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Atomic Frequency Standard based on Coherent Population Trapping in Rb-87 Atoms for Space Application

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Space-borne atomic frequency standards demand a high level of performance and stability throughout the mission life in the harsh environment of space. Recently, atomic clocks employing Coherent Population Trapping (CPT), a quantum interference phenomenon in alkali atoms, have shown much promise for space application. This paper presents the development and realization of compact and reliable CPT atomic clock for ISRO's navigational satellites. In our approach, quantum interference in Rb-87 atoms are pursued for obtaining the clock resonance, owing to their larger ground state hyperfine transition energy (higher Q-factor). Quantum interference is realized by generating two resonant optical laser fields from a VCSEL diode by modulating its drive current at RF frequency which corresponds to the ground state hyperfine separation in Rb-87 atoms. The emission frequency of the laser diode is stabilized by locking it with respect to the D1 hyperfine transition with the help of a servo control loop, thereby the instabilities associated with laser frequency fluctuations are minimized. The resulting CPT resonance (<kHz) as shown in Figure 1 is used as reference to stabilize the crystal oscillator frequency (10 MHz) that serves both as clock output and seed for generating the RF field.

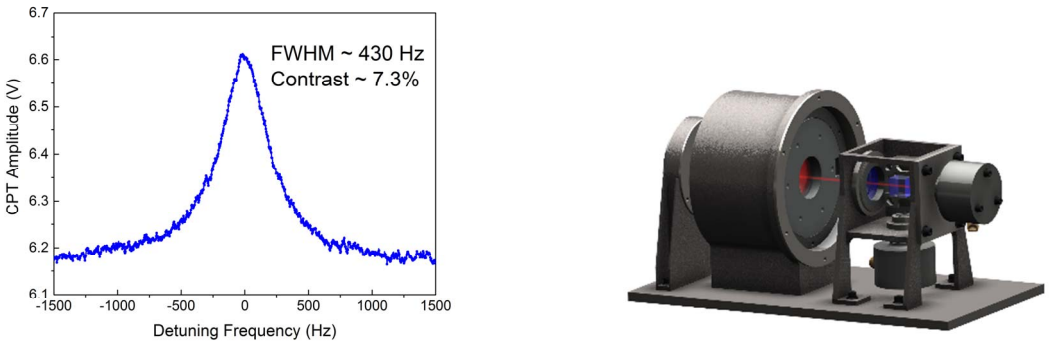

Figure 1. CPT resonance as function of RF detuning frequency (left) and mechanical assembly of Physics Package (right).

As seen in Figure 1, FWHM of the measured CPT resonance involving transition from $m_F = 0$ level is ~430 Hz which would enable the stabilization of OCXO frequency (clock output) to a level < 2×10^{-12} per sec, a pre-requisite for its suitability in navigational satellites. The overall configuration and specifications of individual components of the physics package such as atomic cell assembly, laser source and optics are optimally designed to improve the quality of CPT resonance which critically determines the frequency stability of clock. Furthermore, the absence of microwave cavity in the CPT scheme would allow the miniaturization of these clocks which also make them ideal candidate for space application.

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