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COMPUTATION OF EFFECTS OF TROPOSPHERE ON KU BAND DOWN LINK SIGNAL IN TROPICAL REGIONS

GOVARDHANI.IMMADI[1], M.VENKATA NARAYANA[1] SARAT K KOTAMRAJU[1], K.CH.SRI KAVYA[1], S.V.N.S. MANEESHA[2], K.RAVALI[2], CH.SRAVANI[2]

[1] Dept. of ECE, K L University, Vaddeswaram, Guntur, Andhra Pradesh, India

[2] U G Students, Dept. of ECE, K L University, Vaddeswaram, Guntur, Andhra Pradesh, India

E-mail: govardhanee_ec@kluniversity.in

ABSTRACT

The electromagnetic signal from the satellite while travelling down to the earth should pass through various layers of the atmosphere like troposphere, stratosphere, ionosphere etc. These layers won't act as a transparent layer but instead they provide some obstacles in the path of the signal travel and changes the characteristics of the signal. With the advancements in technology the users are not at all compromising in using the applications like data applications, web applications, simultaneous audio video transfers, etc. which results in excess usage of the conventional frequency bands. So, the modern applications are likely to be designed at higher frequency spectrum i.e. Ku, Ka & V bands. The influence of the layers mainly depends upon the frequency of the signal. As we are dealing with the frequencies above 10 GHz the ionosphere acts as a transparent layer but the troposphere influence the signal characteristics. In this paper, we are going to analyze and compute the tropospheric impairments like attenuation due to rain and tropospheric scintillations for the geographical area of K L University, Vaddeswaram located at 16.44^{o}E latitude and 80.62^{o}N longitude.

Keywords: *Frequency Congestion, Impairments, Tropospheric Scintillations, Rain Attenuation, Beacon Signal*

1. INTRODUCTION

With the growing population, the need for communication has increased rapidly and many systems are designed to establish the communication effectively. Among the developments in satellite communication, one can highlight the appreciation of VSAT/USAT (very/ultra small aperture terminals) systems designed mainly for data applications, like the DTH(Direct-to- home) services provided by DBS (Direct Broadcast Satellite) and extending the scope of satellite communications to NGSO (Non Geostationary Orbit) constellations. Fixed satellite services (FSS), conventional geostationary satellite (GSO) systems including all the above systems, steadily tend to work in higher frequency bands to fulfil the growing capacity essentials. [1]

But as we go to higher frequencies the signal fading rapidly increases and the quality of the signal rapidly decreases. Because the fading of the signal depends on the operating frequency and the geographical conditions of the receiver. There are many types of impairments influence the signal during its travel from space to down earth. In this paper, we are going to discuss some of the signal degradation effects.

While designing a communication system many factors are to be considered for proper functioning of the system. The radio wave signal while propagating through space must propagate through the layers of the atmosphere troposphere, stratosphere, ionosphere etc. These layers show their impact on the propagating signal and cause signal degradation. But the extent and type of degradation depends mainly on the frequency of the signal.

1.1 Reasons for signal degradation

The propagation effects are mainly categorized into two types. They are the ionospheric effects and tropospheric effects. The influence of the effects are mainly concentrated with the operating frequency of the system. The tropospheric effects come into the picture when the frequency is below 3 GHz and if the

