Timing Criticality & GPS 1024 Week Rollover

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Today GPS provides Timing to the World ?

Why is it important ?

Precise Timing Applications

Communications

Financial

Power Grid

Scientific

GPS/USNO Provided Timing Service are Critical to the Modern World's Infrastructure

GPS Provides Time to World

- Many do not fully understands the criticality of GPS provided timing to the world.
- The GPS timing services have been in use by industry for more than 25 years providing an exceptional quality of service.
- GPS timing services provides the global standard for access to precise time supporting:
  - Critical infrastructure
    - Telecommunication,
    - Power Grid,
    - Banking, Financial transactions (Time Stamps),
    - and scientific applications.

Telecommunication

- ***Telecommunication Industry makes wide use of GPS provided timing supporting a variety of applications***

Precise Time Signals

- ***LTE, CDMA and other Cell Phone technology uses precise timing from GPS (1 microsecond)***
- ***Some public key technology require second level of timing synchronization***
- ***Email, database, data ordering, event logging all require time of day information (minutes – seconds)***

Stratum 1, 1E-11 Frequency Accuracy

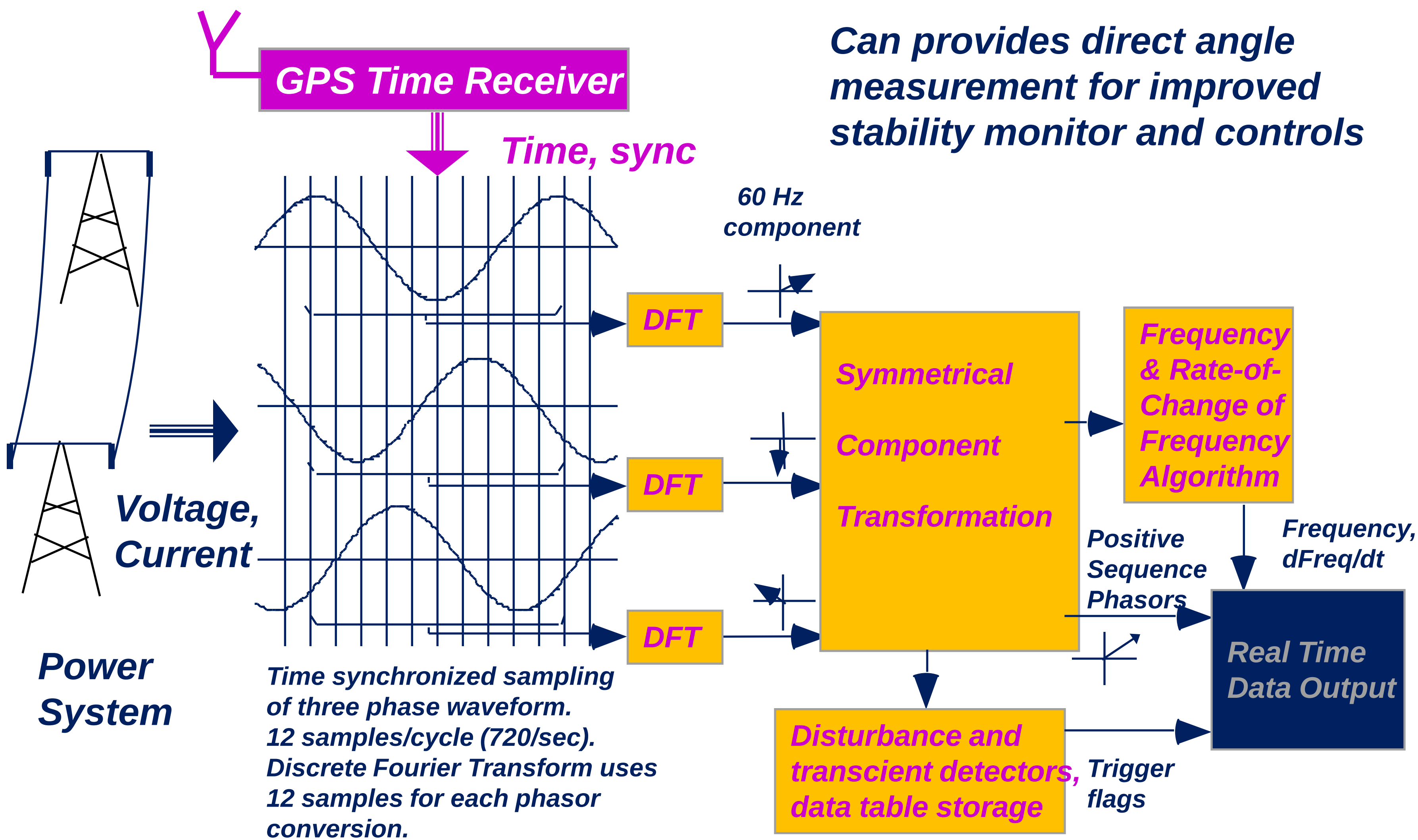
Provide networks accurate frequency reference

