THE ESTABLISHMENT OF A BRAZILIAN ATOMIC TIME SCALE

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Abstract — **The Atomic Time Scale at the Time Service Division of the National Observatory in Rio de Janeiro (ONRJ) has been carried out by commercial cesium clocks. The UTC(ONRJ) time scale based on a single commercial cesium clock selected from the ensemble of clocks is not suitable to attain the bounds of uncertainty recommended by the ITU-R and by the CCTF. The recommendation has suggested to the national time primary laboratories to coordinate with UTC within ±0.1µs.**

The development of atomic time scale system was divided in two parts: the construction of an automated data acquisition system and the implementation of the time scale algorithm that generated a time scale based on the clock ensemble.

The present work will describe the atomic time scale system and report the results obtained using real clocks data from September 27, 2004 to August 15, 2005.

I. INTRODUCTION

The purpose of this paper is to describe the development of Brazilian Atomic Time Scale kept at the Time Service Division of the National Observatory in Rio de Janeiro (ONRJ). The development of atomic time scale system was divided in two parts: the construction of an automated data acquisition system and the implementation of the time scale algorithm, that generated a time scale based on the clock ensemble.

A time scale system can enable a time laboratory to keep time with stability, accuracy, and reliability beyond the performance level of the best physical clock in the laboratory [1]. In practice a time scale system can be divided into three parts. The first part is a clock ensemble that will be used as a reference for the generation of a local UTC time scale; the second, an automated data acquisition system that measures the time differences between the clocks; the third is a time scale algorithm that computes the paper time scale. Fig. 1 shows the block diagram of the Brazilian Atomic Time Scale System [2]. In the first part of the paper we describe the time scale system, them the results of the TAB1(ONRJ) paper clock averaged over the ensemble of five commercial cesium clocks are discussed.

II. TIME SCALE SYSTEM

A. *The Clock Ensemble*

The actual clock ensemble has four commercial cesium beam frequency standards HP5071A, three with high performance tube and one with standard performance tube, and one commercial cesium clock Datum. The atomic clocks are in two separated rooms. In the first room there are one HP5071A (T129) and one Datum 4310 (T126). In the second room located at 5m underground there are two HP5071A (T130) and (T103), and the other HP5071A (T123) inside a shielded enclosure. The nominal ambient temperature is about 25°C±0.5°C and the nominal humidity is 60%±10%.

B. *Automated data acquisition*

The equipment used to measure time difference is a commercial electronic counter. The clock pairs are chosen by means of a multiplexer controlled by a computer, through a parallel output. This computer accepts the readings of the counter through an IEEE-488 interface and stores the data in a hard disk. The time differences between one specific clock and all the others are measured by the hardware every minute and carried out in a few seconds. In practice, the 1pps signal from the reference clock starts the counter and at a time later 1pps signal from another clock stops the counter.

