Performances of UTC(OP) based on LNE-SYRTE atomic fountains

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Abstract

We present the current realization of UTC(OP) generated at LNE-SYRTE, Observatoire de Paris (OP), Paris, France, which is also the source of French legal time. UTC(OP) is based on a H-maser standard steered on the atomic fountains developed by LNE-SYRTE. The steering algorithm and the prediction of UTC(OP) departure from UTC are described, together with the results of the first year of operation. Since October 2012, the departure of UTC(OP) from UTC remained well below 10 ns.

1. Introduction

For many years, UTC(OP), the real-time approximation of UTC built in LNE-SYRTE, Observatoire de Paris (OP), Paris, France, had been based on industrial Cesium (Cs) standards [1]. A new algorithm for the generation of UTC(OP) has been put in operation since October 2012. It is based on the steering of a H-maser signal on the LNE-SYRTE Primary Frequency Standards. The current OP atomic fountain ensemble [2] comprises a Cs fountain called FO1, a dual fountain FO2, working simultaneously with Cs and Rb atoms, and a mobile Cs fountain FOM. All fountains share the same cryogenic oscillator, which is phase locked to a H-maser. Thus all fountains measure the frequency of the same H-maser. An automatic fountain data processing provides hourly preliminary data corrected of all systematic frequency shifts. The steering of the H-maser frequency is calculated daily by a fit to the fountain data. We describe the implementation of all the instruments used for the generation of UTC(OP) together with the current version of the algorithm. The choice of this algorithm has been oriented to obtain robustness of the system instead of the ultimate optimization of performances. We then present the results obtained during the first year of operation.

2. UTC(OP) implementation

Figure 1 shows a simplified block diagram of the current hardware set-up used for the generation of UTC(OP). In normal operation the cryogenic oscillator, that drives the three LNE-SYRTE atomic fountains, is phase locked to the 100 MHz output of the free-running H-maser generating UTC(OP). Currently, the 5 MHz commercial phase micro stepper, historically used to steer commercial Cs standards, is still generating UTC(OP). It is planned to replace this phase micro stepper with the new one operating at 100 MHz that has been developed by SKK Electronics in collaboration with SYRTE [3]. A detailed description of the H-maser frequency distribution, filtered by the cryogenic oscillator can be found in [2]. For several years, and during the preliminary tests based on FOM, a post-processing of data has been running in quasi real time: cleaned and shifts corrected data are made available within about a 1 hour latency. A similar but more sophisticated post-processing was also implemented a couple of years ago for FO2Cs, FO2Rb and FO1 fountains, allowing a quasi-real time monitoring of the fountain operations. A more careful manual processing is performed for the monthly LNE-SYRTE reports to BIPM, aiming at providing data for the steering of TAI [4]. But for the daily steering of the H-maser, the quasi real time data are largely sufficient as they are to guarantee a stability of about a 10^{-16} level for the time scale generation. The frequency of the H-maser is measured simultaneously by all the fountains available in LNE-SYRTE. But in practice only data from one fountain are used for the automated steering. The choice of the selected fountain depends on the planning of operations. Typically we commute from one to another when a fountain is expected to interrupt regular operation for a few days, for planned experiment or maintenance. For instance, FOM is currently in French Space Agency CNES premises for tests on the PHARAO space clock flight model [5]. We plan to use the data of redundant fountains to rise a warning in the case of inconsistent measurement of the H-maser frequency, but this is not implemented yet. We believe that setting up an automated switch in case of bad or missing data might appear too sophisticated for the purpose: owing to the stability of the H-maser, a few days of missing fountain data have a negligible impact on the realization of UTC(OP). In the normal data post-processing of LNE-SYRTE fountains all the systematic shifts are corrected every one cycle. But the resulting files are too large and hard to process in an automated way. For routine fountain comparison, and UTC(OP) generation, the original data files are converted in quasi real time to files with a reduced set of data averaged over 0.1 d. These pack files contain ten frequency values per day dated at pre-established epochs, namely 0.05 d, 0.15 d, etc. Each point is obtained after filtering out some invalidated periods of the original file due to possible problems either in the fiber links

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or in the lock of the cryogenic oscillator. An additional cleaning is performed by fitting linearly the resulting data over each 0.1 d period and removing possible outliers exceeding the 5 sigma limit. The value of the linear fit at the middle of the interval is used to generate the pack file. The steering software predicts once a day the H-maser frequency for the next day by extrapolating the linear fit of pack files covering the last 20 d. The correction to be applied to the phase micro stepper for the next day is the sum of the predicted H-maser frequency and of an additional term updated monthly, that finely adjust the phase and the frequency of UTC(OP) to UTC, based on data published by the BIPM in the Circular T. This fine adjustment is the sum of 2 terms. The first one is the average of the frequency difference between UTC(OP) and UTC calculated over the Circular T period. The second term is calculated to compensate the last known time offset between UTC(OP) and UTC within 60 days.

