# INTERFERENCE FADING PREDICTION ON THE LINE-OF-SIGHT RADIO LINKS

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## Abstract

*The fading on the LOS links is an important factor influencing the reliability of the communication. In this paper predictions models for interference fading are described. Predictions are compared with measured data of the experiment of TESTCOM & CTU PRAGUE in the frequency 13GHz.*

## Keywords

interference fading, absorption fading, average worst month,

## 1. Fading on the Links

Fading on the LOS links can be divided into fading caused by interference and fading caused by absorption. Absorption fading is the phenomenon, where the electromagnetic wave between transmitter and receiver is tempered in the losing media (rain, snow, hail). This fading should last few hours and its value depends on the rain intensity (Fig.1).

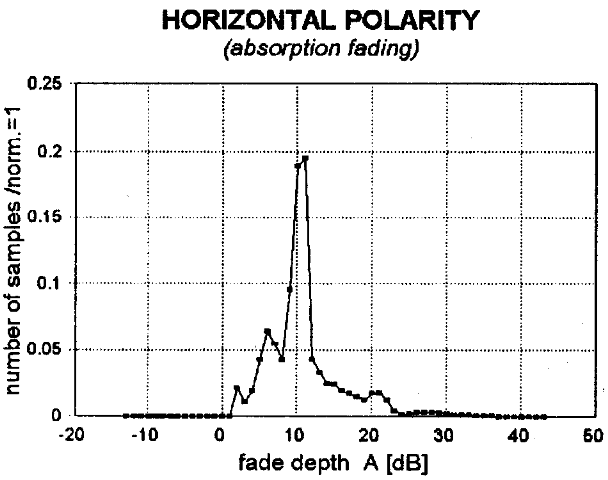


Fig. 1 Absorption fading distribution in January 95 - (H polarity)

The modified prediction model by Lin [10] was used as acceptable model for the experiment realised by TESTCOM & CTU PRAGUE. The average long time rain intensity in our territory is known and a lot of predictions methods were described too.

Interference fading occurs when various electromagnetic waves interfere. (This is caused by the reflections from the medium with different relation index.) As an interference data (Fig.2) is considered the fading without fading caused by absorption. This is a problem of the measurement and appropriate software data selection. In this article only the interference fading is discussed. These results are important for calculation of selective fading too (special case of interference fading).

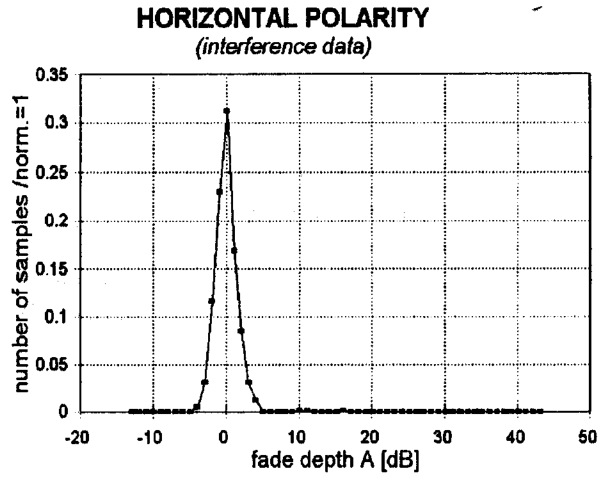


Fig. 2 Interference data distribution in February 95

Copolar time distributions of received signal is usually more useful Fig.3:

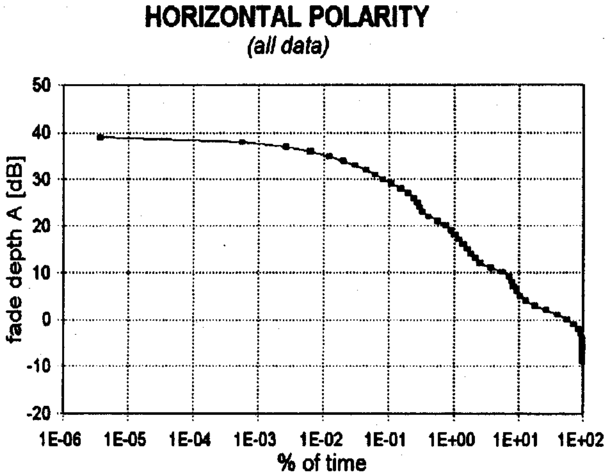


Fig. 3 Received signal (all data) in January 95

The graph in Fig.3 shows fading for the chosen percentage of time. The envelope of single months time distributions graphs in the year defines a curve for the „worst month“.

