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Performance of Low-cost, Dual-frequency GNSS Modules for Ionospheric Studies

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Abstract

Global Navigation Satellite System (GNSS) signals are frequently used for ionospheric studies, costly geodetic or special purpose receivers are utilized for the purpose. Compact, low-cost, dual-frequency GNSS modules are commercially available now, those are typically used for cost-effective geolocation applications. This manuscript presents the results of the study to explore the applicability of such compact modules for ionospheric studies. S_4 indices are calculated and compared for GPS, GLONASS and Galileo signals for multiple frequency bands using data from two Ublox F9P compact modules concurrently operating with a geodetic GNSS receiver, and the values from both types of devices are found to be in good agreement. The results show the potential of the compact modules for the purpose in a cost and size efficient manner.

1. Introduction

The ionosphere is a region of the atmosphere roughly 45 to 965 km above the earth-surface, where the electrons are extracted from the atoms due to the irradiation of ultra-violet rays of the sun. The electron density in the region is irregular that varies due to several reasons. Electromagnetic (em) signals from artificial satellites are affected while passing through the layer because of this density variation and is a major concern for satellite applications. The irregularities in electron density cause fluctuation in signal intensity; this phenomenon is called amplitude scintillation and it is measured by the S_4 index [1]. The consequence of the amplitude scintillation causes signal strength degradation at the receiving end. Abrupt fluctuation in the phase of the signal is called phase scintillation and may lead to loss of lock and cycle slip in a satellite signal tracking receiver. So, this anomalous phenomenon is a major threat to satellite-based applications.

Research have been carried out on monitoring and predicting such activity of the ionosphere, and signals from Global Navigation Satellite System (GNSS) are used for such studies apart from the typical navigation services. Several studies on ionosphere scintillation using GPS, GLONASS, Galileo, and BeiDou constellations from different geographic regions including India have been carried out [2, 1, 3, 4, 5, 6]. Recently, signals from the Indian regional navigation system, NavIC are also used for similar studies in the Indian region [7, 8].

From the above works, it is noticed that generally special purpose or geodetic grade GNSS receivers (~USD 12,000 or higher) with multi-frequency data (two or more frequencies) in high throughput (~ 5 to 50 Hz) are used for such studies. High cost of such receivers limits the affordability for many users. Cost, physical security, size of the electronics and power requirements at the field locations restricts the creation of a network of such receivers over a large geographical location for concurrent, long-term data recording. Currently, low-cost (~100 – 1000 USD), compact (less than 100 gm), multi-constellation, multi-frequency chipsets and receiver board modules are commercially available those provide the National Marine Electronics Association (NMEA) and raw GNSS data. Relevant parameters for the GNSS-based ionosphere research can be obtained using the data provided by these compact modules, and therefore, ionospheric probing using compact GNSS modules is an interesting aspect that is not fully explored yet except for a few works [9, 10, 11, 12].

Commercial availability of the dual-frequency, low-cost GNSS modules generated interest for exploring their potential to calculate the amplitude scintillation index S_4, an important relevant parameter, for the satellites of different GNSS constellations, that is presented in this manuscript. S_4 is defined as the normalized standard deviation of signal intensity over a finite time period that can be calculated using the C/N_0 values using the following formula [13, 14].

$$S_4 = \sqrt{\left[\frac{< S_i^2 > - < S_i >^2}{< S_i >^2}\right]} \quad (1).$$

Where $S_i = 10^{0.1 \times C/N_0}$
Here the angle brackets $\langle \dots \rangle$ denote an ensemble average but in practice indicate spatial or temporal averages [15]. S_4 is calculated over a one-minute time period and the value ranges between 0 and 1 [14]. The fluctuation of the em wave depends on the variation of its amplitude, therefore, S_4 is a convenient parameter to measure the scintillation [13]. However, three levels of scintillation using the S_4 index are defined as weak ($0.3 \leq S_4 < 0.4$), moderate ($0.4 \leq S_4 < 0.7$), and intense ($S_4 \geq 0.7$) [16]. In this manuscript, results of a study to measure weak

