# CCTF 2012 Report on Time & Frequency activities at National Physical Laboratory, India (NPLI)

Major activities of the Time & Frequency division of NPLI in the last three years have been:

1. Maintenance of Time
2. Time Transfer
3. Time Dissemination
4. Development of Rb clock for ISRO
5. Development of first Cs fountain clock
6. Development of second Cs fountain clock

## 1. Time generation

National Physical laboratory, India is a custodian of Indian Standard Time.(IST). There are five commercially available Cs Clocks for recording time data and one of them was designated as the reference clock of NPLI till 2011. A H-Maser has been added to the clock ensemble recently. UTC (NPLI) has been improved by taking the reference output from Hydrogen maser instead of a Cs clock and distributing the standard output through a micro phase stepper to adjust the phase or frequency offset of the reference output. A complete automation system for the generation of Time Scale UTC (NPLI) has been put in place and it is being continually improved. The block diagram of this automatic Time Scale development system is shown in Fig. 1 and actual implementation of the system is shown in Fig. 2. Hydrogen maser is shown in Fig. 3.

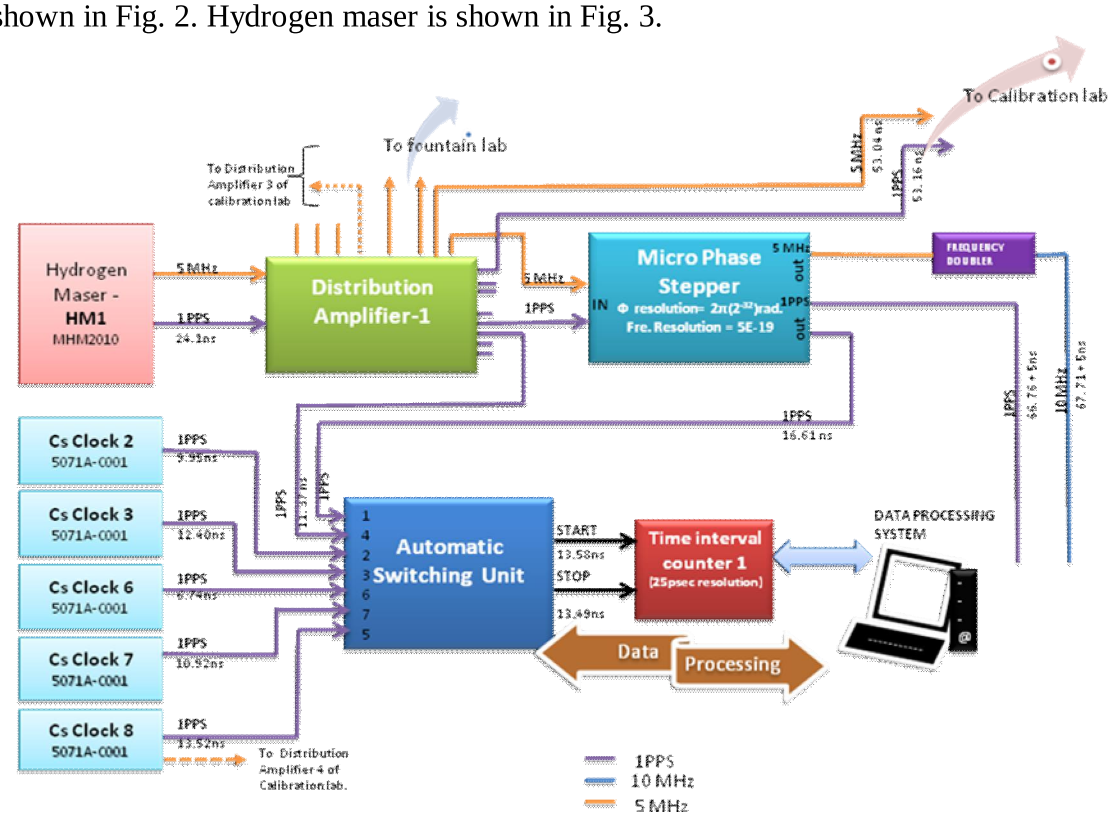


Fig. 1: Block diagram of TIME SCALE UTC(NPLI).

The plan is to generate UTC (NPLI) from several atomic clocks which are treated together as an ensemble. The phase differences of all pairs of clocks are recorded at regular intervals of time using automatic switching system (shown in Fig. 4). These readings are combined through an algorithm designed to generate a smoother time scale rather taking data of an individual clock. This algorithm aims at maintaining UTC (NPLI) as close as UTC in phase and also decides the amount of phase or frequency jump to be given to a particular clock to maintain better stability and accuracy. A micro phase stepper is normally used to give these frequency jumps (Fig. 5).

