Role of the ITU-R in Time and Frequency Dissemination

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Study Group 7-Science Services
Working Party 7A-Broadcast Time and Frequency Services

Responsible for Time and Frequency Signal (TFS) Services both terrestrial and satellite

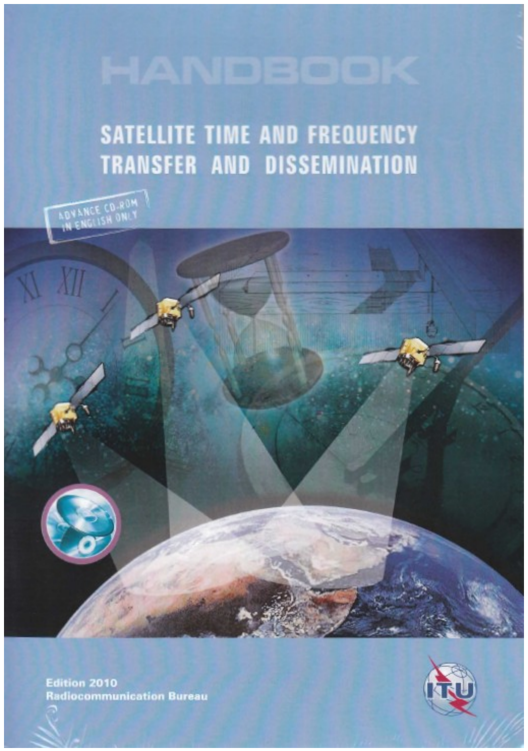
Definition of Time Scale for RadioCommunication Services

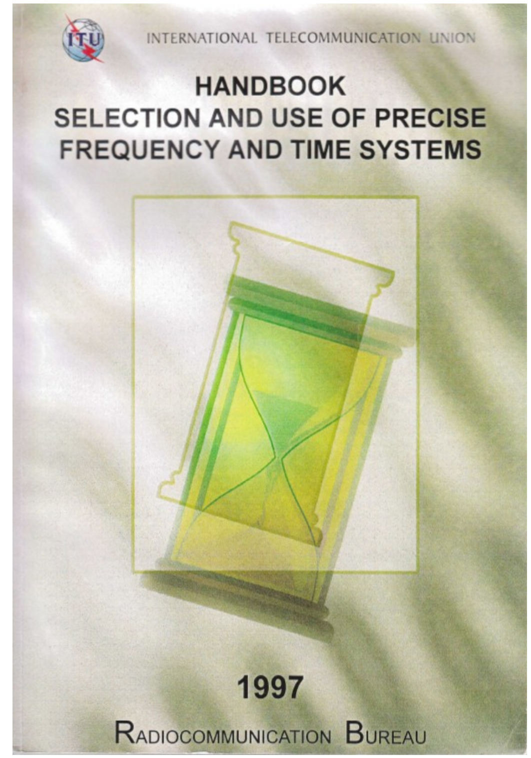
Maintain questions, TF series of recommendations, reports, opinions and handbooks covering fundamentals of TFS generation, measurements and data processing

Technical Areas include

- Time scales and time codes
- Terrestrial TFS transmissions, including HF,VHF and UHF
- Television broadcasting
- Microwave links
- Coaxial and optical cables
- Space based including navigation, communications and metrological satellites
- Frequency standards, clocks and TFS measurements systems
- TFS performance characterization

Handbooks in Time and Frequency Service and Systems





RECOMMENDATION ITU-R TF.460-6
STANDARD-FREQUENCY AND TIME-SIGNAL EMISSIONS

International Telecommunication Union

DEFINES Coordinated Universal Time (UTC) as the standard for Radio- and Tele-Communication purposes

To maintain worldwide coordination of standard frequency and time signals

Disseminate standard frequency and time signals in conformity with the SI second

Continuing need for UT immediate availability to an uncertainty of 0.1 second

All standard-frequency and time-signal emissions conform as closely as possible to UTC

Time signals should not deviate from UTC by more than 1 ms; that the standard frequencies should not deviate by more than 1 part in 10^{10}

TAI - International reference timescale of atomic time based on SI second as realized on a rotating geoid. Continuous scale from origin 1 Jan 1958

UTC - Basis of coordinated dissemination of standard frequency and time signals. Corresponds exactly in rate with TAI but differs by integral number of seconds.
UTC scale adjusted by insertion or deletion of seconds to ensure agreement with UT1

DUT1 - Dissemination to include *predicted difference* UT1 – UTC
(values given by IERS in integral multiples of 0.1 s)

Leaps Seconds may be introduced as the last second of a UTC month
December and June Preferred, March and September second choice

International Telecommunication Union

Coordinated Universal Time (UTC)

Originated from the need to “coordinate” time at different timing centers for their time broadcasts

Defined as a stepped atomic time scale to permit recovery of UT1 from International Atomic Time (TAI)

UTC = TAI + n seconds, where n = integer seconds

Adjusted when the predicted difference will maintain

UT1 – UTC < 0.9 seconds

Rate determined by TAI so basic interval is SI second

Maintained by the Bureau des Poids et Mesures (BIPM) with support from the International Earth Rotation and Reference Systems Service (IERS)

Time and Frequency Dissemination Systems

Satellite Systems have become the primary means of dissemination

- Wide applications in Cellular Networks, synchronized communication systems and distributed time keeping

Radio Broadcast Signals (such as LF transmissions) are available for modest accuracies