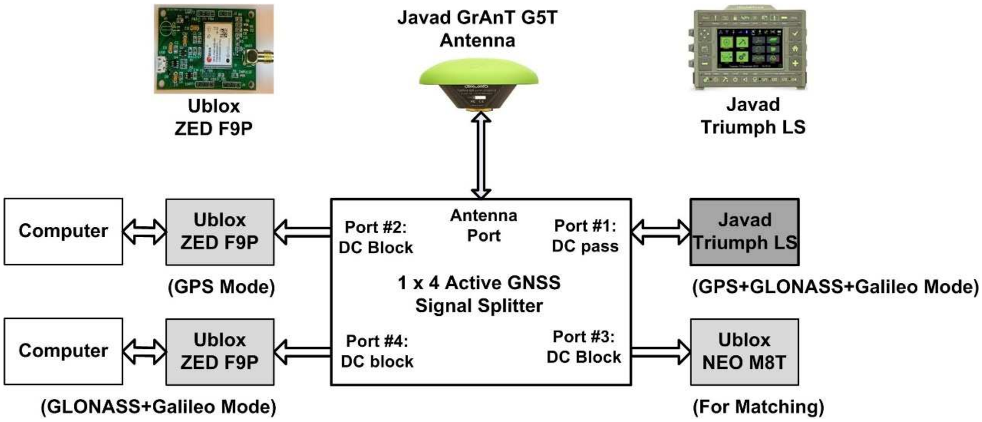


Figure 1. Experimental setup for the comparative study of Ublox ZED F9P and Javad Triumph LS receivers for GNSS-based ionosphere research.

S_4 index using compact, low-cost GNSS modules are presented vis-à-vis a geodetic receiver.

2. Methodology

A Javad GrAnt G5T geodetic antenna is installed on a rooftop with a clear view of the sky in a multipath and interference-free environment at Chandannagar, India (22.8728°N, 88.3647°E, -32.48m). RF signal from the antenna is divided using a 1×4 active GNSS signal splitter as shown in Figure 1. The 4 ports of the splitter are connected to three types of GNSS receivers- 2 compact, low-cost, multi-constellation, dual-frequency (L1 and L2) Ublox ZED F9P modules (~ USD 300), a compact single-frequency Ublox M8T module and a Javad Triumph LS multi-frequency, geodetic receiver (~13,000 USD).

Table 1. Specification of Tracked Signal using Javad Triumph LS and Ublox ZED F9P							
Receiver/ Module	Data Rate	Tracked Signal Band (Freq in MHz), Channel or Code					
		GPS		GLONASS		Galileo	
		L1 Band (1575.42)	L2 Band (1227.60)	G1 Band (1602+ k*9/16)#	G2 Band (1246+ k*716)#	E1 Band (1575.42)	E5b Band (1207.14)
Javad Triumph LS	@5Hz	C/A	L2C (M+L)	C/A	C/A	B+C	I+Q
Ublox ZED F9P		C/A	L2C (L)	C/A	C/A	C	Q

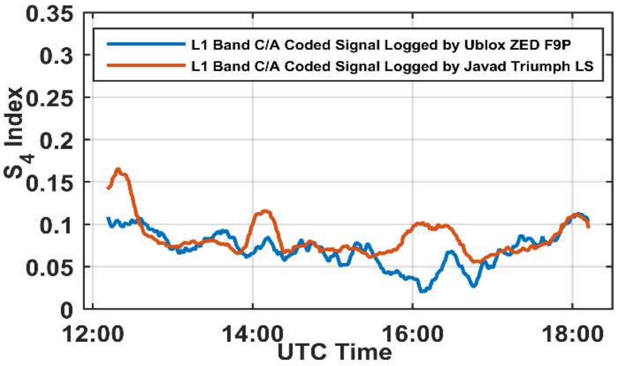
k= -7, -6,…,11,12

The "DC-pass" port of the splitter is connected to the Javad receiver that supplies the antenna DC bias and is operated in GPS+GLONASS+Galileo hybrid mode. Each of the Ports #2 and #4 is connected to an Ublox ZED F9P module. One of the Ublox ZED F9P (at port #2) is operated in GPS-only, and the other Ublox ZED F9P (at port #4) in GLONASS+Galileo hybrid mode. The Ublox M8T compact module at port #3 is used to properly terminate the port. Multi-frequency, multi-constellation GNSS data @5 Hz rate is recorded by the geodetic receiver and by both the Ublox ZED F9P modules. The configuration and specification of tracked signals considered for the study are shown in Table 1. Raw data from the devices are converted to RINEX v3.03 format. For the GPS PRN #10, Galileo PRN #01, and GLONASS slot number #17 are considered as test cases as the signals have long-duration visibility. The S_4 index is calculated over a span of 60 sec @5Hz (300 epochs) and then it is smoothed by taking the moving average of 20 samples to avoid the short-term noises [8].

