

Space & Missile Systems Center
Global Positioning Systems Directorate



Public Interface Control
Working Group (ICWG) & Public Forum

Space & Missile Systems Center



RFC-400: Leap Second and Earth Orientation Parameters

Virtual Public Interface Control Working Group

Capt Michael Telcide

Philip Kwan

7 May 2019, 0830 – 1030 Pacific

Dial-in: 310-653-2663, Meeting ID: 6729512,
Password: 123456



Meeting Purpose

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- The purpose of the meeting is to:

Obtain ICWG approval on the proposed language generated for RFC-400 (Leap Second and Earth Orientation Parameters)

Agenda



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Introduction

Rules of Engagement

GPS Technical Baseline Configuration Management Process

RFC-400 (Leap Second and Earth Orientation Parameters)

Open RFC Discussion Session

Action Item Review

Adjourn



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RFC-400 Requirements Team

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Air Force

Capt Michael Telcide, GPS Enterprise/Space Requirements Lead

Aerospace

Dr. John Berg, Next Generation Control Segment Lead

Dr. Rhonda Slattery, Enterprise Requirements Lead

Karl Kovach, Civil Requirements Lead

MITRE

Gary Okerson, Systems Engineering Lead

Systems Engineering and Integration (SE&I)

Philip Kwan, Responsible Engineer



Roll Call



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Rules of Engagement

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Proprietary



Classified



*Competition
Sensitive*

ABSOLUTELY NO PROPRIETARY, CLASSIFIED, OR COMPETITION SENSITIVE INFORMATION IS TO BE DISCUSSED DURING THIS MEETING.

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Rules of Engagement (Cont'd)

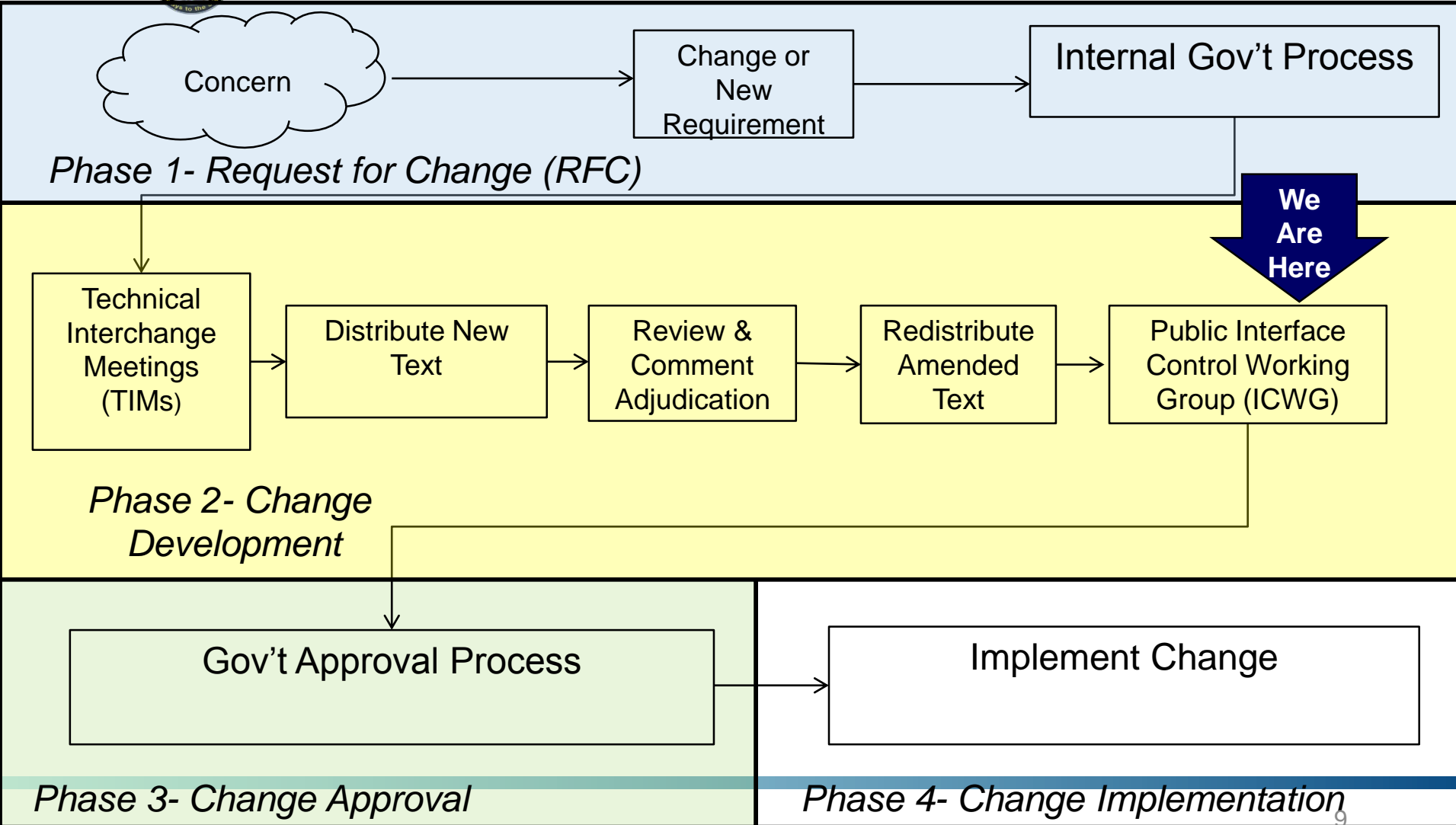
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- Please place your phones on mute when not speaking to minimize background noise
- Please announce your name and organization before addressing the group
- Comments against the topics listed on the official agenda will get priority during discussion
- Topics that warrant additional discussion may be side-barred or deferred
- Ad-hoc topics may be discussed during the open discussion
- Meeting minutes and final Interface Revision Notices (IRNs) will be generated and distributed as a product of this meeting



