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RAIN FADE SLOPE ESTIMATION USING SIGNAL PROCESSING TECHNIQUES

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ABSTRACT

Fade slope estimations extensively depends on the rain type (convective/stratiform), drop size distribution and the melting layer (bright band) height. Tropics show unusual changes in these parameters due to occasional severe thunderstorms, cyclones and seasonal monsoon (SW and NE) currents. An ITU-R prediction based on temperate climatic conditions often fails to estimate accurately rain attenuation and rain fade slopes. Hence, precise experiments and data processing techniques in tropics are quite required to compare the ITU-R results. In this paper we have taken up fade slope estimations over an operational Ku band link in southern India using different signal processing techniques viz., time domain, frequency domain and wavelet domain. For the first time biorthogonal spline wavelets are used to differentiate rain fades to estimate the rain fade slopes. The results are significantly different from ITU-R predictions.

Keywords: Rain Attenuation, Fade Mitigation Techniques, Fade slope, Wavelets, Spline wavelets.

INTRODUCTION

Attenuation on Sat Com links is mainly due to precipitation, Gaseous absorption, cloud attenuation and scintillations caused by refractive index fluctuations. Rainfall induced attenuation is considered to be the major propagation impairment on earth-space links, operating above 10GHz. Fade Slope, defined as rate of change of rain attenuation is an important input for the control loop of propagation impairment mitigation techniques.

In tropical climates, convective rainfall, characterized by heavy, yet short lasting, events contribute largely to the statistical behavior of attenuation. The rainfall in India exhibits large regional and seasonal variations. A pronounced spatial and seasonal variation in DSD [1] is observed during the southwest and north east monsoon climates. Fade slope, termed as the rate of change of the physical variable attenuation is the steep rise or fall fronts of a substantial duration due to a sudden impact or leaving of a rain cell from the radio path. The rain cell edges are characterized by multiple peaks of rain DSD. Thus the rain fade slope characteristically depends on rain drop size distribution. Hence it is imperative to study fade dynamics in different drop size distribution environment. With this motivation the present study is intended to explore the fade dynamics during the NE monsoon period at MCF, Hassan, where an operational Ku band link is monitored for this purpose

Fade slope studies have received tremendous importance owing to their significant role in determining the tracking speed of the control loop of the fade mitigation techniques. Fade slope is a stochastic parameter varying with time. A deterministic relation between attenuation and rain fade slope is barred [2]. The statistical dependence of fade slope on attenuation is investigated by [3-6] and modeled in [6] which form the basis for the ITU-R model [7]. Fade slope is elucidated to depend on climatic parameters like rain type, horizontal wind speed [6] and is also established to be influenced by the dynamic parameters like the filter bandwidth of the receiving system [6,8]. Fade slope also depends on frequency [9] and its dependence on elevation angle is also reported in [10]. The studies reported and those formed basis for the ITU-R model are from temperate regions of the world. The inapplicability of the ITU-R models to the tropical regions is investigated by [11-13] and they developed model fits for their regions viz., for Japan [12] and Brazil [13]. Considering the wide variability of climatic conditions in the tropics, it is imperative to develop models that fit for the specific regions.

Current objective of the work is to provide the fade slope characteristics of a tropical location in India for NE monsoon season using time domain, frequency domain techniques already ascertained by [14-15]. In the case of wavelet domain, method proposed for estimating fade slopes using Daubechies wavelets is presented in [16]. We are the first to apply the biorthogonal spline wavelet differentiation to differentiate rain fades to estimate the rain fade slope profiles. The cumulative and dynamic statistical analyses of the fade slopes are considered.

Database for fade slope statisitics:

Data collected from the satellite receiving antenna available at Hassan, at MCF (Master Control Facility) which is approximately 900m above the sea level on the point of latitude 13.07ºN and 76.8ºE, and directed toward INSAT 3B on the geostationary orbit of longitude 83.5ºE is used for the studies.

Rain attenuation is obtained by subtracting a reference level from the measured signal level. The reference level is obtained by averaging the entire received signal level data during no rain term. It is seen that the normal signal level during no rain term is -80dBm. Rain Attenuation thus obtained is superimposed by a high frequency component, due to scintillations, which is the rapid fluctuation in signal strength due to variations in refractive index in the troposphere.

Secondary statistics such as fade slope are not derivable from primary rain fade statistics; it must be extracted from the time series data. Rain fade slope is measured from the attenuation time series data obtained after low pass filtering.

Estimation of rain fade slope using signal processing techniques:

Fade slope is estimated using different signal processing techniques viz., time domain method, Frequency domain method, Wavelet domain method described for the case of biorthogonal wavelets [18] to compare and to estimate the bias in each case. Description of each method is given below:

Time domain method:

Scintillations are filtered out by employing a simple 10-point moving average window to the attenuation data. The initial transients are removed from filtered output and then delay correction is made to obtain the attenuation time series. It is observed that with increase in window length high frequency scintillations are smoothed out effectively, but the higher attenuation values are also smoothed out and their value is reduced significantly. Fade slope is the time derivative of rain attenuation. In the time domain method fade slope is estimated from the filtered attenuation time series data using,

$$\zeta(i) = \frac{A(i+\Delta t) - A(i)}{2\Delta t} \; dB/s \qquad \text{----------- (1)}$$

where '*A'* is the attenuation, '*i'* is the instant of time at which fade slope is estimated, and Δt is the time duration over which the fade slope is calculated.

