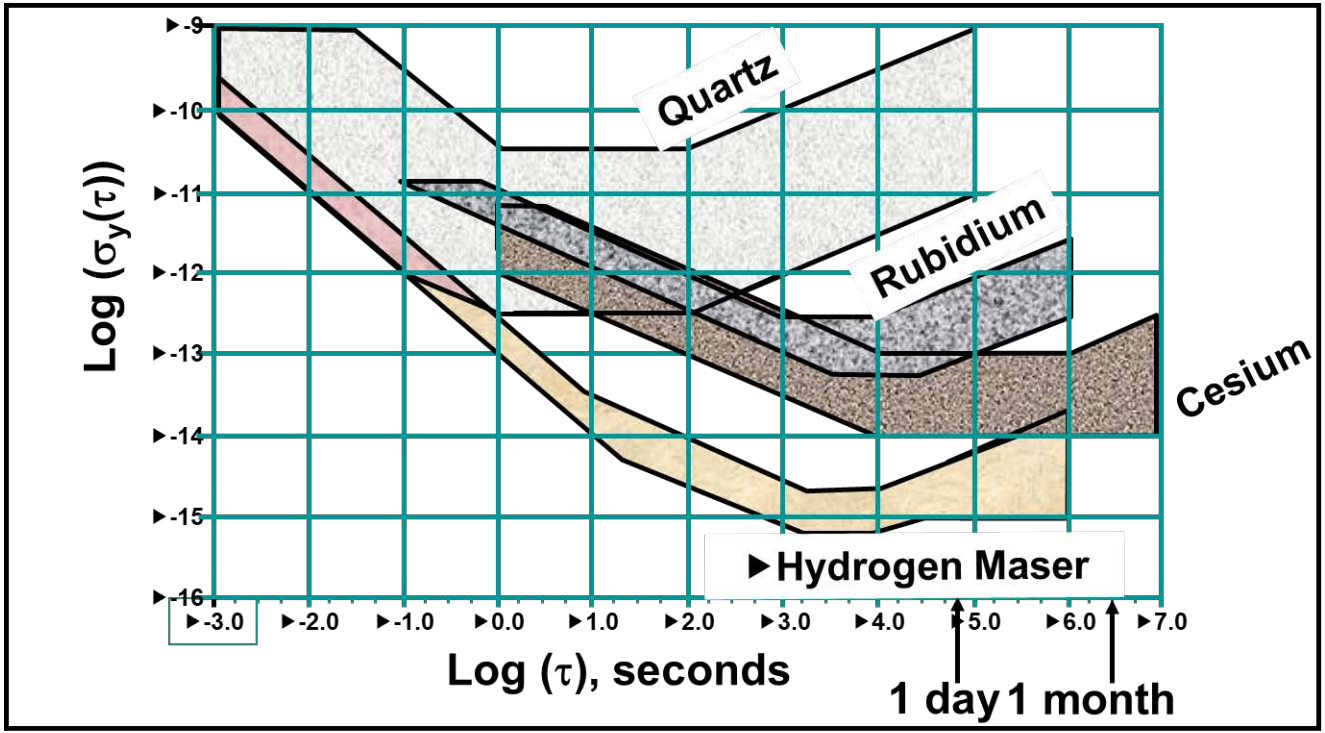
Atomic Clocks Technologies

Pascal Rochat / Managing Director

Clocks comparaison chart



Products overview (Q4 2017):

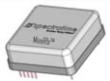
spectratime
iPrecision Timing Solutions®

COMPONENTS

iSource+®

Rb Oscillators




NEW


iSpace+™

Low SWaP Oscillators



OCXO
NEW


MiniRb
Rb

PMs

iSync+®

GPS/GNSS Rb OCXO Oscillators


GPS-locked Rb

GPS Rb or OCXO

GPS-locked Rb & LN OCXO
NEW

AntiVibe

iReference+®

GPS/GNSS Rb OCXO Standards


GPS-locked Rb

GPS Rb & LN OCXO

A/P Masers



iTest+®

Clock Instruments


1ps ADEV

GPS Rb & 1ps ADEV

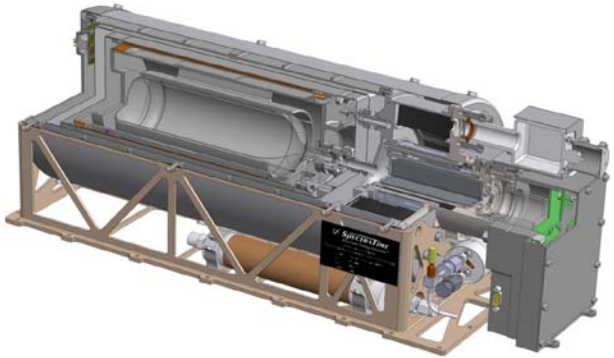
100fs Synthesizer

orolia Group

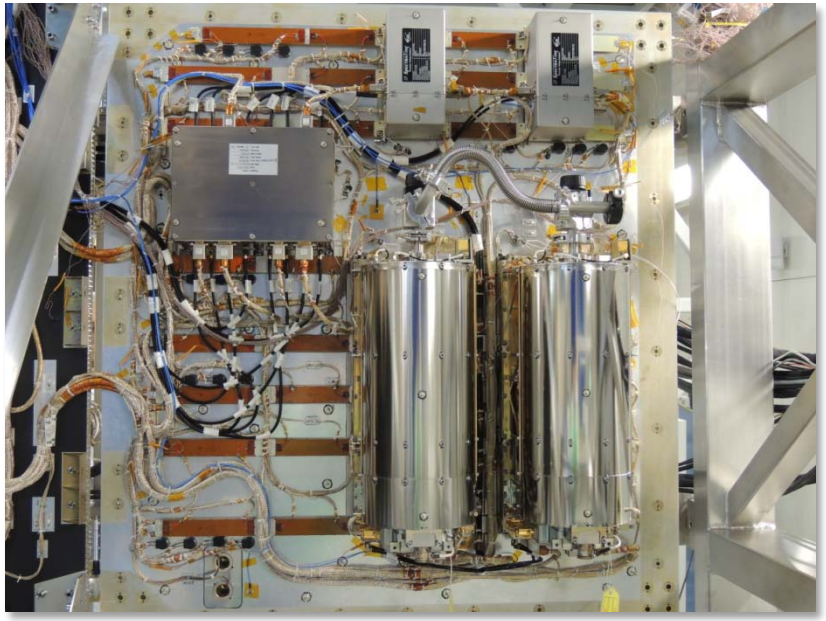
spectratime
iPrecision Timing Solutions®

