Time and Frequency Activities at the JHU Applied Physics Laboratory

Mihran Miranian, Gregory L. Weaver, Jeffrey F. Garstecki, and Richard A. Dragonette

Johns Hopkins University Applied Physics Laboratory, Laurel MD, USA
mihran.miranian@jhuapl.edu

Abstract—The Johns Hopkins University Applied Physics Laboratory Time and Frequency Laboratory (JHU/APL TFL) provides support to multiple NASA missions operated at JHU/APL that span our solar system from the study of the Sun's coronal mass ejections (STEREO) to the examination of the outer planets and the Kuiper Belt objects (New Horizons). This space mission support includes providing precise time and frequency to the integration and testing of flight hardware, frequency reference for spacecraft ranging and communications via the JHU/APL satellite communications facility, and the time-stamping of ground-receipt telemetry packets from various spacecraft. The JHU/APL TFL's ensemble of three high performance cesium standards and three hydrogen masers are integrated to form the APL timescale that is the basis for estimating UTC-UTC(APL) and for evaluating the performance of the individual clocks. Traceability to the USNO, NIST, and UTC is maintained via GPS Common-View and Precise Point Positioning time transfer. The JHU/APL TFL's clocks are also incorporated into the formulation of International Atomic Time (TAI). The JHU/APL TFL Master Clock is a hydrogen maser and the frequency adjustments of UTC(APL) are performed with a high resolution offset generator. This combination of hydrogen maser and high resolution offset generator along with our UTC-UTC(APL) estimation algorithm has made it possible to maintain UTC(APL) within 10 nanoseconds of UTC 95% of the time. In January 2012, the JHU/APL TFL was moved to a new building on the south campus of JHU/APL. This new facility includes an environmentally controlled clock vault which will enable enhanced performance of our atomic clocks and improve the stability of our time and frequency output.

Key words:* *space missions support, spacecraft integration and test, coordinated timekeeping

I. INTRODUCTION

The mission of the Johns Hopkins University Applied Physics Laboratory Time and Frequency Laboratory (JHU/APL TFL) is to provide precise time and frequency in support of critical JHU/APL projects and maintain traceability to U.S. and international timing laboratories. The JHU/APL TFL space missions support includes integration and testing of flight hardware, frequency reference for spacecraft ranging and communications, time-stamping of ground receipt telemetry packets, and the research and development of time and frequency devices and distribution systems. Currently the JHU/APL TFL supports five JHU/APL operated space science missions:

- TIMED – a study of the influences of the Sun and humans on the Thermosphere, Ionosphere, and Mesosphere Energy and Dynamics of the Earth's atmosphere;
- STEREO – two spacecraft of the Solar TErrestrial Relations Observatory mission provide three dimensional imaging of the trajectory of Earth-bound coronal mass ejections from the Sun;
- MESSENGER – MErcury Surface Space ENvironment GEochemistry and Ranging is the first spacecraft to orbit the planet Mercury;
- New Horizons – a mission to Pluto and the Kuiper Belt Objects;

- Van Allen Probes – a pair of satellites which were launched in August 2012 will study the radiation belts that surround the Earth.

About two years ago JHU/APL began construction of a new Space Department building which is now located on the JHU/APL South Campus. The time and frequency support operations section is organized under the Space Department and we were given notice that the JHU/APL TFL would be moved to this new building. In August 2011 the new facilities were ready and our planned move began. This paper will primarily concentrate on the movement of the JHU/APL TFL and lessons learned from our experience.

II. THE NEW JHU/APL TFL FACILITIES

Unlike the old JHU/APL TFL which was constructed in an existing building in 1959, the new facility was planned into the design of the new Space Department building. The primary feature of the new JHU/APL TFL facility was the planned construction of a controlled environment clock vault. This was a feature which we did not have in the prior JHU/APL TFL facility. Atomic clocks, especially hydrogen masers, are affected by temperature and humidity variation which will cause their output frequency to change. The ability to stabilize their environment greatly improves the performance of these clocks, which increases the precision of our signals and our ability to characterize their timekeeping behavior. In addition, the overall new operations facility offers an improved temperature and humidity environment for the TFL support equipment outside of the clock vault.

