



UNIVERSITI PUTRA MALAYSIA

**DEVELOPMENT OF SATELLITE PROPAGATION EFFECTS TOOL
FOR KU-BAND, KA-BAND AND Q/V-BAND LINKS**

NOR AZURA MALINI BINTI AHMAD HAMBALI.

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TOOL FOR KU-BAND, KA-BAND AND Q/V-BAND LINKS**

By

NOR AZURA MALINI BT AHMAD HAMBALI

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia,
in Fulfilment of the Requirements for the Degree of Master of Science**

April 2005



Dedicated to;

Abah,

Mak,

Abang,

Yang,

Adik Hafizul

My sweet Azri

Pak Njang (Ahmad Zaki b. Mohd Saad)
(Malaysia Meteorological Service)

Lecturers,

Friends.



Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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The thesis presents Graphical User Interfaces (GUIs) to analyse satellite propagation effects for Ku-band, Ka-band and Q/V-band links by using Matlab programming languages. The Matlab-based tool allows simulation to be carried out in the step and run modes. The Graphical User Interface (GUI) is a powerful, unique utility and programming interface, usable for research and simulation in the optimisation of microwave signal propagation. The GUIs gives easy access to analyse rain attenuation, cloud attenuation and fog attenuation. These software development tools are a set of Matlab solvers, graphical, computational utilities for quadratic, polynomial and regression programming. The GUIs may also be used as a pre-processor to generate Matlab code for stand-alone execution. Once the software tools for satellite propagation effects on Ku-band, Ka-band and Q/V-bands links GUIs is launched, user can enter input parameter values (frequency, elevation angle, temperature, visibility, cloud cover, rainfall, e.t.c) in text control to analyse the propagation impairments.

In this thesis, the characteristics of the reliable design of satellite communication systems operating at frequency above 10 GHz, Ku (12.5 – 18 GHz), Ka (26.5 – 40



GHz) and Q/V (40 – 50 GHz) band were examined. Rain attenuation, cloud attenuation and fog attenuation are the sources for fading propagation effects in these bands frequency. Analytical and ITU recommendations models were used to predict output attenuation for this analysis. However, the effects on satellite systems operating in the Ku, Ka and Q/V band essentially depends on the propagation characteristics of the transmission medium.

The NOAA ((National Oceanic and Atmospheric Administration) satellite data 2003, which were obtained from the Malaysian Meteorological service, were used in this analysis for area of interest Subang (elevation angle 36.54°), Alor Setar (elevation angle 34.97°), and Batu Embun (elevation angle 37.25°). The rain attenuation due to rainfall depends on the rain rate (mm/hr) distribution at the 0.01% probability as main the input. At the Ku, Ka and Q/V-bands frequencies, rain is a dominant source of attenuation. Thunderstorm activities were found to give large effect on the rain rate values during raining condition. Cloud attenuation is a function of cloud temperature integrated cloud liquid water content (g/m^3) along propagation path. For fog attenuation, visibility and temperature become main meteorological input function along propagation path analysis at the earth station site. Cloud and fog attenuation, which have been neglected at the lower frequencies band, can significantly limit the performance of high frequencies band satellite systems.

However, in recent years, higher frequencies are gradually being used for satellite communications in order to avoid congestion in the traditional low bands (S, L, C and X) frequencies and can be used for high quality satellite service. Unfortunately,

increasing operating frequency from Ku-band to Ka-band and Q/V-band will increase the attenuation level and hence, reducing performance of the satellite.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Master Sains

**PEMBANGUNAN ALATAN BAGI KESAN PERAMBATAN SATELIT
UNTUK PERHUBUNGAN JARAK GELOMBANG KU, KA AND Q/V**

Oleh

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Tesis ini memperkenalkan Antaramuka Pengguna Bergrafik (GUIs) bagi menganalisis kesan perambatan satelit ke atas jarak gelombang Ku, Ka dan Q/V dengan menggunakan pengaturcaraan Matlab. Alatan berasaskan Matlab, membenarkan simulasi dilakukan dengan berbagai langkah dan cara. Antaramuka Pengguna Bergrafik (GUIs), berkuasa, mempunyai kegunaan yang unik dan pengaturcaraan antaramuka, di mana ia berguna untuk penyelidikan dan simulasi secara optimistik bagi perambatan gelombang microwave. GUIs memudahkan akses bagi menganalisis pengecilan isyarat yang disebabkan oleh hujan, awan dan kabus. Pembangunan perkakasan program komputer merupakan set bagi Matlab untuk penyelesaian, grafik, kegunaan pemkomputeran bagi pengaturcaraan kuadratik, polynomial dan berulang. GUIs juga boleh digunakan untuk pra-pemprosesan bagi membolehkan kod-kod Matlab beroperasi secara sendiri. Apabila alatan program komputer bagi kesan satelit ke atas jarak gelombang Ku, Ka dan Q/V dilancarkan, pengguna boleh memasukkan parameter kemasukan (gelombang, sudut dongakan, suhu, jarak penglihatan, ketebalan awan, kadar penurunan hujan dan lain-lain) ke dalam kotak kawalan bagi menganalisis kesan perambatan gelombang.

