Study of GPS Scintillation during Solar Maximum at Malaysia

Emad Fathi Aon¹², Redhwan Qasem Shaddad³⁴, Abdul Rani Othman¹, Yih Hwa Ho¹

¹Faculty of Electronic and Computer Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
²Faculty of Engineering, Tripoli University, Tripoli, Libya
³Lightwave Communications Research Group, Infocomm Research Alliance, Universiti Teknologi Malaysia (UTM), Johor 81310, Malaysia
⁴Faculty of Engineering and Information Technology, Taiz University, Taiz, Yemen

Abstract

The global positioning system (GPS) is one of the most important and useful technology that has been developed for information and communication technology. The propagated wireless signals along GPS link are affected by the ionospheric electron density irregularities, so the GPS signals may experience amplitude and phase fluctuations. The global navigation satellite system (GNSS) ionospheric scintillation and total electron content (TEC) monitor (GISTM) receiver has been installed at UTeM, Malaysia (2.3139° N, 102.3183° E) for the purpose of monitoring ionospheric scintillation during solar maximum cycle 2013/2014 for six months October 2013 – March 2014. In this paper, the GPS ionospheric scintillations are concerned for the dual frequency L1 (fL1 = 1.57542 GHz), and L2C (fL2C= 1.2276 GHz). The ionospheric amplitude/phase scintillation of GPS satellites is reported. Finally, a new algorithm is suggested to enhance the GPS positioning system based on the availability of GPS and precise point positioning (PPP) approach.

Keywords. GPS; ionospheric scintillation; precise point positioning method

1 Introduction

The global positioning system (GPS) signal is electromagnetic wave which is generated by an oscillating energy from a GPS satellite. The GPS signal then propagates along space channel to the GPS user on the earth; this channel is called GPS link. The GPS signal strength decreases due to many factors affect the signal quality depend on the length of GPS link. This is essentially due to attenuation caused by geometric spreading and the attenuation in the troposphere and ionosphere layers [1]. One of these factors is the ionospheric scintillation which is defined as the rapid fluctuations of the amplitude and phase of the satellite radio signals when they propagate through the ionosphere due to electron density irregularities [2]. This phenomenon increases in the equatorial region of the earth especially during maximum solar cycles [3].

*Corresponding author: aonemad@gmail.com
Solar maximum is a normal period of greatest solar activity in the 11 years solar cycle of the sun[4]. During solar maximum, large numbers of sunspots appear and the sun’s irradiance output grows by about 0.07%. [5]. Figure 1 shows the solar cycle, where the 24th solar maximum appears during 2013/2014. The equatorial region is shown in Figure 2. Malaysia is located at this region, so the GPS link ionospheric scintillation and availability will be studied and concerned during solar maximum for this location. This paper analyzes the maximum GPS scintillation in this important period starting October 2013 till March 2014. The results will be discussed in the term of scintillation amplitude (S4), phase scintillation ($\sigma_{\phi}$), availability of GPS satellites and carrier-to-noise (C/No) ratio for the dual GPS frequency (L1, L2C).

Fig. 1 Solar cycle.

Fig. 2 Equatorial region.

Fig. 3 Experimental setup.
2 Experimental Setup and Data Collection

2.1 Experimental Setup

Figure 3 shows the experimental setup to measure and analyze the GPS ionospheric scintillation. The used dataset for this study will be collected at postgraduate research laboratory, faculty of electronics and computer engineering (FKEKK), Universiti Teknikal Malaysia Melaka (UTeM), Malaysia (2.3139° N, 102.3183° E), using scintillation monitor developed by GPStation-6 GISTM Receiver. The average distance between GPS satellite and the GPS receiver is around 24000 km. The antenna of GPS receiver is put at high position to avoid the side effects such as wireless multipath phoneme. The multipath effects almost appears at small elevation angles, so the analysis of ionospheric scintillation will be considered at elevation angles which are greater than 30° [1,8]. Data has been collected over six months; the daily measurements time interval is 24 hours starting after the sunset. The data structures are then organized and analyzed by using MATLAB programming software.

2.2 Data Collection

The GNSS Ionospheric Scintillation and TEC Monitor (GISTM) receiver is a multi-frequency, multi-constellation receiver capable of tracking simultaneously GPS L1-C/A, L2-P(Y), L2C, L5; GLONASS L1, L2; Galileo E1, E5a, E5b, AltBOC; SBAS L1, L5; COMPASS; QZSS. The GISTM provides algorithms for ionospheric scintillation monitoring (ISM) and total electron content (TEC) measurements for all tracked signals. Sampling at 50 Hz, the receiver gives the following main output parameters:

1. the amplitude scintillation index ($S_4$) calculated over 60 s;
2. the phase scintillation index ($\sigma_\phi$) calculated over different time intervals (10, 30, 60 s);
3. the azimuth ($Az$) / elevation ($Elv$) angle for the tracked signal.
4. the Average Carrier-to-noise ($C/N_0$) ratio (60 s);

This project considers all the available GPS satellites (with pseudo random numbers (PRNs) PRN01 – PRN32) at dual frequency L1/L2C. Data are used for the analysis of the ionospheric scintillation effects on the GPS communication system during October 2013 – March 2014, which has been considered during the rising phase of the maximum solar activity which increases the ionospheric scintillation. The universe time (UT) is considered in the collected data, so it must convert to the local time (LT) as $LT = UT + 8$.

