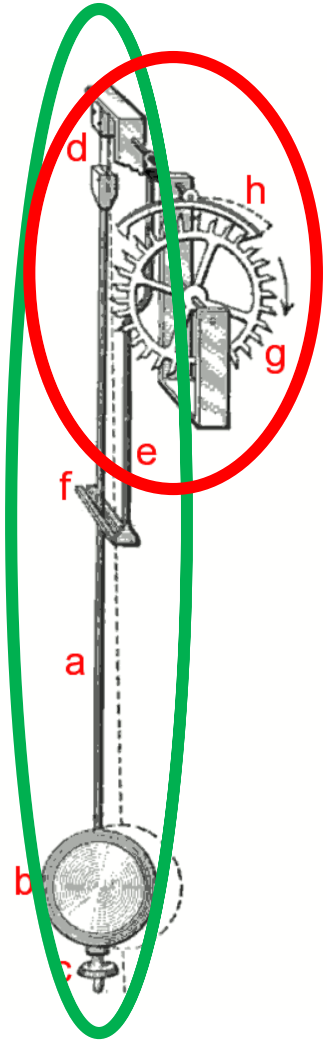
Atomic clocks development at Orolia Switzerland

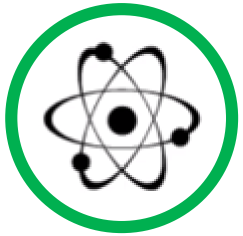
S. Grop

[1] Orolia Switzerland, rue Vauseyon 39, Neuchâtel, Switzerland

TIME & FREQUENCY

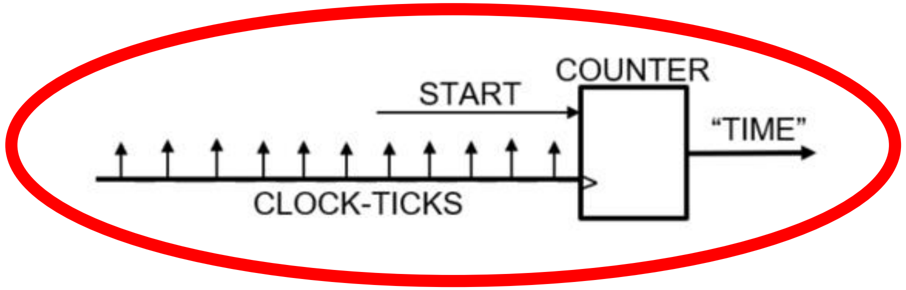


- An atomic clock is a frequency device based on physics (called **Physics Package**)



Provides « ticks » at highly precise intervals (period)

- Electronics count « ticks » for time interval (called **Electronics Package**)



- « Time-Clock » provides the elapsed time from « start »
- Granularity of time related to tick period
- PLL … reduce tick interval; Divider … increase tick interval

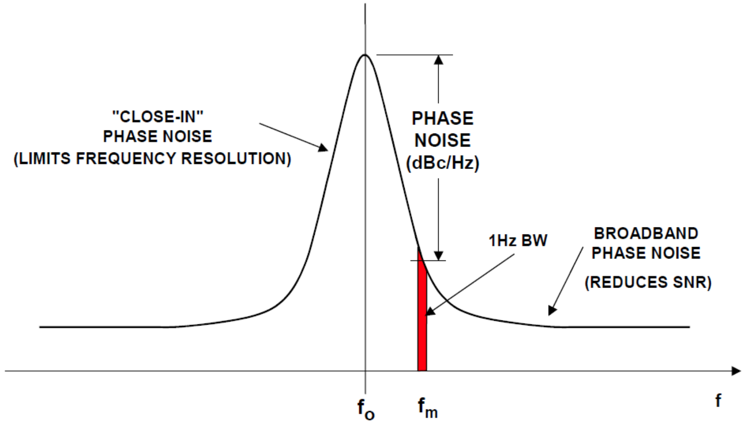
- Time is a combination of a signal (event) and a label (time value) and is always considered in terms of elapsed time from an agreed-upon reference

CHARACTERIZATION TOOLS

Phase noise in dBc/Hz
In the frequency domain

Phase noise is defined as the ratio of the noise in a 1Hz bandwidth at a specified frequency offset, f_m, to the oscillator signal amplitude at frequency f_O.

