



Time & Frequency Activities

Advanced Space PNT Branch

Naval Center for Space Technology

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CGSIC, Timing Subcommittee

25 September 2017



- *GPS Space Atomic Clock Technology*
- *NRL Precise Clock Evaluation Facility*
- *NRL GPS Clock Life Tests*
- *NRL GPS On-orbit Clock Analysis*
- *Next Generation GPS Timescale Support*
- *Alternatives to GPS for timing*
- *PTTI 2018*



- *Navigation Technology Satellites (NTS)*
 - *NRL has contributed to GPS technology and system development since the beginning of the program*
 - *Contributions began with System Concept Studies, and the Development, Orbit and Operation of the NTS*
 - *NTS flew the first GPS pseudo-random ranging code transmitters, and demonstrated the first GPS on-board atomic clock operation (GPS Block I)*
 - *NTS-1 carried Rubidium clocks*
 - *NTS-2 carried Cesium clocks*
- *NRL conducted the Joint GPS Clock Technology Program*
 - *Developed production sources of space and ground hydrogen masers and space cesium atomic clocks for the GPS satellites (GPS Block II)*
 - *Clock Electronics Design*
 - *Transition to Industry Partners for production*





- *PCEF Supports Multiple NRL Programs*
 - *Provides Capability for Measuring and Characterizing Clocks*
 - *Commercial Hydrogen Masers and Cesiums*
 - *Multiple Multi-Channel Precision Dual Mixer Measurement Systems*
 - *Precise Time and Frequency Distribution Systems*
 - *Environmental Control Chambers*
 - *Automated Data Collection and Archival Systems*
 - *Maintain Realization of Coordinated Universal Time, UTC(NRL)*
 - *Reference stability for In-house use; not distributed outside NRL*
 - *Supports the GPS Space Atomic Clock Life Tests*
- *PCEF upgrades*
 - *Environmental chambers*
 - *Active Hydrogen Masers*
 - *Precision Measurement Systems*



Environmental Control



Commercial Cesiums



Commercial Active
Hydrogen Masers

GPS Space Clock Extended Life Testing



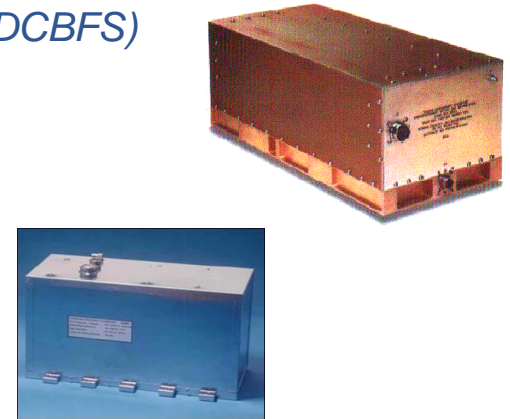
- *NRL Life Tests serve as a baseline for on-orbit clock performance*
 - *Provide long term observation that cannot be conducted in the clock manufacturer's production environment*
 - *Installation in Test Chambers Duplicates Mounting in Satellite*
 - *Simulate on-orbit environment: vacuum and temperature*
 - *Evaluate performance parameters*
 - *Clock, environmental and telemetry*
 - *Identify premature failure modes*
 - *Characterize clock over long term*
- *GPS Life Testing Joint Collaboration*
 - *NRL*
 - *GPS Directorate*
 - *Satellite Manufacturers*
 - *Clock Manufacturers*



GPS Space Clock Extended Life Testing



- *Series of GPS Clock Life Tests conducted at the NRL PCEF*
 - *Two Block IIR Rubidium Atomic Frequency Standards (RAFS)*
 - *1997 to 2004*
 - *Two Block IIF Digital Cesium Beam Frequency Standards (DCBFS)*
 - *Intermittently 2004 to 2006*
 - *Resumed November 2010 to present*
 - *46 Clock and Environmental Telemetry Parameters*
 - *Two Block IIF RAFS*
 - *August 2008 to present*
 - *35 Clock and Environmental Telemetry Parameters*
 - *Two GPS III RAFS – preparations underway*
 - *Expected arrivals December 2017, Spring 2018*
- *Production Units*
- *Validate operation prior to actual flight*

