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Edition 3.1 2017-12

CONSOLIDATED VERSION

colour inside

Quartz crystal units of assessed quality –
Part 1: Generic specification

IEC 60122-1:2002-08+AMD1:2017-12 CSV(en)

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REDLINE VERSION

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Quartz crystal units of assessed quality – Part 1: Generic specification

IEC 60122-1:2002-08+AMD1:2017-12 CSV(en)

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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QUARTZ CRYSTAL UNITS OF ASSESSED QUALITY –

Part 1: Generic specification

FOREWORD

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This Consolidated version of IEC 60122-1 bears the edition number 3.1. It consists of the third edition (2002-08) [documents 49/551/FDIS and 49/558/RVD] and its amendment 1 (2017-12) [documents 49/1254/FDIS and 49/1259/RVD]. The technical content is identical to the base edition and its amendment.

In this Redline version, a vertical line in the margin shows where the technical content is modified by amendment 1. Additions are in green text, deletions are in strikethrough red text. A separate Final version with all changes accepted is available in this publication.

International Standard IEC 60122-1 has been prepared by IEC technical committee 49: Piezoelectric and dielectric devices for frequency control and selection.

This third edition of IEC 60122-1 constitutes a technical revision.

International Standard IEC 60122-1 is the first part of a new edition of the IEC standard series for quartz crystal units of assessed quality.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 3.

IEC 60122 consists of the following parts under the general title: Quartz crystal units of assessed quality:

- Part 1: Generic specification (IEC 60122-1);
- Part 2: Guide to the use of quartz crystal units for frequency control and selection (IEC 60122-2 at present);
- Part 3: Standard outlines and lead connections (IEC 60122-3);
- Part 4: Sectional specification – Capability Approval (IEC 61178-2 at present);
- Part 4-1: Blank detail specification – Capability Approval (IEC 61178-2-1 at present);
- Part 5: Sectional specification – Qualification Approval (IEC 61178-3 at present);
- Part 5-1: Blank detail specification – Qualification Approval (IEC 61178-3-1 at present).

The QC number which appears on the front cover of this publication is the specification number in the IEC Quality Assessment System for Electronic Components (IECQ).

The committee has decided that the contents of the base publication and its amendment 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

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

A bilingual version of this publication may be issued at a later date.

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QUARTZ CRYSTAL UNITS OF ASSESSED QUALITY –

Part 1: Generic specification

1 General

1.1 Scope

This part of IEC 60122 specifies the methods of test and general requirements for quartz crystal units of assessed quality using either capability approval or qualification approval procedures.

1.2 Normative references

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

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

IEC 60050(561):1991, *International Electrotechnical Vocabulary (IEV) – Chapter 561: Piezoelectric devices for frequency control and selection*

IEC 60068-1:1988, *Environmental testing – Part 1: General and guidance*

IEC 60068-2-1:1990, *Environmental testing – Part 2: Tests – Tests A: Cold*

IEC 60068-2-2:1974, *Environmental testing – Part 2: Tests – Tests B: Dry heat*

IEC 60068-2-3:1969, *Environmental testing – Part 2: Tests – Test Ca: Damp heat, steady state*

IEC 60068-2-6:1995, *Environmental testing – Part 2: Tests – Test Fc: Vibration (sinusoidal)*

IEC 60068-2-7:1983, *Environmental testing – Part 2: Tests – Test Ga: Acceleration, steady state*

IEC 60068-2-13:1983, *Environmental testing – Part 2: Tests – Test M: Low air pressure*

IEC 60068-2-14:1984, *Environmental testing – Part 2: Tests – Test N: Change of temperature*

IEC 60068-2-17:1994, *Basic* environmental testing *procedures– Part 2: Tests – Test Q: Sealing*

IEC 60068-2-20:1979, *Environmental testing – Part 2: Tests – Test T: Soldering*

IEC 60068-2-21:1999, *Environmental testing – Part 2-21: Tests – Test U: Robustness of terminations and integral mounting devices*

IEC 60068-2-27:1987, *Environmental testing – Part 2: Tests – Test Ea and guidance: Shock*

IEC 60068-2-29:1987, *Environmental testing – Part 2: Tests – Test Eb and guidance: Bump*

IEC 60068-2-30:1980, *Environmental testing – Part 2: Tests – Test Db and guidance: Damp heat, cyclic (12 + 12-hour cycle)*

IEC 60068-2-32:1975, *Environmental testing – Part 2: Tests – Test Ed: Free fall (Procedure 1)*

IEC 60068-2-45:1980, *Environmental testing – Part 2: Tests – Test XA and guidance: Immersion in cleaning solvents*

IEC 60122-3:2001, *Quartz crystal units of assessed quality – Part 3: Standard outlines and lead connections*

IEC 60444-1:1986, *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 techniques in a π-network*

IEC 60444-2:1980, *Measurement of quartz crystal unit parameters by zero phase technique in a π-network – Part 2: Phase offset method for the measurement of motional capacitance of quartz crystal units*

IEC 60444-4:1988, *Measurement of quartz crystal unit parameters by zero phase technique in a π-network – Part 4: Method for the measurement of the load resonance frequency f_L, load resonance resistance R_L and the calculation of other derived values of quartz crystal units, up to 30 MHz*

IEC 60444-5:1995*, Measurement of quartz crystal unit parameters – Part 5: Methods for the determination of equivalent electrical parameters using automatic network analyzer techniques and error corrections*

IEC 60444-6:1995*, Measurement of quartz crystal unit parameters – Part 6: Measurement of drive level dependence (DLD)*

IEC 60617 (all parts)*, Graphical symbols for diagrams*

IEC 61178-2:1993, *Quartz crystal units – A specification in the IEC Quality Assessment System for Electronic Components (IECQ) – Part 2: Sectional specification – Capability approval*

IEC 61178-3:1993, *Quartz crystal units – A specification in the IEC Quality Assessment System for Electronic Components (IECQ) – Part 3: Sectional specification – Qualification approval*

IEC 61760-1:2006, *Surface mounting technology – Part 1: Standard method for the specification of surface mounting components (SMDs)*

IEC QC 001001:2000, *IEC Quality Assessment System for Electronic Components (IECQ) – Basic Rules*

IEC QC 001002-2:1998, *ICQ Quality Assessment System for Electronic Components (IECQ) – Rules of Procedure – Part 2: Documentation*

IEC QC 001002-3:1998, *IEC Quality Assessment System for Electronic Components (IECQ) – Rules of Procedure – Part 3: Approval Procedures*

IEC QC 001005:2000, *Register of firms, products and services approved under the IECQ System, including ISO 9000*

ISO 1000:1992, *SI units and recommendations for the use of their multiples and of certain other units*

1.3 Order of precedence

Where any discrepancies occur for any reason, documents shall rank in the following order of precedence:

– the detail specification;

– the sectional specification;

– the generic specification;

– any other international documents (for example of the IEC) to which reference is made.

The same order of precedence shall apply to equivalent national documents.

2 Terminology and general requirements

2.1 General

Units, graphical symbols, letter symbols and terminology shall, wherever possible, be taken from the following standards: IEC 60027, IEC 60050(561), IEC 60617 and ISO 1000.

2.2 Terms, definitions and classification of phenomena

The following paragraphs contain additional terminology applicable to quartz crystal units and describe certain phenomena in this context.

2.2.1
crystal element (crystal blank)
piezoelectric material cut to a given geometrical shape, size and orientation with respect to the crystallographic axes of the crystal

2.2.2
electrode
an electrically conductive plate or film in contact with, or in proximity to, a face of a crystal element by means of which an electric field is applied to the element

2.2.3
crystal resonator
a mounted crystal element that vibrates when an alternating electric field exists between the electrodes

2.2.4
mounting
the means by which the crystal resonator is supported (within its enclosure)

2.2.5
enclosure
the enclosure protecting the crystal resonator(s) and mounting

2.2.6
enclosure type
a crystal enclosure of specific outline dimensions and material with a defined method of sealing

2.2.7
crystal unit
a crystal resonator mounted in an enclosure

2.2.8
socket
a component into which the crystal unit is inserted to hold the crystal unit and to provide electrical connection

2.2.9
mode of vibration
the pattern of motion in a vibrating body of the individual particles resulting from stresses applied to the body, the frequency of oscillation and the boundary conditions existing. The common modes of vibration are:

– flexural;
– extensional;
– face shear;
– thickness shear.

2.2.10
fundamental crystal unit
a crystal resonator designed to operate at the lowest order of a given mode

2.2.11
overtone crystal unit
a crystal resonator designed to operate at a higher order than the lowest of the given mode

2.2.12
overtone order
the numbers allotted to the successive overtones of a given mode of vibration from the ascending series of integral numbers commencing with the fundamental as unity. For shear and extensional modes, this overtone is the integral multiple of the fundamental frequency to which the overtone frequency approximates

2.2.13
crystal unit equivalent circuit
the electric circuit which has the same impedance as the crystal unit in the region of the desired resonance and anti-resonance frequencies. It is represented by an inductance, capacitance and resistance in series, this series arm being shunted by the capacitance between the terminals of the unit. The parameters of the series branch of inductance, capacitance and resistance are given by L_1, C_1 and R_1 respectively: these are termed "motional parameters" of the crystal unit. The shunt (parallel) capacitance is denoted by C_0 (see figure 1).

The parameters are independent of frequency for isolated modes of motion. Generally, the mode in question is sufficiently isolated from other modes to permit this assumption. When this is not true, the equations and measuring methods outlined herein do not apply. For identification of symbols used in this standard, see table 1.

NOTE 1 The equivalent circuit does not represent all the characteristics of a crystal unit.

NOTE 2 The values of R_e, X_e, G_p and B_p vary rapidly around the resonance frequency,

where

R_e is the equivalent circuit series resistance of the resonator;

X_e is the equivalent circuit series reactance of the resonator;

G_p is the equivalent circuit parallel conductance of the resonator;

B_p is the equivalent circuit parallel susceptance of the resonator.

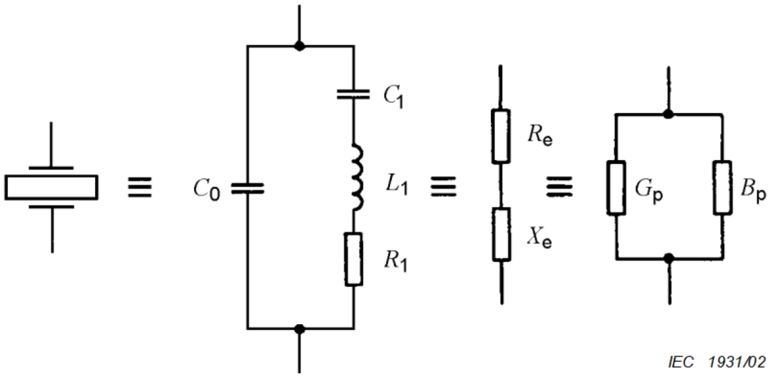


Figure 1 – Symbol and equivalent electrical circuit of a piezoelectric resonator

2.2.14
motional resistance (R_1)
the resistance in the motional (series) arm of the equivalent circuit

2.2.15
motional inductance (L_1)
the inductance in the motional (series) arm of the equivalent circuit

2.2.16
motional capacitance (C_1)
the capacitance in the motional (series) arm of the equivalent circuit

2.2.17
shunt capacitance (C_0)
the capacitance in parallel with the motional arm of the equivalent circuit

2.2.18
parameters of piezoelectric resonators
the fundamental parameters C_1, L_1, R_1 and C_0 define the equivalent electric circuit shown in figure 1, and all other parameters may be derived from them. At a given frequency, the parameters of the equivalent electric circuit generally approach constant values as the amplitude of vibration approaches zero. The amplitude which can be tolerated before the parameters are appreciably affected varies widely between resonators of various types and can only be determined by experiment.

The equation for the impedance Z or admittance Y:

$$Z = \frac{1}{Y} = \frac{j}{\omega C_0} \times \frac{\Omega - j\delta}{1 - \Omega + j\delta} \qquad (1)$$

of the equivalent electric circuit of the piezoelectric resonator is the basic equation describing the relationships between the various parameters.

In equation (1):

$$\Omega = \frac{f^2 - f_s^2}{f_p^2 - f_s^2} \quad \text{and} \quad \delta = 2\pi f C_0 R_1$$

are the normalized frequency factor and the normalized damping factor, respectively. See table 1, for definitions of f_p, f_s, and the other symbols used in equation (1) and for other essential parameters. The characteristic frequencies of equation (1) are defined in table 2.

The magnitude of the impedance of the equivalent electric network ($|Z|$), its resistive component (R_e), its reactive component (X_e), and the reactance X_1 of the L_1, C_1, R_1 branch are plotted as functions of frequency in figure 2, for the purpose of defining the different characteristic frequencies. $|Z_m|$ and $|Z_n|$ denote minimum and maximum impedance respectively, and R_r, R_a the impedances at zero phase angle. These curves, however, have only qualitative character and do not represent a particular piezoelectric resonator.

For further clarification, the impedance and admittance circles of a piezoelectric resonator are reproduced in figure 3. However, the circle representation of the impedance or admittance of a piezoelectric resonator is valid only if the circle diameter of the admittance diagram is large compared with the change of 2 $\pi f C_0$ in the resonance range or if $r \ll Q^2$, which is fulfilled in most resonators. If the latter conditions are not fulfilled, the admittance curve shows a cissoidal character. Throughout the remainder of this standard, it is assumed that the impedance (or admittance) of the resonator can be represented by a circle diagram. Table 3 gives data for Q, r, and Q^2/r for various types of resonators, indicating that this assumption is valid for all practical cases.

It is necessary to make approximations in deriving practical equations for general use. It is the error of these approximations, in addition to the errors of instrumentation that govern the overall accuracy of the experimentally derived parameters.

As a first approximation sufficient for many practical purposes, the following assumptions can be made:

$$f_m = f_r = f_s \quad \text{and} \quad f_a = f_n = f_p$$

More exact relations between the characteristic frequencies f_m, f_r, f_a, f_p, f_n, and the series resonance frequency f_s of a resonator, valid for the figure of merit $M > 10$ and the capacitance ratio $r > 10$, are shown in table 4. These relationships have been derived by various authors under the assumption that $M \gg 1$.

The separation between parallel and series resonance frequencies is given by:

$$\frac{{f_p}^2 - {f_s}^2}{{f_s}^2} = \frac{C_1}{C_0} = \frac{1}{r} \qquad (2)$$

The approximation:

$$\begin{aligned} \frac{f_p - f_s}{f_s} &= \sqrt{1 + r^{-1}} - 1 \\ &= \frac{1}{2r}\left(1 - \frac{1}{4r} + \dots\right) \approx \frac{1}{2r} \\ &= \frac{1}{2}\frac{C_1}{C_0} \end{aligned} \qquad (3)$$

can be used for larger values of r (for example, when r is greater than 25, the error is less than 1 %).

2.2.19
resonance frequency (f_r)
the lower of the two frequencies of the crystal unit alone, under specified conditions, at which the electrical impedance of the crystal unit is resistive

2.2.20
resonance resistance (R_r)
the resistance of the crystal unit alone at the resonance frequency f_r

2.2.21
anti-resonance frequency (f_a)
the higher of the two frequencies of the crystal unit alone, under specified conditions, at which the electrical impedance of the crystal unit is resistive

2.2.22
load capacitance (C_L)
the effective external capacitance associated with the crystal unit which determines the load resonance frequency f_L

2.2.23
load resonance frequency (f_L)
one of the two frequencies of a crystal unit in association with a series or with a parallel load capacitance, under specified conditions at which the electrical impedance of the combination is resistive. The load resonance frequency is the lower of the two frequencies when the load capacitance is in series and the higher when it is in parallel (see figure 4).

For a given value of load capacitance C_L, these frequencies are identical for all practical purposes and are given by the expression

$$\frac{1}{f_L} = 2\pi\sqrt{\frac{L_1 C_1 (C_0 + C_L)}{C_1 + C_0 + C_L}} \qquad (4)$$

NOTE 1 The frequencies defined in 2.2.19, 2.2.21 and 2.2.23 are listed as being the terms more commonly used. The frequencies associated with a quartz crystal are numerous and for a full explanation tables 2 and 4 should be consulted.

NOTE 2 When higher accuracies are required or secondary data (for example, values of crystal unit motional parameters) are to be derived from the frequency measurements, table 1, IEC 60444-1 and IEC 60444-5 should be consulted.

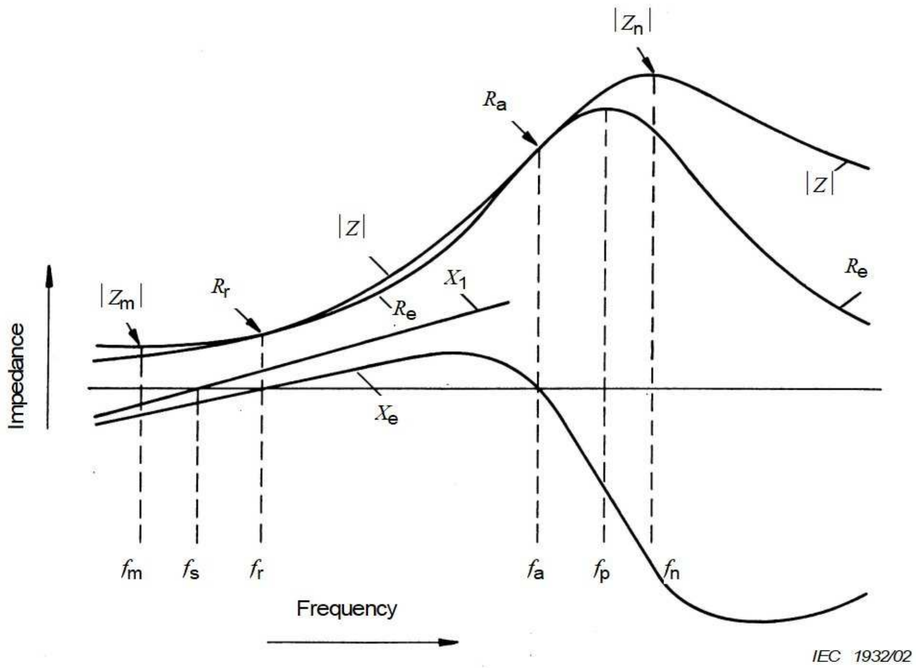


Figure 2 – Impedance |Z|, resistance R_e, reactance X_e, series arm reactance X_1 of a piezoelectric resonator as a function of frequency