Frequency domain method:

The attenuation data are smoothed out to filter out the tropospheric scintillations by employing a low pass filter. The bandwidth of the low pass filter is determined by evaluating the attenuation power spectrum. The frequency at which the attenuation power spectrum begins to have a slope of -20dB is considered as cutoff frequency. Empirically cutoff frequency is considered as 0.02Hz.

Fade slope is estimated in frequency domain by performing the differentiation of the signal in Fourier domain and then converting back to the time domain by employing inverse Fourier transform. Fade slope is estimated in frequency domain using the following algorithmic steps,

I. If $x(n)$, $n=0, 1, 2....L-1$ is the attenuation time series data.
II. Obtain $X(k)$ the N-point FFT of $x(n)$ where N is next power of 2 to the length of $x(n)$
III. Regarding the conjugate anti-symmetry property of FFT, Multiply $X(k)$ with $-j2\pi f$ where $f = k/N$ to obtain $P(k)$
IV. The inverse FFT of the product $P(k)$ is taken and the redundant points for $k>L$ are removed to obtain the rain fade slope.

Wavelet domain method:

A Wavelet is a waveform of limited duration that has an average value of zero. Wavelets are functions defined over a finite interval and having an average value of zero. The wavelet transform is a tool for carving up functions, operators, or data into components of different frequencies, allowing one to study each component separately. Wavelets are especially useful in analyzing transients or time-varying signals.

Discrete wavelet transform:

The Discrete Wavelet transform is a transform with a discrete-time mother wavelet, (non-zero) integer dilation parameter and a discrete translation parameter. In CWT, the signals are analyzed using a set of basis functions which relate to each other by simple scaling and translation. In the case of DWT, a time-scale representation of the digital signal is obtained using digital filtering techniques. The signal to be analyzed is passed through filters with different cutoff frequencies at different scales.

The Discrete wavelet transform is defined for discrete scale parameter *a* of the form 2^{-s} and translation parameter *b* of the form $k2^{-s}$, where $k,s \in Z$. The CWT for these discrete parameters is expressed as

$$W_f(k2^{-s}, 2^{-s}) = 2^{s/2}\int_{-\infty}^{\infty} f(t)\,\psi(2^{s}t - k)\,dt \qquad (2)$$

If the function *f(t)* is a discrete function with a sampling rate of 1, the above equation transforms to

$$W_f(k2^{-s}, 2^{-s}) = 2^{s/2}\sum_{n} f(n)\,\psi(2^{s}n - k) \qquad (3)$$

The above equation represents the Discrete wavelet transform.

The Discrete Wavelet Transform (DWT), which is based on sub-band coding is found to yield a fast computation of Wavelet Transform. It is easy to implement and reduces the computation time and resources required.

Spline wavelet fade slope estimation is easier to implement in signal processing domain than the Daubechies wavelet fade slope estimation which is a numerical differentiation technique.

Biorthognal wavelets:

Biorthogonal spline wavelets basis were introduced by Cohen-Daubechies-Feauveau [17] in order to obtain wavelet pairs that are symmetric, regular and compactly supported. Biorthogonal wavelets build with splines are especially attractive because of their short support and regularity. The symmetry and short support properties are very valuable for reducing truncation artifacts in the reconstructed signals.

In the most general case, the construction of biorthogonal wavelet bases involves two multiresolution analyses of L_2: one for the analysis, and one for the synthesis. These are usually denoted by $\{V_i(\tilde{\varphi})\}_{i\in Z}$ and $\{V_i(\varphi)\}_{i\in Z}$ where $\tilde{\varphi}(x)$ and $\varphi(x)$ are the analysis and synthesis scaling functions, respectively. The corresponding analysis and synthesis wavelets $\tilde{\psi}(x)$ and $\psi(x)$ are then constructed by taking linear combinations of these scaling functions

$$\tilde{\psi}(x) = \sqrt{2}\sum_{k} \tilde{g}_k \tilde{\varphi}(2x-k) \qquad (4)$$

$$\psi(x) = \sqrt{2}\sum_{k} g_k \varphi(2x-k) \qquad (5)$$

They form a biorthogonal set in the sense that

$$\langle \psi_{j,k}, \tilde{\psi}_{j',k'} \rangle = \delta_{j-j',k-k'} \qquad (6)$$

where $\psi_{j,k} = 2^{j/2}\psi(2^j x - k)$

This allows us to obtain the wavelet expansion of any L_2 function as

$$\forall f \in L_2, \; f = \sum_{j,k\in Z} \langle f, \tilde{\psi}_{j,k} \rangle \psi_{j,k}$$

The Attenuation data are decomposed using biorthogonal spline wavelets. Scintillations are removed by employing wavelet shrinkage technique with 'sqtwolog' threshold using 'bior6.8' wavelet. The Analysis wavelet $\tilde{\psi}(x)$ behaves like a γ^{th} order differentiator where γ is the order of approximation of the corresponding scaling function [18].

The discrete wavelet transform is a fast algorithm for discrete signal decomposition, but is non-redundant. The draw-back of non-redundant transform is their non-invariance in time. The stationary wavelet transform is a redundant transform which makes the wavelet decomposition time-invariant. Hence the fade slopes are estimated using the stationary wavelet transform to achieve time invariance.

Fade slope is estimated in wavelet domain by following the algorithmic steps,

1. If *x(n), n=0, 1, 2….L-1* is the attenuation time series data.
2. The data is extended symmetrically in one dimension for reducing the boundary effects in the calculation of SWT.
3. The detail coefficients at level one are multiplied by -1 to obtain the rain fade slope.

