

# **RECENT TIMING ACTIVITIES AT THE U.S. NAVAL RESEARCH LABORATORY**

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## **Abstract**

*The Space Applications Branch at the U.S. Naval Research Laboratory is engaged in GPS Space Clock Development, GPS On-orbit Analysis, GPS Receiver Development, GPS receiver Calibration, GPS Clock Life Testing, and other time and frequency programs. The present status of these activities and their future developments is reported.*

## **INTRODUCTION**

The U.S. Naval Research Laboratory (NRL) has conducted research and technology development activities in time and frequency for many decades. These activities have included basic and applied R&D in the areas of advanced navigation satellite technology and precise time and time interval theory and techniques, as well as timing critical communication systems, supporting both the U.S. and international time and frequency communities. NRL has been instrumental in the development of space-borne atomic clocks used in the Global Positioning System (GPS), which has become a vital resource of the time and frequency, as well as other contributions, including absolute GPS receiver calibration services to the Bureau International des Poids et Mesures (BIPM) and other laboratories contributing to TAI/UTC and leadership of the Clock Products Working Group of the International GNSS Service.

## **UTC (NRL)**

Traceability to international standards has become increasingly important to NRL's R&D activities. To achieve that goal, NRL is now directly participating in formulation of the Coordinated Universal Time (UTC) international time scale by submitting measurements of NRL's reference standards and carrier phase time transfer information to the BIPM from the equipment configuration shown in Figure 1. A local time scale reference may be determined that in accordance with ITU-R recommendation TF.535-2 will be known as UTC (NRL). This reference will facilitate traceability of laboratory measurements to the international UTC standard.

## **GPS CLOCK LIFE TESTING**

NRL has been conducting life tests of GPS space clocks since 1997 [1]. Currently, both cesium and rubidium clocks for GPS Block IIF will be tested. The test of the Digital Cesium-Beam Frequency Standard (DCBFS) began in August 2004. Testing of the Rubidium Frequency Standard (RFS) will begin

in 2008. The purpose of this testing is to run the clocks in a space environment with high-resolution phase and telemetry monitor measurements to identify design or manufacturing defects that may affect the life or performance of the clock and to characterize the performance of the clocks. Figure 2 shows a block diagram of the DCBFS test configuration.

