National Research Council, Canada

Report on Activities to the 16th Session of the Consultative Committee for Time and Frequency

April 2004

This report describes the work done at National Research Council of Canada in the field of time and frequency metrology and some connected activities since the last CCTF meeting.

Caesium Clocks

CsVIA, one of the three caesium clocks (CsV, CsVIA and CsVIC) built by NRC nearly thirty years ago, has still been the source of TA(NRC). UTC(NRC) is generated by the same clock using a frequency offset generator to track UTC within 100 nanoseconds. The clock is behaving relatively well in long term, maintaining an Allan deviation of a few parts in 10^{15} as can be seen from the Circular T data.

Attempts to revive CsV and operate it at the same level of performance obtained in the past have failed due apparently to ovens and/or detectors problems. It is still not clear if the cesium ampoules were contaminated prior to refilling the ovens or if the procedure went wrong; or if the cleaning procedure for the detector's hot wire has failed. Lack of manpower has halted work on the clock. More efforts will be put on the caesium fountain.

Hydrogen Masers

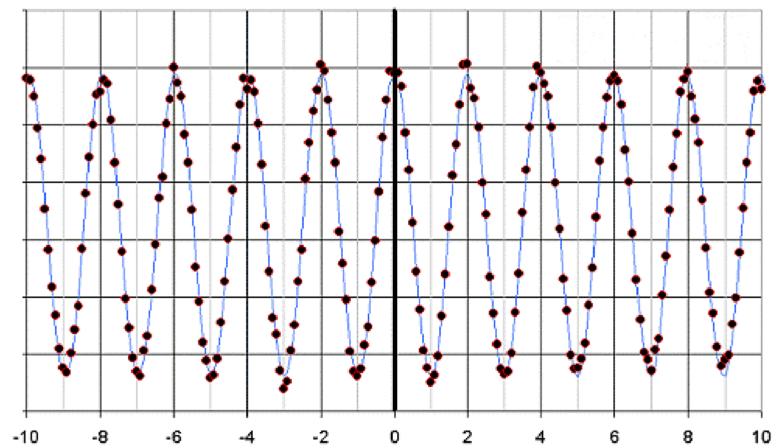
Our two hydrogen masers H3 and H4, built twelve years ago, needed some refurbishing. The ion pump of H3 failed at the end of 2001 and the ion pump on H4 failed at the end of 2002. Pumping elements were changed within a few days in each case. The masers were able to restart full operation within a couple of weeks at most. This was also the opportunity to test some new electronics on these masers. Better power supplies were installed. We are also in the process to replace some other electronics components that have shown aging or deterioration. Better filters are installed in the receiver. Better cables were installed to connect the masers to the frequency distribution units in the laboratory, resulting in the elimination or reduction of some parasitic signals at very low amplitude.

In order to guarantee short term stability as needed by the caesium fountain and the frequency comb generator, we acquired in 2003 a Quartzlock hydrogen maser CH1-75A, which we named R1. With this third maser, it was possible to show that H4 was the noisiest of our maser in short term, exhibiting an excess

Allan deviation of $5\times10^{-13}/\tau$ compared to the other masers. The source of the noise has not been found yet.

Caesium Fountain

The first version of the fountain has been used to provide more knowledge about a tall fountain but it has shown that there is no real advantage to extra height. The fountain was used mainly to test launching and detection schemes and to test the microwave cavity and frequency synthesizer. No light shutters had been installed and the contiguous launching of atoms could not really be tested, light from the MOT interfering with the launched atoms.



Standard launching scheme, with the MOT turned off during ballistic flight of atoms provided good Ramsey fringes (see Figure). That first version of a fountain delivered better short term stability than our current caesium beam tubes. No error budget has been made for the accuracy.

A new version of the fountain has been designed and most parts have been built. Assembly should begin this summer. Light shutters will be installed and tested for contiguous passages of atomic balls of cesium at zero frequency offset. This should get rid of some of the biases associated with frequency modulation. Careful study of the effects of spin exchange will have to be carried.

Phase Comparators

The noise of the frequency sources in the visible is much lower than what can be measured by our current phase comparators operating at 5 MHZ. We continued the development of new phase comparators at 100 MHz. Preliminary tests have shown the possibility to measure noise at the level of 3.5×10^{-14}, an improvement compared to the $5\text{-}7\times10^{-13}$ obtained with our 5 MHz chain. With this setup, we have been able to measure the noise between H3 and R1 and see at one second an Allan deviation of 2×10^{-13}, as expected from their specifications. Conversion to this 100 MHz system will continue.

