Nighttime VHF ionospheric scintillation characteristics near the crest of Appleton anomaly station, Udaipur (24.6°N, 73.7°E)

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The paper presents variation of percentage occurrences of nighttime VHF ionospheric scintillation characteristics in amplitude of radio beacon signals of 244/250 MHz transmitted from Fleet Satellite (positioned at 73°E longitude) received over Udaipur (24.6°N, 73.7°E, dip angle 35°) during different levels of solar activity from March 1986 to April 2000. These long time observations of VHF scintillations phenomenon, spanning a solar cycle (1986 to 2000), which covers low, mid as well as high solar activity period, have shown nighttime temporal hourly, seasonal and solar cycle variations in scintillations occurrences. The percentage occurrences of nighttime VHF radio wave scintillations have been observed with maximum percentage occurrences mostly during the equinoxes months, less during winter and the least during summer months in different phases of solar cycle. The average monthly variations of percentage occurrences of VHF ionospheric scintillations activities have been seen to be enhanced during high solar activity year and reduced during low solar activity year. The peculiar feature of discrete or patchy nature of nighttime VHF amplitude scintillations, specifically over Appleton anomaly region, has also been discussed in the light of seasonal and solar activity dependence of scintillations occurrences and their patch duration. The present observations have been compared with the earlier results reported by researchers at Indian stations specifically over similar Appleton anomaly zone and almost similar behaviour of ionospheric scintillations occurrence has been found.

An attempt has been made to interpret the present findings on the basis of similarities observed between seasonal solar activity dependence of scintillations events in the present work with the earlier reported statistical observations of seasonal solar activity dependence of maximum electron density of F-region (NmF2), occurrence, and duration of range and frequency type of ESF. Furthermore, the present finding of ionospheric scintillations events have also been linked with the coincidence of numerous precursors of equatorial ionospheric parameters like rising of F-region height due to abrupt increase of upward vertical drift resulting in enhancement in eastward electric field as well as eastward drift after the sunset time over equator with experimentally observed by other researchers. The combined effect of equatorial low ionospheric irregularities phenomena such as development of equatorial ionization anomaly strength over off side of equatorial region is also discussed in view of active precursors to produce the scintillations occurrence in patchy nature away from the equatorial side from the reported studies.

Keywords: Ionospheric irregularities, Ionospheric propagation, Ionospheric scintillations, VHF scintillations

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1 Introduction

Ionospheric scintillations refer to random, rapid, irregular and fast fluctuations in various parameters, viz. amplitude, phase as well as frequency shift of radio waves of VHF to L-band transmissions from satellites received at the earth surface, whenever it is propagated through a medium which is non-homogeneous in electron density (i.e. embedded with ionospheric irregularities). It is a well established fact that the amplitude fluctuation of radio waves signal is directly related to level of fluctuation in electron density; presence of ionospheric irregularities; and integrated electron density deviation, \( \int \Delta \text{Nd}l \), along the ray path. In addition, the ionospheric scintillations are controlled by irregularity amplitude \( \Delta N / N \), background electron density N and its distribution in the ionosphere. Satellite in situ measurements have shown that the irregularity amplitude does not change much with solar activity or from equatorial to anomaly crest region. However, the background electron density at certain region undergoes prominent variation by a factor of about 10 from high solar activity to low solar activity period, a factor of 3.5 from equator to anomaly crest sites as well as geomagnetic activity variations at any point on the globe. Further, fluctuations in electron density in space and time do exist with a wide variety of characteristic scales due to various plasma instability processes in the post sunset equatorial...
F-region and they give rise to several nighttime phenomena such as equatorial spread-F (ESF) and ionospheric scintillations.6,7

Significant and serious impact on performance of communication as well as recent GPS navigational satellite system, due to the amplitude as well as phase scintillations, have been observed in the form of signal distortions, message errors, degradations below the nominal signal level and fades, data loss, cycle slips and loss of phase lock in GPS receivers, etc. Therefore, extensive studies of ionospheric scintillations have been carried out world over under national and international space weather science research programmes in the last five decades.8-10 A number of reviews articles covering different aspects and features of ionospheric scintillations based on experimental observations, computerized numerical and modelling studies of instability mechanisms have been published1,4,7-15.

