Boosting global OBN performances with predictive software adapted to precision clocks based on low-power OCXOs

Cyril Boissy[1*] presents the latest technological advances and results in precision clocks based on ultra-low power ovenized oscillators (OCXO), made with lower drift (SC-cut) and higher drift (AT-cut) resonators.

Introduction

The major players in underwater oil exploration now have two different technologies for the precision clocks on board their OBNs. These are chip scale atomic clocks (CSAC) and precision clocks based on ultra-low consumption OCXOs. These clocks must meet three key parameters, namely GPS synchronization accuracy (up to 1 nanosecond), the ability to maintain the precise time over several weeks to several months (1 to 5ms), and lastly the lowest possible energy consumption (less than 150 mW at 5°C). Usually, for the longest missions (>90 days), it is common to see CSACs used as reference clocks. This is where they are most relevant but their prohibitive cost and low availability on the market make them less attractive. Increasingly, users of CSACs are turning to alternative and less expensive solutions that are more available for a certain part of their OBN catalogue. These are high-precision clocks based on ovenized controlled quartz oscillators. The Covid-19 global pandemic and the fall of the oil markets and worldwide demand are causing an unprecedented crisis in our sector. However, the crisis is only accelerating a movement already started in 2018 and in acceleration since 2019. It consists in using more and more OCXOs for increasingly longer missions. This is made possible thanks to the technological progress of OCXOs, with boosted performances thanks to deep learning and predictive algorithms. This article aims to present the latest technological advances for high-precision clocks based on ovenized quartz oscillators. The conclusions of this study will help users to choose the right OCXO technology according to their targets of performance and unit cost per OBN.

An excellent synchronization is needed before dropping the OBNs

During an underwater survey, a few thousands OBNs are dropped on the seabed for an average period of one to three months. These OBNs are equipped with geophones, hydrophones, a high-precision clock and of course a digital electronic circuit to store the acquisition data. The consistency and quality of the recorded data are directly related to these three key components. For its part, the high-precision clock embedded in the OBN has several roles.

At first, it must guarantee that each OBN has the same time base before immersion, with an accuracy of a few tens of nanoseconds given by a master GPS receiver. All OBNs deployed in the same field must be synchronous with each other and on the same time for correct time stamping of acquisition data. Once underwater, it is no longer possible to synchronize the OBN fleet with the GPS signal. This initial synchronization under the GPS signal is therefore performed on board and before the dive. This synch process is very important because without it the data recorded by the entire OBN fleet would not be consistent and exploitable.

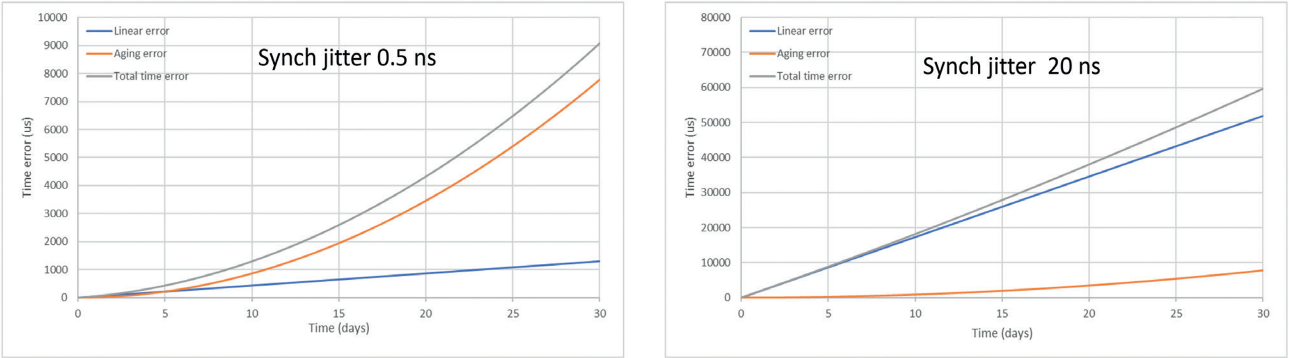

Figure 1 Impact of precise or unprecise synchronization under GPS versus ageing-related time error.