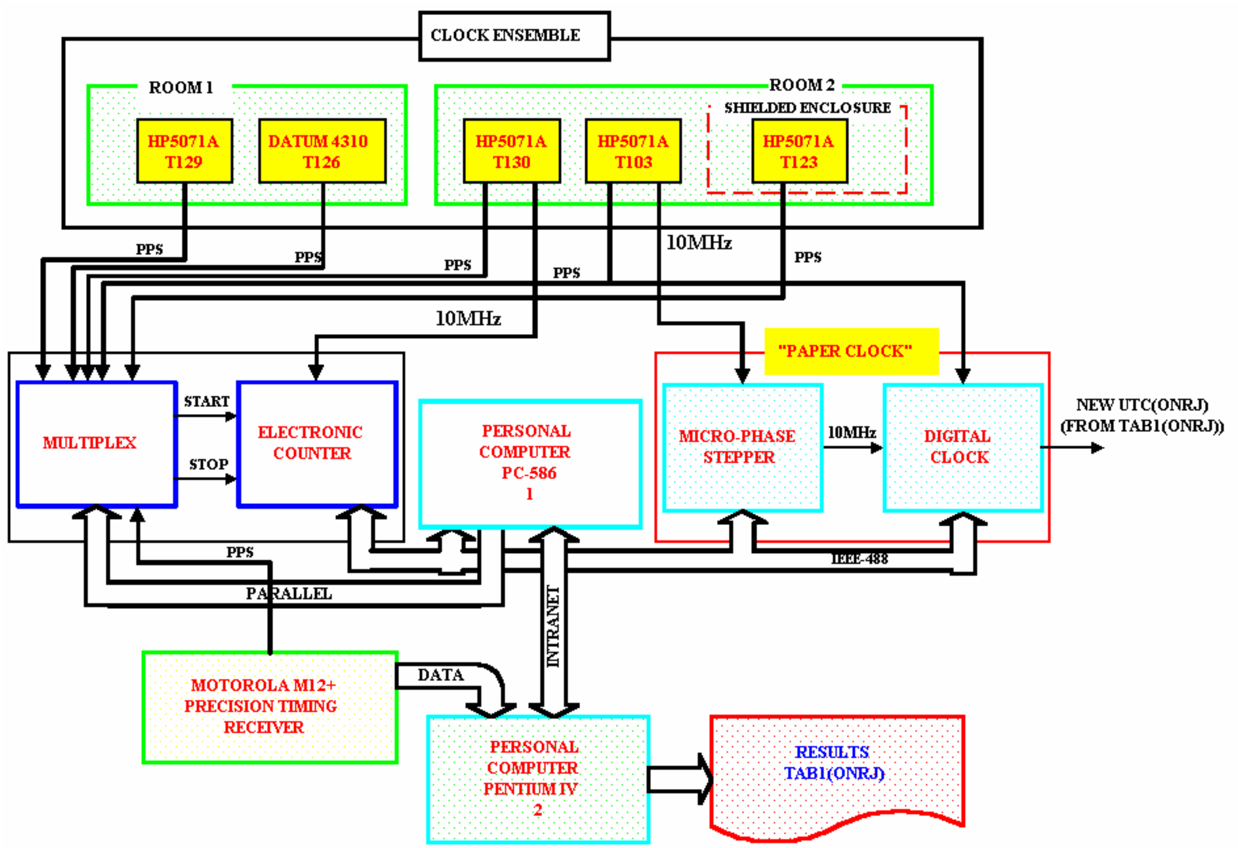

Figure 1. Block Diagram of the Brazilian Atomic Time Scale System

C. The atomic time scale algorithm

In the choice of the algorithm to calculated TAB1(ONRJ) we have consider that the optimum algorithm with a small group of clocks is not obvious and very difficult to find. In general a time scale algorithm takes the time difference measurements between clocks and combines them mathematically to produce an average time scale [3, 4, 5, 6, 7]. The algorithm that generates TAB1(ONRJ) follows the same steps of the main ensemble algorithm used successfully in the NIST [1] and is outlined here shortly.

The inputs to the algorithm are the time difference measurements x_{ij} between all of the clock pairs, with the time intervals between measurements of 3 hours. This interval is long enough to eliminate the influence of the measurement noise.

A first prediction of the time offset for each clock against the ensemble is given by

$$\hat{x}_{ij}(t+\tau) = x_i(t) + y_i(t)\tau\,. \qquad (1)$$

The best estimate of the time offset of each clock j at time $t+\tau$ given the measurements $x_{ij}(t+\tau)$ is

$$x_j(t+\tau) = \sum_{i=1}^{n} w_i(\tau)[\hat{x}_i(t+\tau) - x_{ij}(t+\tau)]\,. \qquad (2)$$

Once the $x_j(t+\tau)$ are known the average frequency of each clock over the last interval can be estimate by

$$\hat{Y}_j(t+\tau) = \frac{x_i(t+\tau) - x_i(t)}{\tau}\,. \qquad (3)$$

An exponentially filtered estimate of the current average frequency of clock i that will be used in the next prediction interval is given by

$$Y_i(t+\tau) = \frac{1}{m_i+1}\left[\hat{Y}_i(t+\tau) + m_i Y_i(t)\right], \qquad (4)$$

where m_i is an exponential time constant determined from the relative levels of white noise and random walk FM, that is

$$m_i = \frac{1}{2}\left(-1 + \left(\frac{1}{3} + \frac{4\tau_{\min i}^2}{3\tau^2} \right)^{1/2} \right). \qquad (5)$$

The clock weights w_i that appear in (2) are calculated from the variances of the time residuals ε_i^2 by

$$w_i = \frac{1}{\sum_{i=1}^{n} \frac{1}{\langle \varepsilon_i^2(\tau) \rangle}} \frac{1}{\langle \varepsilon_i^2(\tau) \rangle} \qquad (6)$$