Computer Networks capabilities increasing in use and capability

- Computerized systems becoming widely used
- Supports mobile phone applications

Satellite Systems

- The Global Positioning System (GPS) has become the primary time transfer and dissemination system used by practically everyone, GALILEO and COMPASS are developing similar capabilities
  - Two basic techniques are used for time comparison/dissemination
    - Passive Receive Only Mode –
      - Operate similar to a navigation user
      - User position may be known from positioning with the received signals
      - Observe ranging modulation signals, or RF signal carrier phase
    - Common View –
      - Two sites in view of the same satellites at the same time
      - User position usually known a priori
      - Observe ranging modulation signals, or RF signal carrier phase
- Two Way Satellite Time and Frequency Transfer is becoming the system of choice for high accuracy and precision users
  - Employs communications satellites as transfer medium with known user position
- Calibration of receiving equipment for either technique a major concern
- Most other navigation systems techniques have declined in use due to performance and cost, mostly cost.

International Telecommunication Union

GPS Concept

PseudoRange to Each Space Vehicle (SV)

$$\rho = c \cdot \Delta t$$

$$\rho = c \cdot \left[\left(t_R - SV_n(t) \right) \right] + \Delta t_{prop} + b_R$$

$$SV_n(t) = t_R + \Delta t_{prop} + b_R - \frac{\rho}{c}$$

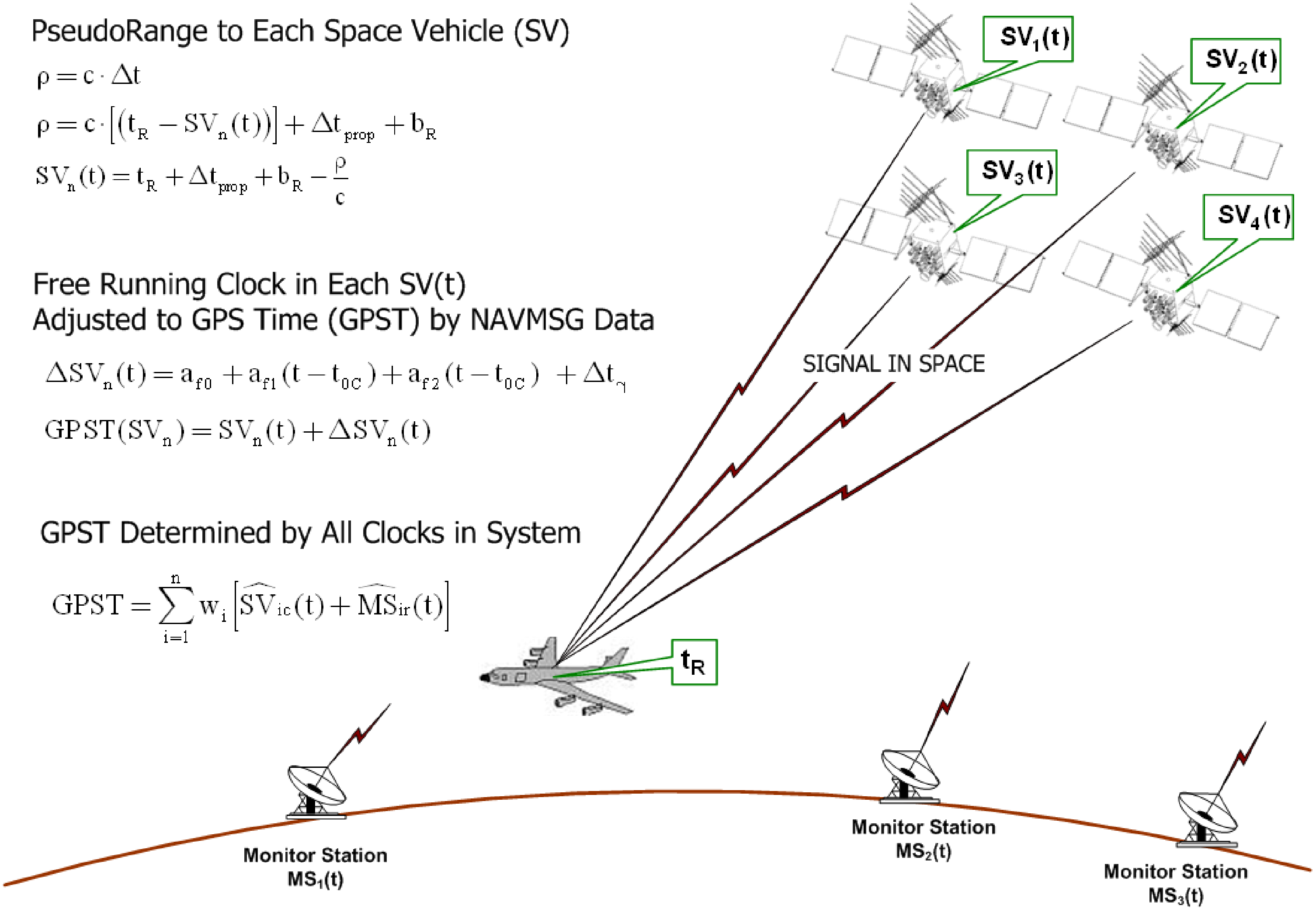
Free Running Clock in Each SV(t)
Adjusted to GPS Time (GPST) by NAVMSG Data

$$\Delta SV_n(t) = a_{f0} + a_{f1}(t - t_{0C}) + a_{f2}(t - t_{0C}) + \Delta t_r$$

