THE APL TIME AND FREQUENCY LAB

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Abstract

The APL Time and Frequency Laboratory supports a wide variety of current and upcoming NASA missions that span the solar system from the study of the Sun's coronal mass ejections to the examination of the planet Pluto and the Kuiper Belt objects. This support can be in the form of providing precise time and frequency to the integration and testing of new hardware or the time-stamping of ground-receipt telemetry packets from various spacecraft. The Lab's ensemble of three cesium standards and one hydrogen maser will soon be expanded with the procurement of two additional hydrogen masers. Also, a new frequency stability measurement system is capable of making up to once-per-second picosecond level phase measurements at 5 MHz from each clock in the ensemble. Traceability to USNO, NIST, and BIPM is maintained via GPS common-view time transfer and will provide a means for incorporating the Lab's clocks into the computation of TAI.

INTRODUCTION

The Time and Frequency Laboratory (T&F Lab) of the Johns Hopkins University Applied Physics Laboratory (APL) disseminates time and frequency reference signals to many critical projects at APL. These signals support the development of hardware for, and operation of, NASA and DoD projects that study the Sun, Mercury, Earth, Mars, Saturn, Pluto, and the Kuiper Belt objects. The heart of the T&F Lab is its ensemble of atomic clocks. The Lab acquired its first atomic clock in 1960, and gradually added more in years to come. This included three NASA Research (NR) masers that were built at the T&F Lab in the early 1980s. In 1995, the Lab purchased a new HP5071A High Performance cesium, but by 2001, most of the atomic clocks were past their useful life and due for replacement. Over the next 3 years, the old cesiums and two of the NR masers were retired, the cesium tube in the HP5071A was replaced, two new cesium clocks of the HP5071 High Performance type were purchased from Agilent, and one new hydrogen maser was purchased from Symmetricom (formerly Datum). Two additional masers from Symmetricom are on order and scheduled for delivery in mid-2004 and mid-2005.

SUPPORTED APL PROJECTS

The T&F Lab provides critical support to many APL satellite, space science instrument, and ultra-stable oscillator projects. This support can take the form of high-stability frequency references, or precise time code signals. The frequency references are used for a variety of flight hardware development and space qualification testing, in addition to providing frequency references to APL's satellite tracking station. Precise time code signals are used for critical event coordination such as satellite propulsion maneuvers and time-tagging of scientific data collected. Several APL satellite projects are briefly described below.

NEAR – **N**ear **E**arth **A**steroid **R**endezvous: The NEAR mission was the first comprehensive study of the physical geology, composition, and geophysics of an asteroid. Launched in 1996, NEAR was inserted into orbit around the asteroid Eros in 2000. After collecting data for 1 year, NEAR made a soft landing on Eros and continued to operate and send signals back to Earth.

TIMED – **T**hermosphere **I**onosphere **M**esosphere **E**nergetics and **D**ynamics: Launched in 2001, the 5-year TIMED mission is studying the influences of the Sun and humans on the least explored and understood region of Earth's atmosphere – the Mesosphere and Lower Thermosphere/Ionosphere (MLTI). The MLTI region is a gateway between Earth's environment and space.

MESSENGER – **ME**rcury **S**urface, **S**pace **EN**vironment, **GE**ochemistry, and **R**anging: MESSENGER will launch in 2004 and after two flybys of the planet will orbit Mercury for 1 Earth year beginning in 2009. MESSENGER's instruments will provide the first images of the entire planet and collect detailed information on the composition and structure of Mercury's crust, its geologic history, and the nature of its thin atmosphere.

STEREO – **S**olar **TE**rrestrial **RE**lations **O**bservatory: STEREO is the third mission in NASA's Solar Terrestrial Probes program. Scheduled for launch in 2005, the 2-year mission will employ two nearly identical space-based observatories to provide the first-ever 3-D stereoscopic images to study the nature of coronal mass ejections.

New Horizons: New Horizons is scheduled to launch in 2006, swing past Jupiter for a gravity boost and scientific studies in 2007, and reach Pluto and its moon, Charon, in 2015. The spacecraft will then head deeper into the Kuiper Belt to study one or more of the icy mini-worlds in that vast region.