These studies indicated that scintillations phenomenon is more frequent and intense in a belt of latitudes ±15° about the geomagnetic equator as well as in the auroral zone, however, the scintillation occurrences are low or rare over mid latitude stations7,11,16. The long term scintillations studies have been carried out close to the magnetic equator in America, Africa and India3,11,17,18.

The observations of intense VHF and L-band scintillations at Ascension Island (dip latitude 17°S) near the southern crest of equatorial anomaly have created interest in VHF scintillations studies at tropical latitudes6. Subsequently, the isolated scintillations studies have also been carried out at various locations of Indian low latitude stations near the northern crest of Equatorial Appleton anomaly, viz. Calcutta19,20, Delhi21,22, Rajkot13,23, Bhopal24, Varanasi15 and Ahmedabad25 for different periods. At these sites, the scintillations have been basically nighttime phenomenon associated with spread-F (ref. 25). It has been observed that nature of scintillations is distinctly different, for example, patchy occurrence at anomaly crest while continuous occurrence at the magnetic equator26. It may be noted that scintillations activity up to 23°N magnetic latitude in the Indian zone, during high solar activity, is strongly field-aligned and primarily controlled by the generation of F-region irregularities over equator having extent of more than 2000 km (N-S) on either side of the magnetic equator27.

Similar scintillations studies of short duration at Indian stations, located from equator to beyond the anomaly crest region, have also been conducted under national campaign and All India Coordinated Programme on Ionospheric Thermospheric Studies (AICPITS)22,26-28. An ionosphere scintillations station was set up at Udaipur (geog lat 24.6°N, geog long 73.7°E, geomag lat 14.5°N, dip angle 35.3°) with help of IIG, Mumbai in 1986 to draw the definite trend of nocturnal temporal, seasonal, solar activity variations and patchy nature of scintillations over Northern Equatorial Appleton Anomaly region. As Udaipur is located virtually under the northern crest of the equatorial anomaly in the Indian longitude sector, it provides an excellent platform for studying equatorial anomaly crest region scintillations29-32. The preliminary results of nighttime ionospheric scintillations over Udaipur have been already reported33. The detailed studies on various aspects such as temporal, month to month, seasonal, solar activity variation, and patchy nature of nighttime ionospheric scintillations at anomaly crest region, Udaipur have been carried out and the nighttime scintillations occurrence trend has been presented in the present paper. Based on this study and current understanding of low latitude ionospheric irregularities, possible generation mechanisms of ionospheric scintillations have been identified and highlighted.

2 Data analysis

Amplitude scintillations of VHF signals at 244/250 MHz from the geostationary satellite FLEESAT (73°E longitude) have been recorded at Udaipur (24.6°N, 73.7°E) since March 1986 employing a simple system, designed and built in Indian Institute of Geomagnetism (IIG), Mumbai. The experimental setup of receiving system consisted of an eleven element Yagi-Uda antenna, a super – heterodyne fixed frequency VHF receiver and a single channel strip chart recorder. The periodic calibrations of the receiving system using Hewellet Packard standard signal generator were done to read out the signal excursions in dB. The dynamic range of the receiver was about 20 dB. The scintillations data were recorded on a strip chart, which is calibrated as 2 cm corresponding to 2.5 dB. The analog chart records were examined and the presence of intensity of scintillations peak to peak 2.5 dB or above were noted at 15 min interval15,23 and the occurrence rate and percentage occurrences of scintillations has been calculated. Some typical records of scintillations recorded at Udaipur have been shown in Fig. 1. Since
scintillation is primarily a nighttime phenomenon, the data collected during 18:00 - 05:00 hrs LT [75° East Meridian Time (EMT)] only have been considered for analysis.