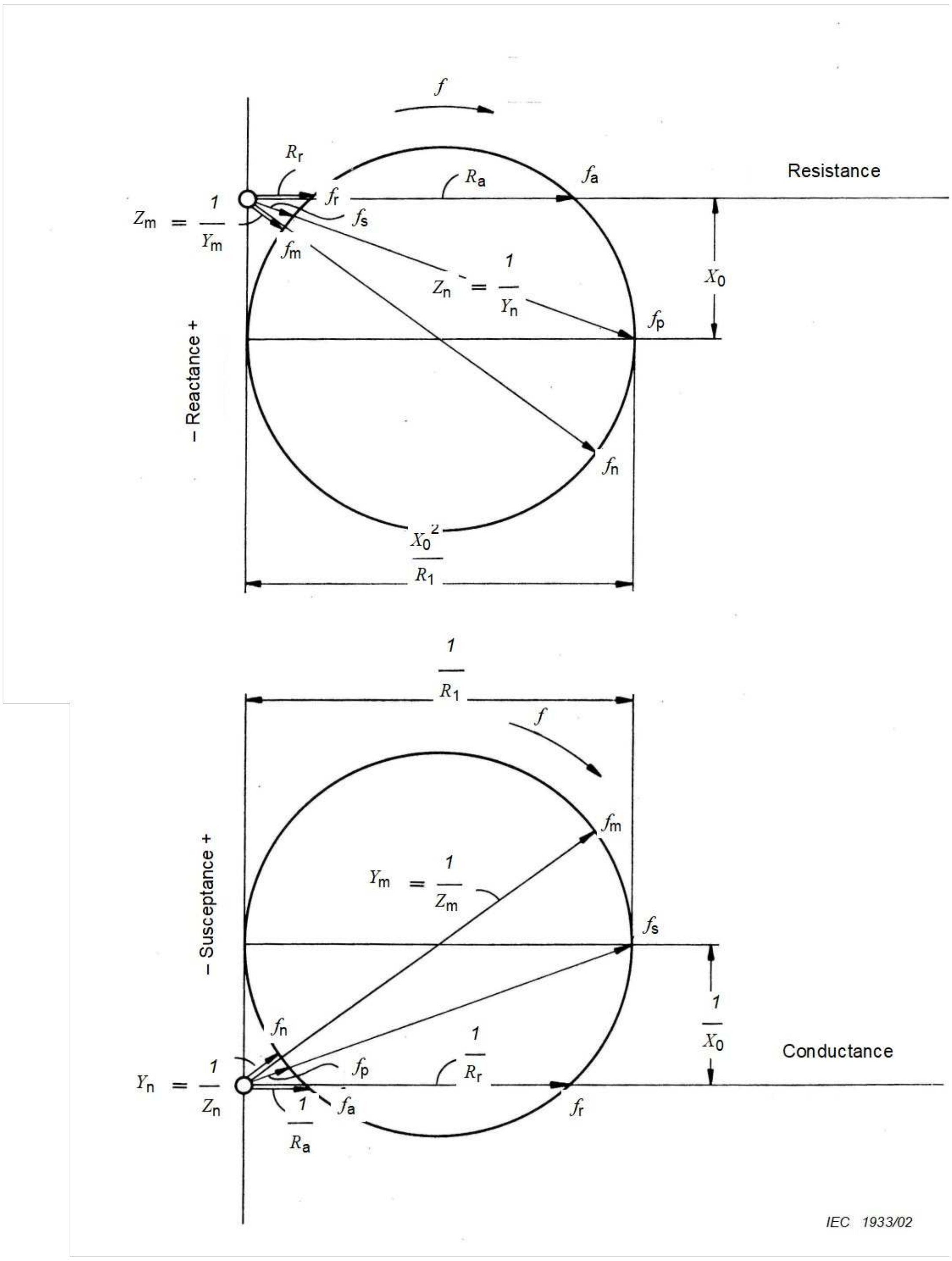
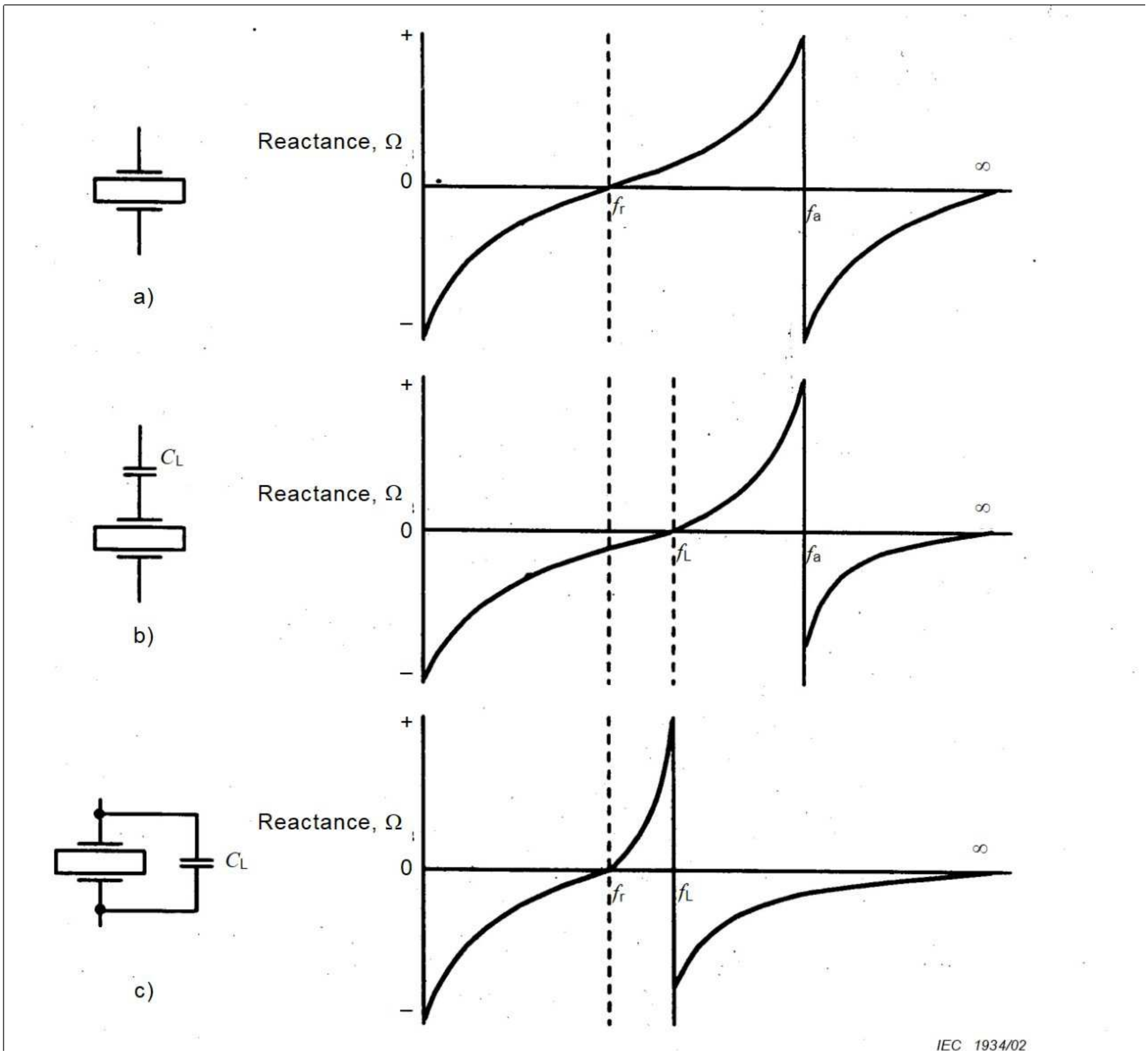


Figure 3 – Impedance and admittance diagram of a piezoelectric resonator

The symbols conform with those in table 1 and figure 2.



NOTE 1 The values of load capacitances shown in b) and c) are equal.

NOTE 2 See 2.2.19, 2.2.21 and 2.2.23.

Figure 4 – Resonance, anti-resonance and load resonance frequencies

2.2.24
load resonance resistance (R_L)
the resistance of the crystal unit in series with a stated external capacitance at the load resonance frequency f_L.

NOTE To a close approximation the value of R_L is related to the value of R_r by the expression:

$$R_L \cong R_r \left(1 + \frac{C_0}{C_L}\right)^2 \tag{5}$$

2.2.25
nominal frequency (f_{nom})
the frequency assigned to the crystal unit by the manufacturer

2.2.26
working frequency (f_{w})
the operational frequency of the crystal unit together with associated circuits

2.2.27
load resonance frequency offset (Δf_{L})

$$\Delta f_{\mathrm{L}} = f_{\mathrm{L}} - f_{\mathrm{r}} \tag{6}$$

It can be calculated approximately from

$$\Delta f_{\mathrm{L}} \cong \frac{f_{\mathrm{r}} C_1}{2(C_0 + C_{\mathrm{L}})} \tag{7}$$

In usage, the load resonance frequency offset Δf_{L} for a given value of load capacitance can be written as, for instance, Δf_{30} or Δf_{20} to indicate the actual value of load capacitance in picofarads involved.

2.2.28
fractional load resonance frequency offset (D_{L})

$$D_{\mathrm{L}} = \frac{f_{\mathrm{L}} - f_{\mathrm{r}}}{f_{\mathrm{r}}} \tag{8}$$

It can be calculated approximately from

$$D_{\mathrm{L}} \cong \frac{C_1}{2(C_0 + C_{\mathrm{L}})} \tag{9}$$

This can also be written as, for instance, D_{30} to indicate the fractional load resonance frequency offset D_{L} with a load capacitance of 30 pF.

2.2.29
frequency pulling range ($\Delta f_{\mathrm{L1,L2}}$)

$$\Delta f_{\mathrm{L1,L2}} = | f_{\mathrm{L1}} - f_{\mathrm{L2}} | \tag{10}$$

It can be calculated approximately from:

$$\Delta f_{\mathrm{L1,L2}} = \left| \frac{f_{\mathrm{r}} C_1 (C_{\mathrm{L2}} - C_{\mathrm{L1}})}{2(C_0 + C_{\mathrm{L1}})(C_0 + C_{\mathrm{L2}})} \right| \tag{11}$$

This can also be written as, for instance $\Delta f_{20,30}$ to indicate the frequency pulling range between load capacitances of 20 pF and 30 pF

2.2.30
fractional pulling range ($D_{\mathrm{L1,L2}}$)

$$D_{\mathrm{L1,\,L2}} = \left| \frac{f_{\mathrm{L1}} - f_{\mathrm{L2}}}{f_{\mathrm{r}}} \right| = \left| D_{\mathrm{L1}} - D_{\mathrm{L2}} \right| \tag{12}$$

It can be calculated approximately from:

$$D_{\mathrm{L1,L2}} = \left| \frac{C_1(C_{\mathrm{L2}} - C_{\mathrm{L1}})}{2(C_0 + C_{\mathrm{L1}})(C_0 + C_{\mathrm{L2}})} \right| \tag{13}$$

This can be written as, for instance, $D_{20,30}$, to indicate the fractional pulling range between load capacitances of 20 pF and 30 pF

2.2.31
pulling sensitivity (*S*)

$$S = \frac{\mathrm{d}D_{\mathrm{L}}}{\mathrm{d}C_{\mathrm{L}}} \cong \frac{-C_1}{2(C_0 + C_{\mathrm{L}})^2} \tag{14}$$

This can be written as, for instance, S_{30}, to indicate the pulling sensitivity at a load capacitance of 30 pF

2.2.32
operating temperature range
the range of temperatures as measured on the enclosure, over which the crystal unit shall be within the specified tolerances

2.2.33
operable temperature range
the range of temperatures as measured on the enclosure over which the crystal unit will not sustain permanent damage though not necessarily functioning within the specified tolerances

2.2.34
storage temperature range
the minimum and maximum temperatures, as measured on the enclosure, at which the crystal unit may be stored without deterioration or damage to its performance

2.2.35
reference temperature
the temperature at which certain crystal measurements are made. For controlled temperature units, the reference temperature is the mid-point of the controlled temperature range. For non-controlled temperature units, the reference temperature is normally 25 °C ± 2 °C

2.2.36
level of drive
a measure of the conditions imposed upon the crystal unit. This may be expressed in terms of current through or power dissipated in the crystal element

2.2.37
drive level dependency
drive level dependency (DLD) is the effect of changes in drive level conditions upon the resonance resistance of the crystal unit. This parameter can be specified by defining the ratio of resistance between two specified drive levels. This ratio is represented by the expression:

$$\frac{R_{\mathrm{r1}}}{R_{\mathrm{r2}}}$$

where

R_{r1} is the resistance at the lower level of drive;

R_{r2} is the resistance at the higher level of drive.

2.2.38
unwanted response
a state of resonance of a crystal resonator other than that associated with the working frequency

2.2.39
frequency tolerance
the maximum permissible deviation of the working frequency due to a specified cause or a combination of causes. The frequency tolerance is usually stated in parts per million (1×10^{-6}) of the nominal frequency

NOTE The tolerances normally used are as follows:

– deviation from nominal frequency at the reference temperature under specified conditions;

– deviation over the temperature range from the frequency at the specified reference temperature;

– deviation as a result of ageing under specified conditions;

– deviation from nominal frequency due to all causes (overall tolerance).

Table 1 – List of symbols used for the equivalent electric circuit of a piezoelectric resonator

Symbols	Meaning	SI units	References		
			Equations	Tables	Figures
B_p	Equivalent parallel susceptance of resonator	S		2	1
C_0	Shunt (parallel) capacitance in the equivalent electric circuit	F	2, 3		1, 5
C_1	Motional capacitance in the equivalent electric circuit	F	2, 3		1, 5
f	Frequency	Hz			3
f_a	Antiresonance frequency, zero susceptance	Hz		2, 4	2, 3
f_m	Frequency of maximum admittance(minimum impedance)	Hz		2, 4	2, 3
f_n	Frequency of minimum admittance(maximum impedance)	Hz		2, 4	2, 3
f_p	Parallel resonance frequency (lossless) $\frac{1}{2\pi\sqrt{L_1 \frac{C_1C_0}{C_1+C_0}}}$	Hz	2, 3	2, 4	2, 3
f_r	Resonance frequency, zero susceptance	Hz		2, 4	2, 3, 4
f_s	Motional (series) resonance frequency $\frac{1}{2\pi\sqrt{L_1C_1}}$	Hz	2, 3	2, 4	2, 3
G_p	Equivalent parallel conductance of resonator				1
L_1	Motional inductance in the equivalent electric circuit	H			1, 5
M	Figure of merit of a resonator $M = \frac{Q}{r}$	Dimensionless		3, 4	

Symbols	Meaning	SI units	References		
			Equations	**Tables**	**Figures**
Q	Quality factor: $Q = \frac{W_s L_1}{R_1}$	Dimensionless		3	
r	Capacitance ratio: $r = \frac{C_0}{C_1}$	Dimensionless	2, 3	2, 3, 4	
R_a	Impedance at zero phase angle near antiresonance	Ω			2, 3
R_e	Equivalent series resistance of resonator	Ω			1,2
R_r	Impedance at f_r , zero phase angle	Ω			2, 3
R_1	Motional resistance in the equivalent electric circuit	Ω	15	2	1, 3, 5
X_e	Equivalent series reactance of resonator	Ω			1, 2
X_0	Reactance of shunt (parallel) capacitance at series resonance: $X_o = \frac{1}{\omega_s C_0}$	Ω			3
X_1	Reactance of motional series arm of resonator: $X_1 = \omega L_1 - \frac{1}{\omega C_1}$	Ω		2	2
Y	Admittance of resonator: $Y = G_p + jB_p = \frac{1}{Z}$	S	1		
Y_m	Maximum admittance of resonator	S			3
Y_n	Minimum admittance of resonator	S			3
Z	Impedance of resonator: $Z = R_e + jX_e$	Ω	1		
Z_m	Minimum impedance of resonator	Ω			2, 3
Z_n	Maximum impedance of resonator	Ω			2, 3
$\lvert Z \rvert$	Absolute value of impedance of resonator: $Z = \sqrt{R_e{}^2 + X_e{}^2}$	Ω		2	2
$\lvert Z_m \rvert$	Absolute value of impedance at f_m (minimum impedance)	Ω			2
$\lvert Z_n \rvert$	Absolute value of impedance at f_n (maximum impedance)	Ω			2
δ	Normalized damping factor: $\delta = \omega C_o R_1$	Dimensionless	1	2	
Ω	Normalized frequency factor: $\Omega = \frac{f^2 - f_s{}^2}{f_p{}^2 - f_s{}^2}$	Dimensionless	1	2	
ω	Circular (angular) frequency: $\omega = 2\pi f$	rad/s		2	
ω_s	Circular frequency at motional resonance: $\omega_s = 2\pi f_s$	rad/s			
C_L	Load capacitance	F	4, 15	1	4, 5
f_L	Load resonance frequency of combination of resonator and C_L $f_L = f_s\sqrt{1 + \frac{C_1}{C_0 + C_L}}$	Hz	15	1	4

Table 2 – Solutions for the various characteristic frequencies

Characteristic frequencies	Meaning	Condition	Constituent equation for frequency
f_m	Frequency of maximum admit–tance (minimum impedance)	$\frac{d\|Z\|}{d\omega} = 0$	$(\Omega^2 + \delta^2)^2 - 2\delta^2(\Omega + r) - 2\Omega r(1 - \Omega) - \Omega^2 = 0$
f_s	Motional (series) resonance frequency	$X_1 = 0$	$\Omega = 0$
f_r	Resonance frequency	$X_e = B_p = 0$	$\Omega(1 - \Omega) - \delta^2 = 0$
f_a	Antiresonance frequency	$X_e = B_p = 0$	$\Omega(1 - \Omega) - \delta^2 = 0$
f_p	Parallel resonance frequency (loss-less)	$\|X_e\| = \infty$ for $R_1 = 0$	$\Omega = 1$
f_n	Frequency of minimum admittance (maximum impedance)	$\frac{d\|Z\|}{d\omega} = 0$	$(\Omega^2 + \delta^2)^2 - 2\delta^2(\Omega + r) - 2\Omega r(1 - \Omega) - \Omega^2 = 0$

Table 3 – Minimum values for the ratio Q^2/r to be expected for various types of piezoelectric resonators

Type of piezoelectric resonator	$Q = M r$	r	Q^2/r min
Piezoelectric ceramics	90 – 500	2 – 40	200
Water-soluble piezoelectric crystals	200 – 50 000	3 – 500	80
Quartz	$10^4 – 10^7$	100 – 50 000	2 000

Table 4 – Approximate relations between the characteristic frequencies and the series resonance frequency f_s of a piezoelectric resonator

Characteristic frequency	1st approximation		2nd approximation	
	$\frac{f}{f_s}$	Deviation $\frac{\Delta f}{f_s}$ from a more precise value	$\frac{f}{f_s}$	Deviation $\frac{\Delta f}{f_s}$ from a more precise value
f_m	$\frac{f_m}{f_s} = 1$	$-\frac{1}{2M^2 r}$	$\frac{f_m}{f_s} = \sqrt{1 + \frac{1}{2r}\left[1 - \sqrt{1 + \frac{4}{M^2}}\right]}$	$\frac{1}{2M^4 r^2}$
f_r	$\frac{f_r}{f_s} = 1$	$\frac{1}{2M^2 r}$	$\frac{f_r}{f_s} = \sqrt{1 + \frac{1}{2r}\left[1 - \sqrt{1 - \frac{4}{M^2}}\right]}$	$\frac{1}{2M^4 r^2}$
f_a	$\frac{f_a}{f_s} = 1 + \frac{1}{2r}$	$-\frac{1}{2M^2 r}\left(\frac{1}{r} + 1\right)$	$\frac{f_a}{f_s} = \sqrt{1 + \frac{1}{2r}\left[1 + \sqrt{1 - \frac{4}{M^2}}\right]}$	$-\frac{1}{2M^2 r} \times \frac{1}{r}$
f_n	$\frac{f_n}{f_s} = 1 + \frac{1}{2r}$	$\frac{1}{2M^2 r}\left(\frac{1}{r} + 1\right)$	$\frac{f_n}{f_s} = \sqrt{1 + \frac{1}{2r}\left[1 + \sqrt{1 + \frac{4}{M^2}}\right]}$	$\frac{1}{2M^2 r} \times \frac{1}{r}$
f_p	$\frac{f_p}{f_s} = 1 + \frac{1}{2r}$	$-\frac{1}{8r^2}$	$\frac{f_p}{f_s} = \sqrt{1 + \frac{1}{r}}$	0

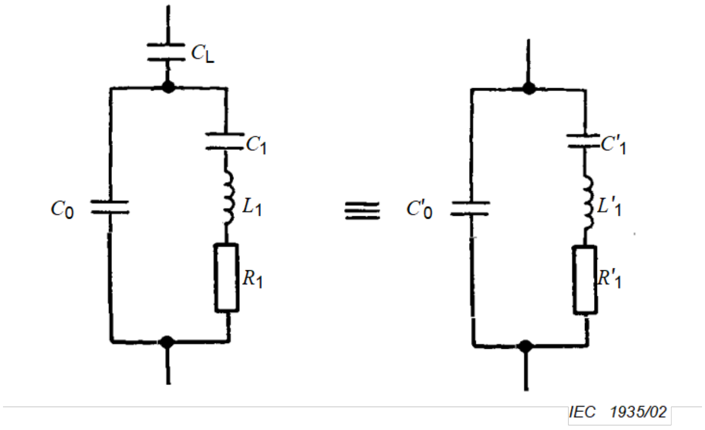


Figure 5 – Equivalent circuit of a piezoelectric resonator with a series (load) capacitance C_L

$$L'_1 = L_1\left(1 + \frac{C_0}{C_L}\right)^2$$

$$C_1' = C_1 \frac{1}{\left(1 + \frac{C_0}{C_L}\right)^2 \left(1 + \frac{C_1}{C_0 + C_L}\right)} \qquad (15)$$

$$R'_1 = R_1\left(1 + \frac{C_0}{C_L}\right)^2$$

$$C'_0 = \left(\frac{C_0 C_L}{C_0 + C_L}\right)$$

$$f_L = f_s\sqrt{1 + \frac{C_1}{C_0 + C_L}} \approx f_s\left(1 + \frac{C_1}{2(C_0 + C_L)}\right)$$

2.3 Preferred ratings and characteristics

Values should preferably be chosen from the following paragraphs.

