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FADE SLOPE ESTIMATION USING TIME DOMAIN METHOD

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Abstract **-** An analysis is made of the measured distributions of the fade slope of rain attenuation, conditional for attenuation values, measured at Eindhoven University of Technology from the satellite Olympus. It is found that the distribution is similar for positive and negative fade slopes and independent of frequency in the range from 12 to 30 GHz. A distribution model for the conditional distribution is found. The only parameter of the distribution is the standard deviation, which is found to be proportional to attenuation level and dependent on rain type, on the low-pass filter bandwidth and on the time interval used in the slope calculation. The observed relation between the standard deviation and attenuation is compared with results from other measurement sites. From this comparison it is found that the fade slope standard deviation is likely to depend on elevation angle and on climate, through its dependence on rain type.

I. INTRODUCTION

Rain Fade slope, defined as rate of change of attenuation, is an essential input statistic for the Propagation Mitigation Techniques Control Loop design. Fade slope is a stochastic parameter and it depends on

(i) Attenuation level (ii) Rain type (widespread/ convective)

It is also expected to depend on

(i) Drop size distribution (ii) Horizontal wind speed (iii) Path length through rain

Fade slope estimations also depends on the dynamic parameters of the receiving system, the filter bandwidth used for separating rain attenuation from troposphere scintillations and on the integration time of the receiver.

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.

Data collected from the downlink (11.7GHz) satellite receiving antenna available at MCF (Master Control Facility) Hassan, which is approximately 900m above the sea level on the point of latitude 13.07ºN and 76.8ºE, and directed towards INSAT 3B on the geostationary orbit of longitude 83.5ºE is used for the studies**.**

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

The attenuation data are smoothed out to reduce the troposphere scintillations or the scintillations are filtered out 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.

Rain fade slope can be extracted using three methods:

1. Time Domain method.
2. Frequency Domain method.
3. Wavelet method.

II. SIGNAL PROCESSING TECHNIQUES FOR THE ESTIMATION OF FADE SLOPE:

Filtering of the signal is performed in various domains to observe its effect on fade slope calculation. The methods followed are: time domain method proposed by ***Stutzman et.al., (1995)[1],*** Frequency domain method proposed by ***Baxter et.al, (2001)[2],*** Wavelet domain method proposed by ***Baxter et.al, (2002)*** where in he also evaluated the effect of the filtering techniques mentioned above using simulated fade slope profiles. The bandwidth of the filter is determined from the power spectral density of the attenuation data.

Filters are a class of a linear time invariant systems. The design of the digital filter involves three basic steps.

(i) The specification of the desired properties of the system.
(ii) The approximation of the specifications using a causal discrete-time system.
(iii) The realization of the system using finite precision arithmetic.

First step is highly dependent on the application and the third step on the technology to be used for the implementation. The digital signal to be filtered is derived from an analog signal by means of periodic sampling. The specifications for both analog and digital filters are often (but not always) given in frequency domain. This is essentially common for frequency selective filters such as low pass, band pass, high pass filters. The analog frequencies are expressed in hertz and the corresponding digital frequencies in terms of radian frequency or angle around the unit circle with l*z1*=1 corresponding to half the sampling frequency.

A separate problem is determining an appropriate set of specifications on the digital filter. Typically specifications often expressed in the form of a tolerance scheme, with no constraints on the phase response other than those imposed by stability and causality requirements. An important step in the development of a digital filter is the determination of a realizable transfer function G (z) approximating the given frequency response.

Given a set of specifications the next step is the filter design approximation. In case of IIR systems we must approximate the frequency response by a rational function, while in FIR case we are concerned with polynomial approximation. There are a variety of design techniques for both types of filters.

TIME DOMAIN METHOD USING FILTERS:

Filtering can be performed directly in time domain by using windowing techniques, which is equivalent to FIR filtering. The moving average filter is optimal for common task such as reducing random noise while retaining sharp step response. The moving average filter operates by averaging a number of points from the input signal to produce each point in the output signal. The output of a moving average filter can be estimated by the equation:

$$\mathbf{y[i]} = \frac{1}{M}\sum_{j=0}^{M-1} \mathbf{x[i+j]} \tag{1}$$

Where x[i] is the input signal and y[i] is the output signal, and M is the number of points of the average. The moving average filter is a convolution of the input signal with a rectangular pulse having an area of one. The frequency response of a moving average filter can be mathematically described by the Fourier transform of a rectangular pulse.

$$\mathbf{H[f]} = \frac{\sin(\pi f M)}{M \sin \pi f} \tag{2}$$

A simple 11,51,101 and 301-point moving average window is applied to the data for eliminating the scintillations from the attenuation data.

