IRNSS scintillation studies near the EIA crest of the Indian longitude Sector

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Abstract: Scintillation 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 scintillation at L1 (1575.42 MHz) band from available SBAS(GAGAN, BeiDou, MTSAT) links and VHF(250.650 MHz) band from FSC are investigated to study the multi-frequency 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 scintillation in the VHF to lower microwave L bands during equinoctial months high solar activity period while the scintillation 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 scintillation, 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 scintillation 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 navigation. 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 scintillation. The result may be discussed in terms of evolution of cluster of equatorial plasma bubbles and its superposition in the post sunset period of equinoctial months.

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 multi-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.

Data: Transionospheric signals at L5 (1176.45MHz) and S (2492.028 MHz) band from Indian Regional Navigation Satellite System (IRNSS) along with VHF (250.650 MHz) signal from the geostationary satellite FSC 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^{0}N, 86.9^{0}E. 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^{0}N, 87.98^{0}E) is being used for comparative study of multi-frequency scintillations.

Results:

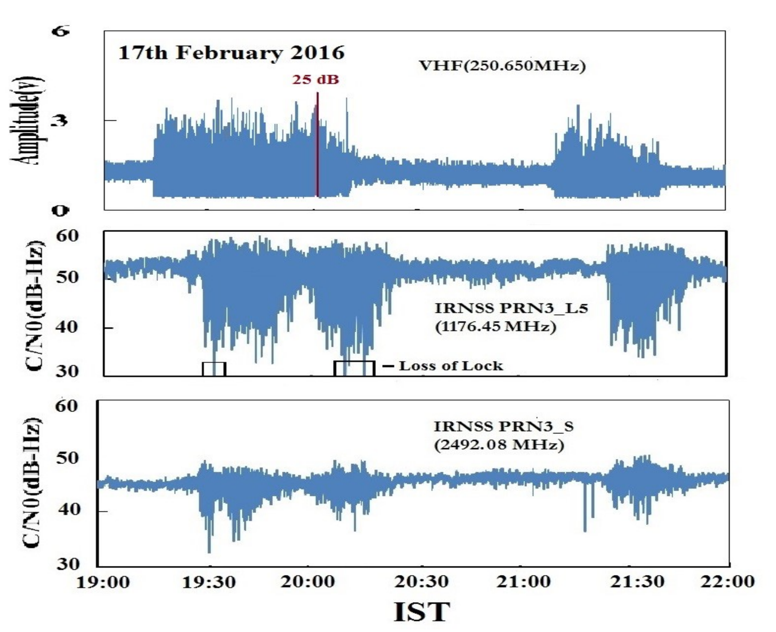

Figure 1(a): Temporal variation of i) amplitude (V) at VHF ii) C/NO (dB-Hz) at L5 and iii) S band respectively. Boxes in the middle panel indicates loss of lock.

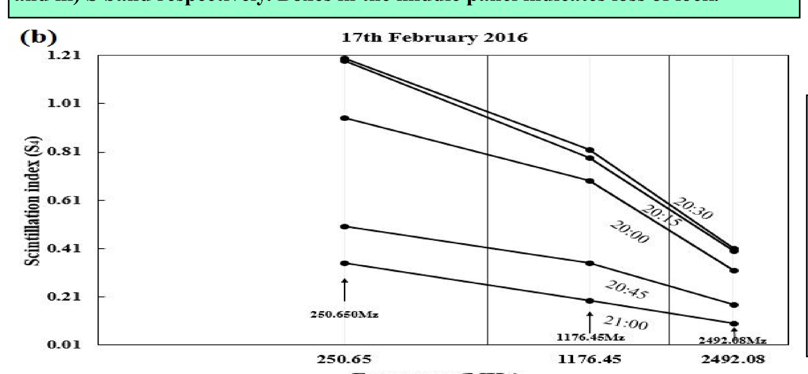

Figure 1(b) : Temporal variation of S4 at multi-frequency bands

- Deep fluctuations often exceeding the dynamic range (>25dB) of the receiver characterize VHF scintillations.
- Comparatively lower level of fluctuations accompanying loss of lock, exceeding 55dB-Hz depth dictates L5 scintillation.
- Much less fluctuations level ,mostly limited to 10dB, with slow fading rate distinguishes the S band scintillation .
- 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.

