BS EN 60444-6:2013

BSI Standards Publication

Measurement of quartz crystal unit parameters

Part 6: Measurement of drive level dependence (DLD)

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National foreword

This British Standard is the UK implementation of EN 60444-6:2013. It is identical to IEC 60444-6:2013. It supersedes BS EN 60444-6:1997 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee EPL/49, Piezoelectric devices for frequency control and selection.

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

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Measurement of quartz crystal unit parameters - Part 6: Measurement of drive level dependence (DLD)

(IEC 60444-6:2013)

Mesure des paramètres des résonateurs à quartz -
Partie 6: Mesure de la dépendance du niveau d'excitation (DNE)
(CEI 60444-6:2013)

Messung von Schwingquarz-Parametern -
Teil 6: Messung der Belastungsabhängigkeit (DLD)
(IEC 60444-6:2013)

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European Committee for Electrotechnical Standardization
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Foreword

The text of document 49/1004/CDV, future edition 2 of IEC 60444-6, prepared by IEC/TC 49, "Piezoelectric, dielectric and electrostatic devices and associated materials for frequency control, selection and detection" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 60444-6:2013.

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)	2014-04-24
• latest date by which the national standards conflicting with the document have to be withdrawn	(dow)	2016-07-24

This document supersedes EN 60444-6:1997.

EN 60444-6:2013 includes the following significant technical changes with respect to EN 60444-6:1997:

a) DLD measurement with oscillation circuit had the traditional method to detect the DLD abnormal modes at present time. Therefore, this method made the transition to the Annex B.

b) High reliability crystal unit is needed to use for various applications at the present day, in order to upgrade the inspection capabilities for DLD abnormal modes, the multi-level reference measurement method was introduced into this specification.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CENELEC [and/or CEN] shall not be held responsible for identifying any or all such patent rights.

Endorsement notice

The text of the International Standard IEC 60444-6:2013 was approved by CENELEC as a European Standard without any modification.

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 60444-1	-	Measurement of quartz crystal unit parameters by zero phase technique in a pi-network - Part 1: Basic method for the measurement of resonance frequency and resonance resistance of quartz crystal units by zero phase technique in a pi-network	EN 60444-1	-
IEC 60444-5	-	Measurement of quartz crystal unit parameters - Part 5: Methods for the determination of equivalent electrical parameters using automatic network analyzer techniques and error correction	EN 60444-5	-
IEC 60444-8	-	Measurement of quartz crystal unit parameters - Part 8: Test fixture for surface mounted quartz crystal units	EN 60444-8	-

CONTENTS

INTRODUCTION

The drive level (expressed as power/voltage across or current through the crystal unit) forces the resonator to produce mechanical oscillations by way of piezoelectric effect. In this process, the acceleration work is converted to kinetic and elastic energy and the power loss to heat. The latter conversion is due to the inner and outer friction of the quartz resonator.

The frictional losses depend on the velocity of the vibrating masses and increase when the oscillation is no longer linear or when critical velocities, elongations or strains, excursions or accelerations are attained in the quartz resonator or at its surfaces and mounting points (see Annex A). This causes changes in resistance and frequency, as well as further changes due to the temperature dependence of these parameters.

At “high” drive levels (e.g. above 1 mW or 1 mA for AT-cut crystal units) changes are observed by all crystal units and these also can result in irreversible amplitude and frequency changes. Any further increase of the drive level may destroy the resonator.

Apart from this effect, changes in frequency and resistance are observed at “low” drive levels in some crystal units, e.g. below 1 mW or 50 μA for AT-cut crystal units). In this case, if the loop gain is not sufficient, the start-up of the oscillation is difficult. In crystal filters, the transducer attenuation and ripple will change.

Furthermore, the coupling between a specified mode of vibration and other modes (e.g. of the resonator itself, the mounting and the back-fill gas) also depends on the level of drive.

Due to the differing temperature response of these modes, these couplings give rise to changes of frequency and resistance of the specified mode within narrow temperature ranges. These changes increase with increasing drive level. However, this effect will not be considered further in this part of IEC 60444.

The first edition of IEC 60444-6 was published in 1995. However, it has not been revised until today. In the meantime the demand for tighter specification and measurement of DLD has increased.

In this new edition, the concept of DLD in IEC 60444-6:1995 is maintained. However, the more suitable definition for the user’s severe requirements was introduced. Also, the specifications based on the matters arranged in the Stanford meeting in June, 2011 are taken into consideration.

MEASUREMENT OF QUARTZ CRYSTAL UNIT PARAMETERS –

Part 6: Measurement of drive level dependence (DLD)

1 Scope

This part of IEC 60444 applies to the measurements of drive level dependence (DLD) of quartz crystal units. Two test methods (A and C) and one referential method (B) are described. “Method A”, based on the π-network according to IEC 60444-1, can be used in the complete frequency range covered by this part of IEC 60444. “Reference Method B”, based on the π-network or reflection method according to IEC 60444-1, IEC 60444-5 or IEC 60444-8 can be used in the complete frequency range covered by this part of IEC 60444. “Method C”, an oscillator method, is suitable for measurements of fundamental mode crystal units in larger quantities with fixed conditions.

