Introduction

With the increase in seismic exploration and monitoring campaigns, Ocean Bottom Nodes (OBNs) are playing a central role in the acquisition of high-resolution geophysical data. However, changing in operational requirements - whether to reach more remote or deeper zones or to extend recording times - impose a growing need for nodes autonomy. Such requirements come with specific challenges for OBNs, one of them being the stability/power consumption of the internal clock. While commonly used oven-controlled crystal oscillators (OCXO) or chip scale atomic clocks (CSAC) have large power consumption, a dual clock technology has been developed allowing to greatly decrease the power consumption without affecting their inherent stability. In this paper we present a series of long duration experiments conducted on dual clocks deployed in OBNs.

Clocks comparison and dual-clock principle

In ocean bottom node (OBN) surveys, autonomous nodes operate without continuous GPS synchronization, relying instead on internal oscillators for which stability is critical.

Among available timing solutions, chip-scale atomic clocks (CSACs) provide superior frequency stability and minimal drift. However, their advantages come with significant drawbacks, notably high power consumption and high cost, often making CSACs either oversized for the intended application. Alternatively, oven-controlled crystal oscillators (OCXOs), when properly characterized for thermal sensitivity, can achieve very high timing performance, largely thanks to their predictable frequency drift compare to CSAC. This predictability enables accurate post-survey drift correction, making OCXOs a viable solution for maintaining the temporal accuracy required for high-quality seismic data processing. Furthermore, this approach allows for the deployment of more cost-effective and energy-efficient timing systems. However, oven stabilization still entails significant power consumption, which must be considered for energy-constrained applications

With the challenge of increasing mission durations, a dual-clock architecture has been developed. As illustrated in Figure 1(a), the node's primary timing relies on a low-power temperature compensated crystal oscillator (TCXO), periodically corrected by a highly stable reference clock, which remains powered off most of the time. Accurate characterization of both oscillators is critical to ensure optimal synchronization, particularly regarding their behavior at power-up. This approach combines the advantages of both systems, achieving high timing stability with minimal power consumption.

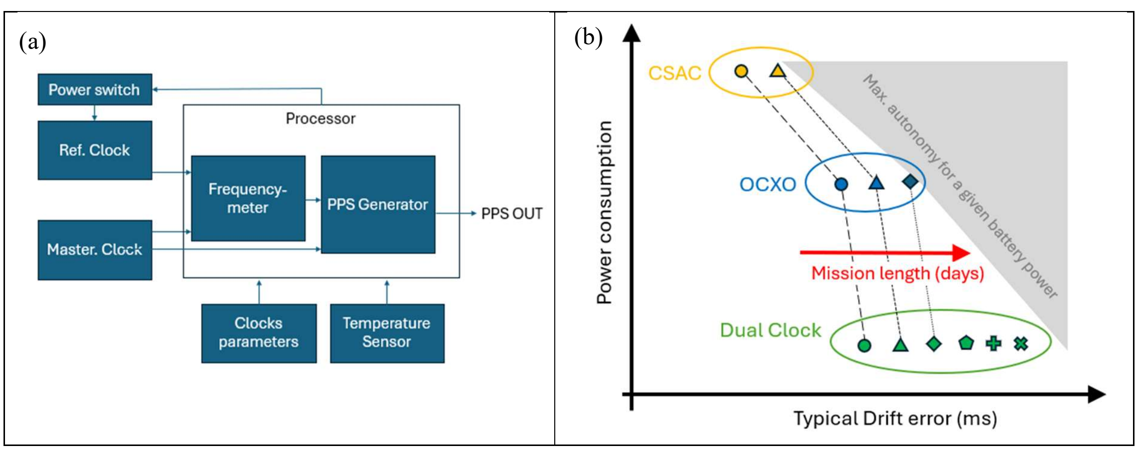

Figure 1 *(a) Dual-clock principle (b) Impact of mission length on typical drift error and comparison of clocks technology power consumption.*

Figure 1(b) illustrates the comparison between timing solutions: while power consumption is drastically reduced for Dual Clock solution—thereby extending autonomy for a given battery capacity—the typical drift error remains comparable to that of an OCXO-based solution. It is important to note that, regardless of the timing approach, longer mission durations will inherently lead to increased drift uncertainty relying on a deterministic clock drift correction. However, OBN surveys are perfectly suited for a data driven estimation of residual clock drift and in that case, the inherent stability of the clock is critical.

