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List of Symbols

$M_{90}$ - degree of modulation of the 90 Hz component
$M_{150}$ - degree of modulation of the 150 Hz component
$E_{SBO}$ - amplitude of the SBO signal
$E_{CSB}$ - amplitude of the CSB signal
$\phi_1$ - carrier phase range due to L1 signal
$\phi_2$ - carrier phase range due to L2 signal
$\phi_e$ - phase error
$\phi_r$ - RF phase angle between $E_{SBO}$ and $E_{CSB}$
$\lambda$ - true wavelength
$V$ - velocity of the EM wave
$V_o$ - velocity of the observer moving towards the source
$f_a$ - frequency of the source
$r$ - radius of the antenna ring
$f$ - orbital frequency
$a_0$ - clock bias term
$a_1$ - clock drift term
$a_2$ - clock drift rate
$t_{oe}$ - reference epoch for the definition of the coefficients
$b_{SI}$ - Satellite differential delay
$b_{Rk}$ - Receiver differential delay
$b_i$ - setting receiver bias
$b_{Rksi}$ - combined bias
$G_r$ - receiving antenna gain
$L_a$ - attenuation in atmosphere
$L_{ta}$ - attenuation due to transmitting antenna
$L_{ra}$ - attenuation due to receiving antenna
$L_p$ - free space loss
$P_r$ - received power
$P_t$ - transmitted power
TEC_{ak} - slant TEC from the receiver k to the satellite i,
E - elevation angle from the receiver k to the tracked satellite i,
TEC_{vi} - vertical TEC at the ionospheric pierce point due to the satellite i.
SPR - Satellite-plus-receiver differential delay
SV_{SF_{i}} - SF of satellite vehicle number 'n' observed from receiver k to the satellite i
TEC_{vi} - vertical TEC at the ionospheric pierce point due to the satellite i.
SV_{ITEC_{n}} - measured slant TEC of SV1 at n^{th} epoch
R - upper triangular matrix
R_{a} - satellite altitude above the earth surface
I - identity matrix
d_{i} - day mean satellite differential delay
\sigma_{d_{i}} - standard deviations of biases
\bar{\sigma}_{d_{i}} - mean of \sigma_{d_{i}}
\sigma_{TEC} - standard deviation of TECs
\Sigma \sigma_{TEC} - sum of all \sigma_{TEC}
\rho_{m} - measured range
\rho - true range
T^{s} - time of transition
N_{1} - Phase ambiguity of L1 signal
N_{2} - Phase ambiguity of L2 signal
N - electron density (el/m^{2})
\Delta_{ion} - ionospheric delay
A_{k} - sum of geometric range, tropospheric error and clock error (m)
P - period of ionospheric delay function
A_{m} - amplitude of ionospheric delay function
A_{a} - aperture area of the receiving antenna (m^{2})
G_{a} - antenna with gain
DC - base ionospheric delay
t_{ion} - ionospheric time delay in the zenith direction
\phi_{om} - geomagnetic latitude of ionospheric subpoint
\epsilon^{ec} - satellite clock error
k - Boltzmann's constant dBW/K/Hz
F - Noise figure of the LNA
T_0 - Temperature of the device in degree Kelvin
B - Noise bandwidth in Hz
P_N - Noise power
\Pi_i - measurement error
A(n) - input sequence
\Sigma - diagonal matrix
Q - orthogonal matrix
\theta - angle measured counter clock wise from observer (O) to the source (S)
V_s - velocity of the source (S) moving towards the observer (O)
\Delta f_s - frequency deviation
f_c - radio frequency carrier
\phi_r - RF phase angle between SBO and CSB signals
\rho - geometric range between the satellite and receiver antenna in m
\phi_{rs} - latitude of reference station
d\rho - satellite orbit error in m
c - the speed of light (m/sec.)
dt - satellite clock error in sec.
dT - receiver clock error in sec.
dion - ionospheric delay error in m,
dtrop - tropospheric delay error in m,
\varepsilon_{mp} - code range multipath error in m
\varepsilon_{m\phi} - carrier phase multipath error in m
\varepsilon_\phi - receiver carrier noise in m.
d_{trop} - total tropospheric delay
d_{dry} - dry delay at zenith
d_{wet} - wet delay at zenith
m_{dry} - mapping factor to map the zenith dry delay to the slant direction
m_{wet} - mapping factors to map the zenith wet delay to the slant direction
e_l - number of electrons
\( \psi \) - earth center angle