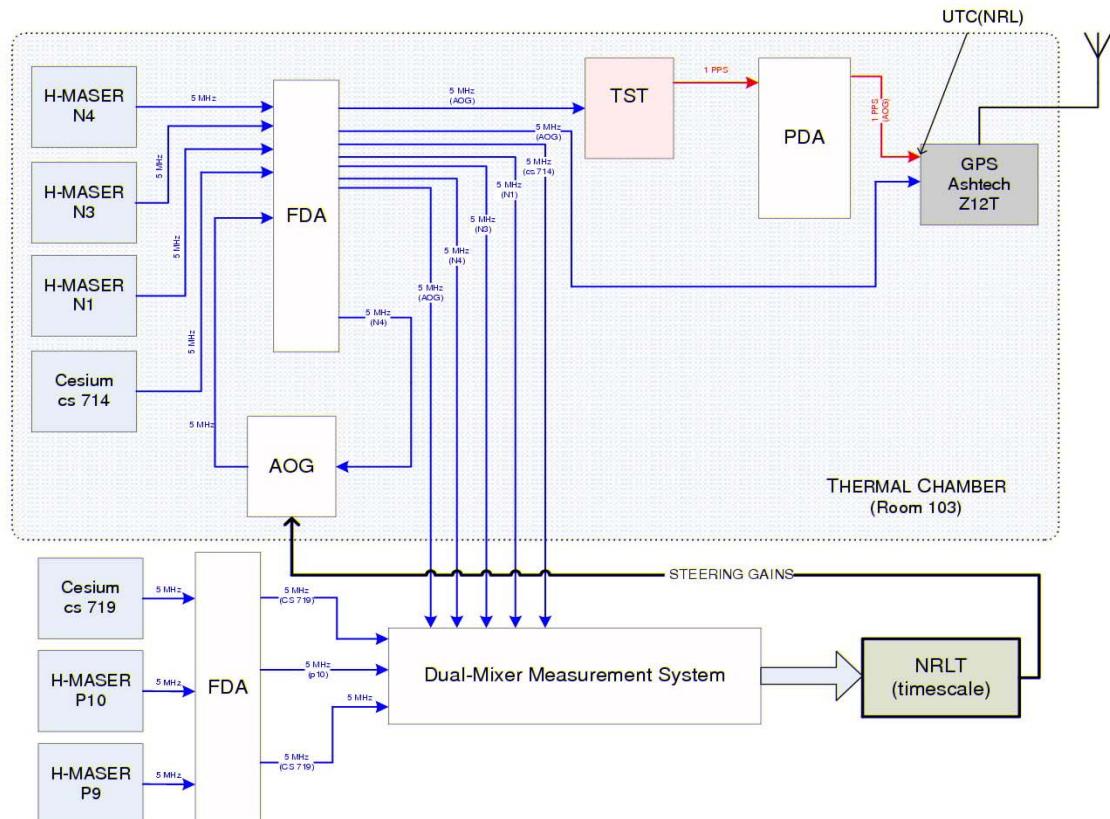


Figure 1. UTC (NRL) configuration.

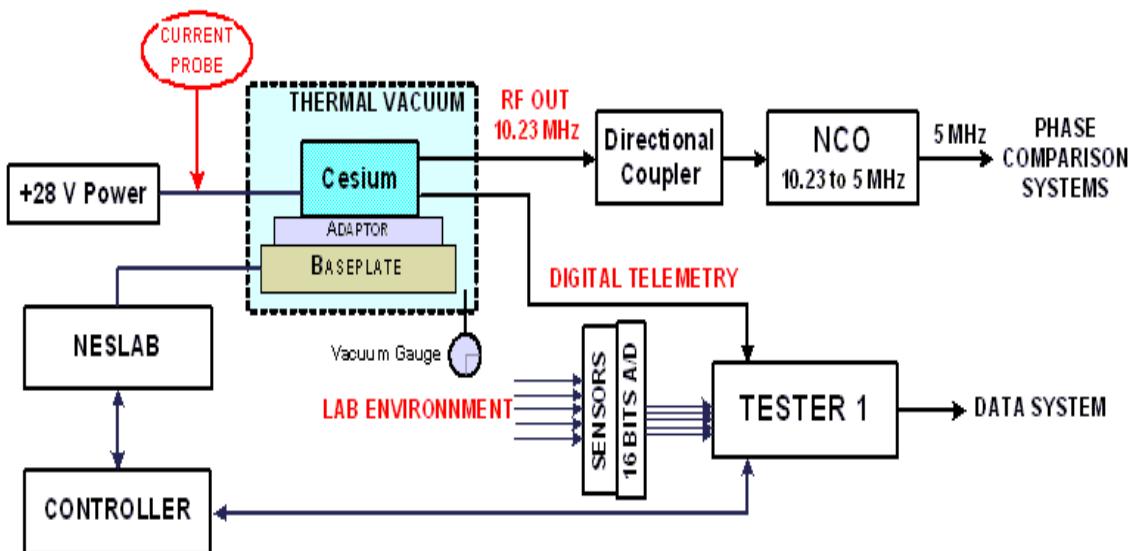


Figure 2. DCBFS Life Test block diagram.

## GPS ON-ORBIT CLOCK ANALYSIS

Since the beginning of the GPS program, NRL has analyzed the performance of the clocks onboard the GPS satellites. A database is maintained for each spacecraft clock and monitor station clock using data from the GPS Control Segment and the International GNSS Service (IGS). NRL documents and reports the status of all GPS system clocks on a quarterly basis to the GPS Control Segment. Figure 3 shows a typical stability plot for the GPS constellation. NRL also reports GPS clock performance through papers at the PTTI Meeting [2].

