S band scintillations studies near the EIA crest of Indian zone

D. Jana[1], S.K. Chakraborty[1, 2], S. Banerjee[1] and A. Dasgupta[3]

[1]Raja Peary Mohan College, Uttarpara, Hooghly, West Bengal-712258, India, janadebasis69@gmail.com

[2]Maharaja Srischandra College, Kolkata-700020, West Bengal, India, skchak2003@yahoo.com

[3]S.K.Mitra Centre for Research in Space Environment, University of Calcutta, Kolkata-700009, India, adg1bkpr@gmail.com

Abstract: The results of statistical and morphological studies of ionospheric scintillation data at S band (2492.08 MHz), still unexplored, in conjunction with those at L5 (1176.45MHz) and VHF (250.650 MHz) band for the period of 2015-2016 are presented. The observations are carried out at Raja Peary Mohan College center (RPMC: 22.66^0 N, 88.4^0 E) situated near the northern crest of the equatorial ionization anomaly (EIA). The morphological studies on the occurance features at multi-frequency bands with SI>3dB level exhibit a decreasing trend with 10.7cm solar flux.Much less occurrence in S band compared to VHF as well as L5 band reflects the frequency dependent features. S band scintillations are mainly observed in the equinoctial months of high solar epochs while at the lower frequency VHF/L5 bands occurrences are recorded in the solstitial months also. During the periods of severe scintillations frequent losses of lock in the L5 channel is recorded. The maximum fade rate is observed in the middle of the patch irrespective of frequency. The study of cumulative amplitude distribution dictates a fade margin of 14 dB in L5 band and 8-9 dB in S band respectively. Power spectral studies of weak scintillation at VHF, L5 and S band reveals the general features of flat low frequency part and roll off around Fresnel frequency. In the strong scintillation conditions two component spectra dominates the VHF and L5 band while S band spectra always exhibits single component. With the increasing strength of scintillation prominent broadening of spectra in all frequency bands are reflected. During the period a good correspondence between the decorrelation time (τ) and perturbation strength as expressed by S_4 index at S band is evident. Multiple scattering appears to be dominating mechanism for strong scintillation at VHF and L5 band while in S band weak scattering is the primary contributing factor.

1. Introduction:

With the ever increasing reliance of our society on spaced based technology using Global Navigation Satellite system (GNSS) as well as Indian Regional Navigation Satellite System (IRNSS) study of ionospheric scintillation at multiple frequency bands has become one of the important components of modern space research activities. A fixed system design (receiver structure) is based upon the specification of a required fade margin. The specification of fade margin requires an estimate of the level of impairment that can be accounted for which in turn needs knowledge of the magnitude of vulnerable ionospheric effects along with its occurrence distribution. One of such effects is the ionosphere scintillation. Though much studies have been made on VHF to L band scintillation, studies on S band scintillation is yet to be explored. The study of scintillation needs two types of data, namely morphology and signal statistics. Under present investigation both type of studies on multi-frequency scintillations extending from VHF to S bands are presented.

2. Data:

Transionospheric signals at VHF (250.650 MHz) from the geostationary satellite FSC along with L5 (1176.45MHz) and S (2492.028 MHz) band signals from Indian Regional Navigation Satellite System (IRNSS) are being recorded simultaneously from Raja Peary Mohan College Centre (RPMC) (geographic 22.66^0 N, 88.4^0 E, geomagnetic 13.11^0 N, 161.9^0 E). The ionospheric pierce point (IPP) at 350 km altitude for satellite FSC is located at 21.1^0N, 86.9^0E. The data are recorded using ICOM-7000 receiver at 50/20 Hz sampling rate. The signals at L5 and S band frequencies from satellite constellation of IRNSS are recorded using ACCORD IRNSS SPS receiver. It gives C/NO data at 1 Hz. Mainly the satellite of IRNSS with PRN #3 (350 km IPP at 21.08^0N, 87.98^0E) is being used for comparative study of multi-frequency scintillations.