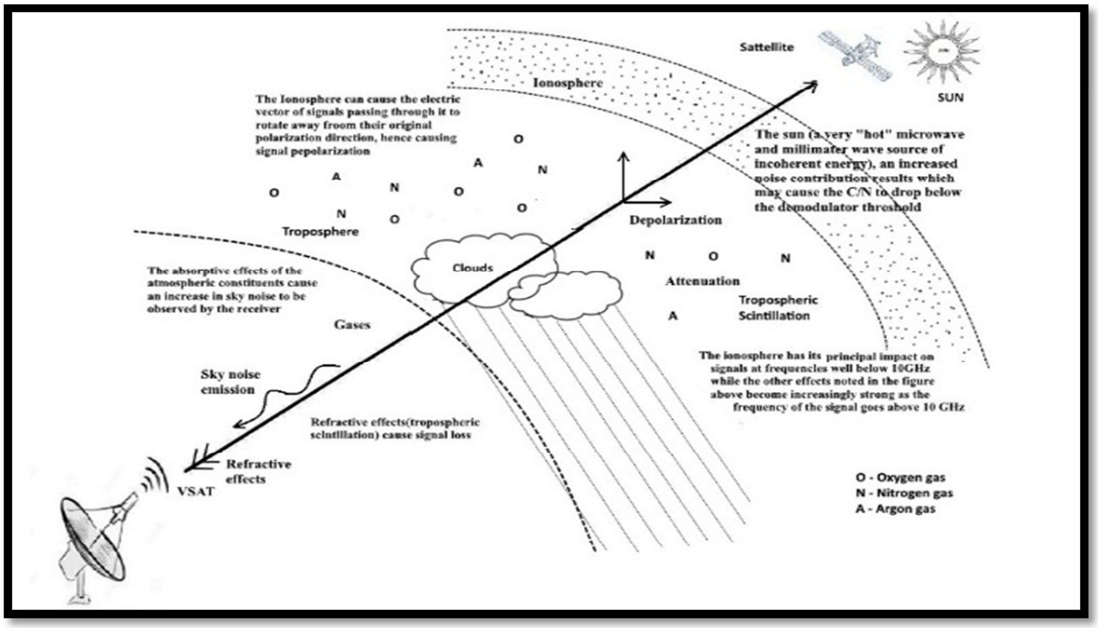

***Figure-1**. Showing the influence of various atmospheric layers on propagating signal*

frequency is above 3 GHz ionospheric effects influence the system. The troposphere is extended from a height of 11 km to 20 km and the ionosphere starts at a height of 50 km and extends up to 1000 km.

Since in this study we are dealing with the frequencies Ku band and above the impairments are mainly due to the tropospheric effects. The types of impairments effecting the signal can be categorized as follows [2]:

- attenuation due to precipitation
- tropospheric scintillations
- gaseous absorption
- cloud attenuation
- melting layer attenuation
- sky noise increase

Even though the higher frequency spectrum i.e. Ku band and above provides larger bandwidth the extent of fade also increases [4]. Out of all these impairments the attenuation due to rain plays a very vital role in the signal degradation by absorbing and scattering the electromagnetic waves. It reduces the reliability of the system. The extent of degradation depends mostly on the frequency and the geographical conditions of the place. [3]

2. EXPERIMENTAL SETUP

In order to carry out the project a beacon receiver was installed at K L University, Vaddeswaram (latitude 16.44^{o}E and longitude of80.62^{o}N) with elevation angle of 65.25^{o} and Offset angle of 25^{o} with the size 90cm.The operating frequency of this beacon receiver was 11.6285 GHz. The received beacon signal is down converted with the cut-off frequencies as 9.75 GHz and 10.5 GHz. Beacon samples were stored with a sampling interval of one sample per second.

Rain is the major source for attenuating the signal, it was recorded by using OTT Parsival disdrometer placed on roof of the C Block K L University, Vaddeswaram. In this project, we use rain intensity to calculate the attenuation of the received beacon signal.

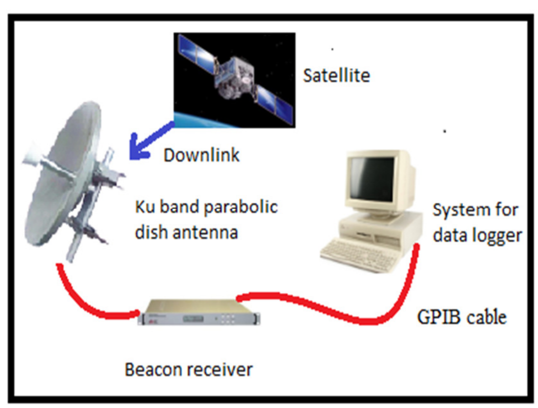

***Figure 2.** Schema of the beacon setup*

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3. ATTENUATION DUE TO PRECIPITATION

Radio waves when propagate through rain, snow, hail, or droplets suffer from power loss due to the scattering of hydrometeor. This hydrometer scattering is the conspicuous limiting factor in EHF (Extremely High Frequency) band. Another major factor which effects the power loss in lower spectral part between 10GHz and 30GHz is hydrometeor absorption. The consequence of both hydrometeor scattering and hydrometer absorption results in power loss. This is the main drawback of operating at Ku, Ka or V bands. [1] [2]

According to satellite systems, the depth of rain fades depends on elevation angle and polarization angle. As rain attenuation depends on rainfall rate and distribution of the rain drop size, it mainly effects subtropical and tropical regions. The fade due to rain is one of the major limiting factors of the satellite communication because at the higher frequencies the size of the rain drop is comparable to the wavelength. The rain attenuation depends on intensity of the rain, size of the rain drops and slant path length of the rain [9] [10].

