



NRL Time & Frequency Activities

Advanced Space PNT Branch
Naval Center for Space Technology

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CGSIC, Timing Subcommittee

16 September 2019



- GPS Space Atomic Clock Technology
- Precise Clock Evaluation Facility
- GPS Clock Extended Life Tests
- GPS On-orbit Clock Analysis
- Next Generation GPS Timescale Support
- Time Transfer Activities
- PTTI 2020



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



Environmental Control

PCEF upgrades

- Environmental chambers
- Active Hydrogen Masers
- Precision Measurement Systems



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
- Validate operation prior to actual flight
- Characterize clock over long term

GPS Life Testing Joint Collaboration

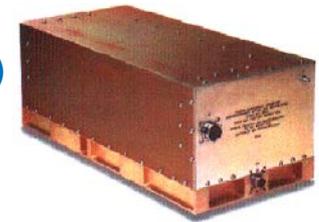
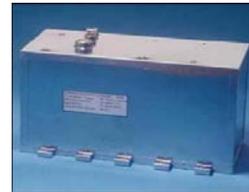
- NRL
- GPS Directorate
- Satellite Manufacturers
- Clock Manufacturers



GPS Space Clock Extended Life Testing



- Series of GPS Clock Extended Life Testing 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
 - Two Block IIF RAFS
 - August 2008
 - Two GPS III RAFS
 - March 2018; April 2019
- Production Units



Additional Atomic Clock Testing



DARPA Atomic Clock with Enhanced Stability (ACES)

- Program exploring the development of next-generation, battery-powered CSAC with 1000x improvement in key performance parameters over existing options
 - Future testing will be conducted at NRL
 - Thermal
 - Vibration
 - Stability Performance

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)

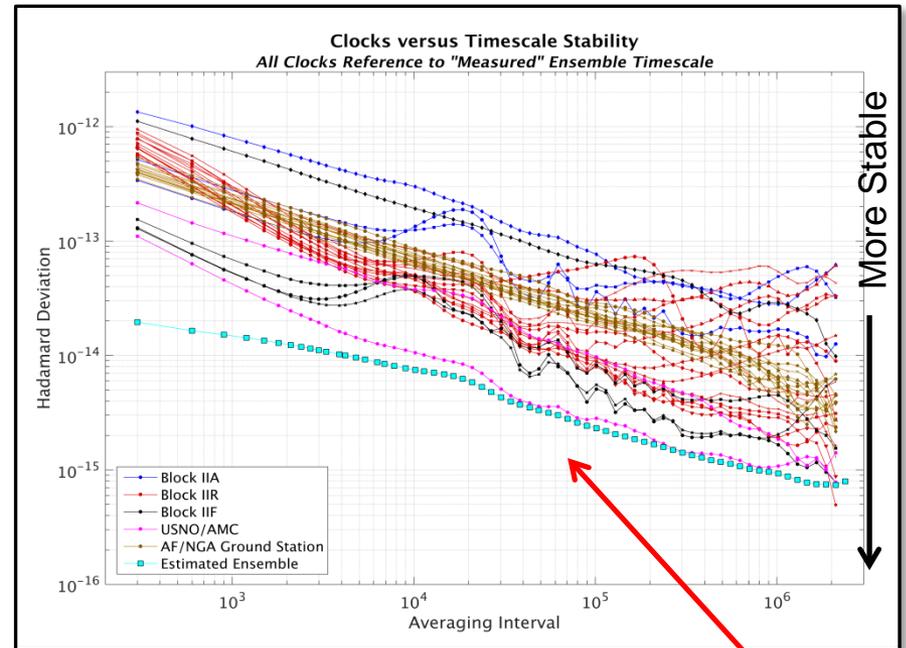
- NRL has analyzed the on-orbit performance of GPS satellite clocks since the beginning of the GPS program
- Measurements are collected from a network of ground monitor stations operated by the USAF and NGA
- NRL Analysis used by 2SOPS to Tune the OCS Kalman Filter
 - Clock estimates computed for all 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

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 has developed the Algorithms and Software for Generating Next-Generation “GPS Time” Timescale within the OCX Operational Kalman Filter
- **NRL:** Supports the Jet Propulsion Lab (JPL) with Timescale Software, called Ensemble Timescale Filter (ETF)
- **JPL:** Main developers of Real-Time Gypsy-x (RTGx) software for GPS orbit and clock solutions
 - NRL utilizes the JPL RTGx Satellite Clock Offsets and generates time, frequency and drift offsets of all clocks relative to a new stable timescale (GPS Time)
- **Harris:** 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

