GPS Timekeeping

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Two GPS Timekeeping Functions

1. ## Navigation
   - orbit determination/prediction
   - internal satellite clock synchronization
   - not intended for timing applications.

2. Metrological
   - provides traceability to UTC
   - support communication systems, banking, power grid management, etc...

GPS Time Products

- **GPS System Time**

  - Internal navigation time scale.

  - Typically the internal navigation system time is only used as part of the navigation solution and is not considered a standard time product.

- **UTC Time** is obtained from GPS by subtracting an integral number of seconds and applying the fine UTC correction information contained in the broadcast navigation data.

Why do GNSS need clocks in space?

- Accuracy depends on precise knowledge of the timing differences between each GNSS satellite and its position in space
  - 1 ns is ~one foot (1/3 meter)

- GPS clock errors grow between satellite updates
  - Currently each GPS satellite is updated at least once per day resulting in errors of less than a few meters

- Better clocks combined with more rapid clock corrections could reduce future GPS system errors to a few decimeters
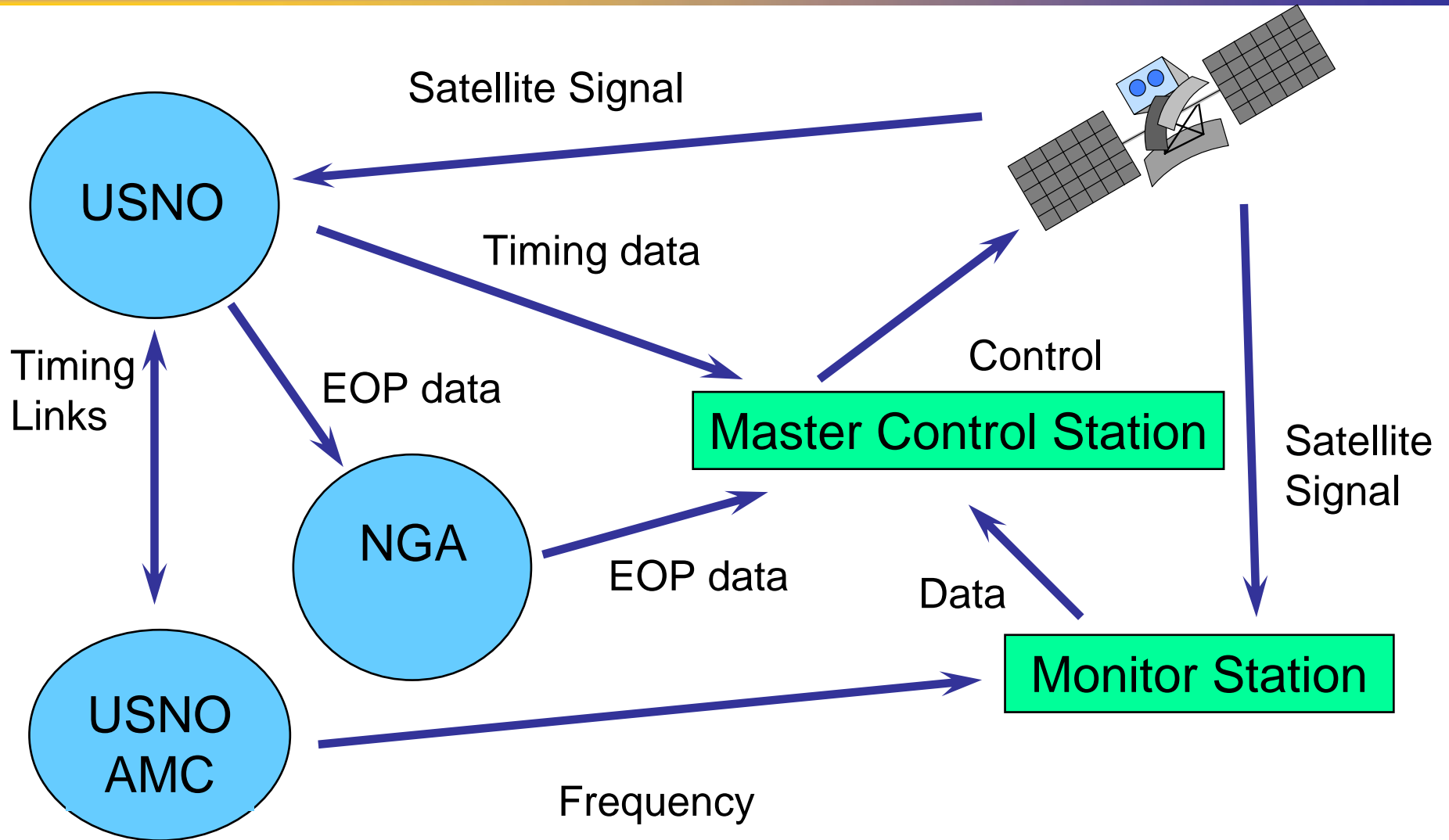
Steering GPS Time

