Fade Duration and Fade Slope Statistics Derived from Long-Term Anik-F2 Satellite Beacon Measurements in Ottawa-Canada

César Amaya[1], *and Tu Nguyen*[2]

[1]Communications Research Centre Canada, Box 11490, Ottawa, Canada, K2H 8S2. E-mail:cesar.amaya@crc.gc.ca

[2]As (1) above, but E-mail:tu.nguyen@crc.gc.ca

Abstract

Fade duration and fade slope statistics are used to describe the dynamic behavior of attenuation experienced by terrestrial and satellite radio links. They provide essential information for the design of fade mitigation techniques such as up-link power control, adaptive coding and modulation, and data throughput reduction. Duration and slope statistics covering the 4-year period 2006-2009 have been calculated using propagation data collected at the Communications Research Centre (CRC) in Ottawa from the 20-GHz beacon signal of Telesat's Anik-F2 satellite. The duration distributions have been used to test the performance of several prediction models, including one recommended by the ITU-R and one developed at CRC, and to investigate possible model refinements. The conditional probability density function (PDF) of fade slope shows general symmetry between positive and negative slope values. Models based on symmetric distributions have been proposed in the literature. The cumulative distribution function (CDF) of the absolute value of fade slope reflects the dependence of the rate of change on fade level. Slope CDFs are used to test the ITU-R prediction model. Finally, the comparison of long-term slope statistics derived from the 20- and 30-GHz ACTS satellite beacon signals collected at CRC confirms the frequency-independent behaviour of fade slope in this band.

1. Introduction

Propagation data collected at Ka- and Q/V-bands during campaigns with the ACTS and Italsat satellites in North America and Europe show that strong rainfall events may induce periods of very deep fading, likely requiring the use of one, or a combination of several, fade mitigation techniques (FMT), such as up-link power control, reduction of data throughput, adaptive change of modulation and/or signal coding, and site diversity reception. Moreover, cloud and atmospheric gas-induced absorption can be substantial at Q/V-band and must be considered in the total power budget. In tropical areas, mitigation techniques may be required even at Ku-band due to extremely intense rainfall events. In addition to long-term attenuation statistics, the design of FMTs require the detailed information on fade behavior provided by second-order statistics, namely, duration of fade and between fades, and the fade rate or fade slope.

The characterization of fade dynamics in the 10-50 GHz frequency band has been underway at CRC for a number of years. It included, more recently, the creation of a large database of fade duration distributions measured in temperate and tropical locations [1], the development of a prediction model for fade duration statistics [2], and the analysis of fade slope statistics derived from Anik F2, ACTS, Olympus, and Italsat satellite beacon data. Duration and slope statistics derived from a new propagation experiment that monitors the 20.199-GHz Anik F2 satellite beacon signal at CRC are used in this paper to further analyze the characteristics of fade dynamics, test the performance of several duration and slope prediction models and investigate refinements of models. Measurements started in Ottawa (45.35°N, 75.89°W) in 2006, using a receiver built in-house and equipped with a 2.4-m diameter Cassegrain antenna. The link elevation angle is 27.3° and the fade dynamic range exceeds 45 dB, allowing the monitoring of very deep fades. More details on the experiment can be found in [3].

2. Fade Duration

The duration of a fade is defined as the time interval between two consecutive crossings of the same attenuation threshold. Fade duration statistics are usually presented as conditional distributions of the number of fade events exceeding certain durations, given that a specified fade threshold has been exceeded. This representation provides information on the number of outages and system availability due to propagation on a link, given a fade margin and an availability specification. The ITU-R defines duration statistics by two different types of conditional CDF [4]: (a) the probability of occurrence of fades of duration d longer than D (s), given that the attenuation a is greater

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than A (dB), expressed as $P(d>D|a>A)$, and called for simplicity $P(d)$ in this paper; and (b) the total fraction of fade time due to fades d longer than D, given that $a>A$, referred to as $F(d)$ in this paper. Fig. 1 shows $P(d)$ and $F(d)$ derived for an 8-dB threshold from data unfiltered and also low-pass filtered using a raised cosine filter with three different integration times, 10, 20 and 30 seconds (filtering is usually applied to remove scintillation). The impact of filtering on $P(d)$ is substantial due to the suppression of a large number of short events. The impact on $F(d)$ is still apparent but less significant. $P(d)$ and $F(d)$ roughly approach a lognormal behaviour as the filter integration time increases. Conditional exponential distributions have also been successfully used to model statistics derived at 20 GHz from data previously filtered [5], and statistics derived from radiometric measurements at 12 GHz [6].

