

PROPOSED CHANGE NOTICE

Affected Document: IS-GPS-200J	IRN/SCN Number xxx-xxx-xxxx	Date: 07-MAY-2019
Authority: RFC-00400	Proposed Change Notice IS200J_RFC400	Date: 20-DEC-2018

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

Document Title: NAVSTAR GPS Space Segment / Navigation User Interfaces

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 and CNAV-2 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. 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.

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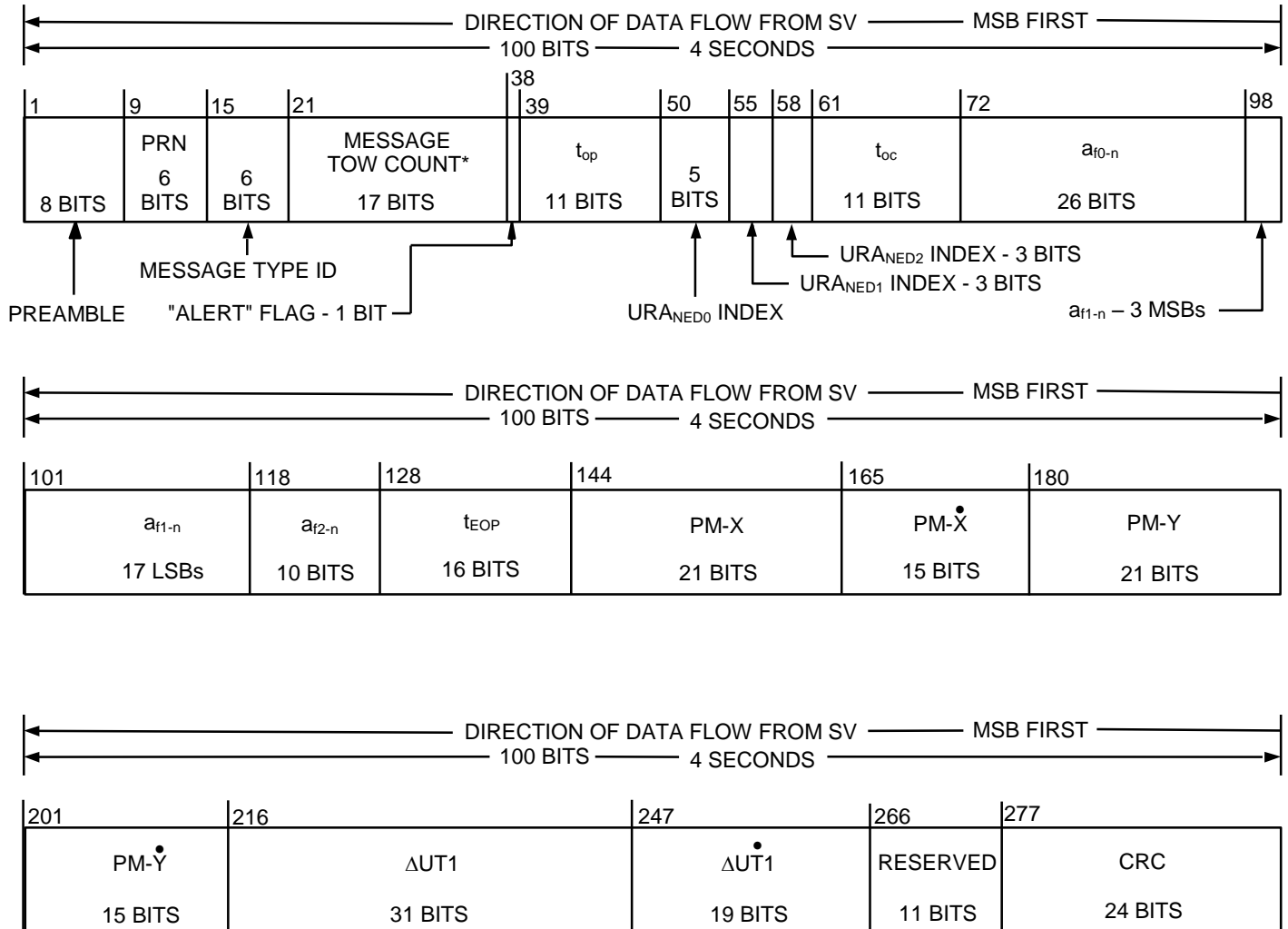
CODE IDENT 66RP1