2.3.1 Temperature ranges in degrees Celsius (°C) suitable for ambient operation

–55 to +125	–30 to +80	–10 to +60
–55 to +105	–30 to +70	–10 to +50
–55 to +100	–25 to +80	0 to +60
–55 to +90	–20 to +85	0 to +50
–40 to +90	–20 to +80	+5 to +55
–40 to +85	–20 to +70	+10 to +40
–40 to +80	–20 to +60	+15 to +50
–40 to +70	–10 to +70	

2.3.2 Elevated temperature ranges in degrees Celsius (°C) suitable for oven control

60 ± 5	75 ± 5
65 ± 5	80 ± 5
70 ± 5	85 ± 5

2.3.3 Frequency tolerance (1×10^{-6})

±200	±25	±7,5
±100	±20	±5
±50	±15	±4
±40	±10	±2,5
±30		±1

2.3.4 Circuit conditions

10 pF load capacitance
15 pF load capacitance
20 pF load capacitance
30 pF load capacitance
50 pF load capacitance
Series resonance.

2.3.5 Levels of drive

Thickness shear/AT:
Current, in µA
150
200
1 000
2 000
Power, in µW
1
10
100
500
Flexure and face shear:
Current, in µA
100
200
Extensional:
Current, in µA
500
1 000

2.3.6 Drive level dependency

Resonance resistance Ω	Resistance ratio, $\frac{R_{r1}}{R_{r2}}$
< 5	2,2
5 to 10	2,0
10 to 20	1,8
20 to 35	1,5
35 to 50	1,3
>50	1,2

2.3.7 Climatic category

55/105/56

For requirements where the operating temperature range of the crystal unit is greater than –55 °C to +105 °C, a climatic category consistent with the operating temperature range shall be specified.

2.3.8 Bump severity

4 000 ± 10 bumps at 390 m/s^2 peak acceleration in each direction along three mutually perpendicular axes (see 4.8.6).

Pulse duration 6 ms.

2.3.9 Vibration severity

10 Hz to 55 Hz 0,75 mm displacement amplitude (peak value) 55 Hz to 500 Hz or 55 Hz to 2 000 Hz 98,1 m/s^2 acceleration amplitude (peak value)	30 min in each of three mutually perpendicular axes at 1 octave/min (see 4.8.7)

10 Hz to 55 Hz 1,5 mm displacement amplitude (peak value) 55 Hz to 2 000 Hz 196,2 m/s^2 acceleration amplitude (peak value)	30 min in each of three mutually perpendicular axes at 1 octave/min (see 4.8.7)

Random vibration severities: under consideration

2.3.10 Shock severity

981 m/s^2 peak acceleration for 6 ms duration; three shocks in each direction along three mutually perpendicular axes (see 4.8.8), half sine pulse, unless otherwise stated in the detail specification.

2.3.11 Leak rate

10^{-3} Pa·cm^3/s (10^{-8} bar·cm^3/s).

2.4 Marking

2.4.1 The information given in the marking is selected from the following list: the relative importance of each item is indicated by its position in the list:

a) type designation as defined in the detail specification;
b) nominal frequency in kilohertz (kHz) or megahertz (MHz);
c) year and week (four digits) of manufacture;
d) factory identification code;
e) manufacturer’s name or trade mark;
f) mark of conformity (unless a certificate of conformity is used).

2.4.2 The crystal units shall be clearly marked with a), b) and c) above and with as many as possible of the remaining items as is considered necessary. Any duplication of information in the marking on the crystal unit should be avoided.

Where the available surface area of miniature crystal enclosures imposes practical limits on the amount of marking, instructions on the marking to be applied shall be given in the detail specification.

2.4.3 The primary package containing the crystal unit(s) shall be clearly marked with all the information listed in 2.4.1.

2.4.4 Any additional marking shall be so applied that no confusion can arise.

3 Quality assessment procedures

Two methods are available for the approval of quartz crystal units of assessed quality. They are qualification approval and capability approval.

3.1 Primary stage of manufacture

In accordance with 3.1.1.2 of IEC QC 001002-3, the primary stage of manufacture is the final surface finishing of the crystal element.

NOTE The final surface finishing of the crystal element could be any of the following operations: lapping; polishing; etching; cleaning, in the case of polished plates.

3.2 Structurally similar components

The grouping of structurally similar components for the purpose of qualifications approval, capability approval and quality conformance inspection shall be prescribed in the relevant sectional specification.

3.3 Subcontracting

These procedures shall be in accordance with 3.1.2 of IEC QC 001002-3.

However, the final surface finishing of the crystal elements and all subsequent processes shall be carried out by the manufacturer to whom approval has been granted.

3.4 Manufacturer's approval

To obtain manufacturer's approval the manufacturer shall meet the requirements of clause 2 of IEC QC 001002-3.

3.5 Approval procedures

3.5.1 General

To qualify a quartz crystal unit, either capability approval or qualification approval procedures may be used. These procedures shall conform to those stated in IEC QC 001001 and IEC QC 001002-3.

3.5.2 Capability approval

Capability approval is appropriate when structurally similar quartz crystal units based on common design rules, are fabricated, by a group of common processes.

Under capability approval detail specifications fall into the following three categories.

a) **Capability qualifying components (CQCs)**

   A detail specification shall be prepared for each CQC as agreed with the National Supervising Inspectorate (NSI). It shall identify the purpose of the CQC and include all relevant stress levels and test limits.

b) **Standard catalogue items**

   When a component covered by the capability approval procedure is intended to be offered as a standard catalogue item, a detail specification complying with the blank detail specification shall be written. Such specifications shall be registered by the IECQ and the component may be listed in IEC QC 001005.

c) **Custom built quartz crystal units**

   The content of the detail specification shall be determined by agreement between the manufacturer and the customer in accordance with 4.3.3 of IEC QC 001002-3.

Further information on detail specifications is contained in the sectional specification IEC 61178-2.

The product and capability qualifying components (CQCs) are tested in combination and approval given to a manufacturing facility on the basis of validated design rules, processes and quality control procedures. Further information is given in 3.6 and in the sectional specification IEC 61178-2.

3.5.3 Qualification approval

Qualification approval is appropriate for components manufactured to a standard design and established production process and conforming to a published detail specification.

The programme of tests defined in the detail specification for the appropriate assessment and severity level applies directly to the quartz crystal unit to be qualified, as prescribed in 3.7 and the sectional specification IEC 61178-3.

3.6 Procedures for capability approval

3.6.1 General

The procedures for capability approval shall be in accordance with IEC QC 001002-3.

3.6.2 Eligibility for capability approval

The manufacturer shall comply with the requirement of 4.2.1 of IEC QC 001002-3 and the primary stage of manufacture as defined in 3.1 of this generic specification.

3.6.3 Application for capability approval

In order to obtain capability approval the manufacturer shall apply the rules of procedure given in clause 4 of IEC QC 001002-3.

3.6.4 Granting of capability approval

Capability approval shall be granted when the procedures in accordance with 4 of IEC QC 001002-3 have been successfully completed.

3.6.5 Capability manual

The contents of the capability manual shall be in accordance with the requirements of the sectional specification. The NSI shall treat the capability manual as a confidential document. The manufacturer may, if he so wishes, disclose part or all of it to a third party.

3.7 Procedures for qualification approval

3.7.1 General

The procedures for qualification approval shall be in accordance with clause 3 of IEC QC 001002-3.

3.7.2 Eligibility for qualification approval

The manufacturer shall comply with the requirements of 3.1.1 of IEC QC 001002-3 and the primary stage of manufacture as defined in 3.1 of this generic specification.

3.7.3 Application for qualification approval

In order to obtain qualification approval the manufacturer shall apply the procedures given in 3.1.3 of IEC QC 001002-3.

3.7.4 Granting of qualification approval

Qualification approval shall be granted when the procedures in accordance with 3.1.5 of IEC QC 001002-3 have been successfully completed.

3.7.5 Quality conformance inspection

The blank detail specification associated with the sectional specification shall prescribe the test schedule for quality conformance inspection.

3.8 Test procedures

The test procedures to be used shall be selected from this generic specification. If any required test is not included, then it shall be defined in the detail specification.

3.9 Screening requirements

Where screening is required by the customer for quartz crystal units this shall be specified in the detail specification.

3.10 Rework and repair work

3.10.1 Rework

Rework is the rectification of processing errors and shall not be carried out if prohibited by the sectional specification. The sectional specification shall state if there is a restriction on the number of occasions that rework may take place on a specific component.

All rework shall be carried out prior to the formation of the inspection lot offered for inspection to the requirements of the detail specification.

Such rework procedures shall be fully described in the relevant documentation produced by the manufacturer and shall be carried out under the direct control of the chief inspector. Sub-contracting of rework is not permitted.

3.10.2 Repair work

Repair work is the correction of defects in a component after release to the customer.

Components that have been repaired can no longer be considered as representative of the manufacturer’s production and may not be released under the IECQ System.

3.11 Certified records of released lots

The requirements of clause 1.5 of IEC QC 001002-2 shall apply. When certified records of released lots (CRRL) are prescribed in the sectional specification for qualification approval and are requested by the customer, the results of the specified tests shall be summarized.

3.12 Validity of release

Crystal units held for a period exceeding two years following acceptance inspection shall be reinspected for the electrical tests detailed in 4.7.1 and 4.7.3, with a sample tested as described in item a) of 4.8.3, prior to release.

3.13 Release for delivery

Quartz crystal units shall be released in accordance with 3.2.6 and 4.3.2 of IEC QC 001002-3.

3.14 Unchecked parameters

Only those parameters of a component which have been specified in a detail specification and which were subject to testing can be assumed to be within the specified limits. It should not be assumed that any parameter not specified will remain unchanged from one component to another. Should it be necessary for further parameters to be controlled, then a new, more extensive, detail specification should be used. Any additional test method(s) shall be fully described and appropriate limits, AQLs and inspection levels specified.

4 Test and measurement procedures

4.1 General

The test and measurement procedures shall be carried out in accordance with the relevant detail specification.

4.2 Alternative test methods

Measurements shall preferably be carried out using the methods specified. Any other method giving equivalent results may be used except in case of dispute.

NOTE By “equivalent” it is meant that the value of the characteristic established by such other method falls within the specified limits when measured by the specified method.

4.3 Precision of measurement

The limits given in detail specifications are true values. Measurement inaccuracies shall be taken into account when evaluating the results. Precautions should be taken to reduce measurement errors to a minimum.

4.4 Standard conditions for testing

Unless otherwise specified, all tests shall be carried out under the standards atmospheric conditions for testing as specified in 5.3 of IEC 60068-1.

Temperature	15 °C to 35 °C
Relative humidity	45 % to 75 %
Air pressure	86 kPa to 106 kPa (860 mbar to 1 060 mbar)

In case of dispute, the referee conditions are:

Temperature	25 °C ± 1 °C
Relative humidity	48 % to 52 %
Air pressure	86 kPa to 106 kPa (860 mbar to 1 060 mbar)

Before measurements are made, the crystal units shall be stored at the measuring temperature for a time sufficient to allow the crystal resonator to reach this temperature.

Controlled recovery conditions and standard conditions for assisted drying are given in 5.4 of IEC 60068-1.

The ambient temperature during the measurements shall be recorded and stated in the test report.

4.5 Visual inspection

Unless otherwise specified, external visual examination shall be performed under normal factory lighting and visual conditions.

4.5.1 Visual test A

The crystal unit shall be visually examined to ensure that the condition, workmanship and finish are satisfactory. The marking shall be legible.

4.5.2 Visual test B

The crystal unit shall be visually examined under ×10 magnification. There shall be no cracks in the glass or damage to the terminations. Minute flaking around the feather edge of a meniscus shall not be considered a crack.

4.5.3 Visual test C

The crystal unit shall be visually examined. There shall be no corrosion or other deterioration likely to impair satisfactory operation. The marking shall be legible.

4.6 Dimensioning and gauging procedures

4.6.1 Dimensions, test A

The dimensions, spacing and alignment of the terminations shall be checked, where appropriate using the gauges specified. The dimensions, spacing and alignment shall comply with the specified values.

4.6.2 Dimensions, test B

The dimensions shall be measured and they shall comply with the specified values. Dimensions are specified in IEC 60122-3 together with the gauging procedure as appropriate or as specified in the detail specification.

4.7 Electrical test procedures

4.7.1 Frequency and resonance resistance

Unless otherwise defined in the detail specification, the measurements shall be carried out at 25 °C ± 2 °C for non-temperature controlled crystal units; or at the mid-point of the temperature range ±1 °C for temperature controlled units.

The frequency and resonance resistance of the crystal unit shall be measured under the conditions stated in the detail specification and be within the specified limits.

NOTE Preferred methods of measurement are described in IEC 60444-1, IEC 60444-2, IEC 60444-4 and IEC 60444-5 depending on the frequency of the crystal unit under test. Any other measurement method may be used provided results correlate with those obtained using preferred values.

4.7.2 Drive level dependency

It is important that when a drive level dependency test is specified, this test shall be carried out at least five days after any previous activation of the crystal unit (see IEC 60444-6).

Measurements specified in 4.7.1 shall be carried out at two specified drive levels. These are normally at a specified low level of drive followed by a high level of drive. Unless otherwise specified, the low level shall be not more than 50 µA and the upper level not less than 1 000 µA. The change of resonance resistance shall not exceed the limit specified in the detail specification.

4.7.3 Frequency and resonance resistance as a function of temperature

NOTE Tests A and B may be combined only if test A is performed with continuously varying temperature, and is started at the lower extreme of the operating temperature range or –30 °C, whichever is the lower.

The level of drive and load capacitance shall be set at the levels stated in the detail specification, at the reference temperature. No subsequent adjustment shall be made to the test equipment during the tests.

Test A

Starting with the crystal unit at an extreme of the operating temperature range, the frequency and resonance resistance (see 4.7.1) shall be measured over the specified temperature range at discrete temperature intervals of not greater than 1,5 °C, allowing the crystal unit to reach thermal equilibrium at each temperature.

The crystal unit may be measured under conditions of continuously varying temperature, provided that tests have shown that with the chosen rate of change of temperature, the results obtained will correlate adequately with those from a stepped variation of temperature.

The crystal unit shall be within the specified limits during this test.

Test B

The temperature of the crystal enclosure shall be raised from –30 °C to +20 °C in a period not exceeding 1 min. During this test, the frequency and the resonance resistance (see 4.7.1) shall be measured from –10 °C, or below, to +20 °C, so as to provide continuous readings. There shall be no discontinuous variation in frequency and/or resistance. Such discontinuity indicates the presence of moisture within the enclosure.

NOTE The presence of moisture can be verified only by a positive temperature change.

4.7.4 Unwanted responses

The frequency shall be scanned over the range stated in the detail specification while monitoring the resistance of the crystal unit at the drive level stated in the detail specification for the main response.

The ratio of the resonance resistance of any unwanted response to that of the response at the desired resonance frequency shall be not less than the value stated in the detail specification. Alternatively, the resonance resistance of unwanted responses shall be greater than the value stated in the detail specification.

4.7.5 Shunt capacitance

The shunt capacitance C_0 (see figure 1) shall be measured at a frequency below the fundamental resonance frequency of the unit, at which the unit shows no oscillation response. The enclosure (if metal) shall be earthed, unless otherwise stated in the detail specification.

NOTE 1 There is no direct method for measuring C_0 precisely. However, in nearly all practical cases, it is adequate to regard C_0 as the mean of two shunt capacitance values obtained at two frequencies equidistant above and below the resonance frequency f_r and sufficiently removed from f_r for the impedance to be independent of any response.

NOTE 2 C_0 is the shunt capacitance between the two electrodes of the resonator but it should be pointed out that the capacitances of both the electrodes to earth are important elements in many network and frequency control applications.

NOTE 3 Therefore, in the general case, it is necessary to consider the crystal unit as a three terminal network and to evaluate C_0 and the stray capacitances of the two electrodes to earth from open- and short-circuit measurements according to the technique customarily employed when dealing with two-port devices.

The crystal enclosures shall be at earth potential, unless otherwise specified in the detail specification, during the entire series of measurements required for evaluation of the resonator parameters. For this purpose, glass-enclosed crystal units shall be provided with metal shields.

4.7.6 Load resonance frequency and resistance

Test methods for the measurement of load resonance frequency and load resonance resistance are described in IEC 60444-4.

4.7.7 Frequency pulling range (f_{L1}, f_{L2})

The difference between the resonance frequencies with the two specified load capacitances shall be determined using the method described in IEC 60444-4 or any alternative method giving frequency correlation to a degree consistent with the accuracy required.

4.7.8 Motional parameters

Test methods for the measurement of motional parameters are described in IEC 60444-1, IEC 60444-2 and IEC 60444-5.

4.7.9 Insulation resistance

Unless otherwise stated in the detail specification, the insulation resistance shall be measured with a d.c. voltage of 100 V ± 15 V for 60 s or less if a stable reading is achieved, applied between:

– terminations isolated from the case;
– isolated terminations connected together and metal parts of the case, if any.

The insulation resistance shall not be less than 500 MΩ.

NOTE When performing this test care should be taken to ensure that no moisture remains on the enclosure from any previous tests.

4.8 Mechanical and environmental test procedures

4.8.1 Robustness of terminations (destructive)

a) Tensile and thrust tests on terminations

The tests shall be performed in accordance with Test Ua_1 (tensile) and Test Ua_2 (thrust) of IEC 60068-2-21.

Unless otherwise stated in the detail specification, the loading mass shall be:

– for pin (plug-in) terminations: 20 N thrust,
– for pin (plug-in) terminations: 20 N tensile,
– for wire (solder) terminations: 10 N tensile.

b) Flexibility of wire terminations

The test shall be performed in accordance with Test Ub (bending) of IEC 60068-2-21.

Unless otherwise stated in the detail specification, the load shall be so restricted that the bend starts 2,5 mm ± 0,5 mm from the body of the crystal unit, the loading mass shall be 5 N and the number of bends shall be three.

c) Terminal bend test (for undercut pins only)

Hold or clamp the body or base of the crystal unit by any convenient means. Use the bending tool shown in figure 6 to engage that segment of the terminals beyond the undercut section of the pins.

NOTE To ensure that bending will occur primarily at the undercut portion, a plate with two clearance holes for the pins may be placed over the pins. This plate may be of such a thickness as to include a portion of the undercut section of the pins.

Bend the pins by means of the tool through 15° ± 2° in one direction, follow by a bend of 30° ± 2° in the opposite direction, and complete by a bend of 15° ± 2° back to the starting position. The rate of bending shall be approximately 5° per second in each direction.

When this test is used, the terminal pins shall not fracture.