3. Results and Discussion:

Figure 1 is a sample plot exhibiting scintillations at VHF, L5 and S band respectively. To study the morphological features of ionospheric scintillation at VHF, L5 and S band percentage occurrence of pre-midnight scintillations for the different months extending from April, 2015 to October 2016 is presented in Figure 2. The monthly mean $F_{10.7}$ solar flux (1SFU= $10^{-22}Wm^{-2}Hz^{-1}$) is also plotted in the same figure. Evidently the occurrence probability decreases with solar flux maintaining a hierarchy in occurrence with respect to frequency. Much less occurrence in S band compared to VHF/L5 band reflects the frequency dependent features. Also the occurrence of S band scintillations are mainly observed in equinoctial months of high solar epochs while the solstial occurrence dominates the lower frequency VHF band. It may be mentioned that during strong scintillation period of VHF to L5 band with S_4> 1.0 the S band fluctuations mostly limited to $S_4 \sim 0.4$.

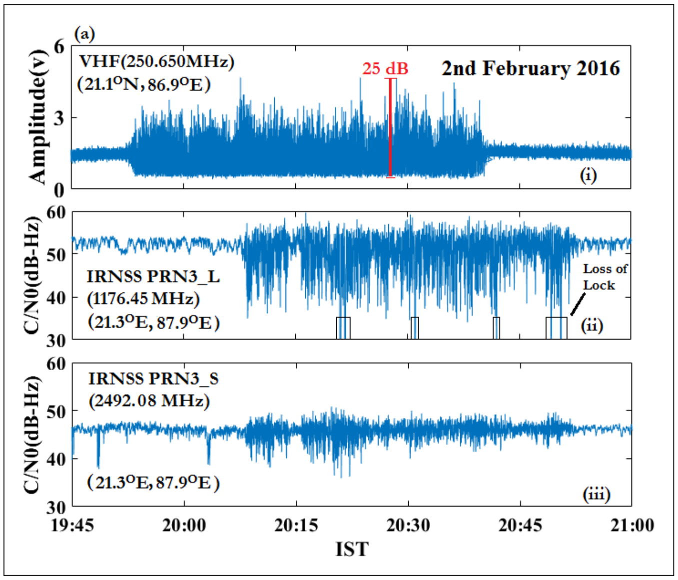

Figure 1: (a) Temporal variation of i) amplitude (V) at VHF ii) C/NO (dB-Hz) at L5 and iii) S band respectively. Boxes in the middle panel indicates loss of lock.

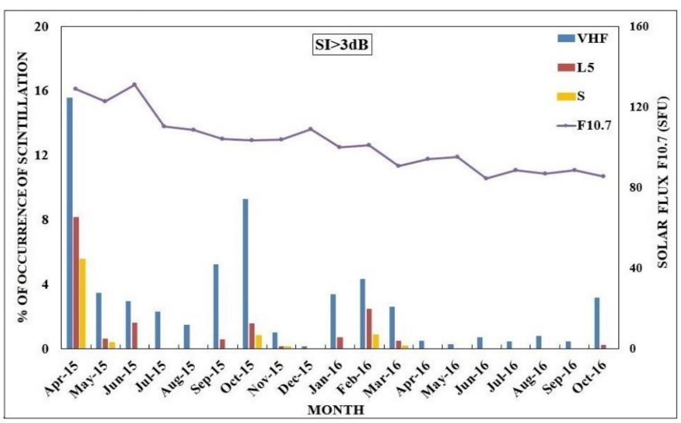

Figure 2: Variation of monthly percentage (%) occurrence of pre-midnight scintillations at VHF (250.650 MHz), L5 (1176.45 MHz) and S (2492.08 MHz) bands. Amplitude scintillations (with SI > 3 dB) for the period April 2015 to October 2016 are presented. Variation of monthly mean solar $F_{10.7}$ solar flux (1SFU = 10^{-22} $Wm^{-2}Hz^{-1}$) is also shown.

Further there is frequent loss of lock in L5 band channel during strong scintillation period of VHF/L5 band but the occurrence of S band is free from such effects. Long duration (>1hour) patches mostly dominates the scintillation at VHF band while at S band the same is mostly limited to 15-45 minutes duration. Negligible scintillation occurs at SI> 10 dB level in S band. The most critical parameters describing scintillations are the fade rate and the depth of fading. The same are estimated considering the initial, middle and end epoch of scintillation patches recorded in the post sunset to pre-midnight period. The highest fade rate is observed in the middle of each patch irrespective of depth of fluctuations as well as frequency bands.

