Analysis of Ionospheric Error Estimation in L2 Frequency band for GPS

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***Abstract*—Global Positioning System (GPS) is a global navigation satellite system. It providessignal accuracy that helps in navigation. The system consists of 24 satellites (MEO satellite) revolvingaround the earth at an altitude of 20,200kms from the surface of the Earth. The satelliteorbits are inclined at an angle of 55 degrees with respect to the equator. The GPS systemhas 6 satellite orbits with each orbit consisting of 4 satellites. The GPS works in L1(1575.42 MHz) and L2 (1227.60 MHz) frequency bands. In this work, ionospheric delayand total electron content (TEC) will be computed for L2 frequency band. It is significantto compute the Ionospheric delay and TEC as Ionospheric delay is a major cause of errorin weakening of the signal. For analysis, MATLAB software is used and 24 samples areused which are obtained using National Geophysical Research Institute (NGRI) data.Vertical Ionospheric delay and TEC will be obtained and tabulated. The work will showthe performance of GPS signal accuracy with respect to ionospheric delay and TEC in L2band.**

Keywords—MEO, TEC, Vertical Ionospheric Delay, NGRI, GPS

I. INTRODUCTION

The positioning results are not completely accurate because GPS satellite signals must traverse the ionosphere region during its way towards GPS users, the signal is delayed and the signal delay is proportional to the number of free ions encountered in ionosphere. The accuracy of the GPS navigation solution is influenced by several kinds of error factors, among which the GPS signal delay by the ionosphere is the greatest after the elimination of selective availability. Many ionospheric error correction models can be used to estimate this delay. Klobuchar is a simple model for ionospheric time delay that estimates ionospheric time delay up to 50% or more. Root Mean Square (RMS) basis is used which is vital to give the appropriate user position for single frequency GPS receivers. Usually all the signals are passed through L1 frequency band so its ionospheric delay and TEC is known. In order to know the delay in L2 frequency band, we calculate vertical ionospheric delay and Total Electron count in L2 frequency band.

II. RELATED WORK

This project presents a comparison between the delays of two frequency bands in order to choose an efficient way of transmitting signals without much loss of information. Ionospheric delay and total electron count of L1 frequency band is known from earlier work.

Most errors in GPS positioning are caused due to the atmosphere. The GPS signal goes through an imaginary vacuum of space changes as it passes through the atmosphere. When both refraction and diffraction occurs, the atmosphere changes the apparent speed and the direction of the signal. This causes adelay in the signal's transit.The upper atmosphere i.e ionosphere has many free electrons that helps in propagation of radiofrequency electromagnetic waves.The ionosphere causes a time delay in the propagation of signalswhich affects positioning.The ionospheric delay changes slowly throughout the day. It is least between midnight and early morning, and most around noon. During the daylight hours in the mid latitudes, the ionospheric delay may grow to be five times greater than it was at night.

When gas molecules are ionized by the sun's ultraviolet radiation, free electrons are released. As their number and dispersion varies, so does the electron density in the ionosphere. This density is often described as *total electron content* (TEC)- It is a measure of the number of free electrons in a column through the ionosphere with a cross-sectional area of 1 square meter: 10^{16} is one TEC unit. The higher the electron density, the larger the delay of the signal and the delay is not constant.The ionosphere's effect on a GPS signal depends on the amount of time that signal spends traveling through it. A signal from a satellite near the observer's horizon goes through a larger amount of the ionosphere to reach the receiver than does a signal from a satellite near the observer's zenith. The longer the signal is in the ionosphere, the greater the ionosphere's effect on it.

Following models are used to compensate delay caused due to ionosphere.