The prediction error of clock i over the interval $t+\tau$ is estimated by

$$\hat{\varepsilon}_i^2 = \left(x_i(t+\tau) - \hat{x}_i(t+\tau) \right)^2 K_i . \qquad (7)$$

Because ensemble time is a weighted average of each clock times, the prediction error estimate (7) is biased, because each clock is a member of the ensemble, so it is necessary to correct this biasing [8] by

$$K_i = \frac{1}{(1-w_i)} . \qquad (8)$$

Since the noise characteristics of a cesium clock may not by stationary, the current prediction error of each clock is exponentially filter where the past prediction error are deweighted in the process, that is

$$\varepsilon_i^2(t+\tau) = \frac{1}{N_\tau + 1}\left[\varepsilon_i^2(t+\tau) + N_\tau \varepsilon_i^2(t) \right], \qquad (9)$$

the time constant for the filter is typically chosen to be $N_\tau = 20$ days and the initial value of ε_i^2 is estimated as $\tau^2 \sigma_y^2(\tau)$.

III. RESULTS

In this section we present some results of the atomic time scale TAB1(ONRJ) computed for the period them September 27, 2004 to August 15, 2005. The clocks used in the scale are give in Table 1 with the respective period of participation

TABLE 1. CLOCKS USED IN THE TAB1(ONRJ)

Clock Number	Type	Period
T103	Cesium Clock HP5071A Tube High Performance	September 27, 2004 to August 15, 2005
T123	Cesium Clock HP5071A Tube Standard	September 27, 2004 to August 15, 2005
T126	Cesium Clock DATUM 4310 High Performance	September 27, 2004 to August 15, 2005
T129	Cesium Clock – HP5071A Tube High Performance	September 27, 2004 to February 18, 2005 and April 20, 2005 to August 15, 2005
T130	Cesium Clock – HP5071A Tube High Performance	September 27, 2004 to August 15, 2005

The clocks had their pps output compared with a 1 pps signal from the GPS receiver Motorola M12+ Precision Timing Receiver (GPS Time). Each individual measurement between clocks and GPS Time is shown in Fig. 2 and the time difference measurement between clocks are shown in Fig. 3.

To evaluate the instability of the clocks the Fig. 4 shows the individual instability by the N-cornered hat technique [9] computed with five cesium clocks for the September 11, 2004 to February 18, 2005.

For the computation of TAB1(ONRJ) the algorithm starts with the initial time offset and average frequency values for each clock estimated with GPS Time as reference for the period September 11, 2004 to September 21, 2004. Fig. 5 shows the differences [TAB1 (ONRJ) – GPS Time]. The weights attributed to the clocks by the algorithm are shown in the Fig. 6. Fig. 7 gives the Allan deviation of the clocks and TAB1(ONRJ) estimated by N-cornered hat.

In Fig. 8 are reported the time differences of the cesium clocks and TAB1(ONRJ) relative to UTC(BIPM) for a period of 125 days.

