IEC 62884-4

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INTERNATIONAL STANDARD

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colour inside

Measurement techniques of piezoelectric, dielectric and electrostatic oscillators – Part 4: Short-term frequency stability test methods

Techniques de mesure des oscillateurs piézoélectriques, diélectriques et électrostatiques – Partie 4: Méthodes d'essai de stabilité à court-terme de la fréquence

IEC 62884-4:2019-05(en-fr)

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Part 4: Short-term frequency stability test methods

FOREWORD

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The text of this International Standard is based on the following documents:

CDV	Report on voting
49/1277/CDV	49/1292/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

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MEASUREMENT TECHNIQUES OF PIEZOELECTRIC, DIELECTRIC AND ELECTROSTATIC OSCILLATORS –

Part 4: Short-term frequency stability test methods

1 Scope

This part of IEC 62884 describes the methods for the measurement and evaluation of the short-term frequency stability tests of piezoelectric, dielectric and electrostatic oscillators. Its purpose is to unify the test and evaluation methods for short-term frequency stability.

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.* Available at www.electropedia.org

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, *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 Short-term frequency stability

The random fluctuations of the frequency of an oscillator over short periods of time [IEV 561-03-16]. In general, the output voltage of the oscillator is expressed by the following equation:

$$v(t) = \left[U_0 + \varepsilon(t)\right] \cdot \cos\phi(t) = \left[U_0 + \varepsilon(t)\right] \cdot \cos\left[2\pi \cdot F_0 \cdot t + \varphi(t)\right]$$

where

U_0 is the nominal output voltage;

$\varepsilon(t)$ is the amplitude noise;

F_0 is the average oscillator frequency;

$\varphi(t)$ is the phase fluctuation.

For the measurement of the short-term frequency stability, the amplitude noise $\varepsilon(t)$ is supressed by a limiter, thus the output voltage of oscillator simplifies as follows:

$$v(t) = U_0 \cdot \cos\phi(t) = U_0 \cdot \cos\left[2\pi \cdot F_0 \cdot t + \varphi(t)\right] = Re(U_0 \cdot e^{j\phi(t)})$$

where

$Re(X)$ means the real part of the complex number X.

This can be presented in a phasor diagram (see Figure 1 below).

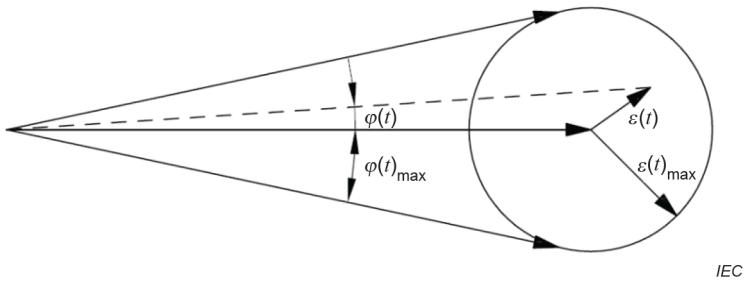


Figure 1 – Phasor diagram of carrier and non-correlated amplitude and phase noise

For the measurement of short-term stability, the amplitude noise $\varepsilon(t)$ is suppressed by a limiter, thus the phasor diagram simplifies as shown in Figure 2.

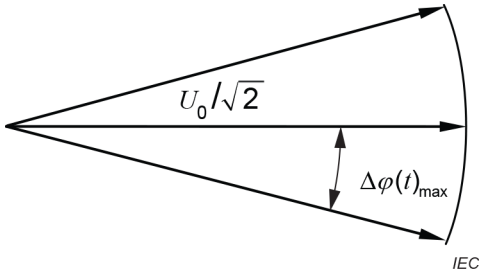


Figure 2 – Phasor diagram after suppression of amplitude noise

The instantaneous frequency $f(t)$ is the time derivative of the phase function.

$$\phi(t) = 2\pi \cdot F_0 \cdot t + \varphi(t)$$

i.e.