A. Klobuchar Model

The daily vertical time delay in Klobuchar is represented by the cosine function with changing period and amplitude plus a constant value, which is set to 5 ns at night. According to the analysis of various data, in the initial phase, the cosine term is set to 14:00 LT. The Klobuchar model reflects the characteristics of ionospheric diurnal variation and essentially ensures the accuracy of ionospheric prediction. The vertical ionospheric error of GPS L1 frequency Δτ is expressed as follows:

$$\Delta\tau = \begin{cases} D + A\cos\left(\frac{2\pi(t-T_P)}{P}\right), & |t-T_p| < P/4 \\ D & ,others \end{cases}$$

where D=5×10−9s. P and A represent the period and amplitude, respectively. Their expressions are as follows:

$$A = \begin{cases} \sum_{i=1}^{4} \alpha_i(\varphi_m)^i, & A > 0 \\ 0 & ,A \le 0 \end{cases}$$

$$P = \begin{cases} \sum_{i=1}^{4} \beta_i(\varphi_m)^i, & P > 72{,}000 \\ 72{,}000 & ,P \le 72{,}000 \end{cases}$$

To compute the slant time delay, Klobuchar uses a mapping function as follows:

$$MF = 1.0 + 16.0 \times (0.53 - el)^3$$

where el is the elevation angle of the satellite divided by π or 180° (in semicircles).

B. BDGIM

As a function describing the physical quantities of global changes, spherical harmonic (SH) function has good mathematical structure and it is the main functional models that describes the ionospheric TEC on a global level. BDGIM is proposed based on an improved spherical harmonic function. It is limited to the capacity of communication of the satellites, nine SH coefficients which describes ionospheric VTEC are chosen and broadcasted to receivers. Moreover, from the remaining SH coefficients, a total of seventeen non-broadcast coefficients are selectedto improve the accuracy further. The specific expression of BDGIM is given by:

$$VTEC = \sum_{i=1}^{9} \alpha_i A_i + \sum_{j=1}^{17} \beta_j B_j$$

Where VTEC is the vertical TEC, αi are the nine parameters broadcasted by BDS-3 satellites. βj is the seventeen non-broadcast parameters obtained from empirical analysis. The expression of Ai is as follows:

$$A_i = \begin{cases} N_{|n_i|,|m_i|} P_{|n_i|,|m_i|}(\sin\varphi') \cdot \cos(m_i \cdot \lambda') \ m_i \ge 0 \\ N_{|n_i|,|m_i|} P_{|n_i|,|m_i|}(\sin\varphi') \cdot \sin(-m_i \cdot \lambda') \ m_i < 0 \end{cases}$$

where P|ni|,|mi| is the standard Legendre function of degree n and order m (n= 0 to 2, m= −2 to 1), φ′ and λ′ denote the geomagnetic latitude and longitude of the IPP based on the solar fixed coordinate system, respectively. Nni,mi is the normalization function, as follows:

$$\begin{cases} N_{n,m} = \sqrt{\frac{(n-m)!(2n+1)\cdot(2-\delta_{0,m})}{(n+m)!}} \\ \delta_{0,m} = \begin{Bmatrix} 1, m = 0 \\ 0, m > 0 \end{Bmatrix} \end{cases}$$

One thing to note here is that Bj and Ai have the same calculation equation. Bj (j = 1~17) is the predicted SH coefficients, which are expressed as follows:

$$\begin{cases} \beta_j = a_{0,j} + \sum_{k=1}^{12} (a_{k,j} \cdot \cos(\omega_k \cdot t_p) + b_{k,j} \cdot \sin(\omega_k \cdot t_p)) \\ \omega_k = \frac{2\pi}{T_k} \end{cases}$$

where a0,j ak,j and bk,j are the non-broadcast parameters of BDGIM, the values of which can be seen in BDS ICD, Tk is the period for each non-broadcast coefficient, and Tp denotes the odd hour of the one day. For calculation, tp that is closest to the time of the current epoch should be chosen.

NTCM-BC

The NTCM is used in receiver's and satellite's hardware bias computation and TEC calibration. It is also used asa background model for grid vertical delay estimation. NTCM-BC is the simplest versions of the NTCM models. The equation of the NTCM-BC is as follows:

$$\mathrm{TEC}_{\mathrm{model}}^{\mathrm{vert}} = F_1 \cdot F_2 \cdot F_3(\mathrm{TECU})$$

