Optimization of a Prototype Atomic Clock Based on Coherent Population Trapping

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Time keeping history

- Ancient time: sun clocks, water clocks
- pendulum clocks
  - 1656 Huygens (1 minute per day)
  - 1721 Graham (1 second per day)
  - 1761 Harrison (1/5 second per day)
  - 1920 Shott a free-pendulum clock (10^{-7} or a few seconds per year)
- 1929 quartz clocks accuracy 10^{-7}
- 1952 Cs atomic clocks accuracy 10^{-10}
- 2001 Cs fountain clock accuracy $4 \cdot 10^{-16}$

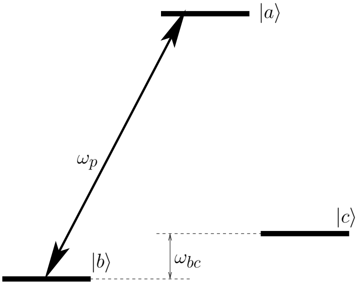
Since 1967 in International System of Units (SI) second.

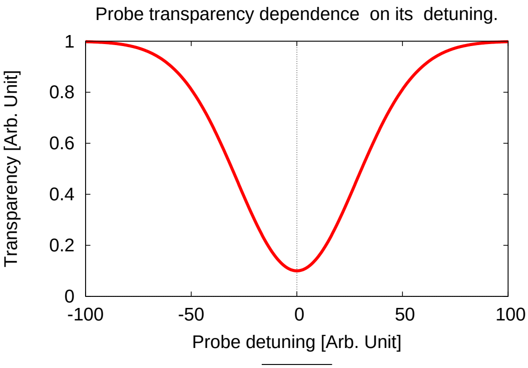
9,192,631,770 periods of the radiation of the ground state hyperfine transition in cesium-133 atom (since 1967). □

Example

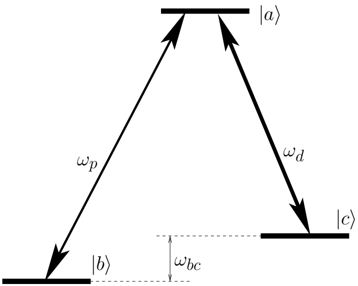
Once we have a clock accurate to 10^{-10} we can find distances across US with 1mm precision

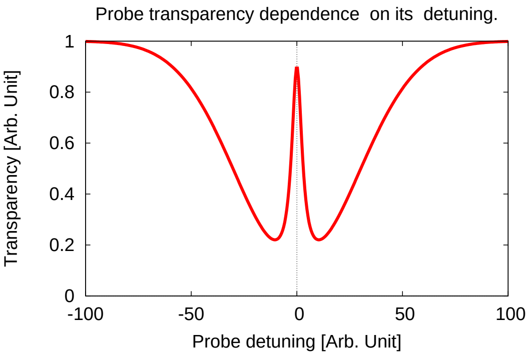
Coherent Population Trapping (CPT)



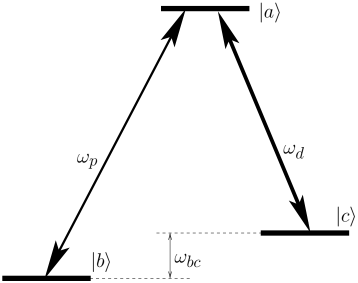


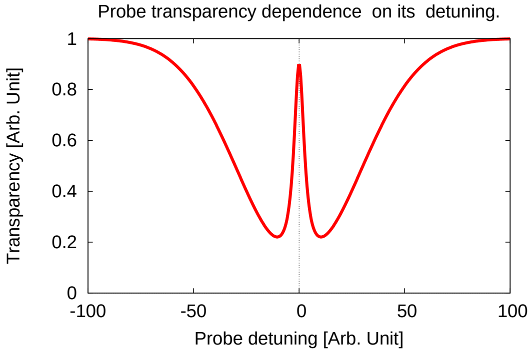
Coherent Population Trapping (CPT)





Coherent Population Trapping (CPT)

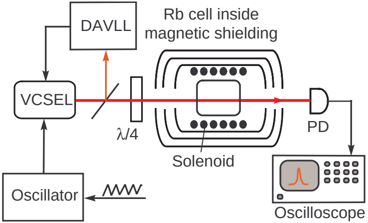


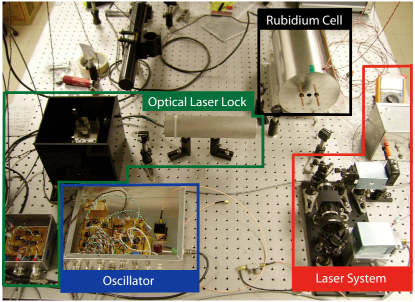


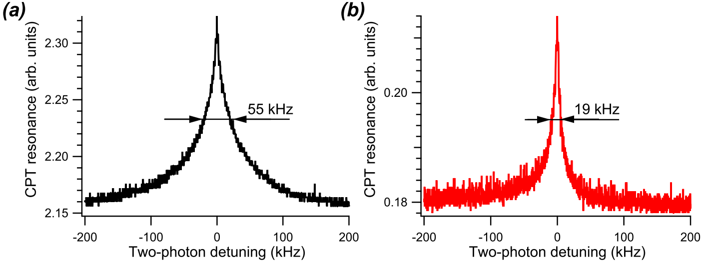
Coherent Population Trapping

- Dark $|D\rangle = \Omega_d|b\rangle - \Omega_p|c\rangle$ and Bright $|B\rangle = \Omega_d|c\rangle + \Omega_p|b\rangle$ states
- resonance width ($\sim$ 10kHz) much smaller then natural line width