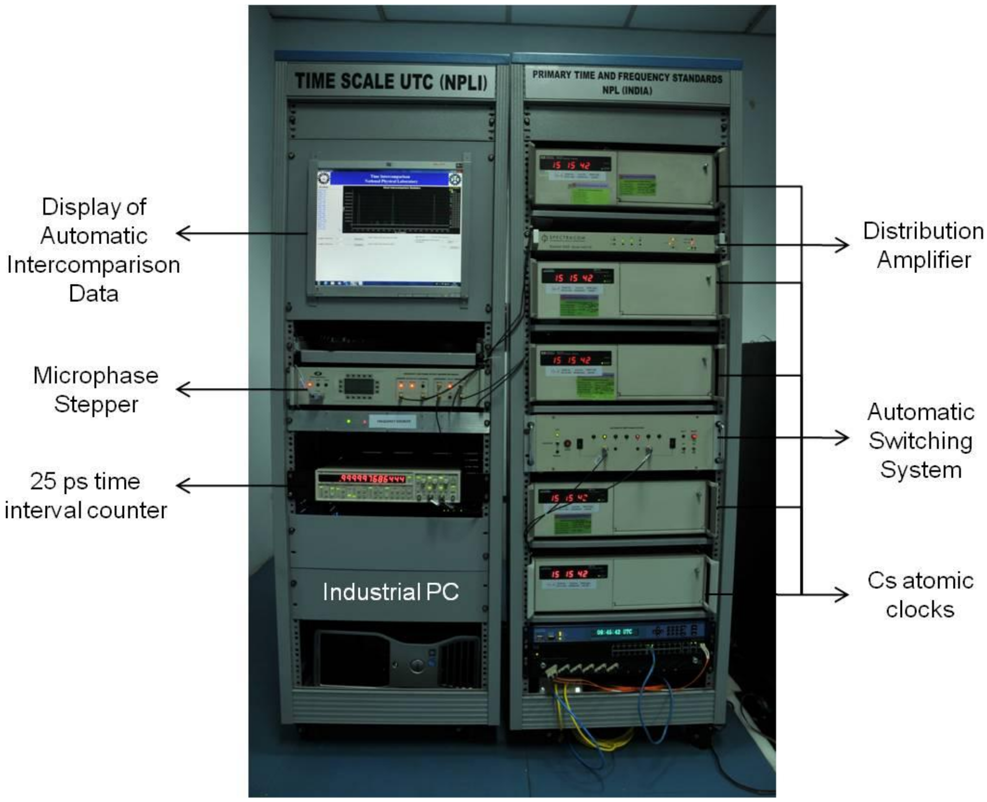


Fig. 2: Time scale UTC (NPLI) system.

Clock intercomparison system is totally automatic and all the comparison data are recorded in an industrial PC. Automatic switching system (refer Fig. 4) has been indigenously developed at NPLI. This system compares a pair of clock at routine intervals of time and records the data into a PC automatically. This system was very crucial (as a first step) to the development of automatic time scale. The overall behavior of UTC (NPLI) with respect to UTC during last five months is shown in Fig. 6.

## 2. Time Transfer

NPLI has been transferring time to BIPM, Paris using GPS network by common view method since many years. This link of time transfer is very stable. A new system of ultra stable time transfer known as Two Way Satellite Time & frequency Transfer (TWSTFT) system was recently introduced at NPLI. The set up of time transfer links at NPLI is shown in Fig. 7.

Fig. 3: Hydrogen Maser


Fig. 4: Automated switching system


Fig. 5: Micro-phase stepper

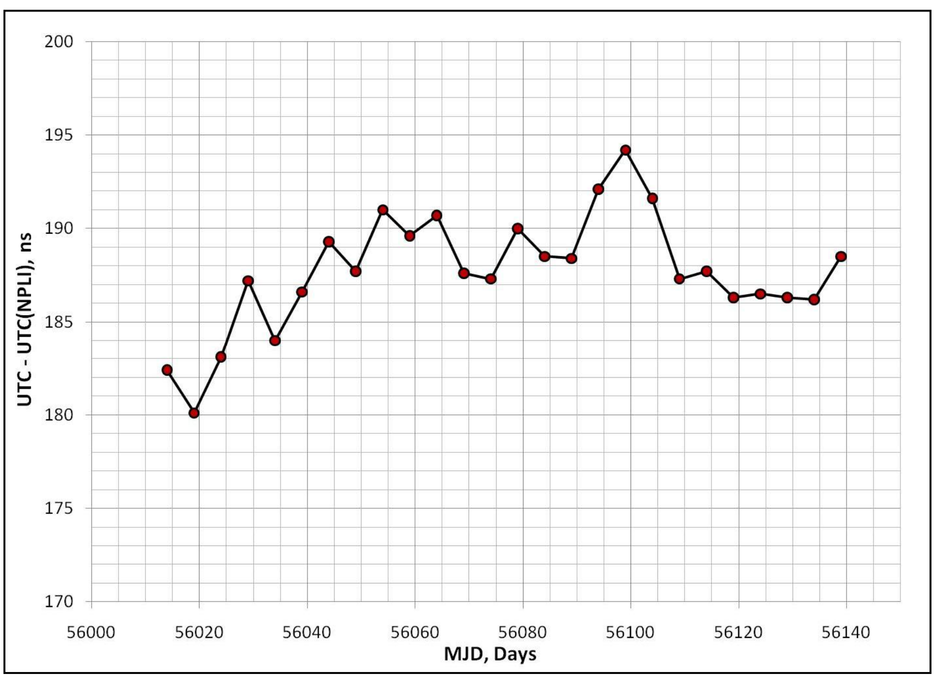


Fig. 6: Behavior of UTC (NPLI) with respect to UTC during last five months.

