**New sharing method between the Fixed**

**Satellite Service and the Aeronautical Mobile**

**Satellite Service in the 14.0-14.5 GHz band**

by

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Thesis submitted to the Faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of

Master of Science

In

Electrical Engineering

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November 18, 2002
Falls Church, VA

Keywords: AMSS, FSS, Co-Channel Interference Analysis

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## Abstract

In the US, the 14.0-14.5 GHz band is allocated on a primary basis to the Radio-Navigation and the FSS with a secondary allocation to the LMSS. The Radio-Navigation service is the use of RADAR for navigation. An example of Radio-Navigation is the ground proximity radar used for airplane collision avoidance. FSS stands for the Fixed Satellite Service. In general, an FSS is a satellite network consisting of a geo-stationary satellite and non-movable earth stations on the ground. An example of an FSS is the earth terminals used at gas stations to verify credit cards and centrally track inventory. The 14.0-14.5 GHz band is also allocated on a secondary basis to the LMSS or Land Mobile Satellite Service. This is a satellite network with a satellite and a movable terrestrial non-aeronautical earth station. An example of an LMSS is a system called "Omnitracs", which provides a satellite-based data connection for the trucking industry. AMSS stands for the Aeronautical Mobile Satellite Service. An AMSS is an LMSS dedicated only to airplanes.

The CPM or Conference Preparatory Meeting after WRC or World Radio Conference-2000 decided there was an urgent need for technical and regulatory studies covering sharing between the FSS and the AMSS. The requirement for a report on the studies was added to the WRC-2003 agenda. The WRC also stipulated that the studies must demonstrate that sharing between the FSS and the AMSS is feasible enough to allocate AMSS a secondary status in the band. The studies need to be completed before WRC-2003. AMSS contends that sharing is feasible if their service can meet the same PFD limits of the LMSS. Presently, the FCC has licensed the AMSS on an experimental non-interference basis.

The FSS contends that characteristics are needed of the AMSS system and a detailed sharing study be completed to verify sharing is feasible. The FSS believes that sharing may not be

feasible if the same transponder is used for AMSS and FSS. The FSS perceives that the AMSS is asking for a super secondary status. Super secondary status implies that the AMSS would only be required to adhere to PFD limits on individual aircraft and not for multiple aircraft in view of a victim FSS receiver. Future studies will clarify this issue.

The issues associated with the sharing analysis are; the modeling of the orbital separation of the satellites, the atmospheric interference into the communication link and the availability of the communication link between the FSS and the AMSS.

The issues associated with modeling of the simulation are the static, verses dynamic modeling environments and developing a dynamic software tool to track airplane movement. This thesis plans to propose a new sharing methodology between the FSS and the AMSS that could be contributed to the WRC-2003 agenda.

Three systems examples were provided at ITU meetings inresponse to the WRC-2003 agenda item. The three systems will abide by the ITU-R S.728 EIRP limits. The three systems indicate that static analysis shows that sharing is feasible involving only one aircraft as the interfere. This is not a reasonable solution for a real time environment because there is only one aircraft used. It is necessary for the link to support multiple aircraft.

The factors that indicate sharing is feasible are: non-harmful interference to the victim and reasonable enough link margin in the interfere system to make it viable. A viable system in the case of aircraft would include high-speed internet and video. The AMSS interfere system cannot propose a power limit that will not allow it to close it's own link.

In order to mitigate the interference, systems can agree to certain interference mitigation techniques. The different techniques are: transmitting power control, geostationary arc avoidance angle and orbital arc separation.

Power control as described above is the centralized control of the interfering antenna into the victim. This is done by simulating the interference environment and pre-scheduling the decreases of the transmitting power. This is a feasible solution except that it decreases the availability and thru-put of the interfere system. This approach can make the system have unrealistic link margins and spotty availability due to the pre-scheduled power control.

Another technique is the geostationary arc avoidance angle. This technique is not applicable since both the AMSS and FSS use geostationary orbits.

The third technique is geostationary separation. This technique requires co-channel systems to maintain a certain orbital spacing between them. FSS systems in certain bands have a minimum of 3 degrees of orbital spacing between co-channel systems. Since the AMSS has

a mobile terrestrial system (aircraft) as part of the link, it requires a higher orbital separation between it and the FSS system.  The results of dynamic analysis indicate that this technique is feasible at 10 degree orbital spacing.

The Monte Carlo analysis completed for this thesis simulated the results of four scenarios: co-located, 3 degree, and 5 and 10-degree orbital separation.  It can be determined from the results that the interference decreases as the orbital separation increases.  These simulations were done based on a 10 aircraft interfere scenario.

# List of Figures

# List of Tables

**Chapter 1 Introduction**

The [7] Fixed Satellite Service (FSS) is a satellite network consisting of a geo-stationary satellite and non-movable earth station on the ground. An example of an FSS is the earth terminals used at gas stations to verify credit cards and centrally track inventory. The FSS has a primary allocation in the 14.0-14.5 GHz frequency band. The band is also allocated on a secondary basis to the LMSS or Land Mobile Satellite Service. The [7] LMSS is a satellite network with a satellite and a movable terrestrial non-aeronautical earth station. An example of this is a system called [10] "Omnitracs". Omnitracs provides a satellite-based data connection for the trucking industry. AMSS stands for: the Aeronautical Mobile Satellite Service. AMSS is similar to the LMSS except airplanes exclusively use the service. At the WRC-2000 or World Radio Conference the member states of the ITU or International Telecommunications Union, recommended that sharing studies be done between the AMSS and the FSS by WRC-2003 in the 14.0-14.5 GHz frequency band.

The problem with the current sharing analysis between the FSS and the AMSS is that only static analyses between the two services have been considered as feasible sharing analyses. This does not take into account the variable nature of satellite links. This thesis plans to use a dynamic sharing simulation tool to analyze the sharing between the two links. This dynamic analysis will provide a more realistic simulation of the environment than previously completed static analyses.

*Thesis Objective*

One of the main objectives of this thesis is to determine whether co-channel frequency sharing is feasible between airplane RF uplinks into Geostationary satellites that are receiving wanted signals from fixed terminals on the ground. This thesis will answer the question: if sharing is feasible; what type of RF interference mitigation techniques are necessary?

There are various methods to demonstrate that sharing is feasible for services and networks. The first steps to take when determining if sharing is feasible are to define what a service is and what a network is. A service is defined as a specific type of system architecture. A network is a particular system operating using a specific architecture. In the FSS, the standard architecture is a geostationary orbiting satellite with fixed earth stations on the ground. The [7] INTELSAT is a network that uses the FSS architecture. Once a service has a standard set of characteristics or architecture, it can use these characteristics to develop standard sharing criteria with other services. These sharing standards are usually in the form of [3] EIRP/PFD limits. EIRP limits specify the amount of power radiated at a set frequency range from a transponder. A PFD is the amount of power per unit area radiated at a set frequency over the ground.

The PFD/EIRP limits serve two purposes in that they are used for inter-system interference and intra-system interference. Inter-system would be defined as sharing between two separate architectures, as the FSS and AMSS systems being analyzed in this thesis do. Intra-system would be defined as sharing between two systems of the same architecture. An example of intra-system interference is the network-to-network FSS coordination between government administrations. In this case, any agreeable power limits between the networks would degrade the performance of the systems, thus it is necessary to have some form of network-to-network face-to-face coordination. The coordination will set up agreements that do not always meet the limits but are agreeable to each party.

Due to the dynamic nature of the AMSS service, for example airplanes moving around the globe simultaneous transmitting, it is not feasible to do individual link coordination as done between FSS systems. The most practical approach to limit AMSS interference into the FSS victim receiver is to have an EIRP limit at the antenna on the aircraft.

Thus far, there have been three contributions to the ITU dealing specifically with AMSS and FSS sharing feasibility. Each of the three systems contributed is very similar and each agrees to abide by a set of EIRP limits. These limits were based on a static view of the environment. An important question is; how many systems can be tolerated in a given environment with out causing interference between themselves or the FSS? This thesis plans to answer this question by analyzing a dynamic environment that takes into account multiple systems.

The main purpose of this thesis is to develop a dynamic sharing methodology. The analysis will take into account the orbit of the geostationary satellite and randomness of moving aircraft.


*Brief Summary of Previous Related Studies*

This section, describes three separate studies that have been previously completed on the subject. The studies contain an explanation of the systems architecture and a static analysis of the AMSS sharing with the FSS.


System A (WP 8D/149) [7]

The first study is detailed in the document titled "Description of a Planned AMSS System Operating in the 14.0-14.5 GHz Frequency Band ". This study is a French contribution to WP 8D and will be referred to in this thesis as System A. The purpose of the document is to provide the characteristics of an AMSS system that has the following capabilities: VPN, Internet access, digital television, telephone and video conferencing and flight and crew operations support.

Because of the document's French origin, the assumption is made that these are the characteristics of a system proposed by Airbus for use in their aircraft. The system uses a set of earth stations positioned around the world to communicate between the aircraft and the satellite. The earth stations also provide the connection for the satellite link to the Internet, phone network, etc. The system plans to mitigate interference by using real time location of the aircraft to control the pointing and power of the antenna to minimize interference in the GSO arc. The system plans to have the aircraft-transmitting antenna abide by Antenna Mask ITU-R S.728-1. The document uses only a static link budget (listed in the results and conclusion section of this thesis), and it's agreement to abide by the S.728-1 recommendation as reason enough to indicate that sharing is feasible with the FSS. The document does not list the maximum numbers of aircraft allowed to be used simultaneously without causing harmful interference to the FSS.

System B (8D/131) [7]

The second document titled "Characteristics of a Typical System Operating in the 14.0-14.5 GHz Frequency Band" will be referred to as System B in this thesis. This document is another French contribution that analyzes the feasibility of sharing between the AMSS and the FSS assuming a 3-degree minimum spacing between the geostationary satellites. A 3-degree minimum spacing implies that the transponders for the FSS and a transponder for the AMSS both on geostationary satellites will be orbiting at least 3 degrees apart. The document uses an "FSS dependant approach" to justify that sharing is feasible.

The FSS dependant approach is a static link budget methodology that uses EIRP limits/masks of the upwardly transmitting terrestrial antenna. In an FSS dependant approach, the antenna mask limits developed for the aircraft-transmitting antenna are used to protect the victim receiving FSS transponder. An aircraft in the ITU is considered a terrestrial object because it never leaves the earth's gravitational field or travels faster than the earth's escape velocity. For this reason, the antenna masks developed for the aircraft are very similar to the ones developed for earth stations. For this thesis, EIRP limits are used instead of antenna masks. EIRP limits/masks are very comparable to antenna masks except that power is factored into the limits.

The document indicated that the AMSS system would try to meet the EIRP limits by having power controlled by a ground network operations center. I believe the document does not provide sufficient analysis to justify that the EIRP limits proposed can be met in a dynamic situation. In order to do this, I believe it is necessary for the system to meet two sets of power limits. The two sets of proposed limits are the EIRP limits to mitigate interference into the FSS and the minimum power required to operate the AMSS. The AMSS system may be able to lower its power to mitigate interference into the FSS, but if it has to lower it so much that it cannot meet it own link margins is it a truly viable system? The AMSS system has to simultaneously

maintain a reasonable availability for its customers and not cause unreasonable interference to the FSS for the system to be viable.


System C (8D/101) [7]


The document 8D/101 is the United States' contribution to the AMSS sharing analysis and will be referred to as System C in this thesis. Boeing, the main U.S. commercial aircraft manufacturer, supports the document. The document is very similar to System B 8D/131, except that the system uses a phased array antenna on the aircraft. Because the system plans to abide by the ITU-R 728 recommendations, I do not see where the architecture changes affect the analysis of the interference.


Satellite Access in FPLMTS [11]


The document "Satellite Access in FPLMTS" is a PHD thesis about 3G wireless using the UMTS Network Architecture. Most of the document does not directly relate to my thesis except for portions of chapter 7. In chapter 7, it describes a term called DCA or Direct Channel Assignments. It describes that using direct channel assignments when assigning a wireless user between a terrestrial and satellite networks can cause out of band emissions from the terrestrial networks into the satellite networks. This is similar to the Dynamic Monte Carlo Simulation described in this thesis in that numerous side lobe interferers are more of a interference problem than a static main beam interference situation.


Feasibility of Managing a Dynamic Constellation to a Fixed Constellation Definition [12]


The document "Feasiblility of Managing a Dynamic Constellation to a Fixed Constellation Definition" is a document about designing the GPS satellite architecture by using the correct values of the 7 line element set to maximize the coverage to provide the user with the ability to have the highest availble 3D coverage. This relates to this thesis in that it analyzes the separation between the satellites and how this is important to the coverage in a dynamic environment.


Aeronautical Broadband Communications via Satellite: Constellation and System Design Issues [13]


This document is about the issues associated with using geostationary satellites to provide AMSS service and the limitations of geostationary orbits at aircraft operating at high latitudes. This issue is important to the AMSS system design specification, it is not an issues WRT to this thesis.

## On Distributed, Geographic-Based Packet Routing for Leo Satellite Networks [14]

The document discusses a routing protocol for a Leo satellite system distributing IP packet broad-band data. This is interesting in that this system could be used in a future study of other satellite orbits to use the AMSS system.

## Optimal Earth Orbiting Satellite Constellations via a Pareto Genetic Algorithm [15]

This document discusses the design of satellite constellations using the Pareto Genetic Algorithm. This algorithm was implemented using a COTS systems called STK. This document relates to my thesis by suggesting the use of a COTS software to implement and simplify the simulation. One of the issues in my thesis is the implementation of a complicated simulation algorithm by writing the code from scratch. This analysis used a COTS product to supplement some of the implementation of the algorithm.

## Internetworking with Satellite Constellations [16]

This document discusses the effects of satellite constellations have on IP packet networks. This is related to my thesis in that a portion of the traffic using a AMSS system will ride over IP. This is interesting in that it brings up issues such as multicast on a IP system that could be analyzed in future work.

Routing and Multicasting in LEO Satellite IP Networks [17]

This document proposes a new *Delay-Coupled Probabilistic Routing Protocol (DC-PRP)* for realtime time applications using leo satellite constellations to carry IP traffic. This document is very similar to reference 16. There must have been considerable research money for this subject. This is the same type of analysis that could be done in a future work but does not directly pertain to my thesis.

## Routing for Best Effort Services in LEO-Based Satellite Systems [18]

This document reviews the various protocols for LEO satellite IP packet routing and concludes that most algorithms work best in a stationary environment. This is very similar reference 16 and 17.

MLSR: A Novel Routing Algorthim for Multilayered Satellite IP Networks [19]

This document reviewed different IP protocols developed for LEO satellite IP traffic routing. It then proposes a new multi-layered approach that uses LEO, MEO and GEO satellite systems to provide services for various users. I think this is an interesting idea in that instead of proposing an integrated protocol for a specific system it takes into account legacy satellite networks. This is truly a more realistic approach to what is really going to happen in the marketplace. I did not take into account a multi-system issues in my thesis. I would like to leave this to future analysis.

Network Layer Integration of Terrestrial and Satellite IP Networks over BGP-S [20]

This document proposed a Border Gateway Protocol for an interface between terrestrial and satellite IP gateways. This is similar to the gateway that will be used by the AMSS earth stations to route the data from the aircraft to its destination. This does not have any direct issues with my current thesis.

*Author's Previous Work in ITU Arena*

Below are summaries of three different documents previously submitted to the ITU. The documents cover the topics of Ku band systems, terrestrial interference into limb sounders, and the atmospheric absorption models. Methodologies from these studies are used in this thesis to develop a better understanding of the FSS and AMSS systems.

The first document, [7] a "Methodology to Derive Continuous Curves of EPFD Versus GSO FSS Antenna Diameter" covered the Ku band systems. This document showed that is it not possible to have a continuous line of Antenna Diameters verses EPFD down for a constant Io/No. A new recommendation needs to be developed to provide continuous curves of equivalent power flux densities versus percentage of time for a range of GSO FSS earth station antenna diameters. WRC-97 adopted provisional EPFD limits in various Ku and K bands that would apply to non-geostationary FSS to protect GSO FSS networks. Annex 2 to Resolution 130 (WRC-97) called for the "development, if practicable, of continuous curves of equivalent PFD versus antenna diameter and/or G/T of the earth station to be protected". This document provided insight for my thesis by revealing the fact that a system has to be able to adhere to continuous curves of PFD limits for a constant Io/No value

The second document [7] "Analysis of Low Earth Orbiting Microwave Limb Sounders Interference" from the FS provided a different methodology to show that sharing was feasible between Limb Sounders and the FS under normal conditions. Microwave Limb Sounders are passive sensors used to detect emissions of gases of the stratosphere and high troposphere. The sensor is a payload on a polar low earth orbiting spacecraft. The spacecraft's sensor is pointed tangential to the horizon of the earth. The path of the sensor through the atmosphere allows it to

maximize the amount of trace species it collects in the atmosphere. These trace species can be collected by the satellite's sensor at 215 GHz using the EESS.

It is proposed that both services (FS and EESS) share a band around 215 GHz. The previous analysis done in the ITU on this topic indicated that sharing was not feasible using the LIEBE 93 model to calculate atmospheric absorption. To show that sharing is feasible is it necessary to demonstrate that the interfering FS signal will be dissipated due to atmospheric absorption.

The interference metric used in this analysis was a radiometric resolution of 0.1K. Radiometric resolution is the change in the noise temperature of the sensor as it flies over an FS transmitter. This analysis used an atmospheric absorption model based on Recommendation ITU-R P.676-3. The results were a set of four charts.

The first chart was the atmospheric absorption plus spreading loss from an elevation angle of 0 to 10 degrees for wet and dry atmospheric conditions. The second chart was the elevation angle of 0 to 10 degrees verses the sensor antenna effective area. The third chart was the maximum FS EIRP in the direction of the sensor from 0 to 10 degrees. The fourth chart was the maximum FS EIRP in the direction of the sensor form 10 to 90 degrees.

These charts indicate sharing is feasible under most atmospheric conditions. The North and South Poles are the only locations where sharing is not feasible due the extremely dry atmospheric conditions that obscure the FS signal into the sensor. This one issue alone will not cause an overall verdict against sharing, since it is highly unlikely that any of these FS transmitters will be operating at the poles. The initial analysis on this subject in the ITU indicated sharing is not feasible. After using a different atmospheric absorption model, my study concluded that sharing is feasible except at the poles. This is an important lesson to take into account when doing analysis in that not to allow the analysis to get wrapped around the use of one model to draw a conclusion to a problem.

The third and final [7] analysis titled "Protection of the FS in the band 8025 MHz – 8400 MHz from GSO/EESS Data Down-links" reviewed PFD limits that protect the FS from the EESS and proposed new PFD limits. The document analyzed the interference into the FS for various EESS systems. Each EESS system had the same characteristics except for variations in the system's noise temperature. An analysis was done for EESS interference into FS systems at 5 degree and 90 degree elevation angles. These results were compared to the various PFD limits. The analysis concluded that the new limits adequately protect the FS. This study was important for my thesis because if sharing is proven practical, a service should allow to share it's band.


*Thesis Contributions*

The goal of this thesis is to develop a new sharing methodology and simulation software to verify the sharing methodology, and use this methodology as a potential contribution to WRC-2003. The methodology will promote more efficient use of the frequency spectrum.