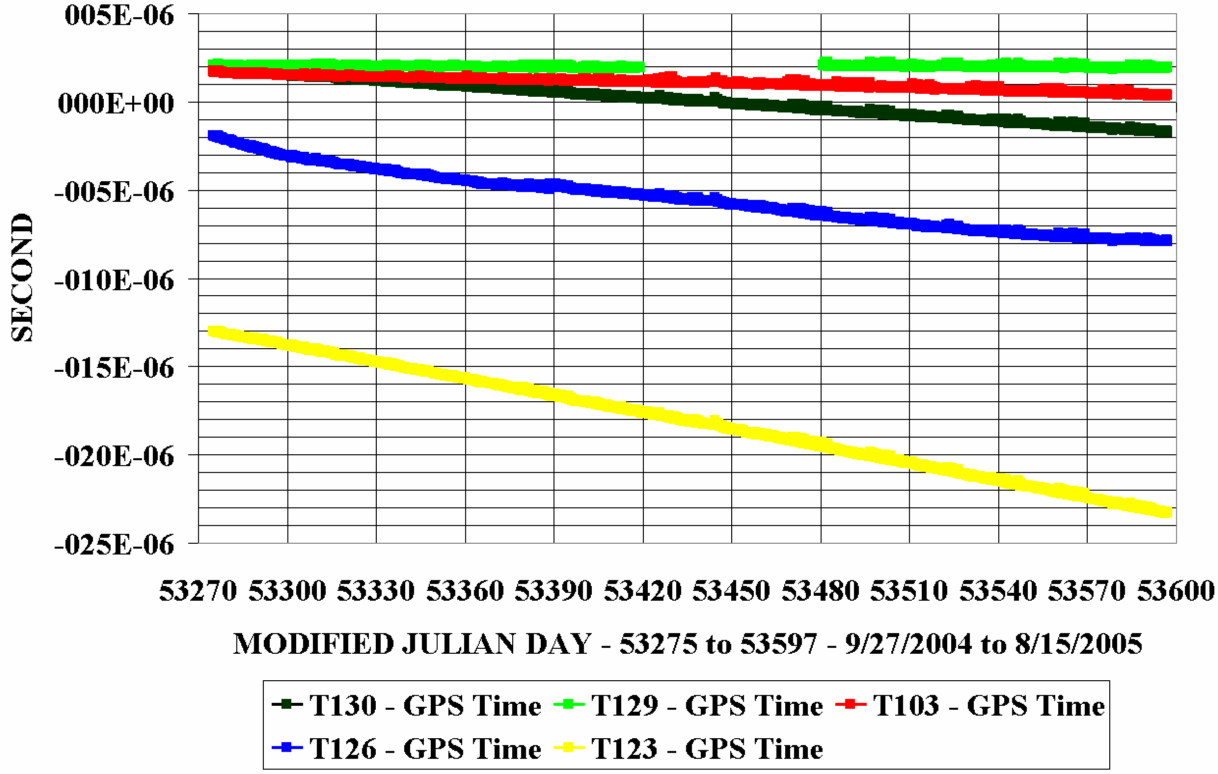

Figure 2. Time Difference with respect to the GPS Time from M12+.