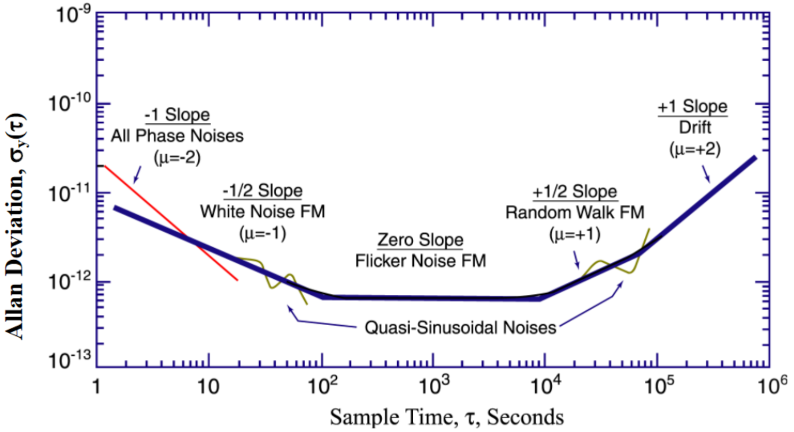
$$S_\varphi(f_m) = 10\log\frac{P_{SSB}}{P_c}$$



Allan Deviation
In the time domain

The Allan variance is most common time domain measure of frequency stability.

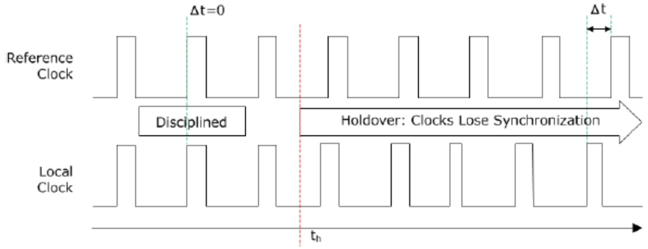
$$\sigma_y^2(\tau) = \frac{1}{2(M-1)}\sum_{i=1}^{M-1}[y_{i+1} - y_i]^2$$



Holdover in s
In the time domain

The holdover is the capability of a clock to keep the 'time' (or phase) when not disciplined by a reference clock.