*Outline of Thesis*

Chapter 1 described previous studies have done, and the motivation and objective of the thesis. Chapter 2 will describe the ITU regulatory process and how this affects the analysis. This will include a brief overview of ITU terminology, a summary of the regulatory process and a detailed explanation of the current spectrum usage of the 14.0 – 14.5 GHz band. Chapter 3 will describe the communication and satellite concepts. This will include brief descriptions of the communication theory, link metrics used in radio frequency interference analysis and also a description of satellite orbit mechanics. Chapter 4 will describe the method for sharing, the processes for the simulation software between the different sharing methodologies and propose a method to derive the dynamic results. Chapter 5 will review the dynamic and static results. And finally Chapter 6 will discuss the conclusion of the thesis and recommend some future work.

**Chapter 2 ITU Issues**

The field of Spectrum Management is centered on the ITU. The ITU or UIT in French, is an international UN affiliated agency headquartered in Geneva, Switzerland. Its mission is to develop standards for the transmission of information via any media and to promote the development of this technology throughout the world.

This chapter will describe the ITU organization and the international regulatory process used for spectrum resource sharing called "Spectrum Management". Spectrum Management is a broad field encompassing the following topics: international regulatory environment, domestic regulatory environment, and technical characteristics of services and sharing techniques.

The international regulatory environment is the portion of Spectrum Management dealing with the ITU, CITEL, Asia Pacific Council, the EU, and bilateral coordination's. The domestic regulatory environment is the portion dealing with each internal countries' frequency management policy. There are two types of frequency management structures for administrations. The management structure used in the US has two separate agencies. The first agency, the FCC, manages commercial frequencies and the second agency, the NTIA, manages government frequencies. The FCC or Federal Communication Commission is a quasi-independent organization controlled by the legislative branch of government. The NTIA or National Telecommunications Information Agency handles frequency management issues for such agencies as NASA, NOAA and the DOD. The NTIA is an executive branch agency in the Department of Commerce. Even though each organization has a different responsibility, sometimes there are disagreements on spectrum management policy. The Department of State is brought in to settle any disputes between the organizations. In most other countries there is only one frequency management agency, which causes a less dynamic debate on spectrum issues.

The international agency that handles spectrum management is the ITU. The ITU is a complicated, and convoluted international organization. Many of the decisions rendered by the ITU are purely political. This thesis plans to look at issues from an independent and technical rather than political perspective.

In order to understand how the ITU works, it is best to describe its' terminology.

There are two classifications for members of the ITU. Member States are countries that have membership in the ITU. Sector Members are companies and non-government organizations that have membership in the ITU.

There are three divisions of the ITU, each with its' own responsibilities. The ITU-D is a section of the ITU used to promote technology in the developing world. The ITU-T is a section of the ITU used to develop standards in the non-RF telecommunications arena. Finally, the ITU-R is the part of the ITU responsible for RF.

The rules that govern the ITU-R are referred to as the Radio Regulations (RR). RR consist of a set of rules agreed to by ITU member states governing the use and allocation of frequency bands. The BR or Radiocommunication Bureau is the administrative wing of the ITU-R that manages paper work, coordinates meetings and acts as the initial interpreter of the RR. The BR interpretation of satellite regulations can be quite controversial on the most mundane of subjects. If a member state does not like the BR interpretation it appeals to the RRB described below.

The Radio Regulations Board or RRB handles appealed disputes concerning interpretations of the RR. The RRB is made of people from various member states. RRB members are elected at an ITU meeting called the Plenipot and their term lasts around six years. The RRB acts as a mediator between the BR and Member Countries and rulings rendered by the RRB are final. The responsibilities of the BR and RRB are to administer and make rulings on the interpretation of the RR but not to change the RR themselves. If a member state does not like the RRB ruling on a subject matter, then it will try to make the issue an agenda item at the next WRC. The responsibility of setting and updating the RR falls on the World Radio Conference.

The World Radio Conference (WRC) is an international meeting of Member States and Sector Members. The WRC meets every two to three years to revise the Radio Regulations.

The WRC modifies the rules of the RR based upon frequency band and geographic location. An example of an RR rule is: the FSS is allocated on 15.0 –15.5 GHz band in the Unites States. The geographic locations of the RR are determined by a three level hierarchy; worldwide, regional, and country. All Member States in the world are assigned to one of three regions. Region 1 covers West Europe and Africa. Region [6] 2, which encompasses the United States, covers North America, South America and Greenland. Region 3 covers Russia, Southeast Asia and the Pacific Rim Countries.

Within a frequency band, at a specific geographic location, there are primary, secondary and non-interference allocations. A service with a primary allocation in a frequency band has the highest level of interference protection. A service with a secondary allocation in a frequency band has a secondary status to the primary allocation. It is the responsibility of a service with a secondary allocation to limit its interference to services with primary allocations based upon specific power limits. A service operating on a non-interference basis or NIB is required to operate in a frequency band with other services below the noise level of the primary and secondary allocations.

Services are allocated to specific frequency bands within geographic locations. There are many services regulated by the ITU-R. A common service is the FSS or Fixed Satellite Service. The FSS is characterized as a system with a geostationary satellite transmitting or receiving to a stationary earth station on the ground. The frequency bands utilized by the FSS tend to provide high data rate connectivity. Recently, the ITU has considered allowing non-geostationary satellites into FSS only bands to allow for the creation of "Skybridge" systems. A "Skybridge" type of system employs more than 150 satellites distributed over the globe to create continuous worldwide coverage of 40 degrees North to 40 degrees South.

Another service regulated by the ITU-R is the Mobile Satellite Service or MSS. The MSS refers to a satellite of any type of orbit, transmitting or receiving to a mobile terrestrial station. The earth station does not have to be moving all the time but has the ability to be easily moved. The Fixed Service or FS regulated by the ITU-R encompasses fixed point-to-point microwave towers. The Space Research service or SR, is a service that is designated for use by the satellites and ground stations used by NASA and other Space Agencies for near earth and far earth exploration. Examples of SR are the Space Shuttle and the International Space Station. The term EESS stands for Earth Exploration Satellite Service. In general EESS are the satellites and ground stations used by NASA and other Space Agencies for near earth exploration. The AMSS or the Aeronautical Mobile Satellite Service is used to allow airplanes to transmit and receive voice and data via satellites. These satellites also provide feeder links to the ground. The AMSS is allowed to use any type of satellite orbit. Radio-Navigation is the use of RADARS to enhance the navigation of airplanes and boats. Land Mobile Satellite Service is the use of land-based mobile earth stations with satellites. The MS or Mobile Service refers to communication between two moving objects. A final service regulated by the ITU-R is Radio Astronomy. In general, Radio Astronomy pertains to sensors that collect information on distant stars and planets.

*WRC 2000 outcome*

Per Resolution 216 (WRC-2000), agenda item 1.11 of WRC-2003 is to consider the secondary allocation of the AMSS in the 14.0-14.5 GHz band. Presently, land and maritime mobile satellite services already operate in this band. Resolution 216 was originally developed at WRC-97 and modified at WRC-2000. The management of the sharing studies for Resolution 216 was assigned to ITU-R Working Party 8D.

*Definition of 14.0 –14.5 GHz Allocation in the US [6]*

Internationally the 14.0-14.5 GHz band is divided into five sub-bands that may have different allocations in different countries and/or different regions. The five sub-bands are 14-14.25 GHz, 14.25-14.3 GHz, 14.3-14.4 GHz, 14.4-14.47 GHz and 14.47-14.5 GHz.

In Regions 1, 2 and 3, the 14-14.25 GHz band is presently allocated on a co-primary basis to the FSS (Earth to Space Only) and the Radio-Navigation Service. On a secondary basis the 14-14.25 GHz band is allocated to SR and the MSS (Earth to Space Only) with the exception of AMSS. In the United States, the Federal Government is allocated on a co-primary basis to Radio-Navigation and on a secondary basis to SR in the 14-14.2 GHz band only. In the United States, the commercial sector is allocated on a co-primary basis to the FSS (Earth to Space Only) and Radio-Navigation, and on a secondary basis to LMSS and SR in the 14-14.2 GHz band only. In the 14.2-14.25 GHz band, the commercial sector is allocated on a primary basis to the FSS and on secondary basis to the LMSS and MS except aeronautical mobile. There is no US government allocation in the 14.2-14.25 GHz band

In Regions 1, 2 and 3, the 14.25-14.3 GHz band is presently allocated on a co-primary basis to the FSS (Earth to Space Only) and the Radio-Navigation service. On a secondary basis the 14.25-14.3 GHz band is allocated to the MSS (Earth to Space) with the exception of aeronautical telemetry. In the 14.25-14.3 GHz band, the commercial sector is allocated on a primary basis to the FSS and on secondary basis to the LMSS and MS, with the exception of aeronautical mobile. There is no US government allocation in the 14.25 –14.3 GHz band.

In Region 1, the 14.3-14.4 GHz band is allocated on a primary basis to the FS, the FSS and the MS, with the exception of aeronautical mobile, and on a secondary basis to the MSS (Earth to Space) with the exception of AMSS and the Radio-Navigation Satellite Service.

In Region 2, the 14.3-14.4 GHz band is allocated on a primary basis to the FSS (Earth to Space) and on a secondary basis to the MSS (Earth to Space) except AMSS and Radio-Navigation Satellite Service. In the US, located in Region 2, the 14.3-14.4 GHz band is allocated to the commercial sector on a primary basis to the FSS (Earth to Space), and on a secondary basis to the LMSS (Earth to Space) and MS except Aeronautical Mobile.

In Region 3, the 14.3-14.4 GHz band is allocated on a co-primary basis to the FS, the FSS (Earth to Space) and the MS except Aeronautical Mobile and on a secondary basis to the MSS (Earth to Space) except AMSS and the Radio-navigation Satellite Service.

In Regions 1, 2 and 3, the 14.4-14.47 GHz band is allocated on a co-primary basis to the FS, the FSS and the MS except Aeronautical Mobile and on a secondary basis to the SR (Space to Earth) and MSS (Earth to Space) except AMSS. The US government is allocated in the 14.4-14.47 band on a secondary basis to the FS and MS. In the US, the commercial sector is allocated on a primary basis to the FSS (Earth to Space) and on a secondary basis to the LMSS (Earth to Space) in the 14-14.7 GHz band.

In Regions 1, 2 and 3, the 14.47-14.5 GHz band is allocated on a co-primary basis to the FS, the FSS (Earth to Space) and the MS, except aeronautical mobile, and on a secondary basis to the Radio-Astronomy Service and the MSS (Earth to Space) except AMSS. In the US, the government is allocated in the 14.47-14.5 GHz band on a secondary basis to the FS and the MS. In the US, the commercial sector is allocated on a primary basis to the FSS (Earth to Space) and on a secondary basis to the LMSS (Earth to Space) in the 14.47-14.5 GHz band.


*Summary of Chapter*


This chapter explained the terminology used to describe services in the ITU, the services that utilize the 14.0-14.5 GHz band and the regulatory process used to change the current allocation of the band. The U.S administration supports the proposed AMSS secondary allocations in the 14.0-14.5 GHz band assuming that studies show that sharing is feasible.

**Chapter 3 Link Budget Metrics and Orbit Mechanics of Satellite Systems**

In order for a satellite and a terrestrial device to communicate, a detailed method must be developed to quantify the power between the two devices. Orbit mechanics describes the satellite systems position in regards to the terrestrial device and the link budget describes the power ratio between the two devices. This chapter will describe the requirements needed to establish a link budget. This chapter will also describe the requirements needed to calculate a satellite's orbit around the earth.

Orbit Mechanics is used to calculate a satellite orbit. To calculate any type of satellite orbit, it is necessary to have a seven-line element set. A seven-line element set is made up of seven parameters that can specifically describe any satellite orbit. Once a satellite orbit has been calculated, this information can be used to calculate off-axis angles between the victim and interfering devices. These angles are used to calculate off-axis gain of the antennas to develop link budget metrics. Orbit Mechanics is discussed near the end of this chapter.

A link budget is developed using either of two interchangeable equations. These equations are: the Friis Transmission equation and Linear Power Equation. Either of these equations is adequate for developing a link budget, but this analysis will utilize the latter. The Linear Power Equation is the basis for developing link budget metrics. This chapter will describe how this equation is transformed into link metrics, the parameters of the link metrics and how these link metrics are used to determine the performance characteristics of the communication link.

*Description of Linear Power[2, 4]*
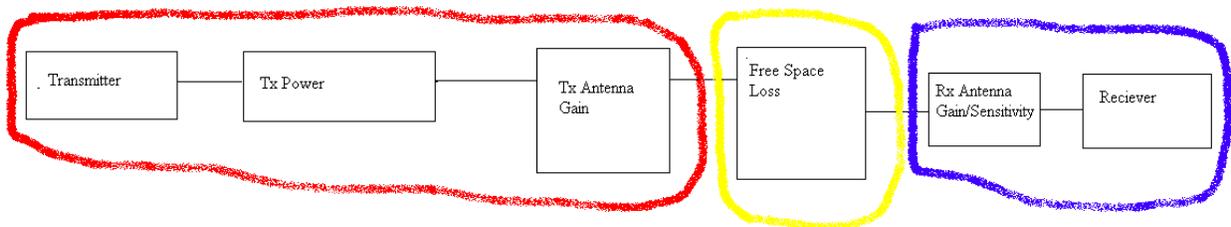


Figure 3.1 Description of Linear Power

Linear power is used in RF communication systems to describe the strength and focus of the signal. In an RF system there is a transmitter and receiver. As a signal moves from the transmitter (Tx) to the receiver (Rx) there are four factors that measure the linear power: Tx Power, Tx Antenna Gain, Rx Antenna Gain/Sensitivity, and Free Space Loss. The relationship of these factors to linear power can be viewed in the Linear Power Equation below.

$$LinearPower = P_t G_t G_r [\lambda / 4\pi R]^2$$

Antenna Masks are used as a standard means to describe a generic antenna characteristic for the transmitting and receiving antenna gains in the Linear Power Equation. An Antenna Mask is used to model the sharing between different services [3]. In general the ITU has established a policy that an antenna mask is developed for a certain service. These policy's are developed in Working Group meetings at the ITU. An example would be in the ITU is chartered to develop methodologies for efficient GSO orbit and frequency use. One of the ways to increase GSO orbit efficiency is to have as narrow as possible earth station antenna main beam and very low power from the side lobes of the antenna. This allows for the least amount of intra-service interference (FSS to FSS network).

Another issue with a standard antenna mask for a particular service, is that it allows for non-operation coordination of the satellite network. Most system operators do not want to coordinate their systems. The operators want to have a set antenna mask and EIRP density that everybody has agreed to. If they do want to coordinate, standard mask simplifies the model thus reducing man-hours for coordination. The antenna mask is a variable in the Linear Power Equation that is used in developing link budget metrics.

The link budget measures the ratio of the power of one device to the power of another device. The results of the Linear Power Equation are used as the numerators and the denominators for these ratios. These ratios are referred to as link budget metrics. There are many forms of these metrics, some often used metrics are: I/N, Io/No, Eb/No, and C/I. Each is similar in that the linear power at each part of the ratio is the same i.e. the transmitting power of one device is being received across the RF at a certain frequency by another device with certain sensitivity. Sensitivity referrs to receiving noise temperature. The lower the noise temperature the more sensitive the device is. The frequency the device oscillates at determines the propagation of the RF signal with lower frequencies being easier to transmit. The metrics are used in satellite coordination, and inter system sharing. An example would be: Io/No = −12.2 dB for GSO network to GSO network.

*Performance Metric*

Each metric has specific characteristics that can be interpreted as to the links performance. C/I is the metric that measures the ratio of the carrier power (C) of the victim verses the interfering power (I) in the direction of the victim station. The greater the C/I value in dB, the better the sharing situation. This metric has a bandwidth/channel factor included to scale the power if the interfering or victim bandwidths are different.

The carrier power is the power of the wanted station transmitting to the victim receiver plus the off axis transmitting antenna gain and the off axis receiving antenna gain minus the path loss between the victim station and the wanted station.

The interfering power is the power of the interfering station plus the off axis antenna gain of the transmitting antenna and the off axis antenna gain of the receiving station with respect to the interfering station's location minus the path loss between the interfering station and the victim station.

The metric Io/No is the ratio on a per hertz basis of the interference power into the victim receiver to the system noise floor. This metric is commonly used in geostationary network to geostationary network satellite coordination. The ITU standard is –12.2 dB.

The differences between Io/No and I/N are that Io/No inputs the power into the equation on a per hertz basis and I/N inputs the power into the equation on a bandwidth specified by the user.

The metric C/N is the ratio on a specified bandwidth of the carrier power into the victim receiver to the system noise floor. This metric is commonly used in link design.

Eb/No metric is similar to the C/N metric except it factors in the data rate and/or FEC instead of the bandwidth. Forward Error Correction or FEC improves spectrum efficiency by allowing a lower system margin metric, i.e. Eb/No, thus the system can tolerate more interference which can allow feasible sharing situations with multiple systems in the same frequency band. The main reason that satellite link metrics are so important is that they translate into how often a link goes down. For example, if the satellite links have an Io/No metric of –12 dB and the link goes below this value, the satellite will have a loss of sync, or a degradation of the link performance. Degradation in the link performance means that at an Io/No or –12 or higher a satellite link is able to transmit at 1.2 Mbps. Below this value the link is only able to transmit at 0.9 Mbps. A loss of sync in link means that there has been a total loss of the link and the transmitter and receiver has to reacquire each other through series of handshakes. During this time the link is totally unavailable. The link margin is the extra amount difference between the system design spec margin ie Eb/No and actual margin based on all the factors. A positive margin indicates the design is feasible and a negative margin indicates problems with the link.

*Atmospheric Propagation Issues[7]*

A communication link can be degraded due to rain effects. This is caused by the rate of rain falling over the link's path. The communications signal can also be degraded due to the effects of oxygen and water vapors, which is called atmospheric absorption. At certain resonate frequencies (22.235 GHz and 100 GHz) the attenuation is so extreme that it is very difficult to design a link. All frequencies above 10 GHz have some attenuation. It is important that a satellite link design takes these factors into account.

If a communication link at an earth station is oriented near 5 degrees elevation angle the signal travels a long path through the atmosphere causing tropospheric multi-path and scintillation effects.

The most common models used for atmospheric propagation are the Liebe 93 or ITU-R P.676-3. Anything above 2.0 GHz is susceptible to some form of atmospheric propagation. The atmospheric propagation varies over different areas of the world. The places in the world with the least atmospheric attenuation are deserts or poles. The areas with the worst atmospheric attenuation tend to be in rain forests. One of the worst places for RF satellite transmission links in the continental United States is Miami, Florida. This is due to the area's annual high rain, humidity and flash rainstorms. High susceptibility to atmospheric attenuation causes the satellite link designer to put more margin in the link, which costs more money. One of the best places for RF satellite transmission links in the continental United States is in New Mexico or Arizona. This is due to the areas' dry and arid climate.