Dalam tesis ini, ciri-ciri yang berkaitan dengan rekabentuk sistem pada satelit komunikasi yang beroperasi pada gelombang 10 GHz ke atas, jarak gelombang Ku (12.5 – 18 GHz), Ka (26.5 – 40 GHz) dan Q/V (40 – 50 GHz) telah dikaji. Pengecilan isyarat yang disebabkan oleh hujan, awan dan kabus merupakan sumber yang mengurangkan kesan perambatan pada jarak-jarak gelombang di atas. Dalam tesis ini, analitika dan model-model yang dicadangkan oleh ITU telah digunakan untuk meramal keluaran pengecilan isyarat. Walau bagaimanapun, kesan ke atas jarak gelombang Ku, Ka and Q/V pada pengoperasian satelit komunikasi, pada dasarnya bergantung kepada ciri-ciri media pancaran.

Data tahun 2003 dari satelit NOAA (Pentadbiran Atmosfera dan Laut), yang diperolehi dari Pusat Kajiucua Malaysia telah digunakan untuk menganalisis daerah Subang (sudut dongakan 36.54°), Alor Setar (sudut dongakkan 34.97°), dan Batu Embun (sudut dongakan 37.25°). Pengecilan isyarat yang disebabkan oleh hujan, bergantung kepada kadar penurunan hujan (mm/hr) pada kebarangkalian 0.01% sebagai sumber utama. Pada jarak gelombang Ku, Ka dan Q/V, hujan merupakan sumber utama yang mempengaruhi pengecilan isyarat. Aktiviti angin ribut yang disertakan dengan kilat dan hujan telah dikesan memberi peningkatan yang tinggi pada kadar penurunan hujan (mm/hr). Pengecilan isyarat yang disebabkan oleh awan, pada dasarnya saling kait mengait dengan kandungan cecair awan (g/m^3) sepanjang perjalanan pancaran. Untuk pengecilan isyarat bagi kabus, jarak penglihatan (km) dan suhu merupakan faktor utama meteorologi sepanjang perjalanan pancaran di stesen bumi. Pengecilan isyarat yang disebabkan oleh awan dan kabus telah diabaikan pada jarak gelombang rendah, tetapi pada jarak gelombang tinggi kecekapan satelit akan dihadkan.

Walau bagaimanapun, baru-baru ini, jarak gelombang yang lebih tinggi secara beransur-ansur telah digunakan bagi satelit komunikasi untuk mengelak kesesakan pada jarak gelombang rendah (S, L, C dan X) dan boleh digunakan untuk mempertingkatkan kualiti perkhidmatan bagi satelit. Tetapi peningkatan pengoperasian gelombang dari jarak gelombang Ku kepada Ka dan Q/V akan meningkatkan pengecilan isyarat dan menurunkan kadar kecekapan satelit komunikasi.

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TABLE OF CONTENT

	Page
DEDICATION	ii
ABSTRACT	iii
ABSTRAK	vi
ACKNOWLEDGEMENT	ix
APPROVAL	x
DECLARATION	xi
LIST OF TABLE	xvi
LIST OF FIGURE	xvii
LIST OF ABBREVIATIONS / SYMBOL	xix

CHAPTER

I	INTRODUCTION	
1.1	Introduction	1
1.1.1	Frequency Bands	3
1.2	Statement of the Problem	4
1.3	Scope of Work	5
1.3.1	Study of Propagation Prediction Models	5
1.3.2	Study of Operating Frequency in the Ka, Ku and Q/V-bands	6
1.3.3	Study and Develop Sub-Method from Attenuation Model	6
1.3.4	Metrological Data Measurement	7
1.3.5	Develop Computer Program	7
1.3.6	Analysis of the Result	7
1.4	Objectives	8
1.5	Thesis Organization	8
II	LITERATURE REVIEW	
2.1	Communication in the Ku, Ka and Q/V-bands	10
2.1.1	Low Frequency Bands for Satellite Communication	10
2.1.1.1	Ku Band	10
2.1.2	Extremely Frequency Bands for Satellite Communication	10
2.1.2.1	Ka Band	11
2.1.2.2	Q/V band	12
2.2	Effects of Propagation Impairment	13
2.2.1	Attenuation due to Rainfall	14
2.2.1.1	Thunderstorm during Rain Condition	17
2.2.2	Attenuation due to Cloud	17
2.2.3	Attenuation due to Fog	19
2.2.4	Other Attenuation	20
2.2.5	Combined Effects of Propagation Impairment	20
2.3	Review of Published Works	21