The interference fading A [dB] can be approximated by (1) for the small percentages of time [2], [3], [5].

$$p_w = p_{in} \cdot 10^{\frac{A}{10}} \qquad (1)$$

where
- $p_w$ exceedance probability [%]
- $p_{in}$ probability of interference fading [%] $p_{in} = P(A>0)$
- $A$ fade depth [dB]

Note 1: Definition $p_{in}$ is described in paragraph 2.

# 2. Probability of Interference Fading

## 2.1 Probability of Interference Fading (Standard Method Definition)

This method was published by A. Vigants [1] and described in [2], [3] later, where specific constants for our locality (the Czech territory) are included. The equation for the calculation of interference fading probability is usually in the form (2), when constants $A_X$, $B$, $C$ are shown in table 1.

$$p_{in} = A_X \cdot f^B \cdot d^C \qquad (2)$$

where
- $p_{in}$ probability of interference fading [%]
- $f$ frequency [GHz]
- $d$ path length
- $A_X$, B, C constants give in Tab. 1

The constant $W$ in table 1 representing the roughness of the terrain profile can be calculated from (3)

$$w = \sqrt{\frac{1}{m} \cdot \sum_{i=1}^{m} h_i^2 - \left( \frac{1}{m} \cdot \sum_{i=1}^{m} h_i \right)^2} \qquad (3)$$

where
- $h_i$ height above the sea level in position $i$ [m]
- $m$ number of points, where the position was calculated [-]

For calculations: this constant is limited within an interval from 6 to 43 metres. Because this constant is greater than the upper limit for majority of our territory [4], use $w$ = 43 m. (For example: For link Klínovec-Zelená hora actual $w$ =148 m by 43 m are replaced [7], [8].)

## 2.2 Method for Initial Planning Purposes

A. For the path location in question the geoclimatic factor K, can be estimated from the contour maps [6] for the percentage of time $p_L$ that the average refractivity gradient in the lowest 100 m of the atmosphere is less than -100 N units/km, and by the following empirical relations:

For overland links where antennas are situated less than 700 m above the mean sea level can be used

$$K = 10^{-(6.5 - C_{Lat} - C_{Lon})} \cdot p_L^{1.5} \qquad (4)$$

For overland links where the antennas are situated higher than 700 m above the mean sea level

$$K = 10^{-(7.1 - C_{Lat} - C_{Lon})} \cdot p_L^{1.5} \qquad (5)$$

where the coefficient $C_{lat}$ is given by

| | | |
|---|---|---|
| $C_{Lat} = 0$ | $53°S \geq \xi \leq 53°N$ | (6) |
| $C_{Lat} = -5.3 + \xi/10$ | 53°N or °S < $\xi$ <60°N or °S | (7) |
| $C_{Lat} = 0.7$ | $\xi \geq$ 60°N or °S | (8) |

and the longitude coefficient $C_{lon}$

| region: | north-west Europe | U.S. | Russia | Czech republic |
|---|---|---|---|---|
| $B$ | 1.0 | 1.0 | 1.5 | 1.0 |
| $C$ | 3.5 | 3.0 | 2.0 | 3.0 |
| *A1*... seaside and tropic regions | | $4.1 \cdot 10^{-5} \left( \frac{W}{15.2} \right)^{-13}$ | $2 \times 10^{-5}$ | |
| *A2*...lowlands and subtropic regions | | $3.1 \cdot 10^{-5} \left( \frac{W}{15.2} \right)^{-13}$ | | $3.0 \cdot 10^{-5} \left( \frac{W}{15.2} \right)^{-13}$ |
| *A3* .. .middle climatic regions | $1.4 10^{-8}$ | $2.1 \cdot 10^{-5} \left( \frac{W}{15.2} \right)^{-13}$ | $4.1 \times 10^{-6}$ | $1.5 \cdot 10^{-5} \left( \frac{W}{15.2} \right)^{-1.3}$ |
| *A4*...mountains regions | | $10^{-5} \left( \frac{W}{15.2} \right)^{-13}$ | | $1.5 \cdot 10^{-5} \left( \frac{W}{15.2} \right)^{-1.3}$ |