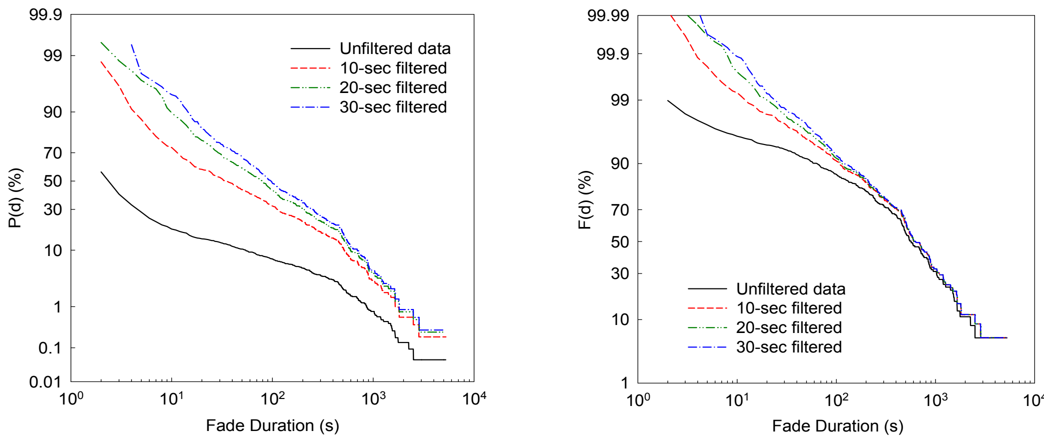

Fig. 1 Conditional CDFs of relative number of fades, $P(d)$, and of total fraction of fade time, $F(d)$, for an 8-dB fade threshold. Dashed lines show CDFs from data filtered using a raised cosine filter with 10-, 20-, and 30-s integration time.

Through the analysis of a large database of duration distributions, CRC proposed a new model to predict statistics derived from unfiltered beacon data [2]. It consists of the sum of two lognormal functions, one accounting for the short- and the second for the long-duration region of the distribution, adopting the form:

$$P(d) = \alpha \; \frac{(Q(\ln(D/m_s)/\sigma_s)}{(Q(\ln(1/m_s)/\sigma_s)} + (1-\alpha)\frac{(Q(\ln(D/m_r)/\sigma_r)}{(Q(\ln(1/m_r)/\sigma_r)} \tag{1}$$

where $D \geq 1$ sec and Q is the standard CDF for a normally distributed variable; m_s and σ_s are the mean and standard deviation of the first lognormal function describing the short-duration region; m_r and σ_r are the mean and standard deviation of the second lognormal function describing long durations (generally ascribed to rain); and α defines the fraction of fades associated with each lognormal. The comparison of measured and modeled $P(d)$ distributions displayed in Fig.2 shows that the CRC model matches the measurements better than the model proposed by the ITU-R [4]. Table 3 presents the mean, standard deviation and RMS values of the difference between predictions by four models and $P(d)$ derived from Anik F2 data collected in 2006-2009.

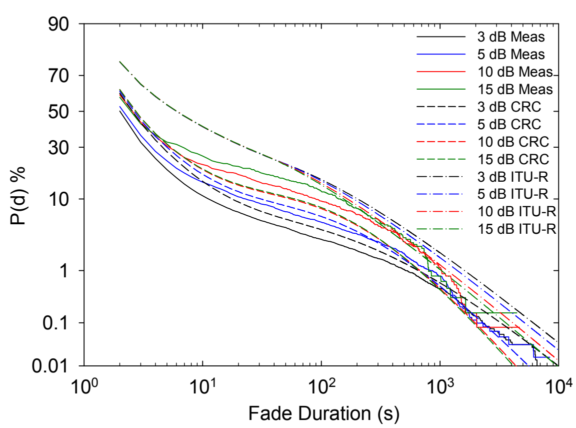

Fig. 2 Comparison of measured $P(d)$ with results from CRC and ITU-R models for 3, 5, 10 and 15 dB fade thresholds.

