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INTERNATIONAL STANDARD

Measurement and test methods for tuning fork quartz crystal units in the range from 10 kHz to 200 kHz and standard values

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MEASUREMENT AND TEST METHODS FOR TUNING FORK QUARTZ CRYSTAL UNITS IN THE RANGE FROM 10 kHz TO 200 kHz AND STANDARD VALUES

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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International Standard IEC 60689 has been prepared by IEC technical committee 49: Piezoelectric and dielectric devices for frequency control and selection.

This second edition cancels and replaces the first edition published in 1980. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) The title of the first edition is *Measurements and test methods for 32 kHz quartz crystal units for wrist watches and standard values*. The title is modified and the frequency range of this second edition is extended to the range from 10 kHz to 200 kHz.
b) The Lissajous method is defined in the first edition as the standard measurement method. The PI network and bridge method are used in this second edition.
c) The PI network has a transformer for impedance matching. This composition differs from that of IEC 60444-1.

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

FDIS	Report on voting
49/809/FDIS	49/815/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the maintenance result 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.

MEASUREMENT AND TEST METHODS FOR TUNING FORK QUARTZ CRYSTAL UNITS IN THE RANGE FROM 10 kHz TO 200 kHz AND STANDARD VALUES

1 Scope

This International Standard applies to measurements and test methods for tuning fork quartz crystal units in the range from 10 kHz to 200 kHz and standard values for frequency control and selection.

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, *International Electrotechnical Vocabulary – Chapter 561: Piezoelectric devices for frequency control and selection*

IEC 60122-1, *Quartz crystal units of assessed quality – Part 1: Generic specification*

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

IEC 60444 (series), *Measurement of quartz crystal unit parameters by zero phase technique in a π-network*

IEC 60617, *Graphical symbols for diagrams*

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

3 Overview

3.1 General

Units, graphical symbols, letter symbols and terminology shall, wherever possible, be taken from the following standards: IEC 60027, IEC 60050-561, IEC 60122-1, IEC 60617, and ISO 1000.

3.2 Applied frequency range

The frequency range is from 10 kHz to 200 kHz.

3.3 Measurement method

The measurement method is according to the IEC 60444 series.

It is permitted to use the bridge method as a simple measuring method.

NOTE Other methods like Lissajous-or oscillator methods are not recommended for measurement of equivalent circuit constants.

3.4 Load capacitance

Currently, defined values of load capacitance are 8 pF, 10 pF, 12 pF, 15 pF, 20 pF and 30 pF.

3.5 Recommended drive level

Currently, the recommended drive level is 0,1 μW.

3.6 Measurement conditions

Measurement conditions are given in 5.2.

3.7 Measurement of frequency-temperature characteristics

The measurement of frequency-temperature characteristics is given in Clause 5.

3.8 Load capacitance frequency characteristics

The present conditions of load capacitance and frequency characteristics are given in 5.3.4.

4 Measurement methods

4.1 Method A

The measurement method according to the IEC 60444 series gives a copy of a block diagram (including a load capacitance), test fixture (for Surface Mounted Device-units included) with additional values of the resistances for high impedance value (standard PI-network 25 Ω) and hardware requirements for a frequency range from 10 kHz to 200 kHz.

This measuring method is a standard measuring method in this document.

4.1.1 Vector network analyzer/vector impedance analyzer

The measurement method using the vector network analyzer or vector impedance analyzer is based on the following method.

4.1.2 Block diagram

Figure 1 is a block diagram of the measurement method using the vector network analyzer or vector impedance analyzer.

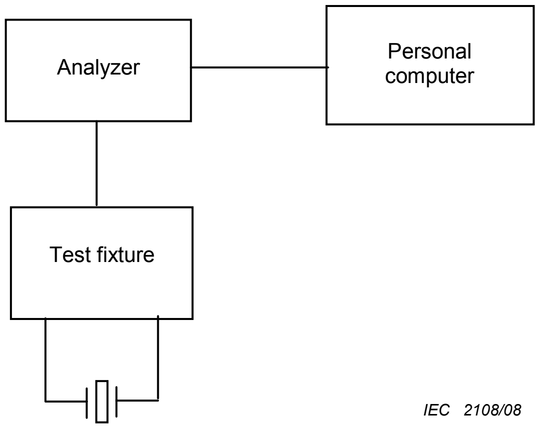

Figure 1 – Block diagram of the measurement method using the vector network analyzer or vector impedance analyzer

4.1.3 Specifications for vector network analyzer/vector impedance analyzer

Specifications for vector impedance analyzer are shown in Table 1.

