National Research Council, Canada

Report on Activities to the 15th Session of the Consultative Committee for Time and Frequency

June 2001

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

Caesium Clocks

Currently, UTC(NRC) is derived from CsVIA, one of the three caesium clocks (CsV, CsVIA and CsVIC) build by NRC more than 25 years ago and still running. Full evaluation has not been done for many years. TA(NRC) is the direct output of CsVIA while UTC(NRC) is corrected from time to time to track UTC within 100 nanoseconds.

Experiments are being conducted to replace the analogue servos by digital ones. One aim is to correct for the infrequent but still disruptive bursts of the detector current. Another aim is to implement automatic measurement of some parameters like C-field, skipping one servo cycle from time to time.

This digital servo also allows the use of a hydrogen maser, H3 built by NRC eight years ago, as a pseudo local oscillator on CsVIC. Phase comparison of the quartz clock with the hydrogen maser provides a short-term error signal, while the caesium beam response corrects the quartz for the long term. Corrections for the evaluated parameters can be applied to the clock through the digital servo avoiding a readjustment of the magnetic field as we have to do now. It gives as expected a much better stability on short term. We are still experimenting with various time constants in order to find the best compromise between the short-term stability of the maser and the long-term stability of the caesium clock. A single maser can be used for several caesium clocks. The results as seen in the BIPM publications for CsVIC do not reflect the true stability of the clock since we are still experimenting.

This last experiment should provide a simple mean to control a quartz oscillator to generate UTC(NRC) under the control of the best clock available.

CsV has been restarted after an interruption of many years. Mauricio J. López from CENAM, Centro Nacional de Metrología, visited us in April 2001, helping with the full evaluation. Unfortunately, one oven ran out of caesium prematurely at the end of May 2001. The beam has been reversed and the clock is running again but the part of the evaluation including the cavity phase shift study by beam reversal is compromised. A full evaluation is being under progress and should be available by the year-end.

Hydrogen masers

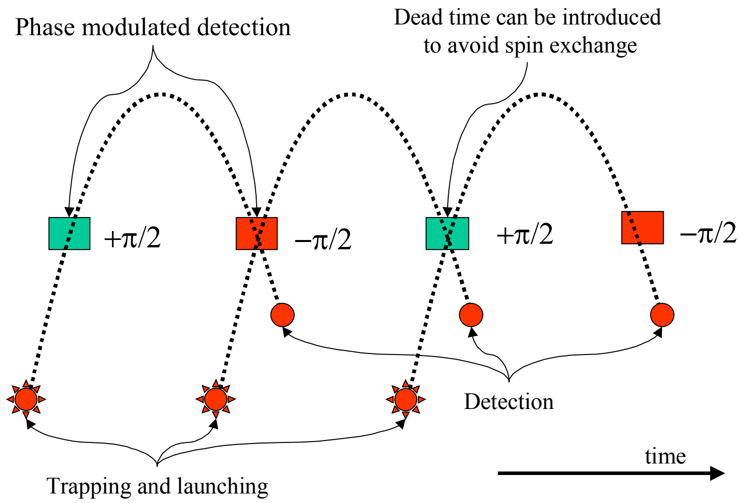
Our two home-built hydrogen masers, H3 and H4, are being rejuvenated by better electronics (hydrogen sources, frequency distribution, etc.). 100 MHz outputs are now available from H3 to be used by the caesium fountain and the new frequency chain based on the frequency comb generated by a femtosecond mode-locked laser.
The H3 maser is used as the local oscillator of the caesium clock CsVIC.

