Chip Scale Atomic Clocks Sources

Motivations

Tommaso Bocchietti

March 5, 2024

University of Waterloo

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 [2]	Microwave	Cs	3×10^{-10}	$< 9 \times 10^{-10}/mo$	120	17
Microsemi MAC SA.5X [3]	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)

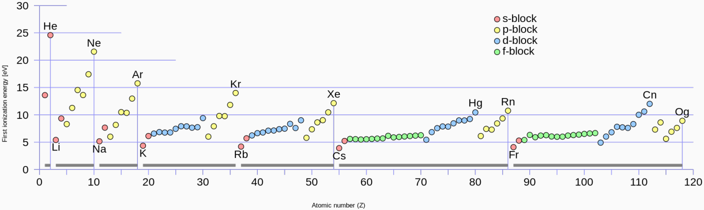

Figure 1: First ionization energy of all the elements

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

Drift

- 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

- 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)

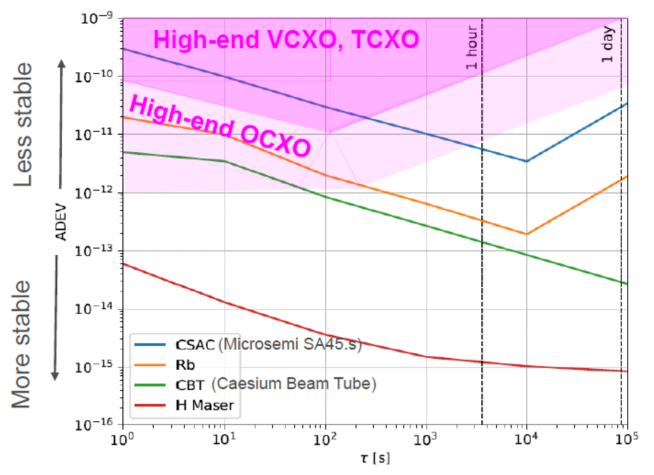

Figure 2: ADEV for traditional MEMS resonator vs. CSAC vs. full size atomic clock [4]

Temperature Sensitivity (Diagram)

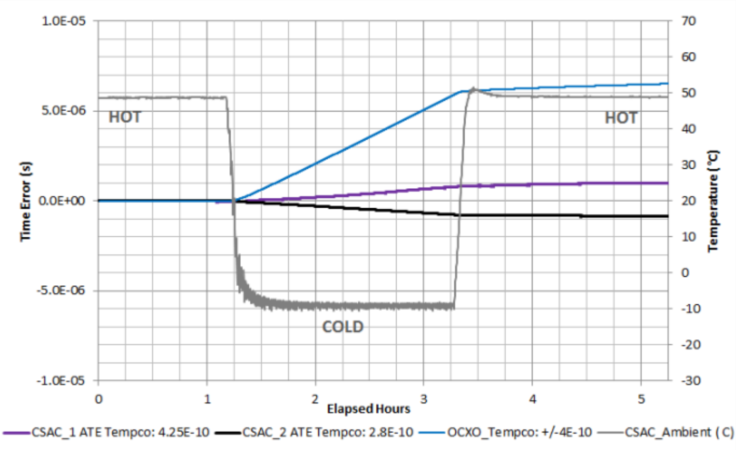

Figure 3: Temperature effect for traditional MEMS resonator vs. CSAC [1]

References i

M. Corporation.
Chip-scale atomic clock (csac) performance during rapid temperature change, 2018.

M. Corporation.
Sa.45s csac and rohs csac options 001 and 003, 2019.

M. Corporation.
Mac-sa5x, 2020.

M. Travglia.
Chip-scale atomic clocks: Physics, technologies and applications, 2021.