Current Status of the French Atomic Time Scales TA(F) and UTC(OP)

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Abstract

The LNE-SYRTE in Observatoire de Paris (OP), Paris, France, is the National Metrology Laboratory in charge of the French Time and Frequency References. In that frame, two atomic time scales are currently generated: the French Atomic Time TA(F) and the real time prediction UTC(OP) of the future UTC. TA(F) is a common frequency reference based on commercial clocks disseminated in nine French institutions or companies. It has been recently improved both in terms of accuracy and long term stability thanks to the steering on the LNE-SYRTE Primary Frequency Standards (PFS) which realize the definition of the SI second. During the last three years, the TA(F) scale unit interval stayed globally close to the SI second on the Geoid, as published monthly by the Bureau International des Poids et Mesures, within a 1.8×10^{-15} limit, exhibiting virtually no drift. This result was made possible thanks to the four LNE-SYRTE PFS, which include three fountains currently in operation. On the other hand, a new UTC(OP) is under development. The signal from one Hydrogen Maser is steered in frequency on an ensemble clock based on OP industrial Cesium standards. In addition, to steer the timescale towards UTC, we apply to the ensemble clock a frequency correction derived from a comparison to the laboratory PFS and from the departure of TAI from the SI second: the goal here is not to be aligned with the SI second, but to stay as close to UTC as possible. This new UTC(OP)_Maser is aiming at staying within a 30 ns departure from UTC. First results obtained from the current operational system are showing that this should be feasible. Current tests are mostly about reliability issues, an essential step before this new time scale will replace the former system.

1. Introduction

The LNE-SYRTE in Observatoire de Paris (OP), Paris, France, is the National Metrology Laboratory in charge of the French Time and Frequency References. In that frame, two atomic time scales are currently generated: TA(F) and UTC(OP). Divided in two parts, the paper shows the current status of both time scales.

The French atomic time scale TA(F) is a common time scale for 9 French institutions or companies spread over France, based on about 20 commercial Cesium standards, aiming at providing a frequency reference to the contributing bodies. In 1997, a new algorithm was put into operation for TA(F), based on Auto-Regressive Integrated Moving Average (ARIMA) models of the contributing clocks [1]. Basically, the ARIMA procedure consists in establishing a noise model of each clock based on a given period of observation of the clock with respect to the ensemble. The time scale computation uses as raw data the departure from the model of each contributing clock. It allowed to reach a stability of TA(F) with respect to the Temps Atomique International (TAI) computed by the Bureau International des Poids et Mesures (BIPM), of about 3×10^{-15} at an averaging period of 30 d in terms of Allan Deviation. The set of standards and institutions contributing to TA(F) was not foreseen to increase during the next decade. Therefore, it was decided in 2005 to steer the up to that date free running time scale on the LNE-SYRTE Primary Frequency Standards (PFS). The goal of this steering is to improve the time scale long term stability and to provide a calibrated scale unit interval close to the definition of the SI second. This was a way to valorise all the French time and frequency metrology activities: the PFS, all the Cs standards from the contributing French institutions, the time transfer techniques (today only GPS CV in that frame) and the TA(F) time scale algorithm. Section 2 describes the steering process and shows the results obtained over the last three years of routine operations.

For decades, UTC(OP), the real time prediction of the Co-ordinated Universal Time UTC realized by OP, has been based on one commercial Cesium standard chosen among an ensemble of eight standards. The design was classical [2], so that the formal Recommendation from the Comité International des Poids et Mesures (CIPM) of a 100 ns limit at one sigma of the UTC(OP) departure from UTC was well kept over the whole period. For a few years now, the development of a new UTC(OP), named UTC(OP)_Maser, has been undertaken. UTC(OP)_Maser is based on an H-Maser signal, which provides the short term stability, steered by an ensemble time scale computed from Cesium

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commercial standards located in OP. In addition, a steering computed from the PFS in a similar way as for TA(F) is also applied. Since the beginning of that project, algorithm robustness and simplicity have been the goal for the ensemble clock: robustness because an operational UTC(k) has to be kept away from trouble as far as possible, simplicity because many differently skilled people may have to identify any potential problem as fast as possible, in order to provide rapidly an appropriate solution. Robustness can only be tested in real conditions during a given period of time chosen as long as possible before the time scale would enter into formal operations. Simplicity called for a time scale algorithm as simple as a weighted average. Because that algorithm had proven for a long time its very good performances, the atomic time scale AT1 developed by National Institute of Standards and Technology (NIST) was chosen as the basis for the ensemble clock in the UTC(OP)_Maser project [3]. Section 3 describes the project status and the first operational results.

