COST Action 280

"Propagation Impairment Mitigation for Millimetre Wave Radio Systems"

Second-Order Statistics of Rain Attenuation in Hungary especially the Fade Slope Statistics

Abstract

Wave propagation at high carrier frequencies (for instance 38 GHz) is highly influenced by precipitation especially by rain. Because of the used high frequency, the most degrading factor is the rain attenuation. To investigate wave propagation phenomena a rain attenuation and weather data measurement system was established. Currently in Hungary a number of point-to-point millimetre wave links operating in the frequency bands of 13, 15, 23 and 38 GHz. The received IF signal powers are collected together with the meteorological data, using weather station for data collection at different locations. Different statistics, which are important for analysis of wave propagation phenomena, are derived from our available measured data such as fade duration, number of events and fade slope.

1. Introduction

In this paper the dynamics of rain attenuation will be presented due determining some second-order statistics such as fade duration and fade slope statistics for the 38 GHz links in Hungary [1]. To prepare these second-order statistics a one year period data measured in 2004 is considered. Fade duration statistics will be compiled for attenuation exceeding different attenuation levels (fade thresholds) from 5 up to 30 dB.

The fade slope statistics will be analyzed different ways. The conditional probability density function of fade slope will be presented. To verify our mathematical model apply to measurement results for calculating conditional distribution function of fade slope [2]. In this contribution to evaluate the dynamics of rain attenuation, the number of events and fade duration statistics has been determined for the 38 GHz links in Hungary. The parameters of the investigated links are described in Tab.1.

The paper is organized as follows: Section 2 presents the fade duration, Section 3 describes fade slope, Section 4 presents our data processing method while Section 5 shows our results and conclusions are given in Section 6.

Balázs Héder (PhD student)
Budapest University of Technology and Economics
Department of Broadband Infocommunications and Electromagnetic Theory
Goldmann György tér 3.
Budapest, H-1111
Hungary
Tel: +36-1-4632769
Fax: +36-1-4633289
E-m: balazs@docs.mht.bme.hu

Róbert Singliar (PhD student)
Budapest University of Technology and Economics
Department of Broadband Infocommunications and Electromagnetic Theory
Goldmann György tér 3.
Budapest, H-1111
Hungary
Tel: +36-1-4632769
Fax: +36-1-4633289
E-m: Roberto@docs.mht.bme.hu

János Bitó (PhD)
Budapest University of Technology and Economics
Department of Broadband Infocommunications and Electromagnetic Theory
Goldmann György tér 3.
Budapest, H-1111
Hungary
Tel: +36-1-4633616
Fax: +36-1-4633289
E-m: bito@mht.bme.hu

Link node	Site name	Frequency band [GHz]	Polarisation	Length [km]	Azimuth [deg]
HU01	BME V2	38	H	0.32	180
HU11	Kondorosi út	38	H	1.5	238.3

Table 1: The investigated links

2. Fade duration

Fade duration indicates the time length during which attenuation will exceed a certain threshold value. Fade duration statistics have been compiled for attenuation exceeding the 5, 10, 15, 20, 25 and 30 dB levels and plotted in Fig. 1-2. Shown is the number of events for which duration exceeds abscissa at the given level. As it was expected the number of events on longer links is higher than on the shorter ones, and also the duration of fade events is longer. The events with long duration (greater than 1000 sec) are presumably caused by sleet or melting snow on the antennas. The data are retrieved from the database files for a one year period (2004). The first processing step is the calculation of the median value of the data. This has been made with using the secondary database containing events with start/end time. The exclusion of the event periods from the calculation of the median provides a more accurate median value. However, our calculation shows that the difference of the value of median if we calculate it by including the events (using every measurement data) is not greater than 0.2 dBm comparing with the value calculated with the aid of the event database.

3. Fade slope

Fade slope indicates the rate of change of rain attenuation. The knowledge of fade slope of attenuation caused by rain or other meteorological events are very important for fade mitigation techniques. Knowledge of this parameter is important for determining the required tracking speed of fade mitigation techniques. The fade slope depends on attenuation level, on sampling time and on climatic parameters (drop size distribution and therefore on the type of rain).