**Antenna Pattern**
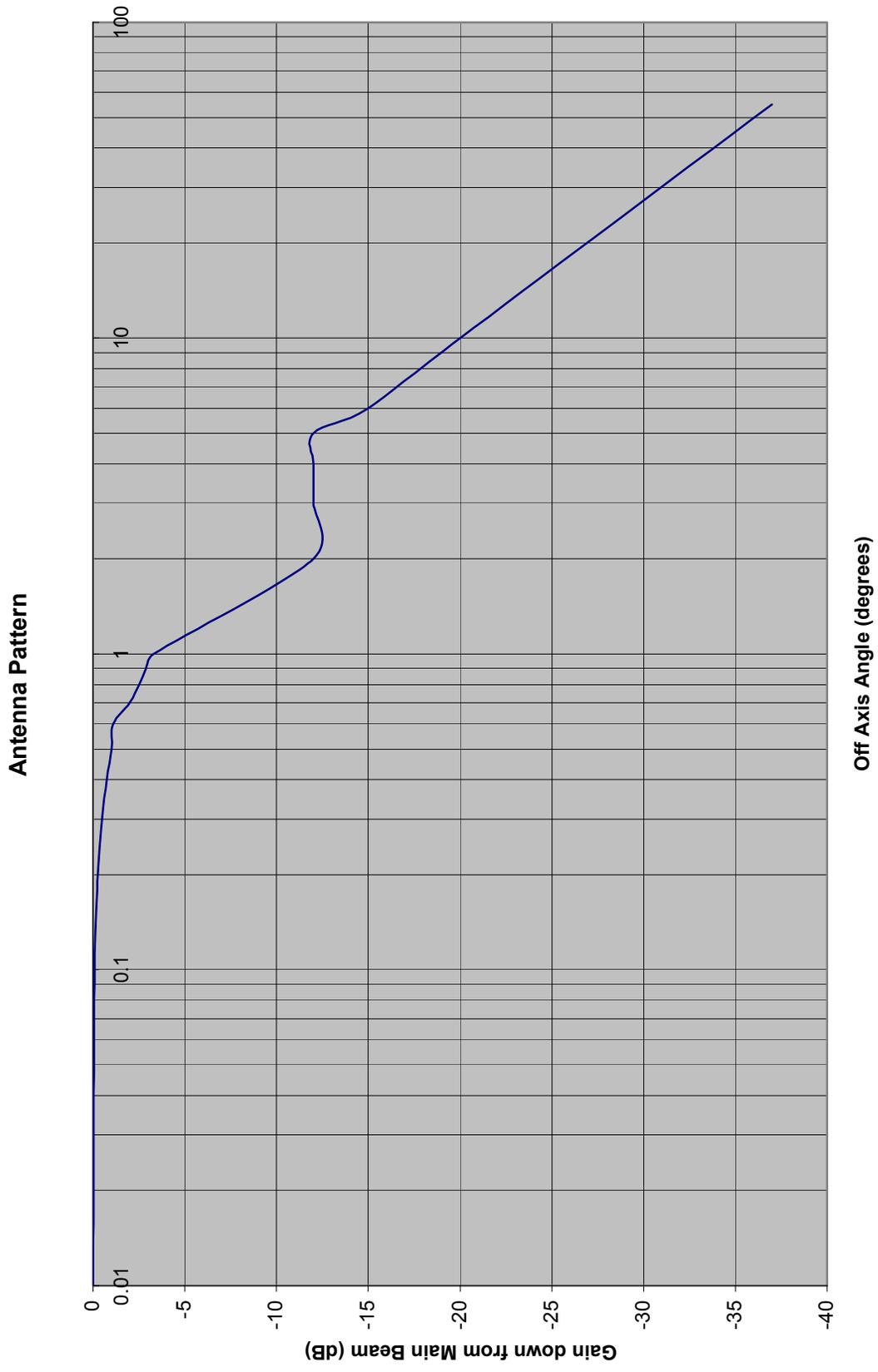


Figure 3.2  Antenna Mask

18

*Figure of interference scenario*
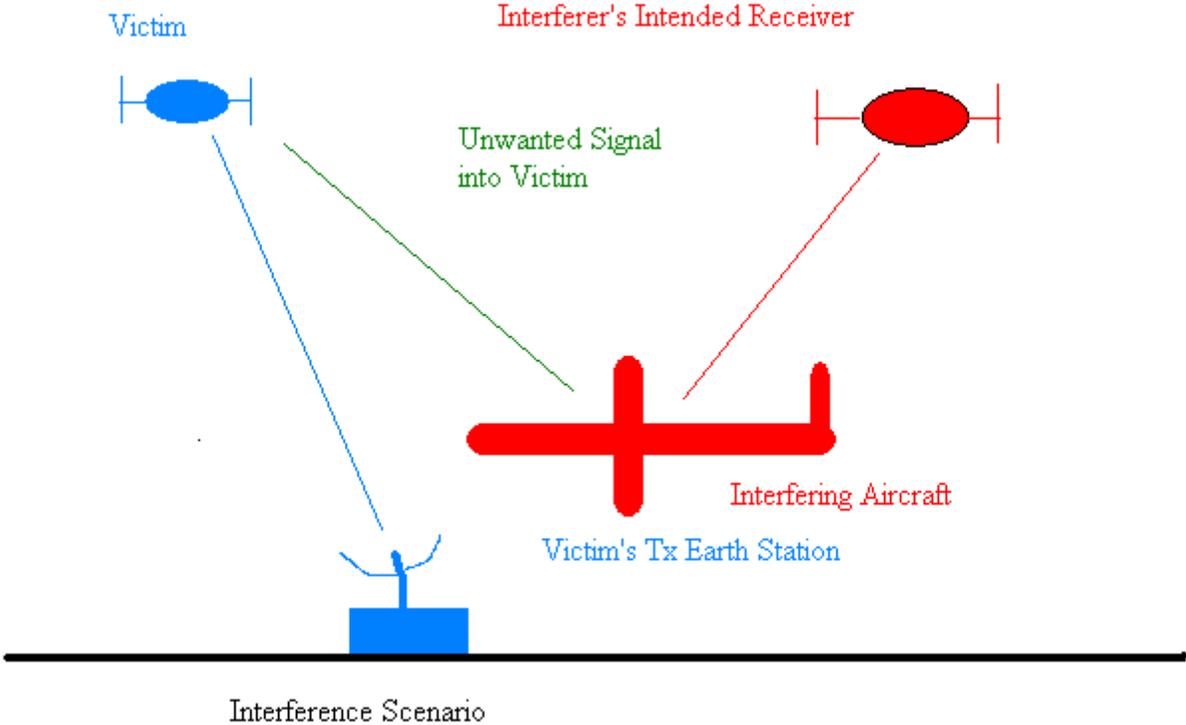


Figure 3.3 Interference Scenario

*Power Scaling[3]*

The power of the interfering transmitter needs to be scaled if the interfere and victim have varying bandwidths. Scaling the power due to differing bandwidths is done because link Budget metrics such as C/I and I/N assume power usage over the entire channel or bandwidth of the signal. When a victim and interfere only has a partial bandwidth overlap, a special process has to be used to scale the power.

The first situation, one interfere bandwidth is totally enclosed by the victim bandwidth. The total power is included in the metric equation for the interfere power (I). The power is scaled in the metric equation by the ratio of the interfere bandwidth minus the victim/carrier bandwidth in dB for the carrier power C.

The second situation, the victim bandwidth is totally enclosed by the interfere bandwidth. The total power is included in the metric equation for the carrier power (C). The power is scaled in the metric equation by the ratio of the carrier bandwidth minus the interfere bandwidth in dB for the interfere power (I).

The final situation, the victim and interfere bandwidth partially overlap each other. The victim/carrier power is scaled by the ratio of the overlap bandwidth minus the carrier bandwidth in dB. Interfere power is scaled by the ratio of the overlap bandwidth minus the interfere bandwidth in dB.

*Dynamic Link Budget*

The dynamic link budget is similar to the static link budget except the link metric is calculated numerous times over a period of time. The period of time simulates the orbit of the satellite. From the numerous link metrics calculations, statistics can be developed to visualize the range of the link budget values based on the extremes of the satellite networks' orbits.

Normally the best case or least amount of interference occurs when the carrier station of the victim is main beam to main beam aligned with the victim receiving station and the interfere is off axis into the victim's side lobe antenna. One of the worst-case scenarios can occur if the victim carrier and interfere are co-located in the main beam.

Another aspect of the overall interference is how often the worst case happens. Most satellites are required to maintain certain availability to their customers. If the availability is not met then the satellite operator must refund a portion of the costs to the customer. If the worst case availability happens so infrequently that it does not impact the satellite operators availability threshold then the victim might

be willing to accept high but very short intervals of interference. This is one of the advantages of a dynamic link budget analysis in being able to precisely calculate interference intervals.

Another aspect of the overall interference is if there are multiple interferes in the model being simulated how do they interact to raise the noise floor and the high interference situations. These two different scenarios can modeled effectively only using a dynamic link budget. The noise floor (N) can be raised to a point where it is above the antenna temperature noise floor in the multiple interfere scenario. Each of the interferes can cause low level interference at the side lobes. Cumulatively, the interference can cause sharing to be not feasible. Multiple interferes can react in such a way in the simulation that cumulatively they enough unavailability to make sharing unfeasible

*Orbit Mechanics Theory[5]*

This section describes the 7 line orbital element sets used to describe any type of satellite orbit. The set consists of the date, semi-major axis, eccentricity, inclination, mean anomaly, argument of perigee, and right ascension of the ascending node. The date is used as a point where the satellite has known orbital elemental quantities. The Semi-major axis is the distance between the center of the ellipse of the satellite orbit and the perigee of the satellite orbit. The eccentricity is the percent factor from zero to one of a satellite being in a circular orbit with one being a circular orbit. Inclination is the angle that the satellite intersects the equator. Geostationary satellites generally tend to have near zero inclination angles. If a satellite had a perfect circular orbit, the mean anomaly is the skewed angle in the orbit that the satellite is phased in the orbit plane. This is the factor mostly used in leo satellite constellations where there are multiple satellites in an orbit plane. Since most satellite orbits are elliptical and the angle between them varies through the orbit it is easier to equally space them using the mean anomaly factor in the plane as appose to the true anomaly factor. I.E. three satellites in a plane 120 degree out of phase from each other. The argument of perigee is the angle between the satellite crossing the equator heading north and where it reaches it perigee. The right ascension of the ascending node is the angle between the vernal equinox and satellite when the satellite crosses the equatorial plane.

*Summary of Chapter*

This chapter describes the requirements used to simulate the orbit of a satellite and the form of the metric the RF communications link. The metrics used and how they are interpreted play a big part in determining feasibility of the

interference.  The 7-line orbital set is the requirements set needed to describe the orbit of any type of satellite.

**Chapter 4 AMSS Sharing Methodology**

A dynamic satellite simulation is the best way to judge how two systems will interact with each other. The dynamic analysis takes into account the movement of the satellite and terrestrial objects, and the variations of the communication links over the simulation time.

This chapter will describe the two different dynamic simulation software programs. The first, Dynamic Simulation Software, takes into account the orbits of the satellites and the movement of aircraft. The second simulation software, or the Monte Carlo Simulation Software, uses the Monte Carlo process to simulate the satellites and the aircraft. Both programs use some form of interference mitigation techniques to limit the interference into the victim receiver.

*Interference Mitigation Techniques*

The interference Mitigation Techniques are GSO arc avoidance angle, EIRP limits, Static Power Control, Operational Power Control and PFD limits. The GSO arc avoidance angles are the angles on either side of the equatorial plane, which together create an interference exclusion zone to mitigate interference into the geostationary orbit.
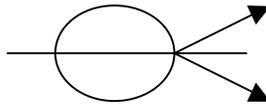


Figure 4.1 Arc Avoidance Angle

EIRP limits are antenna transmission limits set by the ITU-R to control interference. Static Power Control is a form of EIRP limits that force a satellite or earth station to adhere to strict power limits below what the system could normally operate at. Static Power control causes a system to have higher costs per data rate. Geostationary Exclusion Angle is an imaginary angle parallel to the longitude lines at the equator. It is used as a threshold to mitigate interference into gesostationary satellites. PFD limits can have various definitions. This thesis assumes that PFD limits refer to the energy per area directed upwards to the sky. This can be represented as an impulse intersecting a plane (See figure 4.2). To precisely calculate the PFD, the location of a satellite must be determined using a simulation software program.
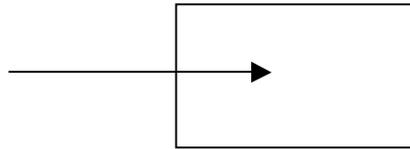
Figure 4.2 Power Flux Density Model

*Description of Dynamic Simulation Software*

The purpose of the Dynamic Simulation Software program is to simulate the interference into the victim for a certain period of time during the orbit of the satellite. There are two values that must be carefully chosen in order for the simulation to produce valid results.

The first value is the period of time to simulate the orbit. This can vary from 100 days to 2 years. Depending on the speed of the CPU processor, it can take anywhere from 10 minutes to 5 days to complete the simulation. A simulation time period must be long enough for the ground track of the satellite to allow the interference metric to have adequate data points to form a continuous line.

The second important value needed to produce valid results is the time step. During the simulation, the program will repeat the same set of steps over and over again at each time step to simulate the orbit of the satellite. An example of a time step is that a satellite does a calculation every second for an hour, which would be equal to 120 time steps in the simulation program. The time step indicates the period in time to increment the satellite orbit in order to complete the next set of calculations. The time step can vary anywhere from .05 seconds to 1 minute. The lower the value of the time step, the higher the processor time.

How does the user know if they are using correct values for the period and time step? When feasible values are used for the period and time step, the result is a continuous line.

After carefully determining the correct period and time step values, a user must choose what metric or metrics the software needs to calculate. Normally the metrics are C/I, Io/No, or Eb/No. This software dynamically calculates the metrics as many times as there are time steps in the time period. The user will then choose a simulation threshold for the metric. The user only cares about metrics that are relevant to the interference threshold that must be met. In order to limit the simulation time, a simulation threshold value is chosen to limit calculated metrics that have no bearing on the determination of the link's feasibility. An example is that is it recommended for an Io/No metric with an interference threshold of –12.2 dB, to set a simulation threshold of –20 dB because harmful interference values are greater than – 12.2 dB. The software then tracks and stores the values at each time step.. The following is a description of the mechanics of the simulation software.

There are four steps that the software completes at each time step. First, using the seven line orbital element set, the position of the satellite is calculated at each time step. The seven line orbital elements are: the semi-major axis, the inclination, the argument of perigee, the right ascension of the ascending node, the mean anomaly, eccentricity, the time of perigee, and the orbit epoch. There are more values that can be used for the 7-line orbit set, but they are simply variations of the 7 values listed above. Secondly, for each time step, the Dynamic Simulation Software calculates the position of the aircraft. The position of the aircraft is calculated by tracking the aircraft along a straight line in either a north/south or east/west direction and varying either the longitude or latitude while keeping the other constant. Thirdly, the off-axis angles between the aircraft and the satellite are calculated for each time step. The angles are calculated using the x, y and z coordinates of the aircraft and satellite and basic trigonometric mathematical concepts. Finally, using the off-axis angles, the software calculates the link budget metric. The off-axis angles are implemented using an antenna mask. Therefore an off-axis angle corresponds to an antenna gain value in the antenna mask equation which is used in the link budget.


Because of the relationship between the off-axis angles and the antenna mask, some general conclusions about the interference received by the satellites can be drawn based upon the dynamic simulation software. The antenna on the AMSS is interfering into the FSS satellite. All the AMSS systems described in this document have some type of beam pointing system on the aircraft, whether it be a mechanically steered antenna or phased array antenna that is controlled by a ground based operations center. Each system guarantees that it will point to its intended receiver by a performance metric of less than 0.5 of a degree. The AMSS systems will have mostly main beam to main beam pointing of the aircraft antenna to the intended satellite antenna. This is necessary to support the high data transfers with a tight interference margin indicated in the static table describing the system. The next greatest factor in determining the interference is the geostationary orbital arc separation between the AMSS and FSS satellites.

Each interfering aircraft's antenna interference can be based on off-axis antenna lobes. The total interference of the AMSS is based on the total number of interferes and at what pointing angle they are to the FSS victim. If these factors were simulated using a Monte Carlo process over a period of time, it would provide more accurate results than simulating the orbit of the satellites WRT the movement of the aircraft.

Statistics can be generated from the cumulative values of the link budget metrics for the simulation period. The interpretation of the output statistics will vary based on the metrics used. For the Io/No metric, the greater the value of the metric, the greater the interference into the victim. For the C/I metric, the lower values of the metric correspond to lower interference into the victim. Normally,

for most satellite orbits, including satellites in geostationary orbit, there will be a finite amount of time step(s) where the alignments of the satellites and earth stations cause the greatest interference into the victim. This interference scenario is a purely theoretical approach to applying the mathematical concepts. In the real world the output from the simulations are used to determine how much band-width can transmit between a plane and a satellite and if a particular architecture is feasible.

*Orbit Simulations*

Below is the flow diagram and the code for the Dynamic Simulation Software. The code is in Appendix 1. This approach was tried but rejected due to the complexity of the code.

```
┌─────────────────────────────────────────────┐
│   Define size and range testing of input Values │
│                                             │
│                                             │
└─────────────────────────────────────────────┘
                      │
          ┌───────────────────────┐
          │    Define Constants    │
          └───────────────────────┘
                      │
            ┌─────────────────────┐
            │   Set J2 Conditions  │
            └─────────────────────┘
                      │
            ┌─────────────────────┐
            │   Input Parameters   │
            └─────────────────────┘
                      │
          ┌─────────────────────────┐
          │ Convert tau to Julian days │
          └─────────────────────────┘
                      │
        ┌───────────────────────────────┐
        │  Establish range of times for ground │
        │  track plot                    │
        └───────────────────────────────┘
                      │
      ┌─────────────────────────────────────┐
      │  Calculate position and velocity vectors │
      └─────────────────────────────────────┘
                      │
      ┌─────────────────────────────────────┐
      │ Find right ascension and declination in │
      │ degrees                              │
      └─────────────────────────────────────┘
                      │
      ┌─────────────────────────────────────┐
      │ Find location of GMST for t=tau at the │
      │ beginning of the time plot           │
      └─────────────────────────────────────┘
```
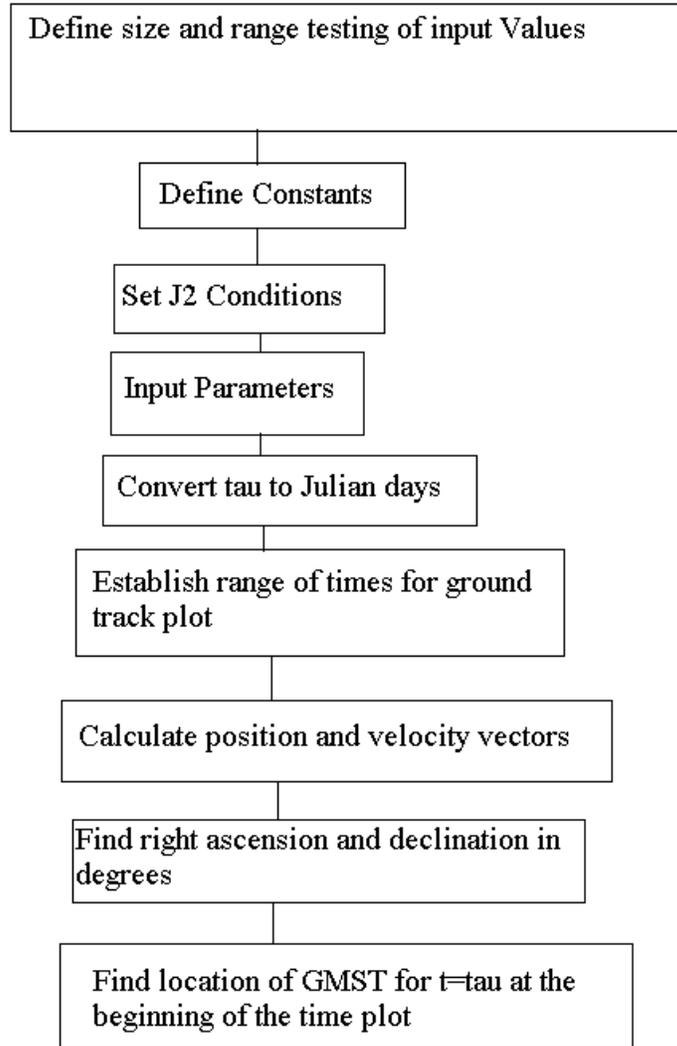
Figure 4.3 Orbital Simulation Flow Diagram

:

*Monte Carlo Simulations*

A second process was developed to analyze the sharing scenario using the Monte Carlo method. The process was used to simulate the randomness of the airplanes transmitting to the satellite. This process has an advantage in that it can take into account multiple interferes and different types of interference scenarios not easily seen by static analysis, but not have to take into account the movements of the aircraft and the orbits of the satellites.