Table 1 – Specifications for vector network analyzer/vector impedance analyzer

Item	Specifications
Frequency range	The measurement range of equipment shall be from 10 kHz to 200 kHz.
Frequency accuracy	1×10^{-6}
Series resistance accuracy	1 %
Signal level adjusted range	5 mV_{rms} – 1V_{rms} or 200 μA_{rms} – 20 mA_{rms}
Spurious	40 dB max.
Others	RC23C, LAN, etc.

4.1.4 Test fixture

A test fixture shall be used. This test fixture shall be electrically and mechanically compatible with the vector network analyzer or the vector impedance analyzer that is used.

Figures 2 and Figure 3 show the block diagrams of the equivalent circuit of the test fixture.

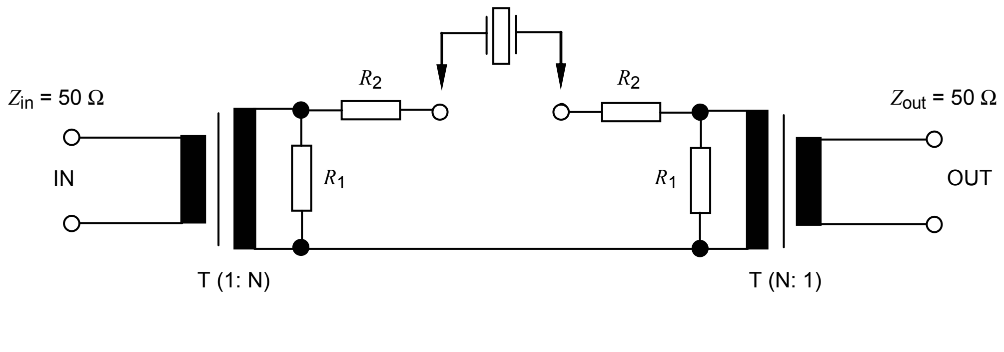

Figure 2 – Block diagram of test fixture

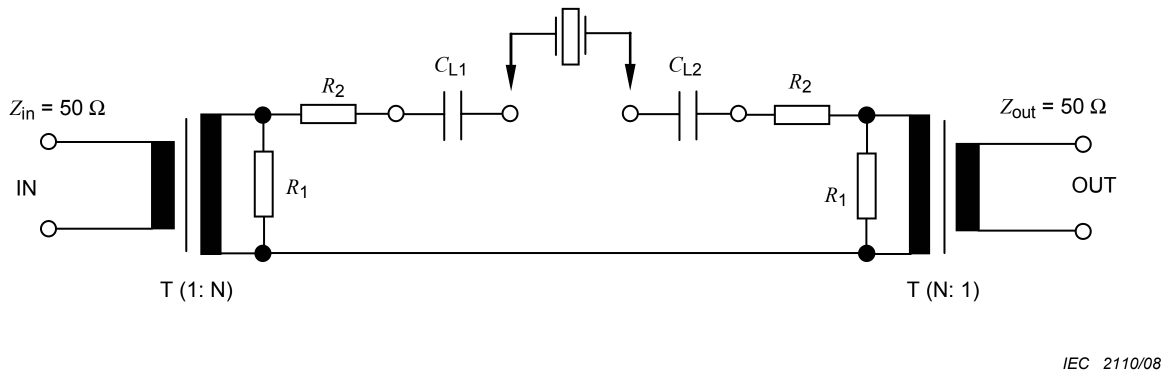

Figure 3 – Block diagram of test fixture (including a load capacitance)

The equivalent series resistance of the crystal units takes on various values according to the design. This resistance value varies in a range from 1 kΩ to 100 kΩ. For this reason, the equivalent series resistance of the crystal units determines R_1 and R_2 appropriately. These values should be determined through a contract with the customer. Since it is the low frequency range, the structure and material of the test fixture are not defined specifically.

EXAMPLE Each constant takes on the following values in the following ranges.