III	METHODOLOGY	
3.1	Procedure	25
3.1.1	Data Collection	25
3.1.2	Elevation Angle Calculation	26
3.1.3	Recommended Prediction Models	27
3.1.3.1	Rain Model	27
3.1.3.2	ITU-R Cloud Model	28
3.1.3.3	Altshuler Model	28
3.1.4	Analysis of Propagation Prediction Model at Low Frequency (Ku) Bands and High Frequency (Ka and Q/V) Bands	28
3.1.5	Software Development	29
3.1.5.1	Matlab Intuitive Programming Language	29
3.1.5.2	Graphical User Interfaces (GUI)	30
3.2	Rain Attenuation	32
3.2.1.	Mathematical Description	32
3.2.1.1	DAH-Model	32
3.2.1.2	Prediction Method for One-Minute Rain Rate Distribution	38
3.2.1.3	Regression Coefficients Techniques for Frequency not listed.	40
3.3	Cloud Attenuation	42
3.3.1	Mathematical Description	42
3.3.1.1	The ITU-R Cloud Attenuation Model	42
3.3.1.2	Cloud Cover and Prediction Method for Total Columnar Liquid Water	44
3.4	Fog Attenuation	45
3.4.1	Mathematical Model	47
3.4.1.1	Altshuler Model	48
IV	RESULTS AND DISCUSSIONS	
4.1	Introduction	50
4.2	Software Tools	50
4.2.1	Graphical User Interface (GUI)	
4.3	Rain Attenuation	55
4.3.1	Rain Rate (mm/hr)	55
4.3.2	Attenuation	57
4.3.3	Discussion	60
4.4	Cloud Attenuation	66
4.4.1	Discussion	73
4.5	Fog Attenuation	73
4.5.1	Discussion	75
V.	CONCLUSION	
5.1	Conclusion	77
5.2	Advantages and Disadvantages for Ka and Q/V-bands	80
5.3	Futures Works	

REFERENCES	82
APPENDICES	86
BIODATA OF THE AUTHOR	111



LIST OF TABLES

Table	Page
3.1: Areas of Interest and Specification	26
3.2: Cloud Cover, Cloud Liquid Water content and Cloud Type from Slobin characteristic.	45
4.1: Comparison rain rate at the 0.01% probability exceeded of time with thunderstorm and ITU recommendation value.	56
4.2: Percentages comparison rain rate at the 0.01% probability exceeded of time between rain rate with and without thunderstorm and ITU recommendation value.	56
4.3: Compare analysis liquid water content from MATLAB with ITU recommendation for heavy cloud cover.	67
5.1: Summary of Propagation Factors Affecting Satellite Communication Links.	80
A.1: Regression Coefficients for Estimating Specific Attenuation	86

LIST OF FIGURES

Figure	Page
2.1: Communication Impaired by Atmosphere Conditions.	13
2.2: Communication Impaired by Rain Condition.	15
2.3: Communication Impaired by Clouds Condition.	18
2.4: Communication Impaired by Fog Condition.	19
3.1: Software Development Tools block diagram	32
3.2: Slant Path Illusion through the Rainfall.	35
4.1: The GUI for Rain Attenuation	51
4.2: The GUI for Cloud Attenuation	53
4.3: The GUI for Fog Attenuation	54
4.4: Rain Attenuation at (a) Ku -band (12.5 – 18 GHz), (b) Ka -band (26.5 – 40 GHz) and (c) Q/V -band (40 – 50 GHz).	59
4.5: Rain Attenuation at Ku (15 GHz), Ka (30 GHz) and Q/V (50 GHz), for (a) Subang, (b) Alor Setar and (c) Batu Embun.	61
4.6: Rain Attenuation Penalty against Frequency. Rain rate with and without thunderstorm during raining.	62
4.7: Rain Attenuation Penalty against Frequency. Rain rate from ITU and rain rate with thunderstorm during raining. Rain rate for Alor Setar lower than ITU (negative values).	63
4.8: Rain Attenuation Penalty against Frequency. Rain rate from ITU and rain rate without thunderstorm. Rain rate for Alor Setar and Batu Embun lower than ITU (negative values).	64
4.9: Cloud Attenuation at (a) Ku -band (12.5 – 18 GHz), (b) Ka -band (26.5 – 40 GHz) and (c) Q/V -band (40 – 50 GHz). Location: Subang (7.0 oktas), Alor Setar (6.7 oktas) and Batu Embun (6.6 oktas).	69
4.10: Cloud Attenuation Penalty against Frequency. Liquid water content from the analysis and ITU	70
4.11: Cloud Attenuation at Ku (15 GHz), Ka (30 GHz) and Q/V (50 GHz) as function of Cloud cover (oktas). Subang - elevation angle = 36.54°	71