- USNO continuously monitors GPS satellites to provide the GPS Master Control Station with observed differences between GPS Time and UTC(USNO)

- The Master Control Station Kalman Filter (MCSKF) generates its clock solutions using data from system clocks and steers to minimize UTC(USNO)-GPS

- The corrections to create both GPS Time and GPS's delivered prediction of UTC(USNO) are broadcast as part of the GPS navigation message which is applied within a users GPS receiver in a process that is transparent to the user.

USNO Contribution to GPS

Satellite Signal

USNO

Timing data

Timing Links

EOP data

Control

Master Control Station

Satellite Signal

NGA

EOP data

Data
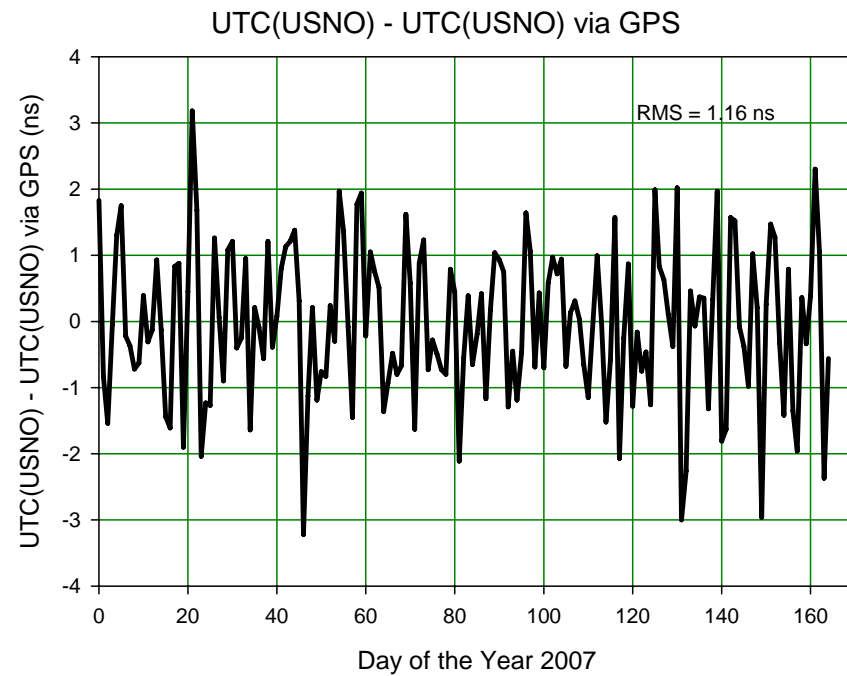
USNO AMC
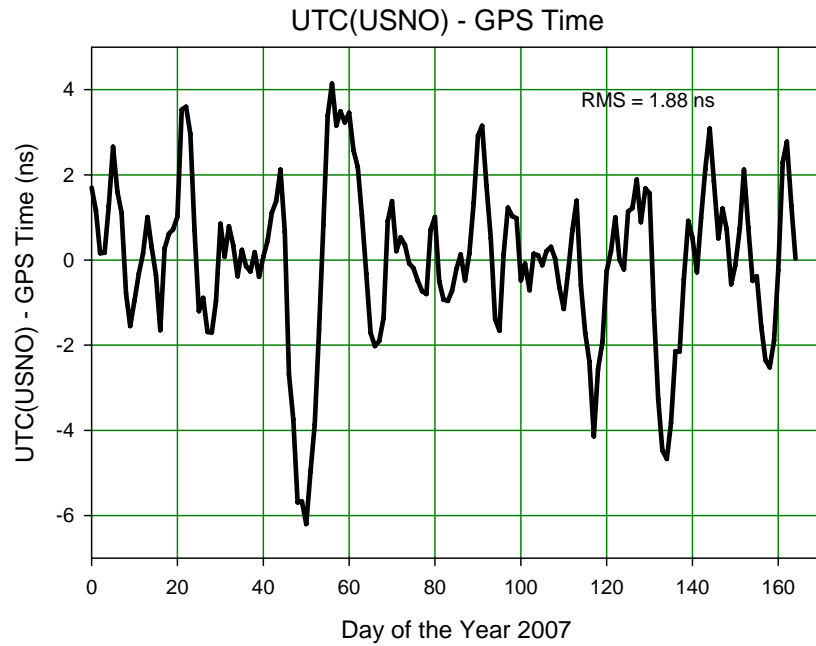
Monitor Station