The seasonal variation of nocturnal percentage occurrences of scintillation has been found by grouping month wise data into three seasons, viz. the equinoxes months (March, April, September and October), summer months (May, June, July and August), and winter months (January, February, November and December). The VHF amplitude scintillations has been recorded during March 1986 - August 1987 (low solar activity, i.e. solar flux < 75 unit); November 1992 - July 1993 (moderate solar activity, i.e. solar flux level between 75 and 150 unit); and November 1998 - April 2000 (high solar activity, i.e. solar flux > 150 unit), which basically covered the complete solar cycle in order to assess the contribution of solar activity levels. Further, an attempt has been also made to examine the patchy nature of ionospheric scintillations durations in each season and solar activity level.

3 Results and Discussions
3.1 Seasonal and nocturnal variation of nighttime scintillations

It is observed from Fig. 1 that scintillations activity at Udaipur started abruptly and reached to peak amplitude of 10-15 dB within few minutes. The nocturnal variation of percentage occurrences of scintillations at one hour duration between 18:00 and 06:00 hrs LT (75° EMT) for three seasons during the periods 1986-1987, 1992-1993 and 1998-2000 have been shown in Fig. 2. It is observed from the figures that in general during equinoxes and winter seasons, the scintillation events start after one or two hours of local sunset time and attain maximum percentage occurrences (15-20%) around 21:00-22:00 hrs LT; after attaining peak values, the percentage occurrences decrease from midnight to post-midnight depending upon the solar activity level. While during summer season, the maximum value of percentage occurrences of scintillations has been found to reduce to a value of about 5-12% at 22:00 hrs LT in low and moderate solar activity but its duration is extended to post-midnight during moderate solar activity.

Fig. 1 — Different types of amplitude scintillations on 250.06 MHz signal from geostationary satellite FLEETSAT (longitude 73°E) recorded at Udaipur
Thus, scintillations activities have been observed more frequent with peak occurrences of about 20 and 14% in equinoxes and winter season, respectively in high solar activity period. However, the peak of occurrence of scintillations activity is clearly visible between 20:00 and 22:00 hrs LT during winter and equinoxes as shown in Fig. 2. During the low solar activity period, the maximum values of percentage occurrences scintillations have been observed to be slightly lower, 11 and 6% in equinoxes and summer months, respectively. Its value has been found to be maximum (11%) during equinoxes and minimum (6%) in summer months of low solar activity period.

During moderate solar activity period, the maximum percentage occurrences of scintillations events have been observed in the intermediate range of 10-14% in all the season. A similar seasonal change in scintillations activities has been observed in low and high solar activity period, i.e. higher percentage in equinoxes and lower in other seasons. Thus, it is clear that scintillations occur predominantly in the pre-mid night period during equinoxes and winter seasons and in the post-midnight period during summer season.

### 3.2 Month-to-month variation of scintillations occurrences

Month-to-month variations of scintillations occurrences have been presented for whole night hours for each month during the period of observations for which sufficient monthly data are available and results have been shown in Fig. 3. The month-to-month variations of average values of 10.7 cm solar fluxes (measures of solar activity level index) along with monthly percentage occurrences of scintillations activity of the same months have also been shown in Fig. 3. It is evident from the figures that on the whole, the scintillations activities increase with the increase of solar activity levels. Also, in different levels of solar activity, the values of percentage occurrences of scintillations is higher (20 - 40%) in most of equinoxes and winter months and lower (in the range 5-15%) in summer months. However, in some summer months of low and mid solar activity period, viz. July and August, the scintillations activity is almost absent and therefore, not shown in the figure. During the high solar activity period, the peak values of percentage occurrences of the scintillations are found up to 32% in the equinoxes and 18% in winter months. During moderate solar activity condition, their corresponding values are found to be 22% and 12% during equinoxes and summer months, while in winter, it is quiet low about 9%. In low solar activity period, the peak values of scintillations event are seen in the lowest order of 10% in equinoxes and 5% in summer months. Hence, it is evident that the percentage occurrences of scintillation events increase with the increase of solar activity level in most of the seasons. However, the maximum values of percentage occurrences of scintillations events are always found during each equinoxes months irrespective of solar activity period.