IS200-520 :

Section Number :

30.3.3.0-10

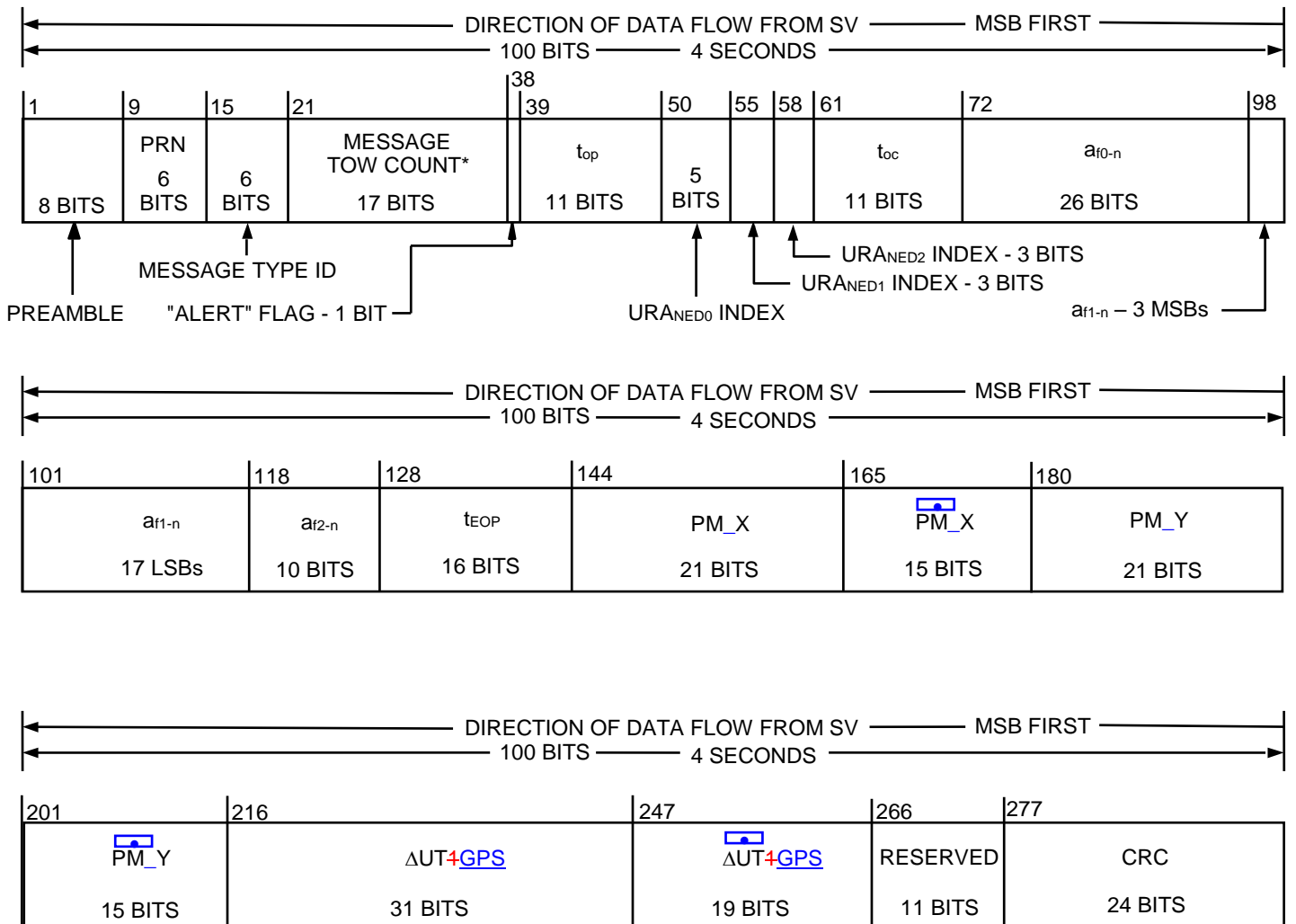
WAS :