All the above algorithms are implemented with Matlab to obtain the rain fade slope profiles.

RESULTS

The dependence of fade slope on fade depth is illustrated by the fade slope conditional distribution. Joint statistics of fade slope, ζ and attenuation, A were generated by storing fade slope values in bins of sizes 0.001dB/s and 1dB for ζ and A, respectively. $A(t)$ values were rounded within ±0.5dB intervals. Lastly the bin counts at each attenuation interval were divided by the product of the total number of samples and the bin size to obtain the probability density function. The conditional probability density of fade slope obtained, using time domain method, frequency domain method and in wavelet domain for different attenuation levels are shown in *Figures 1, 2, 3* respectively. The statistical parameters calculated for the corresponding fade slope conditional densities are given in *Tables 1, 2 and 3* respectively. The fade slope distribution is observed to have time symmetry from the median value calculated from the distributions. Decreasing value of kurtosis with increasing attenuation indicates the fade slope distribution becomes flatter with increasing attenuation. Skewness is decreasing with increasing attenuation indicates that distribution becomes symmetrical at higher attenuation values.

It is observed that the descriptive statistics of fade slope conditional probability distributions obtained with frequency domain and wavelet domain estimated fade slopes are in good comparison from attenuation levels above 3dB. The fade slope distributions are observed to be leptokurtic and the skewness which is the measure of symmetry of a distribution also shown a good performance when obtained using frequency domain estimation. Higher Kurtosis observed in the time domain method and in wavelet estimated fade slope conditional distribution at 1dB, 2dB and 3 dB points out higher variance of the distribution.

If we plot rain attenuation against rain fade slope, this type of plot is referred to as a phase-space representation of the data, provides a better visualization of the dynamics of the rain fading than a simple time series of rain fade slope. In this type of diagram, motion with time occurs as a series of clockwise loops. If the rain fade slope at a time is positive, then rain attenuation is increasing, and in a phase space diagram, A(t+1) must lie to the right of A(t). Similarly, if the rain fade slope at a time t is negative, the attenuation is decreasing and in a phase space diagram A(t+1) must lie to the left of A(t). In a phase space diagram any closed loop must lie across the line $\zeta = 0$, as it is possible to return to the same value of rain attenuation by having a series of positive rain-fade slopes followed by a series of negative rain fade-slopes (or vice versa).

The typical plots of time series of rain attenuation, fade slope and its corresponding phase-space representations obtained using wavelet, frequency and time domain methods are shown in *figure 4(a), 4(b) & 4(c)* respectively. From time series fade slope profiles plotted, a less noisy profile is obtained through wavelet method, a noisier profile is obtained through frequency domain method and a much noisier profile through time domain method. The Fade slopes estimated in wavelet domain method present less noise traces.

The phase-space plots of data obtained are closed contours across the line $\zeta = 0$. The phase-space plots obtained from the frequency domain method presents too smooth plot due to the filtering out of high frequency dynamics of rain attenuation. Lower fade slope estimates of time domain method even at higher attenuation is better depicted from the phase-space plot of data. From the phase-space representation of fade slope, it can be observed that high frequency dynamics of rain attenuation are better depicted in the wavelet domain method in comparison to the frequency domain and time domain methods at higher attenuation levels.

Cumulative distributions of fade slopes estimated using three methods are shown in *Fig.5* and a plot generated using RAPIDS, *Fig. 6* (Radio Propagation Integrated Database System) [19] simulated data for ITU R-model is considered for comparison. It can be observed that the 0.001% time exceedance of fade slope is higher for the fade slopes estimated using wavelet domain method. It can be visualized that wavelet domain estimate of 0.001% time exceedance of fade slope is higher than frequency domain method though both give instantaneous measure of the fade slope. It can be attributed to the fact that wavelet estimates are able to measure high frequency rain attenuation and corresponding fade slope. The time domain and ITU-R estimates are in comparison due to the fact that both involve 10 sec time lag in the fade slope estimation.

CONCLUSIONS

Rain fade slope, an essential input for the fade mitigation technique control loop is estimated using three methods. Rain attenuation is estimated by filtering in time, frequency and wavelet domains. Considering the scintillation removal, wavelet method offers better performance over the frequency domain, which is better in comparison with the time domain method.

Rain Fade slopes estimated using wavelet domain method are able to depict well the high frequency variations of the rain attenuation as wavelet method of differentiation offers good performance while frequency domain differentiation induces high frequency spurious signals inducing noise into the fade slope estimations.

Wavelet domain method of fade slope estimation offers advantages over frequency domain method, as differentiation is stable in wavelet domain rather than in frequency domain. But from the phase-space plot at lower attenuation levels the wavelet domain method is depicting a bit noisier estimates, which may be one of the reasons for higher standard deviation, skewness and kurtosis observed from the conditional probability density for the wavelet domain method. Thus it can be considered the thresholding technique employed for filtering may need some modification for better performance at all attenuation levels. Time domain estimates of fade slope involve time lag in the estimation. Thus we observe lower values of fade slopes in time domain method when compared to other methods.

The biorthogonal spline wavelet differentiation is easy to implement in signal processing domain compared to db wavelet filtering.