3. Results and Discussions

The signal strength values are obtained from the RINEX data, and the S4 indices are calculated using equation (1) for GPS #10, Galileo #01, and GLONASS #17 those are shown against observation time in the Figure 2, 3 and 4 respectively. From these figures, it is observed that the S_4 values calculated from the geodetic receiver data have short-term variations in comparison to those calculated from the compact module data, but the values for both the devices follow similar variation patterns. It is to be considered that the Ublox F9P module provides signal strength (C/N_0) with a resolution of 1 dBHz while that for the Javad Triumph LS has a resolution of 0.25 dBHz and therefore, sometimes the S4 values are calculated to be zero as there is no variation of signal strength values over the corresponding time window for which the S4 value is calculated (300 epochs for the 1-minute data @5 Hz).

To confirm the repeatability of the above findings over a longer period and for other satellite signals, 7 days' data for all GPS+GLONASS+Galileo satellites are studied and the indicative results for GPS (L2) and GLONASS (G1) are shown in Figure 5. The results confirm that the S_4 index variation signatures for both types of the devices are similar. It is to be noted that during the observation period, S_4 values were always much less than 0.3 indicating no occurrence of any scintillation event [16] that indicate the



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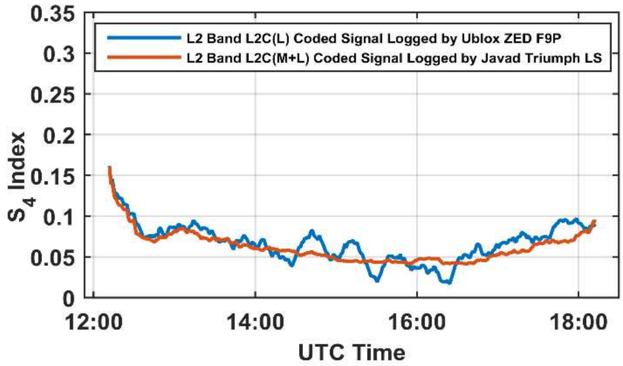
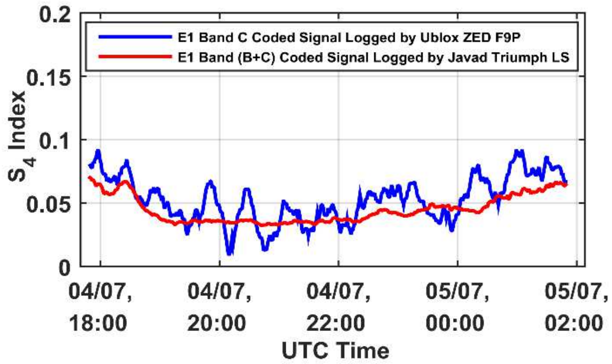


(b)

Figure 2. S_4 index comparison between Javad Triumph LS and Ublox ZED F9P for GPS (a) L1 band and (b) L2 band, derived from C/N_0 values of GPS #10 [Date: 04/07/2020].



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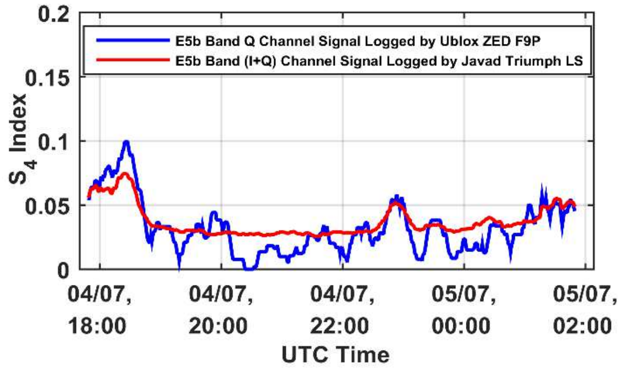
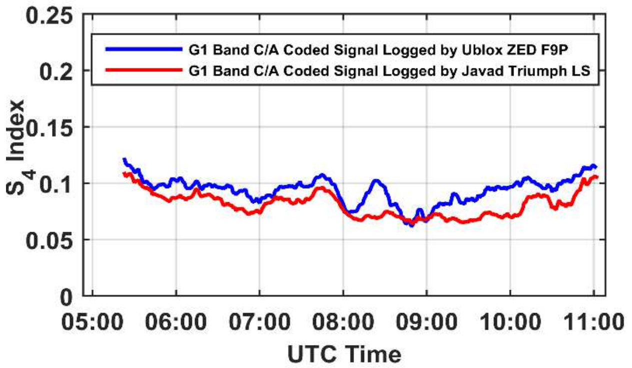