* MESSAGE TOW COUNT = 17 MSB OF ACTUAL TOW COUNT AT START OF NEXT 12-SECOND MESSAGE

Figure 30-5. Message Type 32 – Clock and EOP

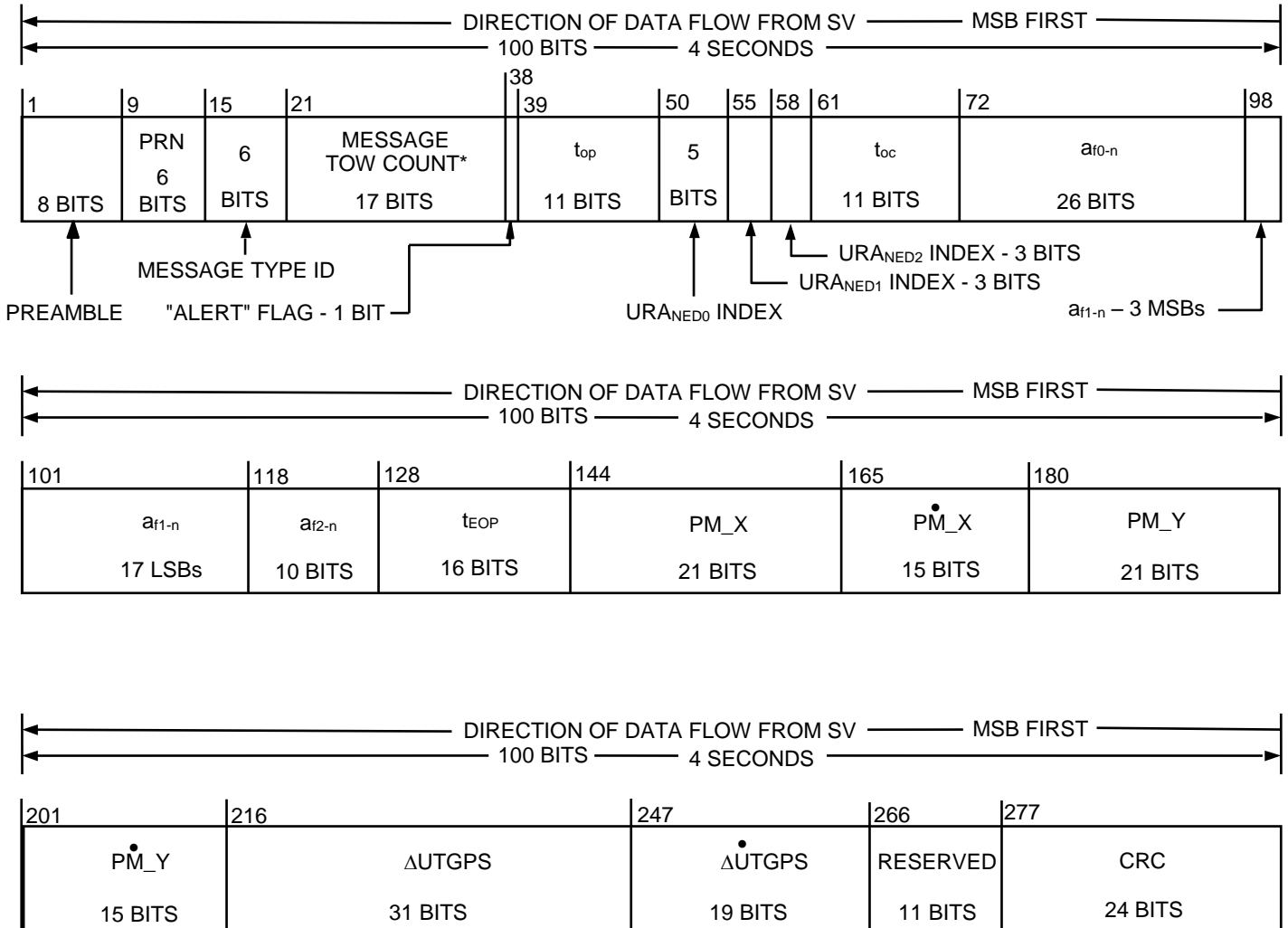
Redlines :



* MESSAGE TOW COUNT = 17 MSB OF ACTUAL TOW COUNT AT START OF NEXT 12-SECOND MESSAGE

Figure 30-5. Message Type 32 – Clock and EOP

IS :



* MESSAGE TOW COUNT = 17 MSB OF ACTUAL TOW COUNT AT START OF NEXT 12-SECOND MESSAGE

Figure 30-5. Message Type 32 – Clock and EOP

Rationale :

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

IS200-618 :

Section Number :

30.3.3.5.1.1.0-1

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 30-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 30-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 $\Delta UT1$ 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.

