Oscillator Short Term Stability and Allan Deviation

Introducing oscillator short term stability specifications.

Why is short term stability important?

It is important to understand the overall frequency stability of a Quartz (or other type) oscillator if the right oscillator is going to be selected for a specific application. Often specific questions referring to an oscillator's short term stability can be asked, mainly for one of two reasons:

Firstly short term stabilities tend to point to effects and influences on oscillator performance that are hard to monitor and predict. Long term effects like an overall offset, aging or change under a steady temperature ramp can be monitored and corrected for. Some of the changes that are much harder to spot coming (e.g. a fan in the system switches on) happen in the short term.

The second reason has to do with over what time-scales you want to be able to be sure of an oscillator's stability. For example if an oscillator is operating closed loop (e.g. it is in a phase locked loop and is 'locked' to another more stable reference) then longer term changes to the oscillator will be 'tracked out' by the loop response and will not have as much effect on the output signal as the reference will dominate. However shorter term changes to the oscillator will make it through the loop and show up at the output.

These are just two of the areas where discussions on oscillator short term stability are likely to focus To understand more about short term stability it is useful to look at frequency stability in general and to look at the different types of frequency stability that you might need to account for.

What is frequency stability?

Stability refers to how well something can be re-produced. It does not say anything about how 'right' or 'wrong' the something is, just how consistent it is. So an oscillator with a large initial frequency offset from nominal can be just as stable as an oscillator that has no initial offset – the frequency stability will be determined by how the frequency offset (if any) changes.

Frequency stability in general then points to how the frequency of an oscillator changes. Looking at an oscillator datasheet there is often a

Key Concepts

Frequency Stability:
How the frequency of an oscillator changes.

Short Term Stability:
How the frequency of an oscillator changes over short time scales, where the time scales are typically more than 0.1s and less than a day.

Allan Deviation:
Statistical measure of the frequency fluctuations of an oscillator over a given time period.

MTIE:
Maximum Time Interval Error. Worst case phase error over a given time period

TDEV:
Time Deviation. Statistical measure of the phase fluctuations of an oscillator over a given time period.

section that lists frequency stabilities (plural), showing that there are lots of ways that the frequency might change. There is the stability over time (aging), stability over temperature and stability over supply or load changes, for example. In each case the effect of other influences is kept to a minimum, so that the stated aging for example is measured within a minimal temperature range.

In all of these examples the end result is a frequency change over time. The distinction between long term stability, short term stability and noise comes from the time scales over which these changes occur.

What is short term stability?

Frequency stability can be discussed in terms of the time scales involved: long term stability is usually measured over periods of a day or more; short term stability is usually measured over periods of perhaps 0.1 second to one day; and phase noise deals with very short periods and the influence looks more like a modulation of a signals phase than an overall change of the frequency.

How these distinctions are made and the terminology used can vary – for example in network communications phase noise is broken down into a jitter component and a wander component. Jitter is taken to mean noise at frequencies above 10Hz from the carrier (or periods or 0.1 seconds or less) and wander is taken to mean noise at frequencies below 10Hz from the carrier (or periods of 0.1 seconds or greater). This second set of terminology makes sense and lines up with the first but can also be confusing, since 'Wander' in the network terminology now covers both short term and long term stabilities.

In general though short term stability is taken to mean changes in frequency that happen over a time scale of 0.1s (10Hz) to a day (~0.01mHz)

How do we specify and measure short term stability?

The short term stability of an oscillator is often specified and measured using the Allan Deviation (ADEV), a measurement that describes the frequency fluctuations of the device over a given time interval by looking at the statistical distribution of those fluctuations (analogous to the way we use standard deviation but calculated in a different manner – see below). Allan Deviation depends on the time period used between the samples used in the calculation: ADEV is a function of tau, along with the distribution of the samples being measured, and is often displayed as a graph rather than a single number. A low Allan Deviation is a characteristic of a clock with good stability over the measured period.

Oscillators like an OCXO can be said to have good stability over shorter time scales whereas a Rubidium based oscillator will have poor stability over short time scales but superior stability over longer time scales. These differences will be reflected in each oscillators ADEV performance. ADEV is the root of the Allan Variance (AVAR) and you will often hear the terms used interchangeably – it is important to remember though that ADEV is the square root of AVAR.