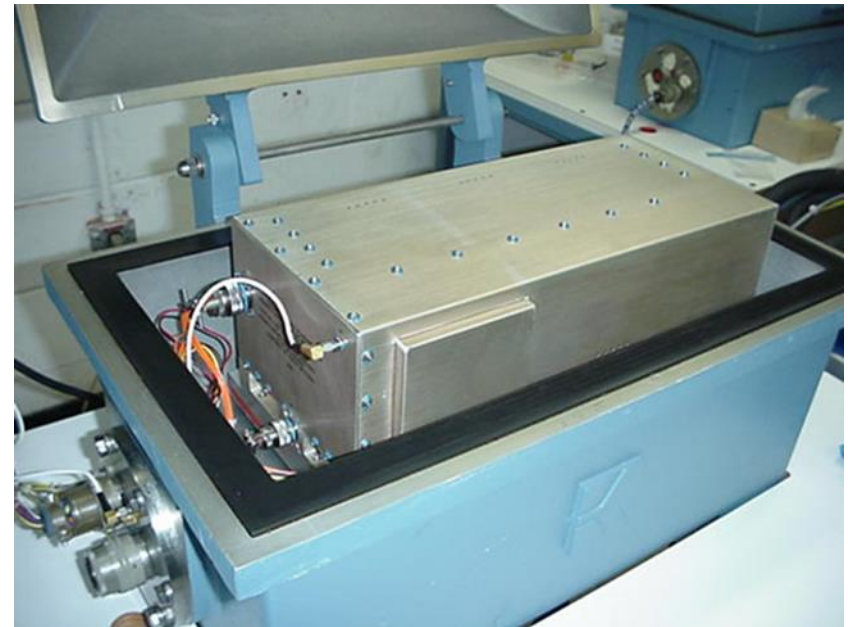




RAFS



DCBFS



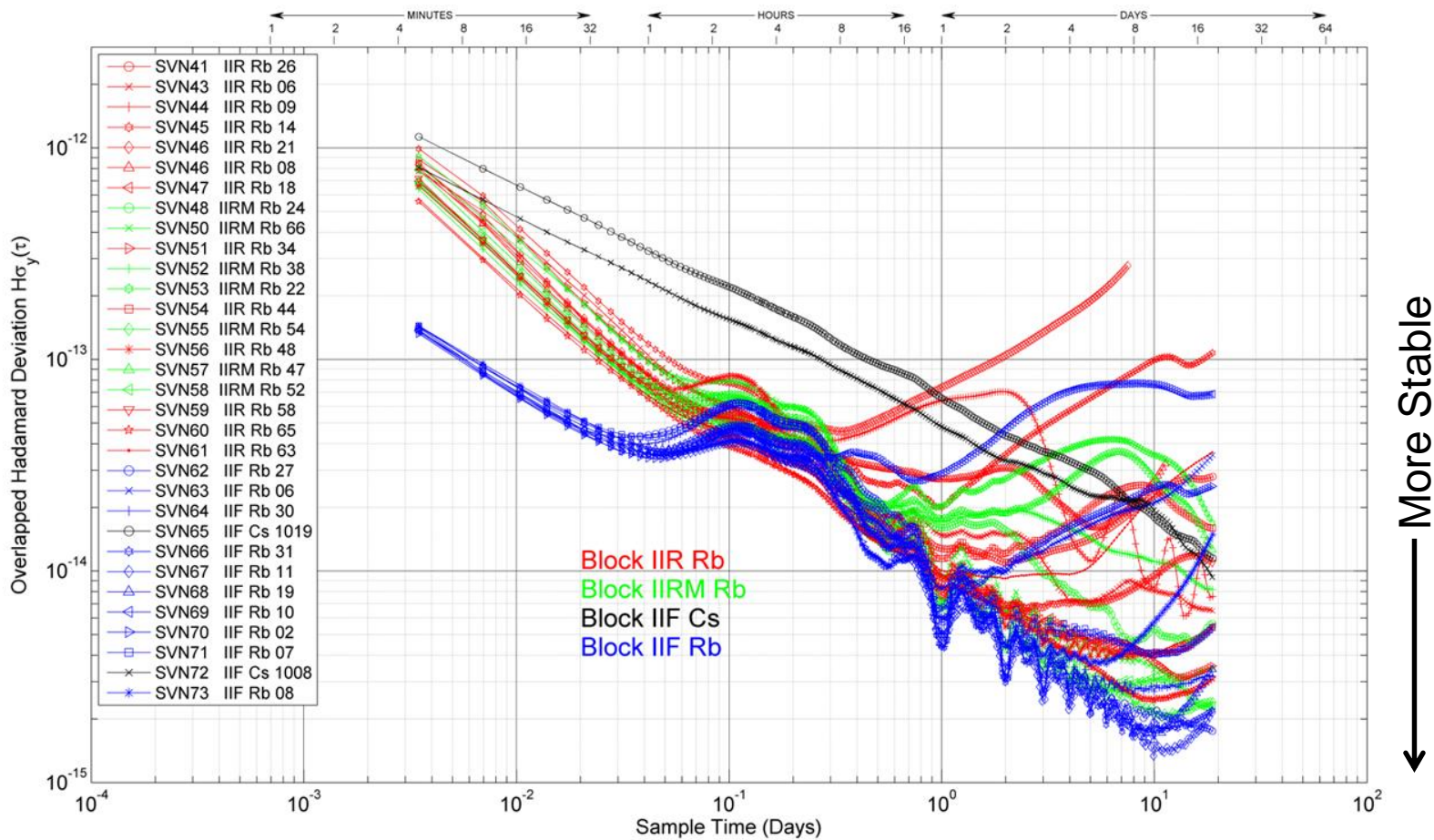
GPS On-Orbit Clock Evaluation & Analysis



