Nig. J. of Pure & Appl. Physics. Vol. 4. pages 1-10, 2005

FADING OF RADIO SIGNALS FROM SPACED SYNCHRONOUS SATELLITES: DEPENDENCE ON SOURCE COORDINATES

Amaeshi, Larry L.N.
Department of (Applied) Physics, University of Lagos, Akoka, Yaba, Lagos, Nigeria.
E-mail: larryama@hotmail.com

Abstract: The fading of radio signals from synchronous satellites has been investigated, by analyzing the fading records radiated from a system of spaced synchronous satellites, all radiating at ~136 MHz, and observed at Legon, Ghana: longitude 0.19^0 west, latitude 5.63^0 north and magnetic dip 8.47^0 south; for the occurrence of scintillation. In particular, the dependence of scintillation occurrence on source coordinates, especially the elevation, was investigated. The investigations revealed, amongst others, that: Equatorial scintillation is indeed a nocturnal phenomenon. Moreover, it sets in rather abruptly about sunset, and disappears sluggishly about dawn and shows a peak occurrence between 2100 h and 0300 h depending on observer's coordinates and the season. Scintillation occurrence, hence signal fading depends strongly on source elevation, and local time. The onset of scintillation is essentially, a west-east event; and it depends strongly on the elevation of the source, the lower the elevation the earlier the onset. Plausible explanations for the observations are proffered.

Keywords: Equatorial ionospheric scintillation; radio signal fading; source coordinate; spaced synchronous satellites.

1. INTRODUCTION

The random fluctuations in amplitude and phase of trans-ionospheric radio waves are known as ionospheric scintillations. They are revelations of the fading suffered by the signal. Thus, their occurrence and intensity are responsible for the scintillations [1-9].

Scintillations are known to have adverse effect on day-to-day radio, television, and satellite communications, [10,11,6,12-19,9,7]. Though they are usually confined to frequencies below 4GHz, in extreme conditions, such as magnetic storms, they are known to cause problems up to 7GHz or more [18-20]. These frequencies fall within the up and down link frequencies of satellite communication in the C-band. Furthermore, ionospheric scintillations can have important impact on Global Positioning Systems (GPS) satellites and satellites systems for mobile communication (such as 'Iridium') systems, especially in the equatorial anomaly region [19]. Nevertheless, the importance of trans-ionospheric VHF/UHF communication cannot be over emphasized, especially in long distance telephony where geo-synchronous satellites play dominant role. Thus, there is the need for thorough understanding of ionospheric scintillations- the mechanism, the parameters on which they depend, and their impact.

Scintillations have been found to be dependent on a variety of parameters. These include hour of the day, and season of the year [21,10,22,6,9,23]. Others are sun spot number and magnetic activity [22,24,25,19,23]; source longitude [25]; observing frequency [26,12,8,18].

However, not much has been reported on the dependence of scintillations, and the associated fading on source coordinates in general and the elevation in particular, especially in the equatorial African region. Yet, there is much need for such information, [26,27,6,20,28,29,30]. The information gathered would enrich our understanding of equatorial ionospheric-scintillations, their nature and the nature of the causative irregularities; and their effect on trans-ionospheric radio waves. In effect, the knowledge gained would: (i) give a more accurate picture of equatorial ionospheric scintillations, thus, the global variation of ionospheric scintillations. This would also add to the long-term database necessary for the global modeling of ionospheric scintillations, as they affect VHF/UHF communication (ii) help in assessing the impact of scintillations on satellite communication and navigation (GPS) systems; and consequently, (iii) help to design robust communication/navigation satellite systems.

Furthermore, in some cases, where a parameter has been identified to affect scintillations, there have been conflicting reports as to the nature and manner of the dependence of scintillations on such a

---

Nig. J. Pure Appl. Phys. (2005) Vol. 4 pp 1-10. .Printed in Nigeria, ISSN 1596-0862. E-mail: njpapfuta@yahoo.com. For rights of reproduction and web access, contact African Journals Online, UK, www.inasp.ajol/journals/njpap

parameter. For example, it has been established that equatorial scintillation is a nocturnal phenomenon [31,32,33,34,22,35,2,6,18,9]. However, Koster [33,22] reported a nocturnal variation with a peak at about 2300 h local time (LT), while Wells [31] reported a diurnal variation with a maximum occurring at about 0300-0500 h LT, and Bhar *et al.* [2] reported a diurnal variation peaking at about 0200 h LT. These results suggest that this nocturnal phenomenon may also depend on other factors such as source coordinates and the local time. However, [18]. reported that ionospheric scintillations, unlike tropospheric ones, are independent of the elevation angle of the radio path. These apparent conflicting observations need to be reconciled. Furthermore, there is a day-to-day variability of equatorial scintillations, which remains an outstanding problem, [20,9].

The foregoing therefore underscores the sustained interest in (equatorial) ionospheric scintillation, especially with respect to the African Equatorial region, where there has been a dearth of data and information.

