DETERMINATION OF THE DOMINANT FADING AND THE EFFECTIVE FADING FOR THE RAIN ZONES IN THE ITU-R P.838-3 RECOMMENDATION

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ABSTRACT

The International Telecommunication Union (ITU) published well-tested models and data set for the prediction of fading (or attenuation) due to multipath and rain based on measurements on radio links across the globe. In respect of rain attenuation, ITU released ITU-R PN.837-1 recommendation in which ITU split the globe into 15 regions according to precipitation intensity. In this paper, a web application was developed to study the variation of rain attenuation, multipath attenuation, dominant attenuation and the effective fading experiencedbyterrestrial line of sight microwave links in any of the 15 ITU rain zones. The web application do generate tables and graph plots for the variation of the dominant fading and the effective fading with respect to frequency, link percentage availability, path inclination and point refractivity gradient. The web application was developed with PHP scripting language, MySQL database management system and then hosted online using apache web server. Sample computations were carried out for microwave frequencies in rain zone N which can be found in some parts of Nigeria. Rain and multipath attenuation data were obtained from ITU published data.In all, the result obtained in the paper showed that rain attenuation is the dominant fading for higher frequencies whereas, multipath fading do dominate at the lower frequencies. The frequency at which the transition from dominant multipath fading to dominant rain fading is not fixed. Rather, the turning point depends on different link parameter combinations. The results obtained in the paper showed how changes in link parameters like the link's percentage availability, the path's point refractivity index and the path inclination , can affect the frequency at which the dominant fading in a given rain zone transit from multipath fading to rain fading.

Keywords: Microwave Communication, Communication Link, Line Of Sight Microwave Communication, Rain Attenuation, Multipath Attenuation, Dominant Attenuation, Effective Attenuation. Web Application.

INTRODUCTION

Over the years, microwave communication links, including terrestrial and Earth-Space satellite links, operating at frequency band of 30-300 GHz, offer the large bandwidth and high capacity required for contemporary applications such as multimedia services. Furthermore, increasing number of users and growing complexity of multimedia have driven a demand for capacity that has pressured regulators to explore higher frequency bands for larger bandwidth. However, most of the atmospheric fade mechanisms are frequency dependent, and higher frequencies are usually associated with higher losses. Studies have found that, apart from free space loss, rain attenuation and multipath fading are major impairments in terrestrial microwave communication systems. Fortunately, research findings indicate that rain attenuation and multipath fading are independent events – they are approximately mutually exclusive. The mutual relation between rain and multipath attenuation, rules out the possibility that the link could be affected by both types of attenuation at the same time – these types of attenuation do not add up. Consequently, to determine the effective fade margin for microwave links, it is necessary to calculate both rain and multipath attenuation (or fading); the larger of the two fading is the dominant fading and the value of the dominant fading is the effective fading. In areas with high precipitation, rain attenuation can be expected to be more prominent. By contrast, links located in drier climates and little inclination, will suffer more from multipath attenuation.

In this paper, a web application is developed to determine rain attenuation, multipath attenuation, dominant attenuation and the effective attenuation that will be experience in microwave links in any of the 15 ITU rain zones. The web application also generated tables and graphs on the variation of the dominant fading and the effective fading with respect to frequency, link percentage availability, path inclination and point refractivity gradient. The web application was developed using PHP scripting language, MySQL database management system and them hosted locally using apache web server. Sample computations of multipath fading, rain fading, as well as the dominant fading and the effective fading were carried out for terrestrial microwave line-of-sight communication link in the ITU rain zones N which can be found in some parts of Nigeria.

REVIEW OF RELATED LITERATURE

There are several sources of signal attenuations that can affect a microwave signal in the troposphere. These attenuations include beam spreading (defocusing), antenna decoupling, atmospheric gaseous absorption, rain attenuation, tropospheric scattering under a clear-air condition, and multipath fading among others [1]. Most of these mechanisms can occur by themselves or in combination with each other [2]. In the determination of fade margin for terrestrial microwave links the rain attenuation, and multipath fading are mostly considered along with the free space pathloss [3].

Rain attenuation is defined as signal loss in dB at the receiver due to rain events. Calculation of rain attenuation for a microwave link requires integration of the specific attenuation along the link's path. [4] provides the international recognized model to calculate specific attenuation of rain from the rain rate. The specific attenuation, γR(dB/km) is obtained from the rain rate R (mm/hr) using the power law relationship:

$$\gamma_R = kR^{\alpha} \qquad (1)$$

where k and α are frequency and polarization dependent coefficients. The rain rates are highly geographical dependent and the specific attenuation increases with frequency and rain rate. For temperate regions, the rainfall rate exceeded for 0.01% of time, that is, $R0.01\%$ can be around 30 mm/hr while for arid regions it is only few mm/hr. For tropical regions that experience monsoon seasons, the $R_{0.01\%}$ can be as large as 150 mm/hr. Normally, radio engineers will design a terrestrial fixed link to have 99.99% availability in an average year, and to fail when it experiences rain rates higher than R0.01% .Several procedures exist to estimate the statistics of rain rate in a particular region. The [5] model provides the annual distribution of rainfall rate with an integration time of 1 minute for the entire globe, derived from numerical weather prediction, but recommends the use of locally measured rain rates if available.

