Quantum Leap

Quantum Sensors Consortium

23/4/2018

The Vision

To use scientific innovations and innovative technologies for implementing breakthrough quantum sensors for commercial use.

Quantum Sensors is a name for a family of products that enable the high precision measurement of basic physical parameters such as **time and frequency (atomic clocks**), **magnetism**, **gravity** and acceleration.

These devices find extensive uses in civil and military systems in communications, location, navigation, computer networks, geo-sensing, medicine, borders protection, earthquake forecasting and more

The Purpose

To develop a variety of generic technologies and methods used in **quantum sensing** to enable the realization of commercial products that challenge the existing sensors in parameters of accuracy, stability, size, operating power, price, and other parameters.

Quantum Sensors

Quantum sensing is typically used to describe one of the following:

I. **Use of a quantum object** to measure a physical quantity (classical or quantum). The quantum object is characterized by quantized energy levels. Specific examples include electronic, magnetic or vibrational states of superconducting or spin qubits, neutral atoms, or trapped ions.

II. **Use of quantum coherence** (i.e., wavelike spatial or temporal superposition states) to measure a physical quantity

III. **Use of quantum entanglement** to improve the sensitivity or precision of a measurement, beyond what is possible classically

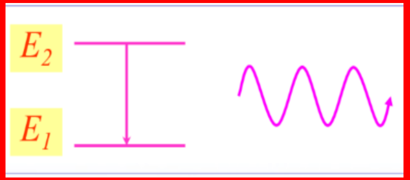
From: "Quantum Sensing", C. L. Degen, F. Reinhard, P. Cappellaro
REVIEWS OF MODERN PHYSICS, Vol. 89, July–September 2017

Quantum Sensors presented in this consortium: Atomic Clocks, Magnetometers, Gravimeters

Quantum Sensors Common Blocks

Optical System Lasers…

Atomic Core



Support Electronics

Algorithm & Software

RF/Microwave

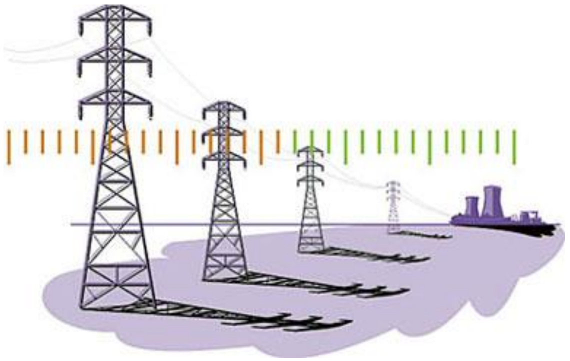
Synergy of Technology : Same Development could be used in several kinds of Sensors

Applications & Market – Clocks & Timing

<u>Civilian</u>

US Homeland Security Report: 15 out of 19 Critical Infrastructures rely on GPS Timing which is vulnerable to spoofing & jamming

- Communication
- Networks
- Oil exploration
- Power Systems
- Finance
- Navigation
- Secure & backup for GPS/GNSS

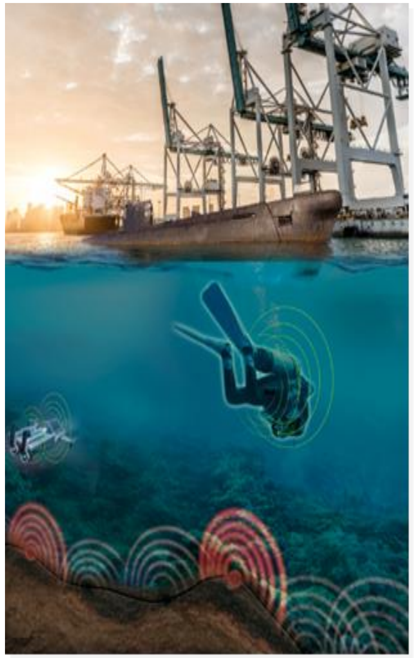


<u>Military</u>

- Communication
- Navigation
- Radar
- C4I
- EW
- IFF
- GNSS Spoofing Detection
- Missile Guidance