The objective of this work has been to investigate the fading of trans-ionospheric radio signals (manifested in form of ionospheric scintillations) at an African equatorial station, by analyzing the fading records radiated from a system of spaced synchronous satellites. Of particular interest were: (i) the diurnal variation of scintillation occurrence, for, as stated by [9], the day-to-day variability of equatorial scintillations has remained a problem. (ii) the prevalence of onset and cessation of scintillations from a more western source, vis-à-vis an eastern one, thus, the effect *albeit,* qualitatively, of the source coordinates, especially the elevation on radio signal fading.

The onset and cessation of scintillations: their nature, and their relative times of occurrence with respect to the sources' coordinates, were of additional interest because: the onset and cessation, hence the time evolution of scintillation activities observed at a ground station relates to the location and the manner of the generation of the causative irregularities, their drift and life time. The knowledge of this dynamics is necessary for the understanding of the theory of the cause of the equatorial irregularities themselves, and their impact on the fading of radio signals, especially with respect to high-speed data communication, [4,28,18].

2. METHODOLOGY

2.1 Fading Records: Observation, Recording, and the Equipment

Fading records of signals radiating from a system of three spaced synchronous satellites) were recorded simultaneously on adjacent channels of a strip chart recorder, from 22-10-76 to 30-04-77, at Legon, Accra, Ghana: latitude 5.6^0 N, longitude 0.19^0 W, and magnetic dip 8.47^0 S. The satellites were Geostationary Operational Exploration Satellite-1 (GOES-1), Symphonie, and International Satellite 2F-2 (INTELSAT 2F-2 or IS2F-2, for short). Relevant information about the observed satellites is given in Table I.

Table I: Relevant Information about the Observed Satellites

Name of Satellite	Elevation (Deg.)	Longitude (Deg.)	F-Long. (Deg.)	Frequency (MHz)	Period of Observation
GOES -1	6	-74.8	-15.07	136.4	22/10/76 – 30/04/77
IS2F-2	78 ~ 37	- 9.0 ~ -45.0	-0.94 ~ -4.60	136.5	22/10/76 –30/04/77
SYMPHONIE	72	-12.6	-1.06	137.0	22/10/76 – 30/03/77

The ionospheric point longitudes (F-Longs, for short) were determined using Koster's, method, [34]. The onset and cessation of scintillations with respect to the two constant coordinate satellites were equally recorded. GOES-1 and Symphonie were each received on a Collins radio receiver model R-390A/URR, using cross-Yagi aerials, each having 20 dipole elements, a reflector, 17 directors and 2 driving elements. The aerials were both installed atop solid walls about 3 meters high, in an E-W direction at the appropriate elevation and azimuth. They were separated by such a distance that their fields did not interact. The tuning frequencies of the receivers were 25.03 and 28.38 MHz respectively. IS2F-2 was received on a RACAL Communication radio receiver; model RA 117, tuned to 24.48 MHz. The bandwidth was 4 KHz in each case. A right circularly polarized seven-turn helical antenna, with a square reflector, and mounted on the ground at appropriate elevation and azimuth was used in this case. The use of the system of circularly polarized aerials was necessary, in order to eliminate the fading of signals due to Faraday rotation.

The recording was on an Evershed strip-chart pen recorder, mounted on a vertical metal support. The chart was driven by the output of a phase sensitive detector (PSD) with a low pass filter connected to it, at a speed of 6" (~ 0.15m) per hour.

The use of the PSD ensured a better noise rejection property of the receiver-detector system, [6]. A motorized clock was externally incorporated to one of the pens. This pen deflected normal to the strip chart on the hour, thus marking the time. This enabled easy determination of the onset and cessation times of scintillations. The excursions of the pens traced on the strip chart fluctuations in amplitude of the received satellites' signals, about the smoothed noise fluctuations, normally zero in the output. The amplitude fluctuations were revelations of scintillations (fading) suffered by the signals as they transversed the ionosphere.

2.2 Data Acquisition and Analysis

2.2.1 Scintillation Occurrence

Each satellite's records were examined daily, for scintillation occurrence, and such information as onset, and cessation of scintillations, was recorded. The onset and cessation times of scintillations were read directly from the strip chart. The daily records from 1800 h to 0600 h were grouped into 48 units of 15 minutes interval each, *for* there were practically no scintillations observed between 0600 h-1800 h. Each interval was classified accordingly, as follows: (i) signal received but no scintillations (ii) scintillations occurred, where scintillations were said to have occurred within an interval, if within the interval, there were scintillation activities for at least 7.5 min.; and (iii) no signal received at all (either due to instrument breakdown or the satellite was switched off). These were coded 0, 1 and 2 respectively. Subsequently, the number of intervals when there was a record- signal received with or without scintillations-was evaluated and coded as 3. This discrete data were stored electronically, for computer analysis later.

The percentage of scintillation occurrence in respect of each satellite was evaluated for each of the 48 15-min. intervals for each day of the period of observation.

Percentage (%) of scintillation occurrence is defined by:

% of scintillation occurrence =

$$\left(\sum_{i=1}^{N} scin_i \Big/ \sum_{j=1}^{N} count_j\right) \text{x}100 \text{.... .... (1);}$$

where $scin_i$ is the i^{th} day that there was scintillation during the interval, $count_j$, the j^{th} day that there was as a record during the interval; and N, is the number of days that records were observed.

The smooth curves of the diurnal variations of the percentage of scintillation occurrence are depicted in Figures 1a and 1b.