The Dynamic Simulation Process simulates the natural movement of airplanes across an area of interest. Since there are numerous ways aircraft could travel over an area on the Earth that might cause interference into the satellite receiving antenna, the movement of aircraft can be considered a random event. This random event is simulated using the "random" function in MATLAB. The random function creates a random off-axis interference angle. This angle is used in the victim satellite antenna mask to calculate the link budget. See figure 3.2. The Monte Carlo Method for this simulation was developed to include the following steps: ten arrays are initiated with random variables between 0 and 180 degrees; each element in the arrays corresponds to a step in time; the ten arrays correspond to ten interfering aircraft and each random array is run through a series of if/then statements that correspond to the side lobes of an antenna mask. The values from the antenna mask are used in the link budget to calculate the interference for the interference metric at each time step. This is the beauty of the Monte Carlo process. Instead of trying to calculate the angles of the moving aircraft WRT the victim satellite receiver as is done in the Dynamic Simulation Software, the Monte Carlo process randomly picks the side lobes of the antenna mask. The off-axis angle that is randomly chosen to be used in the antenna mask corresponds to aircraft moving in and out of the field in view of the victim antenna.

The Monte Carlo Process, is a better process than the Dynamic Simulation Process in calculating the angles of the moving aircraft, because of the complexities of developing code to simulate the movement of the satellite and the code to simulate the movement of the aircraft. With multiple aircraft interfering into the satellite, it is not necessary to know precisely where the interferes are, just which side lobe of the antenna mask in they are located. Since each aircraft is moving randomly and independently of each other at each time step, the side lobe values could change anyway. The simulation was repeated for 0, 3 and 10 degree separation between the victim and interfering satellites. The code for the Monte-Carlo simulation is located in Appendix 2.
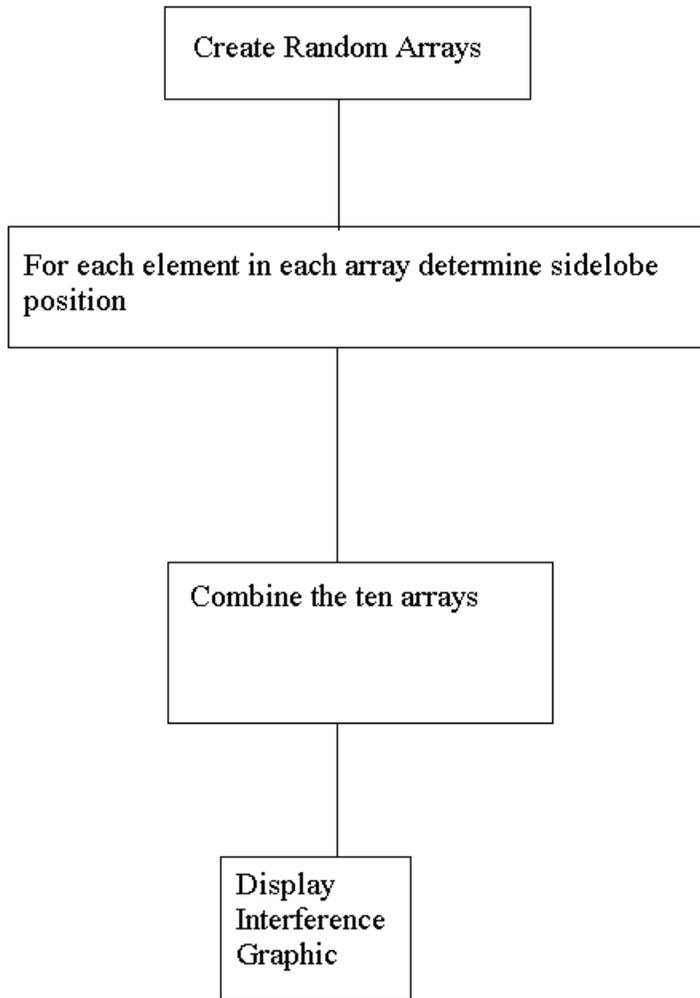
Figure 4.4 Monte Carlo Simulation Flow Diagram

*Summary of Chapter*

This chapter explained the two different approaches to dynamically simulating the interference situation. The Dynamic Simulation Software simulates the movement of the aircraft and the orbit of the satellites to develop an off-axis angle, which is used in the antenna mask that is in the link budget equation metric. The Monte Carlo Simulation Software randomly generates off-axis angles that are used in the antenna mask for the link budget equation metric. The Dynamic Simulation Software is more CPU intensive and difficult to implement that the Monte Carlo method.

The use of the Monte Carlo Method is similar to my previous analysis on limb sounders. In the analysis, the victim receiver orbited the earth and the interference was based on only terrestrial interference. The analysis only took into account the terrestrial interferes as a source of radiated power and did not care where they were coming from. The Monte Carlo approach was taken in this analysis to simplify the simulation, yet provide good results.

**Chapter 5  Results**

Outline of chapter

This chapter will describe the three different GSO orbit assumptions used in the dynamic analysis, the dynamic results of the simulation software and finally the static results of the three interfering AMSS systems introduced in Chapter One and their corresponding FSS victim systems. This chapter will also include the results of the Monte Carlo simulation as described in chapter 4. The static results are based on an alignment scenario causing the highest interference for the victim receiver. The three different GSO orbit assumptions are the Co-located, Three Degree and Ten Degree Orbit Scenarios. The scenarios are between the FSS victim satellite and the AMSS interfere satellite.  Even though the interference is coming from the aircraft in the AMSS system the satellite portion of the AMSS system is the desired signal that the AMSS is suppose to be transmitting to.   The side lobes of the AMSS antenna cause unwanted interference into the FSS system.

*GSO Orbit*

This section lists orbital elements for the three different Geostationary Orbital Arc Scenarios that are being simulated.  The scenarios are the Co-located, the 3-degree and the 10-degree separation.  Each scenario was chosen for a specific reason.  First, the Co-located is the worst case scenario.  Second, the 10 degree is the best case scenario.  And finally, the 3 degree separation value is commonly proposed as a minimum separation value for systems in the Ku band.

3 degrees separation scenario, Table 5.1

| Parameter | Interferer | Victim | Units |
|---|---|---|---|
| Date | 00:00:00 December 27, 1978 | 00:00:00 December 27, 1978 | UT |
| Semi-major axis | 42164.765 | 42164.765 | Km |
| Eccentricity | 0.001181 | 0.001181 | NA |
| Inclination | 0.802 | 0.802 | Degrees |
| Mean Anomaly | 116.636 | 116.636 | Degrees |
| Argument of Perigee | 138.167 | 138.167 | Degrees |
| RA of ascending node | 120 | 125 | Degrees |

10 degree separation scenario, Table 5.2

| Name | Interferer | Victim | Units |
|---|---|---|---|
| Date | 00:00:00 December 27, 1978 | 00:00:00 December 27, 1978 | UT |
| Semi-major axis | 42164.765 | 42164.765 | Km |
| Eccentricity | 0.001181 | 0.001181 | NA |
| Inclination | 0.802 | 0.802 | Degrees |
| Mean Anomaly | 116.636 | 116.636 | Degrees |
| Argument of Perigee | 138.167 | 138.167 | Degrees |
| RA of ascending node | 120 | 130 | Degrees |

Co-Location scenario, Table 5.3

| Name | Interferer | Victim | Units |
|---|---|---|---|
| Date | 00:00:00 December 27, 1978 | 00:00:00 December 27, 1978 | UT |
| Semi-major axis | 42164.765 | 42164.765 | Km |
| Eccentricity | 0.001181 | 0.001181 | NA |
| Inclination | 0.802 | 0.802 | Degrees |
| Mean Anomaly | 116.636 | 116.636 | Degrees |
| Argument of Perigee | 138.167 | 138.167 | Degrees |
| RA of ascending node | 120 | 120 | Degrees |

*Results of Static Analysis*

System A (As taken from 8D/149) [7]

System A as introduced in Chapter 1 is controlled by the Network Operations Center.  The NOC controls the pointing direction of the antenna, and the EIRP of the antenna.The antenna is attached to the top of the aircraft and points to only one transponder on a satellite.  The antenna is used for transmitting and receiving.  It is mechanically steered to maintain contact with the satellite.

Because the aircraft are constantly moving and only transmit to one satellite, the system design requires a certain level of thru-put of the communication links. The constant movement of the antenna to maintain it's contact with the satellite, makes it necessary for a directional antenna to be used.  The directional antenna needs to be constantly calibrated to maintain a communication link with the transponder that is being used.  The mechanical tracking provides half-cone pointing RMS errors of less than 0.3 degrees.  The aircraft up antenna will use power control to keep it in the EIRP envelope specified in ITU-R S.728-1.

Summary of Antenna Characteristics, Table 5.4

| Description | Value | Units |
|---|---|---|
| Tx Frequency Range | 14.0 14.5 | GHz |
| Polarization | Circular or Linear, electronic polarization tracking | NA |
| Tx Main Beam EIRP | up to 49 | dBW |
| Antenna Pattern | Rec. ITU-R 728-1 | NA |
| Rx Frequency Range | 10.7-12.75 | GHz |
| G/T | 9 | dB/K |
| Polarization | Circular or Linear, electronic polarization tracking | NA |

Characteristics of Earth Station, Table 5.5

| Description | Value | Units |
|---|---|---|
| Main Beam EIRP | 70 | dBW |
| G/T | 27.6 | dB/K |

**Airplane communication link characteristics**

Forward link

The aircraft antenna to satellite link uses the DVB-S standard

Table of Parameters, Table 5.6

| Description | Value |
|---|---|
| Outer Coding | Reed Solomon (204, 188, t=8) |
| Chapter 1 Inner Coding | Convolutional ½, 2/3, ¾, 5/6, 7/8 (k=7) |
| Shaping | Root Raised Cosine, roll-off factor = 0.35 |
| Eb/No | 3.7 dB for ½ inner code<br>4.2 dB for 2/3 inner code<br>4.7 dB for ¾ inner code<br>5.2 dB for 5/6 inner code<br>5.6 dB for 7/8 inner code |

Return link

The satellite to airplane link is based on a CDMA format.

Table 5.7

| Description | Value | Units |
|---|---|---|
| Chapter 2 Outer Coding | Reed Solomon (204, 188, t=8) | NA |

| | | |
|---|---|---|
| Inner Coding | Convolutional ½ | NA |
| Shaping | Root Raised Cosine, roll-off factor= 0.35 | NA |
| Modulation | QPSK | NA |
| Spreading bandwidth | 33 | MHz |
| Theoretical Eb/No | 4 | dB |

System B (As taken from 8D/131) [7]

**System Overview**

System B is built on the principle of a minimum of 3 degrees GSO orbit separation to maintain feasible sharing situations. The aircraft uplink power control is continuously adjusted to within an accuracy of +/- 0.5 dB. The resources/bandwidth of the satellite transponder are managed by the NOC. The aircraft antenna has a tracking accuracy of less than 0.3 degrees. Transmissions are stopped if the aircraft detects a pointing error.

**Characteristics of ground to aircraft link**

Table 5.8

| Description | Value |
|---|---|
| Orbital | 13 degrees East |
| Interference hypothesis | 3 degrees spaced satellites, same EIRP |
| Aircraft Location | Oslo (22 degree elevation |
| RF Interface | DVB-S |
| Transponder Bandwidth | 36 MHz |
| Transponder Operation Mode | Single Carrier per Channel |

**Link Budget of ground to aircraft link**

Table 5.9

| Description | Value | Units |
|---|---|---|
| Data rate | 25 | Mbps |

| | | |
|---|---|---|
| Coding rate | ½ | NA |
| Symbol rate | 27.1 | Msps |
| Occupied bandwidth | 35 | MHz |
| Downlink frequency | 11.2 | GHz |
| Satellite EIRP | 49.5 | dBW |
| Free Space Loss | 205.8 | dB |
| Atmospheric Loss | 0.7 | dB |
| Aircraft Antenna G/T | 10 | dB/K |
| Downlink C/No | 81.5 | dBHz |
| Inter and intra-system interference C/Io | 84.8 | dBHz |
| Downlink C/(No + Io) | 79.9 | dBHz |
| Uplink C/(No + Io) based on 5 m HUB | 93.4 | dBHz |
| Over all C/(No + Io) | 79.7 | dBHz |
| Required Eb/No | 5.3 | dB |
| Required C/(No + Io) | 79.2 | dBHz |
| System Margin | 0.5 | dB |

**Characteristics of aircraft link to ground link**

The tables below are the EIRP density per ITU-R recommendation S.728-1 developed for a sharing methodology of (60 cm) VSAT terminals at 14 GHz.

Off Axis EIRP for 3 degree spacing, Table 5.10

| **Off Axis Angle** | **Max EIRP per 40 KHz** |
|---|---|
| $2° \leq \varphi < 7°$ | 33-25 Log φ dBW |
| $7° < \varphi < 9.2°$ | 12 dBW |
| $9.2° < \varphi < 48°$ | 36 –25 Log φ dBW |
| $\varphi > 48°$ | - 6 dBW |

RF interface Characteristics

Aircraft to Ground Link Characteristics, Table 5.11

| Description | Value | | |
|---|---|---|---|
| Data Rate | 1 Mbps | | |
| Burst Format | MPEG packets (188 bytes length) | | |
| Information bits per packet | 1,504 bits | | |
| Modulation | QPSK | | |
| Roll-off Factor | 0.43 | | |
| Multiple Access Mode | MF/TDMA | | |
| Burst Duration | 1.5 ms | | |
| Coding Scheme | Turbo Coding | | |
| Packet Error Ratio | $10^{-7}$ | | |
| Coding Rate | 1/3 | 2/5 | ½ |
| Occupied Bandwidth | 2,207 MHz | 1,850 MHz | 1,494 MHz |
| Required Eb/No | 4 dB | 4.2 dB | 4.7 dB |

Links Budgets

Link Budget Assumptions, Table 5.12

| Description | Value | Units |
|---|---|---|
| GSO Orbit Slot | 13 | Degrees East |
| G/T | 1.5 | dB/K |
| Inter-System C/I | 15 | dB |
| Interference from adjacent FSS | 25 | dBW/40 kHz |
| Aircraft Location | Oslo (22 degree elevation | NA |
| Point Error | 0.5 | dB |
| Uplink Power Control Accuracy | 0.5 | dB |

Link Budget for several Coding Schemes, Table 5.13

| Description | Value 1 | Value 2 | Value 3 | Units |
|---|---|---|---|---|
| Coding Scheme | 1/3 Coding | 2/5 Coding | ½ Coding | NA |
| Information Data Rate per | 1 | 1 | 1 | Mbps |

| Carrier | | | | |
|---|---|---|---|---|
| Occupied Bandwidth | 2,207 | 1,850 | 1,494 | MHz |
| Uplink Frequency | 14 | 14 | 14 | GHz |
| AMSS terminal EIRP | 49.5 | 48.8 | 47.8 | dBW |
| Maximum Allowed AMSS terminal EIRP density in 40 KHz | 32.1 | 32.1 | 32.1 | dB/40 KHz |
| Nominal AMSS terminal EIRP density | 31.6 | 31.6 | 31.6 | dB/40 KHz<br><br>(0.5 dB margin for power control) |
| Pointing Loss | 0.5 | 0.5 | 0.5 | dB |
| Terminal Elevation Angle | 22 | 22 | 22 | Degrees |
| Uplink propagation Loss [1] | 0.7 | 0.7 | 0.7 | dB |
| Free Space Loss | 207.3 | 207.3 | 207.3 | dB |
| Satellite G/T | 1.5 | 1.5 | 1.5 | dB |
| Uplink C/No | 70.7 | 70.7 | 70.7 | dBHz |
| Adjacent systems C/Io | 69.5 | 68.8 | 67.8 | dBHz |
| Intra-system C/Io [2] | 79.4 | 78.7 | 77.7 | dBHz |
| Uplink C/(No + Io) | 66.8 | 66.1 | 65.1 | dBHz |
| Downlink C/(Io + No) [3] | 79.1 | 78.3 | 77.3 | dBHz |

[1] Clear Sky Conditions
[2] Includes out-of-band and cross polarization signal
[3] Based on 5m hub

| Overall C/(Io + No) | 66.5 | 65.8 | 64.8 | dBHz |
|---|---|---|---|---|
| Required Eb/No | 4.0 | 4.2 | 4.7 | dBi |
| Required C/(Io + No) | 64.1 | 64.3 | 64.8 | dBHz |
| System Margin | 2.4 | 1.5 | 0 | dB |

System C (As taken from 8D/101) [7]

System C is very similar to the other systems except it uses active phased arrays antennas on the aircraft. The system may have redundant ground earth stations and is controlled by the NOC. The system controls the power within +/- 0.5 dB of the required Eb/No limits. The NOC operations center controls 99.99 % of off-axis interference of co-channel terminals sharing a single GSO FSS transponder. The NOC controls the transponders so that no malfunctioning transponder will operate and cause harmful interference. The total rms beam pointing is 0.15 degrees rms. The aircraft to satellite link has a data rate of 4.86 Mbit/s. The satellite to aircraft link has a data rate in the range of 16 to 1024 Kbits/s. The chipping rate is so that the spreading bandwidth is equal to 90% of the transponder bandwidth.