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Power consumption matters

Secondly, it is very important that the precision clock consumes as little energy as possible because the energy on board the OBN is limited as room for batteries is limited. Underwater missions can last several months. In general, it is necessary to embed a precision clock with a consumption of less than 150 mW at 5°C.

OBN clocks must be precise (but also predictable enough) in the long run

Finally, the clock must be able to ensure the lowest possible time error over the long periods it is immersed. Whether we are talking about CSAC or OCXO, precision clocks always have a frequency drift, which results in a time (or phase) error. This error is usually expressed in micro-seconds, or in milliseconds for very long durations (three-month missions for example). A set of parameters can cause drifting in a CSAC or OCXO clock. These include variations in temperature, pressure, shocks, vibrations, and of course the long-term ageing of the atomic or quartz oscillator. The long-term ageing parameter can be caused by many factors, including the changing vacuum level of the clock core, outgasings, migration of materials or electrodes, etc. These phenomena are complex and hard to predict.

Boosting OCXO performance with deep learning and predictive learning.

Studies carried out at Syrlinks over the last 12 months show that it is quite possible to suppress almost all frequency drifts of OCXOs which are linked in the first order to temperature variations. Indeed, all OCXO, even the best thermally insulated in the world, present a (small) frequency drift when the temperature of their environment changes. This is a physical phenomenon that has been well known and documented for decades. The thermal profile of an OCXO is dependent on its electro-mechanical architecture and its vacuum level, but it has very stable and predictive thermal impedance equivalent (Z_{th}) in time. However, it requires that the OCXO remains hermetic, which is the case for OCXOs using sealed metal housings. It is therefore possible to know the frequency drift of an OCXO in relation to the outside temperature at any time in relation to an ultra-precise time reference (GNSS or standard Rubidium source). Once the thermal drifts are known, the SGTM timing module allows these drifts to be dynamically compensated for, a bit like a barrier on the side would make a bowling ball thrown sideways return to the centre of the lane). This approach is extremely powerful and can save a factor of 20 to 50 depending on the type of OCXO. For the range of the best-performing OCXO Syrlinks, using a low ageing, high

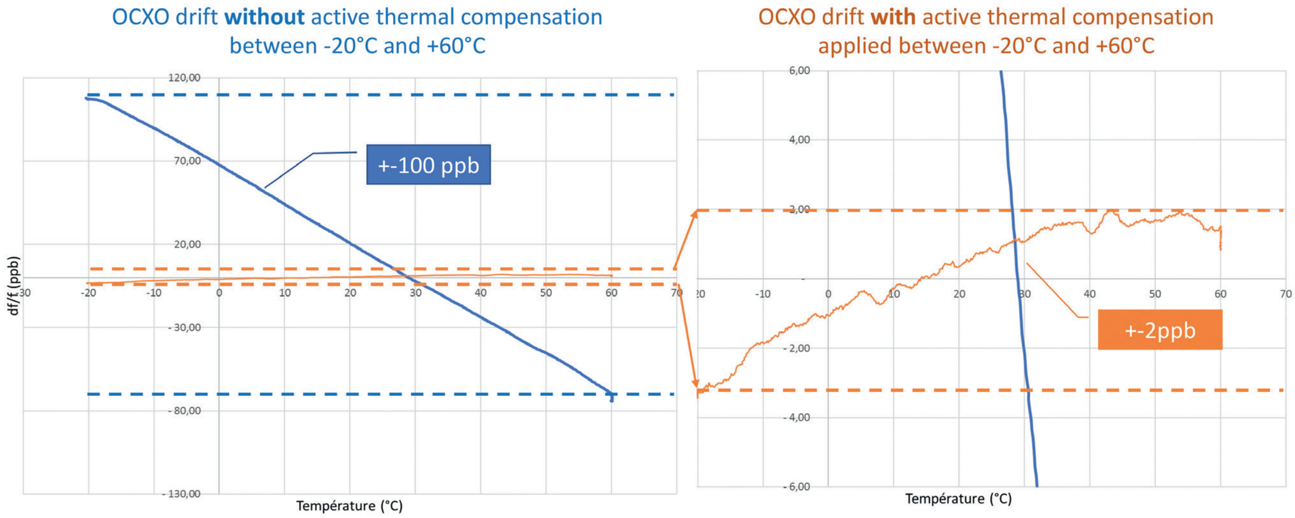

Figure 2 Plot results of x50 gain for thermal drift with digital compensation. AT cuts, SGTM-16.