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 60444-1, *Measurement of quartz crystal unit parameters by zero phase technique in a π-network – Part 1: Basic method for the measurement of resonance frequency and resonance resistance of quartz crystal units by zero phase technique in a π-network*

IEC 60444-5, *Measurement of quartz crystal units parameters – Part 5: Methods for the determination of equivalent electrical parameters using automatic network analyzer techniques and error correction*

IEC 60444-8, *Measurement of quartz crystal unit parameters – Part 8: Test fixture for surface mounted quartz crystal units*

3 DLD effects

3.1 Reversible changes in frequency and resistance

Reversible changes are changes in frequency and resistance occurring under the same drive levels after repeated measurements made alternatively at low and high levels, or after continuous or quasi-continuous measurements from the lowest to the highest level and back, if these changes remain within the limits of the measurement accuracy.

3.2 Irreversible changes in frequency and resistance

Irreversible changes are significant changes in frequency and/or resistance occurring at low level after an intermediate measurement at high level e.g. when a previously high resistance at low level has changed in the repeated measurement to a low resistance. Especially, when the crystal unit has not been operated for several days, its resistance may have changed back to a high value when operated again at a lower level. Greater attention should be paid to the irreversible effect since it can significantly impair the performance of devices, which are operated only sporadically.

3.3 Causes of DLD effects

Whereas the mostly reversible effects are due to excessive crystal drive level, the irreversible effects are due to production, especially to imperfect production techniques. Examples of causes are:

- Particles on the resonator surface (partly bound by oils, cleaning agents. solvents or bound electro-statically);
- Mechanical damage of the resonator (e.g. fissures due to excessively coarse lapping abrasive which may increase in size);
- Gas and oil inclusions in the electrodes (e.g. due to a poor vacuum or an inadequate coating rate during evaporation);
- Poor contacting of the electrodes at the mounting (e.g. the conductive adhesive has an inadequate metal component, was insufficiently baked out or was overheated; also excessive contact resistance between the conductive adhesive and the electrodes or mounting);
- Mechanical stresses between mounting, electrodes and quartz element.

4 Drive levels for DLD measurement

For the DLD measurement, a low and a high level of drive (and possibly further levels) are applied. The high level is the nominal drive level, which should be equal to the level in the application at its steady state.

It should be noted that this level should be below the maximum applicable level that is derived in Annex A. If not specified, a standard value for the crystal current of 1 mA, corresponding to the velocity v max = 0,2 m/s for AT-cut crystal units, shall be used. The drive level in watts is then calculated with the mean value of the specified maximum and minimum resistances.

The minimum drive level occurring at the start-up of an oscillator can be determined only in a few cases by active or passive measuring methods due to the noise limits of the measuring instruments for measurements according to IEC 60444-1, at approximately 1 nW or 10 μA (depending on the equipment, the lowest power value can be reduced to 0,1 nW or 1 μA).

A velocity v max = 0,01 m/s, corresponding to 50 μA for AT-cut crystals, has proved to be practical value for π-network measurements (see “Method A”).

In the following, two methods and one referential method of DLD measurement are described.

“Method A” is based on the π-network method according to IEC 60444-1, which can be used in the complete frequency range covered by this standard. It allows the fast selection of drive level sensitive quartz crystal units by a sequence of three measurements. The allowed variation of the resonance resistances given in Figure 1 is based on long-term examinations of crystal units of different manufacturers and proved to be a reliable indicator for crystal units showing start-up problems. If necessary, this method should also is extended by measuring a large number of different drive levels. However, in practice, this is not necessary in most cases (see 5.1).

“Method B” is used for devices where strict oscillation start-up requirements have to be fulfilled and for high reliability devices.

“Method C” in Annex B is an oscillator method, which is especially suitable for measuring fundamental mode crystal units in larger quantities with fixed measurement conditions (maximum drive level, R_r max) in an economical way.

If the proposed measurement techniques are not sufficient in special cases, the user should have an original oscillator with slightly reduced feedback or an original filter.

“Method B” is stricter than “Method A”.

“Method B” is based on the π-network method or reflection method according to IEC 60444-1, IEC 60444-5 or IEC 60444-8, which can be used in the complete frequency range covered by this standard.

Recommendation: These methods can be used for all types of crystals, however:

- “Method A” is recommended for filter and oscillator crystals.
- “Method B” is recommended for applications with strict start-up conditions, for high reliability and for high stability applications. It is the reference method for failure analysis etc.
- “Method C” in Annex B is a go/no-go measurement technique for oscillator crystals.