2. TA(F)

In 2005, TA(F) relative frequency was at about 10^{-13} away from the SI second, and a slow steering towards the laboratory PFS, TAI or the SI second was more or less equivalent. Therefore, the steering was applied in two steps, the goal here being to keep the timescale stability at 30 d safe during the process [4]. First, an arbitrary small steering was applied monthly aiming at smoothly driving TA(F) towards TAI. In a second step, since January 2007, only the LNE-SYRTE PFS are used for the monthly steering computation. Figure 1 shows the overlapping Allan standard deviation of the difference TA(F) – TAI before the introduction of a steering process, and after the steering process was based on the laboratory PFS only. As can be seen on the Figure, the TA(F) stability with respect to TAI has been largely improved, reaching 1.5×10^{-15} at 30 d in terms of Allan Deviation, where TAI is about eight times more stable. Moreover, the PFS steering leads to a time scale which exhibits virtually no drift anymore for longer averaging periods, where the stability reaches about 7×10^{-16} for an averaging period of 6 months or higher. The smaller short term improvement is related to a better selection and weighting scheme of the contributing clocks.

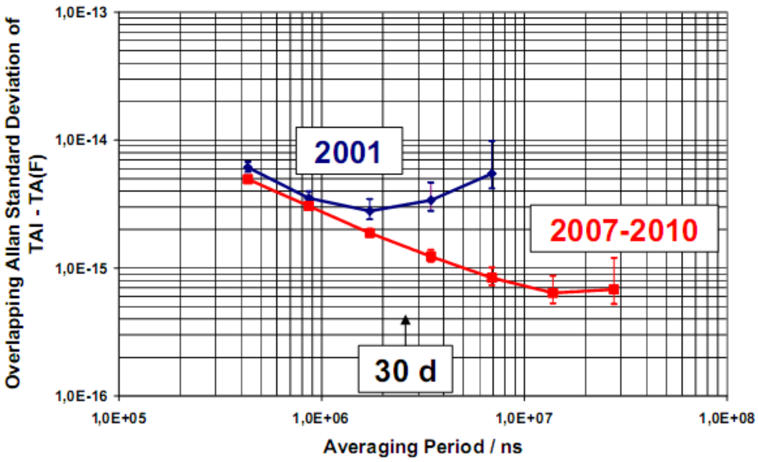

Figure 1. Overlapping Allan standard deviation of the difference TA(F) – TAI. In 2001, TA(F) was a free running time scale, where from 2007 to today, TA(F) is a time scale steered on the laboratory PFS only.

An uncertainty budget was built, taking into account the local connexion between the PFS and the time scale through an H-Maser used as local oscillator for the PFS operations [4]. This led ultimately to the current uncertainty of the TA(F) time scale interval with respect to the SI second of 1.8×10^{-15} ($1\ \sigma$), a conservative estimate. The realization of TA(F) was then compared to the SI second on the Geoid as published monthly by the BIPM in its Circular T, by using TAI as pivot for that computation. The result can be seen in Figure 2: it shows that the current TA(F) realization is for more than three years now entirely in line with the last computed time scale interval uncertainty. Note that if TAI is mandatory to plot these data, TAI is in no way used in the TA(F) computation since January 2007. On the other hand, even if the standards used in the TA(F) computation are all part of the French contribution to the TAI computation, it can be considered that both time scales are almost completely independent, due to the fact that TAI algorithm and clock ensemble are completely different: TAI is currently based on more than 300 standards. Figure 2 also shows incidentally that TAI is drifting away from the SI second, and this has to be taken into account during the study of the new UTC(OP)_Maser, where a similar steering on the laboratory PFS is considered as part of the steering process towards UTC.

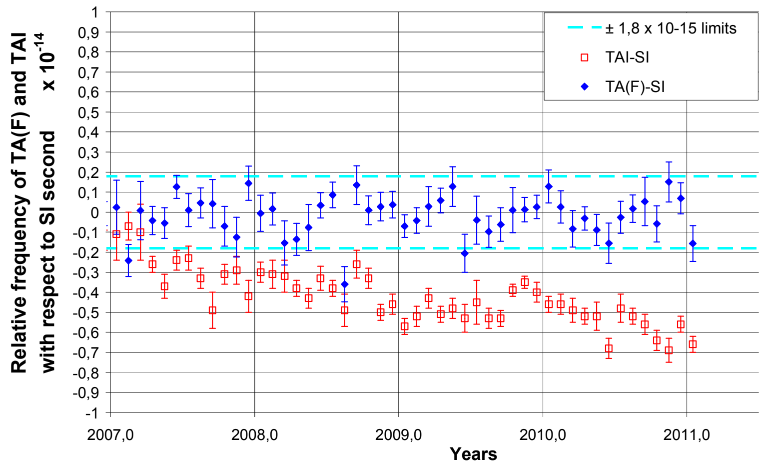

Figure 2. Relative frequency of TA(F) and TAI with respect the SI second on the Geoid as published monthly by the BIPM in its Circular T. The 1.8 x 10^{-15} limits materialize the 1 σ estimate of the TA(F) scale unit interval uncertainty.