R_r is 1 kΩ to 10 kΩ: N_TF = 10 000, R_1 = 49,5 kΩ, and R_2 = 5,008 MΩ

R_r is 10 kΩ to 20 kΩ: N_TF = 17 000, R_1 = 50 kΩ, and R_2 = 15,000 MΩ

R_r is 20 kΩ to 40 kΩ: N_TF = 24 000, R_1 = 50,464 kΩ, and R_2 = 30 MΩ

R_r is 40 kΩ to 70 kΩ: N_TF = 33 000, R_1 = 49,809 kΩ, and R_2 = 55,008 MΩ

R_r is 70 kΩ to 200 kΩ: N_TF = 41, R_1 = 50,119 kΩ, and R_2 = 85,008 MΩ

NOTE The structure and material of the test fixture are determined through due examination.

4.1.5 Measurement of equivalent circuit constants

The measurements of equivalent resistance R_r, resonance frequency f_r, motional capacitance C_1, quality factor Q and load resonance frequency f_L are in accordance with the IEC 60444 series.

The load resonance offset between load resonance frequency f_L and resonance frequency f_r can be calculated from the parameters C_0 and C_1 by the following formula.

$$\frac{\Delta f}{f} = \frac{C_1}{2\left(C_0 + C_L\right)}$$

4.1.6 Frequency pulling

4.1.6.1 General

The frequency pulling shall compensate the frequency shifts by means of the following:

a) tolerances on other components of oscillator (e.g. watch) circuits;
b) adjustment tolerance;
c) ageing during the economic life of oscillator (e.g. watch) circuits;
d) frequency shifts due to shocks and vibrations.

4.1.6.2 Alternative determination of the motional capacitance C_1

The motional capacitance C_1 can be determined alternatively with the frequency difference when the crystal unit is measured with 2 different load capacitances.

The motional capacitance C_1 is determined by a measurement of frequency, with use of two load capacitances C_{L1} and C_{L2}, connected in series with the crystal unit (see Figure 3).

When

$$\Delta C_L = C_{L2} - C_{L1}$$
$$\Delta f = f_{L1} - f_{L2}$$
$$\Delta f_1 = f_{L1} - f_r$$
$$\Delta f_2 = f_{L2} - f_r$$
$$f_r = \text{resonance frequency}$$

f_{L1} and f_{L2} are the resonance frequencies of the crystal unit connected in series with C_{L1} and C_{L2} respectively.

Hence

$$C_1 = \frac{2\Delta C_L}{f_r} \times \frac{\Delta f_1 \Delta f_2}{\Delta f}$$

NOTE The measurements corresponding to the motional capacitance C_1 take a long time. For quality control in production, a fixed value of C_L could be selected, and the frequency change is measured. For application in the watch making industry, the scatter of C_1 is also a very important factor.

4.2 Method B

4.2.1 General

It is permitted to use the bridge method as a simple measuring method. This simple measuring method is permitted only for frequency measurement.

4.2.2 Block diagram

Figures 4 and 5 show the block diagrams of the test fixture for the bridge method. Each resistance is based on a contract with a customer.

