IMPROVED OPERATIONS AT THE APL TIME AND FREQUENCY LABORATORY

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Abstract

During the past year, the APL Time and Frequency Laboratory has improved its operations while continuing to support critical APL projects. The acquisition of new hardware and the development of new computer algorithms have increased the timing capability of the lab to a quality of service that permits the lab to be a contributor to the computation of International Atomic Time. In July, the lab took delivery of a second Sigma Tau hydrogen maser, bringing the facility's complement of masers to three. The position of the lab's GPS antenna was accurately surveyed, greatly improving common-view time transfer accuracy, and the installation of redundant phase microsteppers has made possible the steering of UTC (APL). The implementation of a time scale algorithm has combined the labs three masers and three cesiums into a stable Mean time reference, and a UTC – UTC (APL) prediction algorithm based on the Mean has improved our capability to steer to the BIPM. While improving its timing capability, the lab has continued to support development of three NASA spacecraft (Messenger, Stereo, and New Horizons) in addition to that of flight oscillator projects.

INTRODUCTION

The Time and Frequency Laboratory of the Johns Hopkins University Applied Physics Laboratory (JHUAPL) has made a number of improvements to its operations to enhance support of many critical projects at APL. These improvements have not only increased the timing capability of the lab, but have also made it possible for the lab to become a contributor to the computation of International Atomic Time.

The lab continues to support critical activities for military and NASA space science missions. We are actively supporting three spacecraft currently in flight, and are supporting three more spacecraft now undergoing integration and test. The JHUAPL-built Mercury Surface, Space Environment Geochemistry and Ranging (MESSENGER) spacecraft (Figure 1) was launched from Cape Canaveral Air Force Station on 3 August 2004. This spacecraft is set to be the first to orbit the planet Mercury, and only the second ever to go to Mercury. MESSENGER will investigate key scientific questions regarding Mercury's characteristics and environment **[1]**. The Mission Operations Center (MOC) is located at JHUAPL, and relies on the JHUAPL Time and Frequency Lab for timing signals to time tag data and coordinate time-critical spacecraft events such as propulsion maneuvers. MESSENGER is planned to fly past Mercury in 2008 and 2009, and then begin orbiting the planet in March 2011.

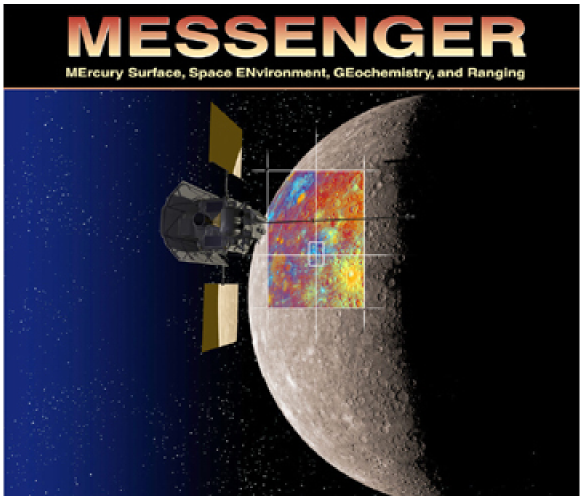

Figure 1. MESSENGER

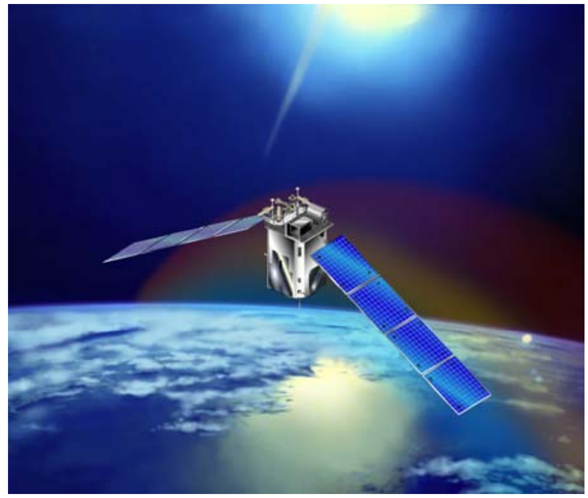

Figure 2. TIMED

The Thermosphere - Ionosphere - Mesosphere Energetics and Dynamics (TIMED) spacecraft (Figure 2) was built by JHUAPL and has completed its planned 2-year mission to explore the Earth's Mesosphere and Lower Thermosphere. Launched in December of 2001, the TIMED spacecraft is in the first year of a 2-year extended mission, and continues to operate nominally and study the influences of the Sun and humans on the least explored and understood region of our atmosphere **[2]**. The TIMED MOC is located at JHUAPL, and relies on the JHUAPL Time and Frequency Lab for timing signals to time tag data and coordinate time critical spacecraft events such as propulsion maneuvers. The JHUAPL satellite tracking facility that communicates daily with the TIMED spacecraft also utilizes the Time and Frequency Lab for frequency reference signals.