Change Management High Level Process Flow

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Background

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- The “Leap Second and Earth Orientation Parameters” solution was briefed as a part of RFC-374 in the 2018 Public ICWG. However, there were additional comments following the 2018 Public ICWG that resulted in a re-work of the entire solution.
- RFC-400 proposes a new solution to the problem and has been reviewed and discussed internally with the stakeholders. The purpose of today’s meeting is to finalize the changes with the public.
- This presentation encompasses the revised solution.



Leap Second and Earth Orientation Parameters

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Problem Statement:

As currently documented in the technical baseline for Earth Orientation Parameters (EOP) data and applications, Civil Navigation (CNAV) and CNAV-2 users may calculate the wrong UT1 time immediately following a leap second change, as the linkage between Coordinated Universal Time (UTC) and UT1 time is not properly captured. This issue affects user applications that require high precision pointing, which may include optical telescopes, spacecraft, or any system with this requirement. The topic was originally a part of RFC-354 (Leap Second and EOPs) & RFC-374 (2018 Public Document Proposed Changes).

Proposed Solution:

Re-define the EOPs such that UT1 is calculated with respect to GPS time instead of UTC time. Therefore, since GPS time does not utilize leap seconds, there is no leap second problem for users when they calculate UT1.

Impacted Public Documents:

IS-GPS-200, IS-GPS-705, IS-GPS-800

Problem



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- EOPs are contained in CNAV (L2 and L5) and CNAV-2 (L1C) to convert earth-centered earth-fixed (ECEF) coordinates to earth-centered inertial (ECI) coordinates
- As currently defined in the GPS interface documents, IS-GPS-200, IS-GPS-705 and IS-GPS-800, the user calculating UT1 from UTC using the EOPs will introduce a one-second discontinuity in UT1 due to a leap second transition in UTC (as shown in the below equation)

$$UT1 = UTC + \Delta UT1 + \dot{\Delta UT1} (t - t_{EOP})^*$$

A one second change in UTC causes a one second change in the other side of the equation (UT1)

- EOPs and the leap second information (Δt_{LSF} , WN_{LS} , DN) are contained in separate messages
- $\Delta UT1 = UT1 - UTC$ is updated by the Control Segment (CS) to account for the leap second change, but the user may obtain this update from the Space Vehicle minutes after the leap second transition
- Conclusion: Users could calculate UT1 that is one second off until they receive newly updated EOPs that follow a leap second transition