**Airborne Antennas**

Description of Receive Antenna Characteristics, Table 5.14

| Description | Value | Units |
|---|---|---|
| Chapter 3 Active Aperture | 38 | cm diameter (uniform illumination) |
| Number of Elements | 873 | NA |
| Frequency | 14.0 to 14.5 | GHz |
| Antenna Beam width | 3.2° to 3.5° at zenith, increasing at $1/\cos(\theta°)$ in the scan plane as a function of scan angle $\theta°$ | |
| Maximum Scan Angle from Zenith: | > 63 | Degrees |
| Polarization | Linear | |

Description of Receive Antenna Characteristics, Table 5.15

| Description | Value | Units |
|---|---|---|
| Active Aperture | 43 X 61 | cm (uniform illumination) |
| Number of Elements | 1515 | |
| G/T | 12.5 at zenith decreasing as a function of the scan angle | dB/K |
| Instantaneous Bandwidth | 500 | MHz between 11.7 and 12.7 |

| | | GHz |
|---|---|---|
| Antenna Beam width | 2.1 X 3.1 | Degrees at zenith |
| Maximum Scan Angle | 63 | Degrees |
| Polarization | Circular, converted to linear after the antenna | |

Waveform Characteristics, Table 5.16

| Description | Value |
|---|---|
| Data Modulation | Direct Sequence Spread Spectrum |
| Chipping Modulation | Offset-Quadrature Phase Shift Keying ("O-QPSK") |
| Spreading Bandwidth | Approximately 0.9 of Transponder Bandwidth |
| Filtering | Square Root Raised Cosine ("SRRC"), Alpha = 0.35 |

**Link Budgets**

Aircraft Position, Table 5.17

| Description | Value | Units |
|---|---|---|
| Longitude | 123.6 | Degrees West |
| Latitude | 47.6 | Degrees North |
| Altitude | 2.05 | Km |
| Heading | -20 | Degrees |
| Pitch | 0 | Degrees |
| Roll | 0 | Degrees |

Gso Satellite Characteristics, Table 5.18

| Longitude | 93 | Degrees West |
|---|---|---|
| Saturated ERIP | 48 | dBW EOC |
| G/T | 1 | dB/K |
| Receive Antenna Gain | 30 | dB |
| Receive Antenna Noise Temperature | 29 | dBK |

Aircraft to Satellite Link Budget Summary, Table 5.19

| Description | Values with 16 Kbps | Values with 1024 Kbps | Units |
|---|---|---|---|
| Receiver Location | Seattle, WA | Seattle, WA | Chapter 4 N A |
| Rain Region | D | D | |
| Transponder Center Frequency | 14.136 | 14.136 | GHz |
| Spread Bandwidth | 24.3 | 24.3 | MHz |
| Available Transmit Bandwidth | 47.0 | 47.0 | dBW |
| Output Back Off | 18.3 | 0.8 | dB |
| Transmit EIRP | 28.7 | 46.2 | dBW |
| Clear Sky Path Loss | 207.2 | 207.2 | dB |
| Atmospheric Attenuation | 0.12 | 0.12 | dB |
| Rain Attenuation | 0.5 | 0.5 | dB |
| Polarization Tracking Loss | 0.04 | 0.04 | dB |
| Pointing Loss | 0.2 | 0.2 | dB |
| Satellite Receive Antenna Gain | 30.0 | 30.0 | dB |
| Receive Power | -149.4 | -131.9 | dBW |
| Information Rate | 16.0<br>42.0 | 1024.0<br>60.1 | Kbps<br>dBHz |
| Eb | -191.5 | -192.0 | dBW/Hz |
| Satellite Receive Noise Temperature | 794<br>29.0 | 794<br>29.0 | K<br>dBK |
| No | -199.6 | -199.6 | dB W/Hz |
| Io Adjacent Satellite Uplink | -202.5 | -202.5 | dB W/Hz |
| Io Spread Spectrum (Co-channel) | -205.0 | -210.7 | dB W/Hz |
| No + Io | -197.1 | -197.6 | dB W/Hz |
| Eb/(No + Io) Uplink | 5.6 | 5.6 | dB |
| Eb/No Downlink | 26.9 | 26.4 | dB |
| Eb/(No + Io) End-to-End | 5.55 | 5.55 | dB |
| Power Control | 0.75 | 0.75 | dB |

| Margin | | | |
|---|---|---|---|
| Transponder Implementation Margin | 0.30 | 0.30 | dB |
| Eb/(No + Io) Total | 4.5 | 4.5 | dB |
| Eb/No Required | 4.5 | 4.5 | dB |

**Methodology for Sharing with FSS**

This system will use ITU-R recommendation S.728-1.

*Results of Dynamic Analysis*

This section list the four scenarios used a co-located, 3-degree orbital separation and 10-degree orbital separation. The figures indicate that interference is greatest when the AMSS carrier satellite (carrier meaning receiving the wanted signal from the interfering aircraft) and the victim satellite (victim meaning receiving the unwanted signal from the interfering aircraft see figure 3.3) are co-located at the same geostationary orbital slot. As the satellites are moved apart, the interference decreases. At 10-degrees, the interference is small enough to allow sharing between the two systems.

Figure 5.1

44

10 Interferes 3 degree orbital separation
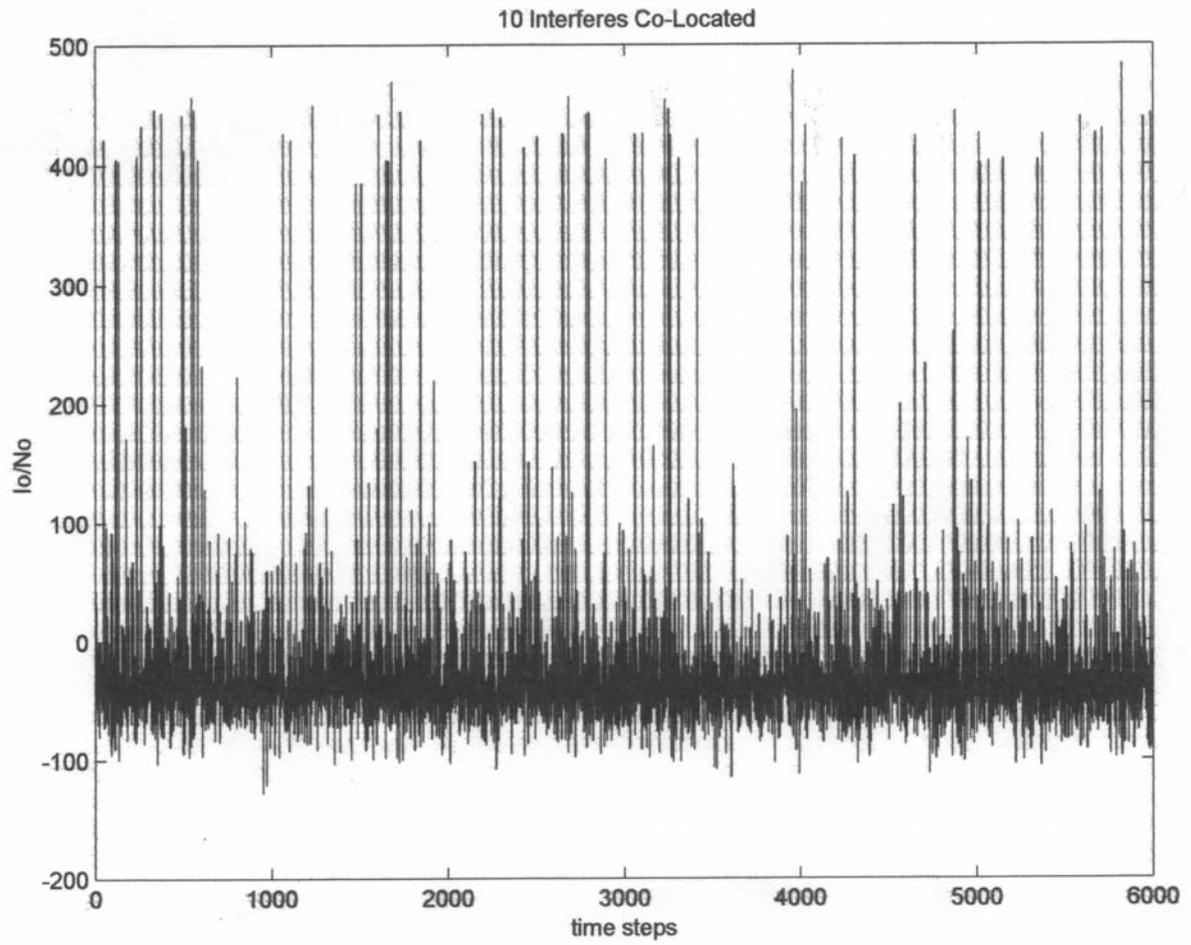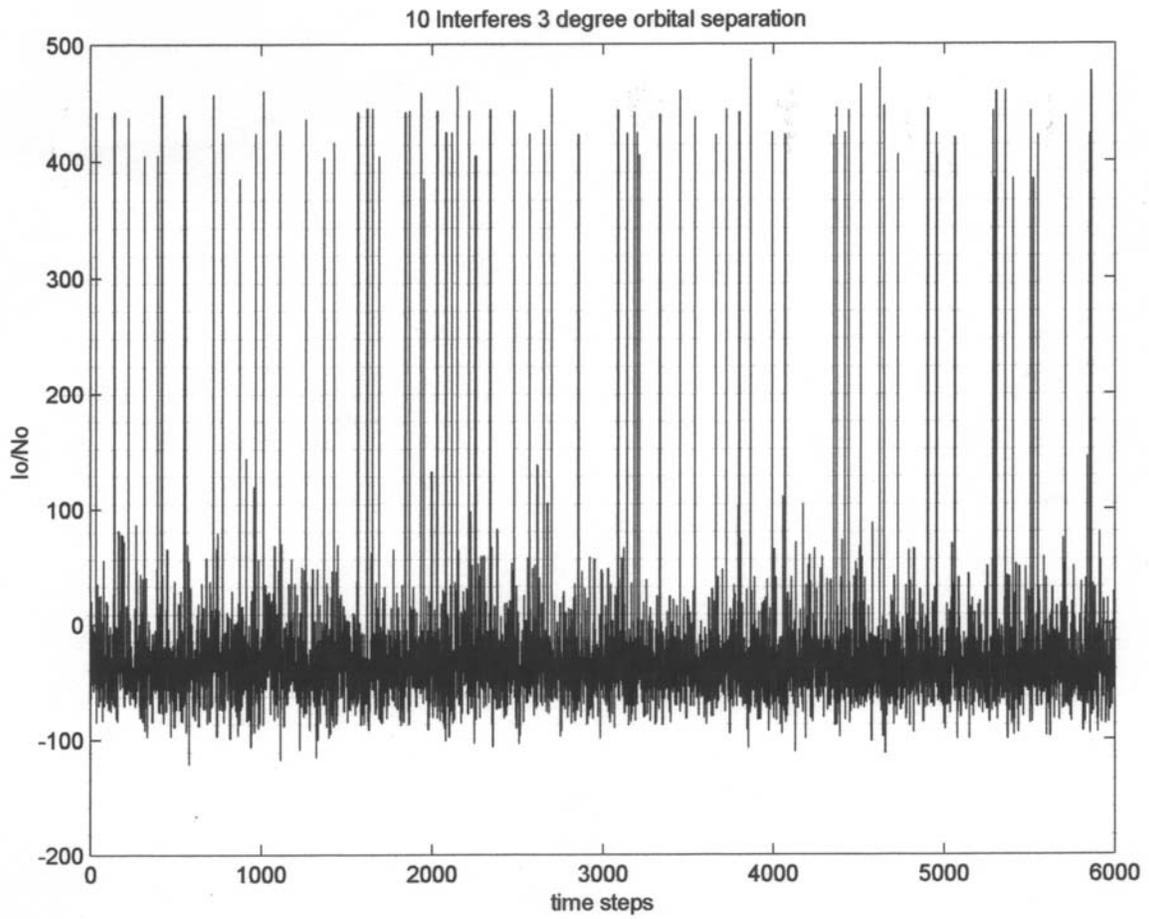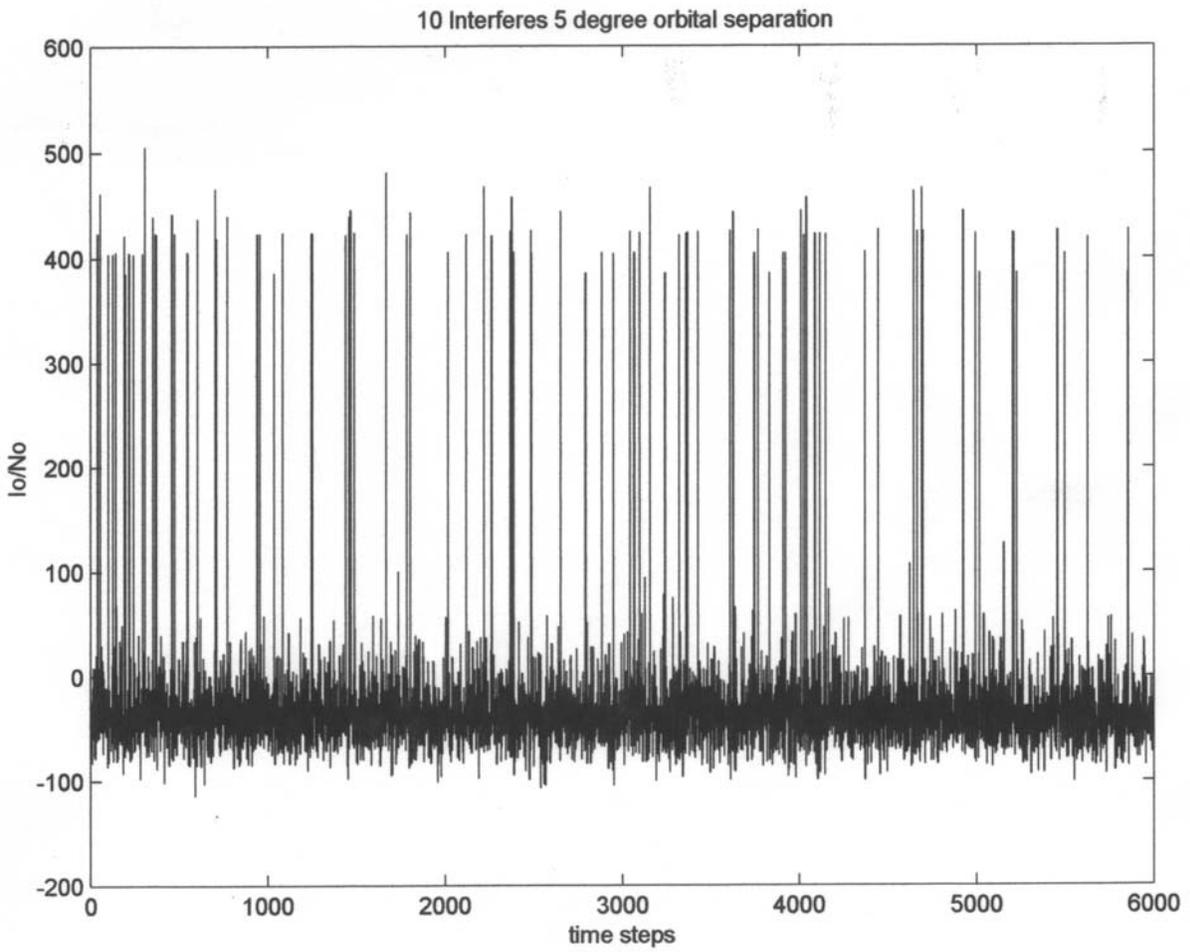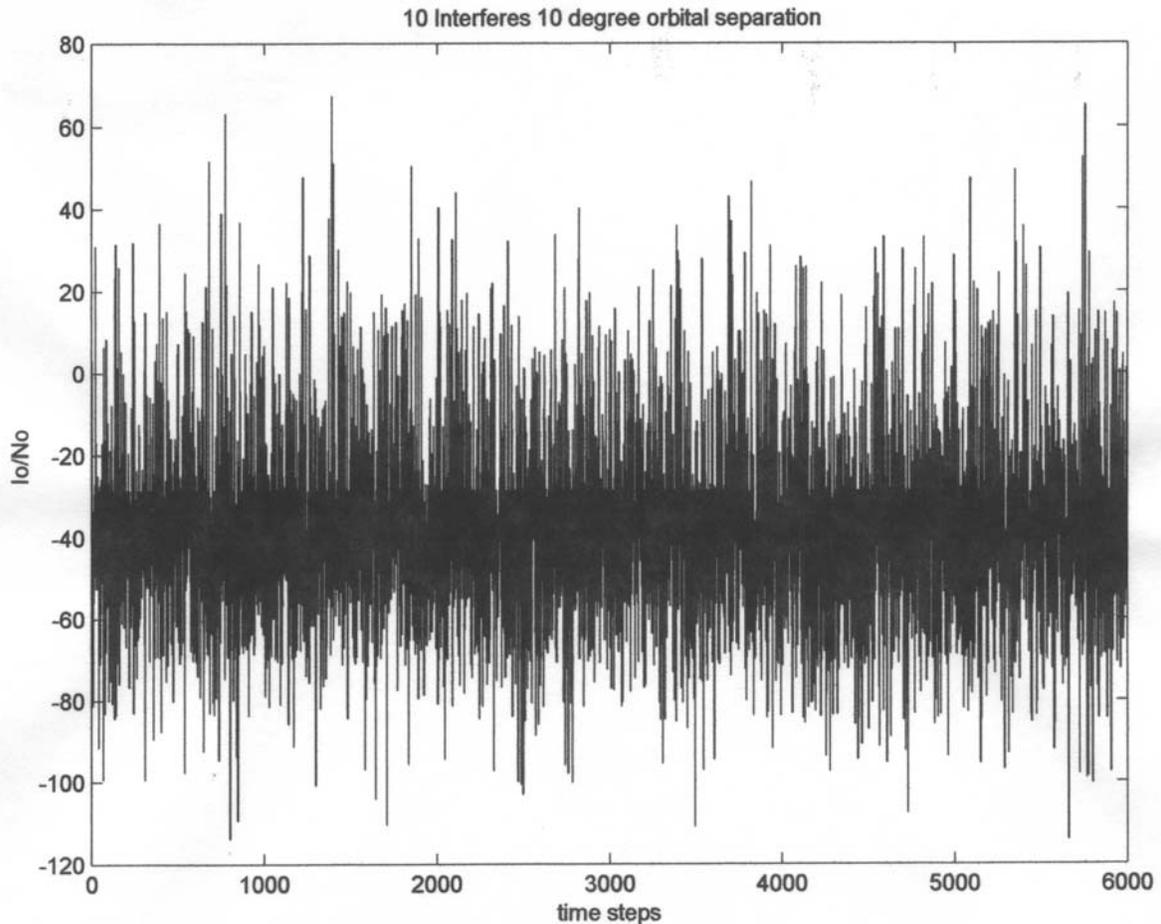
Figure 5.2

Figure 5.3

Figure 5.4

## Static Verses Dynamic Satellite Simulation

When a static analysis is done it is usually to calculate the worst case alignment of the two satellite networks. This normally is the main beam of the interfere into the main beam of the victim. Even though this can happen it does not happen that often and hides the real problem when there are multiple interferes into the victim at the side lobes of the antenna. A dynamic analysis is important in that it describes the level and the duration of interference into the victim.

In a dynamic analysis it is important to run the simulation long enough to make sure that the simulation can take into account all possibilities. In simulations when there is a low earth

47

orbiting satellite, it is ideal to run the simulation with a maximum 1 second time step for two years. In this simulation a geostationary orbit is used. Because a geostationary orbit is used the movement of the satellite is not that important because from the aircraft's point of view the satellite really does not move. The geostationary satellite will drift slightly but since it is so far away the movement is almost unnoticeable for the aircraft.

The simulation of the aircraft movement is the most important factor for determining how long to run the simulation. The movement of the aircraft can be quantified by looking at the results of the dynamic analysis to see if the highest value corresponds to the worst case static value. The worst case is only going to happen X amount of times in the orbit period of a satellite. In a leo satellite orbit, a point on the earth is usually in view 10 times a day to the satellite. As the orbit gets higher, the frequency of the satellite passing over a point on the earth decreases. A geostationary orbit is always in view of the earth station. The greatest factor in determining the interference is how close the interfering aircraft is to the ground-based transmitter of the victim satellite. The closeness is based on the main beam of the victim satellite pointed at the transmitting earth station. The percent of time of the highest interference level is the area on the surface of the earth that corresponds to the main beamwidth of 0.2 degrees (see figure 3.2). This is divided by the entire surface that is being used as the field of view coverage of the geostationary satellite transponder. This relationship would indicate how often it is possible to have a worst case scenario. This should compare to the actual results. How do these compare? If close enough, then the simulation has been run long enough.