Table 1 - constants for expression (2)

Note 2:
Region *A2* is considered:

- LON:(16-18)°E
  LAN:49°N
  (Southern Moravia)
- LON:18°E
  LAN:48.5°N

| | | |
|---|---|---|
| $C_{lon}$= 0.3 | longitudes of Europe and Africa | (9) |
| $C_{lon}$= - 0.3 | longitudes of North and South America | (10) |
| $C_{lon}$= 0 | other locations | (11) |

Note 3: The percentage of time $p_L$ varies during the year, but for the central Europe territory is approximately 2.

**B.** For antenna heights $h_e$ and $h_r$ (in meters above the sea level) the magnitude of path inclination can be calculated by (12)

$$|\varepsilon_P| = |h_r - h_e| / d \qquad (12)$$

where
- $\varepsilon_p$ magnitude of the path inclination [rad]
- $h_e$ , $h_r$ antenna heights ( [m] above sea level)
- $d$ path length [m]

Note 4: In the ITU-R document [5] the milliradians are used in the formula (12). However there was an agreement between predicted and measured data for $|\varepsilon_p|$ using radians as Fig. 4-6 shows. (Antenna heights $h_e$ , $h_r$ and the path length must be in identical units [rad; m, m] or [rad; km, km].)

**C.** The percentage of interference fading $p_{in}$ can be calculated from (13)

$$p_{in} = K \cdot d^{3.6} \cdot f^{0.89} \cdot \left(1 + |\varepsilon_p|\right)^{-1.4} \qquad (13)$$

where
- $p_{in}$ probability of interference fading [%]
- $K$ geoclimatic factor [-]
- $d$ path length [km]
- $f$ frequency [GHz]
- $\varepsilon_p$ magnitude of the path inclination [rad]

## 2.3 Method for Detailed Link Design

**A.** The geoclimatic factor $K$ can be replaced from (14), (15) by:

For overland links, where the antennas are situated less than 700 m above the mean sea level

$$K = 10^{-(5.4 - C_{Lat} - C_{Lon})} \cdot p_L^{1.5} \qquad (14)$$

For overland links, where the antennas are situated higher than 700 m above the mean sea level

$$K = 10^{-(6.0 - C_{Lat} - C_{Lon})} \cdot p_L^{1.5} \qquad (15)$$

**B.** The magnitude of the path inclination $|\varepsilon_p|$ is calculated like in the method 2.2 .

**C.** From the profile of the terrain along the path we can define the terrain heights $h$ for intervals of 1.0 km, beginning 1.0 km from one terminal and ending 1-2 km from the other. Using these heights, caring out a linear regression the equation of the "average" profile can be obtained as (16)

$$h(x) = a_0 x + a_1 \qquad (16)$$

where
- $h(x)$ ... average profile
- $x$ ... distance along the path

The regression coefficients $a_0$, $a_1$ can be calculated from (17), (18)

$$a_0 = \frac{\sum_n x \cdot h - \left(\sum_n x \sum_x h\right)/n}{\sum_n x^2 - \left(\sum_n x\right)^2/n} \qquad (17)$$

$$a_1 = \left(\sum_n h - a_0 \sum_n x\right) \cdot \frac{1}{n} \qquad (18)$$

$n$ the number of profile height samples

The heights of antennas above the average path profile are defined

$$h_1 = h_e - h(0) \qquad h_2 = h_r - h(d) \qquad (19)$$

- $h_1$ , $h_2$ heights of the antennas above the average path profile
- $h_e$ , $h_r$ antenna heights ( [m] above sea level)
- $h(0)$, $h(d)$ heights of the average profile at the ends of path