Frequency

UTC/TAI Timing

- The International Bureau of Weights and Measures (BIPM) coordinates UTC/TAI timing through monthly reports (Circular T) which reports the timing error of contributing timing laboratories over the previous month relative to the UTC/TAI paper clock produced by the BIPM

- Contributing timing laboratories (like USNO) produce a local real time realization of UTC by steering its local realization of UTC/TAI time with a time constant of several months

- GPS Time is then steered to UTC(USNO) with a time constant of approximately one week

- The fine UTC correction broadcast by GPS is updated daily and has an effective time constant of only a few days.
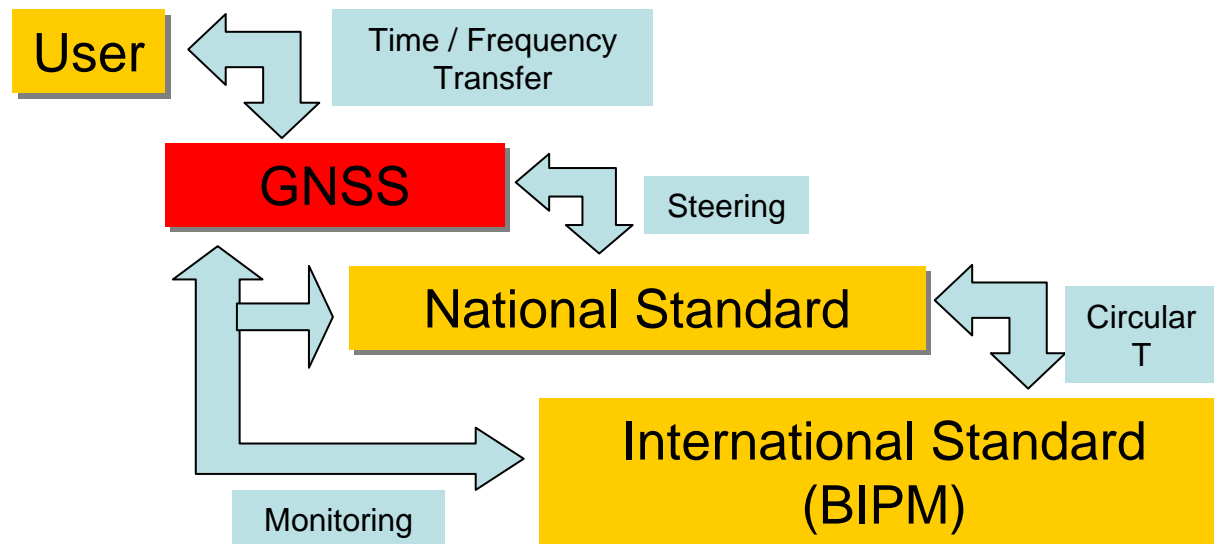
GPS Timing Products in 2007

UTC(USNO) - GPS Time

RMS = 1.88 ns

UTC(USNO) - GPS Time (ns)

Day of the Year 2007

UTC(USNO) - UTC(USNO) via GPS

RMS = 1.16 ns

UTC(USNO) - UTC(USNO) via GPS (ns)

Day of the Year 2007

Traceability

- International Organization for Standardization (ISO) *International Vocabulary of Basic and General Terms in Metrology*, traceability is defined as:

  The property of a result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties.

- The GPS delivered UTC timing service is directly traceable to UTC(USNO) via BIPM Circular T.

- Philosophy is that only a user should decide traceability issues because only that user knows the specifics of their system

User → Time / Frequency Transfer → GNSS

GNSS ← Steering ← National Standard

National Standard ← Circular T ← International Standard (BIPM)

Monitoring → International Standard (BIPM)

Summary

- GPS provides the world a fully traceable UTC timing service
  - Supports communication systems (Cell Phone, telephone, etc…)
  - Power Grid (fault location, phase synchronization, etc…)
  - Banking/Financial transactions