Rain attenuation can affect the transmission range of terrestrial microwave communication links and percentage availability. Comparison of microwave path lengths between temperate and tropical region based on effects of rain attenuation was studied by [6]. The authors studied the maximum path length or hop length for terrestrial link on line of sight point to point communication at 99.99% of availability. The study used the ITU-R path reduction rain model to study the path length for various frequency bands such as 7 GHz, 15 GHz, 23 GHz, 26 GHz and 38 GHz in the temperate and tropical region. From the studies conducted, there are significant differences in path length between temperate region and tropical region. There are wider differences in path length at lower operating frequency compare to higher operating frequency at both temperate and tropical region [6].

Multipath fading is among the dominant fading mechanism for most microwave frequencies. Typically, multipath occurs when a reflected wave reaches the receiver at the same time in opposite phase as the direct wave that travels in a straight line from the transmitter [3]. Multipath propagation gives rise to two kinds of signal degrading effects, namely; flat fading and frequency selective fading. A flat fading is a reduction in input signal level where all frequencies in the channel of interest are equally affected and there is dependent on path length, frequency, and path inclination. In addition, it is strongly dependent on the geoclimatic factor, K [3]. [7] examined the propagation losses between a ground station and a flying aircraft. Typical signal attenuations due to atmospheric gases and rain during propagation through the troposphere and multipath fading were computed for two candidate frequencies, 972 MHz and 5120 MHz. Unavailability of line-of-sight radio links due to propagation multipath was studied by [8]. The study also described comparison results of predicted attenuation obtained from ITU-R formula and empirical data at frequencies 6, 11.5 and 18.6 GHz. According to [8], multipath fading in the atmosphere is not permanent phenomenon. It occurs when there is no wind and the atmosphere is well stratified. It is more frequent at night and in the early morning hours and it is seldom felt at mid-day or during periods of intense rain [8].

Studies have shown thatapart from free space loss, rain and multipath attenuations, are the most frequent phenomena that cause signal fading in terrestrial microwave links. However, mutual relation between rain and multipath attenuation rules out the possibility that the link could be affected by both types of attenuation at the same time – hence, in practice, these types of attenuation do not add up [3]. Consequently, to determine the fade margin or the effective fading in a microwave communication link, it is necessary to calculate both rain and multipath attenuation. The larger of the two types of attenuation determines the value of fade margin. In areas with high precipitation, rain attenuation can be expected to be more prominent. By contrast, links located in drier climates and little inclination, will suffer more from multipath attenuation [3].

METHODOLOGY

Mathematics Of Rain Fade Model

[5and4] provided models for predicting specific rain attenuation and characterization of precipitation across the globe. In [4], for frequencies under 40 GHz and path lengths shorter than 60 km specific attenuation originating from rainfall is defined by $\gamma_{\mathrm{R_{po}}}$in dB/km and modeled using the power-law relationship as follows [9]:

$$\gamma_{R_{po}} = k\left(R_{po}\right)^{\alpha} \tag{2}$$

where R_{po} is the rainfall rate in mm/h exceeded for po% of an average year (or stated another way, R_{po} is the rainfall rate in mm/h for a particular link outage probability, po). R_{po} has different values for each climate zone, also referred to as rain zone [10]. The values of R_{po} for the 15 ITU rain zones are available at [4,11]. k and α are frequency dependent coefficients

[12,10]. Actually, in [4], specific attenuation originating from rainfall is defined separately for horizontal and vertical polarization. For the horizontal polarization;

$$\langle\gamma_{R_{po}}\rangle_h = K_h\left(R_{po}\right)^{\alpha_h} \text{in dB/km} \qquad (3)$$

For the vertical polarization;

$$\langle\gamma_{R_{po}}\rangle_v = K_v\left(R_{\mathrm{po}}\right)^{\alpha_v} \text{in dB/km} \qquad (4)$$

where: k_h, α_h are frequency dependent coefficients for horizontal polarization. They are given in [4]

kv, $\alpha_{,v}$ are frequency dependent coefficients for vertical polarization.

$\langle\gamma_{R_{po}}\rangle_h$ is the rain attenuation per kilometer for horizontal polarization

$\langle\gamma_{R_{po}}\rangle_v$ is the rain attenuation per kilometer for vertical polarization

po is the Percentage outage time (or Percentage unavailability time) of the link.

pa is the Percentage availability time of the link.

$$po = (100\% - pa) \qquad (5)$$

Let τo be the total outage time (or total unavailability time) of the link per year. τo is the total number of hours (or minutes or seconds) in a year when the link is not available.

