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Research Article

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Estimation of Cumulative Distribution of Scintillation Effect on Ku Band Frequencies for One of the Tropical Regions Using Various Models

A.Sree Madhuri*, Govardhani.Immadi and M.Venkata Narayana

Department of ECE, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Guntur, Andhra Pradesh, India – 522502.

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Abstract

Any wireless signal travelling in free space undergoes degradation due to the effects of the atmosphere that are naturally created in its pathway. Amongst all the degradation3 effects scintillation is significant at elevation angles above 5 degrees and also in tropical regions. Scintillation is mainly caused due to the rapid fluctuations in the refractive index of the layers of the atmosphere. Tropospheric scintillation is significant at frequencies above 3GHz. Ionosphere acts as a transparent layer above 10 GHz Tropospheric scintillation is receiving more attention because of the demand for higher bandwidth due to the congestion on the C and Ku bands. The rapid fluctuations induce variations in the received amplitude of the signal which decreases the quality of the signal. For systems with low elevation angle and the link operating with a frequency above 10GHz the effect of tropospheric scintillation is to be taken in to consideration. So, in this paper the effect of tropospheric scintillation is estimated for a Ku band beacon signal whose receiver is installed at K.L. University at a frequency of 11.7GHz. The scintillation amplitude is estimated using the beacon data and also using models that suit the tropical region. By comparing the scintillation amplitudes derived from the models and the with the one derived using beacon data, the best model that fits this geographical location is found which is the Otung model.

Keywords: Scintillation, Troposphere scintillation, elevation angle, amplitude.

1. Introduction

Communication system plays a major role present day human life [1]. Every communication system like satellite, radar communication systems etc should be designed with at most care considering all the effects that disturb the system. Scintillation is one of the adverse effects caused in the signals propagating through the atmosphere [21]. Scintillation can be described as fast fluctuation in amplitude and phase of the millimeter-wave satellite signal[25]. It is caused due to turbulence in the atmosphere [2]. It is most significant in the frequencies above 4GHz (Ku-band). The effect due to scintillation in the frequency ranges less than 4GHz is very little [20]. The degradation of the signal increases with increase in frequencies [18]. It also depends on physical and meteorological parameters such as temperature, humidity, elevation angle, location and refractive index variations of propagation media. [24] So, calculation of scintillation is an important factor to be estimated before designing any efficient communication system [3]. In this paper, we are concentrating on scintillation caused in the troposphere layer.

For low margin systems operating at both higher frequencies as well as low elevation angle, signal attenuation caused by scintillation is observed to be much dominant when compared to rain attenuation [4]. To analyze the fade depth and enhancement of the signal, we must find both short term and long-term scintillation patterns throughout the year [6].

These are to be calculated from the raw beacon data obtained directly from the spectrum analyzer via the low noise block (LNB). Scintillation occurs both under the clear sky and rainy day [5].

2. Prediction Models

There are four scintillation models through which we can evaluate the statistical distribution of scintillation which are based on both theoretical and experimental results [8]. The essential parameters required for calculation of enhancement and fade depth are frequency, elevation angle and diameter of the antenna [19]. In addition, the parameters like standard deviation of the signal amplitude, antenna averaging factor, humidity, surface temperature, water content present in the clouds and reliable scintillation data [7]. They are:

1. Karasawa Model
2. ITU-R Model
3. VanDeKamp Model
4. Otung Model

Table 1. Satellite Specifications

Specification	Value
Beacon Frequency	11.7GHz
Elevation Angle	65.6^o
Antenna Diameter	0.9 m
Polarization	Vertical
Antenna Configuration	Offset Parabolic

*E-mail address: asreemadhuri@gmail.com
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Satellite Position	83^{o}E

2.1. Karasawa Model
This model developed a general technique for predicting Tropospheric scintillation statistics for elevation angles above 4 degrees based on monthly statistics of measured data [9]. It took several averages of meteorological parameters into account [22]. This prediction model represents the long-term scintillation variance as related to the ground refractivity wet term (N_{wet}). Let p denote the percentage of time for which the fade exceeds the certain depth [11].

