PROPOSED CHANGE NOTICE

Affected Document:	IRN/SCN Number	Date:
IS-GPS-705E	PCN-IS-705E_RFC400	19-DEC-2018
Authority:	**Proposed Change Notice**	**Date:**
RFC-00400	IS705E_RFC400	29-NOV-2018

CLASSIFIED BY: N/A
DECLASSIFY ON: N/A

Document Title: NAVSTAR GPS Space Segment / Navigation User L5 Interface

RFC Title: Leap Second and Earth Orientation Parameters

Reason For Change (Driver):
As currently documented in the technical baseline for Earth Orientation Parameters (EOP) data and applications, CNAV/CNAV-2 and MNAV users will 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. Documents affected: IS-GPS-200, IS-GPS-705, IS-GPS-800, ICD-GPS-700, ICD-GPS-801, and IS-GPS-901. The topic was originally a part of RFC-354 & RFC-374.

Description of Change:
Resolve the leap second problem such that the user knows how to calculate the correct UT1 time following a leap second change given the current definition and implementation of EOP and UTC parameters.

Authored By: Philip Kwan **Checked By: Jennifer Lemus**

AUTHORIZED SIGNATURES	REPRESENTING	DATE
	GPS Directorate Space & Missile Systems Center (SMC) – LAAFB	

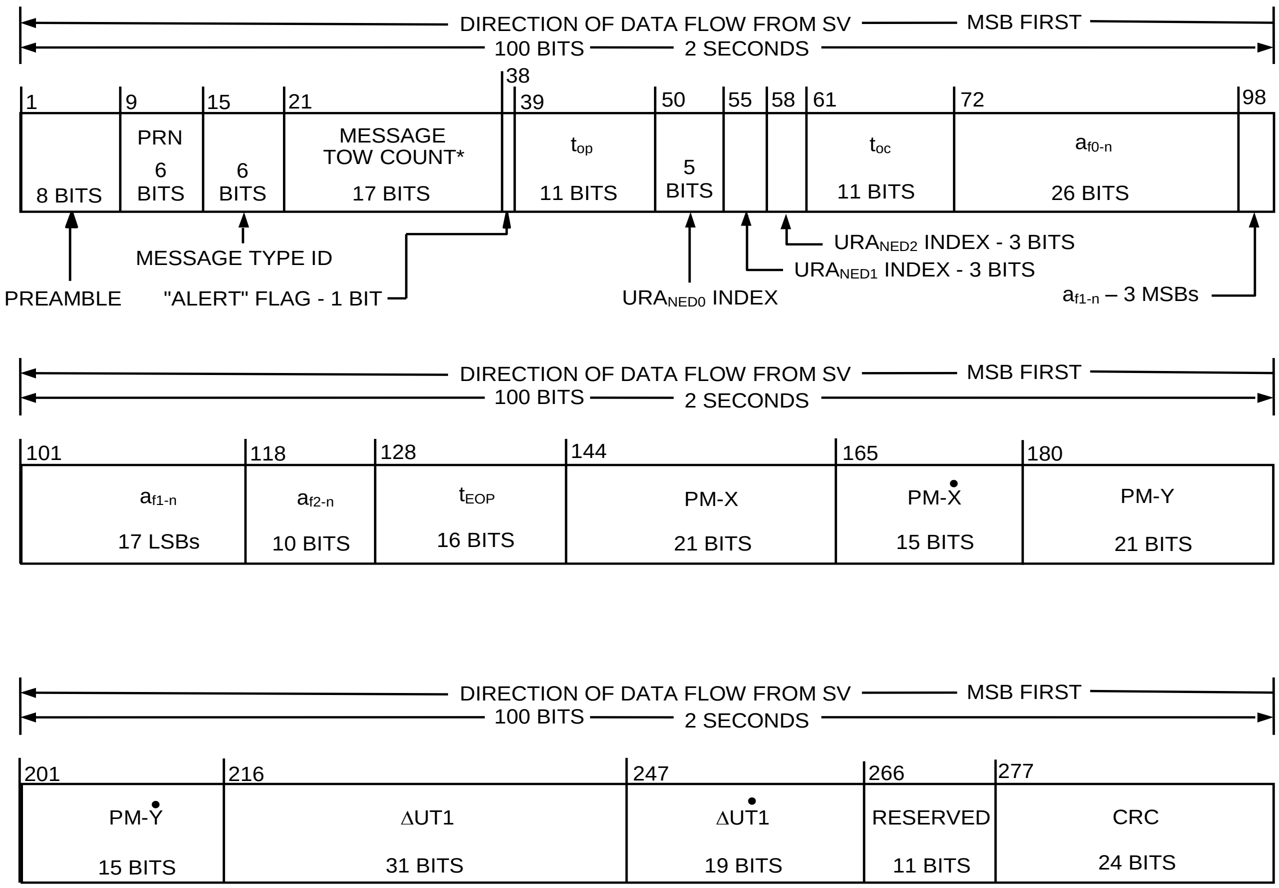
DISTRIBUTION STATEMENT A: Approved for Public Release; Distribution Is Unlimited