The curves were smoothened by the Running Mean Curve Smoothing Technique since scintillation occurrence is a time series event. The five-term version of the technique was employed. The terms were weighted as in the expression:

$$Y_{is} = \tfrac{1}{10}\left(Y_{i-2} + Y_{i+2}\right) + \tfrac{1}{5}\left(Y_{i-1} + Y_{i+1}\right) + \tfrac{2}{5}Y_i \text{ ... (2)}$$

Y_{is} and Y_i are the smoothened and un-smoothened values of the i^{th} element of the series respectively.

Depicted also on Figure 1b is the time displacement of scintillation events, defined by the displacement in time of the half-power point of percentage of scintillation **2300** **2400** occurrence in the two constant coordinate satellites. The mean time displacements of the events were calculated as follows: Referring to Fig. 1b, the maximum percentage of scintillation occurrence in GOES-1 is approximately 80%. This gives a half-power value of 56%, and a corresponding bandwidth, W_G of 34.0 units of time centered about G. Similarly, the bandwidth, W_S with respect to Symphonie, centered about S, is 26.0 units of time, the half-power value being 40%. The displacement, SG, of the center points is given by:

$$SG = \tfrac{1}{2}\left(W_G - W_S\right) \qquad \text{... (3).}$$

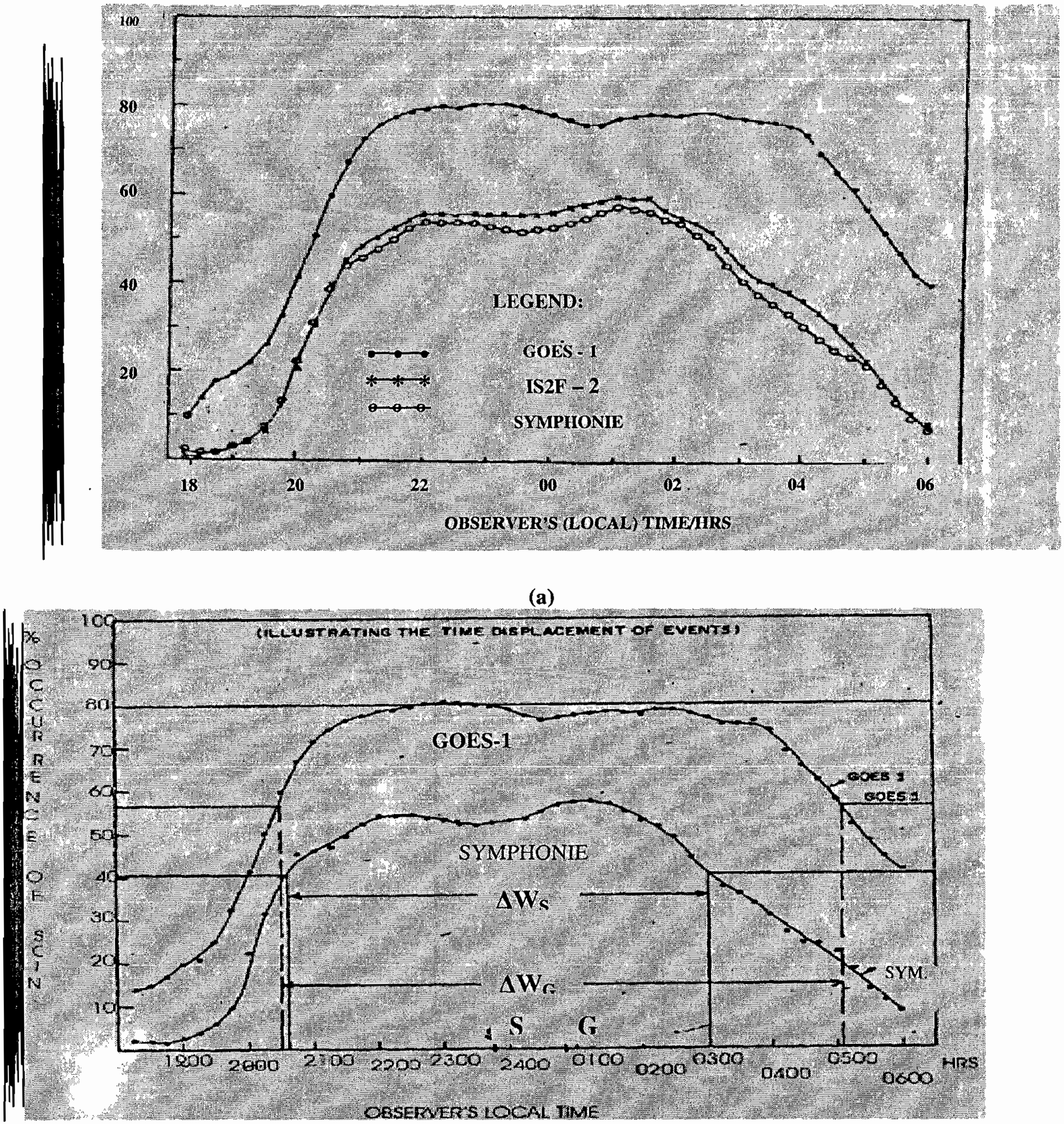
This, on evaluation gives: SG = ½(34.0-26.0) = 4.0 units of time, which is equivalent to 60 minutes.