The formula for scintillation fade at elevation angle (θ) is given (in dB) by [10]

$$A_s(p) = A(p).m$$

where,

$$A(p) = -0.061(\log_{10}p)^3 + 0.072(\log_{10}p)^2 + 1.71(\log_{10} p) + 3 \quad (1)$$

p= percentage of time which varies as 0.01%<p<50.0%.

The formula for enhancement at elevation angle (θ) is given (in dB) by [16]

$$E_s(p) = E(p).m$$

where

$$E(p) = -0.0597(\log_{10}p)^3 - 0.083(\log_{10}p)^2 - 1.26(\log_{10}p) + 2.67 \quad (2)$$

p= percentage of time which varies as 0.01%<p<50.0%.

2.2. ITU-R Model
The ITU-R Model P.618-11 is best suited for predictions in the elevation angle from 4^o-32^o working at the frequency range of (7-14) GHz and antenna diameter ranges from 3 to 36metres [12]. This model is based on the estimation of averages scintillation intensity over a period of one month and relative humidity [23]. The long-term scintillation variance is expressed as N_{wet} as a function of relative humidity (H) and surface temperature (t)[13].

The attenuation fade for given percentage of time is

$$A(p) = -0.061(\log_{10}p)^3 + 0.072(\log_{10}p)^2 - 1.71(\log_{10}p) + 3 \quad (3)$$

p= percentage of time which varies as 0.01%<p<50.0%.

2.3. Van De Kamp Model
It is an enhanced model that extends the Karasawa model to include both the surface layer and cloud scintillation [14].

The enhancement is given by

$$E(p) = a1(p)\sigma_{pre} - a2(p)\sigma_{pre}{}^2 \quad (4)$$

and the fade is given by

$$A(p) = a1(p)\sigma_{pre} + a2(p)\sigma_{pre}{}^2 \quad (5)$$

Where

$a1(p), a2(p)$ are time percentage factors which are expressed as

$$a_1(p) = -0.0515(\log_{10}p)^3 + 0.206(\log_{10}p)^2 - 1.81(\log_{10}p) + 2.81 \quad (6)$$

$\mathrm{p} =$ percentage of time which varies as 0.01% $<$ p 50.0%.

$$a_2(p) = -0.172(log_{10}p)^2 - 0.454(log_{10}p) + 0.274 \quad (7)$$

p= percentage of time which varies as 0.01%<p<50.0%.

2.4. Otung Model
This is similar to ITU-R model, and the major difference lies in the value of σ_{pre}. The fade depth and enhancement is given by [15]

$$E(p) = 3.1782 * \sigma_{pre} * \exp[-0.359 * p - (0.272 - 0.0043 * p) * \log_e p] \quad (8)$$

p= percentage of time which varies as 0.01%<p<50.0%.

$$A(p) = 3.6192 * \sigma_{pre} * \exp[\tfrac{-9.50142*10^{-4}}{p} - (0.40454 + 0.00285p) * \log_e p] \quad (9)$$

p= percentage of time which varies as 0.01%<p<50.0%.

3. Data Analysis and Methodology

3.1. Experimental Setup
The experimental setup consists of an offset parabolic antenna with a diameter of 0.9m at an elevation angle of 65.6^o with an operating frequency of 11.7GHz at K L University with a latitude and longitude of 16.44 and 80.621 respectively. The receiving antenna is aligned in the direction of the INSAT-4A satellite (83^oE). Next the signal reaches the spectrum analyzer in which the raw data is being observed by performing down conversion and recorded in the computer. The data is recorded for every 10 seconds and stored in the form of excel sheets with parameters time, frequency and the corresponding amplitude.

3.2. Extraction of Scintillation Amplitude Vectors
The procedure for extracting scintillation amplitude vectors is as follows: The scintillation amplitude was computed for data samples are collected at a sampling rate of 0.1Hz. [17] The whole data was inspected in MATLAB for identifying the spurious samples. Spurious samples occur in generally due to transitions in the recording the setup which leads to the recording of false samples whose amplitude is very much deviated from those of the normal samples. So, these spurious samples are to be removed from the recorded file to make the extraction process smooth and accurate. One should be careful while working with spurious samples such that the original data will not be affected.

The spurious samples in the figure 1 were removed by taking the sample amplitude as the average of the preceding and succeeding sample. After the removal of spurious samples, data is once again verified for presence of any invalid data to proceed further.