*From IS-GPS-200 Table 30-VIII



Revised Solution

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- RFC-400 addresses the leap second problem by defining a *new* relationship between UT1 and GPS time (GPST) in the EOPs
- Original:
 - $\Delta UT1$ = UT1 and UTC difference at reference time t_{EOP}
 - $\dot{\Delta UT1}$ = Rate of UT1 and UTC difference at reference time t_{EOP}
- Proposed:
 - $\Delta UTGPS$ = UT1 and GPST difference at reference time t_{EOP}
 - $\dot{\Delta UTGPS}$ = Rate of UT1 and GPST difference at reference time t_{EOP}

Observations:

- GPST does not use leap seconds, so the relationship between UT1 and GPST is independent of leap seconds
 - There is no more leap second problem associated with calculating UT1
- UT1 has been put on more equal footing with the polar motion parameters, which are represented as functions of GPST



Additional Changes

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- Updated the scale factor for $\Delta UT1 \rightarrow \Delta UTGPS$ from 2^{-24} to 2^{-23} to double the valid range of $\Delta UTGPS$ from $[-64, 63]$ to $[-128, 127]$
 - Given that $\Delta UTGPS$ has a scale factor of 2^{-24} , the valid range for UTC-GPST is **smaller** than what is permitted:

	UT1-GPST	UT1-UTC	UTC-GPST =(UT1-GPST)-(UT1-UTC)	Δt_{LS}	UTC-GPST (permitted based on Δt_{LS})
Bits	31*			8*	
Scale Factor	2^{-24}			1	
Valid Range	$[-64, 63]$	$(-0.9, 0.9)$	$(-64.9, 63.9)$	$[-128, 127]$	$[-128, 127]$

- If $\Delta UTGPS$ has a scale factor of 2^{-23} , the problem is **fixed**:

	UT1-GPST	UT1-UTC	UTC-GPST =(UT1-GPST)-(UT1-UTC)	Δt_{LS}	UTC-GPST (permitted based on Δt_{LS})
Bits	31*			8*	
Scale Factor	2^{-23}			1	
Valid Range	$[-128, 127]$	$(-0.9, 0.9)$	$(-128.9, 127.9)$	$[-128, 127]$	$[-128, 127]$

*two's complement parameter, with sign bit occupying the Most Significant Bit (MSB)

This change will not introduce statistically significant errors to user applications.



Additional Changes

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2. Updated the “Application of EOP Parameters” table (IS-GPS-200 Table 30-VIII and IS-GPS-705 Table 20-VIII)

	Element/Equation	F	Description
A	$t_{diff} = (t - t_{EOP} + 604800(WN - WN_{ot}))$	[seconds]	Compute difference between GPS time and EOP reference time
B	$UT1 = t + 604800*WN + \Delta UTGPS + \Delta \dot{UTGPS} * t_{diff} / 86400$	[seconds]	Compute UT1 at GPS time
C	$x_p = PM_X + \dot{PM}_X * t_{diff} / 86400$	[arc-seconds]	Polar Motion in the x-axis
D	$y_p = PM_Y + \dot{PM}_Y * t_{diff} / 86400$	[arc-seconds]	Polar Motion in the y-axis
E	GPS system time (t) is expressed in seconds since start of current GPS week, and WN is the current week number expressed in number of weeks since GPS epoch. The divisor 86400 converts rates per day to rates per second.		

A: Added definition of t_{diff} in order to compute the difference between GPS time and EOP reference time (each represented in seconds since GPS epoch)

B: Incorporated (A) and added $604800*WN$ to represent time t in seconds since GPS epoch, included 86400 divisor

C, D: Incorporated (A) into the equations, included 86400 divisor

E: Updated definitions of t, WN, and provide explanation for 86400 divisor

F: Added units to the results of each equation



Additional Changes

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3. Based on updates in the previous slide (see A), the week number for EOP reference time is directly obtained from the WN_{ot} (UTC Reference Week Number) from the UTC message. There is no week number provided in the EOP message. Using WN_{ot} in EOP applications requires coupling the UTC and EOP messages.

