# Study of Rain Rate and Rain Attenuation for finding the Optimum Frequency uses by Maritime Radar at Malaysia

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***Abstract*—Rain attenuation has long been recognized as the main source of atmospheric attenuation in terrestrial and satellite links. There are many rain attenuation prediction models that are exist in the world. If the overseas model is applied to the design and operation of the domestic system such like radar or satellite, it can causes big error compared with real attenuation quantity in domestic environment. To estimate it more correctly, it should be developed appropriate model at domestic environment. This proposal report looks the comparison between the existing rain attenuation models with the measured model that is conducted at the domestic area. This study proposes which existing rain attenuation model is applicable to use at the domestic area according to the data from the measured model and apply it to indentify the optimum frequency use in the domestic area.**

***Index Terms*—rainfall rate, rain attenuation, optimum frequency**

## I. INTRODUCTION

Radar that has been used mostly in the world nowadays is invented by company from Europe or South America, where their environment such as rain, fog and cloud is different from tropical areas. These situations have some significant effect on the radar detection distance. The higher frequency use and the lower the evaluation angle, it will cause higher rain attenuation. This research is conducted to analyze the optimum frequency use by the maritime radar (X-band) using the best rain attenuation model that is suitable for tropical climate in Malaysia.

### Rainfall rate models and technique

**ITU-R:** International Telecommunication Union - Recommendation (ITU-R) model divides the world into 14 rainfall climate zones and estimates the mean cumulative distribution based on the best available experimental data. Therefore, the fig.1 shows the divided zones from ITU-R model and the table 1 shows the rainfall rate that exceed from different percentage of time in zone P [1].( Zone P is where Malaysia is situated).

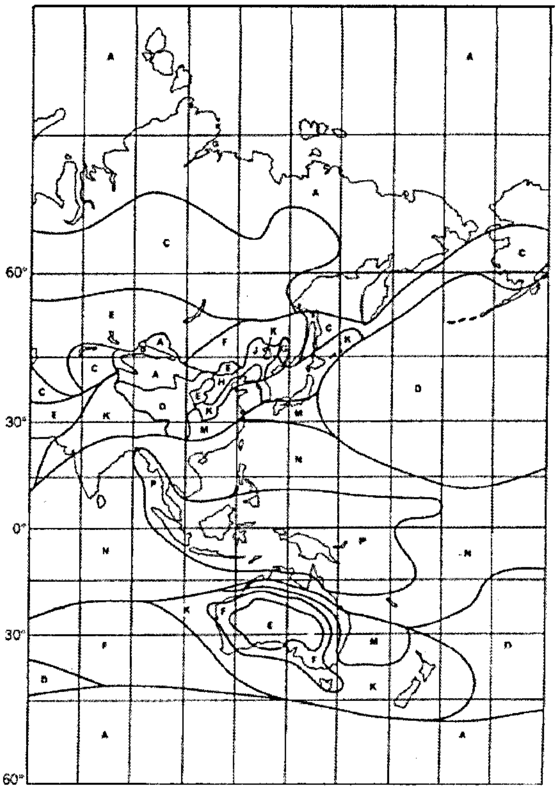

Fig.1: ITU-R Rainfall Climate Zone Map

Table 1: Annual cumulative rain rate distribution (Zone P)

| Percentage of time R exceeded (%) | Zone P (mm/hr) |
|---|---|
| 1.0 | 12 |
| 0.3 | 34 |
| 0.1 | 65 |
| 0.03 | 105 |
| 0.01 | 145 |
| 0.003 | 200 |
| 0.001 | 250 |

**Global Crane [2]:** Global Crane Model is based on the use of geophysical data to determine the surface point rain rate, point-to-path variations in rain rate, and the height dependency of attenuation, given the surface point rain rate or the percentage of the year the attenuation value is exceeded. Determine the global model rain climate region, R, for the ground station of interest from the global maps which show the climate zones for the Americas, Europe and Africa, and Asia, respectively. Once the climate zone has been selected (fig.2), obtain the rain rate distribution values from table 2. (Malaysia lies in H region)

