IEC 60444-11

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INTERNATIONAL STANDARD

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Measurement of quartz crystal unit parameters – Part 11: Standard method for the determination of the load resonance frequency f_L and the effective load capacitance C_{Leff} using automatic network analyzer techniques and error correction

Mesure des paramètres des résonateurs à quartz – Partie 11: Méthode normalisée pour la détermination de la fréquence de résonance à la charge f_L et de la capacité de charge efficace C_{Leff} utilisant des analyseurs automatiques de réseaux et correction des erreurs

IEC 60444-11:2010

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FOREWORD

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International Standard IEC 60444-11 has been prepared by IEC technical committee 49: Piezoelectric, dielectric and electrostatic devices and associated materials for frequency control, selection and detection.

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

CDV	Report on voting
49/852/CDV	49/883/RVC

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.

A list of all parts of the IEC 60444 series under the general title *Measurement of quartz crystal unit parameters* can be found on the IEC website.

The committee has decided that the contents of this amendment and the base publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
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MEASUREMENT OF QUARTZ CRYSTAL UNIT PARAMETERS –

Part 11: Standard method for the determination of the load resonance frequency f_L and the effective load capacitance C_{Leff} using automatic network analyzer techniques and error correction

1 Scope

This part of IEC 60444 defines the standard method of measuring load resonance frequency f_L at the nominal value of C_L, and the determination of the effective load capacitance C_{Leff} at the nominal frequency for crystals with the figure of merit $M > 4$.

M, according to Table 1 of IEC 60122-1:2002, is expressed in the following equation:

$$M = \frac{Q}{r} = \frac{1}{\omega C_0 R_1} \tag{1}$$

This gives good results in a frequency range up to 200 MHz. This method allows the calculation of load resonance frequency offset Δf_L, frequency pulling range $\Delta f_{L1,L2}$ and pulling sensitivity S as described in 2.2.31 of IEC 60122-1:2002. In contrary to the simple method of IEC 60444-4, this measurement technique avoids the use of physical load capacitors, and allows higher accuracy, better reproducibility and correlation to the application. It extends the upper frequency limit from 30MHz by the method of IEC 60444-4 to 200MHz approximately. This method is based on the error-corrected measurement technique of IEC 60444-5:1995, and therefore allows the measurement of f_L and C_{Leff} together with the determination of the equivalent crystal parameters in one sequence without changing the test fixture.

With this method the frequency f_L is searched where the reactance X_C of the crystal has the opposite value of the reactance of the load capacitance.

$$X_C = -X_{CL} = \frac{1}{\omega_L C_L} \tag{2}$$

Furthermore this method allows to determine the effective load capacitance C_{Leff} at the nominal frequency f_{nom}.

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 60122-1:2002, *Quartz crystal units of assessed quality – Part 1: Generic specification*

IEC/TR 60444-4, *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 units parameters – Part 5: Methods for the determination of equivalent electrical parameters using automatic network analyzer techniques and error correction*

3 General concepts

3.1 Load resonance frequencies f_{Lr} and f_{La}

As can be seen in Figure 1, there are two intersection frequencies where $X_C = -X_{CL}$, f_{Lr} with high admittance (low impedance) and f_{La} with low admittance (high impedance).

The load resonant frequency f_L is one of the two frequencies of a crystal unit in association with a series or with a parallel load capacitance, at which the electrical admittance (respectively impedance) of the combination is resistive. The load resonance frequency f_L is the lower of the two frequencies.

In a first approximation f_L can be calculated by:

$$\frac{1}{f_L} \approx 2\pi \sqrt{\frac{L_1 C_1 (C_0 + C_L)}{C_1 + C_0 + C_L}} \qquad (3)$$

