rakon

High Stability Double Oven NCO

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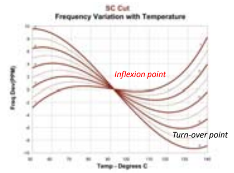
Applications demanding accurate time are requiring stringent error limits from time to time. Packet based time and frequency transport is becoming ubiquitous as well as the need for highly accurate and stable references. GNSS based timing sources combined with embedded atomic clocks are used to meet high performance requirements over temperature variations and over time. Cost and reliability remain the main limiting factor for common adoption of such solutions.

New generation OCXO oscillators can now address such thermal performance, and recent research on quartz crystal behavior has opened up significant benefits regarding ageing performance, which relates to stability over time.

OCXO Fundamentals:

Oven controlled oscillators are based on a simple principle to reach high stability. As crystal stability mainly depends on temperature at the first order, the oven makes it operate at either the turn-over point or the inflexion point.

The lower the temperature of the crystal, the higher the stability ...



crystals are mainly dependent on 2 parameters:

temperature:

$$\frac{\Delta f}{f} = \alpha(T-T_0) + \beta(T-T_0)^2 + \gamma(T-T_0)^3$$

time:

$$\frac{\Delta f}{f} = A.\ln(B.t + C)$$

One can see OCXOs as a sub system ensuring a very tightly controlled temperature (oven). However beside the first order approach, surrounding functions are contributing to frequency instabilities.

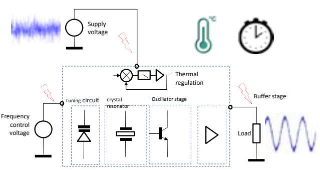
Those instabilities are limiting time keeping ability.

Limiting factors:

Beside the First order contributions (temperature and time) other factors are limiting stability. For instance, ripple on the power supply voltage are translating to phase noise spectrum whereas low variation may modulate power regulation.

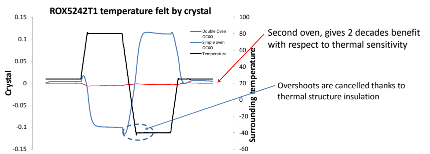
Electrical Frequency Control is a major contributor on frequency output as it does impact output frequency directly. Even though the absolute tuning slope remains low (in the ppm/V range) this becomes more significant when global frequency stability is tight.

Last, load impedance does act on frequency in a second order of magnitude, leading to some limitations as well.



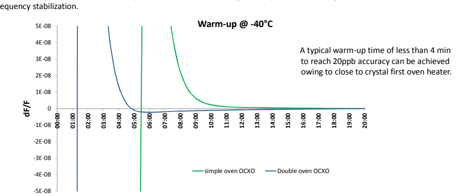
The need for a highly thermal insulated structure

Double oven OCXOs are providing much better capabilities regarding accurate regulation, enhancing equivalent thermal insulation.



Beyond absolute thermal performance regarding temperature felt by crystal, one can see benefits regarding **transient response** with steep thermal gradient. Overshoot are simply suppressed.

Another weakness of high stability OCXOs made with a simple oven is the **warm-up time**, usually limited by structure inertia. Adding a heater close to the crystal makes warm-up time significantly shorter, resulting in more efficient frequency stabilization.



The need for digital compensation:

Even though outstanding thermal performance, down to 0.001°C, can be achieved through double oven structure, only the thermal and thermo mechanical sensitivity are enhanced.

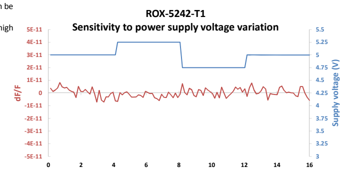
However, some of the frequency stability limitation contributors cannot be further reduced.

Digital functions have been embedded in new generation NCOs, so as to post-compensate unwanted effects.

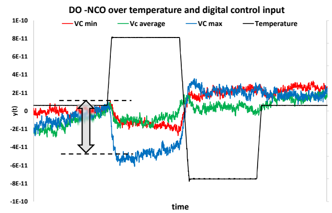
✓ Supply voltage effect

Voltage variation contribution can be minimized using internal compensation based on internal high stability voltage reference

Voltage supply variation are limited to +/- 10ppT

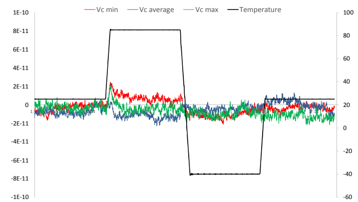


✓ Temperature and tilt effect



Rotation of temperature response with respect to frequency control input voltage

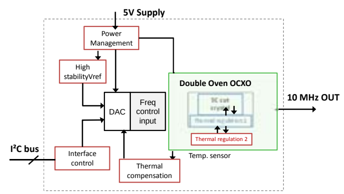
This phenomenon, due to temperature/voltage biasing effect, is called tilt



This unwanted effect results in the frequency stability and absolute frequency voltage control inputs. Absolute voltage control driving the OCXO input results in a different temperature response. This rotation effect can be further compensated.