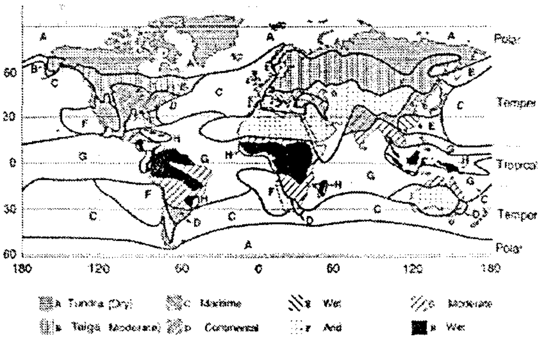

Fig.2: Global Crane Climate Region

Table 2: Global Crane Rain Rate Distribution

| Percentage of time R exceeded (%) | Region H (mm/hr) |
|---|---|
| 0.001 | 253 |
| 0.002 | 220.5 |
| 0.005 | 178 |
| 0.01 | 147 |
| 0.02 | 119 |
| 0.05 | 86.5 |
| 0.1 | 64 |
| 0.2 | 43.5 |
| 0.5 | 22.5 |
| 1.0 | 12.0 |

**Rice-Holmberg model:** A global surface rainfall model developed from extensive long-term rainfall statistics from over 150 locations throughout the world was developed by Rice and Holmberg. The Rice-Holmberg model constructs the rainfall rate distribution from two types of rain, "thunderstorm rain" and "all other rain" [3]. Each mode is modeled by exponentials, and the sum of the two modes produces the total distribution. The percent of an average year for which the rainfall rate exceeds $R$ mm/hr at a medium location is given by:

$$P(R) = \frac{M}{87.6}[0.03\beta e^{-0.03R} + 0.2(1-\beta)(e^{-0.258R} + 1.86e^{-1.63R})]$$

percent (1)

Where:

M = average annual rainfall accumulation, in millimeters

MI = average annual accumulation of thunderstorm rain, in millimeters

$$\beta = \frac{MI}{M} \qquad (2)$$

R = clock minute rainfall rate, in millimeters per hour

Global maps for M, M1, and $\beta$ are provided in the model, or, where available, directly measured data.

**Rain Attenuation model**

**ITU-R P.839** :The input parameters needed for the model are, point rainfall rate for the location for 0.01% of an average year (mm/h), height above sea level of the Earth station (km), elevation angle, latitude of the Earth station (degree), frequency (GHz) and effective radius of the Earth (8500 km)[4].

The calculation is given:

$$L_{RAIN} = \gamma_R D_{RAIN} \qquad (3)$$

Where:

$L_{RAIN}$ is the rain loss in dB

$\gamma_R$ is the specific attenuation (dB/Km)

$D_{RAIN}$ is the path length through the troposphere in Km

Determining $D_{RAIN}$

$$D_{RAIN} = \frac{(h_{RAIN} - h_{ANTENNA})}{\mathrm{Sin}(e)} \qquad (4)$$

Determining $\gamma_R$

$\gamma_R = kR^{\alpha}$ or using nomogram (5)

Where R is rainfall rate at exceeded time

$k$ and $\alpha$ is it coefficient due to frequency[5].

**DAH:** DAH rain attenuation model was developed by Asoka Dissanayake, Jeremy Allnutt, and Fatim Haidara [6]. The prediction model is similar to the ITU-R model where the rain related input to the model is the rain intensity at the 0.01% probability level. The polarization horizontal and vertical directions are accounted for in the prediction in rain condition. The method is applicable for percentage probability range from 0.001% to 10% and frequency between range 4 ~ 35 GHz[7]. The model is given as:

$$A_p = A_{0.01}(p/0.01)^{-(0.655+0.033\ln(p) - 0.045\ln(A_{0.01}) - z(1-p)\sin\theta)}$$

DB (6)

where p is the percentage probability of interest, $\theta$ is antenna elevation angle, $\phi$ is the latitude of the earth station and z is given by

for $p \geq 1\%$, $z = 0$

for $p < 1\%$,

$z = 0$ for $|\phi| \geq 36^0$

$z = -0.005(|\phi| - 36^0)$ for $\theta \geq 25^0$ and $|\phi| < 36^0$

$z = -0.005(|\phi| - 36^0) + 1.8 - 4.25\sin\theta$, for $\theta < 25^0$ and $|\phi| < 36^0$.