For each sample *i* the fade slope $\varsigma(i)$ was calculated as:

$$\varsigma(i) = \frac{A(i+1) - A(i-1)}{2} \quad \text{(dB/s)}, \tag{1}$$

where *A(i)* is attenuation and *i* is the sample number.

Several prediction models of fade duration distribution have been published in literature. We describe only the Van de Kamp model as the most relevant model. The model was compared to measurements from other sites in Europe and the U.S. The model has been proposed to the ITU-R as a draft new model for the prediction of fade slope.

For the conditional distribution of fade slope ς for fixed values of attenuation *A*, a reasonable fit was found with the following model distribution

$$P(\varsigma|\sigma_\varsigma) = \frac{2}{\pi\sigma_\varsigma\left(1+\left(\frac{\varsigma}{\sigma_\varsigma}\right)\right)^2}, \tag{2}$$

where σ_ς is the standard deviation of the conditional fade slope at a given attenuation level, given by:

$$\sigma_\varsigma = SF(f_B, \Delta t)A \quad \text{dB/s} \tag{3}$$

$$F(f_B, \Delta t) = \sqrt{\frac{2\pi^2}{(1/f_B^b + (2\Delta t)^b)^{1/b}}} \tag{4}$$

with A is the attenuation level (dB);

f_B is the 3 dB cut-off frequency of the low pass filter (Hz);

Δt is the time interval length over which fade slope is calculated (s);

b = 2.3;

S is a parameter which depends on climate and elevation angle; an overall average value in Europe and the United States, at elevations between 10 and 50 degree, is S = 0.01

In the case where the filter used to remove scintillation is a moving-average filter, the effective low-pass filter bandwidth f_B can be estimated from the averaging time length t_a of these filters as [2]:

$$f_B = 0.719 / t_a \tag{5}$$

4. AGC data processing, removing scintillation

The measured AGC data of the investigated PDH links are processed at the central measuring node located in Budapest University of Technology and Economics. Using the conversion table the received RF power level can be determined from the measured AGC voltage. Defining the zero dB attenuation, the instantaneous attenuation of any microwave link can be determined from the RF signal level.

To calculate slope of the attenuation component from measured time series, it is necessary to remove the rapid component of the signal, containing fast fluctuations of both rain attenuation and scintillation. This method is discussed in detail in Stutzman *et al* [3]. The quantity of interest, $X_R(t)$ (attenuation due to rain at time *t*) is estimated as $\bar{X}_R(t)$, where

$$\bar{X}_R(t) = \frac{1}{t_a} \sum_{i=t-t_a/2}^{t+t_a/2} X(i), \tag{6}$$

where $\bar{X}_R(t)$ is the moving average time function calculated with t_a second integration time.

5. Results

Figures 1-2 show the fade duration statistics of the investigated links for the year 2004. The curves show how many seconds was the attenuation on the link equal or higher than a given level in the whole year.

On Figures 3-4 the conditional probability density of fade slope determined from the measured data for different attenuation levels are presented. These density functions are symmetrical around zero. Please observe that the density functions determined for link HU11 has higher deviation than the density functions for link HU01. Possibly the different link length causes this phenomena.

Fig. 5 shows the conditional probability density of fade slope for 5 dB attenuation level on link HU11 and the curves determined from Van de Kamp model in eq. (2) and our new result derived from the Van de Kamp model called modified Van de Kamp model given in eq. (7). We can obtain that the Van de Kamp model is not fitting exactly to the measured fade slope curve, because the Van de Kamp model is suggested for less than 38 GHz frequency and for higher elevation angle than 10 degree. The investigated links are operating in 38 GHz and the elevation angles are around zero degree. Therefore we applied our new modified Van de Kamp model which fits more accurately. The $\sigma_\varsigma^{'}$ parameter of this model was determined by minimum RMSE method.

$$P(\varsigma|\sigma_\varsigma^{'}) = \frac{4}{\pi\sigma_\varsigma^{'}\left(1+\left(\frac{\varsigma}{\sigma_\varsigma^{'}}\right)\right)^2} \tag{7}$$