TABLE I. PREDICTION ERROR OF FOUR MODELS WHEN COMPARED WITH $P(d)$ DERIVED FROM ANIK F2 DATA COLLECTED IN 2006-2009

Model	ITU-R	D-H	COST 205	CRC
Mean	0.66	0.40	0.34	-0.2
Std	0.63	0.33	0.52	0.42
RMS	0.91	0.52	0.62	0.46

The models tested are: ITU-R, Dissanayake-Haidara (D-H) [7], COST 205 [8], and CRC. The prediction error is defined as: ln [$P(d)_{modeled} / P(d)_{measured}$], calculated for each attenuation threshold between 2 and 20 dB in 2-dB steps and for each fade duration recommended by the ITU-R. If the RMS value is assumed to be an adequate metric for assessing the prediction deviation, then the CRC model yields the best predictions for this data set.

3. Fade Slope

The fade slope describes the rate of change of attenuation with respect to time, in dB/s. To quantify the slowly-varying rain attenuation, adequate low-pass filtering to suppress scintillation is critical. For this purpose, a raised cosine filter with a 30-s integration time was applied to attenuation time series. After filtering, fade slopes were calculated in time intervals, Δt, of 2 and 10s and joint statistics of slope and attenuation were derived. Fig. 3 shows PDFs of fade rate conditioned to 3-, 5-, 10- and 15-dB attenuation levels, for Δt=2s. As observed, the distributions at every level show general symmetry around zero for positive and negative slopes. The conditional CDFs of the absolute value of fade slope (see Fig. 4), calculated for Δt=2 and 10s, show that the probability of exceeding a given slope value increases with attenuation. Also, the use of Δt=10s instead of 2s produced slightly smaller slope values, for the same fade levels.

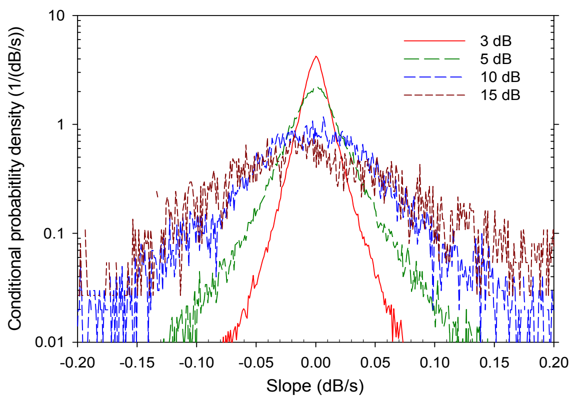

Fig. 3 Conditional PDF of fade slope for various different attenuation levels.

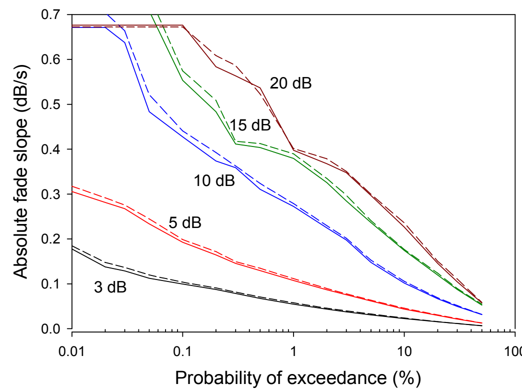

Fig. 4 Conditional CDF of absolute value of fade slope calculated for Δt= 2s (dashed lines) and 10s (continuous lines).

Van de Kamp [9] proposed a fit to measured conditional PDFs of fade slope. It is a distribution symmetrical around zero, expressed as:

$$p(FS \mid A) = 2 / \left[\pi \sigma_{FS} \left(1 + \left(FS / \sigma_{FS} \right)^2 \right)^2 \right] \quad (dB/s)^{-1} \tag{2}$$

where σ_{FS} is the standard deviation of the conditional fade slope at a given attenuation level. In ITU-R Rec. P.1623 [4], σ_{FS} is defined as:

$$\sigma_{FS} = sF(f_B, \Delta t)A \quad (dB/s) \qquad with \qquad F(f_B, \Delta t) = \sqrt{2\pi^2 / [1/f_B{}^b + (2\Delta t)^2]^{1/b}} \tag{3}$$

where b=2.3 and s is a parameter which depends on climate and elevation angle. A value of 0.01 is recommended for Europe and the U.S. The function F gives the dependence on Δt, and on f_B, the 3-dB low-pass filter bandwidth used to remove scintillations. In the expressions above, fade slope is independent of frequency. The conditional probability that the absolute value of fade slope is exceeded for a given attenuation level, is derived from Eq. 2 [4] as:

$$P(|FS| \mid A) = 1 - \frac{2(|FS|/\sigma_{FS})}{\pi(1 + (|FS|/\sigma_{FS})^2)} - \frac{2\arctan(|FS|/\sigma_{FS})}{\pi} \tag{4}$$