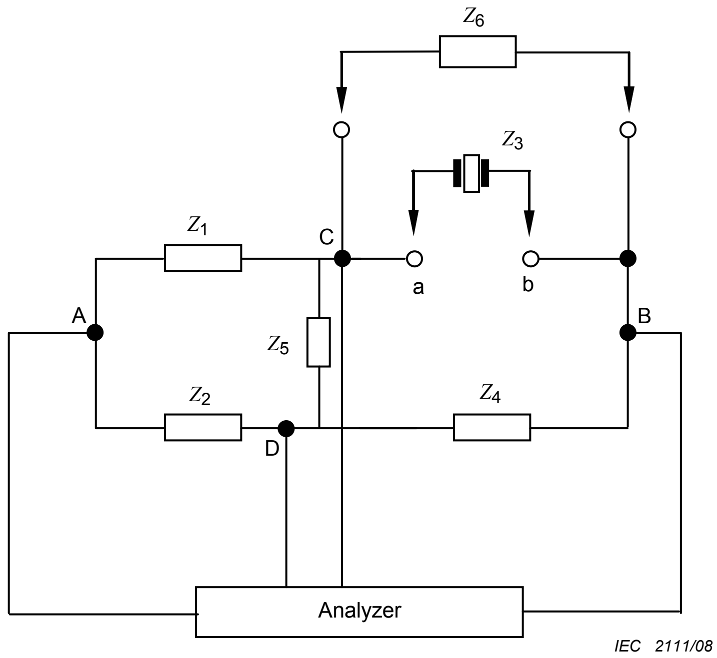

Figure 4 – Block diagram of test fixture for bridge method

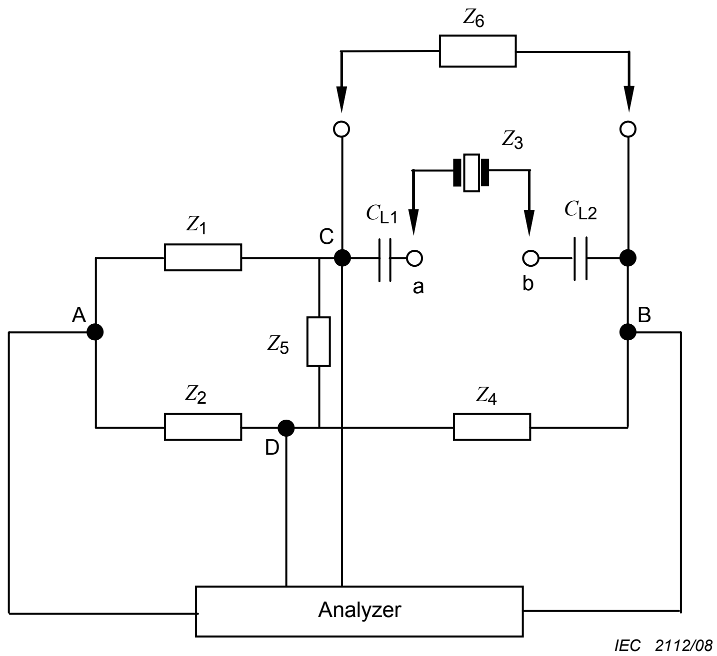

Figure 5 – Block diagram of test fixture for bridge method (including a load capacitance)

4.2.3 Calibration

The standard impedance Z_6 (resistance) is connected between terminals CB. This impedance has almost the same value as the equivalent series impedance (resistance) of the crystal units to be measured. After that, the zero phase and drive level of this measurement system are determined.

4.2.4 Procedure

The procedure is as follows:

1) after completing the initial calibration, the crystal units to be measured are connected between the terminals ab.

   When applying the load capacitance C_L, a load capacitance adapter (C_{L1} and C_{L2}) is connected between terminals CB. Relationship between C_{L1} and C_{L2} is given by Equation (a);

$$C_{L1} = C_{L2} = 2 \cdot C_L \qquad \text{(a)}$$

2) the signal from the analyzer is added between terminals AB;
3) the frequency in the analyzer changes. Phase between terminals CD is set at zero. At this time, the frequency is the series resonance frequency F_S;
4) the equivalent series resistance R_r is given by Equation (b).

$$R_r = Z_3 = \frac{Z_1}{Z_2} Z_4 \qquad \text{(b)}$$

NOTE 1 When changing frequency, the phase of the analyzer changes. At this time, the phase between terminals CD is not in an equilibrium situation. For this reason, it does not suit a measurement of an equivalent circuit constant.

NOTE 2 Since it is the low frequency range, the structure and material of the test fixture are not defined specifically. These are based on a contract with the customer.

NOTE 3 The structure and material of the test fixture are determined through due examination.

NOTE 4 This bridge method may apply to the automatic bridge method.

5 Measurement conditions

5.1 General

A typical example is shown below.

The following conditions can be changed through a contract between manufacturer and users.

5.2 Measurement conditions

The measurement conditions are as follows:

a) enclosure not earthed;
b) the test fixture shall not apply any mechanical stress on the crystal unit to avoid causing frequency changes;
c) the synthesizer shall have a frequency resolution of at least 10 MHz;
d) temperature: see Figure 7; in the worst case (turnover point at 30 °C, measurement at 21 °C); the slope at T °C is about 1×10^{-6}/°C;
e) load capacitance C_L: the tolerance on the load capacitance should be decided appropriately so that the frequency change does not exceed 10 % of the frequency tolerance (see IEC 60122-1).