Interface Control Contractor:
SAIC (GPS SE&I)
200 N. Pacific Coast Highway, Suite 1800
El Segundo, CA 90245
CODE IDENT 66RP1

IS705-202 :

Section Number :
20.3.3.0-10

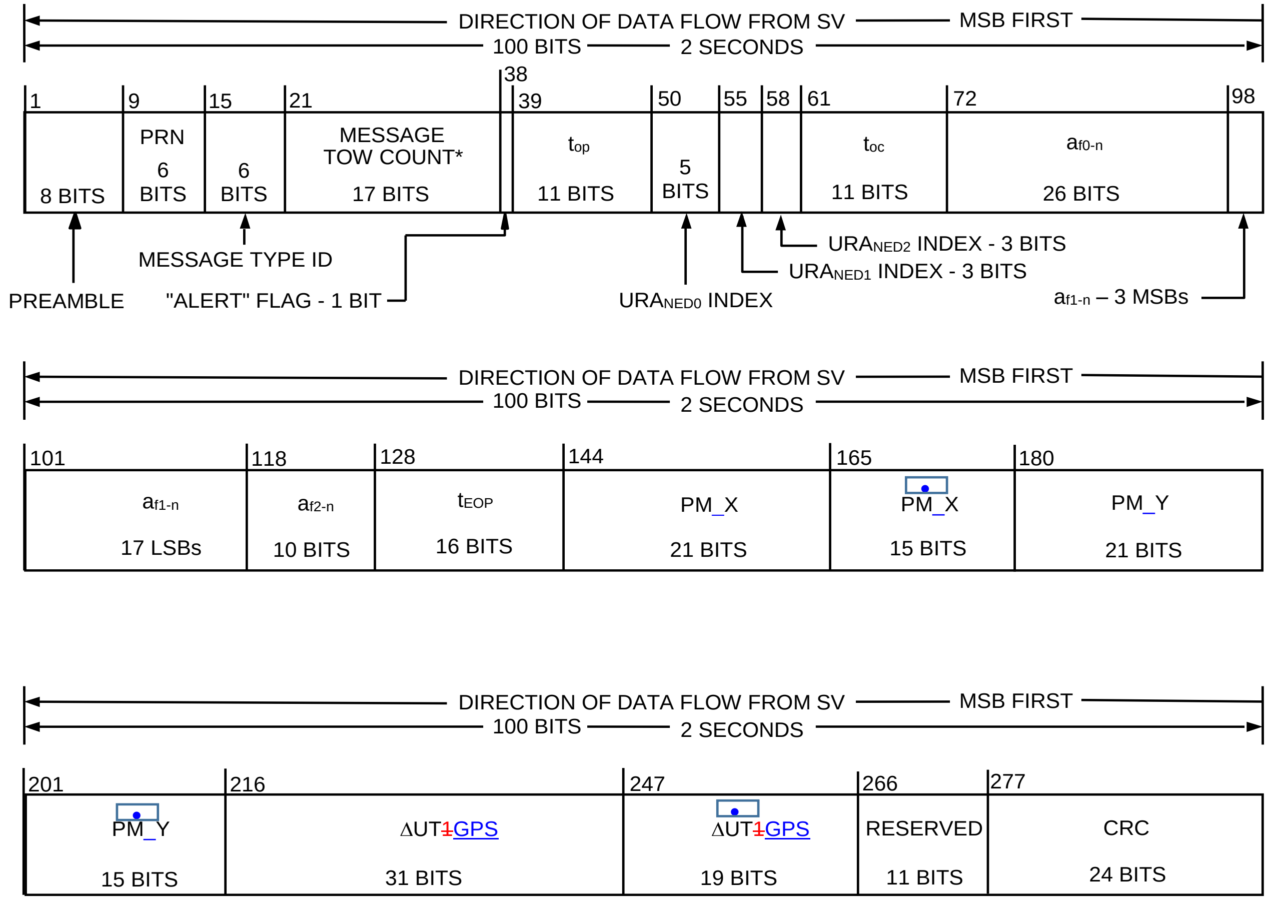
WAS :



