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Research paper

Modification of ITU-R Parameters to Improve the Prediction of Tropospheric Scintillation for Tropical Regions

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Abstract

Scintillation is the rapid fluctuation of the received signal. It is caused by the variation in the refractivity structure of the atmosphere profile. This phenomenon leads to the signal degradation and is significant in low fade margin links and at low elevation angles. So, analyzing the scintillation intensity and its statistics are vital for a system designer to design an efficient system for the satellite communication link. This paper presents the methodology to extract the scintillation intensity from the raw beacon signal and comparison of ITU-R scintillation prediction model with the measured results to test its acceptability over tropical region. When compared with measured results, ITU-R model overestimates the scintillation fade. Hence the parameters of the time percentage factor are modified to obtain near fit to the measured results.

Keywords: *Rain Attenuation, Satellite Communications, Scintillation, Tropical Region.*

1. Introduction

Scintillation is the rapid fluctuations in received signal caused by the irregularities in the troposphere, present in the channel(medium) of the propagation path. In earth space communications, the received signal comprises of the signal attenuation by the clear, cloudy and rainy atmospheres in addition to scintillation[1]. At lower communication frequencies, scintillation has negligible effect on signal degradation. As the communication frequency increases, the effect of scintillation contributes considerable signal degradation, especially in low margin systems. So, analysis of scintillation amplitude is important in designing low margin satellite communication systems at high frequencies[2]. The statistical analysis is carried out by different authors in different regions with different climatic conditions and developed scintillation prediction models by monitoring the recorded signal at their respective regions[3]. The performance of these models is yet to be tested in the south Indian region. So, there is a need to analyze the performance of ITU-R model. In order to extract the scintillation from the beacon signal received, a careful selection of the high pass filter cut-off frequency is to be implemented. Authors have extracted the scintillation amplitude in our region from beacon signal, but have used cut-off frequency, which is previously used in the research papers[4][5]. Weather the cut-off frequency is suitable for our region or not is to be investigated[6]. The cut-off frequencies for our region is calculated using the measured scintillation fades. The statistical analysis of the scintillation amplitude requires the extraction of the scintillation amplitude from the beacon signal, for which a suitable cut-off frequency is to be calculated based on the power spectral density of the beacon signal, which provides the signal strength of different components present in the signal[7]. The statistical analysis of the extracted scintillation amplitude gives the maximum, average and minimum scintillation occurred in a year and at which time the scintillation is higher and lower. Thus the scintillation amplitude is extracted from 1-year data, at KL University. Any modifications in the parameters used in those models also will be changed according to our region, to increase the performance of the model[8]. ITU-R model used to predict the scintillation is tested with the measured signal and the performance analysis of model is presented. The performance analysis of the models shows the efficiency of the model to predict the scintillation amplitude for our region.

2. Data Set

For this study, the experimental setup is installed at K L University, Green Fields, Vaddeswaram located at 16.44^0 N, 80.62^0 E. It comprises of an offset parabolic dish of 90 cms diameter, pointed to GSAT-10 located at 80^0 E with azimuth angle of 171.6^0 and elevation angle of 70.5^0. A low noise block converter converts the received 11.7 GHz Ku-band signal to respective L-band signal. This L-band signal is given to a L-band beacon receiver which converts to respective voltage signal, which is recorded in a system. The data thus obtained is scrutinized and spurious signals are eliminated upon close examination. In addition, Pluvio Rain Gauge is also installed in KL University, which concurrently records the rain data. The data is then validated by the recording time of 94.67% for entire one year.

3. ITU-R Scintillation Model

The scintillation model embedded in International Telecommunication Union (ITU) is based on the surface temperatures of the region, which is the initial point to estimate the temperatures in the vertical column and estimating the effect of the column on the radio wave signal propagation. If the surface temperatures are not available in a region, the net effective wet term of radio refractivi-

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ty can be estimated using the ITU-R P.453. This prediction model is valid for the experimental set-up, where the elevation angle is greater than 5o. The standard deviation of the scintillation amplitude is calculated by standard deviation of reference signal amplitude, frequency of operation, antenna averaging factor, elevation angle and effective path length.