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REFERENCES

1. Radhakrishna B, Narayana Rao T, Narayana Rao D, Prabhakara Rao N, Nakamura K and Ashok Kumar Sharma. Spatial and seasonal variability of rain drop size distributions in southeast India. J. Geophys. Res., 2009; 114.
2. Sweeney G Dennis and Charles W Bostian. The Dynamics of Rain-Induced Fades. IEEE Trans Ant Prop 1992; 40 (3): 275-8.
3. Matricciani E. Rate of change of signal attenuation from SIRIO at 11.6GHz. IEE Electron Lett 1981; 17(3): 139-41.
4. Stutzman WL, B Nelson. Fade slope on 10-30GHz Earth-Space Communication links-measurements and modeling. IEE Proc Microw Ant Prop 1996; 143: 353-7.
5. Timothy IK, JT Ong and EBL Choo. Descriptive Fade Slope Statistics on INTELSAT Ku-band Communication link. Electron Lett 2000; 36(16): 1422-4.
6. Van de Kamp MMJL. Statistical Analysis of Rain Fade Slope. IEEE Trans Ant Prop 2003; 51(8):1750-9.
7. ITU-R P.1623-1. Prediction method of fade dynamics on Earth-space paths. 2003-05; 1-7.
8. Matricciani E. Effects of filtering on rate of change of rain-induced Attenuation. Electron Lett 1982; 18: 477-8.

9. Rucker F. Frequency and Attenuation dependent Fade Slope Statistics. Electron Lett 1993; 29: 744-6.
10. Erkki T Salonen, Pasi AO Heikkinen, Fade slope analysis for low elevation angle satellite links, International Workshop of COST Actions 272 and 280, Satellite Communications- From Fade Mitigation to Service Provision, *ESTEC*, Noordwijk, The Netherlands, (2003).
11. Franklin FF, Fujisaki K, Tateiba M. Fade dynamics on Earth-space paths at Ku-Band in Fukuoka, Japan Fade- Slope Evaluation, Comparison and Model. IEEE Ant Wireless Prop Lett 2006; 5: 80-3.
12. Dao H, Md Rafiqul Islam, Al-Khateeb ASK. Fade Dynamics Review of Microwave Signals on Earth-Space Paths at Ku-Band. Proceedings International Conference on Computer and Communication Engineering (2008): 1243-7.
13. Couto de Miranda E, Maria Christina Quesnel, and LAR da silva Mello. Empirical Model for the Statistical Characterization of Rain Fade Slope in Tropical Climates. J Microwave, Optoelectronic and Electromagnetic Applications. 2009; 8(1): 143S-153S.
14. Van de Kamp,M.M.J.L., Climatic Radiowave Propagation Models for the design of Satellite Communications Systems, Ph.D. Thesis, Eindhoven University of Technology, 1999.
15. Baxter PD, Upton GJG, and Eden D. Revised method for calculation of fade slope. IEE Electron Lett May 2001; 37(10): 658-60.
16. Baxter PD, Upton GJG, and Eden D. Measurement of Rain-fade-slope: Fourier and Wavelet methods. Open Symposium on Propagation and Remote Sensing, URSI Commision F, Feb 2002; 1-13.
17. A. Cohen, I. Daubechies and J. Feauveau. Biorthogonal basis of compactly supported wavelets. Comm Pure Appl Math 1992; 45**:** 485–560.
18. Unser M, Blu T. Wavelet Theory Demystified. IEEE Trans Sig Proc Feb 2003; 51(2):470-483.
19. Alain Rogister, D. Mertens, D. Vanhoenacker-Janvier, Antonio Martellucci, and Bertram Arbesser-Rastburg. RAPIDS: RAdio Propagation Integrated Database System, *COST 280.*

Table 1. Statistical parameters of the conditional probability density of time domain estimated fade slope

Parameter	1dB	2dB	3dB	4dB	5dB	6dB	7dB
Mean	**0.0005**	**0.0005**	**0.0005**	**0.0005**	**0.0005**	**0.0005**	**0.0005**
Median	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**
STD	**0.0100**	**0.0104**	**0.0076**	**0.0032**	**0.0030**	**0.0032**	**0.0031**
Skewness	**24.3544**	**25.4722**	**24.5097**	**8.7236**	**8.0744**	**9.0453**	**8.7916**
Kurtosis	**635.8783**	**692.6396**	**655.7587**	**89.9883**	**80.2517**	**104.4850**	**100.7694**

Table 2 Statistical parameters of conditional probability density of Fade slope obtained using frequency domain method

Parameter	1dB	2dB	3dB	4dB	5dB	6dB	7dB
Mean	**0.0005**	**0.0005**	**0.0005**	**0.0005**	**0.0005**	**0.0005**	**0.0005**
Median	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**
STD	**0.0040**	**0.0042**	**0.0031**	**0.0017**	**0.0018**	**0.0019**	**0.0020**
Skewness	**9.7240**	**10.1831**	**10.1355**	**4.2518**	**4.5624**	**4.4103**	**4.6884**
Kurtosis	**102.7613**	**112.5274**	**117.5097**	**24.3351**	**29.8284**	**24.6513**	**28.6078**

Table 3 Statistical parameters of conditional probability density of Fade slope obtained in wavelet domain

Parameter	**1dB**	**2dB**	**3dB**	**4dB**	**5dB**	**6dB**	**7dB**
Mean	**0.0005**	**0.0005**	**0.0005**	**0.0004**	**0.0003**	**0.0003**	**0.0003**
Median	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**
STD	**0.0149**	**0.0147**	**0.0090**	**0.0013**	**0.0011**	**0.0012**	**0.0011**
Skewness	**31.8818**	**31.6575**	**34.0755**	**5.2749**	**4.0659**	**4.7346**	**5.3833**
Kurtosis	**1024.37**	**1006.22**	**1216.12**	**38.7395**	**22.0730**	**29.4098**	**38.6667**