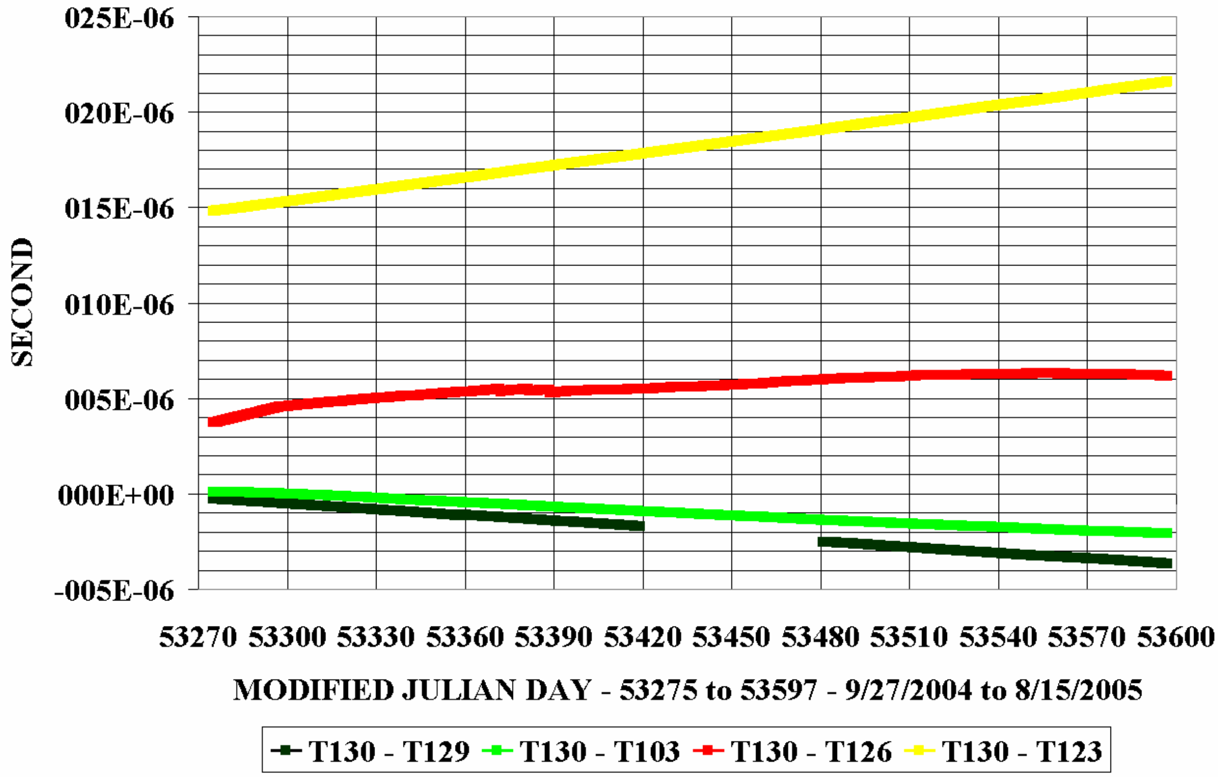

Figure 3. Time Difference between clocks.

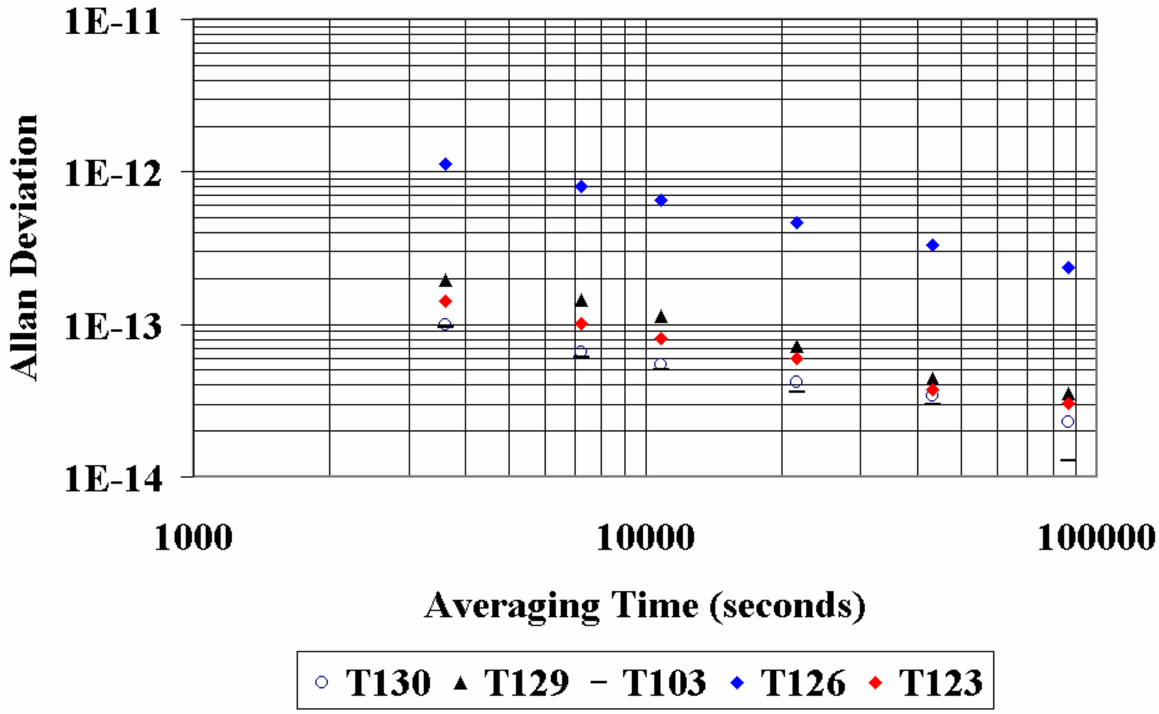

Figure 4. Comparison of Allan deviations of the clocks.