**D.** Average grazing angle corresponding to 4/3 earth radius model ($a_e$= 8 500 km) can be calculated

$$\varphi = \frac{h_1 + h_2}{d}\left[1 - m \cdot \left(1 + b^2\right)\right] \qquad (20)$$

where
- $\varphi$ the average grazing angle [mrad]
- $h_1$ , $h_2$ the heights of the antennas above the average path profile [m]
- $d$ length link [km]
- $m$, $c$, $b$ constants from (21), (22), (23)

$$m = \frac{d^2}{4 \cdot a_e \cdot (h_1 + h_2)} \qquad (21)$$

$$c = |h_1 - h_2| / (h_1 + h_2) \qquad (22)$$

$$b = 2 \cdot \sqrt{\frac{m+1}{m}} \cdot \cos\left[\frac{\pi}{3} + \frac{1}{3}\arccos\left(\frac{3c}{2}\sqrt{\frac{3m}{(m+1)^3}}\right)\right] \qquad (23)$$

Note 5: In the calculation of the coefficient $m$ and $c$, the variables $a_e$, $d$, $h_1$ , $h_2$ must be in the same units. The grazing angle $\varphi$ will be in the desired units of milliradians ($h_1$ , $h_2$ in metres, d in kilometres) - compare with [5].

**E.** The percentage of interference fading $p_{in}$ can be obtained as (24)

$$p_{in} = K \cdot d^{3.3} \cdot f^{0.93} \cdot \left(1+|\varepsilon_P|\right)^{-1.1} \cdot \varphi^{-1.2} \tag{24}$$

where
- $p_{in}$ probability of interference fading [%]
- $K$ geoclimatic factor [-]
- $d$ path length [km]
- $f$ frequency [GHz]
- $\varepsilon_p$ magnitude of the path inclination [rad]

## 3. Predicted and Measured Attenuation for Small Percentage of Time

For prediction of fading we use equation (1). Method described in section 2.1 for experimental link [7], [8] gives $p_{in}$=10.64%. Method described in paragraph 2.2 gives $p_{in}$=10.57% and method described in paragraph 2.3 gives $p_{in}$=2.26%. In Fig.4 prediction lines and measurement data from the link are compared.

As we can see, for method 2.1 and 2.2 there is a difference between measured and predicted agreement for fade depth greater that 7dB, because the experimental link is long and probability of interference fading is relatively big. The validity of this prediction is considered for fade depths greater than approximately 15 dB or for the exceedance probability value exceeding 0.1 % time of the worst month, whichever is greater [5]. The validity depends on $p_{in}$ as well. For $p_{in}$ > 1-2 %, we can consider validity for fade depths greater than about 10 dB.

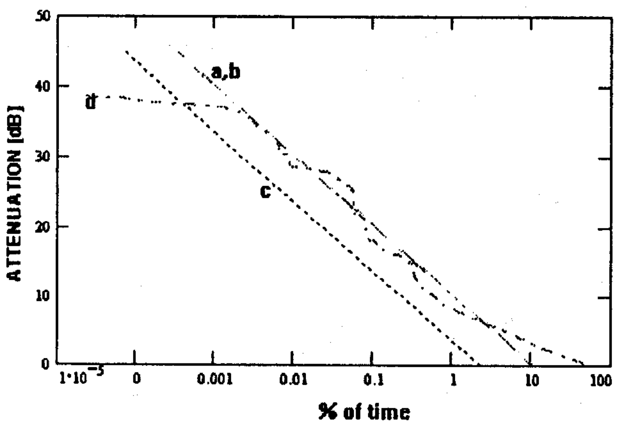


Fig. 4 - The distribution for small percentage of time:
a ... prediction method described in 2.1
b ... prediction method described in 2.2
c ... prediction method described in 2.3
d ... measurement interference data ( horizontal polarity ) - „worst month“ during May 1994 - April 1995

