,8	50
	3,9	2,9	0,99	−0,1	250	0,62	−4,1	100	0,44	−7,1	50
	4,7	3,3	1,08	0,7	250	0,69	−3,3	100	0,48	−6,3	50
	5,6	3,9	1,18	1,5	250	0,75	−2,5	100	0,53	−5,5	50
	6,8	4,5	1,30	2,3	250	0,82	−1,7	100	0,58	−4,7	50
	8,2	5,2	1,43	3,1	250	0,91	−0,9	100	0,64	−3,9	50
	10	6,0	1,58	4,0	250	1,00	0,0	100	0,71	−3,0	50
	12	6,8	1,73	4,8	250	1,10	0,8	100	0,77	−2,2	50
	15	8,0	1,94	5,7	250	1,22	1,8	100	0,87	−1,2	50
	18	8,9	2,12	6,5	250	1,34	2,6	100	0,95	−0,5	50
	22	10,1	2,35	7,4	250	1,48	3,4	100	1,05	0,4	50
	27	11,4	2,60	8,3	250	1,64	4,3	100	1,16	1,3	50
100	33	2,5	2,87	9,2	250	1,82	5,2	100	1,28	2,2	50
	39	2,9	3,12	9,9	250	1,97	5,9	100	1,40	2,9	50
	47	3,3	3,43	10,7	250	2,17	6,7	100	1,53	3,7	50
	56	3,9	3,74	11,5	250	2,37	7,5	100	1,67	4,5	50
	68	4,5	4,12	12,3	250	2,61	8,3	100	1,84	5,3	50
	82	5,2	4,53	13,1	250	2,86	9,1	100	2,02	6,1	50
	100	6,0	5,00	14,0	250	3,16	10,0	100	2,24	7,0	50
	120	6,8	5,48	14,8	250	3,46	10,8	100	2,45	7,8	50
	150	8,0	6,12	15,7	250	3,87	11,8	100	2,74	8,8	50
	180	8,9	6,71	16,5	250	4,24	12,6	100	3,00	9,5	50
	220	10,1	7,42	17,4	250	4,69	13,4	100	3,32	10,4	50
	270	11,4	8,22	18,3	250	5,20	14,3	100	3,67	11,3	50
1 k	330	2,5	9,08	19,2	250	5,74	15,2	100	4,06	12,2	50
	390	2,9	9,87	19,9	250	6,24	15,9	100	4,42	12,9	50
	470	3,3	10,8	20,7	250	6,86	16,7	100	4,85	13,7	50
	560	3,9	11,8	21,5	250	7,48	17,5	100	5,29	14,5	50
	680	4,5	13,0	22,3	250	8,25	18,3	100	5,83	15,3	50
	820	5,2	14,3	23,1	250	9,06	19,1	100	6,40	16,1	50
	1,0 k	6,0	15,8	24,0	250	10,0	20,0	100	7,07	17,0	50
	1,2 k	6,8	17,3	24,8	250	11,0	20,8	100	7,75	17,8	50
	1,5 k	8,0	19,4	25,7	250	12,2	21,8	100	8,66	18,8	50
	1,8 k	8,9	21,2	26,5	250	13,4	22,6	100	9,49	19,5	50
	2,2 k	10,1	23,5	27,4	250	14,8	23,4	100	10,5	20,4	50
	2,7 k	11,4	26,0	28,3	250	16,4	24,3	100	11,6	21,3	50
10 k	3,3 k	2,5	28,7	29,2	250	18,2	25,2	100	12,8	22,2	50
	3,9 k	2,9	31,2	29,9	250	19,7	25,9	100	14,0	22,9	50
	4,7 k	3,3	34,3	30,7	250	21,7	26,7	100	15,3	23,7	50
	5,6 k	3,9	37,4	31,5	250	23,7	27,5	100	16,7	24,5	50
	6,8 k	4,5	41,2	32,3	250	26,1	28,3	100	18,4	25,3	50
	8,2 k	5,2	45,3	33,1	250	28,6	29,1	100	20,2	26,1	50

Table 1 (2 of 2)