### i. Time Transfer via GPS Network:

The reference clock of NPLI i.e. UTC (NPLI) is continuously traceable to BIPM through GPS network using common view technique. We already have two single frequency 8 channel GPS receivers, TTS2-A & TTS2-B. In October 2011, we included Septentrio PolaRX3e receiver which is a dual frequency multichannel receiver. Latest addition to the set of receivers is a TTS4 receiver. Recently, we used PPP mode to refine our GPS co-ordinates which results in more precise readings. We are currently uploading GPS data in both RINEX and CGTTS formats to BIPM on a daily basis. Fig. 8 shows the graph representing UTC (NPLI) performance with respect to the GPS data. Antenna unit of TTS2 and Septentrio receiver mounted on rooftop is shown in Fig. 9.

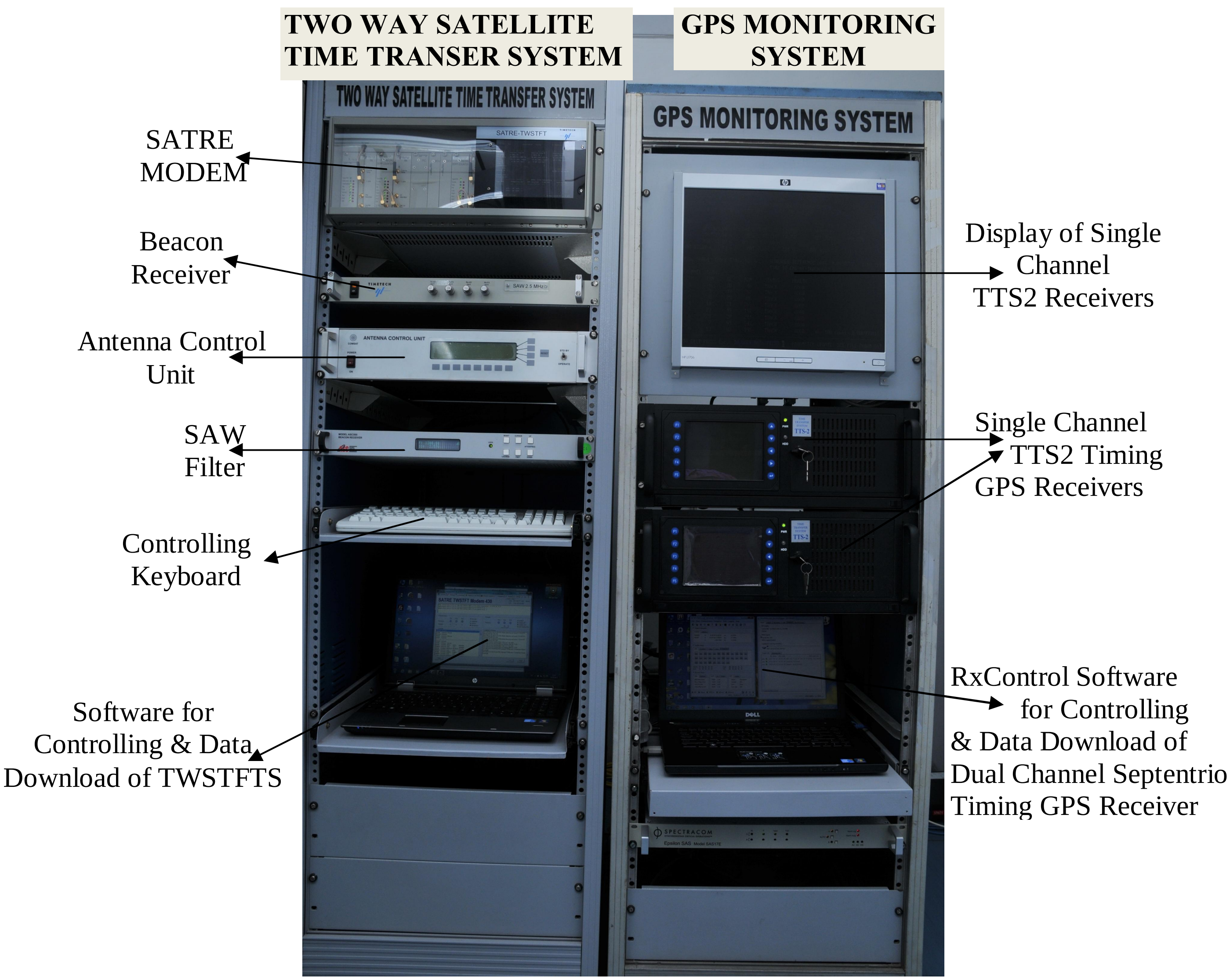


Fig. 7: TWSTFT & GPS System arrangement

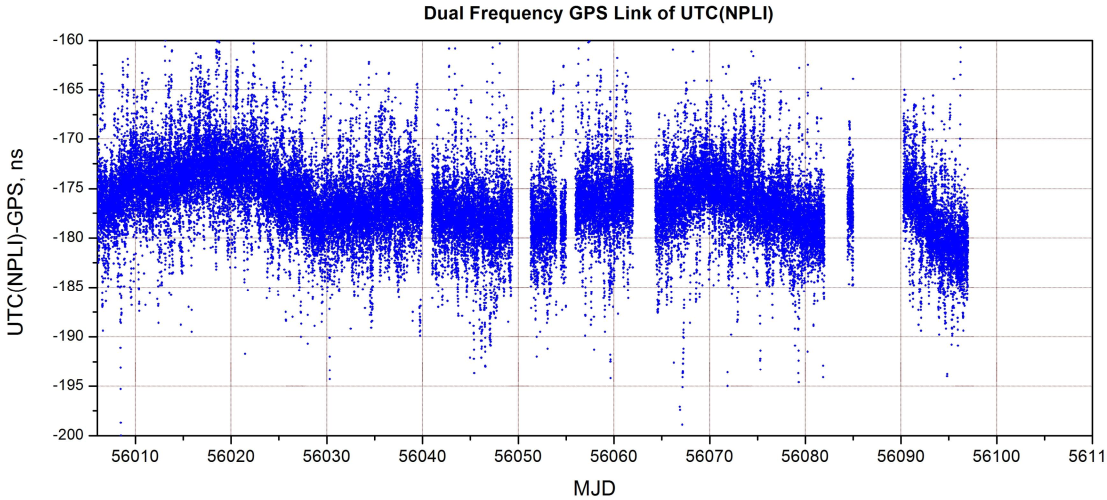


Fig. 8: Graph representing the behavior of UTC (NPLI) with respect to GPS data.

Fig. 9: GPS antenna unit of TTS2 receiver and Septentrio receiver system installed

### ii. Time Transfer via TWSTFT link

Since October 2011, NPLI has joined the Europe-Asia TWSTFT link. The Europe-Asia two-way link is constructed by NPLI, NICT, TL, NIM, NTSC, KRISS, NMIT, PTB and VNIIFTRI. We established the link to NICT and PTB through AM-2 satellite (parked at 80.2$^o$E). The working time of the transponder is between 13:00 UTC