5 Test methods

5.1 Method A (Fast standard measurement method)

5.1.1 Testing at two drive levels

Testing is performed at low and high drive levels as described in Clause 3 with measurements of resonance frequency and resistance according to IEC 60444-1. The tolerances are ± 10 % for the levels of current and ± 20 % for those of power.

a) Storage for at least one day at 105 °C and after that at least 2 hours at room temperature or, storage for one week at room temperature.
b) The temperature should be kept constant during the measurement (in accordance with IEC 60444-1 and IEC 60444-5).
c) Measurement at low drive level (10 µA): $f_r = f_{r1}, R_r = R_{11}$.
d) Measurement at high drive level (1 mA): $f_r = f_{r2}, R_r = R_{12}$.
e) Measurement at low drive level (10 µA): $f_r = f_{r3}$, $R_r = R_{13}$.
f) Calculation of $\gamma_{12} = R_{11}/R_{12}$. The value of γ_{12} shall be smaller than the maximum value of γ given by the line drawn in Figure 1 (abscissa = R_{12}).
g) The tolerable frequency change $|f_{r2} - f_{r1}|$ shall be $5 \times 10^{-6} \times f_{r1}$ unless otherwise specified in the detail specification.
h) Calculation of $\gamma_{13} = R_{11}/R_{13}$. The value of γ_{13} shall be smaller than $(\gamma + 1)/2$, where the value of γ is taken from Figure 1(abscissa = R_{13}).
i) The tolerable frequency change $|f_{r3} - f_{r1}|$ shall be $2{,}5 \times 10^{-6} \times f_{r1}$, unless otherwise specified in the detail specification.
j) The resistance value shall not exceed the maximum value given by the detail specification at any drive levels.

5.1.2 Testing according to specification

Testing is performed at low to high drive levels and back again to low level as described in 5.1.1. These and, if necessary, further levels with their tolerances, the permissible deviations of the frequency and resistance as well as storage conditions shall be specified in the detail specification.

NOTE 1 The given γ-curve was verified by results obtained over many years of experience with crystal units for many oscillator types. In most cases, there will be no trouble in start-up, but in critical oscillator configurations, problems may occur. As it is not possible to manufacture crystal units, which have a constant resistance at any drive level, the proposed Γ-curve gives tolerable relations.

Definition of drive level values can be agreed between manufacturer and customer.

Use the nominal drive level of the detail specification as value for the high drive level. For measurement at very high drive levels an additional amplifier may be required.

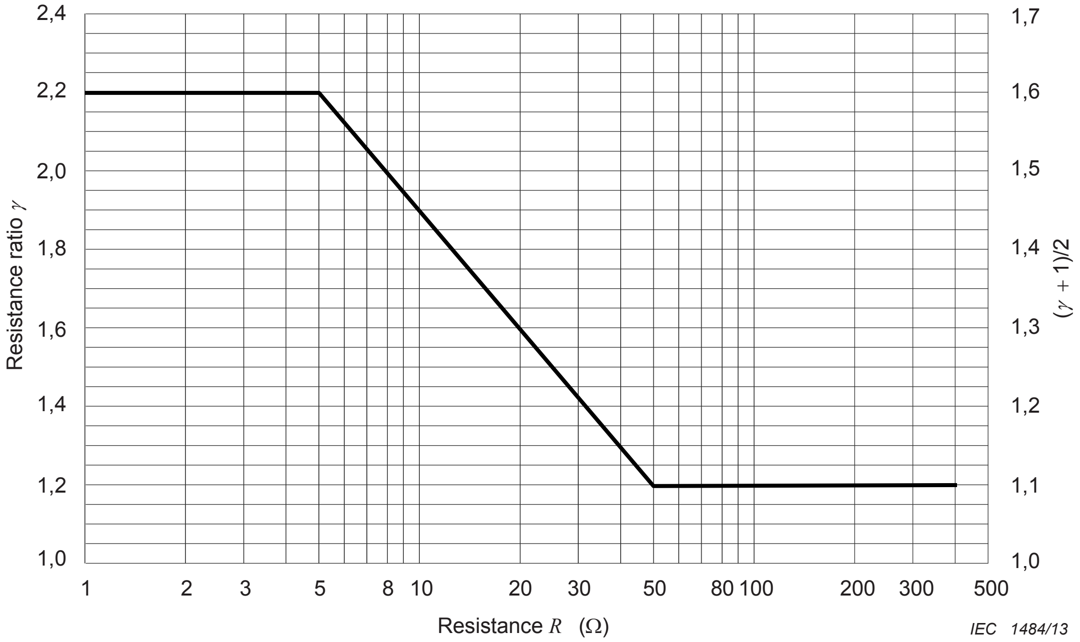


Figure 1 – Maximum tolerable resistance ratio γ for the drive level dependence as a function of the resistances R_{r2} or R_{r3}

NOTE 2 The equation for the recommended drive level (if not otherwise specified in the data sheet) is as follows. Details can be found in Annex A of IEC 60122-2-1:1991, Amendment 1:1993.

$$I_q = K \cdot \frac{nA}{\sqrt{f}}$$

where,

I_q is the recommended current for oscillating state;
n is the overtone, fundamental vibration mode, n = 1;
A is the electrode size in mm^2;
f is the frequency in MHz;
K is 0,35 mA · mm^{-2} · S$^{-1/2}$.

5.2 Method B (Multi-level reference measurement method)

Testing is performed at low and high drive levels as described in Clause 3 with measurements of resonance frequency and resistance according to IEC 60444-5. The tolerances are ±10 % for the levels of current and ±20 % for those of power.

a) Storage for at least one day at 105 °C and after that at least 2 hours at room temperature or storage for one week at room temperature.