IS-GPS-200 (Table 30-VIII), IS-GPS-705 (Table 20-VIII):

When calculating $UT1$, x_p , and y_p in Table 30-VIII, the week number for t_{EOP} is equal to the WN_{ot} value in Message Type 33 when both criteria are met:

- t_{EOP} in Message Type 32 is equal to the t_{ot} in Message Type 33
- t_{op} in Message Type 32 is equal to the t_{op} in Message Type 33

If both criteria are not met, the data between the two message types may be inconsistent with each other and should not be used in the calculations in Table 30-VIII.

IS-GPS-800:

When calculating $UT1$, x_p , and y_p in Table 30-VIII of IS-GPS-200, the week number for t_{EOP} is equal to the WN_{ot} value in subframe 3 page 2 when both criteria are met:

- t_{EOP} in subframe 3 page 1 is equal to t_{ot} in subframe 3 page 2
- Subframe 3 page 1 and subframe 3 page 2 were transmitted within a continuous 4-hour period

If both criteria are not met, the data between the two pages may be inconsistent with each other and should not be used for the calculations in Table 30-VIII of IS-GPS-200.



Additional Changes

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4. Added a statement to the user to determine the original UT1-UTC offset using the parameters provided in the EOP message and the UTC message:

Users who may need $\Delta UT1$ (UT1-UTC) as detailed in Chapter 5 of IERS Technical Note 36: IERS Conventions (2010) can calculate this parameter from UT1-UTC, or more accurately as $(UT1-GPS) + (GPS-UTC)$, using intermediate quantities (UT1-GPS) and (GPS-UTC) which are produced during calculation of UT1 and UTC.

- The change to the EOPs does not remove the user's ability to calculate $\Delta UT1$ (= UT1-UTC)



Additional Changes

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5. Made it clear that PM_X , \dot{PM}_X , PM_Y , \dot{PM}_Y *already* account for diurnal and semi-diurnal tides and should not be further applied by the user, and that ΔUT_{GPS} and $\dot{\Delta UT}_{GPS}$ *already* account for zonal, diurnal, and semi-diurnal tides and should not be further applied by the user

- Otherwise, users may apply the effects again
- Update parameters table and description of EOP messages

Earth Orientation Parameters Table (excerpt)*

Parameter	No. of Bits**	Scale Factor (LSB)	Valid Range***	Units
PM_X †.†††	21*	2^{-20}		arc-seconds
\dot{PM}_X †††	15*	2^{-21}		arc-seconds/day
PM_Y ††.†††	21*	2^{-20}		arc-seconds
\dot{PM}_Y †††	15*	2^{-21}		arc-seconds/day
ΔUT_{GPS} †††	31*	2^{-2423}		seconds
$\dot{\Delta UT}_{GPS}$ †††	19*	2^{-25}		seconds/day

††† With zonal tides restored. Already account for zonal, diurnal, and semi-diurnal tides and should not be further applied by the user.

†††† Already account for diurnal and semi-diurnal tides and should not be further applied by the user.

*See IS-GPS-200 Table 30-VII, IS-GPS-705 Table 20-VII, IS-GPS-800 Table 3.5-5

Description of EOP messages changes: IS200-618 (§30.3.3.5.1.1.0-1), IS705-320 (§20.3.3.5.1.1-1)



Additional Changes

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6. Added requirements describing how often the CS shall upload the EOPs to the Space Vehicles (SVs)

- Gives some insight into the validity time for EOPs
- Framed similarly to other parameters like UTC and Ionospheric Correction parameters

The EOP parameters shall be updated by the CS at least once every three days while the CS is able to upload the SVs. If the CS is unable to upload the SVs, the accuracy of the EOP parameters transmitted by the SVs will degrade over time.