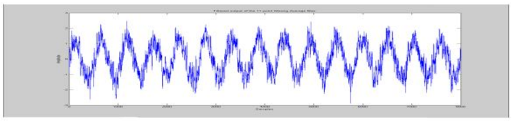


Fig 1: 11-point moving average filter

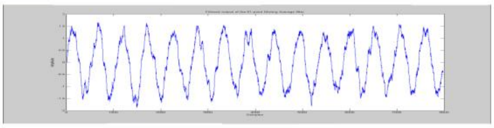


Fig 2: 51-point moving average filter

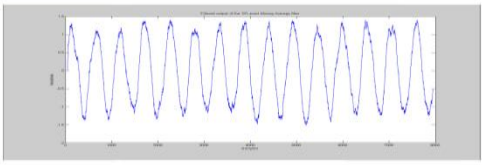


Fig 3: 101-point moving average filter

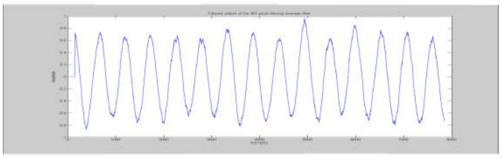


Fig 4: 301-point moving average filter

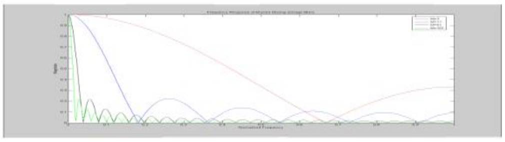


Fig 5: Frequency response of moving average filter

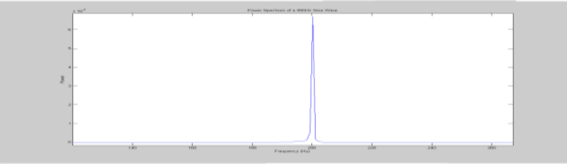


Fig 6: Power spectral estimation of Moving Average Filter

FREQUENCY DOMAIN METHODS:

(i) POWER SPECTRAL DENSITY ESTIMATION USING FAST FOURIER TRANSFORM (FFT) METHOD:

Power spectral density of the received signal variations is estimated by FFT method. Power spectral density of the attenuation time series is obtained by calculating the power at each sampling interval and the corresponding frequencies are also calculated from 0 to half the maximum sampling frequency.

Power spectral density is estimated by taking the FFT of the attenuation time series. Multiplying the FFT of the time series with its complex conjugate gives an estimate at each frequency. Corresponding frequencies are calculated using the formula) where is the time interval between the successive samples and N is the number of data samples.

(ii) FREQUENCY DOMAIN FILTER DESIGN

Filtering in frequency domain is performed by designing digital filters for given magnitude specifications. In general the filter design problem begins from a set of desired specifications in terms of the discrete-time frequency variable. Incase of IIR filter design, the most common practice is to convert the digital filter specifications into analog low pass prototype filter specifications, to determine the analog low pass filter transfer function *Ha(s)* meeting these specifications, and then to transform it into the desired digital filter transfer function G(z). Recursive digital filter approximations can be obtained from analog-filter approximations using the following methods:

1. Impulse-Invariant method.
2. Backward difference method.
3. Bilinear transformation.

Stable analog filters will be transformed to stable digital filters with the same frequency response when Bilinear transformation is employed. Non-recursive filter approximations, on the other hand, can be obtained by using Fourier series and numerical-analysis formulas. In order to be realizable as a recursive filter, a transfer function must satisfy the following constraints:

1. It must be a rational function of z with real coefficients.
2. Its poles must lie within the unit circle of the z-plane.
3. The degree of the numerator polynomial must be equal to or less than that of the denominator polynomial.

Filter to be designed must possess flat pass band and flat stop band; hence a Butterworth IIR filter was employed for filtering purposes. The bandwidth of the digital filter is chosen by evaluating the power spectra of the signal variations.

a) BUTTERWORTH FILTER

A Fifth order Butterworth low pass filter is designed in MATLab with a Pass band ripple of 1dB, stop band ripple of 10 dB and pass band frequency 0.018Hz, stop band frequency is selected as 0.028 Hz. The corresponding frequency response is shown in fig.

