GNSS Carrier Frequency Dependence of Ionospheric Scintillation Index in Equatorial Regions

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Ionospheric scintillation is one of the most challenging threats to Global Navigation Satellite System (GNSS)-based applications, since it may cause cycle slips or complete signal losses of lock. The scintillation effects can be alleviated by multi-frequency carrier signals of the new generation of GNSS satellites. This frequency diversity can provide backup ranging sources when one carrier frequency is lost and enables receivers to maintain signal tracking during strong scintillation. It is also known that the degree of scintillation (which can be measured with amplitude and phase scintillation indices, $S_4$ and $\sigma_\phi$) is dependent on the signal frequency, but the relationship gets complicated as the scintillation becomes severe, especially in equatorial regions. This motivates us to investigate the relationship of scintillation across different frequencies in equatorial regions and to define a simple mathematical expression on the frequency dependence of scintillation index with estimated uncertainty bounds.

Previous efforts based on the weak scatter theory derived a simple power-law dependence of the $S_4$ index with an exponent of power law index [1]. The power-law relationship between GPS L1CA, L2C, and L5 signals for both amplitude and phase scintillation has been investigated using high-latitude scintillation measurements [2]. However, this relationship is limited to weak scattering theoretically and the validity of power-law dependence needs to be assessed for strong scintillation as the $S_4$ index increases. An alternative approach was proposed based on the inverse diffraction technique which back-propagates high-rate GNSS scintillation measurements to construct an equivalent phase screen [3]. However, this approach has a practical limitation in real-time operation since the inverse diffraction method requires high-rate GNSS measurements to construct an equivalent phase screen model for the realization of scintillations and their statistics (i.e., scintillation index).

In this study, we investigate the frequency dependence of scintillation indices ($S_4$ and $\sigma_\phi$) and define the relationship for different scintillation cases classified by parameters available in real-time including the $S_4$ index and effective scan velocity. This analysis uses multi-frequency GNSS measurements collected from two stations msbd01 and msbd02 in Bahir Dar, Ethiopia. The two stations, located close to each other along the east-west direction, enable us to estimate the zonal drift velocity of ionosphere [4]. For different $S_4$ index values and effective scan velocities, we estimate the relationship of scintillation index across carrier frequencies and also determine an uncertainty bound of the estimates.

The results from this study can be applied to GNSS-based applications that require scintillation indices to be obtained in near real-time or real-time operation. The scintillation index of a temporarily lost signal at a certain carrier frequency can be estimated using measured scintillation indices of signals at the other carrier frequencies. The estimated scintillation index, for example, can be used as an input to a real-time scintillation monitor.

References


