URSI GASS 2021, Rome, Italy, 28 August - 4 September 2021

Studies of IRNSS Scintillation near the Northern EIA crest of the Indian zone

Debasis Jana* [(1)], S.K. Chakraborty [(1)]
(1) Maharaja Srischandra College, Kolkata 700003, India
*currently at Indian Institute of Technology (BHU), Varanasi, India

Abstract

Scintillations of trans ionospheric signals at S(2492.08 MHz) and L5(1176.45 MHz) bands from satellite constellation of Indian Regional Navigation Satellite System(IRNSS) along with scintillations at L1(1575.42 MHz) band from available SBAS(GAGAN, BieDou, MTSAT) links and VHF(250.650 MHz) band from FSC are investigated to study the multifrequency and multi-satellite occurrence features in the context of navigation. The observation are made from Raja Peary Mohan College(22.660 N, 88.40 E) located virtually below the northern crest of the Equatorial Ionization Anomaly(EIA) during the period April2015 to April2017. The results of analysis indicates occurrence to severe scintillations in the VHF to lower microwave L bands during equinoctial months high solar activity period while the scintillations at S band is mostly limited to 10dB fluctuations While multiple scattering , appearance of dual slope, lowest coherence length characterizes the VHF to L band scintillations, single scattering dominates the scintillation at S band. A study of CDF leads to fade margin of 14dB at L5 band while the same at S band estimated to be 6dB for faithful navigation below the saturation limits. There are periods when multi-satellite trans ionospheric links located within the 1Oo span of IPPs (satellites located between 55oE IRNSS and 145oE MTSAT) exhibit scintillations simultaneously. The period is also permeated by loss of lock in the different GNSS links. During the period availability of GNSS links(GPS, GLONASS etc.) attains a value of less than 4, minimum requirement for faithful navigations. Analysis of Total Electron Content(TEC) data of the various GNSS tracks reveal severe depletion along with high value of ROTI, evolution and shifting of wavelet structure pattern of multiple periods in detrended TEC during multi satellite scintillations. The result may be discussed in terms of evolution of cluster of equatorial plasma bubbles and its superposition in th post sunset period of equinoctial months.

1 Introduction

Ionospheric scintillation near the equatorial ionization anomaly crest (EIA) is one of the major problems in maintaining fail safe navigation/communication links. One of the methods to mitigate the scintillation effect is to use the frequency diversity technique such that if one frequency band is corrupted due to severe signal fluctuations another at higher frequency region may be utilized for navigation, as higher the frequency lower the probability of scintillation. Uses of multiple frequencies in GNSS navigation may be the outcome of such diversity technique. A study of fading characteristics of trans-ionospheric signals at multiple frequency from the region near the EIA crest is urgently needed to decide the fade margin of the receiving system as most severe scintillation are observed in the zone. The study may form an important data base to revisit the effectiveness of frequency diversity technique. With this view multi-frequency, extending from VHF (250.650MHz) to L5 (1175.45MHz) and S band (2492.08 MHz) scintillation studies are initiated from Raja Peary Mohan College (RPMC) center (22.65°N, 88.36°E) located near the EIA crest since April 2015.A comparative study of multi frequency scintillation fading features, particularly at L5 and S bands are reported for the first time from the northern EIA crest of the Indian zone.

2 Data

The VHF signal at 250.650MHz from geostationary satellite FSC is monitored at RPMC using ICOM-7000 receiver. The amplitude signal is received at 50/20Hz sampling rate. The signal at L5 (1176.45 MHz) and S (2492.08 MHz) bands are recorded using ACCORD GPS IRNSS receiver employing IRNSS #3 satellite in GEO. The sampling rate of said receiver is 1Hz. The 350km pierce point location of FSC and IRNSS #3 are (21.1ON, 86.9OE) & (21.3ON, 87.9OE) respectively. For L1 (1575.42 MHz) signal GAGAN satellite of PRN #128 with IPP at 21.3ON, 88.0OE is used. Intensity of scintillation is expressed through S4 Index which is estimated as the normalized standard deviation of signal intensity fluctuations over one minute interval. To estimate decorrelation time 3 minutes sample and 10 minutes section of scintillation data at VHF and L5/S band are subjected to autocorrelation analysis when S4 more of less remain stable. The results of observation pertaining to equinoctial months of 2015-2016 are mainly presented.