In support of the strategic defense initiative, the Mid-Course Space Experiment (MSX) spacecraft (Figure 3) was developed at JHUAPL to demonstrate the ability to track missiles from space. After being launched into Earth orbit in 1996, MSX successfully demonstrated this. Its mission soon evolved, however, into the study of Earth's atmosphere with its hyper-spectral imagers. MSX is now focused on celestial and terrestrial backgrounds, surveillance demonstrations, and contamination and environmental research **[3]**. The JHUAPL satellite tracking facility serves as the mission ground station, and relies on the JHUAPL Time and Frequency Lab for frequency reference and timing signals to support communications and time tagging of data.

We are also building the New Horizons spacecraft (Figure 4), which will fly past Pluto and Kuiper belt objects in an attempt to answer basic questions about their surface properties, geology, interior makeup, and atmospheres **[4]**. Set to launch in January 2006, the New Horizons spacecraft will utilize a gravity-assist maneuver at Saturn before intercepting Pluto in July 2015. The JHUAPL Time and Frequency Lab is supporting the ongoing integration and test activities with timing and frequency reference signals, and after launch will support the JHUAPL MOC with timing signals. The Time and Frequency Lab is also supporting the development of a quartz-based Ultra-Stable Oscillator (USO) for this spacecraft. As this oscillator is going to support an uplink radio-science measurement of Pluto's sparse atmosphere, good short-term frequency is critical. The Time and Frequency Lab supplies reference signals for setting the USO on frequency, measuring short-term stability, and measuring drift rate.

Figure 3. MSX

Figure 4. New Horizons

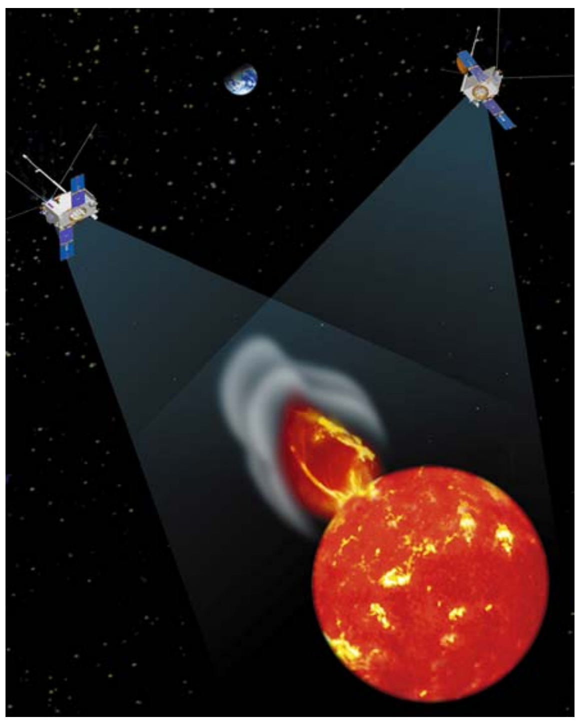

Figure 5. STEREO

Two spacecraft for the Solar-Terrestrial Relations Observatory (STEREO) mission (Figure 5) are also being supported by the JHUAPL Time and Frequency lab while undergoing integration and test at JHUAPL. One spacecraft will lead Earth in its orbit and the other will lag behind, each carrying a cluster of telescopes. When simultaneous telescopic images are combined with data from the two observatories, the trajectory of Earth-bound coronal mass ejections can be tracked in three dimensions **[5]**. The JHUAPL Time and Frequency Lab is supporting the ongoing integration and test activities with frequency reference signals for communication system testing and calibration in addition to timing signals for operations coordination. After launch, the Time and Frequency Lab will support the STEREO MOC at JHUAPL with timing signals. These spacecraft will be launched on the same launch vehicle in February 2006 with a planned 2-year mission duration.