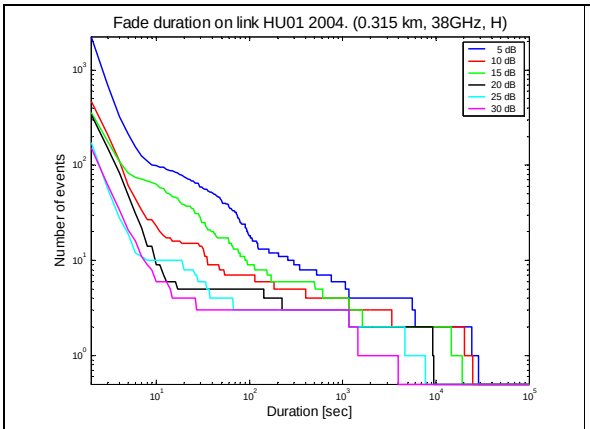

Fig.1. The Fade Duration on link HU01

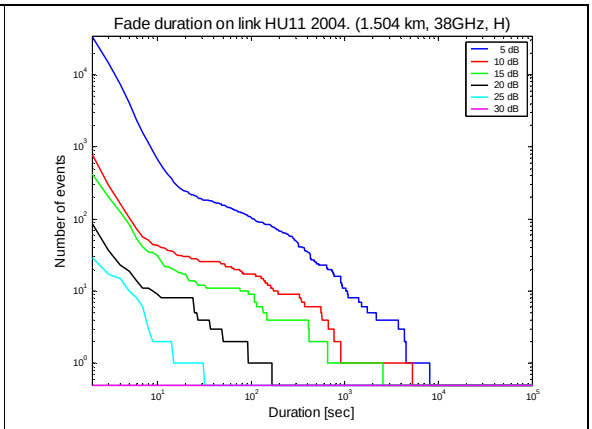

Fig.2. The Fade Duration on link HU11

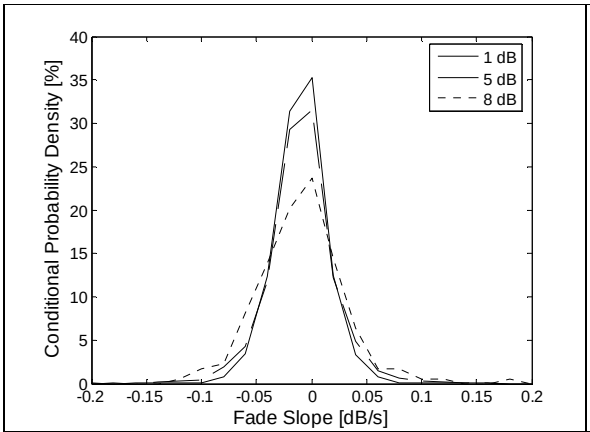

Fig.3. The Conditional Probability Density of Fade Slope for different attenuation levels on link HU01

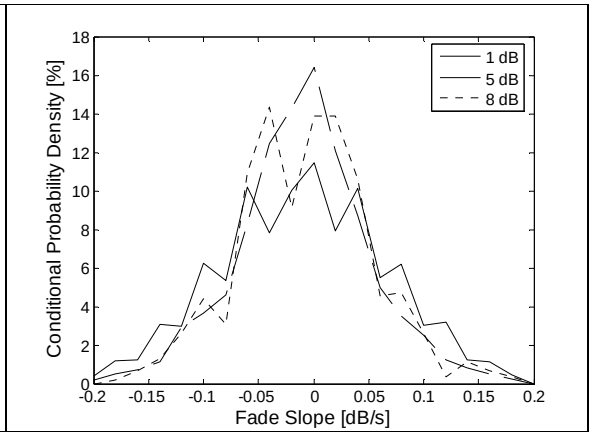

Fig.4. The Conditional Probability Density of Fade Slope for different attenuation levels on link HU11

The *SSE (Sum of Squares of Errors)* and *RMSE (Root Mean Squared Error)* can be determined with evaluating (8) and (9). In the expressions m is the number of the fitted coefficients, n is the residual degrees of dependence, y_i is the data to fit and the $\hat{y}_i$ is the fitted data.