2.3 Methods

The amplitude scintillation, $S_4$ index is defined as the standard deviation of the de-trended signal intensity by normalization. The $S_4$ index is calculated as:

$$ S_4 = \sqrt{S_4^2 - S_4^2_{cor}} $$  \hspace{1cm} (1)

where the amplitude scintillation recorded by the GPStation-6 receiver which has two parameters: total scintillation ($S_4$) and corrected scintillation ($S_4_{cor}$). The total $S_4$ is recorded over 60-second interval in real-time but includes the effect of ambient noise, while the corrected $S_4_{cor}$ was calculated by removing the ambient noise.
The values of $S_4$ are on the interval $[0, 1]$, where [1]:

\[ S_4 > 0.4 \quad \text{(strong scintillation)} \]
\[ 0.2 \leq S_4 \leq 0.4 \quad \text{(moderate scintillation)} \]
\[ S_4 < 0.2 \quad \text{(low and negligible scintillation)} \] (2)

The GPS satellites, with elevation angle greater than 30°, are only considered at measurements, since the signals from satellites with low elevation angles usually suffer large fluctuations due to multipath effects.

The GISTM receiver calculates the phase scintillation component by monitoring the measurements of standard deviation of the detrended carrier phase, $\sigma_\phi$, received from GPS satellites as:

\[ \sigma_\phi^2 = \frac{\pi D}{k f_n p^{-1} \sin\left(\frac{(2k+1-p)\pi}{2k}\right)} \text{ radian} \] (3)

where $D$ is the spectral strength of the phase (PSD) at 1 Hz, $p$ is the spectral slope of the phase PSD, $k$ is the order of the phase-locked loop (PLL) in the receiver (equal to 3) and $f_n$ is the loop natural frequency (equal to 1.91 Hz).

3 Results and Discussions

During solar maximum period, the ionospheric scintillation $S_4$ index has been calculated from the collected data and analyzed for the dual frequency (L1 and L2C) considering all the available GPS satellites as shown in Figure 4. The $S_4$ index for L1 frequency is presented by green curve, while the red curve represents L2 frequency. Each plot shows the $S_4$ index for the corresponding month versus the local time (LT) at Elv > 30°. During this period, the $S_4$ index almost has values in the range $[0, 0.4]$ which mean moderate and low scintillation for the dual frequency L1 and L2C. It is clear that, many values of $S_4$ index greater than 0.4 arise obviously during January 2014; especially at morning and midnight. The sunspot maximum occurred at January and February 2014 [6,7]. For the low elevation angles (Elv < 30°) GPS signals suffer large fluctuations due to multipath effects. Figure 5 shows the $S_4$ index for the GPS with PRN=17, it shows that the $S_4$ index for L2C (red circles) almost is greater than its for L1 (green squares).

![Fig. 4 Amplitude scintillation index during solar maximum period.](image-url)
Figure 6 shows the month-to-month variations of the phase scintillation ($\sigma_{\phi}$) activities observed at UTeM, Malaysia from October 2013 to March 2014. The most suitable range of the phase scintillation is $[0, 0.1]$ rad as shown from Figure 6. The phase scintillation sometimes exceeds the normal range early morning 2:00 - 8:00 am during the months December 2013, January 2014, and February 2014. In addition, the phase scintillation overshoots for the frequency L1 (average 2 rad) are greater than its for frequency L2C (average 1.4 rad) at different GPS satellites, but for the GPS satellite with specified PRN the phase scintillation for L2C almost is greater than its for L1 as shown in Figure 7 as example for the GPS with PRN=17.

![Fig. 5 S4 index for the GPS with PRN=17.](image)

![Fig. 6 Phase scintillation during solar maximum period.](image)
4 Minimizing Positioning Error

There is a new algorithm to enhance the GPS positioning system based on the availability of GPS and precise point positioning (PPP) method [9]. To minimize the positioning error, the new algorithm is proposed based on the following considerations:

1. The PPP technique randomly uses any four available GPSs to get the position of the receiver, but there are many effects (such as ionospheric scintillation) introduce error to positioning calculations. This algorithm considers the most important factor ionospheric scintillation.
2. There are many important parameters for GPS ionospheric scintillation; which are must be considered. The main parameters are stated in Sec. 2.2.
3. The availability of GPS versus time LT is very important to determine the available GPSs for the frequencies $L_1 = 1.57542$ GHz, and $L_2 = 1.2276$ GHz. The available GPSs will be considered at each step time ($\Delta T$) to get a minimum positioning error, since $\Delta T = 60$ sec.

The new algorithm is given by the flow chart which is given in Figure 8. It is summarized by finding the available GPSs (respect to its PRNs) within one minute. The algorithm chooses the best four GPSs that have less effect from the ionospheric scintillation with long lock time.

5 Conclusion

The study of ionospheric scintillations has been done using GPS measurements recorded at UTeM, Malaysia during solar maximum between October 2013 and March 2014. Strong scintillations with $S_4 > 0.4$ and $\sigma_\phi > 0.1$ rad often occurred between January 2014 and February 2014 especially at early morning. A new algorithm has been presented to enhance the GPS positioning system based on the availability of GPS and PPP technique. In the future, the TEC and ROT will be analyzed and linked with the ionospheric scintillations for this period.
Fig. 8 A new algorithm to minimize the positioning error.

Acknowledgments

The authors are thankful to the Ministry of Higher Education for supporting this project under research grant FRGS/2012/FKEKK/SG02/02/1/F00125 and also to Universiti Teknikal Malaysia Melaka for the research lab and equipment systems supporting.
References