$$\Delta t(\tau) = \Delta t_0 + y_0\tau + \frac{D\tau^2}{2} + \sigma_x(\tau).$$

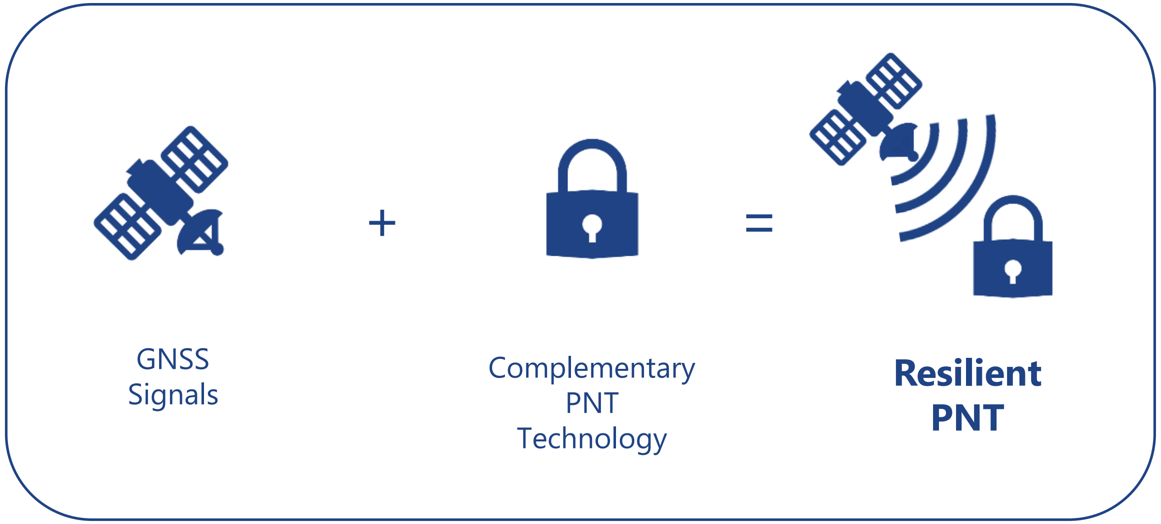


Reference : Miniature Atomic Clock Holdover, a white paper from Microsemi

OROLIA IS THE WORLD LEADER IN RESILIENT PNT

Resilient PNT

At the Core of Mission Critical Applications



In today's world, GNSS signals are not always accurate. Orolia makes these signals virtually fail-safe for critical applications in defense and commercial industries worldwide.

With robust, accurate GNSS-based systems and proven technologies, Orolia is the world leader in Resilient Positioning, Navigation and Timing (PNT) solutions.

Time and Location You Can Trust™

Bolt-on, retrofit solutions that are ready to deploy

OROLIA CH portfolio

Over than 25 years of atomic clock design

COMPONENTS | **SYSTEMS**

ISOURCE+®

Rb Oscillators

mRO-50
Rb Oscillator
Low SWaP

LPFRS
Rb Oscillator
High-Performance

LPFRS/AV1
Rb Oscillator
Rugged airborne

StarLPRO-1500
Rb Oscillator
Compatible to Datum LPRO

iSYNC+®

GPS/GNSS Sync Rb OCXO Oscillators

SRO-100
Rb Oscillator
Disciplined

SRO-5680
Rb Oscillator
Rugged, Disciplined,
Low G

GRClock-1500
Rb Oscillator +
GNSS Rx

LNRClock-1500
Rb Oscillator
Low Noise + GNSS Rx

iSPACE+™

Space-Qualified Oscillators

LNMO
OCXO
Ultra low noise
Master Oscillator

MO
OCXO
Master
Oscillator

Passive Hydrogen Maser

RAFS
Ultra low noise
Rb Frequency
standard

iREFERENCE+®

GPS/GNSS Rb/Maser Standards

GNSSource-2500
Primary reference source
OCXO+Rb+GNSS Rx

RBSource-1500
Rb reference
Disciplined
Compact 1U

Active Hydrogen Maser

Passive Hydrogen Maser

iTEST+®

Clock Instruments

FemtoStepper
High-Performance
Freq. Synthesizer

PicoTime-1U
High-performance
Clock ADEV Stability
analyzer

OROLIA CH portfolio

Over than 25 years of atomic clock design

COMPONENTS			SYSTEMS	
ISOURCE+ ®	**iSYNC+ ®**	**iSPACE+ ™**	**iREFERENCE+ ®**	**iTEST+ ®**

ISOURCE+ ®

Rb Oscillators

mRO-50
Rb Oscillator
Low SWaP

LPFRS
Rb Oscillator
High-Performance

LPFRS/AV1
Rb Oscillator
Rugged airborne

StarLPRO-1500
Rb Oscillator
Compatible to
Datum LPRO

iSYNC+ ®

GPS/GNSS Sync Rb OCXO Oscillators

SRO-100
Rb Oscillator
Disciplined

SRO-5680
Rb Oscillator
Rugged, Disciplined,
Low G

GRClock-1500
Rb Oscillator +
GNSS Rx

LNRClock-1500
Rb Oscillator
Low Noise + GNSS Rx

iSPACE+ ™

Space-Qualified Oscillators

LNMO
OCXO
Ultra low noise
Master Oscillator

MO
OCXO
Master
Oscillator

Passive Hydrogen Maser

RAFS
Ultra low noise
Rb Frequency
standard

iREFERENCE+ ®

GPS/GNSS Rb/Maser Standards

MIC **HP-CPT**

GNSSource-2500
Primary reference source
OCXO+Rb+GNSS Rx

RBSource-1500
Rb reference
Disciplined
Compact 1U

Active Hydrogen Maser

Passive Hydrogen Maser

iTEST+ ®

Clock Instruments

FemtoStepper
High-Performance
Freq. Synthesizer

PicoTime-1U
High-performance
Clock ADEV Stability
analyzer

Spectratime mRO-50 specifications

Miniaturized Rubidium Oscillator (mRO-50)