$$RMSE = \sqrt{\frac{SSE}{n-m}} \tag{8}$$

$$SSE = \sum_{i=1}^{n} (y_i - \hat{y}_i)^2 \tag{9}$$

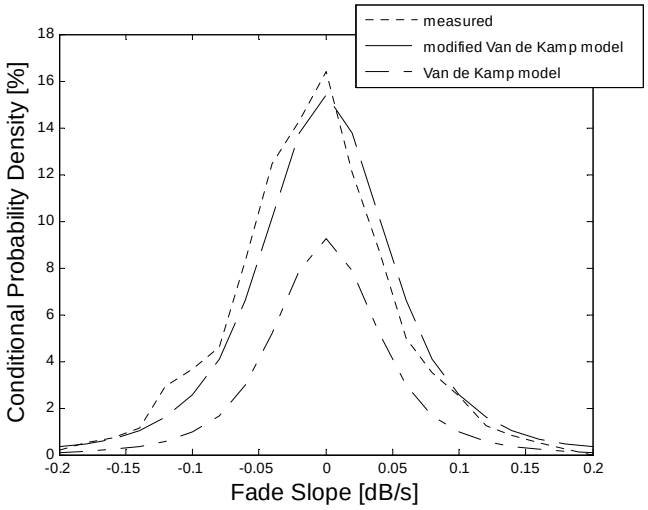

Fig.5. The Conditional Probability Density of Fade Slope for 5 dB attenuation level on link HU11 determined from measured data, from Van de Kamp model (2) and from the modified Van de Kamp model (7)

Link	Treshold [dB]	σ_ς	σ'_ς	SSE	RMSE
HU01	1	0.014	0.036	230.2	3.393
	5	0.069	0.04	176	2.967
	8	0.11	0.055	68.43	1.85
HU11	1	0.014	0.123	32.52	1.275
	5	0.069	0.083	20.97	1.024
	8	0.11	0.092	64.88	1.801

Tab.2. The σ_ς parameter of the Van de Kamp model, the σ'_ς parameter and the RMSE (4) and SSE (5) values of the modified Van de Kamp model by fitting for different threshold levels

On Fig. 6-11 the measured and from the modified Van de Kamp model obtained conditional probability densities of fade slope are depicted for 1, 5 and 8 dB attenuation levels and for two different links. The σ'_ς parameters of the model are presented in Tab.2 for the different links and the different attenuation levels. The obtained SSE and RMSE values are also shown in Tab.2.

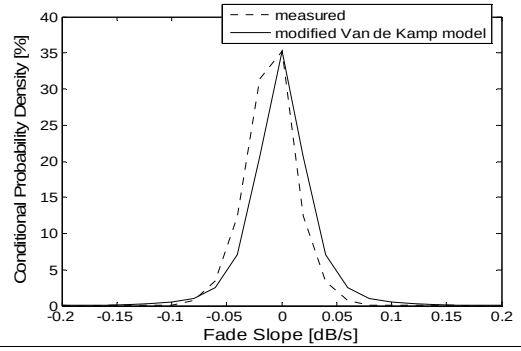

Fig.6. The Conditional Probability Density of Fade Slope for 1 dB attenuation level on link HU01 determined from measured data, and from the modified Van de Kamp model (7)

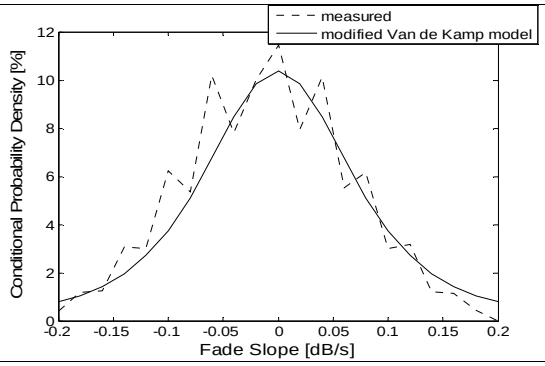

Fig.7. The Conditional Probability Density of Fade Slope for 1 dB attenuation level on link HU11 determined from measured data, and from the modified Van de Kamp model (7)