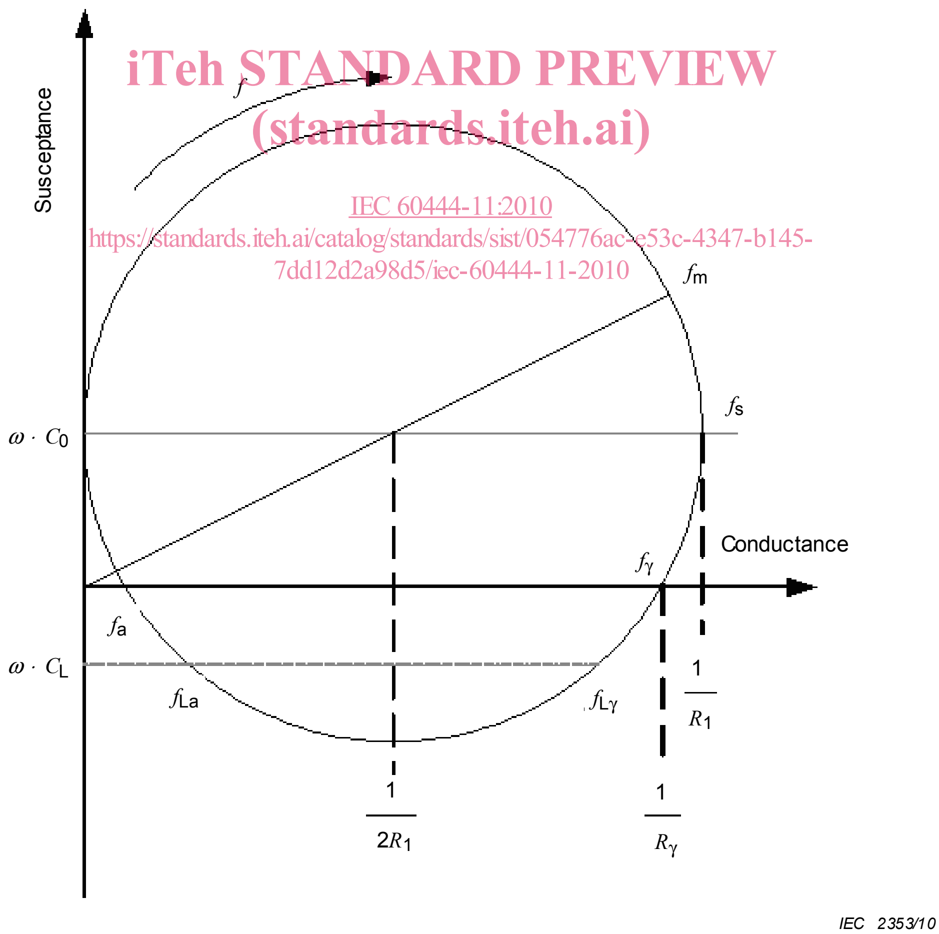

Figure 1 – Admittance of a quartz crystal unit

3.2 Effective load capacitance C_{Leff}

C_{Leff} is defined by the reactance of the crystal at the nominal frequency

$$C_{\text{Leff}} = \frac{1}{\omega_{\text{nom}}\, X_{\text{C}}(\omega_{\text{nom}})} \tag{4}$$

4 Reference plane and test conditions

4.1 General

Reference plane: as in 8.4 of IEC 60444-5:1995.

Test conditions: crystal case not grounded.

Level of drive: the output level of the generator is set, such that at its (series) resonance frequency, the crystal under test is measured at the nominal drive level.

The measurement at the load resonance frequency using the method described below leads to a level of drive, which is remarkably lower than at the (series) resonance frequency due to the relative high reactance value. Therefore a correction measurement is performed, for details see 4.2.

4.2 Principle of measurement

The principles of measurement are the following.

a) Calibration

Due to the high impedance measurements with this method special care has to be taken in the calibration of the test set-up.

Similar to IEC 60444-5:1995, use the following three known calibration elements:

1) short-circuit (0 Ω) or resistor with low resistance;
2) resistor of 25 Ω or 50 Ω nominal;
3) open circuit (infinite resistance) or capacitor of 10 pF nominal;

where Z_1 is the impedance of calibration element 1
Z_2 is the impedance of calibration element 2
Z_3 is the impedance of calibration element 3
V_1 is the measured voltage with calibration element 1
V_2 is the measured voltage with calibration element 2
V_3 is the measured voltage with calibration element 3

The following parameters are then used for the measurement of quartz crystal units:

R_{T} is the termination impedance of the π-network
V_{s} is the error-corrected “short” voltage
V_{o} is the error-corrected “open” voltage

b) Calibration with three known calibration elements:

1) short-circuit calibration;
2) calibration load (25 Ω or 50 Ω);
3) open circuit calibration (or calibration capacitor of 10 pF);

$$R_{\text{T}} = \frac{Z1Z2(V1-V2)+Z2Z3(V2-V3)+Z3Z1(V3-V1)}{Z1(V2-V3)+Z2(V3-V1)+Z3(V2-V2)} \tag{5}$$

$$V_S = \frac{V_3 Z_1 Z_2 (V_1 - V_2) + V_1 Z_2 Z_3 (V_2 - V_3) + V_2 Z_3 Z_1 (V_3 - V_1)}{Z_1 Z_2 (V_1 - V_2) + Z_2 Z_3 (V_2 - V_3) + Z_3 Z_1 (V_3 - V_1)} \quad (6)$$

$$V_0 = \frac{Z_1 V_1 (V_2 - V_3) + Z_2 V_2 (V_3 - V_1) + Z_3 V_3 (V_1 - V_2)}{Z_1 (V_2 - V_3) + Z_2 (V_3 - V_1) + Z_3 (V_1 - V_2)} \quad (7)$$

NOTE If Z_3 is taken as infinite number (ideal open circuit), the above Equations (5), (6) and (7) result is not allowed divisions of infinite by infinite.

c) Measurement of a quartz crystal unit impedance Z_c

From the measured voltage with a quartz crystal unit V_c, the impedance Z_c of the quartz crystal unit is calculated with:

$$Z_C = R_T \frac{(V_S - V_C)}{(V_C - V_0)} \quad (8)$$

d) Measurement procedure for f_L

At load resonance frequency, the impedance of a quartz crystal unit is

$$Z_{CL} = R_L + jX_c \quad (9)$$

For the determination of the load resonance frequency, the frequency f_L the lower frequency is searched for which Equation (2) is fulfilled, i.e.

$$X_C + X_{CL} = 0 \quad (10)$$

With network analyzers, the frequency f_L is easily determined by using «marker search». functions.

e) Evaluation of R_L

The computation of the load resonance resistance R_L from the real part of Z_c at the load resonance frequency f_L by the formula:

$$R_L = R_c(\omega_L) = \mathrm{Re}\left(Z_c(\omega_L)\right) \quad (11)$$

may result in excessive inaccuracy, because – especially for low frequency crystals – the angle of the voltage V_c is close to 90°.

Only for $\frac{X_{CL}}{R_L} < 10$ this method yields reasonable results.

In all other cases, the R_L should be computed from the equation given in IEC 60122-1:

$$R_L = R_1 \left(1 + \frac{C_0}{C_L}\right)^2 \quad (12)$$

f) Measurement procedure for C_{Leff}

The reactance $X_c(\omega_{nom})$ is measured at the nominal frequency and the effective load capacity C_{Leff} is then calculated with the following equation:

$$C_{Leff} = \frac{1}{\omega_{nom} X_C(\omega_{nom})} \quad (13)$$

Figure 2 shows X_C as a function of frequency (solid line) in the vicinity of f_L.

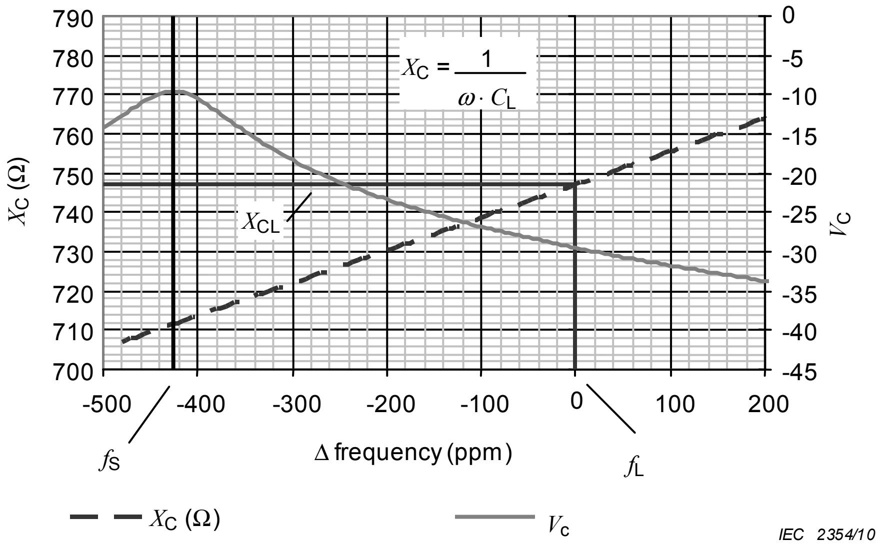

Figure 2 – X_C as a function of frequency (solid line) in the vicinity of f_L

g) Level of drive

At the resonance frequency f_r, the level of drive P of a quartz crystal unit in a π-network is given by the voltage V_{xr} across the crystal.