* MESSAGE TOW COUNT = 17 MSB OF ACTUAL TOW COUNT AT START OF NEXT 6-SECOND MESSAGE

Figure 20-5. Message Type 32 – Clock & EOP

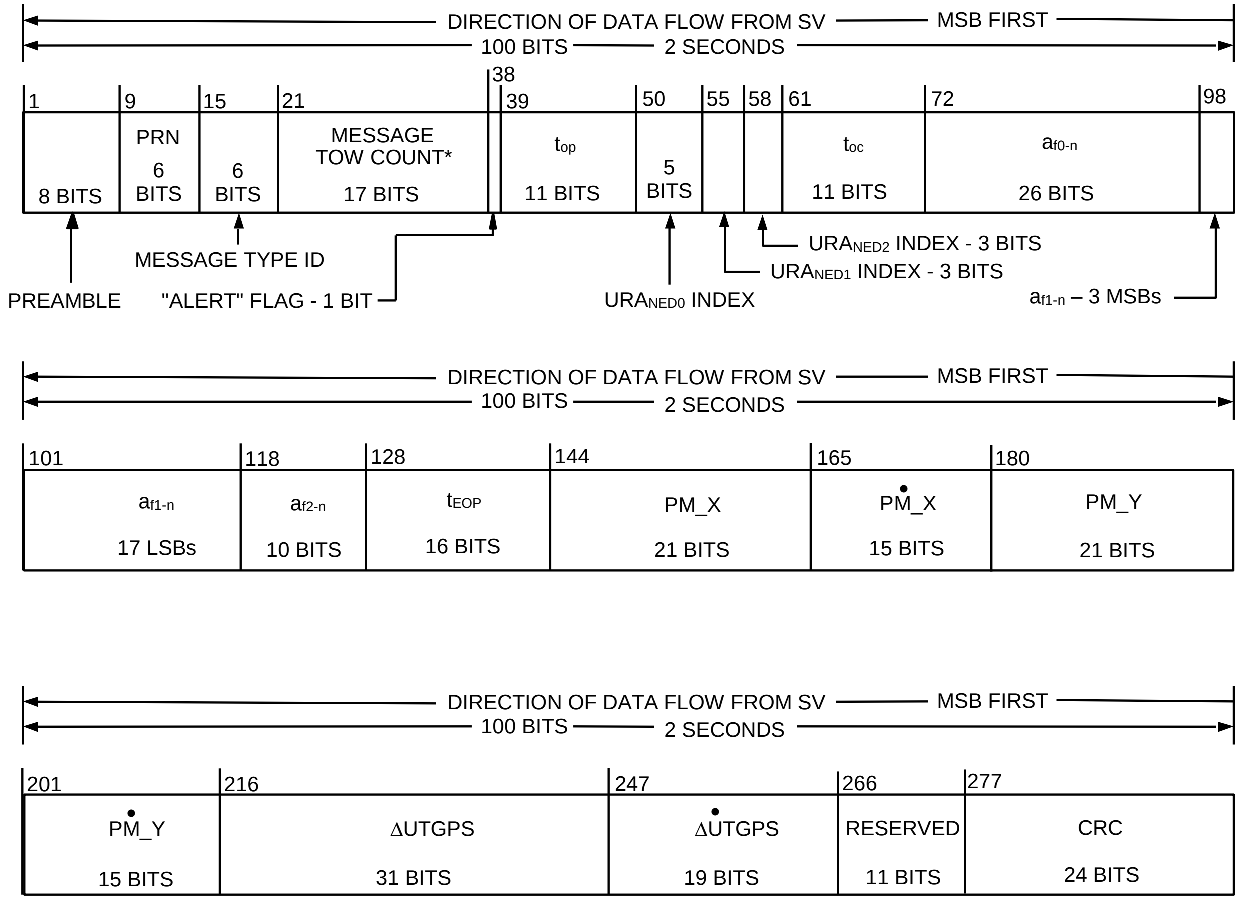
Redlines :