The standard deviation of reference signal amplitude is calculated by

$$\sigma_{ref} = 3.6 \times 10^{-3} + 10^{-4} \times N_{wet} \quad \text{dB}$$

Antenna averaging factor

$$g(x) = \sqrt{3.86\,(x^2+1)^{11/12} \cdot \sin\left[\frac{11}{6}\tan^{-1}\frac{1}{x}\right] - 7.08\,x^{5/6}}$$

Where

$$x = 1.22\,D_{eff}^2\,(f/L)$$

$$D_{eff} = \sqrt{\eta}\,D \quad \text{m}$$

Effective path length

$$L = \frac{2h_L}{\sqrt{\sin^2\theta + 2.35 \times 10^{-4}} + \sin\theta} \quad \text{m}$$

By using the above parameters, the standard deviation is given as

$$\sigma = \sigma_{ref}\; f^{7/12}\; \frac{g(x)}{(\sin\theta)^{1.2}}$$

The time percentage factor is calculated as

$$a(p) = -0.061\left(log_{10}^{p}\right)^3 + 0.72\left(log_{10}^{p}\right)^2 - 1.71\left(log_{10}^{p}\right) + 3.0$$

where p is the percentage of time.

The fade depth of the scintillation is

$A(p) = a(p) \cdot \sigma$ dB

By analyzing the equations used to calculate the ITU-R scintillation fade, it can be clearly observed that the standard deviation of the signal is only a scaling factor of the scintillation curve and the coefficients in time percentage factor are the shaping factors for the scintillation fade level estimation.

4. Methodology to Extract Scintillation

To extract scintillation from the beacon signal, the beacon signal is passed through high pass filter with a cut-off frequency to remove the slow variations[9]. To select the cutoff frequency for high pass filter, the power spectral density of the recorded beacon signal is plotted to see the power accumulation for different components present in the signal and a careful selection of the cutoff frequency is done[10]. By selection of the cutoff frequency, scintillation is extracted. After extracting, the statistical analysis is carried out to find the variations in the scintillation amplitude and the percentage calculation of scintillation is done. This result is then compared with the ITU-R model discussed and the error plot is presented. To reduce the error, the parameters of the time percentage factor are modified. By integrating the obtained parameters, in the ITU-R model is able to predict the scintillation fades for tropical region near to the measured ones.

5. Results

The beacon signal for one day, recorded on site was presented to show the scintillation effect on the signal level.

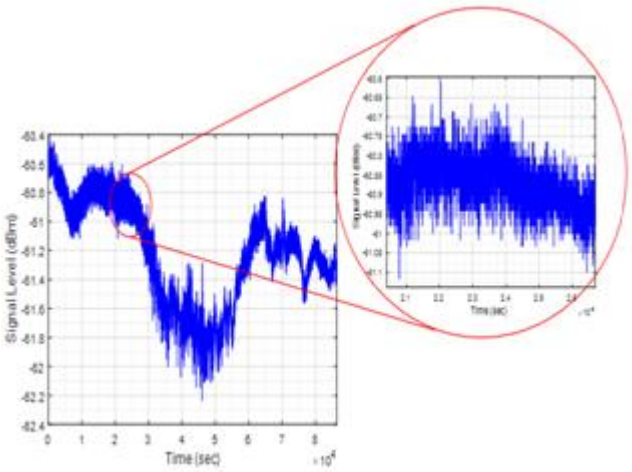

Fig. 1: Beacon Signal on 13th Nov 2016

The above graph shows the thickened signal level, where the signal is spread over an amplitude. This effect is caused by the scintillation and the satellite designers have to know the depth of the scintillation in planning the future missions.

The plot for the cut off frequency selection of scintillation extraction from the beacon signal is