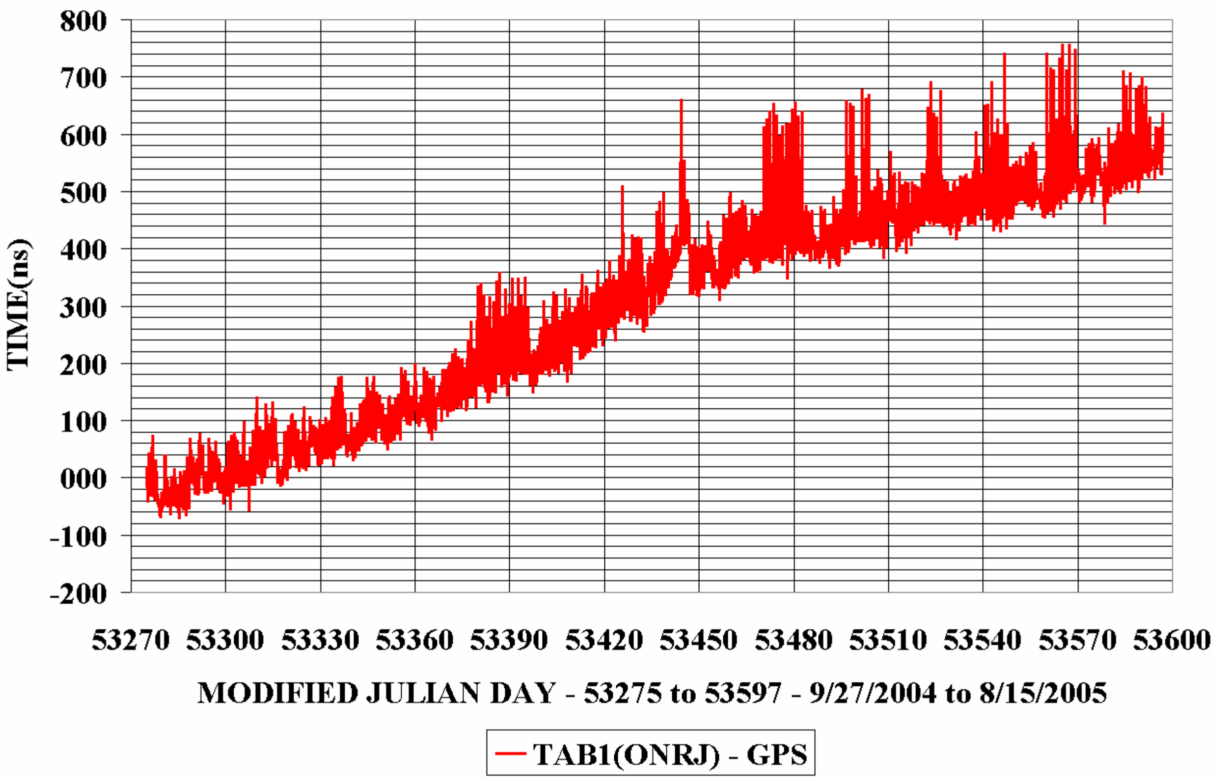

Figure 5. Difference between TAB1(ONRJ) and GPS Time.