PHM (Passive Hydrogen Maser)

Mini PHM Physics Package

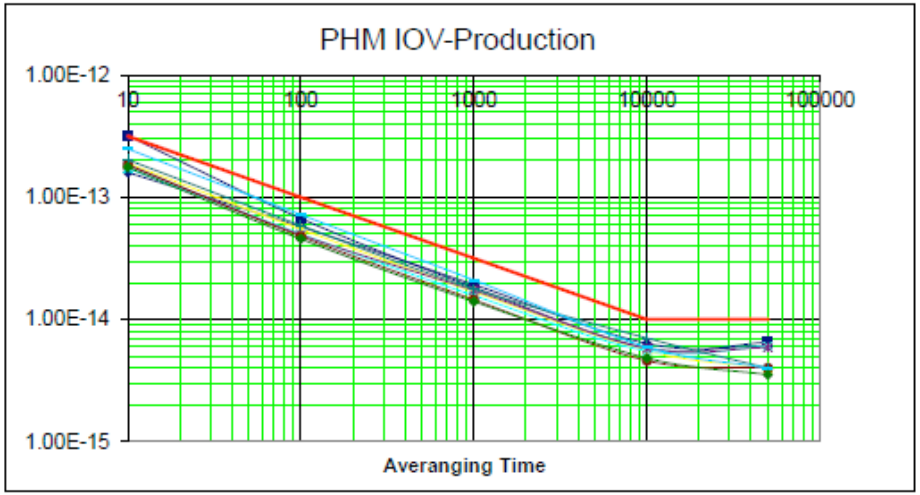


PP Galileo MINI PHM : ~ 8kg

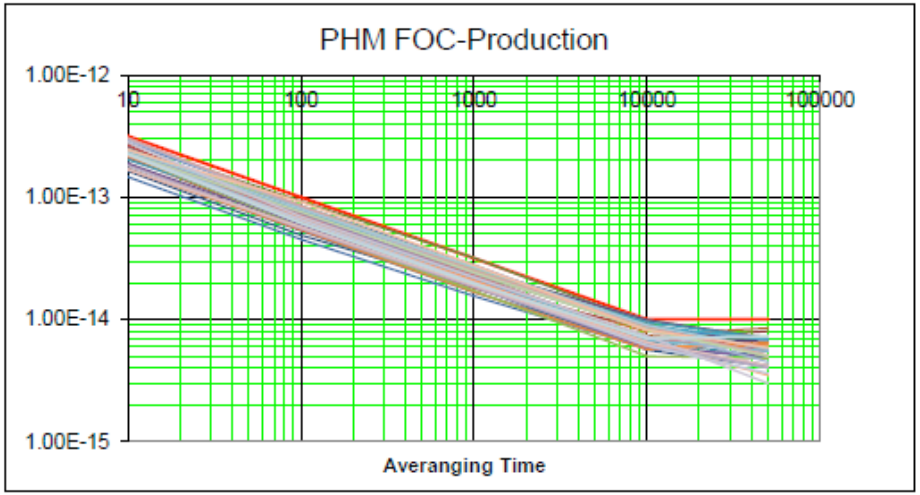


Galileo Payload :Timing sub-system

Galileo Passive Maser performances



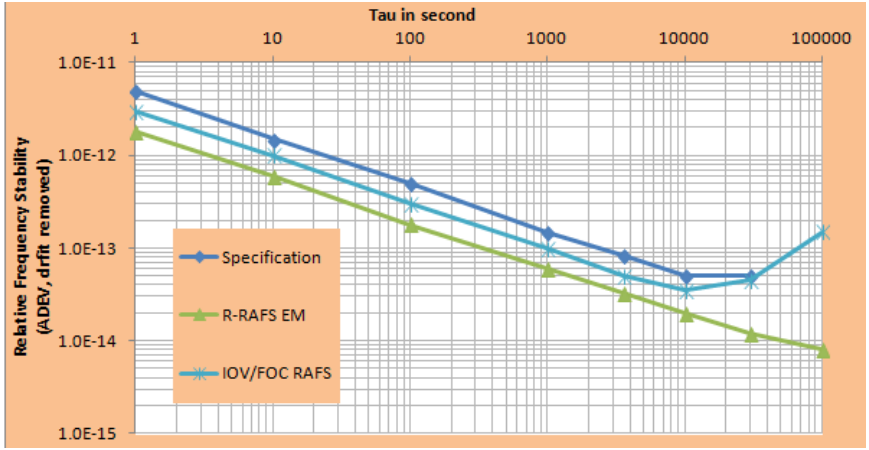
8 Units

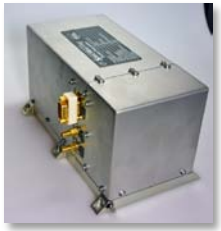


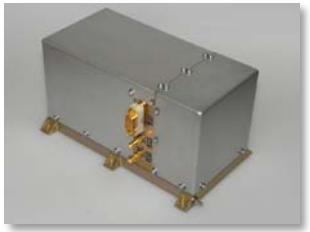
44 Units

R-RAFS (Robust Rb Atomic Frequency Standard)

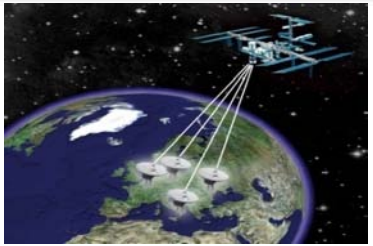
- Removal of frequency discontinuity observed in original design (1/20 light shift reduction)
- Improvement of the drift predictability over several days
- 100% Compatible with previews design (electrical, mechanical and thermal)





