Which High Precision Clock to choose for high performance and competitive OBN?

Cyril Boissy[1*] and Nicolas Vorobyev[1] present an overview of a strategic component for underwater seismic acquisition, available solutions and technologies based on ovenized quartz oscillators or chip scale atomic clocks.

Introduction

Two different high precision clock technologies are available for OBN manufacturers: OCXO clocks and CSAC clocks. The CSAC clock is being pushed by the oil majors, although it is extremely expensive. Technological progress is being made by the OCXO manufacturers. Their attractive price and their better market availability make them an attractive compromise for the OBN manufacturers who wish to segment their OBN product offerings besides their CSAC-based OBN. OCXO and CSAC clocks' key parameters and performances are reviewed below. Their advantages and limitations, both technically, economically and strategically, are studied.

This article presents the latest advances in the field of OCXO. An effective benchmark between CSAC and OCXO is presented to demonstrate when it may be more advantageous to choose a CSAC or an OCXO as the reference precision clock for OBN.

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.

Secondly, the clock must guarantee the lowest possible time error for the entire duration of the mission, once the OBN is immersed (in time-frequency jargon, it is known as long-term drift of the clock). This drift, even extremely small, always exists and is caused by several physical factors such as temperature variations seen by the clock, the natural ageing of its metrological core (quartz resonator or cesium atomic core), atmospheric pressure, gravity, vacuum level of the oscillator core, levels of shocks, vibrations, etc. The challenge here is that the clock can globally guarantee the lowest possible frequency drift, whatever it sees. The long-term drift of a good low power clock is reputed to be within 0.05 to 0.2 ppb/day (frequency drift per day is then 0.0016 Hz given a 16 MHz oscillator, with an ageing drift of 0.1 ppb/day). For comparison purposes, and to better understand the orders of magnitude for long term drift parameter, the TCXOs on the market used in telecom synchronization equipment have a value of 1 to 10ppb/day, which translates to a drift of 0.16 Hz/day if their relative frequency ageing equals 10 ppb/day.

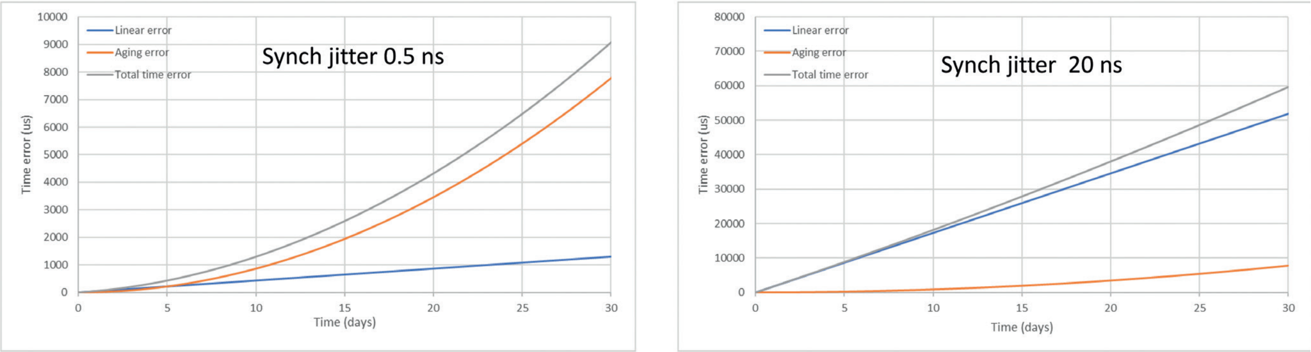

Figure 1 Impact of precise or unprecise synchronization under GPS versus ageing-related time error.

[1] Syrlinks, France
[*] Corresponding author, E-mail: Cyril.Boissy@syrlinks.com
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Figure 2 SGTM16 product.

Clock consumption

OCXO clock or atomic clock manufacturers use different techniques to limit the thermal sensitivity or the long-term drift of a quartz or an atomic-based oscillator. One of them is to heat the metrological core at a specific turnover point (TP). The core of an OCXO is heated and thermally regulated at the TP, just like the core of a CSAC, in order to maintain it at a precise and unchanging thermal point even if the outside temperature of the clock fluctuates. This heating creates an energy consumption that can represent up to 90% of the total consumption in the case of an OCXO. The challenge for manufacturers is then to implement heating technologies that consume as little energy as possible, and to thermally insulate the core of the clock. Syrlinks, a specialist in compact and ultra-low power OCXO, is one of the world leaders in this field. The EWOS16HP-UW is perfectly adapted to the OBN application. It has a consumption 10 to 20 times lower than other OCXO on the market, i.e. around 90 mW at 25°C. This very low power consumption will allow the OBN manufacturers to reduce the size of the battery pack and increase the duration of the underwater mission.