   NOTE If considered as necessary, the customer and the maker agree on a higher temperature and a longer duration for the storage before DLD measurement.

b) The temperature should be kept constant during the measurement IAW (in accordance with IEC 60444-5).

c) The drive level is applied by two types of measurement units. It should also be applied sequentially starting from the lowest to the highest value and then back to the lowest value. A definition for the unit of drive levels shall be specified between the crystal manufacturer and the user.

1) When the unit of a drive level is mA;

   Measurement drives level: from 2 μA to nominal drive level in at least 7 levels which are logarithmically scaled. (Refer to the equation given under line item f)).

2) When the unit of a drive level is μW;

   Measurement drives level: From 2 nW to nominal drive level in at least 7 levels which are logarithmically scaled. (Refer to the equation given under line item f)).

d) The maximum frequency excursion over all drive levels shall be less than following specifications.

(1) $\frac{f_{\text{s}}(i)_{\text{,max}} - f_{\text{s}}(i)_{\text{,min}}}{f_{\text{NOM}}} < 5 \times 10^{-6}$

or,

(2) $\frac{f_{\text{s}}(i)_{\text{,max}} - f_{\text{s}}(i)_{\text{,min}}}{f_{\text{NOM}}} < 0{,}5 \times f_{\text{ADJ}}$

where

$f_{\text{s}}(i)_{\text{,max}}$ is the maximum value for frequency measurement values with i = 1 to $2 \cdot N$-1 drive levels;

$f_{\text{s}}(i)_{\text{,min}}$ is the minimum value for frequency measurement values with i = 1 to $2 \cdot N$-1 drive levels;

f_{NOM} is the nominal frequency;

f_{ADJ} is the practical specification for frequency adjustment tolerance.

e) The maximum ratio of resistance change and the maximum resistance over drive levels shall be as following specifications.

(1) $\frac{R_1(i)_{\text{,max}}}{R_1(i)_{\text{,min}}} < \gamma$

and

(2) $\frac{R_1(1)}{R_1(2 \cdot N - 1)} < \frac{(\gamma + 1)}{2}$

and

(3) $R_1(i)_{\text{,max}} < R_{1\text{,max}}$

where,

$R_1(i)_{\text{,max}}$ is the maximum value for resistance measurement values with i = 1 to $2 \cdot N$-1 drive levels;

$R_1(i)_{\text{,min}}$ is the minimum value for resistance measurement values with i = 1 to $2 \cdot N$-1 drive levels;

$R_{1\text{,max}}$ is the maximum resistance, specified by the detail specification.

γ is the resistance ratio.

f) The N drive levels should be logarithmically scaled, i.e. $DL_{N+1} = DL_N \times K$. The equation for the recommended drive level (if not otherwise specified in the data sheet) is as follows.

$$K = \left(\frac{DL_{\text{max}}}{DL_{\text{min}}} \right)^{\frac{1}{N-1}}$$

g) A larger number of drive levels may be necessary in special applications, e.g. those caused by mechanical coupling with nonlinear spurious resonances (dips) and for failure analysis.

Annex A
(normative)

Relationship between electrical drive level and mechanical displacement of quartz crystal units

The power loss of a crystal unit in watts is given by:

$$P_\mathrm{c} = I^2 \cdot R_1$$

where

I is the current through the crystal unit in amperes.
R_1 is the motional resistance in ohms.

The reactive power is given by:

$$P_\mathrm{B} = \frac{I^2}{2\pi f \cdot C_1} = P_\mathrm{c} \cdot Q$$

where

f is the resonance frequency in hertz.
C_1 is the motional capacitance in farads.
Q is the quality factor.

The electric energy in watt seconds is given by:

$$A_\mathrm{EL} = \frac{P_\mathrm{B}}{f} = \frac{I^2}{2\pi f^2 \cdot C_1}$$

The mechanical energy of a crystal unit can be represented by the following terms:

$$A_\mathrm{mech} = A_\mathrm{kin} + A_\mathrm{elast} + A_\mathrm{pot} + A_\mathrm{B}$$

$A_\mathrm{kin} = \frac{1}{2} \cdot \rho \cdot V \cdot v^2$ (kinetic energy)

$A_\mathrm{elast} = \frac{1}{2} \cdot c \cdot V \cdot x^2$ (elastic energy)

$A_\mathrm{pot} = \frac{1}{2} \cdot \rho \cdot V \cdot s^2 \cdot (2\pi f)^2$ (potential energy)

$A_\mathrm{B} = \frac{1}{2} \cdot \frac{\rho \cdot V \cdot b^2}{(2\pi f)^2}$ (acceleration work)

$\rho = 2\ 650\ \mathrm{kg/m^3}$ (density) where

V	is the volume of the oscillating area in cubic meters (m^3);
$v = \mathrm{d}s/\mathrm{d}t$	is the velocity in meters per seconds (m/s);
c	is the modulus of elasticity of the mode of vibration (for AT-cut crystal units, $c = c'_{66} = 2{,}93 \times 10^{10}\ \mathrm{N/m^2}$)
x	is $\Delta l/l$ is the elongation;
s	is the excursion from rest position in meters;
$b = \mathrm{d}^2s/\mathrm{d}t^2$	is the acceleration in meters per square seconds (m/s^2);
n	is the overtone order.