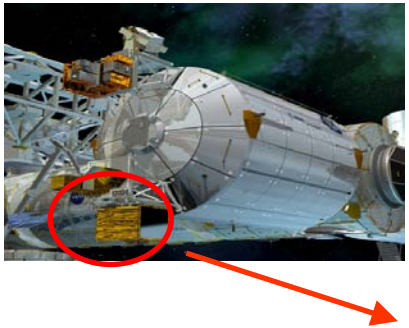


SHM (Space Hydrogen Maser) for Space Science



ACES mission on the International Space Station

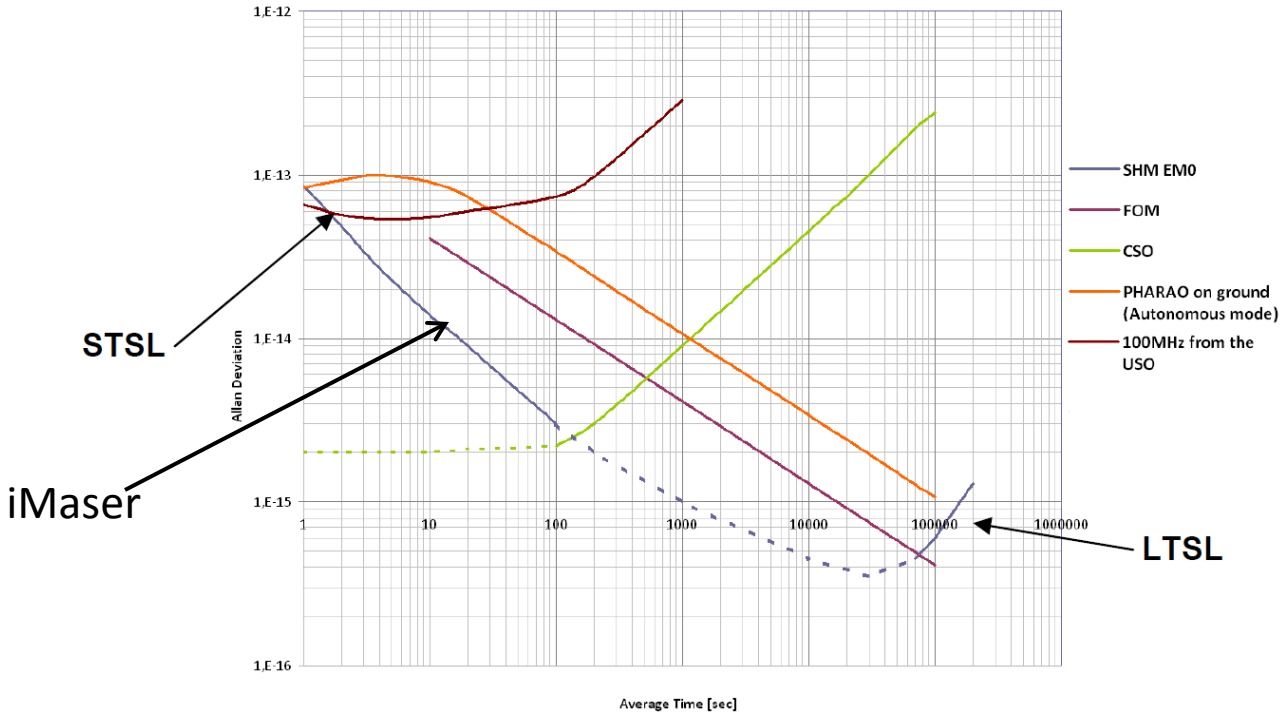
- Launch: 2019
- Demonstrate the high performances of a new generation of space clocks
- Perform fundamental physics tests (Einstein's general relativity and theories of gravitation)



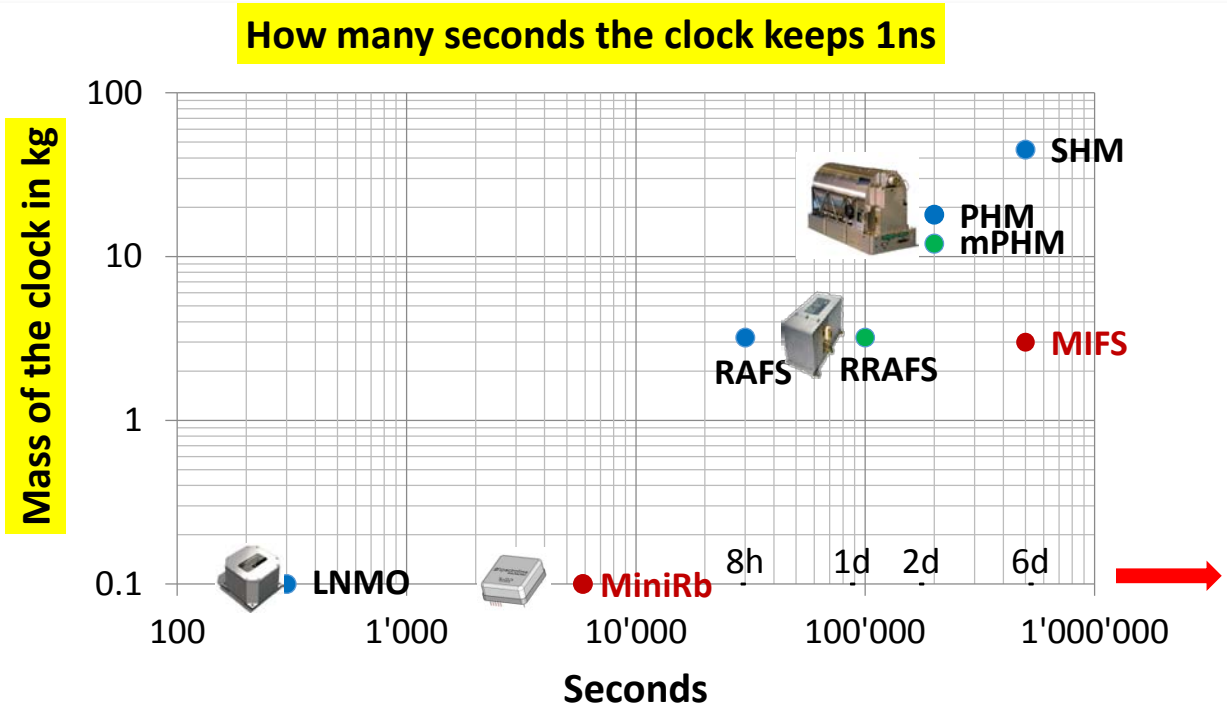
Cooperation in space science

- Fundamental physics:
  E-GRIP - Einstein Gravitational Red-Shift Probe
  Chinese Space Station ?
- Astrophysics: *Space VLBI ?*