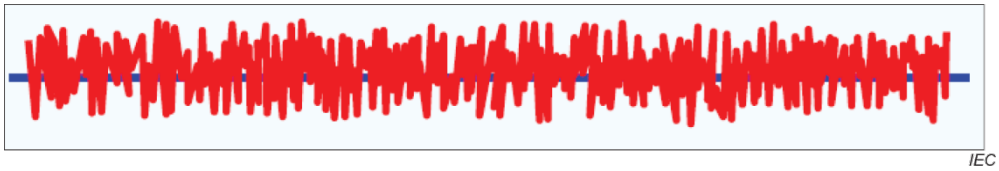
$$f(t) = \frac{1}{2\pi}\frac{d\phi(t)}{dt} = F_0 \cdot \left(1 + \frac{1}{2\pi F_0} \cdot \frac{d\varphi(t)}{dt}\right) = F_0 \cdot (1 + y(t))$$

$$y(t) = \frac{1}{2\pi F_0}\frac{d\varphi(t)}{dt}$$

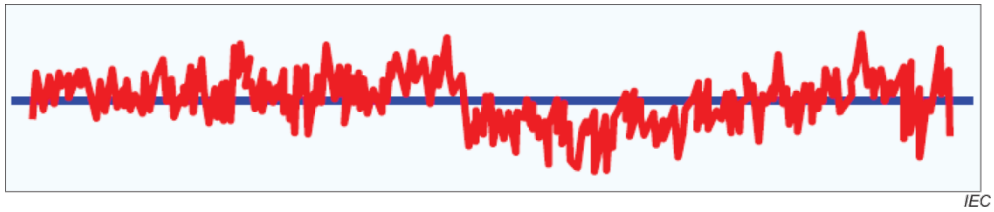
where

$y(t)$ is the fractional frequency deviation to the average oscillator frequency F_0.

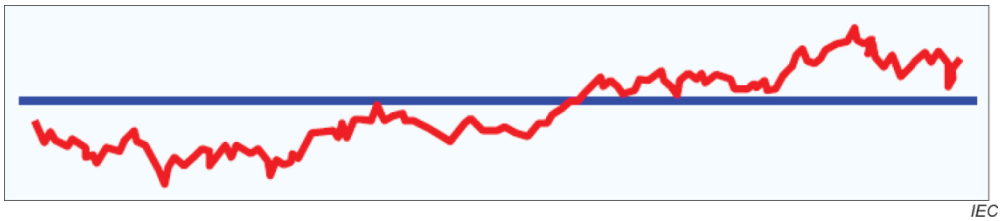
The phase and frequency fluctuations can be distinguished according to their appearances over time as shown in Figure 3.



a) White frequency noise (α = 0)



b) Flicker frequency noise (α = −1)



c) Random walk frequency noise (α = −2)

d) Flicker walk frequency noise (wander) (α = −3)

Figure 3 – Various noise mechanisms over time

with α being the exponent of the fractional frequency fluctuation, i.e. the slope in the double-logarithmic phase noise response

$$S_y \sim f^{\alpha}$$

Usually, short-term stability is considered over time intervals of > 0,001 to 1 000 seconds.

$$y_k = \frac{1}{\tau}\int_{t_k}^{t_k+\tau} y(t)dt = \frac{1}{2\pi F_0 \tau}\cdot\left[\varphi(t_k+\tau)-\varphi(t_k)\right] = \frac{1}{\tau}\cdot\left[x(t_k+\tau)-x(t_k)\right]$$

$$y_k = \frac{\varphi(t_k)}{2\pi F_0}$$

$x(t)$ is the phase-time fluctuation, that is, the random phase fluctuation converted into time and measured in seconds.

The relation of $x(t)$ and $y(t)$ is represented as follows:

$$y(t) = \frac{d(x(t))}{dt}$$

The classical variance σ^2 and the standard deviation σ at M samples of y_i is represented as

$$\sigma^2 = \frac{1}{M-1}\sum_{i=1}^{M}(y_i - \bar{y})^2$$

Using the mean value $\bar{y}$.

$$\bar{y} = \frac{1}{M}\sum_{i=1}^{M} y_i$$

The $\bar{y}$ from small sampling of y_i is not suitable for the analysis of frequency stability, because of lack of convergence for some common types of clock noise. Their value depends on the number of samples taken.

5 Allan variance (AVAR)

The Allan variance $\sigma_y(\tau)$ is the most common measure for time domain stability.

It is an unbiased estimate of the preferred definition in the time domain of the short-term stability characteristics of the oscillator output frequency:

$$\sigma_y^2(\tau) = \frac{1}{M-1}\sum_{k=1}^{M-1}\frac{(y_{k+1} - y_k)^2}{2}$$

where

y_k are the average fractional frequency fluctuations obtained sequentially, with no systematic dead time between measurements;

τ is the sample time over which measurement is averaged;

M is the number of measurements.

The confidence on the estimate improves as M increases.

AVAR can be alternatively derived from phase measurement samples x_i taken in measurement intervals τ:

$$\sigma_y^2(\tau, M) = \frac{1}{2\cdot(M-2)\cdot\tau^2}\sum_{i=1}^{M-2}(x_{i+2} - 2\cdot x_{i+1} + x_i)^2$$

6 Allan deviation (ADEV), RMS fractional frequency fluctuations

In detail specifications, instead of the variance AVAR, usually its square root σ is used, which is called Allan deviation (ADEV). It has the same order of magnitude as the relative frequency fluctuations that are to be characterized.

