PROPAGATION STUDY OF MICROWAVE SIGNALS BASED ON RAIN ATTENUATION MODEL AT 18 GHz FOR LINK BUKIT LANJAN – TV3 SRI PENTAS

Nazri Arshad
2003193374

Associate Prof. Norasimah Khadri
Faculty of Electrical Engineering
Universiti Teknologi MARA
40450 Shah Alam, Selangor
nazr88i@yahoo.com

Abstract
The usage of microwave signal above 10 GHz seems to be the best solution to the currently congested frequency band problems faced by most service providers. However the applications of this frequency region face another weaknesses / constraint i.e rain attenuation. This paper is to study and to present results on propagation study of microwave signals based on attenuation which is model at 18 GHz and using the microwave link between Bukit Lanjan and TV3 Sri Pentas stations. The study conducted by using the ITU-R standards based on formula $\gamma = kR^{\alpha}$ and the results is presented by MATLAB application. The outcome from this study is hope could be used as the threshold in order to decide on future application of microwave frequencies above 10 GHz.

Keyword

Microwave, frequency, rain attenuation, ITU-R, horizontal and vertical.

1 INTRODUCTION

Spectrum congestion at conventional microwave frequencies has forced communication system designers to explore and investigate higher and higher frequencies, well into the millimetric band. This part of the radio spectrum is currently underutilized and offers a very wide bandwidth and permits higher data rates as well as more channels [1]. However, the applications of this frequency region are subject to another weaknesses / constraint i.e the rain attenuation. Therefore a concrete data and a good knowledge on the effect of the rain attenuation on the microwave signals above 10 GHz are very crucial before the usage of the radio spectrum could be certified. In a tropical region, like Malaysia, where excessive rainfall is a common phenomenon throughout the year, the knowledge of the rain attenuation at the frequency of operation is extremely critical for the design of a reliable terrestrial and earth space communication link at a particular location. This project is intended to highlight the propagation study of microwave signals above 10 GHz and how severe the rain attenuates / effect on it. This project is referring to microwave link Bukit Lanjan to TV3 Sri Pentas where the working frequency is at 18 GHz (belong to Celcom Berhad).

The two site stations involved in this study are Bukit Lanjan and Sri Pentas. The path length between Bukit Lanjan and and Sri Pentas is about 3.53 km. The carry data for this link is STM-1 (155.52 mbps). The working frequency is at 18 GHz. The antenna is in the vertical polarization and the status of the link is monitored by NOC (Network Operation Center).

The method used in this study is the ITU-R method and a few comparisons with other study like the one carried out by the National University of Singapore [5].

2 THEORY

Rain has long been recognized as the main cause of unwanted signal loss at the centimeter and millimeter waves propagating through the lower part of the atmosphere. Furthermore, at smaller percentages of the year of interest to communication system designers, rain is considered to be the dominant cause of increased path attenuation. As reported in most of the literature, it is not feasible to predict theoretically the attenuation of radio waves above 10 GHz which propagating through the atmosphere, because of the complex variability of meteorological factors affecting the propagation. In particular, it appears to be a still unsolved problem to predict accurately the rain attenuation of radio waves propagating over a longer distance, where considerable nonuniformity of rainfall exists.[1]

Microwave radio links above 15 GHz tend not to be affected by multipath because of link lengths are short due to the design limitations imposed by high microwave rain absorption. However, microwave links operating in these frequencies are affected by rain and other forms of precipitation (i.e., freezing fog). Subsequent outages affect the annual availability objective.

Taking into account the severity of rainstorms in a given region, typically each radio link is designed to achieve between 99.99 and 99.999 percent availability. The ITU-R published rainfall maps (Figure 1) enable designers to predict the expected rain outage. In short, good system design limits rain outage to a predetermined level to meet International Reliability Standards G.827.