Let τa be the total availability time of the link per year. τa is the total number of hours (or minutes or seconds) in a year when the link is available.

The total number of hours in one year is 24 *365 = 8760 hours/year. Then;

$$\tau a = \frac{(pa * 8760\,)}{100} hours\ /year \qquad (6)$$

$$\tau o = (8760 - \tau a) \qquad (7)$$

Likewise

$$\tau o = \frac{(po * 8760\,)}{100} = 8760 - \tau a hours/year \qquad (8)$$

For instance, if the link availability, $pa = 99.99\%$, then

$$po = (100\% - 99.99) = \ 0.01\%$$

$$\tau a = \frac{(pa\ * 8760\,)}{100} hours/year = 8759.124\, Hours/year$$

$$\tau o = \frac{(po\ * 8760\,)}{100} hours/year = 0.876\ \ Hours/year$$

So, the link with availabilityof$pa = 99.99\%$, will be unavailable for a total of $0.876\ \ Hours/year$, which is also link outage of 52.56 minutes in one year.

Fundamentally, rain attenuation, A_R(dB) is the product of specific rain attenuation,γ in dB/km and the propagation path length, d (km) between the transmitter and the receiver.

$$A_R = (\gamma)d \qquad \text{(dB)} \qquad (9)$$

In respect of ITU-R recommendations PN.838, the following terms can be defined;

$A_{R(h)}$ is the rain attenuation for horizontal polarization

$A_{R(v)}$ is the rain attenuation for vertical polarization

$A_{R(eff)}$ is the effective rain attenuation considering both horizontal and vertical polarization.

Hence,

$$A_{R(h)} = \langle\gamma_{\mathrm{R_{po}}}\rangle_{\mathrm{h}} = \mathrm{K_h}\left(\mathrm{R_{po}}\right)^{\alpha_{\mathrm{h}}} \quad \text{(dB))} \qquad (10)$$

$$A_{R(v)} = \langle\gamma_{\mathrm{R_{po}}}\rangle_{\mathrm{v}} = \mathrm{K_v}\left(\mathrm{R_{po}}\right)^{\alpha_{\mathrm{v}}} \quad \text{(dB))} \qquad (11)$$

$$A_{R(eff)} = \text{maximum}\left(A_{R(h)}, A_{R(v)}\right) = \text{maximum}\left(\langle\gamma_{\mathrm{R_{po}}}\rangle_{\mathrm{h}}, \langle\gamma_{\mathrm{R_{po}}}\rangle_{\mathrm{v}}\right) \quad \text{(dB))} \qquad (12)$$

Mathematics Of Multipath Fade Model

The percentage of time po that multipath fade depth, A(dB) is exceeded in the average worst month can be calculated as follows (ITU_R, 2005b):

$$po = Kd^{3.2}(1+|\varepsilon_P|)^{-0.97}\times 10^{\left(0.032f-0.00085h_L-\frac{A}{10}\right)} \tag{13}$$

where:
d is link distance (km)
f is frequency (GHz)
h_L is altitude of lower antenna (m)
A is multipath fade depth (dB)
K is geoklimatic factor and can be obtained from:

$$K = 10^{(-4.2-0.0029dN1)} \tag{14}$$

The term dN1 is provided on a 1.5° grid in latitude and longitude in ITU-R Recommendation P.453. The data are available in a tabular format and are available from the Radio communication Bureau (BR). The path inclination, $|\varepsilon_P|$ (in mrad) is calculated from the antenna heights h1 and h2 (meters about sea level), using the following expression:

$$|\boldsymbol{\varepsilon_p}| = \frac{(|\boldsymbol{h_1}-\boldsymbol{h_2}|)}{\boldsymbol{d}} \tag{15}$$

Where d is link distance (km) and h_1, $h_2$are the antenna heights above sea level (m)
Now, multipath Fade Depth, A (in dB) is obtained from the expression for po as follows;

$$\mathrm{A} = 10(0.032f - 0.00085h_L) - (10)\log\left(\frac{po}{\left\{K(d^{3.2})(1+|\varepsilon_p|)^{-0.97}\right\}}\right) \tag{16}$$

Dominant Fading And Effective Fading

In this paper, two categories of fade mechanisms are considered, namely; rain and multipath fading. Fortunately, mutual relation exists between rain and multipath fading which rules out the possibility that the link could be affected by both types of attenuation at the same time. Essentially, these types of attenuation do not add up. Consequently, to determine the effective fade margin for terrestrial microwave links, it is necessary to calculate both rain and multipath attenuation (or fading); the larger of the two fading is the dominant fading and the value of the dominant fading is the effective fading.