GPS

We acquired an Ashtech Z-12T geodetic GPS receiver. The antenna was located on the highest point on the roof of the building, slightly higher than the position of the older antennas used by other GPS equipment. The Ashtech receiver is used in part for the CACS, Canadian Active Control System, and in part for the time laboratory of NRC. Data is collected every second for the CACS and processed in real time to give correction to the GPS for geodetic purpose. This is done by the Geodetic Survey Division of Natural Resources Canada (NRCan). Once a day, the data is reformatted in the RINEX format appropriate for the program provided by Pascale Defraigne to generate the BIPM schedule. The new maser, R1, provides the frequency reference for the Z-12T.

The calibration of the internal delays of our GPS receiver was done during the month of December 2003 against the BIPM calibration station.

We also have three Novatel OEM3 receivers, one used at our CHU station (see below) to monitor the clocks. A second one is on the same antenna than the Ashtech Z-12T receiver. Thus we can compare directly the performance of the two receivers although the processing of the data of the Novatel is done differently. Data is analyzed at the end of the day, not waiting for the next day data. It can also be processed in near real time. Results are comparable with a small advantage for the process used by Pascale Defraigne. This software seems to make better use of the satellites ephemeris. It might also be that the Z-12T is better than the Novatel OEM3.

Time and Frequency Dissemination

CHU: this radio station is still transmitting at three short wave frequencies but the cost of operation is increasing while the need is probably decreasing. Users are turning to GPS and low frequency transmitters as WWVB with time code. This last system does not cover well the north-eastern part of North America, and much pressure is put on us to provide an equivalent signal to WWVB.

NTP: internet being more popular than ever, our Network Time Protocol service is in high demand, with over 5 millions hits per day. Any disruption or appearance of disruption of service is immediately signaled by our clients. We have to educate them to the fact that timing through internet is not always very accurate, depending on the load of the network.

Frequency transfer through GPS: Some clients in Canada are starting to use their GPS data to compare with the data of our old single channel GPS, published every day on our web site for the last four days. We intend to provide some means of using these measurements done by the client as a traceable method of frequency. We will soon publish on our web page the Z-12T data as well as the single channel GPS data.

Optical Frequency Standards:

Work continued on the front of optical frequency standards, taking advantage of the frequency comb generator to improve the link with the caesium reference and the new probe laser stabilized on an ULE cavity. Some highlights of the key activities going on:

Frequency comb generator: the new frequency chain built around a femtosecond laser has replaced the old frequency chain which required at least four lasers at different frequencies, ranging from low infrared to visible. This has simplified the comparison of frequencies at virtually any wavelength from microwave to visible. The 1-s comb measurements of the ultra stable laser's frequency (assumed to be quiet) suggest that the comb is adding additional noise to the measurement, with the result that the standard deviation of the 1-s measurements was 4 to 5×10^{-13}, more than twice the 1-s Allan deviation of the hydrogen maser to which the comb was locked. This additional instability is thought to be a result of the comb's acoustically noisy environment.

Ultra stable laser: a new ultra-stable laser has been built, stabilized on ULE Fabry-Perrot cavity. The best operating temperature, minimizing the expansion coefficient of the cavity has been found. The drift appears to be 0.1 Hz per second, allowing a much better tracking of the transition of the strontium ion. The line width of the laser is better than 100 Hz, closer to 50 Hz most of the time.

Single ion trap: experiments with the old Strontium single ion trap are continuing. A study of the systematic shifts[1] has been done and resulted in better understanding and characterization of the ion trap. A series of measurements has been done, reducing the uncertainty budget to a few parts in 10^{14}, using any improvement that has been added to the frequency chain and the new probe laser. It is our intention to use this trap concurrently with the new ion trap under construction.

I2/HeNe laser: the comb was used to measure the frequency of the I_2/HeNe laser in three sets of measurements, including both before and after this laser was transported to the BIPM. Our comb measurements are in excellent agreement with measurements performed at the BIPM and show the outstanding reproducibility of this standard laser after intercontinental transport. Reproducibility better than 600 Hz (1×10^{-12}) was obtained[2].

Measurements on the current trap are now at the limit of the lowest uncertainty available from our realization of the SI second, using our caesium beam tubes. The expected performance of the new trap or any improvement of the current trap requires that we put more effort in the realization of the caesium fountain in a very near future in order to provide a commensurate realization of the SI second.

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[1] A.A. Madej, J.E. Bernard, P. Dubé, and L. Marmet, "Absolute Frequency of the $^{88}Sr^+$, 5s $^2S_{1/2}$ - 4d $^2D_{5/2}$ Reference Transition at 445 THz and Evaluation of Systematic Shift Parameters for the Single Ion Standard," submitted to Phys. Rev. A.

[2] A. A. Madej, J.E. Bernard, L. Robertsson, L.-S. Ma, M. Zucco, and R.S. Windeler, "Long Term Absolute Frequency Measurements of 633 nm Iodine Stabilized Laser Standards at NRC and Demonstration of High Reproducibility of such Devices in International Frequency Measurements", Metrologia (accepted for publication, Jan. 2004).