FREQUENCY STANDARDS WORK AND TIMEKEEPING AT THE NATIONAL RESEARCH COUNCIL OF CANADA

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For many years, the primary means of establishing the international time scale TAI was through the Loran C navigation network. When the East Coast network was reconfigured in 1979, with the introduction of Seneca as the master of the North East Coast chain, it had some rather surprising effects on international time keeping.

In Ottawa we found that the time of arrival of signals received from Nantucket and Seneca showed a seasonal variation of over 1 μs[1]. This is the result of changes in propagation delay, and the changes introduced in the emission times of the Loran C stations by the local area monitor at Sandy Hook. Our path to Seneca is short and much over water, while the path to Nantucket is over the Adirondacks. For USNO the reverse is true, and when the USNO started reporting Seneca in mid 1979, a large seasonal variation was introduced into their time scale, and because of their weight of clocks, into TAI. In Figure 1, it can be seen that the time scales of NRC and PTB have a strongly correlated seasonal variation, in opposite phase to that of the USNO, which is an indication that the observed seasonal variation was in TAI. The TAI mean frequency also increased by 1×10^{-13}. Of course all clocks and all Loran C paths might contribute to seasonal effects to some degree, but the change in the Loran C network made this particularly obvious for the USNO scale.

In 1983 the USNO began reporting to the BIH by GPS satellites, so the seasonal effect should disappear, and it did. There is some variation, but it is not seasonal.

But, in the PTB scale, the seasonal variation is still there, and this time, the NRC can offer little help. For 1983 and to June 1984, we see a very similar seasonal variation, but then we ran into trouble. CsV ran out of cesium, both ovens within six weeks, and when the ovens were refilled, before CsV was evaluated, work started on "improving" the air-conditioning of the building to save energy. The loss of temperature control in the CsVI room made it impossible to use them as references for the CsV evaluation.

An evaluation was finished in January 1985, as can be seen in Figure 1, but problems with temperature remained through 1986. There will be a separate controller for the CsVI room shortly, and it is hoped to be back to normal operation soon.

There might be signs of the correlation returning between NRC and PTB, but the question of where the seasonal variations arise is still not answered.

