TIME AND FREQUENCY ACTIVITIES AT THE U.S. NAVAL OBSERVATORY

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Abstract

The U.S. Naval Observatory (USNO) has provided timing for the Navy since 1830 and, via DoD Directive 4650.05, is the sole source of timing for the Department of Defense. In cooperation with other institutions, the USNO also provides timing for the United States and the international community. Its Master Clock (MC) is the source of UTC (USNO), USNO's realization of Coordinated Universal Time (UTC), which has stayed within 5 ns rms of UTC since 1999 and within 4 ns rms in 2010. The data used to generate UTC (USNO) are based upon 69 cesium and 26 hydrogen maser frequency standards in four buildings at two sites. USNO disseminates time via voice, telephone modem, Network Time Protocol (NTP), GPS, and Two-Way Satellite Time Transfer (TWSTT). To meet space limitations, this document will describe only the timescale algorithm and GPS time transfer precision. Further details and explanations of our services can be found online at http://www.usno.navy.mil/usno.

I. Time Generation

The most important part of USNO's Time Service Department is its staff, which currently consists of 32 positions. Of these, the largest group, about 40% of the staff, is directly involved in time transfer. The rest are fairly evenly divided between those who service the clocks, those who monitor them, and those who are working to develop new ones.

Before averaging data to form a timescale, real-time and postprocessed clock editing is accomplished by analyzing deviations in terms of frequency and time; all the clocks are detrended against the average of the best detrended cesiums **[1]**. A maser average represents the most precise average in the short term, and the detrending ensures that it is equivalent to the cesium average over periods exceeding a few months. A.1 is USNO's operational timescale; it is dynamic in the sense that it weights recent maser and cesium data by their inverse Allan variance at an averaging time (tau) equal to the age of the data. Plottable files of both A.1 and the maser mean are available below http://tycho.usno.navy.mil.

UTC (USNO) is created by frequency-steering the A.1 timescale to UTC using a steering strategy called "gentle steering" **[2-4]**, which minimizes the control effort used to achieve the desired goal, although at times the steers are so small that they are simply inserted. To realize UTC (USNO) physically, we use the one pulse per second (1-PPS) output of a frequency divider fed by a 5 MHz signal from an Auxiliary Output Generator (AOG). The AOG creates its output from the signal of a cavity-tuned maser steered to a timescale that is itself steered to UTC **[2-5]**. The MC has a backup maser and an AOG in the same environmental chamber. On 29 October 2004, we changed the steering method so that state estimation and steering are achieved hourly with a

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Kalman filter with a gain function as described in **[6]**. A second master clock (mc), duplicating the MC, is located in an adjacent chamber. In a different building, we have the same arrangement for a third mc, which is steered to the MC. Its backup AOG is steered to a mean timescale, based only on clocks in that building, which is itself steered to the MC.

The operational unsteered timescale (A.1) is based upon averaging only the better clocks, which are first detrended using past performance. As a result of a study conducted in 2000 **[8]**, we have widened the definition of a "good clock" and are recharacterizing the clocks less frequently, and new methods of clock characterization are under development **[9]**. We are also continuing to work on developing algorithms to combine optimally the short-term precision of the masers with the longer-term precision of the cesiums and the accuracy of International Atomic Time (TAI) itself, which is frequency-calibrated using the primary (fully calibrated) frequency standards operated by other institutions. It is planned to implement an algorithm that steers the MC hourly and tightly to a timescale based only upon masers, which are individually or collectively steered to a cesium-only timescale that itself is steered to UTC using the information in the Circular T **[6, 10]**. The steered cesium-only timescale is based upon a Kalman-filter **[11]**. Individual masers would be steered to the cesium-only timescale before being averaged to create the maser-only timescale.

Figure 1 shows how UTC (USNO) has compared to UTC and also how its fractional frequency has compared to the unsteered maser mean, relative to an overall constant offset, and Figure shows how GPS time and GPS's delivered prediction of UTC(USNO) appear to the user.

