# STUDY OF IONOSPHERIC SCINTILLATION USING IRNSS DATA OVER BENGALURU

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**Abstract -** *The Indian Regional Navigation Satellite System (IRNSS) is an independent, indigenously developed satellite navigation system. Among the natural interferences to an IRNSS receiver, Ionospheric scintillation is one among the strongest that affects the performance of navigation systems. The major impacts include power fading and rapid carrier phase variation. As a result, the transmitted signals degrade by several uncertainties. The main frame work of this paper is to study the scintillation effects for the recorded IRNSS data and to make a comparison study of week and day with reference to plots. Also to plot the C/N (carrier to noise ratio) v/s time for IRNSS data for L5 and S Bands and to analyze the plots.*

***Keywords:*** *IRNSS, Ionosphere scintillation, Navigation, Carrier to noise ratio*

## INTRODUCTION

IRNSS aims at providing navigational service of about 1500 kilometers around India. It is also capable of receiving SPS (Standard Position Services) signal at L5 or S band frequency. Its SPS service is transmitted on L5 (1164.45 – 1188.45 MHz) and S (2483.5-2500 MHz) bands. One of the main reasons for the cause of Ionospheric scintillation is a small scale structure that occurs in the Ionospheric electron density along the signal path and it also occurs due to the interference of refracted or diffracted waves. Deep signal power fading and rapid phase variations are the typical characteristics of Ionospheric scintillation. The propagation speed of radio waves in an ionosphere is resoluted by the density of electrons, which in turn measured in terms of Total Electron Count (TEC). It is expressed in units of electrons/$m^2$.

One unit of TEC is referred as a TECU, which is equal to $10^{16}$ electrons per square meter i.e.

**1 TECU = $10^{16}$ electrons/$m^2$**

To achieve the higher accuracies and control level of positioning in land surveying, especially in IRNSS surveying, we need to reduce the error caused by Ionospheric delay. The study of TEC contributes to development of a new algorithm that reduces the errors in IRNSS signals. The estimated TEC values combined with other scientific data gives the complete Ionospheric information. The above information is ideally helpful for environmental studies such as continuous weather monitoring, microwave communication signals, climatology and other geoscience application.

At L1 carrier frequency of f1, Ionospheric time delay is given by:

$$t_1 = 40.3 \times \left( {TEC}/{C} \cdot f_1^2 \right)$$

Where C is the velocity of light in free space. Dual frequency (f1 and f2) receiver measures the difference in time delay between the two frequencies, i.e $\Delta_t = t_2 - t_1$, given by:

$$\Delta t = \left( {40.3}/{C} \right) \times \frac{TEC}{[(1/f_2^2) - (1/f_1^2)]}$$

Scintillation is quantified by two indexes: S4 for amplitude scintillation and σφ (sigma-phi) for phase scintillation. The two indexes point the variability of the signal over a period of time, usually considered as one minute. Scintillation is predominant at low and high latitudes, but in mid-latitudes, such as United States, experience much less scintillation. Scintillation is a strong function of season, local time, geomagnetic activity and solar cycle. But it also influenced by propagating waves from the lower atmosphere. The below Fig-1 shows IRNSS Signal-to-Noise Power Ratio for healthy & scintillated signals.

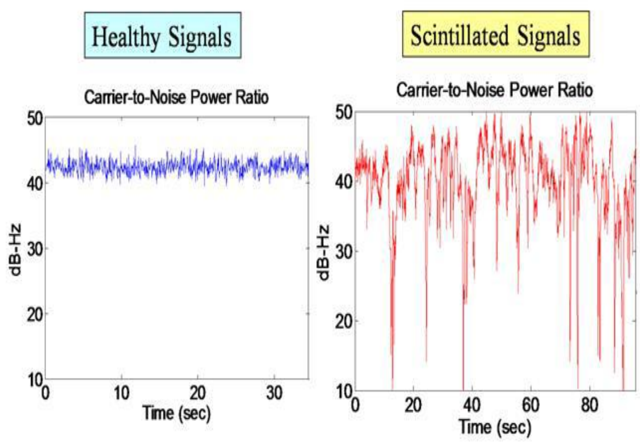



**Fig-1:** IRNSS Signal-to-Noise Power Ratio for Healthy and Scintillated Signals

Ionospheric scintillation can be decomposed into two components: phase scintillation and amplitude scintillation, in which both are defined by their power spectral densities (PSD) and probability density functions (PDF). The PSD of phase scintillation employs an inverse power law, which is given in the following form:

$$S_{\delta\phi_p}(f) = \frac{T_{sct}}{(f_0^2 + f^2)^{p/2}} \quad radians^2/Hz$$

Where $T_{sct}$ is the magnitude of the PSD at frequency 1 Hz, f is the frequency of phase fluctuations, $f_0$ is the frequency corresponding to the maximum deviation in the ionosphere and p is the slope of the PSD. S4: the intensity scintillation index is the normalized root mean square (RMS) intensity and is given by:

$$S_4 = \sqrt{\frac{\langle I^2 \rangle - \langle I \rangle^2}{\langle I \rangle^2}}$$

Where I is the signal intensity.

The PDF of the amplitude scintillation is modeled as a Nakagami-m distribution, which his given by:

$$f_A(A) = \frac{2m^m A^{2m-1}}{\Gamma(m)\langle A^2\rangle^m} e^{-mA^2/\langle A^2\rangle} \quad A \geq 0$$

where A is the signal amplitude, m is defined as $m = 1/S4^2$.

**Section 2** Describes the data collection and extraction done at MVJ College of Engineering, Bengaluru to carry out this study.

**Section3** Presents data analysis of scintillation occurrence with reference to plots (day, week, carrier to noise ratio v/s time)

$$f_A(A) = \frac{2\left(\frac{1}{S_4^2}\right)^{\frac{1}{S_4^2}} A^{2\frac{1}{S_4^2}-1}}{\Gamma\left(\frac{1}{S_4^2}\right)\langle A^2\rangle^{\frac{1}{S_4^2}}} e^{-\frac{1}{S_4^2}A^2/\langle A^2\rangle} \quad A \geq 0$$

## A.CAUSES OF IONOSPHERIC SCINTILLATION

Scintillation results from refractive index irregularity of the Ionospheric medium, in turn it is the result of inhomogeneities such as plasma bubbles. These irregularities are the main responsible for the scintillation occurrence predominantly at the altitudes between 200 and 1000 km in the F-layer of the ionosphere. Irregularities in E-layer such as sporadic-E and auroral-E also contribute for the scintillation, but the impact on L-band GPS signals is minimal.

In geographic distribution, Ionospheric scintillation peaks in the sub-equatorial anomaly regions located on average ~15° either side of the geomagnetic equator.

## B.IMPACT OF IONOSPHERIC SCINTILLATION

Ionospheric scintillation affects trans-Ionospheric radio signals up to a few GHz in frequency. It has detrimental impacts on Satellite-based navigation and communication systems. It also affects scientific instruments. Scintillation has a major impact in accurate position calculation in GPS. Losing lock on even a single satellite can severely degrade the quality of the position. It also impacts the continuity and reliability of GPS/IRNSS systems by reducing the performance of the code and carrier tracking loops of a receiver. Reducing the radio signal amplitude degrades its power level, in-turn directly affects the signal to noise ratio. Thus impending the base station's ability to detect and receive the signal while phase fluctuations increases. The phase error which when exceeds tracking threshold leads to loss of phase lock. During normal atmospheric conditions, a nominal Carrier to Noise Ratio (C/N0) value acquired by a commercial GPS receiver is about 44 dB-Hz [1] and 50 dB-Hz for IRNSS.

## C. RELATED WORK

The detailed study on various aspects of scintillation has been carried out in various locations of India like West Bengal, Hyderabad, Bengaluru and Sangli. The detailed study of all these centers aims at drawing a definite pattern of scintillation variability relative to seasonal fluctuations and to study different performance parameters with respect to scintillation.

## II DATA COLLECTION

The below Fig-2 shows data recording & data extraction done from IRNSS receiver (Serial No: A039) at MVJ College of Engineering, Bengaluru.

