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 · 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)

\[ |a\rangle \]
\[ \omega_d |b\rangle \rightarrow \omega_{bc} |c\rangle \]

Probe transparency dependence on its detuning.

\[ \text{Transparency [Arb. Unit]} \]
\[ \text{Probe detuning [Arb. Unit]} \]

\[ \text{Transparency [Arb. Unit]} \]
\[ \text{Probe detuning [Arb. Unit]} \]

Dark \[ D \rangle = \Omega_d |b\rangle - \Omega_p |c\rangle \]

Bright \[ B \rangle = \Omega_d |c\rangle + \Omega_p |b\rangle \]

states resonance width (\( \sim 10\text{kHz} \)) much smaller than natural line width
Coherent Population Trapping (CPT)

\[ |a\rangle \]

\[ \omega_p \]

\[ |b\rangle \]

\[ \omega_{bc} \]

\[ |c\rangle \]

\[ \omega_d \]

\[ |a\rangle \]

\[ \omega_p \]

\[ |b\rangle \]

\[ \omega_{bc} \]

\[ |c\rangle \]

Probe transparency dependence on its detuning.

Transparency [Arb. Unit]
Probe detuning [Arb. Unit]

Transparency dependence on its detuning.
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 ($\sim 10\text{kHz}$) much smaller then natural line width
CPT observation

(a) CPT resonance (arb. units)

(b) CPT resonance (arb. units)

Two-photon detuning (kHz)

Two-photon detuning (kHz)
Clock setup

- VCSEL
- DAVLL
- Rb cell inside magnetic shielding
- Solenoid
- PID controller
- Oscillator
- Frequency counter
- Slow frequency modulation
- Lock-In amplifier
- 6.835GHz frequency synthesizer
- PD
- 1/4

Eugeni Mikhailov (WM)
CPT Atomic clock
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Stability

Oscillator frequency ($\nu - 6834793$) kHz

Free-running oscillator

Oscillator is locked on CPT resonance

Time (hr)
Stability

Allan deviation of $6 \times 10^{-12}$ 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

F=2

m=−2 m=−1 m=0 m=1 m=2

F=1

(b)

CPT resonance (arb.units)

Two-photon detuning (kHz)

B=0

B=220 mG
CPT with linearly polarized light

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

F=1

F=2

m=−2 m=−1 m=0 m=1 m=2

F=2

F=1

CPT resonance (arb.units)

Two-photon detuning (kHz)

B=0

B=220 mG

CPT resonance (arb.units)

Two-photon detuning (kHz)
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
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