- ***BITS clock distribution of signals***

Power Grid

- *The world power grid requires synchronization of the alternating current (50/60 Hz) which historically has been accomplished by adjusting the phase at local power generating plants to match the overall power grids phase.*
- *Small phase inaccuracy will reduce efficiencies and larger errors may result in damage to equipment and power outages.*
- *GPS based Phasor synchronization equipment is starting to be installed globally resulting in:*
  - *Higher efficiency in power transmission*
  - *Fewer black outs*
  - *Better fault isolation*
- *Power line fault isolation is often accomplished using GPS timing to measure the distance to a break in a power line, which greatly reduces the time to find the break and to restore service*

Syncro-Phasor Measurement



Banking and other Financial Transactions

- *With billions of financial transactions per day and the emergence of fully automated computer trading, precisely timing of trades are critical.*

- *An inaccurate time stamps could result in unfair advantage being gained and loss of revenue.*

- *Today time stamp traceability requirements are at the single second level, and within a few years millisecond timing will be required to support high speed computer trading.*

History of Precise Time Dissemination

- *HF Time (millisecond) Navy Time broadcast started in 1902, today NIST operates WWV, WWVB*
- *GOES (50 microsecond) 1972-2004*
- *Transit (10-25 microsecond) 1964 – 1996*
- *VHF/Omega (microsecond/day) Off Sept 1997*
- *Loran-C (microsecond) DoD end use mid-1990’s with transfer to local governments and full system shutdown in 2010*
- *GPS (10-100 nanosecond) 1970’s - Today*
- *TWSTT (1-5 nanosecond) USNO TWSTT program starts in 1962 with Launch of Telestar 1, to Today*
- *NTP (millisecond over IP networks), PTP future*

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GPS is Great, but what if GPS is not available ? Are there Alternatives ?

Other GNSS system

- ***There are presently three other GNSS in various stages of development that can be used as PTTI reference***
  - ***GLONASS (Russia Federation)***
  - ***BeiDou (China)***
  - ***Galileo (European Union)***
- ***But, they are largely the same as GPS with same weakness of low signal strength broadcasting on same or nearly the same frequency.***

Hold Over Clocks

- ***Commercial Cesium clocks provide stratum 1, frequency accuracy directly without external referencing.***
- ***Rubidium clocks can provide microsecond holdover for up to one week.***
- ***Chip scale atomic clocks are presently available that enable microsecond timing level hold over for many hours with relatively low SWAP.***
- ***Other R&D efforts are being conducted to produce much better clock performance also with reduced SWAP.***
- ***Several programs may emerge over the coming year that might greatly enhance holdover times, but market is unclear.***
  - ***Advanced clocks may replace the 5071A Cesium and MASER***
  - ***Several groups are investigating optical clocks***

Few Alternative to GPS Provided Timing

- Ground based high power transmitters like Loran/E-Loran could support sub-microsecond level timing across the US,
- Use of existing communication infrastructure
  - DME re-engineered to support navigation and timing
  - NTP/IEEE 1588 (PTP)
  - HDTV transmitted signals other broadcast signals
  - Optical fiber networks
  - Cell System provide E-911 navigation
- WAAS with MT-12 and directional antenna