Similar studies on seasonal as well as solar activity dependence of the VHF scintillation activities on equatorial Appleton anomaly region have been also reported in the past decades by several groups over

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**Fig. 2** — Nocturnal variation of average percentage occurrences of scintillations at Udaipur for different seasons during 1986 - 2000

**Fig. 3** — Month-to-month variation of percentage occurrences of scintillations in night hours during 1986 - 2000
Indian longitude, e.g. Calcutta, Rajkot, Bhopal, and Varanasi. They have also observed the highest percentage occurrences in equinoxes and lowest in summer and reported the increasing trend of scintillations activity with the increase of solar activity in winter and equinoxes. Their results have also shown the basic features of nocturnal variations of scintillations occurrences values, about 20 to 30%, over anomaly region (e.g. Rajkot, Bhopal, Varanasi, Calcutta) and further reduced to 10% at Delhi, which are similar, reasonable and confirm the present findings. In the present study, the annual value is around 18% which is lower in comparison to all the above stations except Delhi (as it is located more toward the north from equatorial station as compared to Udaipur). Thus, the characteristics of scintillations during different solar activity condition at Udaipur are reasonably in good agreement and confirm well with earlier results obtained over other similar low latitude stations located nearby and in anomaly crest zone like Bombay, Rajkot, Ahmedabad and Calcutta.

As it is well recognised fact that the nighttime VHF scintillations are primarily produced due to presence of ionospheric F-region plasma density irregularities. In the direction of identifications of various possible causes, origin and precursors for the onset time of VHF ionospheric scintillations occurrence, extensive experimental, modelling as well as theoretical work has been carried out in the recent past over equator and away from equatorial stations for understanding basic causes and precursors of VHF ionospheric scintillations events with association of ESF phenomena. They have also shown the high levels of similarities of seasonal and solar cycle variation of VHF ionospheric scintillations activity with the seasonal and solar cycle variation of the ESF occurrence and duration during post-sunset hours over equatorial region. Further, they also observed and suggested the remarkable couplings in variations of VHF scintillations activity over equator and at any station situated off the magnetic equator with maximum values of F- region electron density (Nm F2) (ref. 38) and equatorial electro jet strength (EEJS) (ref. 39).

Earlier workers have also suggested the linking of ionospheric scintillation events with various precursors of occurrences and persistence of ESF (ref. 37), abrupt rise of F-region height, equatorial ionization anomaly gradient, zonal drift, vertical drift, reversal of electric field during post-sunset hours over and near equator sites.

As in the present work, the nighttime scintillations are observed most frequently around 22:00 hrs LT and maximum in equinoxes, winter and least in summer season. These results of onset scintillations activity period and season are coincided with higher values of occurrence of range type spread-F and enhancement of post-sunset vertical drift values in equinoxes, winter and reduction in summer months over equatorial and away from equatorial site. Several investigators have also demonstrated the association of scintillations events with the nocturnal/seasonal behaviours of vertical drift velocity and with range type spread-F before midnight hours and with frequency type spread-F after midnight hours.

At the same time, such morphological studies about the occurrences of spread-F in the light of seasonal variability have also revealed that in the Indian longitudes, equinoctial months are more favoured for the ESF occurrence followed by winter months and the least in summer months which further confirm the present findings about the peak value of scintillations activity in equinoxes and then in winter and the least in summer seasons.

Lee et al. from the results obtained over the west side of American zone near equator, have also reported similar variations about the pre-reversal drift (ExB) and equatorial ionization anomaly asymmetry (Ia) with monthly variation of ESF occurrences over the west side of American zone near equator to stations away from Appleton anomaly region. Their finding gave more clear evidence about the ESF or indirectly VHF scintillations activity about larger association with larger value of ExB drift velocity (20 m s\(^{-1}\)) and with larger value of Ia (+0.3). It may be noted here that Ia measures the strength of pre-reversal drift and causes the extra perturbation in electron density near equatorial sites due to diffusion of electrons along the geomagnetic field line from equatorial station resulting in equatorial Appleton anomaly phenomena. They also reported that the two peak values, viz. 28 and 32 m s\(^{-1}\), appeared in October and March, respectively, while smallest ExB drift value of 14 m s\(^{-1}\) appeared in summer month.