## 4. Combination of Rayleigh and Logaritmic-Normal Distribution

Vigants [1] considers prediction the distribution as

$$\Phi = (100 - p_{in}) \cdot \Phi_g + p_{in} \cdot \Phi_r \tag{25}$$

where
- $\Phi$ distribution function for fading
- $\Phi_q$ logaritmic-normal distribution
- $\Phi_r$ Rayleigh distribution
- $p_{in}$ probability of interference fading [%]

Fišer [9] modified original Vigants method and published empirical constants for this method (26)

$$P_m(A>A_{um}) = (1-p_{in}) \cdot (1-\Phi_q\{\frac{A_{um}-A_m}{\sigma_1}\}) + p_{in} \cdot \Phi_r\{A_{um}\} \tag{26}$$

$\sigma_1$ = 2.6 dB, $A_m$ = 0.7774 dB

where
- $P_m(A > A_{um})$ probability, that fade depth is more than $A_{um}$ [%]
- $p_{in}$ probability interference fading [%]
- $A_m$ empirical constant 0.7774 dB
- $\sigma_1$ empirical constant 2.6dB

$$\Phi_g(z) = \frac{1}{\sqrt{2\pi}} \cdot \int_{-\infty}^{z} e^{\left(-\frac{t^2}{2}\right)} dt \tag{27a,b}$$

$$\Phi_r(z) = 1 - e^{-10^{-\frac{z}{10}}} \qquad z \text{ in [dB]}$$

This prediction method of interference fading is appropriate also for large % of time as shows Fig. 5.

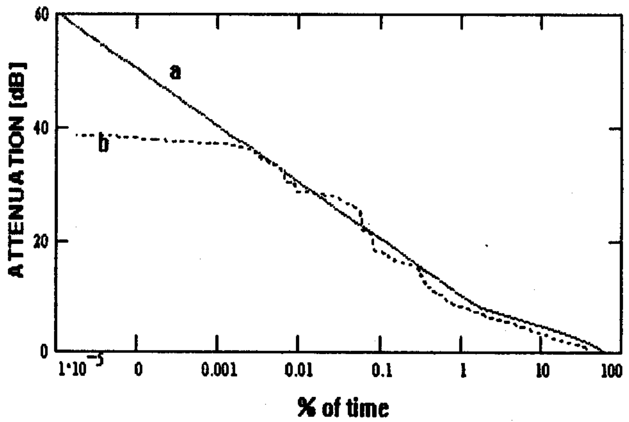


Fig. 5 - The combination of Rayleigh and Logaritmic-Normal distribution:
a ... this prediction method
b ... real interference data - „worst month“ during May 1994 - April 1995

## 5. Method for Various Percentage of Time (STEP-BY-STEP Method)

This method is described in detail in [5].

**A.** The percentage interference fading can be calculated by the some of the methods described in the paragraph 2. The percentage of time $p_w$ for 35 dB must be calculated from (1).

**B.** The value $q'_a$ gives the corresponding value for the fading fade depth $A$=35 dB and $p_w$ from step A.

$$q'_a = \frac{-20}{A}\cdot\log_{10}\left[-\ln\left(\frac{100-p_w}{100}\right)\right] \qquad (28)$$

where $p_w$ percentage of time that a fade depth is exceeded (exceedance probability) [%]
$A$ fade depth [dB]

**C.** The parameter $q_t$ is defined from (29)

$$q_t = (q'_a - 2)/[(1+0.3\cdot 10^{-A/20})\cdot 10^{-0.014\cdot A}] - 4.3(10^{-A/20} + A/800)$$

where $A$ fade depth [dB] (29)
$q'_a$ expression (28)

**D.** If $q_t > 0$ , steps A to C are repeated for $A$=25 dB.

**E.** The percentage of time $p_w$ that the fade depth $A$ is exceeded for $A$ >25 dB or $A$ > 35 dB is calculated using methods from paragraph 3. The percentage of time $p_w$ that $A$ is exceeded for $A$< 25dB, or $A$<35 dB is calculated from (30)

$$p_w = 100[1-\exp(10^{-q_a\cdot A/20})] \qquad (30)$$

where (31)

$$q_a = 2 + [1+0.3\cdot 10^{-A/20}]\cdot 10^{-0.014\cdot A}\cdot[q_t + 4.3(10^{-A/20} + A/800)]$$