**Fig-2:** Screenshots depicting IRNSS data recording

Once the data recording is complete, the data has to be extracted. The extracted data will be in the form of LOG files. Extracted IRNSS data has files which contains 24 hours data.

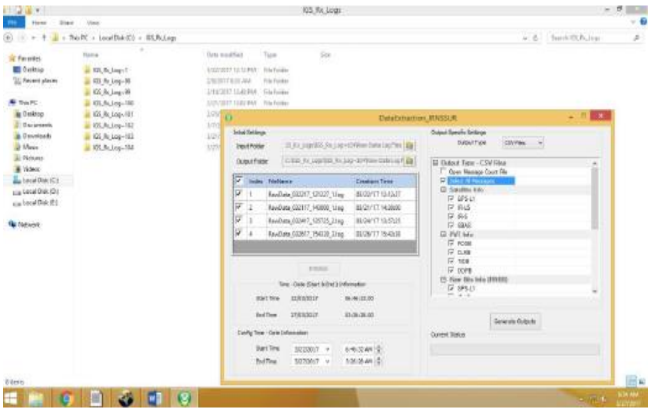
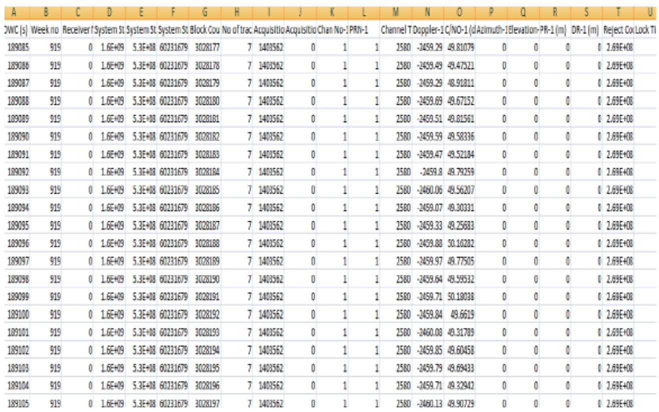


**Fig-3:** Screenshot depicting IRNSS data extraction

The IRNSS raw data (LOG Files) from satellite is obtained is unreadable and by using Convert-4 tool the data is converted to the readable form. Then the data is stored in a workspace table which contains columns as TOWC(s), week number, azimuth angle, PRN number etc.