Let A_e be the effective link attenuation (fading), which is the larger of the two types of fading considered in the research. Hence;

$$A_e = minimum(\boldsymbol{A},\ A_{R(eff)}) \tag{17}$$

$$\left.\begin{array}{c}\text{Dominant Fading} = \text{“Rain Fading” for } A_{R(eff)} \geq \boldsymbol{A} \\ \text{Otherwise} \\ \text{Dominant Fading} = \text{“Multipath Fading” for } A_{R(eff)} < \boldsymbol{A}\end{array}\right\} \tag{18}$$

RESULTS AND DISCUSSION

The rain fading and multipath fading are calculated and the dominant fading and the effective fading were determines for various network parameter combinations. In the first scenario, the rain fading and multipath fading are calculated and the dominant fading and the effective fading were determined for various frequency bands, as shown in Table 4.1 and Fig 4.1. In Table 4.1 and Fig 4.1 the following link parameters are used: d = 6 km ; Transmit Power = 10.dB ; Transmitterd = 6 km ; Transmit Power = 10.dB ; Transmitter Antenna Gain = 35dBi; Receiver Antenna Gain = 35dBi ; Rain Zone is N; Link Percentage Availability (Pa) = 99.9% ; dN1 = - 400; Transmitter Antenna Height (ht) = 50m; and Receiver Antenna Height (hr) = 50 m. According to the results in Table 4.1 and Fig 4.1, for rain zone N and with the given set of link parameters, the multipath fading dominates the fade rain for frequencies up to about 11 GHz. However, the rain fading dominated from 12 GHz and for all the higher frequencies above 12 GHz. Essentially, in network planning for rain zone N, the concern at lower frequencies less than 12GHz is the multipath fading. However, the network designers should focus on rain fading for frequencies from 12GHz and above.

Table 4.1: Rain Fading, Multipath Fading, Dominant Fading and Effective Fading Vs Frequency

Frequency Band	Frequency (GHz)	Effective Rain Attenuation (dB)	Multipath Fading (dB)	Effective Fading (dB)	Dominant Fading (dB)
S band	2	0.02	4.72	4.72	**MULTIPATH**
C band	6	1.21	6.00	6.00	**MULTIPATH**
X band	8	3.46	6.64	6.64	**MULTIPATH**
K_u band	12	9.59	7.92	9.59	**RAIN**
K_u band	16	16.32	9.20	16.32	**RAIN**
K band	20	23.55	10.48	23.55	**RAIN**
K band	24	31.02	11.76	31.02	**RAIN**
K_a band	28	38.43	13.04	38.43	**RAIN**

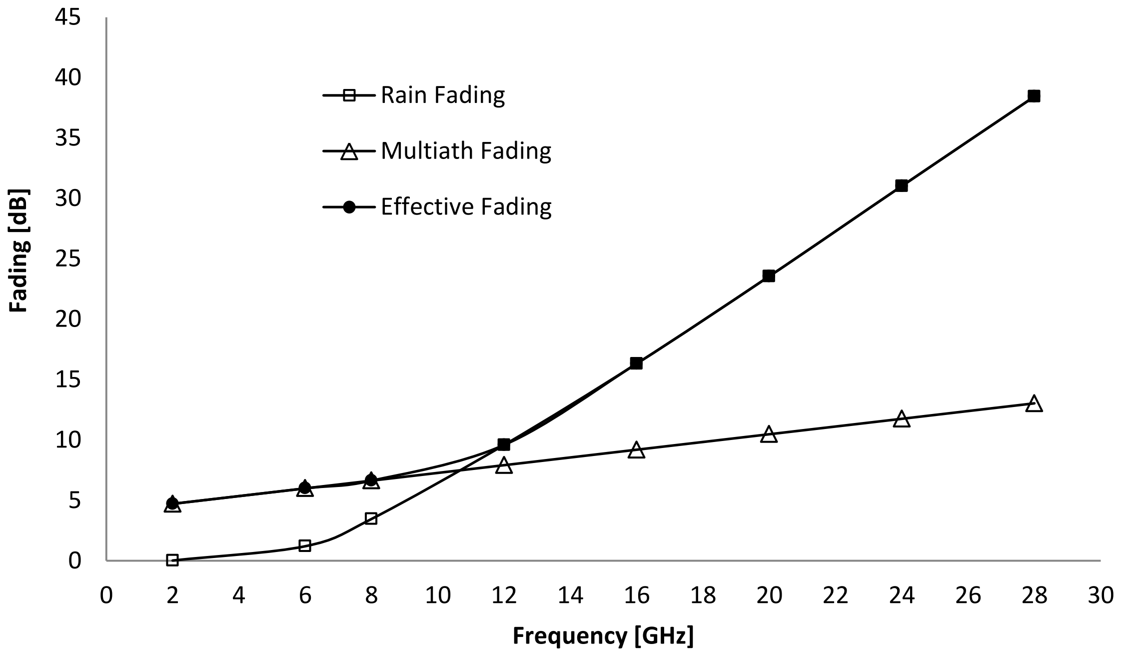

Fig 4.1: Rain Fading, Multipath Fading and Effective Fading Vs Frequency

In any case, 12Ghz may not be the specific turning point of the dominant fading from multipath to rain fading in all situations. Changes in other link parameters like link percentage availability, path point refractivity index and path inclination , among others can affect the frequency at which the dominant fading in a given rain zone transit from multipath fading to rain fading. These facts are given in the results of Table 4.2a, Table 4.3a , Table 4.4a, Table 4.2a, Table 4.3a , Table 4.4a ,Fig 4.2, Fig 4.3, and Fig 4.4.

