FREE SPACE PATH LOSS FORMULATION FOR TROPICAL REGION

BY

ATIKAH BALQIS BINTI BASRI

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Kulliyyah of Engineering
International Islamic University Malaysia

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ABSTRACT

A link budget is a way of quantifying the link performance. In the design of wireless communications links between transmitter and receiver, issues of range and received signal quality are of critical importance to the system engineer. Link budget analysis accounts for all gains and losses in the communication link. FSPL is a factor to be considered in the link budget. Free Space Path Loss (FSPL) is the major menace to all propagation links regardless of operating frequency in the tropics during the clear sky. An adequate power margin is typically worked out in mitigating such a problem for the specific desired quality of service (QoS). However, the calculation is simple and straight forward, but the solution is not cheap. A signal fade margin can be computed, configured, and implemented to increase system availability. FSPL typically dictates the fade margin values. This effort correspondingly will help to reduce the greenhouse effect. In the case of clear sky attenuation, the value is much dependent on the atmospheric layer conditions and their compositions. For absolute Free Space, the signal loss is only dependent on distance and frequency. The effects of power, distance, and frequency were analyzed in this study to identify the most appropriate clear sky attenuation. The objectives can be achieved by designing, assembling, and carrying out an empirical experimental set up to evaluate FSPL values. This involved the process of verifying the variation between the free space path loss's theoretical and empirical values. The empirical experiment was conducted at Electromagnetic Compatibility (EMC)chamber at the Malaysian National Space Agency located at Banting Selangor. The development of revised formulation can Empirical. The clear sky conditions were confirmed using S-band (Terminal Doppler Weather Radar) TDWR reflectivity information acquired from the Malaysian Meteorology Department (MMD). Validation for the proposed revised FSPL equation using RazakSAT S-band (2.232 GHz) transmission signal data was furnished by the Malaysian National Space Agency (ANGKASA). By eliminating any possible signal variation due to atmospheric impairments (La) the RazakSAT processed received signal level can be considered. As a result, the revised free space path loss equation proposed a better FSPL value than the ITU-R proposed equation for RazakSAT received signal. The revise formulation is undoubtedly a significant improvement as compared to ITU-R estimation. This research will be valuable for future engineers in configuring the best communication establishment for satellite systems operating in the tropics.

خلاصة البحث

ميزانية الارتباط هي طريقة لقياس اداء الارتباط. في تصميم روابط الاتصالات اللاسلكية بين المرسل والمستقبل، تعتبر قضايا المدى وجودة الإشارة المستقبلة ذات أهمية حاسمة لمهندس النظام. ربط تحليل الميزانية بحسابات لجميع المكاسب والخسائرفي ارلتباط الاتصال. يعتبر برنامج FSPLغاملا يجب مراعاتة في ميزانية الارتبط. فقدان مسار الفضاء الحر(FSPL)هو الخطر الرتيسي لجميع روابط الانتشار بغض النظر عن تردد التشغيل في المناطق المدارية اثناء السماء الصافية. عادة ما يتم عمل هامش طاقة مناسب للتخفيف من مثل هزه المشكلة لجودة الخدمة المطاوية. ومع ذلك ، فان الحساب بسيط ومباشر ، لكن الحل ليس رخيصتا. يمكن حساب هامش الاشارة وتكوينه وتنفيذه لزيادة توفر النظام. تحدد FSPLعادة قيم هامش الخبو. سيساعد هذا الجهد في المقابل علي تقميل تاثير الاحتباس الحراري . في حالة السماء الصافية ، تعتمد الفيمة الي حد كبير علي ظروف طبقة الغلاف الجوي وتركيباتها. بالنسبة للمساحة الحرة المطاقة ، تعتمد خسارة الاشارة فقط علي المسافة والتردد. تم تحليل تاثير ات القدرة والمسافة والتردد قي هذه الدر اسة لتحديد انسب فقد لتكون السماء الصافية. يمكن تحقيق الاهداف من خلال تصميم وتجميع وتنفيذ مجمو عة تجريبية لتقييم قيم FSPLتضمن ذلك عملية التحقق من التباين بين القيم النظرية والتجريبية لخسارة مسار الفضاء الحر. اجريت التجربة التجريبية في غرفة التوافق الكهر و مغناطيسي (EMC)في وكلة الفضاء الوطنية الماليزية الواقعة في بانتينج سيلانجور. يمكن ان يكون تطوير الصيغة المنقحة تجريبيتا. تم تاكيد ظروف السماء الصافية باستخدام معلومات انعكاسية TDWRالتي تم الحصول عليها من قسم الارصاد الجوية الماليزي (MMD)في النطاق S(رادار طقس دوبلر طرفي). تم التحقق من صحة معادلة FSPLالمنقحة المقترحة باستجدام بيانات اشارة ارسال RazakSAT S-band (GHz 2.232)من فبل وكالة الفضاء الوطنية الماليزية (ANGKASA).من خلال القضاء علي اي تغيير محتمل للاشارة بسبب الاتحطاط الجوي (La)، يمكى النظر في مستوى الاشارة المستقبلة التي تمت معالجتها بواسطة RazakSAT .ونتيجة لذلك ، اقتر