4.12: Fog Attenuation at (a) Ka-band (26.5 – 40 GHz) and (b) Q/V-band (40 – 50 GHz).	74
4.13: Fog Attenuation at Ka-band (30 GHz) and Q/V-band (50 GHz) Batu Embun- temperature 22°C for lowest visibility (0.1 km)	75
A.1: Matlab System Design for Attenuation due to Rainfall	89
A.2: Matlab System Design for Attenuation due to Clouds	91
A.3: Matlab System Design for Attenuation due to Fog	92

LIST OF ABBREVIATIONS / SYMBOLS

EHF		Extremely high frequency
WMO		World Meteorological Organization
Oktas		Cloud cover unit
NOAA		National Oceanic and Atmospheric Administration
ITU		International Telecommunication Union
f	(GHz)	Frequency
θ	(Degree)	Elevation angle
ϕ	(Degree)	Latitude of the ground station receiver
T	(Celsius)	Temperature
A_r	(dB)	Rain attenuation
R	(mm/hr)	Rainfall intensity/rate
R_E	(km)	Effective earth radius
h_R	(km)	Height of the rain
h_S	(km)	Altitude of the ground receiver site from sea level
γ_R	(dB/km)	Specific rain attenuation
L_s	(km)	Slants path length
L_G	(km)	Horizontal projection
r	()	Reduction factor of rain rate ($R_{0.01}$)
k_H	()	Specific attenuation coefficient at the frequency and polarization angle interest (Horizontal)
k_V	()	Specific attenuation coefficient at the frequency and polarization angle interest (Vertical)
α_H	()	Specific attenuation coefficient at the frequency and polarization angle interest (Horizontal)



α_v	()	Specific attenuation coefficient at the frequency and polarization angle interest (Vertical)
H	()	Horizontal polarization
V	()	Vertical polarization.
rv	()	Vertical adjustment factor
Le	(km)	Effective path length through rain
M	(mm)	Average total rainfall (mm)
M_m	(mm)	Highest rainfall observed over year consecutive.
P	(%)	Probability exceeded of time for rain rate
U_m	(number)	Average annual number of thunderstorm days
β	()	Thunderstorm ratio
ϕ	()	Inverse temperature constant
ϵ	()	Complex dielectric permittivity of water
Ac	(dB)	Cloud attenuation
f_p	(GHz)	Principal and relaxation frequency
f_s	(GHz)	Secondary relaxation frequency
K_{AC}	(dB/km)	Cloud specific attenuation coefficient.
L	(kg/m ²)	Columnar liquid water content of the cloud
Lw	(g/m ³)	Cloud liquid water content
TH	(km)	Cloud thickness
a_f	(dB)	Fog attenuation
M_f	(g/m ³)	Fog density/ liquid water
V_f	(km)	Visibility
L_f	(km)	Fog extent
a_f	((dB/km)/(g/m ³))	Normalized fog attenuation

CHAPTER 1

INTRODUCTION

1.1 Introduction

The exploitation of satellite for communication purposes has increased considerably during the last decades, in order to satisfy the growing demand for long distance communication. As the C-band is already congested, Ku-band (12.5 – 18 GHz) is filling up rapidly, recently interest focused on the utilisation of higher bands. Some satellites systems are already designed to operate in the Ka-band (26.5 – 40 GHz) and it is probability serious that serious consideration will be given soon to utilising the Q/V-band (40 – 50 GHz) [1].

The adoption of these bands for satellite communication has many advantages. This bands offer wider bandwidths, higher data rates, the amount of data transmitted, smaller component sizes, small earth receiving station and which to lead greater mobility as well as vastly improved anti-jam performance for source communications application [2].