$p_w$ percentage of time when fade depth is exceeded [%]
$A$ fade depth [dB]
$q_t$ function given by (29)

This prediction methods can be compared with measured data on Fig.6

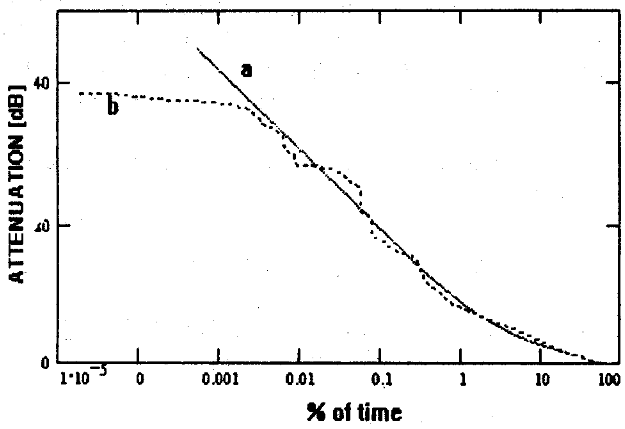


Fig. 6 - Method for various percentages of time:
a ... Step-by-Step prediction method
b ... measured interference data ( horizontal polarity ) - „worst month" during May 1994 - April 1995

## 6. Conclusion

The „hand-made" data selection has to be done very carefully, because two fundamentally mistakes can be observed. If we indicate as absorption fading „no rain time", the percentage occurrence of the absorption fading will be greater than possible. As shows in [11], 50 years statistics of rain intensity in the Czech Republic indicate probability of rain 5% of time roughly. If we don't cut out all absorption fading from the data, experimental curve (for the worst month) won't correspond with prediction models for interference fading. Experimental curve will be more unfavourable than prediction models.

For very small percentages of time the results are influenced by the dynamic range of measurement apparatus.

I would like to thank for support during data survey to my senior lectures Doc.Ing.M.Mazánek,CSc. (CTU) and Ing.V.Kvičera,CSc. (TESTCOM) and for valuable advice at work with predictions models of Ing.S.Ďurovič,DrSc. (TESTCOM) and Ing.O.Fišer,CSc.

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## About author...

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# INTERNATIONAL MEETING OF DEPARTMENTS OF RADIOELECTRONICS

The 19th International Seminar of Institutions a Departments of Radioelectronics of the Faculties of Electrical Engineering of Czech and Slovak Republics was held by the Department of Electronics FEI VŠB-TU in Ostrava and Society of Radioelectronic Engineering from 22th to 24th May 1996 at Soláň in Beskydy, Czech Republic. The participants of seminar came from fifteen departments of radioelectronics and electronics of technical universities in Belgium, Brasilia, Czech Republic, Slovakia, and Poland. As the guests of seminar was invited Prof. Paul Raes, (BME, Gent, Belgium), Prof. Stanley Novak, (Military University, Rio de Janeiro, Brasilia), Doc. Dr. Ing. Miroslav Pokorný, (vice-dean for Development FEI, VŠB-TU Ostrava, Czech Republic), Prof. Edward Hrynkiewicz, (Polytechnika Slaska, Gliwice, Poland), Ing. Václav Čížek, CSc., (AVČR, Praha).

Programme of Seminar started from the visit of the department of electronics of FEI, VŠB and its laboratories in VŠB Ostrava-Poruba campus. On the beginning was held the working session of participants with basic information about structure and working activities of departments. Education activities of departments as the new forms of education, bachelor-, master- and doctoral- (PhD) study, hitherto existing experience take turns by the excursion in Glass-works in Karolínka, or by the trip to Beskydy mountains.

The meeting of Society of Radioelectronic Engineering, and Editorial Board of Journal *RADIOENGINEERING* was held at the second day evening. Experiences from foreign universities and other cooperations was proceed on the last day morning. The weather changed from raining to sunshine. The end of seminar was very optimistic and it fulfil expectation of participants. The symbolic "relay peg" was handed over to Department of Radioelectronics FEI STU Bratislava, Slovakia.

*Karel Vlček*