4.8.2 Sealing tests (non-destructive)

a) Gross leak test

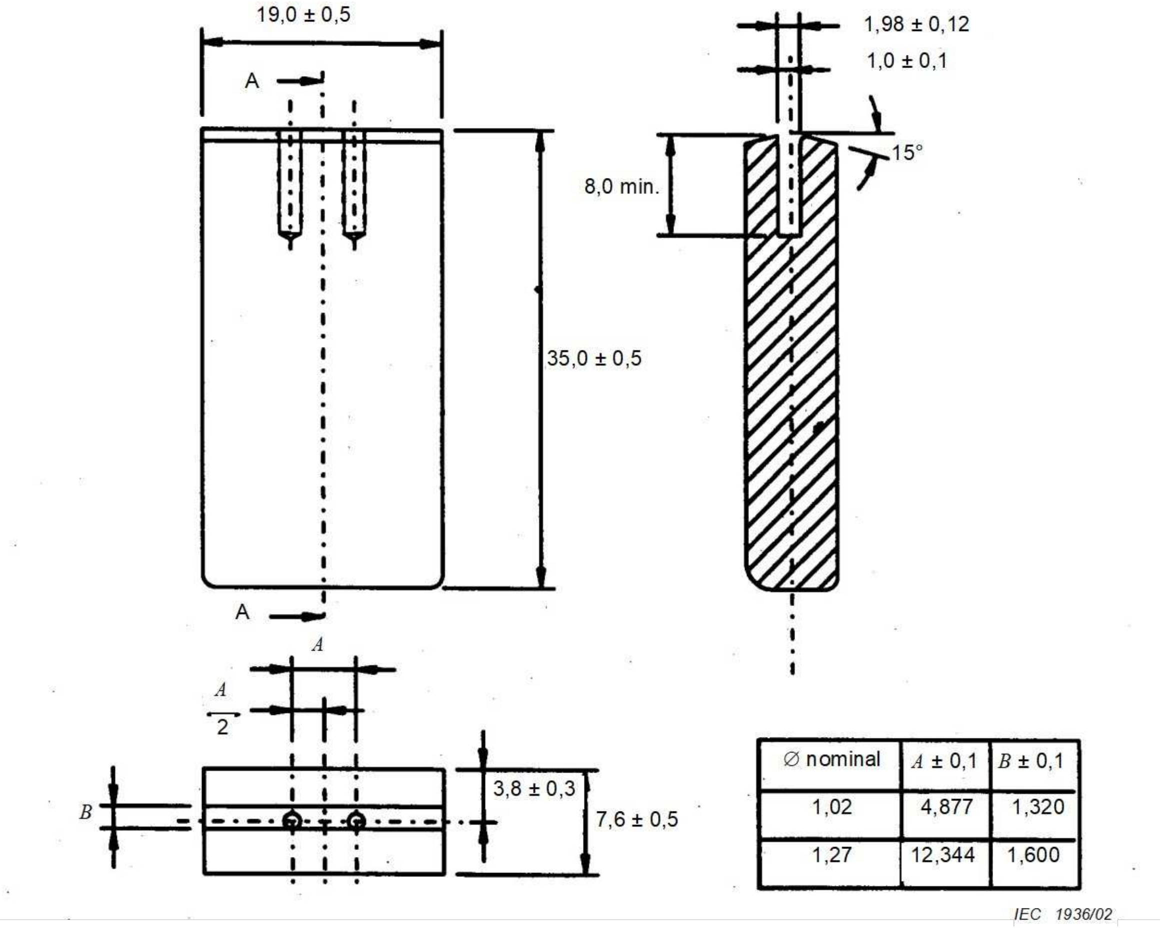
This test shall be performed in accordance with the procedure specified in Test Method 1 or 2 of Test Qc of IEC 60068-2-17.

Method 1

The liquid shall be degassed water and the pressure of air above the water shall be reduced to 8,5 kPa (85 mbar) or less and it shall not be necessary to drain or remove the specimen from the water before breaking the vacuum.

Method 2

The liquid shall be maintained at 125 °C ± 5 °C. The immersion time shall be 30 s, unless otherwise specified in the relevant detail specification.



∅ nominal	A ± 0,1	B ± 0,1
1,02	4,877	1,320
1,27	12,344	1,600

Dimensions in millimetres

Figure 6 – Terminal bend test tool

After 1 min, the unit shall be removed from the chamber and exposed to the controlled recovery conditions specified in 5.4.1 of IEC 60068-1.

During the test there shall be no evidence of leakage of gas or air from the inside of the crystal unit. The continuous formation of bubbles shall be evidence of leakage.

b) Fine leak test

The test shall be performed in accordance with 6.4 Test Method 1 of Test Qk of IEC 60068-2-17. Unless otherwise stated in the detail specification, the pressure in the pressure vessel shall be 200 kPa (2 bar).

The maximum leak rate shall not exceed the value given in 2.3.11, unless otherwise stated in the detail specification.

c) Vacuum test for evacuated crystal units (glass enclosure types only)

The vacuum shall be checked by applying a peak voltage not exceeding 15 kV derived from a Tesla coil.

To avoid damage to the crystal unit, the point of application of the test electrode shall be as remote as possible from the crystal resonator and its terminations. To facilitate observation of the resulting discharge, the test shall be carried out in semi-darkness. There shall be no indication of arcing within the enclosure. Where a uniform discharge occurs, it shall be a pale bluish colour.

NOTE This test should be conducted in the shortest possible time, as this test may cause changes in the nominal frequency of the crystal unit under test.

4.8.3 Soldering (solderability and resistance to soldering heat) (destructive)

a) Solderability

This test shall be performed in accordance with Method 1 of Test Ta of IEC 60068-2-20. A screen of thermally insulating material shall be used to prevent the component being heated by direct radiation from the solder bath. It shall also allow the immersion of the terminations up to a point 2 mm away from the emergence of the terminations from the body, unless otherwise specified in the detail specification. The terminations shall be examined for good tinning, as evidenced by free flowing of the solder with wetting of the terminations.

b) Resistance to soldering heat

This test shall be performed in accordance with Method 1A of Test Tb of IEC 60068-2-20. The immersion time shall be 5 s ± 1 s, unless otherwise specified in the detail specification. A screen of thermally insulating material shall be used to prevent the component being heated by direct radiation from the solder bath. It shall also allow the immersion of the terminations up to a point 2 mm away from the emergence of the terminations from the body, unless otherwise specified in the detail specification.

4.8.4 Rapid change of temperature, two-fluid bath method (non-destructive)

The test shall be performed in accordance with Test Nc of IEC 60068-2-14. The units shall be subjected to one cycle in a downward direction from 98 °C ± 3 °C for 15 s to 1 °C ± 1 °C for 5 s.

4.8.5 Rapid change of temperature with prescribed time of transition (non-destructive)

The test shall be performed in accordance with Test Na of IEC 60068-2-14.

For non-temperature-controlled crystal units, the low and high test chamber temperatures shall be the extreme temperatures of the operating range stated in the detail specification. For temperature-controlled crystal units, the low and high temperatures shall be –40 °C ± 3 °C and +100 °C ± 3 °C respectively.

The crystal units shall be maintained at each extreme of temperature for 15 min, unless otherwise specified in the detail specification.

The crystal units shall be subjected to 10 complete thermal cycles and then exposed to standard atmospheric conditions for recovery for not less than 2 h.

4.8.6 Bump (destructive)

The test shall be performed in accordance with Test Eb of IEC 60068-2-29. The crystal units shall be suitably mounted with clamps on the body. The three mutually perpendicular axes in which the bump is to be applied shall include:

– an axis parallel with the terminations;

– an axis perpendicular to the mounting structure at the crystal element.

The degree of severity shall be as specified in 2.3.8, unless otherwise stated in the detail specification.

4.8.7 Vibration (destructive)

a) Vibration (sinusoidal)

The test shall be performed in accordance with Test Fc of IEC 60068-2-6. The crystal units shall be suitably mounted with clamps on the body. The three mutually perpendicular axes in which the acceleration is to be applied shall include:

– an axis parallel with the terminations;

– an axis perpendicular to the mounting structure at the crystal element.

The degree of severity shall be as specified in the detail specification.

b) Random vibration

Under consideration.

4.8.8 Shock (destructive)

The test shall be performed in accordance with Test Ea of IEC 60068-2-27. The crystal units shall be suitably mounted with clamps on the body. The three mutually perpendicular axes in which the shock is to be applied shall include:

– an axis parallel with the terminations;

– an axis perpendicular to the mounting structure at the crystal element.

The degree of severity shall be as specified in 2.3.10, unless otherwise stated in the detail specification.

4.8.9 Free fall (destructive)

The test shall be performed in accordance with Procedure 1 of Test Ed of IEC 60068-2-32. The crystal unit shall be suspended by its terminations at a height of 1 000 mm and the number of falls shall be two, unless otherwise specified in the detail specification.

4.8.10 Acceleration, steady state (non-destructive)

The test shall be performed in accordance with Test Ga of IEC 60068-2-7. The crystal units shall be suitably mounted with clamps on the body. The procedure and severity shall be as stated in the detail specification.

This test may be considered destructive at certain severities.

4.8.11 Dry heat (non-destructive)

The test shall be performed in accordance with Test Ba of IEC 60068-2-2. The conditioning shall be carried out at the upper temperature indicated by the climatic category for a duration of 16 h.

4.8.12 Damp heat, cyclic (destructive)

This test shall be performed in accordance with Test Db variant 1 of IEC 60068-2-30, at severity b), 55 °C, for six cycles.

4.8.13 Cold (non-destructive)

This test shall be performed in accordance with Test Aa if IEC 60068-2-1 at the lower temperature indicated by the climatic category for a duration of 2 h.

4.8.14 Climatic sequence (destructive)

The tests and measurements shall be performed in the following order:

– dry heat see 4.8.11
– damp heat cyclic see 4.8.12 (first cycle only)
– cold see 4.8.13
– damp heat cyclic see 4.8.12 (remaining five cycles).

In the climatic sequence, an interval of not more than three days is permitted between any of these tests, except between damp heat cyclic (first cycle) and dry cold.

In such a case, the cold test shall follow immediately after the recovery period specified for the damp heat test.

4.8.15 Damp heat, steady state (destructive)

This test shall be performed in accordance with Test Ca of IEC 60068-2-3 for 56 days, unless otherwise stated in the detail specification.

4.8.16 Immersion in cleaning solvents (non-destructive)

This test is applicable to superficial marking only.

To establish the permanence of marking, this test shall be performed in accordance with test method 1 of test XA of IEC 60068-2-45. The detail specification shall prescribe the solvent to be used.

The marking shall be legible.

4.9 Endurance test procedure

4.9.1 Standard ageing ~~(non-destructive)~~ test for production verification

~~Crystal units shall be maintained non-oscillating at 85 °C ± 2 °C for a continuous period of 30 days. The frequency and resonance resistance shall be measured at intervals of not longer than one week. The initial measurement of frequency and resonance resistance shall be taken at the end of the first 24 h and the final measurement at the end of the 30-day test.~~

~~The difference between the initial ageing measurement temperature and subsequent measurement temperature shall not exceed ±0,5 °C. The drive level shall be as specified in the detail specification. Measurements shall be carried out according to 4.7.1 except that the measurements shall be made at 85 °C ± 2 °C.~~

~~The difference between the highest and lowest frequency measurements shall not exceed the specified value.~~

~~The resonance resistance shall not be greater than the value stated in the detail specification.~~

~~The frequency resetability accuracy of the measurement system shall be ±5 × 10^{-7} or ±10 % of the allowed ageing, whichever is the smaller.~~

4.9.1.1 Purpose

This test is usable for the statistical verification of aging performance in the production process.

4.9.1.2 Procedure

- Take sample from the production lot.
- Initial measurement of f_s and R_1 at (25 ± 2) °C.
- Store in oven at T_{oven} = (+85 ± 3) °C.
- Take and record additional measurements after 1 day and at least three more times at time intervals recommended in Annex A.
- For the measurement, remove the crystals from oven, and store at room temperature for 1 h, avoiding temperature shocks. Measurement of f_s and R_1 at (25 ± 2) °C in accordance with IEC 60444-5 or equivalent.
- Final measurement of f_s and R_1 at (25 ± 2) °C after 30 days.

4.9.1.3 Evaluation

The difference between the highest and lowest frequency measurement shall not exceed the specified value. The resistance R_1 shall never exceed the specified maximum values.

4.9.2 Accelerated aging

4.9.2.1 Purpose

For special applications, an accelerated aging procedure at higher temperatures is applied to shorten the verification time and/or to gain performance data at higher operating temperatures.

4.9.2.2 Procedure

The procedure is as in 4.9.1, except that the preferred oven temperature is T_{oven} = +105 °C, +125 °C or +150 °C. This temperature has to be lower or equal to the specified maximum storage temperature.

The ratio between the storage time at 25 °C and the storage time at an elevated temperature T_{oven} to achieve the same amount of frequency aging is called "time acceleration factor" (TAF). This factor depends on the design of the crystal unit and on the production process. It can be determined experimentally as described in Annex A, or taken from experience with structurally similar crystals, or can be mutually agreed between the manufacturer and the user.

If the time acceleration factor TAF is not otherwise specified, the following approach is recommended.

Applying Arrhenius's law, the time acceleration factor TAF is related to the activation energy E_a (in eV) by the following equation:

$$\mathrm{TAF} = e^{\frac{E_a \cdot \left(\frac{1}{T_{ref}} - \frac{1}{T_{oven}}\right)}{k}}$$

where

k is Boltzmann's constant ($k \approx 8{,}617 \times 10^{-5}$ eV/K), and the temperatures are given in K.

Published experimental results (see [6] and [7]) show that the activation energy E_a is decreasing over time, i.e. the acceleration factor becomes lower with the aging time. Furthermore, E_a varies between the different crystals and oscillators, depending on frequency, package size, resonator design and production processes. The observed values of E_a were between > 0,1 eV and < 1 eV.

A common assumption is TAF = 12 for T_{oven} = +85 °C, i.e. 30 days (1 month) aging at 85 °C are considered to be equivalent to 365 days (12 months) aging at 25 °C, which corresponds to an activation energy E_a of 0,38 eV.

With this value of E_a, the time acceleration factor for other aging temperatures can be calculated. Table 5 below shows the time acceleration factor TAF and the number of days N_d equivalent to 365 days at 25 °C.

Table 5 – Time acceleration factors for E_a = 0,38 eV

T_{oven} °C	TAF	N_d days
+25	1	365
+85	12	30
+105	23	16
+125	41	9
+150	79	5

Other time acceleration factors may be agreed between the manufacturer and the user based on their own reliability calculations.

4.9.2.3 Evaluation

The evaluation is as in 4.9.1.

4.9.3 Reference aging test

4.9.3.1 Purpose

This procedure is used for higher confidence level. This method should be used for high-precision crystals and as reference method in case of dispute.

4.9.3.2 Procedure

See Annex A.

4.9.3.3 Evaluation

The test data of the series resonance frequency f_s is subjected to the data fitting procedure.

The frequency measurement data $f_i(t)$ shall be fitted using the method of least squares of the following function (logarithmic fit):

$$\left[\frac{\Delta f(t)}{f_{init}}\right] = a_0 + a_1 \times \ln(a_2 \times t + 1)$$

where

$\Delta f(t)$ is the frequency difference of the crystal t days after the start of the aging cycle and the initial frequency f_{init} measured after the stabilization time t_{stab} (the time origin for measurements analysis shall be the beginning of the stabilization period).

The coefficients a_0, a_1 and a_2 are constants to be determined from the least squares fit.

The default fitting algorithm is the logarithmic fit. In some cases, namely when the aging response has a very small curvature, the logarithmic fit may not yield reasonable results. In this case, the following polynomial fit is recommended to be calculated additionally:

$$\left[\frac{\Delta f(t)}{f_{\text{init}}}\right] = a_0 + a_1 \times t + a_2 \times t^{\frac{1}{2}} + a_3 \times t^{\frac{1}{3}}$$

This approach should only be used if the square root of the least square fit variance (SLQ) of the measurements from the polynomial fit is at least five times smaller than that of the logarithmic fit.

The total frequency change and the aging rate at the end of the specified aging period ($t = T_a$) shall be determined from the fitting equation using the constants determined from the least squares fit. The square root of the least squares fit variance of the measurements from the curve-fit function shall not exceed 5 % of the total aging change allowed during the test period.

For the logarithmic fitting (default), the aging rate (in ppm or ppb[1] per day) at $t = T_a$ is:

$$\left[\frac{d\left(\frac{\Delta f(t)}{f_{\text{init}}}\right)}{dt}\right]_{t=T_a} = \frac{a_1 \times a_2}{a_2 \times T_a + 1} \approx \frac{f(T_a + 1) - f(T_a)}{f_{\text{init}}}$$

If the polynomial fitting was used, the aging rate at $t = T_a$ ($T_a > 0$) is:

$$\left[\frac{d\left(\frac{\Delta f(t)}{f_{\text{init}}}\right)}{dt}\right]_{t=T_a} = a_1 + \frac{a_2}{2} \times T_a^{-\frac{1}{2}} + \frac{a_3}{3} \times T_a^{-\frac{2}{3}}$$

The projected total frequency change for a time period shall be calculated with the following formulas:

Aging per month $\approx \dfrac{f(T_a + 30) - f(T_a)}{f_{\text{init}}}$

Aging per (1st) year $\approx \dfrac{f(T_a + 365) - f(T_a)}{f_{\text{init}}}$

1 ppm = parts per million; ppb = parts per billion.

$$\text{Aging over } N \text{ years } \approx \frac{f(T_a + N \times 365) - f(T_a)}{f_{\text{init}}}$$

The resistance R_1 shall never exceed the specified maximum values.

~~4.9.2~~4.9.4 Extended ageing ~~(non-destructive)~~

4.9.4.1 Purpose

The purpose is to evaluate the reliability and long-term performance.

4.9.4.2 Procedure

This test shall be carried out in accordance with 4.9.1, except that the continuous periods shall be 1 000 h, 2 000 h or 8 000 h, as prescribed in the detail specification and shall be used for information purposes only.

The measurements shall be carried out ~~according to 4.7.1 except that they shall be made~~ at (25 ± 2) °C or any other specified reference temperature in accordance with IEC 60444-5 or equivalent.

The measurement intervals can be extended to two weeks or longer. For the intermediate and the final measurement, the crystals can be removed from the oven, and stored at room temperature for 1 h. Thermal shocks should be avoided.

4.9.4.3 Evaluation

The difference between the highest and lowest frequency measurement shall not exceed the specified value (if applicable). The resistance R_1 shall never exceed the specified maximum values.

~~NOTE These tests are conducted~~ This test shall be used for information only. The crystal units used for these tests should not be supplied to any customer.

This test shall be used for information only. The crystal units used for these tests should not be supplied to any customer.

Annex A
(normative)

Procedure for the determination of the fitting parameters for the frequency aging

A.1 Assumption

A general description of frequency aging is possible in the form of:

$$\Delta f/f\,(t,T) = g(t) \times h(T)$$

where

$$g(t) = b_0 + b_1 \times \log(b_2 \times t + 1) \text{ (logarithmic fit);}$$

or

$$g(t) = c_0 + c_1 \times (t - t_0) + c_2 \times (t - t_0)\text{\^{}}(1/2) + c_3 \times (t - t_0)\text{\^{}}(1/3) \text{ (polynomial fit);}$$

and

$$h(T) = a_1 \times \exp(E_a \times (1/T_{ref} - 1/T)/k)$$

where

k is Boltzmann's constant ($k \approx 8{,}617 \times 10^{-5}$ eV/K), and the temperatures are given in K;

T_{ref} is 298 K.

A.2 Determination of the fitting parameters b_0, b_1, b_2 (and/or c_0, c_1, c_2, c_3) and a_1, and E_a

The procedure of Table A.1 shall be applied.

Table A.1 – Procedure for the determination of the frequency aging parameters

Procedure	Conditions
Aging test procedure	Passive
Reflow solder test	2x ROHS-profile (IEC 61760-1:2006) [a]
Initial pre-aging (time and temperature)	48 h at >20 K above upper operating temperature, but T < upper storage temperature
Sample size per lot (from one production lot)	≥ 30[*] depending on needed confidence level
Number of aging temperatures	3
Recommended aging temperatures	85 °C, 105 °C, 125 °C, 150 °C[a] depending on application, T < specified upper storage temperature
Recommend temperature for measurement	(25 ± 2) °C, measurement > 1 h after removal from the temperature chamber. Avoid thermal shocks.
Recommended aging time	500 h, 1 000 h, 2 000 h [a] depending on needed confidence level
Test intervals (in "logarithmic" steps)	After 48 h stabilization: 24 h, 72 h, 250 h, 500 h, 750 h, 1 000 h (1 500 h, 2 000 h)
Algorithms to determine g(t) and h(T)	Least square fitting[b] $g(t)$: log fit and polynomial fit Polynomial fit – only if sum of least squares SLQ < 5 times SLQ of logarithmic fit $h(T)$: least square fitting Result: E_a E_a may vary with time. Use E_a for t ≥ 500 h

[a] If not otherwise specified.

