Observation and Modeling of Quasi-Periodic Scintillations Observed at Low Latitude.

Kalpana Patel¹, A K Singh¹,³ and R P Singh¹,²
¹Atmospheric Research Lab., Department of Physics, Banaras Hindu University, Varanasi-221005, India.
²Vice-Chancellor, V. K. S. University, Ara, Bihar, India.
³To whom any correspondence should be addressed.

E-mail: abhay_s@rediffmail.com

Abstract. Quasi-periodic scintillations are characterized as primary deep fade-out infield strength, associated with regular ringing patterns before and after it. In this paper, observations of quasi-periodic scintillation using geostationary satellite (FLEETSAT) transmissions operating at frequency 250 MHz at low latitude ground station, Varanasi (geomag. lat 14° 55′ N, long. 154°E) are reported. The results indicate that the quasi-periodic scintillations are most likely produced by plasma blobs/bubbles present in the E and F-region of the ionosphere. The various characteristics features of the quasi periodic scintillations are discussed after the auto-correlation, power spectrum and scintillation index analysis. The computed horizontal scale size of the quasi periodic scintillation producing irregularity varies from 100 m to 1300 m which shows that the irregularities are of intermediate-scale sizes. The spectral index obtained from the slopes of power spectrum varies from -2 to -8. The observed fading patterns, especially the modulation of the diffraction pattern (fading envelope) can be explained by considering an obstacle called radio lens in the ionosphere elongated in one direction. We have simulated successfully the amplitude versus time plot of quasi periodic scintillation patches and found that our theoretical and experimental results of quasi periodic scintillation patches compares well with each other and also with the earlier published works.

1. Introduction
In general, ionospheric scintillation is a random type, in which no regular variation in the amplitude and phase are recognized [1]. Although, in some cases peculiar periodic fluctuations in the field strength with a systematic change in amplitude and phase is observed which persists for one to several minutes when geostationary satellite is used [1-3] and for some 10 sec when orbiter satellite is used [4-5]. These phenomena are called quasi-periodic scintillations, distinguished from random scintillations. It is characterized as primary deep fade-out in strength, associated with regular ringing patterns before and after it [6]. Generation of quasi-periodic scintillation (QPS) is believed to be due to an obstacle in the radio wave propagation path, which is small-scale density enhancement/ depletion or blobs/bubbles acts as a concave radio lens [2,7]. Davies and Whitehead [2] and Karasawa et al. [3] reproduced quasi - periodic Fresnel diffraction patterns due to columnar shaped obstacle using thin...
phase screen model that advances the phase for the radio wave passing through it. Franke et al. [8] explained that QPS patterns occur either at the beginning or end of scintillation patch. Chen et al. [9] introduced a new time-frequency analysis method of Hilbert-Huang transform (HHT) to analyze the quasi-periodic scintillation data taken at Ascension Island to understand the characteristics of corresponding ionospheric irregularities. They concluded that the quasi-periodic scintillation diffraction patterns were produced by the steep irregularity structure located very near the edges or walls of the plasma bubble/blob.

Kelleher and Martin [6] have given various features of quasi-periodic scintillations in their results from travelling satellite and geostationary satellite. Their travelling satellite results showed that annual variation of occurrence of quasi periodic scintillations was high in June and July and with zero occurrence in Dec.–Jan. Considering, geostationary satellite, Kelleher and Martin [6] observed quite extensive ringing patterns in the time interval 05 – 08 LT and 18 – 22 LT whereas from 08 – 18 LT, they were single and lasts longer. They concluded that no common diurnal variation was obtained. Hajkowicz et al. [10] showed that out of total records of QPS, 57 % were asymmetrical, 7 % had an extended initial part of the ringing pattern, 13 % were symmetrical and 23% had only the trace of ringing pattern. To explain the quasi-periodic scintillation observations, many theoretical models have been developed [2,7,8,11,12]. Heron [12] modelled the random amplitude scintillations from small number of discrete and possibly regular, ionospheric irregularities. Davies and Whitehead [2] modelled the irregularities considering the cylindrical lens of about 100 m across in the ionosphere. They modelled theoretically the observed fading patterns of quasi periodic scintillations on 140 MHz and 360 MHz from geostationary satellite ATS-6, showing quasi-periodic fading before and after a deep central minimum. Titheridge [7] produced the Gaussian distribution of phase across the wavefront, using Kirchoff integral process to get the diffraction pattern due to the radio lens in the ionosphere. He gave the procedures for the rapid calculations of refraction and diffraction pattern produced by isolated irregularities. Giving the theory of large, small and dense irregularities, he further explained that for large irregularities compared to first Fresnel zone, the ground pattern can be obtained by a simple ray theory. Calculations should be made through diffraction theory for small irregularities and it has different patterns. Hajkowicz [13] has pointed out that the quasi-periodic scintillations may be closely linked with an interference effect of waves simultaneously transmitted by two satellites moving within the bandwidth of the receiving antenna. Apart from lots of study of quasi periodic scintillations, it was found that still the generation of quasi periodic scintillations is not well understood as well as most of the studies are of short period and long term of quasi periodic scintillations is lacking, especially for the low-latitude region.