3 Results

Figure 1(a) is a sample plot of temporal variation in amplitude (v), C/NO at VHF, L5 and S band frequency on the date and time mentioned. Fluctuations in amplitudes from VHF to S band called scintillations are evident. Severe scintillations exceeding the dynamic range (~25 dB) of the receiver at VHF distinguished the weak scintillations mostly limited to 7 dB at S band. Severe scintillations followed by the loss of lock in L5 channel is also evident (shown by boxes in the middle panel). The decorrelation time (τ1/2), which is defined as the time lag to obtained 50% autocorrelation value at three frequencies, are plotted in figure 1(b). It is an important parameter in the severe scintillation condition when the scintillation index S4 does not give any information of the perturbation strength. τ1/2 is related to perturbation strength in strong scintillation cases. Lowest values of decorrelation time at VHF and highest at S band marked the multi-frequency features. The said time is inversely proportional to the fade rate. Lowest values imply faster fading rate at VHF compared to slow fading at higher GHz bands (L5 and S).

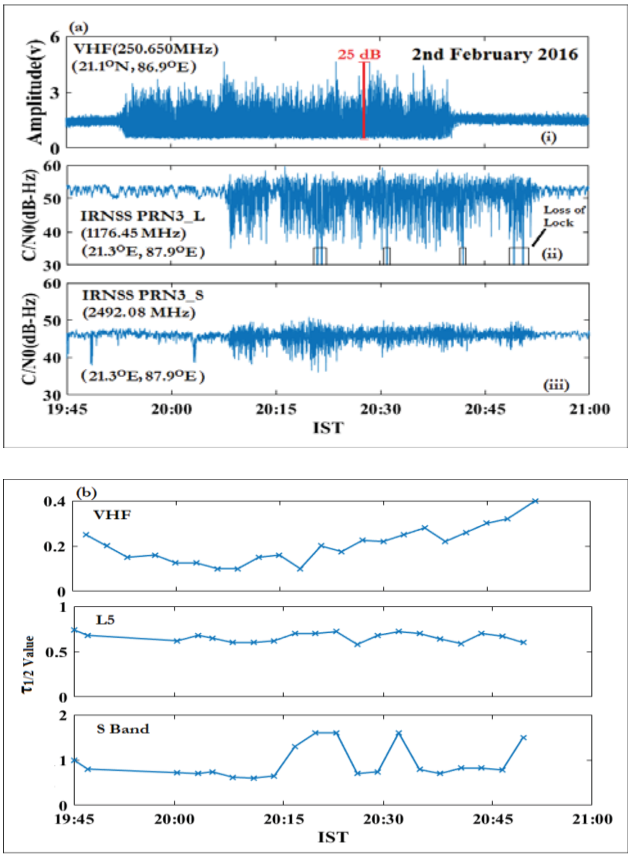

Figure 1. (a) Temporal variation of i) amplitude (V) at VHF ii) C/NO (dB-Hz) at L5 and iii) S band respectively. (b) Temporal variation of decorrelation time ($\tau_{1/2}$) (second) for the respective patches shown in upper panel.

3.1 Scintillation occurrence features

Equatorial scintillation are observed near the EIA crest in the form of discrete patches of variable duration. It is due to width tapering nature and filamentary structure of N-S elongated irregularity clouds. A study of variability in scintillation intervals along with fading characterises is important for deciding the adaptive capability of the receiving system as loss of tracking and acquisition time are mostly dependent on these factors. Figure 2(a& b) exhibits multi-frequency (VHF, L5, L1, S) patch distribution in the pre-midnight sector for the month of October and June 2015. Mostly S band scintillation patches are limited to 15-30 minutes duration while longer duration patches dominate the low frequency band (VHF). The percentage is estimated using the available pre-midnight patches. Negligible occurrence in S band in summer solistial months is evident. Scale size and life time of irregularities may be attributed to such variable patch duration at multi-frequency band while the seasonal differences may be attributed to scale size, generation mechanism of scintillation producing irregularities.