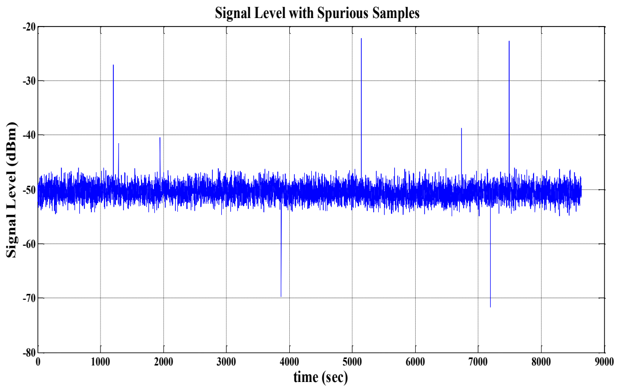

Fig. 1. Signal Level with Spurious Samples.

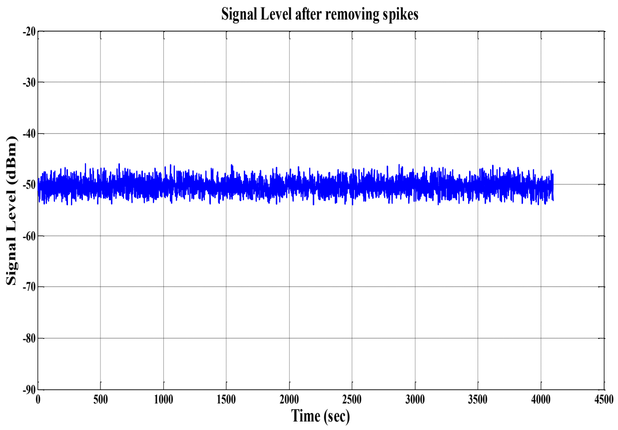

Fig. 2. Signal Level after Removing Spurious Samples

The figure 2 shows the sample data after removing the spurious samples. In order to proceed, the raw data is to be split from quantization levels to a relative signal level using fifth order calibration polynomial. The data consisting of 4096 samples was split into seven half overlapping blocks of 1024 samples and then the mean was removed from each block. Then, the psd (dB^2/Hz) was computed for each block of data and then the intermediate result was multiplied with a hanning window and finally the periodograms of the modified segments are averaged. The PSD was passed through a third order median filter for smoothing. Next, the smoothed data was passed through the 6^{th} order Butterworth filter to observe a flat frequency response so that no ripples are present. Finally, the goodness of fit test was performed on the resultant data and found that it followed a Gaussian distribution and the first 1minute data was removed to eliminate the filter startup effects.

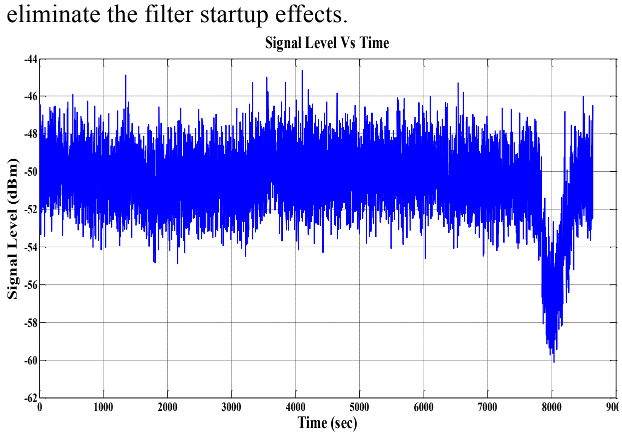

Fig. 3. Beacon signal level w.r.t Time

4. Results and Discussions

The figure 3 indicates the beacon signal level varying with respect to time, consisting of two events namely the

1. The Non-Rainy Event.
2. Rainy Event.

1. The Non-Rainy Event: - The event started from 1:00:10 hours in the early hours of the day and extended till 9:51:10 in the night. The average signal level in this event is around -51.25dBm. The maximum and minimum amplitude observed in this particular were -44.64dBm and -54.88dBm.

2. Rainy Event: -The rainy event started around 9:51:20 in the night. Due to the effect of rain the signal deteriorated and the least amplitude observed was -60.11dBm. And after 10:58:20 the rain rate began to decrease, and signal level started to restore.