Tulasi Ram et al. have also made an excellent attempt in understanding the basic cause of monthly occurrence of VHF scintillations occurrence during different level of solar activity in terms of post-sunset
vertical drift (E×B) at equator and equatorial ionization gradient or in predicting the onset of VHF scintillations occurrence over Waltair. They have observed the existence of remarkable similarity between the monthly variation of post-sunset vertical drift velocity at equator and monthly mean percentage occurrences of VHF scintillations over Waltair during low as well as high solar activity conditions. Their works clearly demonstrated higher value of scintillations events along with higher value of pre-reversal E×B drift of the order of 40 to 50 m s\(^{-1}\) in equinoxes months, medium values of percentage occurrences of scintillations activity with E×B drift velocity range of 30 - 50 m s\(^{-1}\) in winter month and further low value or rare occurrence of scintillations event corresponds to observed low E×B drift value order of 10 - 20 m s\(^{-1}\) in summer months of high sunspot period. Almost similar nature of variation among them with lower magnitude is observed in low sunspot activity year. The higher value of pre-reversal E×B drift could be due to large inhomogeneous electron densities and ionospheric conductivities values around daylight and night hours termination point during high level of solar activities.

Furthermore, the critical and advance work of Sreeja et al.\(^{45}\) over Trivandrum has shown the increase of persistence of ESF from 100 to 800 minute in high solar activity and 200 to 400 minutes in low solar activity and vertical drift speed magnitude of about 10 - 70 m s\(^{-1}\) and 3 - 40 m s\(^{-1}\) depending on the solar activity levels. They have also found that the highest threshold values of vertical drift velocity is around 30 m s\(^{-1}\) in equinoxes, winter months and low values of about the 15 m s\(^{-1}\) in summer months of high solar activity year and similar lowest threshold values for low solar activity year are 25 m s\(^{-1}\) during winter month and no values were observed in equinoxes and summer months. Thus, from the comparison of above studies about behaviours of several precursors of ESF during different seasons of solar activity levels like the control of vertical drift with ESF's occurrences and persistence along with their seasonal and solar activity dependence with the seasonal and solar activity variation of VHF ionospheric scintillations activities may also further resembles and give clear evidence and established facts to interpret the present observations of higher percentage occurrences of the scintillations events during high solar activity period in equinoxes and winter and its trend are further reduced to low solar activity period over Udaipur.

Referring to the above discussed results based on current work reported on the statistical features of seasonal and solar activity variation of ESF, its occurrence and persistence its further linking with timing of abrupt rise of height of F-layer, eastward and upward vertical drift over equator during each season of various level of solar activity levels, it may be quite obvious that source and causes of scintillations activities over Udaipur station seems to be primarily linked and controlled due to equatorial and low latitude ionospheric irregularities and dynamics associated phenomena like ESF, EIA, uplifting of F-region height above threshold values about 800 km in post-sunset hours due to increase in the vertical drift and pre-reversal enhancement of eastward electric field. Similar supported arguments are also given by Kumar & Gwal\(^{28}\), Kumar et al.\(^{34}\) and Singh et al.\(^{34}\) to interpret their ionospherical scintillations activities finding over Bhopal and Varanasi and these proposed arguments are further supported from experimental studies of equatorial spread-F performed over the equatorial and away from equatorial side by Dabas et al.\(^{34}\), Lee et al.\(^{40}\), Tulasi Ram et al.\(^{44}\) and Sreeja et al.\(^{45}\).