   C_{L1} and C_{L2} shall be as near as possible to the crystal unit: the accuracy of the measurement is dependent on this;
f) measuring level (Method A):

   when only the voltage is given, the following formula can be used:

$$P = \frac{V^2}{R_r}$$

$$R_L = Z_3 = R_r \cdot (1+\frac{C_0}{C_L})^2$$

where

V is the r.m.s. value of the voltage at resonance frequency across the terminals of the crystal unit;

P is specified in 3.5.

g) measuring level (Method B):

when only the voltage is given, the following formula can be used:

$$P = \frac{V_3^{\ 2}}{Z_3}$$

where

$Z_3\,(R_r)$ is measured in accordance with f);

V is the r.m.s. value of the voltage at resonance frequency across the terminals of the crystal unit;

P is specified in 3.5.

5.3 Measurement of the frequency-temperature dependence

5.3.1 General

It is permitted to use the frequency-temperature dependence as a simple measuring method. This simple measuring method is permitted only for frequency measurement.

5.3.2 Block diagram

Figure 6 shows the block diagram of measurement of the frequency-temperature dependence.

A thermo-couple or an equivalent device can be used for a thermometer device. The test fixtures and the analyzer are used for Method A (see 4.1) or Method B (see 4.2). It is acceptable that this measurement system be exchanged for an automatic system by contract between customer and supplier.

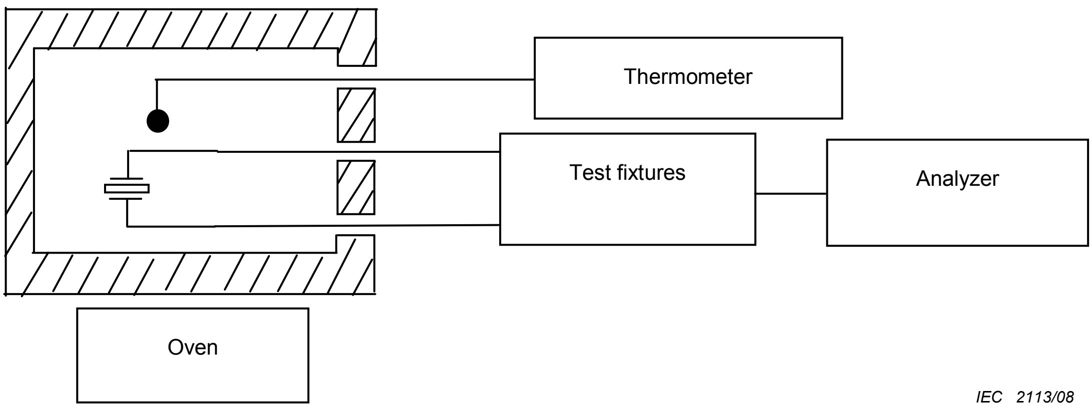

Figure 6 – Block diagram of measurement of the frequency-temperature dependence

5.3.3 Determination of the turnover point and parabolic coefficient *β* (standard reference method)

It is recommended to measure at least five points. In general, the nominal turnover point and four points symmetrically located and nearest the first one, are considered.

The measurement accuracy shall be better than $\pm 1 \times 10^{-6}$ and the temperature shall be controlled within ± 0,3 °C and measured within ± 0,1 °C.

The temperature stabilization time should be about 10 min for each measurement.

The turnover point and parabolic coefficient *β* are obtained by computation (e.g. linear regression).

In the worst case, the error on the determination of the turnover point is ± 1 °C.

5.3.4 Measurement of the frequency versus temperature characteristics (mass production method)

When it is not necessary to determine the turnover temperature, a 3-point measurement of frequency versus temperature is sufficient.

The limiting points of the operating temperature range are chosen (–10 °C, +60 °C), as well as the reference temperature.

The frequency variation shall remain within the limits of Figure 7, for the stated values of *β* and the turnover point.