Propagation is the study of how radio waves travel from one point to the other point. It is most important in communication application in predictions the propagation impairment. At frequencies above 10 GHz, effects due to ionosphere can be neglected. Troposphere effects however, can cause signal degradation on earth space along propagation path, which lead to reduction in the quality and availability of satellite communication service. Attenuation on radio wave propagation paths is generally caused by atmospheric components such as, gases, water vapour, oxygen, cloud, rainfall, thunderstorm during raining and fog. Rain attenuation is the dominant

propagation impairment at the Ku, Ka and Q/V-bands frequencies. Most important is, rain attenuation facing severe problem of satellite communication system design. Generally, rain attenuation is not the only propagation factor likely to degrade satellite system performance. Cloud and fog, which have been neglected at the lower frequencies, can significantly limit the performance of Ka and Q/V-bands satellite links models.

Many propagation prediction models have been developed to predict rainfall, cloud and fog attenuation. However there is no single reliable and universally accepted model at this date. Most popular references models and widely used are developed by The International Telecommunication Union (ITU). Different propagation prediction models can be found in Refs. 2, 3, 4, 5, 6 and 7.

When designing a satellite network, it very important to have the meteorological data available across for the satellite coverage area. Since the propagation impairment originates in the troposphere, the input parameters to the predictions models include meteorological data such as rainfall, thunderstorm during raining condition, cloud cover, visibility, temperature and humidity. Meteorological data, usually taken at the surface, is the most frequently data available. It is typically collected from earth station site and depending on the purpose of the site. Records of weather observations may be taken for every one-minute, hour, day, monthly or annual average of the year. One of the largest organisations organises for meteorological data collected including point data is National Oceanic and Atmospheric Administration (NOAA). Since the analyses of this thesis only focus on Malaysia satellite coverage area, Malaysia Meteorological Service data collections are used.

1.1.1 Frequency Bands

In order to establish the satellite communication link, only selected frequency can be used. Generally, this comprises L (1 - 2 GHz), S (2 - 4 GHz), C (4 - 8 GHz), X (8 - 12.5), Ku (12.5 - 18 GHz), K (18 - 26.5 GHz), Ka (26.5 - 40 GHz) and Q/V (40 – 50 GHz) [33]. Frequency bands above Ku-band are considered extremely high frequency bands. Commercial satellite transmissions are currently carried on either C-band or Ku-band with the uplink and downlink using different carrier frequencies [1].

The L-band is least effective by rainfall, thunderstorm during raining condition, clouds and fog, as all attenuation is negligible at this frequency range. C-band is the most heavily developed and used portion of the satellite spectrum. C-band offers larger bandwidth than L and S-bands and most popular used of the satellite spectrum because excellent in the service characteristics. X-band is allocated for military service. One of the attractive features that led to the use of C and L-bands for satellite communications is the low susceptibility to attenuation by rain or cloud. Ku-band becomes quite interactive because spectrum allocations here are more abundant than in the C-band. Digital Direct To Home (DTH) services such as DirecTV use this band. With an increased demand in satellite communications, the current spectrum allocation at C, Ku and Ka-bands are quickly becoming overcrowded. This has led to an increased interest from industry to utilize the Q/V-band frequency spectrum. Currently, several industry leaders are in the process of developing satellite communication system that operated at the Q/V-band frequencies.

Ka-band has many challenges, especially for the heaviest attenuation due to the rainfall. For Q/V-band, the implications for commercial satellite communications technology are uncertain.

1.2 Statement of the Problem

The propagation of radio frequency signal between an earth station and a satellite must pass through the earth atmosphere. The inhomogeneous and dynamic nature of the atmosphere makes it a non-conductive medium for transmission. Imperfections in the atmosphere come from sources such as the ionosphere, atmosphere gases, cloud cover, fog and more especially rain (with and without thunderstorm during raining). These natural phenomena cause impairment to the signal such as attenuation, depolarisation, delay and dispersion.

Due to increasing demand of satellite communication service, in addition to the frequency congestion and management problems [1] at lower frequency bands, design engineers have direct their attention towards the use of EHF (extremely high frequency) such as Ka and Q/V-bands for communication. This is exacerbated by the recent demand for multimedia communication and high data rate capabilities [2]. Hence, this interest in EHF band is justified due to high data rate capabilities [1], minimum interference and high achievable gain with narrow beam widths of small antenna [12]. As the frequency increases above Ku-band, the severity of the impairment also increases. The severity of the metrological effects increases with the increment of frequency. To design effective satellite communication system operation at extremely high frequency band (Ka and Q/V-bands), the effect of meteorology is important compared to Ku-band frequencies. At high frequency band,