Report on GPS activities

2017

Stefania Römisch

57th CGSIC Meeting – Timing Subcommittee
OUTLINE

GPS Time Transfer for Coordinated Universal Time (UTC)

Time Dissemination and Services via GPS

Advancing GPS and its applications
Coordinated Universal Time (UTC) is the official world time scale.

UTC is computed by the International Bureau of Weights and Measures (BIPM) in France.

- UTC(NIST) is the local realization of UTC. The UTC(NIST) time scale consists of an ensemble of hydrogen masers and cesium clocks.

- NIST maintains and operates UTC(NIST) and the U. S. Primary Frequency Standards, cesium fountain devices F1 and F2.

- The time transfer links between NIST and BIPM are based on
  - Two-Way Satellite Time and Frequency Transfer (TWSTFT) measurements utilizing geostationary satellites.
  - GPS common-view measurements.
UTC

GPS Common-view

Two-Way Satellite Time and Frequency Transfer

57th CGSIC Meeting – Timing Subcommittee
The Physikalisch-Technische Bundesanstalt is the pivot point for UTC

**GPS:** common-view

**TWSTFT:** Direct intercontinental satellite link

---

57th CGSIC Meeting – Timing Subcommittee
UTC

**USNO** shares with **NIST** the responsibility of maintaining accurate realizations of UTC in the US.

**GPS**: common-view

**TWSTFT**: Indirect satellite link going through PTB

**SUV**: TWSTFT mobile station owned by USNO, periodically driven to NIST in Boulder, CO

**GPS with SUV cal**: common-view calibration

---

*Graph showing time difference vs. Modified Julian Date [days]*

- **GPS**
- **SUV cal**
- **GPS with SUV**
- **TWSTFT via PTB**
BIPM issued updated Calibration Guidelines for all laboratories contributing to UTC

NIST (Boulder, CO, USA)
CNM (Queretaro, MEXICO)
CNMP (PANAMA)
INTI (Buenos Aires, ARGENTINA)
INXE (Rio de Janeiro, BRAZIL)
NRC (Ottawa, CANADA)
ONRJ (Rio de Janeiro, BRAZIL)
INM (Bogota, COLOMBIA)
INCP (Lima, PERU)

USNO (Washington, DC, USA)
APL (Laurel, MD, USA)
IGNA (Buenos Aires, ARGENTINA)
NRL (Washington, DC, USA)
ONBA (Buenos Aires, ARGENTINA)
G2 CALIBRATION CAMPAIGNS

Trip 1:
- ✔ NRC (Ottawa, CANADA)

Trip 2:
- ✔ CNM (Queretaro, MEXICO)
- ✔ CNMP (PANAMA)

Trip 3:
- ✔ NRC (Ottawa, CANADA)

Trips 4-5:
- ✔ INTI (Buenos Aires, ARGENTINA)
- ✔ INXE (Rio de Janeiro, BRAZIL)
- ✔ ONRJ (Rio de Janeiro, BRAZIL)

EARLY 2018

UTC
NIST provides common-view GPS measurement systems to its remote customers, allowing them to compare their clocks to UTC(NIST) by using the GPS.

The common-view data is processed in real-time and shows the time or frequency difference between UTC(NIST) and the customer’s clock.

- **FMAS**: reports frequency uncertainty to the customer
- **TMAS**: reports time uncertainty to the customer
- **NISTDO**: locks the customer’s clock (rubidium or cesium) to the UTC(NIST)

Customers can then show traceability to the International System (SI) of units through NIST.
GPS Common-view: TMAS and FMAS

UTC(NIST) – GPS Measurement

GPS Receiver

Time Interval Counter

Internet Server

GPS Satellites

Remote Clock

UTC(NIST) – GPS Measurement

Time Interval Counter

Remote Clock Measurement

57th CGSIC Meeting – Timing Subcommittee
DISSEMINATION

GPS Common-view: NISTDO

uncertainty is \(~5 \times 10^{-14}\) at \(\tau = 1\) day for frequency, \(~10\) ns for time, \(k = 2\)
Map of Common-View GPS Systems Maintained by NIST
(78 total systems deployed, 53 at customer sites and 25 in SIM Time Network)
A NISTDO is the station clock at WWVH in Kauai

- The Boulder-Kauai baseline is long (5324 km) and Internet access at WWVH is through a satellite and is not always available.
- Even so, the average time offset is near 0 and peak-to-peak time variations are usually within ±10 ns of UTC(NIST) in Boulder.

