Report on the Time and Frequency Activities of the Time Service Department of the U.S. Naval Observatory

I. Time and Frequency Generation

The USNO timescale is currently based on 70 HP5071 cesiums and 16 cavity-tuned "Sigma-Tau" masers, which are located in two buildings in Washington, D.C. and also at the USNO Alternate Master Clock (AMC), located at Schriever Air Force Base in Colorado. All clocks are kept in environmental chambers whose temperatures are kept constant to 0.1 degree and whose relative humidities (for all masers and most cesiums) are kept constant to 1%.

The USNO is constructing a cesium fountain, which has a measured stability of 1.E-15 at one day, and anticipating the delivery of a Trapped-Ion Mercury standard (LITE) within the next year.

In Washington, the USNO has recently upgraded its clock measurement system so that all signals are transmitted via temperature-compensated cables and sma-connectors. Our operational system is based upon switches and counters that compare each clock against each of three master clocks once per hour and store the data on multiple computers. The measurement noise is about 25 ps, which is less than the variation of a cesium standard. Masers are also measured using a system marketed by Timing Solutions, which is used to generate comparisons every 20 seconds, with a measurement noise of 2 ps. Similar systems are in place at the USNO-AMC, but they are simpler as that facility has only 3 masers and 12 cesiums. All clock data, and time transfer data, are gathered by redundant computer systems that are protected by a firewall and backed up nightly on tape. The USNO has made some studies into n-cornered hat analyses, and a stability analysis based upon six years of clock data was presented at PTTI-01.

Switch data from the USNO clocks are used to generate timescales using the Percival algorithm, which averages frequency data from clocks that have been detrended by removing the clock's frequency rate and drift using the unsteered average as a reference. The integrated frequency scale is then steered to UTC using linear extrapolations from the most recent Circular T. Algorithms with averaging times between 45 and 90 days can be used to predict UTC-UTC(USNO) with an accuracy of 5.6 ns RMS 30 days in advance. The integrated frequency scale is currently steered so as to remove about half its time and frequency difference with UTC within 30 days, with the minimal amount of control ("gentle steering"). This strategy resulted in UTC-UTC(USNO) having an RMS of about 5 ns last year, while avoiding excessive frequency variations in the Master Clock. In particular, simulations have shown that gentle steering does not perceptibly degrade UTC(USNO)'s stability over periods of 0 to 10 days, and this is consistent with user requirements. In order to assist any users desiring greater long-term frequency stability, it is possible to download the USNO "maser mean" from our Web pages. Although UTC(USNO) itself is a real-time realization of UTC, USNO Web pages also provide real-time predictions of UTC-UTC(USNO) , which are accurate to 3 ns RMS 15 days after the last Circular T point.

The USNO is working on developing algorithms to optimally combine the short-term precision of its masers with the longer-term precision of its cesiums and the accuracy of TAI itself.

II. Time Transfer

USNO is the timing reference for both GPS and LORAN, and data are provided daily to those systems so that they can steer to UTC(USNO). The USNO has worked with a manufacturer to develop an all-in-view dual-frequency code and carrier-phase GPS PPS receiver, the TTR-12. USNO has also upgraded its single-frequency SPS receivers from TTR-6 to the BIPM-sponsored Motorola units. In order to reduce multipath, a 4-meter structure was built for the purpose of mounting GPS antennas.

The USNO has for many years operated a Two Way Satellite Time Transfer (TWSTT) program for maintaining a timing link between its facility in Washington, the AMC, and other users. Using TWSTT and modern steering theory, the Master Clocks of the USNO in Washington and at the AMC have been kept synchronous to 1 ns RMS in the past year. Calibrations between the various sites are typically performed every 6 months, and demonstrate a repeatability of about 0.4 ns RMS between calibrations.

The USNO has participated in the Two Way Satellite Time Transfer (TWSTT) program for TAI-generation, and in May replaced its 16 year-old Mitrex modem with a carrier-phase compatible SATRE modem. In May 2000 the USNO-PTB link was calibrated, and a calibration of the USNO-NPL link is ongoing. USNO plans to supplement its TAI-generation work with X-band observations with the PTB. In addition, the USNO maintains an active program of TWSTT with users who do not participate in TAI.

The USNO also uses Network Time Protocol (NTP) on the Internet to transfer time, and currently handles 36 billion timing requests per year in 16 sites.

The Time Service Department of the USNO has also actively pursued development of GPS carrier phase time transfer, in cooperation with the International GPS Service (GPS). With assistance from the Jet Propulsion Laboratory (JPL), the USNO has developed continuous filtering and shown that it can be used to greatly reduce day-boundary discontinuities without introducing long-term systematic variations. Working with the manufacturer, the USNO has helped to develop a modification of TurboRogue/Benchmark receivers, which preserve timing information through receiver resets. Using IGS data, the USNO has published a frequency scale and a timescale. The USNO is currently contributing to real-time carrier phase systems run by JPL/NASA and the Canadian network.

III. International Cooperation

The USNO looks forward to working with the international community to improve all aspects of timing, from frequency standards to time transfer to time scale generation.

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