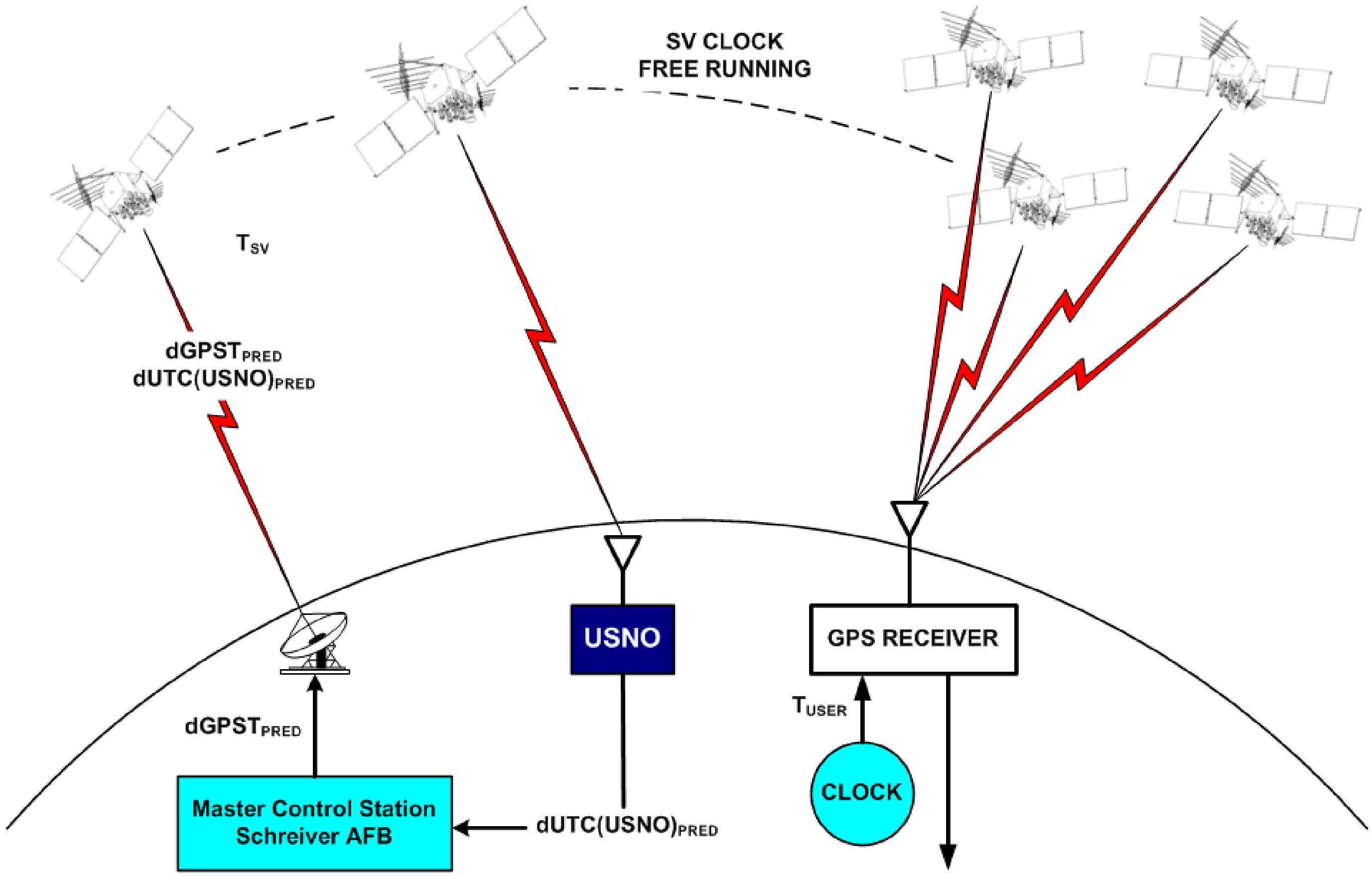
$$GPST(SV_n) = SV_n(t) + \Delta SV_n(t)$$

GPST Determined by All Clocks in System

$$GPST = \sum_{i=1}^{n} w_i \left[\widehat{SV}_{ic}(t) + \widehat{MS}_{ir}(t) \right]$$