Each voltage control needs a correction over temperature span, so the overall drift can be contained in some restricted range.

Block diagram approach:

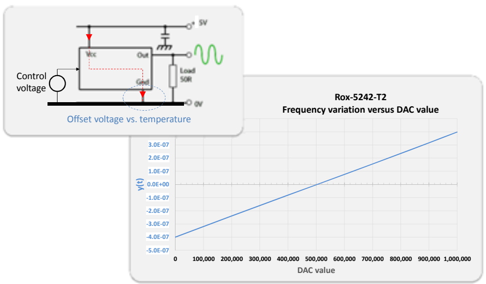


NCOs are **digitally controlled**. It makes them more versatile and easy to drive.

Besides cost aspects (external expensive DAC are no longer needed) this can be considered as a remote system with embedded compensation not sensitive to any external change.

For instance, at cold temperature, high power consumption leads to high current consumption translating to low voltage offset on the power line.

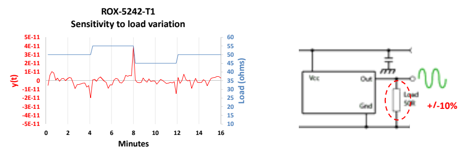
Although insignificant at first glance, this tiny offset may lead to several tens of parts per trillions, exceeding the total stability budget.



Additional instabilities factor:

OCXOs are sensitive to output load variation as output buffer isolation is finite, then as the load is changing. Even in a limited range, this does affect frequency stability.

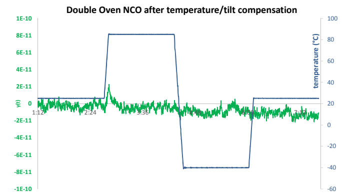
NCOs are made of high isolation output buffers reducing their load sensitivity.



Overall new generation NCO performances:

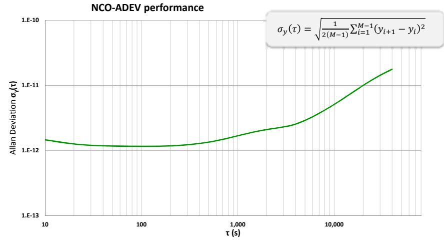
Outstanding performance is now achieved with NCOs, in a 52x41mm package size.

NCOs can meet **10ppT per 10°C** range, worst case less than 100ppT total over -40°C to +85°C



Total budget of 50ppT over extended temperature range

A pull-in range of +-400ppb with **20bits** input control resolution, maintains Allan deviation integrity (typically in the 10^{-12} range over 10-1000s integration time)

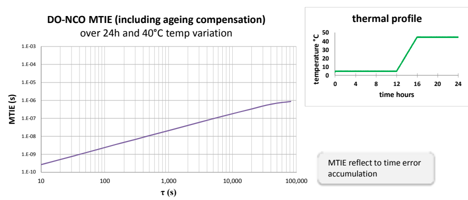


$$\sigma_y(\tau) = \sqrt{\frac{1}{2(M-1)}\sum_{i=1}^{M-1}(y_{i+1}-y_i)^2}$$

Constant improvements in crystal processes have lead to significant benefits regarding ageing performance as well as **ageing predictability.** In particular, ageing linearity becomes a key factor for accurate extrapolations and further compensation.

This opens up opportunities for **time keeping** applications even over severe thermal conditions.

Even when the asymmetrical temperature profile is applied (leading to phase accumulation) the temperature contribution remains really low so it makes it easy to separate ageing and thermal contribution. Ageing can be compensated thanks to digital input control.



MTIE reflect to time error accumulation

Time holdover of NCO can be limited to **1.5µs** over a time period beyond 24h including monotonic temperature variation.

100ns stability can be observed over a few hours.

Double Oven NCOs are now well positioned to fulfill future high demanding TDD applications as well as packet based network applications