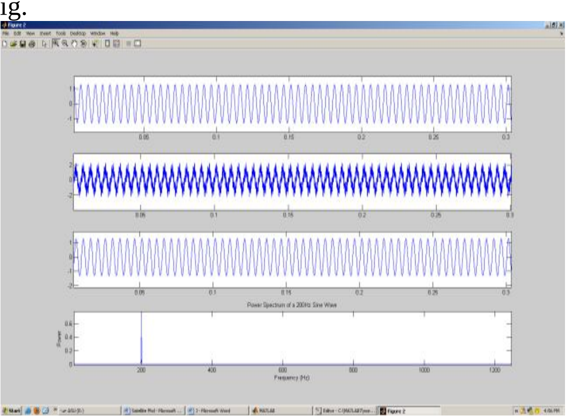


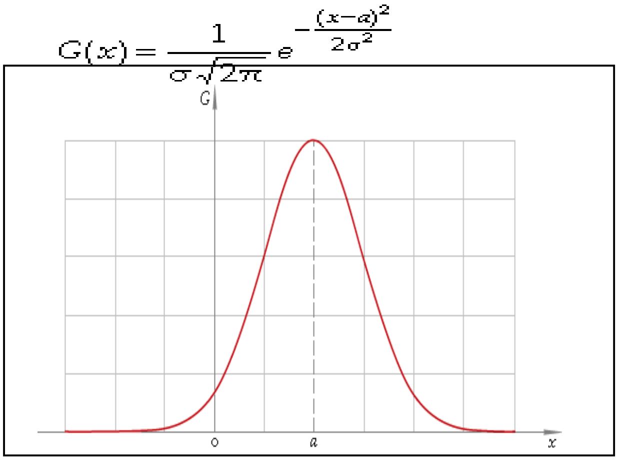
Fig 7: output response of Butterworth Filter

(b) GAUSSIAN FILTER:

Gaussian filter is a filter whose impulse response is a Gaussian function. Gaussian filters are designed to give no overshoot to a step function input while minimizing the rise and fall time. This behavior is closely connected to the fact that the Gaussian filter has the minimum possible group delay.

Mathematically, a Gaussian filter modifies the input signal by convolution with a Gaussian function The Gaussian function is non-zero for and would theoretically require an infinite window length. However, since it decays rapidly, it is often reasonable to truncate the filter window and implement the filter directly for narrow windows, in effect by using a simple rectangular window function. In other cases, the truncation may introduce significant errors. Better results can be achieved by instead using a different window function.

The Fourier transform of the Gaussian function yields a Gaussian function; the signal (preferably after being divided into overlapping windowed blocks) can be transformed with a Fast Fourier transform, multiplied with a Gaussian function and transformed back.



$$G(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-a)^2}{2\sigma^2}}$$

A Gaussian IIR filter was employed for filtering purposes. The bandwidth of the digital filter is chosen by evaluating the power spectra of the signal variations.

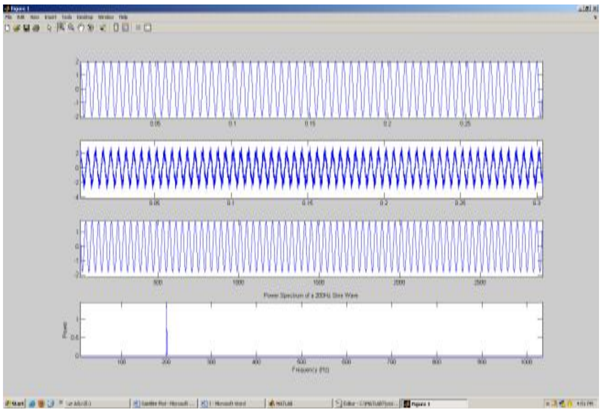


Fig 8: Output response of the Gaussian Filter

III. FADE SLOPE ESTIMATION:

For the fade slope analysis, the attenuation data were low-pass filtered to remove fluctuations due to scintillation. The filter bandwidth was chosen by evaluating the power spectra of the signal variations. For many separate events, the threshold frequency was determined between the attenuation spectrum, which decreases with frequency, and the flat part of the scintillation spectrum. The value of this threshold frequency depends on the strength of both the attenuation and scintillation fluctuations and therefore varies from event to event. A value of 20 MHz was found as a lower limit of this frequency. With a filter bandwidth fb of 20 MHz it can thus be expected that the scintillation fluctuations are effectively removed.

Nevertheless, also a part of the attenuation spectrum is cut off, which may affect the fade slope results. The low-pass filtering was performed in software, by making a FFT transform of the signal of each separate event, sharply cutting off all frequency components above fb and transforming back..

Next, for each sample the fade slope was calculated as

$$\varsigma(i) = \frac{A(i+\Delta t) - A(i-\Delta t)}{2\Delta t}\ \mathrm{dB/sec}$$

Where A is attenuation and i is the sample number. Joint statistics of □and A were generated for each beacon signal. The size of the bins were 0.001 dB/s for 0 and 1 dB for A.

The model is valid for the following ranges of parameters:

- Frequencies from 10 to 30 GHz
- Elevation angles from 10° to 50°.