MSX – **M**idcourse **S**pace E**X**periment: MSX is a Ballistic Missile Defense Organization project which offers major benefits for both the defense and civilian sectors. MSX experiments are providing critical first-time observations of missile target signatures against Earth-limb, auroral- and celestial-cluttered backgrounds, monitoring on-orbit contamination of optical instruments, and investigating the composition of the Earth's atmosphere.

TIME AND FREQUENCY DISSEMINATION

The T&F Lab disseminates time and frequency reference signals in several formats; 1 MHz, 5 MHz, 10 MHz, 1 PPS, IRIG-B APL local time, and IRIG-B UTC (Universal Coordinated Time). The criticality of these signals warrants a high degree of continuous self-monitoring within the Lab. This monitoring is accomplished through clock-to-clock comparison within the ensemble and common-view GPS clock comparisons with external facilities. Recently the T&F Lab clock-to-clock comparison capabilities were enhanced through the purchase of a new TSC2000 multi-channel frequency measurement system from Timing Solutions Corporation (TSC). This new system is capable of making up to once-per-second picosecond level simultaneous phase measurements at 5 MHz of each clock in the ensemble. These data will make it possible to evaluate both the long- and short-term stability of each clock and provide advance warning of impending clock degradation.

The T&F Lab also disseminates time and frequency reference signals to projects that require traceability to either the National Institute of Standards and Technology (NIST) or the United States Naval Observatory (USNO). Two new GPS common-view time transfer receivers provide independent traceability to both NIST and the USNO. These receivers will also provide traceability to the Bureau

International des Poids et Measures (BIPM) and make it possible to incorporate the Lab's clocks into the computation of International Atomic Time (TAI).

TIME AND FREQUENCY LAB HARDWARE

Figure 1 shows a simplified functional block diagram of the T&F Lab. The diagram shows the interconnection between the atomic frequency standards, the clock measurement systems, and the signal distribution system.

Each atomic clock supplies a 5 MHz signal to the TSC-2000 measurement system and a 1 PPS signal to the long-term drift rate measurement system. The ensemble of cesium standards is used as the source for 5 MHz and IRIG-B distribution. The distribution system is redundant. All three cesium standards provide reference signals. Redundant time code generators generate IRIG-B signals from 1 MHz or 5 MHz references. Redundant distribution amplifiers and fiber-optic transmitters distribute signals throughout the APL campus.

IRIG-B is widely distributed by the T&F Lab. Two distribution systems are used, APL local time and UTC. APL local time, which is Eastern Standard Time/Eastern Daylight Saving Time, is distributed to clock displays throughout APL. Mildly customized Truetime time code generators use a 5 MHz reference to generate an IRIG time display in a 12-hour format that autonomously switches between standard and daylight saving time. APL local time is only used for clock displays.

IRIG-B UTC is used for scientific applications. The control centers for APL operated spacecraft use IRIG-B UTC to time-stamp telemetry frames as they are received from the spacecraft. In conjunction with 1 PPS and 5 MHz signals, IRIG-B UTC is used during spacecraft integration and test to verify performance of both the spacecraft clock and the software used by the spacecraft to time-tag telemetry as it is broadcast to a ground station. Typically APL missions require sub-millisecond accuracy of the time tags of science data archived from APL spacecraft.

For applications that require better than millisecond accuracy, 1 PPS and/or 5 MHz signals are provided to supplement the IRIG-B. The 1 PPS signal is used in applications that require traceability to UTC (USNO). Typical applications of the 5 MHz signals include short-term characterization of high-precision ovenized oscillators, and external time bases for equipment located in the Satellite Tracking Facility or in the various Mission Operations Center facilities.

Figure 2 presents a photograph of the APL T&F Lab facility. The photograph shows the cesium standard ensemble, TSC-2000, and 1 PPS clock monitoring systems. Also shown are the time code generators, distribution amplifiers, and fiber-optic transmitters making up the APL T&F Lab distribution system.

CONCLUSION

The APL Time and Frequency Lab is critical to the R&D and operations of the Johns Hopkins University Applied Physics Laboratory. With the implementation of state-of-the-art timekeeping and time dissemination equipment, the Lab will ensure that its capability to support users will remain ahead of their requirements. By maintaining traceability to other timing labs and to International Atomic Time, the Lab will again be recognized as a productive member of the world timekeeping community.