The very low clock consumption is also of great interest outside water or during OBN storage periods. Indeed, to avoid the disruption of the oscillator frequency, it recommended to keep the OCXO powered permanently, even out of the water when the mission is over. Once an OCXO has been turned off, it will not return to the same accurate frequency once it is turned on again. This effect is called RETRACE. It is measurable in ppb and to avoid this frequency offset at power-on, it is common to keep the OCXO permanently powered. This also helps to maintain the long-term drift of the OCXO in a more predictable and linear drift area. For an OCXO, the Retrace parameter is specified at 10 ppb max, measurement of frequency is performed 24 hours after powering on again the OCXO (OFF-period before restart = 24 hours also).

Zooming-in the retrace parameter

The retrace parameter is one of the key advantages of atomic clocks. This is where it benefits from the key performance of atomic technology and where the gap with OCXO technology is one of the widest. For a CSAC clock, retrace is specified at 0.05 ppb, so 200 times better than an OCXO. However, as soon as a CSAC or an OCXO would remain permanently powered on inside an OBN, this key performance loses its value since it is no longer exploited (e. g. suppression of ON-OFF cycles of the atomic or quartz oscillator that could disturb the frequency). More generally, atomic clocks are found in systems requiring reduced cold start time and very precise frequency accuracy after a power-on (e. g. GNSS radio positioning application or hardened radiocommunications for the defence market)

Clocks and homogeneity of an OBN fleet

We have seen that a low long-term drift and very accurate GPS synchronization before diving are extremely important elements to ensure the consistency and quality of the recorded seismic data. Given the large number of OBNs deployed on an oil exploration field, the behaviour of each clock over time must be as homogeneous as possible for the entire fleet deployed. From this point of view, OCXO technology is interesting because it is a much older one, and therefore naturally more mature from the industry standpoint than the more recent CSAC clock. The CSAC atomic clock is a very complex object involving various start-of-

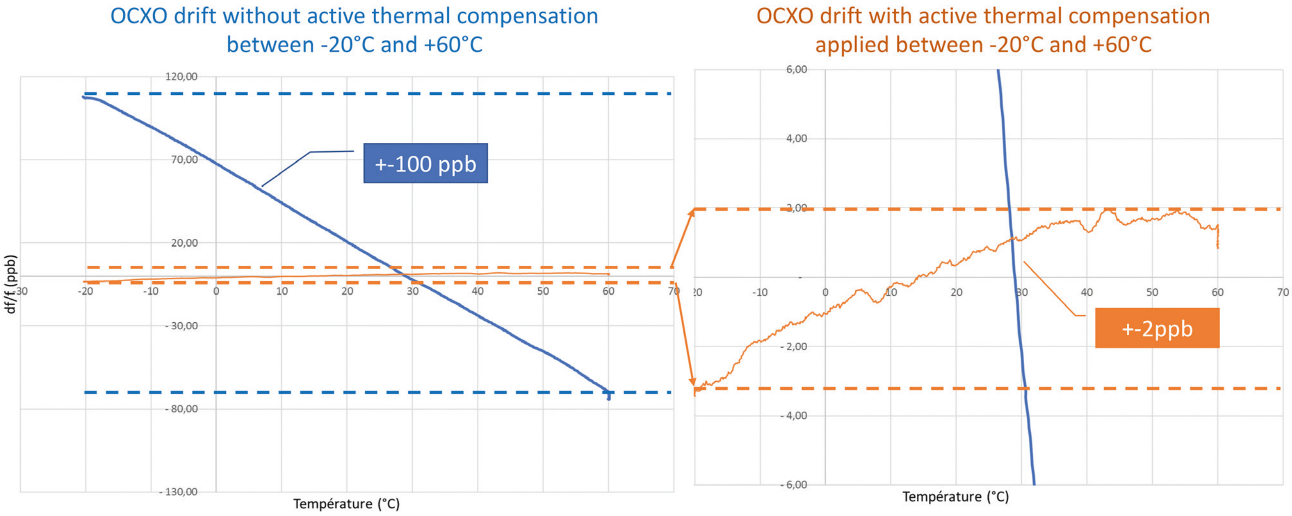

Figure 3 Plot results of x50 gain for thermal drift with digital compensation.

the-art technologies such as hermetical MEMS trapping a cesium vapour, optical and magnetic elements, VCSEL laser diode, microwave electronics, that are all sensitive to the environment. This may result in a certain level of typical behaviour discontinuity, such as unexpected frequency jumps, while remaining within the specifications indicated by the manufacturer. This difficulty is by nature less present in the case of an OBN carrying an OCXO. The technological bricks of an OCXO are less complex and quartz resonator technology is more than 50 years old. The Syrlinks' low power OCXO EWOS16HP-UW is built around a dedicated proprietary ASIC and a resonator generally procured from the same quartz batch. It is a good way to get an optimized fleet homogeneity when several thousand units are deployed on the sea floor.

