Report from JPL Frequency Standards Test Laboratory

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Frequency And Timing Advanced Instrument Development Group

JPL is a federally funded research and development center managed for NASA by Caltech. The Jet Propulsion Laboratory is a unique national research facility that carries out robotic space and Earth science missions. JPL developed and manages NASA's Deep Space Network, a worldwide system of antennas that communicates with interplanetary spacecraft.
DSN Frequency & Timing System (FTS)

@ Goldstone, Canberra, Madrid

Integrated Master Clocks

Frequency & Time References:
- Focus on high stability <12 hours
  - transit times of solar system
  - require knowledge of Offsets from UTC

Main Users:
- Radio Science & Astronomy
- Navigation
- Antenna Pointing
- Telemetry

Main System Components
- Atomic Standards & Frequency Distribution
  - Two H-masers plus backup per complex.
- Master Clock & Timing Distribution
- GPS CV receivers for time synchronization
  - (GPS CP receivers for ionosphere corrections)
- Phase Calibration System S,X band
- Performance Measurements
  - Time Analyzer
  - Frequency Stability Analyzer

22 antennas on 3 sites,
- Mojave Desert, California
- Madrid, Spain
- Canberra, Australia

(Each site with distances up to 30 km)

9/24/2018, CGSIC Timing Subcommittee, ION-GNSS+ 2018
DSN Frequency & Timing System (FTS)
Frequency Standards Test Lab @ JPL
State-of-Art Clock Technologies and Characterization

Stability Measurements

Environmental Tests

GPS Antennas

Atomic Standards

DSN Clocks

Ultra-Stable Hg+ Clocks (LITS-10-12)
(NASA, DOD, ESA, Commercial)

Low Noise Oscillators

T-Hz Ultra-stable Lasers

Optical Frequency Comb

H-Masers
Distributed Frequency & Timing within a DSCC
Goldstone, California

Central Control Room
- Atomic standards
- Master Clock
- GPS (All-in View)

Antennas = 9
Number of timing users ~ 100
Maximum distance ~ 30 km

(Unless indicated, standard telecom fiber cables are used)
GPS utilization and fiber-link timing in FTS-DSN/FSTL

- Central Frequency standards & Clock calibrated to UTC(k)
  - All-in/Common View Comparison (primary)
  - Steering to UTC(k)
    - Manually change frequency (operational)
    - Manually input linear drift rate (in test)
    - Automatic linear drift rate removal (in test)
  - Carrier-Phase+PPP Comparison (in test)
- Advanced Optical Oscillator (in FSTL)
  - 1Hz commercial ultra stable laser as optical clean up oscillator.
  - Optical frequency comb convert to RF
  - Low drift rate material (operational) study
  - Steering to UTC(k) via CP+PPP using JPL’s 30s and 300s GIPSY product (Future)

- Fiber Freq Dissemination (within 1 local complex)
  - RF over optical carrier (primary)
  - research
- Fiber Time Dissemination (within 1 local complex)
  - Master Clock and TCTs
  - 30ps resolution

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NASA/JPL Mercury Trapped Ion Clocks

- **Long life, continuous, high stability operation**

- **Mercury Linear Ion Clock Paths and Applications:**
  1. **Ultra-Stable Performance:** UTC timescales, ESA ACES mission
     “Compensated” Multi-pole ion clock technologies:
        - $10^{-16}$ at 1 to 10 days, drift $\leq 10^{-17}$/day.
        - $10^{-15}$ short term stability (~1 sec) via super LO’s.
  
  2. **Space:** DSAC Technology Demonstration Mission (TRL 5-7),
     - Quartz USO based LO’s.
     - NASA Deep Space: ~ 20W and 5 kg goal
     - GNSS (MAFS) : ~ $1 \times 10^{-13}$ short term, $10^{-15}$ at 1 to 10 D
     - Science and other apps….
  
  3. **Miniature, low power:** DARPA ACES program
     - 30 cm$^3$ scale ion trap
     - Miniature UV light sources and LO’s
Various Hg+ Standard Implementations with differing Local Oscillators

Space Clock Stability < 1 ns at 10 days ($10^{-15}$)

Time uncertainty (ns)

Autonomous time interval of operation (sec)

(No drift removal)

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GPS Disciplined High Performance Local Oscillator for Deep Space Navigation and Science

- H-Maser steered to UTC(k) via All-in-View GPS comparison
  - Manual Loop (Human input linear drift removal in Microsemi H-Maser), approaching operational in DSN
  - Auto Loop (test in FSTL)
- H-Maser steered to UTC(k) via GPS Carrier-Phase+PPP comparison
  - Auto Loop, architecture under development in FSTL.
- Photonic Local Oscillator (PLO), i.e. 1Hz-ultra stable laser, steered to remote clocks
  - With optical frequency comb,
  - linear drift removal hardware development
  - calibration of drift (all in FSTL)
- Low drift operational PLO study,
- simplified operational, long life frequency comb study.

Goal/Challenge:
1. Operational Lower drift?
2. Close GPS calibration fast
Frequency & Timing Advanced Development Group (335E)

Technical Group Supervisor: Dr. Robert Tjoelker


April 2012

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Recent Frequency and Timing Student Interns

Jacob Harburg (16,17)  
Cornell U. (Jr. and Sr.)  
Now at MIT Lincoln

- NI-FPGA based Atomic clock controller (JPL new technology report, i.e. NTR)
- Thermal and mechanical simulation of ultra-stable Fabry-Perot cavity

Michael Toennies (17)  
U. Of Michigan (Sr.)  
Now at Boeing

- Low SWaP-C Ka-band Synthesizer (IFCS 2018, conference paper)
- Ultra-low power Atomic clock controller with single IC. (JPL NTR)
- Real-Time Frequency Analyzer User Interface (JPL NTR)

Joseph Zuckerman (17)  
Harvard U. (Jr.)

- Low power high voltage electronics (DARPA project)
- Low power ion trapping electronics. (DARPA project)
- Low power field emitter electronics. (DARPA project)

Calvin Lin (17)  
Stanford U.(Jr.)

- Ka-band Comb generation electronics (DSN project)
- Amplitude-Phase Noise Instr. control software (JPL NTR)

Andrei Isichenko (18)  
Cornell U.(G.)

- Mercury clock DUV optical source monitoring system (TBD)
- 1310nm Piezo/Stage based fiber stabilized distribution with CW and pulsed laser (TBD)

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Thank you