Without GPS

- *Alternative methods of synchronization are needed and/or;*

- *a much Improved fly wheel clock can provide robust hold over but does not provide initial synchronization.*

- *In my opinion, a layered approach is best, GPS/GNSS plus alternate time transfer technologies engineered into a blended solution managing local fly wheel clocks. All calibrated to the unifying Master Clock.*

NAVAL METEOROLOGY AND OCEANOGRAPHY COMMAND

GPS Timing Service Performance and GPS Week Rollover

GPS Timekeeping Function

Navigation Service

- **Navigation Timekeeping:**
  GPS Time is critical for navigation mission, needed for satellite clock synchronization determination/ prediction and internal satellite clock synchronization not intended for timing applications.

- **UTC Timekeeping:**
  not critical for navigation, but needed to provide UTC timing services (time dissemination) to support communication systems, banking, power grid management, etc…

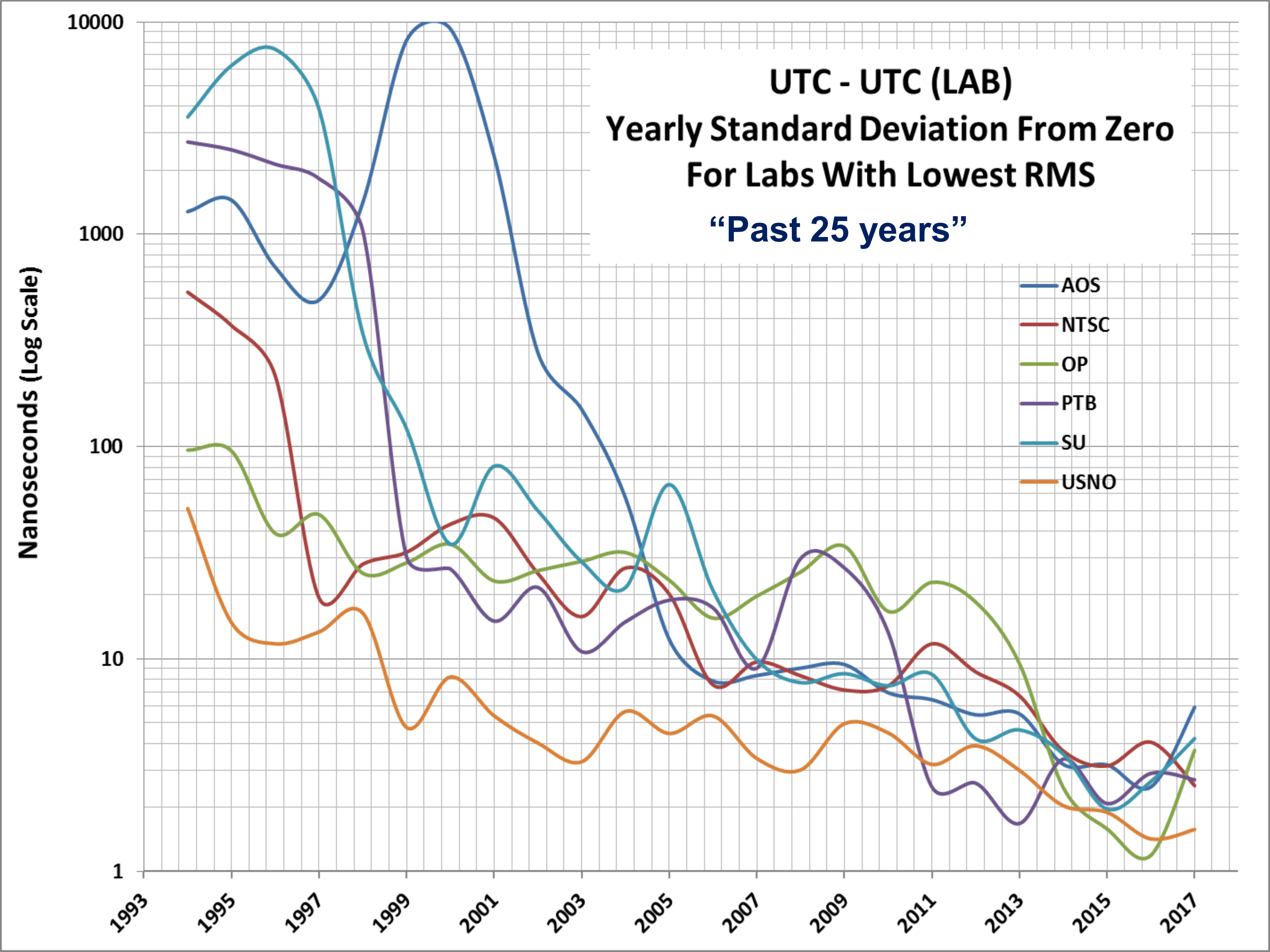
Timing Service