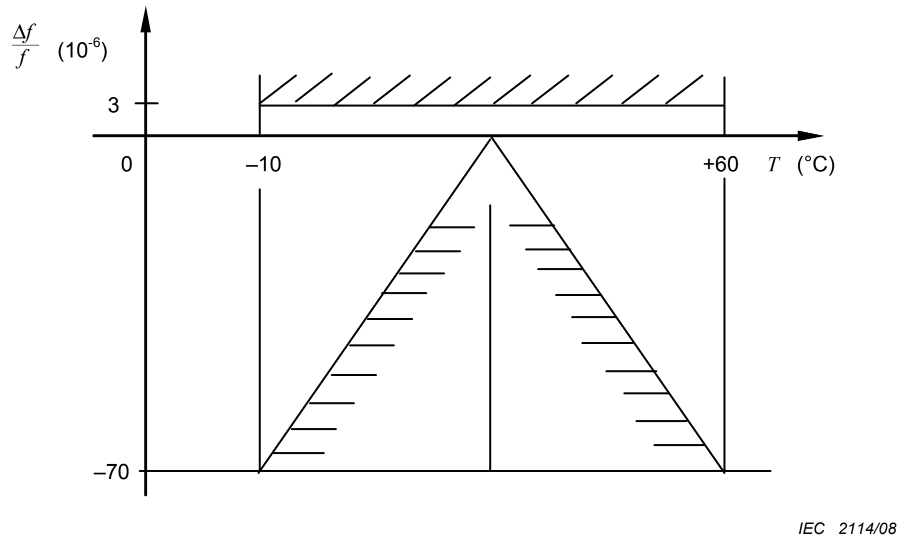

Figure 7 – Frequency–temperature template (Turnover point: 25 ± 5 °C, $\beta = -45 \times 10^{-9}/°C^2$)

5.3.5 Frequency C_L curve

Figures 8a) and 8b) show the frequency versus C_L curve. Two different C_{Ls} are used.