- The GPS UTC Timing service is fully traceable to UTC
  - traceable through UTC(USNO)
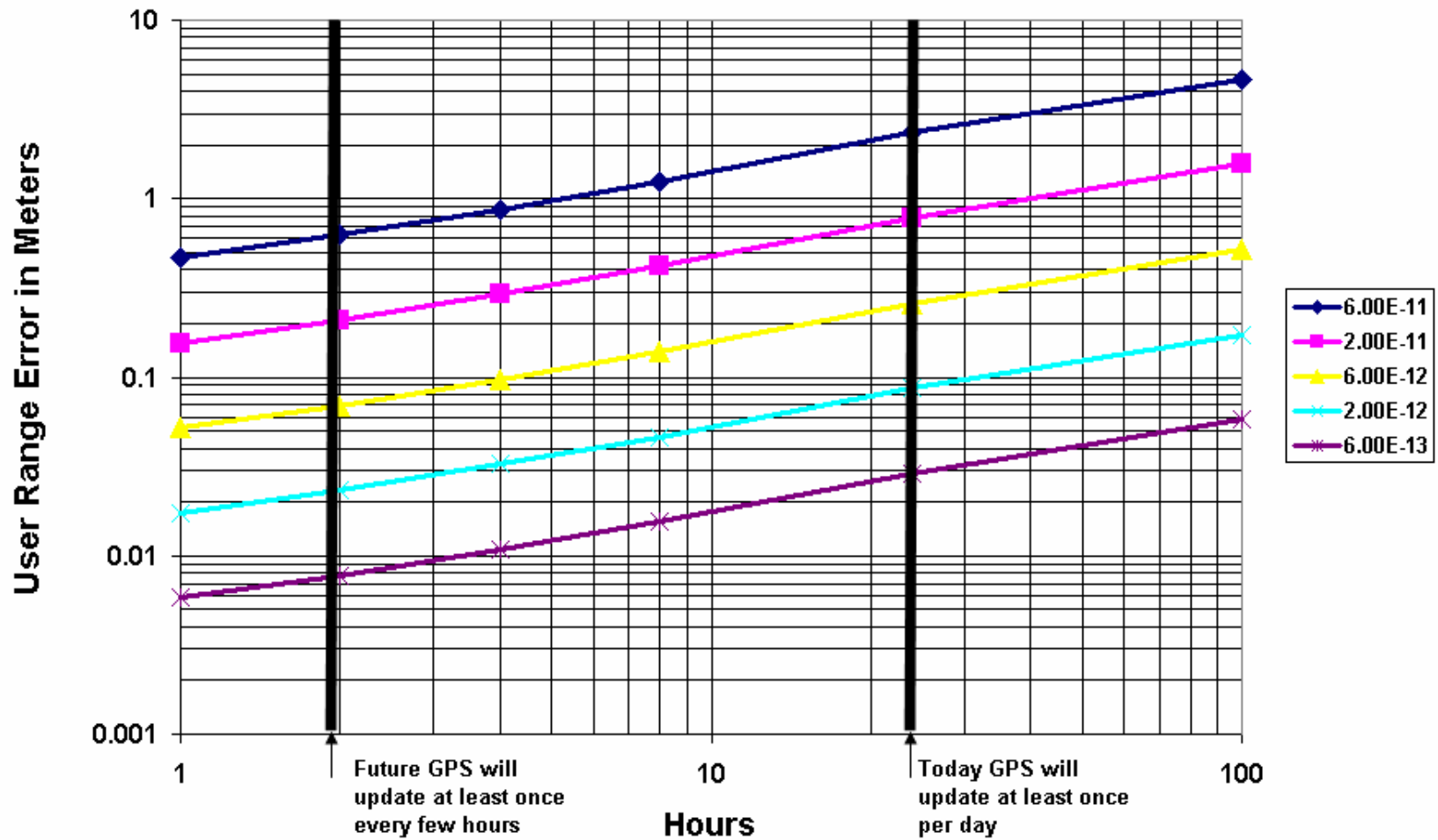
BACKUP

Clock Accuracies

GNSS Space Atomic relationship to update interval

GPS Time and UTC Timing Service

- GPS Time counts in weeks and seconds of a week from midnight of January 5/6, 1980 UTC

- Weeks begin at the Saturday/Sunday transition

- Weeks are counted using 10 bits and roll-over every 19.7 years (1024 weeks - Aug 22, 1999 was last GPS Time rollover)

- The time during the week is determined by counting the number of 1.5 second epochs since the beginning of the week

- The GPS UTC correction defines leap second offset and also contains the precise corrections to UTC(USNO), typically accurate to a few nanoseconds

BIPM Weights by Country
June 2007