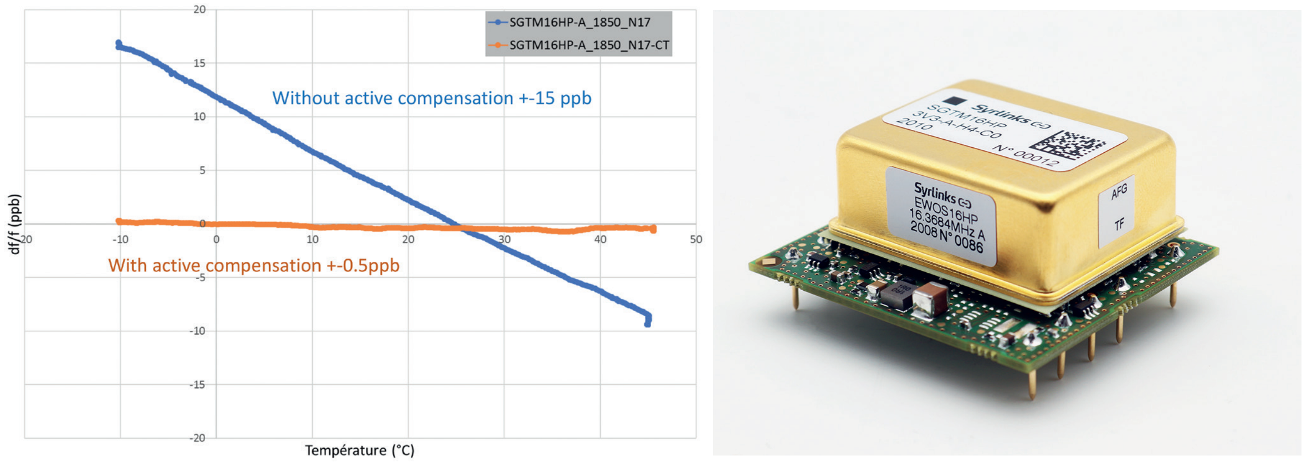

Figure 3 Plot results of x20-30 gain for thermal drift with digital compensation for SGTM16HP clock (Gold metal enclosure).

Q-factor resonator, the thermal drift is reduced from +-20ppb to a lower limit of +-1ppb, equivalent to the thermal noise of the OCXO. For AT cut OCXOs, which are much smaller and less consuming, up to a factor of 50 can be gained, reducing a product set at +-100ppb to +-2ppb. This is spectacular.

AT-cut or SC-cut OCXO-based precision clocks — which one is best for OBNs?

If we go into a little more detail about the SGTM clock modules, there are two types of clocks at Syrlinks with OCXO. The first one embeds a micro-OCXO using an AT resonator, and the other one uses an OCXO with a bigger metal case, which integrates an SC resonator. The AT and SC resonators are very different and bring opposite compromises of stability and energy consumption. This is linked in particular to the quality factor of AT and SC quartz crystals, which is much higher for SC quartz crystals than AT quartz.

AT resonators are very small (5mm x 3.2mm), and the OCXOs that use them are ultra-low power (50 mW at 25°C). On the other hand, their long-term frequency drift is quite high, about 1 to 2 ppb/day due to the lower quality factor and smaller size of the quartz blank. That said, we will see below that they have a definite interest for OBN missions because their frequency drift is very near to a linear one and the residual phase error is very low. To obtain the best recording accuracy on long missions, it is equally important to have a low daily drift and having a frequency drift as linear as possible. An OCXO ‘AT’ with high frequency drift can give superior results after removal of the residual error if its frequency drift is really linear day after day. It is therefore interesting to study the drift of OCXOs with a higher daily ageing provided that they present a kind of predictable drift. These OCXOs will then be a good compromise since the energy they consume is also very low (50 mW at 25°C) and the residual error very limited as well.