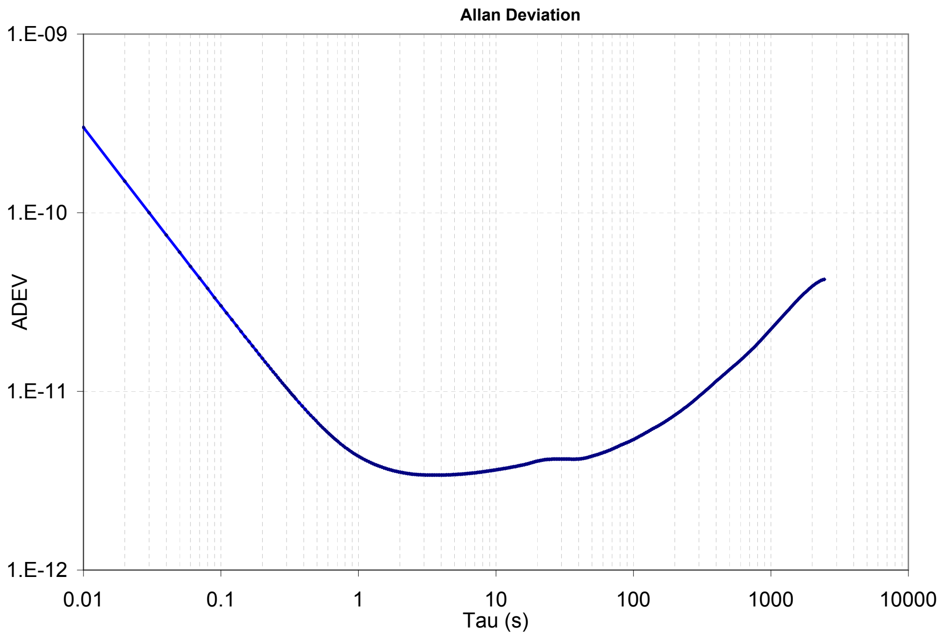
The equation for the Allan deviation is:

$$\sigma_y(\tau) = \frac{1}{f_0} \cdot \sqrt{\frac{1}{2\cdot(M-1)} \cdot \sum_{i=1}^{M-1} \left(y_{i+1} - y_i\right)^2}$$

where y_i is a frequency offset measurement M is the number of measurements in the y_i series, and the data are equally spaced in segments τ seconds long.

A graph of Allan deviation for an oscillator is shown below. It shows how the stability of the oscillator improves as the averaging period 'tau' gets longer, since some noise types can be removed by averaging. At some point though, increased averaging no longer improves the results. This lowest point on the graph is called the noise floor. Beyond this point (at longer averaging periods) nonstationary processes that influence the frequency like aging or random walk take over and the ADEV increases as a function of tau.

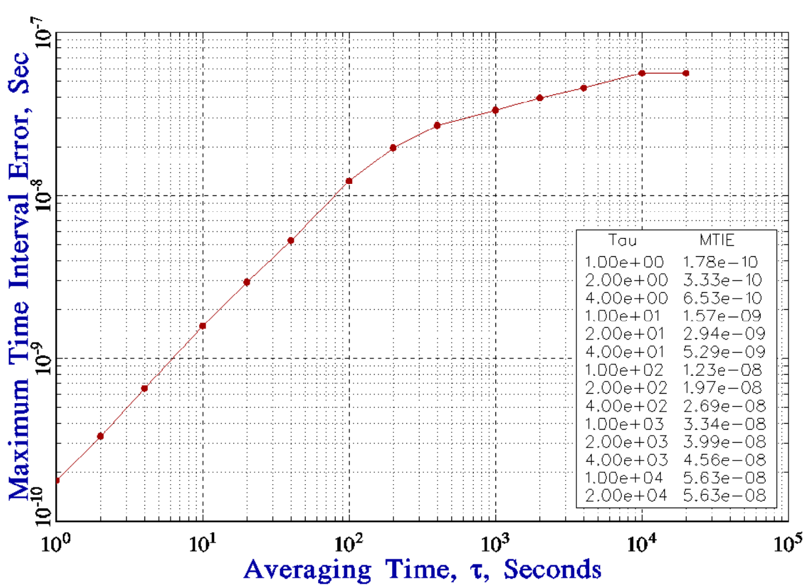
An ADEV Plot.
Allan Deviation is plotted against averaging period tau, showing how frequency fluctuations vary over different averaging periods.