Public Comments

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- Discussion of public-submitted comments



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RFC-400 Comment Summary

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CRM – COMBINED REVIEW STATUS					
Disposition/Type	Critical	Substantive	Administrative	Totals	Concurrence
Accept			3	3	3
Accept with Change		1		1	1
Reject					
Defer					
Grand Totals:		1	3	4	4

DOORS ID	IS200-618, IS705-320, IS800-240		
Paragraph	30.3.3.5.1.1.0-1, 20.3.3.4.1.1-1, 3.5.4.2.3.0-1	Comment Number	1
Comment Type	S - Substantive	Disposition	<i>Accept with Comments</i>
Comment Originator(s)	Steven Hutsell (2SOPS)		
Comment	As discussed in a previous working meeting, the statement added for EOP validity time is unclear. Three days has not been supported analytically. The meaning of “updated by the CS” is unclear – does that mean that the CS updates the time tag of the message or the time tag and data (as provided by outside sources) as well?		
Directorate Response	<p>Need to keep a vague statement in since no details have been clearly outlined yet, but the user should know that the accuracy of the EOP data will degrade over time.</p> <p>Take as an action that the definition of “updated by the CS” should be clarified.</p> <p>Public ICWG comment: change “uploaded” to “updated” because “updated” is more accurate. The data can be updated by the CS even if they do not receive a new EOP bulletin from the NGA.</p>		
PIRN TEXT (IS)		PROPOSED TEXT	
See next slide.		See next slide.	

[IS200-618, IS705-320]... Users are advised that the broadcast Message Type 32 EOPs already account for the following effects and should not be further applied by the user:

(1) zonal, diurnal and semi-diurnal effects (described in Chapter 8 of the IERS Conventions (2010))

(2) A_0 , A_1 , A_2 and the leap second count in Message Type 33

The EOP parameters shall be updated by the CS at least once every three days while the CS is able to upload the SVs. If the CS is unable to upload the SVs, the accuracy of the EOP parameters transmitted by the SVs will degrade over time.

[IS200-618, IS705-320]...Users are advised that the broadcast Message Type 32 EOPs already account for the following effects and should not be further applied by the user:

(1) zonal, diurnal and semi-diurnal effects (described in Chapter 8 of the IERS Conventions (2010))

(2) A_0 , A_1 , A_2 and the leap second count in Message Type 33

EOPs that are not updated by the CS will degrade in accuracy over time.

[IS800-240] The EOP fields in subframe 3, page 2 contain the EOP needed to construct the ECEF-to-ECI coordinate transformation. The user computes the ECEF position of the SV antenna phase center using the equations shown in Table 3.5-2. The coordinate transformation, for translating to the corresponding ECI SV antenna phase center position, is derived using the equations shown in IERS Technical Note 36 and Table 30-VIII of IS-GPS-200 in accordance with Section 30.3.3.5.1.1 of IS-GPS-200. The coordinate systems are defined in Section 20.3.3.4.3.3 of IS-GPS-200.

The EOP parameters shall be updated by the CS at least once every three days while the CS is able to upload the SVs. If the CS is unable to upload the SVs, the accuracy of the EOP parameters transmitted by the SVs will degrade over time.

[IS800-240] The EOP fields in subframe 3, page 2 contain the EOP needed to construct the ECEF-to-ECI coordinate transformation. The user computes the ECEF position of the SV antenna phase center using the equations shown in Table 3.5-2. The coordinate transformation, for translating to the corresponding ECI SV antenna phase center position, is derived using the equations shown in IERS Technical Note 36 and Table 30-VIII of IS-GPS-200 in accordance with Section 30.3.3.5.1.1 of IS-GPS-200. The coordinate systems are defined in Section 20.3.3.4.3.3 of IS-GPS-200.

EOPs that are not updated by the CS will degrade in accuracy over time.

DOORS ID	IS200-618, IS200-1619, IS705-320, IS705-1546, IS800-237		
Paragraph	Global	Comment Number	2
Comment Type	A - Administrative	Disposition	<i>Accept</i>
Comment Originator(s)	Nick Stamatakos (USNO)		
Comment	“EOP parameters” is used frequently throughout the document but is redundant; read as “Earth Orientation Parameters parameters”		
Directorate Response	Globally fix redundancy in IS-GPS-200, IS-GPS-705, and IS-GPS-800		
PIRN TEXT (IS)		PROPOSED TEXT	
...EOP Parameter... ...EOP Parameters...		...EOP... ...EOPs...	