* MESSAGE TOW COUNT = 17 MSB OF ACTUAL TOW COUNT AT START OF NEXT 6-SECOND MESSAGE

Figure 20-5. Message Type 32 – Clock & EOP

IS :



* MESSAGE TOW COUNT = 17 MSB OF ACTUAL TOW COUNT AT START OF NEXT 6-SECOND MESSAGE

Figure 20-5. Message Type 32 – Clock & EOP

Rationale :

Change UT1-UTC difference and rate of UT1-UTC difference to use GPS time to simplify UT1 calculations. Update the variables here (namely PM_X, PM_Y, their drifts, and rate of UT1-GPS difference) to be consistent with the other instances of these variables elsewhere in the document.

IS705-320 :

Section Number :
20.3.3.5.1.1-1

WAS :
The EOP fields in the message type 32 contain the EOP data 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 20-II. The full coordinate transformation for translating to the corresponding ECI SV antenna phase center position may be accomplished in accordance with the computations detailed in Chapter 5 of IERS Technical Note 36: IERS Conventions (2010) and equations for UT1, x_p and y_p as documented in Table 20-VIII. Figure 5.1 on page 73 of that document depicts the computational flow starting from GCRS (Geocentric Celestial Reference System) to ITRS (International Terrestrial Reference System). Ongoing WGS 84 re-adjustment at NGA and incorporating the 2010 IERS Conventions, are expected to bring Earth based coordinate agreement to within 2 cm. In the context of the Conventions, the user may as a matter of convenience choose to implement the transformation computations via either the "Celestial Intermediate Origin (CIO) based approach" or the "Equinox based approach". The EOP parameters for ΔUT1 are to be applied within the "Rotation to terrestrial system" process, and the parameters for x_p and y_p are applied in the "Rotation for polar motion" process. Users are advised that the broadcast message type 32 EOP parameters already account for zonal, diurnal and semidiurnal effects (described in Chapter 8 of the IERS Conventions (2010)), so these effects should not be further applied by the user.

The relevant computations utilize elementary rotation matrices $R_i(\alpha)$, where α is a positive rotation about the i^{th}-axis ordinate, as follows:

$$R_1(\alpha) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\alpha) & \sin(\alpha) \\ 0 & -\sin(\alpha) & \cos(\alpha) \end{bmatrix}, \qquad R_2(\alpha) = \begin{bmatrix} \cos(\alpha) & 0 & -\sin(\alpha) \\ 0 & 1 & 0 \\ \sin(\alpha) & 0 & \cos(\alpha) \end{bmatrix}$$

$$R_3(\alpha) = \begin{bmatrix} \cos(\alpha) & \sin(\alpha) & 0 \\ -\sin(\alpha) & \cos(\alpha) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Redlines :
The EOP fields in the message type 32 contain the EOP data 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 20-II. The full coordinate transformation for translating to the corresponding ECI SV antenna phase center position may be accomplished in accordance with the computations detailed in Chapter 5 of IERS Technical Note 36: IERS Conventions (2010) and equations for UT1, x_p and y_p as documented in Table 20-VIII. For UT1, Table 20-VIII documents the relationship between GPS time and UT1 with ΔUTGPS and $\Delta\dot{U}$TGPS, which are provided in message type 32. Users who may need ΔUT1 (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. Figure 5.1 on page 73 of that document depicts the computational flow starting from GCRS (Geocentric Celestial Reference System) to ITRS (International Terrestrial Reference System). Ongoing WGS 84 re-adjustment at NGA and incorporating the 2010 IERS Conventions, are expected to bring Earth based coordinate agreement to within 2 cm. In the context of the Conventions, the user may as a matter of convenience choose to implement the transformation computations via either the "Celestial Intermediate Origin- (CIO) based approach" or the "Equinox based approach". The EOP parameters for UT1 are to be applied within the "Rotation to terrestrial system" process, and the parameters for x_p and y_p are applied in the "Rotation for polar motion" process. Users are advised that the broadcast message type 32 EOP parameters already account for zonal, diurnal and semidiurnal effects (described in Chapter 8 of the IERS Conventions (2010)), so these effects should not be further applied by the user. The EOP parameters are used to calculate UT1 (applied in the "Rotation to terrestrial system" process) and the polar motion parameters, x_p and y_p (applied in the "Rotation for polar motion" process). Details of the calculation are given in Table 20-VIII. Users are advised that the broadcast message type 32 EOP parameters 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.