- At VHF sharp rise in S_4 at the onset phase leads to higher S_4 values compared to lower values at the higher GHz bands.

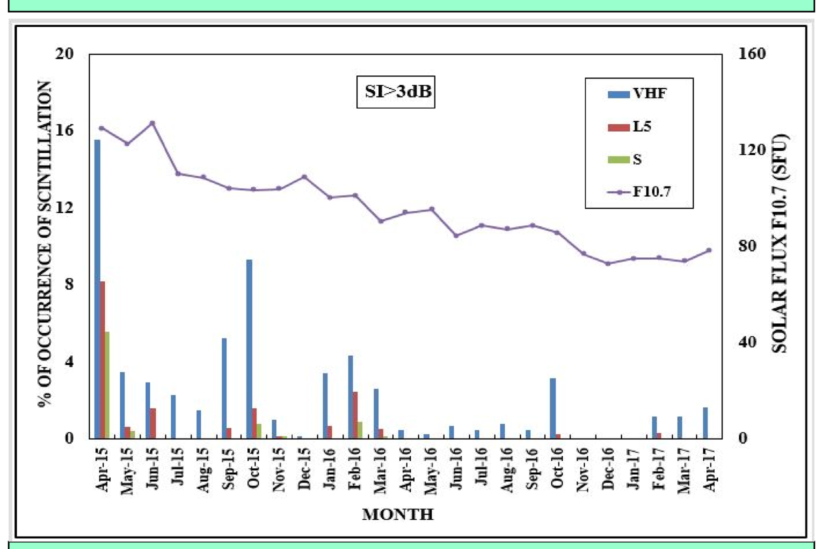

Figure 2: Variation of monthly percentage (%) occurrence of pre-midnight scintillations at VHF (250.650 MHz), L5 (1176.45 MHz) and S (2492.08 MHz) bands. Amplitude scintillations with SI > 3 dB for the period April 2015 to April 2017 are shown. Variation of monthly mean solar $F_{10.7}$ solar flux (1SFU = 10^{-22} Wm^{-2}Hz^{-1}) is also shown.

- The occurrence probability decreases with solar flux .
- Much less occurrence in S band compared to VHF/L5 band reflects the frequency dependent features .
- The occurrence of S band scintillations are mainly observed in equinoctial months of high solar epochs while the solstitial occurrence dominates the lower frequency VHF band .