The volume V can be calculated from the electrode area F_{EL} and the electrode spacing d.

From the static capacitance:

$$C_{\mathrm{e}} = \varepsilon_{\mathrm{r}} \cdot \varepsilon_0 \cdot \frac{F_{\mathrm{EL}}}{d} = C_0$$

where

ε_{r}	is the relative dielectric constant of AT-cut quartz material and is equal to 4,54;
ε_0	is the electric field constant and is equal to $8{,}86 \times 10^{-12}$ F/m;
N	is the frequency constant equal to $f \cdot (d/n)$. N = 1 665 Hz·m for AT-cut crystal units;
n	is the overtone order.

We obtain the following:

$$V = \frac{C_0}{\varepsilon_{\mathrm{r}} \cdot \varepsilon_0} \cdot \frac{n^2 \cdot N^2}{f^2}$$

and the maximum current from the maximum velocities, elongations, excursions or accelerations of the mechanical vibrations:

$$I_{\max} = K_1 \cdot n \cdot \sqrt{C_0 \cdot C_1} \cdot v_{\max} \quad \text{where} \quad K_1 = \sqrt{\frac{\pi \cdot \rho \cdot N^2}{\varepsilon_{\mathrm{r}} \cdot \varepsilon_0}}$$

$$I_{\max} = K_2 \cdot n \cdot \sqrt{C_0 \cdot C_1} \cdot x_{\max} \quad \text{where} \quad K_2 = \sqrt{\frac{\pi \cdot c \cdot N^2}{\varepsilon_{\mathrm{r}} \cdot \varepsilon_0}}$$

$$I_{\max} = K_3 \cdot n \cdot \sqrt{C_0 \cdot C_1} \cdot s_{\max} \quad \text{where} \quad K_3 = \sqrt{\frac{4 \cdot \pi^3 \cdot \rho \cdot N^2}{\varepsilon_{\mathrm{r}} \cdot \varepsilon_0}}$$

$$I_{\max} = K_4 \cdot n \cdot \sqrt{C_0 \cdot C_1} \cdot \frac{b_{\max}}{f} \quad \text{where} \quad K_4 = \sqrt{\frac{\rho \cdot N^2}{4 \cdot \pi \cdot \varepsilon_{\mathrm{r}} \cdot \varepsilon_0}}$$

For non-convex AT-cut crystal units, the following also applies:

$$C_0/C_1 = \gamma = 200 \cdot n^2$$

where

n is the overtone order.

The following is obtained with C_o = 5 pF for the currents:

$I_{\text{max},1}$ = 50 mA $I_{\text{max},2}$ = 1 mA
v_1 = 0,01 m/s v_2 = 0,2 m/s
$x_1 = 1{,}8 \times 10^{-6}$ $x_2 = 3{,}6 \times 10^{-5}$

at f = 10 MHz:

$s_1 = 6{,}7 \times 10^{-11}$ m $s_2 = 1{,}3 \times 10^{-9}$ m
$b_1 = 2{,}6 \times 10^{5}$ m/s^2 $b_1 = 5{,}3 \times 10^{6}$ m/s^2
$s_1 = 6{,}7 \times 10^{-12}$ m $s_2 = 1{,}3 \times 10^{-10}$ m
$b_1 = 2{,}6 \times 10^{6}$ m/s^2 $b_2 = 5{,}3 \times 10^{7}$ m/s^2

Depending on the frequency, quality factor and mode of vibration of the crystal unit and the volume of the vibrating zone, maximum currents or levels result from limit considerations for every type of a crystal unit. These shall not be exceeded when using these devices in oscillators and filters.

The maximum drive level shall be selected so that with a further increase of the drive level by 50 %, the resistance does not increase reversibly by more than 10 % or the frequency changes by more than $0{,}5 \times 10^{-6}$.

Annex B
(normative)

Method C: DLD measurement with oscillation circuit

To detect the DLD effect over the whole drive level range, the method described in 5.1 is very costly and is not applicable as a 100 % go/no-go test. The method proposed below tests the crystal units on its maximum R_r during start-up in an economical manner. This method can be applied as a 100 % final inspection as well as in a 100 % incoming inspection. It can also be used as an instrument to judge whether the crystal unit meets the requirements on R_{rmax} given in the detail specification.

The crystal unit in the oscillator can be represented as indicated in Figure B.1.

There will be no oscillation when the magnitude of the $-R_{osc}$ of the circuit is lower than R_r of the crystal unit.

During start-up, the R_r of the crystal unit may behave as shown in Figure B.2.

When measuring the crystal unit several times, the characteristic can shift slightly to the right or to the left or it can flatten.

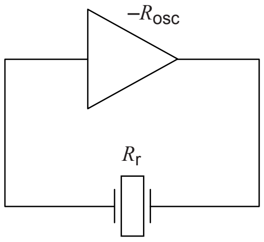
The ratio $\gamma = R_{r2}/R_{r1}$ may also differ from measurement to measurement. This ratio does not necessarily mean that the oscillator may stop working if a certain value of γ is reached. The most important aspect is the safety margin between the maximum occurring R_r of the crystal unit and the value of R_{osc} of the oscillator circuit.

