IEC 62884-3

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INTERNATIONAL
STANDARD

Measurement techniques of piezoelectric, dielectric and electrostatic oscillators –
Part 3: Frequency aging test methods

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INTERNATIONAL
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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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MEASUREMENT TECHNIQUES OF PIEZOELECTRIC, DIELECTRIC AND ELECTROSTATIC OSCILLATORS –

Part 3: Frequency aging test methods

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International Standard IEC 62884-3 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 International Standard is based on the following documents:

CDV	Report on voting
49/1248/CDV	49/1272/RVC

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

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

A list of all parts in the IEC 62884 series, published under the general title *Measurement techniques of piezoelectric, dielectric and electrostatic oscillators*, can be found on the IEC website.

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

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- withdrawn,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

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

INTRODUCTION

This document was developed from the works related to IEC 60679-1:2007 (third edition), the measurement techniques of which were restructured into different parts under a new project reference. This document describes the measurement method for frequency aging only.

MEASUREMENT TECHNIQUES OF PIEZOELECTRIC, DIELECTRIC AND ELECTROSTATIC OSCILLATORS –

Part 3: Frequency aging test methods

1 Scope

This part of IEC 62884 describes the methods for the measurement and evaluation of frequency aging tests of piezoelectric, dielectric and electrostatic oscillators, including Dielectric Resonator Oscillators (DRO) and oscillators using FBAR (hereinafter referred to as "Oscillator"). The purpose of those tests is to provide statistical data supporting aging predictions.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 – Part 561: Piezoelectric, dielectric and electrostatic devices and associated materials for frequency control, selection and detection*

IEC 60469, *Transitions, pulses and related waveforms – Terms, definitions and algorithms*

IEC 60617, *Graphical symbols for diagrams*, available at http://std.iec.ch/iec60617

IEC 60679-1, *Piezoelectric, dielectric and electrostatic oscillators of assessed qualify – Part 1: Generic specification*

IEC 62884-1:2017, *Measurement techniques of piezoelectric, dielectric and electrostatic oscillators – Part 1: Basic methods for the measurement*

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

3 Terms and definitions, units and symbols

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60679-1 apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

• IEC Electropedia: available at http://www.electropedia.org/

• ISO Online browsing platform: available at http://www.iso.org/obp

3.2   Units and symbols

Units, graphical symbols, letter symbols and terminology shall, wherever possible, be taken from the following standards:

- IEC 60027;
- IEC 60050-561;
- IEC 60469;
- IEC 60617;
- ISO 80000-1.

4   Frequency aging test

4.1   General

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

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

- detail specification;
- sectional specification;
- 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.

4.2   Test and measurement conditions

4.2.1   General

General test and measurement conditions refer to IEC 62884-1, and especially the output frequency measurement to 4.5.4 of IEC 62884-1:2017.

4.2.2   Active aging test (non-destructive)

Purpose: Statistical verification of aging performance.

Unless otherwise specified, the operating oscillator unit shall be maintained at the specified temperature for a continuous period as given in Annex A.

During the period of test, the control of temperature and the accuracy of frequency measurement shall be consistent with the accuracy of the maximum frequency variations specified. The oscillator unit shall remain in the chamber throughout the duration of the test and shall be continually supplied with input power, unless otherwise specified.

After insertion into the oven, the oscillator shall be allowed to equilibrate with chamber air temperature. Then the oscillator shall be energized and stabilized prior to beginning of and during the measurement acquisition cycle.

The stabilization time t_{stab} depends on the type of oscillator as shown in Table 1.

The initial frequency f_{init} of the oscillator shall be measured immediately after the stabilization period t_{stab} and thereafter at intervals as shown in Table 1.

Table 1 – Measurement parameters depending on the oscillator type

Oscillator type	Stabilization time t_{stab}*	Test intervals*	Aging temperature T_{oven} (°C)*	Aging temperature tolerance**
SPXO, VCXO	1 h	See Annex A	See Annex A	± 3 K
TCXO	48 h	See Annex A	See Annex A	± 3 K
OCXO	48 h	See Annex A	+25 °C	± 3 K
* unless otherwise specified				
** measurement tolerance < ± 0,5 K				

The measurement interval should be divided logarithmically.

If the aging test is used for qualification, at least 5 oscillators of identical or structurally similar type shall be tested.

The frequency change between the initial frequency f_{init} and all subsequent frequencies measured within the specified period shall not exceed the maximum frequency change specified. Measurements shall be carried out according to 4.5.4 of IEC 62884-1:2017.

4.2.3   Data fitting

If a projected total frequency change for a period (such as 365 days (1 year)) is specified, an extrapolation shall be used from the end of the aging measurement period using the coefficients determined from a curve fitting to the measurements.

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

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

where $\Delta f(t)$ is the frequency difference of the oscillator at 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.

