Temperature Stabilised Crystal Oscillator (OCXO)

If oscillators are to meet with requirements such as high frequency stability, low phase noise and low aging per day/year independently from exterior influences only Oven Controlled Crystal Oscillators (OCXO) are used as they are developed and manufactured at Quintenz Hybridtechnik. In the following the most important features and properties of quartz crystals and OCXOs will be explained.

1. Quartz Crystals

In quartz oscillators a quartz crystal is used as a reference component. Quartz is a crystal that, because of its piezoelectric property, can be driven electrically and swing mechanically. Such high quality (Q-factor $>10^6$) can't be achieved with an electric resonance circuit. Because of this quartz oscillators are especially suitable to create very exact and constant frequencies. The properties and the price of the quartz depend on a great extend on the type of the quartz and (in the best of the cases) the client and the manufacturer of the oscillators decide together which the most adequate one is. The most important properties of a quartz are its:

- Swing mode
- Cut of the quartz crystal
- Equivalent circuit
- Fundamental mode, overtone

By **swing mode** the type of mechanical swing is meant, which is chosen accordingly to the frequency. In the frequency coverage of 1 to 150 MHz thickness shear modes are used.
The quartz is cut from a one-crystalline bar of silicon dioxide (SiO_2) and fixed between two electrodes. The **cut of the quartz** indicates which angle with reference to the crystallographic axis in the quartz crystal is to be chosen. Just what the characteristics of the quartz are depends on the angle of cut. Especially the electric properties of the quartz and the dependence of the frequency from the temperature are influenced by the angel of cut. For oscillators that are to work nearly independently from the temperature AT- or SC-cut crystals are used.
Because of electric-mechanical analogy at its terminals the mechanical resonator can be figured in a simplified diagram (figure 1). The **equivalent components** R, L_1, C_1 and C_0 are to be specified by the manufacturer of the oscillator. This equivalent circuit results in the different resonance frequencies that the quartz can reach.
Quartz can swing at different resonance frequencies. The lowest frequency is called **fundamental mode**, the higher ones **overtone**. The frequency of an overtone is always an uneven multiplication of the fundamental mode. Unwanted frequencies near the oscillator set frequency are to be reduced by a specific circuit.

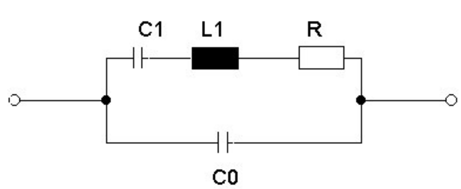


Figure 1: simplified diagram of the equivalent circuit

2. OCXO

The resonance frequency of quartz highly depends on the temperature (figure 2.1). In an OCXO the quartz and the whole circuit, existing of an oven circuitry and an oscillator circuitry, work in an oven at constant temperature. The temperature of the oven is chosen so that it is equal with the inflection point of the range of temperature of the quartz because in theory Δf/f is zero. By this only very little frequency variation is caused by the temperature variation, which can't be avoided even with large-scale oven circuitry.

2.1 Frequency-Temperature Stability

The values of an OCXO are up to $df/f = 1*10^{-8}$ (AT-Cut) or respectively $df/f = 0.5*10^{-8}$ (SC-Cut) at ambient operating temperature (-20…+70°C). In figure 2 the frequency transient of a SC-cut high-performance OCXO at operating temperature range is shown.

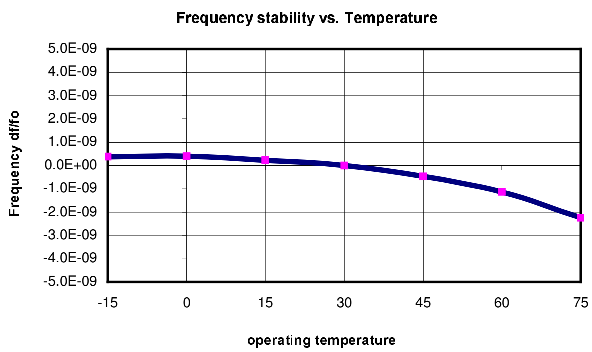


Figure 2: Temperature-Frequency Stability

2.2 Short Term Stability

By short term stability the frequency variation in a period of a split second or some seconds is meant. The short term stability can usually be given in time or frequency domain.

Time domain short term stability is computed using the Allan variance. For this the frequency in a time interval t_M between 0.1s and some seconds is measured. The difference $\Delta f\ (t_M)$ of the two values is divided by the reference frequency f_0. With it the relative frequency variation $y\ (t_M)$ can be calculated.

$$y(t_M) = \frac{\Delta f(t_M)}{f_0}$$

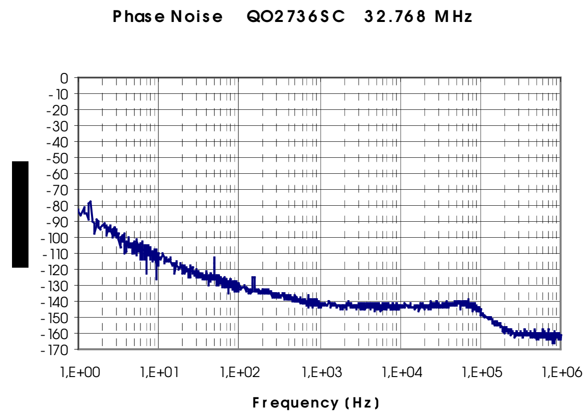
These measures have to be performed various times and the Allan variance σ^2_y can be determined using the following formula:

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

t_M: time of measure
M: number of measures
y_K: frequency variation

Frequency domain short term stability is the spectral composition of the signals of the oscillator. That is why the side band noise caused by the frequency and phase modulations have to be evaluated. As the spectrum is symmetric to its carrier one side can be neglected. The **s**ingle **s**ide **b**and noise L (f), specified in dBc/Hz, (in relation to the carrier) is given. The noise of oscillators with high phase noise can be measured with spectrum analysers. The phase noise in quartz oscillators is so low that they have to be measured in a special phase noise measurement system. In figure 3 a possible transient of phase noise of a high-performance SC-cut OCXO operating at 32.768 MHz is shown.