Though the scintillation index (SI)/S_4 mainly characterizes the severity of scintillation, the said indices fail to describe precisely the fading characteristics of signal in sufficient details for engineers interested in propagation effects or the space scientist interested in determining the scatter mechanisms for the signals. The percentage of time the signal fades below different dB levels as a function of local time, latitude, season, solar and magnetic activity is required for complete evolution of the expected performance of any proposed system. The statistical signal level in dB correspond to typical cdfs for two frequencies is found to fit a polynomial of second order. The good correspondence between the observed data and the assumed fit leads to determination of the fade margin. Under strong scintillation conditions (S_4~1) for reception of L5 signal for 99% of the time system fade margin of ~14 dB is essential while for reception of signal at S band a fade margin of 8-9 dB seems to be sufficient.

Scintillation measurements are sensitive to the irregularity structures integrated along the propagation path through the medium. The power spectrum of intensity of a scintillating signal is closely related to the spectrum of the irregularities [Yeh and Liu, 1982]. If the irregular medium perturbs the probing wave only slightly a measurement of the temporal spectrum corresponds to filtered measurement of the two dimensional irregularity spectrum. When the effect of irregularities on the probing wave is strong, i.e., under strong scintillation condition the simple correspondence is destroyed. Thus simultaneous availability of weak and strong scintillation data at multiple frequency gives a potentially good opportunity for studying evolution of the irregularity spectrum over various scale size regimes.

Figure 2(a), (b) and (c) are the sample plots of power spectra estimated over the different epochs of a single patch recorded on 2nd February, 2016. Each plot pertains to particular average S_4 values. In the VHF case sharp rise in S_4 at the onset phase leads to higher S_4 values compared to lower values at the GHz bands. According to theory the power spectra for weak scintillation (S_4<0.5) should reflects a flat low frequency part and around the Fresnel frequency it should start rolling off. The two features are reflected in all the equinoctial weak scintillation spectra that have been estimated throughout the period of observation. The estimated Fresnel scale size at L5 band is found to vary in the range 536±48m and for S band 436±47m respectively. While the same for VHF is estimated to be 940±58m assuming a drift speed of 100 m/s.

The slope of the high frequency portion of scintillation spectrum is another feature of interest. The analysis shows that the high frequency asymptote or the slopes to the high frequency roll off in the case of S band weak scintillation varies from -2.1 to -3.9. The average value is the order of -2.8 ± 0.64. Similarly for L5 band it varies from -3.7 to -6.1 and at VHF -4.1 to -6.7 with the corresponding averages are4.8±0.87 and 5.4±0.92 respectively. The power spectra of a particular frequency band at various level of scintillations categorized by S_4 values exhibits broadening of spectra. It suggests that when the scintillation activities grows the spectra expand towards the smaller scale size irregularities. This is due to generation of small scale irregularities from larger one by cascade mechanisms. Similarly during the decay phase of scintillation activity the scale size increases and shrinking of spectra from high frequency side results. This is due to faster decay of small size irregularities. The spectra for severe scintillation conditions at L5 and VHF band exihibit double slope features. Such high value of spectral slope is attributed to thick layer of irregularities common during equinoctial months of high solar activity epochs.

