NRL Time & Frequency Activities
Advanced Space PNT Branch
Naval Center for Space Technology

Francine M. Vannicola
CGSIC, Timing Subcommittee
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Overview

- 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
NRL Precise Clock Evaluation Facility (PCEF)

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
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
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
**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
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
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
• 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
Precise Time and Time Interval Meeting
PTTI 2020
(www.ion.org/ptti)

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 Gertsvolf, NRC
(Com-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