GPS Passive Time Transfer



$$GPST = T_{SV(n)} + d(GPST)_n$$

$$GPST_{USER} = T_{USER} + \left[GPST - T_{USER}\right] + CAL_{USER}$$

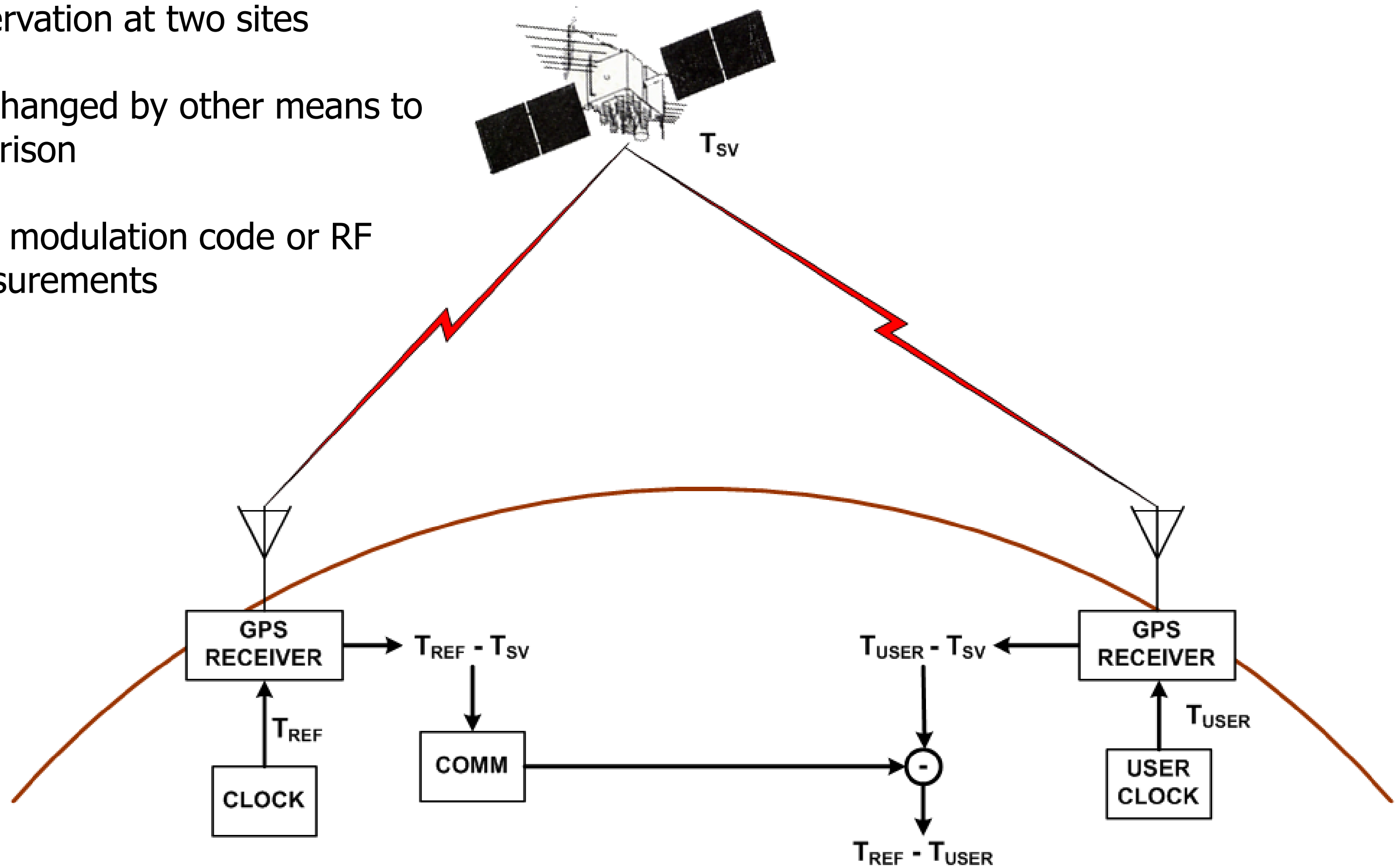
$$UTC_{USER} = GPST_{USER} + \left[UTC(USNO)_{PRED} - T_{USER}\right]$$

GPS Common View

Simultaneous observation at two sites

Observed data exchanged by other means to derive time comparison

May employ signal modulation code or RF carrier phase measurements



GPS RF Carrier Phase Techniques

Developed as a result of the International GNSS Service (IGS) - BIPM Pilot Project that ended in 2004 and became a regular service from IGS

