How Atomic Clocks Will Improve Undersea Survey

— by Steve Fossi, Director of New Business Development

Symmetricom®

First introduced in 2011, the chip scale atomic clock (CSAC) will likely see quick adoption by companies doing seismic surveys to look for oil and gas deposits beneath the ocean floor. The CSAC can replace the OCXOs (oven controlled crystal oscillators) or TCXOs (temperature controlled crystal oscillators) currently used in underwater sensors deployed in large grids on the ocean floor.

Regardless of the type of oscillator employed, however, the function is the same: to measure the time for sonic pulses fired from a surface ship to reflect off subsea formations and travel back to the sensors. These times vary depending on the types of subsea formations the pulses encounter—oil, gas, rocks, sediment, etc.—thus creating a 3D map of likely oil and gas locations. The more accurate the timing, the more accurate the map; hence, the likely shift to atomic timekeeping in undersea sensors.

Mapping precision is of obvious importance to those looking for oil and gas deposits under the ocean floor. The cost of drilling a "dry" hole, especially in deep water drilling, is enormous; but so is the opportunity cost of not fully exploiting an already producing field. Many operators report that up to a third of a field's available oil and gas may remain untapped simply because surveys of the field lacked sufficient detail or were incomplete.

Another significant cost is the expense of crews deploying and retrieving sensor grids. If grids can remain unattended and underwater longer, crews can make fewer trips—giving more flexibility to operations and also reducing operational expense.

Atomic clocks offer advantages on both counts: they enable more precise mapping and they can stay out longer underwater once they've been deployed. Let's discuss precision first.

Precision Advantages

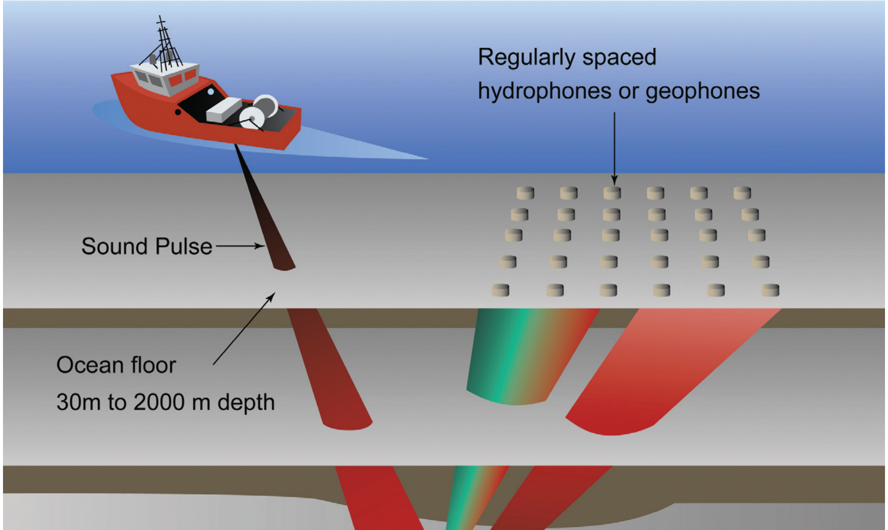
For an underwater sensor to provide precise timing, it must offer superior specifications in three areas: initial accuracy, drift (or aging), and frequency change with temperature (also known as temperature coefficient or "tempco.")

Initial accuracy is just what it says. It is how accurate the clock keeps time right after it's been set. Time is the reciprocal of frequency, so another way to look at initial accuracy is by the uniformity of the periods, or spacing, between clock "ticks." In an ideal clock, all the periods would be identical in all sensors—it would be as if all sensors were operating on the same clock—so all sensor reflections off each object would correlate perfectly, resulting in a super-clear image. To the extent initial clock accuracy is not perfect, correlation among sensors is not perfect, and the image detail becomes a bit blurred.

Another factor affecting precision is drift or aging, i.e., the rate at which a clock gains or loses time as time passes. As soon as it is set, a clock starts to drift. All clocks gain or lose time, some faster than others. Because aging is constantly occurring, it causes a steady change in frequency, which results in a time error that varies as the square of the elapsed time since the clock was last set. This means that the data from any two sensors running off different clocks will be further and further out of agreement the longer the sensors remain on the bottom. The more uncorrelated the clocks become, the blurrier the image.