\( \phi_i \) - geographic latitude of subionospheric point in radians

\( \varepsilon_p \) - receiver code noise in m

\( d_p \) - orbit errors

\( dt \) - satellite clock error

\( dT \) - receiver clock error

\( \varepsilon_{PR} \) - pseudorange noise

\( \varepsilon_p \) - carrier phase range noise and multipath

\( d_{\text{ion}} \) - ionospheric delay error

\( d_{\text{trop}} \) - tropospheric delay error

\( N \) - carrier phase integer ambiguity (in number of cycles)

\( L_1 \) - GPS signal frequency (1575.42MHz)

\( L_2 \) - GPS signal frequency (1227.5MHz)

\( D(t) \) - navigation message

\( W(t) \) - W-code

\( f_1 \) - GPS L1 signal carrier wave

\( f_2 \) - GPS L2 signal carrier wave

\( C/A \) - course acquisition code (1.023 MHz)

\( v_g \) - group velocity

\( v_p \) - phase velocity

\( c \) - speed of the light in a vacuum

\( \lambda_o \) - wavelength in a vacuum

\( dN \) - differential number of cycles

\( n_g \) - group index of refraction (troposphere and ionosphere)

\( n_p \) - phase index of refraction (troposphere and ionosphere)

\( \Delta \phi_{io} \) - phase ionospheric range delay

\( d_s \) - path length

\( \Delta P_{io} \) - group ionospheric range delay

\( \text{PR}_1 \) - pseudoranges measured on L1 frequency in m

\( \text{PR}_2 \) - pseudoranges measured on L2 frequency in m
\( \phi_{cr} \) - carrier phase range
\( \phi_{pp} \) - latitude of IPP
\( \lambda_{pp} \) - longitude of IPP
\( \phi_{ss} \) - geographic coordinate latitude
\( \lambda_{ss} \) - geographic coordinate longitude
\( \phi_{i} \) - geographic latitude of subionospheric point
\( \lambda_{i} \) - geographic longitude of subionospheric point
\( \psi_{pp} \) - earth center angle
\( \phi_{u} \) - User latitude
\( \lambda_{u} \) - User longitude
\( h_{i} \) - height of the maximum electron density (assumed to be equal to 350km)
\( h_{sat} \) - satellite height above the earth's surface
\( D_{ivp} \) - vertical ionospheric delay
\( h_{io} \) - altitude of ionospheric shell
\( h_{rs} \) - height of ionospheric reference station
\( \phi_{rs} \) - latitude of reference station
\( \phi_{m} \) - geomagnetic latitude
\( \lambda_{rs} \) - longitude of reference station
\( \varepsilon^{sc} \) - satellite clock error
\( \text{nsec} \) - nanoseconds
\( t_{oc} \) - reference epoch for the definition of the coefficients
\( e \) - eccentricity of the ellipsoid
\( A_{2} \) - satellite azimuth angle
\( t_{c} \) - satellite clock reference epoch
\( \text{ID} \) - satellite PRN number
Health - health of the Satellite
Week - current GPS week
\( t_{ce} \) - reference epoch in sec within the current week (s)
\( e^{2} \) - square of WGS-84 first eccentricity
\( (e')^{2} \) - square of WGS-84 second eccentricity
$M_0$ - mean anomaly (rad)
$\omega$ - argument of perigee (rad)
$\Omega_o$ - longitude of the node at weekly epoch (rad)
$\Omega$ - drift of node's right ascension per second (rad/s)
$\sqrt{a}$ - square root of semi major axis (m$^{1/2}$)
a - semi major axis
b - semi minor axis
$\nu$ - true anomaly
$\mu$ - WGS-84 value of the earth's universal gravitation constant ($3.986005 \times 10^{14}$ m$^3$/sec$^2$)
$\Omega_e$ - WGS-84 value of the earth's rotation rate ($7.2921151467 \times 10^{-5}$ rad/sec)
$\Delta n$ - mean motion difference
$i_o$ - inclination
$i,(IDOT)$ - rate of inclination angle
t_c - satellite clock reference epoch
$Cic$ - amplitude of cosine correction to angle of inclination
$Cis$ - amplitude of sine correction to angle of inclination
$Crc$ - amplitude of cosine correction to orbit radius
$Crs$ - amplitude of sine correction to orbit radius
$Cuc$ - cosine correction term to the satellite argument of latitude
$Cus$ - amplitude of sine correction to argument of latitude
$\Omega_r$ - Omega cross r term
$x_i$ - satellite ECEF x coordinate system
$y_i$ - satellite ECEF y coordinate system
$z_i$ - satellite ECEF z coordinate system
$x_u$ - user ECEF x coordinate
$y_u$ - user ECEF y coordinate
$z_u$ - user ECEF z coordinate
$r_e$ - mean earth radius
### List of Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>AAI</td>
<td>Airports Authority of India</td>
</tr>
<tr>
<td>ARNC</td>
<td>Aeronautical Radio Navigation Service</td>
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<tr>
<td>ATM</td>
<td>Air Traffic Management</td>
</tr>
<tr>
<td>ATC</td>
<td>Air Traffic Control</td>
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<tr>
<td>BPSK</td>
<td>Binary Phase Shift Keying</td>
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<td>CAT I</td>
<td>Category I</td>
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<tr>
<td>C/A</td>
<td>Coarse Acquisition</td>
</tr>
<tr>