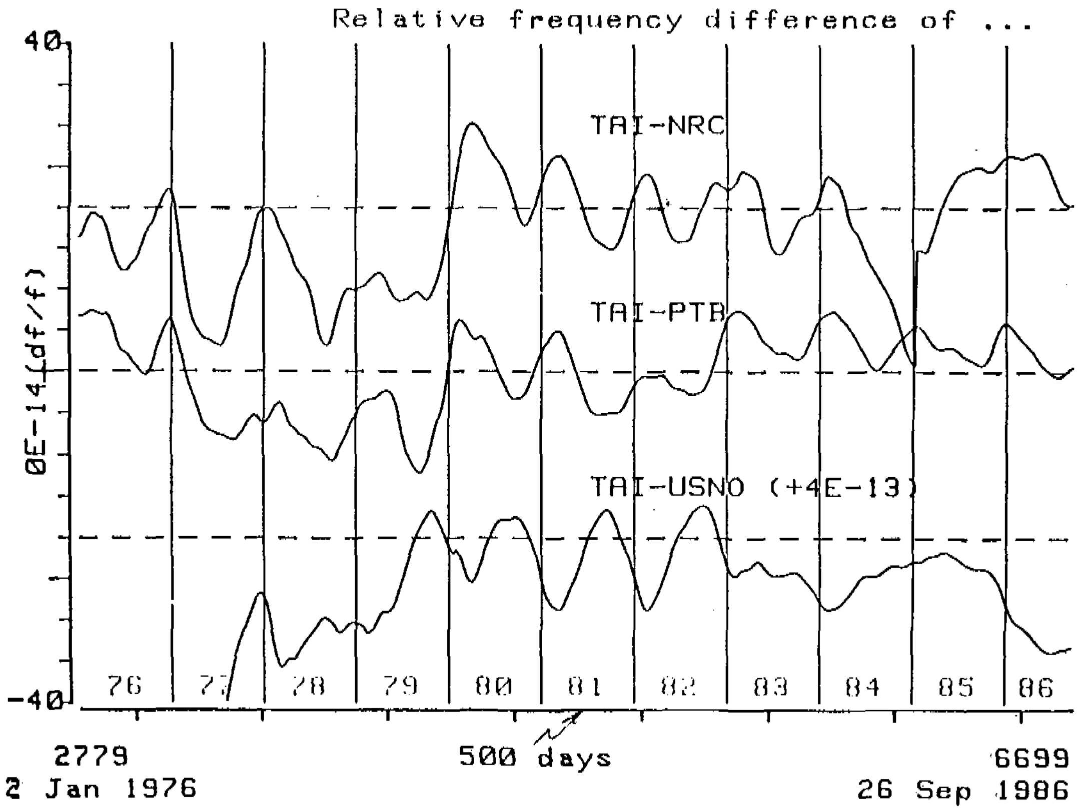

Figure 1. The relative frequency differences between TAI and the time scales of NRC, PTB and USNO. For each curve the dotted line is TAI.

The PTB has now two primary cesium clocks in operation, and they have reported an extraordinary agreement at CPEM '86[2], 2×10^{-14}, throughout the year. It is hard to believe that two independent primary cesium clocks could track so closely if there is a large seasonal effect.

We were quite sure in 1980 and 1981 that the seasonal swings of over 1×10^{-13} were not in the NRC and PTB primary clocks. The time transfer by the Symphonie satellite, Figure 2, over this period showed no evidence of seasonal variations. The change at MJD 44520 was the evaluation of CsV. The vertical lines are the dates on which PTB reversed their beam in CS1, and we thought that we detected a $\pm 2 \times 10^{-14}$ bias on reversal. The PTB was sure that this was not so, but it was exciting then to measure with such precision between laboratories 5,500 km apart. We hope before long that two-way satellite time transfer using the Hartl modems will be a matter of daily routine.

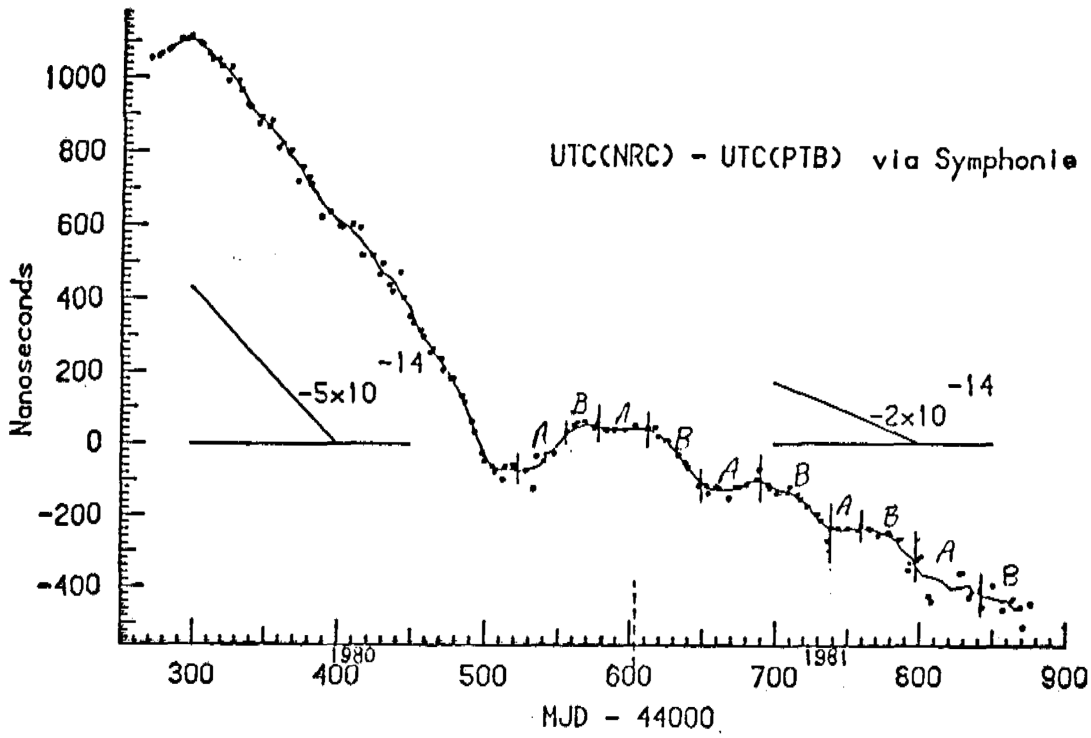

Figure 2. The difference between the UTC time scales of NRC and PTB as measured by two-way time transfer via the Symphonie satellite.