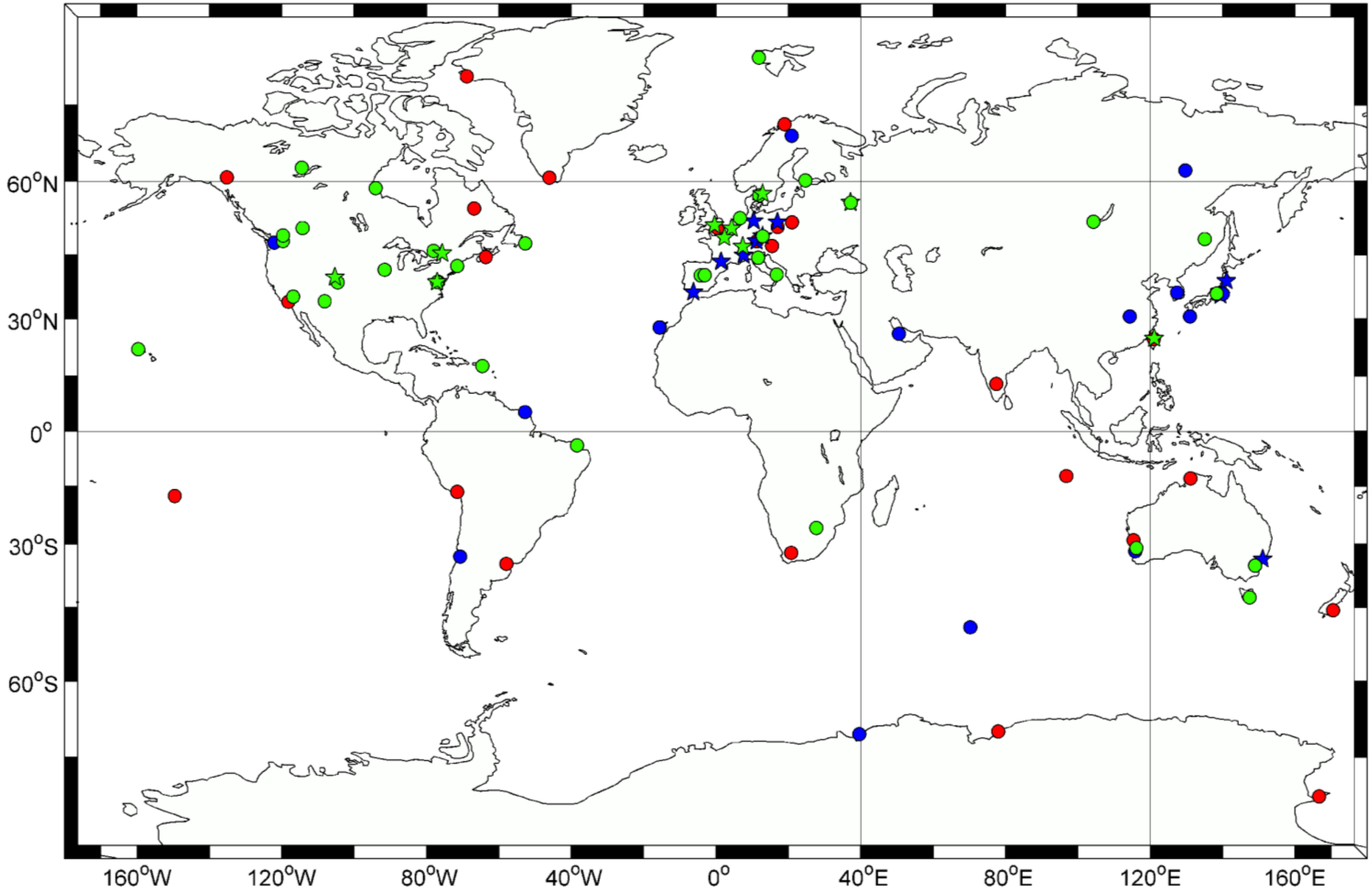
- IGS originated as a network of participating sites for earth physics using geodetic receivers
- Timing Centers that contribute to TAI/UTC joined the network linking their atomic clocks to the geodetic dataset
- The Pilot Project extended the geodetic data from the network to measurement synchronization to a common time scale

The IGS produces accurate geodetic data sets incorporating the precise geophysical and timing measurements and a IGS Time Scale

The IGS Time Scale enables high precision time comparisons between the contributing sites and UTC

Passive receiver operation observing RF carrier phase and geodetic processing with IGS datasets is known as Precise Point Positioning (PPP)