<td>CDI</td>
<td>Course Deviation Indicator</td>
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<tr>
<td>CDMA</td>
<td>Code Division Multiple Access</td>
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<tr>
<td>CNS</td>
<td>Communication, Navigation and Surveillance</td>
</tr>
<tr>
<td>CONUS</td>
<td>Continental United States</td>
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<tr>
<td>COSPAR</td>
<td>Committee On Space Research</td>
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<tr>
<td>CRC</td>
<td>Cyclic Redundancy Check</td>
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<tr>
<td>CSB</td>
<td>Carrier with Side Band</td>
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<tr>
<td>CWAAS</td>
<td>Canadian WAAS</td>
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<tr>
<td>DDM</td>
<td>Difference in Depth of Modulation</td>
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<td>DME</td>
<td>Distance Measuring Equipment</td>
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<tr>
<td>DOD</td>
<td>Department of Defense</td>
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<tr>
<td>DOP</td>
<td>Dilution Of Precision</td>
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<tr>
<td>DVOR</td>
<td>Doppler Very High Frequency Omni Range</td>
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<tr>
<td>ECEF</td>
<td>Earth Centered Earth Fixed</td>
</tr>
<tr>
<td>ECI</td>
<td>Earth Centered Inertial</td>
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<tr>
<td>EIRP</td>
<td>Effective Isotropically Radiated Power</td>
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<tr>
<td>FAA</td>
<td>Federal Aviation Administration</td>
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<tr>
<td>FANS</td>
<td>Future Air Navigation System</td>
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<tr>
<td>FIR</td>
<td>Flight Information Region</td>
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<td>FIU</td>
<td>Flight Inspection Unit</td>
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<td>FOP</td>
<td>Final Operational Phase</td>
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<td>FPL</td>
<td>Flight Plan</td>
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<td>GAGAN</td>
<td>GPS Aided Geo Augmented Navigation</td>
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<td>Abbreviation</td>
<td>Description</td>
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<tr>
<td>GDOP</td>
<td>Geometric Dilution of Precision</td>
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<td>GEOS</td>
<td>Geostationary Earth Orbit Satellite</td>
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<td>GES</td>
<td>Ground Earth Station</td>
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<tr>
<td>GIVE</td>
<td>Grid Ionospheric Vertical Error</td>
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<td>GIVEI</td>
<td>Grid Ionospheric Vertical Error Indicator</td>
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<tr>
<td>GNSS</td>
<td>Global Navigation Satellite System</td>
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<td>GPS</td>
<td>Global Positioning System</td>
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<td>HAL</td>
<td>Horizontal Alert Limit</td>
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<td>HDOP</td>
<td>Horizontal Dilution Of Precision</td>
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<tr>
<td>ICAO</td>
<td>International Civil Aviation Organization</td>
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<tr>
<td>IDW</td>
<td>Inverse Distance weighted</td>
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<tr>
<td>IEP</td>
<td>Initial Experimental phase</td>
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<tr>
<td>IFB</td>
<td>Inter Frequency Bias</td>
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<td>IFR</td>
<td>Instrument Flight Rules</td>
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<td>IGP</td>
<td>Ionospheric Grid Point</td>
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<td>ILS</td>
<td>Instrument Landing System</td>
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<td>INLUS</td>
<td>Indian Navigation Land Uplink Station</td>
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<td>INMMCC</td>
<td>Indian Mission control center</td>
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<tr>
<td>INRES</td>
<td>Indian Reference Station</td>
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<td>INWAAS</td>
<td>Indian WAAS</td>
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<tr>
<td>IOD</td>
<td>Issuance of Data</td>
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<td>IODC</td>
