Change Topic: Technical Note 36

This change package accommodates the text changes to support the proposed solution (see table below) within the public Signals-in-Space (SiS) documents. All comments must be submitted in Comments Resolution Matrix (CRM) form.

The columns in the WAS/IS table following this page are defined below:

Section Number: This number indicates the location of the text change within the document.

(WAS) <Document Title>: Contains the baseline text of the impacted document.

Proposed Heading: Contains proposed changes to existing section titles and/or the titles to new sections

Proposed Text: Contains proposed changes to baseline text.

Rationale: Contains the supporting information to explain the reason for the proposed changes.

PROBLEM STATEMENT:
Current Signal in Space (SiS) documents reference an outdated coordinate conversion standard (Technical Note 21) between earth centered earth fixed (ECEF) and earth centered inertial (ECI).
SOLUTION: *(Proposed)*
Update GPS technical baseline documents to reflect the latest coordinate conversion standard between ECEF and ECI as documented in Technical Note 36.

Start of WAS/IS for IS-GPS-200E Changes

Section Number	IS-GPS-200 Rev E Navstar GPS Space Segment/Navigation User Interfaces	Proposed Heading	Tech Note 36 Proposed Text	Rationale
30.3.3.5.1	Message type 32, Figure 30-5, provides SV clock correction parameters (ref. Section 30.3.3.2) and earth orientation parameters. The EOP message provides users with parameters to construct the ECEF and ECI coordinate transformation (a simple transformation method is defined in Section 20.3.3.4.3.3.2). The number of bits, scale factors (LSBs), the range, and the units of all EOP fields of message type 32 are given in Table 30-VII. The equations described in this section are based on (International Earth Rotation and Reference Systems Service) IERS Technical Note 21. However, these equations will be updated to a new Technical Note in the next revision.		Message type 32, Figure 30-5, provides SV clock correction parameters (ref. Section 30.3.3.2) and earth orientation parameters. The EOP message provides users with parameters to construct the ECEF and ECI coordinate transformation (a simple transformation method is defined in Section 20.3.3.4.3.3.2). The number of bits, scale factors (LSBs), the range, and the units of all EOP fields of message type 32 are given in Table 30-VII.	The GPS Directorate will only provide description on information that is broadcasted in the navigational message. It is not Directorate's responsibility to show users on how to utilize that information.
30.3.3.5.1.1	The EOP fields in the message type 32 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 30-II. The coordinate transformation, for translating to the corresponding ECI SV antenna phase center position, is derived using the equations shown in Table 30-VIII. The coordinate systems are defined in Section 20.3.3.4.3.3		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, xp and yp 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 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 GPS Directorate will only provide description on information that is broadcasted in the navigational message. It is not Directorate's responsibility to show users on how to utilize that information. Details for the calculation of Inertial-to-Geodetic rotation matrix can be found in IERS TN36.
30.3.3.5.1.	An ECI position, R_{eci}, is related to an ECEF position, R_{ecef}, by a series of rotation matrices as		The relevant computations utilize elementary rotation matrices $R_i(\alpha)$, where α is a positive	The GPS Directorate will