<u>Market Size:</u> For miniature clocks only –$2.4B per year

Applications & Market – Magnetometers



Civilian

- Land & Marine Perimeter Protection
- Communication & Pipelines Infrastructure
- Geophysical Mapping
- Humanitarian Demining
- Medical Magnetometry
- Transportation

Military

- Mines, UXO & IED Detection
- Perimeter Monitoring Protection
- Submarine Detection
- Borders Control
- Tunnels Detection

Market Size: 100-200M$

Quantum Sensors Consortium

Core Industries

AccuBeat
- Mini. Clocks
- Cold Clock
- Time/Freq. Dissemination

IAI-RAMTA
- Magnometer High Field
- Multi Sensor System

RAFAEL Am.
- Magnometers Low field
- Gravimeters

RAFAEL MANOR
- Quantum devices miniaturization (mainly clocks)

Academia

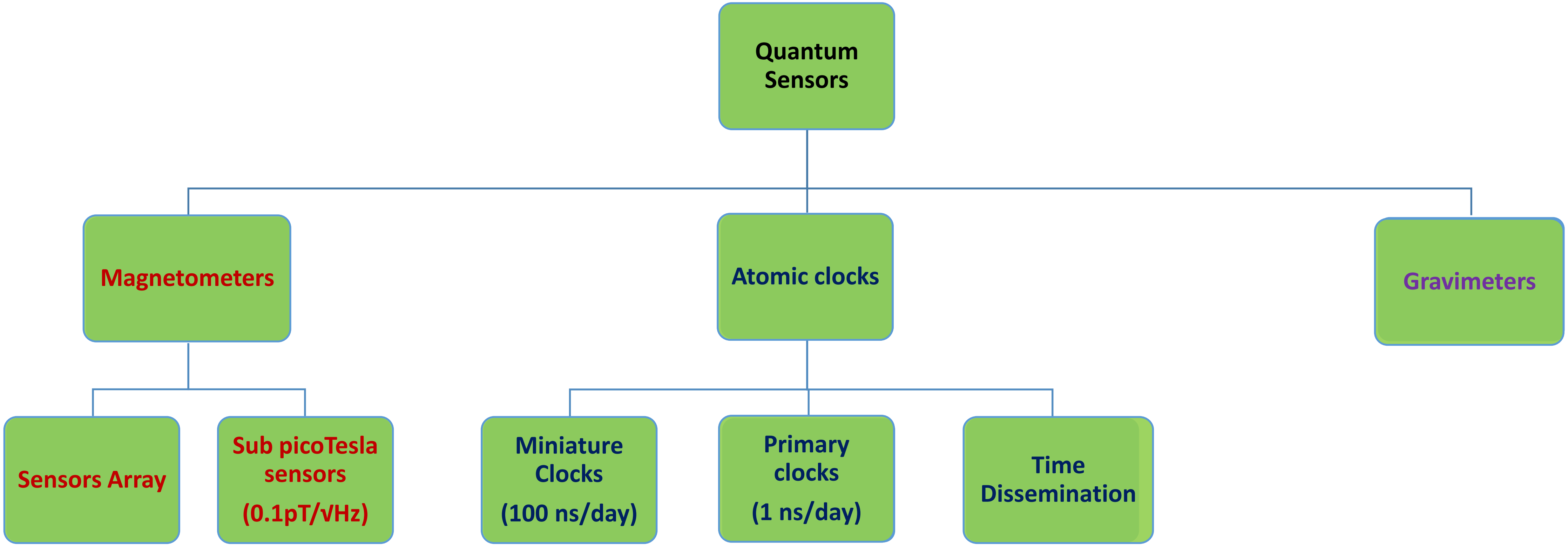
BGU -Folman
- Cold Atoms
- Magnomtr.

BGU - Shuker
- Magnomtrs
- Clocks?

WIZ - Ozeri
- Optical clocks
- T/F Disseminati.