RECENT IMPROVEMENTS

GPS Antenna Survey — APL carries out continuous GPS common-view time transfer with the U.S. Naval Observatory (USNO). A linear fit is made through the 13-minute common-view values to produce a daily value for zero hours UTC of each day. It was noticed that the rms for the daily values of the individual common-view values averaged around 9.5 nanoseconds. This was much larger than expected, given that the two laboratories are only about 20 kilometers apart. Although a number of things could contribute to this, one of the first that comes to mind is antenna coordinates. The coordinates being used were from a survey that was made many years ago, and it was not certain that they were even in the WGS84 coordinate system. Therefore, it was decided a new survey was needed. We were able to acquire the use of a Turbo-Rough Geodetic GPS receiver, and data was collected for 5 days. The data were converted to RINEX format and sent to NIMA for processing. The difference between the old and new coordinates translated to a total difference of 8.4 meters. The new coordinates were entered into our GPS receivers and the rms of the linear fit dropped to 1.5 nanoseconds. There was also a time step of -14 nanoseconds (Figure 6).

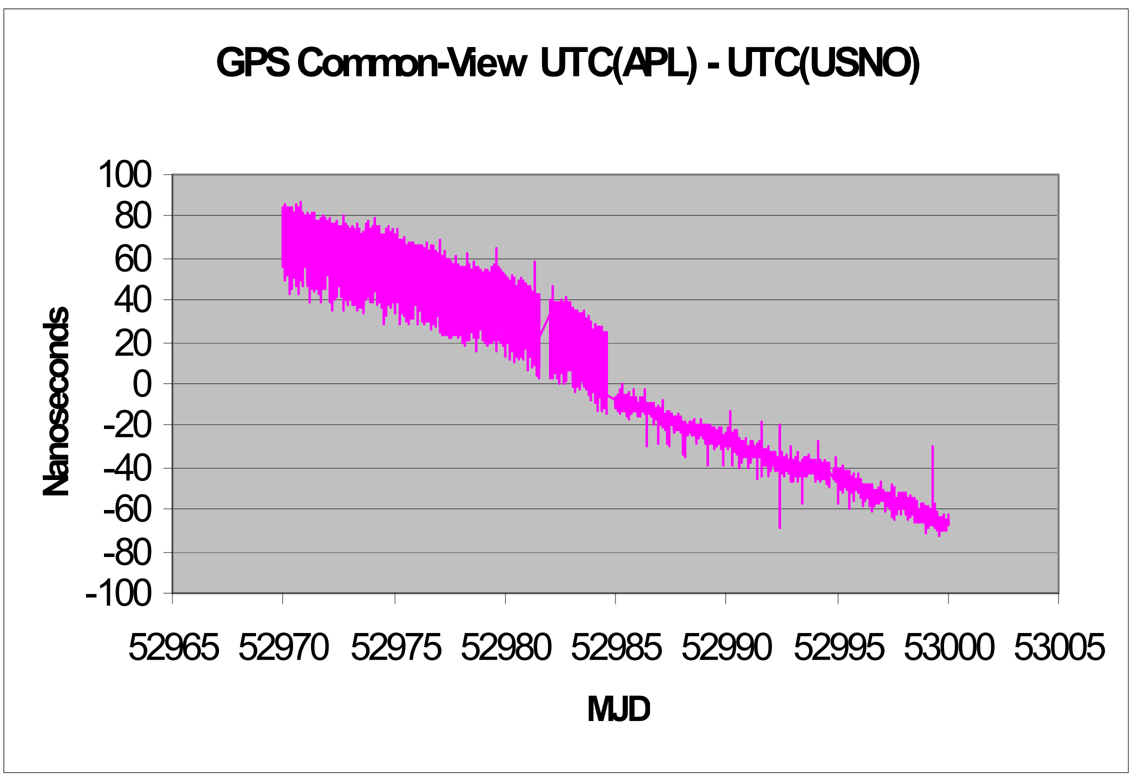

Figure 6

Installation of a Phase Microstepper — Until last year, the reference for UTC (APL) was a free-running Agilent 5071A High-Performance Cesium Frequency Standard. In order to maintain UTC (APL) as close as possible to UTC, it would be necessary to steer the output of the cesium. Although the 5071A provides a means for advancing