to 23:00 UTC. During this 10 hour duration, time transfer is performed every 5 minutes with 1 minute gap using the SATRE modem and the data is uploaded to BIPM in ITU-R format on a daily basis. The behavior of UTC (NPLI) with respect to UTC (PTB) is shown in Fig. 11.


Fig. 10: Antenna unit of TWSTFT system installed on terrace of main building of NPLI.

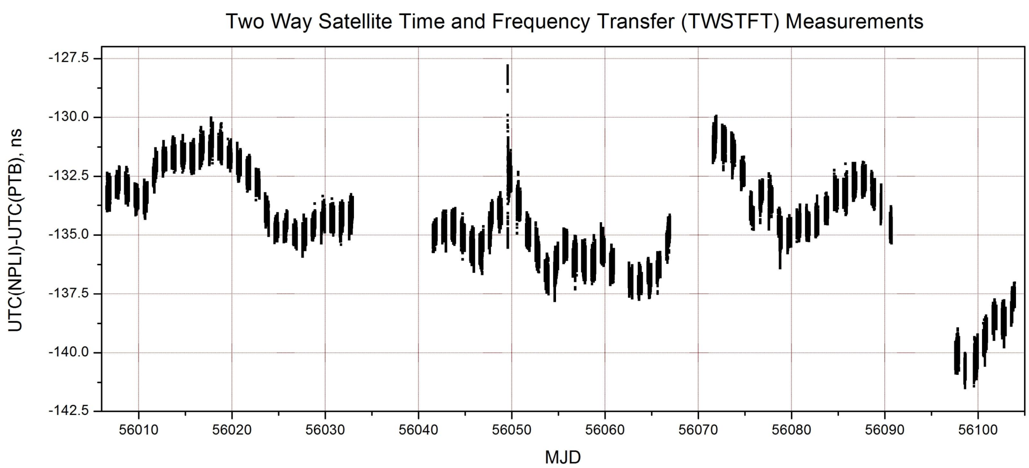


Fig. 11: Behavior of UTC(NPLI) with respect to UTC (PTB) using the TWSTFT data.

## 3. Time Dissemination

One of the recently added time synchronization services by NPLI is Network Time Synchronization service. In this service, Network Time Protocol (NTP) is used to synchronize the clocks of computers in the internet with the national standard time. The time server host name is time.npli.in. We have begun to provide this service since March 2012.

NPLI also provides a telephone time service which is called a ñTeleclockò service. In this service, coded time information is generated by the time code generator of NPLI referenced to UTC (NPLI). This service can be accessed by using the Teleclock Receiver which has been developed by NPLI. Thesereceivers utilize landline telephone or mobile network depending on the type of receivers. This servicecan be used to synchronize the real time clock (RTC) of a computer also. NPLI has developed software for this purpose. The screenshot of the software is shown in Fig. 12.