It is a measure in the time domain of the short-term frequency stability of an oscillator, based on the statistical properties of a number of frequency measurements, each representing an average of the frequency over the specified sampling interval τ.

$$\sigma_y(\tau, M) = \sqrt{\frac{1}{2 \cdot (M-1)} \sum_{i=1}^{M-1} (y_{i+1} - y_i)^2}$$

ADEV can be alternatively derived from phase measurement samples x_i taken in measurement intervals τ.

$$\sigma_y(\tau, M) = \sqrt{\frac{1}{2 \cdot (M-2) \cdot \tau^2} \sum_{i=1}^{M-2} (x_{i+2} - 2 \cdot x_{i+1} + x_i)^2}$$

NOTE In IEC 60679-1:1997, 2.2.24, ADEV was called RMS fractional frequency fluctuation.

M shall be sufficiently large in order to achieve a satisfactory confidence interval. A simple approximation for the confidence interval u for ±1 σ error (with no consideration of the noise type) is

$$u = \pm \frac{\sigma_y(\tau)}{\sqrt{M}}$$

The confidence interval u is usually depicted as error bars in the ADEV chart. If not, the number of samples M should be indicated in the test report.

ADEV is either defined for certain discrete values of τ or it is displayed graphically as a function of the sample interval τ (Sigma-Tau diagram) with the confidence interval for each value shown as error-bars. This presentation allows for the identification of the various underlying noise types (see Figure 4).

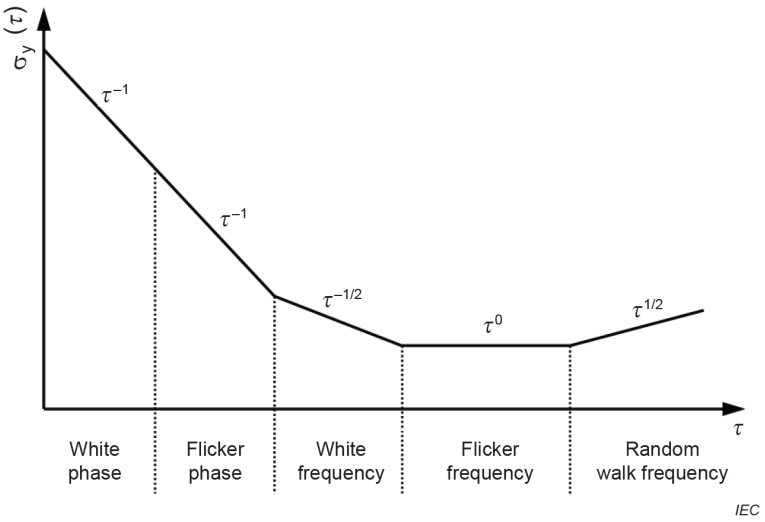


Figure 4 – Chart of Allan deviation (ADEV) as a function of τ

7 Overlapping Allan variance (OAVAR) and overlapping Allan deviation (OADEV)

A form of the normal Allan variance $\sigma_y^2(\tau)$, that makes maximum use of a data set by forming all possible fully overlapping samples at each averaging time τ. It can be estimated from a set of M frequency measurements for averaging time $\tau = m \cdot t_0$, where m is the averaging factor and t_0 is the basic measurement interval.

$$\sigma_y^2(\tau) = \frac{1}{2m^2 \cdot (M - 2m + 1)} \sum_{j=1}^{M-2m+1} \left[\sum_{i=j}^{j+m-1} (y_{i+m} - y_i) \right]^2$$

Derived from phase data:

$$\sigma_y^2(\tau) = \frac{1}{2 \cdot (M - 2m) \cdot \tau^2} \sum_{i=1}^{M-2m} (x_{i+2m} - 2 \cdot x_{i+m} + x_i)^2$$

Usually the square root $\sigma_y(\tau)$ of these expressions is used, which is called overlapping Allan deviation (OADEV).

The Overlapping Allan Deviation OADEV is the most widely used general purpose measure of frequency short-term stability (even if it is often erroneously named Allan deviation).

The confidence interval of OADEV is better than that of a normal ADEV.

8 Modified Allan variance (MVAR) and modified Allan deviation (MDEV)

The modified Allan variance (MVAR) and the modified Allan deviation (MDEV) allow to distiguish between flicker PM noise, which appears with a slope of (τ^{-1}) and white PM, which