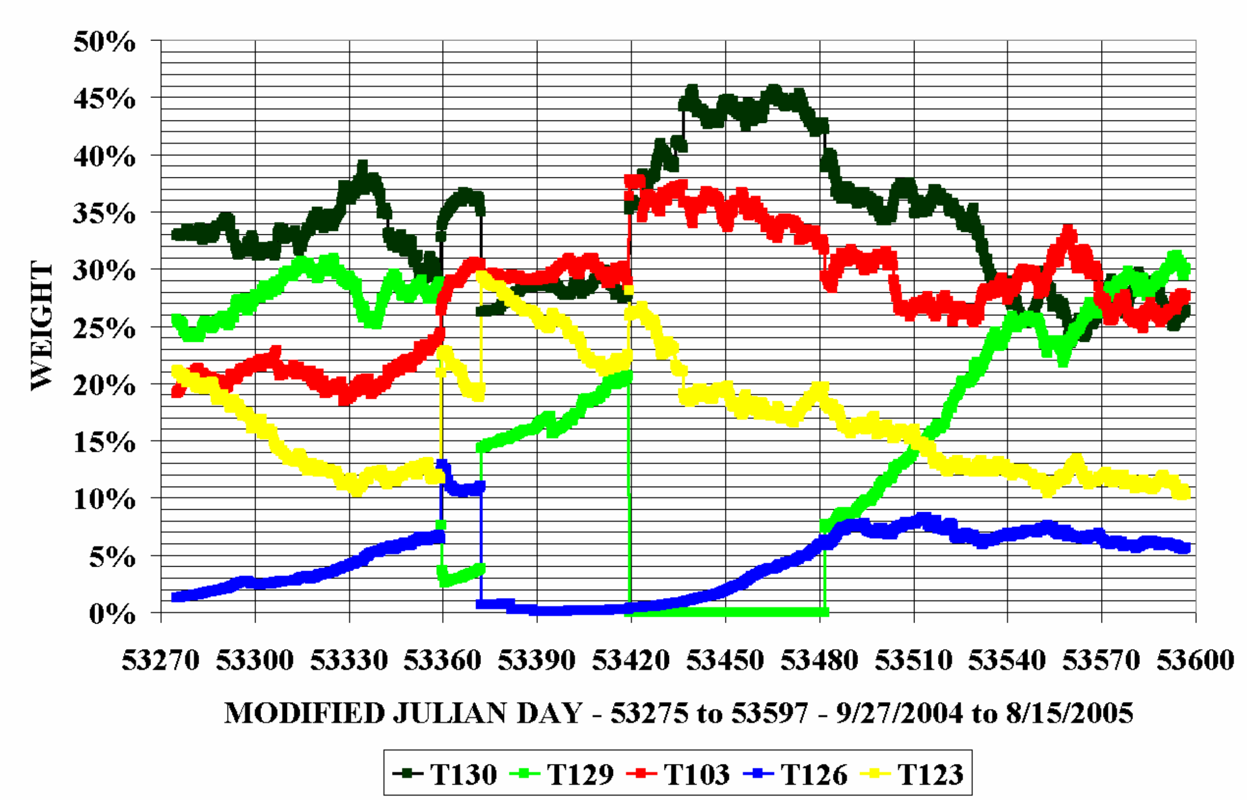

Figure 6. Weighting factors of clocks used in TAB1(ONRJ).

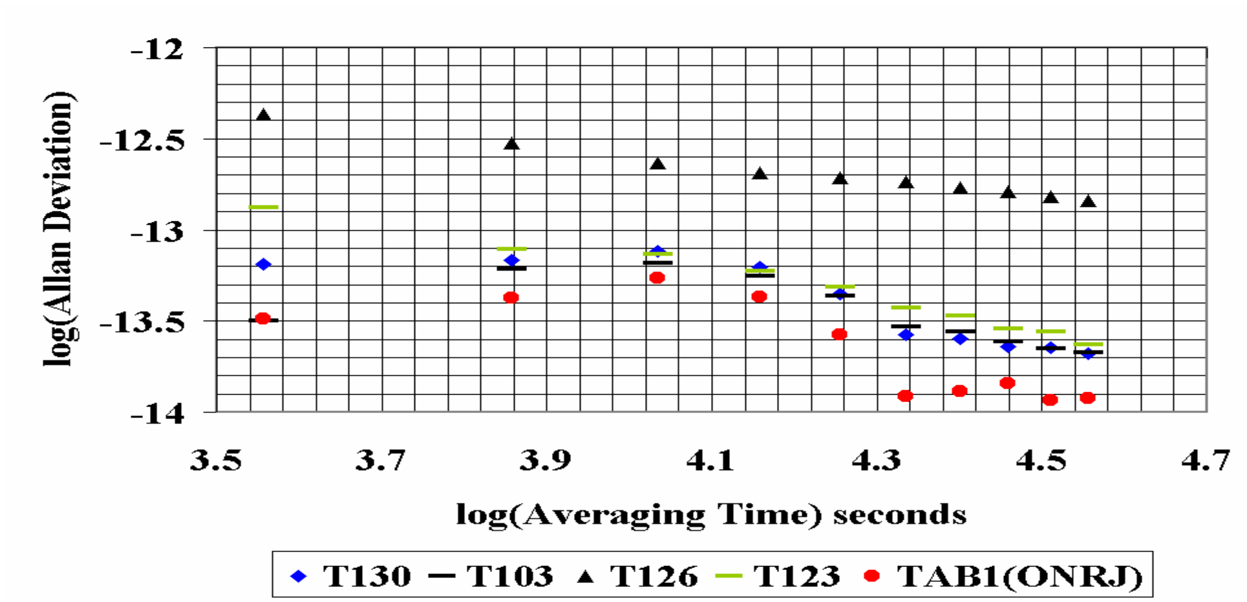

Figure 7. Frequency Stability of Clocks and TAB1(ONRJ) (Corner Hat Results).