Figure 3: phase noise



Generally the quartz causes the noise near the carrier whereas the circuit causes the noise far away from the carrier. The better the quality Q of the crystal quartz and its application to the circuit and the lower the noise of the active and passive components, the lower is the phase noise.

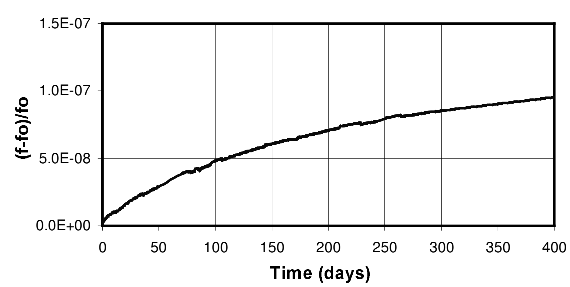
2.3 Aging (long term stability)

By short term stability the frequency variation in a period of some days or some years is meant. The main cause for this is the dependence of the crystal parameter from the time. For this there are three causes:

1. Aging of the material (i.e. variation of the properties and the structure of the quartz crystal)
2. Aging of the construction (i.e. the fixing => mechanic forces on the quartz)
3. Aging due to manufacturing (i.e. deformation of the atomic lattice, contamination of the electrode)

In the first days of an oscillator there are sharp frequency variations (figure 2.4) so high-performance oscillators are aged before being supplied. To achieve very good aging rates low-frequency overtone AT- and SC-cut crystals (i.e. 10 MHz) are used and they are operated at a minimum load. High-performance oscillators have a long term stability of $df/f <= \pm 0.5 * 10^{-9}$ /day or respectively $df/f <= 50*10^{-9}$ /year.

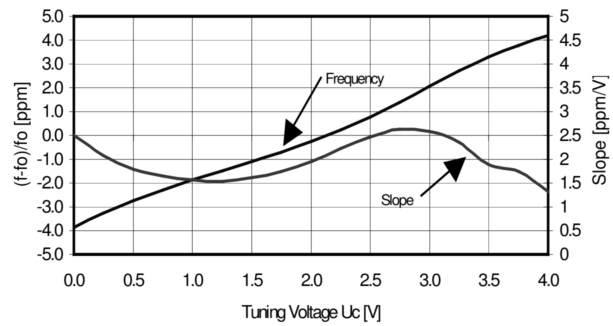
Figure 4: long term stability



2.4 Frequency Adjustment

Applying an external voltage the frequency of an oscillator can be varied (pulled). The tuning voltage is applied to a capacity diode which is part of the resonance circuit. The variation of the capacity of the diode changes the resonance frequency. The tuning range of a frequency indicates the possible amount of frequency change of the oscillator.
The maximum deviation of the modulation curve from the ideal curve is called linearity and is usually specified in %.

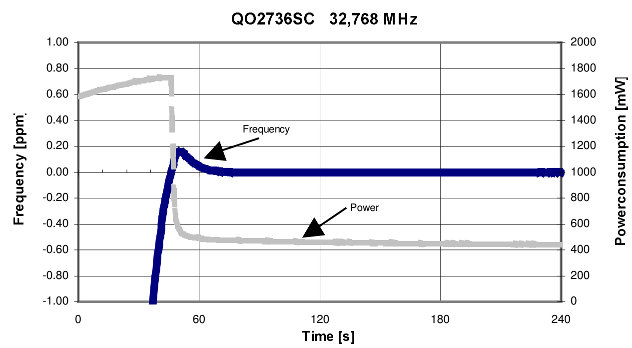
Figure 5: frequency tuning curve



2.5 Power Consumption

Choosing the most suitable circuit, using the appropriate materials, small enclosures and a good isolation to the exterior, the power consumption at 25°C is less than 0.5 Watt (if the oscillator is warmed up) and the warm-up time is only 60s. In figure 6 the typical warm-up transient at 25°C for a SC-OCXO is shown.

Figure 6: warm-up transient



3. Specification Guideline

These characteristics have to be shown in the specification guideline of the OCXO:

- Size of the enclosures
- Weight
- Terminals

Electrical considerations:

- Input voltage
- Power consumption (during the warm-up period/ at 25°C)
- Times of stabilization

- Output characteristics
- Nominal frequency
- Frequency stability

  - At operating temperature
  - At input voltage variation
  - At variation of load
  - Short term stability
  - Long term stability

Frequency adjustment properties:

  - Tuning range
  - Tuning voltage
  - Linearity

To obtain optimal properties for the application and possibly low cost the definition of the specification characteristics is to be made by the client and the manufacturer together.