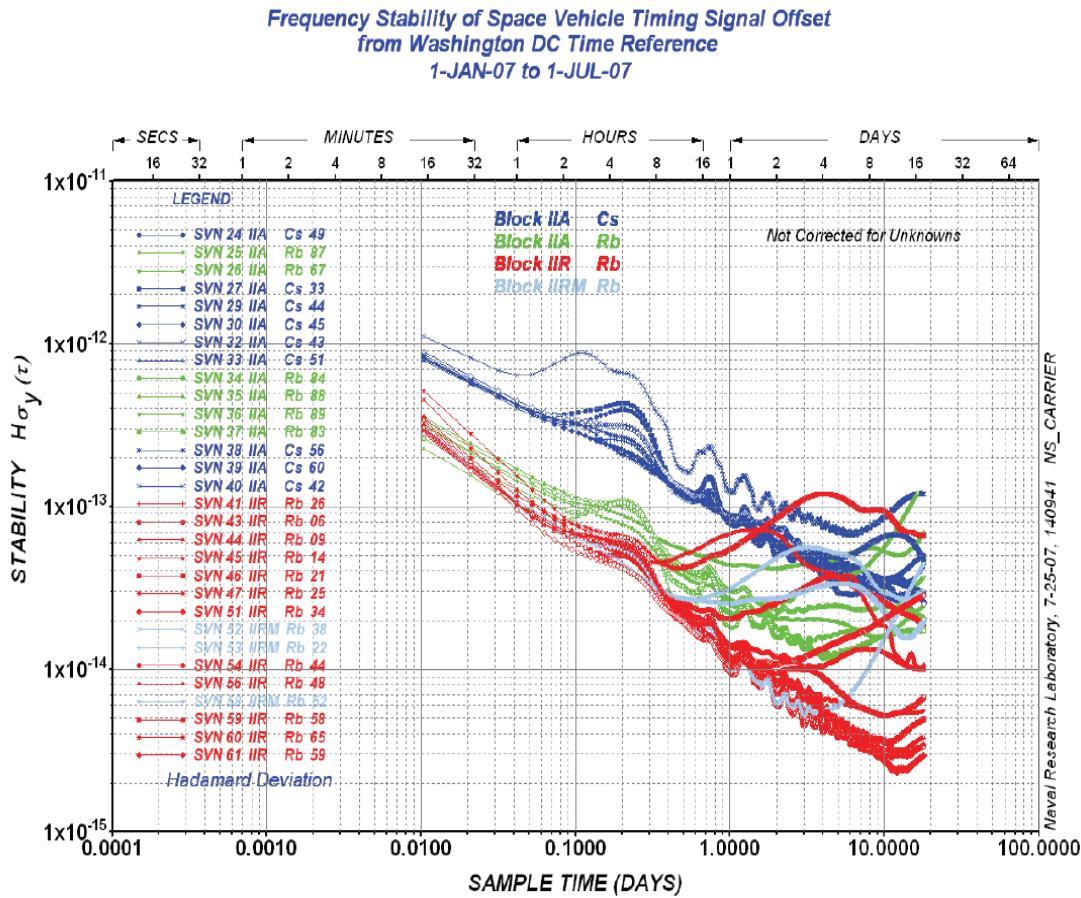
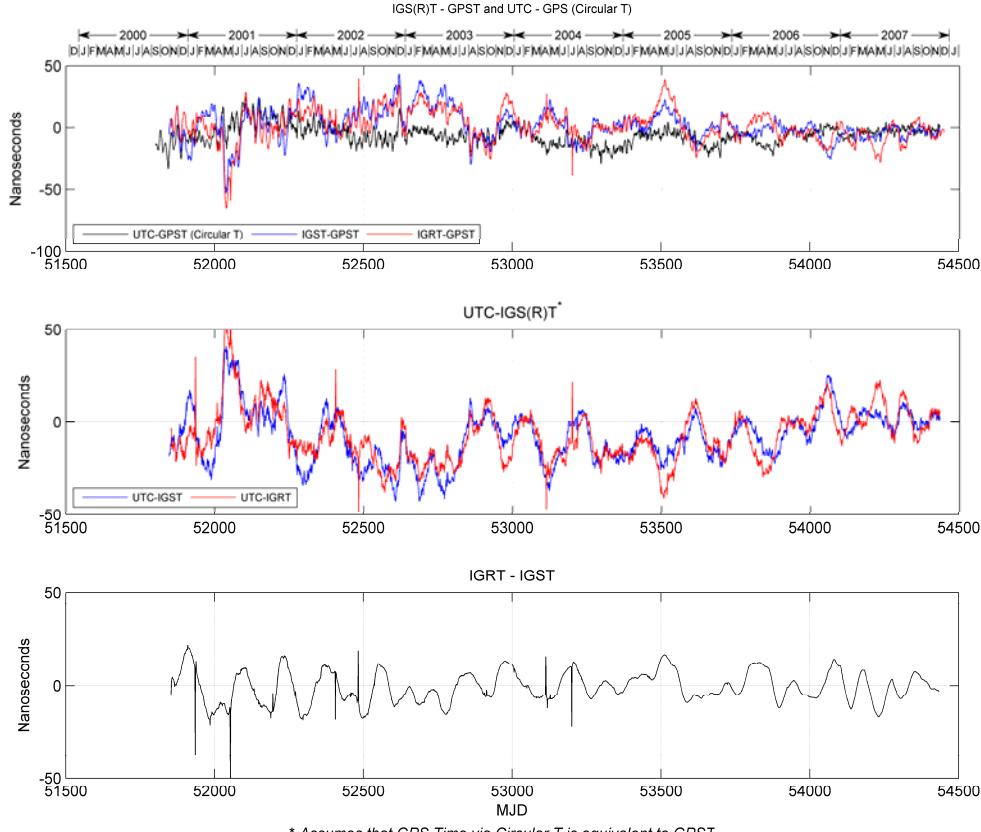