It is recommended that the circuit should have a $|-R_{osc}|$ of $\geq 3|R_{r\ max}|$ because in the temperature range, the $R_{r\ max}$ as well as $-R_{osc}$ can shift.

During the start-up, the drive level will move from the low values (left side of the graphics in Figure B.3) to the nominal drive level.

The principle of measurement is presented in Figure B.4.

The test set-up consists of a carefully designed crystal oscillator which can be considered as a true negative resistance over a wide frequency range, a feedback network which limits the power dissipation in the crystal unit to 1 mW and a detector circuit with an LED for visual indication.



IEC 1485/13

Figure B.1 – Insertion of a quartz crystal unit in an oscillator

Oscillation conditions:

- loop gain $>$ 1, which means $|-R_{\mathrm{osc}}| > R_{\mathrm{r}}$
- feedback signal at oscillator input shall have correct phase.

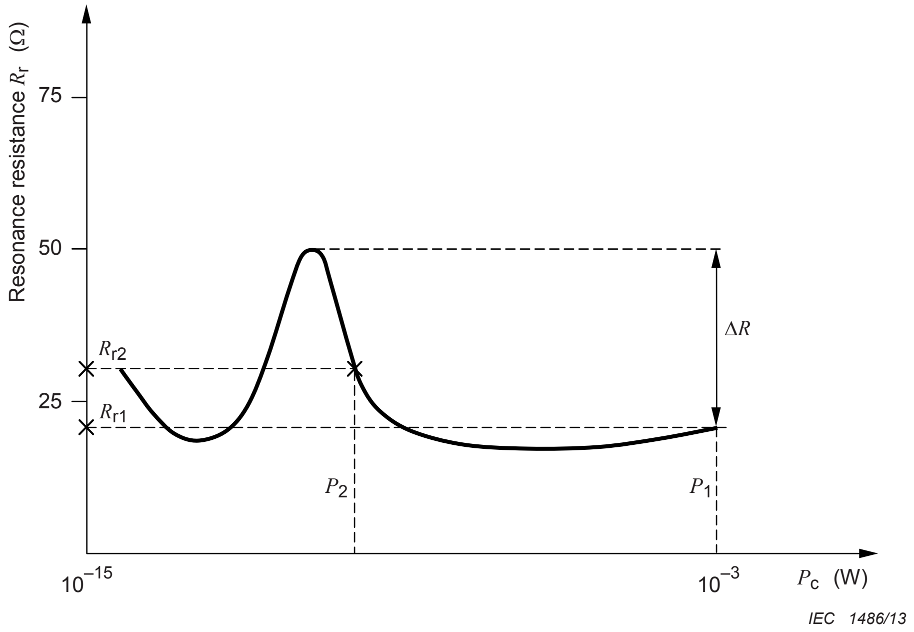


Figure B.2 – Crystal unit loss resistance as a function of dissipated power

NOTE The ratio R_{r2}/R_{r1} is not a reproducible value since the crystal unit curve slightly shifts at different measurement cycles.

The negative resistance (and with it the DLD reject level) of the oscillator can be changed by connecting a positive resistor in series with the oscillator. In this manner, each value between 0 Ω and 200 Ω may be selected. Connecting a quartz crystal unit with a sufficiently low R_{r} value between the test clamps, the oscillation will build up starting from the initial noise level (approximately 10^{-16} W to 10^{-15} W) to its limiting point for 1 mW as shown in Figure B.5.

During the start-up, the $R_{\mathrm{r,max}}$ of the crystal unit is continuously compared with a Calibrated-R_{osc} and the result is detected and transferred into a go/no-go decision.

If the crystal unit under test shows a certain degree of DLD, it is possible that the oscillation amplitude will not reach the 1 mW limiting point (point B in Figure B.6). In the example given in Figure B.6, the build-up of the oscillation is terminated at a much lower level of drive (point A). Normally in such cases, no oscillation is observed and only with very sensitive equipment can some oscillation be detected.

If a crystal unit reaches the 1 mW level (point B), the LED indicator will light up. This means that the quartz crystal unit's resonance resistance did not exceed the DLD reject level during the start-up.

The advantages of this measurement method are that it is fast, easy to calibrate, inexpensive and it has a simple set-up. A detailed electrical diagram is shown in Figure B.7. The equipment is commercially available.

