Sandia National Laboratories

Quantum Sensing and Timing Technologies

Dan Thrasher, PhD (dathras@sandia.gov)

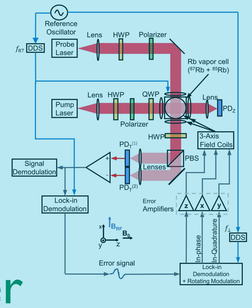
Optical Magnetometers

Advantages compared to classical magnetometers:

- Sensitivity: ~fT/$\sqrt{\text{Hz}}$
- Accuracy: < 1 nT
- Common mode rejection > 2000
- improved rejection of vehicle magnetic signature

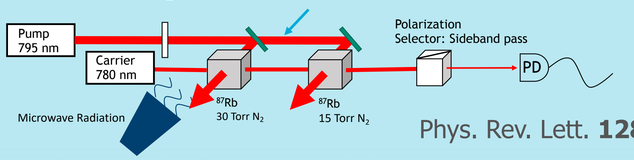
RF magnetometer

Physics Package : 600 cc, 2.5 W
Sensing bandwidth : 1.5 kHz
(tunable from 10 kHz to 1 MHz)
Sensitivity (unshielded): 9 fT/$\sqrt{\text{Hz}}$
Phys. Rev. Applied 18, 044052



Pulsed Gradiometer

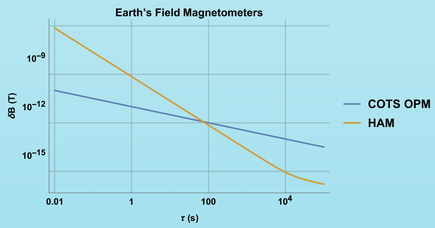
Transduces gradient magnetic field to RF laser modulation
Sensitivity (unshielded): 20 fT/ $\sqrt{\text{Hz}}$/cm,
Physics Package: 300 cc, 2.5 W



Phys. Rev. Lett. **128**, 163602

Helium Ultra-stable Magnetometer

New idea! Spin-exchange optically pumped Rb-He magnetometer. NMR of He detected using pick-up coil. Long nuclear spin coherence ideal for long integration measurements. Promises very small size.



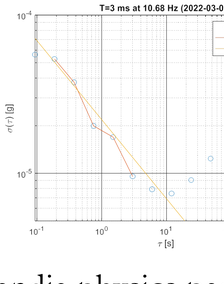
	COTS OPM	HUM
Size (cc)	76	17
Weight (g)	50	50
Power (mW)	2,000	<100
Sensitivity (pT/$\sqrt{Hz}$)	1	0.005*
Heading error (nT)	2	<0.1

Matter-Wave Gravimeter

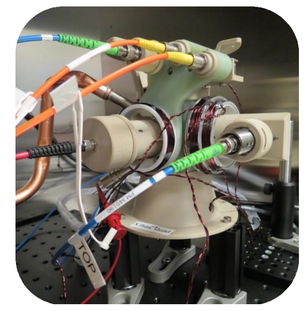
	Navigation Grade (HG9900)	Light-Pulse Atom Interferometer (LPAI) Lab Demo	High Data-Rate LPAI with a standard MOT
Accel Bias (1σ) [μg]	< 25	< 10^{-4}	< 0.5 μg
Accel SF (1σ) [PPM]	< 100	< 10^{-4}	< 1
Accel Random Walk [μg/rt-Hz]	not reported, QA ~ 10	10^{-5}	0.7 to 30 μg/rt-Hz
Data rate [Hz]	500-1500	0.01 to 1	50-300 Hz
Size [L]	1.7 (6-axis)	≫ 3000	< 20 L (sensor head)
Gyro Bias (1σ) [deg/hr]	< 0.003	< 7 x 10^{-5}	
Gyro SF [PPM]	< 5	< 5	
Gyro Random Walk (1σ) [deg / rt-hour]	< 0.002	2 x 10^{-6}	

Quantum gravimeters promise improved accuracy compared to classical gravimeters. Miniaturization is an ongoing effort.