Rain attenuation can degrade the system performance and edge the usage of higher frequency ranges for terrestrial Line of sight communication system. As mentioned earlier, the attenuation via signal path because of rain plays a key role at frequencies more than 10 GHz, considering of these factors, it's obvious that the attenuation because of rain is needed. [11]

Attenuation due to precipitation on the line of sight and interference between two systems operational at an equivalent frequency and on the far side every other's radio horizon because of rain scatter. The strategies for scheming the magnitude of the results of rain given the special distribution of intensity area unit out there. The applied math knowledge needed for the prediction of the special distribution of precipitation intensity are not available. [12]

3.1 SAM Model

SAM is nothing but the simple model for the calculation attenuation in the presence of the rain. This SAM model makes use of rate of the rainfall which is used in measuring the attenuation. The improvements for SAM has been made and it incorporates the consequence of the wave polarization. This model is helpful for indication of attenuation due to rain at earth-satellite links which are operating at Ku and Ka bands. By using the average rainfall rate, some calculations have been made to know the attenuation values. Using these values, we can predict attenuation due to rain in specific regions.

State University Blacksburg and Virginia institute has sacrificed many years for the advancement in models of the attenuation and their measurement details. A model names as Piecewise Model is enhanced and developed with new features and it is named as SAM. This SAM possesses the features of both types of rainfalls named as stratiform and convective. In order to calculate the attenuation following are used.

$$A = Al * L \tag{1}$$

$$L = (He - Ho) \div \sin(\theta) \tag{2}$$

$$a=4.21*10^{-5}*f^{2.42} \tag{3}$$

$$b=1.41*f^{-0.0779} \tag{4}$$

Where,

Hc	:	Height of the rain
Ho	:	Isothermal height at sea level
L	:	Length of the Slant path
Θ	:	Angle of the elevation
Al	:	Specific attenuation
a,b	:	constants

This SAM model is Semi empirical which determines the spatial rainfall across the path of length L. This model has been enhanced a lot compared with the previous version and it considers the wave polarization. This Model is helpful for describing the rain attenuation at Ku and Ka frequency bands. Hence the SAM model is taken into consideration to estimate the rain attenuation at our University.

3.2 Methodology

The beacon signal which is recorded using the data logger is taken to calculate the attenuation due to rain. The rain intensity which is measured using disdrometer and the data is recorded in the data logger. The period for which the rainfall exists is to be separated from the complete data. The beacon strength in the clear air conditions is noted. The attenuation at a particular rain instant is taken as the absolute difference between the actual received signal strength and the strength of the signal at the clear air conditions.

Here is a table showing the calculations of beacon attenuation at every rain instant on October 2nd 2016. This table gives us a clear picture of the

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beacon strength available at that instant and signal attenuation at that particular instant.

Table 1: Showing the attenuation computations on October 2nd 2016

Sample Number	Time (seconds)	Rain Intensity (mm/h)	Signal Strength (dB)	Attenuation (dB)
1	10	0.28	-92.7273	0.1637
2	20	0.15	-92.6	0.0364
3	30	0.1	-92.5818	0.0182
4	40	0.11	-92.4364	0.1272
5	50	0	-92.3091	0.2545
6	60	0	-93.6545	1.0909
7	70	0.21	-93.1636	0.6
8	80	0.74	-93.3818	0.8182
9	90	1.38	-94.3061	1.7425
10	100	0.47	-94.3673	1.8037
11	110	0.24	-95.4286	2.865
12	120	0.7	-95.6939	3.1303
13	130	1.26	-96.24	3.6764
14	140	1.13	-95.9388	3.3752
15	150	1.33	-97.1731	4.6095
16	160	0	-93.4182	0.8546
17	170	0	-93.0545	0.4909
18	180	0	-94.9388	2.3752
19	190	0.19	-95.6939	3.1303
20	200	0.22	-94.9388	2.3752
21	210	0.57	-93.4182	0.8546
22	220	0.37	-93.5273	0.9637
23	230	0.37	-92.4909	0.0727
24	240	0.27	-92	0.5636
25	250	0	-92.2545	0.3091
26	260	0.11	-91.75	0.8136
27	270	0.2	-91.8833	0.6803
28	280	0.18	-91.3833	1.1803
29	290	0.1	-91.3167	1.2469
30	300	0	-91.6667	0.8969
31	310	0	-91.6333	0.9303
32	320	0.12	-91.65	0.9136
33	330	0.13	-91.4333	1.1303
34	340	0	-91.6	0.9636

Same type of analysis is performed for some days by considering the time period for which the rain existed. The clear air condition value is taken from the day which doesn't have any rain fall. These results are stored in excel for the future analysis.