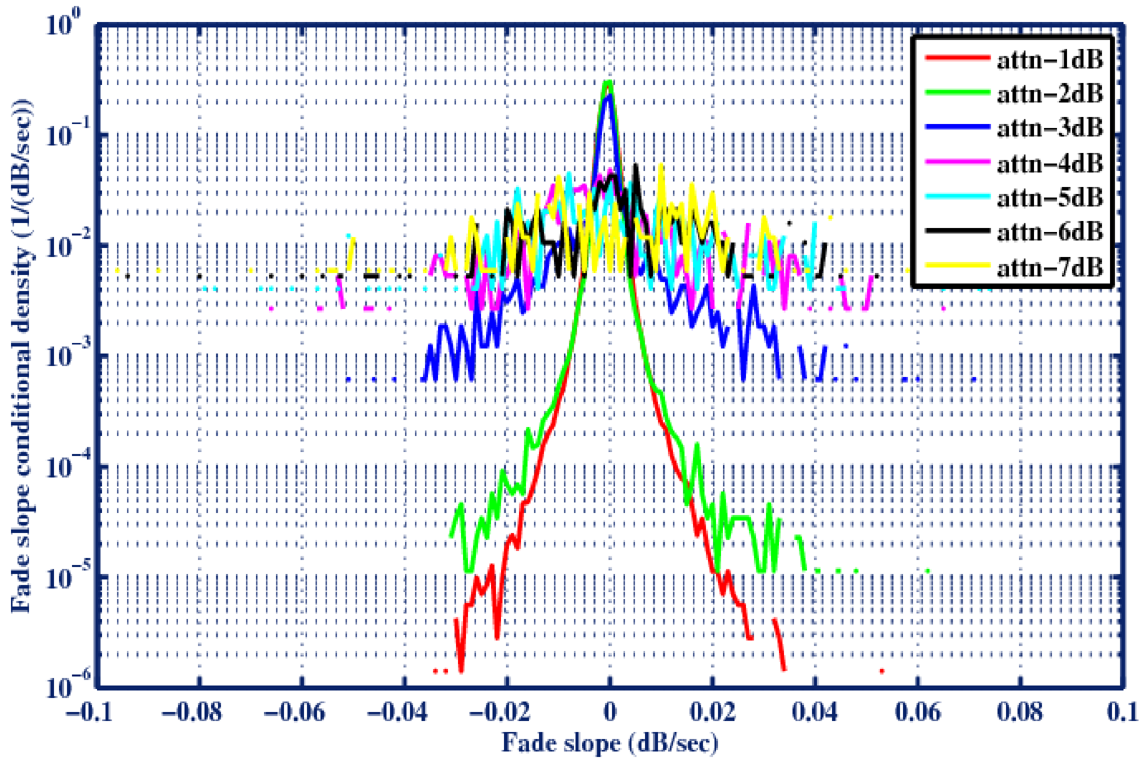

Fig.1. Conditional Probability density of fade slope obtained using Time domain method as a function of attenuation

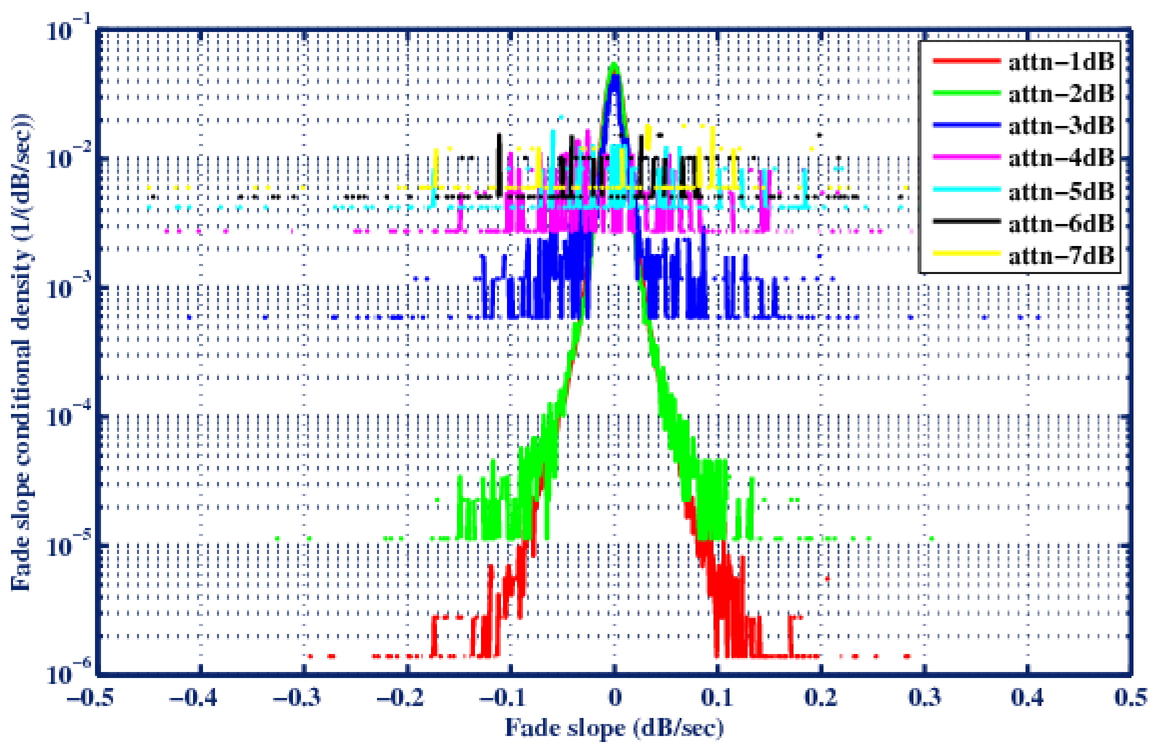

Fig.2. Conditional Probability density of fade slope obtained using Frequency domain method as a function of attenuation