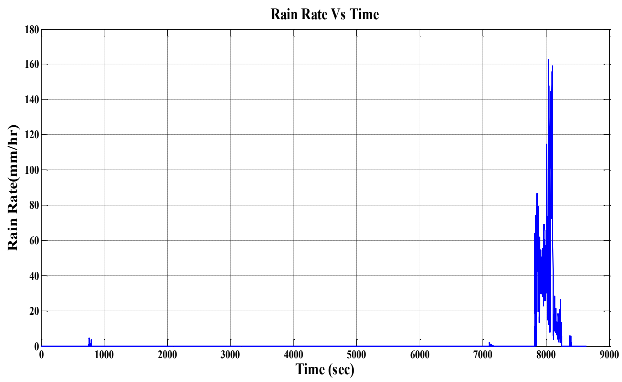

Fig. 4. Rain Rate variation w.r.t Time

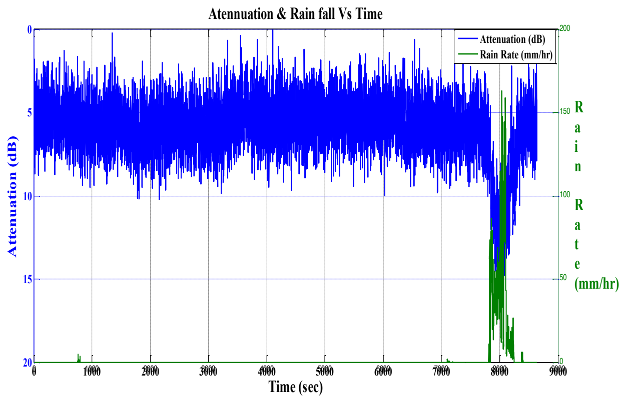

Fig. 5. Rain rate and Attenuation w.r.t Time

The figure 4 indicates the variation of rain rate with respect to time for a single day. It can be observed the rain rate during the day time was almost zero except two small instances and the major rain event occurred at 9:51:20 in the night and rain event took place for almost 1:07:10.The maximum rain rate observed in this period was 162.86(mm/hr).

The figure 5 shows the variation of rain rate and attenuation with respect to time. The blue color indicates the variation of attenuation and the green indicates the variation of rain rate. It can be observed that attenuation is found to be maximum at the point where the rain rate is maximum that is at a rain rate of 162.86 (mm/hr) the maximum attenuation was 16. 2dB.Due to the effect of rain the signal strength decreases which results in attenuation.

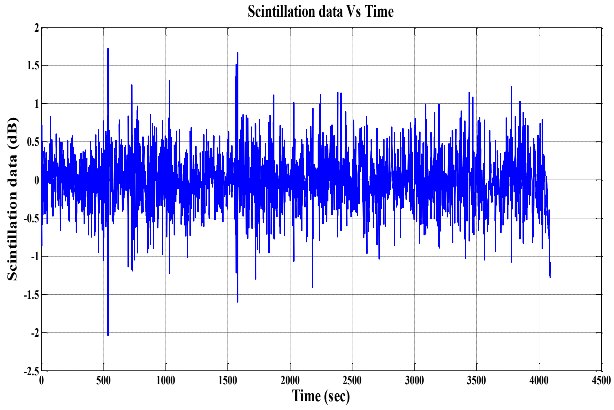

Fig 6. Scintillation Amplitude w.r.t Time

The figure 6 represents the variation of extracted scintillation amplitudes with respect to time. The maximum scintillation amplitude observed was 2. 05dB.The numerous variations observed in the graph is due to variation in the temperature which results in rapid changes in refractive indices of the troposphere.

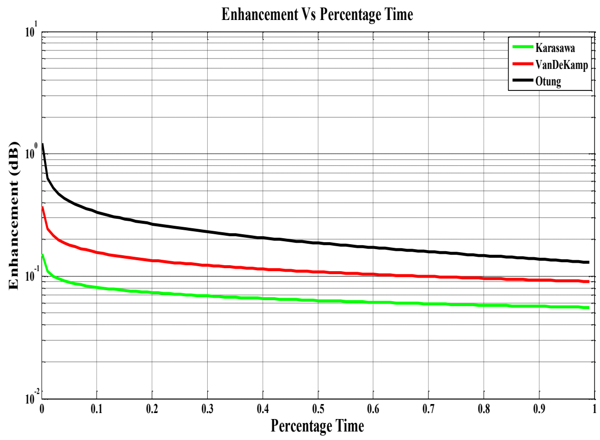

Fig. 7. Enhancement amplitude Vs Percentage time.