حت معادلة خسارة مسير الفضاء الحر المنقحة قيمة (FSPL)افضل من المعادلة التي اقتر حها قطاع الاتصالات الر اديوية للاشارة المستقبلة (RazakSAT)تعد صياغة المر اجعة بلا شك تحسنا هاما مقارنة بتقدير قطاع الاتصالات الر اديوية. سيكون هذا البحث ذاقيمة لمهندسي المستقبل في تكوين افضل موسسة اتصالات لآنظمة الاقمار الصناعية العاملة في المناطف المدارية

APPROVAL PAGE

The thesis of Atikah Balqis binti Basri has been approved by the following:

Khairayu Badron
Supervisor

Ahmad Fadzil Ismail
Co-Supervisor

Othman O. Khalifa
Internal Examiner

Aduwati Sali
External Examiner

Nor Hisham Khamis
External Examiner

Mohammad Naqib Eisan Jan
Chairman

DECLARATION

I hereby declare that this thesis is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

Atikah Balqis binti Basri

Signature .... Date ....

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All glory is due to Allah, the Almighty, whose Grace and Mercies have been with me throughout the duration of my program.

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Next, it is my utmost pleasure to dedicate this work to my dear parents, husband, children and my family, who granted me the gift of their unwavering belief in my ability to accomplish this goal and prayers: thank you for your support and patience.

I wish to express my appreciation and thanks to those who provided their time, effort and support for this project. To the members of my dissertation committee, thank you for sticking with me.

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LIST OF ABBREVIATIONS

ANGKASA	Malaysian National Space Agency
CAPPI	Constant Altitude Plan Position Indicator
dBZ	Decibel Relative to Z
EMC	Electromagnetic Compatibility
FSPL	Free Space Path Loss
GISM	Global Ionospheric Scintillation Model
IIUM	International Islamic University Malaysia
ITU-R	Radiocommunication Sector
KLIA	Kuala Lumpur International Airport
La	Atmospheric Impairments
LEO	Low Earth Orbit
MAE	Mean Absolute Error
MMD	Malaysian Meteorology Department
QoS	Quality of Service
RMSE	Root Mean Square Error
SDE	Standard Deviation Error
TDWR	Terminal Doppler Weather Radar
VNA	Vector Network Analyser
VSWR	Voltage Standing Wave Ratio
Z/R	Reflectivity-Rainfall Rate
3-D	Three Dimensional

LIST OF SYMBOLS

θ	Elevation
$^\circ$	Degree

CHAPTER ONE

INTRODUCTION

1.1 OVERVIEW

In today's worldwide communication service scenario, it is observed that services providing voice, data, and video are increasingly merged and delivered to devices that are expected to be used at anytime and anywhere. At present, the satellite industry seems to play a vital role in providing telecommunication services even when they are facing stiff competition from terrestrial service providers. Satellite is a self-contained communication system with the ability to receive and transmit signals from Earth to satellite and vice versa via the transponder. The two essential elements of a satellite communication system, as shown in Figure 1.1 are the space segment comprising the spacecraft and flight mechanism; and the other, the ground segment of Earth station and network control centre of the entire satellite system.