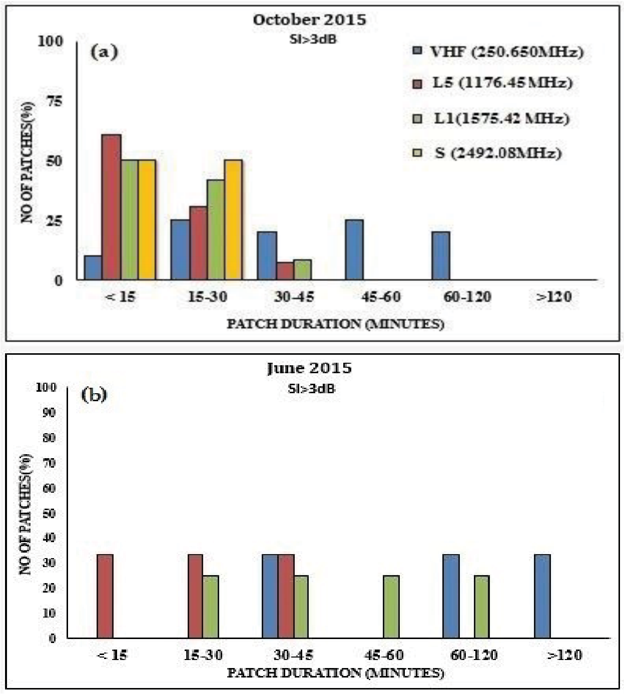

Figure 2. Distribution of scintillation patches of variable duration at SI>3dB for the month of (a) October 2015 and (b) June 2015 at VHF, L5, L1 & S band frequencies

3.2 Cumulative amplitude distribution function (CDF)

Various researchers (Whitney et al, 1977) have been shown that the cumulative distribution function of the ionospheric scintillations follow the Nakagami's m distribution.

The distribution function of intensity in dB, x, is given by,

$$P(x) = \frac{2m^m}{M\Gamma(m)} \exp\left[m\left\{\frac{2x}{M} - \exp\left(\frac{2x}{M}\right)\right\}\right]$$

Where,

m = Nakagami's parameter

$M=20\log_{10}e=8.6286$

This distribution is related to with the other distribution functions.

Such as, if a variable has a Nakagami's m distribution, the square of this variable has a gamma distribution.

For m=1 it becomes Rayleigh distribution.

For m=0.5 it becomes one sided normal distribution.

Nakagami's m distribution thus can be regarded as different generalization of the Rayleigh distribution.

It has been shown earlier that $S4= (1/m)^{1/2}$ $(m \geq 0.5)$

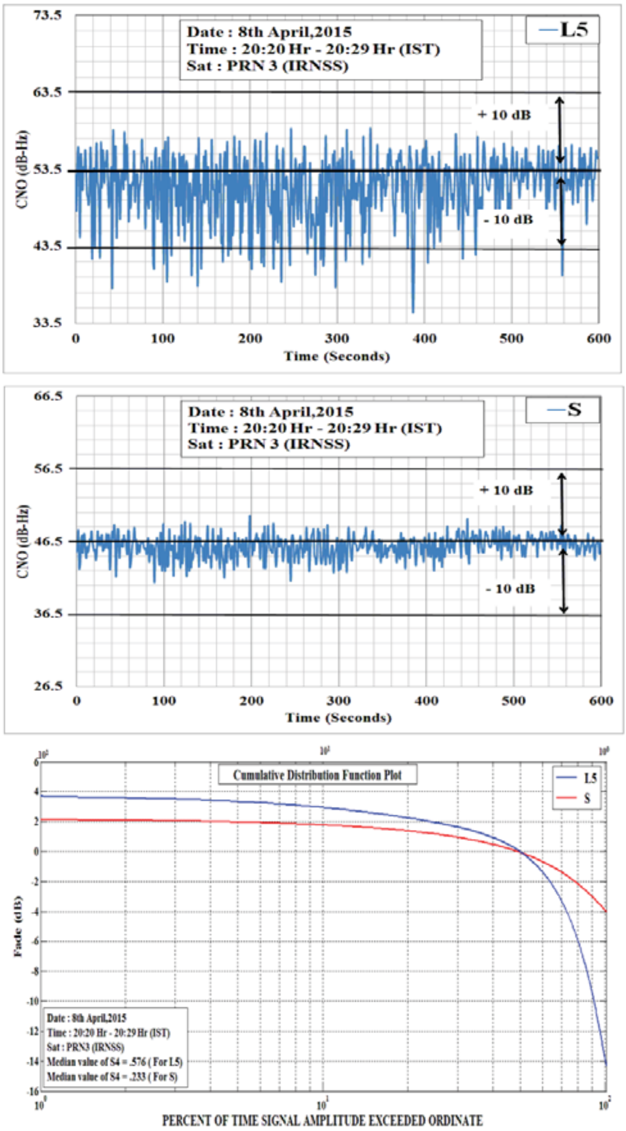

Figure 3. Sample plot of signal fluctuation at L5 band and S band. Cumulative amplitude distribution at L5 band for specified scintillation level and Cumulative amplitude distribution for S band (lower panel).