Section Number	IS-GPS-200 Rev E Navstar GPS Space Segment/Navigation User Interfaces	Proposed Heading	Tech Note 36 Proposed Text	Rationale
1	following: $R_{ecef} = [A][B][C][D]\, R_{eci}$ where the rotation matrices, A, B, C, and D, represent the effects of Polar Motion, Earth Rotation, Nutation and Precession, respectively. The message type 32 specifies the EOP parameters used in the construction of the Polar Motion, A, and Earth Rotation, B, matrices. The rotation matrices, A, B, C and D are specified in terms of elementary rotation matrices, $R_i(\alpha)$, where α is a positive rotation about the i^{th}-axis ordinate, as follows: $R_1(\alpha) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\alpha) & \sin(\alpha) \\ 0 & -\sin(\alpha) & \cos(\alpha) \end{bmatrix}$, $R_2(\alpha) = \begin{bmatrix} \cos(\alpha) & 0 & -\sin(\alpha) \\ 0 & 1 & 0 \\ \sin(\alpha) & 0 & \cos(\alpha) \end{bmatrix}$ $R_3(\alpha) = \begin{bmatrix} \cos(\alpha) & \sin(\alpha) & 0 \\ -\sin(\alpha) & \cos(\alpha) & 0 \\ 0 & 0 & 1 \end{bmatrix}$		rotation about the i^{th}-axis ordinate, as follows: $R_1(\alpha) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\alpha) & \sin(\alpha) \\ 0 & -\sin(\alpha) & \cos(\alpha) \end{bmatrix}$, $R_2(\alpha) = \begin{bmatrix} \cos(\alpha) & 0 & -\sin(\alpha) \\ 0 & 1 & 0 \\ \sin(\alpha) & 0 & \cos(\alpha) \end{bmatrix}$ $R_3(\alpha) = \begin{bmatrix} \cos(\alpha) & \sin(\alpha) & 0 \\ -\sin(\alpha) & \cos(\alpha) & 0 \\ 0 & 0 & 1 \end{bmatrix}$	only provide description on information that is broadcasted in the navigational message. It is not Directorate's responsibility to show users on how to utilize those information. Details for the calculation of Inertial-to-Geodetic rotation matrix can be found in IERS TN36.
30.3.3.5.1.1	The user shall compute the Inertial-to-Geodetic rotation matrix, ABCD using the equations shown in Table 30-VIII.		The Inertial-to-Geodetic rotation matrix shall be calculated in accordance with the computations detailed in Chapter 5 of IERS Technical Note 36: IERS Conventions (2010) and equations for UT1, xp and yp as documented in Table 30-VIII.	The GPS Directorate will only provide description on information that is broadcasted in the navigational message. It is not Directorate's responsibility to show users on how to utilize those information. Details for the calculation of Inertial-to-Geodetic rotation matrix can be

<table>
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<tr><td></td><td></td><td></td><td></td><td>found in IERS TN36.</td></tr>
<tr><td>30.3.3.5.1.1</td><td>
<table>
<tr><th colspan="2">Table 30-VIII. Application of EOP Parameters (Part 1 of 2)</th></tr>
<tr><th>Element/Equation</th><th>Description</th></tr>
<tr><td>$TDT = t + 51^{s}.184$</td><td>Compute Terrestrial Dynamical Time relative to GPS Time t</td></tr>
<tr><td>J.E.D. = TDT expressed in days of 86400 sec</td><td>Compute Julian Ephemeris Date</td></tr>
<tr><td>$g = \frac{\pi}{180^\circ}\left[357^\circ.528 + 35999^\circ.05\,\frac{J.E.D. - 2451545}{36525}\right]$</td><td>Compute Mean Anomaly of Earth in its orbit, g</td></tr>
<tr><td>$J.B.D. = J.E.D. + \frac{0^{s}.001658\sin(g + 0.0167\sin g)}{86400s}$</td><td>Compute Julian Date in Barycentric Dynamical Time</td></tr>
<tr><td>$T = \frac{J.B.D. - 2451545}{36525}$</td><td>Compute time from J2000 Julian Epoch in Julian Centuries</td></tr>
<tr><td>$\zeta = 2306''.2181\,T + 0''.30188\,T^2 + 0''.017998\,T^3$
$z = 2306''.2181\,T + 1''.09468\,T^2 + 0''.018203\,T^3$
$\theta = 2004''.3109\,T - 0''.42665\,T^2 - 0''.041833\,T^3$</td><td>Compute Precession Fundamental Angles at time t</td></tr>
<tr><td>$D = R_3\left(-90^{o} - z\right) R_1(\theta)\, R_3\left(90^{o} - \zeta\right)$</td><td>Calculate Precession Matrix at time, t</td></tr>
<tr><td>$\bar{\varepsilon} = 23^\circ 26' 21''.448 - 46''.815\,T - 0''.00059\,T^2 + 0''.001813\,T^3$</td><td>Compute Mean Obliquity, $\bar{\varepsilon}$, at time t</td></tr>
<tr><td>$C = R_1\left(-(\bar{\varepsilon} + \Delta\varepsilon)\right) R_3(-\Delta\psi)\, R_1(\bar{\varepsilon})$</td><td>Compute Nutation Matrix at time, t</td></tr>
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Details for the calculation of Inertial-to-Geodetic rotation matrix can be found in IERS TN36.</td></tr>
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<table>
<tr><th colspan="2">Table 30-VIII. Application of EOP Parameters (Part 2 of 2)</th></tr>
<tr><th>Element/Equation</th><th>Description</th></tr>
<tr><td>$\Delta\psi = \sum_{i=1}^{106} a_i \sin\left(\sum_{j=1}^{5} e_j E_j\right)$ ††</td><td>Nutation in Longitude</td></tr>
<tr><td>$\Delta\varepsilon = \sum_{i=1}^{64} b_i \cos\left(\sum_{j=1}^{5} e_j E_j\right)$ ††</td><td>Nutation in Obliquity</td></tr>
<tr><td>$UT1 = UTC + \Delta UT1 + \Delta \dot{UT1}\ (t - t_{EOP})$</td><td>Compute Universal Time at time t</td></tr>
<tr><td>$T_U = \frac{J.D. - 2451545}{36525}$
where J.D. = UT1 expressed in days of 86400 sec</td><td>Compute Universal Time from J2000 Julian Epoch in Julian Centuries</td></tr>
<tr><td>$\bar{\alpha} = \frac{2\pi}{24^h}\left(\begin{array}{l} UT1 + 6^h41^m50^s.54841 \\ + 8640184^s.812866 T_U \\ + 0^s.093104 T_U^2 - 6^s.2\times10^{-6} T_U^3 \end{array}\right)$</td><td>Compute Mean Greenwich Hour Angle</td></tr>
<tr><td>$\alpha = \bar{\alpha} + \Delta\psi \cos(\bar{\varepsilon} + \Delta\varepsilon)$</td><td>Compute True Greenwich Hour Angle</td></tr>
<tr><td>$B = R_3(\alpha)$</td><td>Compute Rotation Matrix at time, t</td></tr>
<tr><td>$A = R_2(-x_p)\ R_1(-y_p)$
where $x_p = PM\_\dot{X} + PM\_X\ (t - t_{EOP})$
$y_p = PM\_\dot{Y} + PM\_Y\ (t - t_{EOP})$</td><td>Compute Polar Motion Matrix at time, t</td></tr>
<tr><td>$ABCD = [A][B][C][D]$</td><td>Compute Inertial-to-Geodetic Rotation matrix, ABCD</td></tr>
<tr><td colspan="2">t is GPS system time at time of transmission, i.e., GPS time corrected for transit time (range/speed of light).