Here figure 7 indicates the scintillation enhancement in dB for different values of percentage time like 0.001, 0.01, 0.1, 0.2 etc. The scintillation enhancement was plotted for different models like Karasawa, Van De Kamp, and Otung using predefined procedures. Enhancement is the deviation of the signal level from the mean level along the positive side. Otung model has highest enhancement amplitude among all the models compared to the Karasawa and Van De Kamp models.

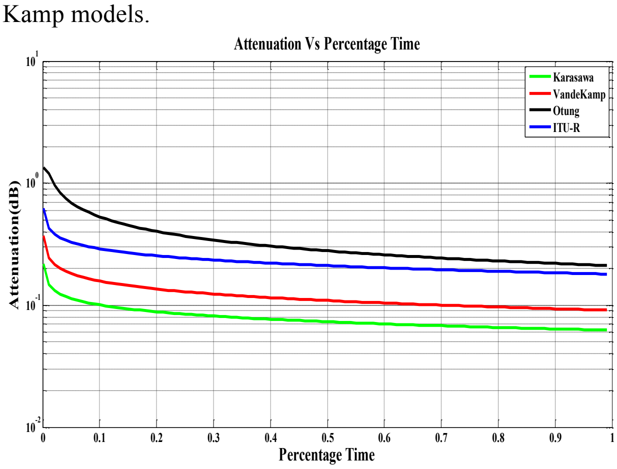

Fig. 8. AttenuationVsPercentage Time

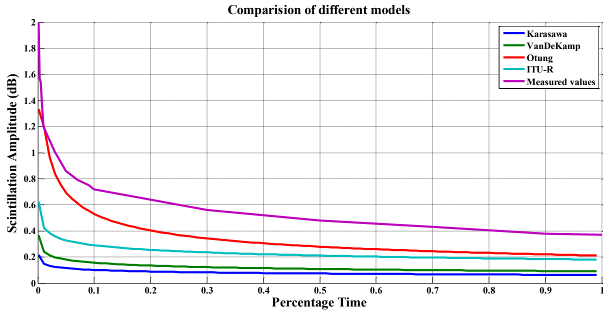

Fig. 9. Comparison of different models with measured scintillation.

The figure 8 represents the scintillation attenuation (fade depth) in dB for different values of percentage time like 0.001, 0.01, 0.1, 0.2 etc. The fade depth was plotted for different models like Karasawa, Van De Kamp, Otung, and ITU-R using predefined procedures. The Otung model predicted the fade to be 1.33dB approximately 1.33dB for 0.001 percentage of time. The ITU-R model predicted the scintillation at 0.001 percentage of time was 0.624dB, Van De Kamp prediction was around 0.366 dB and that of Karasawa was 0.216 dB.

The comparison between measured scintillation and the scintillation prediction models like Karasawa, Van De Kamp, Otung and ITU-R is shown in figure 9 . The measured scintillation was found to be 2dB for 0.001 percentage of time. The Otung model was found to predict the scintillation amplitude close to the measured scintillation. The scintillation amplitudes estimated using different models represented in table 2 is given as

Table 2. Estimated Scintillation Amplitude

S. No	Model	Estimated Scintillation amplitude
1.	ITU-R	0.624dB
2.	Karasawa	0.216dB
3.	Van De Kamp	0.366dB
4.	Otung	1.33dB

5. Conclusion

Tropospheric scintillation is dominant in tropical regions where the elevation angle above 5 degrees. The signal degradation is observed to be dominant in this geographical location as the elevation angle was above 65.6 degrees. The maximum scintillation amplitude for the received beacon signal was found to be 2.05dB. The scintillation amplitude is also obtained from different models where in which the Otung model was proved to give accurate estimation of the scintillation amplitude which is around 1. 33dB.Finally, it is concluded that Otung model best suits this geographical location for estimating the scintillation amplitude.

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