Frequency distribution, phase comparators

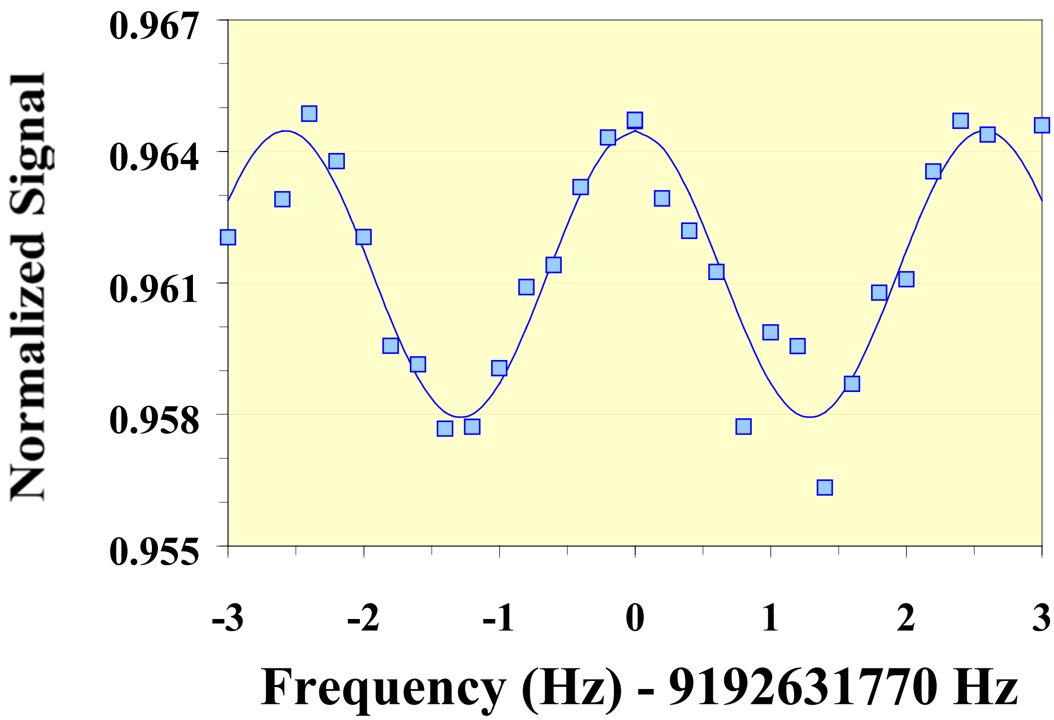
Frequency distribution, phase comparators and general measuring equipment need improvements. Many old cables are being replaced by cables less sensitive to temperature changes. That was a source of some instability in our measuring system, limiting primarily the medium term stability of our phase comparators to several parts in 10^{16} over one day.
100 MHz frequency distribution boxes are being installed to replace the 5 MHz distribution system currently available in the building. Multipliers from 5 to 100 MHz will feed the new phase comparators that are under development.
Our current phase comparators based on the offset frequency method at 5MHz is limited to $5 \times 10^{-13}/\tau$. Some channels are sometimes twice as bad. The new phase comparators will be running at 100 MHz. First attempts have shown a factor two of improvement as expected going from 5MHz to 10 MHz. Higher multiplying factors for the input frequency require modifications to some components of the system and should push the limits below 10^{-14} on one second.

Caesium Fountain

This measurement capacity is needed for our caesium fountain running in continuous phase measurement mode (See figure below)



This scheme of operation reduces the Dick effect of the servo; many other effects that are dependent on the modulation width (cavity pulling, microwave pulling, etc.) can benefit from this type of operation. The collision shift is still a problem but can be handled as well as in any other configuration.
Our first Ramsey fringes were obtained in December 1999. The signal to noise ratio was very low: about one. (See figure below) There was no preparation of the atoms.



The size of the laser beams was too small at 1 cm. This was limiting the number of atoms being trapped. Acceleration time was too short and only a few atoms could reach the proper velocity and be maintained as cooled as in the fixed molasses. We added more laser power to increase the diameter and still trap enough atoms. Daily realignment of the lasers has been improved by orders of magnitude when pinholes were replaced by fibre optics, also reducing the number of mirrors and lenses. Thanks to more power per beam (10mW), the number of trapped Cs atoms has been increased by a factor 100 (reaching 10^9 atoms), the temperature of these atoms decreased to below 2 μK (from 10 μK). The longitudinal temperature of the atoms does not change much after launching at speeds up to 6 m/s. The transverse temperature has not been measured accurately enough to draw a conclusion. The overall improvement of the expected stability of NRC-F1 has been improved by a factor greater than 1000 in the period from August 2000 to March 2001.
Our fountain has the 110 trapping and launching geometry in order to trap atoms while a cloud of atoms is travelling in the clock region. A crude shutter has been

designed and successfully demonstrated. It provides 60 dB isolation per stage. Double stage should be about one to two cm high device, without the vacuum enclosure. The final version of this shutter should operate under vacuum and avoid magnetic field perturbation.