†† The Nutation in Longitude and the Nutation in Obliquity are as described in The Astronomical Almanac (1983), pp. S23-S26, evaluated at time T.</td></tr>
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<tr><td>$y_p = PM\_Y + PM\ \dot{Y}\ (t - t_{EOP})$</td><td>Polar Motion in the y-axis</td></tr>
<tr><td colspan="2">t is GPS system time at time of transmission, i.e., GPS time corrected for transit time (range/speed of light).</td></tr>
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Details for the calculation of Inertial-to-Geodetic rotation matrix can be found in IERS TN36.</td>
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End of WAS/IS for IS-GPS-200E

Start of WAS/IS for IS-GPS-705A Changes

Section Number	**IS-GPS-705 Rev A L5 SS and Nav User Segment Interfaces**	**Proposed Heading**	**Tech Note 36 Proposed Text**	**Rationale**
20.3.3.5.1	An ECI position, R_{eci}, is related to an ECEF position, R_{ecef}, by a series of rotation matrices as following: $R_{ecef} = [A][B][C][D]R_{eci}$, where the rotation matrices, A, B, C, and D, represent the effects of Polar Motion, Earth Rotation, Nutation and Precession, respectively. The message type 32 specifies the EOP parameters used in the construction of the Polar Motion, A, and Earth Rotation, B, matrices. The rotation matrices, A, B, C and D are specified in terms of elementary rotation matrices $R_i(\alpha)$, where α is a positive rotation about the i^{th} - axis ordinate, as follows: $R_1(\alpha) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\alpha) & \sin(\alpha) \\ 0 & -\sin(\alpha) & \cos(\alpha) \end{bmatrix}$, $R_2(\alpha) = \begin{bmatrix} \cos(\alpha) & 0 & -\sin(\alpha) \\ 0 & 1 & 0 \\ \sin(\alpha) & 0 & \cos(\alpha) \end{bmatrix}$ $R_3(\alpha) = \begin{bmatrix} \cos(\alpha) & \sin(\alpha) & 0 \\ -\sin(\alpha) & \cos(\alpha) & 0 \\ 0 & 0 & 1 \end{bmatrix}$		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, xp and yp 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: $R_1(\alpha) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\alpha) & \sin(\alpha) \\ 0 & -\sin(\alpha) & \cos(\alpha) \end{bmatrix}$, $R_2(\alpha) = \begin{bmatrix} \cos(\alpha) & 0 & -\sin(\alpha) \\ 0 & 1 & 0 \\ \sin(\alpha) & 0 & \cos(\alpha) \end{bmatrix}$ $R_3(\alpha) = \begin{bmatrix} \cos(\alpha) & \sin(\alpha) & 0 \\ -\sin(\alpha) & \cos(\alpha) & 0 \\ 0 & 0 & 1 \end{bmatrix}$	The GPS Directorate will only provide description on information that is broadcasted in the navigational message. It is not Directorate's responsibility to show users on how to utilize that information.
20.3.3.5.	The user shall compute the Inertial-to-Geodetic rotation matrix, ABCD using the equations shown in		The Inertial-to-Geodetic rotation matrix shall be calculated in accordance with the	The GPS