WIZ –Dav./First.
- Magnetometrs
- Gravimeters

R&D Vectors

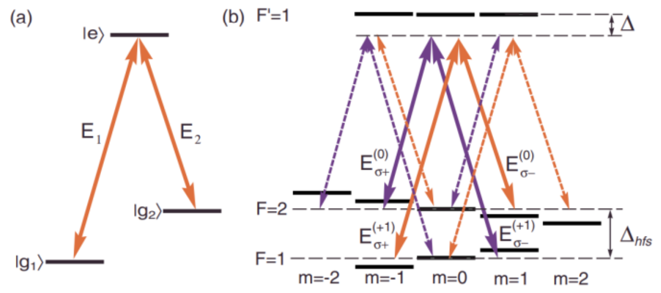


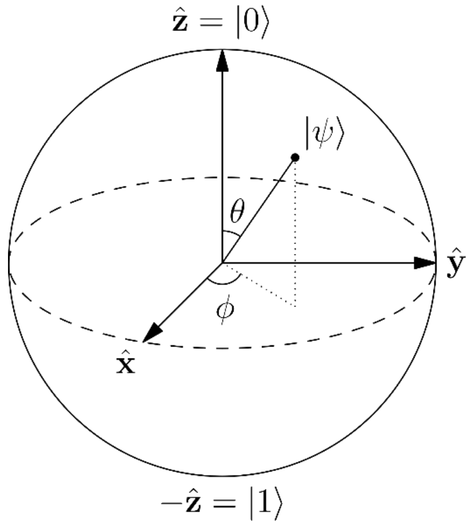
	Magnetometers	Atomic clocks	Gravimeters
Initiator:	Ramta	AccuBeat	Rafael
Supporting groups:	Ron Folman (BGU) Reuben Shuker (BGU)	Ron Folman (BGU) Roee Ozeri (Weizmann) Rafael	Nir Davidzon (Weizmann) Ofer firstenberg (Weizmann)

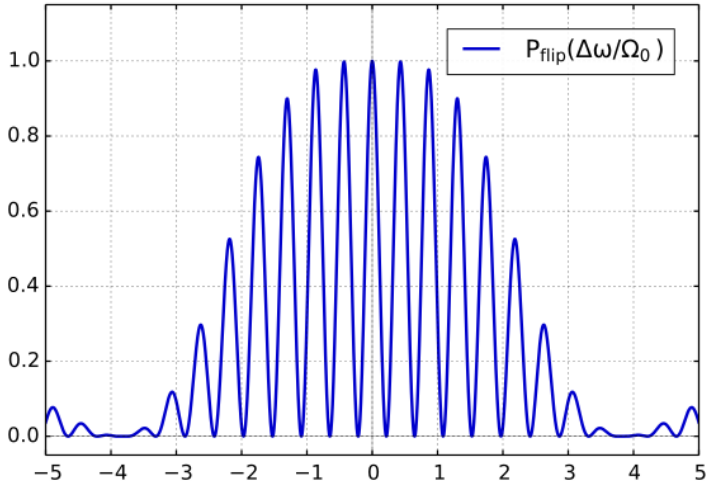
The Technologies

Methods for preparing and interrogating the quantum state

For example, polarization of atoms by optical pumping, phase measurement between two states in the Ramsey method, preparing and interrogating the coherence of an anti-symmetric superposition state in Coherent Population Trapping.