Optical Frequency Standards

We are operating one single Sr+ ion trap, using the 5s2S1/2-4d2D5/2 transition at 445 THz (674 nm) as an absolute reference in the visible region. Limits of accuracy and stability have been identified and a new trap is being designed and built. Discussions were performed with researchers with the National Physical laboratory (U.K.) who have had previous experience with the development of a new type of ion trap based on the “end cap trap” configuration. The future comparison of the two traps will reduce the uncertainty budget that was obtained in the past by measurement against the caesium clocks through the old frequency chain (a few parts × 10^{-13}).
A new probe laser, stabilised laser on ULE cavity, is under development to improve the stability of the measurements on the ion trap. We are considering the possibility of using an optical frequency standard based on the single ion trap as our future frequency reference. This could become a reality since new frequency chains are being developed.
Absolute frequency measurements of the 474 THz iodine stabilised laser standard were performed using the single ion reference. Measurements were performed over three different experimental periods resulting in a determination of the absolute operating frequency of the NRC INMS 3 laser to an accuracy of 0.7 kHz (1.5 X 10^{-12}).
NRC co-ordinated and hosted an international intercomparison of 633-nm HeNe standards from the BIPM (Sèvres, France) and JILA/NIST (Boulder, Col., U.S.A). The output from this joint collaborative measurement resulted in the world-wide improvement of the recommended value for the widely used 633-nm reference frequency. Also, the measurement of the JILA/NIST travelling 633-nm standard provided crucial confirmation in the measurement technology based on femtosecond laser generated frequency combs.

Frequency Chains

Our old frequency chain based on mixing and frequency lock of a series of lasers ranging from the far infrared to the visible is still operational but is requiring a lot of efforts to operate. Any frequency from the visible down to the far infrared can be linked to the caesium frequency with an uncertainty around 10^{-13}.
Improvements to this design are too costly and results are not guaranteed.
The new technique in which a femtosecond mode-locked laser is used to produce an evenly spaced comb of optical frequencies is much more promising. The optical frequencies of the comb can be known to an accuracy limited only by the microwave reference itself. One of the hydrogen masers will be used to control the repetition rate of the mode-locked laser.

Time and Frequency Dissemination

A new caesium clock, HP5071A, has been installed at our short wave station **CHU**. Two Rubidium clocks are adding security to the CHU time scale. The whole station is monitored through GPS common view with our main laboratory. Because of the popularity of the Network Time Protocol (NTP) service, we installed an ensemble of NTP servers at the CHU station. The hits on our servers are now over 3×10^6 per day, increasing at a rate of 50% per year. This arrangement provides NTP servers from two independent sources under our direct control. One of the 12 servers has been set up to provide TAI as the reference time instead of UTC. The address is

tai1.chu.nrc.ca .

We use it for our data acquisition systems in order to avoid the ambiguity of the leap seconds, where it could matter.

GPS, WAAS, TWTT

Common-view GPS time transfer using the BIPM tracking schedule was done routinely with an “NBS type” receiver. Last three days of data are available on our Internet page for general use by clients. Two-way time transfer with USNO and NIST continued through the period at a rate of once per week. NRC is participating in the USNO/NRC/GSD Real-Time Clock Synchronization Joint Project using carrier phase GPS for synchronisation via the CACS (Canadian Active Control System) developed by the Geodetic Survey Division of Natural Resources Canada (NRCan).

We also have started some measurements using WAAS satellite, using a 3-meter dish antenna. We compared one of our hydrogen masers to one of the USNO hydrogen masers. Preliminary results are encouraging.