IGS Contributing Timing Centers

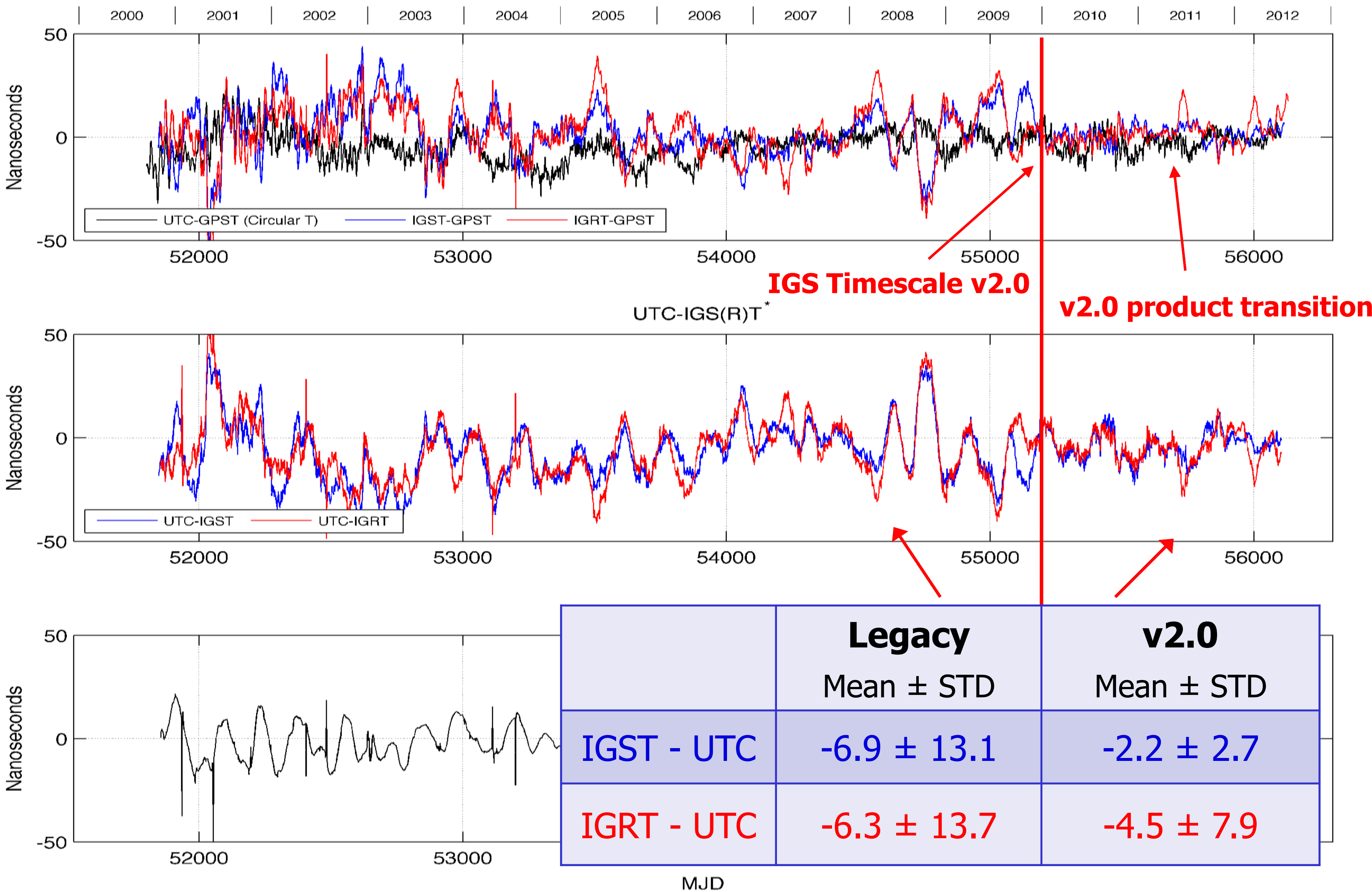


- masers (54)
- cesiums (32)
- rubidiums (27)

★ time lab stations (25)

+ GPS space clocks …

IGS Timescale now linked to UTC



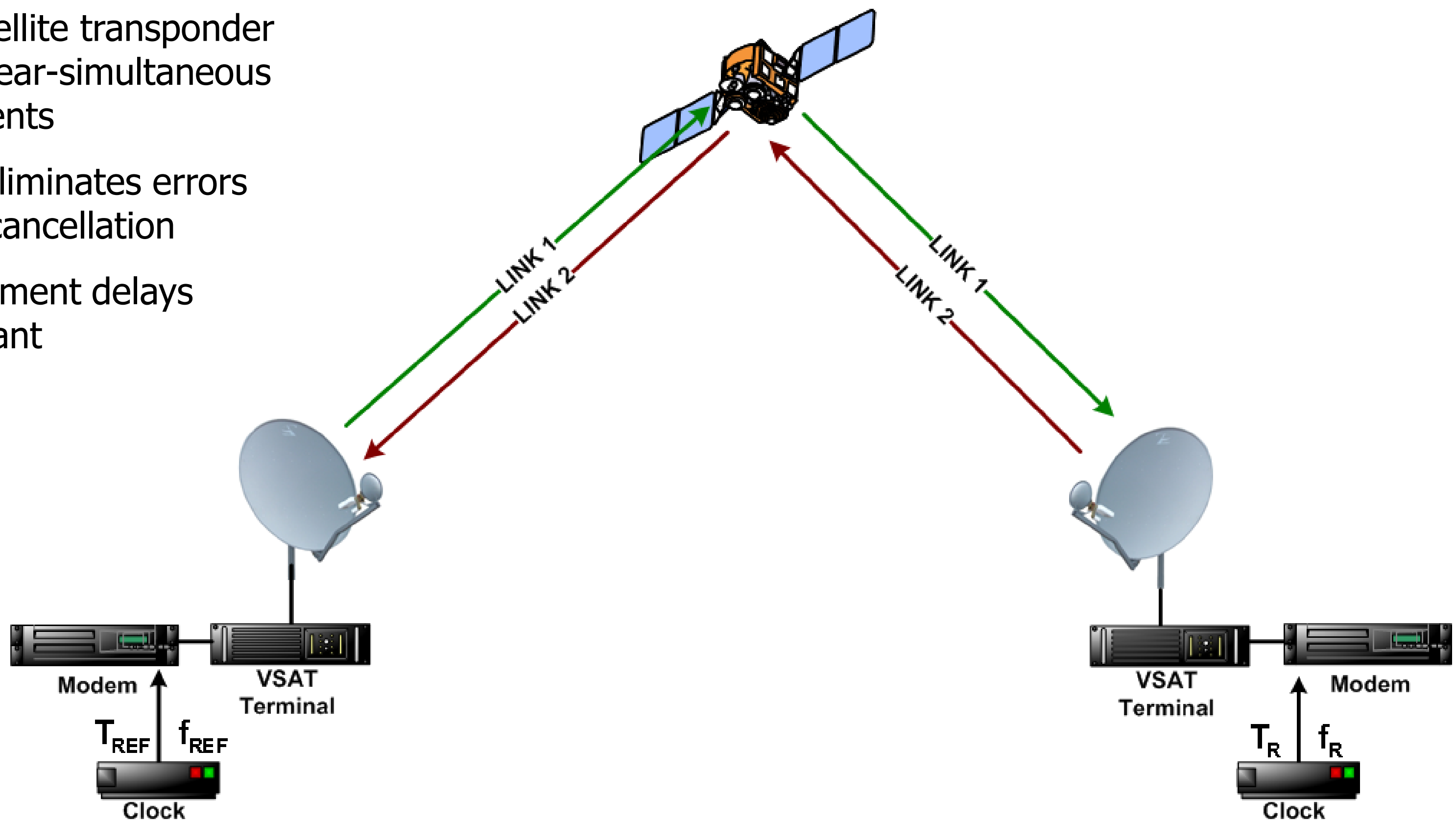
	Legacy Mean ± STD	v2.0 Mean ± STD
IGST - UTC	-6.9 ± 13.1	-2.2 ± 2.7
IGRT - UTC	-6.3 ± 13.7	-4.5 ± 7.9