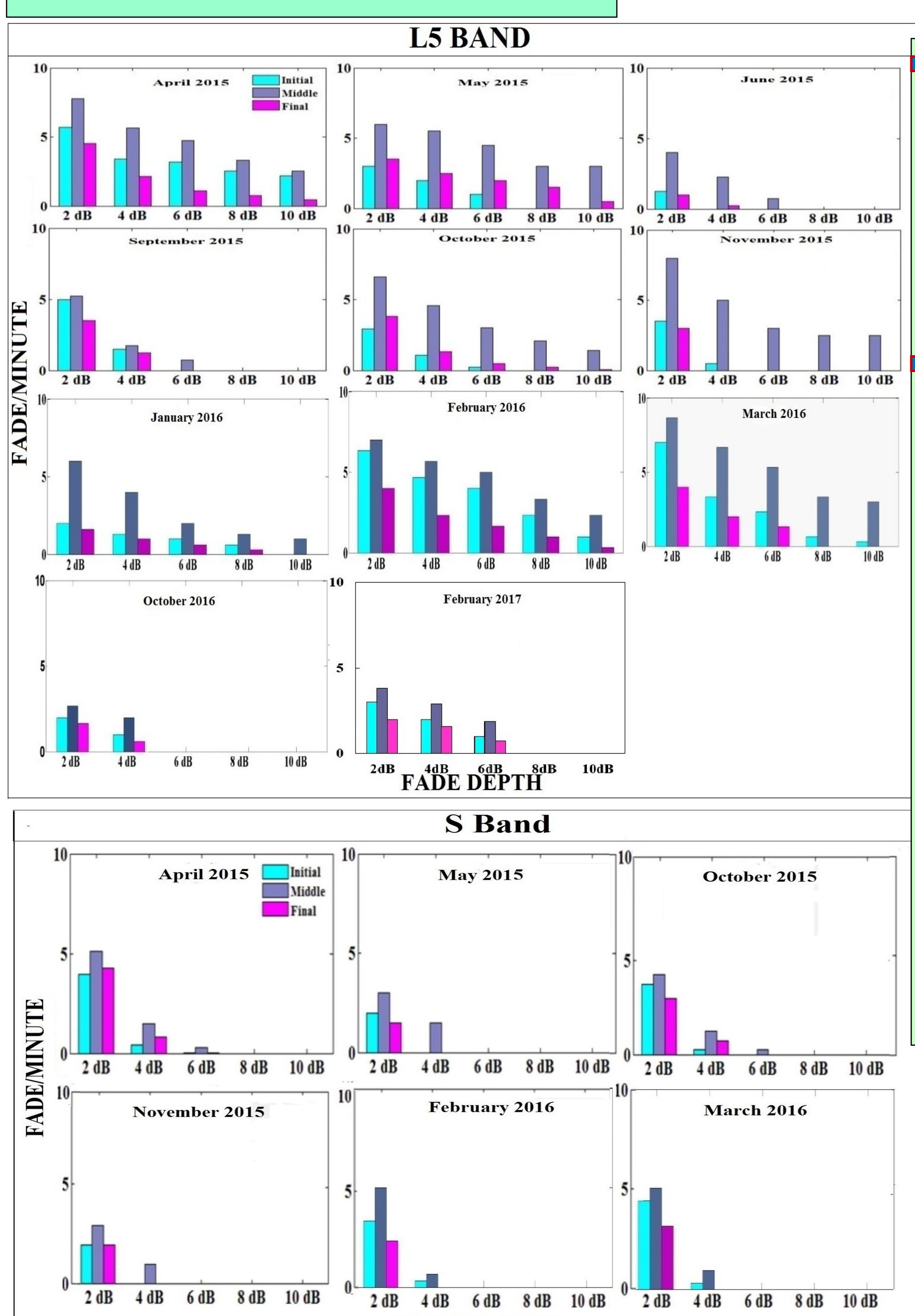

Figure 3: Monthly distribution of fade rate vs. fade depth at initial, middle and end epochs of pre-midnight scintillation patches at L5 and S band. Monthly median value of fade rate are given.

- The values represent the median fade rate of several patches estimated on monthly basis considering the initial, middle and end epoch of scintillation recorded in the post sunset to pre-midnight period .
- Due to least patch duration at S band only two epochs (initial and final) are shown in few cases.
- The highest fade rate is observed at the middle of each patch irrespective of depth of fluctuations and frequency bands.

The present analysis pertains to scintillation patches with $S_4 \leq 0.6$.