In this paper, we have analyzed VHF amplitude scintillation recorded at Varanasi (geomag. lat. = 14° 55‘ N, long. = 154° E, Dip angle = 37.3°, Sub-ionospheric dip = 34°) for the period of 1991-1999. We have chosen quasi-periodic scintillation patches from our whole VHF scintillation data and tried to study the occurrence statistics as well as various properties of the quasi-periodic scintillations producing irregularities. Data selection and analysis of the quasi-periodic scintillations patches is explained in section 2. The theoretical formulation is shown in section 3. The results and discussions of quasi-periodic scintillation patches and their observed characteristic are given in section 4. Last, section 5 contains the summary of the results.

2. Experimental Set-up and Data Analysis
The fluctuations in the amplitude of 250 MHz signals transmitted from geostationary satellite, FLEETSAT situated at 73° E longitudes were recorded continuously at Varanasi (geomag. lat. = 14° 55‘ N, long. = 154° E, Dip angle = 37.3°, Sub-ionospheric dip = 34°) using a fixed frequency VHF receiver and a strip chart recorder [14]. At Varanasi, amplitude scintillations were observed mostly in the nighttime, predominantly in the pre-midnight periods and occur in small patches with duration < 30 minutes [15,16]. For the present study, VHF amplitude scintillation data recorded from Jan. 1991 to Dec. 1993, the declining phase of the solar cycle and Apr. 1998 to Dec. 1999, the ascending phase of the next solar cycle have been analyzed to study the characteristic of quasi-periodic scintillations.
The scintillations having peak-to-peak amplitude greater than 3 dB were considered and examined. The obtained quasi patches are classified into seven different types as shown by Maruyama [1]. Typical examples of different types of quasi-patches are shown in Figure 1. The Figure clearly shows quasi-periodic scintillation patches of type 1, primary fade out followed by a ringing pattern and no ringing beforehand; type 2, primary fade out accompanied by short ringing before and long extended ringing after; type 3, primary fade out accompanied by extended ringing before and short ringing after; type 4, burst like scintillations; type 5, valley like scintillations (V-type); type 6, spike type scintillation with periodicity; type 7, long duration ringing pattern. Apart from these seven types of quasi patches, we have also obtained some quasi-periodic scintillation patches, which we have categorized under unidentified ones as their category is not clearly defined. From the classification of total obtained patches at Varanasi, we have obtained only 2.7 % of type I, 4.8 % of type II, 4.3 % of type III, and 33 % of type IV. In addition to it, we have obtained about 25% valley type, 7 % spike...
type, 10% long extended form and 12% were un-identified. We have studied the various characteristic features of the quasi periodic scintillation patches obtained at Varanasi like its shape, characteristic length, strength, occurrence rate on the basis of analysis of auto-correlation function, power spectrum and scintillation index.

3. Theoretical formulation
For the theoretical modeling, of the observed events of quasi periodic scintillation patches recorded at Varanasi we have used the radio-lens theory model as given by [2] which is the extension of classical Cornu Spiral [17]. The geometry of the cylindrical produces a Gaussian distribution of phase ($\theta$) across the emergent wave front as [2]

$$\theta = \theta_0 \exp \left\{ -\frac{(S - S_0)^2}{2\ell^2} \right\}$$

(1)

where, $\theta$ = phase across the emergent wave front, $\theta_0$ = phase advance for the wave passing through the center of the lens at $S_0$ from the perpendicular from the observing point P to the incident wavefront, $S$ = Distance along the emerging wavefront, $S_0$ = Center of the lens, $\ell$ = scale size of the lens. $S$, $S_0$ and $\ell$ are measured in terms of the radius of the first Fresnel zone. In case of cylindrical lens, the in-phase and quadrature amplitude components $A_1$ and $A_2$ are obtained from the modified Fresnel Integrals [2]

$$A_1 = \int_{-\infty}^{+\infty} \cos \left\{ \frac{\pi}{2} S^2 + \theta_0 \exp \left\{ -\frac{(S - S_0)^2}{2\ell^2} \right\} \right\} dS$$