| A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q | R | S | T | U |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| OWC (s) | Week no | Receiver | System St | System St | System St | Block Cou | No of trac | Acquisitio | Acquisitio | Chan No-1 | PRN-1 | Channel T | Doppler-1 | C/NO-1 (d | Azimuth-1 | Elevation- | PR-1 (m) | DR-1 (m) | Reject Co | Lock Ti |
| 189085 | 919 | 0 | 1.6E+09 | 5.3E+08 | 60231679 | 3028177 | 7 | 1403562 | 0 | 1 | 1 | 2580 | -2459.29 | 49.81079 | 0 | 0 | 0 | 0 | 2.69E+08 | |
| 189086 | 919 | 0 | 1.6E+09 | 5.3E+08 | 60231679 | 3028178 | 7 | 1403562 | 0 | 1 | 1 | 2580 | -2459.49 | 49.47521 | 0 | 0 | 0 | 0 | 2.69E+08 | |
| 189087 | 919 | 0 | 1.6E+09 | 5.3E+08 | 60231679 | 3028179 | 7 | 1403562 | 0 | 1 | 1 | 2580 | -2459.29 | 48.91811 | 0 | 0 | 0 | 0 | 2.69E+08 | |
| 189088 | 919 | 0 | 1.6E+09 | 5.3E+08 | 60231679 | 3028180 | 7 | 1403562 | 0 | 1 | 1 | 2580 | -2459.69 | 49.67152 | 0 | 0 | 0 | 0 | 2.69E+08 | |
| 189089 | 919 | 0 | 1.6E+09 | 5.3E+08 | 60231679 | 3028181 | 7 | 1403562 | 0 | 1 | 1 | 2580 | -2459.51 | 49.81561 | 0 | 0 | 0 | 0 | 2.69E+08 | |
| 189090 | 919 | 0 | 1.6E+09 | 5.3E+08 | 60231679 | 3028182 | 7 | 1403562 | 0 | 1 | 1 | 2580 | -2459.59 | 49.58336 | 0 | 0 | 0 | 0 | 2.69E+08 | |
| 189091 | 919 | 0 | 1.6E+09 | 5.3E+08 | 60231679 | 3028183 | 7 | 1403562 | 0 | 1 | 1 | 2580 | -2459.47 | 49.52184 | 0 | 0 | 0 | 0 | 2.69E+08 | |
| 189092 | 919 | 0 | 1.6E+09 | 5.3E+08 | 60231679 | 3028184 | 7 | 1403562 | 0 | 1 | 1 | 2580 | -2459.8 | 49.79259 | 0 | 0 | 0 | 0 | 2.69E+08 | |
| 189093 | 919 | 0 | 1.6E+09 | 5.3E+08 | 60231679 | 3028185 | 7 | 1403562 | 0 | 1 | 1 | 2580 | -2460.06 | 49.56207 | 0 | 0 | 0 | 0 | 2.69E+08 | |
| 189094 | 919 | 0 | 1.6E+09 | 5.3E+08 | 60231679 | 3028186 | 7 | 1403562 | 0 | 1 | 1 | 2580 | -2459.07 | 49.30331 | 0 | 0 | 0 | 0 | 2.69E+08 | |
| 189095 | 919 | 0 | 1.6E+09 | 5.3E+08 | 60231679 | 3028187 | 7 | 1403562 | 0 | 1 | 1 | 2580 | -2459.33 | 49.25683 | 0 | 0 | 0 | 0 | 2.69E+08 | |
| 189096 | 919 | 0 | 1.6E+09 | 5.3E+08 | 60231679 | 3028188 | 7 | 1403562 | 0 | 1 | 1 | 2580 | -2459.88 | 50.16282 | 0 | 0 | 0 | 0 | 2.69E+08 | |
| 189097 | 919 | 0 | 1.6E+09 | 5.3E+08 | 60231679 | 3028189 | 7 | 1403562 | 0 | 1 | 1 | 2580 | -2459.97 | 49.77505 | 0 | 0 | 0 | 0 | 2.69E+08 | |
| 189098 | 919 | 0 | 1.6E+09 | 5.3E+08 | 60231679 | 3028190 | 7 | 1403562 | 0 | 1 | 1 | 2580 | -2459.64 | 49.59532 | 0 | 0 | 0 | 0 | 2.69E+08 | |
| 189099 | 919 | 0 | 1.6E+09 | 5.3E+08 | 60231679 | 3028191 | 7 | 1403562 | 0 | 1 | 1 | 2580 | -2459.71 | 50.18038 | 0 | 0 | 0 | 0 | 2.69E+08 | |
| 189100 | 919 | 0 | 1.6E+09 | 5.3E+08 | 60231679 | 3028192 | 7 | 1403562 | 0 | 1 | 1 | 2580 | -2459.84 | 49.6619 | 0 | 0 | 0 | 0 | 2.69E+08 | |
| 189101 | 919 | 0 | 1.6E+09 | 5.3E+08 | 60231679 | 3028193 | 7 | 1403562 | 0 | 1 | 1 | 2580 | -2460.08 | 49.31789 | 0 | 0 | 0 | 0 | 2.69E+08 | |
| 189102 | 919 | 0 | 1.6E+09 | 5.3E+08 | 60231679 | 3028194 | 7 | 1403562 | 0 | 1 | 1 | 2580 | -2459.85 | 49.60458 | 0 | 0 | 0 | 0 | 2.69E+08 | |
| 189103 | 919 | 0 | 1.6E+09 | 5.3E+08 | 60231679 | 3028195 | 7 | 1403562 | 0 | 1 | 1 | 2580 | -2459.79 | 49.69433 | 0 | 0 | 0 | 0 | 2.69E+08 | |
| 189104 | 919 | 0 | 1.6E+09 | 5.3E+08 | 60231679 | 3028196 | 7 | 1403562 | 0 | 1 | 1 | 2580 | -2459.71 | 49.32942 | 0 | 0 | 0 | 0 | 2.69E+08 | |
| 189105 | 919 | 0 | 1.6E+09 | 5.3E+08 | 60231679 | 3028197 | 7 | 1403562 | 0 | 1 | 1 | 2580 | -2460.13 | 49.90729 | 0 | 0 | 0 | 0 | 2.69E+08 | |