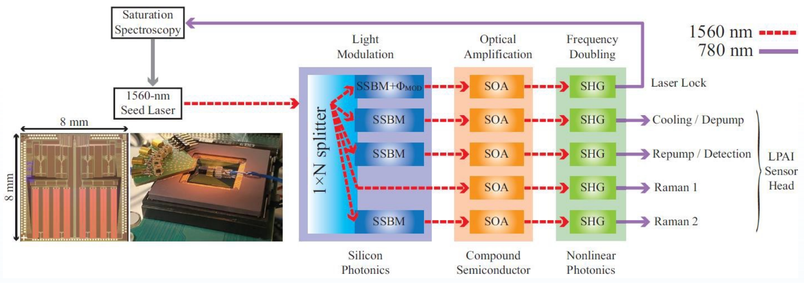
Prototype



Sandia physics package data



Sandia physics package



Photonic integrated circuit laser system

Future

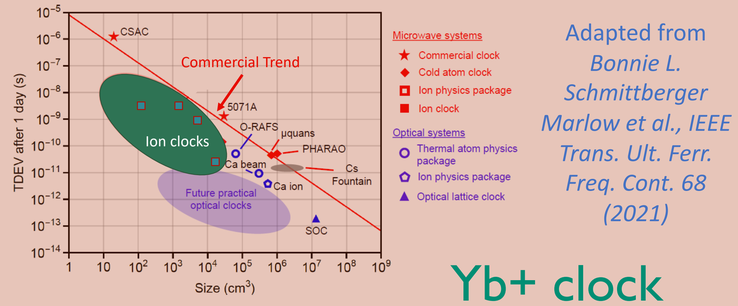
Additional miniaturization of photonic integrated circuit and physics package.

Nature Comm. 13, Article number 5131 (2022)

Microwave Ion Clocks

Advantages compared to other atomic clocks:

- Improved long term stability
- Lower power consumption (no vapor cell to heat)

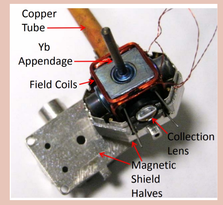


Adapted from *Bonnie L. Schmittberger Marlow et al., IEEE Trans. Ult. Ferr. Freq. Cont. 68 (2021)*

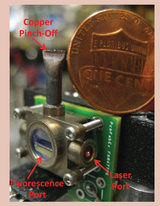
Yb+ clock

Demonstrated physics packages as small as 1 cc. Physics package remains operable for more than 10 years!

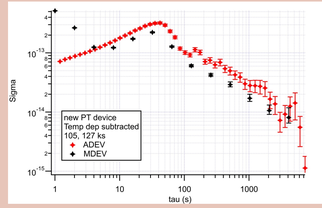
3 cc



1 cc



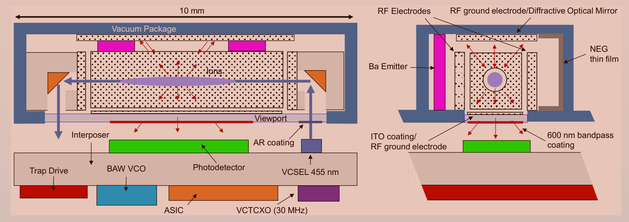
Measured stability 3 cc



Review of Scientific Instruments **87**, 053112 (2016)

Future Miniaturization

New ideas! Change species to match recent advances in vertical cavity surface emitting blue laser technology. Utilize piezoelectric transformer to source high voltage for biasing trap rods.



NEG: non-evaporable getter, BAW: bulk acoustic wave resonator, VCO: voltage controlled oscillator, ITO: indium tin oxide, VCTCXO: voltage controlled temperature compensated crystal oscillator

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NNSA National Nuclear Security Administration

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