(2)

$$A_2 = \int_{-\infty}^{+\infty} \sin \left\{ \frac{\pi}{2} S^2 + \theta_0 \exp \left\{ -\frac{(S - S_0)^2}{2\ell^2} \right\} \right\} dS$$

(3)

From equation (2) and (3) we get the amplitude of the signal as

$$A = \sqrt{A_1^2 + A_2^2}$$

(4)

For our theoretical modeling of quasi-periodic scintillation patches obtained at Varanasi, we have used equations (4) and tried to simulate the recorded quasi periodic scintillation patches using appropriate modelled parameters for low latitude region.

4. Results and Discussions
Quasi-periodic scintillations are the outcome of the radio-lens entrance in the propagation path of the radio signals. Quasi periodic scintillations are in agreement with the thin phase screen diffraction model, through which when radio wave passes by, the phase advancement is produced due to the small scale density enhancement/ depletion called as plasma blob/ bubble [2,5,7,18]. Figure 1 shows the example of various types of patches observed.
The monthly variation of the mean percentage occurrence of quasi-periodic scintillations observed at Varanasi during Jan.1991- Dec.1993 and Apr.1998-Dec.1999 is shown in figure 2. The figure shows clearly that the occurrence rate is maximum in the year 1992 and minimum in 1999. The seasonal variation of occurrence of quasi-periodic scintillation patches shows that the quasi-periodic scintillation producing irregularities are found to be maximum in summer months and minimum in winter months. By the analysis of auto-correlation function we have computed the characteristic length of the irregularities. Figure 3 (a) shows a typical example of the auto-correlation function of quasi periodic scintillations data recorded on 3-3-1993 at 1509 – 1515 hrs IST with half de- correlation time 4.1 sec. The computed characteristic length for all quasi patches ranges from 100 m to 1300 m which shows that the quasi periodic scintillation producing irregularities lies in the intermediate scale range with peak occurrence rate between 300 m- 400 m. Figure 3 (b) shows a typical example of the power spectrum plotted from the digitized quasi periodic scintillation data recorded on 3-3-1993 at 1509 – 1515 hrs IST with their corresponding spectral index calculated as -5.14. The spectral indices of all quasi-periodic scintillations patches recorded at Varanasi lies in the range of -1 to -8 with mean value of -4.5. At our low latitude station Varanasi, the obtained scintillation index ranges from 0.1 to 0.6, this shows that the irregularities are of weak or moderate type.

Using equation (4) and other computed modeled parameters for low latitude region we have computed the amplitude of the signal at different frequencies for E and F regions of the ionosphere and plotted against time which, is shown in figures 4(a, b, c) for signal frequencies at 140 MHz, 250 MHz and 1.5 GHz respectively. From our computed diffraction patterns we observed that our model represents a very narrow and intense cylindrical lens in the ionosphere [2].

The characteristics of the simulated quasi-periodic scintillations producing irregularities at E and F-region of the ionosphere are also studied theoretically using the computed amplitudes at different frequencies and then further computing the power spectrum, auto-correlation function and scintillation index. Slopes of the power spectrums give the spectral indices of the irregularities, which lie in the range -2 to -6. The characteristic lengths of the simulated quasi periodic scintillations producing irregularities are also computed for the assumed drift velocity to be 100 m/s, which lies in the range of 250 m to 600 m for the E and F region irregularities respectively. This shows that the quasi-periodic scintillations producing irregularities are of intermediate scale sizes. The computed scintillation index
S_d, which gives the information about the strength of the irregularities, ranges from 0.1 to 0.2, which shows that the irregularities are weak in strength.

Figure 3: Typical examples of (a) the auto-correlation function and (b) the power spectrum plotted from the quasi-periodic scintillation data recorded on 3-3-1993 at 1509 – 1515 hrs IST.

All the above theoretically computed results are found to be in very much close agreement with that of experimental results obtained for quasi-periodic scintillations patches recorded at our low latitude station Varanasi.