**Fig-4:** Screenshots depicting converted data in Excel

The above screenshot shows the converted data stored in Excel. The first record in the data section of Excel sheet contains the satellite's TOWC(s), Week number, Receiver status, System status and Number of tracked channels. The subsequent records contain information about broadcast orbit of the satellite, satellite health, PRN and other relevant information.

## III DATA ANALYSIS

After extracting data in the Excel sheet format, a Matlab code is written for visualization of graph for scintillation and analysis of graph. This work is concerned with evaluating the impact of scintillation on the performance of IRNSS receivers. By using Matlab software, a code is written to visualize a plot of C/No (Carrier to Noise Ratio) versus time. For this data a Matlab code is written and analysis of graph for Day and Week is done. Based on the graph we can analyze how scintillation takes place.

The below Fig-5 depicts the methodology employed for plotting the graphs.

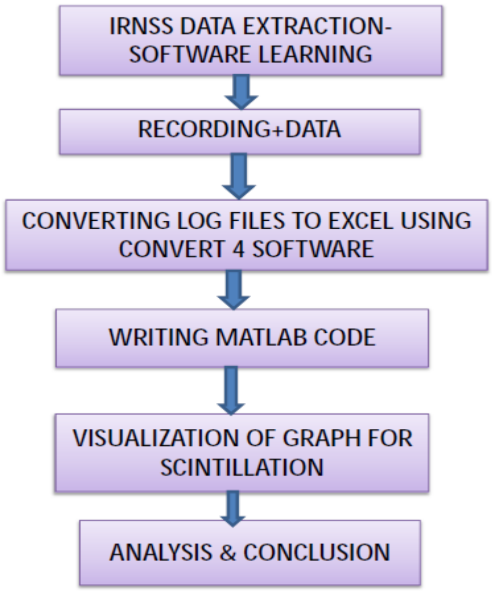



**Fig-5:** Flowchart of methodology

Matlab code is used to check the various conditions in the table. Multipath interference is caused by reflected signals from surface near the IRNSS receiver that can either interface with or be mistaken for the true signal that follows an uninterrupted path from a satellite. Such conditions can be checked using the matlab code and the analysis is done based on the graphical representation of the data. For many purposes, it is acceptable to use IRNSS satellites above 30 degree elevation angle to minimize the effect of geometric factors. To minimize the external influence that may biases our results we used only satellites with elevation angle above 30 degree. And the multipath interference is not considered as scintillation.

## III RESULTS AND DISCUSSION

### Description for Day Graph

The L5 frequency (1176.25 MHz) in IRNSS will eliminate the TEC effect (range delay ionosphere errors) using dual frequency receivers but the problem of scintillation will still remain.

During the post sunset period of equinoctial month scintillation at L5 band of IRNSS is found to be much severe often causing loss of lock in the receiver. The fading/fluctuations in L5 band are more.

In post sunset sector there are periods when scintillations in excess of 10 dB at L5 band plagued the links of IRNSS-1A, 1B, 1C & 1D simultaneously.

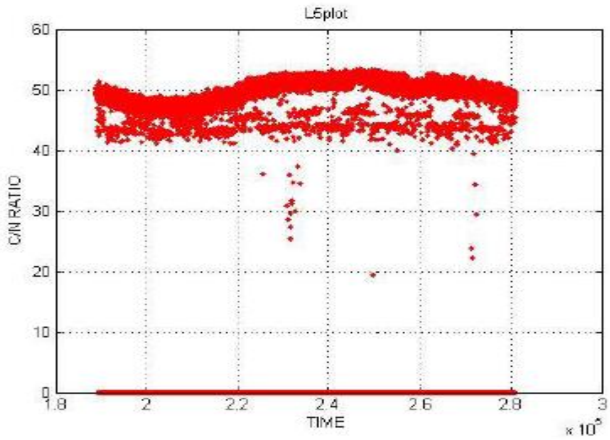



**Fig-6:** L5 band day plot

The S band frequency (2492.048MHz) in the IRNSS will eliminate the TEC effect (range delay ionosphere errors) using dual frequency receivers but the problem of scintillation will still remain. Compare to L5 band, S band has zero or less Scintillation as fading/fluctuation observed in S band are less. S band signals experiences a constant 0-5 dB Hz variation in C/No.