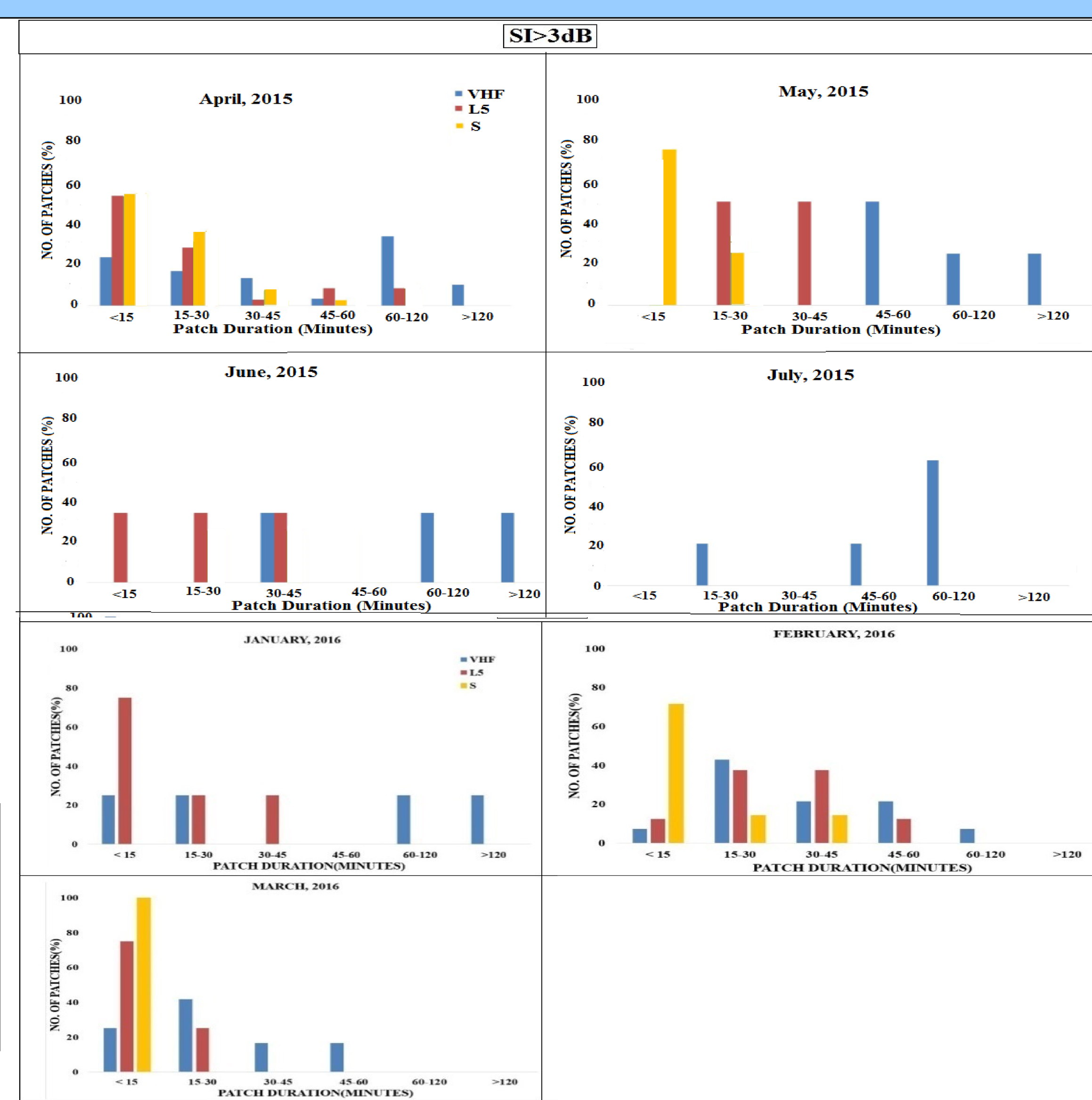

Figure 4: Percentage distribution of patches of variable duration at VHF, L5 and S band at SI>3dB.

- Study of variability in scintillation interval is important for deciding the adaptive capability of receiving system
- The occurrence percentage is estimated over the total number of available patches at respective dB levels in the said months.
- As reflected 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.
- The patch duration for fluctuation level >3dB at L5 band varies in a broad range of ~15 to ~120 minute with percentage occurrence ~10-60%.