This is in good agreement with the theoretical value of 56 minutes, the time equivalence of the difference, of 14^0, between the sub-ionospheric-point longitudes of the two satellites.

2.2.2 Scintillation Onset and Cessation

The onset and cessation times of scintillations on Symphonie relative to GOES-1 were analyzed respectively, first on a " Yes-No-Neither" basis, corresponding respectively to scintillation starting (or disappearing) first on the more eastern satellite, on the more western one, or simultaneously on both satellites. The respective time lags, Δt, measured in minutes were evaluated, for each day of observation, where

$$\Delta t = time\ of\ event\ on\ GOES - 1 - time\ of\ the\ corresponding\ event\ on\ Symphonie\ ;$$



(a)

(b)

Fig. 1 Diurnal Variation of Percentage Occurrence of Scintillations on: (a) The three satellites: GOES-1, IS2F-2 & Symphonie;(b) The two constant coordinate satellites: GOES-1 (Elevation: 6^0; and F-Long: -15.07^0) Symphonie (Elevation: 72^0; and F-Long: -1.06^0), Showing also the 'Time Displacement of Events'
***Note*: The coordinates of IS2F-2 varied as follows: Elevation, from 78^0 to 37^0, & F-Long from -0.94^0 to -4.60^0**

and by event we mean the onset or disappearance of scintillations, as applicable. In the case of onset (cessation) times Δt is positive (negative) if the event occurred first on Symphonie, the more eastern satellite. This convention is adopted, if we assume that an event, as defined, would occur first at a more easterly sub-ionospheric longitude vis-à-vis satellite, since F-Region Equatorial scintillation is mainly a nocturnal phenomenon. In other words, scintillations ought to start, and disappear first on the more eastern satellite. Any day there was no record, or it was impossible to determine, the appropriate time lag was left out accordingly. In all, there were 122 days of useful records.

The respective daily time lags were grouped in intervals of 60 minutes, and the frequency distributions of the time lags plotted. These are depicted in Figs. 2a and 2b respectively.

3 RESULTS AND DISCUSSION

3.1 Diurnal Variations

Figures 1a and1b show that: (1) indeed, equatorial scintillation is strongly a nocturnal phenomenon, as has been widely reported, [31,32,33,34,22,35,36,6]. In particular, it is seen that: (i) there were no scintillation activities before 1800 h, and after 0600 h LT, and very little between 1800 h and 1930 h. In effect, the onset of scintillations follows ground sunset by one to two hours. (ii) There were very little scintillation activities between 0400 h and 0600 h, LT. (iii) Indeed, most of the scintillation activities occurred between 2100 h and 0300 h LT, with a rapid rise from 1930 and 2030 h on GOES-1, and Symphonie/IS2F-2 respectively, and showing what might be termed a primary peak at about 2300 and 2200 h respectively. This result is consistent with the diurnal variation of the scintillation index, reported by [1,27]. This suggests equally pronounced signal fading about this time of the night, as is supported by Koster's results in [27] on the diurnal variation of fading depths (in dB). (iv) There was some sort of trough, which occurred at about 2330 h, and 0030 h on Symphonie/IS2F-2 and GOES-1 respectively. This was followed by what might be called a secondary maximum that occurred at 0100 h and 0200 h on Symphonie/IS2F2 and GOES-1 respectively. Similar features have been reported by [33] whose results show that the trough and secondary maximum occurred at 0130 and 0430 h respectively. The explanation for this slight dip in percent scintillation occurrence around midnight is not obvious. Overall, the tops of the curves seem to exhibit some sort of 'saturation', (maximum) between 2100 and 0300 h. (v) the post-sunset rise (of percentage occurrence of scintillation) with respect to all the satellites is rather steep. The above results suggest an abrupt onset of scintillations hence signal fading, as has been reported by [33]. It also suggests an almost explosive beginning of equatorial irregularities, characterized by very deep fading, as has been observed by [27]; and by extension, a sharp boundary between the quiet and disturbed ionosphere. (vi) The curves drop off much more slowly, compared to their rise. This suggests that the cessation of scintillations is much less abrupt than their onset. In effect, it suggests that the decay of the causative irregularities is rather gradual, as against a sudden generation. The gradual disappearance of scintillations is due to the progressive disappearance of lower levels of scintillations, a result that Koster [27] has observed earlier.

(2) The low elevation satellite shows higher percent occurrence of scintillations than the high elevation ones. Indeed, a closer look at Fig.1a reveals similar difference in percentage occurrence of scintillation and the elevations, *albeit* small, between Symphonie and IS2F2. Moreover, the curve for the lower elevation satellite, GOES-1 is wider than those for the satellites near the zenith. (3) The time difference between the midpoints of the half-power points for GOES-1 and Symphonie, (see Fig.1b), is 60 min. This is in good agreement with the theoretical value of 56 min., which is the time equivalence of the difference in their F-longitudes.