Aging is less of an issue in timing applications like mobile telephone cell towers that have access to timing signals broadcast from GPS satellites, and so can reference a known accurate time source. In these applications, the local oscillator can be "disciplined," i.e., brought back to the correct frequency by GPS. Underwater, however, sensors' clocks have no access to GPS signals, and so they must rely on their own internal physics—atomic or quartz—to stay accurate over time.

A third metric that significantly impacts mapping precision is temperature coefficient, or tempco. Tempco describes how much a clock's frequency changes (or shifts) in response to changes in temperature. A clock that produces a signal at one frequency on the warm deck of a surface ship will produce a signal at a different frequency when submerged into cold seawater. The tempco specification indicates the maximum shift in frequency the clock is guaranteed not to exceed. Since the frequency shift of each sensor's clock is different, this adds to the correlation errors caused by initial inaccuracy and aging. Some sensors use software models to correct for these errors, but the best approach is to minimize them to begin with.



Sonic pulses launched from a surface ship reflect off subsea formations and travel back to the sensors where they are time-stamped

The superior initial accuracy and aging of atomic clocks compared to crystal-based oscillators are well known. And the CSAC brings that accuracy and stability to portable applications (e.g., subsea sensing) for the first time. In fact, the first commercially available CSAC—Symmetricom's SA.45s—has an initially accuracy of ±5.0E-11, which is at least 100 times more accurate than most OCXOs, and 1000 times more accurate than most TCXOs. The aging rate is 3.0E-10/month; again, about 100 times better than most OCXOs and 1000 times better than most TCXOs.

An atomic clock also has better tempco performance than TCXOs or OCXOs. Here's why: Atomic clocks work by exciting atoms of a particular gas (typically cesium, hydrogen or rubidium) to resonance within a chamber, producing an extremely precise and stable spectral emission line. This resonance is also less sensitive to changes in temperature than are the mechanical phenomena used to generate frequencies in TCXOs and OCXOs.

The CSAC's innovative design results in an atomic clock that is extremely small— the CSAC is less that 16 cubic centimeters in volume and weighs less than 35 grams. That means that sensor designers can easily integrate the CSAC into existing sensor cards. But the CSAC's design also surrounds its physics package with a high-quality vacuum for very high thermal isolation. As a result, the CSAC can specify a tempco of ±5.0x10-10 over its operating range of -10°C to +70°C. This is orders of magnitude better than what can be obtained from TCXOs or OCXOs.

Cost Advantages

A key cost driver in this application is oscillator power consumption. That's because the oscillator is by far the biggest consumer of power in the sensor, and this is why the vast majority of the sensor's volume consists of batteries.

And here is where the Symmetricom SA.45s CSAC delivers an overwhelming advantage. With just 115 mW of power consumption, it has about 1/40th the power consumption of any other OEM atomic clock on the market. But underwater sensors typically don't employ atomic clocks—precisely because of their power consumption—and so the more relevant comparison is with the OCXOs that most underwater sensors employ. Here, the Chip Scale Atomic Clock represents an incredible 80 to 90 percent savings in power.

The benefit for users is that they get to save money either of two ways: 1) by reducing battery cost and therefore sensor cost; or 2) by using the same batteries and extending mission life (10-15x longer than when using an OCXO-equipped sensor). Longer mission life means more flexibility in scheduling crews and deployments, saving money on operational costs.

So what about TCXO-based sensors? TCXOs do use less power than the CSAC, but they rely on software algorithms to correct for temperature changes and for aging performance, neither of which are intrinsically good enough for the intended application. Since these algorithms only apply an average correction factor, the map's accuracy is less than it could be.

And For Even Lower Power Consumption ...

Marine survey teams which use sensors equipped with CSACs also have another way to further reduce power consumption. The CSAC's ultra-low power mode turns off the CSAC's physics package to operate the unit as a free-running TCXO. Of course, if left undisciplined the TCXO's timing will start to degrade. But the physics package can be periodically (also programmatically) turned back on so that, after warm-up (<100 sec), it re-disciplines the TCXO. Operating the SA. 45s in this mode enables average power consumption levels well below 50mW.

Consider Your Timing Options

With the introduction of the Symmetricom SA.45s CSAC, designers of underwater sensors have a new option in their ongoing efforts to increase mapping precision and decrease costs. The accuracy of sensor time stamps, the cost of sensor deployment and retrieval, and the length of time that sensors can remain underwater are all factors that can be greatly improved by using the CSAC.