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The results are plotted against rain intensity (mm/hour) and signal strength (dB) for given time (seconds) and against rain intensity (mm/hour) and Attenuation (dB) for given time (seconds) using MATLAB software. The obtained results for some days are shown below:

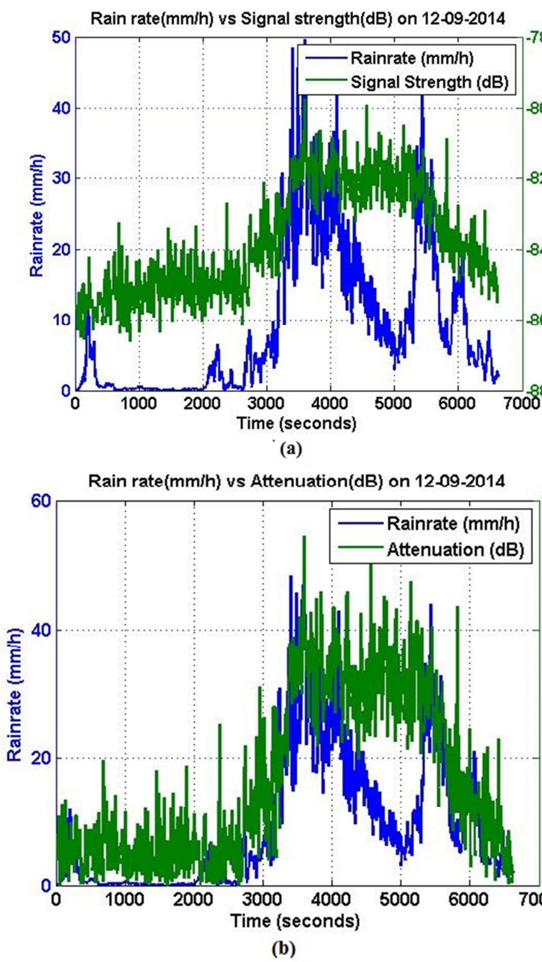


Figure 3. Plot of (a) Rain rate vs. Signal strength (b) Rain rate vs. Attenuation on 12-Sept-2014

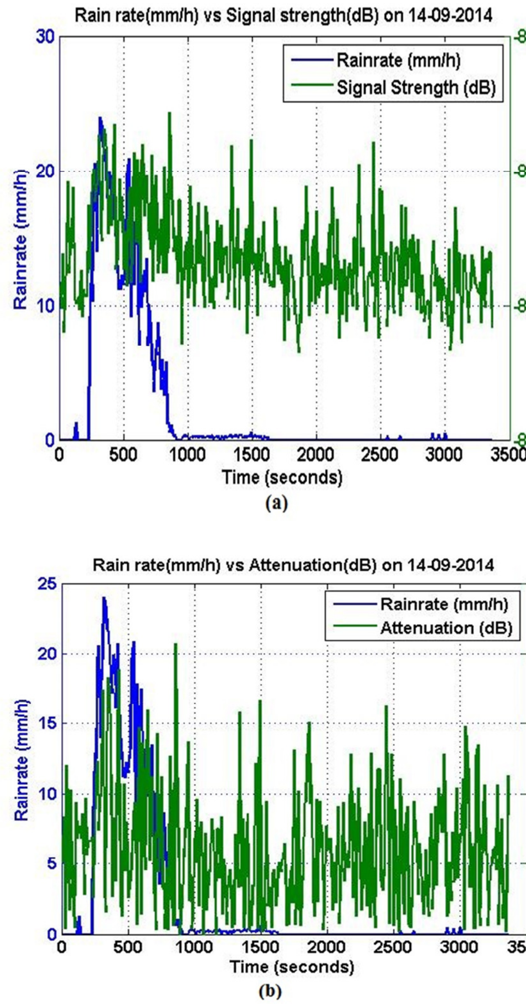
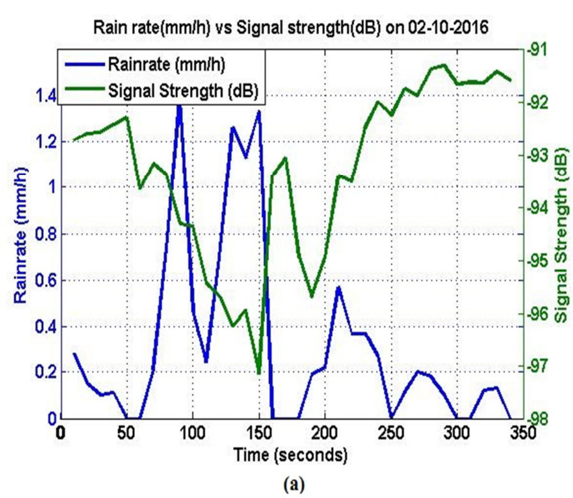