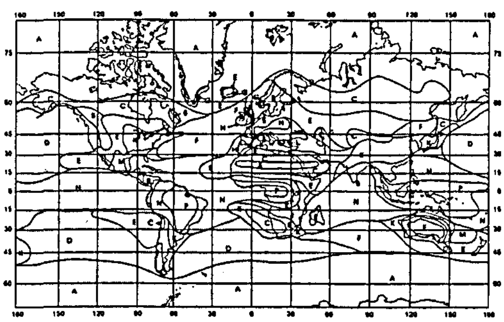


Figure 1:ITU world rain region

	Percentage of time (%)						
	1.0	0.3	0.1	0.03	0.01	0.003	0.001
A	<0.1	0.8	2	5	8	14	22
B	0.5	2	3	6	12	21	32
C	0.7	2.8	5	9	15	26	42
D	2.1	4.5	8	13	19	29	42
E	0.6	2.4	6	12	22	41	70
F	1.7	4.5	8	15	28	54	78
G	3	7	12	20	30	45	65
H	2	4	10	18	32	55	83
J	8	13	20	28	35	45	55
K	1.5	4.2	12	23	42	70	100
L	2	7	15	33	60	105	150
M	4	11	22	40	63	95	120
N	5	15	35	65	95	140	180
P	12	34	65	105	145	200	250

Figure 2: ITU-R837 Rainfall intensity exceeded (mm/h)

Attenuation due to rainfall can severely degrade the radiowave propagation at centimeter or millimeter wavelengths. It restricts the path length of radio communication systems and limits the use of higher frequencies for line-of-sight microwave links and satellite communications. The attenuation will pose a greater problem to communication as the frequency of occurrence of heavy rain increases.

Free-space Loss

The Friis free-space propagation equation is commonly used to determine the attenuation of a signal due to spreading of the electromagnetic wave.
Free space loss is given as:

Attenuation (dB) = 92.467 + 20 log10(fGHz) + 20 log10(Dkm)

Where: fGHz = frequency in GHz, and
Dkm = distance between antennas (link) in *kilometers*;

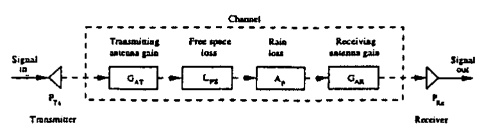


Figure 3: Block diagram of communication system

For frequencies above 10 GHz, there are several additional issues that effect the propagation, including:

- Absorption due to gasses or water vapor;
- Attenuation due to mist, fog, or rainfall.

Many gasses and pollutants have absorption lines in the millimeter bands but, due to their low densities, their effect is negligible in microwave and millimeter wave frequencies below 30 GHz. Water vapor, though, has an absorption line at 22.235 GHz and can affect microwave frequencies above 10 GHz. The amount of water vapor in the atmosphere at sea level can vary from 0.001 grams per cubic meter in a cold, dry climate to as much as 30 grams per cubic meter in hot, humid climates. In addition, the effects of precipitation can be significant at microwave frequencies above 10 GHz. The attenuation due to rainfall is dependent on the size and distribution of the water droplets. Because snowfall rates are generally less than rainfall rates, propagation is less effected by snowfall. For both snow and fog, the attenuation loss is a function of temperature and can vary by a factor of 3 between 0°C and 40°C.

Total transmission loss for a microwave link is given by Freeman as;

Attenuation (dB) = 92.467 + 20 $\log_{10}(f_{GHz})$ + 20 $\log_{10}(D_{km})$ + excess attenuation (dB) due to water vapor, mist, fog and rainfall.[2]