The experiment

The company conducted a series of laboratory experiments in which a node deployment process was simulated over 10 nodes. The node deployment process was performed at 25°C for one day; the temperature around the node was lowered to 5°C over a 30 minute period; the node operated at this lower temperature for more than 60 days. For all nodes, the clock frequency and clock drift was continuously recorded. Independently the temperature trend of each clock was measured.

Results

Figure 2 presents the experimental results. In (a), raw drift measurements for the 10 tested units are shown. Raw clock drift remains below 10 ms over the 60-day test period, consistent with typical best OCXO performances but with more than 3 times less power consumption. Figure 2(b) shows the residual clock stability after applying a second-order polynomial fit to the raw drift, following data-driven drift estimation methods. Over the 60-day test period, all dual-clock units exhibit residual stability better than 50 µs.

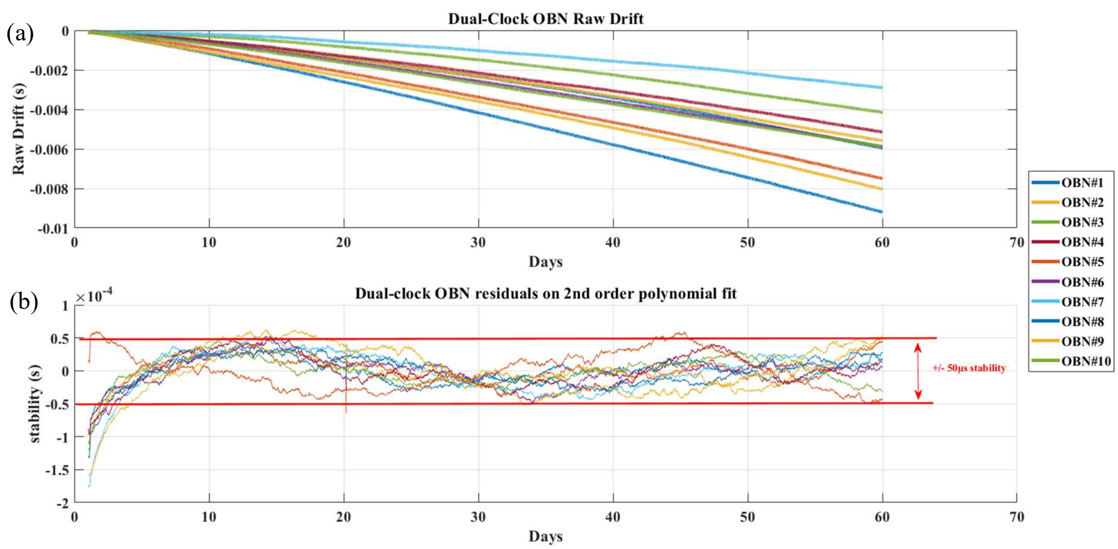

***Figure 2** (a) Dual-clock OBN raw drift over the 10 products (b) dual-clock residuals after 2nd order polynomial fit on frequency drift..*

Conclusion

The new dual-clock solution offers the major advantage of drastically reducing the power consumption of the timing function, thereby increasing OBN autonomy without compromising timing accuracy. No chaotic behavior related to the switching mechanism was observed in the recorded data. On the contrary, the clocks proved to be highly stable and predictable with a high degree of precision.

EAGE

Title: Dual-clock timing solution for Ocean Bottom Node acquisition

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