Economical and strategic aspects related to the choice of the clock

The choice of clock technology is not only important in terms of the OBNs intrinsic accuracy while recording the acquisition data. It is also essential when it comes to the cost-competitiveness and the chosen clocks must comply with delivery deadlines imposed by oil majors' call for tenders. The Time-to-Deploy is then a fundamental success criterion. In the market today, man can see a factor of about 10 between the price of a CSAC and the one of an OCXO. Moreover, as the market demand is difficult to anticipate and as the market seeks a very short OBN deployment time, it requires that the entire supply chain adapts to this (procurement of components and OBN manufacturing cycle). The OBN market is rapidly growing, and in shortage. Oil majors are looking to reduce costs and make OBN available within a few months. It requires clocks or sensors manufacturers to be very reactive and deliver earlier. Even if ultra-low power OCXO manufacturers are rare on the market, there are still three main players in the world today. The OBN manufacturer therefore has the possibility to double-source its precision clock and ensure the reactivity of its supply chain. On the other hand, an OBN manufacturer using CSAC will be blocked in its OBN shipments if they have not anticipated its supplies very far in advance (up to one year). In addition, there are no other CSAC sources available on the market. In summary, although less efficient on a few parameters such as retrace or long-term drift, the lower unit price and better supply of OCXO make high-precision quartz-based precision clocks very attractive and less economically risky for some specific OBN market segments, such as the ones with shorter mission durations (30 to 60 days).

Boosting intrinsic OCXO performances

In parallel with the continuous improvement of its OCXO products and the power consumption reduction adapted to underwater applications, Syrlinks has developed a new timing module built around its OCXO and a very low power digital electronic circuit. The SGTM (Syrlinks GNSS Timing Module) allows to precisely control the frequency and phase of the EWOS OCXO being disciplined against the GPS signal. Once underwater, when GPS reference is lost, the SGTM will take control and maintain accurate time thanks to the ultra-stability of the embedded OCXO.

Figure 4 SGTM16HP-UW product.

The SGTM16HP-UW can be used as an alternative of a CSAC without modifying the OBN equipment. Its footprint has been designed to facilitate a quick pre-testing and deployment in production without effort. As such, it becomes a dual source, allowing the OBN manufacturer to supply another component if the CSAC is not available within the desired time frame. The digital electronics of the SGTM16HP-UW has many advantages over the use of the OCXO alone. It simplifies the OBN manufacturer's design work as the GPS synchronization function is fully managed by the SGTM. The disciplining of OCXO's phase and frequency with respect to GPS is fully automated and reaches a record level of 0.5~1.0 ns jitter when copying the PPS signal. This performance is linked to a proprietary disciplining algorithm and a inhouse hyperfine drive of the OCXO frequency. The reduction of the residual initial synchronization error under GPS makes it easier to reveal the secondary order parabolic drifts related to long term ageing or thermal drift. Post-processing of the acquisition data will then be concentrated on optimizing ageing-related corrections. The curves below show the accumulated time error in case of an initial synchronization that is not efficient (jitter 20 ns) versus the one done with SGTM at 0.5 ns. In the first case, the linear accumulated error totally masks the other types of drifts that must also be post-processed to obtain a better resolution of oceanic subsoils.

Digital learning algorithms for improving thermal sensitivity

In addition to generating a PPS signal from the OCXO frequency, the SGTM allows to boost some of the OCXO's key parameters to unprecedented levels, such as its thermal sensitivity. Syrlinks has a perfect knowledge of the thermal behaviour of its EWOS16HP range. The company developed a predictive algorithm dedicated to its OCXOs. Depending on the type of OCXO (AT cut, SC cut) the gain ranges from a factor of 50 to 20. Each SGTM module is calibrated individually to compensate its intrinsic and natural thermal drift. For an EWOS16 (DIL14 enclosure, AT-cut quartz resonator), this gain is a factor of 50, reducing the thermal sensitivity to +-2ppb whereas initially it is about +-100 ppb. For

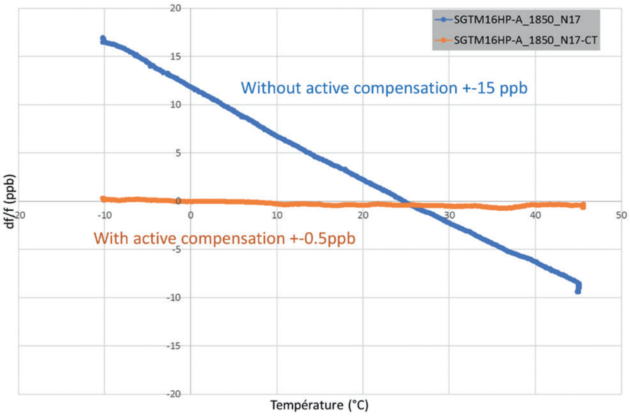

Figure 5 Plot results of x20 gain for thermal drift with digital compensation.

