# Characterization of Ku-Band Amplitude Scintillation on Earth-Space Path over Akure, SW Nigeria.

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*Abstract*—**Due to its dependence on meteorological and link factors, tropospheric amplitude scintillation experiences significant spatio-temporal variation which must be statistically characterized for effective budgeting on any earth-space path. A detailed experimental study of this phenomenon on a satellite link over Akure, South-western Nigerian (7.17°N, 5.18°E, 358m) is being carried out using radio beacon signals from EutelSat W4/W7 satellite link. The measurement uses spectrum analyzer (Tektronix Y400 NetTek Analyzer) at 1-second integration time. Results of clear-air scintillation intensity analysis show that strong scintillation intensity are short-lived for longer duration of time than the shorter time duration.**

**Keywords—scintillation; troposphere; variation; link; parameter;**

## I. INTRODUCTION

Irregularities in the refractive conditions of a transmission medium caused by turbulent mixing of air masses and random distribution of scatterers, lead to rapid fluctuations in the amplitude of the received signals about a mean position, a phenomenon known as amplitude scintillation. For satellite communications at Ku-band (14/11 GHz), scintillation arises purely from tropospheric refractive index perturbations since electron density variations in the ionosphere do not affect signals above 10 GHz frequency [1, 2]. Although rain attenuation may be the predominant cause of signal degradation at this frequency range, scintillation however becomes important for low-availability and low-fade margin systems, systems operating at low elevation angles, and very small aperture terminal (VSAT) [1, 3]. Also, knowledge of the dynamic characteristics of scintillation is important for designing uplink power control and antenna tracking systems as well as preventing, in a multi-carrier satellite transponder, increase and decrease in intermodulation noise and carrier/interference (C/I) ratio respectively [1, 7, 9]. In view of the foregoing, accurate estimates of signal degradation due to amplitude scintillation must be included in the design of satellite communication systems [4, 3, 5, 6, 7, 8]

Many studies have been done theoretically and experimentally on tropospheric amplitude scintillation on satellite link [1 - 13] leading to several prediction models being proposed [1, 3, 4, 5, 9, 10, 11, 12] and the dependence of scintillation on local climatology and link factors – frequency, elevation angle and antenna diameter, have been reported [1, 4, 7, 9]. However, no experimental work on tropospheric scintillation has been reported from Nigeria, and data from this region are sparsely considered in developing global models for scintillation characterisation.

Due to significant and continuous spatio-temporal variations in weather parameters across different parts of the world, global scintillation models such as ITU, Karasawa, Otung, Moulsley-Vilar etc. do not always accurately predict scintillation intensity in locations outside the regions where they were developed [14]. In order to remedy this anomaly, the development of location-based empirical models for scintillation studies is more than justified. Consequently, this work presents the results on investigation of clear weather turbulence induced Ku-band amplitude scintillation on earth-space path in Akure South-western Nigeria.

## AMPLITUDE SCINTILLATION THEORY

In radiowaves applications, signal scintillation is usually characterized by the received power amplitude, its standard deviation and variance which connote scintillation amplitude, intensity and strength respectively [1]. The log of the received power expressed in dB defines the scintillation amplitude as:

$$\chi_{dB} = 20\log_{10}\left(\frac{A_i}{A_o}\right) \text{ (dB)} \quad (1)$$

**where $A_i$ is the received signal amplitude and $A_o$ is the average received amplitude.**

**The standard deviation and variance is given by (2) and (3) as follows:**

$$\sigma_x = \left[\frac{1}{N-1}\sum_{i=1}^{i=N}\left(A_i - A_o\right)^2\right]^{\frac{1}{2}} \quad (2)$$

$$\sigma_x{}^2 = \frac{\sum\left(A_i - A_o\right)^2}{\left(N-1\right)} \quad (3)$$

**But in terms of the transmission parameters the variance is given as [1]:**

$$\sigma_x^2 = 42.25\left(\frac{2\pi}{\lambda}\right)^{7/6} \int_0^L C_n^2(x) x^{5/6} dx \quad (4)$$

where A is the received signal amplitude, $A_o$ is the average received amplitude; λ is the wavelength, x is the distance along the path, and L is the total path length; and $C^2_n$ is the refractive index structure constant which depends not only on the variance of the atmospheric refractive index, but also on the outer scale of irregularities. Therefore, it is not feasible to determine such parameters directly from available meteorological elements available, and as such remains difficult to evaluate [15].

Another quantitative measure of scintillation activity on a communication link is the **peak to peak** scintillation amplitude ( $\chi_{pp}$ ) which is the sum of the maximum enhancement ( $\chi_+$ ) and the absolute value of the maximum fade ( $\chi_-$ ).