Figure 3. GPS constellation frequency stability.

## IGS CLOCK PRODUCTS

NRL continues its role as Coordinator of the International GNSS Service (IGS) Clock Products Working Group. This working group is responsible for the generation of the IGS timescales, as well as for the investigation of future improvements to the existing clock products. Currently, the IGS clock products, along with the orbit ephemeris, allow for global autonomous point positioning at the centimeter level and for remote comparison of clocks at similar levels. Also, the products currently allow for dissemination of UTC to better than 50 nanoseconds, as depicted in Figure 4.



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Figure 4. Phase offsets of various timescales. The top panel shows each IGS timescale (Rapid IGRT in red, Final IGST in blue) versus GPS Time, as well as UTC (black) versus GPS Time. The middle panel shows the differences of the series from the top panel, resulting in UTC-IGRT (red) and UTC-IGST (blue). The bottom panel shows IGRT-IGST.

## TELEVISION TIME TRANSFER

NRL and the U.S. Naval Observatory (USNO) have used a Washington area television station for relative time transfer for several years. The current system [3] uses the analog carrier signal from WTTG, Channel 5. The United States is changing from analog to digital television (DTV) formats. All stations are to convert to digital format by February 2009. The new digital format is an entirely different waveform that is not compatible with the current time transfer hardware. NRL has built and tested a new system using the DTV pilot tone, which is 309,440.6 Hz above the bottom of the channel. The carrier frequency has also changed from 77.240 MHz to 602 MHz. Initial zero-baseline tests show excellent results (see Figure 5). Split site tests with USNO will be done in early 2008.