Figure 3 is showing the cumulative Nakagami distribution plot. Comparing figure (lower panel) with the cdf obtained from L5 and S Band frequency, value of m is determined. With this m value S4 was obtained by using the equation written above. A comparison table of this S4 value is shown in table below showing a good fit for both weak and moderate scintillation.

Date	Time (IST)	Frequency	Nakagami distribution parameter(m)	Calculated S4 from m value $[S4 = \left(\frac{1}{m}\right)^{\frac{1}{2}}]$	Median value of S4 (experimentally observed)
8th April,2015	20:20-20:29	L5	3	.577	.576
		S	20	.223	.233
11th May,2015	23:26-23:35	L5	3	.577	.549
		S	20	.223	.224
20th November,2015	20:13-20:22	L5	3.5	.534	.535
		S	20	.223	.201

3.3 Fade characteristics

Figure 4 showing the distribution of fades below several levels for both L5 band and S band corresponding to the CNO samples shown in figure 3. Data at L5 and S Band were recorded at the rate of 1 Hz. Therefore intervals shorter than 1 second could not be resolved. It can be seen from figure 4 that at L5 band when the fade margin is -2 dB the cumulative numbers of fades corresponding to duration of 2 second or less is 26. Similarly at S band the number of fades with durations 2 second or less at -2 dB fade level are 13. This confirms that fade rate has decreased with increase in frequency.

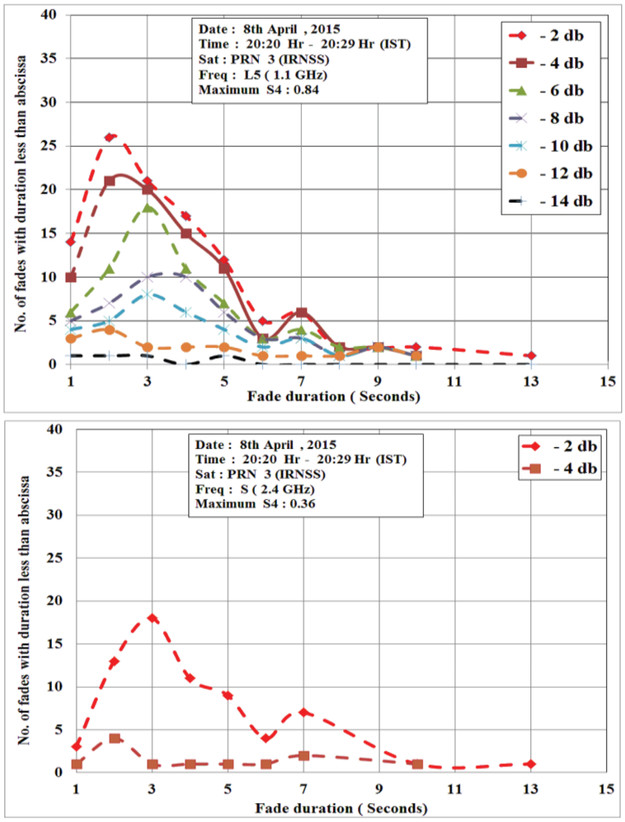

Figure 4. Distribution of fade along with duration at L5 (upper panel) and S band (lower panel)

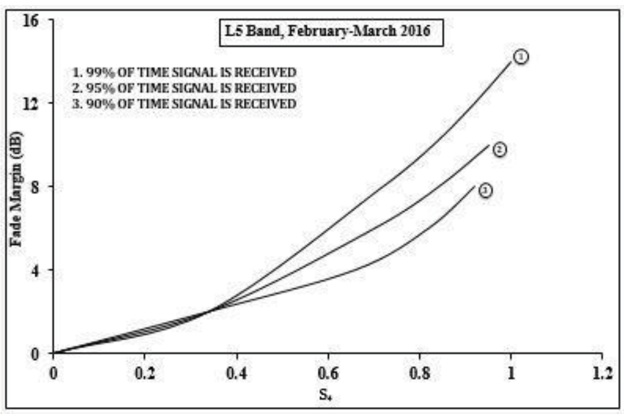

Figure 5. Relation between S4 index and fade margin required to receive signals for different percentage of time.

The fade margin in dB to be allowed at L5 band for receiving the signals at a given percentage of time versus S4 is shown in figure 6. The fade margin shown is obtained from the median cdf's for February and March 2016 for different S4 values. Under severe scintillation conditions (S4~1), for reception of signal (L5) for 99% of time a 14 dB fade margin of the receiver may be allowed though the result is receiver sensitive. It may be mentioned that fade margin does not indicate message reception reliability but percent of time the signal can be received on the average. It yields maximum possible value of message reliability.

