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Indigenous Instrumentation for Development of Atomic Primary Frequency Standards at NPLI

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Research and development on atomic frequency standards is advancing significantly as far as accuracy in precise measurements of time and frequency is concerned. Cesium (Cs) fountain atomic clock [1], which has an uncertainty of the order of 10^{-16}, is regarded as a primary frequency standard (PFS). Since Cs fountain clocks are not yet commercially available, these are indigenously developed. India is only the ninth country in the world to realize a working Cs fountain clock (NPLI-CsF1) and operate it as a PFS for contributing to international atomic time (TAI). Apart from NPLI-CsF1, CSIR-NPL (NPLI) is developing a second-generation Cs fountain clock as well as a single trapped Yb+ ion based optical clock. For the development of such precision atomic clocks, a variety of instruments have been indigenously designed over last several years. The development of a PFS requires multiple electronic devices and instruments with specific characteristics that are not often available in the market. Most of the peripheral control electronics and instruments have been indigenously developed, some of which are described in this paper.

Laser frequency stabilization is critical for the operation of fountain clock. For this purpose, a laser frequency stabilization circuit is designed for locking both maser as well as repump diode laser@852 nm to the saturated absorption peaks of 3-F' and 4-F' transitions of cesium-133 atoms. The laser can be locked up to four days without any disturbances using this locking circuit. Another critical instrument is the fountain sequence controller which consists of various microcontrollers and radio frequency (RF) generation cards. Frequency distribution amplifier cards for generation of different frequencies as well as the distribution of these frequencies to the Acousto-Optical Modulator (AOM) [2] have been designed in-house. AOMs are commonly used for blocking and unblocking laser lights faster than few ms during fountain operation. Pulse distribution Amplifier has also been developed for synchronization and distribution of 1PPS (Pulse Per Second).

In the optics setup domain, we have indigenously developed a shutter with remarkable characteristics, for instance low acoustic noise, vibrations free, compact and quite affordable. For controlling the entire experiment, out of all the instruments designed, noteworthy are a constant current source and a multi-channel data logger. The constant current source is crucial for maintaining homogenous magnetic field in the flight zone of cesium atoms. A 16-channel data logger is already utilized for the constant monitoring and logging of the various parameters like temperature, pressure, humidity and power output of the laser for the continuous ongoing of the clock. An upgraded 64-channel data-logger with completely automated controls is currently being developed.

[1] Amitava Sen Gupta et al., "Development of cesium fountain frequency standard at the National Physical Laboratory, India," Current Science, **100**, 9, 10 May 2011, pp. 1393-1399.

[2] S. Yadav et al., "An electronic sequence controller for the Cs fountain frequency standard developed at CSIR-NPL India," Measurement, **75**, November 2015, pp. 192–200, doi: 10.1016/j.measurement.2015.07.041.