Thus, all these equatorial and low latitude ionospheric dynamics process give the possible favourable conditions for the generation of plasma instabilities due to the generalized Rayleigh - Taylor instability (GRTI) mechanism; or generation of various scales sizes of ionospheric irregularities from few meters to several hundred kilometer; or plasma bubbles specially over the equatorial region. These caused intense scintillations activity in equinoxes and weak in summer month depending upon the solar activity level near the edge of equatorial anomaly region depending on threshold value h\(_{\text{max}}\) and vertical drift of F-region in post-sunset hours over equator.

The equatorial F-region irregularities like plasma bubbles are incapable to rise over the magnetic equator above 800 km that diffuse downward along the geomagnetic field and scattered away from the equator and also not make the signature of scintillations activity over the edge of equatorial Appleton anomaly region\(^{24,39}\) in summer month of low solar activity level due to the low occurrences and persistence of ESF, reduction of F-region height and vertical drift along with low ambient electron density in low solar activity. Therefore, in the present work, occurrence of the probability of scintillations activity in summer months is low or zero.
In view of the above, about the similarities of seasonal as well as solar activity variation in nighttime ionospheric scintillation characteristics with equatorial F-region irregularities phenomena and its associated parameters (such as EFS occurrences and duration in terms with precursors observed over equator during post-sunset hours and equatorial ionization anomaly strength, etc.) are quiet corroborated. These most suitable plausible causes explain the present observed result of monthly average behaviour of percentage occurrences of scintillations activities with solar activity dependence. Thus, cause of VHF scintillations over Udaipur is mainly of equatorial origin as per suggestions made by Singh et al.\textsuperscript{34}, Kumar & Gwal\textsuperscript{24}, Kumar et al.\textsuperscript{28}, or local origin types as observed depletion and enhancement in TEC values vice-versa plasma depletion and plasma bubbles activities from GPS TEC experiments over equatorial Appleton anomaly site by Dashora & Pandey\textsuperscript{31} and Chen et al.\textsuperscript{32}.

### 3.3 Patchy occurrence of ionospheric scintillations

Scintillations at off-equatorial stations is known to occur in discrete patches nature in contrast to continuous nature of equatorial scintillations\textsuperscript{15,17,19,21,26,34,43}. Seasonal variations of patchy occurrences during different seasons of various solar activity periods have been carried out for entire period of observations. The percentage occurrences of patches intervals of 0-30, 30-60, 60-90 min, etc. have been computed from the average number of patches per night for each season of the available data of low, moderate and high solar activity period, separately for pre-midnight and post-midnight hours events. Figures (4-6) show the distribution of patch duration in different seasons. The average values of scintillations patches duration of each season for all three levels of solar activities are shown in Table 1.

It is observed from Fig. 4 that in pre-midnight hours of low sunspot period, the duration of these patches is distributed in the range of 5-330 min in summer months and shorter duration of 5-120 minute in equinoxes months. While in post-midnight hours, the scintillations events interval is observed in range of 5-360 and 5-210 min during summer and equinoxes months, respectively. Thus, longer duration of patch as well as higher mean values of scintillations patch duration are observed in summer season and comparatively short interval of patchy scintillations interval in equinoxes. It is also seen from the Table 1 that the mean values of scintillations interval are found to be higher in post-midnight hours as compared to the pre-midnight hours in both the summer and equinoxes season. However, average value of scintillations patches duration is higher in summer than equinoxes.

Figure 5 represents the histograms of percentage occurrences of scintillations patches interval for the moderate solar activity year 1992-1993. The scintillations events duration are observed in the range of 5-150, 5-240 and 5-300 min during pre-midnight hours of equinoxes, winter and summer months, respectively. While in post-midnight hours of the above season, their corresponding values are seen in the range of 5-240, 30-240 and 5-300 min in equinoxes, winter and summer, respectively. Thus, it is clear that the scintillations activities intervals are always longer in post-midnight hours and shorter in pre-midnight hours of equinoxes and summer months. However, summer average magnitude of scintillations patches interval both in pre-midnight and post-midnight hours are always found higher as compared to other seasons.