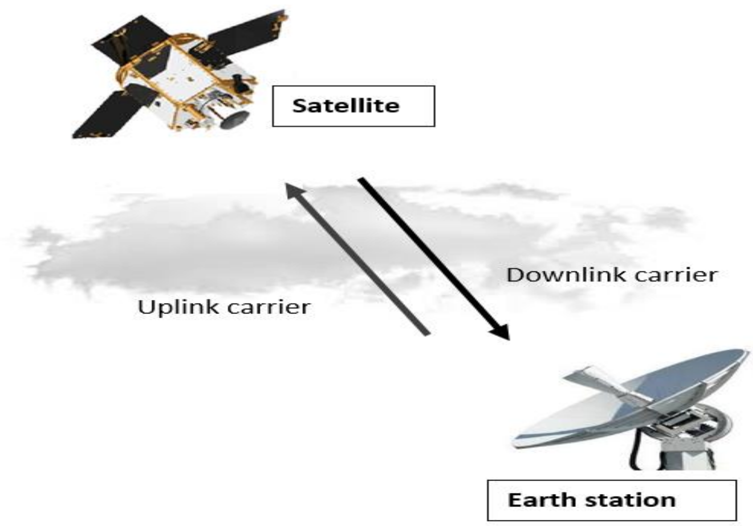

Figure 1.1 Schematic Diagram of Satellite Uplink and Downlink System (Tato, A. 2018)

Today, Low Earth Orbit (LEO), Medium Earth Orbit (MEO), and Geostationary Earth Orbit (GEO) continue to be the members among the hundreds of operational telecommunications satellites. The operating frequency bands of satellites are typically recognized by letter: L, S, C, X, Ku, Ka, and V. Larger antennas are needed to receive and transmit microwave signals at lower band frequencies (L-band, S-band, and C-band). Operations in the higher end of the frequency spectrum like X-band, Ku-band, Ka-band, and V-band sanctioned the use of smaller receiver dishes with size less than the one-meter diameter. Today's increasing demand for video, voice, and data traffic that requires more substantial amounts of bandwidth will drive the satellite services to operate at higher frequency bands. It is crucial to determine as accurately possible the power margins requirements as the frequency increases. It is also necessary to identify as detailed possible all propagation variances to be experienced at the frequency range of interest.

On such note, the atmospheric and weather effects on frequency bands between 3–30 GHz become significant. They are no longer negligible as compared to those at the lower frequency bands 3 GHz and below. There are mainly two dominant types of attenuation that dictate the power margin requirement for such high-frequency links. One is the atmospheric gaseous absorption, while another is the rain attenuation when microwave signals pass through the rain. Other environmental phenomena, such as cloud, fog, ice, snow, aerosol, and dust can also cause critical signal impairment as operating frequency increases. Several anomalous propagation modes (such as ducting and tropospheric scatter) may also play significant roles in the trans-horizon interference for a tiny percentage of the time. At a low elevation angle, the atmospheric scintillation and multipath fading will become significant. A microwave propagation scenario through the atmospheric medium experienced by an LEO satellite, i.e. RazakSAT, Malaysian owned satellite, operated in 2009 is shown in Figure 1.2

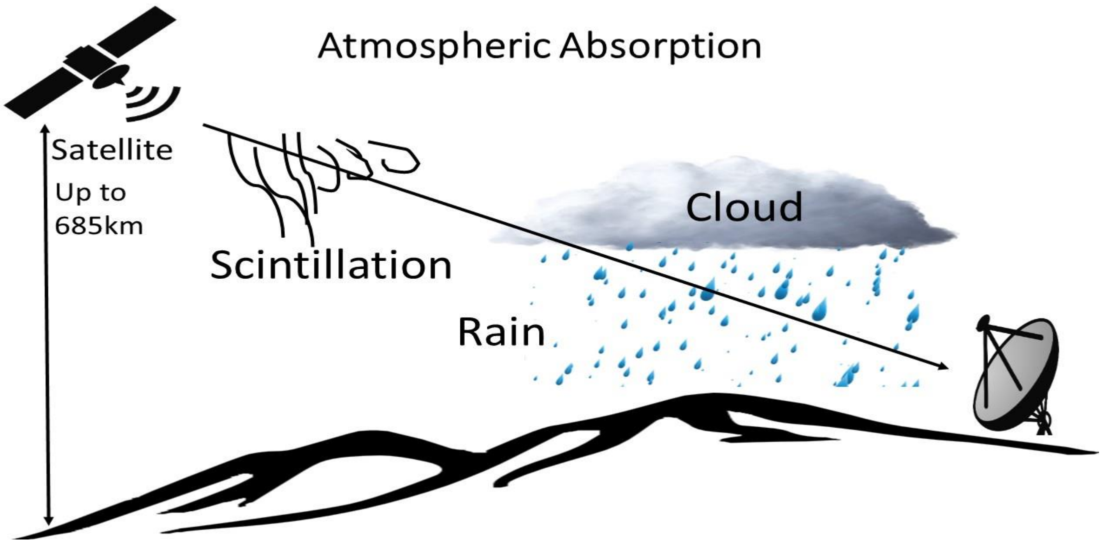

Figure 1.2 Microwave Propagation Scenario (Chaturvedi P.K.,2018)