R_3 Ω	R_T [a] Ω	Δ [b] dB	**Specimen's rated dissipation P_r**								
			$P_r \geq 0,25$ W			0,25 W > $P_r \geq 0,1$ W			0,1 W > P_r		
			U_1 [c] V	D [d] dB	P mW	U_1 [c] V	D [d] dB	P mW	U_1 [c] V	D [d] dB	P mW
10 k	10 k	6,0	50,0	34,0	250	31,6	30,0	100	22,4	27,0	50
	12 k	6,8	54,8	34,8	250	34,6	30,8	100	24,5	27,8	50
	15 k	8,0	61,2	35,7	250	38,7	31,8	100	27,4	28,8	50
	18 k	8,9	67,1	36,5	250	42,4	32,6	100	30,0	29,5	50
	22 k	10,1	74,2	37,4	250	46,9	33,4	100	33,2	30,4	50
	27 k	11,4	82,2	38,3	250	52,0	34,3	100	36,7	31,3	50
100 k	33 k	2,5	90,8	39,2	250	57,4	35,2	100	40,6	32,2	50
	39 k	2,9	98,7	39,9	250	62,4	35,9	100	44,2	32,9	50
	47 k	3,3	108	40,7	250	68,6	36,7	100	48,5	33,7	50
	56 k	3,9	118	41,5	250	74,8	37,5	100	52,9	34,5	50
	68 k	4,5	130	42,3	250	82,5	38,3	100	58,3	35,3	50
	82 k	5,2	143	43,1	250	90,6	39,1	100	64,0	36,1	50
	100 k	6,0	158	44,0	250	100	40,0	100	70,7	37,0	50
	120 k	6,8	173	44,8	250	110	40,8	100	77,5	37,8	50
	150 k	8,0	194	45,7	250	122	41,8	100	86,6	38,8	50
	180 k	8,9	212	46,5	250	134	42,6	100	94,9	39,5	50
	220 k	10,1	235	47,4	250	148	43,4	100	105	40,4	50
	270 k	11,4	260	48,3	250	164	44,3	100	116	41,3	50
	330 k	12,7	287	49,2	250	182	45,2	100	128	42,2	50
	390 k	13,8	312	49,9	250	197	45,9	100	140	42,9	50
	470 k	15,1	343	50,7	250	217	46,7	100	153	43,7	50
	560 k	16,4	374	51,5	250	237	47,5	100	167	44,5	50
	680 k	17,8	412	52,3	250	261	48,3	100	184	45,3	50
	820 k	19,3	453	53,1	250	286	49,1	100	202	46,1	50
	1,0 M	20,8	500	54,0	250	316	50,0	100	224	47,0	50
	1,2 M	22,3	548	54,8	250	346	50,8	100	245	47,8	50
	1,5 M	24,1	612	55,7	250	387	51,8	100	274	48,8	50
	1,8 M	25,6	671	56,5	250	424	52,6	100	300	49,5	50
	2,2 M	27,2	742	57,4	250	469	53,4	100	332	50,4	50
	2,7 M	28,9	822	58,3	250	520	54,3	100	367	51,3	50
	3,3 M	30,6	908	59,2	250	574	55,2	100	406	52,2	50
	3,9 M	32,0	987	59,9	250	624	55,9	100	442	52,9	50
	4,7 M	33,6	1 084	60,7	250	686	56,7	100	485	53,7	50
	5,6 M	35,1	1 183	61,5	250	748	57,5	100	529	54,5	50
	6,8 M	36,8	1 304	62,3	250	825	58,3	100	583	55,3	50
	8,2 M	38,4	1 432	63,1	250	906	59,1	100	640	56,1	50
	10 M	40,1	1 581	64,0	250	1 000	60,0	100	707	57,0	50
	12 M	41,7	1 732	64,8	250	1 095	60,8	100	775	57,8	50
	15 M	43,6	1 936	65,7	250	1 225	61,8	100	866	58,8	50
	18 M	45,2	2 121	66,5	250	1 342	62,6	100	949	59,5	50
	22 M	46,9	2 345	67,4	250	1 483	63,4	100	1 049	60,4	50

[a] The parameters for other values of R_T than those shown here shall be calculated using the resistance R_T, the dissipation P and, if applicable, a limitation to the fundamental voltage U_1.

[b] The given figures for the correction term Δ only apply if the measuring circuit uses the source impedances R_3 shown here.

[c] A limitation may apply to the voltage at fundamental frequency, thereby limiting the value D and the actual dissipation P.

[d] The decibel ratio D of the fundamental voltage is based upon U_{ref} = 1 V for the 0 dB reference level.

Annex A
(informative)

Reference to IEC/TR 60440

The drafting of this standard has resulted in a new structure. The following table indicates the new clause and subclause numbers with respect to the Technical Report, published in 1973.

IEC/TR 60440 [a] Clause/Subclause	**IEC 60440:2012** **1st edition** Clause/Subclause	**Notes**
1	1	Scope and object are merged into one
2		
—	2	New clause
—	3	New clause
3	4.1	—
4.0		
4.1	4.2	—
4.2		
4.3	4.1	—
4.4		
4.5	4.3	Divided into subclauses
4.6	5.1	—
4.7	4.3.7	—
5	5	Divided into subclauses
—	6	New clause

[a] See Bibliography.

Bibliography

IEC 60027 (all parts), *Letter symbols to be used in electrical technology*

IEC/TR 60440:1973, *Method of measurement of non-linearity in resistors*

IEC 60617, *Graphical symbols for diagrams*

ISO 80000-1, *Quantities and units – Part 1: General*

Danbridge A/S, *"Reliability Testing of Nominally Linear Components by Measuring Third Harmonic Distortion"*, Application Note, 2002

Kühl, R.W. and Ewell, G.J., *"Third Harmonic Testing: Current Resistor Applications"*, Proceedings, 15th European Passive Components Symposium CARTS-EUROPE 2001, Copenhagen, Denmark, 2001, pp. 85 - 93.

Kuehl, R.W., "*Reliability of thin-film resistors: Impact of third harmonic screening*", Microelectronics Reliability 42 (2002), pp. 807

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