Figure 6 exhibits the patch duration of scintillations activities during high solar activity period. It is evident that the patch duration of scintillations occurs in the range of 5-200 and 5-180 min in pre-midnight hours of equinoxes and winter month. During post-midnight time, the ranges are 5-240 and 30-270 min in equinoxes and winter, respectively. Here also, mean values of scintillations patches are higher in post-midnight and lower in pre-midnight hours.

In view of the above, it is observed that average values of scintillations interval activities vary from 90

| Table 1 — Average value of duration of scintillations patches in minutes observed over Udaipur in each season of different levels of solar activity period |
|----------|----------------|-----------------|----------------|
| Season   | Low solar activity (Solar flux = 40-75 unit) | Moderate solar activity (Solar flux = 75-140 unit) | High solar activity (Solar flux = 140-190 unit) |
|          | Pre-midnight, minutes | Post-midnight, minutes | Pre-midnight, minutes | Post-midnight, minutes | Pre-midnight, minutes | Post-midnight, minutes |
| Equinoxes| 64.8 ±11.2 | 85 ±7.2 | 104.2 ±14.6 | 58.8 ± 5.1 | 89.3 ± 11.2 | 133.3 ± 7.4 |
| Winter   | No Data | No Data | 97.6±8.4 | 113 ± 9.5 | 90.00 ± 9 | 139.4 ± 13.3 |
| Summer   | 79.6 ± 3.6 | 94.2 ± 4.7 | 129.3 ± 8.7 | 142±16 | No Data | No Data |
Fig. 4 — Distribution of patch duration (in minutes) of the scintillations recorded in pre-midnight and post-midnight hours at Udaipur during 1987 - 1988.

Fig. 5 — Distribution of patch duration (in minutes) of the scintillations recorded in pre-midnight and post-midnight hours at Udaipur during 1992 - 1993.
to 120 min and 5 to 140 min in different seasons of various levels of solar activities of pre-midnight and post-midnight hours, respectively. Thus, longer duration of scintillations patches are always seen in post-midnight hours as compared to pre-midnight hours of different seasons irrespective of intensity of solar activity levels. However, maximum average value of scintillations patches duration is observed in winter or summer and least in the equinoxes.

Mathew et al.\textsuperscript{23} have also reported the longer duration of patchy nature of scintillations of mean interval 98 min in winter at Rajkot. During equinoxes and summer months, its time intervals are of the order of 53 and 48 min. Similar studies over Varanasi observed the scintillations occur at irregular interval and last for a short while (30 min) (ref. 34). Furthermore, higher mean values of duration of these scintillations have been found in winter and equinoxes, of the order 34 and 36 min, respectively but low mean values, i.e. 23 min in summer\textsuperscript{34}. Rama Rao et al.\textsuperscript{35} have reported that annual mean patchy duration over Waltair vary between 5 and 150 min, with the most probable value of occurrences of scintillations patches duration of 10 to 45 min.

Chandra et al.\textsuperscript{27} and Kumar et al.\textsuperscript{28} have analysed scintillations data recorded at chain of stations in India and shown that the scintillations become patchy and patch duration decreases as one moves away from the equator which is also observed in present work.

Thus, it is summarised that over Udaipur, the most probable value of patch duration lies in the range of 55-140 min. The higher mean values of scintillations activity interval is observed in post-midnight hours and lower in pre-midnight hours in all the seasons of various levels of solar activity. These results are also in the close agreement of same interval of scintillations patches time as observed by the earlier studies for Rajkot and Waltair\textsuperscript{23,34}. However, in the present study, the longer duration of scintillations patches interval are seen either in winter or summer and always shorter duration in equinoxes. However, other stations researchers have observed the higher mean values in winter. But in contrary, at Varanasi the minimum mean value of scintillations activity is in summer instead of equinoxes\textsuperscript{34}.