The relevant computations utilize elementary rotation matrices $R_i(\alpha)$, where α is a positive rotation about the i^{th}-axis ordinate, as follows:

$$R_1(\alpha) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\alpha) & \sin(\alpha) \\ 0 & -\sin(\alpha) & \cos(\alpha) \end{bmatrix}, \qquad R_2(\alpha) = \begin{bmatrix} \cos(\alpha) & 0 & -\sin(\alpha) \\ 0 & 1 & 0 \\ \sin(\alpha) & 0 & \cos(\alpha) \end{bmatrix}$$

$$R_3(\alpha) = \begin{bmatrix} \cos(\alpha) & \sin(\alpha) & 0 \\ -\sin(\alpha) & \cos(\alpha) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

IS :
The EOP fields in the message type 32 contain the EOP data 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 20-II. The full coordinate transformation for translating to the corresponding ECI SV antenna phase center position may be accomplished in accordance with the computations detailed in Chapter 5 of IERS Technical Note 36: IERS Conventions (2010) and equations for UT1, x_p and y_p as documented in Table 20-VIII. For UT1, Table 20-VIII documents the relationship between GPS time and UT1 with ΔUTGPS and $\Delta\dot{U}TGPS$, which are provided in message type 32. Users who may need ΔUT1 (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. Figure 5.1 on page 73 of that document depicts the computational flow starting from GCRS (Geocentric Celestial Reference System) to ITRS (International Terrestrial Reference System). Ongoing WGS 84 re-adjustment at NGA and incorporating the 2010 IERS Conventions, are expected to bring Earth based coordinate agreement to within 2 cm. In the context of the Conventions, the user may as a matter of convenience choose to implement the transformation computations via either the "Celestial Intermediate Origin (CIO) based approach" or the "Equinox based approach". The EOP parameters are used to calculate UT1 (applied in the "Rotation to terrestrial system" process) and the polar motion parameters, x_p and y_p (applied in the "Rotation for polar motion" process). Details of the calculation are given in Table 20-VIII. Users are advised that the broadcast message type 32 EOP parameters 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.

The relevant computations utilize elementary rotation matrices $R_i(\alpha)$, where α is a positive rotation about the i^{th}-axis ordinate, as follows:

$$R_1(\alpha) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\alpha) & \sin(\alpha) \\ 0 & -\sin(\alpha) & \cos(\alpha) \end{bmatrix}, \qquad R_2(\alpha) = \begin{bmatrix} \cos(\alpha) & 0 & -\sin(\alpha) \\ 0 & 1 & 0 \\ \sin(\alpha) & 0 & \cos(\alpha) \end{bmatrix}$$

$$R_3(\alpha) = \begin{bmatrix} \cos(\alpha) & \sin(\alpha) & 0 \\ -\sin(\alpha) & \cos(\alpha) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Rationale :
Clarify that EOP parameters are for UT1 and provide additional information for calculating ΔUT1. Provide details for the definition of the new UTGPS terms and describe what effects have already been included in the EOP parameters. Add information to tell the user how often EOP data is uploaded and how the data will degrade over time if the CS is unable to upload the SVs.