Maser vs other clocks

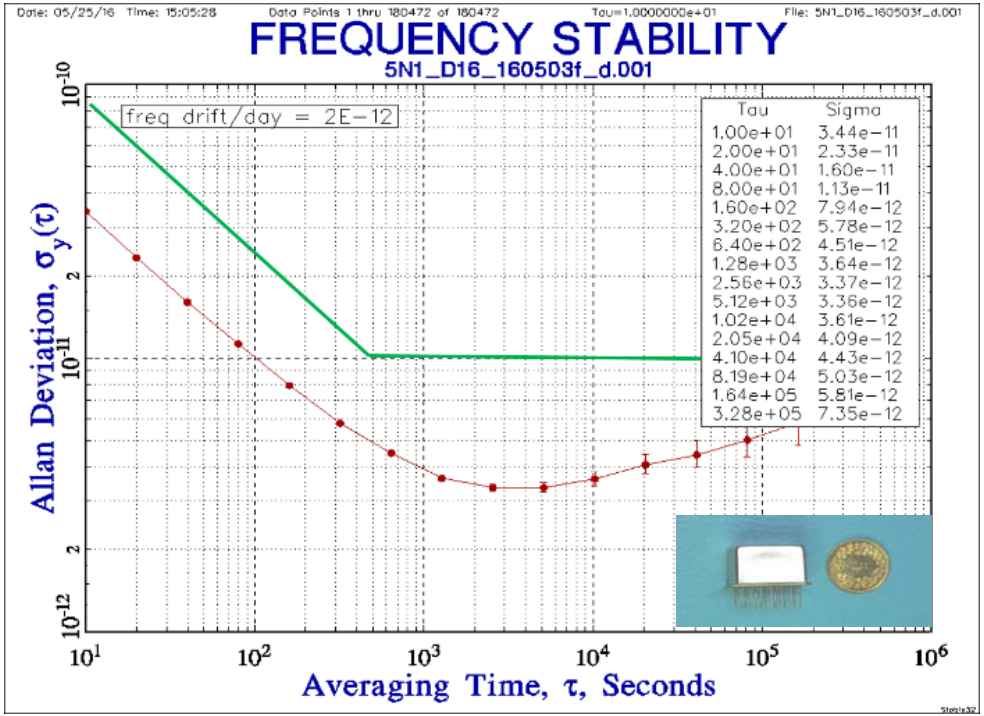


Time keeping capabilities comparaison



- High accuracy and stability atomic frequency clock
- Low SWAP (Size, Weight and Power) and cost features
- Enhanced CSAC (Chip Scale Atomic Clock) technology
- Small form factor & ultra-portable packaging
- Standard quartz oscillator pinouts

MiniRb™ Specifications



Extremely compact Physics Package (2 cc)