It is well established fact that after the local sunset hours, the bottom side F-region irregularities over the geomagnetic equator is controlled by the GRTI
mechanism. The plasma density irregularity generated and developed through GRT instability could account for the observed large ionospheric depletion or enhancement often called equatorial plasma bubbles which could rise beyond the F-region peak height by the non-linear evolution of bubbles and ExB drift due to uplifting of F-region irregularities during enhancement of eastward drift in post-sunset hours. Such irregularities can move and diffuse along the geomagnetic field line or subsequently drifting toward the low latitude and breaking into smaller patches which seems the main cause of discrete nature of scintillations. This has also been reported in present study with small duration of scintillations activity patches at edge of equatorial anomaly region or away from equatorial stations which infers equatorial plasma bubbles as primary well explanation of observed discrete nature of VHF ionospheric scintillations away from equator site.

On the basis of VHF and L-band scintillations characteristics over an Indian low latitude station Waltair, Rama Rao et al. have suggested the possible argument of close association of VHF ionospheric scintillations duration with mainly two types of ionospheric irregularities like plasma bubble induced (PBI) and bottom side sinusoidal (BSS). They observed that occurrence of PBI are maximum during post-sunset hours of corresponding higher value of F-region E-W drift speed in equinoctial and winter months. However, peak occurrence of BSS type irregularities is found in post-midnight hours of the summer months. Furthermore, they also investigated the association of east west extent of PBI type of irregularities with medium scale size irregularities about 100 to 500 km, while the corresponding extent for the BSS type concerned to large scale size of irregularities order up to a few thousand kilometres. As the result of higher post-sunset F-region zonal drift speed of irregularities and medium size of F-irregularities may be one of the cause of observed shorter duration of scintillations activities in pre-midnight hours, while in post-midnight hours, the longer duration of scintillations may be observed due to fact of lower F-region zonal drift speed and larger size of ionospheric irregularities specially in summer seasons. Hence, larger zonal drift velocities may be one of the possible causes of fast drifting the scintillations or shorter duration of scintillation patches, while small zonal drift velocity during low solar activity forces the patches to drift slowly and therefore, duration of scintillations patches is seen to be more.

4 Conclusions

In the present work, experimentally observed characteristics of nighttime VHF ionospheric scintillations over the crest of equatorial ionospheric scintillations the observed large ionospheric depletion or enhancement often called equatorial plasma bubbles which could rise beyond the F-region peak height by the non-linear evolution of bubbles and ExB drift due to uplifting of F-region irregularities during enhancement of eastward drift in post-sunset hours. Hence, larger zonal drift velocities and larger size of ionospheric irregularities specially in sunset hours of corresponding higher value of F-region that occurrence of PBI are maximum during post-ionospheric irregularities like plasma bubble induced scintillations duration with mainly two types of activity forces the patches to drift slowly and therefore, while small zonal drift velocity during low solar activity. While in summer months, the peak occurrence 20 - 11% and reduced in the range 12-14% during winter. While in summer months, the peak value of scintillations occurrence is further reduced to the range 9-12% in low and mid solar activity period. The scintillations events often start after one or two hours of local sunset hours and attain it maximum percentage around 21:00 - 22:00 hrs after attaining peak values, the percentage occurrences show decreasing trend during midnight to post-midnight hours during winter and equinoxes months depending upon the solar activity level. While during summer season, the maximum value of percentage occurrences of scintillations has been found at 22:00 hrs LT in low and moderate solar activity condition but its duration has been further extended to post-midnight hours during moderate solar activity condition.

The month-to-month variation of percentage occurrences has clearly established the fact that the maximum values of percentage occurrences of scintillations events increase with the enhancement of solar activity level in most of the seasons. However, the maximum values of percentage occurrences of scintillations events are seen during equinoxes months irrespective of solar activity period.
The night hour scintillations event occurs often in discrete and patchy nature which seems the unique features of scintillations activity nature over equatorial anomaly region or off side of equatorial region. The mean values of scintillations interval activities vary from 90 to 120 min and 5 to 140 min in different seasons of various levels of solar activities of pre-midnight and post-midnight hours, respectively. The scintillations patches are of longer duration in post-midnight hours than pre-midnight hours in different seasons irrespective of intensity of solar activity levels. The scintillations patches average value is of maximum duration in winter or summer and least in the equinoxes.

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