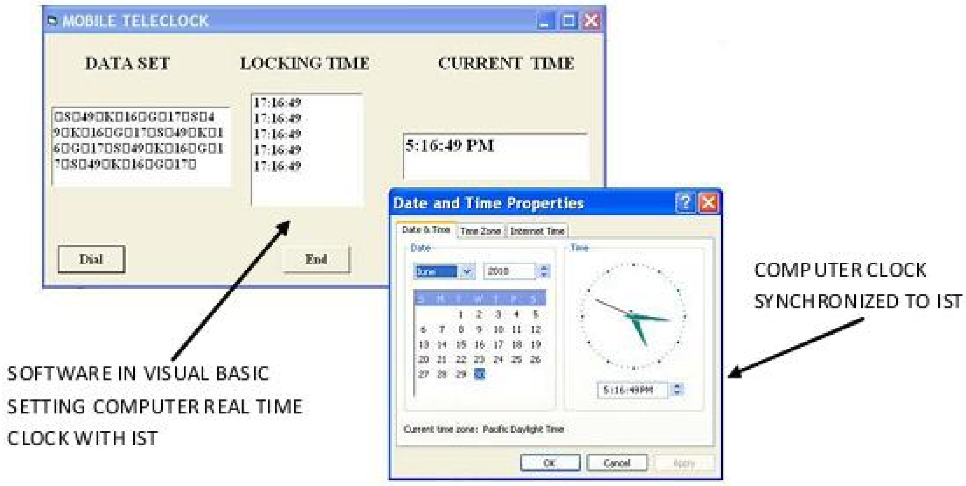


Fig. 12: Screenshot illustrating the synchronization of computer real time clock via software accessing Teleclock service.

## 4. **Development of Rb clock for ISRO**

For Indian Satellite based navigation system, Time and Frequency Division in collaboration with Indian Space Research Organization (ISRO) is developing a Rubidium atomic clock. Design verification models consisted of imported Rubidium bulbs and cells, which are critical components of the Rubidium clock. For the engineering thermal model of the atomic clock, indigenous development of these components is under progress at NPL. For this purpose, a rubidium filling station consisting of UHV pumps, high purity buffer gas cylinders, different kinds of gauges and glass manifold have been developed, as shown in Fig. 13.

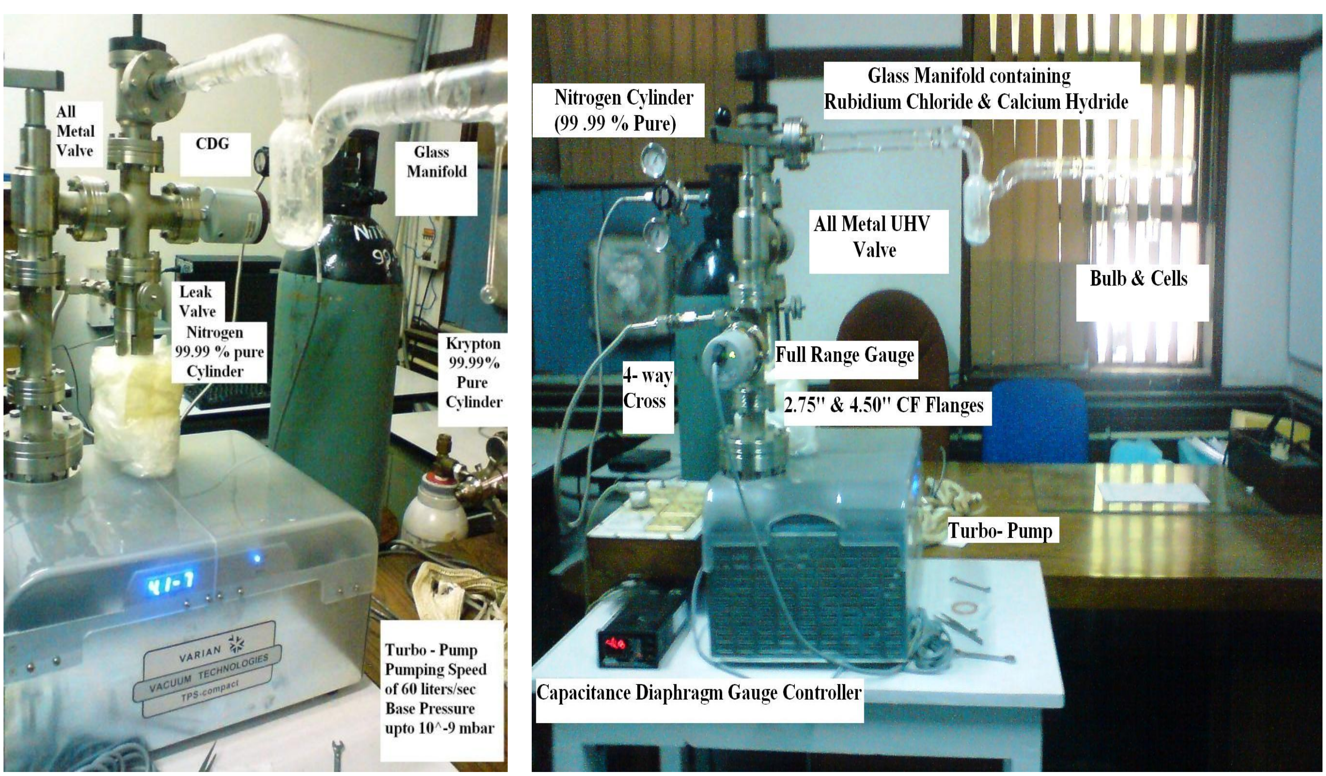


Fig. 13: Rubidium Filling station

A manifold that can be connected to UHV system consisting of borosilicate glass bulbs is shown in Fig. 14. Work is under progress to fill Rubidium and high purity inert gases in the space-qualified bulbs and cells.