Figure 4. Plot of (a) Rain rate vs. Signal strength (b) Rain rate vs. Attenuation on 14-Sept-2014



Journal of Theoretical and Applied Information Technology
15th May 2017. Vol.95. No 9

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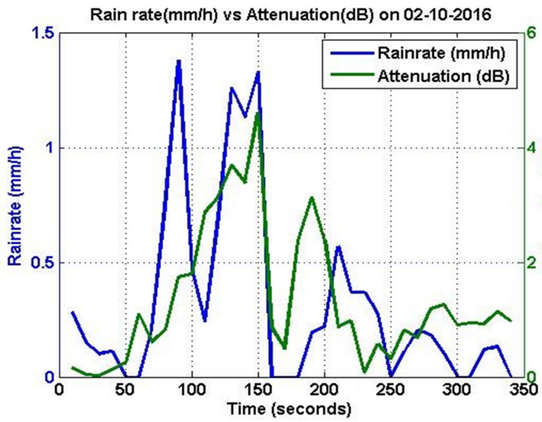

(b)

Figure 5. Plot of (a) Rain rate vs. Signal strength (b) Rain rate vs. Attenuation on 02-Oct-2016

From the plots of Rain rate vs. Signal Strength it is obvious that the signal strength decreases with the increase in the rainfall and vice versa i.e. it indicates that the signal strength is inversely proportional to the intensity of the rainfall. From the plots of Rain rate vs. Attenuation the attenuation varied in direct proportion with the rain intensity because as the rain intensity increases the losses in the tropospheric layer increases due to the presence of clouds, rain, fog etc. because the energy of the electromagnetic signal is absorbed by the obstructions present in the tropospheric layer.

We had also taken the MMR data recorded at K L University to compare the rain attenuation obtained using beacon and disdrometer. The plots of rain rate drawn time vs. height for the date 14 – 09 – 2016 and 30 – 09 – 2016 are given below

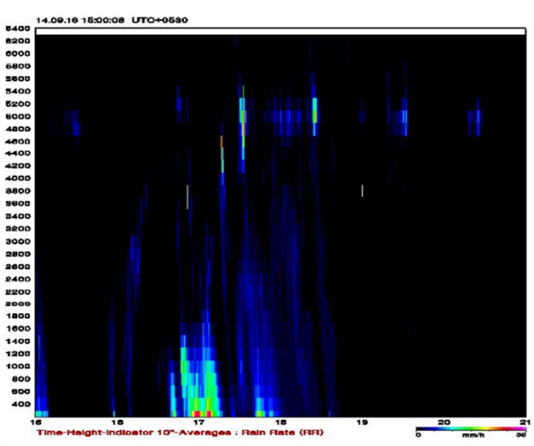

Figure: 6(a)

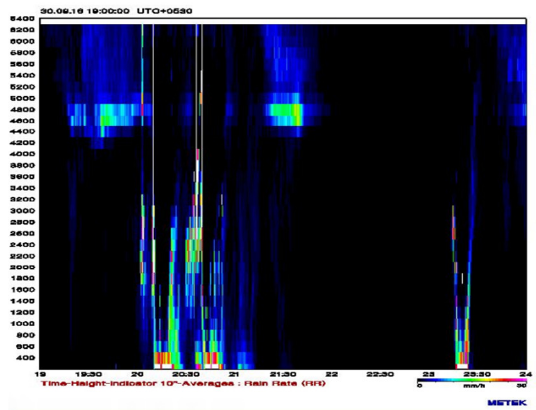

Figure: 6(b)

Figure 6. Plots showing the rain rates on 14 – 09-2016 and 30 – 09 – 2016

The path integration attenuation which is the total attenuation obtained during the uplink and the downlink process is also recorded using the MMR device and the average PIA is calculated and the result is plotted against the height. The plot is obtained as shown below.