Table 4.2a: Effective Fading Vs Frequency and Link Percentage Availability (Pa%)

Frequency Band	**Frequency (GHz)**	**Effective Fading (dB)for Link Availability, Pa =99.0%)**	**Effective Fading (dB)for Link Availability, Pa =99.9%)**	**Effective Fading (dB)for Link Availability, Pa =99.99%)**	**Effective Fading (dB)for Link Availability, Pa =99.999%)**
S band	2	**0.003**	**4.716**	**14.716**	**24.716**
C band	6	**0.055**	**5.996**	**15.996**	**25.996**
X band	8	**0.231**	**6.636**	**16.636**	**33.766**
K_u band	12	**0.960**	**9.587**	**31.223**	**66.479**
K_u band	16	**1.887**	**16.319**	**49.369**	**100.264**
K band	20	**3.012**	**23.551**	**67.654**	**132.926**
K band	24	**4.345**	**31.019**	**85.048**	**162.187**
K_a band	28	**5.843**	**38.426**	**101.008**	**187.497**

Table 4.2b: Dominant Fading Vs Frequency and Link Percentage Availability (Pa%)

Frequency Band	**Frequency (GHz)**	**Effective Fading (dB)for Link Availability, Pa =99.0%)**	**Effective Fading (dB)for Link Availability, Pa =99.9%)**	**Effective Fading (dB)for Link Availability, Pa =99.99%)**	**Effective Fading (dB)for Link Availability, Pa =99.999%)**
S band	2	RAIN	MULTIPATH	MULTIPATH	MULTIPATH
C band	6	RAIN	MULTIPATH	MULTIPATH	MULTIPATH
X band	8	RAIN	MULTIPATH	MULTIPATH	RAIN
K_u band	12	RAIN	RAIN	RAIN	RAIN
K_u band	16	RAIN	RAIN	RAIN	RAIN
K band	20	RAIN	RAIN	RAIN	RAIN
K band	24	RAIN	RAIN	RAIN	RAIN
K_a band	28	RAIN	RAIN	RAIN	RAIN

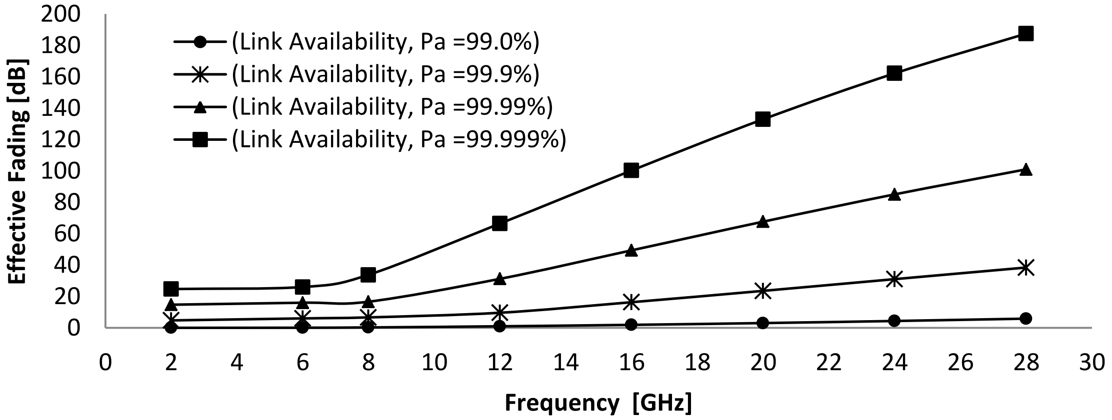

Fig 4.2 : Effective Fading vs Frequency for Various Link Percentage Availability (Pa %)

In the second scenario, the rain fading and multipath fading are calculated and the dominant fading and the effective fading were determined for various frequency bands and link percentage availability (Pa%), as shown in Table 4.2a, Table 4.2b and Fig 4.2. In Table 4.2a, Table 4.2b and Fig 4.2 the following link parameters are used: d = 6 km ; Transmit Power = 10.dB ; Transmitter Antenna Gain = 35dBi; Receiver Antenna Gain = 35dBi ; Rain Zone is N; dN1 = - 400; Transmitter Antenna Height (ht) = 50m; and Receiver Antenna Height (hr) = 50 m.According to the results in Table 4.2a, Table 4.2b and Fig 4.2 , for rain zone N and with the given set of link parameters, the multipath fading dominates the fade rain for frequencies up to about 6 GHz for link percentage availability (Pa = 99.999%). However, for the Pa = 99.999%, the rain fading dominated from 8 GHz and for all the higher frequencies above 8 GHz. Essentially, in network planning for rain zone N and with Pa = 99.999%, the concern at lower frequencies less than 6GHz is the multipath fading. However, the network designers should focus on rain fading for frequencies from 6 GHz and above.