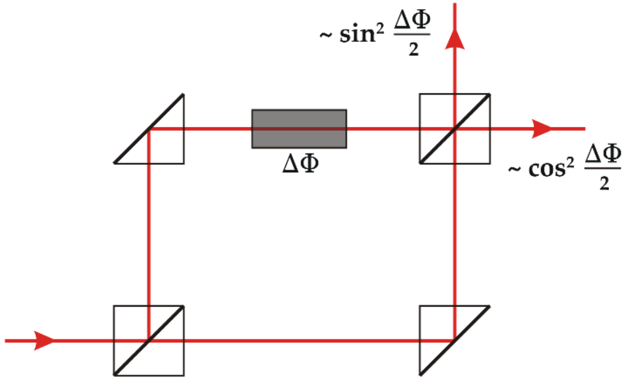


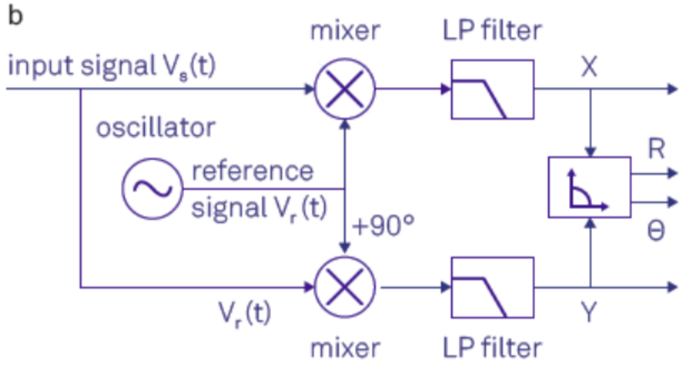


The Technologies

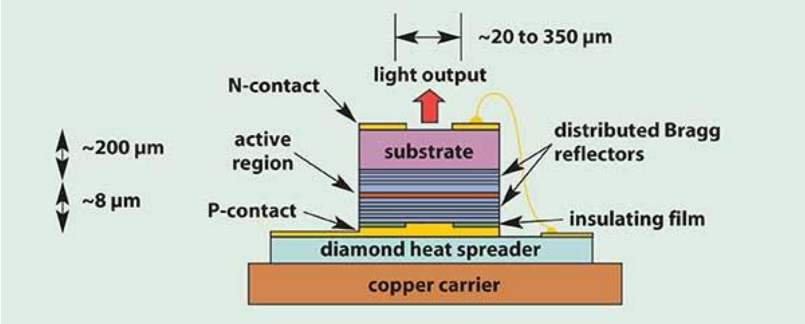
<u>Methods for signal and noise processing and control</u> –

- Algorithm for extracting the sensor's signal from the noise and improving signal to noise ratio.
- Stabilizing parameters using control methods.
- Noise reduction beyond the quantum boundary.
- Interferometry methods for signal detection.





The Technologies



<u>Narrow linewidth modulated lasers –</u>

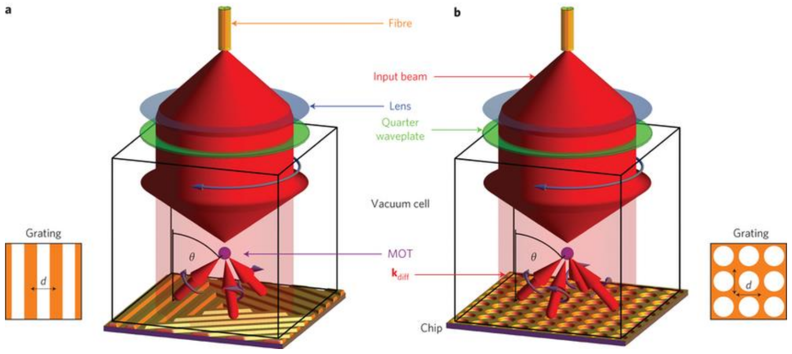
Development of Vcsel diode lasers with enhanced performance:

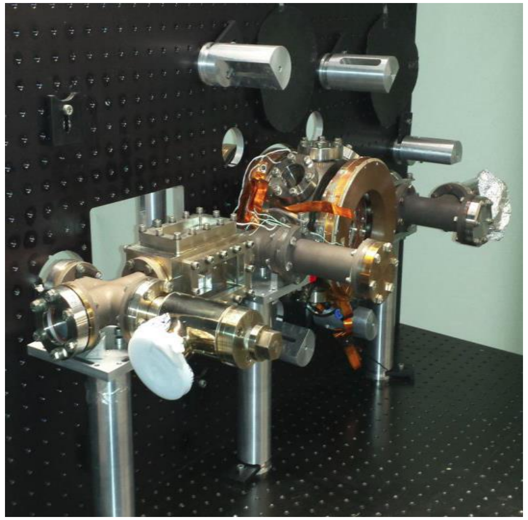
- Narrow linewidth (<10 MHz; today ~100 MHz),
- High power (> 10 mw; today ~2 mW)
- integrated modulators for, power, phase and polarization. .