In addition, the results of the analysis in Section 2.2, which are discussed in Section 3.2.1, show that the abrupt onset and rise of scintillations depend, very likely, on the source coordinates. It is seen to have started earlier on GOES-1, the more westerly, but lower elevation satellite than on IS2F-2 and SYMPHONIE the more easterly and higher elevation satellites. This result and (2), (3) above further suggest a strong dependence of scintillation occurrence hence, signal fading on the coordinates, especially the elevation, of the source. Koster, [27] had made similar observations, *albeit,* qualitatively. He also reported that a low elevation satellite frequently shows relatively small scintillation indices (SI) while a satellite near the zenith showed none at all. This further supports the revelation that scintillation occurrence and the depth of fading depend on the elevation of the source. The foregoing results show that both scintillation occurrence and its depth are greater at lower elevations. A plausible explanation is that the signal traverses longer ionospheric path in this case, and consequently, encounters greater causative irregularities as it traverses the ionosphere.

The dependence of the onset of scintillations on source coordinates, and the sharp nature of the onset imply a sharp E-W gradient in the forces producing the causative irregularities thus, an explosive beginning of equatorial irregularities. This postulate (the existence of sharp E-W boundary between the disturbed and quiet ionosphere) fits into Beer's Resonance Theory for the generation of the irregularities, [36].

3.2 Results of Analysis of Scintillation Onset and Cessation

The relative onset and cessation of scintillations on the two fixed coordinate satellites were analyzed on a "Yes-No-Neither" basis, as described in Section 2.2.2. For the sake of clarity, the two satellites and the relevant parameters are as shown in Table 1.

3.2.1 Results of Onset Time Analysis

Beginning day (of record taking) ...... 22-10-76.
Ending day ....25-03-77.
Days with East Satellite first (Onset first on Symphonic: a "Yes")......... ....29.
Days with West Satellite first (Onset first on GOES-1: a "No").............. ...... .88.
Days with simultaneous onset of scintillation on both satellites (a "Neither") ...5
Quiet days (No of days when no scintillations where observed) 24
Days rejected (Difficult to ascertain the relative onset times) 9
Total days of useful records: (29 +88 + 5) ... 122.
Total days of simultaneous observation :(29 +88 +5 + 24 +9) ....155.

The frequency distribution histogram of the time lag in respect of the 122 days of useful records is depicted in Figure 2a.

The results show that scintillations started much more frequently, (about 72% of the days of useful records), on the more western satellite than on the one further east. This is against 24% only, when scintillations started first on the satellite further east, as expected, and 4% when it started simultaneously on both satellites. This result is puzzling, for, since scintillation is a nocturnal phenomenon, and seems to be triggered off in some way by ionospheric sunset, one had expected to find scintillations starting (and disappearing) first much more frequently on the satellite further east than on the one further west, of an E-W pair.

The puzzling result above raises a number of questions, namely:

(i) Could it possibly just be a statistical fluctuation from using too small a number of cases in the study - barely six months of data were used, and only a pair of E-W satellites considered. In other words, could the same result be obtained if one had used more data? (ii) Is this unusual result due to a genuine longitudinal variation in the frequency, and the percentage of scintillation occurrence? (iii) Can the results be explained in terms of a difference in elevation, since the more eastern satellite was relatively at a high elevation ~ 72°, compared to the one further west, which was at a low elevation~ 6°? However, results of similar work by Koster [27], triggered off by earlier observations by Amaeshi [27], and using data obtained from a three year period of observation were in conformity with this result. This eliminates possibility (i) above. To answer question (ii) above one needed data from, at least two satellites at comparable elevations but with very different longitudes. Unfortunately, one had no such data. There were no data from satellites east of Legon. However, Bandyoopodyay and Aarons [35] observed that on the average scintillations started first on a more eastern satellite than on the one further west. Unfortunately, their sources' coordinates-elevations and longitudes are unavailable in Literature to the author. This leaves question (ii) unresolved

Nevertheless, one can proffer some answers to question (iii): The result can be explained in terms of the difference in elevation of the two satellites.

The results obtained herein show, as can be seen in Fig.1, that the curve of the diurnal variation of percentage occurrence of scintillation for the lower elevation satellite is wider than, and lay above that of the satellite near the zenith. Also, it seen from Fig.2 that, for at least 50% of the time when scintillation started first on the western satellite, which was the low elevation satellite, the difference in the onset times was about 60 min. This is approximately equal to the time equivalence of the difference in their sub-ionospheric points (F-Longs), which themselves depend on the elevation of the satellites. These results suggest quite strongly that the result above can be explained in terms of the differences in elevation angle. In other words, scintillation onset depends on source elevation; it commences earlier on a lower elevation satellite than on that nearer the zenith. However, while one can easily explain the increase in both the depth and percentage of scintillation occurrence as the elevation decreases, in terms of ionospheric path (see Section 2.3.1), the reason why scintillation has to start first more frequently on a low elevation satellite than on that nearer the zenith is not obvious.