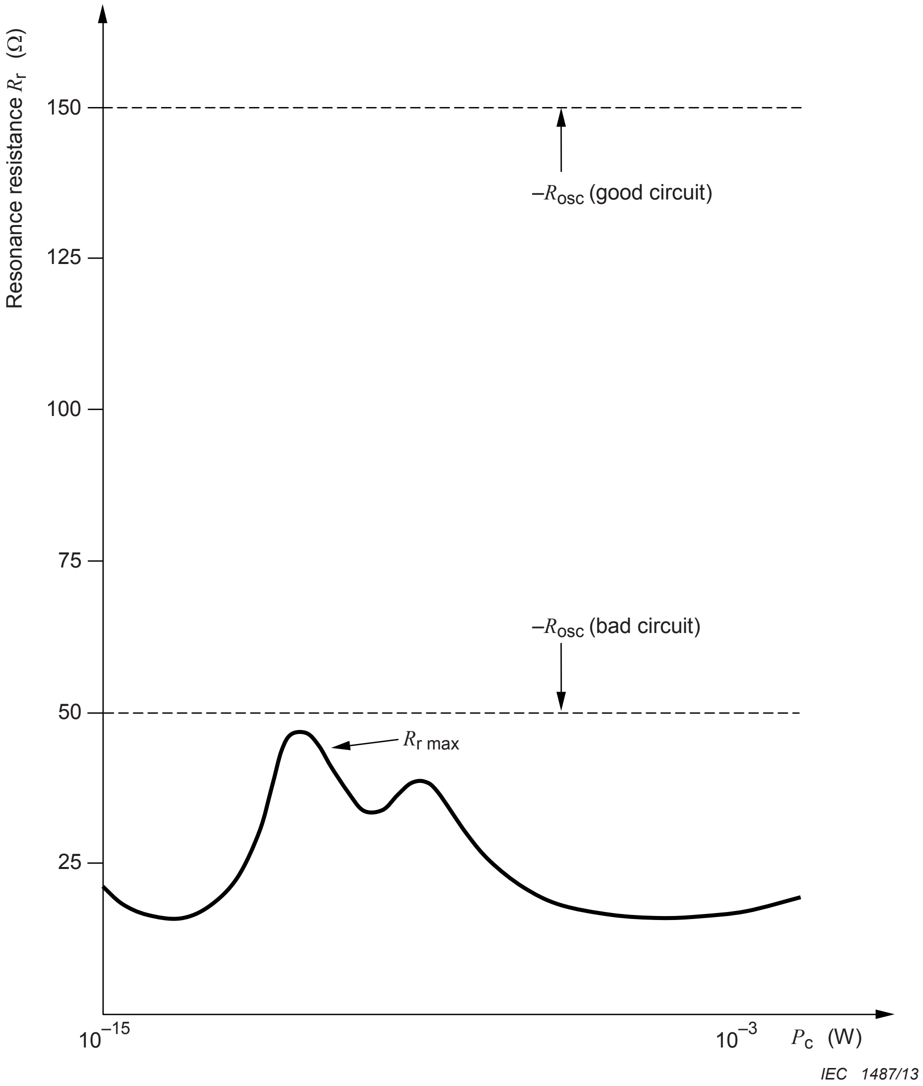


Figure B.3 – Behaviour of the R_r of a quartz crystal units

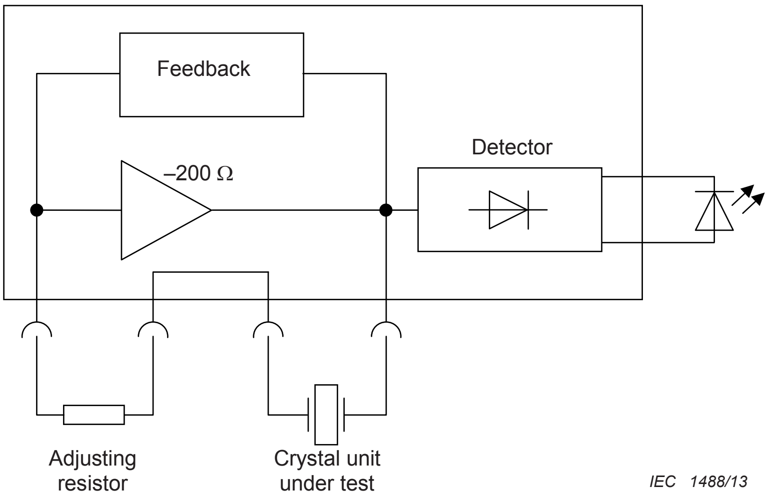


Figure B.4 – Block diagram of circuit system

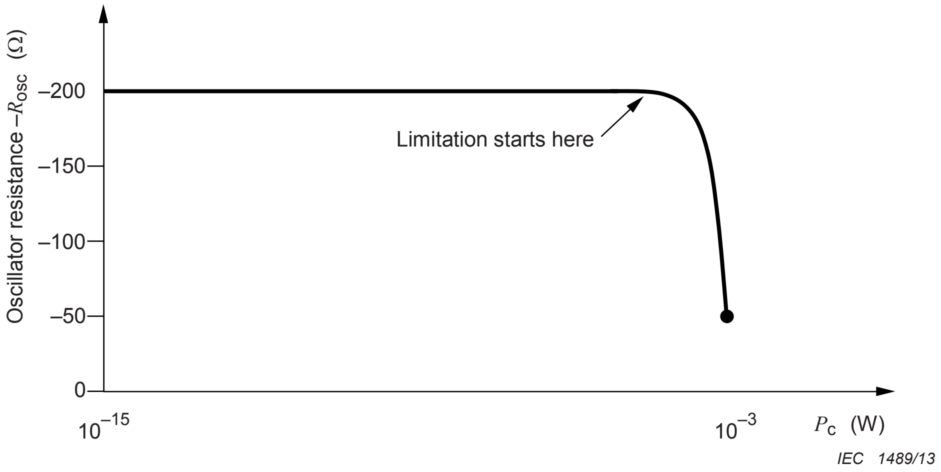


Figure B.5 – Installed $-R_{\text{osc}}$ in scanned drive level range

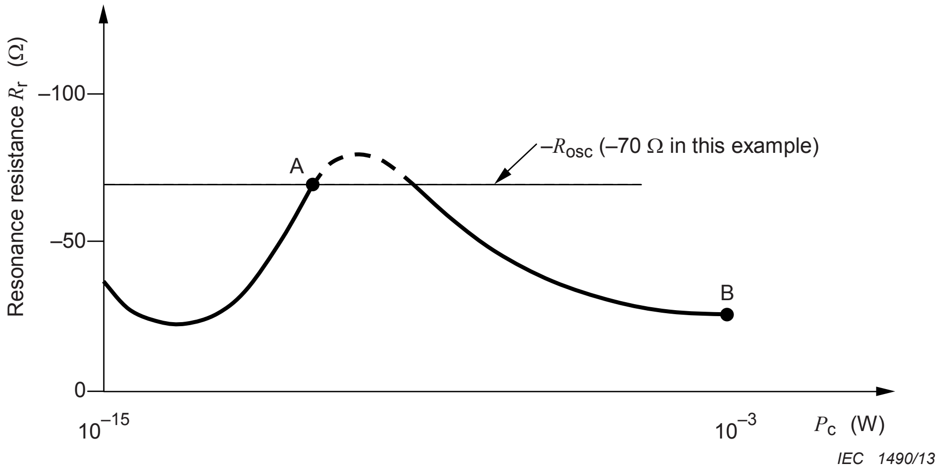