Two Way Satellite Time and Frequency Transfer (TWSTFT)

Communication satellite transponder used for two way near-simultaneous ranging measurements

Simultaneous use eliminates errors by common mode cancellation

Calibration of equipment delays difficult and important



$$T_R - T_{REF} = \frac{1}{2}\left[\left(M_{(R-REF)} - M_{(REF-R)}\right) - \left(\delta t_{\text{Ref receiver}} - \delta t_{\text{R receiver}}\right)\right]$$

GNSS Augmentation Systems

Wide Area Augmentation System (WAAS) – USA

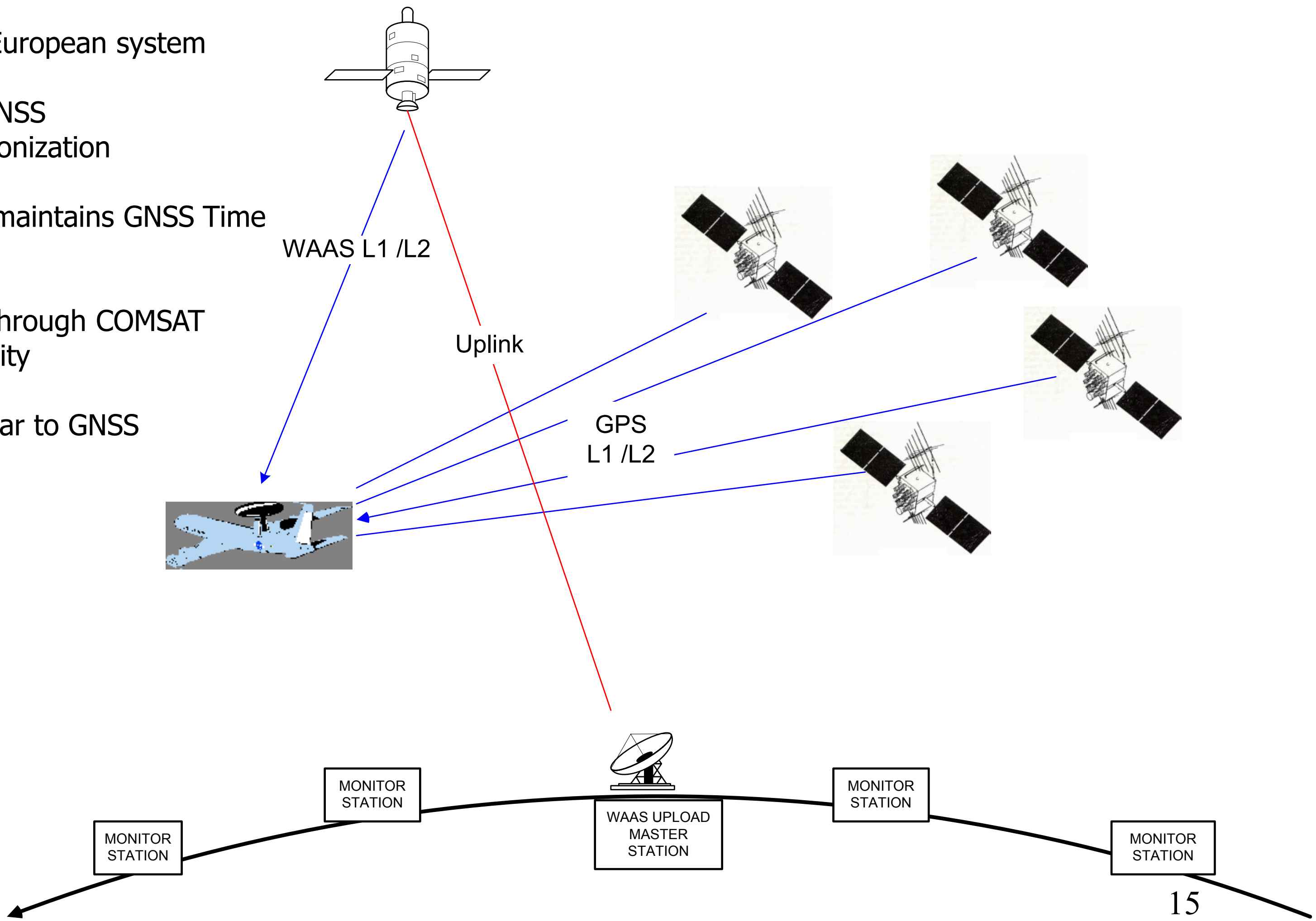
European GNSS (EGNOS) – European system

Ground Segment monitors GNSS signals and maintains synchronization

Associated ground segment maintains GNSS Time of system being augmented

Transmit GNSS-Like Signals through COMSAT transponder for Signal Integrity

Time Transfer capability similar to GNSS



GNSS Time Transfer Techniques

International Telecommunication Union

Parameter	Passive GPS (SPS)	Passive GPS (PPS)	Common View (Short Base)	Common View (Long Base)	Advanced Common View	Carrier Phase	WAAS/GPS
Precision (ns) rms [Range]	≤ 8 ns[2, 3] wrt UTC(USNO)	≤ 8 ns wrt UTC(USNO)	3-8 ns (point to point)	5-10 ns (point to point)	≤ 5 ns (point to point)	≤ 5-10 ns (point to point)	≤ 20 ns wrt UTC(USNO)
Major Error Sources	SA, Multi-Path, Clock, Iono, Tropo, UE, RF Enviro, Temp (RX & Ant)	Multi-Path, Clock, UE, RF Enviro, Temp (RX & Ant)	UE, Path Reciprocity, Ephemeris, Enviro (Temp)	UE, Path Reciprocity, Ephemeris, Enviro (Temp)	UE, Path Reciprocity, Ephemeris, Enviro (Temp)	UE, Multi-Path, Cycle Slips	Clock, Ephemeris
Stability (Value @ Ave)	≤ 8 ns @ 13 min ≈ 1 ns @ 1 day	≤ 5 ns @ 13 min ≈ 1 ns@ 1 day	≤ 4 ns @ 1 hr ≤ 1 ns @ 48 hrs	≤ 4 ns @ 1 hour ≤ 1 ns @ 48 hours	≤ 4 ns @ 1 hour ≤ 1 ns @ 48 hours	<< 1ns @ 6 min	< Passive SPS
Calibratibility	3-5 ns Against Std RX	3-5 ns Against Std RX	3-5 ns Against Std RX	3-5 ns Against Std RX	3-5 ns Against Std RX	<< 1 ns With	3-5 ns Against Std RX
Sample Rate	1 per 13 min	1 per 5 min 1 per 13 min	1 per 13 min	≥ 1 per 13 min (post processed)	1 per 5 min 1 per 13 min	Similar To Passive & Common View	TBD
Availability	Real Time	Real Time	Schedule Dependent	Schedule Dependent	Schedule Dependent	Processing Dependent	Real-Time

Notes:
- **to attain the stated accuracy**
- **fixed location with 3D position known to > 1 meter, 3D**
- **depending on User Equipment**
- **approaches the phase noise floor**

Two Way Techniques

Parameter	TWSTFT	Optical Fiber LAN-WAN	Optical Fiber Long Haul	Two-Way In Comms (OTA)
Accuracy (pt To pt) [Range] (ns rms)	≈ 1 ns (Ku-Band) ≈ 1 ns (X-Band) ≈ 3 ns (C-Band)	≤ 1 ns @ 200 km	≤ 2 ns @ 8000 km	≤ 5 ns @ 200 km
Major Error Sources	Path Reciprocity, Enviro (Temp),	Path Reciprocity, Enviro (Temp),	Path Reciprocity, Enviro (Temp),	Path Reciprocity, Enviro (Temp),
Stability (Value @ Avg'g Time)	200 ps @ 1 hour 100 ps @ 12 hour	100 ps rms	TBD	TBD
Calibratibility (Level in ns)	≈ 1	≈ 1	≈ 2	≈ 3-5
Sample Rate	1 per 5 min	Continuous	Continuous	Continuous
Timeliness	Near Real Time	Real Time	Real Time	Real Time

Working Party 7A
Current Activities

The suitability of the reference timescale UTC has been in question since 2000

- A new ITU-R Question 236/7 was accepted in 2000 to initial studies on the issue