or retarding its 5 MHz output, it was decided that it would be more efficient to use a phase microstepper. This would allow us to both use the cesium as a reference for UTC (APL) and also include it in the APL Time Scale. Two phase microsteppers were acquired and installed, one operational and one backup. The 5 MHz output of the cesium was split so that it could be an input to the microstepper and also an input to our clock measurement system. The output of the microstepper was also made an input to the clock measurement as UTC (APL) and all clock measurements were referenced to the microstepper output. At first it was necessary to do some aggressive steering to remove the high rate of the cesium to align the time a frequency of UTC (APL) with our prediction of UTC – UTC (APL), but now that it has been stabilized, we only adjust the microstepper once or twice a month (Figure 7).

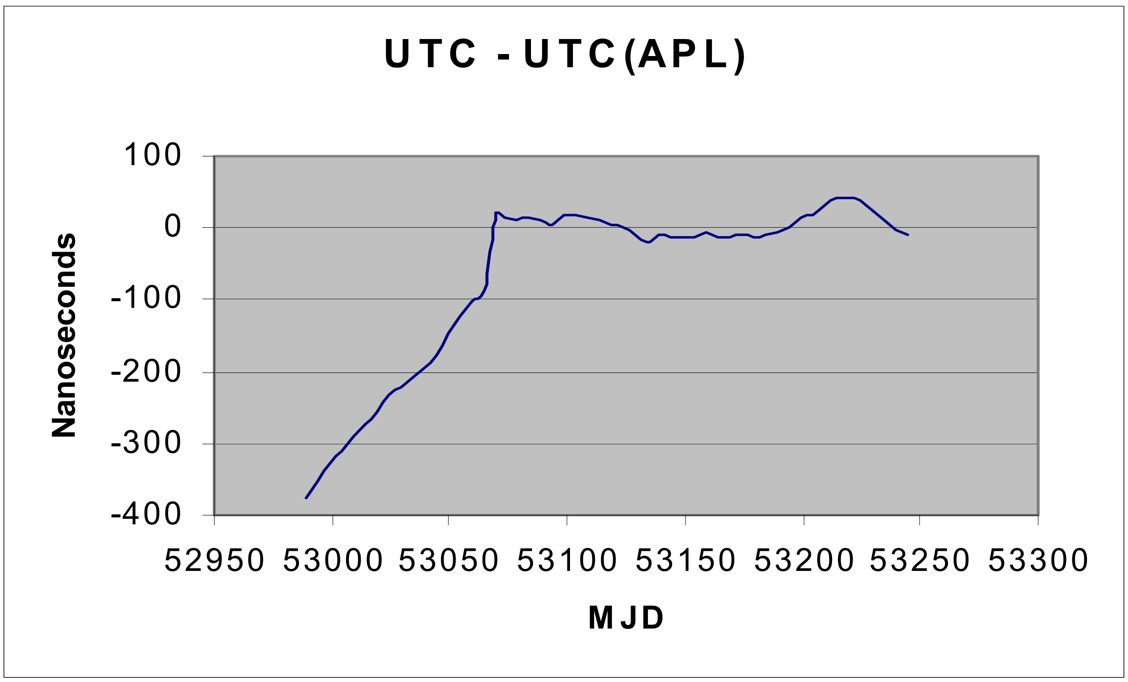

Figure 7

UTC – UTC (APL) Predictor — Circular-T data from the BIPM can be as much as 30 days old. Therefore, to be able to steer UTC (APL) to UTC with any degree of certainty in near real-time, we must make a prediction of the difference between UTC and UTC (APL). A prediction algorithm was developed so that an extrapolation could be made on the latest data published in the BIPM's Circular T. The algorithm is based on the last 15 published data points of UTC - UTC (APL), a prediction of UTC minus the APL Time Scale, and the difference between UTC (APL) and the APL Time Scale. The prediction error varies from month to month, but is usually around ±5 nanoseconds after 30 days (Figure 8).