UTC Time from GPS

- *The GPS Internal Navigation Time Scale "GPS Time" is formed by creating a virtual "paper clock" through the weighted average of most GPS satellite and ground station clocks. GPS Time is slowly adjusted to maintain alignment with UTC(USNO) modulo leap second offsets with a time constant of several days. GPS time is used as the reference for the GPS satellite clock correction message that is critical for user navigation solution. Each nanosecond of relative satellite clock synchronization error can add one foot of ranging error (1 ns = 1 foot).*

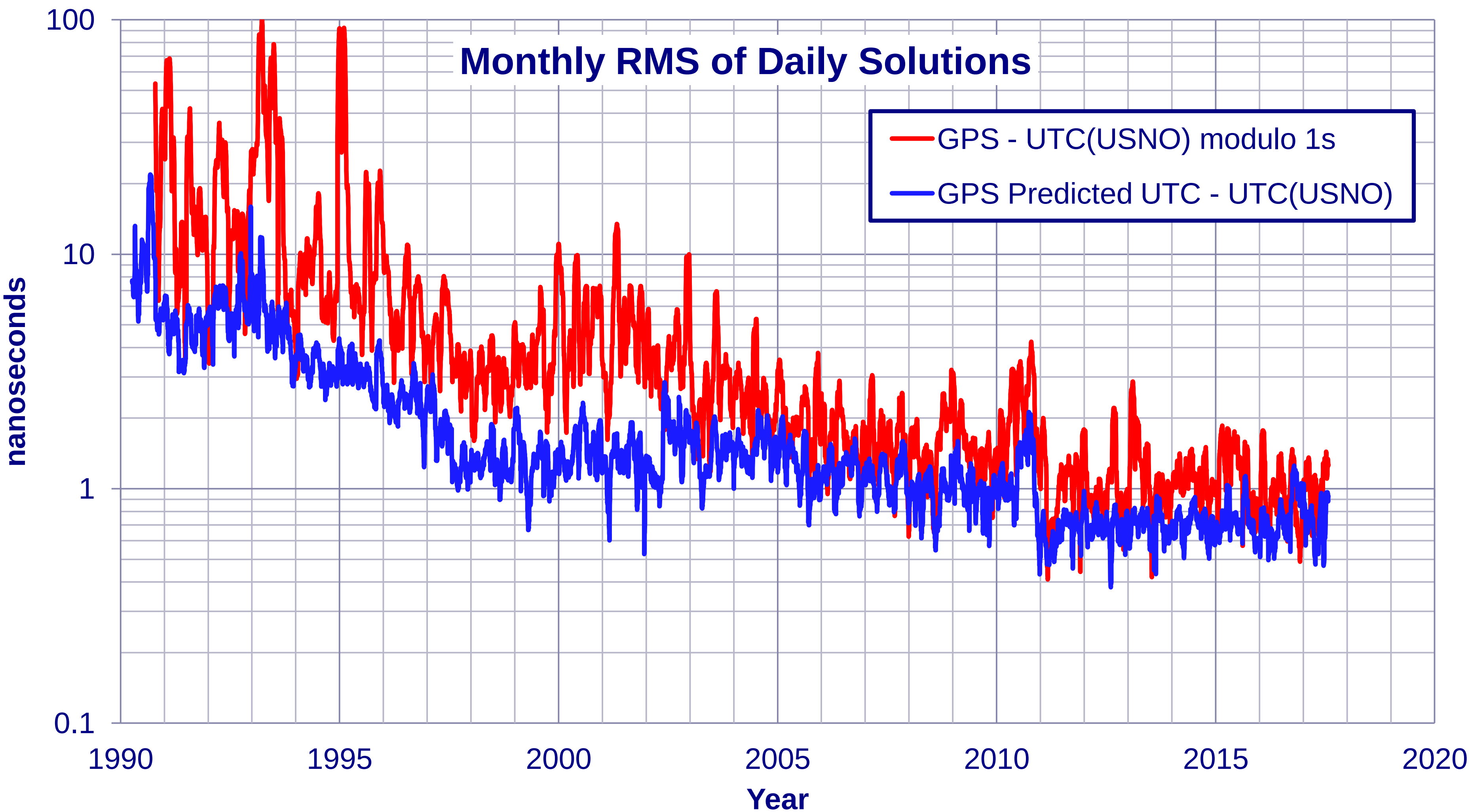
- *The GPS Timing receiver applies the UTC corrections message contained in the GPS sub-frame 4, page 18, to produce UTC time traceable to UTC(USNO). This allows the GPS timing user access to the international accepted legal definition of UTC time needed to support many applications. Modernized CNAV and MNAV navigation messages have improved versions of the UTC correction (MT-33). (> 2 ns since 1997)*