Where F1 is the equation of variation with local time, F2 is the geomagnetic latitude equation, and F3 is the equation describing the ionization peaks of low-latitude anomaly areas. F1 includes three harmonic components: diurnal (VD), semidiurnal (VSD) and ter-diurnal (VTD), which are given by:

$$F_1 = \cos\chi^{***} + \cos\chi^{**}(c_1\cos V_D + c_2\cos V_{SD} + c_3\sin V_{SD} + c_4\cos V_{TD} + c_5\sin V_{TD})$$

$$V_D = \frac{2\pi(LT-14)}{24}$$
$$V_{SD} = \frac{2\pi\text{-}LT}{12}$$
$$V_{TD} = \frac{2\pi\text{-}LT}{8}$$

$$\cos\chi^{**} = \cos(\varphi-\delta) - \frac{2}{\pi}\cdot\varphi\cdot\sin\delta$$
$$\cos\chi^{***} = \cos(\varphi-\delta) + 0.4$$

where cosχ** and cosχ*** denote the TEC dependency on the solar zenith angle χ; φ and δ are the geographic latitude and the declination of the sun (all angles in radians), respectively. LT denotes the local time.

$$F_2 = 1 + c_6\cos\varphi_m$$

$$F_3 = c_7 + c_8\exp(EC_1) + c_9\exp(EC_2)$$

$$EC_1 = -\frac{(\varphi_m-\varphi_{c1})^2}{2\sigma_{c1}^2}$$
$$EC_2 = -\frac{(\varphi_m-\varphi_{c2})^2}{2\sigma_{c2}^2}$$

where φc1=16∘N and φc2=10∘. σc1=12∘ and σc2=13∘ r epresent the corresponding Gaussian half-widths, respectively.

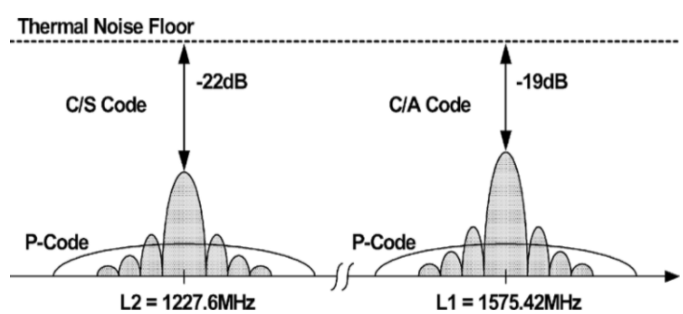
For converting VTEC to STEC,both BDGIM and NTCM-BC utilize the mapping function. The expression of MF is given by:

$$M_F = \frac{1}{\sqrt{1-\left(\frac{\mathrm{Re}}{\mathrm{Re}+H_{\mathrm{ion}}}\cdot\cos(E)\right)^2}}$$

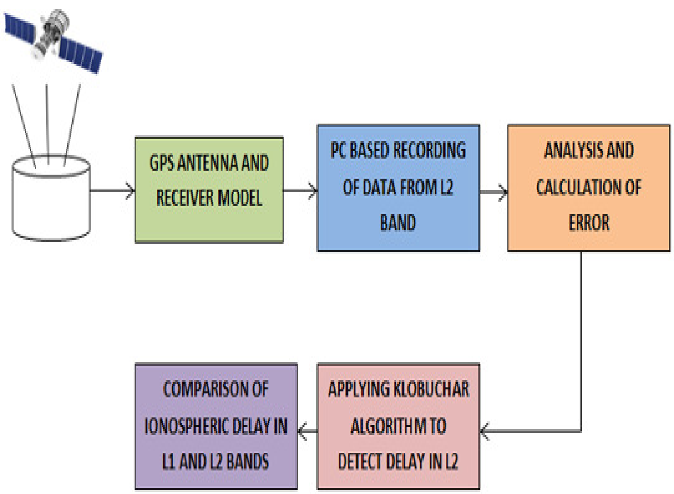
where Re denotes the earth's mean radius. Hion represents the height of the thin shell of the ionosphere, and it is set to 400 km. E: elevation angle of the IPP (in radians).