DOORS ID	IS200-621, IS705-322, IS800-241		
Paragraph	Table 30-VII, Table 20-VII, Table 3.5-5 (footnotes)	Comment Number	3
Comment Type	A – Administrative	Disposition	<i>Accept</i>
Comment Originator(s)	Dennis McCarthy (USNO)		
Comment	Change Celestial Ephemeris Pole (CEP) to Celestial Intermediate Pole (CIP) which is consistent with IERS Tech Note 36.		
Directorate Response	Based on the IERS Tech Note 36, the IAU resolutions on reference systems include recommending that "the terminology "Celestial Intermediate Origin" (CIO) and "Terrestrial Intermediate Origin" (Terrestrial Intermediate Origin) be used in place of the previously introduced "Celestial Ephemeris Origin" (Celestial Ephemeris Origin) and "Terrestrial Ephemeris Origin" (Terrestrial Ephemeris Origin)"		

PIRN TEXT (IS)

[†] Represents the predicted angular displacement of instantaneous Celestial **Ephemeris** Pole with respect to semi-minor axis of the reference ellipsoid along Greenwich meridian.

^{††} Represents the predicted angular displacement of instantaneous Celestial **Ephemeris** Pole with respect to semi-minor axis of the reference ellipsoid on a line directed 90° west of Greenwich meridian.

PROPOSED TEXT

[†] Represents the predicted angular displacement of instantaneous Celestial **Intermediate** Pole with respect to semi-minor axis of the reference ellipsoid along Greenwich meridian.

^{††} Represents the predicted angular displacement of instantaneous Celestial **Intermediate** Pole with respect to semi-minor axis of the reference ellipsoid on a line directed 90° west of Greenwich meridian.

DOORS ID	IS800-875		
Paragraph	3.5.2.0-7 Figure 3.5-3	Comment Number	4
Comment Type	A – Administrative	Disposition	<i>Accept</i>
Comment Originator(s)	Steven Brown (Lockheed Martin)		
Comment	Top of each row of figure where it says "Direction of data flow from SV" and "MSB first" is not like shown in figure 3.5-4 and on...please fix at same time as update		
Directorate Response	<p>Done. Please review changes in the following slide.</p> <p>Public ICWG comment: In addition, updated the figure to ensure there is more spacing around the words “DIRECTION OF DATA FLOW FROM SV” and “MSB FIRST”. Defer a comment to move these phrases closer together.</p>		
PIRN TEXT (IS)		PROPOSED TEXT	
See next slide.		See next slide.	



PIRN TEXT (IS)