The performance of the CsVI clocks against TAI is shown in Figure 3. As in Figure 1, the dotted line represents TAI for each curve. While the performance has been somewhat disappointing, it must be pointed out that they have never been steered, and that the frequency of each clock is determined only by individual evaluation.

For the future on our cesium standards we still hope that time can be found to reduce the sensitivity of our CsVI's to temperature and to mechanical shocks. It is essential that we insulate the Ramsey cavities to eliminate the thermoelectric currents which are sensitive to both temperature and vibrations.

For CsV, it is now 14 years old, it has about 15 grams of cesium somewhere inside, and we don't know what effects this might have. The electronics have been steadily improved, and cables replaced, because contacts can deteriorate over such time. We have been adding digital servo systems to monitor the analog servos, and we may go to fully digital servos.

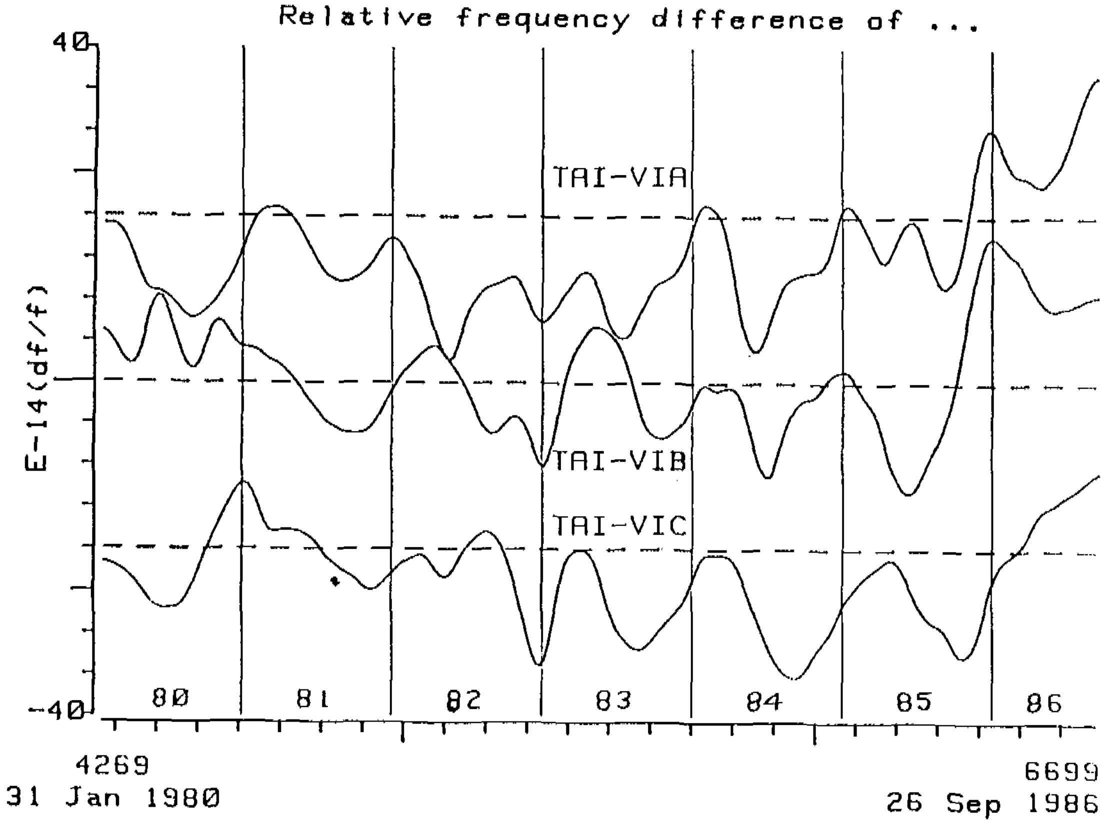

Figure 3. The relative frequency difference between TAI and the time scales of CsVI A, CsVI B, and CsVI C.

The paper[3] we gave here two years ago described a new method to determine the velocity distribution in the cesium beam and a very accurate determination of the Second Order Doppler correction. If you set the frequency at the center of the Ramsey resonance, and vary the microwave excitation power, a Fast Fourier Transform of the resulting curve will give the time-of flight distribution, which is readily converted to velocity distribution. To check, the Ramsey pattern can be calculated, and compared with the experimental curve. We found differences of less than 1%, and reduced the uncertainty in the Second Order Doppler correction from 2×10^{-14} to 1×10^{-15}.[4]

Last year, we reported[5] on the recording of the transient of the cesium beam that occurs with the square wave frequency modulation that we use. The atoms that have passed through the first cavity, and are caught in between the cavities when the frequency is shifted to the other side of the resonance, give a pulse that is dependent on the velocity distribution. For each velocity you have the upper half of a sine wave, which begins when the atoms from the second cavity reach the detector, and ends when the atoms from the first cavity reach the detector. From the known velocity distribution, you can compute the shape of the pulse and compare it with the experimental curve. The excellent agreement confirms the correctness of the velocity distribution, and the method can be used at a later date to check whether or not the distribution has changed, without interrupting the operation of the standard.