Provide Long-Term Performance Analysis of all Operational GPS Satellite and Monitor Station Clocks for the 2nd Space Operations Squadron (2 SOPS) at the GPS Master Control Station (MCS)

- *NRL has analyzed the on-orbit performance of GPS satellite clocks since the beginning of the GPS program*
- *Measurements are collected from a network of 16 ground monitor stations operated by the USAF and NGA*
- *NRL Analysis used by 2SOPS to Tune the OCS Kalman Filter*
 - *Clock estimates computed for all GPS on-orbit and ground clocks*
 - *Reports provided on a quarterly basis*
- *Metrics used in the analyses include:*
 - *Clock Frequency and Drift Performance*
 - *Frequency stability based on the Allan (ADEV) and Hadamard (HDEV) Deviations*
 - *Referenced to UTC(USNO)*
- *Maintain comprehensive on-line database for all satellite and monitor station tracking data*

GPS Satellite Clock Frequency Stability Referenced to UTC(USNO)

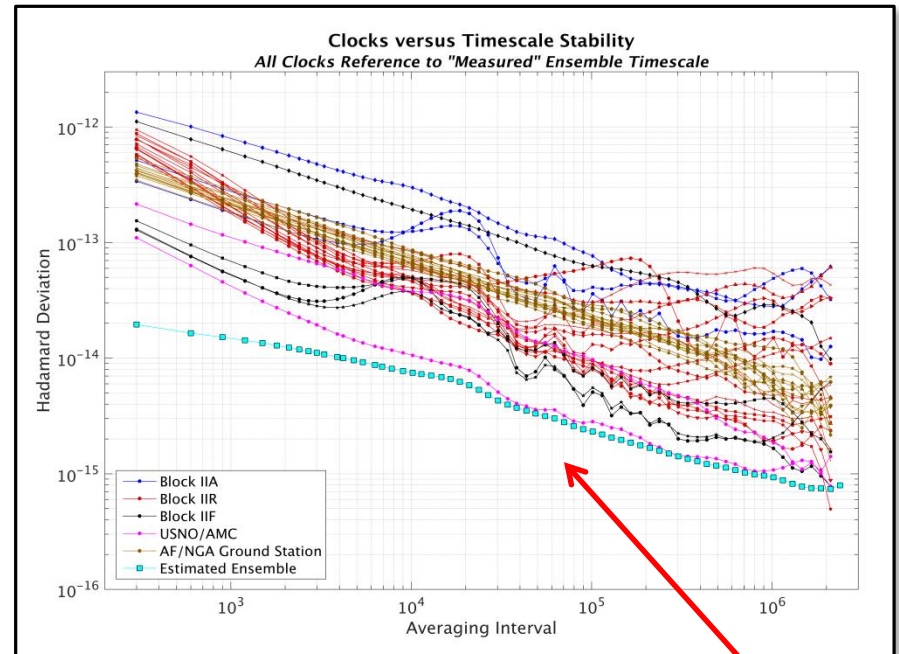


Next Generation “GPS Time” Timescale



Provide Algorithms and Software for Next Generation GPS System Time as part of the GPS OCX Ground Segment Upgrade