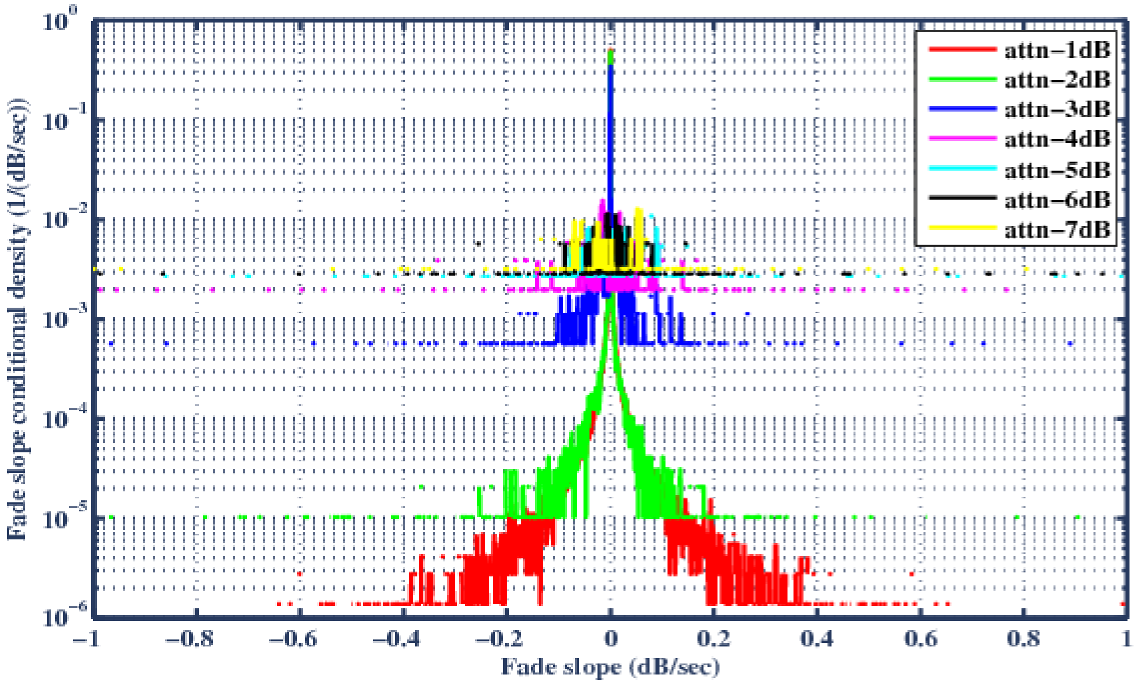

Fig.3. Conditional Probability density of fade slope obtained in wavelet domain method as a function of attenuation

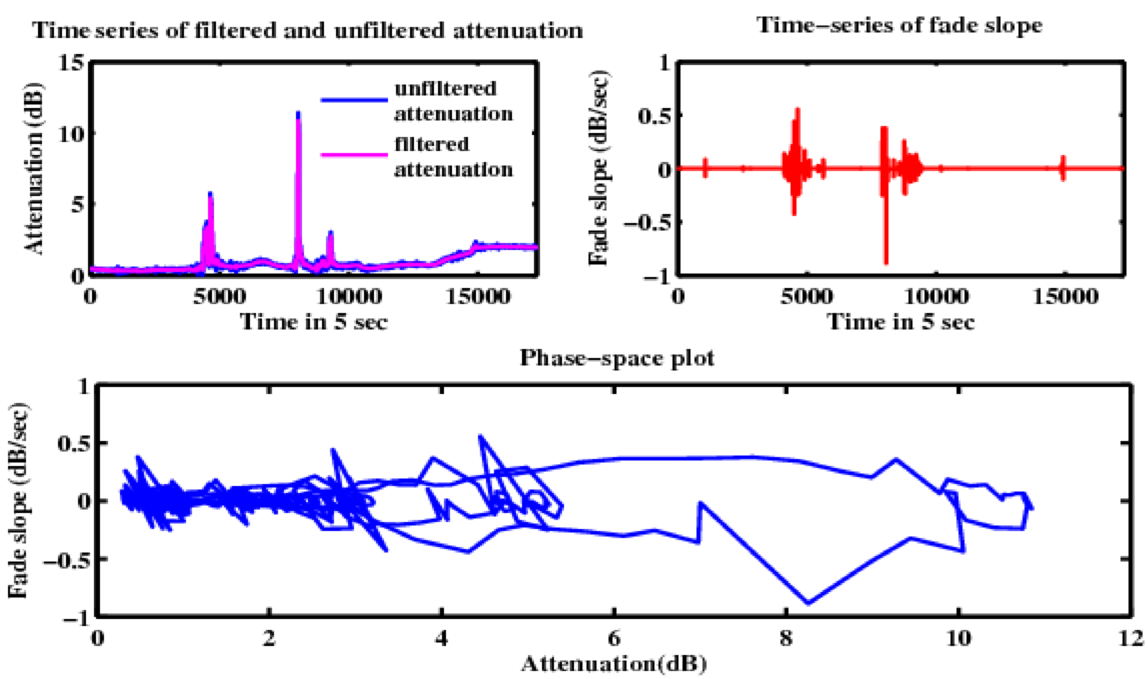

Fig.4(a) Time series of Rain attenuation, Fade slope and phase-space plot of Oct 13'04 using bi-orthogonal spline wavelets

