Report of the NRC to the 20th Meeting of the CCTF

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National Research Council, Ottawa, Canada

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1. Introduction

This report describes the activities of the National Research Council of 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

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. Three NRC 5071A clocks and one hydrogen maser are reported to the BIPM for contribution to TAI. Four 5071A clocks and two hydrogen masers are reported to the BIPM for the Rapid UTC pilot project.

Caesium Clocks: A total of twelve commercial clocks (Agilent 5071A) are available. At our main lab we run four commercial clocks simultaneously, three high-performance and one low-performance. Two NRC-built clocks, CsVIa and CsVIc, are operating as a backup. Two low-performance Agilent 5071A clocks are in operation at the short wave radio station (CHU).

Hydrogen Masers: Two hydrogen masers are in use: NRC-built H4 and Symmetricom MHM-2010 (provides a local oscillator reference for the GPS receivers).

Frequency Measurements of Molecular Transitions: Since September 2012, one series of absolute frequency measurements has been performed of each of the two NRC-built 193-THz (1.54 µm) reference laser systems stabilized on component P(16) of the $\nu_1 + \nu_3$ band of $^{13}C_2H_2$. The two systems were inter-compared on the P(16) and P(21) components in one separate series of measurements.

Two series of absolute frequency measurements were conducted since September 2012 of the group's three iodine-stabilized 474-THz (633-nm) HeNe lasers for the reference "d", "e", "f", and "g" (a_{18}, a_{17}, a_{16}, and a_{15}) lines of the R(127) 11-5 transition in $^{127}I_2$. All systems continue to operate within the specified accuracy, and long-term reproducibility at the kilohertz level is achieved for these standards.

Phase Comparators: We currently use 3 multi-channel phase comparators: 5 MHz NRC-built, 80-MHz from Timetech and 100 MHz from Timetech.

Time Interval Counters: We operate two CNT 91 counters that are part of our K001.UTC system.

Frequency combs: Two 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 NRC Dimensional Metrology Laboratory (544 nm, 594 nm, 612 nm, and 1153 nm).
A fibre comb is used for the measurements of the clock transition frequency at 445 THz (674 nm) of the single strontium ion standard against the hydrogen maser H4, thus providing a link to TAI. A second 100-MHz frequency comb is under construction to be used as a source of rf signals for direct comparison with microwave standards.

3. Time and Frequency Standards in Development

Cesium Fountain: The NRC cesium fountain frequency standard is currently under major refurbishment. The optical system has been modified to replace the injection locked diode lasers with tapered amplifiers. As a result the system remains locked for days at a time. Optical pumping has been added to the fountain system, significantly improving the SNR that is now quantum projection noise limited [1]. We are currently working on replacing the fountain body using a verified design with a longitudinal magnetic field.

Strontium Ion Standard: The $^{88}Sr^{+}$ ion optical frequency standard system based on an endcap trap design has been evaluated. Its fractional frequency uncertainty is 1.2×10^{-17}, currently limited by the evaluation of the blackbody radiation field at the ion [2-4]. The system includes an endcap ion trap designed to control micro-motion shifts down to fractional frequency levels of 10^{-17}. Further decrease of the micro-motion shifts to the 10^{-19} level is achieved by selecting the trap drive frequency such that the second-order Doppler shift and the scalar Stark shift cancel each other [4]. The blackbody shift uncertainty has also been reduced compared to the first evaluation given in [3] using a high-accuracy determination of the differential scalar polarizability of the clock transition [4]. Significant improvements to the stability of the single-ion frequency standard were also made by implementing a clear-out laser and a state-preparation step using optical pumping, yielding a stability of about 3×10^{-15} at 1 s averaging.

Ultra-stable Lasers: The 674 nm ULE laser linewidth has been demonstrated to be below 4.0 Hz and its thermal noise is estimated to be $\approx 3 \times 10^{-16}$. The ULE cavity is stabilized at the temperature where its thermal expansion coefficient vanishes. The isothermal creep rate is 10 mHz/s.

4. Time Comparison and Dissemination

GPS: GPS all-in-view is used to compare UTC(NRC) with other clocks around the world. We currently use 9 GPS receivers and 4 antennas located at our main building and at the CHU radio station. An Ashtech Z-12T is a part of our K001.UTC system. We are in the process of preparing a newly acquired Septentrio PolRx4TR as a replacement for the Ashtech as a K001.UTC system receiver. Other receivers include a Topcon NET-G3A, Novatel OEMV and OEM4 receivers and a Javad TRE_G3T DELTA. We participate in TAIPPP and Rapid-UTC projects at BIPM and in the SIM time and frequency comparison.

CMC: The Calibration and Measurement Capabilities, CMC, for Time and Frequency were successfully externally peer-reviewed by CENAM in May 2015. We participate in the international key comparisons: K001.UTC (ongoing), CCL-K11 key comparisons of optical frequency/wavelength standards (Sept. 2009 and Aug. 2012) and a SIM-organized stopwatch comparison (May 2010 to Feb. 2011).

Time Dissemination: Time is disseminated continuously through a telephone talking clock, computer time code via telephone, a web clock, network time protocol, shortwave radio broadcasts from CHU and on the national broadcaster, CBC/Radio-Canada. For a listing of our services, see http://www.nrc-cnrc.gc.ca/eng/services/time/index.html and http://www.nrc-cnrc.gc.ca/fra/services/heure/index.html. Low-level calibrations are routinely performed for stopwatches and quartz crystals. High-level calibrations for Cs and Rb frequency standards as well as H masers are performed as a routine service. Calibrations of laser frequency/wavelength are offered for wavelengths from 530 to 1200 nm and from 1510 to 1560 nm.

For redundancy purposes, the NRC time dissemination laboratoy has a secondary remote location at the CHU facility. At that location, two low performance Agilent 5071A clocks and two commercial rubidium standards (HP 5065 and Symmetricom 8040C) along with two GPS receivers (Novatel OEMV and OEM4) are in operation and provide a backup for time dissemination services and the NRC time scale.

[1] S. Beattie, J. Alcock, B. Jian, M. Gertsvolf, and J. Bernard, 8th SFSM (2015), accepted.
[2] A.A. Madej, P. Dubé, Z. Zhou, J.E. Bernard, and M. Gertsvolf, Phys. Rev. Lett. **109**, 203002 (2012).
[3] P. Dubé, A.A. Madej, Z. Zhou, and J.E. Bernard, Phys. Rev. A **87**, 023806 (2013).
[4] P. Dubé, A.A. Madej, M. Tibbo, and J.E. Bernard, Phys. Rev. Lett. **112**, 173002 (2014).