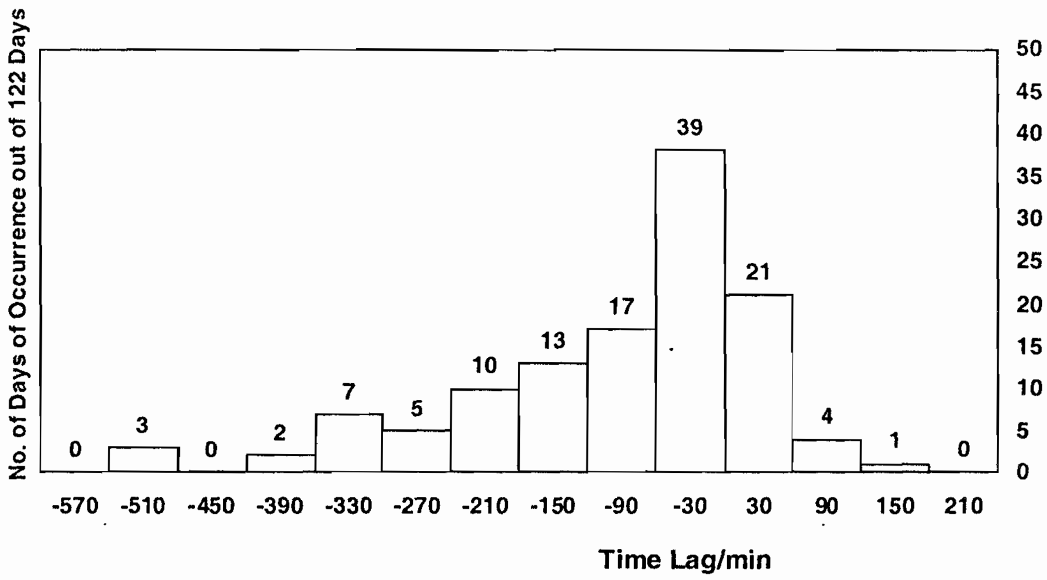


Fig.2a: Onset Time Lag Histogram

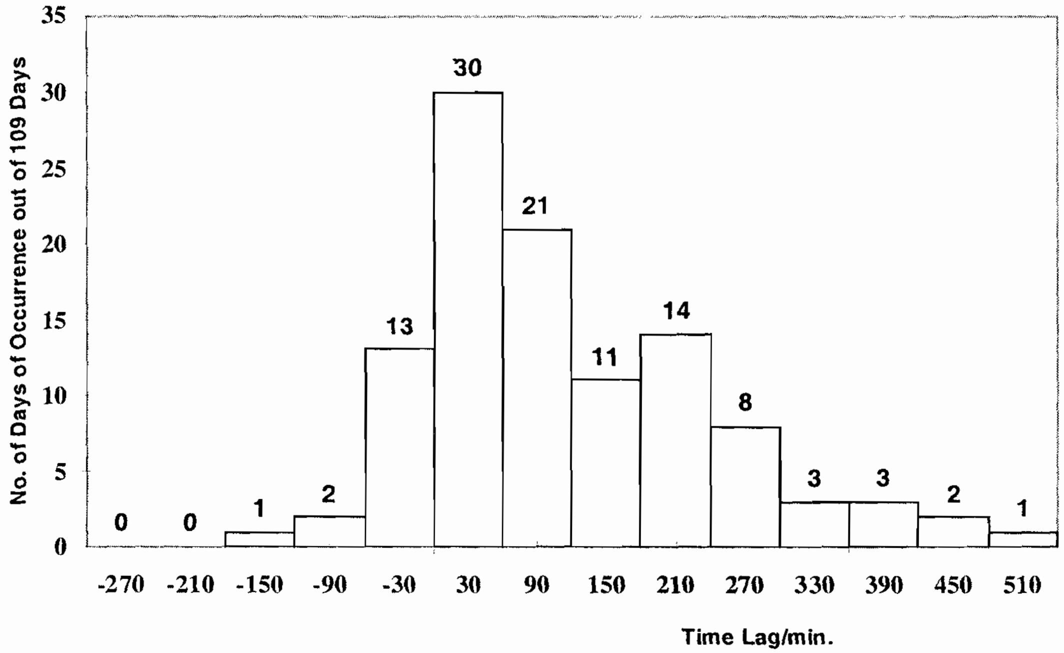


Fig.2b: Cessation Time Lag Histogram

Fig. 2 Frequency Distribution Histogram of Scintillation Onset, and Cessation Time Lags of GOES-1 (Elevation, 6^0; F-Long-15.07^0) relative to SYMPHONIE (Elevation 72^0; F-LONG-1.06^0) (a) Onset Time Lag Histogram (b) Cessation Time Lag Histogram

3.2.2 Results of Cessation Time Analysis

Similarly, the relative time of the cessation of scintillations on the two satellites were analyzed. The results show that (i) in this case, there were 109 days of useful records out of the 155 days of simultaneous observation of the two satellites. (ii) Scintillation disappeared first on the more eastern satellite, Symphonie, on 91, out of the 109 days of useful records. This is approximately 83% of the time. And it disappeared first on the more western satellite, GOES-1, on 16 out of the 109 days, while it disappeared simultaneously on both satellites on 2 days. These correspond to approximately, 15% and 2% of the time respectively. These results show that scintillation disappeared first much more frequently on the more eastern satellite than on the one further west. This is consistent with expectation, based on the hypothesis stated earlier in Subsection 3.2.1.