- *NRL developing the Algorithms and Software for Generating Next-Generation “GPS Time” Timescale within the OCX Operational Kalman Filter*
- *Utilize on-orbit satellite and monitor station clocks*
- **NRL:** *Supports the Jet Propulsion Lab (JPL) with Timescale Software*
- **JPL:** *Main developers of Real-Time Gypsy-x (RTGx) software for GPS orbit and clock solutions*
- **Harris Corporation:** *Responsible for broader integration of the JPL and NRL software contributions*
- *NRL → JPL → Harris → Raytheon*

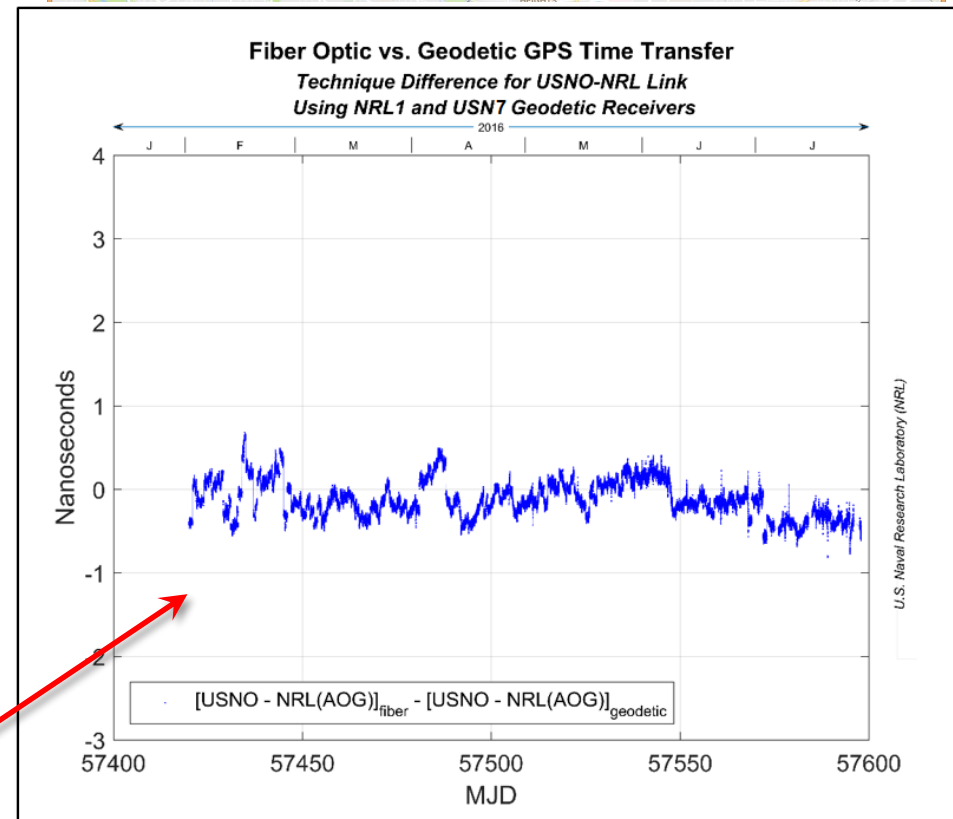
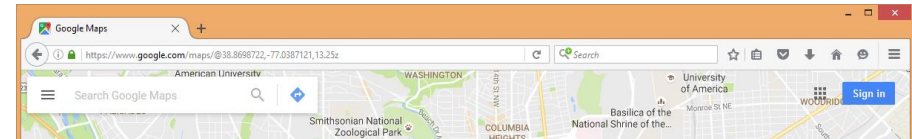


Generating a new robust timekeeping capability for the Next Generation GPS



Laboratory Time Transfer Links

- 11km between NRL and USNO
- Multiple time transfer techniques
 - Geodetic GPS
 - Dedicated Fiber link (USNO-NRL)
 - Ku-Band TWSTT
 - X-Band TWSTT
 - Link-16 (Raytheon BNN)
 - Television (WTTG DTV) Common-View