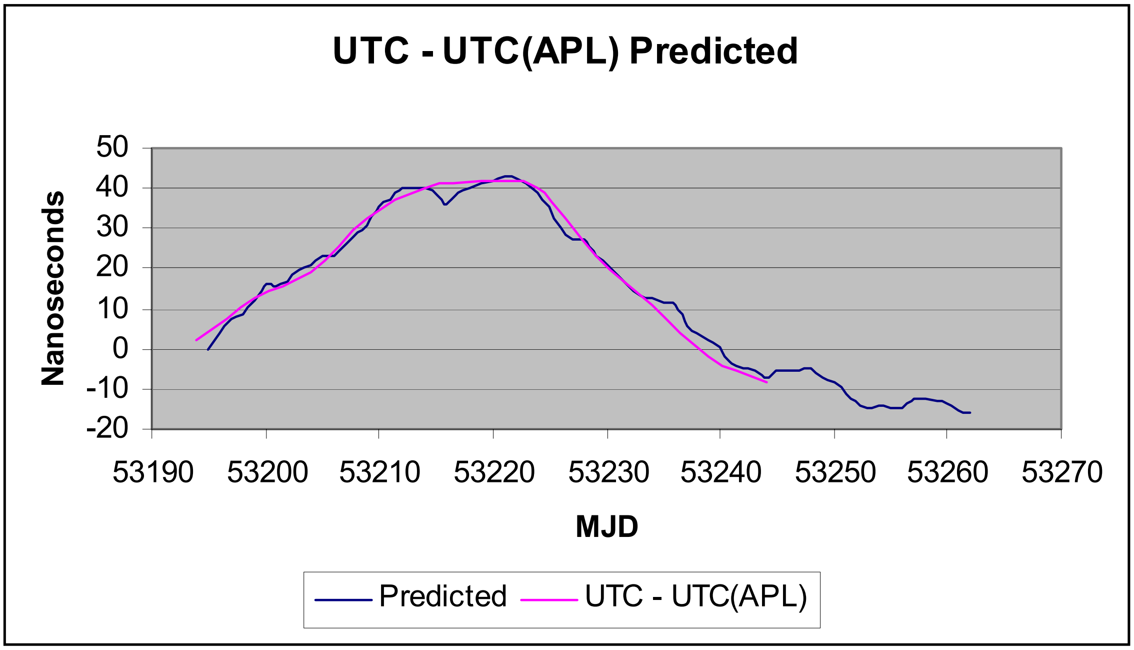

Figure 8

The APL Time Scale ─ Currently the APL clock ensemble consists of two new Symmetricom (formally Datum) model MNM-2010 hydrogen masers and three Agilent High-Performance 5071A cesium standards. We also have one operational APL-NASA hydrogen maser that was engineered for NASA by APL in the 1980s. Although this maser has good short-term stability, it has grown unreliable in the long-term and, therefore, is not included in the time scale. The APL time scale is a modified version of the Percival time scale algorithm. The cesiums are characterized based on their rates referenced to the time scale and the masers are characterized based on their rates and drifts referenced to the time scale. Once characterized, the frequencies of the clocks are averaged for each hourly epoch to produce the frequency of the time scale. The characterization of each clock is checked daily by evaluating the slope of the difference of the characterized clock and the time scale.

APL Clocks in TAI ─ The APL Time and Frequency Laboratory began sending GPS and clock data to the BIPM in January 2004. Currently, the BIPM is receiving clock data from our three cesiums and two Symmetricom hydrogen masers. The APL link to Physikalisch-Technische Bundesanstalt (PTB) is via the USNO. Multi-channel Global Positioning System (GPS) common-view time transfer is carried out between APL and the USNO and two-way time and frequency transfer is carried out between the USNO and PTB.

FUTURE IMPROVEMENTS

In July 2005, APL is scheduled to receive its third hydrogen maser from Symmetricom. This will increase our complement of atomic clocks to three cesiums and four hydrogen masers. In 2006, we plan to acquire two Auxiliary Output Generators. This will allow us to precisely control the 5 MHz output of our hydrogen masers and will make it possible to switch the reference to UTC (APL) from one of our cesiums to one of our masers. Currently, there are plans to move the Time and Frequency Laboratory to a new building in 2007 or 2008. If this is done, the new lab will be fitted with an environmental chamber to house our clocks. With better temperature and humidity control, we should see improved performance from these clocks.

REFERENCES

[1] http://messenger.jhuapl.edu

[2] http://www.timed.jhuapl.edu

[3] http://sd-www.jhuapl.edu/MSX/

[4] http://pluto.jhuapl.edu/

[5] http://stereo.jhuapl.edu/