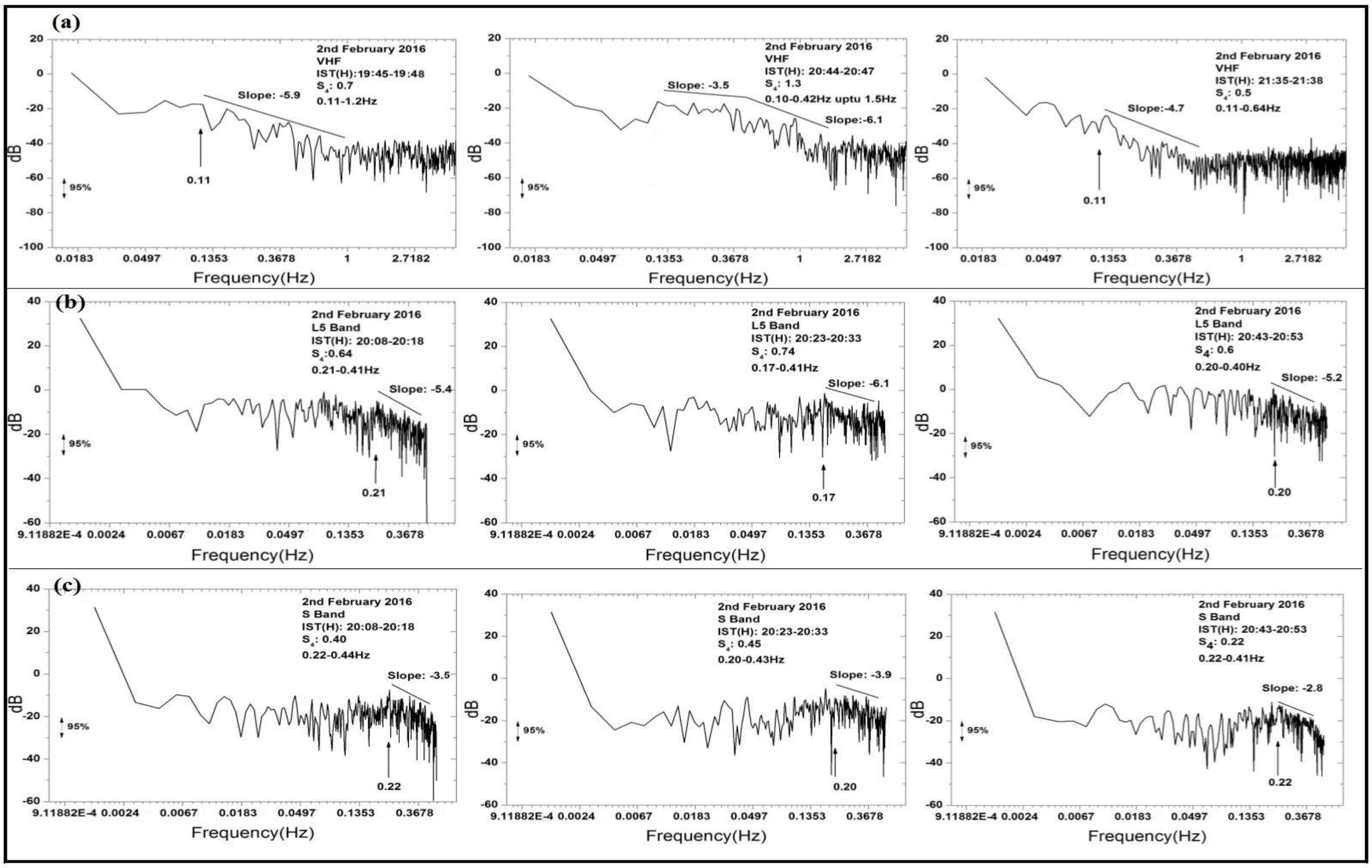

Figure 3: Sample plots of power spectra corresponding to different phases of a scintillation patch at (a) VHF, (b) L5 and (c) S band respectively. The plots demonstrates the evolution feature of irregularity spectrum.

When the strength of scintillation increases the spectral index is no longer directly related to the size of the Fresnel zone [Umeki et al, 1977]. The correlation time (τ) values during the period provide much insight into the strong scatters [Liu and Franke, 1986]. Under the condition τ is controlled by perturbation strength. According to weak phase screen model the scintillation index is proportional to the perturbation strength (σ_φ^2). Since the data are obtained on different nights all the computed coherence time (τ) have been normalized to average coherence interval at S band ($S_{\tau av}$) for the events. The normalized coherence ratio (dimensionless) are plotted for three frequency band as function of S_{4S} in figure 4. It is clear that coherence ratio at S band is independent of S_{4S} (c) but for L5 and VHF band (middle & top panels) the said ratio decrease with S_{4s} showing anti-correlation at highly significant level.

The results demonstrate that as the perturbation strength increases multiple scattering as revealed through lower values of τ dominates. It may be mentioned that the estimated coherence length at VHF is found to be largely reduced (< 15 m at VHF) indicating extreme decorrelation of signal owing to multiple scattering.