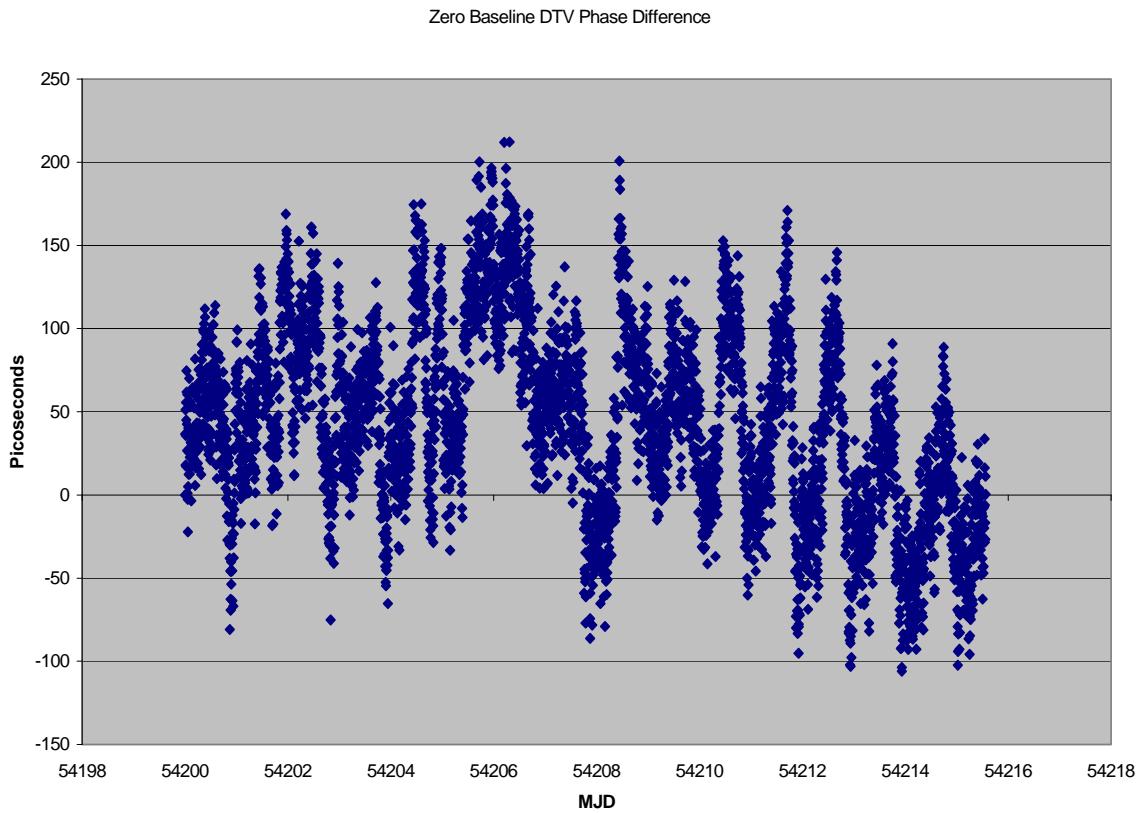


Figure 5. DTV time transfer results.

## GPS TIMING RECEIVER ABSOLUTE CALIBRATIONS

NRL performed absolute delay calibrations in 2007 on receivers from BIPM and NIST. The method [4] uses a GPS satellite signal simulator. This approach allows an absolute calibration of the receiver's internal delays without the effects of GPS system errors, multipath, or other perturbing factors outside the receiver [4]. Figure 6 shows how the calibration is configured.

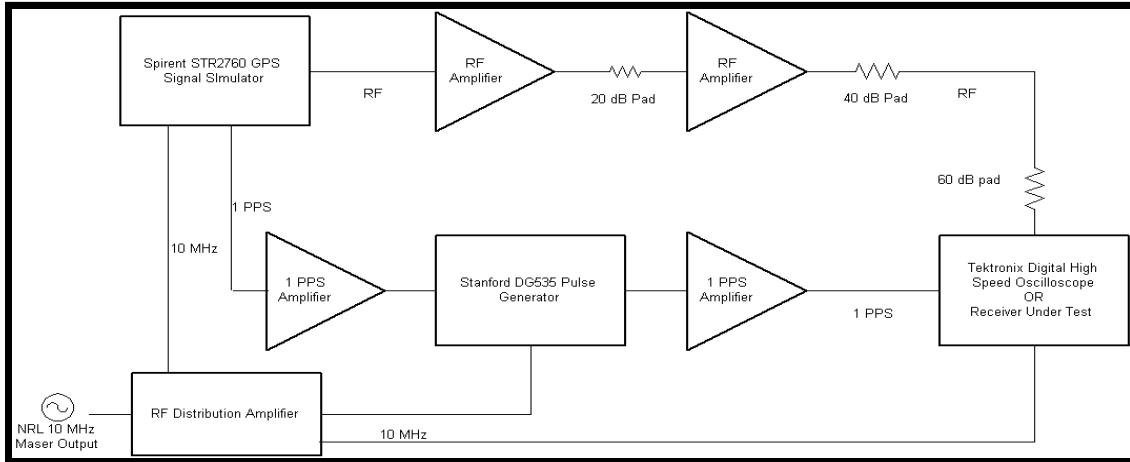


Figure 6. Timing receiver calibration configuration.

## REFERENCES

- [1] R. Beard, J. Buisson, F. Danzy, M. Largay, and J. White, 2002, “*GPS Block IIR Rubidium Frequency Standard Life Test Results*,” in Proceedings of the 2002 IEEE International Frequency Control Symposium & PDA Exhibition, 29-31 May 2002, New Orleans, Louisiana, USA (IEEE Publication 02CH37234), pp. 499-504.
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- [3] D. Boehm and R. Gross, 2005, “*Remote Frequency Measurement of TV5 Rubidium*,” in Proceedings of the 2005 Joint IEEE International Frequency Control Symposium and Precise Time and Time Interval Systems and Applications (PTTI) Meeting, 29-31 August 2005, Vancouver, Canada (IEEE Publication 05CH37664C), pp. 636-638.
- [4] J. White, R. Beard, G. Landis, G. Petit, and E. Powers, 2001, “*Dual Frequency Absolute Calibration of a Geodetic GPS receiver for Time Transfer*,” in Proceedings of the 15<sup>th</sup> European Frequency and Time Forum (EFTF), 6-8 March 2001, Neuchâtel, Switzerland (Swiss Foundation for Research in Microtechnology, Neuchâtel), pp. 167-170.