## II. METHODOLOGICAL APPROACH

### A. Experimental Setup

This work presents results from an experiment in which concurrent measurement of radio beacons and weather parameters was carried out at Federal University of Technology, Akure (7.17◦N, 5.18◦E), which is in the South-Western part of Nigeria. Akure has a climate that typifies a tropical region exhibiting two clear climatic seasons, dry and wet spanning November to March and April to October respectively. The scintillation data are taken from a 12.599-GHz Eutelsat W4/W7 beacon at an elevation angle of 036E and a sampling rate of 1 second using a digital radio spectrum analyzer (Tektronix Y400 NetTek Analyzer). Corresponding measurement of rainfall rate, rainfall amount, temperature, pressure, humidity, wind speed and wind direction were taken at 1-minute integration time using an electronic weather station Davis 6250 Vantage Vue having Integrated Sensor Suit (ISS). This current study utilized one year data of received radio beacon signal from January to December 2016. The specifications of the satellite beacon receiver system are given in Table 1.

TABLE I. SATELLITE SPECIFICATIONS

| | Specifications |
|---|---|
| Antenna height above seas level | (358+5.2) m |
| Beacon frequency | 12.50 GHz |
| Elevation angle | 053.5E |
| Polarization | Horizontal |
| Antenna configuration | Parabolic antenna |
| Antenna diameter | 90 cm |
| Satellite position | 036E (orbital) |
| Satellite EIRP | -38 dBm V (Max) |

### B. Data Analysis

The raw beacon results were extracted, inspected and smoothed to remove spurious samples. Also, using a cut off frequency of 0.004 Hz, an 8th order Butterworth high pass filter (HPF) was designed to separate between the effects of rain attenuation and scintillation, leaving behind time-dependent data whose fluctuations are due mainly to scintillation [13]. Thereafter, computation of scintillation intensity was done from the valid samples for seven distinct time intervals *T* from the radio beacon data measured during the period of observation.

T = 1, 5, 10, 15, 20, 30 and 60 minutes (5)

The time steps were selected to examine the effects of length of measurement interval on the statistics of scintillation intensity.

## III. RESULTS AND DISCUSSION

### A. Scintillation Amplitude Distribution

A 1-minute sample of signal amplitude being made of positive (enhancements) and negative (fades) values are shown in figure 1, with maximum enhancement of 0.54 dB and maximum fade of 0.76 dB. Knowledge of both fades and enhancement are significant for fade margin determination on any satellite link and this can be quantified through the peak-to-peak excursion ($\chi_{pp}$).

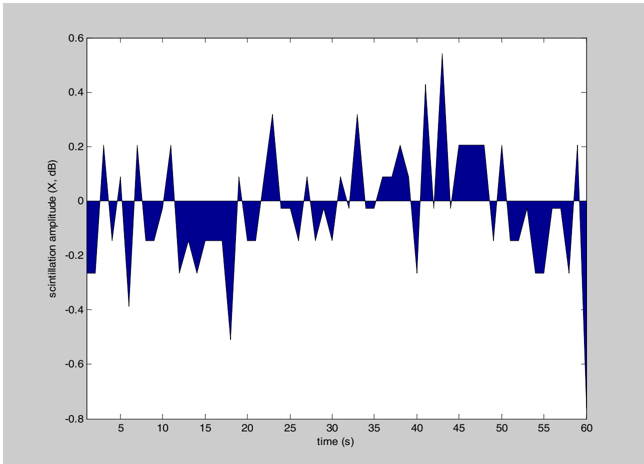


Fig. 1. Wave plot of scintillation amplitude showing enhancements and fades

There exist strong linear correlation between the peak-to-peak amplitude and scintillation intensity. The coefficient of determination $R^2$ increased inversely as the integration time (Table II).

TABLE II CORRELATION OF PEAK-TO-PEAK EXCURSION WITH SCINTILLATION INTENSITY

| **Integration time** | **1 min** | **5 min** | **10 min** | **15 min** | **20 min** | **30 min** | **60 min** |
|---|---|---|---|---|---|---|---|
| **$R^2$ value** | 0.89 | 0.86 | 0.84 | 0.83 | 0.81 | 0.80 | 0.78 |

The distribution of peak-to-peak excursion of scintillation amplitude for a typical month (January) is shown in figure 2. Modal occurrence for 1-minute measurement interval are between 1.5 and 1.7 dB bin and between 0.2 and 0.5 dB bin for both 5-minute and 60-minute intervals. Further inspection showed that $\chi_{pp}$ values as high as 4.8 dB and 4.5 dB were recorded in the 60-minute and 5-minute windows, they were however very sparse. This confirms that strong scintillation are often short-lived.