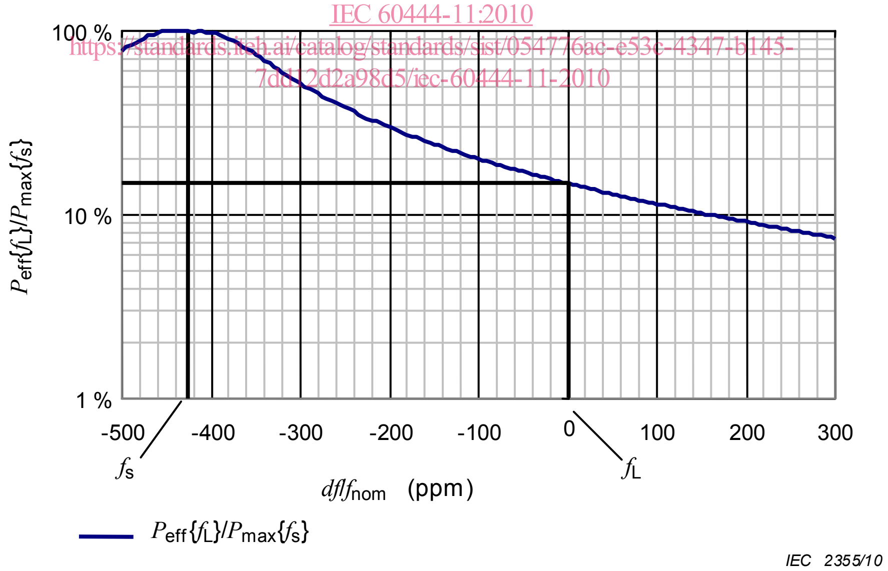

Figure 3 – Level of drive of a crystal in a π-network vs. frequency

with

$$P = \frac{V_{xr}^2}{R_r} \tag{14}$$

and

$$V_{Xr} = \frac{V_g \, R_r}{R_r + R_T} \tag{15}$$

$$V_g = \sqrt{P R_r}\,\frac{R_r + R_T}{R_r} \tag{16}$$

At load resonance frequency f_L, the impedance Z_L of a quartz crystal unit is given by the load resonance resistance R_L and the modulus of the reactance of the load capacitor X_L:

$$|Z_L| = \sqrt{R_L^2 + X_L^2} \tag{17}$$

and therefore the drive level is

$$P = \frac{V_{xr}^2}{Z_L}$$

$$V_{gL} = \sqrt{P \cdot R_1} \cdot \sqrt{\frac{X_{CL}^2\left(1 + X_{CL}^2 + (R_L + R_T)^2\right)^2 + R_L^2\left((R_L + R_T)^2 - 1\right)}{R_L^2 + X_{CL}^2}} \tag{18}$$

In order to get the same level of drive at the load frequency f_L as at the series resonance frequency f_s , it is necessary to increase the output power of the generator by the ratio:

$$ABS\left[\frac{V_{gL}}{V_{gr}}\right] = \sqrt{\frac{R_r}{R_L}}\,\frac{\sqrt{(R_L + R_T)^2 + X_{CL}^2}}{R_r + R_T} \tag{19}$$

NOTE If the required power cannot be reached by the generator, a second measurement at resonance frequency f_r is performed with a by factor $ABS\left(\frac{V_{gL}}{V_{gr}}\right)$ lower level and the difference of both series resonance measurements is added to the load resonance frequency f_L.

4.3 Evaluation of errors

a) General comments

According to the application of quartz crystal units in oscillators, the measurement accuracy of the load resonance frequency f_L is presented here. The accuracy of the load capacitance C_{Leff} can be calculated then from the frequency accuracy and the equivalent parameters of the crystal C_0 and C_1 from the relation

$$\frac{f_L - f_s}{f_s} = \frac{C_1}{2(C_0 + C_L)} \tag{20}$$

b) Accuracy of measurement

The accuracy of the measurement is given by the calibration resistors and the measured voltages. In order to achieve an accuracy of the voltages of 1 %, it may be necessary to calibrate the test equipment in the whole power range.