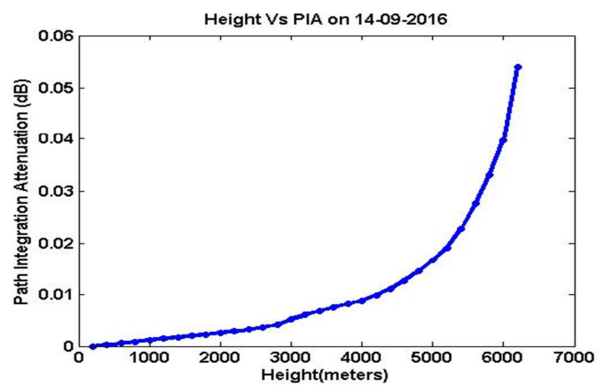

Figure 7. *Showing the average PIA vs. Height (m)*

From the graph it is evident that the Path Integration Attenuation of a day varies in direct proportion with height.

4. TROPOSPHERIC SCINTILLATIONS

Scintillation is one of the most severe effect caused during the radio wave propagation. As we are dealing with the signals of higher frequencies the scintillations of the troposphere are only significant as the ionosphere acts as a transparent layer and will not show any effect on the signal [5]. Thus we can term the scintillations as the unwanted and continuous fading and enhancements in the amplitude and phase of the signal about a mean

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level [6] [7]. The scintillations mainly depends on the temperature, humidity, elevation angle, latitude and longitude. Scintillations occur mainly due to the variation in the refractive index of the medium of propagation. Scintillation doesn't depends on the type of the climate. The variations in the amplitude of the received raw signal occurs both in the rainy and clear sky conditions [6] [7]. The turbulent nature of the atmosphere is mainly responsible for scintillations. [8].

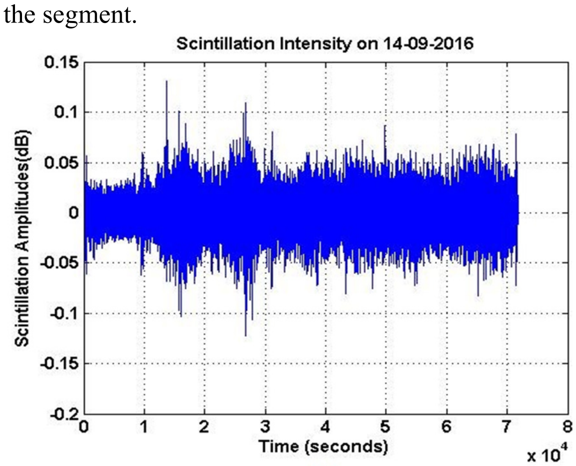
There are many models to calculate the attenuation. Some of the important models are:

- VanDeKamp model
- Kasarawa model
- Otung model
- ITU – R model

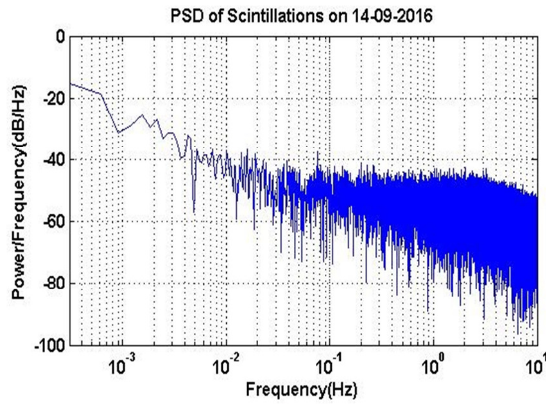
We have opted the ITU- R model for our analysis at our University.

4.1 Calculation of Scintillation Amplitudes

The scintillation amplitudes are calculated using the beacon data recorded using the beacon receiver at K L University, Vaddeswaram. The raw data, which is obtained in the volts scale is converted into dB scale and the calculations are performed. The data obtained is passed through a fifth order calibration filter and after the quantization the output consists of 8192 samples. By splitting a block of 4096 samples into seven half overlapping segments which comprises of 1024 samples the power spectral density is calculated and the calculated mean was subtracted from each of the segment.