III. EXPERIMENTS

The ionospheric delay and total electron count of L2 band is calculated from the values obtained in L1 frequency band. We use MATLAB to plot the error estimation between each band. Frequency band spectrum of L1 and L2 bands is given below:



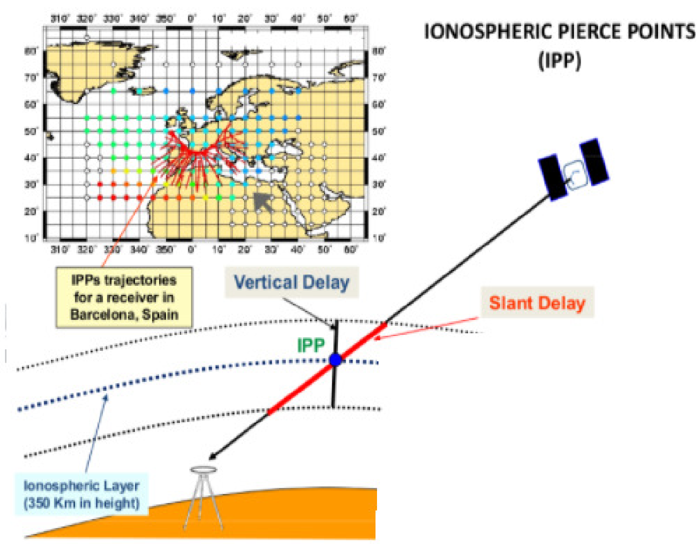
The block diagram of the proposed model is given below:



Two factors are calculated from L1 bands to L2 bands to portray a comparison of the possibility of better transmission in either of the two bands. These two factors are Vertical ionospheric delay and Total electron content.

A. Vertical Ionospheric Delay

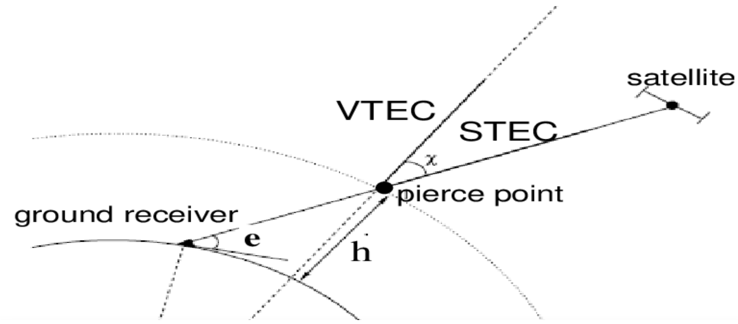
When the signal reaches an altitude of about 1000km above the Earth's surface, it penetrates the upper layer of the atmosphere, namely, the ionosphere. Ionosphere includes various types of gases that can be instantly ionized by the sun's radiation. The condition of the ionosphere can be mainly determined by the intensity of solar activity, but it is also affected by season and time of day. These three parameters change the refractive indices of the layers of the ionosphere. This influences the signal transit time measured by the receiver.



B. Total Electron Content

Total electron content (or TEC) is an important parameter for the ionosphere of the Earth. TEC is the sum of number of electrons present between two points, along a length of one meter squared cross section. TEC unit is defined as $TECU=10^{16} el/m^2$.

TEC helps in determining the scintillation and group & phase delays of a radio wave through a medium. Ionospheric TEC is found by observing carrier phase delays of received radio signals transmitted from satellites located above the ionosphere. Solar activity strongly affects TEC.



C. Formulas

1. To calculate L2 ionospheric delay from L1 band:

$$Ionospheric\ Delay_{L2} = \left(\frac{Band\ Frequency_{L1}}{Frequency_{L2}}\right)^2 \times Ionospheric\ Delay_{L1}$$

2. To calculate L2 total electron content from L2 band:

$$VTEC = \frac{Ionospheric\ Delay}{40.3} \times Band\ Frequency^2$$

The proposed model is based on taking a 24 hour GPS readings of total electron content and ionospheric delay of a day.

Time in Hours (Local Time)	Ionospheric Range Delay in (meters)	Ionospheric Time Delay in (ns)	Ionospheric TEC in (TECU)
1	1.86	6.22	11.47
2	2.25	7.52	13.88
3	2.70	9.03	16.68
4	3.22	10.75	19.84
5	3.76	12.57	23.21
6	4.59	15.31	28.27
7	5.43	18.13	33.48
8	6.25	20.85	38.50
9	7.00	23.35	43.12
10	7.61	25.39	46.89
11	8.04	26.82	49.52
12	8.33	27.80	51.34
13	8.52	28.42	52.48
14	8.57	28.61	52.84
15	8.52	28.44	52.52