We also discussed last year the potential of laser cooling of cesium atoms to create a Zacharias fountain, to bring a cesium standard into parts in 10^{16} range. We have been purchasing hardware as the first step towards this goal, but with many other projects demanding time, progress in this exciting project might be slower than we would wish.

Development of two hydrogen masers, H1 and H2, was started at NRC in 1964 and oscillation first occurred in 1966. Since 1975, accurate frequency comparisons between the masers under auto-tuner control and the NRC primary cesium standards have been carried out. Data are available up to the end of 1985.

The frequency of each of the masers has shown a decrease with time with respect to the cesium frequency. After examination of other possible causes, this frequency change has been attributed to an increase in the wall shift of the Teflon coating of each of the storage bulbs. The effect is typically several parts in 10^{13} per year. Data for two particular storage bulbs are as follows: -

1. Bulb in maser H1. Data over 5 years.
   A change in slope occurred after about 2 years. Prior to that, the wall shift drift was -5×10^{-13} per year. Since then, it has been -13×10^{-13} per year.

2. Bulb in maser H2. Data over 11 years.
   A change in slope occurred after about 8 years. Prior to that, the drift was -3×10^{-13} per year. Since then, it has been -17×10^{-13} per year.

The reason for this drift is still not understood. It is thought to be due to a change in the physical characteristics of the Teflon surface with time, such that the effective surface area is increased. It does not appear to be the result of contamination since, in that case, a corresponding decrease in line-Q would be expected to occur. In fact, no significant decrease in line-Q has been observed over the periods concerned.

Wall shift drifts have been observed, at least for some coatings, by Japanese, Australian and Russian workers. Other laboratories have reported no drift so it seems that coating of the bulbs is still not an exact science.

Two new hydrogen masers, H3 and H4, are now under construction and it is hoped to observe oscillation in late 1987. They are full-size active masers which incorporate a number of improvements over the design of H1 and H2. For example, the magnetic shielding of the resonant cavity region will be greatly improved over that of the present masers by the use of five magnetic shields instead of three, and by the use of smaller holes through the shield baseplates for the vacuum pipe. Metal vacuum seals will be used throughout, instead of the Viton O-rings used previously. This should result in a cleaner vacuum environment for the storage bulb. Attention has also been paid to improved mechanical and thermal isolation of the resonant cavity, in order to improve the long-term frequency stability.

It is expected that H3 and H4 will exhibit better long-term stability and greater reliability for continuous operation than H1 and H2. If this proves to be true, one or both of them may eventually be used as clocks and as contributors to the NRC time scale. In addition, it may be possible to shed some further light on the problem of wall shift changes.

We have had preliminary discussions with Telesat Canada on the possibility of broadcasting time signals from the proposed MSAT satellites. The question of adding a 400.1 MHz transmitter was discussed and discarded, because it would be impractical due to the weight of the added hardware that would be needed. The best solution seems to be to lease a few kHz on the satellite. The time signal under our control would be uplinked from the main ground station. It is thought that, from the experience with NBS GOES program that this could provide a service much superior to the shortwave service.

While general approval for the MSAT satellite has been given in Canada, we understand that it can only go ahead if an essentially identical pair of satellites are launched by the States, and the last that we heard, the situation there is not clear. There are several competing proposals, and the frequency allocation is uncertain. At the moment the proposal for MSAT is in limbo.

Another proposal by our Department of Transport is to locate a VLF station at Cambridge Bay in the Canadian Arctic, approximately 105° W longitude and 69° N latitude. A frequency allocation in the 25-30 kHz band has been requested. The station would serve to supplement the Omega system for navigation in the Arctic. Consideration is being given to include a time code in the broadcast, if this can be done without impairing the navigation signals. There is already a 600 ft antenna on the site. As radio reception in the shortwave is frequently impossible in the Arctic, it could be a useful service. If it does go ahead we would use the same code as WWVB.

References

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