The clock design is based on the “classical” rubidium clock heritage at Orolia. It has been adapted for low power (0.36W@3.3V) and small size (51cc).

Key Features

- ADEV ≤ 4E-11 @1s (S option)
- < 0.45W @ 5V or < 0.36W @ 3.3V
- < 5E-12/day (A option)
- < 51cc

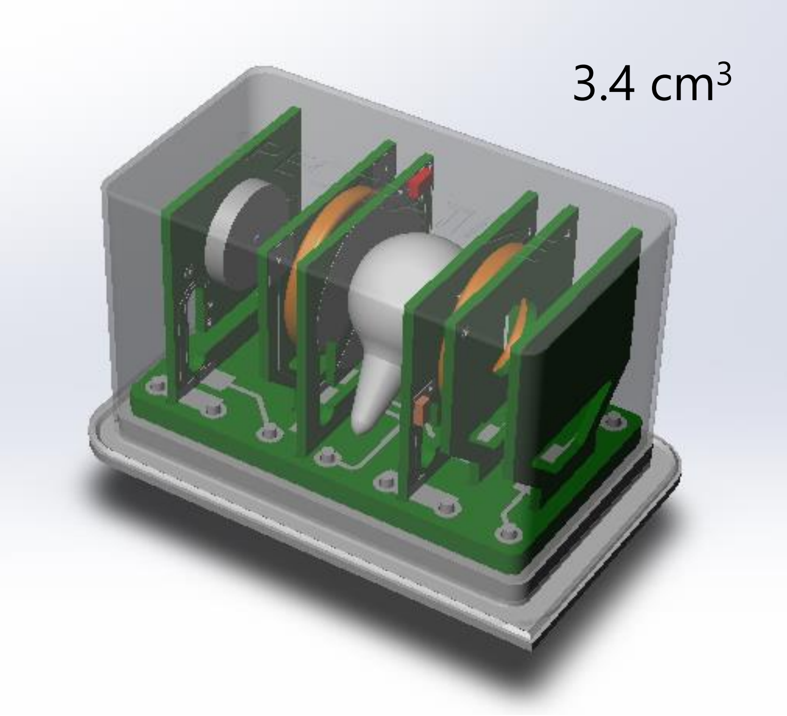
Frequency	10 MHz
Temperature range	-10°C to +60°C
Frequency change over Temp. range	< 4E-10
Short term stability (ADEV)	1E-10 @ 1s (standard)
Aging (after 3 month)	< 1E-11 / day

Size	50.8 × 50.8 × 19.5mm.
Weight	75 g max.
Volume	< 51 cc
Power	0.45 W

MRO-50 PHYSICS PACKAGE DESIGN

Design changes to reduce volume and power consumption

- **The plasma-lamp (few Watts) is replaced with a low power VCSEL (few mW)**
- The glass-blown vapor cell is reduced to a sphere with 5 mm diameter
- The physics package is encapsulated in a DIL-14 package with Xenon backfill (**40% power consumption reduction**)
- 85Rb (3 GHz), D1 line (795nm) double-resonance
- Cavity replaced by simple ring-antenna
- Worldwide patented