<td>Issuance of Data Clock</td>
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<td>IODE</td>
<td>Issuance of Data Ephemeris</td>
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<td>Issue of Data for Fast Corrections</td>
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<td>Issuance of Data PRN</td>
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<td>IOR</td>
<td>Indian Ocean Region</td>
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<td>IPP</td>
<td>Ionospheric Pierce Point</td>
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<tr>
<td>IRI</td>
<td>International Reference Ionosphere</td>
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<tr>
<td>ISRO</td>
<td>Indian Space Research Organization</td>
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<tr>
<td>LNA</td>
<td>Low Noise Amplifier</td>
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<td>LT</td>
<td>Local Time</td>
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<td>Abbreviation</td>
<td>Description</td>
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<tr>
<td>MB</td>
<td>Magnetic Bearing</td>
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<td>MDA</td>
<td>Minimum Distance Altitude</td>
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<td>MMSE</td>
<td>Minimum Mean Squares Estimator</td>
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<td>NAVSTAR</td>
<td>Navigation Satellite Timing And Ranging</td>
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<tr>
<td>NDB</td>
<td>Non Directional Beacon</td>
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<td>NETRU</td>
<td>Research and Training Institute for Navigational Electronics</td>
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<td>NGRI</td>
<td>National Geophysical Research Institute</td>
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<td>NPA</td>
<td>Non-Precision Approach</td>
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<td>PA</td>
<td>Precision Approach</td>
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<td>P code</td>
<td>Precise code</td>
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<td>PDOP</td>
<td>Position Dilution Of Precision</td>
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<td>PPS</td>
<td>Precise Positioning Service</td>
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<td>PR</td>
<td>Pseudorange</td>
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<td>PRN</td>
<td>Pseudo Random Noise</td>
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<td>RF</td>
<td>Radio Frequency</td>
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<td>RINEX</td>
<td>Receiver Independent Exchange Format</td>
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<td>RNP</td>
<td>Required Navigation Performance</td>
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<td>RVR</td>
<td>Runway Visual Range</td>
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<td>SA</td>
<td>Selective Availability</td>
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<tr>
<td>SACNS</td>
<td>Satellite Aided Communication, Navigation and Surveillance</td>
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<td>SBAS</td>
<td>Satellite Based Augmentation System</td>
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<td>SBO</td>
<td>Side Band Only</td>
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<td>SF</td>
<td>Slant Factor</td>
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<td>SNR</td>
<td>Signal to Noise Ratio</td>
</tr>
<tr>
<td>SPS</td>
<td>Standard Positioning Service</td>
</tr>
<tr>
<td>SV</td>
<td>Satellite Vehicle</td>
</tr>
<tr>
<td>TDS</td>
<td>Technology Demonstration System</td>
</tr>
<tr>
<td>TEC</td>
<td>Total Electron Content</td>
</tr>
<tr>
<td>TECu</td>
<td>Total Electron Content unit</td>
</tr>
<tr>
<td>TOA</td>
<td>Time of Arrival</td>
</tr>
<tr>
<td>UIVE</td>
<td>User Ionospheric Vertical Error</td>
</tr>
<tr>
<td>URSI</td>
<td>International Union of Radio Science</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
</tr>
<tr>
<td>--------------</td>
<td>-------------</td>
</tr>
<tr>
<td>USA</td>
<td>United States of America</td>
</tr>
<tr>
<td>UTC</td>
<td>Universal Coordinated Time</td>
</tr>
<tr>
<td>VDOP</td>
<td>Vertical Dilution Of Precision</td>
</tr>
<tr>
<td>VHF</td>
<td>Very High Frequency</td>
</tr>
<tr>
<td>VOR</td>
<td>VHF Omni-Directional Range</td>
</tr>
<tr>
<td>VTECu</td>
<td>Vertical Total Electron Content unit</td>
</tr>
<tr>
<td>WAAS</td>
<td>Wide Area Augmentation System</td>
</tr>
<tr>
<td>WGS</td>
<td>World Geodetic System</td>
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