The Technologies

Cells for hot and cold atoms –

Technologies for the production of vapor cells of alkaline metals in glass or MEMS. Technologies for cooling and maintaining atoms and ions. Miniaturized vacuum cells for holding of hot and cold atoms and ions.





The Technologies

Miniaturization and industrialization of optical systems-

- Optical placement methods
- Micro integration of elements
- “On chip” integrated optics
- Meeting with real environmental conditions

END OF PRESENTATION

AccuBeat Ltd.
Accurate Frequency & Time

RUBIDIUM ATOMIC CLOCKS

GPS-Synchronized Rubidium Clocks
Time & Frequency Systems

Nano Atomic Clock – NAC 1

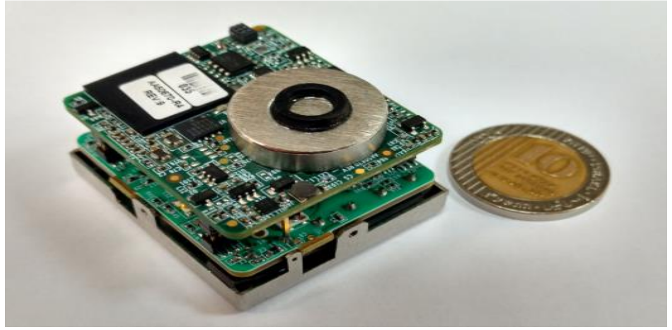
Based on CPT interaction

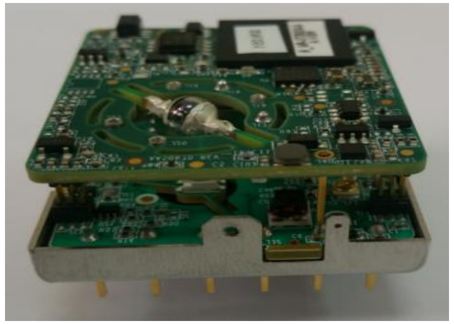
↓

No MW cavity is required

↓

Miniaturization is enabled

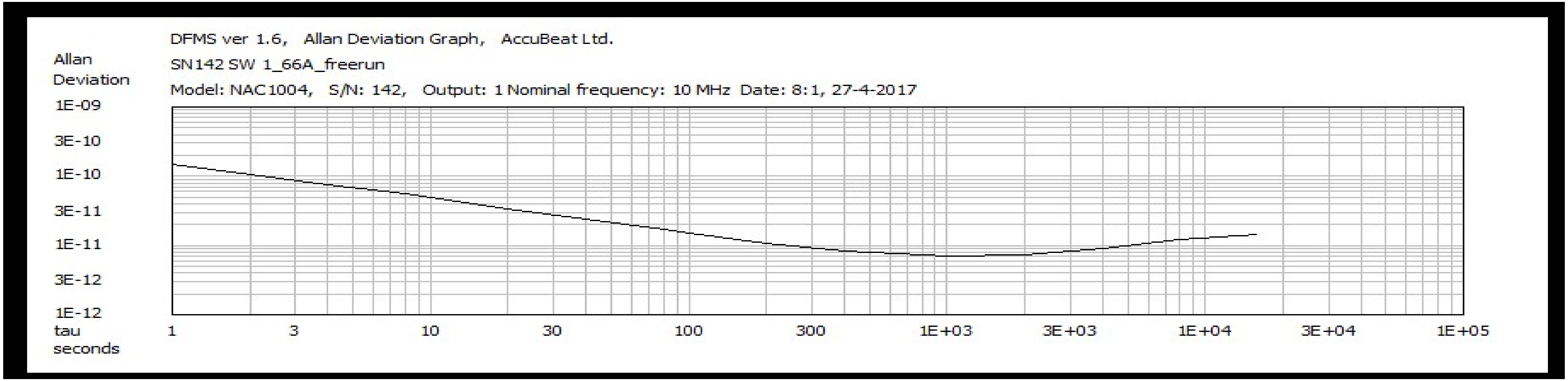


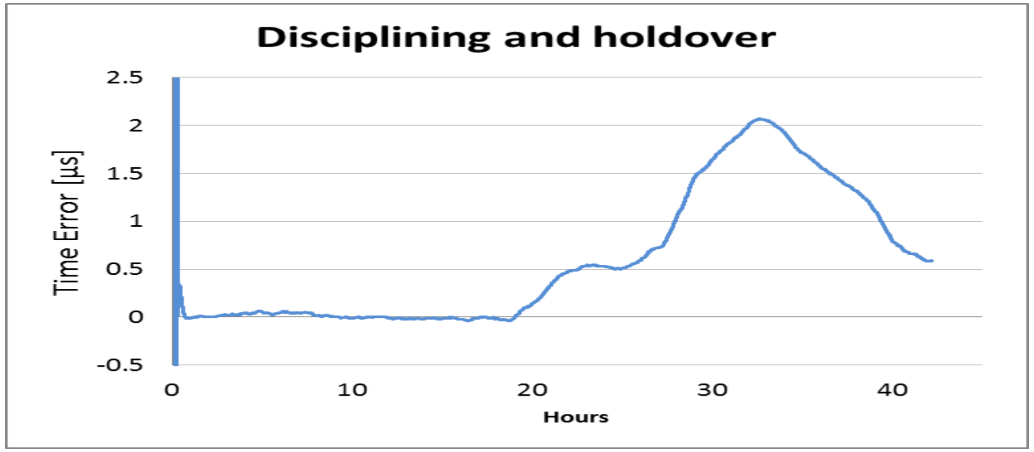


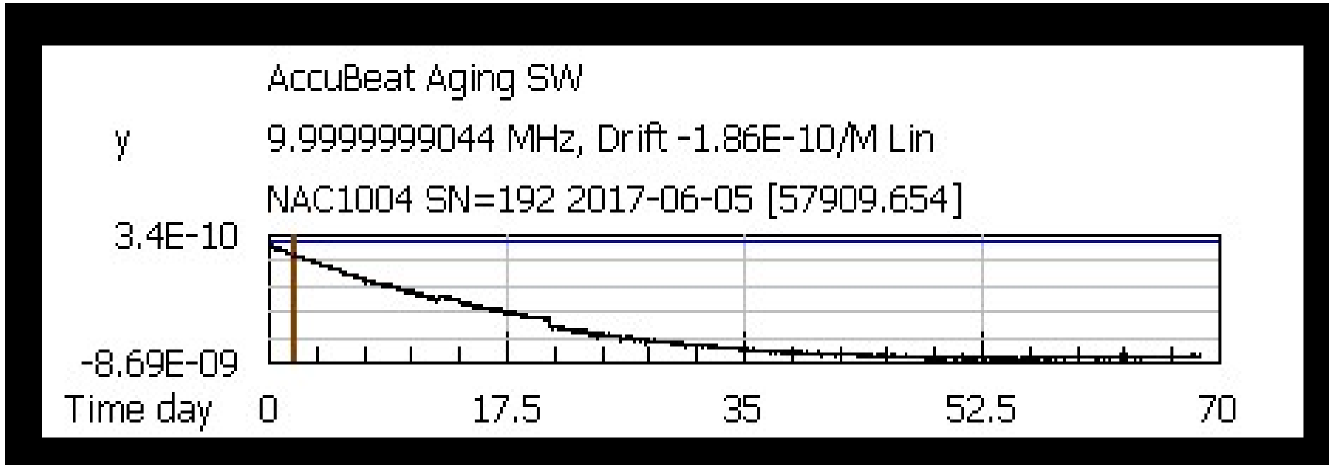
Phase noise (floor): -150dBc / Hz
Stability: 1E-10 @ 1s; 8E-12 @ 1000s
Power Consumption: < 1.2W
Size: 32cc (41.1mm X 35.3mm X 22 mm)

NAC 1 - performances

SN142 – ADEV free run 20 Hours at room Temperature







Technological demonstrator

Clock operation:

Pyramid MOT

~1 M atoms @ 7 μK

Falling for 20 ms

Ramsey spectroscopy

Single optical axis system

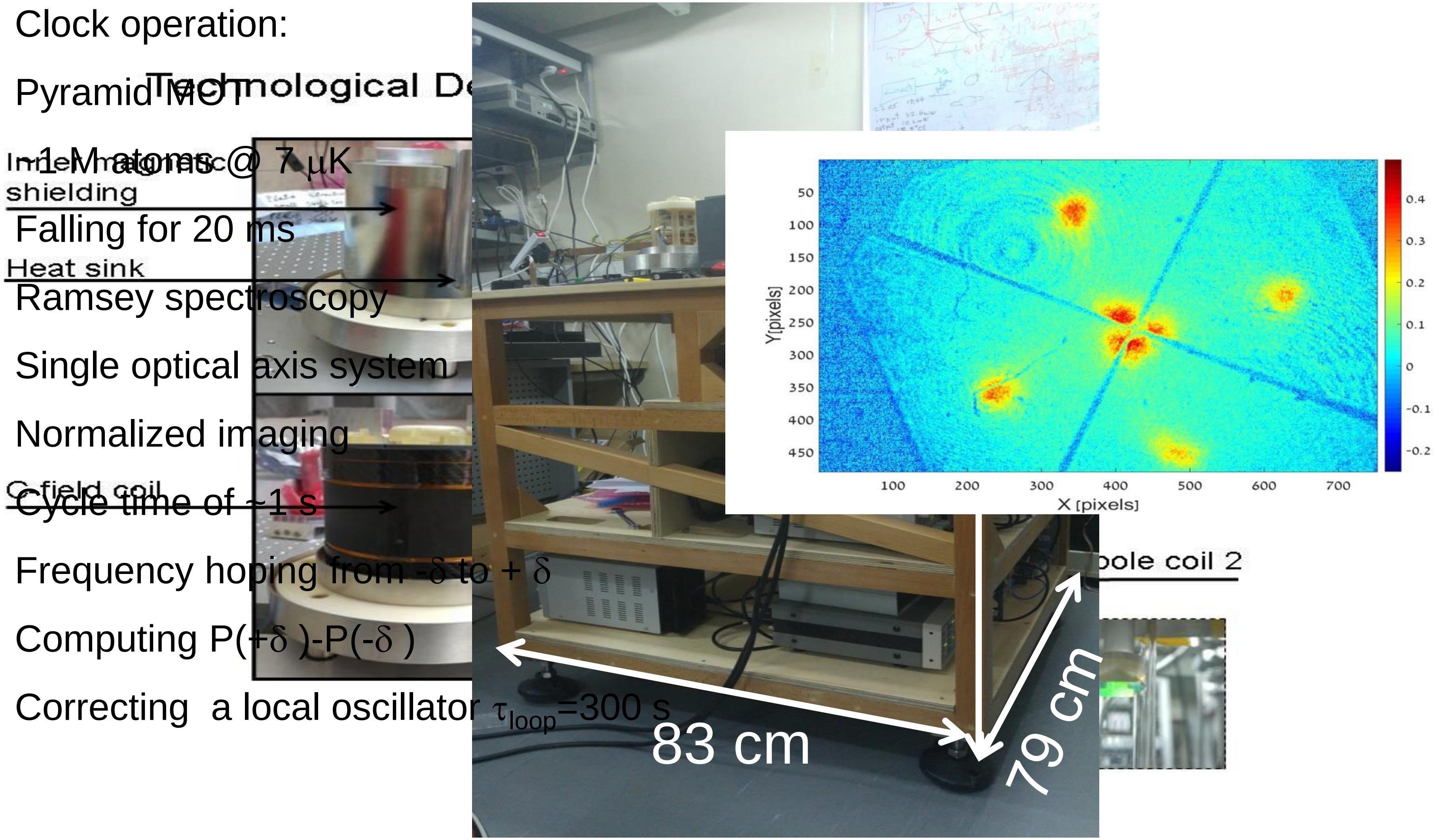
Normalized imaging

Cycle time of ~1 s

Frequency hoping from -δ to + δ

Computing P(+δ)-P(-δ)

Correcting a local oscillator τ_{loop}=300 s



Cold atoms clock

Achievements & Results

Results in BGU 24/5/17

~20 ns per day during 3 days!