UNIVERSITY OF WATERLOO

Chip Scale Atomic Clocks Sources

Applications

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Agenda

1. Global Navigation Satellite Systems (GNSS)
2. Ocean Bottom Seismic (OBS)
3. Military field
4. Conclusion

Recap from "Technology comparison"

The *absolute best* CSACs doesn't exist.

In general, performance of the clock are proportional to its SWaP (Size Weight and Power) and cost.

The choice of the clock depends on the application requirements.

Global Navigation Satellite Systems (GNSS)

Trilateration in GNSS networks

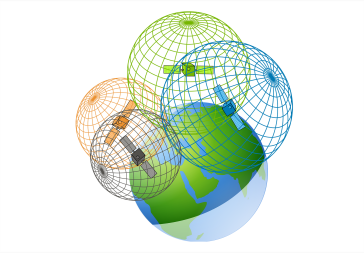
System of equations involved in trilateration (**δt is the receiver clock delay**):

$$\Delta d_i = c \cdot (\Delta t_i + \delta t) = \sqrt{(x_r - x_i)^2 + (y_r - y_i)^2 + (z_r - z_i)^2}, \quad i = 1, 2, 3, 4$$

$$\underbrace{x_r, y_r, z_r, \delta t}$$

4 Unknowns requires 4 satellites

Final position strongly depends on δt.



[0] In the equation above, c is the speed of light which is approximately 3×10^8 m/s.

Role of CSAC

Better holdover capabilities → eliminate the need for the 4th satellite after the first clock calibration.

More accurate timing → more precise trilateration and indeed a more accurate position.

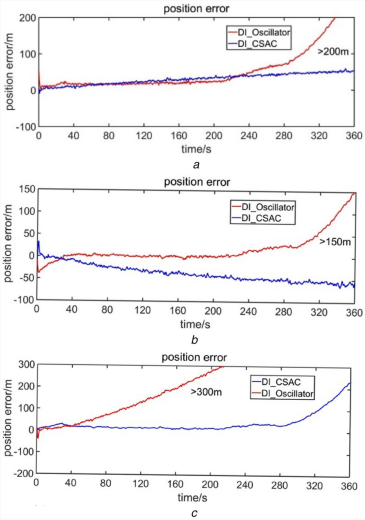


Figure 1: TCXO, CSAC

Ocean Bottom Seismic (OBS)

Seismic Methods & Oil Exploration

Seismic or acoustic methods measure the travel times of the reflected or refracted waves detected by a series of geophones and are able to estimate the location and depth of the targets.

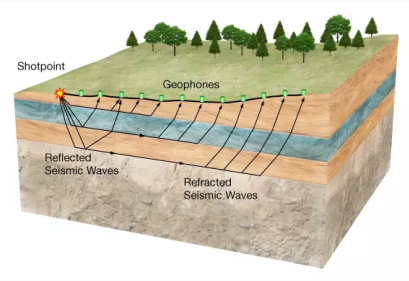


Figure 2: Seismic method applied from Earth's surface.

A **precise timestamp is required** to measure the travel time of the waves.

Seismic methods are used for oil exploration since they can estimate the location and depth of the oil reservoirs.

Role of CSAC

Small short & medium drifts $\rightarrow$ no GNSS required for nodes synchronization.

Low battery consumption $\rightarrow$ long-lasting measurements campaigns (weeks or months).

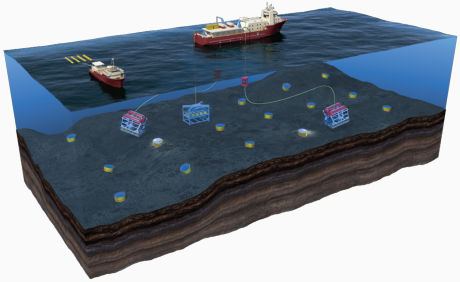


Figure 3: Thanks to CSAC, mapping is now done by placing the geophones on the ocean floor and not on the surface, obtaining more accurate results.

Military field

IED (Improvised Explosive Devices) Jammers

IED Jammers are devices that prevent the detonation of IEDs by blocking the radio signals used to trigger them.

A single jammer can cover a limited area, so multiple jammers are used to cover a larger area. In order to work together, **the network must be tightly synchronized**.