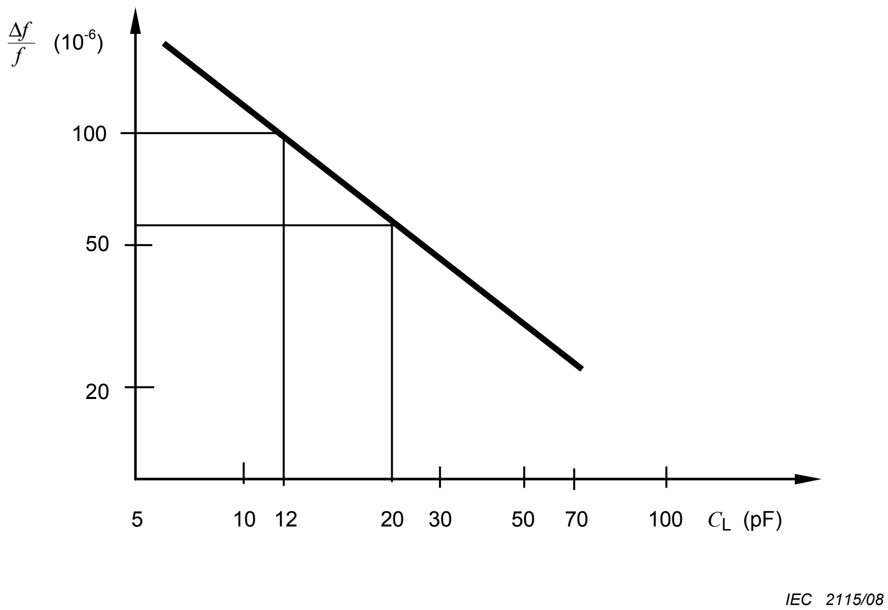

Figure 8a) – $\Delta f/f$ versus C_L curve

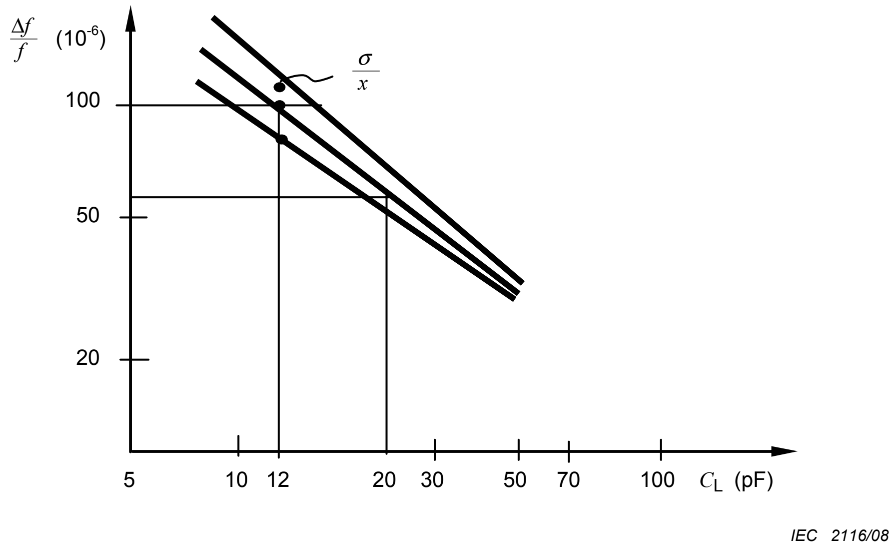

Figure 8b) – $\Delta f/f$ versus C_L curve

Figure 8 – $\Delta f/f$ versus C_L curve with different C_{Ls}

6 Test and environmental examination

6.1 Application of the definition of IEC 60122-1

The definition of IEC 60122-1 applies to the following:

Vibrations, shocks, mechanical stresses on terminals, insulation resistance between enclosure and the leads, solderability of the leads, other methods of fixing, sealing overpressure, marking and date of manufacture, these should be decided by the manufacturer and the user.

6.2 Magnetism – Influence of a magnetic field on the frequency

The crystal unit is placed in a magnetic field for 1 min along each of the three principal directions, and the frequency is measured. The change in frequency during and after the test is noted.

NOTE The need of the test is subject to agreement between manufacturer and user.

6.3 Enclosure

Lead type package depends on IEC 60122-3. Lead-less surface mounted type package has already been put to practical use. This has been added to an appropriate document.

6.4 Measuring conditions and electric performance

6.4.1 General

Insulation resistance is 100 V, 500 MΩ.

Measurement conditions and standard values are as follows:

6.4.2 Measurement conditions

The measurement conditions are as follows:

a) reference temperature should be fixed between 21 °C and 25 °C;

b) tolerance of the fixed reference temperature ± 0,5 °C for items 1 and 2; ± 1 °C for other items;

c) drive level 0,1 μW;

d) load capacitance: 8 pF, 10 pF, 12 pF, 15 pF, 20 pF and 30 pF.

6.4.3 Standard values

Standard values are given in Table 2 hereinafter.

Table 2 – Standard values

Characteristics		Symbol	Unit	Standard values	
				Type 1[a]	**Type 2**[b]
1	Nominal frequency	f	kHz	32,768	
2	Frequency tolerance	$\frac{\Delta f}{f}$	10^{-6}	± 20	± 20
3	Maximum resonance resistance under all operating conditions	Rr	kΩ	30	100
4	Minimum motional capacitance	C_1	fF	2,0	0,8
5	Quality factor	Q	–	See 4.1.5	
6	Turnover temperature	T_i	°C	25 ± 5	
7	Maximum parabolic coefficient	β	10^{-6} / °C ^{2}	–0,04	
8	Operating temperature range	–	°C	–10 to +60	
9	Storage temperature range	–	°C	–30 to +70	
10	Frequency variation due to vibration	$\frac{\Delta f}{f}$	10^{-6}	3	
11	Frequency variation due to shock	$\frac{\Delta f}{f}$	10^{-6}	5	
12	Frequency variation due to ageing during the first year	$\frac{\Delta f}{f}$	10^{-6}	3	5
13	Frequency variation due to mechanical stress on terminals	$\frac{\Delta f}{f}$	10^{-6}	3	
14	Effect of support	$\frac{\Delta f}{f}$	10^{-6}	3	
15	Insulation resistance at 100 V		MΩ	500	
16	Maximum drive level	P	µW	1	

[a] Type 1 = so-called “thick” tuning fork.

[b] Type 2 = so-called “thin” tuning fork.

NOTE The standard value of the nominal frequency (32,768 kHz) is one of the examples.

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1 This publication has been withdrawn and replaced by the on-line certificate system available at <http://certificates.iecq.org/>.

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