57th CGSIC Meeting – Timing Subcommittee
NIST FMAS/TMAS Customers by Sector

- Electronics and Instrument Manufacturers: 31%
- Financial Markets / Stock Exchanges: 15%
- U. S. Military: 14%
- Aerospace: 14%
- Defense Contractors: 10%
- U. S. Government: 8%
- Private Calibration Laboratories: 4%
- Telecommunications: 2%
- Nuclear Energy: 2%

57th CGSIC Meeting – Timing Subcommittee
International GNSS Service (IGS) Tracking Network

Receiver NIST is an active station [https://igscb.jpl.nasa.gov/network/site/nist.html](https://igscb.jpl.nasa.gov/network/site/nist.html)

NIST data archives:

- One-way GPS data vs UTC(NIST) [http://www.nist.gov/pml/div688/grp40/gpsarchive.cfm](http://www.nist.gov/pml/div688/grp40/gpsarchive.cfm)
- Common-view UTC(USNO)-UTC(NIST) [http://www.nist.gov/pml/div688/grp50/nistusno.cfm](http://www.nist.gov/pml/div688/grp50/nistusno.cfm)
In 2014, the **Revised RINEX-Shift (RRS)** technique was proposed at NIST, to solve the day-boundary discontinuity problem for CP (typically, ~ 200 ps) [1]. However, the latency of RRS is more than 5 days.

**RRS_rapid** reduces the latency to ~ 3 days.

An example: the figure shows the behavior of UTC(NIST) with respect to UTC(PTB) and UTC(USNO), published on **Apr. 19, 2017**. There is no day-boundary discontinuity.

NIST is involved in the Air Force Research Lab program to support the Navigation Technology Satellite 3 (NTS-3), as well as possible future clocks for GPS.

The current clock technology is unlikely to be significantly improved.

- Terrestrial measured
- in space
- NTS-3 on-orbit goal

17”
13kg < 30W
Volume ~ 1.3 * legacy KernCo
GPS vulnerability to adjacent-band interference

In-Band (IB) max transmitted power
Out-Of-Band (OOB) masks

GPS vulnerability to adjacent-band interference

At each step:
- Receiver cold start
- 15 min GPS only
- 20 min LTE or baseline
- No changes in setup
- Same constellation

High-precision positioning receivers:
- Leica GR50
- Novatel FlexPak 628
- Novatel ProPak 6
- Trimble NetR9
GPS vulnerability to adjacent-band interference

Best Case  UL2  DUT9

\[ \Delta t = \delta t - \delta t_{LTE} \]

\[ \delta t = \text{REF-GPS} \]

Typical noise in the code is \( \sim 0.5 \) ns

\[ \Delta t > 10 \text{ ns} \] not shown: receiver has lost lock.
EXPLORING NEW IDEAS

Data processing to reduce time transfer uncertainties

• Doppler-aided navigation: including Doppler information from RINEX files
• Development of filtering techniques to combine carrier-phase data and Doppler information

Atomic Clock Ensemble in Space (ACES) mission support

Development of Precise Point Positioning (PPP) algorithm to accurately determine the position of the International Space Station (ISS) to allow for the best frequency transfer between ground stations and ISS.

Tests of General Relativity

Noise estimation and analysis of pseudorange data to better understand the acceleration noise of spacecrafts used in various test missions

Studying the effect of lunar and solar tidal perturbations on the frequency of GPS clock

Prediction and eventual verification with cool-atom clocks on orbit

57th CGSIC Meeting – Timing Subcommittee
PEOPLE

Atomic Standards
S. Römisch – Leader
T. Parker
B. Patla
J. Savory
V. Zhang

Time and Frequency Services
J. Lowe – Leader
M. Deutch, WWV/WWVB
M. Lombardi
A. Novick
D. Okayama, WWVH

Primary Frequency Standards
S. Jefferts – Leader
Y. Dudin
N. Ashby
J. Shirley

Network Synchronization
J. Levine – Leader
J. Yao

THANK YOU!

57th CGSIC Meeting – Timing Subcommittee