REFERENCES

[1] L. A. Breakiron, 1992, "Timescale Algorithms Combining Cesium Clocks and Hydrogen Masers," in Proceedings of the 23rd Annual Precise Time and Time Interval (PTTI) Applications and Planning Meeting, 3-5 December 1991, Pasadena, California, USA (NASA CP-3159), pp. 297-305.

[2] D. N. Matsakis, M. Miranian, and P. A. Koppang, 2000, "Alternative Strategies for Steering the U.S. Naval Observatory (USNO) Master Clock," in Proceedings of the ION 56th Annual Meeting, 26-28 June 2000, San Diego, California, USA (Institute of Navigation, Alexandria, Virginia), pp. 791-795.

[3] D. N. Matsakis, M. Miranian, and P. A. Koppang, 2000, "Steering the U.S. Naval Observatory (USNO) Master Clock," in Proceedings of 1999 ION National Technical Meeting, 25-27 January 2000, San Diego, California, USA (Institute of Navigation, Alexandria, Virginia), pp. 871-879.

[4] P. A. Koppang and D. N. Matsakis, 2000, "New Steering Strategies for the USNO Master Clocks," in Proceedings of the 31st Annual Precise Time and Time Interval (PTTI) Systems and Applications Meeting, 7-9 December 1999, Dana Point, California, USA (U.S. Naval Observatory, Washington, D.C.), pp. 277-284.

[5] P. Koppang, D. Johns, and J. Skinner, 2004, "Application of Control Theory in the Formation of a Timescale," in Proceedings of the 35th Annual Precise Time and Time Interval (PTTI)

Systems and Applications Meeting, 2-4 December 2003, Long Beach, California, USA (U.S. Naval Observatory, Washington, D.C.), pp. 319-325.

[6] J. Skinner, D. Johns, and P. Koppang, 2005, "Robust Control of Frequency Standards in the Presence of Systematic Disturbances," in Proceedings of the 2005 Joint IEEE International Frequency Control Symposium and the 37th Annual Precise Time and Time Interval (PTTI) Systems and Applications Meeting, 29-31 August 2005, Vancouver, British Columbia, Canada (IEEE 05CH37664C), pp. 639-641.

[7] J. G. Skinner and P. A. Koppang, 2002, "Effects of Parameter Estimation and Control Limits on Steered Frequency Standards," in Proceedings of the 33rd Annual Precise Time and Time Interval (PTTI) Systems and Applications Meeting, 27-29 November 2001, Long Beach, California, USA (U.S. Naval Observatory, Washington, D.C.), pp. 399-405.

[8] L. A. Breakiron and D. N. Matsakis, 2001 "Performance and Characterization of USNO Clocks," in Proceedings of the 32nd Annual Precise Time and Time Interval (PTTI) Systems and Applications Meeting, 28-30 November 2000, Reston, Virginia, USA (U.S. Naval Observatory, Washington, D.C.), pp. 269-288.

[9] J. Skinner, D. Johns, and P. Koppang, 2009, "Statistics of Modeling Errors in an Ensemble Mean," presented at the 40th Annual Precise Time and Time Interval (PTTI) Systems and Applications Meeting, 2-4 December 2008, Reston, Virginia, USA, but not published in the Proceedings.

[10] P. A. Koppang, J. G. Skinner, and D. Johns, 2007, "USNO Master Clock Design Enhancements," in Proceedings of the 38th Annual Precise Time and Time Interval (PTTI) Systems and Applications Meeting, 5-7 December 2006, Reston, Virginia, USA (U.S. Naval Observatory, Washington, D.C.), pp. 185-192.