3. UTC(OP)_Maser

When considering the algorithm AT1, the original development of OP was devoted to the clock weight optimization. Extensive tests led to an optimized weight obtained from an average between the ADEV at 30 d of the Cesium clock stability with respect to the ensemble on one side, and the departure from the prediction error of the clock with respect to the ensemble on the other side [3]. An automated control of the clocks in and out of the ensemble has also been completed, in order to preserve the phase and frequency continuity of the time scale. The resulting ensemble algorithm uses data from all the OP Cesium standards, generating that way a timescale signal. Two additional steering are added. One is a steering on the laboratory PFS, which allows to obtain over a shorter period of time (one month) a time scale interval close to the SI second as shown in the Section above. But in that case, another frequency correction should be applied, which takes into account the departure of TAI from SI second, as can be also seen on the Figure 2: the goal here is to generate a time scale close to UTC, hence not necessarily close to the SI second. This can only be achieved with a basic two month delay: BIPM estimate for the TAI departure from the SI second for one given month is known by the Circular T publication at the beginning of the following month, hence the correction to be applied can only be derived for the next following month. The resulting timescale is called TA(OP). In addition, another steering on UTC is also applied when necessary. Similarly as explained just above, that additional frequency correction can only be derived over a two month period because we have to wait for the Circular T to have access to the UTC – UTC(OP) differences. This whole ensemble is used to steer daily the H-Maser signal, which leads to UTC(OP)_Maser.

This new algorithm has been tested extensively in 2009 on past data. UTC(OP)_Maser was put into operation early 2010 as a prototype in parallel with the formal UTC(OP) signal, by using the spare micro phase stepper unit of the actual chain. Operational results over a few months are showing that the target of a maximum departure of 30 ns from UTC might be reached with this new time scale [5]. Moreover, the algorithm proved some robustness when confronted to operational problems on clocks or other instruments involved: as an example, there was a source signal change when the H-Maser in operation had to be replaced in November 2010 (MJD 55504), and this went relatively smoothly.

Figure 3 shows the last results obtained, but should be looked at as being only representative of a work in progress. UTC(OP)_Maser is plotted against two references: TA(OP), which is the ensemble time scale generated in OP, based on commercial Cesium standards and steered on the laboratory PFS and on UTC; and UTC via UTC(OP). Clearly, UTC(OP)_Maser - TA(OP) stays close to the arbitrary 0 which was set at the start of operations, the maximum departure being a little higher than 10 ns. UTC(OP)_Maser – TA(OP) actually provides the residuals of the steering, giving a good indication of its quality. On the other hand, it appears obviously that some trends and oscillations are common to both plots, indicating that the physical signal UTC(OP)_Maser is the source for this. But the departure from UTC stayed as targeted within 30 ns over more than 400 d. Therefore, we expect from this new time scale to stay close to the state of the art when it will formally replace the current realization.

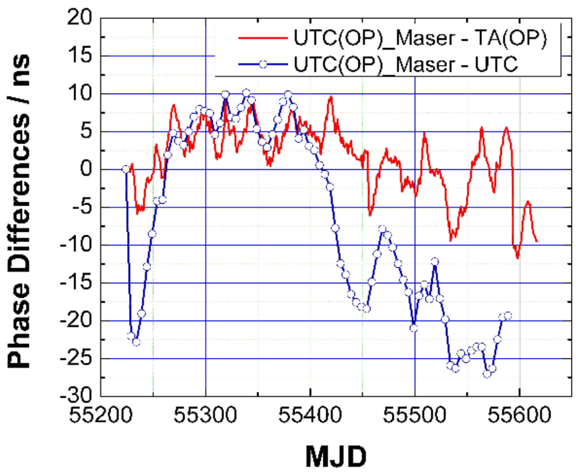

Figure 3. UTC(OP)_Maser against two references: TA(OP), which is the ensemble time scale generated in OP steered on the laboratory PFS and on UTC; and UTC via UTC(OP).

4. Conclusion

TA(F) is currently a time scale which scale unit interval routinely realizes the SI second on the Geoid within a proven conservative uncertainty of 1.8 x 10^{-15} (1 σ). This major result was achieved thanks to the PFS in operation in LNE-SYRTE during the last few years, among which three cold atom fountains.

Unfortunately, both best H-Masers in OP have been requiring some maintenance since Summer 2010, and the delivery of two new units formally agreed at the end of 2009 to take place in July 2010 has proven to be impossible with the selected company. Therefore, the UTC(OP)_Maser prototype could not, as originally planned, replace formally at the end of 2010 the current UTC(OP). It will now depend on the quality of the H-Maser signal available in OP for such purposes.

The next development of an H-Maser ensemble signal has already started. It will provide a better local oscillator source signal for all the frequency standards in LNE-SYRTE. Once operational, the new UTC(OP)_Maser would also help to cancel one additional link internal to OP: there is currently a difference between UTC(OP) and the source for time transfer links to the outside, which is today the H-Maser used as local oscillator by the PFS. In the future, the new UTC(OP)_Maser will be directly the source for all time transfer links.

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