[b] For monotonic aging, all measurements shall be used for the curve fitting. If the aging trend is not monotonic, the measurement period shall be extended up to 40 days or longer after the extremum in the aging trend, and the measurements form 12 days after the extremum is reached at the end of the aging measurement period shall be fit to the above functions for $g(t)$.

Bibliography

[1] IEC 60068-2-58:1999, *Environmental testing – Part 2: Tests – Test Td: Solderability, resistance to dissolution of metallization and soldering heat of Surface Mounting Devices (SMD)*

[2] IEC 60068-2-64:1993, *Environmental testing – Part 2: Tests methods – Test Fh: Vibration, broad-band random (digital control) and guidance*

[3] IEC 60410:1973, *Sampling plans and procedures for inspection by attributes*

[4] IEC QC 001002-1:1998, *IEC Quality Assessment System for Electronic Components (IECQ) – Rules of procedure – Part 1: Administration*

[5] IEC Guide 102:1996, *Electronic components. Specification structures for quality assessment (Qualification approval and capability approval)*

[6] Wang S-Y, Neubig B., Sato K., Hosoda T., Seydel E, Wu J-H, Ma T-F, Wang Ji, *Aging Models and Parameters of Quartz Crystal Resonators and Oscillators*; Proc. 2015 Symp on Piezoelectricity, Acoustic Waves and Device Applications, p. 382-385

[7] Shen, C-N, Yang X-W, Chang C, Chao M-C, *The Study of Activation Energy (Ea) by Aging and High Temperature Storage for Quartz Resonator's Life Evaluation*; Proc. 2010 Symp on Piezoelectricity, Acoustic Waves and Device Applications, p. 118-122

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FINAL VERSION

Quartz crystal units of assessed quality –
Part 1: Generic specification

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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QUARTZ CRYSTAL UNITS OF ASSESSED QUALITY –

Part 1: Generic specification

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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This Consolidated version is not an official IEC Standard and has been prepared for user convenience. Only the current versions of the standard and its amendment(s) are to be considered the official documents.

This Consolidated version of IEC 60122-1 bears the edition number 3.1. It consists of the third edition (2002-08) [documents 49/551/FDIS and 49/558/RVD] and its amendment 1 (2017-12) [documents 49/1254/FDIS and 49/1259/RVD]. The technical content is identical to the base edition and its amendment.

This Final version does not show where the technical content is modified by amendment 1. A separate Redline version with all changes highlighted is available in this publication.

International Standard IEC 60122-1 has been prepared by IEC technical committee 49: Piezoelectric and dielectric devices for frequency control and selection.

This third edition of IEC 60122-1 constitutes a technical revision.

International Standard IEC 60122-1 is the first part of a new edition of the IEC standard series for quartz crystal units of assessed quality.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 3.

IEC 60122 consists of the following parts under the general title: Quartz crystal units of assessed quality:

- Part 1: Generic specification (IEC 60122-1);
- Part 2: Guide to the use of quartz crystal units for frequency control and selection (IEC 60122-2 at present);
- Part 3: Standard outlines and lead connections (IEC 60122-3);
- Part 4: Sectional specification – Capability Approval (IEC 61178-2 at present);
- Part 4-1: Blank detail specification – Capability Approval (IEC 61178-2-1 at present);
- Part 5: Sectional specification – Qualification Approval (IEC 61178-3 at present);
- Part 5-1: Blank detail specification – Qualification Approval (IEC 61178-3-1 at present).

The QC number which appears on the front cover of this publication is the specification number in the IEC Quality Assessment System for Electronic Components (IECQ).

The committee has decided that the contents of the base publication and its amendment 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

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

A bilingual version of this publication may be issued at a later date.

QUARTZ CRYSTAL UNITS OF ASSESSED QUALITY –

Part 1: Generic specification

1 General

1.1 Scope

This part of IEC 60122 specifies the methods of test and general requirements for quartz crystal units of assessed quality using either capability approval or qualification approval procedures.

1.2 Normative references

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

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

IEC 60050(561):1991, *International Electrotechnical Vocabulary (IEV) – Chapter 561: Piezoelectric devices for frequency control and selection*

IEC 60068-1:1988, *Environmental testing – Part 1: General and guidance*

IEC 60068-2-1:1990, *Environmental testing – Part 2: Tests – Tests A: Cold*

IEC 60068-2-2:1974, *Environmental testing – Part 2: Tests – Tests B: Dry heat*

IEC 60068-2-3:1969, *Environmental testing – Part 2: Tests – Test Ca: Damp heat, steady state*

IEC 60068-2-6:1995, *Environmental testing – Part 2: Tests – Test Fc: Vibration (sinusoidal)*

IEC 60068-2-7:1983, *Environmental testing – Part 2: Tests – Test Ga: Acceleration, steady state*

IEC 60068-2-13:1983, *Environmental testing – Part 2: Tests – Test M: Low air pressure*

IEC 60068-2-14:1984, *Environmental testing – Part 2: Tests – Test N: Change of temperature*

IEC 60068-2-17:1994, *Basic* environmental *testing procedures– Part 2: Tests – Test Q: Sealing*

IEC 60068-2-20:1979, *Environmental testing – Part 2: Tests – Test T: Soldering*

IEC 60068-2-21:1999, *Environmental testing – Part 2-21: Tests – Test U: Robustness of terminations and integral mounting devices*

IEC 60068-2-27:1987, *Environmental testing – Part 2: Tests – Test Ea and guidance: Shock*

IEC 60068-2-29:1987, *Environmental testing – Part 2: Tests – Test Eb and guidance: Bump*

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IEC 60068-2-32:1975, *Environmental testing – Part 2: Tests – Test Ed: Free fall (Procedure 1)*

IEC 60068-2-45:1980, *Environmental testing – Part 2: Tests – Test XA and guidance: Immersion in cleaning solvents*

IEC 60122-3:2001, *Quartz crystal units of assessed quality – Part 3: Standard outlines and lead connections*

IEC 60444-1:1986, *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 techniques in a π-network*

IEC 60444-2:1980, *Measurement of quartz crystal unit parameters by zero phase technique in a π-network – Part 2: Phase offset method for the measurement of motional capacitance of quartz crystal units*

IEC 60444-4:1988, *Measurement of quartz crystal unit parameters by zero phase technique in a π-network – Part 4: Method for the measurement of the load resonance frequency f_L, load resonance resistance R_L and the calculation of other derived values of quartz crystal units, up to 30 MHz*

IEC 60444-5:1995*, Measurement of quartz crystal unit parameters – Part 5: Methods for the determination of equivalent electrical parameters using automatic network analyzer techniques and error corrections*

IEC 60444-6:1995*, Measurement of quartz crystal unit parameters – Part 6: Measurement of drive level dependence (DLD)*

IEC 60617 (all parts)*, Graphical symbols for diagrams*

IEC 61178-2:1993, *Quartz crystal units – A specification in the IEC Quality Assessment System for Electronic Components (IECQ) – Part 2: Sectional specification – Capability approval*

IEC 61178-3:1993, *Quartz crystal units – A specification in the IEC Quality Assessment System for Electronic Components (IECQ) – Part 3: Sectional specification – Qualification approval*

IEC 61760-1:2006, *Surface mounting technology – Part 1: Standard method for the specification of surface mounting components (SMDs)*

IEC QC 001001:2000, *IEC Quality Assessment System for Electronic Components (IECQ) – Basic Rules*

IEC QC 001002-2:1998, *ICQ Quality Assessment System for Electronic Components (IECQ) – Rules of Procedure – Part 2: Documentation*

IEC QC 001002-3:1998, *IEC Quality Assessment System for Electronic Components (IECQ) – Rules of Procedure – Part 3: Approval Procedures*

IEC QC 001005:2000, *Register of firms, products and services approved under the IECQ System, including ISO 9000*

ISO 1000:1992, *SI units and recommendations for the use of their multiples and of certain other units*

1.3 Order of precedence

Where any discrepancies occur for any reason, documents shall rank in the following order of precedence:

– the detail specification;

– the sectional specification;

– the generic specification;

– any other international documents (for example of the IEC) to which reference is made.

The same order of precedence shall apply to equivalent national documents.

2 Terminology and general requirements

2.1 General

Units, graphical symbols, letter symbols and terminology shall, wherever possible, be taken from the following standards: IEC 60027, IEC 60050(561), IEC 60617 and ISO 1000.

2.2 Terms, definitions and classification of phenomena

The following paragraphs contain additional terminology applicable to quartz crystal units and describe certain phenomena in this context.

2.2.1
crystal element (crystal blank)
piezoelectric material cut to a given geometrical shape, size and orientation with respect to the crystallographic axes of the crystal

2.2.2
electrode
an electrically conductive plate or film in contact with, or in proximity to, a face of a crystal element by means of which an electric field is applied to the element

2.2.3
crystal resonator
a mounted crystal element that vibrates when an alternating electric field exists between the electrodes

2.2.4
mounting
the means by which the crystal resonator is supported (within its enclosure)

2.2.5
enclosure
the enclosure protecting the crystal resonator(s) and mounting

2.2.6
enclosure type
a crystal enclosure of specific outline dimensions and material with a defined method of sealing

2.2.7
crystal unit
a crystal resonator mounted in an enclosure

2.2.8
socket
a component into which the crystal unit is inserted to hold the crystal unit and to provide electrical connection

2.2.9
mode of vibration
the pattern of motion in a vibrating body of the individual particles resulting from stresses applied to the body, the frequency of oscillation and the boundary conditions existing. The common modes of vibration are:

– flexural;
– extensional;
– face shear;
– thickness shear.

2.2.10
fundamental crystal unit
a crystal resonator designed to operate at the lowest order of a given mode

2.2.11
overtone crystal unit
a crystal resonator designed to operate at a higher order than the lowest of the given mode

2.2.12
overtone order
the numbers allotted to the successive overtones of a given mode of vibration from the ascending series of integral numbers commencing with the fundamental as unity. For shear and extensional modes, this overtone is the integral multiple of the fundamental frequency to which the overtone frequency approximates

2.2.13
crystal unit equivalent circuit
the electric circuit which has the same impedance as the crystal unit in the region of the desired resonance and anti-resonance frequencies. It is represented by an inductance, capacitance and resistance in series, this series arm being shunted by the capacitance between the terminals of the unit. The parameters of the series branch of inductance, capacitance and resistance are given by L_1, C_1 and R_1 respectively: these are termed "motional parameters" of the crystal unit. The shunt (parallel) capacitance is denoted by C_0 (see figure 1).

The parameters are independent of frequency for isolated modes of motion. Generally, the mode in question is sufficiently isolated from other modes to permit this assumption. When this is not true, the equations and measuring methods outlined herein do not apply. For identification of symbols used in this standard, see table 1.

NOTE 1 The equivalent circuit does not represent all the characteristics of a crystal unit.

NOTE 2 The values of R_e, X_e, G_p and B_p vary rapidly around the resonance frequency,

where

R_e is the equivalent circuit series resistance of the resonator;

X_e is the equivalent circuit series reactance of the resonator;

G_p is the equivalent circuit parallel conductance of the resonator;

B_p is the equivalent circuit parallel susceptance of the resonator.

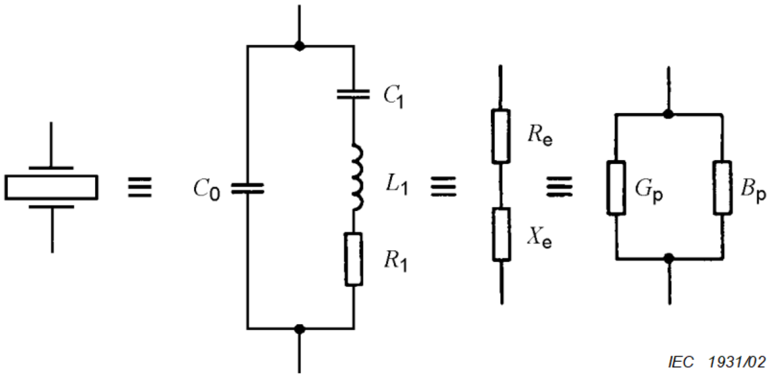


Figure 1 – Symbol and equivalent electrical circuit of a piezoelectric resonator

2.2.14
motional resistance (R_1)
the resistance in the motional (series) arm of the equivalent circuit

2.2.15
motional inductance (L_1)
the inductance in the motional (series) arm of the equivalent circuit

2.2.16
motional capacitance (C_1)
the capacitance in the motional (series) arm of the equivalent circuit

2.2.17
shunt capacitance (C_0)
the capacitance in parallel with the motional arm of the equivalent circuit

2.2.18
parameters of piezoelectric resonators
the fundamental parameters C_1, L_1, R_1 and C_0 define the equivalent electric circuit shown in figure 1, and all other parameters may be derived from them. At a given frequency, the parameters of the equivalent electric circuit generally approach constant values as the amplitude of vibration approaches zero. The amplitude which can be tolerated before the parameters are appreciably affected varies widely between resonators of various types and can only be determined by experiment.

The equation for the impedance Z or admittance Y:

$$Z = \frac{1}{Y} = \frac{j}{\omega C_0} \times \frac{\Omega - j\delta}{1 - \Omega + j\delta} \qquad (1)$$

of the equivalent electric circuit of the piezoelectric resonator is the basic equation describing the relationships between the various parameters.

In equation (1):

$$\Omega = \frac{f^2 - f_s^{\,2}}{f_p^{\,2} - f_s^{\,2}} \quad \text{and} \quad \delta = 2\pi f C_0 R_1$$

are the normalized frequency factor and the normalized damping factor, respectively. See table 1, for definitions of f_p, f_s, and the other symbols used in equation (1) and for other essential parameters. The characteristic frequencies of equation (1) are defined in table 2.

The magnitude of the impedance of the equivalent electric network ($|Z|$), its resistive component (R_e), its reactive component (X_e), and the reactance X_1 of the L_1, C_1, R_1 branch are plotted as functions of frequency in figure 2, for the purpose of defining the different characteristic frequencies. $|Z_m|$ and $|Z_n|$ denote minimum and maximum impedance respectively, and R_r, R_a the impedances at zero phase angle. These curves, however, have only qualitative character and do not represent a particular piezoelectric resonator.

For further clarification, the impedance and admittance circles of a piezoelectric resonator are reproduced in figure 3. However, the circle representation of the impedance or admittance of a piezoelectric resonator is valid only if the circle diameter of the admittance diagram is large compared with the change of 2 $\pi f C_0$ in the resonance range or if $r \ll Q^2$, which is fulfilled in most resonators. If the latter conditions are not fulfilled, the admittance curve shows a cissoidal character. Throughout the remainder of this standard, it is assumed that the impedance (or admittance) of the resonator can be represented by a circle diagram. Table 3 gives data for Q, r, and Q^2/r for various types of resonators, indicating that this assumption is valid for all practical cases.

It is necessary to make approximations in deriving practical equations for general use. It is the error of these approximations, in addition to the errors of instrumentation that govern the overall accuracy of the experimentally derived parameters.

As a first approximation sufficient for many practical purposes, the following assumptions can be made:

$$f_m = f_r = f_s \quad \text{and} \quad f_a = f_n = f_p$$

More exact relations between the characteristic frequencies f_m, f_r, f_a, f_p, f_n, and the series resonance frequency f_s of a resonator, valid for the figure of merit $M > 10$ and the capacitance ratio $r > 10$, are shown in table 4. These relationships have been derived by various authors under the assumption that $M \gg 1$.

The separation between parallel and series resonance frequencies is given by:

$$\frac{f_p{}^2 - f_s{}^2}{f_s{}^2} = \frac{C_1}{C_0} = \frac{1}{r} \tag{2}$$

The approximation:

$$\begin{aligned} \frac{f_p - f_s}{f_s} &= \sqrt{1 + r^{-1}} - 1 \\ &= \frac{1}{2r}\left(1 - \frac{1}{4r} + \ldots\right) \approx \frac{1}{2r} \\ &= \frac{1}{2}\frac{C_1}{C_0} \end{aligned} \tag{3}$$

can be used for larger values of r (for example, when r is greater than 25, the error is less than 1 %).

2.2.19

resonance frequency (f_r)

the lower of the two frequencies of the crystal unit alone, under specified conditions, at which the electrical impedance of the crystal unit is resistive

2.2.20

resonance resistance (R_r)

the resistance of the crystal unit alone at the resonance frequency f_r

2.2.21

anti-resonance frequency (f_a)

the higher of the two frequencies of the crystal unit alone, under specified conditions, at which the electrical impedance of the crystal unit is resistive

2.2.22

load capacitance (C_L)

the effective external capacitance associated with the crystal unit which determines the load resonance frequency f_L

2.2.23

load resonance frequency (f_L)

one of the two frequencies of a crystal unit in association with a series or with a parallel load capacitance, under specified conditions at which the electrical impedance of the combination is resistive. The load resonance frequency is the lower of the two frequencies when the load capacitance is in series and the higher when it is in parallel (see figure 4).

For a given value of load capacitance C_L, these frequencies are identical for all practical purposes and are given by the expression

$$\frac{1}{f_L} = 2\pi\sqrt{\frac{L_1 C_1 (C_0 + C_L)}{C_1 + C_0 + C_L}} \qquad (4)$$

NOTE 1 The frequencies defined in 2.2.19, 2.2.21 and 2.2.23 are listed as being the terms more commonly used. The frequencies associated with a quartz crystal are numerous and for a full explanation tables 2 and 4 should be consulted.

NOTE 2 When higher accuracies are required or secondary data (for example, values of crystal unit motional parameters) are to be derived from the frequency measurements, table 1, IEC 60444-1 and IEC 60444-5 should be consulted.