AFRL NTS-3 Program

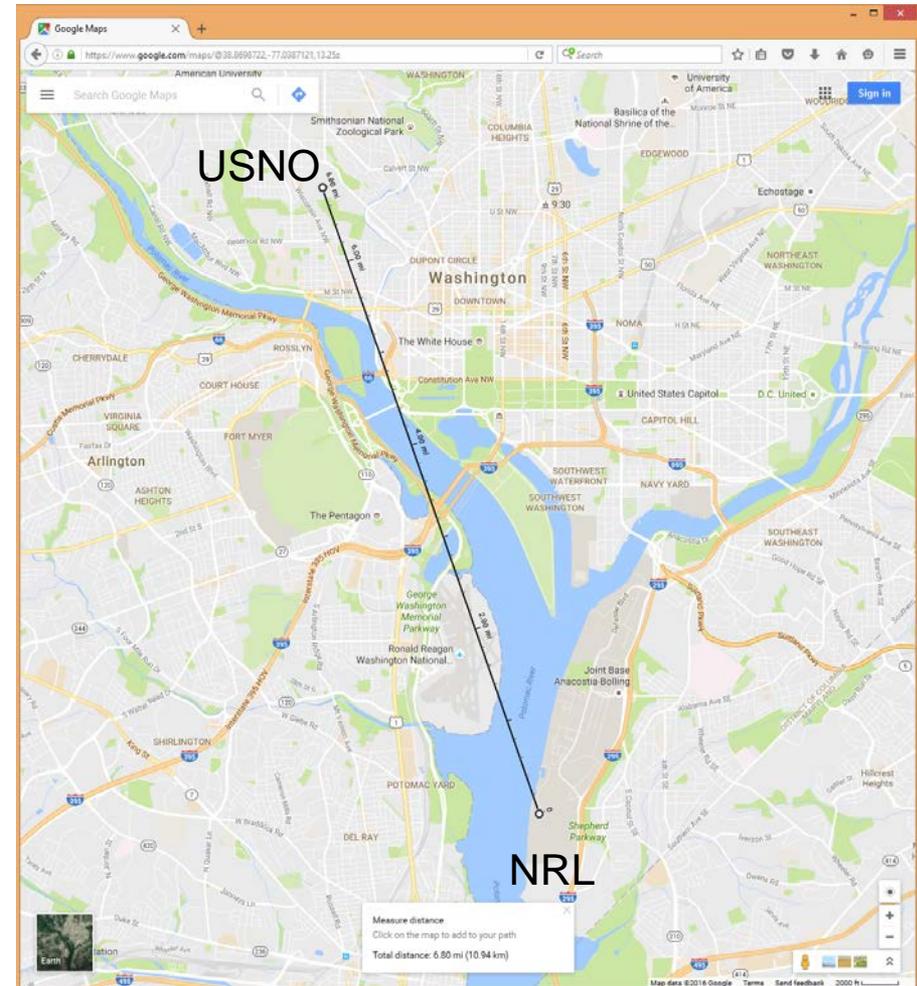


- First experimental PNT spacecraft in over 40 years
- Unique testbed in Geostationary orbit
- Experimentation with multiple integrated advanced technologies and development of new concepts of operation
- NRL will support NTS-3 with ETF timescale software



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)
 - Digital Television (WTTG DTV)
 - Common-View





January 21 – 24, 2020, Hyatt Regency Mission Bay, San Diego, CA

General Chair – Dr. Michael Coleman, NRL

Program Chair – Dr. Jennifer Taylor, USNO

Tutorials Chair – Dr. Marina Gertszov, NRC

(Co-located with ION International Technical Meeting)

PTTI Technical Program Sessions

- Advances in Next Generation Clocks
- Emergent Timing Infrastructure for GNSS Providers (Joint PTTI/ITM Session)
- Laboratory Reports and Activities
- PTTI Applications and Techniques
- Time and Frequency Transfer Beyond GNSS
- Time and Frequency Transfer Using GNSS and RNSS
- Timekeeping in Commercial Applications
- Timescales and Algorithms

PTTI Tutorials Session

(prior to start of meeting January 21)

- Time and Frequency Transfer Over Fiber
- Frequency Combs
- Timescales and UTC Generation
- GNSS and GNSS Time Transfer
- Optical Clocks

Abstract Submissions Due: October 10