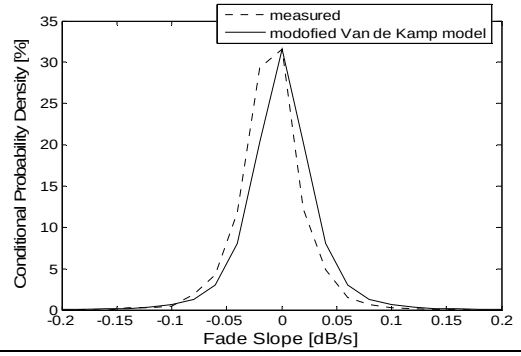

Fig.8. The Conditional Probability Density of Fade Slope for 5 dB attenuation level on link HU01 determined from measured data, and from the modified Van de Kamp model (7)

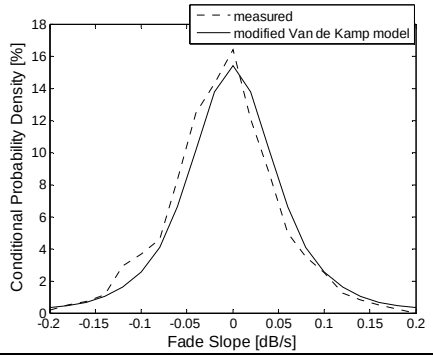

Fig.9. The Conditional Probability Density of Fade Slope for 5 dB attenuation level on link HU11 determined from measured data, and from the modified Van de Kamp model (7)

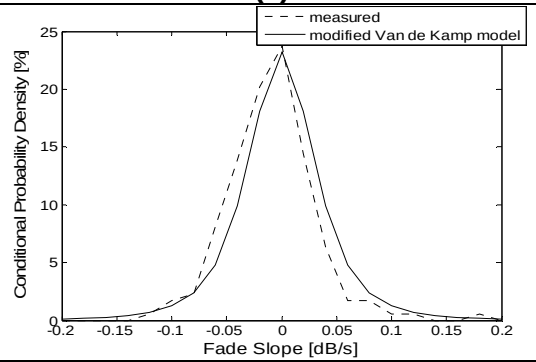

Fig.10. The Conditional Probability Density of Fade Slope for 8 dB attenuation level on link HU01 determined from measured data, and from the modified Van de Kamp model (7)

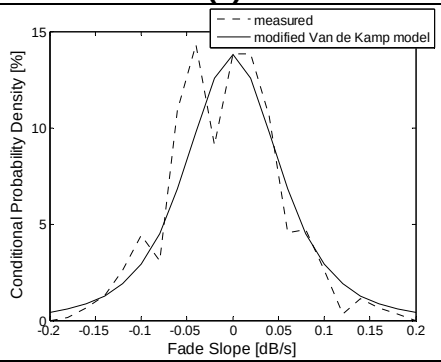

Fig.11. The Conditional Probability Density of Fade Slope for 8 dB attenuation level on link HU11 determined from measured data, and from the modified Van de Kamp model (7)

7. Conclusions

We have been investigating fade duration and fade slope statistics of a one year measured data for two point-to-point microwave link operating in 38 GHz. We draw the conclusion that the Van de Kamp model isn't perfect for this frequency band and for terrestrial links. However our new model derived from Van de Kamp's results called modified Van de Kamp model is better to estimate the measured fade slope density functions for terrestrial microwave links. The deviation parameter of this modified model was determined by SSE and RMSE method. As future work an exact expression of this parameter should be provided.

Acknowledgement

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References

[1] ITU-R P. 1623, "Prediction method of fade dynamics on Earth-space paths", *ITU*, Geneva, Switzerland, 2003

[2] Max M. J. L. van de Kamp, "Statistical Analysis of Rain Fade Slope", *IEEE Transactions on Antennas and Propagation*, Vol. 51, No. 8, August 2003, pp 1750-1759

[3] Stutzman W.L.,Pratt T., Shafaai-Jazi A., Remaklus P.W., Latse J., Nelson B. and Ajay H., "Results from the Virginia Tech propagation experiment using the Olympus satellite 12, 20 and 30 GHz beacons", *IEEE Transactions on Antennas and Propagation*, Vol. 43, No. 1, 1995, pp 54-62