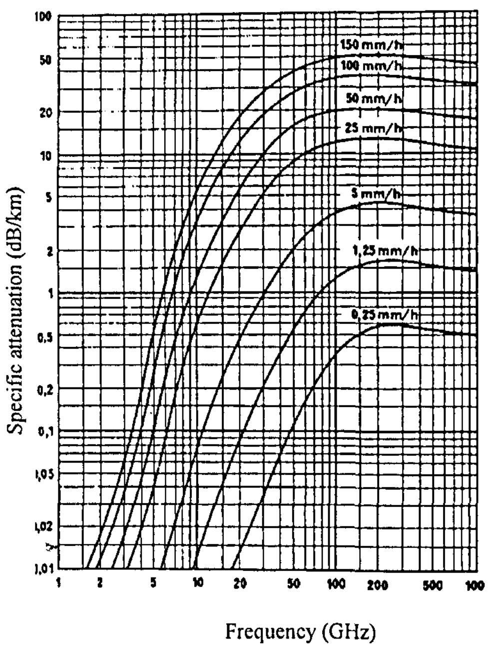


Figure 1 : ITU-R standard for specific rain attenuation as a function of frequency

Rec. ITU-R P.838-1 enables to compute the specific attenuation, in dB/km, for any frequency, rainfall rate, polarization and path geometry..[1]

ITU-R838 Specific Attenuation Model for Rain

The rain attenuation is one of dominant factors in determining the reliability of microwave and millimeter system, the specific rain attenuation is a fundamental quantity in calculation of rain attenuation statistics for terrestrial and earth-space paths. The power-law relationship of specific rain attenuation;

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

where γ_R is the specific attenuation in dB/km and R the rain rate in mm/h is widely used and the values of k and α can refer to Recommendation ITU-R P.838. The values tabulated in table are particularly convenient for estimation of specific attenuation in experimental applications or link designs at specific frequency, and the interpolated values should be used for other frequencies. However, It would be quite useful for system studies requiring calculations at many frequencies to have the simple analytic expressions which give results in good agreement with the values tabulated. For this reason the regression to determine the relationships between the parameters, k and α, and frequency has been done and the regressed expressions corresponding to the Table 1 of Recommendation ITU-R P.838 are proposed as follows.

The specific attenuation is calculated using the following power law relationship eq. 1

The frequency-dependent coefficients *k* and *a* for linear polarizations (horizontal - H, vertical - V)

horizontal path equations are given by

$$k_H = 4.0848\text{x}10^{-5} f^{(1.4550+0.3952 \ln f)} \qquad \text{(eq. 2)}$$
for $1 \le f \le 15$ GHz

$$k_H = 2.8790\text{x}10^{-7} f^{(5.7988-0.5431 \ln f)} \qquad \text{(eq. 3)}$$
for $15 \le f \le 400$ GHz

$$\alpha_H = 0.8424+((0.3151)/((\ln f - 2.0462)^2+0.6394)) \qquad \text{(eq. 4)}$$
for $1 \le f \le 15$ GHz

$$\alpha_H = 0.6879 + 0.7005\exp(-0.02600f) \qquad \text{(eq. 5)}$$

for $15 \leq f \leq 400$ GHz

vertical path equation are given by;

$k_V = 3.7332\text{x}10^{-5} f^{(1.4169+0.4067 \ln f)}$ (eq. 6)
for $1 \leq f \leq 15$ GHz

$k_V = 2.9220\text{x}10^{-7} f^{(5.7189-0.5297 \ln f)}$ (eq. 7)
for $15 \leq f \leq 400$ GHz

$\alpha_V = 0.8158+((0.2850)/((\ln f-2.0775)^2+0.5694)$ (eq. 8)
for $1 \leq f \leq 15$ GHz

$\alpha_V = 0.6887 + 0.6371\exp(-0.02600 f)$ (eq. 9)
for $15 \leq f \leq 400$ GHz

(f = frequency in GHz)

The coefficients k and α can be calculated using data given in Table 1,2,3,4,5 and 6 for vertical and horizontal linear polarizations and terrestrial paths to have the rain attenuation rate per kilometre.

The following equation is using (eq. 10 and 11) for calculating the value of k and α .