For monotonic aging, all the measurements shall be used for the curve fitting. If the aging trend is not monotonic, the measurement period shall be extended to 40 days or longer after the extremum in the aging trend, and the measurements from 12 days after the extremum is reached to the end of the aging measurement period shall be fit to the above function (unless otherwise specified).

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:

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

This approach should only be used if the square root of the least square fit variance 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 percent of the total aging change allowed during the test period.

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

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

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

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

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

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

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

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

If polynomial fitting was used inflection of the aging response may occur over time.

If aging after N_{op} days operation is specified (for OCXO usually T_{op} = 30 days), in the above formulae T_a should be replaced by ($T_a + N_{op}$).

4.2.4 Accelerated aging (non-active)

For special applications, it is possible to accelerate the aging of SPXO, VCXO and TCXO at higher temperatures, e.g. at +85 °C, +105 °C or +125 °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 used crystal unit and on the production process. It can be determined experimentally as described in Annex A, or taken from experience with structurally similar oscillators, or can be mutually agreed between manufacturer and user.

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

Applying Arrhenius' law, the acceleration factor TAF is related to the activation energy E_a by the following equation:

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

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

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.

For example, 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 2 below shows the time acceleration factor TAF and the number of days N_d for to equivalent of 365 days at +25 °C.

<div align="center">

Table 2 – 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

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

4.2.5   Extended aging

Purpose: Evaluation of reliability and long-term performance.

This test shall be carried out in accordance with 4.2.1, except that the continuous periods shall be 1 000 h, 2 000 h or 8 000 h, as prescribed in the detail specification. Measurements shall be carried out according to 4.5.4 of IEC 62884-1:2017, except that they should be made at (25 ± 2) °C or any other specified temperature. The measurement intervals can be extended to 2 weeks or longer. For the intermediate and the final measurements, the oscillator can be removed from the oven, and stored at room temperature for 1 hour. Thermal shocks should be avoided. The frequency measurement shall be performed at a reference temperature of (25 ± 2) °C.

This test shall be used for information purposes only.

Annex A
(normative)

Experimental verification of the frequency aging performance

Assumption:

Frequency aging can generally be expressed as

$$\frac{\Delta f}{f}(t,T) = g(t) \cdot h(T)$$

where

$\dfrac{\Delta f}{f}$ is the relative frequency change due to aging;

t is the time, usually in days;

T is the temperature in K;

$g(t)$ describes the time dependence of the frequency aging;

$h(T)$ describes the temperature dependence of the frequency aging,

and with:

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

or

$$g(t) = c_0 + c_1 \cdot t + c_2 \cdot t^{\frac{1}{2}} + c_3 \cdot t^{\frac{1}{3}} \qquad \text{(polynomial fit)}$$

and

$$h(T) = a_1 \cdot \exp\left(\frac{E_a \cdot \left(\dfrac{1}{T_{ref}} - \dfrac{1}{T}\right)}{k}\right)$$

with k = Boltzmann's constant ($k \approx 8.617 \cdot 10^{-5}$ eV/K), and the temperatures given in k, where T_{ref} = 298 K.

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 are determined by the procedure indicated in Table A.1:

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

Procedure	SPXO, VCXO, TCXO	OCXO, high-stability TCXO, and high-reliability oscillators
Aging test procedure	passive	active
Reflow Solder test	2x ROHS-profile (IEC 61760-1)*	2x RoHS -profile (IEC 61760-1)* if applicable
Initial pre-aging (time and temperature)	48 hours at > 20K above upper operating temperature, but T < upper storage temperature	OCXO: 48 hours active aging. Others: 48 hours at > 20K above upper operating temperature, but T ≤ upper operable temperature
Sample size per lot (from one production lot)	≥ 30* depending on needed confidence level	OCXO: ≥ 5* Others: 10* depending on needed confidence level
Number of aging temperatures	3	OCXO: 1 Others: 3
Recommended aging temperatures	+85 °C, +105 °C, +125 °C, +150 °C* depending on application, T < specified upper storage temperature	OCXO: +25 °C Others: +85 °C, +105 °C, +125 °C* depending on application, T < specified upper operating temperature
Recommend temperature for measurement	(+25 ± 1) °C, measurement > 1 hour after removal from temperature chamber. Avoid thermal shocks	OCXO: (+25±3) °C Others: (+25±1) °C, measurement > 1 hour after removal from temperature chamber. Avoid thermal shocks
Recommended aging time	500, 1 000, 2 000* hours depending on needed confidence level	OCXO: 30 days Others: 500, 1 000, 2 000* hours 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)	OCXO: After 48 h stabilization: minimum 4 times per week (7 days) at intervals of at least 20 hours Others: After 48 h stabilization: 24 h, 72 h, 250 h, 500 h, 750 h, 1 000 h, (1 500 h, 2 000h)
Algorithms to determine $g(t)$ and $h(T)$	Least square fitting** $g(t)$: 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 $t ≥ 500h$	Least square fitting** $g(t)$: 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

*   Unless otherwise specified

** 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 to the end of the aging measurement period shall be fit to the above functions for $g(t)$.