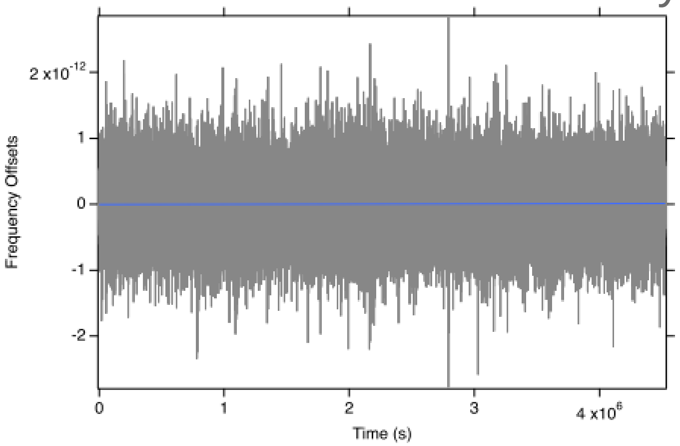


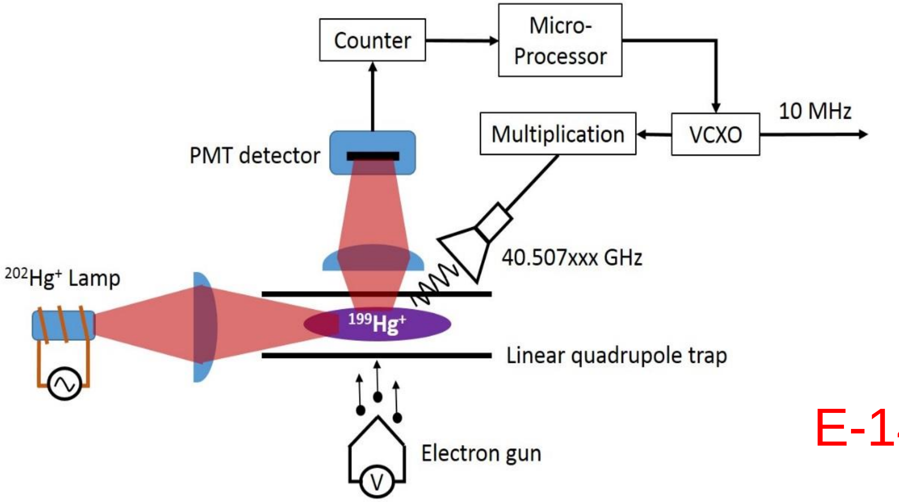
3.4 cm^3

Needs of VCSEL supplier 795nm +/- 0.5nm / < 130uW optical power / mono-mode / linewidth < 100MHz

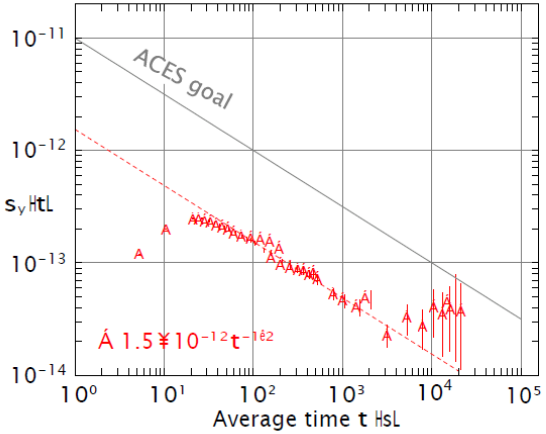
HG ION CLOCK (MIC)

