μQUANS

PRECISION QUANTUM SENSORS

MuClock

A high-performance frequency standard based on cold atoms

MuClock is the first commercially available atomic clock based on laser-cooled atoms. This unique solution is the result of more than 15 years of research conducted by our academic partners: LP2N and LNE-SYRTE, the French National Metrological Institute for time and frequency and one of the major international experts in the field of frequency standards.

MuClock features **within a single device** unmatched performances in terms of short and long-term frequency stability, as well as accuracy and predictability. It therefore offers a very **interesting alternative to usual H-Maser / Cs clocks ensembles** for the generation of highly stable time scales, among others. Originally inspired by the atomic fountains developed at LNE-SYRTE, our product is based on several technological innovations which allow to propose a **compact and robust, turnkey** and fully automated system. MuClock provides a new solution that brings the performances of cold atom frequency metrology, in a **stand-alone, easy-to-use equipment**.

The approach developed by Muquans relies on the **laser manipulation of cold atoms**. The principle of operation is based on the microwave interrogation of a large atomic cloud, cooled down with laser beams to a **temperature of a few μK**. This unique atomic medium shows an **exceptional stability over time**, independent of the external conditions. This technique offers the possibility to perform over months spectroscopy measurements with an exceptionally high signal-to-noise ratio and a remarkable stability.

General view of Muquans's cold atom frequency standard. The lower racks contain all the electronics, control units, and laser systems. The upper part visible inside the frame is a magnetic shield containing the atomic resonator.

Muquans - Institut d'Optique d'Aquitaine, Rue François Mitterrand, 33400 Talence - FRANCE - + 33 (0)5 57 01 73 50 - www.muquans.com

Key Technologies

▸ Isotropic Laser Cooling

The general idea behind the system design is to prepare the cold atom cloud inside the microwave cavity and interrogate the atoms at the same place. This is achieved with isotropic laser cooling (ILC). ILC utilizes the reflections on the inner surface of the microwave cavity to produce a well-controlled laser field for efficient cooling of the atoms. The preparation of the atomic cloud is quickly followed by its microwave interrogation. This measurement sequence is repeated at a 10-Hz repetition rate. With this approach, we therefore obtain performances close to atomic fountains with a significant weight and volume reduction and improvement in compactness, ease of use, and robustness to the environment.

▸ Telecom-based, entirely fibered laser technologies

The laser system developed by Muquans is based on the utilization of an amplified seed laser operating at 1560 nm, which is then frequency-doubled to generate the required wavelength of 780 nm. This approach therefore gives access to a wide variety of high performance fibered optical components, originally developed for high-bit-rate optical communications systems. Thanks to the technological effort conducted over the last 20 years by the telecom industry, these components present unique features:

- All-fibered components: no optical alignment required
- Extreme optical and electrical performances
- Compliance with Telcordia qualification procedures (extended temperature range)
- High reliability (lifetime > 50 000 h)

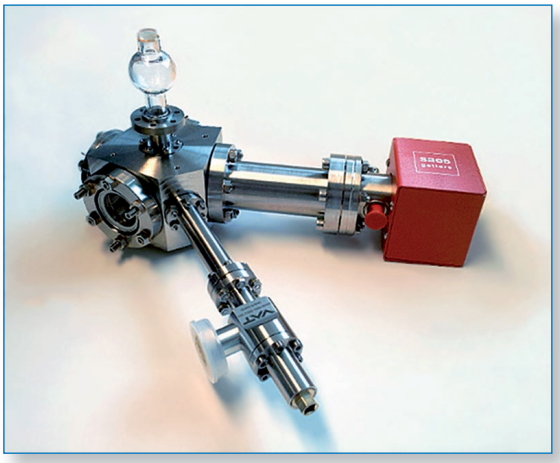
Specifications

▸ Frequency stability

1 s	≤ $3.0\ 10^{-13}$
10 s	≤ $9.5\ 10^{-14}$
100 s	≤ $3.0\ 10^{-14}$
1000 s	≤ $9.5\ 10^{-15}$
10000 s	≤ $3.0\ 10^{-15}$
1 day	≤ $2.0\ 10^{-15}$
Flicker floor	≤ $2.0\ 10^{-15}$ (@ 10 days)

▸ Phase noise

Offset (Hz)	5MHz Output
1	-121 dBc
10	-151 dBc
100	-163 dBc
1,000	-168 dBc
10,000	-176 dBc
100,000	-178 dBc



The heart of MuClock is a vacuum chamber. The low pressure Rubidium vapor inside is laser cooled in the spherical glass cell, and interrogated thanks to a spherical micro-wave cavity surrounding it (not on the picture).

▸ Accuracy

High predictability: low noise floor and accuracy of a few 10^{-15}

▸ Available outputs

Output frequencies: 5, 10 and 100 MHz
Synchronization options: PPS input & output

▸ Power

Operating power	200 W
Peak power	250 W

▸ Physical characteristics

Dimensions

Height	155 cm
Width	55 cm
Depth	80 cm
Weight	135 kg

References

- Esnault et al, Advances in Space Research **47**, 854-858 (2011)
- Guéna et al, Contributing to TAI with a secondary representation of the SI second. Metrologia 2014, **51**, 108-120
- BIPM, Recommended values of standard frequencies for secondary representations of the definition of the second, CIPM (2015) www.bipm.org/utils/common/pdf/mep/87Rb_6.8GHz_2015.pdf

μQUANS

Contact

Should you have any inquiry regarding our products or our technologies, please feel free to contact us.

sales@muquans.com

www.muquans.com