$k = [k_H + k_V + (k_H-K_V)\cos^2\theta\cos2\zeta]/2$ (eq. 10)

$\alpha =[k_H\alpha_H+ k_V\alpha_V+(k_H\alpha_H - k_V\alpha_V)\cos^2\theta\cos2\zeta]/ 2k$ (eq. 11)

where θ is the path elevation angle and ζ is the polarization tilt angle relative to the horizontal. ζ have certain criteria. For circular polarization ζ will be, 45°, for horizontal polarization ζ will be 0° and for vertical polarization ζ will be 90° .[3]

Techniques to reduce the effect of rain attenuation

The use of space diversity, frequency diversity, adaptive equalizers and shortening the path length does nothing to reduce the effects of rain fading. Changing the polarization from horizontal to vertical or reducing the length of the hop may produce some relief.[4]

Fresnel Zone

Fresnel (frä nel'), named after Jean Augustin Fresnel, 1788-1827, French physicist. The Fresnel zone is an elliptically shaped conical zone of power that propagates from the transmitting antenna to the receiving antenna due to cancellation of some part of the wavefront by other parts that travel different distances. If the total path distance between the transmitting antenna, mountain peak, and receiving antenna is one wavelength greater than the direct distance between antennas, then the clearance is said to be two Fresnel zones.[2]

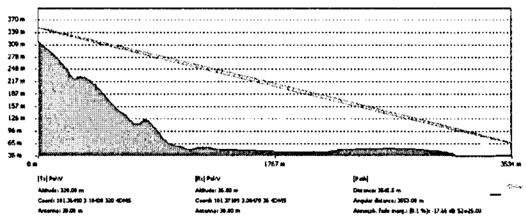


Figure 2:The Fresnel zone between two station at 18 GHz frequency. The size of fresnel is small compare to lowest frequencies.

2. METHODOLOGY

The study requires 2 methods in order to obtain good results. The first one is using Matlab and second method is using Telekom Malaysia simulation software in calculating the rain attenuation at microwave signal.

For the simulation using MATLAB, Gamma raindrop size distribution, Lognormal raindrop size distribution, Marshall and Palmer raindrop size distribution and the Laws and Parsons Raindrop Size Distribution are used as recommended by ITU-R.

Based on the data, the calculation of k and α value is achieved by using equation 10 and 11. This calculation process is carried out by mean of MATLAB software.

After the calculation on k and α value is completed, the value is once again is used in calculating rain attenuation using equation 1. The result obtained is then illustrated in graphical form.

The entire graph shown below is based on the amount of rain collected within an hour. From the graph, it can be identified or estimated that fading occurs on the signal. All calculations base on frequency 18 GHz.

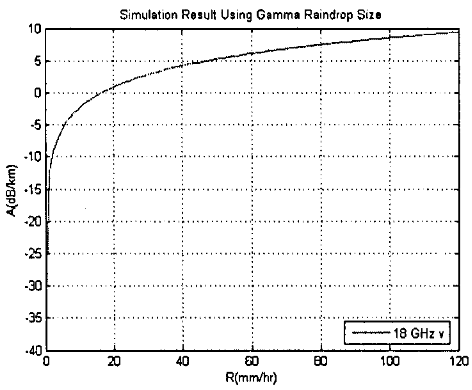
Apart of this rain attenuation study, the k and α value from the analysis conducted by the National University of Singapore [5] is also considered. However, the analysis only provide the value of k and α at frequency 15 GHz and 21 GHz. It is assumed that the rain attenuation for the 18 GHz falls between the attenuation for 15 GHz and 21 GHz.