In this analysis with a 10 degree geostationary separation, the results indicate that the worst case situation with 10 interferes would be an interference metric of $Io/No = 70.3$ dB. This is taken from the values used in the Appendix 2 Monte-Carlo simulation software. This is very close to the maximum values in figure 5.4. In Figure 5.4 there are three high interference scenarios. This corresponds to the highest interference level of 0.05 % of time. The theoretical percentage, which corresponds to the relationship of the main beamwidth of 0.2 degrees and the total footprint with a beamwidth of 180 degrees, corresponds to highest interference level 0.11 % of the time. This difference is due to the length of the simulation run time.

*Summary of Chapter*

This chapter provided the results of the software simulation and static analyses. The static analyses included results for systems A, B, and C. The software simulation only included results using the Monte Carlo Method. The static results indicated that sharing is feasible with only one interfering aircraft. The Monte Carlo results indicated that sharing is feasible with a 10-degree separation between the FSS and AMSS geostationary satellites with ten interfering aircraft.

# Chapter 6 Conclusion and reflection

In the US, the 14.0-14.5 GHz band is allocated on a primary basis to the Radio-Navigation and the FSS with a secondary allocation to the LMSS. The Radio-Navigation service is the use of RADAR for navigation. An example of Radio-Navigation is the ground proximity radar used for airplane collision avoidance. FSS stands for the Fixed Satellite Service. In general FSS is a satellite network consisting of a geo-stationary satellite and a non-movable earth station on the ground. An example of the FSS is the earth terminals used at gas stations to verify credit cards and centrally track inventory. The 14.0 to 14.5 GHz band is also allocated on a secondary basis to the LMSS or Land Mobile Satellite Service. This is a satellite network with a satellite and a movable terrestrial non-aeronautical earth station. An example of this is a system called "Omnitracs", which provides a satellite-based data connection for the trucking industry. AMSS stands for the Aeronautical Mobile Satellite Service. AMSS is similar to the LMSS except airplanes use it.

The CPM after WRC-2000 decided the need for urgent technical and regulatory studies for sharing between the FSS and the AMSS. A report on the studies was added to the WRC-2003 agenda. The future sharing studies need to demonstrate that sharing is feasible and that it is justifiable to allocate AMSS a secondary status allocation in the band. These sharing studies must be completed before WRC-2003. Presently, the FCC has licensed the AMSS on an experimental non-interference basis.

The AMSS and the FSS disagree on the feasibility of sharing. The AMSS contends that sharing is feasible if their service can meet the same PFD limits of the LMSS. The FSS contends that sharing will only be feasible if the AMSS provides certain characteristics and a detailed sharing study using these characteristics verifies the feasibility of sharing. These characteristics where provided in Systems A, B, and C. One of the FSS issues is that sharing may not be feasible if the same transponder is used for AMSS and FSS. FSS also contends that the AMSS is asking for a Super Secondary Status. The Super Secondary Status would mean that the AMSS will only have to meet a PFD limit on individual aircraft and not for multiple aircraft in view of a victim FSS receiver.

The issues associated with the sharing analysis are: modeling the orbital separation of the satellites, atmospheric interference into the communication link and the availability of the communication link by the FSS and the AMSS.

The issues associated with modeling simulation are: the static verses dynamic modeling environments and developing a dynamic software tool to track airplane movement.

The three systems A, B, and C, have slightly different architectures but all abide by the ITU-R S.728 EIRP limits. Static analysis shows that sharing is feasible involving only one aircraft as the interfere. This is not a reasonable solution for a real time environment because there is only one aircraft used as the interfere and at any given moment in a real time environment, it is necessary for the link to support multiple aircraft.

The factors that indicate sharing is feasible are: non-harmful interference to the victim and reasonable enough link margin in the interfere system to make it viable. A viable system in the case of aircraft would include high-speed internet and video. The AMSS interfere system cannot propose a power limit that will not allow it to close it's own link.

In order to mitigate the interference, systems can agree to certain interference mitigation techniques. The different techniques are: transmitting power control, geostationary arc avoidance angle and orbital arc separation.

Power control as described above is the centralized control of the interfering antenna into the victim. This is done by simulating the interference environment and pre-scheduling the decreases of the transmitting power. This is a feasible solution except that it decreases the availability and thru-put of the interfere system. This approach can make the system have unrealistic link margins and spotty availability due to the pre-scheduled power control.

Another technique is the geostationary arc avoidance angle. This technique is not applicable since both the AMSS and FSS use geostationary orbits.

The third technique is geostationary separation. This technique requires co-channel systems to maintain a certain orbital spacing between them. FSS systems in certain bands have a minimum of 3 degrees of orbital spacing between co-channel systems. Since the AMSS has a mobile terrestrial system (aircraft) as part of the link, it requires a higher orbital separation between it and the FSS system. The results of dynamic analysis indicate that this technique is feasible at 10 degrees orbital spacing.

The Monte Carlo analysis completed for this thesis simulated the results of four scenarios: co-located, 3 degree, and 5 and 10-degree orbital separation. It can be determined from the results that the interference decreases as the orbital separation increases. These simulations were done based on a 10 aircraft interfere scenario. This is more realistic than the one-interferer scenario analyzed in the static situations.

This thesis determined that co-channel sharing is feasible between the AMSS and the FSS assuming an orbital separation of at least 10 degrees.

In the future, additional analysis should include a longer more complex monte carlo simulation using a moving satellite network such as an Iridium type of constellation. Reference 13 indicated that one of the system limitations is that aircraft operate in high latitude situations that cause coverage limitations when using geosationary orbits. An interesting subject for a future analysis would be to develop a design that would use various satellite and terrestrial devices to design a spectrum and economic efficient system that would have true global coverage. One of the limitations of a geostationary system is that the terrestrial receiver has problems viewing the satelltie if the aircraft is at greater than 40 degrees latitude. Another interesting analysis would be to take into account LEO/MEO and GEO systems providing service to the AMSS system. This idea was proposed in reference 19.

*Lessons Learned*

Develop an outline for thesis document earlier.

*STK (free version)*

STK is used in this thesis to rapidly visualize satellite orbits.

*Matlab*

Matlab is used in this thesis to analyze complex mathematical functions.

*MS Excel*

Excel is used to develop matrix of airplanes, and to calculate the static link budgets.

*Reference Documents*

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5. Space Flight Mechanics by Tolson, 1999

6. NTIA Frequency Management Manual website, www.ntia.doc.gov

These site are associated with the Spectrum Management issues:
http://www.ntia.doc.gov/osmhome/allochrt.html

http://www.ntia.doc.gov/osmhome/redbook/redbook.html


7. ITU Website, www.itu.int

These sites describe ITU working issues:

http://www.itu.int/ITU-R/
http://www.itu.int/ITU-R/information/mission/index.html
http://www.itu.int/ITU-R/conferences/rrb/index.html
http://www.itu.int/ITU-R/conferences/wrc/wrc-03/index.asp

   These sites are associated with the FSS:

http://www.itu.int/ITU-R/study-groups/rsg4/rwp4a/index.asp
http://www.itu.int/md/meetingdoc.asp?lang=e&type=sfolders&parent=R00-WP4A-C

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*lf*

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18. Routing for Best Effort Services in LEO-Based Satellite Systems by C. Rosenburg, presented at ESTEC, 13 January 1999, http://www.estec.esa.nl/artes3/workshop/Presentations/catherine.pdf

*19.MLSR: A Novel Routing Algorithm for Multilayered Satellite IP Networks by I Akyildiz, 2002, http://www.eleceng.ohio-state.edu/%7Eekici/papers/mlsr.pdf*

20. Network Layer of Terrestrial and Satellite IP Netoworks over BGP-S by E Ekici, I Akyildiz and M Bender, 2001, http://www.eleceng.ohio-state.edu/%7Eekici/papers/bgps.pdf

```matlab
function F=KeplerH(M,e,tol,ichk)
%E=Kepler(M,e,tol,ichk)
% This function calculates an array of hyperbolic eccentric anomalies, E,
% given an array of mean anomalies, M, eccentricity, and a tolerance
%Input: M - array of mean anomalies
%      e  - the eccentricity of the orbit 0<e<=1
%      tol  - tolerance for the accuracy of E
%      ichk - 1 for input checking other for no checking
%Output: E - An nx1 array of Hyperbolic Eccentric Anomalies

if ichk==1      % do size and range testing
 if min(size(M))>1, error('M must be an array of nx1'),end
 if max(size(e))>1,error('e must be a scalar'),end      % inputs are scalars
 if max(size(tol))>1,error('tol must be a scalar'),end
 if e<1, error('e must be greater than or equal to 1'), end
 if tol<=0, error('tol must be positive'), end
end% if ichk==1

%initialize arrays
F1=zeros(size(M));
F=asinh(M);

%Perform iteration on page 3-10 for values outside of tolerance
ind = find(abs(F-F1)>tol);
while ind
  F1(ind)=asinh((M(ind)+F(ind))/e);
  ind = find(abs(F-F1)>tol);
  F=F1;
end

% **************************************************


function [Y,M,D,H,Mn,S]=JD2YMD(JD)
% function [Y,M,D,H,Mn,S]=JD2YMD(JD)
% Input is n by 1 or 1 by n, output is n by 6
% algorithm from Astronautical Algorithms pg 63
[n,m]=size(JD);
if min([n,m])>1, error('Input JD must be a vecttor'),end
```

```matlab
if m>n, jd=JD'; else jd=JD; end          % make a column vector
x=jd+0.5;
z=floor(x);
F=x-z;
alpha=floor((z-1867216.25)/36525.25);
A=z+1+alpha-floor(alpha/4)
p=find(z<2299161);
if length(p)>0, A(p)=z(p); end
B=A+1524; C=floor((B-122.1)/365.25);
DD=floor(365.25*C); E=floor((B-DD)/30.6001);
day=B-DD-floor(30.6001*E)+F;       % includes fractional part
D=floor(day);
[H Mn S]=Sec2HMS(86400*(day-D));
M=E-1;
p=find(E>13);
if length(p)>0, M(p)=E(p)-13; end
Y=C-4716;
p=find(M<3);
if length(p)>0, Y(p)=C(p)-4715; end


% *************************************************

function Phi=rotate313(alpha, beta, gamma, ichk)
%Phi=rotate313(alpha, beta, gamma, ichk)
%This function calculates the rotation matrix for a
%   set of 3-1-3 Euler Angles as input
%Input: alpha - first rotation angle in radians
%       beta - second rotation angle in radians
%       gamma - third rotation angle in radians
%       ichk - 1 for input checks
%Output: Phi - a 3x3 orthogonal matrix


if ichk == 1
  [n,m]=size(alpha); if m*n>1,error('alpha must be a scalar'),end
  [n,m]=size(beta); if m*n>1,error('beta must be a scalar'),end
  [n,m]=size(gamma); if m*n>1,error('gamma must be a scalar'),end
  if mod(beta,pi)<1e-8 | mod(beta,pi)>(pi-1e-8), error('beta causes a singularity'), end
end
```

```
Phi= [cos(gamma)*cos(alpha)-sin(gamma)*cos(beta)*sin(alpha),
cos(gamma)*sin(alpha)+sin(gamma)*cos(beta)*cos(alpha), sin(gamma)*sin(beta)
   -sin(gamma)*cos(alpha)-cos(gamma)*cos(beta)*sin(alpha), -
sin(gamma)*cos(alpha)+cos(gamma)*cos(beta)*cos(alpha), cos(gamma)*sin(beta)
   sin(beta)*sin(alpha), -sin(beta)*cos(alpha), cos(beta)];


% ***************************************************

function [wdot,Wdot,Lamdot]=J2Precess(a,e,i,J2,mu,R,ichk)
%[wdot,Wdot,Lamdot]=J2Precess(a,e,i,J2,mu,R,ichk)
%This program calculates the precession of the orbital elements, argument of periapsis
%        longitude of the ascending node, and mean longitude
%Inputs : a - semi major axis
%        e - eccentricity
%        i - inclination in radians
%        J2 - J2 coefficient
%        mu - GM - gravitational constant times the masses of the orbited body
%        R - mean radius of the body
%        ichk - 1 for input check
%Outputs: wdot - Secular variation in the argument of periapsis
%        Wdot - Secular variation in the longitude of the ascending node
%        Lamdot - Secular variation in the mean longitude

if ichk==1
   if max(size(a))>1,error('a must be a scalar'),end
   if max(size(e))>1,error('e must be a scalar'),end
   if max(size(i))>1,error('i must be a scalar'),end
   if max(size(J2))>1,error('J2 must be a scalar'),end
   if max(size(mu))>1,error('mu must be a scalar'),end
   if max(size(R))>1,error('R must be a scalar'),end
   if a<=0, error('a must be greater than 0'), end
   if e<0, error('e must be greater than or equal to 0'), end

if i<0, error('i must be greater than or equal to 0'), end

if J2<0, error('J2 must be greater than or equal to 0'), end

   if mu<=0, error('mu must be greater than 0'), end
   if R<=0, error('R must be greater than 0'), end
end
```

```
n=sqrt(mu/a^3);
p=a*(1-e^2);
njRp2=0.75*n*J2*(R/p)^2;
ci=cos(i);
si=sin(i);
wdot=njRp2*(5*ci^2-1);
Wdot=-2*njRp2*ci;
Lamdot=njRp2*sqrt(1-e^2)*(3*si^2-2);


% *************************************************

function E=Kepler(M,e,tol,ichk)
%E=Kepler(M,e,tol,ichk)
% This function calculates an array of eccentric anomalies, E,
% given an array of mean anomalies, M, eccentricity, and a tolerance
%Input: M - array of mean anomalies
%       e  - the eccentricity of the orbit 0<e<=1
%       tol  - tolerance for the accuracy of E
%       ichk - 1 for input checking other for no checking
%Output: E - An nx1 array of Eccentric Anomalies

[n,m]=size(M);
if m>n
   M = M';
end

if ichk==1      % do size and range testing
 if min(size(M))>1, error('M must be an array size nx1'),end
 if max(size(e))>1,error('e must be a scalar'),end        % inputs are scalars
 if max(size(tol))>1,error('tol must be a scalar'),end
 if e<=0 | e>1, error('e must be between 0 and 1'), end
 if tol<0, error('tol must be positive'), end
 if tol == 0, error('tol cannot equal zero'), end

end% if ichk==1
E1=zeros(size(M));
E=zeros(size(M));


sM=sin(M);
ind=find(sM~=0);
```

```
E(ind)=M(ind)+0.85*e*(sM(ind))./abs(sM(ind));
E1=zeros(size(M));
ind = find(abs(E-E1)>tol);


while ind

   E1(ind)=E(ind)+(M(ind)-E(ind)+e*sin(E(ind)))./(1-e*cos(E(ind)));
   ind = find((E-E1)>tol);
   E=E1;

end




function [R]=J2k2Planet(JD,a,d,Wo,Wd,ichk)
%R=J2k2Planet[JD,a,d,W,Wd,ichk]
%This function calculates the 3x3 rotation matrix from J2000
%    to the planet equator, prime meridian system.
%Input: JD - Julian Date in Days (J2000 = JD 2451545.0)
%       a  - Right ascension of the planet's pole location in degrees
%       d  - Declination of the planet's pole location in degrees
%       W  - the location of the planet's prime meridian in degrees
%       Wd - rotation rate of planet's prime meridian in degrees/day
%       ichk - 1 for input checking other for no checking
%Output: R - a 3x3 orthogonal matrix of the rotation from J2000
%            to the planet equator, prime meridian system

if ichk==0      % do size and range testing
 [n,m]=size(JD); if m*n>1,error('JD must be a scalar'),end       % inputs are scalars
 [n,m]=size(a); if m*n>1,error('a must be a scalar'),end
 [n,m]=size(d); if m*n>1,error('d must be a scalar'),end
 [n,m]=size(W); if m*n>1,error('W must be a scalar'),end
 [n,m]=size(Wd); if m*n>1,error('Wd must be a scalar'),end
 if a<-2451545, error('a must greater than -2451545'),end  % range testing

 if mod(90-d,180)<5 | mod(90-d,180)>175, error('d cause a singularity'), end
```

```
end% if ichk==1

dr = pi/180;
J2000 = JD - 2451545;
W = Wo + Wd*J2000;
  while W>360
    W=W-360;
  end

  while W<0
    W=W+360;
  end

ea = [a+90 90-d W];


ea = dr*ea;

R = [cos(ea(3))*cos(ea(1))-sin(ea(3))*cos(ea(2))*sin(ea(1)),
cos(ea(3))*sin(ea(1))+sin(ea(3))*cos(ea(2))*cos(ea(1)), sin(ea(3))*sin(ea(2))
  -sin(ea(3))*cos(ea(1))-cos(ea(3))*cos(ea(2))*sin(ea(1)), -
sin(ea(3))*sin(ea(1))+cos(ea(3))*cos(ea(2))*cos(ea(1)), cos(ea(3))*sin(ea(2))
  sin(ea(2))*sin(ea(1)), -sin(ea(2))*cos(ea(1)), cos(ea(2))];


function [r,phip]=Geod2Geoc(h,phi,a,f,ichk)
% function [r,phip]=Geod2Geoc(h,phi,a,f,ichk)
% Calculates geocntric radius and latitude
% Input    h       geodetic altitude above reference ellipsoid
%          phi     geodetic latitude, radians
%          a,f     reference ellipsoid radius and flattening
%          ichk    1 for input checking else no checking
% Output r     geocentric radius
%          phip    geocentric latitude, radians


%test input variables
if ichk==1
 if min(size(h))>1,error('h must be a nx1 array'),end % test h array
 if size(phi)~=size(h); error('phi and h must be the same size'),end   %test h and phi for same size
 if max(size(a))>1, error ('a must be a scalar'), end; %test a and f are scalars
```

```matlab
if max(size(f))>1, error ('f must be a scalar'), end;
if a<0, error('a must be positive'), end;  %test a & f are positive


 if f<0, error('f must be positive'), end;
end% if ichk==1

cosp=cos(phi);
sinp=sin(phi);

C=(cosp.^2+(1-f)^2*sinp.^2).^(-1/2);

S=(1-f)^2*C;

x=a*C.*cosp+h.*cosp;
z=a*S.*sinp+h.*sinp;

phip=atan(z./x);               %Convert z and x to geocentric coordinates
r=sqrt(x.^2+z.^2);

function [r,v]=Orb2XJ2(t,OE,mu,tol,J2,R,ichk)
%[r,v]=Orb2X(t,OE,mu,tol,ichk)
%This function calculates the position and velocity vectors given a set of Orbital elements
% and an array of times t and includes J2 precession effects
%Input: t  - time  - a nx1 array of times in Julian days
%      OE - A 6x1 array of the orbital elements in the following order (z,p,i,Omega,omega, and
tau)
%        - z=1/a, p: semi-latus rectum, i: inclination, Omega: longitude of the ascending node,
%        - omega: argument of periapsis, tau: time of periapsis passage julian days
%      mu - GM - gravitational constant times the masses of the orbiting bodies
%      tol  - tolerance for the accuracy of E
%      J2 - J2 coefficient
%      R - mean radius of the body
%      ichk - 1 for input checking other for no checking
%Output: r  - the position vector in cartesian coordinates (nx3 array)
%       v  - the velocity vector in cartesian coordinates (nx3 array)
% This function uses the Functions Kepler, KeplerH, J2Precess, and rotate313

if ichk==1      % do size and range testing
 if max(size(OE))~=6,error('OE must be an 6x1 array'),end      % inputs are scalars
 if min(size(OE))~=1, error('OE must be an 6x1 array'), end
```

```matlab
  if min(size(t))~=1, error('t must be an nx1 array'), end
  if max(size(mu))>1,error('mu must be a scalar'),end
  if max(size(tol))>1,error('tol must be a scalar'),end
  if max(size(J2))>1,error('J2 must be a scalar'),end
  if max(size(R))>1,error('R must be a scalar'),end
  if tol<=0, error('tol must be greater than 0'), end
  if mu<=0, error('mu must be greater than 0'), end
  if R<=0, error('R must be greater than 0'), end
end% if ichk==1

z=OE(1);
p=OE(2);
i=OE(3);
Omega=OE(4);
omega=OE(5);
tau=OE(6);

[n,m]=size(t);
if m>n
  t = t';
end

a=1/z;
e=sqrt(1-p*z);

[wdot,Wdot,Lamdot]=J2Precess(a,e,i,J2,mu,R,ichk);
Omega=Omega+Wdot*(t-tau);
omega=omega+wdot*(t-tau);
dlam=Lamdot*(t-tau);

if z>0
  n=sqrt(mu*z^3);
  tau=tau-dlam/n;
  M=n*(t-tau);
  E=Kepler(M,e,tol,ichk);
  mr=(1-e*cos(E))/z;
  rd=n*e*sin(E)./(z^2*mr);
  f=atan2(sqrt(1-e^2)*sin(E),(cos(E)-e));
elseif z==0
  n=sqrt(mu/p^3);
  tau=tau-dlam/n;
```

```matlab
  f=Barker(t,tau,p,mu,ichk);
  IF J2~=0,
  mr=p/(cos(f)+1);
  rd=n*p*sin(f);
else
  n=sqrt(-mu*z^3);
  tau=tau-dlam/n;
  M=n*(t-tau);
  F=KeplerH(M,e,tol,ichk);
  mr=(1-e*cosh(F))/z;
  rd=n*e*sinh(F)./(z^2*mr);
  f=atan2(sqrt(e^2-1)*sinh(F),e-cosh(F));
end

thetadot=sqrt(mu*p)./mr.^2;
theta=omega+f;

ci=cos(i);
si=sin(i);
cO=cos(Omega);
sO=sin(Omega);
ct=cos(theta);
st=sin(theta);

er=[ct.*cO-st.*sO*ci ct.*sO+st.*cO*ci st*si];
et=[-st.*cO-ct.*sO*ci -st.*sO+ct.*cO*ci ct*si];

rtd=mr.*thetadot;
r=[mr mr mr].*er;
v=[rd rd rd].*er+[rtd rtd rtd].*et;


function []=plottime;
% function []=plottime  places date in lower left and time in lower right corners
dmy=date;
time=clock;
text(-0.1,-0.1,dmy,'sc')
text(0.95,-0.1,[int2str(time(4)),':',int2str(time(5)),' RHT'],'sc')

function f=Barker(t,tau,p,mu,ichk)
%f=Barker(t,tau,p,mu,ichk)
```

```
% This function calculates the angle between periapsis and the position of a satelite
%Input: t - array of times in Julian Days
%      tau  - the time of periapsis passage in Julian Days
%      p  - semi-latus rectum
%      mu  - GM - gravitational constant times the masses of the orbiting bodies
%      ichk - 1 for input checking other for no checking
%Output: f - angle between periapsis and the position of the satelite

if ichk==1     % do size and range testing
 if min(size(t))>1, error('t must be an array size nx1'),end
 if max(size(tau))>1,error('tau must be a scalar'),end      % inputs are scalars
 if max(size(p))>1,error('p must be a scalar'),end
 if max(size(mu))>1,error('mu must be a scalar'),end
end% if ichk==1

[n,m]=size(t);
if m>n
  t = t';
end

B= 3*sqrt(mu/(p^3))*86400*(t-tau);
A=(abs(B)+sqrt(1+B.^2)).^(2/3);
f=2*atan((2*A.*B)./(1+A+A.^2));

function []=LEOgt(z,p,i,OMEGA,omega,tau,ti,J2on,ichk)
%[]=LEOgt(z,p,i,omega,OMEGA,tau,ti,J2on,ichk)
%This function generates a ground track for a satellite in a low earth orbit
%Inputs :  z - 1/a
%        p - semi-latus rectum
%        i - inclination
%        Omega - longitude of the ascending node
%        omega - argument of periapsis
%        tau - time of periapsis passage 6x1 array -(year month day hour minutes seconds)
%        ti - time interval in days
%        J2on - 1 to include J2 precession
%        ichk - 1 for information check
%This function uses functions Ymd2JD, Ymd2GMST, Orb2XJ2, Kepler,
%           KeplerH, J2Precess, and rotate313

if ichk==1     % do size and range testing
 if max(size(z))>1,error('z must be a scalar'),end
```