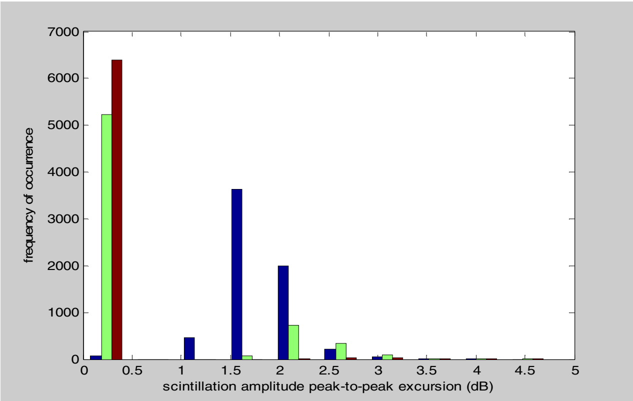


Fig. 2. Distribution of scintillation amplitude peak-to-peak excursion

*B. Scintillation Intensity Distribution*

The description of the relative distribution of a random variable such as scintillation intensity (σ) can be described through its probability density function (pdf) [1]. The pdf of scintillation intensity for two of the time windows were plotted, and their distribution compared with normal, lognormal and gamma distributions. The results are presented in figures 3A and 3B. The intensity fit very well with the normal distribution at weak intensity ($\sigma < 0.3$ dB) as well as around $\sigma = 0.6$ dB. Although not perfectly fitted at the peak, the trend still agrees with other distributions.

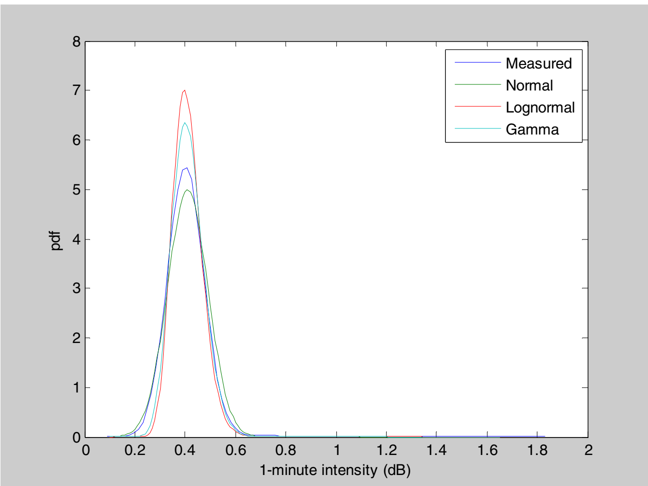


Figure 3A

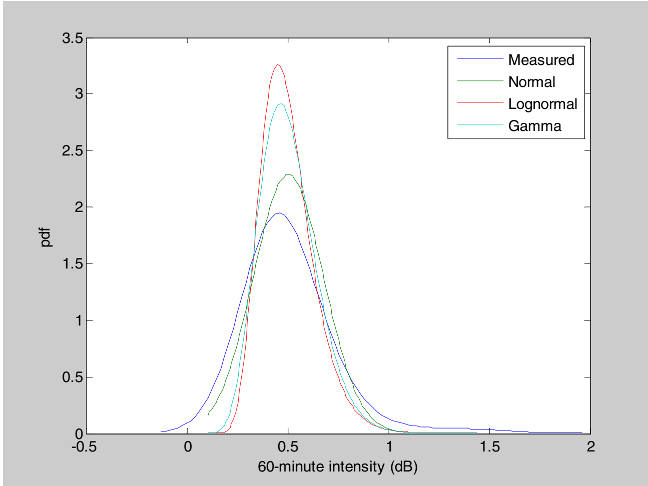


Figure 3B

Fig.3. Probability density function of (A) 1-minute; (B) 5-minute; and (C) 60-minute scintillation intensity.

For 60-minute intensity distribution, there was a fairly good fit with the three distribution functions around $\sigma = 0.6$ dB. The distribution at the low and high density regions, elsewhere the performance shows very poor fit. This signifies that short-time interval scintillation fit well with normal, lognormal and gamma functions whereas, the same thing cannot be said of long-time interval scintillation intensities.

Since scintillation phenomenon are not deterministic, its results are best presented in form of cumulative distribution on annual basis. Figures 4A and 4B show the cumulative distribution of the 1-minute and 60-minute intensity for the duration of the study. It further established that strong scintillations ($\sigma > 0.5$ dB) are short duration phenomena, rarely occurring and highly short-lived – to a few minutes maximum.