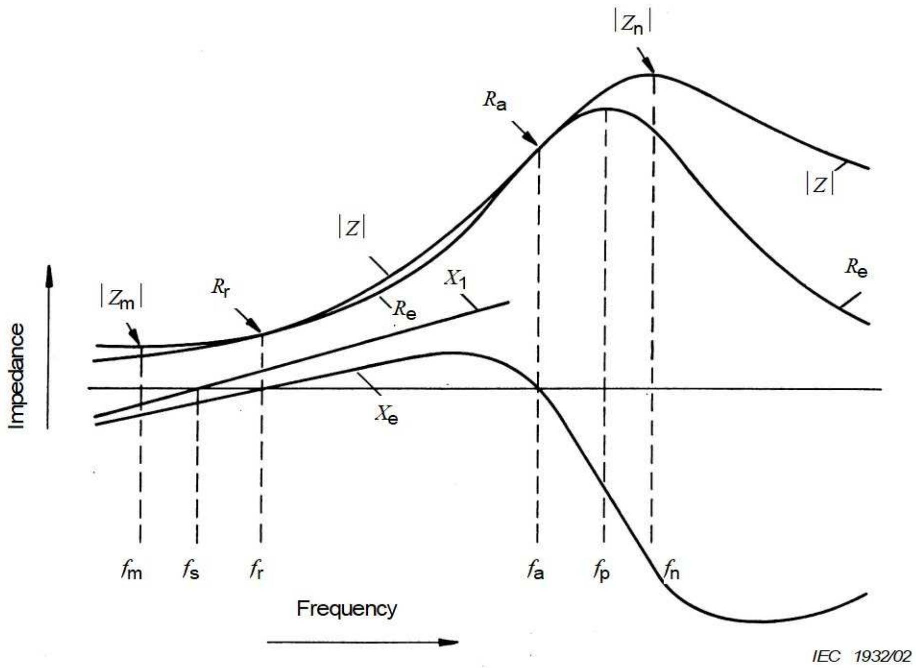


Figure 2 – Impedance |Z|, resistance R_e, reactance X_e, series arm reactance X_1 of a piezoelectric resonator as a function of frequency

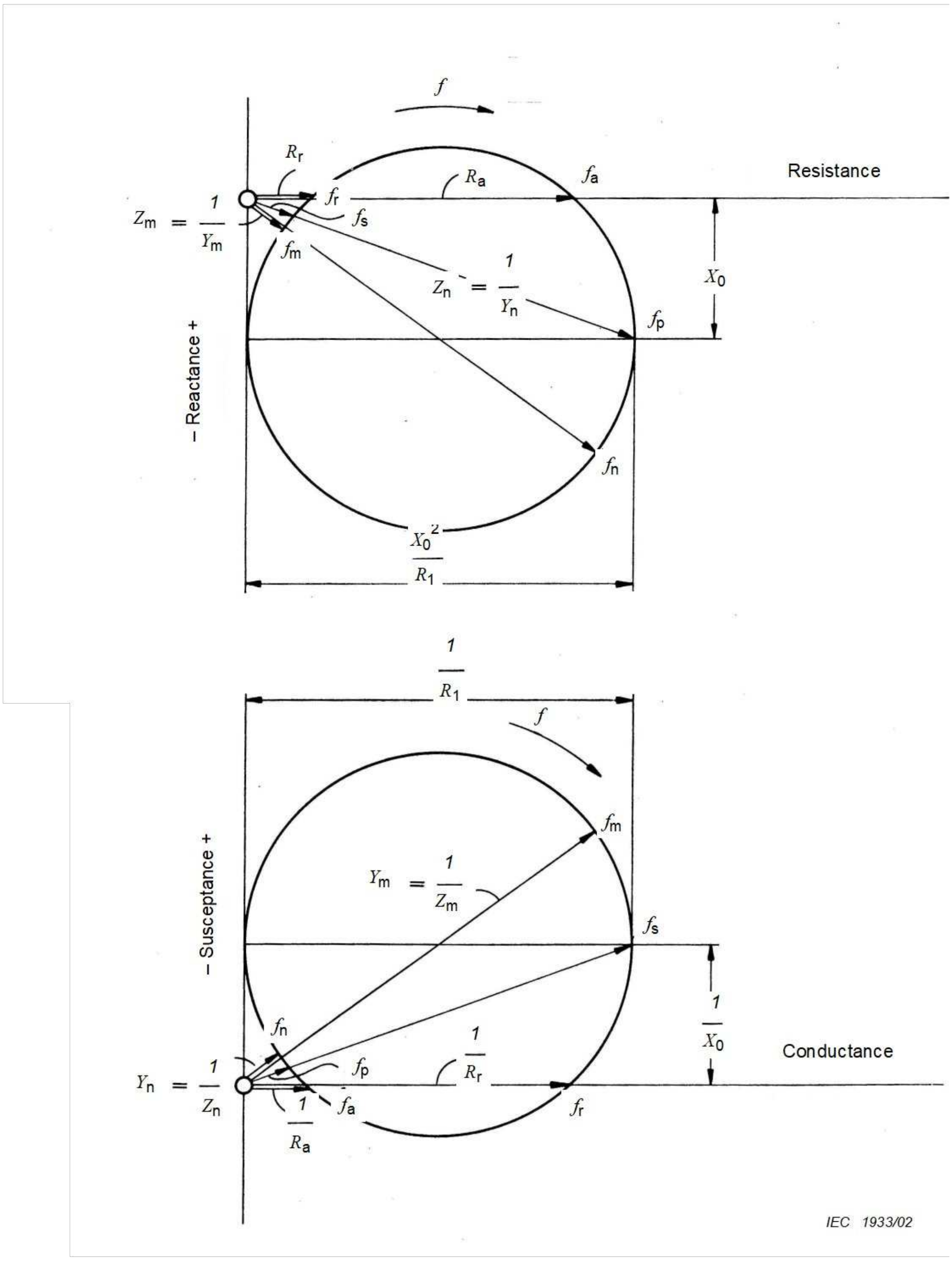
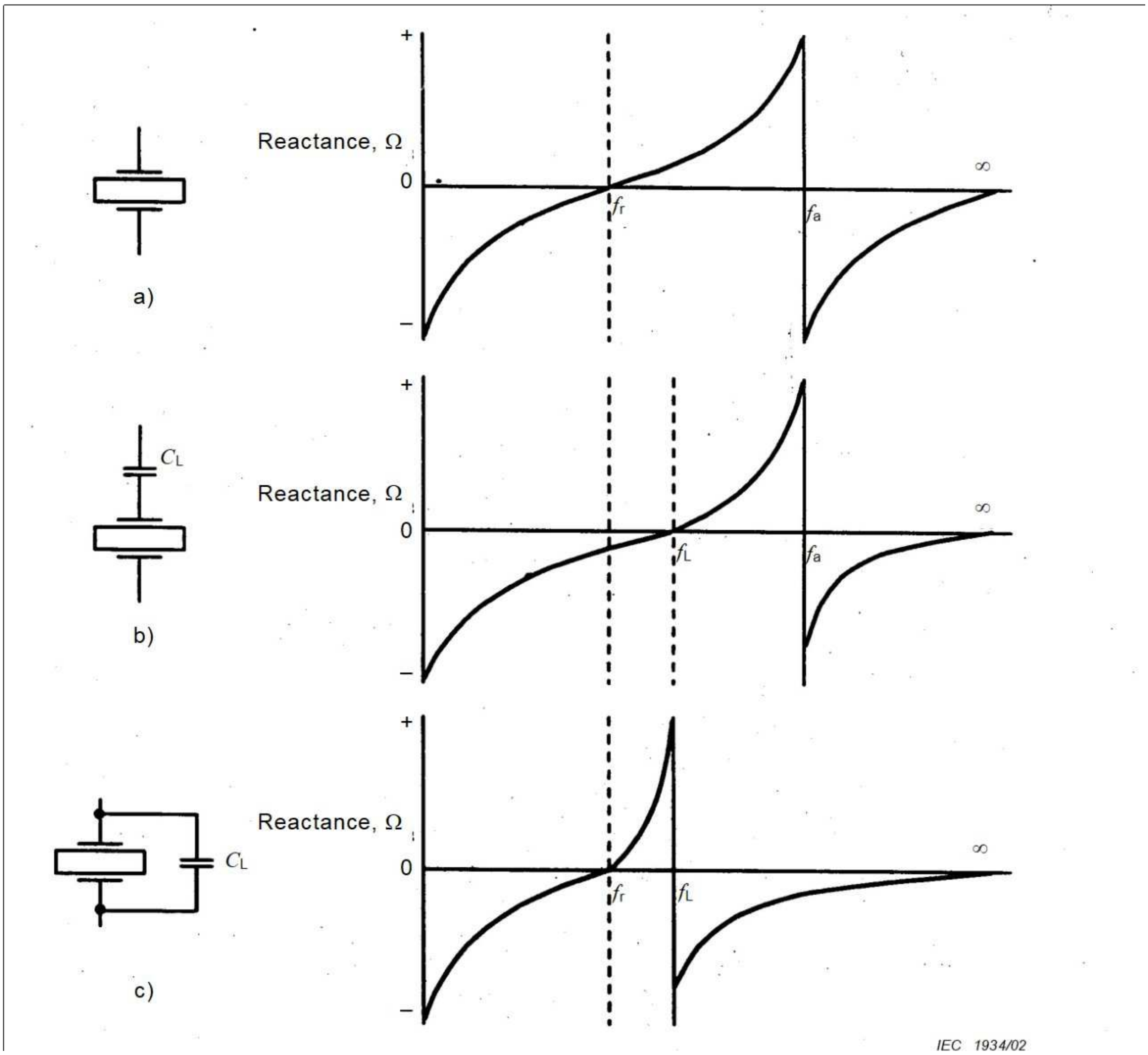


Figure 3 – Impedance and admittance diagram of a piezoelectric resonator

The symbols conform with those in table 1 and figure 2.



NOTE 1 The values of load capacitances shown in b) and c) are equal.

NOTE 2 See 2.2.19, 2.2.21 and 2.2.23.

Figure 4 – Resonance, anti-resonance and load resonance frequencies

2.2.24
load resonance resistance (R_L)
the resistance of the crystal unit in series with a stated external capacitance at the load resonance frequency f_L.

NOTE To a close approximation the value of R_L is related to the value of R_r by the expression:

$$R_L \cong R_r \left(1 + \frac{C_0}{C_L}\right)^2 \tag{5}$$

2.2.25
nominal frequency (f_{nom})
the frequency assigned to the crystal unit by the manufacturer

2.2.26
working frequency (f_w)
the operational frequency of the crystal unit together with associated circuits

2.2.27
load resonance frequency offset (Δf_L)

$$\Delta f_L = f_L - f_r \tag{6}$$

It can be calculated approximately from

$$\Delta f_L \cong \frac{f_r C_1}{2(C_0 + C_L)} \tag{7}$$

In usage, the load resonance frequency offset Δf_L for a given value of load capacitance can be written as, for instance, Δf_{30} or Δf_{20} to indicate the actual value of load capacitance in picofarads involved.

2.2.28
fractional load resonance frequency offset (D_L)

$$D_L = \frac{f_L - f_r}{f_r} \tag{8}$$

It can be calculated approximately from

$$D_L \cong \frac{C_1}{2(C_0 + C_L)} \tag{9}$$

This can also be written as, for instance, D_{30} to indicate the fractional load resonance frequency offset D_L with a load capacitance of 30 pF.

2.2.29
frequency pulling range ($\Delta f_{L1,L2}$)

$$\Delta f_{L1,L2} = | f_{L1} - f_{L2} | \tag{10}$$

It can be calculated approximately from:

$$\Delta f_{L1,L2} = \left| \frac{f_r C_1 (C_{L2} - C_{L1})}{2(C_0 + C_{L1})(C_0 + C_{L2})} \right| \tag{11}$$

This can also be written as, for instance $\Delta f_{20,30}$ to indicate the frequency pulling range between load capacitances of 20 pF and 30 pF

2.2.30
fractional pulling range ($D_{L1,L2}$)

$$D_{L1,\,L2} = \left| \frac{f_{L1} - f_{L2}}{f_r} \right| = \left| D_{L1} - D_{L2} \right| \tag{12}$$

It can be calculated approximately from:

$$D_{L1,L2} = \left| \frac{C_1(C_{L2} - C_{L1})}{2(C_0 + C_{L1})(C_0 + C_{L2})} \right| \quad (13)$$

This can be written as, for instance, $D_{20,30}$, to indicate the fractional pulling range between load capacitances of 20 pF and 30 pF

2.2.31
pulling sensitivity (S)

$$S = \frac{dD_L}{dC_L} \cong \frac{-C_1}{2(C_0 + C_L)^2} \quad (14)$$

This can be written as, for instance, S_{30}, to indicate the pulling sensitivity at a load capacitance of 30 pF

2.2.32
operating temperature range
the range of temperatures as measured on the enclosure, over which the crystal unit shall be within the specified tolerances

2.2.33
operable temperature range
the range of temperatures as measured on the enclosure over which the crystal unit will not sustain permanent damage though not necessarily functioning within the specified tolerances

2.2.34
storage temperature range
the minimum and maximum temperatures, as measured on the enclosure, at which the crystal unit may be stored without deterioration or damage to its performance

2.2.35
reference temperature
the temperature at which certain crystal measurements are made. For controlled temperature units, the reference temperature is the mid-point of the controlled temperature range. For non-controlled temperature units, the reference temperature is normally 25 °C ± 2 °C

2.2.36
level of drive
a measure of the conditions imposed upon the crystal unit. This may be expressed in terms of current through or power dissipated in the crystal element

2.2.37
drive level dependency
drive level dependency (DLD) is the effect of changes in drive level conditions upon the resonance resistance of the crystal unit. This parameter can be specified by defining the ratio of resistance between two specified drive levels. This ratio is represented by the expression:

$$\frac{R_{r1}}{R_{r2}}$$

where

R_{r1} is the resistance at the lower level of drive;

R_{r2} is the resistance at the higher level of drive.

2.2.38
unwanted response
a state of resonance of a crystal resonator other than that associated with the working frequency

2.2.39
frequency tolerance
the maximum permissible deviation of the working frequency due to a specified cause or a combination of causes. The frequency tolerance is usually stated in parts per million (1×10^{-6}) of the nominal frequency

NOTE The tolerances normally used are as follows:

– deviation from nominal frequency at the reference temperature under specified conditions;

– deviation over the temperature range from the frequency at the specified reference temperature;

– deviation as a result of ageing under specified conditions;

– deviation from nominal frequency due to all causes (overall tolerance).

Table 1 – List of symbols used for the equivalent electric circuit of a piezoelectric resonator

Symbols	Meaning	SI units	References		
			Equations	Tables	Figures
B_p	Equivalent parallel susceptance of resonator	S		2	1
C_0	Shunt (parallel) capacitance in the equivalent electric circuit	F	2, 3		1, 5
C_1	Motional capacitance in the equivalent electric circuit	F	2, 3		1, 5
f	Frequency	Hz			3
f_a	Antiresonance frequency, zero susceptance	Hz		2, 4	2, 3
f_m	Frequency of maximum admittance(minimum impedance)	Hz		2, 4	2, 3
f_n	Frequency of minimum admittance(maximum impedance)	Hz		2, 4	2, 3
f_p	Parallel resonance frequency (lossless) $\frac{1}{2\pi\sqrt{L_1 \frac{C_1 C_0}{C_1 + C_0}}}$	Hz	2, 3	2, 4	2, 3
f_r	Resonance frequency, zero susceptance	Hz		2, 4	2, 3, 4
f_s	Motional (series) resonance frequency $\frac{1}{2\pi\sqrt{L_1 C_1}}$	Hz	2, 3	2, 4	2, 3
G_p	Equivalent parallel conductance of resonator				1
L_1	Motional inductance in the equivalent electric circuit	H			1, 5
M	Figure of merit of a resonator $M = \frac{Q}{r}$	Dimensionless		3, 4	

Symbols	Meaning	SI units	References		
			Equations	Tables	Figures
Q	Quality factor: $Q = \frac{W_s L_1}{R_1}$	Dimensionless		3	
r	Capacitance ratio: $r = \frac{C_0}{C_1}$	Dimensionless	2, 3	2, 3, 4	
R_a	Impedance at zero phase angle near antiresonance	Ω			2, 3
R_e	Equivalent series resistance of resonator	Ω			1,2
R_r	Impedance at f_r , zero phase angle	Ω			2, 3
R_1	Motional resistance in the equivalent electric circuit	Ω	15	2	1, 3, 5
X_e	Equivalent series reactance of resonator	Ω			1, 2
X_0	Reactance of shunt (parallel) capacitance at series resonance: $X_o = \frac{1}{\omega_s C_0}$	Ω			3
X_1	Reactance of motional series arm of resonator: $X_1 = \omega L_1 - \frac{1}{\omega C_1}$	Ω		2	2
Y	Admittance of resonator: $Y = G_p + jB_p = \frac{1}{Z}$	S	1		
Y_m	Maximum admittance of resonator	S			3
Y_n	Minimum admittance of resonator	S			3
Z	Impedance of resonator: $Z = R_e + jX_e$	Ω	1		
Z_m	Minimum impedance of resonator	Ω			2, 3
Z_n	Maximum impedance of resonator	Ω			2, 3
$\|Z\|$	Absolute value of impedance of resonator: $Z = \sqrt{R_e{}^2 + X_e{}^2}$	Ω		2	2
$\|Z_m\|$	Absolute value of impedance at f_m (minimum impedance)	Ω			2
$\|Z_n\|$	Absolute value of impedance at f_n (maximum impedance)	Ω			2
δ	Normalized damping factor: $\delta = \omega C_o R_1$	Dimensionless	1	2	
Ω	Normalized frequency factor: $\Omega = \frac{f^2 - f_s{}^2}{f_p{}^2 - f_s{}^2}$	Dimensionless	1	2	
ω	Circular (angular) frequency: $\omega = 2\pi f$	rad/s		2	
ω_s	Circular frequency at motional resonance: $\omega_s = 2\pi f_s$	rad/s			
C_L	Load capacitance	F	4, 15	1	4, 5
f_L	Load resonance frequency of combination of resonator and C_L $f_L = f_s\sqrt{1 + \frac{C_1}{C_0 + C_L}}$	Hz	15	1	4

Table 2 – Solutions for the various characteristic frequencies

Characteristic frequencies	Meaning	Condition	Constituent equation for frequency
f_m	Frequency of maximum admit–tance (minimum impedance)	$\frac{d\lvert Z\rvert}{d\omega} = 0$	$\left(\Omega^2 + \delta^2\right)^2 - 2\delta^2(\Omega + r) - 2\Omega r(1 - \Omega) - \Omega^2 = 0$
f_s	Motional (series) resonance frequency	$X_1 = 0$	$\Omega = 0$
f_r	Resonance frequency	$X_e = B_p = 0$	$\Omega(1 - \Omega) - \delta^2 = 0$
f_a	Antiresonance frequency	$X_e = B_p = 0$	$\Omega(1 - \Omega) - \delta^2 = 0$
f_p	Parallel resonance frequency (loss-less)	$\lvert X_e\rvert = \infty$ for $R_1 = 0$	$\Omega = 1$
f_n	Frequency of minimum admittance (maximum impedance)	$\frac{d\lvert Z\rvert}{d\omega} = 0$	$\left(\Omega^2 + \delta^2\right)^2 - 2\delta^2(\Omega + r) - 2\Omega r(1 - \Omega) - \Omega^2 = 0$

Table 3 – Minimum values for the ratio Q^2/r to be expected for various types of piezoelectric resonators

Type of piezoelectric resonator	$Q = M r$	r	Q^2/r min
Piezoelectric ceramics	90 – 500	2 – 40	200
Water-soluble piezoelectric crystals	200 – 50 000	3 – 500	80
Quartz	$10^4 - 10^7$	100 – 50 000	2 000

Table 4 – Approximate relations between the characteristic frequencies and the series resonance frequency f_s of a piezoelectric resonator

Characteristic frequency	1st approximation		2nd approximation	
	$\frac{f}{f_s}$	Deviation $\frac{\Delta f}{f_s}$ from a more precise value	$\frac{f}{f_s}$	Deviation $\frac{\Delta f}{f_s}$ from a more precise value
f_m	$\frac{f_m}{f_s} = 1$	$-\frac{1}{2M^2 r}$	$\frac{f_m}{f_s} = \sqrt{1 + \frac{1}{2r}\left[1 - \sqrt{1 + \frac{4}{M^2}}\right]}$	$\frac{1}{2M^4 r^2}$
f_r	$\frac{f_r}{f_s} = 1$	$\frac{1}{2M^2 r}$	$\frac{f_r}{f_s} = \sqrt{1 + \frac{1}{2r}\left[1 - \sqrt{1 - \frac{4}{M^2}}\right]}$	$\frac{1}{2M^4 r^2}$
f_a	$\frac{f_a}{f_s} = 1 + \frac{1}{2r}$	$-\frac{1}{2M^2 r}\left(\frac{1}{r} + 1\right)$	$\frac{f_a}{f_s} = \sqrt{1 + \frac{1}{2r}\left[1 + \sqrt{1 - \frac{4}{M^2}}\right]}$	$-\frac{1}{2M^2 r} \times \frac{1}{r}$
f_n	$\frac{f_n}{f_s} = 1 + \frac{1}{2r}$	$\frac{1}{2M^2 r}\left(\frac{1}{r} + 1\right)$	$\frac{f_n}{f_s} = \sqrt{1 + \frac{1}{2r}\left[1 + \sqrt{1 + \frac{4}{M^2}}\right]}$	$\frac{1}{2M^2 r} \times \frac{1}{r}$
f_p	$\frac{f_p}{f_s} = 1 + \frac{1}{2r}$	$-\frac{1}{8r^2}$	$\frac{f_p}{f_s} = \sqrt{1 + \frac{1}{r}}$	0

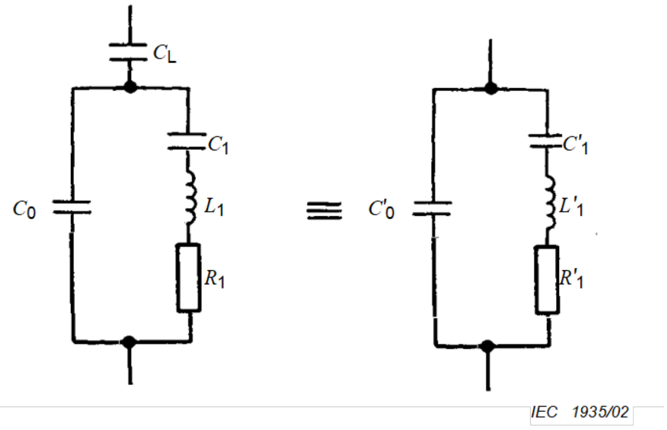


Figure 5 – Equivalent circuit of a piezoelectric resonator with a series (load) capacitance C_L

$$L'_1 = L_1\left(1 + \frac{C_0}{C_L}\right)^2$$

$$C'_1 = C_1 \frac{1}{\left(1 + \frac{C_0}{C_L}\right)^2 \left(1 + \frac{C_1}{C_0 + C_L}\right)} \qquad (15)$$

$$R'_1 = R_1\left(1 + \frac{C_0}{C_L}\right)^2$$

$$C'_0 = \left(\frac{C_0 C_L}{C_0 + C_L}\right)$$

$$f_L = f_s\sqrt{1 + \frac{C_1}{C_0 + C_L}} \approx f_s\left(1 + \frac{C_1}{2(C_0 + C_L)}\right)$$

2.3 Preferred ratings and characteristics

Values should preferably be chosen from the following paragraphs.