From Table 4.2a, Table 4.2b and Fig 4.2, it is shown that the turning point for the dominant fading for rain zone N and with Pa = 99.999% is 6GHz. Similarly, for rain zone N and with Pa = 99.99% the turning point is 8 GHz; for rain zone N and with Pa = 99.9% the turning point is 8 GHz; for rain zone N and with Pa = 99.0% rain fading dominated in all the frequencies considered. Essentially, the link percentage availability do affect the frequency at which the rain or multipath fading dominates.

Table 4.3a: Effective Fading Vs Frequency for Various Point Refractivity Gradient (dN1)

Frequency Band	**Frequency (GHz)**	**Effective Fading (dB)for Point Refractivity Gradient, dN1 = - 200**	**Effective Fading (dB)for Point Refractivity Gradient, dN1 = - 300**	**Effective Fading (dB)for Point Refractivity Gradient, dN1 = - 400**	**Effective Fading (dB)for Point Refractivity Gradient, dN1 = - 700**
S band	2	**0.023**	**1.816**	**4.716**	**13.416**
C band	6	**1.208**	**3.096**	**5.996**	**14.696**
X band	8	**3.464**	**3.736**	**6.636**	**15.336**

K_u band	12	**9.587**	**9.587**	**9.587**	**16.616**
K_u band	16	**16.319**	**16.319**	**16.319**	**17.896**
K band	20	**23.551**	**23.551**	**23.551**	**23.551**
K band	24	**31.019**	**31.019**	**31.019**	**31.019**
K_a band	28	**38.426**	**38.426**	**38.426**	**38.426**

Table 4.3b: Dominant Fading Vs Frequency for Various Point Refractivity Gradient (dN1)

Frequency Band	**Frequency (GHz)**	**Effective Fading (dB)for Point Refractivity Gradient, dN1 = - 200**	**Effective Fading (dB)for Point Refractivity Gradient, dN1 = - 300**	**Effective Fading (dB)for Point Refractivity Gradient, dN1 = - 400**	**Effective Fading (dB)for Point Refractivity Gradient, dN1 = - 700**
S band	2	RAIN	MULTIPATH	MULTIPATH	MULTIPATH
C band	6	RAIN	MULTIPATH	MULTIPATH	MULTIPATH
X band	8	RAIN	MULTIPATH	MULTIPATH	MULTIPATH
K_u band	12	RAIN	RAIN	RAIN	MULTIPATH
K_u band	16	RAIN	RAIN	RAIN	MULTIPATH
K band	20	RAIN	RAIN	RAIN	RAIN
K band	24	RAIN	RAIN	RAIN	RAIN
K_a band	28	RAIN	RAIN	RAIN	RAIN

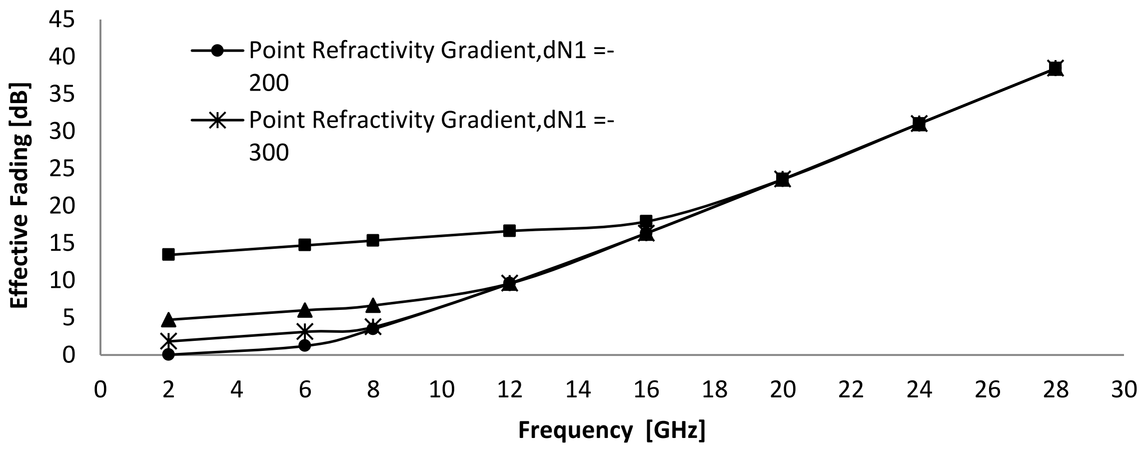

Fig 4.3 : Effective Fading vs Frequency for Various Point Refractivity Gradient (dN1)