56 days





E-14/day



3E-16/day

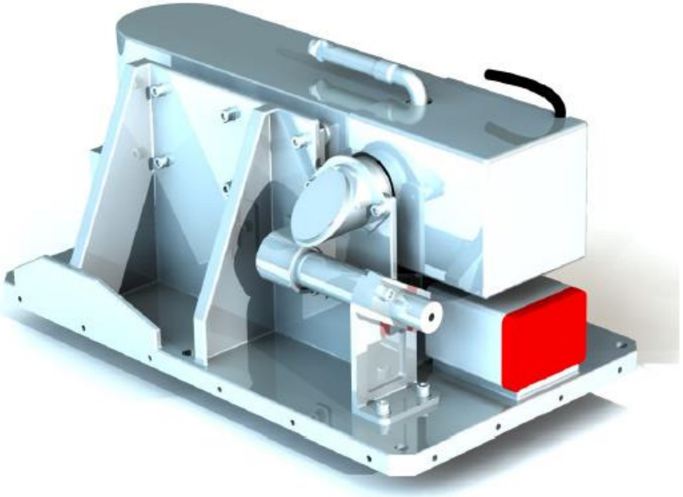


Figure 1. The ~ 3 liter physics package with baseplate, photomultiplier tube and vacuum tube mounting through the two layer magnetic shield. An outer magnetic shield is not shown.

SWaP reduction

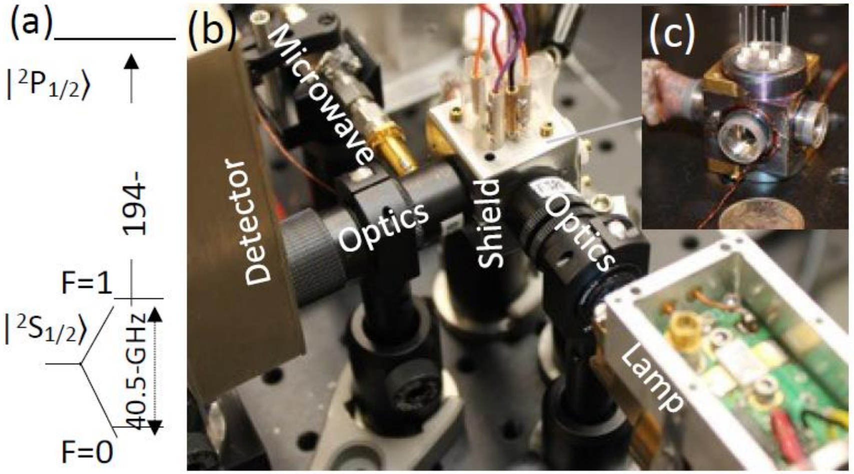


Fig. 1. (a) Simplified energy diagram of the $^{199}Hg^{+}$ ions. (b) The main components of the mercury-ion clock include a 15-cc vacuum trap tube inside one layer of magnetic shield (mu-metal box), mercury lamp, microwave source, associated optics, and detector. (c) A photograph of the 15-cc vacuum trap tube.

T. M. Hoang et al., Stability Demonstration of a 15-cc Mercury-Ion Vacuum Trap Tube, IFCS/EFTF 2020

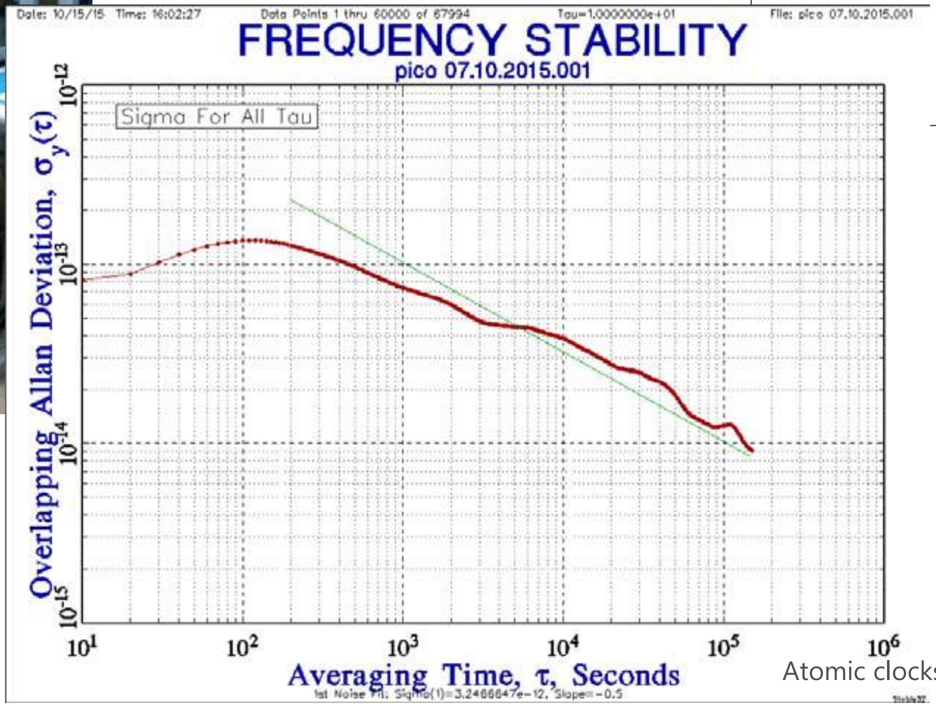
E. A. Burt et al., The Deep Space Atomic Clock: the first demonstration of a trapped ion Atomic click in space, 2020