- PP power consumption < 150mW
- Hermetically sealed PP DIL14

Excellent long term stability

- Typical frequency drift : 2E-12 / day

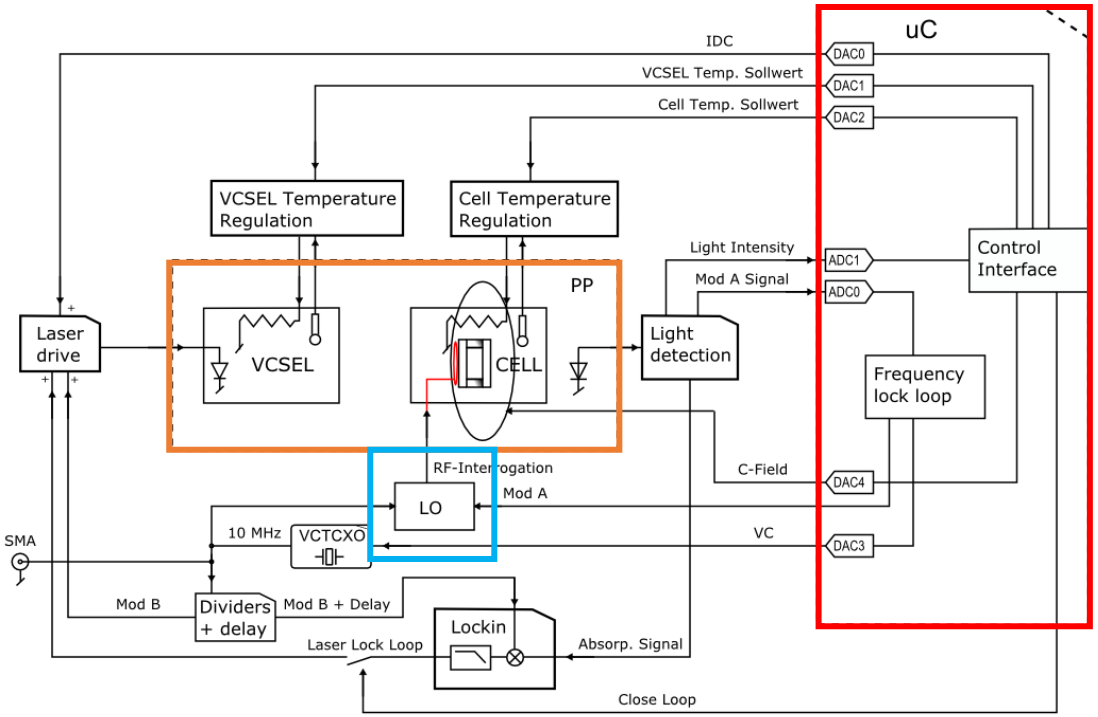
Mid term stability

- Guaranteed < 1E-11 @ 1 day

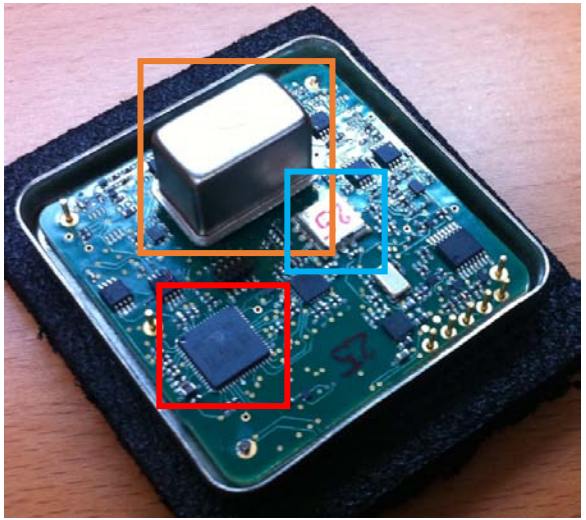
Manufacturing techniques :

- Collective manufacturing
- Collective 3D printing

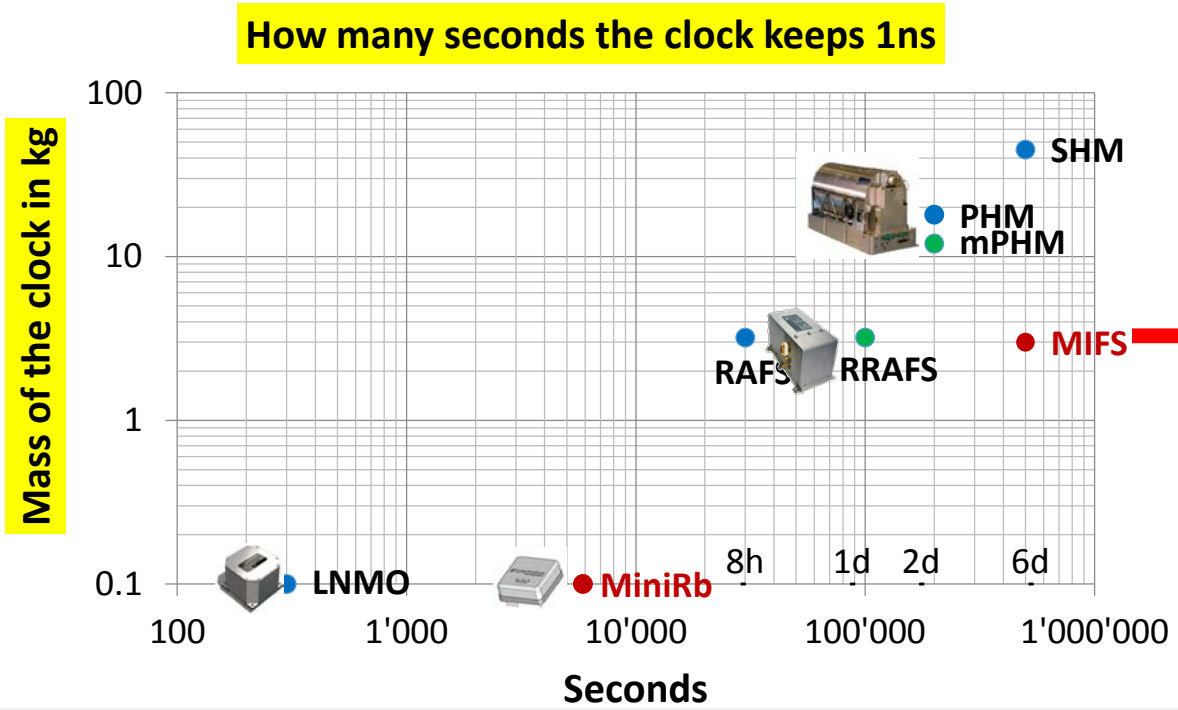
MiniRb™ Low Power Technology



- Physics Package (DIL-14)
- VCO @3GHz
- DSP micro-processor

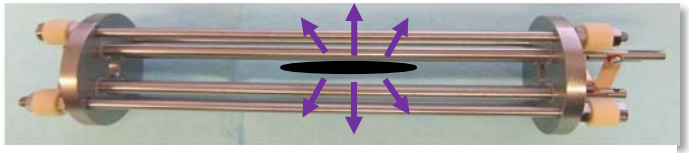


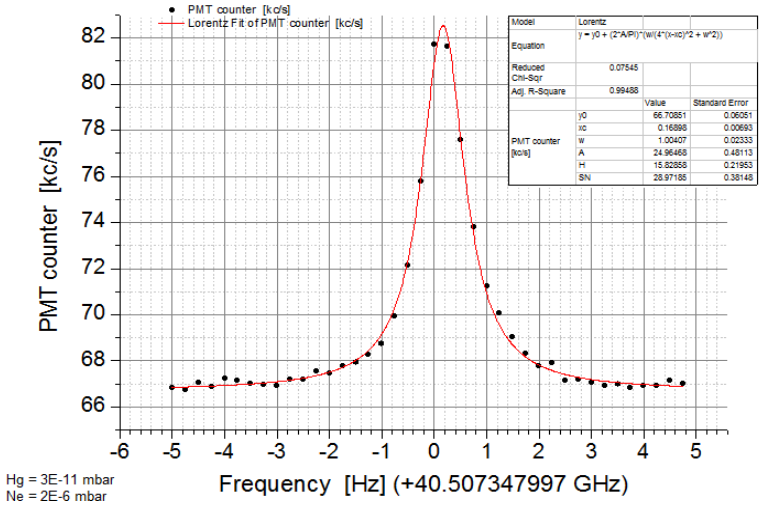
MIFS (Mercury Ion Frequency Standard) Project Goal