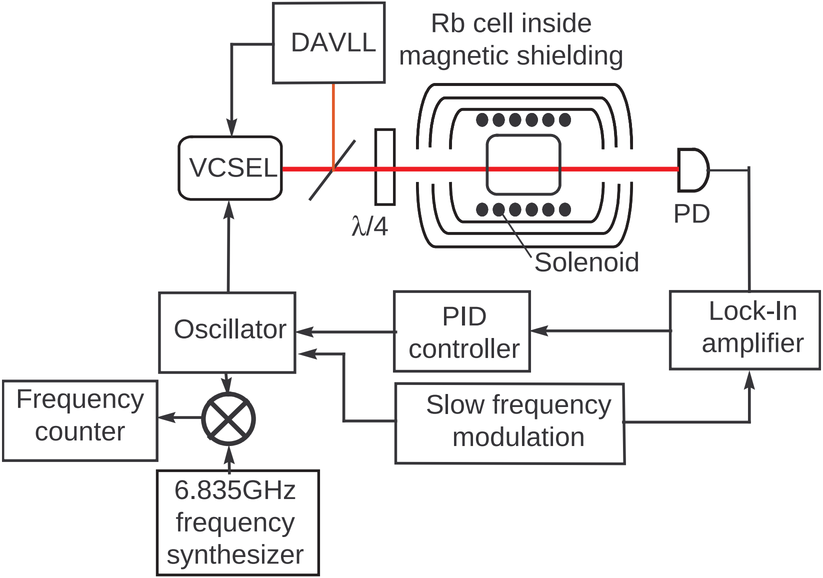
CPT observation



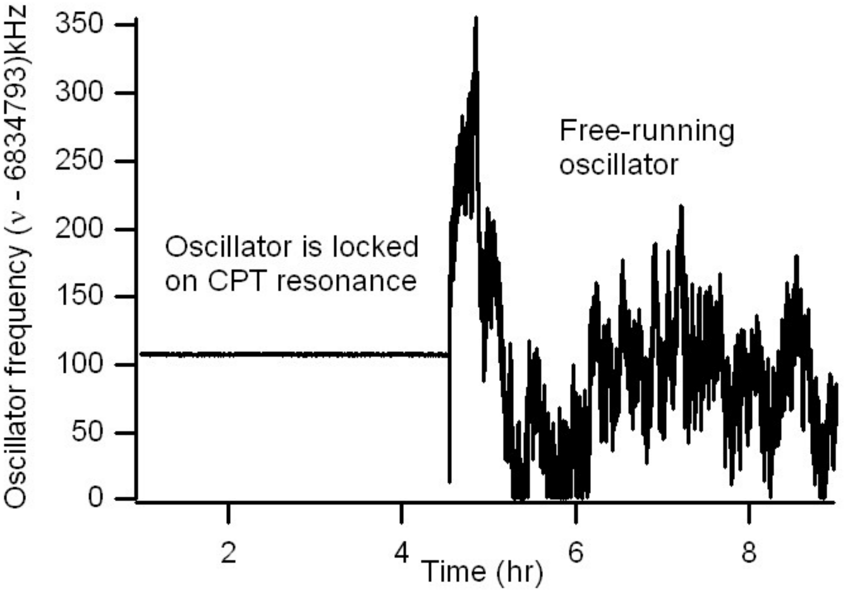




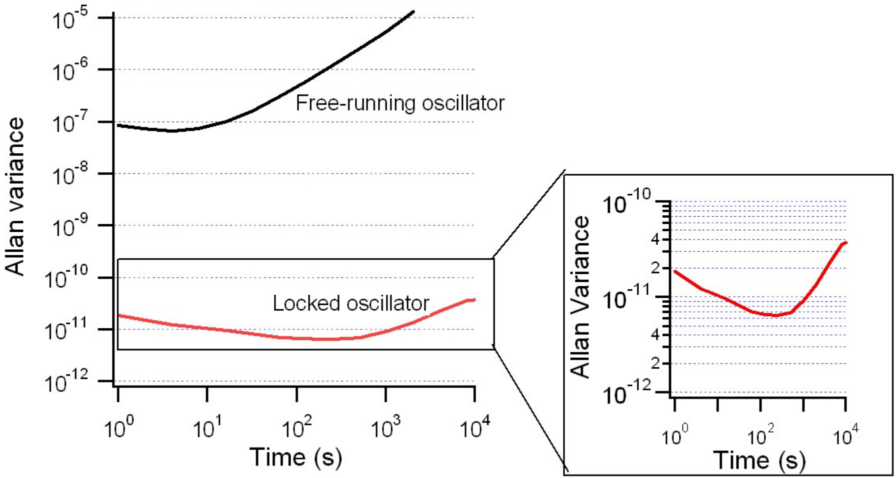
Clock setup



DAVLL
Rb cell inside
magnetic shielding
VCSEL
λ/4
PD
Solenoid
Oscillator
PID
controller
Lock-In
amplifier
Frequency
counter
Slow frequency
modulation
6.835GHz
frequency
synthesizer