The following parameters are required as input to the model:

A : attenuation level (dB): 0-20 dB

f_B : 3 dB cut-off frequency of the low pass filter (Hz): 0.001-1 Hz

Δt : time interval length over which fade slope is calculated (s): 2-200 s.

CALCULATION STEPS FOR SLOPE:

The step-by-step calculation of the fade slope distribution is as follows:

***Step 1*:** Calculate the function F which gives the dependence on the time interval length Δt and the 3 dB cut-off frequency of the low pass filter f_B:

$$F(f_B, \Delta t) = \sqrt{\frac{2\pi^2}{\left(1/f_B^b + (2\Delta t)^b\right)^{1/b}}}$$

with b □ 2.3.

***Step 2*:** Calculate the standard deviation □□ of the conditional fade slope at a given attenuation level as:

$$\sigma_\zeta = s\, F(f_B, \Delta t) A \qquad \mathrm{dB/s}$$

Where s is a parameter which depends on climate and elevation angle; an overall average value in Europe and the United States of America, at elevations between 10° and 50°, is s □ 0.01.

***Step 3a*:** Calculate $p(\zeta \mid A)$ the conditional probability (probability density function) that the fade slope is equal to ζ for a given attenuation value, A:

$$p(\zeta \mid A) = \frac{2}{\pi\sigma_\zeta \left(1 + (\zeta/\sigma_\zeta)^2\right)^2}$$

***Step 3b*:** If required, calculate $p(\zeta \mid A)$, the conditional probability (complementary cumulative distribution function) that the fade slope ζ is exceeded for a given attenuation value, A:

$$P(\zeta \mid A) = \frac{1}{2} - \frac{(\zeta/\sigma_\zeta)}{\pi\left(1 + (\zeta/\sigma_\zeta)^2\right)} - \frac{\arctan\ (\zeta/\sigma_\zeta)}{\pi}$$

or calculate $p(\zeta \mid A)$, the conditional probability that the absolute value of the fade slope ζ is exceeded for a given attenuation value, A:

$$P(|\zeta| \mid A) = \int_{-\infty}^{-\zeta} p(x \mid A)\,\mathrm{d}x + \int_{\zeta}^{\infty} p(x \mid A)\,\mathrm{d}x = 1 - \frac{2(|\zeta|/\sigma_\zeta)}{\pi\left(1 + (|\zeta|/\sigma_\zeta)^2\right)} - \frac{2\arctan\left(|\zeta|/\sigma_\zeta\right)}{\pi}$$

The model given in equation was tested against data between 12.5 GHz and 50 GHz.

In Figure the conditional probability densities are shown for the fade slope □for attenuations in the bins 1 dB - 5 dB. This figure shows that the fade slope is always distributed around 0 dB/s, and has a spread which increases with attenuation. Furthermore, the distributions are very similar for the different beacons, even though the samples were very differently distributed over the attenuation bins for the three frequencies. This suggests that the conditional distribution of □for a certain value of A is independent of frequency.

Some properties of these distributions will be studied and a model for the distribution will be formulated in the following sections Fig 8.

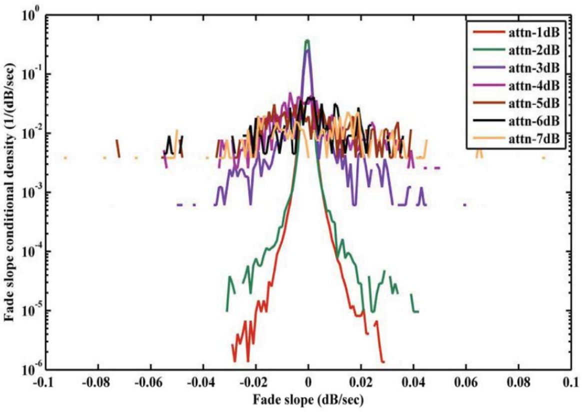


Fig 8: expected result of the Fade Slope
It is observed that the:

1. Fade slope distribution dependence on fade depth is confirmed
2. The fade (19)slope distribution is observed to have time symmetry from the median value calculated from the distributions.
3. Decreasing value of kurtosis with increasing attenuation indicates the fade slope distribution becomes flatter with increasing attenuation.
4. Skewness shows the degree of asymmetry, skewness is decreasing with increasing attenuation.

IV. CONCLUSION:

The Fade Slope is estimated by filtering the scintillation for the low pass filter and the estimating the power spectrum of the output. Here in this project different filters are designed to observe the faded slope and which filter will give the accurate value of the fade slope. The theoretical and practical value have to be estimated to get the Faded slope using the above best filter i.e Gaussian Filter, Moving Average Filter and Butterworth Filter.

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