The comparison of curves calculated using the ITU-R prediction model expressed by Eq. 4 with CDFs derived from Anik F2 measurements is displayed in Fig. 5. At the 3- and 5-dB attenuation levels the agreement is generally good for slope values below about 0.1 and 0.2 dB/s, respectively, above which the curves diverge; general good agreement was observed for the 10 and 15 dB levels. Fig. 5 shows CDFs derived from the 20- and 30-GHz NASA ACTS satellite beacon data collected at CRC during the period November 1997-October 2001. The distributions at the same attenuation level are very close to each other, confirming the independence of fade slope on frequency, valid at least up to 50-GHz as has been demonstrated by the analysis of slopes derived from Italsat data at 20-, 40-, and 50-GHz.

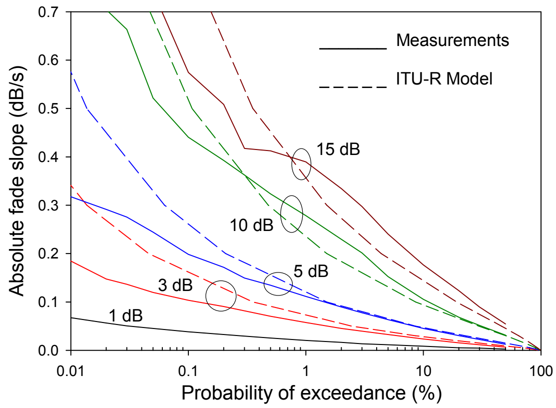

Fig. 5 Comparison of absolute fade slope CDFs derived from Anik F2 with the model in ITU-R Rec. P.1623 [4].

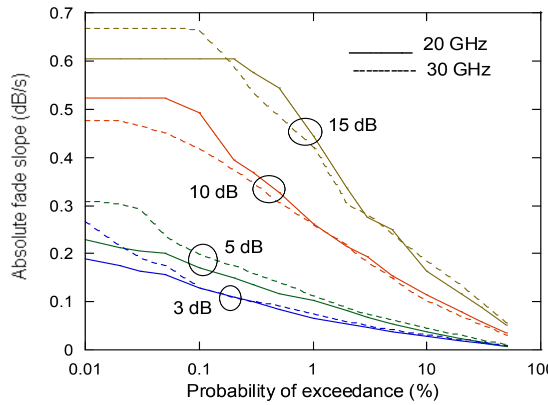

Fig. 6 Conditional CDFs of absolute fade slope from the 20 and 30-GHz ACTS satellite data collected at CRC during 4 years.

4. Conclusion

Fade duration and fade slope statistics derived from the 20-GHz Anik F2 beacon signal data collected at CRC during the period 2006-2009 were analyzed. It was observed that low-pass data filtering substantially increases the probability of occurrence of fades and, to a lesser degree, the total fraction of fade time. This fact must be considered when developing empirical models based on the fitting of measured distributions, and during the test of existing models. The performance of four fade duration models was tested using distributions derived from unfiltered Anik F2 beacon data. The best predictions were produced by a new model proposed by CRC and based on the combination of two lognormal distributions. Conditional PDFs of fade slope showed general symmetry between positive and negative slopes. CDFs of absolute fade slope displayed a clear dependence of fade rate on attenuation level. The comparison of fade slope CDFs with the prediction model in ITU-R Rec. P.1623 showed general good agreement. Predictions at the 3- and 5-dB fade levels were accurate for rates below about 0.1-0.2 dB/s; better results were obtained at 10- and 15-dB. The frequency-independent behaviour of fade slope was confirmed through the comparison of CDFs derived from the 20- and 30-GHz ACTS satellite beacon signals collected at CRC between 1997 and 2001.

5. References

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