Cable conduits and raceways were also designed into the building features for intra-laboratory signal distribution within the Space Department building and cable access to the dedicated antenna platform on the roof. Extremely low-loss cables were pulled from the TFL to the other labs in the building and to the antenna platform. Also, a fiber-optic signal distribution system to all JHU/APL laboratories beyond the Space Department building was installed. The entire TFL is serviced by un-interruptible electrical power, backed up with stand-alone generators. Figure 1 shows the new JHU/APL TFL facility. Visible in the Fig. 1 image is GPS signal monitoring and performance monitoring of UTC(APL) in the left most equipment rack, clock display and distribution in the two center-most racks, and the precision frequency offset generator/master clock signal system in the right most rack.

Figure 1. Interior of new JHU/APL TFL facility.

III. PLANNED MOVE TO THE NEW TFL FACILITIES

The plan to move into the new lab was divided into three phases.

A. Phase One: Establish UTC(APL) in the New Lab

The re-formation of UTC(APL) in the new TFL first involved moving one hydrogen maser, the installation of a new GPS receiver/antenna system, and a new offset generator into the new facility. The GPS antenna position was to be surveyed and the output of the new offset generator would have to be put on time and frequency to the offset generator that remained operational in the old lab facility. We chose to move all of our clocks powered to reduce the start-up period after the move into the clock vault of the new TFL. This required the use of the transport vehicle batteries along with DC/AC inverters to keep the clocks running during transport. As an additional contingency, the internal back-up batteries in all the clocks were replaced.

We were informed in August 2011 that there would be a five month delay in the installation of the antenna masts and the pulling of the antenna cables due to a push-out on the delivery of the cables. It was decided to continue with Phase One of our plan, but delay synchronizing the two labs until GPS time recovery was operational. TFL Maser #2 was moved to the new TFL facility on September 8, 2011. This was completed with no complications and the maser was installed in the clock vault. The new GPS receiver and offset generator were also installed soon after, but the establishment of UTC(APL) in the new lab would have to wait until the two labs were synchronized.

B. Phase Two: Phase-in Dissemination of Time and Frequency Service to JHU/APL Users

A fiber optic link between the two labs and a few of the buildings on the main campus had been established prior to the move of TFL Maser #2 so it was possible to begin disseminating time and frequency service on a limited scale. Due to the lack of fiber optic links to the other buildings, the old TFL facility was used as a distribution hub until all additional fiber links to these buildings were established.

TFL Masers #1 & 3 and Cesiums #1, 3 & 4 were moved while powered to the new TFL facility on January 25, 2012, with no complications. Cesium #2 was left in the old TFL as a back-up in case there was a problem with the installation of the clocks into the new TFL. The 5MHz phase comparator system was moved the following day. Less than one day of clock data was lost during the move. Analysis of the clock data after one week of operation in the new clock vault showed no significant frequency changes in the clocks. Cesium #2 was moved one month later. Figure 2 shows the interior of the TFL clock vault after the completion of the movement of all clocks and 5MHz phase comparator system.

Figure 2. JHU/APL clock vault; 5 MHz phase comparator and cesium standards are in the left rack, Masers 1, 2, and 3 are freestanding to the center and right.

C. Phase Three: Restart UTC(APL) Contribution to the Formulation of International Atomic Time (TAI)

The antenna masts were installed and the cables were pulled in early January 2012 and the two GPS antennas were mounted, one as the primary and the other as the backup. A Novatel Propak-V3-L1L2-G receiver was put into operation in the new TFL and five days of GPS RINEX data from each antenna were sent to the NOAA National Geodetic Survey (*opus@ngs.noaa.gov*) for an NGS OPUS Solution Report of our GPS antenna locations. GPS common-view time transfer was determined between the old and new TFL facilities and UTC(APL)_New Lab was synchronized to UTC(APL)_Old Lab. We began sending GPS and TFL clock data from the new TFL to the BIPM starting in early March 2012.

IV. NEW JHU/APL TFL OPERATIONS

The new JHU/APL TFL became fully operational in June 2012. The new clock vault was found to maintain temperature at 68 +/- 0.5 degrees F and humidity at 50 ± 1%. The 5MHz phase comparator system is also located in the clock vault, see Fig. 2. We distribute 5MHz, 10MHz, and 1PPS via copper coaxial line to all laboratory installations within the Space Department building and via fiber optic transmission to the other buildings on the JHU/APL campus. We also distribute APL Local Time and UTC(APL) via IRIG-B and to the APL Network Time Protocol (NTP) servers.

Our new GPS receiver installation makes it possible for the JHU/APL TFL to perform both precise point positioning (PPP) and multi-channel common-view time transfer. We share common-view time transfer data with NIST and the USNO and maintain GPSPPP time transfer with the BIPM.