IS705-322 :

Section Number :
20.3.3.5.1.1-4

WAS :

Table 20-VII. Earth Orientation Parameters

Parameter Symbol	Parameter Description	No. of Bits**	Scale Factor (LSB)	Valid Range***	Units
t_{EOP}	EOP Data Reference Time	16	2^{4}	0 to 604,784	seconds
PM_X †	X-Axis Polar Motion Value at Reference Time.	21*	2^{-20}		arc-seconds
$\dot{\text{PM}}$_X	X-Axis Polar Motion Drift at Reference Time.	15*	2^{-21}		arc-seconds/day
PM_Y ††	Y-Axis Polar Motion Value at Reference Time.	21*	2^{-20}		arc-seconds
$\dot{\text{PM}}$_Y	Y-Axis Polar Motion Drift at Reference Time.	15*	2^{-21}		arc-seconds/day
ΔUT1 †††	UT1-UTC Difference at Reference Time.	31*	2^{-24}		seconds
$\Delta\dot{\text{UT}}$1 †††	Rate of UT1-UTC Difference at Reference Time	19*	2^{-25}		seconds/day

* Parameters so indicated are two's complement, with the sign bit (+ or -) occupying the MSB;

** See Figure 20-5 for complete bit allocation in message type 32;

*** Unless otherwise indicated in this column, valid range is the maximum range attainable with indicated bit allocation and scale factor.

† 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.

††† With zonal tides restored.

Redlines :

Table 20-VII. Earth Orientation Parameters

Parameter Symbol	Parameter Description	No. of Bits**	Scale Factor (LSB)	Valid Range***	Units
t_{EOP}	EOP Data Reference Time	16	2^{4}	0 to 604,784	seconds
PM_X †, ††††	X-Axis Polar Motion Value at Reference Time.	21*	2^{-20}		arc-seconds
$\dot{P}$M_X ††††	X-Axis Polar Motion Drift at Reference Time.	15*	2^{-21}		arc-seconds/day
PM_Y ††, ††††	Y-Axis Polar Motion Value at Reference Time.	21*	2^{-20}		arc-seconds
$\dot{P}$M_Y ††††	Y-Axis Polar Motion Drift at Reference Time.	15*	2^{-21}		arc-seconds/day
ΔUT~~1~~GPS †††	~~UT1-UTC~~UT1-GPS Difference at Reference Time.	31*	~~2^{-24}~~ 2^{-23}		seconds
Δ$\dot{U}$T~~1~~GPS †††	Rate of ~~UT1-UTC~~UT1-GPS Difference at Reference Time.	19*	2^{-25}		seconds/day

* Parameters so indicated are two's complement, with the sign bit (+ or -) occupying the MSB;

** See Figure 20-5 for complete bit allocation in message type 32;

*** Unless otherwise indicated in this column, valid range is the maximum range attainable with indicated bit allocation and scale factor.

† 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.

††† ~~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.

IS :

Table 20-VII. Earth Orientation Parameters

Parameter Symbol	Parameter Description	No. of Bits**	Scale Factor (LSB)	Valid Range***	Units
t_{EOP}	EOP Data Reference Time	16	2^{4}	0 to 604,784	seconds
PM_X [†, ††††]	X-Axis Polar Motion Value at Reference Time.	21*	2^{-20}		arc-seconds
P$\dot{M}$_X [††††]	X-Axis Polar Motion Drift at Reference Time.	15*	2^{-21}		arc-seconds/day
PM_Y [††, ††††]	Y-Axis Polar Motion Value at Reference Time.	21*	2^{-20}		arc-seconds
P$\dot{M}$_Y [††††]	Y-Axis Polar Motion Drift at Reference Time.	15*	2^{-21}		arc-seconds/day
ΔUTGPS [†††]	UT1-GPS Difference at Reference Time.	31*	2^{-23}		seconds
$\Delta\dot{U}$TGPS [†††]	Rate of UT1-GPS Difference at Reference Time.	19*	2^{-25}		seconds/day

* Parameters so indicated are two's complement, with the sign bit (+ or -) occupying the MSB;

** See Figure 20-5 for complete bit allocation in message type 32;

*** Unless otherwise indicated in this column, valid range is the maximum range attainable with indicated bit allocation and scale factor.

† 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.

††† 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.

Rationale :
Change UT1-UTC difference and rate of UT1-UTC difference to use GPS time to simplify UT1 calculations. To be consistent with the notation of these parameters elsewhere in the document, the dots (for PM_X, PM_Y, and Delta UTGPS) have been moved over the second character in the term. Update the notes at the bottom of the table to make clear that the tides are already accounted for in the parameters.

