

Chip Scale Atomic Clocks Sources

Motivations

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Source Types

In the following table are reported the main types of clock sources that are based on atomic physics.

Model	Transition	Species	Drift ($\tau = 1$)	Aging	Power (mW)	Size (cm ³)
Microsemi SA.45s [?]	Microwave	Cs	3×10^{-10}	$< 9 \times 10^{-10}/mo$	120	17
Microsemi MAC SA.5X [?]	Microwave	Rb	3×10^{-11}	$< 5 \times 10^{-11}/mo$	6300	47
NIST (experimental)	Optical	Rb	$\approx 10^{-13}$	Still unknowable	420	35

Table 1: Comparison of clock sources

It's clear how compared to the traditional MEMS resonator, the atomic clock sources have a much better performance in terms of both drift and aging. Temperature sensitivity is also much lower, but the size and cost are higher.

Applications

In terms of applications, chip-scale optical atomic clocks are still in the experimental phase, while microwave atomic clocks are already used in commercial applications due to their lower cost, size and power consumption (battery-operated devices).

The most important applications are related to **GNSS and GPS systems**. A high-precision synchronization between the satellites then permit a more reliable and accurate network synchronization on the ground. This open the door to a wide range of applications where a precise timing (or positioning) is required, such as:

- Defense applications (i.e. UAVs)
- Airline navigation (i.e. GPS-based landing systems)
- Cellphone telecommunications (next generation 5G networks)
- Financial transactions (i.e. high-frequency trading)

Notes slides

Rubidium (Rb) & Cesium (Cs)

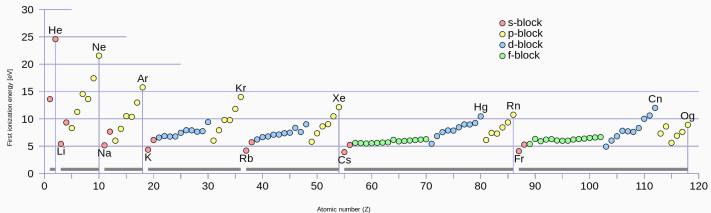


Figure 1: First ionization energy of all the elements

https://en.wikipedia.org/wiki/Alkali_metal

- Drift refers to the gradual change in a clock's frequency over a short period of time.
- It can be caused by factors such as changes in temperature, mechanical stresses, or other environmental influences.
- Is usually observed over hours, days, or weeks, and it describes how the clock's frequency changes during these relatively short intervals.

- Aging refers to the long-term change in a clock's frequency over an extended period.
- Is often associated with factors such as the properties of the atoms used in the clock, interactions with materials in the clock's construction, and other intrinsic factors.
- Becomes apparent over days, weeks, months, or even years. It describes how the clock's frequency gradually changes over these longer periods.

Allan Variance/Deviation

- The Allan variance (AVAR) $\sigma_y^2(\tau)$ is a measure of frequency stability in clocks, oscillators and amplifiers.
- The Allan deviation (ADEV) is the square root of the Allan variance ($\sigma_y(\tau)$).
- The Allan variance is calculated by measuring the frequency of a clock over a period of time and then analyzing the data to determine how the clock's frequency changes over different time intervals.

An Allan deviation of 1.3×10^{-9} at observation time 1 s (i.e. $\tau = 1$ s) should be interpreted as there being an instability in frequency between two observations 1 second apart with a relative root-mean-square (RMS) value of 1.3×10^{-9} .

Allan Deviation (Diagram)

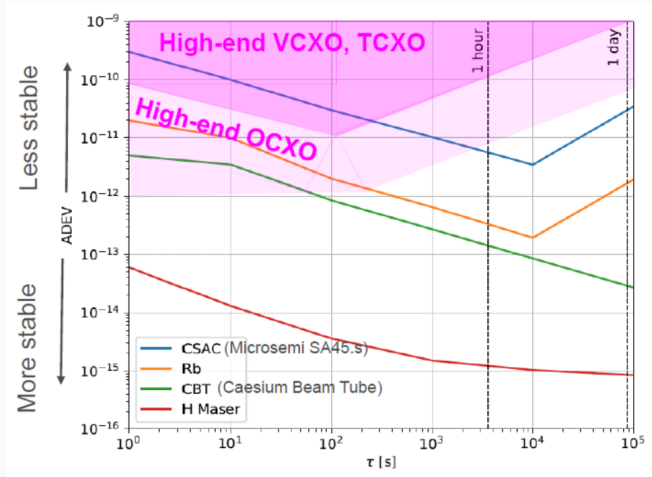


Figure 2: ADEV for traditional MEMS resonator vs. CSAC vs. full size atomic clock [?]

Temperature Sensitivity (Diagram)

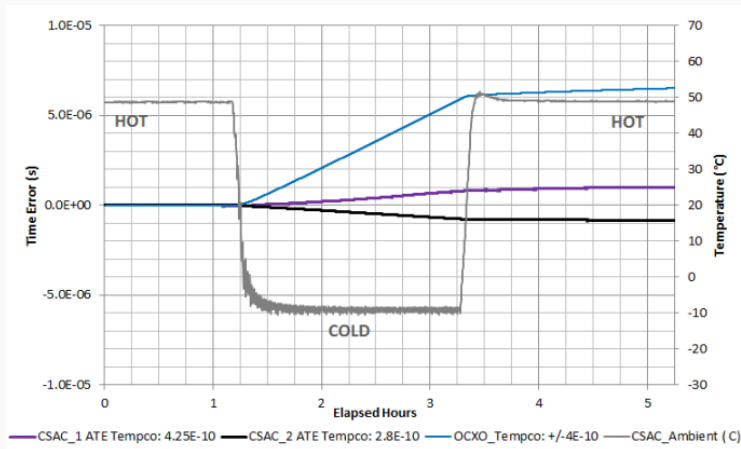


Figure 3: Temperature effect for traditional MEMS resonator vs. CSAC [?]