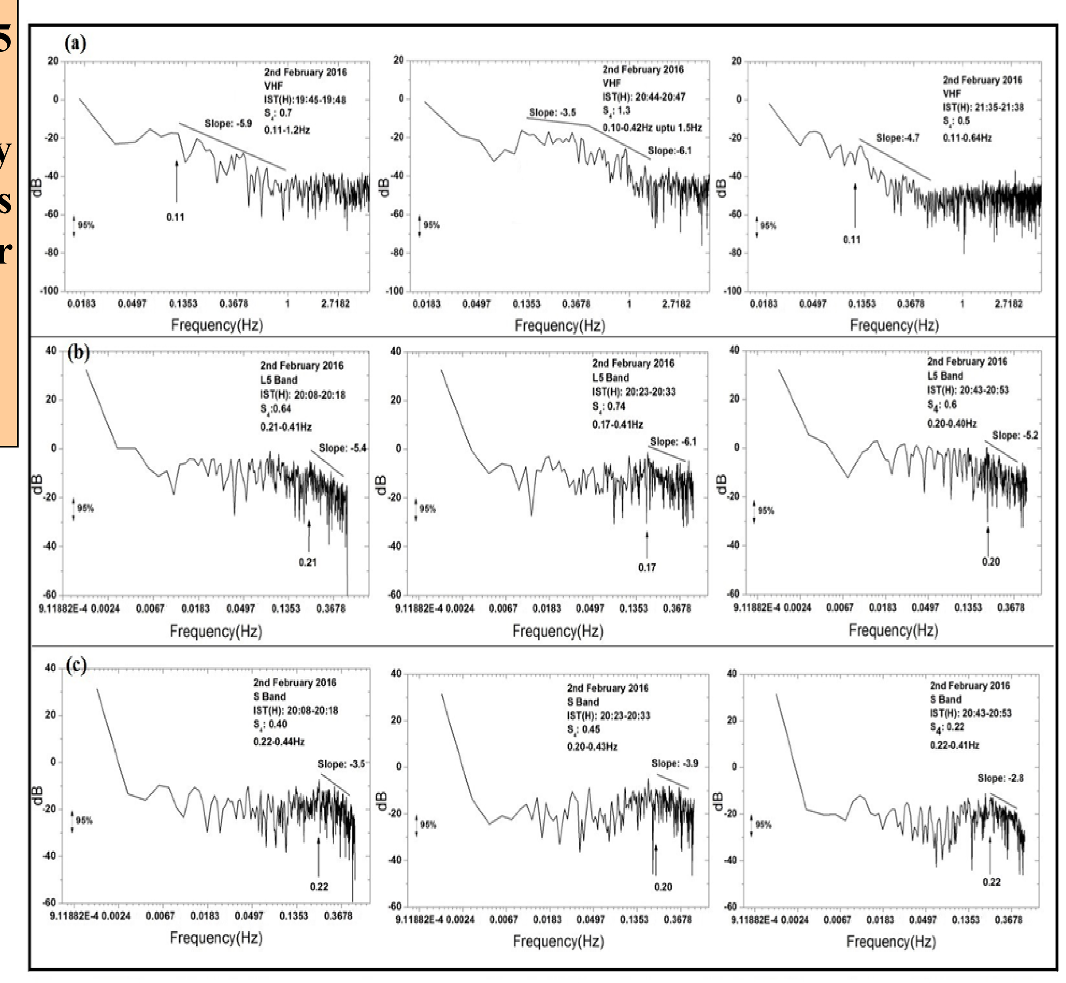

Figure 5(a): Sample plots of power spectra corresponding to different phases of a scintillation patch at (a) VHF, (b) L5 and (c) S band respectively. The plots demonstrates the evolution feature of irregularity spectrum.

- The power spectra for weak scintillation (S_4<0.5) reflect a general flat low frequency part and around the Fresnel frequency it starts rolling off.
- 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 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

For severe scintillation conditions at L5 and VHF band exhibit double slope features.

- High value of spectral slope is attributed to thick layer of irregularities common during equinoctial months of high solar activity epochs.

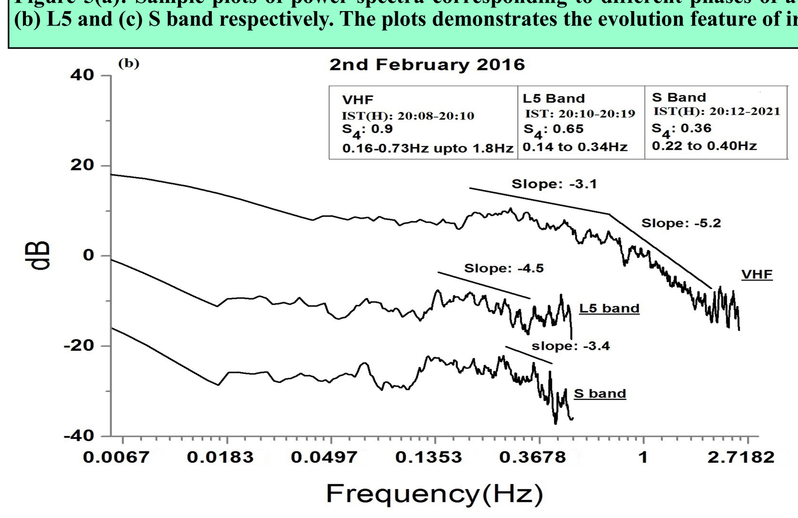

Figure 5(b): Multi frequency spectra showing broadening

- The power spectra of a particular frequency band at various level of scintillations categorized by S_4 values exhibits broadening of spectra.
- 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.