FIGURE 1:
APL Time and Frequency Lab
Functional Block Diagram

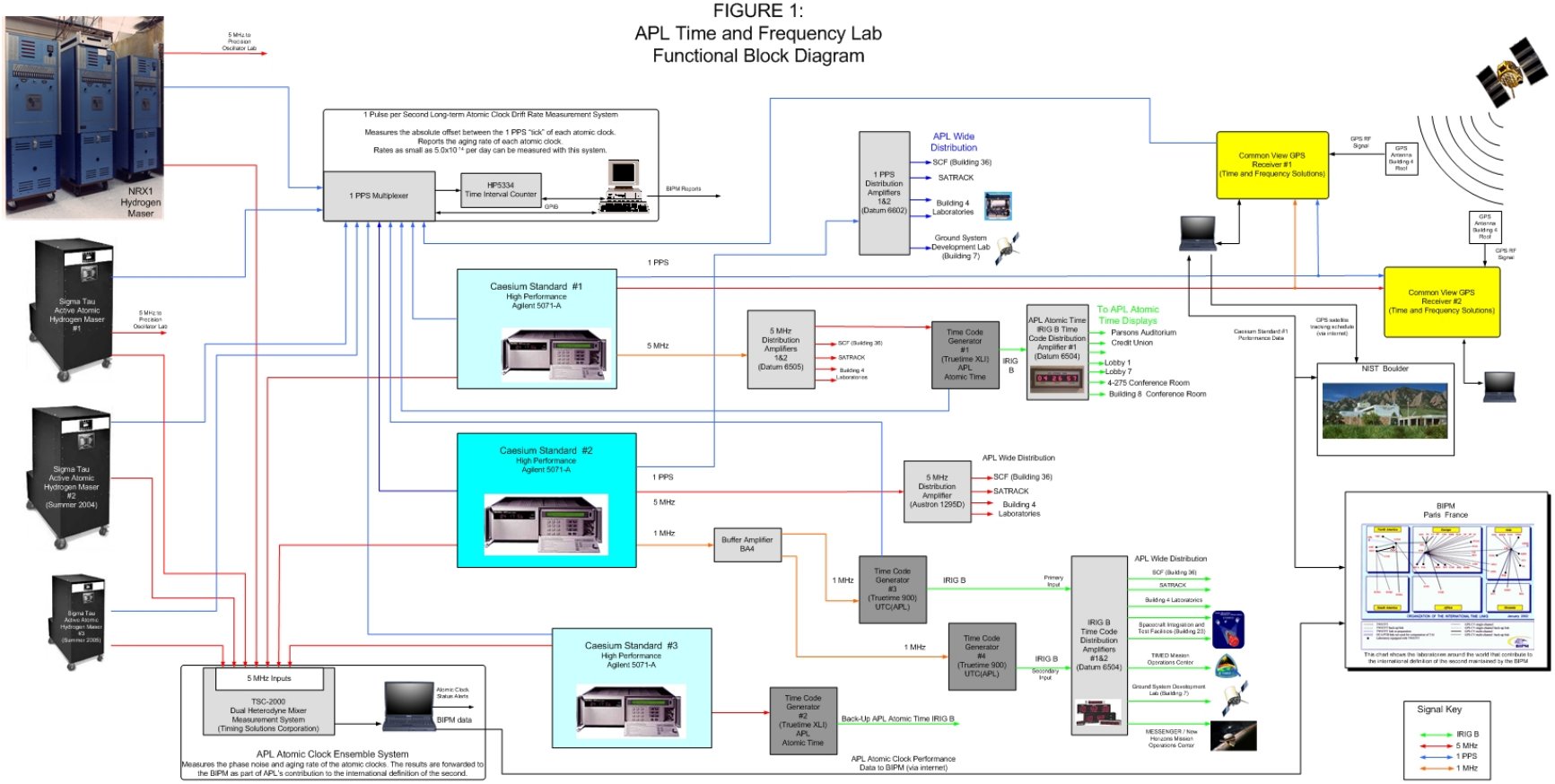

FIGURE 2: The APL Time and Frequency Laboratory