2.3.1 Temperature ranges in degrees Celsius (°C) suitable for ambient operation

–55 to +125	–30 to +80	–10 to +60
–55 to +105	–30 to +70	–10 to +50
–55 to +100	–25 to +80	0 to +60
–55 to +90	–20 to +85	0 to +50
–40 to +90	–20 to +80	+5 to +55
–40 to +85	–20 to +70	+10 to +40
–40 to +80	–20 to +60	+15 to +50
–40 to +70	–10 to +70	

2.3.2 Elevated temperature ranges in degrees Celsius (°C) suitable for oven control

60 ± 5	75 ± 5
65 ± 5	80 ± 5
70 ± 5	85 ± 5

2.3.3 Frequency tolerance (1×10^{-6})

±200	±25	±7,5
±100	±20	±5
±50	±15	±4
±40	±10	±2,5
±30		±1

2.3.4 Circuit conditions

10 pF load capacitance
15 pF load capacitance
20 pF load capacitance
30 pF load capacitance
50 pF load capacitance
Series resonance.

2.3.5 Levels of drive

Thickness shear/AT:
Current, in µA
150
200
1 000
2 000
Power, in µW
1
10
100
500
Flexure and face shear:
Current, in µA
100
200
Extensional:
Current, in µA
500
1 000

2.3.6 Drive level dependency

Resonance resistance Ω	Resistance ratio, $\frac{R_{r1}}{R_{r2}}$
< 5	2,2
5 to 10	2,0
10 to 20	1,8
20 to 35	1,5
35 to 50	1,3
>50	1,2

2.3.7 Climatic category

55/105/56

For requirements where the operating temperature range of the crystal unit is greater than –55 °C to +105 °C, a climatic category consistent with the operating temperature range shall be specified.

2.3.8 Bump severity

4 000 ± 10 bumps at 390 m/s^2 peak acceleration in each direction along three mutually perpendicular axes (see 4.8.6).

Pulse duration 6 ms.

2.3.9 Vibration severity

10 Hz to 55 Hz 0,75 mm displacement amplitude (peak value) 55 Hz to 500 Hz or 55 Hz to 2 000 Hz 98,1 m/s^2 acceleration amplitude (peak value)	30 min in each of three mutually perpendicular axes at 1 octave/min (see 4.8.7)

10 Hz to 55 Hz 1,5 mm displacement amplitude (peak value) 55 Hz to 2 000 Hz 196,2 m/s^2 acceleration amplitude (peak value)	30 min in each of three mutually perpendicular axes at 1 octave/min (see 4.8.7)

Random vibration severities: under consideration

2.3.10 Shock severity

981 m/s^2 peak acceleration for 6 ms duration; three shocks in each direction along three mutually perpendicular axes (see 4.8.8), half sine pulse, unless otherwise stated in the detail specification.

2.3.11 Leak rate

10^{-3} Pa·cm^3/s (10^{-8} bar·cm^3/s).

2.4 Marking

2.4.1 The information given in the marking is selected from the following list: the relative importance of each item is indicated by its position in the list:

a) type designation as defined in the detail specification;
b) nominal frequency in kilohertz (kHz) or megahertz (MHz);
c) year and week (four digits) of manufacture;
d) factory identification code;
e) manufacturer’s name or trade mark;
f) mark of conformity (unless a certificate of conformity is used).

2.4.2 The crystal units shall be clearly marked with a), b) and c) above and with as many as possible of the remaining items as is considered necessary. Any duplication of information in the marking on the crystal unit should be avoided.

Where the available surface area of miniature crystal enclosures imposes practical limits on the amount of marking, instructions on the marking to be applied shall be given in the detail specification.

2.4.3 The primary package containing the crystal unit(s) shall be clearly marked with all the information listed in 2.4.1.

2.4.4 Any additional marking shall be so applied that no confusion can arise.

3 Quality assessment procedures

Two methods are available for the approval of quartz crystal units of assessed quality. They are qualification approval and capability approval.

3.1 Primary stage of manufacture

In accordance with 3.1.1.2 of IEC QC 001002-3, the primary stage of manufacture is the final surface finishing of the crystal element.

NOTE The final surface finishing of the crystal element could be any of the following operations: lapping; polishing; etching; cleaning, in the case of polished plates.

3.2 Structurally similar components

The grouping of structurally similar components for the purpose of qualifications approval, capability approval and quality conformance inspection shall be prescribed in the relevant sectional specification.

3.3 Subcontracting

These procedures shall be in accordance with 3.1.2 of IEC QC 001002-3.

However, the final surface finishing of the crystal elements and all subsequent processes shall be carried out by the manufacturer to whom approval has been granted.

3.4 Manufacturer's approval

To obtain manufacturer's approval the manufacturer shall meet the requirements of clause 2 of IEC QC 001002-3.

3.5 Approval procedures

3.5.1 General

To qualify a quartz crystal unit, either capability approval or qualification approval procedures may be used. These procedures shall conform to those stated in IEC QC 001001 and IEC QC 001002-3.

3.5.2 Capability approval

Capability approval is appropriate when structurally similar quartz crystal units based on common design rules, are fabricated, by a group of common processes.

Under capability approval detail specifications fall into the following three categories.

a) Capability qualifying components (CQCs)

A detail specification shall be prepared for each CQC as agreed with the National Supervising Inspectorate (NSI). It shall identify the purpose of the CQC and include all relevant stress levels and test limits.

b) Standard catalogue items

When a component covered by the capability approval procedure is intended to be offered as a standard catalogue item, a detail specification complying with the blank detail specification shall be written. Such specifications shall be registered by the IECQ and the component may be listed in IEC QC 001005.

c) Custom built quartz crystal units

The content of the detail specification shall be determined by agreement between the manufacturer and the customer in accordance with 4.3.3 of IEC QC 001002-3.

Further information on detail specifications is contained in the sectional specification IEC 61178-2.

The product and capability qualifying components (CQCs) are tested in combination and approval given to a manufacturing facility on the basis of validated design rules, processes and quality control procedures. Further information is given in 3.6 and in the sectional specification IEC 61178-2.

3.5.3 Qualification approval

Qualification approval is appropriate for components manufactured to a standard design and established production process and conforming to a published detail specification.

The programme of tests defined in the detail specification for the appropriate assessment and severity level applies directly to the quartz crystal unit to be qualified, as prescribed in 3.7 and the sectional specification IEC 61178-3.

3.6 Procedures for capability approval

3.6.1 General

The procedures for capability approval shall be in accordance with IEC QC 001002-3.

3.6.2 Eligibility for capability approval

The manufacturer shall comply with the requirement of 4.2.1 of IEC QC 001002-3 and the primary stage of manufacture as defined in 3.1 of this generic specification.

3.6.3 Application for capability approval

In order to obtain capability approval the manufacturer shall apply the rules of procedure given in clause 4 of IEC QC 001002-3.

3.6.4 Granting of capability approval

Capability approval shall be granted when the procedures in accordance with 4 of IEC QC 001002-3 have been successfully completed.

3.6.5 Capability manual

The contents of the capability manual shall be in accordance with the requirements of the sectional specification. The NSI shall treat the capability manual as a confidential document. The manufacturer may, if he so wishes, disclose part or all of it to a third party.

3.7 Procedures for qualification approval

3.7.1 General

The procedures for qualification approval shall be in accordance with clause 3 of IEC QC 001002-3.

3.7.2 Eligibility for qualification approval

The manufacturer shall comply with the requirements of 3.1.1 of IEC QC 001002-3 and the primary stage of manufacture as defined in 3.1 of this generic specification.

3.7.3 Application for qualification approval

In order to obtain qualification approval the manufacturer shall apply the procedures given in 3.1.3 of IEC QC 001002-3.

3.7.4 Granting of qualification approval

Qualification approval shall be granted when the procedures in accordance with 3.1.5 of IEC QC 001002-3 have been successfully completed.

3.7.5 Quality conformance inspection

The blank detail specification associated with the sectional specification shall prescribe the test schedule for quality conformance inspection.

3.8 Test procedures

The test procedures to be used shall be selected from this generic specification. If any required test is not included, then it shall be defined in the detail specification.

3.9 Screening requirements

Where screening is required by the customer for quartz crystal units this shall be specified in the detail specification.

3.10 Rework and repair work

3.10.1 Rework

Rework is the rectification of processing errors and shall not be carried out if prohibited by the sectional specification. The sectional specification shall state if there is a restriction on the number of occasions that rework may take place on a specific component.

All rework shall be carried out prior to the formation of the inspection lot offered for inspection to the requirements of the detail specification.

Such rework procedures shall be fully described in the relevant documentation produced by the manufacturer and shall be carried out under the direct control of the chief inspector. Sub-contracting of rework is not permitted.

3.10.2 Repair work

Repair work is the correction of defects in a component after release to the customer.

Components that have been repaired can no longer be considered as representative of the manufacturer’s production and may not be released under the IECQ System.

3.11 Certified records of released lots

The requirements of clause 1.5 of IEC QC 001002-2 shall apply. When certified records of released lots (CRRL) are prescribed in the sectional specification for qualification approval and are requested by the customer, the results of the specified tests shall be summarized.

3.12 Validity of release

Crystal units held for a period exceeding two years following acceptance inspection shall be reinspected for the electrical tests detailed in 4.7.1 and 4.7.3, with a sample tested as described in item a) of 4.8.3, prior to release.

3.13 Release for delivery

Quartz crystal units shall be released in accordance with 3.2.6 and 4.3.2 of IEC QC 001002-3.

3.14 Unchecked parameters

Only those parameters of a component which have been specified in a detail specification and which were subject to testing can be assumed to be within the specified limits. It should not be assumed that any parameter not specified will remain unchanged from one component to another. Should it be necessary for further parameters to be controlled, then a new, more extensive, detail specification should be used. Any additional test method(s) shall be fully described and appropriate limits, AQLs and inspection levels specified.

4 Test and measurement procedures

4.1 General

The test and measurement procedures shall be carried out in accordance with the relevant detail specification.

4.2 Alternative test methods

Measurements shall preferably be carried out using the methods specified. Any other method giving equivalent results may be used except in case of dispute.

NOTE By “equivalent” it is meant that the value of the characteristic established by such other method falls within the specified limits when measured by the specified method.

4.3 Precision of measurement

The limits given in detail specifications are true values. Measurement inaccuracies shall be taken into account when evaluating the results. Precautions should be taken to reduce measurement errors to a minimum.

4.4 Standard conditions for testing

Unless otherwise specified, all tests shall be carried out under the standards atmospheric conditions for testing as specified in 5.3 of IEC 60068-1.

Temperature	15 °C to 35 °C
Relative humidity	45 % to 75 %
Air pressure	86 kPa to 106 kPa (860 mbar to 1 060 mbar)

In case of dispute, the referee conditions are:

Temperature	25 °C ± 1 °C
Relative humidity	48 % to 52 %
Air pressure	86 kPa to 106 kPa (860 mbar to 1 060 mbar)

Before measurements are made, the crystal units shall be stored at the measuring temperature for a time sufficient to allow the crystal resonator to reach this temperature.

Controlled recovery conditions and standard conditions for assisted drying are given in 5.4 of IEC 60068-1.

The ambient temperature during the measurements shall be recorded and stated in the test report.

4.5 Visual inspection

Unless otherwise specified, external visual examination shall be performed under normal factory lighting and visual conditions.

4.5.1 Visual test A

The crystal unit shall be visually examined to ensure that the condition, workmanship and finish are satisfactory. The marking shall be legible.

4.5.2 Visual test B

The crystal unit shall be visually examined under ×10 magnification. There shall be no cracks in the glass or damage to the terminations. Minute flaking around the feather edge of a meniscus shall not be considered a crack.

4.5.3 Visual test C

The crystal unit shall be visually examined. There shall be no corrosion or other deterioration likely to impair satisfactory operation. The marking shall be legible.

4.6 Dimensioning and gauging procedures

4.6.1 Dimensions, test A

The dimensions, spacing and alignment of the terminations shall be checked, where appropriate using the gauges specified. The dimensions, spacing and alignment shall comply with the specified values.

4.6.2 Dimensions, test B

The dimensions shall be measured and they shall comply with the specified values. Dimensions are specified in IEC 60122-3 together with the gauging procedure as appropriate or as specified in the detail specification.

4.7 Electrical test procedures

4.7.1 Frequency and resonance resistance

Unless otherwise defined in the detail specification, the measurements shall be carried out at 25 °C ± 2 °C for non-temperature controlled crystal units; or at the mid-point of the temperature range ±1 °C for temperature controlled units.

The frequency and resonance resistance of the crystal unit shall be measured under the conditions stated in the detail specification and be within the specified limits.

NOTE Preferred methods of measurement are described in IEC 60444-1, IEC 60444-2, IEC 60444-4 and IEC 60444-5 depending on the frequency of the crystal unit under test. Any other measurement method may be used provided results correlate with those obtained using preferred values.

4.7.2 Drive level dependency

It is important that when a drive level dependency test is specified, this test shall be carried out at least five days after any previous activation of the crystal unit (see IEC 60444-6).

Measurements specified in 4.7.1 shall be carried out at two specified drive levels. These are normally at a specified low level of drive followed by a high level of drive. Unless otherwise specified, the low level shall be not more than 50 µA and the upper level not less than 1 000 µA. The change of resonance resistance shall not exceed the limit specified in the detail specification.

4.7.3 Frequency and resonance resistance as a function of temperature

NOTE Tests A and B may be combined only if test A is performed with continuously varying temperature, and is started at the lower extreme of the operating temperature range or –30 °C, whichever is the lower.

The level of drive and load capacitance shall be set at the levels stated in the detail specification, at the reference temperature. No subsequent adjustment shall be made to the test equipment during the tests.

Test A

Starting with the crystal unit at an extreme of the operating temperature range, the frequency and resonance resistance (see 4.7.1) shall be measured over the specified temperature range at discrete temperature intervals of not greater than 1,5 °C, allowing the crystal unit to reach thermal equilibrium at each temperature.

The crystal unit may be measured under conditions of continuously varying temperature, provided that tests have shown that with the chosen rate of change of temperature, the results obtained will correlate adequately with those from a stepped variation of temperature.

The crystal unit shall be within the specified limits during this test.

Test B

The temperature of the crystal enclosure shall be raised from –30 °C to +20 °C in a period not exceeding 1 min. During this test, the frequency and the resonance resistance (see 4.7.1) shall be measured from –10 °C, or below, to +20 °C, so as to provide continuous readings. There shall be no discontinuous variation in frequency and/or resistance. Such discontinuity indicates the presence of moisture within the enclosure.

NOTE The presence of moisture can be verified only by a positive temperature change.

4.7.4 Unwanted responses

The frequency shall be scanned over the range stated in the detail specification while monitoring the resistance of the crystal unit at the drive level stated in the detail specification for the main response.

The ratio of the resonance resistance of any unwanted response to that of the response at the desired resonance frequency shall be not less than the value stated in the detail specification. Alternatively, the resonance resistance of unwanted responses shall be greater than the value stated in the detail specification.

4.7.5 Shunt capacitance

The shunt capacitance C_0 (see figure 1) shall be measured at a frequency below the fundamental resonance frequency of the unit, at which the unit shows no oscillation response. The enclosure (if metal) shall be earthed, unless otherwise stated in the detail specification.

NOTE 1 There is no direct method for measuring C_0 precisely. However, in nearly all practical cases, it is adequate to regard C_0 as the mean of two shunt capacitance values obtained at two frequencies equidistant above and below the resonance frequency f_r and sufficiently removed from f_r for the impedance to be independent of any response.

NOTE 2 C_0 is the shunt capacitance between the two electrodes of the resonator but it should be pointed out that the capacitances of both the electrodes to earth are important elements in many network and frequency control applications.

NOTE 3 Therefore, in the general case, it is necessary to consider the crystal unit as a three terminal network and to evaluate C_0 and the stray capacitances of the two electrodes to earth from open- and short-circuit measurements according to the technique customarily employed when dealing with two-port devices.

The crystal enclosures shall be at earth potential, unless otherwise specified in the detail specification, during the entire series of measurements required for evaluation of the resonator parameters. For this purpose, glass-enclosed crystal units shall be provided with metal shields.

4.7.6 Load resonance frequency and resistance

Test methods for the measurement of load resonance frequency and load resonance resistance are described in IEC 60444-4.

4.7.7 Frequency pulling range (f_{L1}, f_{L2})

The difference between the resonance frequencies with the two specified load capacitances shall be determined using the method described in IEC 60444-4 or any alternative method giving frequency correlation to a degree consistent with the accuracy required.

4.7.8 Motional parameters

Test methods for the measurement of motional parameters are described in IEC 60444-1, IEC 60444-2 and IEC 60444-5.

4.7.9 Insulation resistance

Unless otherwise stated in the detail specification, the insulation resistance shall be measured with a d.c. voltage of 100 V ± 15 V for 60 s or less if a stable reading is achieved, applied between:

– terminations isolated from the case;
– isolated terminations connected together and metal parts of the case, if any.

The insulation resistance shall not be less than 500 MΩ.

NOTE When performing this test care should be taken to ensure that no moisture remains on the enclosure from any previous tests.

4.8 Mechanical and environmental test procedures

4.8.1 Robustness of terminations (destructive)

a) Tensile and thrust tests on terminations

The tests shall be performed in accordance with Test Ua_1 (tensile) and Test Ua_2 (thrust) of IEC 60068-2-21.

Unless otherwise stated in the detail specification, the loading mass shall be:

– for pin (plug-in) terminations: 20 N thrust,
– for pin (plug-in) terminations: 20 N tensile,
– for wire (solder) terminations: 10 N tensile.

b) Flexibility of wire terminations

The test shall be performed in accordance with Test Ub (bending) of IEC 60068-2-21.

Unless otherwise stated in the detail specification, the load shall be so restricted that the bend starts 2,5 mm ± 0,5 mm from the body of the crystal unit, the loading mass shall be 5 N and the number of bends shall be three.

c) Terminal bend test (for undercut pins only)

Hold or clamp the body or base of the crystal unit by any convenient means. Use the bending tool shown in figure 6 to engage that segment of the terminals beyond the undercut section of the pins.

NOTE To ensure that bending will occur primarily at the undercut portion, a plate with two clearance holes for the pins may be placed over the pins. This plate may be of such a thickness as to include a portion of the undercut section of the pins.

Bend the pins by means of the tool through $15^\circ \pm 2^\circ$ in one direction, follow by a bend of $30^\circ \pm 2^\circ$ in the opposite direction, and complete by a bend of $15^\circ \pm 2^\circ$ back to the starting position. The rate of bending shall be approximately 5° per second in each direction.

When this test is used, the terminal pins shall not fracture.