- A Special Rapporteur Group was formed to help focus issues and studies
- Surveys by the Bureau and Associated organizations were conducted
- Data calls were conducted and results complied
- A proposed revised Recommendation was prepared but consensus was not reached
- The revised recommendation was forwarded for resolution to the Radio Assembly and World Radio Conference (WRC-12)
- The proposed recommendation was returned to the Working Party for further study
- An agenda item was introduced for WRC-15 on this issue

Member states are invited to participate in studies on this issue by submitting contributions to the ITU-R

The Future of The UTC Time Scale

Question ITU-R 236/7
(2000)

1. What are the requirements for globally-accepted time scales for use both in navigation and telecommunications systems, and for civil time-keeping?
    - Accuracy, Stability, Based on the SI Second
    - Uniformity, Accessibility
    - Reliability
    - Availability
    - Civil / National Timekeeping

2. What are the present and future requirements for the tolerance limit between UTC and UT1?
    - |UT1 – UTC| Tolerance of 0.9 seconds
    - Could a Greater Tolerance be Accommodated?

3. Does the current leap second procedure satisfy user needs, or should an alternative procedure be developed?
    - Availability of Leap Second Information for Users
    - Alternatives Used (Establishing System Independent Time)
    - Relationship of Telecom & NAVSAT System Internal Time to Time Scales

Previous Considerations

Create a new time scale with a new name, such as International Time (TI)

- Eliminate UTC and replace with TI

Use TAI instead of UTC

- TAI is metrologic scale and not distributed
- Transition would result in major time step

Adopt GPS Time as the official international time scale

- GPS Time is a system real time internal time scale
- Derived from system clocks not global timing centers
- Rate and time steps variable and made in accord with system synchronization needs

Increase maximum tolerance of DUT1

- One hour previously proposed similar to Daylight Savings Time (Summer Time)

Major scientific and GNSS organizations have not taken issue with the subject

- There has been ample opportunity and encouragement to contribute

A variety of continuous internal system time scales have proliferated to provide a solution to discontinuities in UTC

Future Work

There still exists clear misunderstandings of the definitions and applications of time scales and system times for internal synchronization

UTC is the only international standard time scale, represented by local approximations in time laboratories, that should be used for worldwide radiocommunication time coordination and measurement traceability

TAI is not an option for applications needing a continuous reference as it has no means of dissemination, and it is not physically represented by clocks

GPS time is not a reference time scale, it is an internal time for GPS system synchronization, as other GNSS system times would be

A variety of continuous internal system time scales have proliferated to provide a solution to the problems associated with discontinuities in UTC