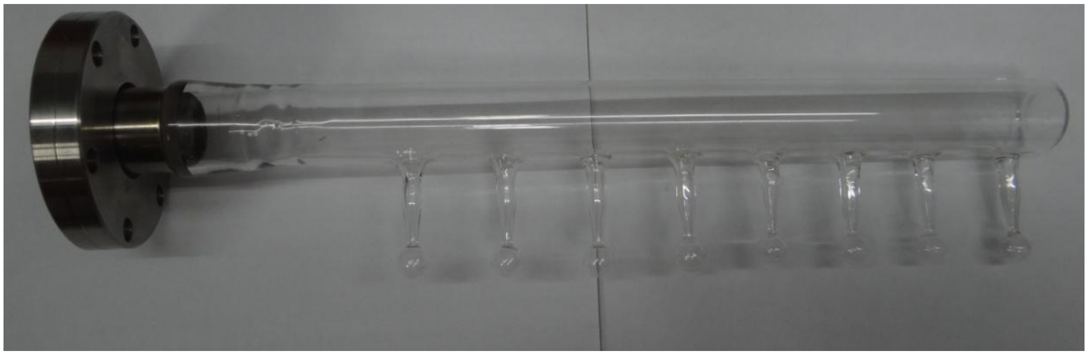

Fig. 14: Glass Manifold consisting of bulbs

## 5. **Development of Cesium atomic fountain India-CsF1**

### i. Ramsey fringes

The laser cooled Cesium fountain clock named India CsF1, designed and developed by T&F Division became operational in May 2011. Fig. 15 shows the layout and assembly of the Physics package of the fountain. This clock, when operated continuously, will lose or gain one second in several million years. It will also serve as a primary frequency standard. Such an ultra precise measurement device has been developed completely in India and puts India in the elite club of 7 developed nations having such a standard.

The fountain is now fully operational and is ready for complete frequency evaluation including all systematic and statistical biases. It is now possible to trap about 10 million cesium atoms, cool them to about 6 εK temperature, launch them to about 70 cm high and to detect relatively clean return signals after interaction of atoms with the microwaves. The detected signals are collected using a National Instruments data acquisition card (DAQ). A labview program has been developed to collect the detected signals via DAQ. The signals are then processed to calculate the transition probability. The same program is used to tune the microwave synthesizer in order to obtain the Ramsey fringes. The signal to noise ratio has been considerably improved and is evident from the clock signals as shown in Fig. 16.

