Report of the NRC to the 18th Session of the CCTF

Frequency and Time Group,
Institute for National Measurement Standards,
National Research Council, Ottawa, Canada

May 4, 2009

Report from NRC to the 18th session of the Consultative Committee for Time and Frequency (CCTF), 4^{th} - 5^{th} June 2009

1 Introduction

This report describes the activities of the National Research Council Canada in time and frequency metrology since the last CCTF meeting. The report is divided into three sections on Time and Frequency Generation, Time and Frequency Standards in Development, and Time Comparison and Dissemination.

2 Time and Frequency Generation

Since January 2006, an Agilent 5071A is the source of TA(NRC). UTC(NRC) is generated by the same clock using a frequency offset generator to track UTC within 100 nanoseconds. Four NRC 5071A clocks are reported to the BIPM for contribution to TAI. The stability of the NRC timescale is limited to temperature fluctuations in the comparator room. Plans are underway to move some clocks and comparators to a temperature stabilized room.

Cesium Clocks: Four commercial clocks (Agilent 5071A) were purchased, bringing the total to six available commercial clocks. We run four commercial clocks simultaneously: three provide a reliable source for UTC(NRC) and the fourth is a backup under evaluation.

In view of the high price of cesium beam tubes, work is under way to revive the homemade clocks (CsV, CsVIA and CsVIC built at NRC in the late 1970's) since they have proven to be more stable than commercial clocks. New electronic circuits will be constructed for these clocks. Once operational, each homemade clocks will replace a commercial clock.

Hydrogen Masers: Three hydrogen masers are in use. The two hydrogen masers H3 and H4 (NRC-built in 1991) are operating normally (stability $\approx 2 \times 10^{-13}/\tau$). The hydrogen maser R1 (Quartzlock CH1-75A) has a stability floor of 2×10^{-15}. One of them provides the signal for our GPS multi-channel receivers. Their excellent short term stability allows a good link between the cesium standards, through the frequency comb, to the optical frequency of the strontium ion.

Frequency Measurements of Molecular Transitions: Absolute frequency measurements have been performed of the reference a16 component of the R(127) line in iodine stabilized 633-nm HeNe lasers. Additional absolute frequency measurements were made of the reference component P(16) of the $^{13}C_2H_2$ acetylene stabilized NRC diode laser based system.[1] Measurements were also made of over 50

[1] J. Jiang, J. E. Bernard , A. A. Madej, A. Czajkowski , S. Drissler, and D. J. Jones, "Measurement of Acetylene-d Absorption Lines with a Self-Referenced Fiber Laser Frequency Comb," J. Opt. Soc. Am. B 24 (no.10), 2727-2735 (2007)

lines in C_2HD.[2] Four reference absorption lines in $^{14}NH_3$ were measured in absolute frequency in the 1510nm - 1560nm region.

Phase Comparators: We currently use 5 MHz phase comparators. Our prototype phase comparators operating at 10 MHz, 80 MHz and 100 MHz provide a few channels that can measure at the level of 3.5×10^{-14} in one second.

Frequency combs: Three frequency combs are in use in our laboratory. A Ti:sapphire comb is used in calibrations of optical frequency/wavelength for standard lasers in our group (I_2/HeNe at 633 nm and acetylene-stabilized lasers in the region of 1540 nm), and for lasers belonging to the Length Standards Laboratory (544 nm, 612 nm and 1153 nm).

Two fibre combs were constructed in a collaboration with a group from the University of British Columbia. One fibre comb is designed for general calibrations of optical frequency in the optical telecommunication bands. It has been used in a series of measurements of the $^{13}C_2H_2$, C_2HD and $^{14}NH_3$ absorption lines. The other fibre comb in its present configuration is used for measurements of the clock transition frequency at 445 THz (674 nm) of the single strontium ion standard. It will soon be modified to provide an rf output when locked to the ultrastable probe laser. It is hoped that the high short-term stability of this system will serve in the evaluation of our microwave standards.

3 Time and Frequency Standards in Development

Cesium Fountain: Ramsey fringes were seen for the first time with the fountain clock NRC-FCs1. The standard is loaded from a magneto-optical trap, uses a transverse C-field, a rectangular TM_{210} cavity with a Q=4300 temperature tuned at 29C. The launch and state preparation are being optimized before its evaluation. The fountain clock features electrostatic driven optical shutters to minimize light shifts and a small cryogenically cooled internal shield to measure the blackbody radiation shift. The targeted relative inaccuracy of the standard is 1×10^{-15}.

Sr ion Standard: New frequency measurements (Oct. 2008) of the Sr^+ clock transition are in agreement with previous measurements (May 2004) to within 0.4 ± 4.5 Hz (1σ), confirming the high level of reproducibility of the single ion standard and the equivalence of the new frequency comb apparatus in the determination of the absolute frequency. New lasers at 1092 nm and 1033 nm are being built to improve trapping times. A new trap of the end-cap design is also being built. Probing and cooling will be obtained over three orthogonal directions. The new system will feature a large fluorescence collection efficiency, well controlled magnetic environment, imaging the ion motion using a photon counting camera and photon detection correlation.