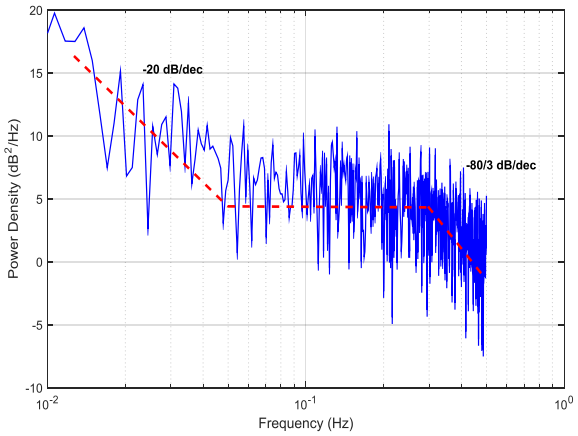

Fig. 2: Selection of Scintillation Cut-off Frequency

The above figure is the power spectral density plot of the beacon signal recorded in this region. By closely observing the graph, the maximum power is located at very low frequency components and has a slope of -20 dB/dec, which is due to the rain attenuation. At the normalized frequency of 0.05 Hz, the power level is constant, which states that the scintillation intensity exists from 0.05 Hz and continues till the end of the frequency line. The end frequency line is decaying at a rate of -80/3 dB/dec, which is the noise spectrum, which has negligible power when compared to the scintillation power. The cut-off frequency to extract the scintillation from the beacon signal is chosen at 0.05 Hz.

The comparison of the measured scintillation and ITU-R predicted scintillation and the modified ITU-R predicted scintillation are shown in Figure 3. The graph states that the ITU-R scintillation model is underestimating the scintillation fade and is not suitable for estimation of scintillation in tropical regions, as the parameters are designed using the readings from temperate climate regions. So there is a need to modify the parameters in the ITU-R in order to used it in tropical region.

The equation of the time percentage factor is modified to

$$a(p) = -0.2707\left(log_{10}^{p}\right)^3 + 0.7371\left(log_{10}^{p}\right)^2 - 2.24\left(log_{10}^{p}\right) + 2.53$$

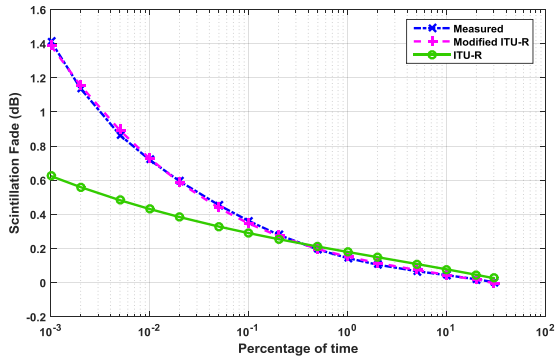

Fig. 3: Comparison of measured, ITU-R predicted and modified Scintillation fade

The error for the ITU-R scintillation model is very high and reaches 126.53% and -89.88% in the worst condition, whereas the modified ITU-R scintillation model has error rates less than 2.5%.

Table 1: Error Analysis of Scintillation Fade

S. No	Percentage Times	Measured Scintillation Fade	ITU-R Scintillation Fades	Error (%)	Modified ITU-R	Error (%)
1	0.001	1.4148	0.6245	126.5	1.3897	0.02
2	0.002	1.1371	0.5594	103.2	1.1545	-0.02
3	0.005	0.8642	0.4828	78.98	0.8919	-0.03
4	0.01	0.7188	0.4311	66.74	0.7265	-0.01
5	0.02	0.5946	0.3841	54.78	0.5867	0.01
6	0.05	0.4538	0.3283	38.19	0.4368	0.04
7	0.1	0.3615	0.2901	24.59	0.3463	0.04
8	0.2	0.2803	0.2546	10.05	0.2726	0.03
9	0.5	0.1941	0.2110	-8.05	0.1965	-0.01
10	1	0.1438	0.1797	-19.96	0.1517	-0.05
11	2	0.1052	0.1491	-29.49	0.1149	-0.08
12	5	0.0671	0.1089	-38.44	0.0739	-0.09
13	10	0.0436	0.0779	-44.06	0.0454	-0.04
14	20	0.0198	0.0456	-56.74	0.0161	0.23
15	30	0.0026	0.0260	-89.88	0.0025	-2.07

6. Conclusion

In this paper, universally accepted ITU-R scintillation model is compared with the measured scintillation fades and found that the ITU-R scintillation model is under estimating the measured scintillation fades and the error is greater than 100%, which when used lead to the under designing of the equipment to encounter such large fades. Here the ITU-R scintillation model is analyzed and the time percentage factors are modified by using the measured scintillation fades, which are extracted from the beacon signal by passing through the high pass filter having cut-off frequency of 0.05Hz normalized frequency, which is calculated by clearly observing the power spectral density function of the beacon signal. The modified ITU-R scintillation model is plotted, where the error has been reduced to less than 2.5%, a massive reduction in the error. This modified ITU-R scintillation model is suitable for this region to estimate the scintillation fades for different conditions and also this model has to be valid with the other practical measurements to be applicable for tropical region.

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