3 RESULTS

1. The Gamma Raindrop Size Distribution at a Rain

f(GHz)	k_H	α_H	k_V	α_V
18.0	0.0492	1.11	0.0446	1.08

Table 1

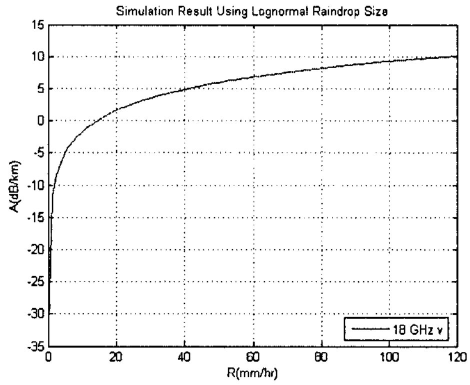


Graph 1

2. The Lognormal Raindrop Size Distribution

f(GHz)	k_H	α_H	k_V	α_V
18.0	0.0566	1.11	0.0506	1.08

Table 2

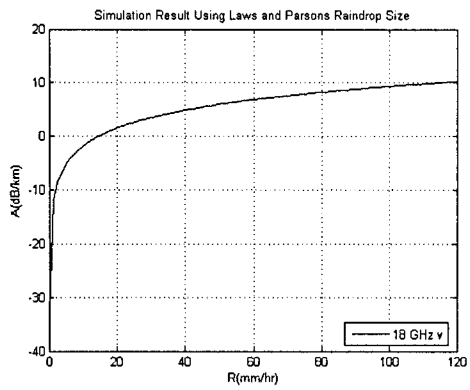


Graph 2

3. The Laws and Parsons Raindrop Size Distribution

f(GHz)	k_H	α_H	k_V	α_V
18.0	0.0523	1.13	0.0472	1.09

Table 3

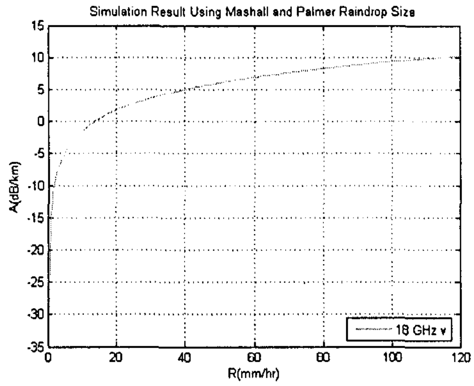


Graph 3

3. Marshall and Palmer Raindrop Size Distribution

f(GHz)	k_H	α_H	k_V	α_V
18.0	0.0607	1.10	0.0556	1.06

Table 4



Graph 4

4. Singaporean (National University of Singapore) Raindrop Size Distribution

i) 15 GHz , $A = 0.6336R^{0.6206}$

(Gamma Parameter)

f(GHz)	k_H	α_H	k_V	α_V
15.0	0.0317	1.11	0.0286	1.09

Table 5

(When do a calculation using gamma parameter, $k = 0.0298$ and $\alpha = 1.0945$)

ii) 21 GHz, $A = 0.6064R^{0.7486}$

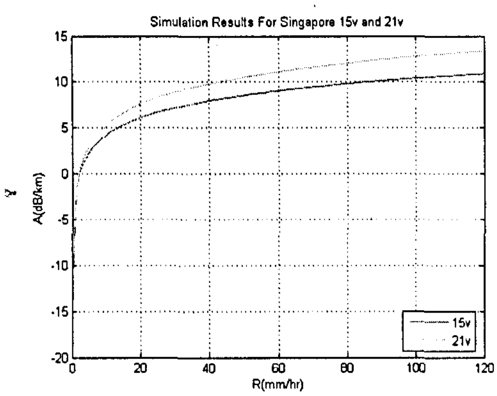
(Gamma Parameter)

f(GHz)	k_H	α_H	k_V	α_V
21.0	0.0708	1.09	0.0641	1.07

Table 6

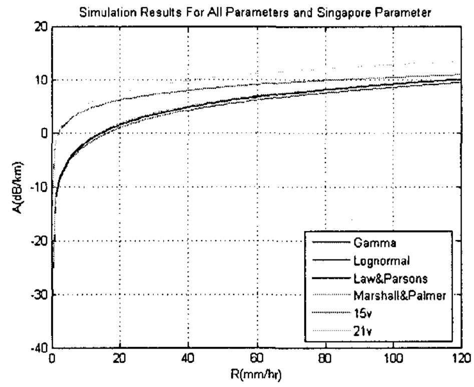
(When do a calculation using gamma parameter, $k = 0.0655$ and $\alpha = 1.0745$)