Fixed arrows above each row

PROPOSED TEXT

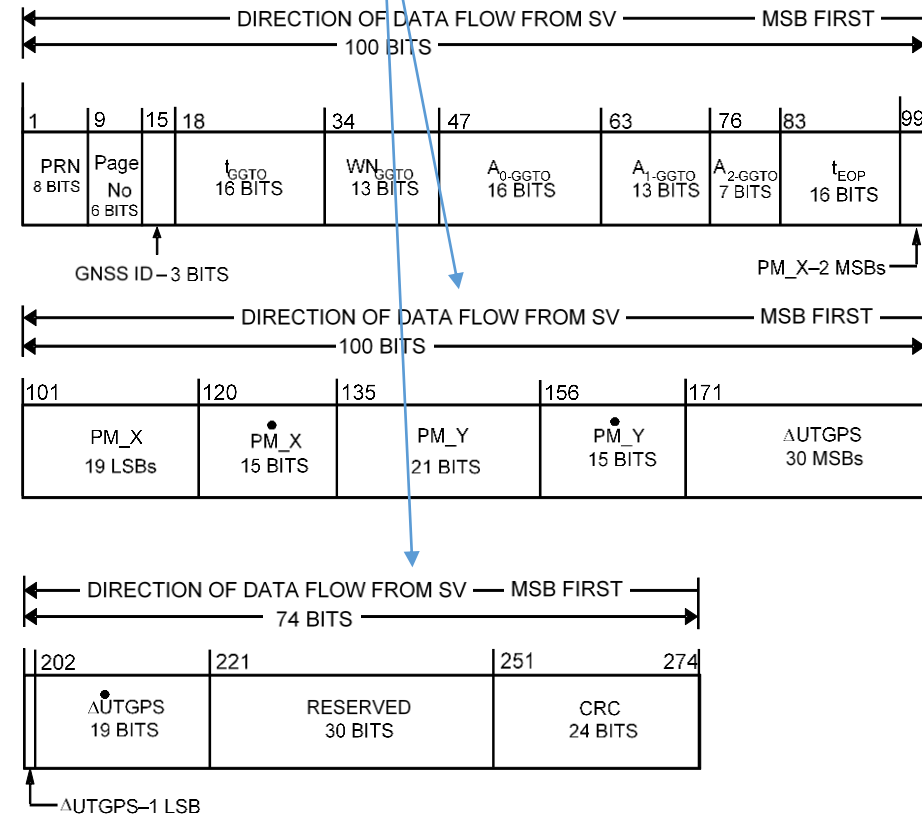
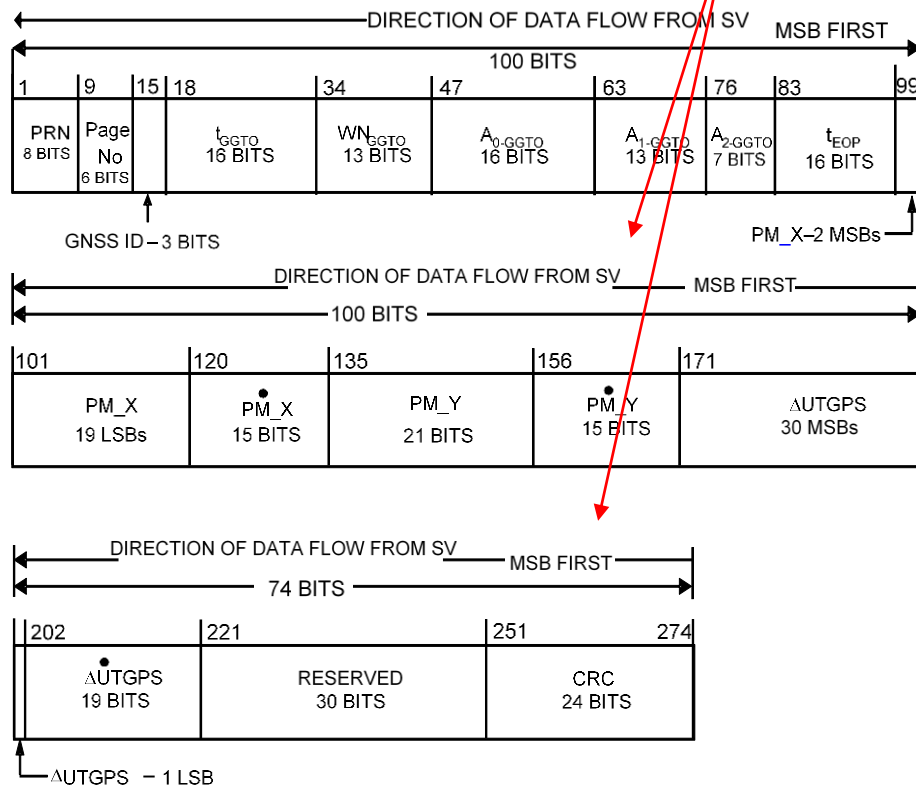


Figure 3.5-3 Subframe 3, Page 2

Figure 3.5-3 Subframe 3, Page 2



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Open RFC Discussion

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- Questions/comments?



Next Steps

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- An announcement will be made as to when EOPs with the newly updated definitions (i.e., Δ UTGPS and $\Delta\dot{U}$ TGPS) will be broadcast



Action Item Review



Closing Comments

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- Any changes will be sent out for a 2-week review after today's PICWG
- Final minutes will be posted to GPS.gov following government approval
- IRNs will be available on GPS.gov following approval by the Configuration Control Board and Public Affairs

- Direct any follow-up communication related to this meeting to smcgper@us.af.mil
- Please provide feedback to the GPS requirements team to enable the continual improvement of this meeting

- The 2019 Public Interface Control Working Group and Public Forum is tentatively scheduled for Wednesday, September 25, 2019
 - RFC-395 (2019 Public Document Proposed Changes)
 - RFC-403 (Health Bit Clarification)