However, in most cases, 54 out of the 91 days when scintillation disappeared later on the more western, and low elevation satellite, the time lag was much greater than the expected value of 56 min. This suggests, most likely, that the irregularity patch that triggered the scintillation onset was not the same one, in terms of morphology, that disappeared, just before ionospheric-sunrise, resulting in the observed scintillation cessation. In other words, in the course of its E-W drift, a patch might have broken into a hierarchy of sizes, as has been reported elsewhere, [25], with the smaller patches disappearing first; and the larger ones disintegrating further, dissipating their energies in the process. The process continued until the entire patch had disappeared, and no more scintillation observed. The whole process is, more or less, tantamount to a gradual, sluggish decay of the irregularity patches. The corollary to this theory is that no new irregularity patches are formed after ionospheric midnight. However, how much/long the observed scintillation effect is, would depend among others, on the path length of the ionospheric irregularity, in effect on the total electron content of the column, traversed by the signal. This is greater, the lower the source elevation. This suggests a greater persistence of scintillation on low elevation source. This plausibly explains the result above, that: though, scintillations disappeared first much less frequently on GOES-1, the more western, but low elevation (near horizon) satellite, than on Symphonie, the more eastern, but the high elevation (near the zenith) satellite, however, on the average, the time lag was much greater than what longitudinal variation only would predict. Thus, the observations are due, probably, more to source elevation, than its longitudinal effect.

4. CONCLUSIONS AND RECOMMENDATIONS

The investigation has revealed among others, that:

(1) Equatorial scintillation, resulting in the fading of trans-ionospheric radio signal in the equatorial region, is strongly a nocturnal phenomenon. The onset follows ground sunset by one or two hours, and most of the scintillation activities occur between 2100 h and 0300 h local time, with maximum occurrence at about 2300 h, depending on the coordinates of the source, especially the elevation.

(2) The onset of scintillation is abrupt, and the post sunset-rise rather steep, indicating an almost explosive beginning of the causative equatorial ionospheric irregularities. This in itself suggests a sharp boundary between the quiet and disturbed ionosphere, which is consistent with the resonance theory of the generation of equatorial irregularities.

(3) The cessation of scintillations, on the other hand, is rather gradual, suggesting equally, a gradual decay of the causative irregularity patches.

(4) Ionospheric scintillations, in general, (hence fading of trans-ionospheric radio signal) - the diurnal variation of percentage occurrence, and the onset and cessation times - are strongly dependent on the source coordinates, especially the elevation. The diurnal percentage occurrence is greater, the lower the elevation; and the lower the source elevation the earlier the onset and, on the average, the later the cessation.

Plausible explanations have been proffered for the diurnal variation, and for the cessation results. However, it is not clear, why scintillations should start more frequently first on a more western but a lower elevation source, than on the one further east, even though the later is nearer the zenith. It is therefore, recommended that further investigations be carried out, especially, to ascertain, unambiguously, the effect of the source longitude. This is feasible if and whenever a system of synchronous satellites at same elevation, but separated in longitudes can be monitored simultaneously at the same station.

REFERENCES

[1] Koster, J.R., (1963). “Some Measurements of the Irregularities giving rise to the Radio Star Scintillation at the Equator”. *J. Geophys. Res.* Vol. 68, #9, 2579.

[2] Bhar, J.N. A. Das Gupto and Su. Basu. (1970), "Studies of Equatorial F-Region Irregularities at low latitudes from Scintillations of Satellite Signals" *Radio Sci.*, Vol. 5 #6 939

[3] Wernick, A.W., and C.H. Liu, (1974). "Ionospheric Irregularities Causing Scintillations of GHz Frequency Radio Signals". *J. Atmos. Terr. Phys.* Vol. 36. P 871

[4] Basu Sunanda, Basu, S., Aarons J., McClure, J.P. Lattot, Bashy, A. and Woodman, R.F., (1977). "Preliminary Comparison of VHF Radar Maps of F-Region Irregularities with Scintillations in Equatorial Region". *J. Atmos. Terr. Phys.* 39, 1251.

[5] Basu Sunanda and Kelly, M.C., (1977). "Review of Equatorial Scintillation Developments in the Theory and Measurements of Equatorial Irregularity". *J.Atmos.Terr.Phys.* 39, 1263.

[6] Amaeshi, L.L.N., (1978). *"The Fading of Radio Signals from Spaced Synchronous Satellites." M.Sc. Thesis.* Department of Physics, University of Ghana, Legon, Accra, Ghana.

[7] Dabas, R.S. and B.M. Reddy, (1986). "Nighttime VHF Scintillations at 23^0 N Magnetic Latitude and their Association with Equatorial F-Region Irregularities". *Radio Sci.* 21 453.

[8] Bhattacharyya B.M. and R.G. Rastogi, (1990). "Signal Frequency Dependence of Scintillation Amplitude". *Radio Sci.* 21 , 289-297.

[9] Basu, S., (2003), *"Ionospheric Scintillations: A Tutorial"*. CEDAR Workshop @ Longmont, Colorado, 15-20th. June 2003

[10] Koster, J.R., (1962). "Ionospheric Irregularities at the Equator". *Ghana J. Sci.* 2, 1, 17.

[11] Whitney, H.E. and Basu, Santima, (1972). "Effect of Ionosphere on VHF/UHF Satellite Communication. *Radio Sci.* 12 #1, 123.