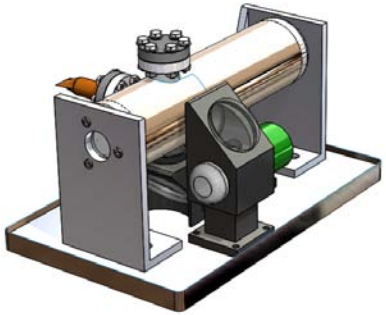


- Low magnetic sensitivity
- No wall collision
- High Q atomic line
- Low frequency drift
- Low temperature sensitivity

MIFS Developement

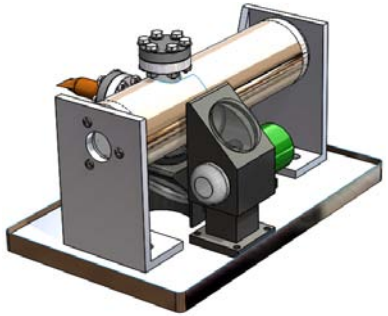






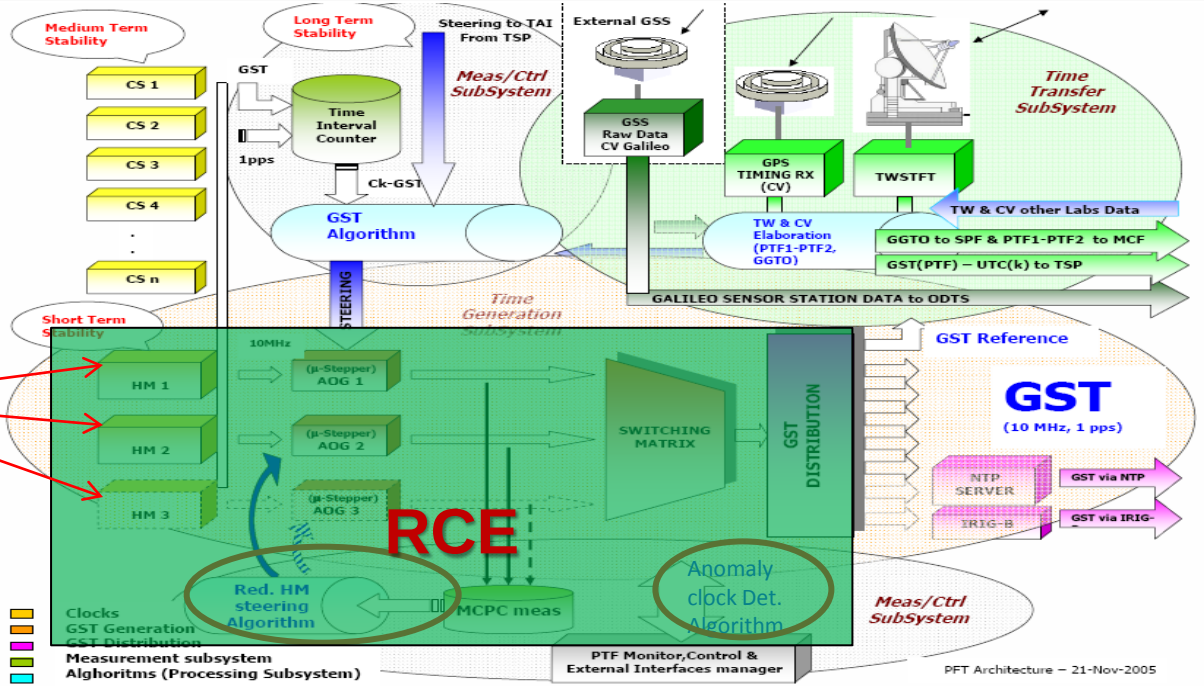
MIFS Developement

Parameter		Clock Technology		
	Unit	PHM	RAFS	MIFS (target)
ADEV@1s	-	< 1E-12	3E-12	< 1E-12
ADEV@1d	-	< 5E-15	3E-14	< 1E-14
Frequency drift	1/day	<1E-15	< 1E-13	< 1E-15
Magnetic sensitivity	1/G	< 3E-13	< 1E-13	< 1E-14
Thermal sensitivity	1/°C	< 3E-14	< 5E-14	< 1E-15
Volume	litre	28	2.5	< 5
Mass	kg	18	3.4	< 5
Power	W	60	< 35	< 30
Lifetime	years	12	> 15	> 15
Time to 1 ns error	days	2	0.3	10



- ESA TRP = TRL 3
- ESA GSTP 6.1 = TRL 4/5 (2017-2018)

RCE : Robust Clock Ensemble on ground
Precise Timing Facility (PTF) of Galileo GMS

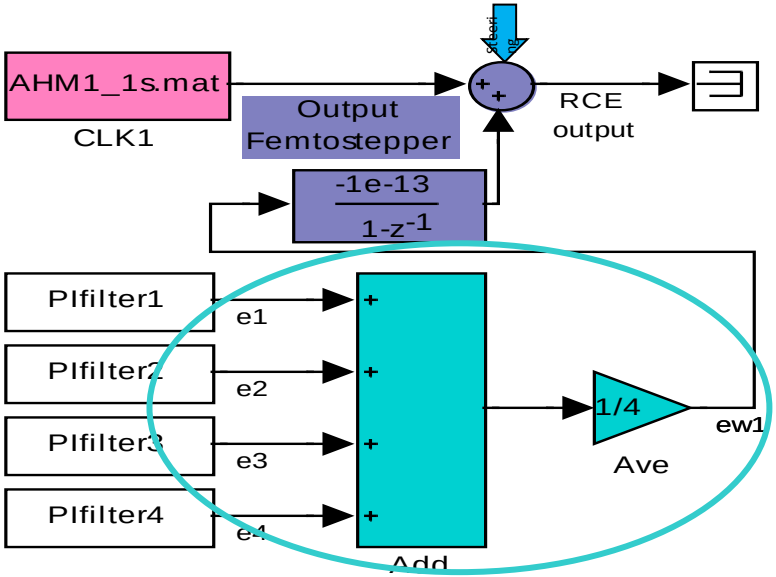


Robust Clock Ensemble (RCE) solution for physical realization of GST for next PTF generation