(R = rain rate in mm/h)



Graph 5

6. The combination graph result from all above



Graph 6

The result using TM Simulation Tools (Software) for link Bukit Lanjan and Sri Pentas

Tranmit Level (dBm) Bukit Lanjan	Receive Level (dBm) Sri Pentas	Amount of Rain (mm/h)	Attenuation Rain (dB/km)
24.0	-20.38	(no rain)	0
24.0	-20.85	2.5	No change
24.0	-31.37	50	5.51
24.0	-49.43	145	23.57

Table 7

4 DISCUSSION

Comparing Between the Graphs Simulate the signal loss during raining per kilometer.

Type parameter	**Rain rate at 20 mm/h**	**Rain rate at 50 mm/h**
Gamma 18 GHz	0.8993 dB	5.2388 dB
Law and Parsons 18 GHz	1.4528 dB	5.8789 dB
Lognormal 18 GHz	1.5761 dB	5.9406 dB
Marshall and Palmer 18 GHz	1.7361 dB	6.023 dB
Singapore 15 GHz	6.0923 dB	8.5620 dB
Singapore 21 GHz	7.5671 dB	10.5461 dB
TM 18 GHz		5.51 dB

Table 8

From the above table the rain attenuation are different for each parameter.

The lowest rain rate attenuation is Gamma parameter.

The highest rain rate attenuation is the data from Singaporean study.

From table 8, TM Simulation is following ITU-R Recommendation (close to Law and Parson). If compared with Singapore, rain rate is higher.

ITU-R should study the raindrop size in detail for tropical countries. The rate of attenuation is much higher with the ITU-R Recommendation references.

If Singaporean parameter gazette as ITU-R Recommendation, company like Telekom Malaysia (telecom operator) can take their data as part of reference purpose in studying/simulation the propagation signal during raining season.

For every countries raindrop are different in size. The detail study shall be conducted in order to get the exact and accurate data. From the graph plotted, it can be observed that the different values of k and α exist.

The ITU-R Recommendation data may be suitable to be applied for country like Europe but for Malaysia, further study / research is required to be conducted in order to establish a more realistic data for future reference. To design a microwave radio link at frequency above 10 GHz, rain is a factor that needs to be seriously considered. If good prediction could be achieved, the maximum distance between two stations the signal can travel could be identified within threshold value during raining season. The correct estimation is important to get the maximum distance through the usage of identified frequency during the setting up of the network. This can reduce the number of repeater required to set-up the overall network and at the same time optimize the cost incurred.

The most used method today for calculating rain attenuation was developed by the International Telecommunication Radio Section. However, there are other methods, such as the Crane method (used mainly in the United States) and methods more suitable for specific radio climates, such as wet tropical and equatorial areas. There are differences between the most popular models, the ITU terrestrial and Crane models, which produced slightly different estimates of the long term fade probability.

5 CONCLUSION

The conclusion that can be made from this project is that the rain sizes are different between regions. The ITU-R Recommendation study can be adopted by countries from Europe Continent but for countries like Singapore and Malaysia the k and α may not be suitable. The value should be further analyzed in order to achieve a good prediction result. A country like Singapore [5] had taken about eight years to come out with their own k and α value. It is worth to know that the same ITU- R standard approach had been used through out their experiment. The reason why the values are relevant to a country like Malaysia because the amount of rain received is more or less the same.

From the geographical factor, Tropical countries like Malaysia receive high amount of rain compare with European countries. Ideally, it is agreed that rain attenuation rate for Malaysia is also very much higher.

This prediction model is important in system design especially to have flexible and broadband feeder network. As we know, nowadays all telecommunication systems are based on bandwidth demand. So this prediction model will help the service provider to provide best service during raining season.

6 FUTURE DEVELOPMENT

For future development it is recommended that:

a. Comparison using different model for example Crane model.

b. The future study should be conducted base on more than one frequency model .

c. The setting up of UiTM's own microwave link to further enhance the research facility.

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