4.8.2 Sealing tests (non-destructive)

a) Gross leak test

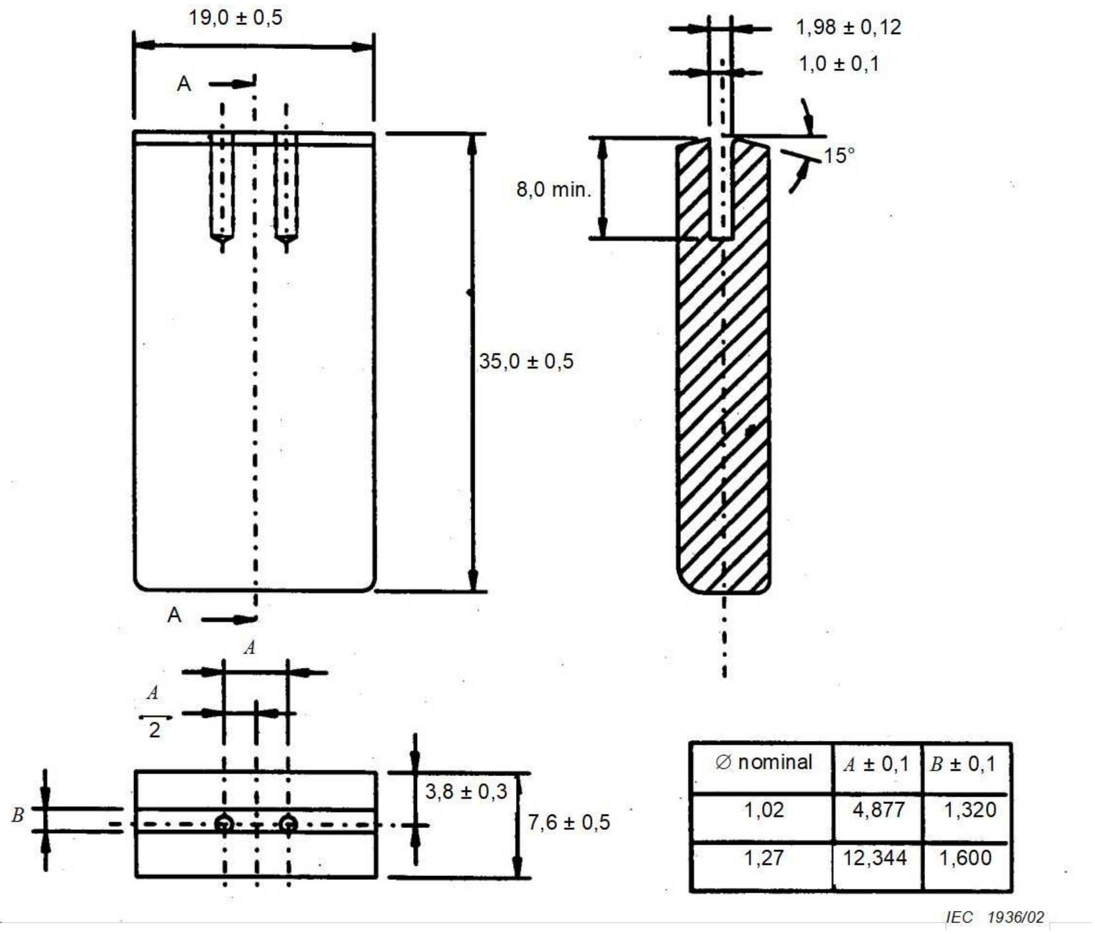
This test shall be performed in accordance with the procedure specified in Test Method 1 or 2 of Test Qc of IEC 60068-2-17.

Method 1

The liquid shall be degassed water and the pressure of air above the water shall be reduced to 8,5 kPa (85 mbar) or less and it shall not be necessary to drain or remove the specimen from the water before breaking the vacuum.

Method 2

The liquid shall be maintained at 125 °C ± 5 °C. The immersion time shall be 30 s, unless otherwise specified in the relevant detail specification.



∅ nominal	*A* ± 0,1	*B* ± 0,1
1,02	4,877	1,320
1,27	12,344	1,600

Dimensions in millimetres

Figure 6 – Terminal bend test tool

After 1 min, the unit shall be removed from the chamber and exposed to the controlled recovery conditions specified in 5.4.1 of IEC 60068-1.

During the test there shall be no evidence of leakage of gas or air from the inside of the crystal unit. The continuous formation of bubbles shall be evidence of leakage.

b) Fine leak test

The test shall be performed in accordance with 6.4 Test Method 1 of Test Qk of IEC 60068-2-17. Unless otherwise stated in the detail specification, the pressure in the pressure vessel shall be 200 kPa (2 bar).

The maximum leak rate shall not exceed the value given in 2.3.11, unless otherwise stated in the detail specification.

c) Vacuum test for evacuated crystal units (glass enclosure types only)

The vacuum shall be checked by applying a peak voltage not exceeding 15 kV derived from a Tesla coil.

To avoid damage to the crystal unit, the point of application of the test electrode shall be as remote as possible from the crystal resonator and its terminations. To facilitate observation of the resulting discharge, the test shall be carried out in semi-darkness. There shall be no indication of arcing within the enclosure. Where a uniform discharge occurs, it shall be a pale bluish colour.

NOTE This test should be conducted in the shortest possible time, as this test may cause changes in the nominal frequency of the crystal unit under test.

4.8.3 Soldering (solderability and resistance to soldering heat) (destructive)

a) Solderability

This test shall be performed in accordance with Method 1 of Test Ta of IEC 60068-2-20. A screen of thermally insulating material shall be used to prevent the component being heated by direct radiation from the solder bath. It shall also allow the immersion of the terminations up to a point 2 mm away from the emergence of the terminations from the body, unless otherwise specified in the detail specification. The terminations shall be examined for good tinning, as evidenced by free flowing of the solder with wetting of the terminations.

b) Resistance to soldering heat

This test shall be performed in accordance with Method 1A of Test Tb of IEC 60068-2-20. The immersion time shall be 5 s ± 1 s, unless otherwise specified in the detail specification. A screen of thermally insulating material shall be used to prevent the component being heated by direct radiation from the solder bath. It shall also allow the immersion of the terminations up to a point 2 mm away from the emergence of the terminations from the body, unless otherwise specified in the detail specification.

4.8.4 Rapid change of temperature, two-fluid bath method (non-destructive)

The test shall be performed in accordance with Test Nc of IEC 60068-2-14. The units shall be subjected to one cycle in a downward direction from 98 °C ± 3 °C for 15 s to 1 °C ± 1 °C for 5 s.

4.8.5 Rapid change of temperature with prescribed time of transition (non-destructive)

The test shall be performed in accordance with Test Na of IEC 60068-2-14.

For non-temperature-controlled crystal units, the low and high test chamber temperatures shall be the extreme temperatures of the operating range stated in the detail specification. For temperature-controlled crystal units, the low and high temperatures shall be –40 °C ± 3 °C and +100 °C ± 3 °C respectively.

The crystal units shall be maintained at each extreme of temperature for 15 min, unless otherwise specified in the detail specification.

The crystal units shall be subjected to 10 complete thermal cycles and then exposed to standard atmospheric conditions for recovery for not less than 2 h.

4.8.6 Bump (destructive)

The test shall be performed in accordance with Test Eb of IEC 60068-2-29. The crystal units shall be suitably mounted with clamps on the body. The three mutually perpendicular axes in which the bump is to be applied shall include:

– an axis parallel with the terminations;
– an axis perpendicular to the mounting structure at the crystal element.

The degree of severity shall be as specified in 2.3.8, unless otherwise stated in the detail specification.

4.8.7 Vibration (destructive)

a) Vibration (sinusoidal)

The test shall be performed in accordance with Test Fc of IEC 60068-2-6. The crystal units shall be suitably mounted with clamps on the body. The three mutually perpendicular axes in which the acceleration is to be applied shall include:

– an axis parallel with the terminations;
– an axis perpendicular to the mounting structure at the crystal element.

The degree of severity shall be as specified in the detail specification.

b) Random vibration

Under consideration.

4.8.8 Shock (destructive)

The test shall be performed in accordance with Test Ea of IEC 60068-2-27. The crystal units shall be suitably mounted with clamps on the body. The three mutually perpendicular axes in which the shock is to be applied shall include:

– an axis parallel with the terminations;
– an axis perpendicular to the mounting structure at the crystal element.

The degree of severity shall be as specified in 2.3.10, unless otherwise stated in the detail specification.

4.8.9 Free fall (destructive)

The test shall be performed in accordance with Procedure 1 of Test Ed of IEC 60068-2-32. The crystal unit shall be suspended by its terminations at a height of 1 000 mm and the number of falls shall be two, unless otherwise specified in the detail specification.

4.8.10 Acceleration, steady state (non-destructive)

The test shall be performed in accordance with Test Ga of IEC 60068-2-7. The crystal units shall be suitably mounted with clamps on the body. The procedure and severity shall be as stated in the detail specification.

This test may be considered destructive at certain severities.

4.8.11 Dry heat (non-destructive)

The test shall be performed in accordance with Test Ba of IEC 60068-2-2. The conditioning shall be carried out at the upper temperature indicated by the climatic category for a duration of 16 h.

4.8.12 Damp heat, cyclic (destructive)

This test shall be performed in accordance with Test Db variant 1 of IEC 60068-2-30, at severity b), 55 °C, for six cycles.

4.8.13 Cold (non-destructive)

This test shall be performed in accordance with Test Aa if IEC 60068-2-1 at the lower temperature indicated by the climatic category for a duration of 2 h.

4.8.14 Climatic sequence (destructive)

The tests and measurements shall be performed in the following order:

- dry heat see 4.8.11
- damp heat cyclic see 4.8.12 (first cycle only)
- cold see 4.8.13
- damp heat cyclic see 4.8.12 (remaining five cycles).

In the climatic sequence, an interval of not more than three days is permitted between any of these tests, except between damp heat cyclic (first cycle) and dry cold.

In such a case, the cold test shall follow immediately after the recovery period specified for the damp heat test.

4.8.15 Damp heat, steady state (destructive)

This test shall be performed in accordance with Test Ca of IEC 60068-2-3 for 56 days, unless otherwise stated in the detail specification.

4.8.16 Immersion in cleaning solvents (non-destructive)

This test is applicable to superficial marking only.

To establish the permanence of marking, this test shall be performed in accordance with test method 1 of test XA of IEC 60068-2-45. The detail specification shall prescribe the solvent to be used.

The marking shall be legible.

4.9 Endurance test procedure

4.9.1 Standard ageing test for production verification

4.9.1.1 Purpose

This test is usable for the statistical verification of aging performance in the production process.

4.9.1.2 Procedure

- Take sample from the production lot.
- Initial measurement of f_s and R_1 at (25 ± 2) °C.
- Store in oven at T_{oven} = (+85 ± 3) °C.
- Take and record additional measurements after 1 day and at least three more times at time intervals recommended in Annex A.
- For the measurement, remove the crystals from oven, and store at room temperature for 1 h, avoiding temperature shocks. Measurement of f_s and R_1 at (25 ± 2) °C in accordance with IEC 60444-5 or equivalent.
- Final measurement of f_s and R_1 at (25 ± 2) °C after 30 days.

4.9.1.3 Evaluation

The difference between the highest and lowest frequency measurement shall not exceed the specified value. The resistance R_1 shall never exceed the specified maximum values.

4.9.2 Accelerated aging

4.9.2.1 Purpose

For special applications, an accelerated aging procedure at higher temperatures is applied to shorten the verification time and/or to gain performance data at higher operating temperatures.

4.9.2.2 Procedure

The procedure is as in 4.9.1, except that the preferred oven temperature is T_{oven} = +105 °C, +125 °C or +150 °C. This temperature has to be lower or equal to the specified maximum storage temperature.

The ratio between the storage time at 25 °C and the storage time at an elevated temperature T_{oven} to achieve the same amount of frequency aging is called "time acceleration factor" (TAF). This factor depends on the design of the crystal unit and on the production process. It can be determined experimentally as described in Annex A, or taken from experience with structurally similar crystals, or can be mutually agreed between the manufacturer and the user.

If the time acceleration factor TAF is not otherwise specified, the following approach is recommended.

Applying Arrhenius's law, the time acceleration factor TAF is related to the activation energy E_a (in eV) by the following equation:

$$\text{TAF} = e^{\frac{E_a \cdot \left(\frac{1}{T_{ref}} - \frac{1}{T_{oven}} \right)}{k}}$$

where

k is Boltzmann's constant ($k \approx 8{,}617 \times 10^{-5}$ eV/K), and the temperatures are given in K.

Published experimental results (see [6] and [7]) show that the activation energy E_a is decreasing over time, i.e. the acceleration factor becomes lower with the aging time. Furthermore, E_a varies between the different crystals and oscillators, depending on frequency, package size, resonator design and production processes. The observed values of E_a were between > 0,1 eV and < 1 eV.

A common assumption is TAF = 12 for T_{oven} = +85 °C, i.e. 30 days (1 month) aging at 85 °C are considered to be equivalent to 365 days (12 months) aging at 25 °C, which corresponds to an activation energy E_a of 0,38 eV.

With this value of E_a, the time acceleration factor for other aging temperatures can be calculated. Table 5 below shows the time acceleration factor TAF and the number of days N_d equivalent to 365 days at 25 °C.

Table 5 – Time acceleration factors for E_a = 0,38 eV

T_{oven} °C	TAF	N_d days
+25	1	365
+85	12	30
+105	23	16
+125	41	9
+150	79	5

Other time acceleration factors may be agreed between the manufacturer and the user based on their own reliability calculations.

4.9.2.3 Evaluation

The evaluation is as in 4.9.1.

4.9.3 Reference aging test

4.9.3.1 Purpose

This procedure is used for higher confidence level. This method should be used for high-precision crystals and as reference method in case of dispute.

4.9.3.2 Procedure

See Annex A.

4.9.3.3 Evaluation

The test data of the series resonance frequency f_s is subjected to the data fitting procedure.

The frequency measurement data $f_i(t)$ shall be fitted using the method of least squares of the following function (logarithmic fit):

$$\left[\frac{\Delta f(t)}{f_{init}}\right] = a_0 + a_1 \times \ln(a_2 \times t + 1)$$

where

$\Delta f(t)$ is the frequency difference of the crystal t days after the start of the aging cycle and the initial frequency f_{init} measured after the stabilization time t_{stab} (the time origin for measurements analysis shall be the beginning of the stabilization period).

The coefficients a_0, a_1 and a_2 are constants to be determined from the least squares fit.

The default fitting algorithm is the logarithmic fit. In some cases, namely when the aging response has a very small curvature, the logarithmic fit may not yield reasonable results. In this case, the following polynomial fit is recommended to be calculated additionally:

$$\left[\frac{\Delta f(t)}{f_{init}}\right] = a_0 + a_1 \times t + a_2 \times t^{\frac{1}{2}} + a_3 \times t^{\frac{1}{3}}$$

This approach should only be used if the square root of the least square fit variance (SLQ) of the measurements from the polynomial fit is at least five times smaller than that of the logarithmic fit.

The total frequency change and the aging rate at the end of the specified aging period ($t = T_a$) shall be determined from the fitting equation using the constants determined from the least squares fit. The square root of the least squares fit variance of the measurements from the curve-fit function shall not exceed 5 % of the total aging change allowed during the test period.

For the logarithmic fitting (default), the aging rate (in ppm or ppb[1] per day) at $t = T_a$ is:

$$\left[\frac{d\left(\frac{\Delta f(t)}{f_{\text{init}}}\right)}{dt}\right]_{t=T_a} = \frac{a_1 \times a_2}{a_2 \times T_a + 1} \approx \frac{f(T_a + 1) - f(T_a)}{f_{\text{init}}}$$

If the polynomial fitting was used, the aging rate at $t = T_a$ ($T_a > 0$) is:

$$\left[\frac{d\left(\frac{\Delta f(t)}{f_{\text{init}}}\right)}{dt}\right]_{t=T_a} = a_1 + \frac{a_2}{2} \times T_a^{-\frac{1}{2}} + \frac{a_3}{3} \times T_a^{-\frac{2}{3}}$$

The projected total frequency change for a time period shall be calculated with the following formulas:

Aging per month $\approx \dfrac{f(T_a + 30) - f(T_a)}{f_{\text{init}}}$

Aging per (1st) year $\approx \dfrac{f(T_a + 365) - f(T_a)}{f_{\text{init}}}$

Aging over N years $\approx \dfrac{f(T_a + N \times 365) - f(T_a)}{f_{\text{init}}}$

The resistance R_1 shall never exceed the specified maximum values.

4.9.4 Extended ageing

4.9.4.1 Purpose

The purpose is to evaluate the reliability and long-term performance.

1 ppm = parts per million; ppb = parts per billion.

4.9.4.2 Procedure

This test shall be carried out in accordance with 4.9.1, except that the continuous periods shall be 1 000 h, 2 000 h or 8 000 h, as prescribed in the detail specification and shall be used for information purposes only.

The measurements shall be carried out at (25 ± 2) °C or any other specified reference temperature in accordance with IEC 60444-5 or equivalent.

The measurement intervals can be extended to two weeks or longer. For the intermediate and the final measurement, the crystals can be removed from the oven, and stored at room temperature for 1 h. Thermal shocks should be avoided.

4.9.4.3 Evaluation

The difference between the highest and lowest frequency measurement shall not exceed the specified value (if applicable). The resistance R_1 shall never exceed the specified maximum values.

This test shall be used for information only. The crystal units used for these tests should not be supplied to any customer.

This test shall be used for information only. The crystal units used for these tests should not be supplied to any customer.

Annex A
(normative)

Procedure for the determination of the fitting parameters for the frequency aging

A.1 Assumption

A general description of frequency aging is possible in the form of:

$$\Delta f/f\,(t,T) = g(t) \times h(T)$$

where

$$g(t) = b_0 + b_1 \times \log(b_2 \times t + 1) \text{ (logarithmic fit);}$$

or

$$g(t) = c_0 + c_1 \times (t - _{t0}) + c_2 \times (t - t_0)\text{\^{}}(1/2) + c_3 \times (t - t_0)\text{\^{}}(1/3) \text{ (polynomial fit);}$$

and

$$h(T) = a_1 \times \exp(E_a \times (1/T_{ref} - 1/T)/k)$$

where

k is Boltzmann's constant ($k \approx 8{,}617 \times 10^{-5}$ eV/K), and the temperatures are given in K;

T_{ref} is 298 K.

A.2 Determination of the fitting parameters b_0, b_1, b_2 (and/or c_0, c_1, c_2, c_3) and a_1, and E_a

The procedure of Table A.1 shall be applied.

Table A.1 – Procedure for the determination of the frequency aging parameters

Procedure	Conditions
Aging test procedure	Passive
Reflow solder test	2x ROHS-profile (IEC 61760-1:2006) [a]
Initial pre-aging (time and temperature)	48 h at >20 K above upper operating temperature, but T < upper storage temperature
Sample size per lot (from one production lot)	≥ 30[*] depending on needed confidence level
Number of aging temperatures	3
Recommended aging temperatures	85 °C, 105 °C, 125 °C, 150 °C[a] depending on application, T < specified upper storage temperature
Recommend temperature for measurement	(25 ± 2) °C, measurement > 1 h after removal from the temperature chamber. Avoid thermal shocks.
Recommended aging time	500 h, 1 000 h, 2 000 h [a] depending on needed confidence level
Test intervals (in "logarithmic" steps)	After 48 h stabilization: 24 h, 72 h, 250 h, 500 h, 750 h, 1 000 h (1 500 h, 2 000 h)
Algorithms to determine g(t) and h(T)	Least square fitting[b] $g(t)$: log fit and polynomial fit Polynomial fit – only if sum of least squares SLQ < 5 times SLQ of logarithmic fit $h(T)$: least square fitting Result: E_a E_a may vary with time. Use E_a for t ≥ 500 h

[a] If not otherwise specified.

[b] For monotonic aging, all measurements shall be used for the curve fitting. If the aging trend is not monotonic, the measurement period shall be extended up to 40 days or longer after the extremum in the aging trend, and the measurements form 12 days after the extremum is reached at the end of the aging measurement period shall be fit to the above functions for $g(t)$.

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