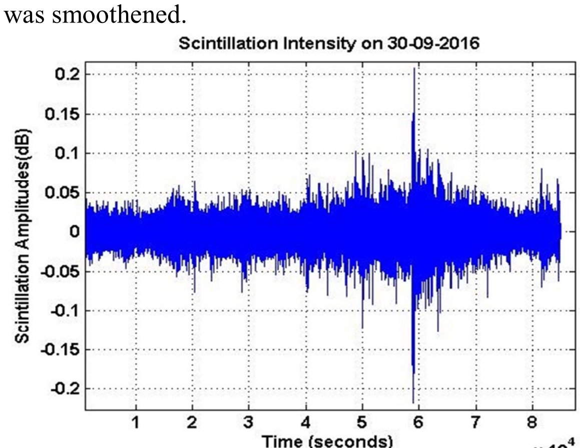
(a)



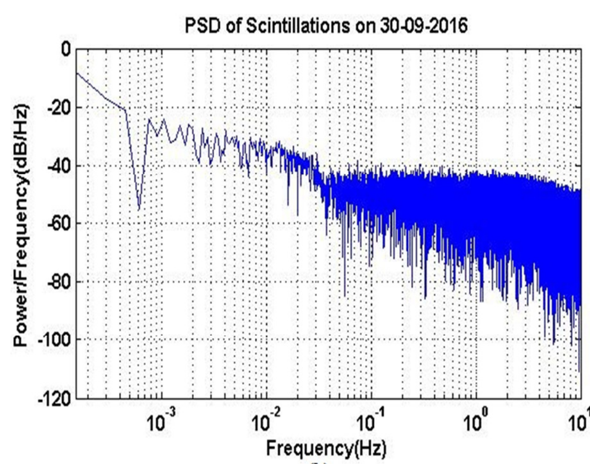
(b)

Figure 8. Showing the (a) Scintillation amplitudes and (b) Power spectrum of the scintillation amplitudes on 14-Sep-2016

Then the resultant is multiplied with a hamming window and the period grams are averaged. Finally using a third order filter the power spectral density was smoothened.



(a)



(b)

Figure 9. Showing the (a) Scintillation amplitudes and (b) Power spectrum of the scintillation amplitudes on 30-Sep-2016

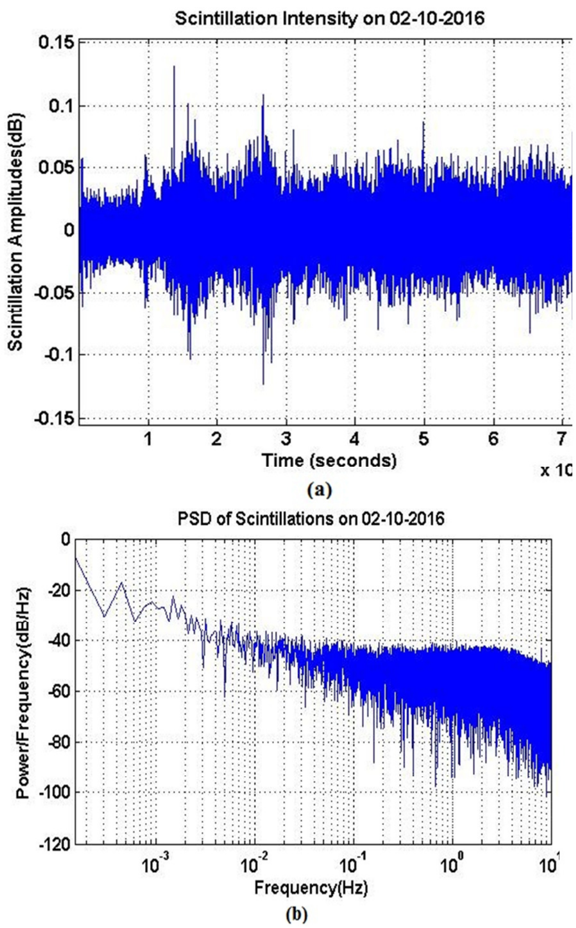


Figure 10. Showing the (a) Scintillation amplitudes and (b) Power spectrum of the scintillation amplitudes on 02-Oct-2016

From the graphs it is obvious that the scintillation amplitudes are varying around 0 dB because the frequency variation of the received signal is zero. The scintillations are observed both in the clear air conditions and during the rainy days. Thus it shows that scintillations doesn't depend on the climatic conditions and exists in any type of climate.

For a particular day the attenuation due to rain is obtained by subtracting the attenuation obtained from beacon at a particular instant and the scintillation at that instant.

The power spectral density of a function gives the distribution of the power at a particular frequency. From the PSD of Scintillations it is evident that most of the power is located at the lower frequencies and as the frequency increases the power became stable.