Figure B.6 – Drive level behavior of a quartz crystal unit if $-R_{\text{osc}}$ = 70 Ω is used as test limit in the “Annex B” test

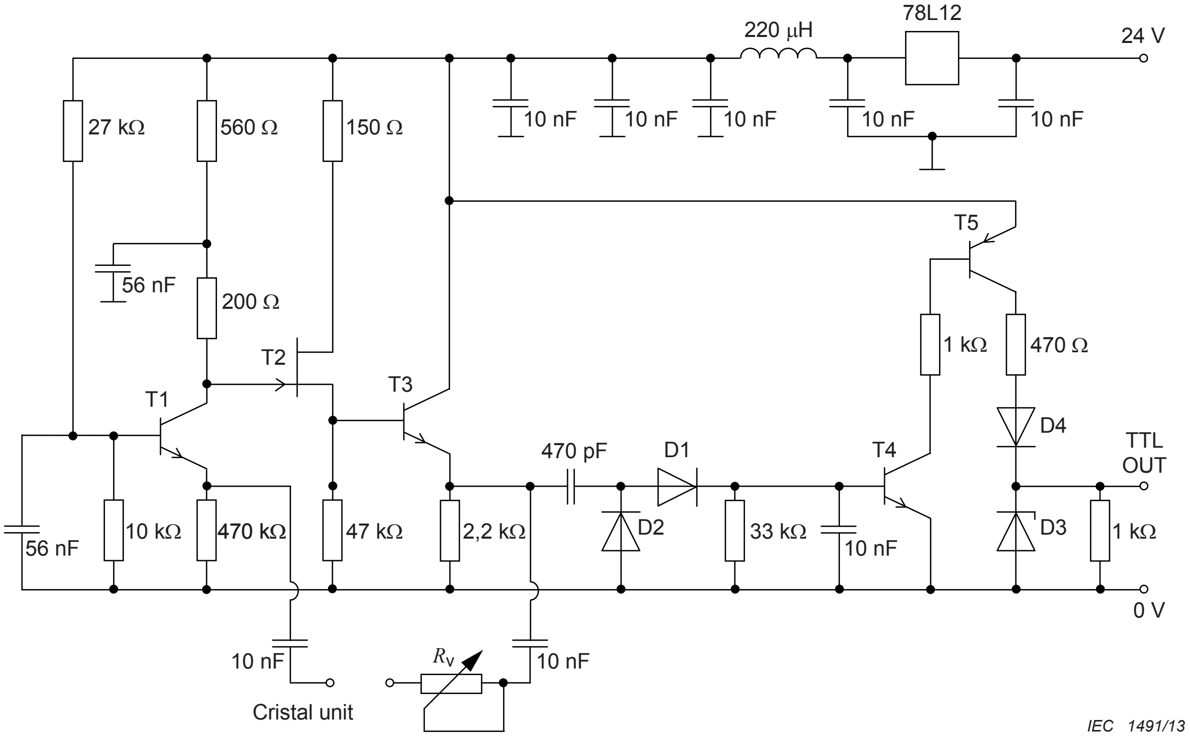


Figure B.7 – Principal schematic diagram of the go/no-go test circuit

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Amendment 1:1993

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