$A_{0.01}$ is attenuation exceeded for 0.01% of an average year is obtained from

$$A_{0.01} = \gamma_{R0.01} L_e \text{ dB} \quad (7)$$

whereby

$$\gamma_{R0.01} = 0.02(R_{0.01})^{1.2} \text{ dB/km} \quad (8)$$

and

$$L_e = L_r / \{1 + \sqrt{\sin\theta}\,[31(1\text{-}e^{-(\theta/(1+\chi))}) \sqrt{L_r\gamma / f^2} - 0.45]\} \text{ km} \quad (9)$$

whereby, f is the operating frequency and

$\chi = 36 - |\phi|$ for $|\phi| < 36^0$

$\chi = 0$ for $|\phi| \geq 36^0$

$$L_r = \begin{cases} L_g rh_{0.01} / \cos\theta \text{ km} & \text{for } \zeta > \theta \\ (h_{fr} - h_s) / \sin\theta \text{ km} & \text{for } \zeta \leq \theta \end{cases} \quad (10)$$

where $\zeta = \tan^{-1}[(h_{fr} - h_s)/(L_g rh_{0.01})]$, polarization angle (degrees) and

$$rh_{0.01} = 1/[1 + 0.78\sqrt{L_g\gamma_{R0.01} / f} - 0.38(1\text{-}\exp(-2L_g))] \quad (11)$$

$h_{fr}$ is the freezing height during rain.

$h_s$ altitude of the earth station above sea level.

$L_g$ horizontal projection of the slant path length

## II. DATA COLLECTION

### A. *USM (Nibong Tebal)[8]*

The data is collected in 2 years research by using the receiver and satellite as illustrate in fig.3.This study was done by Madeep Singh Jit Singh, Syed Idris Syed Hassan and Mohd Fadzil Ain from school of electrical and electronic engineering, University Science Malaysia.

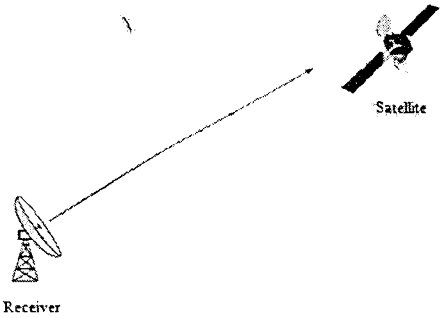

Fig.3: Satellite and receiver antenna

The specification of this experimental set-up from USM (Nibong Tebal) is show in table 3.

Table 3 : USM (Nibong Tebal) experiment specification

| | |
|---|---|
| USM(Nibong Tebal) position | $5.17^0$N and $100.4^0$E |
| Antenna elevation angle | $40.1^0$ |
| Receiver diameter | 2.4m |
| Satellite name | Superbird C |
| Satellite location | $144^0$E |
| Frequency | 12.255Ghz |
| Polarization | Horizontal |

The rainfall rate data also is obtained at USM (Nibong Tebal) using the tipping bucket rain gauge with 0.5mm capacity and 1 minute integration of time is placed near the antenna.

### B. *Malaysian Meteorological Department (MMD)*

The Malaysian Meteorological Department in Peninsular Malaysia consists of 24 stations. According to Malaysian Meteorological Department, the characteristics features of the climate of Malaysia are uniform temperature, high humidity and abundant rainfall (Peninsular Malaysia receives average rainfall of 2500mm). In Malaysia, there is 2 monsoon occurs, which is southwest monsoon (May to September) and northeast monsoon (November to March). Peninsular Malaysia receives more rainfall during the northeast monsoon.