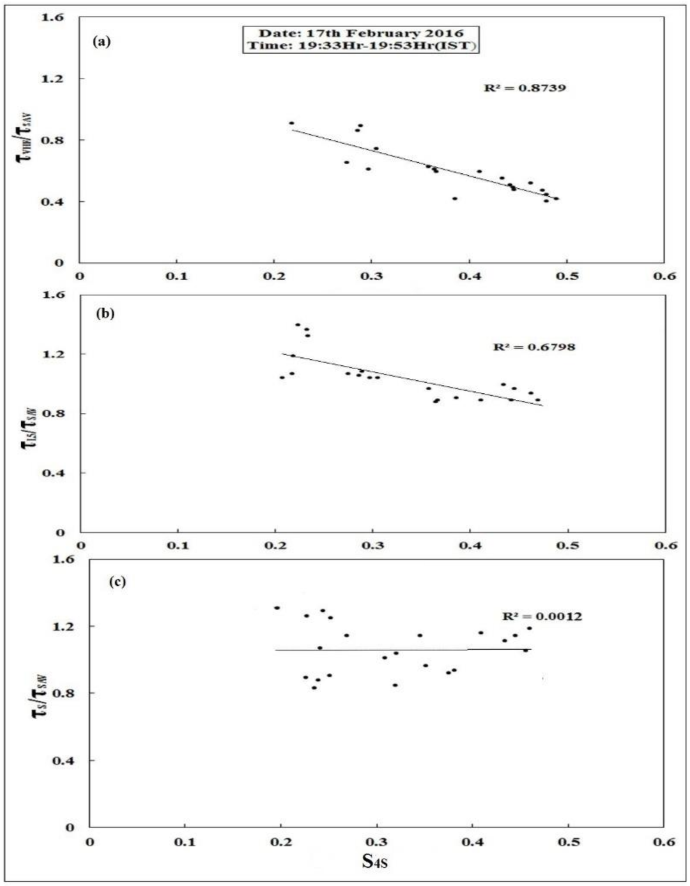

Figure 4: Variation of τ/τ_{sav} (τ_{sav} is the average value of decorrelation time at S band for specific scintillation level S_4) vs. perturbation strength specified by S_4 at S band (S_{4S}). Plots (a,b,c) pertain to VHF, L5 and S band respectively.

4. Summary:

A comparative study of multi-frequency, extending from VHF to S band scintillations during the period 2015-2016 from a region near the EIA crest reveals that

(i) Occurrence of S band scintillation is comparatively less than that of VHF and L5 band.

(ii) Occurrence probability decreases with decrease of solar flux for all the frequency bands studied.

(iii) Smaller duration patches mostly limited to 15-45 minutes dominate the scintillations at S band with corresponding S_4 limited to 0.4. VHF scintillation are characterized by longer duration patches (>120 minutes) mostly in the saturated regime (S_4>1) for the equinoctial period.

(iv) Larger fade rate and fade depth is recorded in the middle of each patch irrespective of frequency band.

(v) Study of cdfs at L5 and S band reveals a fade margin of ~14 dB and 8-10 dB for L5 and S band respectively.

(vi) Power spectral study demonstrates that multiple scattering is the dominating mechanism for strong scintillation in VHF to L5 band while single scattering mostly contributes to S band scintillation occurrence.

(vii) Study of smaller decorrelation time and coherence length during strong scintillation period of VHF, L5 band signify decomposition of large scale structure and uncorrelated diffraction pattern in the severe scintillation epochs.

Theoretical studies are needed to explain the evolution of uncorrelated ground diffraction pattern under severe scintillation condition.

5. Acknowledgement:

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6. References:

Liu, C. H., and S. J. Franke, (1986). Experimental and theoretical studies of ionospheric irregularities using scintillation techniques, *Radio Sci., 21,363-374*.

Umeki, R., C.H. Liu, and K.C. Yeh, (1977). Multi-frequency studies of ionospheric scintillations, *Radio Sci., 12, 311.*

Yeh, K. C., and C. H. Liu, (1982). Radio wave scintillations in the ionosphere, *Proc. IEEE, 70, 324–360.*