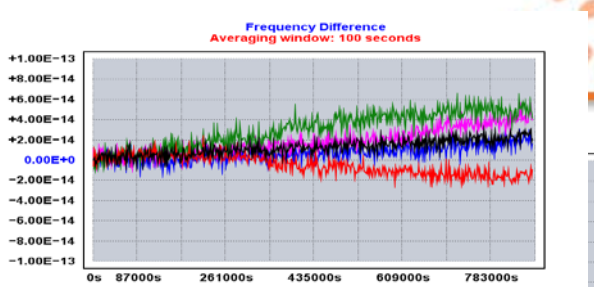
- Robustness
- Redundancy
- Improved performance within E-15 level over a day
- Reliable anomaly detection and automatic fault compensation or smooth switch-over
- Continuity in frequency and phase
  - reliable satellite clock modeling for navigation
- Simple

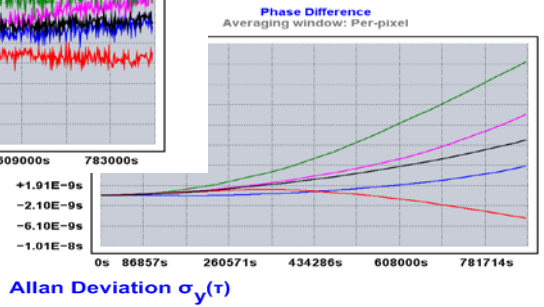
B. One CLock Ensemble (ONCLE)

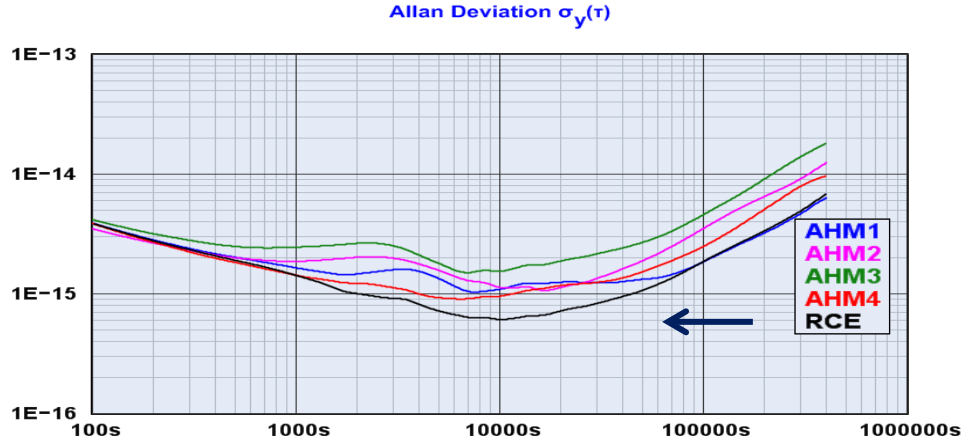
- Ensemble generation: weighted or simple average of clocks



$$ew1 = -(e1+e2+e3+e4)/4$$

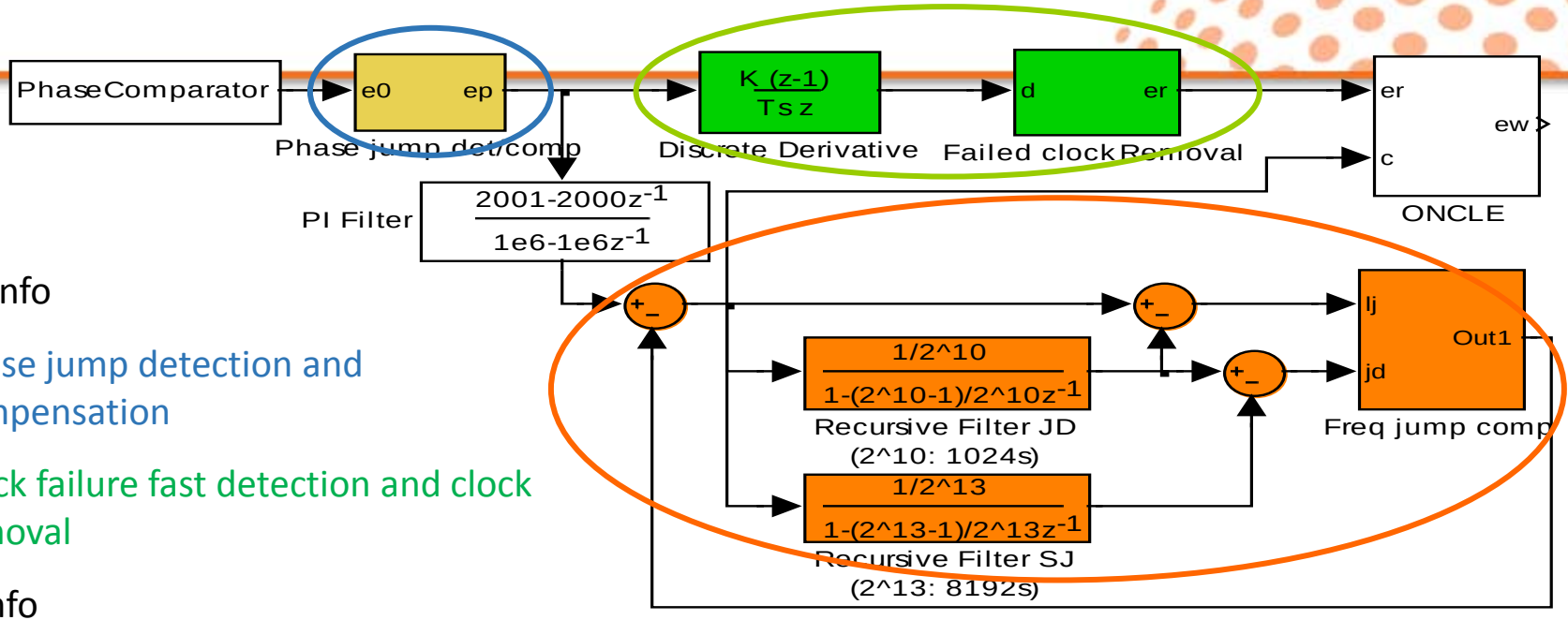






- Freq. stability imp. $1/\sqrt{N}$
- Freq. drift: average, adjustable via FemtoStepper by correction command