63

```matlab
if max(size(p))>1,error('p must be a scalar'),end
if max(size(i))>1,error('i must be a scalar'),end
if max(size(OMEGA))>1,error('OMEGA must be a scalar'),end
if max(size(omega))>1,error('omega must be a scalar'),end
if min(size(tau))~=1|max(size(tau))~=6, error('ymdhms must be a 6x1 array'), end
if max(size(ti))>1,error('ti must be a scalar'),end
if max(size(J2on))>1,error('J2on must be a scalar'),end
TEST a>0 ALSO
end% if ichk==1

%Define constants
mu1 = 398600.5; %km^3/s^2
R=6378.14; % radius of the earth
ppo = 4000; %points per orbit
dr = pi/180; %degrees to radian conversion
ds = 86400; %days to seconds conversion
sid2utc=1.002737909350795; %sidereal time to utc time
tol = 1e-12; %Set tolerance for kepler iteration
mu = mu1*(ds^2);    %convert mu to km^2/day^2
n=sqrt(mu*z^3);     %1/day
Period=2*pi/n;      %day

%set J2 Conditions
if J2on ==1
  J2= 0.108263e-2;
  ttl = 'Ground track for LEO with J2 precession';
else
  J2=0;
  ttl = 'Ground track for LEO without J2 precession';
end

%input parameters
OE(1)=z;
OE(2)=p;
OE(3)=i;
OE(4)=OMEGA;
OE(5)=omega;

%Convert tau to julian days
OE(6) = Ymd2JD(tau,ichk);    %tau -Julian date
```

```matlab
%Establish range of times for ground track plot
tplot=[0:Period/ppo:ti]'; %Array of range of times - days
t=tplot+OE(6);          %Array of range of times beginning with periapsis

%Calculate the position and velocity vectors
[r,v]=Orb2XJ2(t,OE,mu,tol,J2,R,ichk);

%find right ascension and declinations in degrees
alpha = atan2(r(:,2),r(:,1))/dr;                %right ascension for plot range
delta = atan(r(:,3)./sqrt(r(:,1).^2+r(:,2).^2))/dr;    %declination for plot range


%Find location of GMST for t=tau at the beginning of the plot time
GMSTo = Ymd2GMST(tau,ichk);          %GMST for initial plot time - in hours

%Find Latitude and Longitude from ascension declination and GMST
%Latitude equals the declination
%Longitude from the Greenwich meridian : difference between right ascension and GMST
lat=delta;                       %Latitude over plot range
long =mod(alpha -(GMSTo*15+360*sid2utc*tplot),360);  %Longitude from -180 to 180
scale = find(long>180);
long(scale)=long(scale)-360;          %Range of longitude: -180 to 180 degrees

%Plot groundtrack
figure
plot(long,lat);
title(ttl)
xlabel('Longitude - Degrees')
ylabel('Latitude - Degrees')
axis([-180 180 10*floor(min(lat)/10) 10*ceil(max(lat)/10)])

grid
plottime




function [r,v]=Orb2Xags(t,OE,mu,tol,ichk)
%[r,v]=Orb2X(t,OE,mu,tol,ichk)
%This function calculates Orbital elements from the position and velocity vectors
%Input: t  - time  - a nx1 array of times
```

```matlab
%       OE - A 6x1 array of the orbital elements in the following order (z,p,i,Omega,omega, and
tau)
%         - z=1/a, p: semi-latus rectum, i: inclination, Omega: longitude of the ascending node,
%         - omega: argument of periapsis, tau: time of periapsis passage julian days
%       mu - GM - gravitational constant times the masses of the orbiting bodies
%       ichk - 1 for input checking other for no checking
%Output: r  - the position vector in cartesian coordinates (3x1 array)
%        v  - the velocity vector in cartesian coordinates (3x1 array)
% This function uses the Functions Kepler, Barker, and KeplerH
if ichk==1        % do size and range testing
 if max(size(OE))~=6,error('OE must be an 6x1 array'),end        % inputs are scalars
 if min(size(OE))~=1, error('OE must be an 6x1 array'), end
 if min(size(t))~=1, error('t must be an nx1 array'), end
 if max(size(mu))>1,error('mu must be a scalar'),end
 if max(size(tol))>1,error('tol must be a scalar'),end
 if tol<=0, error('tol must be greater than 0'), end
 if mu<=0, error('mu must be greater than 0'), end
end% if ichk==1

z=OE(1);
p=OE(2);
i=OE(3);
Omega=OE(4);
omega=OE(5);
tau=OE(6);

[n,m]=size(t);
if m>n
  t = t';
end

e=sqrt(1-p*z)
if z>0
 n=sqrt(mu*z^3);
 M=n*(t-tau);
 E=Kepler(M,e,tol,ichk);
 mr=(1-e*cos(E))/z;
 rd=n*e*sin(E)./(z^2*mr);
 f=atan2(sqrt(1-e^2)*sin(E),(cos(E)-e));
elseif z==0
 f=Barker(t,tau,p,mu,ichk);
```

```
 mr=p/(cos(f)+1);
 rd=n*p*sin(f);
else
 n=sqrt(-mu*z^3);
 M=n*(t-tau);
 F=KeplerH(M,e,tol,ichk);
 mr=(1-e*cosh(F))/z;
 rd=n*e*sinh(F)./(z^2*mr);
 f=atan2(sqrt(e^2-1)*sinh(F),e-cosh(F));
end

thetad=sqrt(mu*p)./mr.^2;
theta=omega+f;

ci=cos(i);
si=sin(i);
cO=cos(Omega);
sO=sin(Omega);
ct=cos(theta);
st=sin(theta);

er=[ct*cO-st*sO*ci ct*sO+st*cO*ci st*si];
et=[-st*cO-ct*sO*ci -st*sO+ct*cO*ci ct*si];

rtd=mr.*thetad;
r=[mr mr mr].*er;
v=[rd rd rd].*er+[rtd rtd rtd].*et;


function OE=X2Orb(t,r,v,mu,ichk)
%OE=X2Orb(t,r,v,mu,ichk)
%This function calculates Orbital elements from the position and velocity vectors
%Input: t - time
%      r  - the position vector (3x1 array)
%      v  - the velocity vector (3x1 array)
%      mu  - GM - gravitational constant times the masses of the orbited body
%      ichk - 1 for input checking other for no checking
%Output: OE - A 6x1 array of the orbital elements in the following order (z,p,i,Omega,omega,
and tau)
%         - z=1/a, p: semi-latus rectum, i: inclination, Omega: longitude of the ascending node,
%         - omega: argument of periapsis, tau: time of periapsis passage
```

```matlab
%make v and r verticle arrays
[n,m]=size(v);
if m>n
  v = v';
end
[n,m]=size(r);
if m>n
  r = r';
end

if ichk==1      % do size and range testing
 if min(size(v))>1, error('v must be a 3x1 array'), end
 if max(size(v))~=3, error('v must be a 3x1 array'), end
 if max(size(v~=size(r)), error('r must be a 3x1 array'), end
 if max(size(t))>1,error('t must be a scalar'),end        % inputs are scalars
 if max(size(mu))>1,error('mu must be a scalar'),end
 if mu<0, error('mu must be positive'), end
end% if ichk==1

%find magnitude of v and r
mr=norm(r);
mv=norm(v);


z=(2/mr-mv^2/mu);  %equation 3-5
h=cross(r,v);      %calculate angular momentum
mh=norm(h);        %magnitude of the angular momentum
p=mh^2/mu;         %find p from h and mu
i=acos(h(3)/mh);   %equation 3-7
Omega = atan2(h(1),-h(2)); %equation 3-9
%omega between 0 and 2Pi
if Omega<0
  Omega=Omega+2*pi;
end

e=cross(v,h)/mu-r/mr; %equation 3-6
me=norm(e);            %magnitude of the e vector
ew=e/me;
eOmega=[cos(Omega)     %find the eOmega vectors
```

```matlab
    sin(Omega)
    0];

omega = atan2(ew'*cross(h/mh,eOmega),ew'*eOmega); %equation 3-11
if omega<0
    omega=omega+2*pi;
end

if abs(z*mr)<1e-9
    z=0;
end

%Calculate tau for eliptic, parabolic or hyperbolic motions
if z>0
    n=sqrt(z^3*mu);
    E=acos((1-z*mr)/me);   %equation 'a' on pg 3-9
    E=sign(dot(r,v))*E;    %quadrant check for E
    M=E-me*sin(E);         %equation 3-14
    tau=t-M/n;             %equation 3-14
elseif z==0
    n=sqrt(mu/p^3);
    f=acos(p/mr-1);        %equation 'b' on pg 3-9
    f=sign(dot(r,v))*f;    %quadrant check for f
    Tf=tan(f/2);
    M=Tf^3/6+Tf/2;         %equation 3-16
    tau=t-M/n;             %equation 3-16
else
    n=sqrt(-z^3*mu);
    F=acosh((1-z*mr)/me);  %equation 'c' on pg 3-9
    F=sign(dot(r,v))*F;    %quadrant check for F
    M=me*sinh(F)-F;        %equation 3-15
    tau=t-M/n;             %equation 3-15
end

OE=[z,p,i,Omega,omega,tau];


function JD =Ymd2JD(ymdhms,ichk)
% function JD =Ymd2JD(ymdhms,ichk)
% Calculates the Julian Day given the year, month, day, hour, minute and seconds
% Input     ymdhms  nx6 array where the rows are in the following format
```

```
%            [YYYY,MM,DD,HH,MM,SS.SSSS].  Years, Months, Days, Hours, Minutes,
Seconds
%            All numbers must be integers except seconds
%            Numbers must fall in range for that variable (ie Months 1-12, Seconds 0-60)
%         ichk      1 for input checking else no checking
% Output JD     nx1 array of Julian Dates


[n,m]= size(ymdhms);


%test input variables
[n,m]= size(ymdhms);
if ichk==1
   if m~=6,error('ymdhms must be a nx6 array'),end  % test size of array
   if max(max(mod(ymdhms(:,1:5),1)~=0))~=0
      error('Columns 1:5 in ymdhms must be integers'), end %test ymdhms for integers
   if min(ymdhms(:,1)+4713)<0, error('year must be greater than or equal to -4713'), end % test
range of numbers
   if min(ymdhms(:,2))<1, error('month must be greater than or equal to 1'), end
   if min(ymdhms(:,3))<1, error('day must be greater than or equal to 1'), end
   if max(max(ymdhms(:,4:6)<0)),error('Hours minutes and seconds must be positive numbers'),
end
   if max(ymdhms(:,4))>23, error('hours must be less than or equal to 23'), end
   if max(ymdhms(:,5))>60, error('minutes must be less than or equal to 60'), end
   if max(ymdhms(:,6))>60, error('seconds must be less than or equal to 60'), end
   if max(ymdhms(:,2))>12, error('month must be less than or equal to 12'), end
   if max(ymdhms(:,3))>31, error('days must be less than or equal to 31'), end
p30=find(ymdhms(:,2)==4 | ymdhms(:,2)==6 | ....==11)) % points to april, june, sept and nov
if length(p30)>0, if ymdhms(p30,3)>30, error(), end, end
p31=find(...)
etc

   for ind = 1:n     %leap year check
      if
(ymdhms(ind,2)==4|ymdhms(ind,2)==6|ymdhms(ind,2)==9|ymdhms(ind,2)==11)&ymdhms(ind,
3)>30
        error('Days must be less than or equal to 30 for the month')
      elseif  ymdhms(ind,2)==2&ymdhms(ind,3)>29
        error('Not a Leap year - Days in Feb must be less than or equal to 29')
      elseif ymdhms(ind,2)==2&ymdhms(ind,3)==29&mod(ymdhms(ind,1),4)~=0
        error('Not a Leap year - Days in Feb must be less than or equal to 29')
```

```matlab
    elseif
ymdhms(ind,2)==2&ymdhms(ind,3)==29&mod(ymdhms(ind,1),100)==0&mod(ymdhms(ind,1),
400)~=0
        error('Not a Leap year - Days in Feb must be less than or equal to 29')
    end
  end
end% if ichk==1

% when month is 1 or 2, add 12 to month and subtract 1 from year
p=find(ymdhms(:,2)<3;
if length(p)>0, ymdhms(p,2)=ymdhms(p,2)+12; ymdhms(p,1)=ymdhms(p,1)-1; end
for ind = 1:n
  if ymdhms(ind,2)<3
    ymdhms(ind,1)=ymdhms(ind,1)-1;
    ymdhms(ind,2)=ymdhms(ind,2)+12;
  end
end

%day calculation including hours minutes and seconds
D=ymdhms(:,3)+ymdhms(:,4)/24+ymdhms(:,5)/1440+ymdhms(:,6)/86400;

%Julian day calculation MAE 276 pp.1-12 Eq(1-10)

A =floor(ymdhms(:,1)/100);
B= 2-A+(floor(A/4));
JD=floor(365.25*(ymdhms(:,1)+4716))+floor(30.6001*(ymdhms(:,2)+1))+D+B-1524.5;

function GMST =Ymd2GMST(ymdhms,ichk)
% function GMST =Ymd2GMST(ymdhms,ichk)
% Calculates the Greenwich Mean Sidereal Time given the year, month day hour, minute and
seconds
% Input    ymdhms  nx6 array where the rows are in the following format
%             [YYYY,MM,DD,HH,MM,SS.SSSS].  Years, Months, Days, Hours, Minutes,
Seconds
%             All numbers must be integers except seconds
%             Numbers must fall in range for that variable (ie Months 1-12, Seconds 0-60)
%          ichk    1 for input checking else no checking
% Output GMST   nx1 array of GMST in degrees between mean equinox and Greenwich mean
meridian
%test input variables
```