4. RESULTS AND CONCLUSIONS

From the figure 11 and figure 12 maximum rain rate observed on the day 13-9-14 was 74.141 mm/hour and the signal intensity and attenuation are -81.8 dB and 3.4 dB respectively. Minimum rain rate on 13-9-14 was 0.117 mm/hour and the attenuation was 0.2 dB. The maximum and the minimum rain intensity recorded on 14-9-16 are 0.62 and 0.1 and the signal strength and attenuations at these rain rates are -90.7, 0.3353 dB and -91.283, 0.1833 dB. The maximum and the minimum rain intensity recorded on 30-9-16 are 1.5 and 0.1 and the signal strength and attenuations at these rain rates are -92.1636, 0.78 dB and -92.8, 0.1 dB.

As the attenuation of the signal depends on various factors like rain, cloud, fog, scintillations, cable losses etc., the attenuation obtained from the beacon is the combination of all these parameters. The maximum rain rate observed in our studies is 74.141 mm/hour, the attenuation obtained at that instant is 4.6 dB out of which scintillations contribute 1 dB, cable losses 1 dB and the attenuation due to atmospheric parameters other than rain estimate to 0.6 dB. The major degrading factor, rain, can attenuate the signal, around 2 dB. In order to compensate these losses to some extent we can go for adaptive power control technique at the transmitter end. This can be done using spot beams where we can raise the transmitting signal strength to the areas experiencing heavy signal losses.

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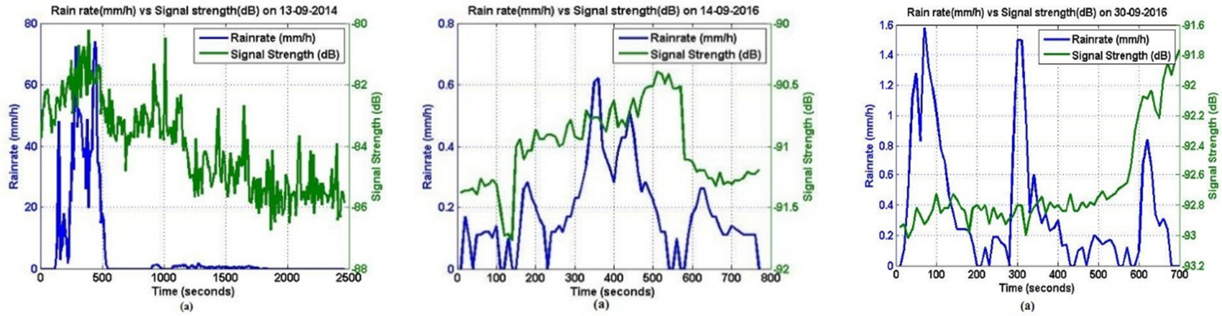
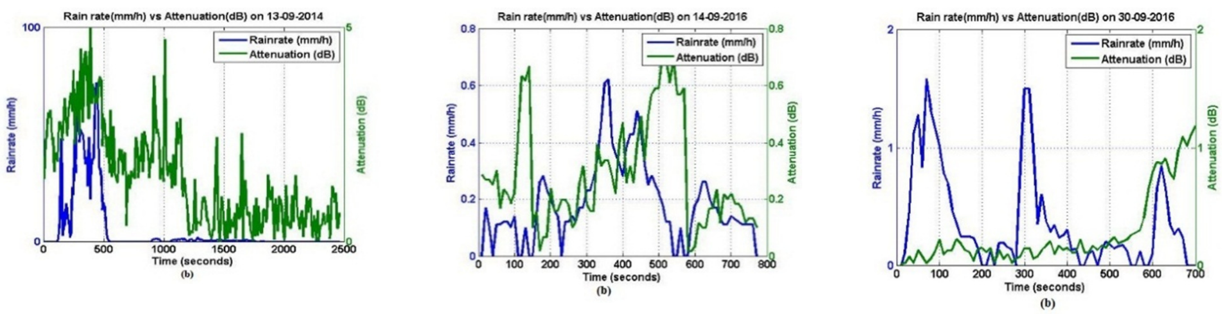


(a) **(b)** **(c)**

Fig 11. Plot showing the Rain rate Vs. Signal Strength on (a)13-9-14, (b) 14-9-16, (c) 30-9-16



(a) **(b)** **(c)**

Figure 12. Plot showing the Rain rate Vs. Attenuation on (a)13-9-14, (b) 14-9-16, (c) 30-9-16