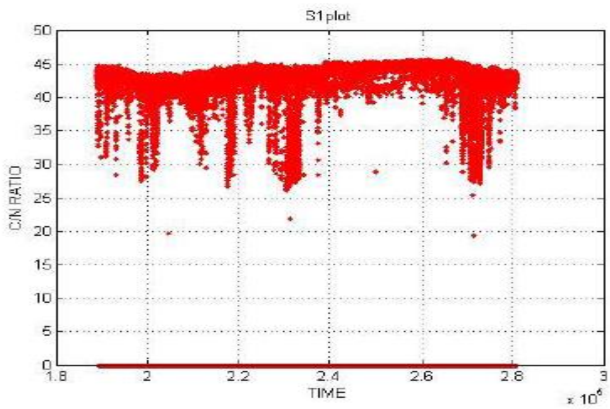



**Fig-7:** S band day plot

### Description for Week Graph

The below graph depicts L5 Band week plot. In L5 band the scintillation occurs in between 40 dB to 50 dB and each bar refers to a day starting from Sunday to Saturday respectively. It is observed that Monday and Wednesday the scintillation is less compared to other days.

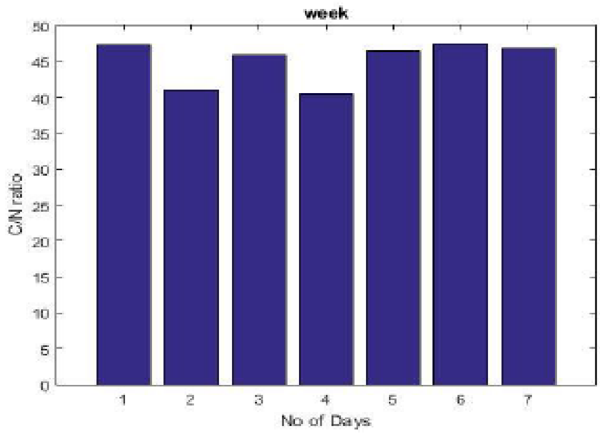



**Fig-8:** L5 band week plot

The below graph depicts S Band week plot In S band the scintillation occurs in between 35 dB to 45 dB and each bar refers to a day starting from Sunday to Saturday respectively. It is observed that Monday and Wednesday the scintillation is less compared to other days

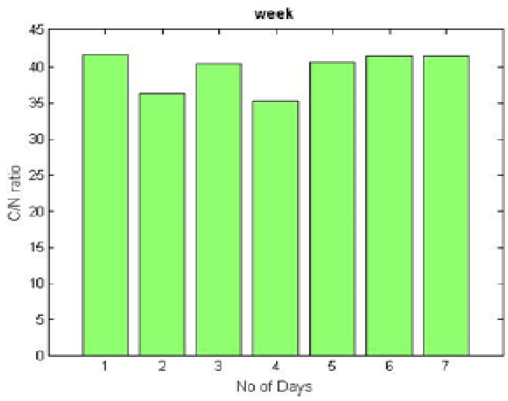



**Fig-9:** S band week plot

## CONCLUSION

In this paper, the study of Ionospheric scintillation affecting the IRNSS receiver is observed and evaluated at the Bengaluru which is located at the southern part of the Indian continent, that is oriented close to equator and so scintillation is observed frequently at this station in the post sunset hours (i.e. between 6pm to 12 am) of equinoctial months.

Matlab code is written to plot graphs of Day and Week. The graphs are evaluated and analyzed with respect to scintillation effect.

## FUTURE WORK

Consequent to the observations of the scintillation events, the work will be extended to study the impact of scintillation on GNSS Receiver performance and also address the scintillation mitigation techniques.

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