[11] J. G. Skinner and P. A. Koppang, 2007, "Analysis of Clock Modeling Techniques for the USNO Cesium Mean," in Proceedings of the 38th Annual Precise Time and Time Interval (PTTI) Systems and Applications Meeting, 5-7 December 2006, Reston, Virginia, USA (U.S. Naval Observatory, Washington, D.C.), pp. 373-378

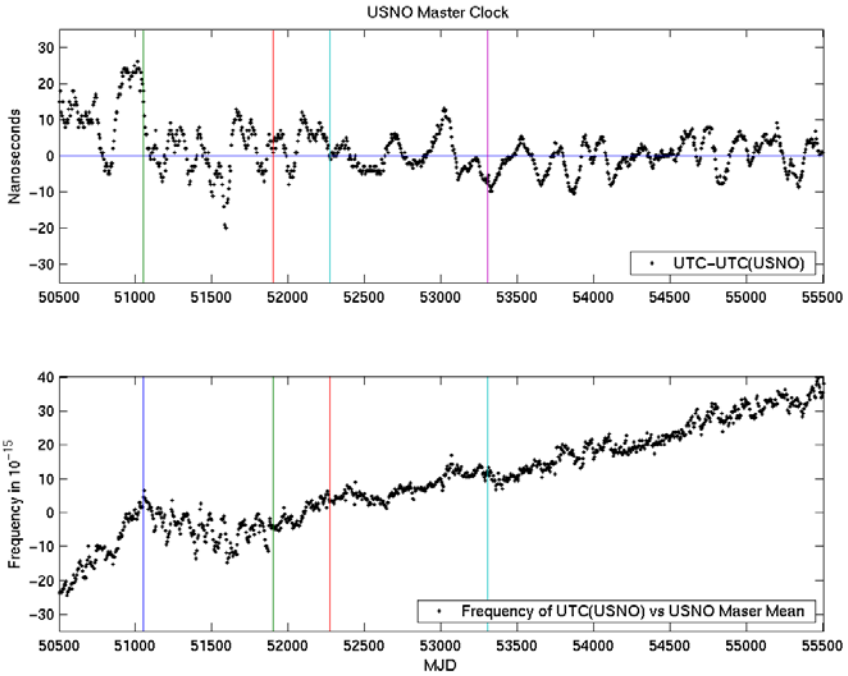

Figure 1. Interplay between the time and fractional frequency stability of the USNO Master Clock, from February, 1997 to the present.

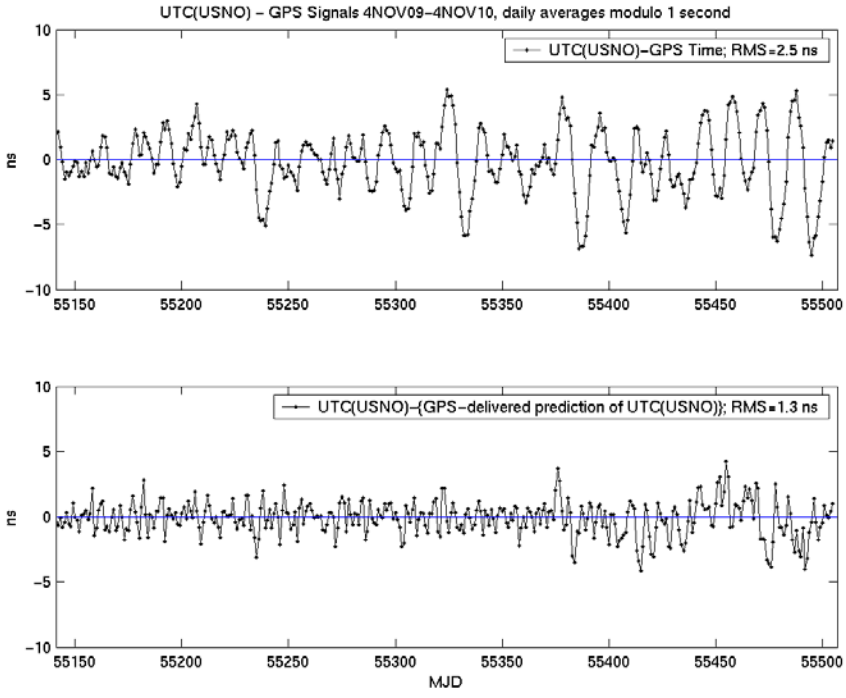

Figure 2. Recent daily averages of UTC (USNO) minus GPS Time and UTC minus GPS's delivered prediction of UTC (USNO).