## III. RAINFALL RATE MEASUREMENT RESULTS AND ANALYSIS

Rain rate for 0.01% of the time or $R_{0.01}$ is an important parameter in rain attenuation. The determination of the rain rate for 0.01 percent of time or $R_{0.01}$ comes from the fact that a good system must provide at least 99.99% reliability [9]. This value is use by design and system engineers to construct communications system such that the link is available for 99.99% of time.

The two years of USM experiment results indicate that the measured $R_{0.01}$ rainfall rate at USM (Nibong Tebal) is 120mm/hr. The International Telecommunication Union – Radio, ITU-R, has categorized Malaysia ad Region P [10], countries with very high rain precipitation. According to ITU-R version, rain intensity that will cause the interruption of a communication link for 0.01% per year is 145mm/hr. On the others side, Global Crane model selected Malaysia in H region [11], where that region is a wet area. The Global Crane model indicates that, the rain rate for 0.01% per year is 147mm/hr. Moreover, the calculation result for Rice Holmberg model show that, for percentage of time $R_{0.01}$, the rain rate is 64mm/hr. Therefore, the region P region of ITU-R, the region H of Global Crane model and calculation from Rice Holmberg model is over estimate for USM (Nibong Tebal). The following fig.4 shows us about the rainfall characteristic at USM (Nibong Tebal) compared with, ITU-R, Global Crane and Rice Holmberg model.

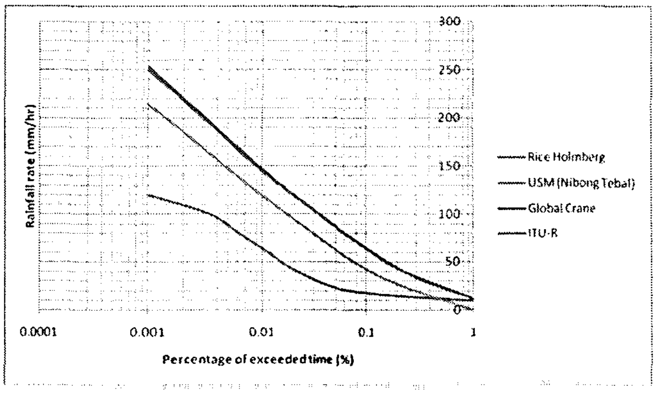

Fig.4 : Comparison between measured with prediction model of rainfall rate.

## IV. RAIN ATTENUATION MEASUREMENT RESULTS AND ANALYSIS

The rain attenuation for satellite links can be calculated using following models:

- DAH model (Dissanayake, Allnutt, Haidara)
- ITU-R P.839

To confirm the suitable model to be use in Malaysia, field measurements should also be carried out. Measurements of rain attenuation in Malaysia have been done for satellite links in USM (Nibong Tebal). The data is collected and its show that after 2 years of the research that have been done in USM (Nibong Tebal), the result indicate that the measured $A_{0.01}$ rain attenuation is 20dB. It also has been found out, after analysis, that the DAH model for rain attenuation prediction is valid for Malaysia, beside the ITU-R model.

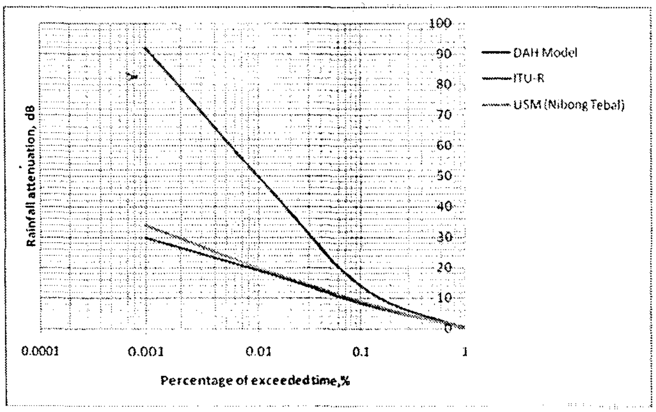

Fig.5: Comparison between measured with prediction model of rain attenuation.