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 30-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 30-VIII. [For UT1, Table 30-VIII documents the relationship between GPS time and UT1 with \$\Delta UT_{GPS}\$ and \$\Delta \dot{U}T_{GPS}\$. 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.](#) 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 $\Delta UT1$ 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 EOPs 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 30-VIII. 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-n}\$, \$A_{1-n}\$, \$A_{2-n}\$ and the leap second count in Message Type 33](#)

[EOPs that are not updated by the CS will degrade in accuracy over time.](#)

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 30-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 30-VIII. For UT1, Table 30-VIII documents the relationship between GPS time and UT1 with ΔUTGPS and $\Delta\dot{\text{UTGPS}}$. 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 EOPs 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 30-VIII. 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-n} , A_{1-n} , A_{2-n} and the leap second count in Message Type 33

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

Rationale :

Clarify that EOPs 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 EOPs.

Add information to tell the user the data will degrade over time if the CS is unable to update the EOPs.

IS200-621 :

Section Number :

30.3.3.5.1.1.0-5

WAS :

Table 30-VII. Earth Orientation Parameters

Parameter		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^\dagger	X-Axis Polar Motion Value at Reference Time.	21*	2^{-20}		arc-seconds
$\dot{PM_X}$	X-Axis Polar Motion Drift at Reference Time.	15*	2^{-21}		arc-seconds/day
$PM_Y^{\dagger\dagger}$	Y-Axis Polar Motion Value at Reference Time.	21*	2^{-20}		arc-seconds
$\dot{PM_Y}$	Y-Axis Polar Motion Drift at Reference Time.	15*	2^{-21}		arc-seconds/day
$\Delta UT1^{\dagger\dagger\dagger}$	UT1-UTC Difference at Reference Time.	31*	2^{-24}		seconds
$\dot{\Delta UT1}^{\dagger\dagger\dagger}$	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 30-5 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 30-VII. Earth Orientation Parameters

Parameter		No. of Bits**	Scale Factor (LSB)	Valid Range***	Units
t_{EOP}	EOP Data Reference Time	16	2^4	0 to 604,784	seconds
$PM_X^{\dagger, \dagger\dagger\dagger}$	X-Axis Polar Motion Value at Reference Time.	21*	2^{-20}		arc-seconds
$\dot{PM}_X^{\dagger\dagger\dagger}$	X-Axis Polar Motion Drift at Reference Time.	15*	2^{-21}		arc-seconds/day
$PM_Y^{\dagger\dagger, \dagger\dagger\dagger}$	Y-Axis Polar Motion Value at Reference Time.	21*	2^{-20}		arc-seconds
$\dot{PM}_Y^{\dagger\dagger\dagger}$	Y-Axis Polar Motion Drift at Reference Time.	15*	2^{-21}		arc-seconds/day
$\Delta UT - GPS^{\dagger\dagger\dagger}$	UT - UTC UT1 - GPS Difference at Reference Time.	31*	$2^{-24.23}$		seconds
$\dot{\Delta UT} - GPS^{\dagger\dagger\dagger}$	Rate of UT - UTC UT1 - GPS Difference at Reference Time.	19*	2^{-25}		seconds/day
<p>* Parameters so indicated are two's complement, with the sign bit (+ or -) occupying the MSB;</p> <p>** See Figure 30-5 for complete bit allocation in Message Type 32;</p> <p>*** Unless otherwise indicated in this column, valid range is the maximum range attainable with indicated bit allocation and scale factor.</p> <p>† Represents the predicted angular displacement of instantaneous Celestial Ephemeris <u>Intermediate</u> Pole with respect to semi-minor axis of the reference ellipsoid along Greenwich meridian.</p> <p>†† Represents the predicted angular displacement of instantaneous Celestial Ephemeris <u>Intermediate</u> Pole with respect to semi-minor axis of the reference ellipsoid on a line directed 90° west of Greenwich meridian.</p> <p>††† With zonal tides restored. <u>Already account for zonal, diurnal, and semi-diurnal tides and should not be further applied by the user.</u></p> <p>†††† <u>Already account for diurnal and semi-diurnal tides and should not be further applied by the user.</u></p>					