C. Clock Fault Detection and Compensation (CFDC)



Phase info

- Phase jump detection and compensation
- Clock failure fast detection and clock removal

Freq. info

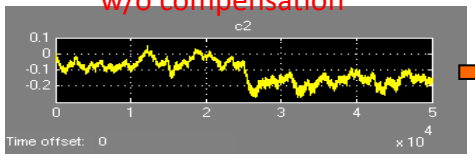
- Frequency jump detection and compensation

Frequency jump detection and compensation - 3

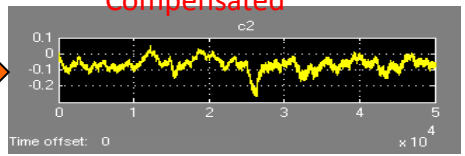
Example 2. Freq. jump of 1e-14: det. & comp. in 1470s

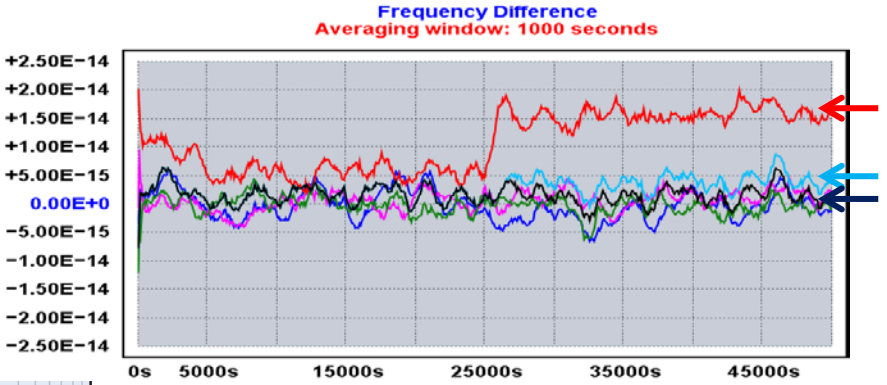
Freq output of PI filter

w/o compensation

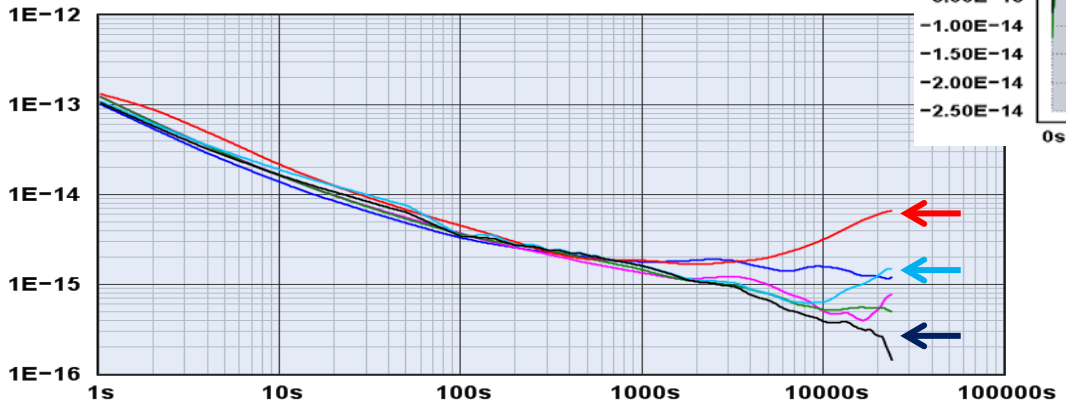


Compensated





Allan Deviation $\sigma_y(\tau)$



AHM2 (Master)
AHM3
AHM4
AHMx_f1e-14
RCE w/o jump comp
RCE jump comp

- Technique verified by testing on EBB of robust On-board FRS

ONCLE

- A novel concept of the ONCLE for a robust time and frequency reference system was firstly proposed by SpT in 2009.

  ONe CLock Ensemble *or* ON-board CLock Ensemble

- Robustness
  - Automatic removal of failed clock and smooth clock switch
  - Efficient real-time detection and correction of clock feared events (frequency/phase jumps, frequency drift, noise increases)

  Filtering: Low-pass recursive filters with different T → Little memories & registers

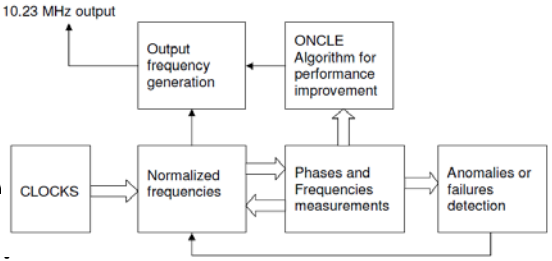
- Improved performance
  - Generation of output signal from an ensemble of clocks

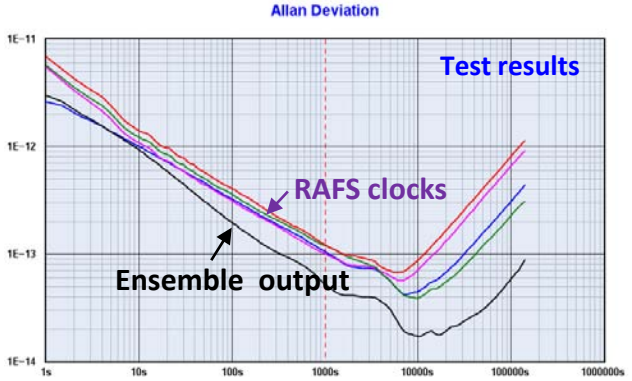
  Ensembling: Weighted or simple average of clocks → Reliable

- Fully transparent from user side and can be handle like a single clock.

ONCLE for Space

- Improved version of on-board timing system in present Galileo system
  - Improved availability, continuity, performances
  - Simple and robust to be implementable in on-board FPGA





- Developments under ESA's EGEP:
  - 2012 – 2014, **FRS**: Robust On-board Frequency Reference Subsystem (EBB)
  - 2015 – ongoing, **CMCU+**: On-board Clock Ensemble CMCU (EM)

Thanks for your attention

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