Oscillator frequency (ν - 6834793)kHz
350
300
250
200
150
100
50
0
Oscillator is locked
on CPT resonance
Free-running
oscillator
2
4
6
8
Time (hr)

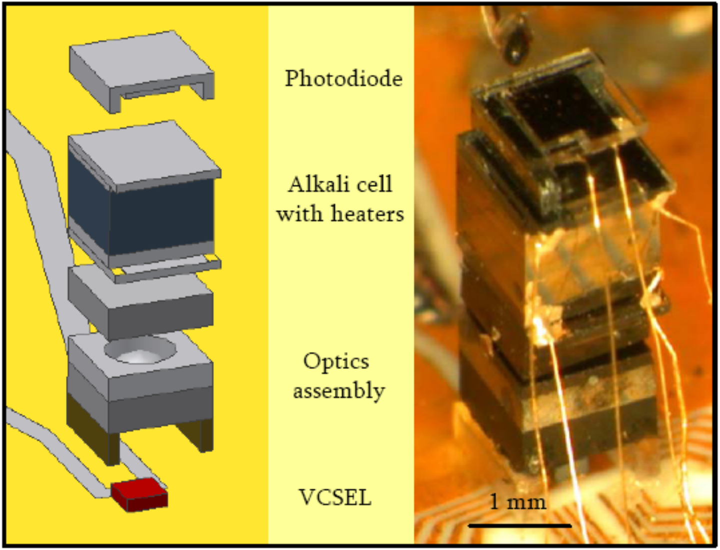
Stability



Allan deviation of $6 \cdot 10^{-12}$ corresponds to 1 second per 5000 years clock inaccuracy.

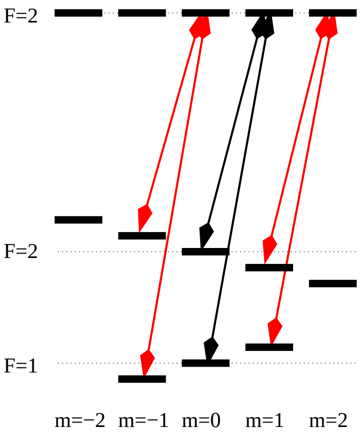
Miniature atomic clock

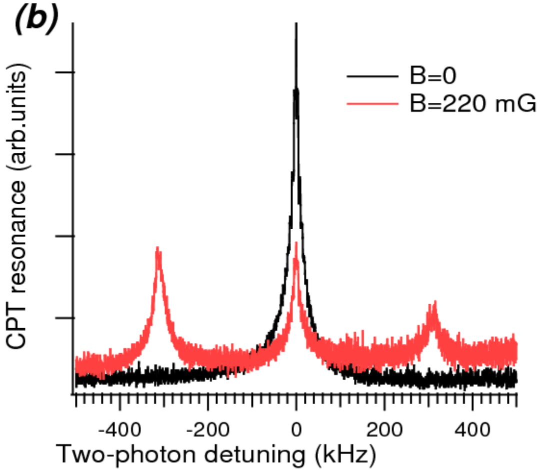
NIST clock with 1cm^3 volume



There is no 3-level atom and Rb is not one of them

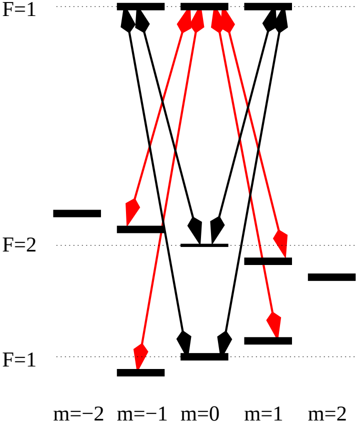
CPT with circularly polarized light

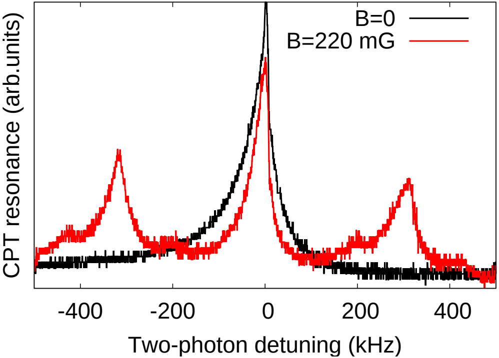




CPT with linearly polarized light

Suggested by A.V. Taichenachev, V.I. Yudin, and S.A. Zibrov





Summary

- Clock with Allan deviation of $6 \cdot 10^{-12}$ demonstrated
- Similar stability for magneto insensitive configuration demonstrated
- Nathan Belcher, Eugeniy E. Mikhailov, and Irina Novikova **arXiv:0810.2071**