OROLIA MIC TECHNOLOGY

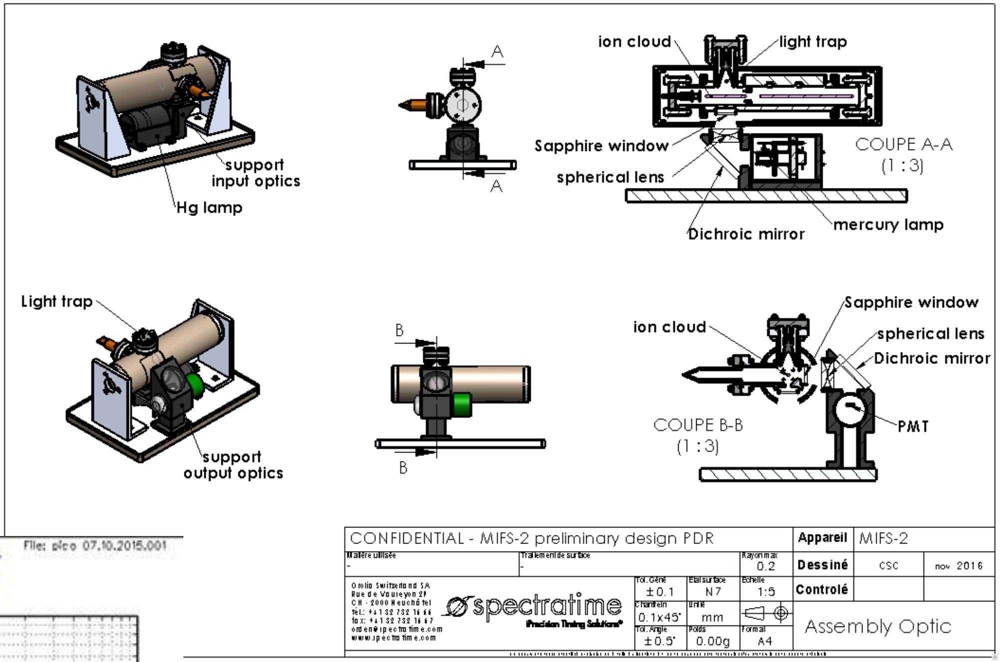
Single photon PMT:

- 194nm
- S = 60mW/A
- Gain = 1E7
- QE = 20-30%

EBB



In development



Light source:

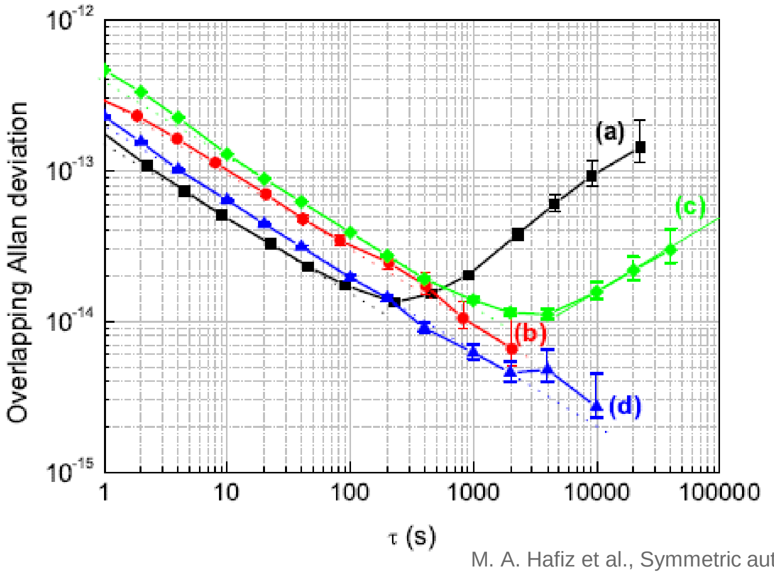
- 194nm
- DFB or DBR
- Mono-mode
- Linewidth < 500MHz
- > 10 µW

HIGH PERFORMANCE CPT

- Pros:
  - Keep the use of glass cell (legacy of Orolia CH for 25 years)
  - Show impressive long term stability in compact form factor

- Cons:
  - Use of OEM for modulation > increase complexity and price
  - Sensitivity to RIN (Relative Intensity Noise)
    - Low Frequency noise required due to FM to AM noise conversion

Very promising technology when DBR or DFB laser diode will be able to be modulated at few GHz



Light source:
- **795nm**
- **DFB or DBR**
- **Mono-mode**
- **Linewidth < 10MHz**
- **150 µW**
- **Modulation bandwidth 1.5GHz**

M. A. Hafiz et al., Symmetric autobalanced Ramsey interrogation for high-performance coherent-population-trapping vapor-cell atomic clock, APL 2018

USA FUNDINGS FOR ATOMIC CLOCKS

FY2022-

Expand support across Quantum Science Roadmap technology areas: **next-GEN Atomic clocks & optical clock prototyping - $29M**

DARPA's atomic clock with enhanced stability to reach technology readiness level (TRL) 7 by 2025 - **$25.4M**

Finalise the **Low-Cost Chip Scale Atomic Clock (LCCSAC)- $8.7M**

FY2021-

Low-Cost Chip Scale Atomic Clock (LCCSAC) – **$7.7M**

DARPA's atomic clock with enhanced stability to reach technology readiness level (TRL) 7 by FY 2025 and commercial availability by FY 2027 - **$27M**

FY2020 –

High Performance, Versatile Iodine Platform-Enabled Reference (**VIPER**+) - designed a new **optical clock physics package** and conducted laboratory testing – **$3.6M**

FY2019 –

Prototyping a new, highly **compact clock** that will aid in navigation and timing for **small platforms** - **$5.1M**

Emphasis on approaches to do quantum state transfer between a trapped ion and photon and leverage the ions for quantum sensing and **quantum clocks - $5.2M**

FY2018 –

Approaches to couple together quantum state transfer between a trapped ion and photon and leveraging the ions for quantum sensing and **quantum clocks** – **$5.1M**

CONCLUSION

Ultra high performance is not a need, compactness and robustness are required

Miniaturize Rubidium Oscillator (mRO-50):

- VCSEL 795nm +/- 0.5nm / < 130uW / mono-mode / linewidth < 100MHz

Mercury Ion Clock (MIC):

- DFB / DBR 194nm / > 10uW / mono-mode / linewidth < 500MHz
- PMT 194nm / S = 60mW/A / Gain = 1E7 / QE = 20-30%

High Performance – Coherent Population Trapping (HP - CPT):

- DFB / DBR 795nm / < 150uW / mono-mode / linewidth < 10MHz / modulation bandwidth 1.5GHz

STAY CONNECTED

Keep up with the latest on Orolia and don't hesitate to get in touch if you have any questions or need additional information. Explore the channels below for the best ways to reach us and stay connected.

DIGITAL

www.Orolia.com

sales@Orolia.com

support@Orolia.com

SOCIAL

company/Orolia

@OroliaPNT

Search for Orolia

R&D manager:
serge.grop@orolia.com