As depicted in the figure, atmospheric absorption, clouds, fog, precipitation, and scintillation instigate energy losses in the transmitted signal. These losses can be deemed negligible at the lower frequencies, for instance, in the case of L-band link. As the frequency increases, such an assumption can no longer be acceptable. It is necessary to identify all the propagation mechanisms and estimate attenuation that might arise in the higher frequency bands.

The challenge is more evident in Equatorial and Tropical regions where high rainfall rates are more common. When the frequencies increase, the propagation signal will experience higher energy reduction due to higher absorption rate when passing through intense rain events as when compared to lower frequencies. In Malaysia, it is more common to classify the condition as wet and dry. The conditions experienced by orbiting satellites in the space above Malaysia fluctuate in terms of time, length of occurrence, and severity. The phenomenon where signal amplitude reduction, which is only due to increases in distance and frequency in a vacuum (free space) is defined as Free Space Path Loss (FSPL). Increasing the distance and frequency cause higher signal attenuation, thus degrade the reliability and performance of the system. To mitigate such circumstance, the link margin for the service has to be properly configured. The knowledge of the potential variation of system performance due to propagation effects that may occur at any time interval is indeed crucial. More detailed information is required to develop a better system such as the possible or potential impairments to be encountered on the satellite-Earth link. This is to make sure that the design incorporates sufficient system gain or sensitivity to accommodate expected fading, to ensure that the required quality of service is maintained.

1.1.1 Fundamentals of Free-Space Path Loss (FSPL)

In telecommunication, Free-Space Path Loss (FSPL) is the loss in signal strength of an electromagnetic wave that would result from a line-of-sight path through free space, with no obstacles nearby to cause reflection or diffraction. It does not include factors such as the gain of the antennas used at the transmitter and receiver, nor any loss associated with hardware imperfections.

FSPL is proportional to the square of the distance between the transmitter and receiver, and also proportional to the square of the frequency of the radio signal. The signals do disperse over distances. For satellite communication, this is the primary cause of signal attenuation or impairment. Transmitted signal attenuates over distance because the signal is being spread over a longer expanse. This form of attenuation is expressed in terms of the ratio of the radiated power to the power received by the antenna or, in decibels, by taking 10 times the log of that ratio.

$$\text{FSPL (dB)} = 20 \text{ Log} \left(\frac{4\pi d}{\lambda}\right) \quad (1.1)$$

$$\text{Where: } \lambda = \frac{c}{f} \quad (1.2)$$

For an ideal isotropic antenna, FSPL is typically denoted as Equation 1.1 where: λ is the signal wavelength (in meters), f is the signal frequency (in hertz), d is the distance from the transmitter (in meters), and c in Equation 1.2 is the speed of light in a vacuum.

Thus, for the same antenna dimensions and separation, the shorter the carrier wavelength (the higher the carrier frequency), the higher would be the FSPL value. The equation indicates that as the frequency increases, the FSPL value also increases and becomes more burdensome. However, the equation shows that the increased loss can be compensated with antenna gains. The increase in distance and frequency results in an increased loss measured as outlined in Equation 1.3.

$$FSPL(dB) = 20\log_{10} d + 20\log_{10} f + 32.4 \quad (1.3)$$

Where: d = distance (km)

f = frequency (MHz)

(ITU-R P.525-3, 2016)

Looking into the future, expending communication requirements will lead to frequency spectrum congestion (Chaves et al. 2015). Theoretically, this path attenuation is the dominant factor that limits the use of higher frequency for a Line of Sight (LoS) microwave links and satellite communication links in Malaysia. Malaysian engineers must be aware that the integrity of the microwave systems that had been designed for use in countries with temperate climate may not be capable of adapting conditions in