Section Number	IS-GPS-705 Rev A L5 SS and Nav User Segment Interfaces	Proposed Heading	Tech Note 36 Proposed Text	Rationale
1	Table 20-VIII.		computations detailed in Chapter 5 of IERS Technical Note 36: IERS Conventions (2010) and equations for UT1, xp and yp as documented in Table 20-VIII.	Directorate will only provide description on information that is broadcasted in the navigational message. It is not Directorate's responsibility to show users on how to utilize that information. Details for the calculation of Inertial-to-Geodetic rotation matrix can be found in IERS TN36.

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$\theta = 2004''.3109\,T - 0''.42665\,T^2 - 0''.041833\,T^3$</td><td>Compute Precession Fundamental Angles at time t</td></tr>
<tr><td>$D = R_3\left(-90^{o} - z\right) R_1(\theta)\, R_3\left(90^{o} - \zeta\right)$</td><td>Calculate Precession Matrix at time, t</td></tr>
<tr><td>$\bar{\varepsilon} = 23^\circ 26' 21''.448 - 46''.815\,T - 0''.00059\,T^2 + 0''.001813\,T^3$</td><td>Compute Mean Obliquity, $\bar{\varepsilon}$, at time t</td></tr>
<tr><td>$C = R_1\left(-(\bar{\varepsilon} + \Delta\varepsilon)\right) R_3(-\Delta\psi)\, R_1(\bar{\varepsilon})$</td><td>Compute Nutation Matrix at time, t</td></tr>
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<tr><td>$\alpha = \bar{\alpha} + \Delta\psi \cos(\bar{\varepsilon} + \Delta\varepsilon)$</td><td>Compute True Greenwich Hour Angle</td></tr>
<tr><td>$B = R_3(\alpha)$</td><td>Compute Rotation Matrix at time, t</td></tr>
<tr><td>$A = R_2(-x_p)\,R_1(-y_p)$
where $x_p = PM\_X + PM\_\dot{X}(t - t_{EOP})$
$y_p = PM\_Y + PM\_\dot{Y}(t - t_{EOP})$</td><td>Compute Polar Motion Matrix at time, t</td></tr>
<tr><td>$ABCD = [A][B][C][D]$</td><td>Compute Inertial-to-Geodetic Rotation matrix, ABCD</td></tr>
<tr><td colspan="2">t is GPS system time at time of transmission, i.e., GPS time corrected for transit time (range/speed of light).
†† The Nutation in Longitude and the Nutation in Obliquity are as described in The Astronomical Almanac (1983), pp. S23-S26, evaluated at time T.</td></tr>
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<tr><td>$y_p = PM\_Y + PM\ \dot{Y}\ (t - t_{EOP})$</td><td>Polar Motion in the y-axis</td></tr>
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End of WAS/IS for IS-GPS-705A

Start of WAS/IS for IS-GPS-800A Changes

Section Number	IS-GPS-800 Rev A Navstar GPS Space Segment/User Segment L1C Interface	Proposed Heading	Tech Note 36 Proposed Text	Rationale
2.2			IERS Technical Note 36 International Earth Rotation and Reference System Technical Note 36	ECEF-ECI conversion details can be found in IERS TN36.
3.5.4.2.3	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 Section 30.3.3.5.1.1 and Table 30-VIII of IS-GPS-200. The coordinate systems are defined in Section 20.3.3.4.3.3 of IS-GPS-200.		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. The coordinate systems are defined in Section 20.3.3.4.3.3 of IS-GPS-200.	ECEF-ECI conversion details can be found in IERS TN36.

End of WAS/IS for IS-GPS-800A