16	8.32	27.76	51.26
17	8.06	26.88	49.64
18	7.81	26.05	48.10
19	7.41	24.72	45.65
20	6.79	22.67	41.86
21	5.86	19.57	36.13
22	4.90	16.35	30.20
23	3.83	12.78	23.61
24	2.65	8.84	16.33

Table 1 Ionospheric parameters estimated on typical day of 1st August, 2012

IV. RESULTS

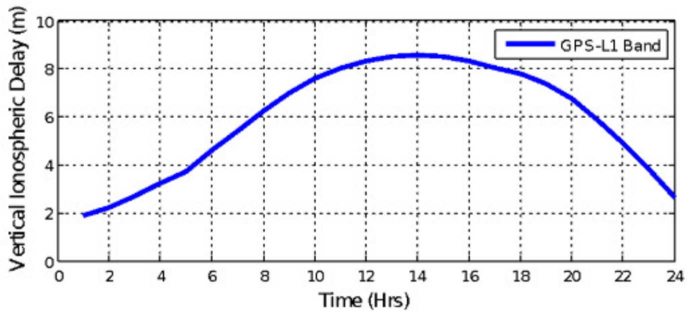


Figure 1Vertical Ionospheric Delay in L1 band

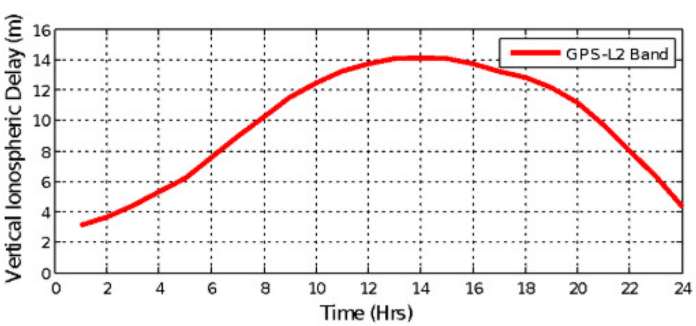


Figure 2Vertical ionospheric delay in L2 band

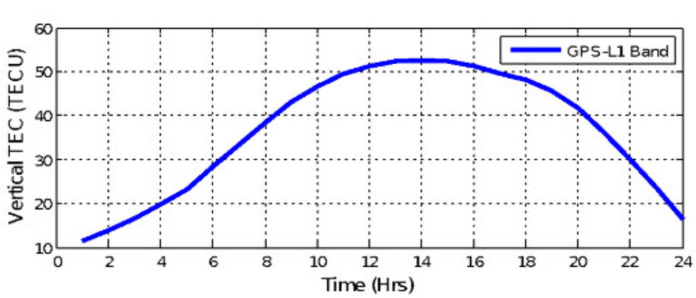


Figure 3 Vertical TEC in L1 band

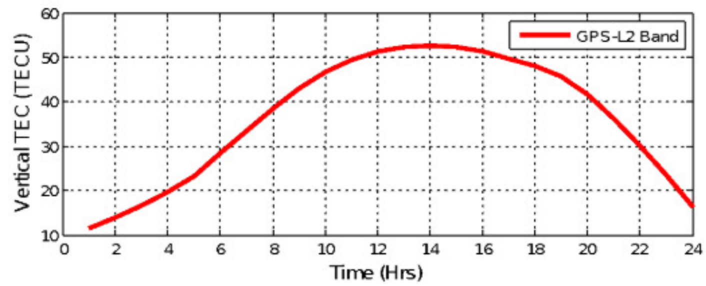


Figure 4 Vertical TEC in L2 band

Comparison of Ionospheric Delay

GPS Band	Maximum	Minimum	Std. Deviation
L1	8.57m	1.86m	2.31m
L2	14.11m	3.06m	3.8m

Table 1: Comparison of ionospheric delay

Comparison of Total Electron content

GPS Band	Maximum	Minimum	Std. Deviation
L1	52.7798	11.4551	14.1986
L2	52.7798	11.4551	14.1986

Table 2: Comparison of Total Electron content

V.CONCLUSION

The ionospheric delay of L2 band is more than L1 band and the total electron content of both L1 and L2 bands is the same. This concludes that L1 band is ideal for propagation of signal transmission.

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