Another aspect of frequency stability is its effect on the phase of the oscillator. Frequency is the rate of change of phase, so we can expect to see changes in frequency show up as changes in phase. There are two important metrics that timing system designers use that look at changes in phase that are connected to oscillator short term stability: MTIE (Maximum Time Interval Error) and TDEV (Time Deviation).

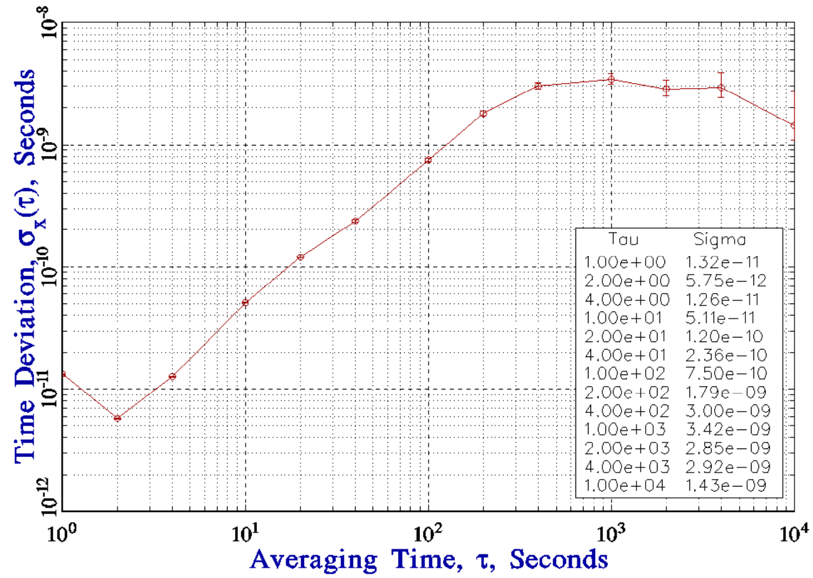
MTIE is a 'worst case' metric that looks at the peak to peak Time Interval Error (TIE) in a given observation window, so like ADEV MTIE is a function of a sample period.

An MTIE Plot
Maximum Time Interval Error is plotted against observation window tau, showing how the worst case phase error varies over window size.



TDEV is similar to ADEV in that it looks at the statistical distribution over a sample period, but TDEV is looking at the distribution of time errors instead of frequency. Like ADEV, TDEV is a function of the sample period.

A TDEV Plot.
Time Deviation is plotted against averaging period tau, showing how phase fluctuations vary over different averaging periods.



Both MTIE and TDEV are usually system level specifications. For example they might be used to characterize the performance of a PLL based system that contains an oscillator and not the oscillator alone. However the short term stability performance of the oscillator will have an influence on the overall performance as measured by MTIE and TDEV.

What influences the short term stability of an oscillator?

The short term stability of an oscillator looks like noise and is not usually predictable so quite often the performance in the short term is discussed in terms of noise. Fundamental random noise processes in the oscillator do indeed drive short term stability and can be measured using a metric like ADEV, so it is appropriate to talk about 'low noise' oscillators giving better short term stability performance (for example in a comparison between AT cut and SC cut based oscillators).

However the short term stability (and hence ADEV) can also be influenced by other non-noise unpredictable influences. Diurnal wander (frequency changes that happen on a daily basis), systematic frequency changes due to short term temperature changes (e.g. a fan blowing on the oscillator), vibration, supply line noise and unexpected events such as frequency jumps are some examples of unpredictable events that will influence an oscillator's short term stability.

For a more detailed discussion on how both the noise processes and the environmental effects can influence an oscillator see the Vectron Whitepaper *'Environmental Influences on Quartz Oscillator Short Term Stability'*, which can be obtained from Vectron at:

http://www.vectron.com/products/1588/index.htm

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For Additional Information, Please Contact

USA:
Vectron International
267 Lowell Road
Hudson, NH 03051
Tel: 1.888.328.7661
Fax: 1.888.329.8328

Europe:
Vectron International
Landstrasse, D-74924
Neckarbischofsheim, Germany
Tel: +49 (0) 7268.8010
Fax: +49 (0) 7268.801281

Asia:
Vectron International
1589 Century Avenue, the 19th Floor
Chamtime International Financial Center
Shanghai, China
Tel: +86 21 6081.2888
Fax: +86 21 6163.3598