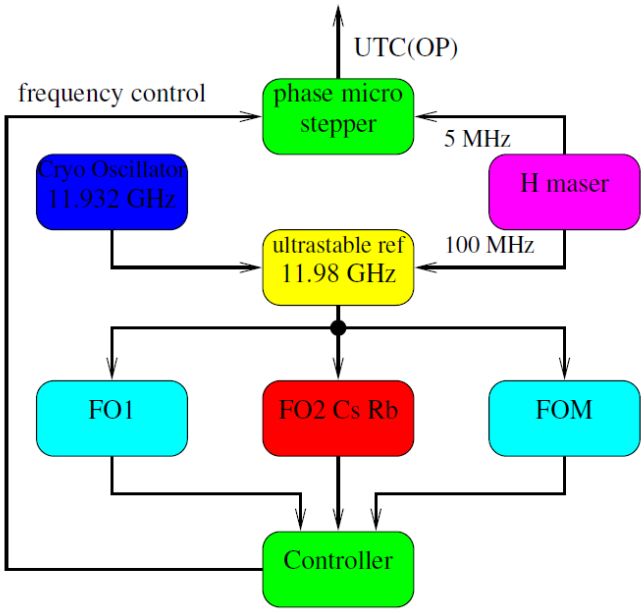

Fig. 1. Simplified block diagram of UTC(OP) generation.

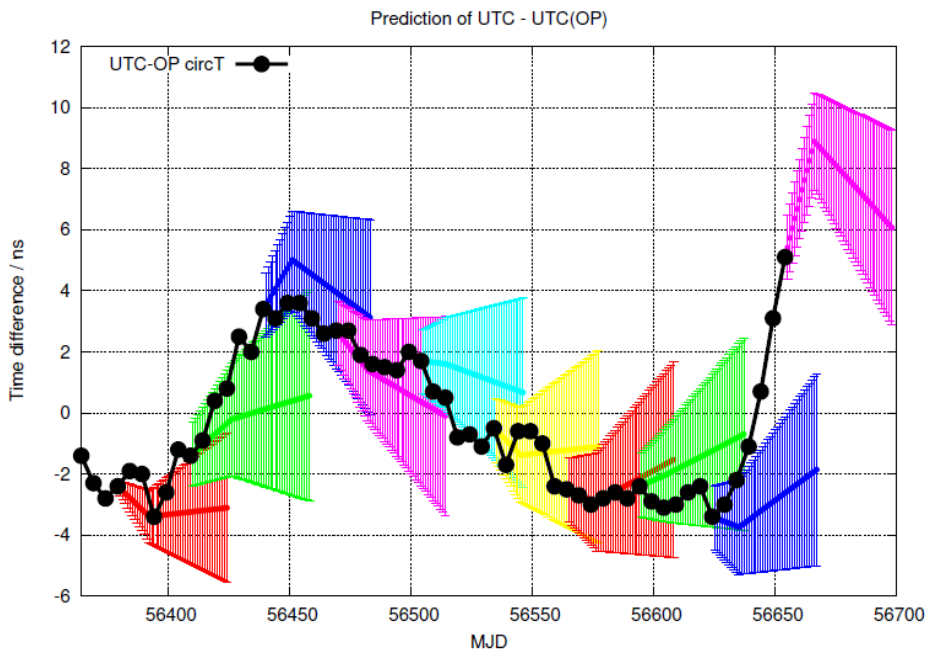

Fig. 2. The black dots/lines show UTC-UTC(OP) as reported in Circular T. The colored dots with error bars are the predictions and prediction error propagation of UTC-UTC(OP).

3. Results

When the steering algorithm has been implemented, the additional term based on data published in the Circular T was manually computed. After a few months, the algorithm has been coded in a simple script that is manually launched each time a Circular T is released. The same script generates also a prediction of the difference between UTC(OP) and UTC for the next month, together with a prediction of the propagation error. The quality of the prediction can be verified a posteriori when a new Circular T is published. A historical plot of such predictions, together with the time differences UTC - UTC(OP) as published in the Circular T, is shown in Fig. 2. The slope variation that can be seen around the 10th day of each prediction period is due to the fact that Circular T is released about 10 d after the last date of the computed UTC - UTC(k) points. This technical delay complicates a little bit the analysis of the servo loop and imposes a time constant long enough to avoid oscillations. One can see on Fig. 2 that the prediction and prediction error propagation achieved each month remained close to what was expected except during two periods. We nevertheless estimate that the performances of the current UTC(OP) are competitive with the best UTC(k) realizations available today.

4. Conclusion

Since the beginning of operation of the new algorithm in October 2012, the departure of UTC(OP) from UTC remained well below 10 ns. We expect that these performances will be kept over a long term period of time with the current system. We have already planned two upgrades. First some hardware components are going to be replaced to fulfill the requirements for hosting a ground station in the frame of the European Space Agency (ESA) project Atomic Clock Ensemble in Space (ACES) [6], allowing for a fine monitoring of the onboard clocks that include the PHARAO clock. Second, we are developing a switch allowing the hot-swapping of the reference H-maser, potentially unattended in the case of H-maser failure.

5. Acknowledgment

The authors would like to thank the technical staff of SYRTE Références Nationales de Temps for the continuous support and monitoring. We also acknowledge the precious support of SYRTE Service d'Electronique for improving the reliability of the frequency distribution and measurement systems.

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