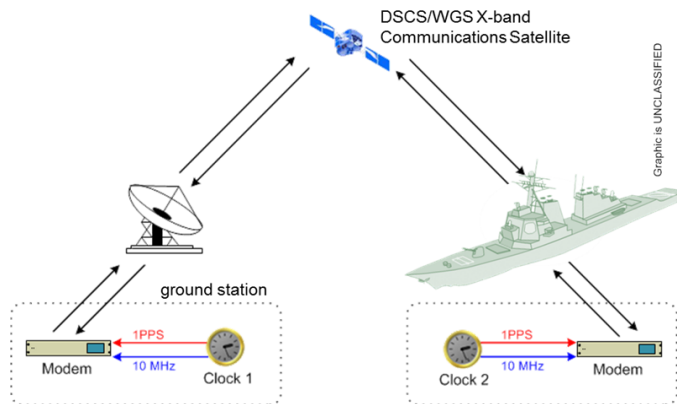


Dedicated USNO-NRL fiber link showing excellent results, RMS = 216 ps versus geodetic GPS



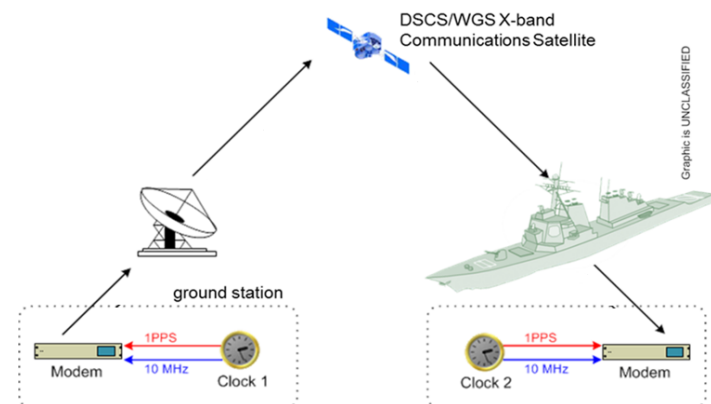
NEXTANT 1.0: Demonstrate Alternate Time Transfer Capability to an At-Sea Platform by Two Way Satellite Time Transfer

- Goal was to demonstrate a GPS independent **nanosecond-level** time transfer or time synchronization capability for the Navy
- Utilized Existing Shipboard Comms Equipment
- Utilized DoD Ground Network for the Demo
- Successfully Demonstrated to USS O’Kane in Summer 2016 (Trident Warrior 16)



OWSTT & NEXTANT 2.0: Develop & Demonstrate a New One Way Satellite Time Transfer Capability to an At-Sea Platform

- Goal to demonstrate a GPS independent passive time transfer capability for the Navy
- Will **not** Be Nanosecond Level (TBD)
- Utilize Existing Shipboard Comms Equipment
- Utilize DoD Ground Network for the Demo
- To Be Demonstrated End of CY 2017





January 29 – February 1, 2018, Hyatt Regency, Reston, Virginia

General Chair – Mr. Ryan Dupuis, Excelitas Technologies

Program Chair – Dr. James Hanssen, USNO

Tutorials Chair – Dr. Michael Coleman, NRL

(Co-located with ION International Technical Meeting)

- *Timing Laboratory Activities and Updates*
- *Time Scales and Algorithms*
- *Advances in PTTI Measurement Techniques*
- *Advances in Ultrastable Microwave and Optical Clocks*
- *Fieldable Atomic Clocks*
- *Advances in Computer Time Transfer: NTP, PTP, and Related Systems*
- *Advances in Geostationary Satellite Time and Frequency Transfer*
- *Advances in GNSS Time Transfer*
- *Advances in Time Transfer via Ground Based Radio Signals*
- *Advances in Optical Time Transfer (free-space and fiber based)*
- *The Role of PTTI in Telecommunications*
- *The Role of PTTI in the Financial Sector*
- *The Role of PTTI in Electric Power Distribution*
- *The Role of PTTI in Improving GNSS Invulnerability, Reliability, and Performance*
- *Next Generation PTTI Applications*
- *Tutorials prior to start of meeting*

Abstract Submissions Due: October 10