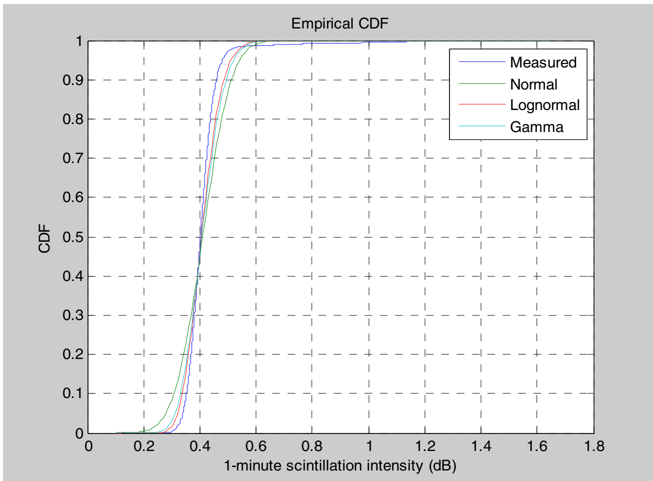


Fig. 4A. cumulative distribution of 1-minute intensity

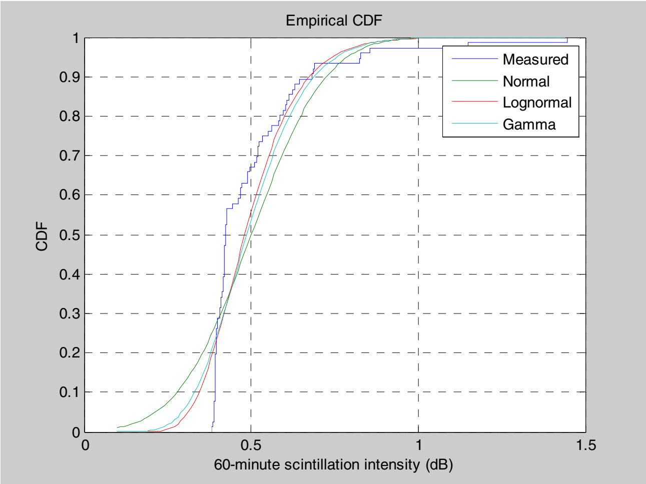


Fig. 4B. Cumulative distribution of 60-minute intensity

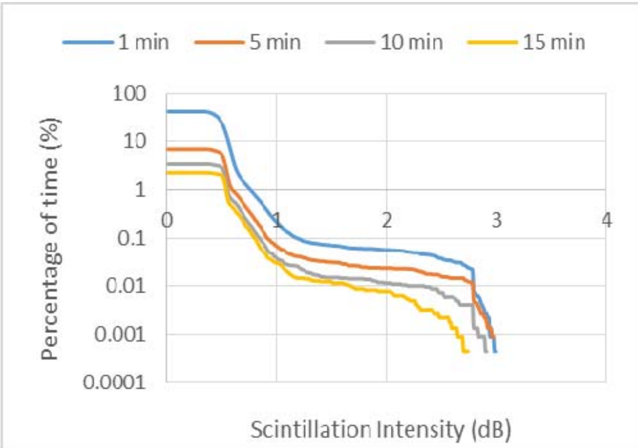


**Fig. 5A:** Scintillation intensity (σ) exceedance probability

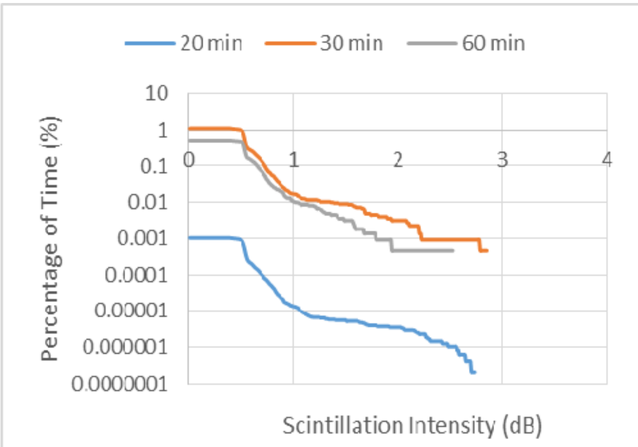


**Fig. 5B**. Scintillation intensity (σ) exceedance probability

Figure 5 (A and B) relates the percentage exceedance probability of scintillation intensity for each of the seven measurement intervals. This further proves the fact that strong scintillations are short lived. ($\sigma > 0.5$ dB) occurred for far less than 1% of the entire measurement window for the longer duration (20, 30 and 60 minutes) as against the shorter duration (1, 5, 10 and 15 minutes).

## IV. Conclusion

Results of satellite radio beacon measurement have been analysed for earth-space path over Akure, SW Nigeria. Distribution of scintillation amplitude peak-to-peak excursion and intensity have been examined. A good agreement has been established between peak-to-peak excursion and scintillation intensity. Short integration time intensity were found to fit well with normal, gamma and lognormal distributions, while 60-minute intensity did not fit so well. Also, strong intensities $\sigma > 0.5$ have been found to be short-lived and occur rarely.

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