Ultra stable lasers: Our 4.3 Hz wide laser at 674nm has shown a stability of 5×10^{-16} at 3000 s (after subtraction of the linear drift) when measured against the Sr^+ ion.[3] This stability is below the thermal limit obtained for 10 cm long cavities, but still above the thermal limit for our 25 cm cavity. Measurements of the probe laser frequency have been extended to durations exceeding three days.

Sr Lattice Clock: Work has begun in collaboration with a visiting scientist from MIKES (Finland) in the design and construction of the primary laser cooling source at 461 nm. Work has also been devoted to the construction of an ultra-stable laser system that will serve to probe the neutral Sr system reference transition at 429 THz and the existing Sr+ optical frequency/time standard reference at 445 THz.

[2] Jiang, J., Bernard, J.E., Madej, A.A., Czajkowski, A., Drissler, S., Jones, D.J. "Measurement of acetylene-d absorption lines with a self-referenced fiber laser frequency comb," J. Opt. Soc. Am. **B** 24 (10), 2727-2735, October 2007.

[3] P. Dubé, A.A. Madej, J.E. Bernard, L. Marmet, and A.D. Shiner, "A narrow linewidth and frequency-stable probe laser source for the $^{88}Sr^+$ single ion optical frquency standard," Appl. Phys. **B** 95, pp. 43-54 (2009).

4 Time Comparison and Dissemination

GPS: GPS common-view is used to compare UTC(NRC) with other clocks around the world. The old NBS type GPS receiver, which was our official link with TAI, has been replaced by the Ashtech Z-12T GPS receiver. This has greatly improved the links with other laboratories. We are also running Novatel OEM3 and OEM4 receivers which can be used as backup for the official GPS link.

We also participate to the SIM (Systema Interamericano de Metrologia) Time and Frequency Comparisons via Common-View GPS.[4]

Since December 2008, we participate in the TAIPPP experiment.

Quality System and Client Calibrations: Accreditation has been obtained for our Quality System under ISO 17025. Calibration and Measurement Capabilities, CMC, for Time and Frequency has been reviewed by the Sistema Interamericano de Metrologia (SIM) Time and Frequency Group and will be soon reviewed by others Regional Metrology Organization.

The scope of accreditation of the Time Standards Laboratory states that the uncertainty in frequency calibrations is $1 \times 10^{-13}(k = 2)$, while the scope of the Optical Frequency Standards Laboratory lists an uncertainty for comb-based calibrations of $3 \times 10^{-14}(k = 2)$. Recent calibrations in the Time Standards Laboratory have achieved uncertainties of $1 \times 10^{-14}(k = 2)$.

The Ti:sapphire comb is part of our quality system and we use it to offer calibrations of optical frequency/wavelength in the visible and near infrared. These calibrations are listed in the NRC CMC's for Length. A call has gone out for participation among SIM laboratories in a K11 key comparison of laser frequency for 633-nm I_2/HeNe lasers, planned for September, 2009. NRC is serving as the node laboratory for the K11 comparison for SIM.

Time Dissemination: Time is disseminated continuously through the talking clock, the web clock, network time protocol, radio broadcasts from CHU and CBC/Radio Canada.

Low-level calibrations are routinely performed for stopwatches and quartz crystals. The Web Clock is also a popular service for those who would like to see official time with a browser. This service uses the SNTP protocol in order to display the correct time on a user's computer.

The use of the Network Time Protocol (NTP) continues to increase. The internet servers for this service get a total of 20 million hits per day. We also offer authenticated NTP service for clients who require greater security.

A survey conducted in 2006 - 2007, showed that there is a small but loyal audience who use the shortwave service, not only for official time but as a frequency reference as well. The user range from amateur radio operators to amateur and professional astronomers. In 2007 funds were allocated to refurbish the aging transmitters of the shortwave radio station. Recent changes by the ITU had reallocated part of the 40 meter band to broadcast service. International broadcast stations started transmitting on our 7335 kHz broadcast frequency. Consequently on January 1, 2009, we changed the transmitting frequency from 7335 kHz to 7850 kHz (the other frequencies are 3330 kHz and 14670 kHz). Backup transmitters for each frequency will be completed this summer. One low-performance commercial 5071A clock is located at the CHU transmitter to drive the carrier frequencies.

[4] M. A. Lombardi, A. N. Novick, J. M. Lopez, J. S. Boulanger, and R. Pelletier, "The Interamerican Metrology System (SIM) Common-View GPS Comparison Network," Proceedings of the 2005 IEEE Frequency Control Symposium, August 2005, pp. 691-698.