In the third scenario, the rain fading and multipath fading are calculated and the dominant fading and the effective fading were determined for various frequency bands and point refractivity index (dN1), as shown in Table 4.3a, Table 4.3b and Fig 4.3. In Table 4.3a, Table 4.3b and Fig 4.3.the following link parameters are used: d = 6 km ; Transmit Power = 10.dB ; Transmitter Antenna Gain = 35dBi; Receiver Antenna Gain = 35dBi ; Rain Zone is N; Link Percentage Availability (Pa) = 99.9% ; Transmitter Antenna Height (ht) = 50m; and Receiver Antenna Height (hr) = 50 m. According to the results in Table 4.3a, Table 4.3b and

Fig 4.3., for rain zone N and with the given set of link parameters, the multipath fading dominates the fade rain for frequencies up to about 16 GHz for point refractivity index (dN1= -700). However, for the dN1= -700, the rain fading dominated from 20GHz and for all the higher frequencies above 20 GHz. Essentially, in network planning for rain zone N and with dN1= -700, the concern at frequencies less than 16 GHz is the multipath fading. However, the network designers should focus on rain fading for frequencies from 16 GHz and above.

From Table 4.3a, Table 4.3b and Fig 4.3., it is shown that the turning point for the dominant fading for rain zone N and with dN1= -700, is 16GHz. Similarly, for rain zone N and with dN1= -400, the turning point is 8 GHz; for rain zone N and with dN1= -300, the turning point is also 8 GHz; for rain zone N and with dN1= -200, rain fading dominated in all the frequencies considered. Essentially, the path's point refractivity index (dN1) do affect the frequency at which the rain or multipath fading dominates.

Table 4.4a: Effective Fading Vs Frequency for various Path Inclinations (ε_p)

Frequency Band	**Frequency (GHz)**	**Effective Fading (dB)for Path Inclination , ε_p = 0**	**Effective Fading (dB)for Path Inclination , ε_p = 0.5**	**Effective Fading (dB)for Path Inclination , ε_p = 1.0**	**Effective Fading (dB)for Path Inclination , ε_p = 1.5**
S band	2	**4.716**	**1.796**	**3.008**	**0.856**
C band	6	**5.996**	**3.076**	**4.288**	**2.136**
X band	8	**6.636**	**3.716**	**4.928**	**3.464**
K_u band	12	**9.587**	**9.587**	**9.587**	**9.587**
K_u band	16	**16.319**	**16.319**	**16.319**	**16.319**
K band	20	**23.551**	**23.551**	**23.551**	**23.551**
K band	24	**31.019**	**31.019**	**31.019**	**31.019**
K_a band	28	**38.426**	**38.426**	**38.426**	**38.426**

Table 4.4b: Dominant Fading Vs Frequency for various Path Inclinations (ε_p)

Frequency Band	**Frequency (GHz)**	**Effective Fading (dB)for Path Inclination , ε_p = 0**	**Effective Fading (dB)for Path Inclination , ε_p = 0.5**	**Effective Fading (dB)for Path Inclination , ε_p = 1.0**	**Effective Fading (dB)for Path Inclination , ε_p = 1.5**
S band	2	MULTIPATH	MULTIPATH	MULTIPATH	MULTIPATH
C band	6	MULTIPATH	MULTIPATH	MULTIPATH	MULTIPATH
X band	8	MULTIPATH	MULTIPATH	MULTIPATH	RAIN
K_u band	12	RAIN	RAIN	RAIN	RAIN
K_u band	16	RAIN	RAIN	RAIN	RAIN
K band	20	RAIN	RAIN	RAIN	RAIN
K band	24	RAIN	RAIN	RAIN	RAIN
K_a band	28	RAIN	RAIN	RAIN	RAIN