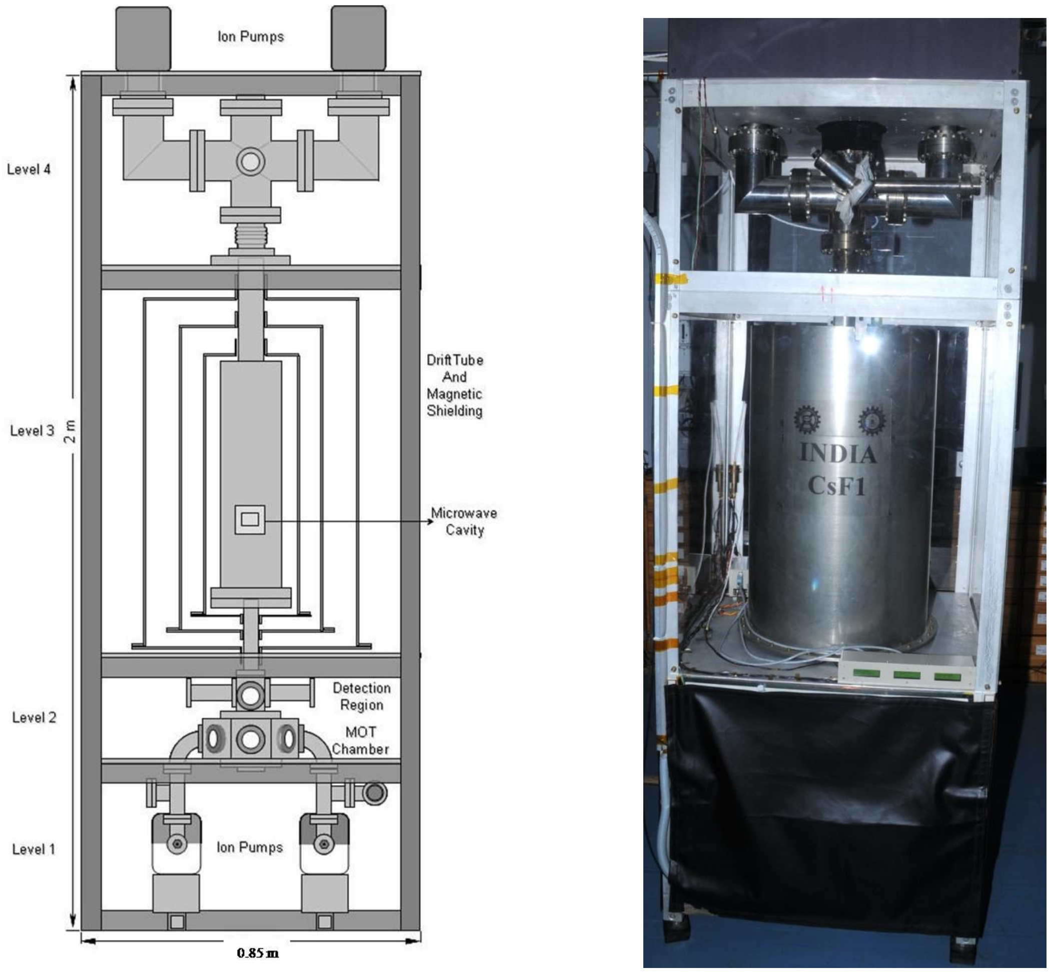


Fig. 15: Planned layout (left) of the Physics package of the fountain and assembled fountain (right).

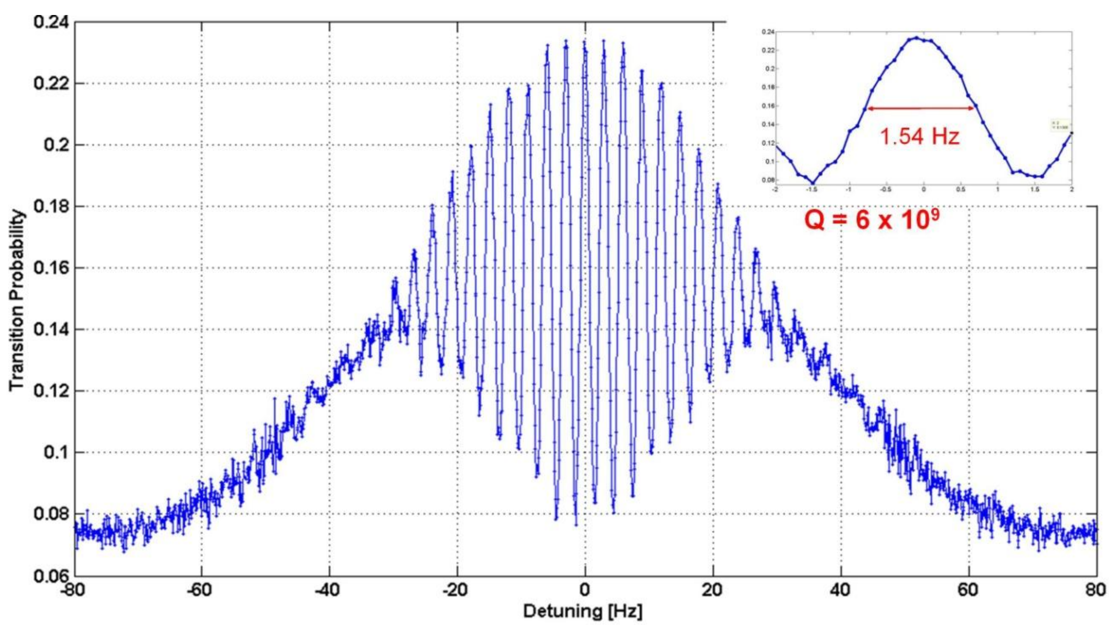


Fig. 16: The observed Ramsey fringes for a toss height of 65.4 cm; Ramsey Time: 325 ms. Inset: enlarged central fringe..

### ii. Magnetic field mapping

One of the most important frequency corrections of cesium frequency standards is the frequency shift due to the C-field. C-field is used to remove the degeneracy of the magnetic substates in cesium atoms during their interaction with the microwaves. A long solenoid coil around the central vacuum chamber produces a static magnetic field. Several compensation coils are used at the top and bottom of the vacuum chamber to create highly homogeneous magnetic field in the flight region. It is crucial to have high magnetic field homogeneity and therefore, it becomes important to monitor the magnetic field during fountain operation. In order to precisely measure the magnetic field strength, linear Zeeman frequency shift of magnetically sensitive transitions $\left|F, m_f \neq 0\right\rangle$ is measured. In practice, the position of the central fringe of $m_f = 1$ transition is monitored by launching the atoms to different toss heights (in steps of ~ 1 cm) and a map of $\nu_{1-1}$ as a function of toss height is obtained. Using Breit-Rabi formula $\langle B \rangle$ is calculated as function of toss height. Magnetic field profile is then reconstructed by deconvolution of the average magnetic field and the ballistic time of flight as shown in Fig. 17. The magnetic field is quite homogeneous in the atomic flight region and the measured average magnetic field strength is 104.5 nT which is very close to the value measured with a magnetometer in the drift region before the assembly of the fountain.