The JHU/APL TFL collection of three hydrogen masers and three high performance cesium beam standards are used in an ensemble to formulate the APL Time Scale. The six contributing clocks are selectively weighted in the ensemble, and the resulting time scale is referenced to UTC(APL) [1]. The UTC(APL) 5 MHz and 1 PPS signals are the output of a precision frequency offset generator driven by one of the masers. Figure 3 is a plot of UTC-UTC(APL) during the instantiation of the new TFL with Phase One beginning near MJD 55800 MJD (August 27, 2011) with major events, planned and unexpected, indicated along the plot.

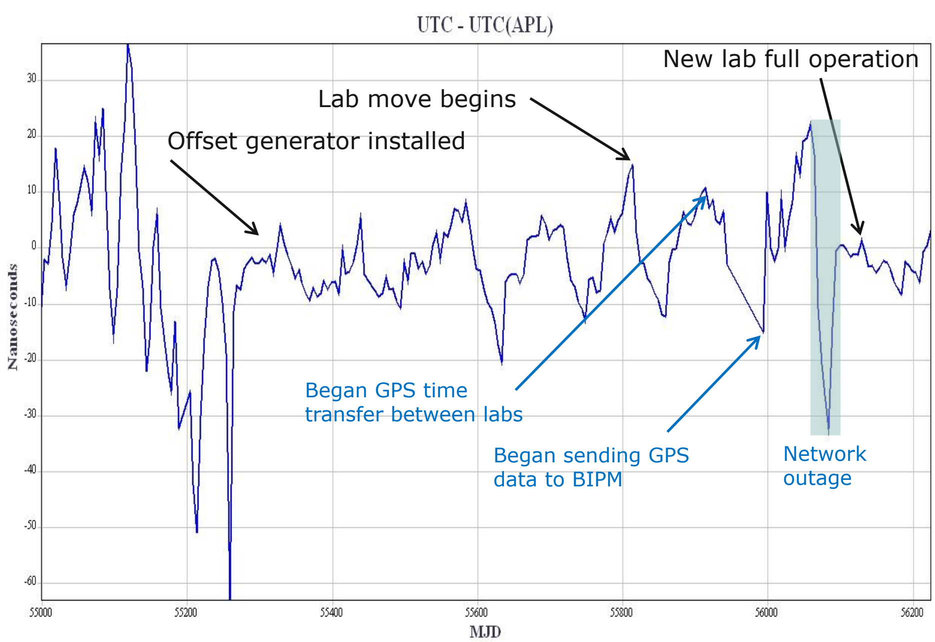

Figure 3. Timekeeping of UTC-UTC(APL) over period of instantiation of the new TFL facility.

For example, Phase Two of the planned move ends at around MJD 56000, where clock and GPS time recovery data began to be transferred to the BIPM. For nearly 60 days previous to this period, the UTC(APL) master clock was allowed to free-run without any steering information, resulting in the nearly negative 20 ns run in phase. The unexpected event with the most noticeable impact to UTC(APL) occurred at around MJD 56080, when a network outage defeated the ability to recover and share GPS time data. Since about MJD 56100, the new TFL has been operating with all equipment and planned improvements in place, showing the expected capability of UTC-UTC(APL) maintaining a required maximum time error of no more than ± 10 ns.

V. CONCLUSION

The move to the new APL Time and Frequency Laboratory was carried out successfully with no adverse impact on APL users and minimal disruption in our contribution to the formulation of TAI. This was accomplished by maintaining two labs during the transition and by following a three phase plan, which was accomplished with only a few set-backs. The clocks were moved while powered to minimize start-up time and frequency drift. We now have a controlled environment clock vault which should improve the stability of our clocks and the maintenance of the APL Time Scale. This should also improve our ability to estimate UTC-UTC(APL) for the purpose of steering to UTC. The uncertainty of UTC(APL) in time transfer with the BIPM has improved from 1.5ns to 0.3ns, attributable to new GPS receiver/antenna installation that allows the use of GPSPPP time transfer. After more than 50 years of service to space missions operation from the old TFL, the new JHU/APL TFL will now begin a new epoch in timekeeping for the enhanced requirements of future JHU/APL space programs.

REFERENCES

[1] M. Miranian, G. L. Weaver, and M. J. Reinhart, "Autonomous characterization of clock drift for timescale improvement at the JHU/APL Time and Frequency Laboratory," Joint Proc. IEEE International Frequency Control Symposium and 37th PTTI Meeting, pp. 207-212, August 2005.