IS :

Table 30-VII. Earth Orientation Parameters

Parameter		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{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{PM}_Y ††††	Y-Axis Polar Motion Drift at Reference Time.	15*	2^{-21}		arc-seconds/day
$\Delta UTGPS$ †††	UT1-GPS Difference at Reference Time.	31*	2^{-23}		seconds
$\dot{\Delta UTGPS}$ †††	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 30-5 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 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.

††† 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 its rate to be in terms of GPS time to simplify UT1 calculations. Left align the footnotes to be consistent with other table formatting, and move the dot over the U for $\Delta UTGPS$ for consistency. Update the notes at the bottom of the table to make clear that the tides are already accounted for in the parameters.

In addition, 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)"

IS200-1619 :

Section Number :

30.3.3.5.1.1.0-6

WAS :

Table 30-VIII. Application of EOP Parameters

Redlines :

Table 30-VIII. Application of ~~EOP Parameters~~[EOPs](#)

IS :

Table 30-VIII. Application of EOPs

Rationale :

Administrative: remove redundancy with "EOP Parameters."

IS200-623 :

Section Number :

30.3.3.5.1.1.0-7

WAS :

Table 30-VIII. Application of EOP Parameters

Element/Equation	Description
$UT1 = UTC + \Delta UT1 + \dot{\Delta UT1} (t - t_{EOP})^*$	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
<p>*t is GPS system time at time of transmission, i.e., GPS time corrected for transit time (range/speed of light). Furthermore, the quantity (t-t_{EOP}) shall be the actual total time difference between the time t and the epoch time t_{EOP}, and must account for beginning or end of week crossovers. That is, if (t-t_{EOP}) is greater than 302,400 seconds, subtract 604,800 seconds from (t-t_{EOP}). If (t-t_{EOP}) is less than -302,400 seconds, add 604,800 seconds to (t-t_{EOP}).</p>	

Redlines :

Table 30-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
$UT1 = UTC_t + 604800*WN + \Delta UT1 + \Delta \dot{UT1}(t - t_{EOP}) * \Delta UTGPS * t_{diff} / 86400$ [seconds]	Compute Universal Time UT1 at GPS time-t
$x_p = PM_X + PM \dot{X}(t - t_{EOP}) * PM_X * t_{diff} / 86400$ [arc-seconds]	Polar Motion in the x-axis
$y_p = PM_Y + PM \dot{Y}(t - t_{EOP}) * PM_Y * t_{diff} / 86400$ [arc-seconds]	Polar Motion in the y-axis
<p>— *t is GPS system time at time of transmission, i.e., GPS time corrected for transit time (range/speed of light). — Furthermore, the quantity (t - t_{EOP}) shall be the actual total time difference between the time t and the epoch time t_{EOP}, and must account for beginning or end of week crossovers. That is, if (t - t_{EOP}) is greater than 302,400 seconds, subtract 604,800 seconds from (t - t_{EOP}). If (t - t_{EOP}) is less than -302,400 seconds, add 604,800 seconds to (t - t_{EOP}). <u>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.</u> <u>The divisor 86400 converts rates per day to rates per second.</u></p>	

IS :

Table 30-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
$UT1 = t + 604800*WN + \Delta UTGPS + \Delta \dot{UTGPS} * t_{diff} / 86400$ [seconds]	Compute UT1 at GPS time
$x_p = PM_X + PM \dot{X} * t_{diff} / 86400$ [arc-seconds]	Polar Motion in the x-axis
$y_p = PM_Y + PM \dot{Y} * t_{diff} / 86400$ [arc-seconds]	Polar Motion in the y-axis
<p>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.</p>	

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.

IS200-1672 :

Section Number :

30.3.3.5.1.1.0-8, after IS200-623 (see previous):

WAS :

N/A

Redlines :

<INSERTED OBJECT>

IS :

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.

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 to use a week number for EOP data.