NOTE: The timing calibration bias of the GPS internal navigation time scale is physically established at the United States Naval Observatory (USNO). USNO is responsible for measuring and maintaining the calibration of both the GPS internal navigation time scale and the UTC time products produced by GPS.



UTC - UTC (LAB)
Yearly Standard Deviation From Zero
For Labs With Lowest RMS
“Past 25 years”
Nanoseconds (Log Scale)
10000
1000
100
10
1
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
AOS
NTSC
OP
PTB
SU
USNO

27 Years of GPS Timing Stability



GPS Week Rollover

- GPS Time as defined in the legacy GPS navigation message (ICD-200), uses 10 bits to count GPS Week Numbers. This representation can only cover a finite period of 1024 weeks (19.7 year epoch).
- GPS Time started on Jan 6, 1980
- The first GPS Time Epoch ended on Aug 21/22 1999.
- GPS Time is presently in its second Epoch which will end on April 6, 2019
- It’s up to the user receiver to resolve this week number ambiguity
- Newer receivers fully compliant with GPS ICD should handle this event OK
- In the Future the Modernized GPS Navigation (CNAV and MNAV) message contains a 13-bit representation of the GPS week number, which for all practical purposes solves this ambiguity

What could happen

- UTC timing displayed and/or time tags of receiver data containing PNT information could jump by 19.7 years, resulting in system failures
- Any month/year conversion could also fail
- Navigation solution should be OK since GPS time is internally self consistent, but associated time tags could be incorrect thus corrupting navigation data at the system level
- And the failure is not limited to April 6/7 2019
- A common fix for week number ambiguity was to hard code new pivot date, which shifts event to unknown date/time in future
  - December 2014, older legacy USNO monitor receiver failed
  - Feb 14, 2016 Endrun technology receivers using a Trimble GPS engine failed
  - Aug 14, 2016 Motorola Oncore UT+ older firmware failed
  - July 22, 2017 older Novatel GPS engine failed, notice was posted in Spring 2017 to upgrade firmware, but many did not check

Does your receiver have a problem with GPS Week Roll Over

- Most newer receivers are likely going to be OK if ICD-200 was followed
- Older receiver may be problematic
- “Trust but Verify” consult you manufacture
- Conduct testing using GPS simulator