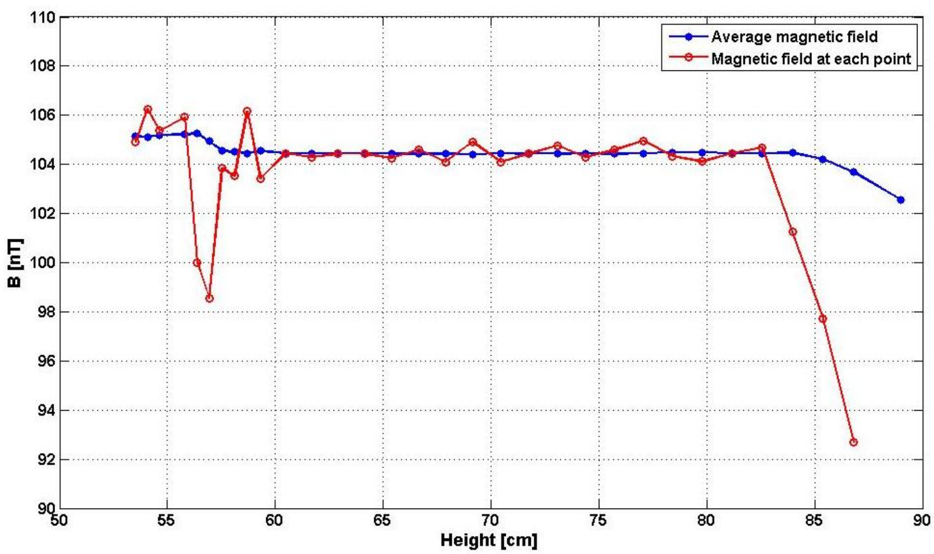


Fig. 17: Variation of magnetic field along the axis of the NPLI fountain. The arrow shows the position of the center of the Ramsey cavity.

### iii. Frequency stability analysis

The interrogated microwave frequency is locked to the narrow Ramsey resonance by the frequency modulation locking method, in which the microwave is toggled between f0 ī æɜ/2and f0 + æɜ/2 where f0 is the microwave central frequency, and æɜ is the linewidth of the Ramsey fringe, at each cycle. Fig. 18 shows the Allan deviation of the fountain frequency with the Hydrogen maser frequency.

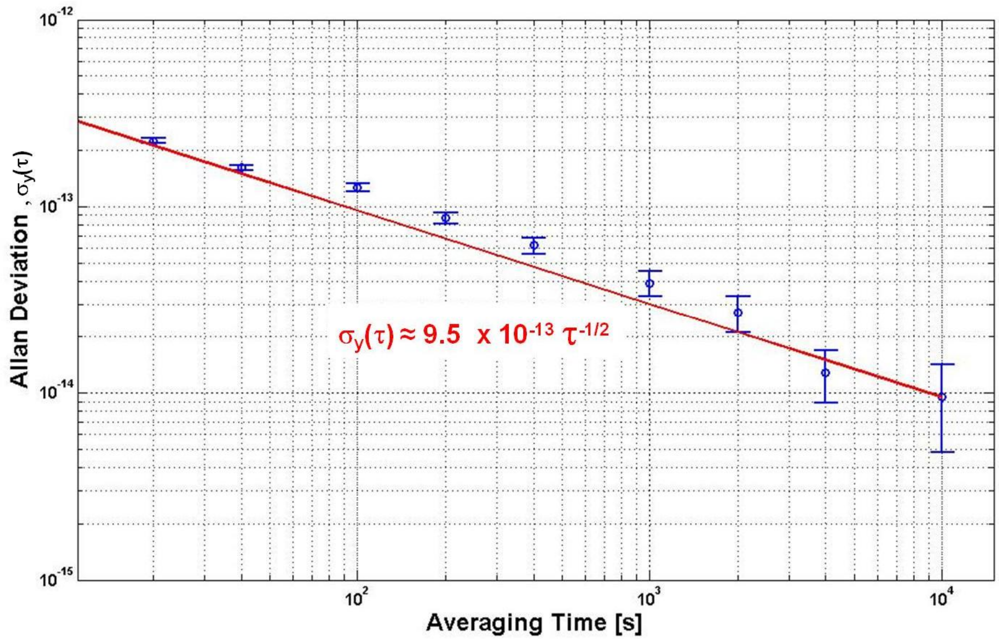


Fig. 18: Frequency stability of India-CsF1

As shown in Fig. 18, the noise averages down as white-frequency noise law and reaches the level $\sigma_y(\tau) = 9.5 \times 10^{-13} \tau^{-1/2}$. We clearly need to improve the short term stability of the fountain. Thereafter, a complete frequency evaluation of the fountain is planned.

## 6. Development of 2nd Cs fountain clock

The objective of the project is to design and build a second Cs fountain at NPL with special design features that enable us to carefully investigate the systematic errors in order to have a frequency standard with accuracy of few parts in $10^{16}$ ï which would be at the level of the best in the world. During the first year (2011-12) of the project, the design of the optical set-up and physics package of the fountain has been finalized. Some of the electronic subsystems such as current sources, microwave synthesizer and microwave cavity have also been designed.