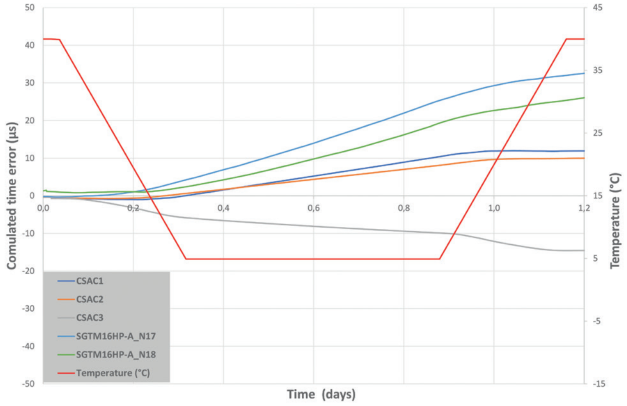

Figure 6 Cumulated time error for CSAC and SGTM16HP-UW.

its most efficient OCXO (SC cut quartz resonator), the gain can be up to a factor of 20, reducing frequency stability over the temperature range to +-1 ppb.

This secondary benefit obtained digitally by SGTM is very important since the OBN can see rapid temperature variations when the OBN is immersed or retrieved to the surface. In warm climate areas (Gulf of Mexico or Persia), or in cold areas (North Sea, Alaska, etc.), there will always be a thermal shock between diving and when the OBN will stabilize on the sea floor, where the temperature is reputed to be constant at ~5°C. Finally, and this is less well known, once the OBN is positioned and stabilized on the seafloor, it may turn out that the on-board electronics undergo small thermal changes due to on-off cycles of some part of the embedded electronics, evolving up and down by a few degrees throughout the mission. The Syrlinks proprietary software to contain the OCXO's thermal sensitivity to +-1ppb also boosts the overall system performance and increases the quality of seismic recordings.

The thermal drift compensation technique has also been implemented on OCXOs that are inherently more stable and dedicated to underwater applications: SGTM16HP-UW. The gain in thermal sensitivity obtained is a factor of 20, which is proportionally lower than the compensation result on OCXO DIL14 which is explained by the fact that the EWOS16HP-UW is natively very stable (typ. +-15 ppb). The thermal drift over the temperature range [-10°C; +45 °C] is typically +-0.5 ppb, which brings this value to the thermal noise of the OCXO.

At this point, we have seen the importance of good GPS synchronization before immersion, as well as the importance of reducing the thermal sensitivity of OCXOs using predictive tools and an adapted algorithm uploaded at the factory before shipment. It is natural now to evaluate the real behaviour of an SGTM16HP-UW against CSACs and compare the overall timing error over a few days.

InApril, a Norway-based supplier of Ocean Bottom Nodal technologies, offers a highly innovative and efficient OBN solution called Venator with a fully handsfree deployment, retrieval and onboard handling of OBNs. InApril has participated in these tests and follows Syrlinks developments closely. The test scheme is as follows. Stabilization of SGTM and CSAC at +40°C, drop in temperature to 5°C to simulate the seabed temperature and finally the temperature is raised again back to +40°C with an opposite slope. The objective of this test is to demonstrate the relevance of the thermal behaviour of an SGTM versus a CSAC. The results are presented in Figure 6.

We notice here that the 3 CSACs have opposite drift slopes, which is not the case with OCXO. In addition, for SGTM and CSAC, the drift is very linear and easily correctable with post-processing of the data. Finally, it should be noted that slope breaks are less pronounced with SGTMs than CSAC during rapid temperature changes (particularly true on CSAC3)

Conclusion

This study demonstrated the value of ultra-low power OCXOs for OBN applications, as well as SGTM timing modules to achieve performance approaching those of a CSAC atomic clock with respect to clock synchronization and drift related to thermal sensitivity. SGTM16HP-UW delivers record performances for this type of power consumption and makes this solution a highly relevant alternative to the CSAC clock for short to medium-term missions, when cost pressure is high. On longer-term missions requiring an even lower ageing drift, Syrlinks is working on technical solutions to meet current and future needs of underwater seismic players.