## V. MARITIME RADAR OPTIMUM FREQUENCY ANALYSIS

The rainfall rate data is the most important factor for determining the degree of rain attenuation in communication link system. Field measurement for long time periods are the best method to know the rainfall rate in a country [12]. Rainfall rate at $R_{0.01}$ is the point rain rate that exceeded for 0.01% of a year (mm/hr). In Malaysia, the average rainfall rate is 2500mm/years. Therefore, the 0.01% of the average rain per year is equal to 0.25mm/hr. In 2007, the number of rain hours that exceed for 0.01% of a year is 814 out of 922[13].That means; $R_{0.01}$ is equal to 88mm/hr (814/922 x 100 mm/h).

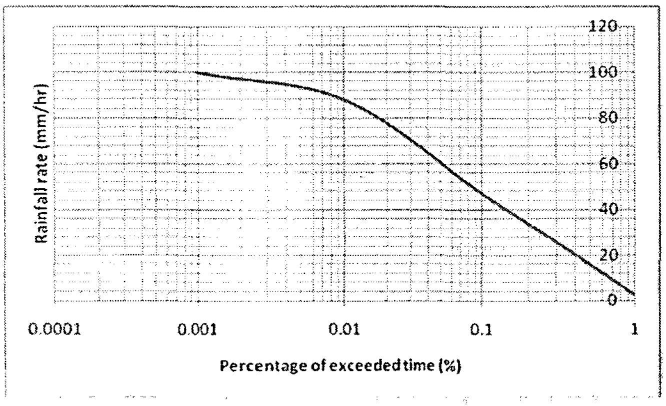

Fig.6: Peninsular Malaysia rainfall rate in a year

For obtaining the optimum frequency, the equipment specification must been indentify first. The table 4 below shows the Royal Malaysian Navy radar specification [14].

### *A. System*

Table 4: Royal Malaysian Navy radar system specification

| Parameter | Metric units | Decibels |
|---|---|---|
| Radiated Power | 1000000 | 60dBW |
| Antenna Gain | 7079 | 38.5 dB |
| Radar Cross Section | 5 $m^2$ | |
| Minimum Detectable Signal | $5.10^{-15}$W | -113dBm |
| Sum of Losses | 128.8 | 21.1 dB |

### *B. Antenna*

Table 5: Royal Malaysian Navy radar antenna specification

| Type | Monopulse |
|---|---|
| Frequency band | X-band (8-12 GHz) |
| Diameter | 1315 meter |
| Polarization | Vertical |
| Antenna Gain | 38.5 dB |

| Elevation | $0^0$ |
|---|---|
| Antenna Height | 16 meter |

DAH model will be use to calculating the rain attenuation according to the Royal Malaysian Navy radar specification. Fig.7 shows the rain attenuation at rainfall rate 88mm/hr of 0.01% exceed time.

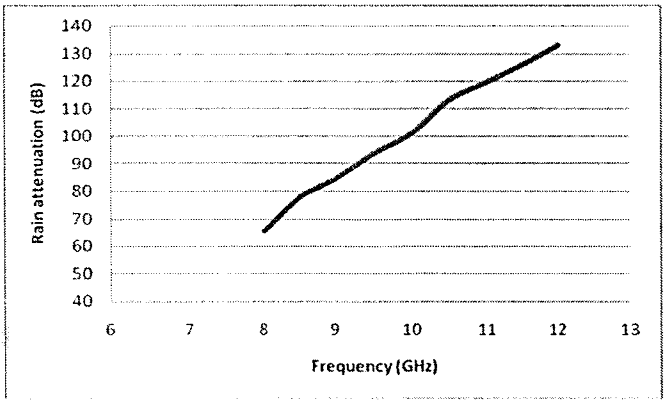

Fig.7: Rain attenuation versus frequency

The higher the frequency, the higher the rain attenuation will be. The optimum frequency is choosing base on range of Royal Malaysian Navy radar after insert this loss (attenuation at $R_{0.01}$) to the radar system. The calculation for finding radar range is done by varying the frequency within the X-band. Fig.8 and Fig.9 represent the maximum radar range without the rain attenuation and with rain attenuation corresponding to frequency.