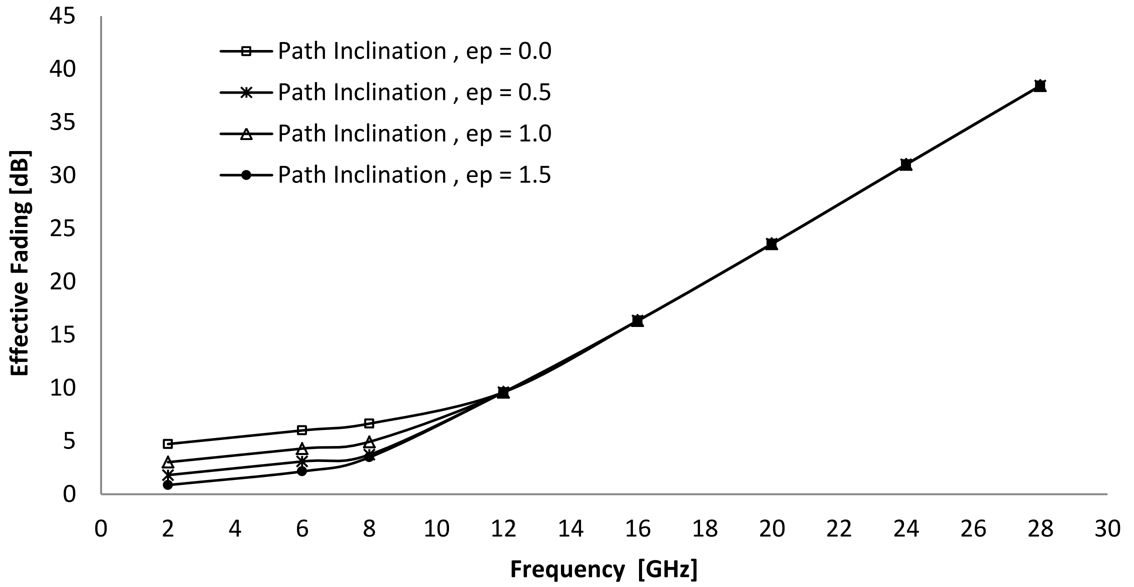

Fig 4.4 : Effective Fading vs Frequency for Various Path Inclination

In the fourth scenario, the rain fading and multipath fading are calculated and the dominant fading and the effective fading were determined for various frequency bands and path inclination ($\boldsymbol{\varepsilon_p}$), as shown in Table 4.4a, Table 4.4b and Fig 4.4. In Table 4.4a, Table 4.4b and Fig 4.4.the following link parameters are used: d = 6 km ; Transmit Power = 10.dB ; Transmitter Antenna Gain = 35dBi; Receiver Antenna Gain = 35dBi ; Rain Zone is N; Link Percentage Availability (Pa) = 99.9% ; Lower Antenna Height (hl) = Receiver Antenna Height (hr) = 50 m. Transmitter Antenna Height (ht) varies with the Path Inclination. According to the results in Table 4.4a, Table 4.4b and Fig 4.4., for rain zone N and with the given set of link parameters, the multipath fading dominates the fade rain for frequencies up to about 6 GHz for path inclination ($\boldsymbol{\varepsilon_p}$= 1.5). However, for the $\boldsymbol{\varepsilon_p}$= 1.5, the rain fading dominated from 8 GHz and for all the higher frequencies above 8 GHz. Essentially, in network planning for rain zone N and with $\boldsymbol{\varepsilon_p}$= 1.5, the concern at frequencies less than 6 GHz is the multipath fading. However, the network designers should focus on rain fading for frequencies from 6 GHz and above.

From Table 4.4a, Table 4.4b and Fig 4.4., it is shown that the turning point for the dominant fading for rain zone N and with $\boldsymbol{\varepsilon_p}$= 1.5, is 6GHz. Similarly, for rain zone N and with $\boldsymbol{\varepsilon_p}$= 1.0, the turning point is 8 GHz; for rain zone N and with $\boldsymbol{\varepsilon_p}$= 0.5, the turning point is also 8 GHz; for rain zone N and with $\boldsymbol{\varepsilon_p}$= 0, the turning point is also 8 GHz. Essentially, the path inclination ($\boldsymbol{\varepsilon_p}$), do affect the frequency at which the rain or multipath fading dominates. The smaller the path inclination ($\boldsymbol{\varepsilon_p}$) , the more the effect of multipath fading in the path.

CONCLUSION

The paper presented the prediction of rain fading and multipath fading along with the determination of the dominant fading and the effective fading that will be experienced in a terrestrial microwave communication link. Web application was developed to automate the computation of the various fading discussed in the paper. The web application was developed using PHP scripting language, MySQL database management system and them hosted locally using apache web server. Sample computations of the multipath fading, rain fading, as well as the dominant and effective attenuation were carried out for terrestrial microwave line-of-sight communication link in rain zone N. In all, the result obtained in the paper showed that rain attenuation is the dominant fading for higher frequencies whereas, multipath fading do dominate at the lower frequencies. The frequency at which the transition from dominant multipath fading to dominant rain fading is not fixed. Rather, the turning point depends on different link parameter combinations. The results obtained in the paper showed how changes in link parameters like the link's percentage availability, the path's point refractivity index and the path inclination , can affect the frequency at which the dominant fading in a given rain zone transit from multipath fading to rain fading.

RECOMMENDATIONS FOR FUTURE WORK

The work presented in this paper is only a part of a larger system for link analysis and design. So, further work is required to integrate this work into link analysis and design software suite.

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