(b)

Figure 3. S_4 index comparison between Javad Triumph LS and Ublox ZED F9P for Galileo (a) E1 and (b) E5b bands [04/07/2020 - 05/07/2020, Galileo #01]



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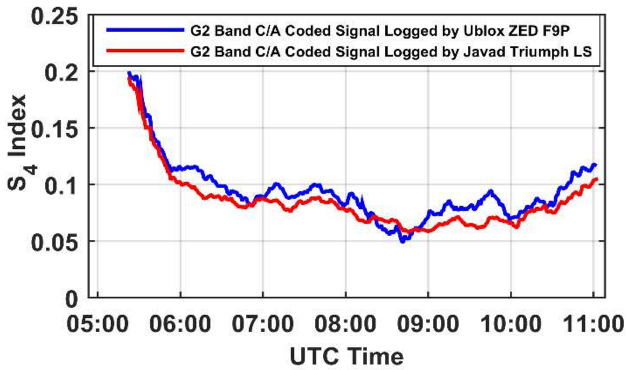
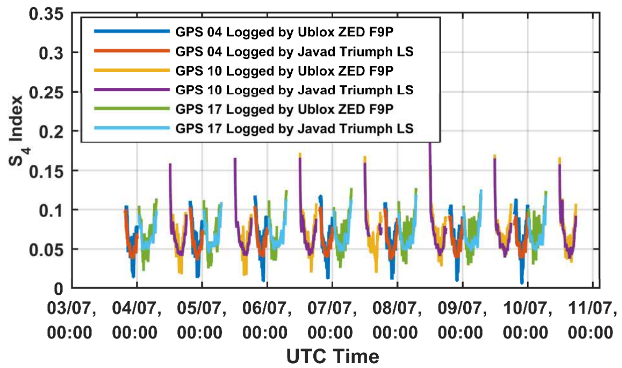


(b)

Figure 4. S4 index comparison between Javad Triumph LS and Ublox ZED F9P in GLONASS (a) G1 and (b) G2 bands [05:00 - 11:00 UTC, 04/07/2020, GLONASS #17].



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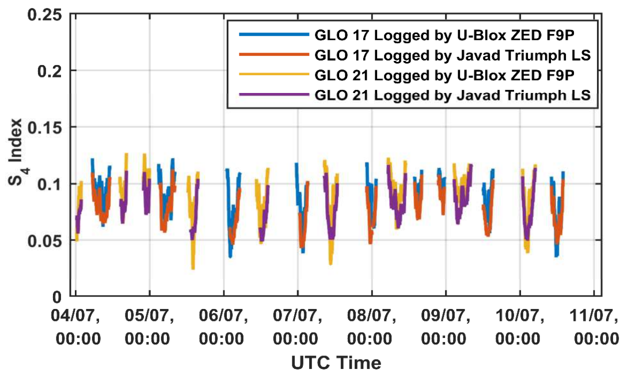

(b)

Figure 5. S_4 index comparison between Javad Triumph LS and Ublox ZED F9P for (a) GPS L2 band (GPS #04, #10, #17) and (b) GLONASS G1 band (GLONASS #17, #21) [04/07/2020 to 10/07/2020]

nominal fluctuations of the signal strengths. The figures show that the S_4 values obtained from the low-cost receivers are comparable with those obtained from the high-end, geodetic receiver even when the S_4 values are small and establish the potential of low-cost, compact GNSS modules for ionospheric studies.

4. Conclusions

This manuscript presents the potential of applicability of low-cost, compact GNSS modules for ionospheric research, which are generally used for geolocation application. The observations obtained through well-planned experiments establish the applicability of the low-cost, commercial GNSS modules for efficient study of the scintillation events with clear advantages of cost, size and power requirement over their geodetic counterparts. The results would be useful for the GNSS-based ionospheric research community in establishing networked monitoring infrastructure for concurrent data collection over a large geographic region within a reasonable cost. Future work in this regard would be to repeat the study during higher ionospheric disturbances and to use modules from other manufacturers to find out the model specific calibration factors.

5. Acknowledgements

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