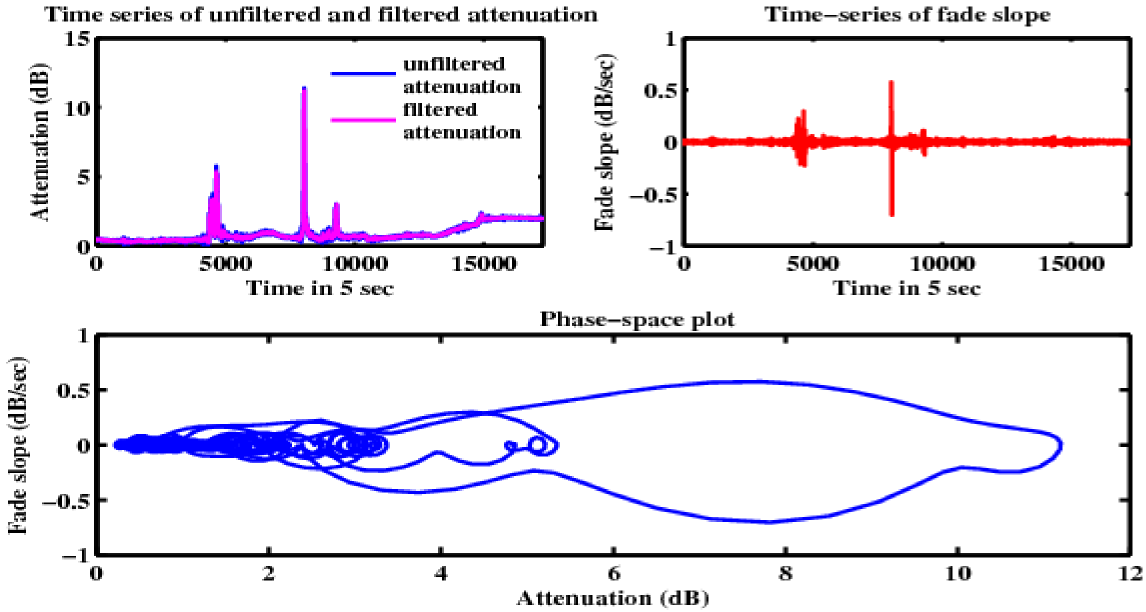

Fig. 4(b) Time series of Rain attenuation, Fade slope and phase-space plot of Oct 13'04 using DFT method

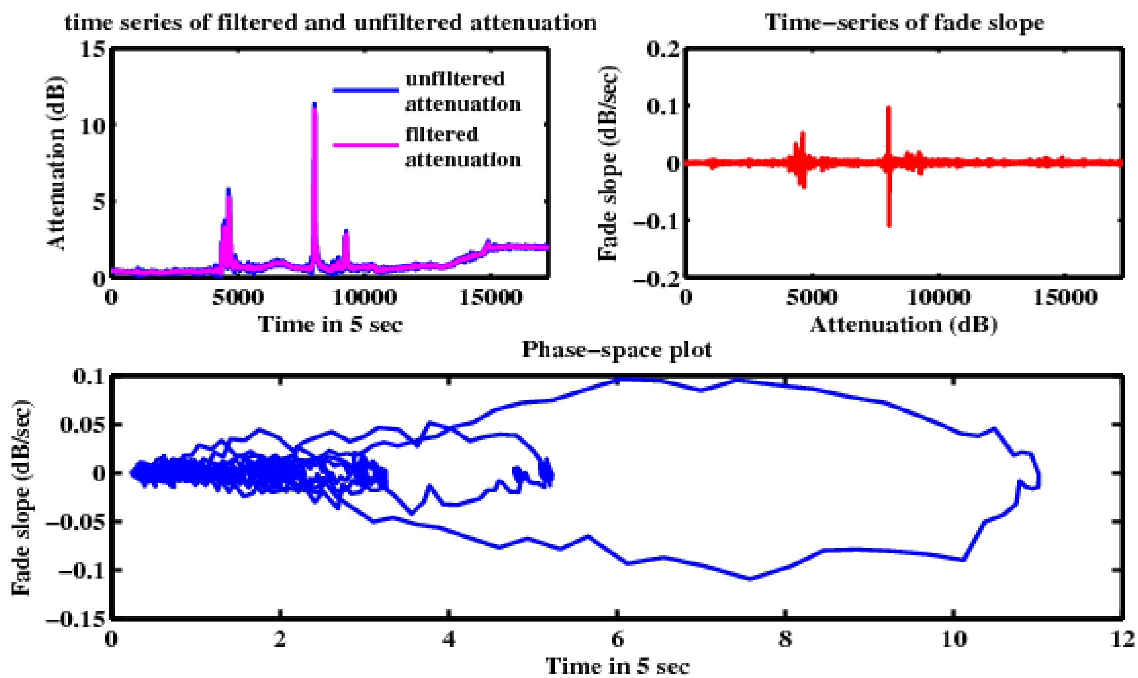

Fig. 4(c) Time series of Rain attenuation, Fade slope and phase-space plot of Oct 13'04 using Time domain method