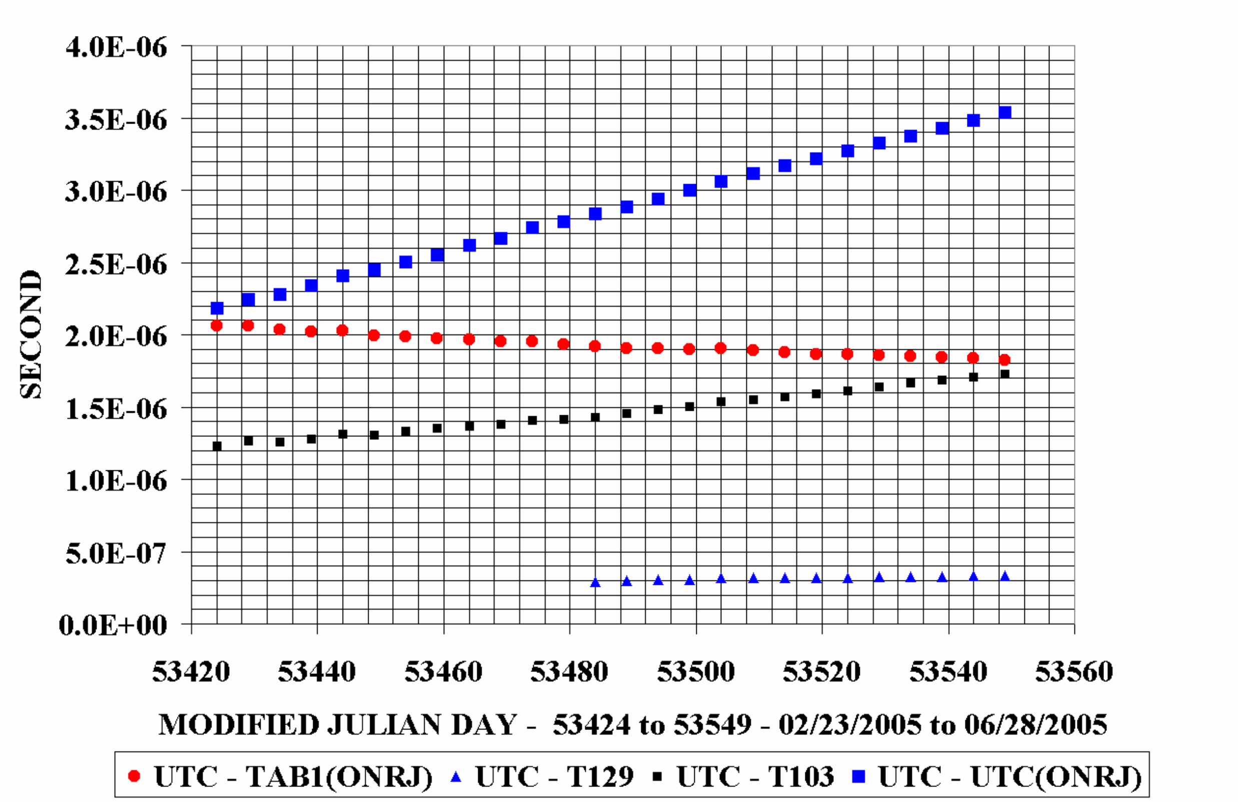

Figure 8. Time differences of the cesium clocks and TAB1(ONRJ) relative to UTC(BIPM).

IV. CONCLUSION

We showed that it is possible to generate an atomic time scale with the group of available clocks in the Time Service Division at National Observatory. But in the Fig. 6 we can see that it is necessary to incorporate more clocks with high performance tube to the clock ensemble if we want more stability, and obviously more reliability. In the Fig. 7 we can see that the stability of TAB1(ONRJ) is better than any of its contributing clocks. The next step will consist in making the system almost fully automated, by implementing the automatic detection of clock anomalies and to allow for the maintenance, to add or remove clock from the system in easily fashion. Besides some additional tests should be made for best estimate the time constant used in the algorithm to improve the uniformity of the scale. When we have more accumulated data we will begin them tests for the steering TAB1(ONRJ) to UTC(BIPM). Another objective is to implement with a micro phase stepper and electronic clock the $UTC(ONRJ)_{new}$ in real time because the UTC(ONRJ) generated presently from one commercial cesium clock, HP5071A named T130 is not suitable to attain the bounds of uncertainty recommended by the ITU-R and by the CCTF. Further improvements in the TAB1(ONRJ) will be obtained only if the number of clocks that participating in the TAB1(ONRJ) increases.

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