5. Conclusion
The characteristic features of the quasi-periodic scintillations at a low latitude station Varanasi are discussed. The observations predict that quasi-periodic scintillations are the outcome of the plasma blobs/bubbles present in the E and F-region of the ionosphere. Most of the quasi-periodic scintillations are non-symmetrical in nature with the maximum occurrence of burst-like scintillations, produced by the plasma blobs, which are non-symmetrical in nature with the steep density gradient at the backside.

By the auto-correlation function analysis, the horizontal scale sizes of the quasi-periodic scintillation producing irregularities varies from 100 m to 1300 m which shows that the irregularities are of intermediate - scale size. The spectral indices obtained from the slopes of power spectrum vary
Figure 4: The computed fading diffraction patterns for signal frequencies at (a) 140 MHz, (b) 250 MHz and (c) 1.5 GHz.

from -2 to -8 and the obtained scintillation index shows that the quasi-periodic scintillations are of weak strength.

Thus, we conclude that our theoretical and experimental results of quasi-periodic scintillation patches compares well with each other and also with the earlier published works. Apart from this the study of quasi periodic scintillations still seems to be curtailed as most of the work is related to short term of quasi periodic scintillation and long term study (for a complete solar cycle) is lacking especially in low latitude regions. Thus, there is a need to study the phenomena of quasi-periodic
scintillation in more details for a longer period (a complete solar cycle) especially in the low altitude region.

Acknowledgements
The work is partly supported by DST, New Delhi under SERC project and partly by ISRO, Bangalore under CAWSES program.

References
[1] Maruyama T 1991 Observations of quasi periodic scintillations and their possible relation to the dynamics of E, plasma blobs Radio Sci. 26 691-700.
[2] Davies K and Whitehead J D 1977 A radio lens in the ionosphere, J. Atmos. Terr. Phys. 39 383-387.
[3] Karasawa Y, Yasukawa K and Yamada M 1985 Ionospheric scintillation measurements at 1.5 GHz in mid-latitude region Radio Sci. 20 643-651.
[4] Hajkowicz L A and Dearden D J 1988 Observations of random and quasi-periodic scintillations at southern mid-latitudes over a solar cycle J. Atmos. Terr. Phys. 50 511-517.
[5] Bowman G G 1989 Quasi-periodic scintillation at mid-latitudes and their possible association with ionospheric sporadic-E structures Ann. Geophys. 7 259-268.
[6] Kelleher R F and Martin P 1975 Fresnel-type fading on satellite records at low latitudes J. Atmos. Terr. Phys. 37 1109-1116.
[7] Titheridge J E 1971 The diffraction of satellite signals by isolated ionospheric irregularities J. Atmos. Terr. Phys. 33 47-69.
[8] Franke S J, Liu C H and McClure J P 1984 Interpretation and modeling of quasiperiodic diffraction patterns observed in equatorial VHF scintillation due to plasma bubbles J. Geophys. Res. 89 A12 10891-10902.
[9] Chen K Y, Su S Y, Liu C H and Basu S 2005 Ionospheric irregularity characteristics from quasiperiodic structure in the radio wave scintillation Radio Sci. 40 RS3001, doi:10.1029/2004RS003178..
[10] Hajkowicz L A, Bramley E N and Browning R 1981 Drift analysis of random and quasi periodic scintillations in the ionosphere J. Atmos. Terr. Phys. 43 723-733.
[11] Singleton D G 1964 Broadband radio-star scintillations, Part I. Observations Radio Sci. D 68 867-880.
[12] Heron M L 1974 Diffraction from discrete and homogeneously structured ionospheric irregularities Radio Sci. 14 97-102.
[13] Hajkowicz L A 1974 Radio transmissions from two satellites as a possible cause of quasiperiodic scintillations in amplitude recordings. J. Atmos. Terr. Phys. 36 1689-1693.
[14] Singh A K 1993 Study of VLF whistlers and VHF scintillations Ph.D. Thesis Banaras Hindu University Varanasi.
[15] Singh A K and Singh R P 1997 Observations and modelling of nocturnal ionospheric irregularities in low latitude region J. Geomag. Geoelectr. 49 1115-1129.
[16] Singh R P, Patel R P and Singh A K 2004 Effect of solar and magnetic activity on VHF scintillations near the equatorial anomaly crest Ann. Geophys. 22 2849-2860.
[17] Jenkins, F A and White H E 1957 Fundamentals of Optics (University of California) chapter 8 pp 353-381.
[18] Karasawa Y 1987 Interpretation of quasi periodic scintillation at frequencies above 1 GHz Trans. Inst. Electron. Commun. Eng. Jpn. E70 768-774.