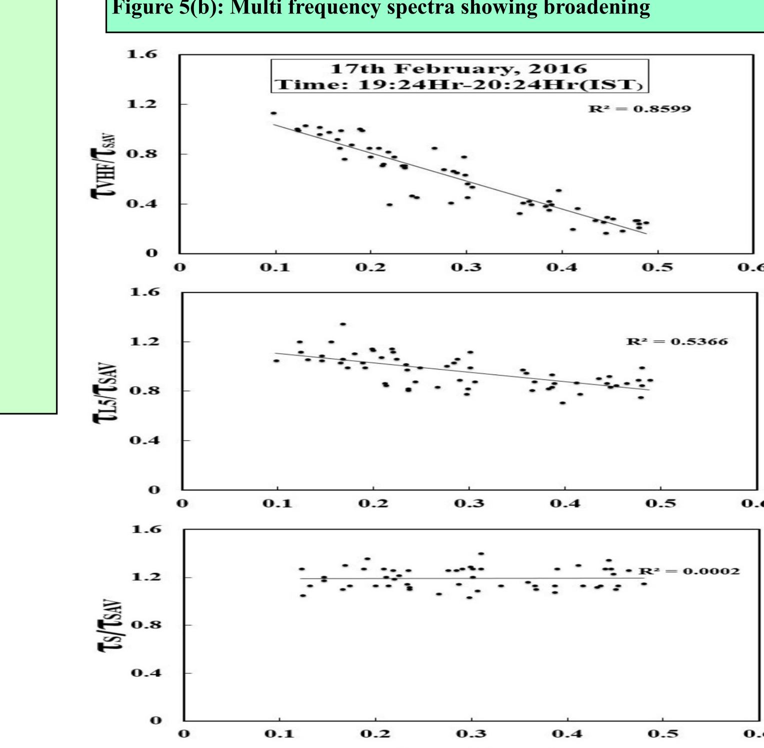

Figure 6: Variation of τ/τ_{4s}, (τ_{4s}, is the average value of decorrelation time at S band for specific scintillation level S_4) vs. perturbation strength specified by S_4 at S band (S_{4S}). Plots (a,b,c) pertain to VHF, L5 and S band respectively.

- Under the condition of severe scintillation correlation time (τ) is controlled by perturbation strength.
- L5 and VHF band (middle & top panels) the ratio decrease with S_{4s} showing anti-correlation at highly significant level.
- As the perturbation strength increases multiple scattering as revealed through lower values of ratio dominates.
- The estimated coherence length at VHF is found to be largely reduced (<15m at VHF) indicating extreme decorrelation of signal owing to multiple scattering.

TABLE 1: Coherence length (meter) at VHF, L5 and S band frequencies during initial, middle and end phases of scintillations.

Patch epoch	Frequency bands		
	VHF	L5	S
Initial	9.2±3.5	71.7±6.7	82.3±5.8
Middle	4.5±1.1	68.6±6.1	70.6±3.8
End	15.0±5.1	82.5±4.0	94.1±3.4

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) The occurrence probability of S band scintillation is comparatively low than that of VHF and L5 band.
ii) Occurrence probability decreases with decrease of solar flux for all the frequency bands studied.
iv) Smaller duration patches mostly limited to 15-45 minutes dominate the scintillations at S band with corresponding depth of fades limited to 10dB. VHF scintillation are characterized by longer duration patches (>120 minutes) mostly in the saturated regime (S_4>1) for the equinoctial period.
v) Power spectral study demonstrates that multiple scattering is the dominating mechanism for strong scintillation at VHF to L5 band while single scattering mostly contributes to S band scintillation occurrence.
vi) 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.

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