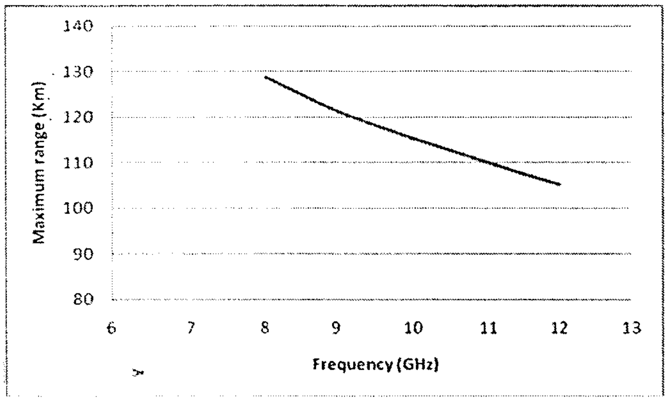

Fig.8: Radar maximum range without rain attenuation range versus frequency

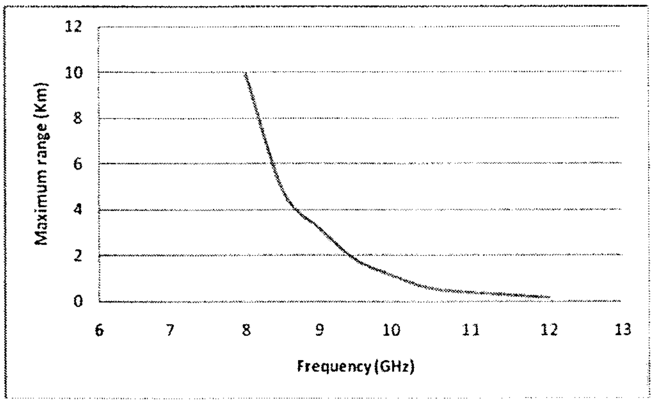

Fig.9: Radar maximum range with rain attenuation versus frequency

It is a huge different in term of maximum radar range between clear weather (without rain attenuation) and rainy weather (with rain attenuation).This means that rainfall in Malaysia will seriously affect the radar range.

It shows that the optimum frequency that can be use here in Malaysia base on the Royal Malaysian Navy radar is 8 GHz. The decision is made because, this frequency gives a large range compared to others and it is low rain attenuation. These 8 GHz frequency gives 9.92 km maximum range to radar when rain at 88mm/hr and 128.86 km when clear weather. It also provide 99.99% communication link thru the year.

The optimum frequency is uses to identify the range of detection. To make it more significations to the actual condition, the radar horizon must be calculated. The radar horizon [15] means that the signal that transmits will not bend according to the earth curved .Where the signal move slightly across the earth curved. Even though the radar maximum range is very far, but due to this, it would not detect the target (normally small ship). After calculating the radar horizon, it is equal to 16.77 km. If the radar horizon is take account to the optimum frequency 8 GHz in clear weather condition. At the range of maximum which is 128.86 km., it can only detect object that 1.32 km height. Mean while, in rainy condition, the maximum range that the radar detect is only 9.92 km. It is in the range of the radar horizon. So, the size of the object is does not matter whether it is small or big.

## VI. CONCLUSION

The existing rainfall rate model is not accurate to be applying in Malaysia. This is due to the large different between model and measured data. Moreover, the DAH model rain attenuation is the best models that can be apply in this domestic area (Malaysia). The rain attenuation is higher in higher frequencies. The attenuation found during the evaluation process is very large. The attenuations found in different rain rate percentages are very useful for designing any communication network service in these regions. The data for rainfall occurs is very important in choosing the optimum frequency. It is conclude that the optimum frequency to be use in Malaysia is 8GHz.

## ACKNOWLEDGMENT

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