As far as the SC cut resonators are concerned, they are more voluminous and therefore the OCXO which uses them will consume more energy (up to two times more, ie. 100mW at 25°C). The great advantage of using them in OBNs is that they have an extremely low raw long-term ageing rate of about 0.1 to 0.2 ppb/day, i.e. 10 times lower than an ‘AT’ OCXO. The curves below show the phase error expressed in microseconds for SGTM16 (AT) and SGTM16HP (SC) clocks. Both types of clocks use the Syrlinks temperature compensation algorithm, which allows the frequency drifts linked to temperature variations in the laboratory to be removed from the study. Figures 4 and 5 show the phase error as raw data, in the same scale on the vertical axis. It is quite easy to understand the magnitude of superiority of SC OCXO versus AT OCXO. However, after removal of the residual error for AT OCXO, and after 15 days of measurement, it is remarkable to see the phase error of an SGTM16 (AT) and SGTM16HP (SC) to be similar. Residual error of SGTM16 (AT) after removal of parabolic fit can be seen on figure 6. This result shows that AT cut OCXO could be envisaged for precision clocks for OBNs.

Conclusion

In order to optimize the performance of OBNs and the accuracy of underwater seismic recordings, we have seen how important it is to choose the right precision clock: a CSAC atomic clock, an OCXO SC clock but also the value of an OCXO AT clock has been demonstrated. The latter was previously little considered because of the high frequency drift, but their extremely low energy consumption makes them attractive once residual error has been removed at post-processing.

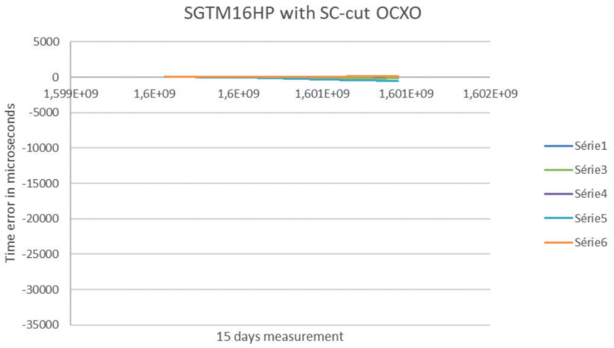

Figure 4 Phase error after 15 days in micro-seconds, for SGTM16 (AT) and SGTM16HP (SC).

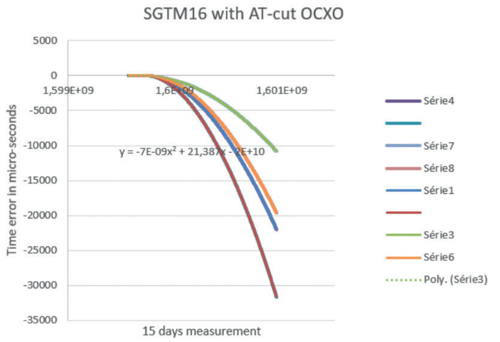

Figure 5 Phase error after 15 days zoomed for SGTM16HP (SC), in micro seconds.

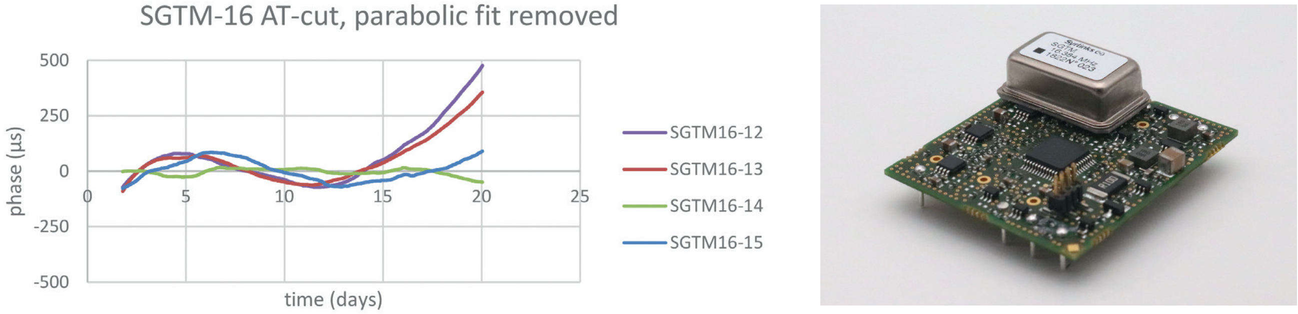

Figure 6 Phase error after 20 days, raw data (top) and after removal of residual error for SGTM16 (AT) and SGTM16HP precision clock photo.