3.4 Spectral features of S band scintillation

Figure 5 is showing a typical power spectrum density plot for 8th April of 2015 for VHF, L5 and S band frequencies. At S band frequency weak scintillation was occurred on that time. Fresnel frequency of that patch is .24 Hz. Spectral slope of this power spectrum is -2.97. At L5 band frequency moderate scintillation was occurred. Fresnel frequency of this patch is .21 Hz and spectral slope of this power spectrum is -3.57. For VHF frequency strong scintillation was occurred. It is clearly visible that this power spectrum has the dual slope nature. The break frequency of this spectrum is 1.1 Hz which is very high compared to the calculated Fresnel frequency for the VHF signal. The reason behind this mismatch is at strong scintillation, Fresnel formula is not hold properly due to multiple scattering. Calculated scale sizes at L5 and S band frequency for this plot are 465 m and 320 m respectively taking transverse irregularity velocity = 100 m/s.

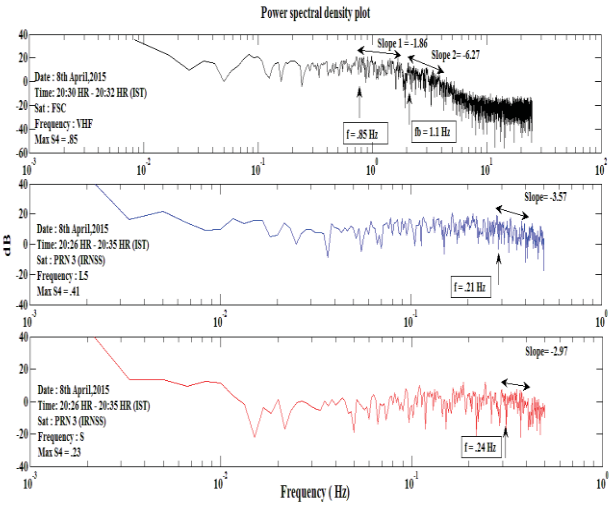

Figure 6. Power Spectral density plot for 8th April, 2015 at VHF (Top), L5 (Middle) and S (Bottom) band frequencies.

Another feature is noticeable from this plot is that falling slope is decreasing with the increase of frequency. For VHF, L5 and S band, falling slope was varied from -4 to -6, -3 to -4 and -2 to -3 for moderate and weak scintillations.

4 Conclusion

In the EIA region it is the strength of irregularities which control primarily the fading pattern of scintillation. The fading time scale depends upon both the speed of scintillation pattern across the ground and spatial scale called Fresnel length. A higher velocity and/or smaller scale size irregularities may lead to faster fading hence lower $\tau_{1/2}$ values. The lower fade rate at s band pertains to irregularities of Fresnel dimension. The pre-requisites for strong scintillation with fast fading rate are to have sufficiently high electron density fluctuations at the scale size comparable to Fresnel dimension and sharp gradient in electron density which may be tested using latitudinal profile of TEC. The correlation time $\tau_{1/2}$values during strong scintillation provide much insight into the strength of scattering while no additional information can be obtained from the S_4 index. The decrease in coherence time may be a good indicator of the perturbation strength in intensity scintillation event when S_4 saturates. A study of diffraction scale on the ground as dictated by the decorrelation time provides a good indication for nature of scattering. The coherence length in the saturation epoch of VHF scintillation is found to be 4.5±1.1 m while at L5 and S band it is found to be 68.6±6 m and 70.6±3 m respectively. This is an indirect indication of multiple scattering, particularly at VHF when no correspondence between multi-frequency irregularity structures is reflected.

5 References

1. Chakraborty, S. K.; Chatterjee, S.; Jana, Debasis (2017) A study on multifrequency scintillations near the EIA crest of the Indian zone, *Advances in Space Research*, **60,** Issue 8, p. 1670-1687.

2. S Chatterjee and S. K Chakraborty (2013), Variability of ionospheric scintillation near the equatorial anomaly crest of the Indian zone, *Ann Geo phys*, **31**, 697-711.

3. S band scintillations studies near the EIA crest of Indian zone August 2017 *DOI: 10.23919/URSIGASS.2017.8105338* Conference: 2017 XXXIInd General Assembly and Scientific Symposium of the International Union of Radio Science (URSI GASS)