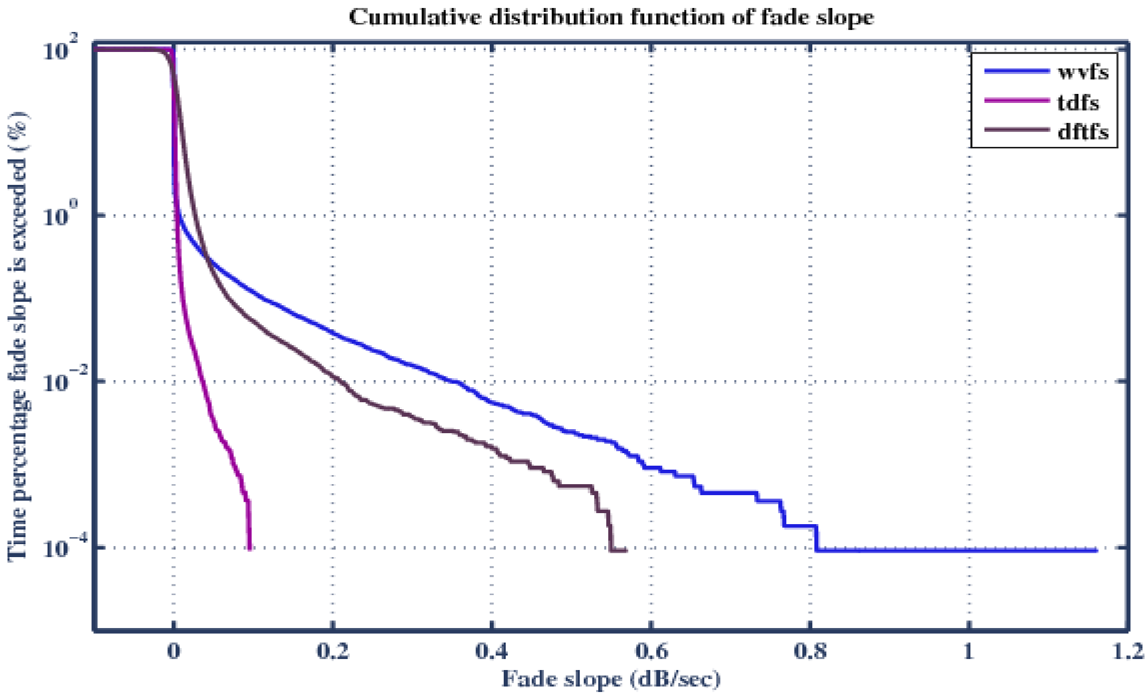

Fig.5 Cumulative distribution function of fade slope estimated using three signal processing methods

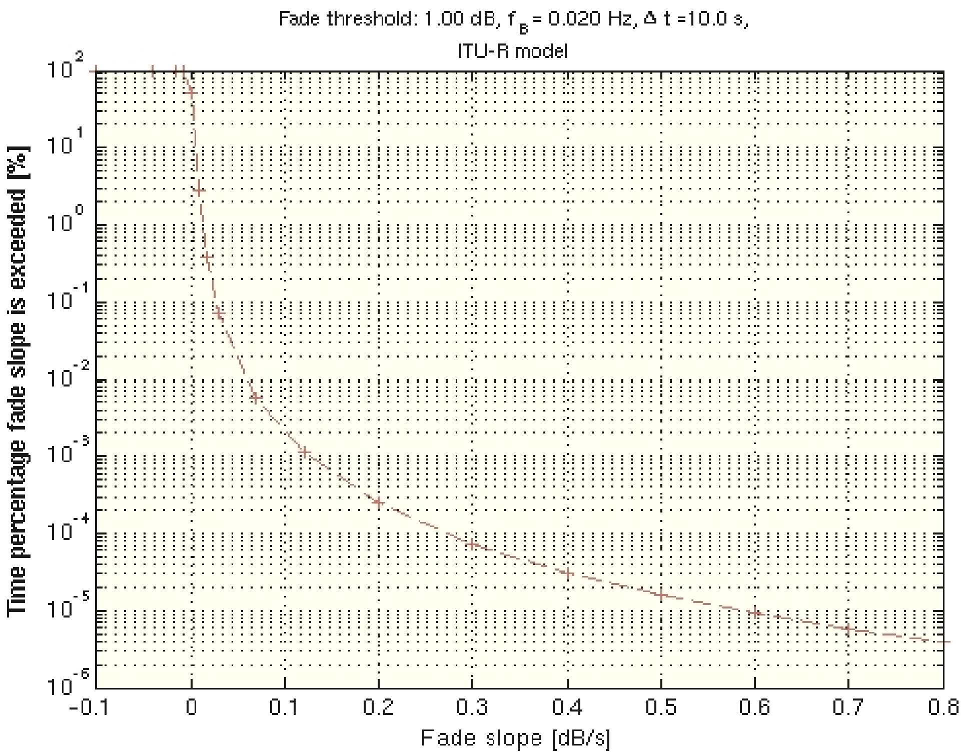

Fig. 6. Simulated plot for CDF of fade slopes from RAPIDS (Source: RAPIDS)