[12] K.N. Iyer and R.G. Rastogi, (1978). "Ionospheric Scintillations of VHF Radio Signals form Satellites at Ahmedabad". *Indian J. Radio and Space Phys.*7, 9-12.

[13] Aarons, J., H.E. Whitney, E.M. Mackenzie and S. Basu, (1981). " Microwave Equatorial Scintillation Intensity During Solar Maximum" *Radio Science* 16, 939

[14] Fang, D.J., (1981). "C-Band Ionospheric Scintillation Measurements at Hong Kong Earth station during the peak of Solar Activities in Sunspot cycle 21", in: *Symposium On The Effect of the Ionosphere on the Radiowave System*, ed. J.M. Goodman. P181. Naval Research and Air Force Geophysics Laboratory, Washington DC.

[15] Basu S., J.P. McClure and Su. Basu, W.B Hanson and J. Aarons (1980). "Coordinated Study of Equatorial Scintillation and In-situ Region Irregularities". *J. Geophys. Res.* 85, 5119.

[16] Basu, S. and Su. Basu, (1981). "Equatorial Scintillations– A Review". *J. Atmos. Terr. Phys.* 43, 473.

[17] Basu S., E. Mackenzie and Su. Basu, (1988). "Ionospheric Constraints on VHF/UHF Communication Links during Solar Maximum and Minimum Periods". *Radio Sci.* 23, 363.

[18] Richaria, M. (1999). Satellite Communication Systems: Principles of Design. 2nd, ed. Pp84-88. Macmillan Press Ltd. Gt. Britain.

[19] Babayev, E.S. (2001) "Influence of the Solar and Magnetic Activity on Trans-Ionospheric Radio Wave Scintillation" Proc. Regional Meeting on Solar Physics *"Solar Researches in the South-Eastern European Countries: Present and Perspective"*. Bucharest, Romania, 24-28th April 2001.

[20] Allnutt, J.E., (1989), Satellite-to-Ground Radiowave Propagation: Theory, Practice and System Impact at Frequencies above 1GHz. Peter Peregrinus Ltd., London, Ch 2 pp 58-97.

[21] Ryle, M. and Hewish A., (1950). "The Effect of the Terrestrial Ionosphere on the Radio Wave from Discrete Sources in the Galaxy". *Mon. Not. Roy. Astr. Soc.*, 110 381.

[22] Koster, J.R., (1972). "Equatorial Scintillations". *Planet. Space Sci.* 20 1999.

[23] Dandekar, B.S and K.M. Groves, (2004). "Using Ionospheric Scintillation Observations for Studying the Morphology of Equatorial Ionospheric Bubbles". *Radio Sci.*, 39, RS3010, doi: 10. 1029/2003RS3010.

[24] Dabas, R.S., D.R. Lakshmi, and B.M. Reddy, (1989). "Effect of Geomagnetic Disturbances on VHF Nighttime Scintillation Activity at Equatorial and Low Latitudes". *Radio Sci.* 24, 563.

[25] Basu Sunanda, Basu S. and Khan, B.K., (1976). "Model of Equatorial Scintillation from In-situ measurements". *Radio Sci.* Vol 11 # 10 821.

[26] Beer, Tom (1974). "On the Dynamics of Equatorial Spread-F". *Austr. J. Phys.* 27, 391.

[26] Koster, J.R., (1976). "Study of the Equatorial Ionosphere". Interim Scientific Report #3, Department of Physics, University of Ghana, Legon, Accra, Ghana.

[27] Koster, J.R., (1978). "Phase and Amplitude Scintillation at the Equator". Final Scientific Report. Department of Physics, University of Ghana, Legon, Accra, Ghana. Pp1-26.

[28] Barclay, L.W., (1993). *"Ionospheric Effects on Modern Telecommunication Systems"*, presented at the 3rd. ICTP-URSI College on Theoretical and Experimental Radio Propagation Physics. Miramare-Trieste, Italy. 1-26 February 1993.

[29] Radicella, S.M. (1993). Personal Communication, at the 3rd. ICTP-URSI College on Theoretical and Experimental Radio Propagation Physics. ICTP, Trieste, Italy. 1st. -26th. February 1993.

[30] Secan, J.A., R.M. Bussey, E.J. Fremouw and Sa. Basu, (1995)." An improved model of Equatorial Scintillation". *Radio Sci.* 30, 607-617

[31] Wells, H.W., (1954), "F-scatter at Huancayo, Peru, and Relation to Radio Star Scintillation" *J.Geophys. Res.* 59 273

[32] Booker, H.G., (1958). "The use of Radio Stars to study irregular refraction of the Ionosphere" *Proc. IRE,* 46, 298

[33] Koster, J.R. (1958). "Radio Star Scintillation at an Equatorial Station". *J. Atmos. Terr. Phys.* Vol. 12, 100.

[34] Koster, J.R., (1967). "Studies of the Equatorial Ionosphere Using Transmissions from Active Satellites". Final Scientific Report. Department of Physics, University of Ghana, Legon, Accra, Ghana. Chap. 3, pp 40-47.

[35] Bandyopadhyay, P., and Aarons Jules, (1970). "The Equatorial F-layer Irregularities as Observed from Huancayo, Peru". *Radio Sci.* 5, 931.