SAASM (Selective Availability Anti-Spoofing Module)

SAASM is a module that provides decryption and encryption capabilities to GPS receivers.

The use of a CSAC reduce the time needed to acquire the signal and allows the **use of longer GPS codes (encrypted P(Y) code)** that are less susceptible to jamming and spoofing.

Conclusion

Applications of CSACs

CSACs find applications in sectors that require **high precision timing** sources, **network synchronization** without GNSS, **low power** consumption and **portable devices**.

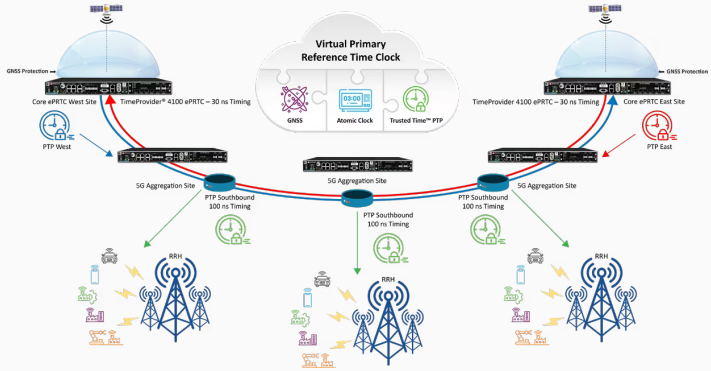
The relative high cost of CSACs (2000$ - 6000$) is still a barrier to their widespread adoption in large-scale market or consumer products.

Extra slides

5G networks

5G networks require highly accurate timing sources for synchronization (max shift in the order of $100ns/day$).

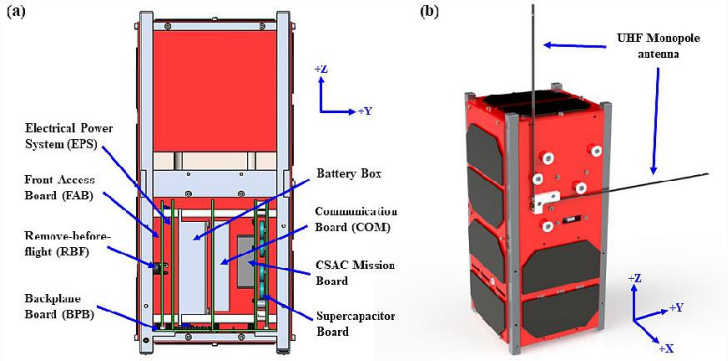
In case of failure of the primary source, CSAC holdover capabilities can be used to maintain synchronization at base stations.



Space experiments

Space versions of CSACs are being developed for scientific missions and data collection.

SPATIUM (Space Precision Atomic-clock Timing Utility Mission) is a mission with the objective to model the ionosphere TEC (Total Electron Content) based on multipoint measurements formed by a constellation of small satellites.



References i

K. Aheieva, R. Rahmatillah, R. Ninagawa, I. O. Adebolu, H. Masui, T. Yamauchi, S. Kim, M. Cho, C. L. Chow, M. S. Tse, and K. H. H. Li.
Cubesat mission for ionosphere mapping and weather forecasting using chip-scale atomic clock.
In *2017 Progress in Electromagnetics Research Symposium - Fall (PIERS - FALL)*, pages 761–766, 2017.

GISGeography.
How gps receivers work - trilateration vs triangulation.
https://gisgeography.com/trilateration-triangulation-gps/.

C. Jiang, S. Chen, Y. Chen, and Y. Bo.
Research on a chip scale atomic clock driven gnss/sins deeply coupled navigation system for augmented performance.
IET Radar, Sonar & Navigation, 13(2):326–331, 2019.

References ii

F. I. John Smythe.
A nodal approach.
https://www.hartenergy.com/ep/exclusives/nodal-approach-176191.

J. Keller.
Northrop to build electronic warfare (ew) rf jammers to protect warfighters from improvised explosives.
https://www.militaryaerospace.com/rf-analog/article/14196810/electronic-warfare-ew-rf-jammers-improvised-explosives.

Microchip.
Microchip technology inc. (website).
https://www.microsemi.com/.

PEOIEWS.
Dagr.
https://www.flickr.com/photos/69349609@N02/6326407470.

References iii


P. Shine.
Seismic methods.
https://petroshine.com/seismic-methods.

Questions?

Thank you!