IS705-324 :

Section Number :
20.3.3.5.1.1-6

WAS :

Table 20-VIII. Application of EOP Parameters

Element/Equation	Description
$UT1 = UTC + \Delta UT1 + \Delta \dot{UT1}\ (t - t_{EOP})$	Compute Universal Time at time t
$x_p = PM\_X + PM\ \dot{X}\ (t - t_{EOP})$	Polar Motion in the x-axis
$y_p = PM\_Y + PM\ \dot{Y}\ (t - t_{EOP})$	Polar Motion in the y-axis
t is GPS system time at time of transmission, i.e., GPS time corrected for transit time (range/speed of light).	

Redlines :

Table 20-VIII. Application of EOP Parameters

Element/Equation		Description
$t_{diff} = (t - t_{EOP} + 604800(WN - WN_{ot}))$	[seconds]	Compute difference between GPS time and EOP reference time
UT1 = ~~UTC~~t + 604800*WN + ~~ΔUT1~~ΔUTGPS + ~~$\Delta \dot{U}T1(t - t_{EOP})$*~~$\Delta\dot{U}TGPS*t_{diff}/86400$	[seconds]	Compute ~~Universal Time~~ UT1 at GPS time ~~t~~
x_p = PM_X + ~~$P\dot{M}X$~~$P\dot{M}\_X$*~~$(t - t_{EOP})$~~$t_{diff}/86400$	[arc-seconds]	Polar Motion in the x-axis
y_p = PM_Y + ~~$P\dot{M}Y$~~$P\dot{M}\_Y$*~~$(t - t_{EOP})$~~$t_{diff}/86400$	[arc-seconds]	Polar Motion in the y-axis

~~t is GPS system time at time of transmission, i.e., GPS time corrected for transit time (range/speed of light).~~
GPS system time (t) is expressed in seconds since start of current GPS week, and WN is the current week number expressed in weeks since GPS epoch.
The divisor 86400 converts rates per day to rates per second.

IS :

Table 20-VIII. Application of EOP Parameters

Element/Equation		Description
$t_{diff} = (t - t_{EOP} + 604800(WN - WN_{ot}))$	[seconds]	Compute difference between GPS time and EOP reference time
$UT1 = t + 604800*WN + \Delta UTGPS + \Delta\dot{U}TGPS*t_{diff}/86400$	[seconds]	Compute UT1 at GPS time
x_p = PM_X + $P\dot{M}\_X*t_{diff}/86400$	[arc-seconds]	Polar Motion in the x-axis
y_p = PM_Y + $P\dot{M}\_Y*t_{diff}/86400$	[arc-seconds]	Polar Motion in the y-axis

GPS system time (t) is expressed in seconds since start of current GPS week, and WN is the current week number expressed in weeks since GPS epoch.
The divisor 86400 converts rates per day to rates per second.

Rationale :
Update equations to calculate UT1 based on GPS time to avoid leap second discontinuities. Convert rates per day to rates per second by dividing by 86400.

IS705-1529 :

Section Number :
20.3.3.5.1.1-8 (inserted after IS705-324):

Table 20-VIII. Application of EOP Parameters

Element/Equation	Description
$UT1 = UTC + \Delta UT1 + \Delta \dot{UT1}\ (t - t_{EOP})$	Compute Universal Time at time t
$x_p = PM\_X + PM\ \dot{X}\ (t - t_{EOP})$	Polar Motion in the x-axis
$y_p = PM\_Y + PM\ \dot{Y}\ (t - t_{EOP})$	Polar Motion in the y-axis
t is GPS system time at time of transmission, i.e., GPS time corrected for transit time (range/speed of light).	

WAS :
N/A

Redlines :
<INSERTED OBJECT>

IS :
When calculating UT1, x_p, and y_p in Table 20-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 for the calculations in Table 20-VIII.

Rationale :
Originally inserted in RFC-354 and further modifications provided in RFC-400. Provide detailed instructions to the user on how to use corresponding EOP and UTC messages given the current implementation of linking the EOP and UTC messages.