71

```matlab
[n,m]= size(ymdhms);

if ichk==1
  if m~=6,error('ymdhms must be a nx6 array'),end  % test size of array
  if max(max(mod(ymdhms(:,1:5),1)~=0))~=0
    error('Columns 1:5 in ymdhms must be integers'), end %test ymdhms for integers
  if min(ymdhms(:,1)+4713)<0, error('year must be greater than or equal to -4713'), end % test
range of numbers
  if min(ymdhms(:,2))<1, error('month must be greater than or equal to 1'), end
  if min(ymdhms(:,3))<1, error('day must be greater than or equal to 1'), end
  if max(max(ymdhms(:,4:6)<0)),error('Hours minutes and seconds must be positive numbers'),
end
  if max(ymdhms(:,4))>23, error('hours must be less than or equal to 23'), end
  if max(ymdhms(:,5))>60, error('minutes must be less than or equal to 60'), end
  if max(ymdhms(:,6))>60, error('seconds must be less than or equal to 60'), end
  if max(ymdhms(:,2))>12, error('month must be less than or equal to 12'), end
  if max(ymdhms(:,3))>31, error('days must be less than or equal to 31'), end

  for ind = 1:n     %leap year check
    if
(ymdhms(ind,2)==4|ymdhms(ind,2)==6|ymdhms(ind,2)==9|ymdhms(ind,2)==11)&ymdhms(ind,
3)>30
      error('Days must be less than or equal to 30 for the month')
    elseif  ymdhms(ind,2)==2&ymdhms(ind,3)>29
      error('Not a Leap year - Days in Feb must be less than or equal to 29')
    elseif ymdhms(ind,2)==2&ymdhms(ind,3)==29&mod(ymdhms(ind,1),4)~=0
      error('Not a Leap year - Days in Feb must be less than or equal to 29')
    elseif
ymdhms(ind,2)==2&ymdhms(ind,3)==29&mod(ymdhms(ind,1),100)==0&mod(ymdhms(ind,1),
400)~=0
      error('Not a Leap year - Days in Feb must be less than or equal to 29')
    end
  end
end% if ichk==1
% when month is 1 or 2, add 12 to month and subtract 1 from year
for ind = 1:n
  if ymdhms(ind,2)<3
    ymdhms(ind,1)=ymdhms(ind,1)-1;
    ymdhms(ind,2)=ymdhms(ind,2)+12;
  end
end
```

%day calculation including hours minutes and seconds
D=ymdhms(:,3)+ymdhms(:,4)/24+ymdhms(:,5)/1440+ymdhms(:,6)/86400;

%Julian day calculation MAE 276 pp.1-12 Eq(1-10)
A =floor(ymdhms(:,1)/100);
B= 2-A+(floor(A/4));
JD=floor(365.25*(ymdhms(:,1)+4716))+floor(30.6001*(ymdhms(:,2)+1))+D+B-1524.5;

% calculate T
JDm = (JD - 2451545);
h=mod(JDm-.5,1);
T=(JDm-h)/36525;

% calculate GMST @ 0 hours
GMST0 = 100.4606184 + 36000.77005*T + (0.00038793)*T.^2 - (2.6*10^-7)*T.^3;

% calculate delta GMST 1 degree
GMSTdelta = 15*1.002737909350795*h*24;

% calculate GMST
GMST = GMST0 + GMSTdelta;

%Make GMST between 0 and 360
GMST=mod(GMST,360);


function [r,v]=X2Xags(t,t1,r1,v1,mu,tol,ichk)
%[r,v]=X2X(t,t1,r1,v1,mu,tol,ichk)
%This function transforms the position and velocity from an initial state at t1 to an array of times.
%Input: t - time - nx1 array of times
%      t1 - initial time of the position
%      r1  - the position vector at time t1 (3x1 array)
%      v1  - the velocity vector at time t1 (3x1 array)
%      mu  - GM - gravitational constant times the masses of the orbited body
%      tol - the tolerance FOR CONVERGENCE OF KEPLER'S EQUATION [of the final position and velocity vectors]
%      ichk - 1 for input checking other for no checking
%Output: r  - the position vector in cartesian coordinates (3x1 array)
%       v  - the velocity vector in cartesian coordinates (3x1 array)

```matlab
%make v and r verticAL arrays
[n,m]=size(v1);
if m>n
  v1 = v1';
end
[n,m]=size(r1);
if m>n
  r1 = r1';
end

if ichk==1      % do size and range testing
 if min(size(t))~=1, error('t must be an nx1 array'), end
 if max(size(t1))>1,error('t must be a scalar'),end      % inputs are scalars
 if min(size(v1))~=1, error('v must be a 3x1 array'), end
 if max(size(v1))~=3, error('v must be a 3x1 array'), end
 if max(size(v1~=size(r1)), error('r must be a 3x1 array'), end
 if max(size(mu))>1,error('mu must be a scalar'),end
 if max(size(tol))>1,error('tol must be a scalar'),end
 if mu<=0, error('mu must be greater than 0'), end
 if tol<=0, error('tol must be greater than 0'), end
end% if ichk==1

%find magnitude of v and r
mr1=norm(r1);
mv=norm(v1);
z=(2/mr1-mv^2/mu);  %equation 3-5
n=sqrt(z^3*mu);
h=cross(r1,v1);      %calculate angular momentum
e=cross(v1,h)/mu-r1/mr1; %equation 3-6
me=norm(e);            %magnitude of the e vector

Eo=acos((1-z*mr1)/me);   %equation 'a' on pg 3-9
Eo=sign(dot(r1,v1))*Eo;    %quadrant check for Eo
Mo=Eo-me*sin(Eo);         %equation 3-14
tau=t1-Mo/n;           %equation 3-14
M=n*(t-tau);

E=Kepler(M,me,tol,ichk);

dE=E-Eo;
```

```
sE=sin(dE);
cE=cos(dE);

F=1+(cE-1)/(z*mr1);
G=(t-t1)+(sE-dE)/n;

r=r1*F+v1*G;
mr=sqrt(sum(r.*r));
Fd = -n*sE./(z^2*mr*mr1);
Gd = 1+(cE-1)./(z*mr);
v=r1*Fd+v1*Gd;
r=r';
v=v';
```

Appendix 2

*Code for Monte Carlo simulation*

```
% int i;
% real MainBeam;
% real NumAirOn;
% int LenSimdays;
LenSimdays = 100*60;
%*60*24;
TxEIRPMaxC = 28.7 -10*log10(40000);
FreeSpaceLoss = 198;
Boltzman = -228.6;
RcvAntgain = 24;
RcvTemp = 10*log10(200);

NumAirOn = 10;
for i = 1:LenSimdays

s1(i) = rand*100;
s2(i) = rand*100;
s3(i) = rand*100;
s4(i) = rand*100;
s5(i) = rand*100;
s6(i) = rand*100;
s7(i) = rand*100;
s8(i) = rand*100;
s9(i) = rand*100;
s10(i) = rand*100;


end;

for j = 1:LenSimdays

if s1(j) < 2
  o1(j) = TxEIRPMaxC + RcvAntgain - FreeSpaceLoss - Boltzman - RcvTemp;
elseif s1(j) < 7
  o1(j) = 33-25*log10(s1(j)) + RcvAntgain - FreeSpaceLoss - Boltzman -
RcvTemp;
elseif s1(j) < 9.2
  o1(j) = 12 + RcvAntgain + FreeSpaceLoss - Boltzman - RcvTemp;
elseif s1(j)< 48
  o1(j) = 36 - 25*log10(s1(j))+ RcvAntgain - FreeSpaceLoss - Boltzman -
RcvTemp;
else s1(j) > 48
  o1(j) = -6 + RcvAntgain - FreeSpaceLoss - Boltzman - RcvTemp;
end;
```

```
if s2(j) < 2
   o2(j) = TxEIRPMaxC;
elseif s2(j) < 7
   o2(j) = 33-25*log10(s1(j));
elseif s2(j) < 9.2
   o2(j) = 12;
elseif s2(j)< 48
   o2(j) = 36 - 25*log10(s1(j));
else s2(j) > 48
   o2(j) = -6 ;
   end;

 if s3(j) < 2
   o3(j) = TxEIRPMaxC;
elseif s3(j) < 7
   o3(j) = 33-25*log10(s1(j));
elseif s3(j) < 9.2
   o3(j) = 12;
elseif s3(j)< 48
   o3(j) = 36 - 25*log10(s1(j));
else s3(j) > 48
   o3(j) = -6 ;
end;

if s4(j) < 2
   o4(j) = TxEIRPMaxC;
elseif s4(j) < 7
   o4(j) = 33-25*log10(s1(j));
elseif s4(j) < 9.2
   o4(j) = 12;
elseif s4(j)< 48
   o4(j) = 36 - 25*log10(s1(j));
else s4(j) > 48
   o4(j) = -6 ;
   end;

  if s5(j) < 2
   o5(j) = TxEIRPMaxC;
elseif s5(j) < 7
   o5(j) = 33-25*log10(s1(j));
elseif s5(j) < 9.2
   o5(j) = 12;
elseif s5(j)< 48
   o5(j) = 36 - 25*log10(s1(j));
else s5(j) > 48
   o5(j) = -6 ;
   end;

  if s6(j) < 2
  o6(j) = TxEIRPMaxC;
```

```
elseif s6(j) < 7
   o6(j) = 33-25*log10(s1(j));
elseif s6(j) < 9.2
   o6(j) = 12;
elseif s6(j)< 48
   o6(j) = 36 - 25*log10(s1(j));
else s6(j) > 48
   o6(j) = -6 ;
   end;

if s7(j) < 2
   o7(j) = TxEIRPMaxC;
elseif s7(j) < 7
   o7(j) = 33-25*log10(s1(j));
elseif s7(j) < 9.2
   o7(j) = 12;
elseif s7(j)< 48
   o7(j) = 36 - 25*log10(s1(j));
else s7(j) > 48
   o7(j) = -6 ;
   end;

   if s8(j) < 2
   o8(j) = TxEIRPMaxC;
elseif s8(j) < 7
   o8(j) = 33-25*log10(s1(j));
elseif s8(j) < 9.2
   o8(j) = 12;
elseif s8(j)< 48
   o8(j) = 36 - 25*log10(s1(j));
else s8(j) > 48
   o8(j) = -6 ;
   end;

   if s9(j) < 2
   o9(j) = TxEIRPMaxC;
elseif s9(j) < 7
   o9(j) = 33-25*log10(s1(j));
elseif s9(j) < 9.2
   o9(j) = 12;
elseif s9(j)< 48
   o9(j) = 36 - 25*log10(s1(j));
else s9(j) > 48
   o9(j) = -6 ;
   end;

   if s10(j) < 2
   o10(j) = TxEIRPMaxC;
elseif s10(j) < 7
   o10(j) = 33-25*log10(s1(j));
```

```matlab
elseif s10(j) < 9.2
   o10(j) = 12;
elseif s10(j)< 48
   o10(j) = 36 - 25*log10(s1(j));
else s10(j) > 48
   o10(j) = -6 ;
   end;


end;
o11 = o1 + o2 + o3 + o4 + o5 + o6 + o7 + o8 + o9 + o10;
plot(o11)
xlabel ('time steps')
ylabel ('Io/No')
title (' 10 Interferes')



% int i;
% real MainBeam;
% real NumAirOn;
% int LenSimdays;
LenSimdays = 100*60;
%*60*24;
TxEIRPMaxC = 28.7 -10*log10(40000);
FreeSpaceLoss = 198;
Boltzman = -228.6;
RcvAntgain = 24;
RcvTemp = 10*log10(200);

NumAirOn = 10;
for i = 1:LenSimdays

s1(i) = rand*177+ 3;
s2(i) = rand*177+ 3;
s3(i) = rand*177+ 3;
s4(i) = rand*177+ 3;
s5(i) = rand*177+ 3;
s6(i) = rand*177+ 3;
s7(i) = rand*177+ 3;
s8(i) = rand*177+ 3;
s9(i) = rand*177+ 3;
s10(i) = rand*177+ 3;
```

```matlab
end;

for j = 1:LenSimdays

if s1(j) < 2
    o1(j) = TxEIRPMaxC + RcvAntgain - FreeSpaceLoss - Boltzman -
RcvTemp;
elseif s1(j) < 7
    o1(j) = 33-25*log10(s1(j)) + RcvAntgain - FreeSpaceLoss -
Boltzman - RcvTemp;
elseif s1(j) < 9.2
    o1(j) = 12 + RcvAntgain + FreeSpaceLoss - Boltzman - RcvTemp;
elseif s1(j)< 48
    o1(j) = 36 - 25*log10(s1(j))+ RcvAntgain - FreeSpaceLoss -
Boltzman - RcvTemp;
else s1(j) > 48
    o1(j) = -6 + RcvAntgain - FreeSpaceLoss - Boltzman - RcvTemp;
end;

if s2(j) < 2
    o2(j) = TxEIRPMaxC;
elseif s2(j) < 7
    o2(j) = 33-25*log10(s1(j));
elseif s2(j) < 9.2
    o2(j) = 12;
elseif s2(j)< 48
    o2(j) = 36 - 25*log10(s1(j));
else s2(j) > 48
    o2(j) = -6 ;
    end;

 if s3(j) < 2
    o3(j) = TxEIRPMaxC;
elseif s3(j) < 7
    o3(j) = 33-25*log10(s1(j));
elseif s3(j) < 9.2
    o3(j) = 12;
elseif s3(j)< 48
    o3(j) = 36 - 25*log10(s1(j));
else s3(j) > 48
    o3(j) = -6 ;
end;
```

```matlab
if s4(j) < 2
    o4(j) = TxEIRPMaxC;
elseif s4(j) < 7
    o4(j) = 33-25*log10(s1(j));
elseif s4(j) < 9.2
    o4(j) = 12;
elseif s4(j)< 48
    o4(j) = 36 - 25*log10(s1(j));
else s4(j) > 48
    o4(j) = -6 ;
    end;

  if s5(j) < 2
    o5(j) = TxEIRPMaxC;
elseif s5(j) < 7
    o5(j) = 33-25*log10(s1(j));
elseif s5(j) < 9.2
    o5(j) = 12;
elseif s5(j)< 48
    o5(j) = 36 - 25*log10(s1(j));
else s5(j) > 48
    o5(j) = -6 ;
    end;

    if s6(j) < 2
    o6(j) = TxEIRPMaxC;
elseif s6(j) < 7
    o6(j) = 33-25*log10(s1(j));
elseif s6(j) < 9.2
    o6(j) = 12;
elseif s6(j)< 48
    o6(j) = 36 - 25*log10(s1(j));
else s6(j) > 48
    o6(j) = -6 ;
    end;

if s7(j) < 2
    o7(j) = TxEIRPMaxC;
elseif s7(j) < 7
    o7(j) = 33-25*log10(s1(j));
elseif s7(j) < 9.2
```

```matlab
    o7(j) = 12;
elseif s7(j)< 48
    o7(j) = 36 - 25*log10(s1(j));
else s7(j) > 48
    o7(j) = -6 ;
    end;

    if s8(j) < 2
    o8(j) = TxEIRPMaxC;
elseif s8(j) < 7
    o8(j) = 33-25*log10(s1(j));
elseif s8(j) < 9.2
    o8(j) = 12;
elseif s8(j)< 48
    o8(j) = 36 - 25*log10(s1(j));
else s8(j) > 48
    o8(j) = -6 ;
    end;

    if s9(j) < 2
    o9(j) = TxEIRPMaxC;
elseif s9(j) < 7
    o9(j) = 33-25*log10(s1(j));
elseif s9(j) < 9.2
    o9(j) = 12;
elseif s9(j)< 48
    o9(j) = 36 - 25*log10(s1(j));
else s9(j) > 48
    o9(j) = -6 ;
    end;

    if s10(j) < 2
    o10(j) = TxEIRPMaxC;
elseif s10(j) < 7
    o10(j) = 33-25*log10(s1(j));
elseif s10(j) < 9.2
    o10(j) = 12;
elseif s10(j)< 48
    o10(j) = 36 - 25*log10(s1(j));
else s10(j) > 48
    o10(j) = -6 ;
    end;
```

```matlab
end;
o11 = o1 + o2 + o3 + o4 + o5 + o6 + o7 + o8 + o9 + o10;
plot(o11)
xlabel ('time steps')
ylabel ('Io/No')
title (' 10 Interferes 3 degree orbital separation')



% int i;
% real MainBeam;
% real NumAirOn;
% int LenSimdays;
LenSimdays = 100*60;
%*60*24;
TxEIRPMaxC = 28.7 -10*log10(40000);
FreeSpaceLoss = 198;
Boltzman = -228.6;
RcvAntgain = 24;
RcvTemp = 10*log10(200);

NumAirOn = 10;
for i = 1:LenSimdays

s1(i) = rand*170+ 10;
s2(i) = rand*170+ 10;
s3(i) = rand*170+ 10;
s4(i) = rand*170+ 10;
s5(i) = rand*170+ 10;
s6(i) = rand*170+ 10;
s7(i) = rand*170+ 10;
s8(i) = rand*170+ 10;
s9(i) = rand*170+ 10;
s10(i) = rand*170+ 10;


end;

for j = 1:LenSimdays
```

```
if s1(j) < 2
    o1(j) = TxEIRPMaxC + RcvAntgain - FreeSpaceLoss - Boltzman -
RcvTemp;
elseif s1(j) < 7
    o1(j) = 33-25*log10(s1(j)) + RcvAntgain - FreeSpaceLoss -
Boltzman - RcvTemp;
elseif s1(j) < 9.2
    o1(j) = 12 + RcvAntgain + FreeSpaceLoss - Boltzman - RcvTemp;
elseif s1(j)< 48
    o1(j) = 36 - 25*log10(s1(j))+ RcvAntgain - FreeSpaceLoss -
Boltzman - RcvTemp;
else s1(j) > 48
    o1(j) = -6 + RcvAntgain - FreeSpaceLoss - Boltzman - RcvTemp;
end;

if s2(j) < 2
    o2(j) = TxEIRPMaxC;
elseif s2(j) < 7
    o2(j) = 33-25*log10(s1(j));
elseif s2(j) < 9.2
    o2(j) = 12;
elseif s2(j)< 48
    o2(j) = 36 - 25*log10(s1(j));
else s2(j) > 48
    o2(j) = -6 ;
    end;

 if s3(j) < 2
    o3(j) = TxEIRPMaxC;
elseif s3(j) < 7
    o3(j) = 33-25*log10(s1(j));
elseif s3(j) < 9.2
    o3(j) = 12;
elseif s3(j)< 48
    o3(j) = 36 - 25*log10(s1(j));
else s3(j) > 48
    o3(j) = -6 ;
end;

if s4(j) < 2
    o4(j) = TxEIRPMaxC;
elseif s4(j) < 7
```

```
   o4(j) = 33-25*log10(s1(j));
elseif s4(j) < 9.2
   o4(j) = 12;
elseif s4(j)< 48
   o4(j) = 36 - 25*log10(s1(j));
else s4(j) > 48
   o4(j) = -6 ;
   end;

  if s5(j) < 2
   o5(j) = TxEIRPMaxC;
elseif s5(j) < 7
   o5(j) = 33-25*log10(s1(j));
elseif s5(j) < 9.2
   o5(j) = 12;
elseif s5(j)< 48
   o5(j) = 36 - 25*log10(s1(j));
else s5(j) > 48
   o5(j) = -6 ;
   end;

   if s6(j) < 2
   o6(j) = TxEIRPMaxC;
elseif s6(j) < 7
   o6(j) = 33-25*log10(s1(j));
elseif s6(j) < 9.2
   o6(j) = 12;
elseif s6(j)< 48
   o6(j) = 36 - 25*log10(s1(j));
else s6(j) > 48
   o6(j) = -6 ;
   end;

if s7(j) < 2
   o7(j) = TxEIRPMaxC;
elseif s7(j) < 7
   o7(j) = 33-25*log10(s1(j));
elseif s7(j) < 9.2
   o7(j) = 12;
elseif s7(j)< 48
   o7(j) = 36 - 25*log10(s1(j));
else s7(j) > 48
```

```matlab
   o7(j) = -6 ;
   end;

   if s8(j) < 2
   o8(j) = TxEIRPMaxC;
elseif s8(j) < 7
   o8(j) = 33-25*log10(s1(j));
elseif s8(j) < 9.2
   o8(j) = 12;
elseif s8(j)< 48
   o8(j) = 36 - 25*log10(s1(j));
else s8(j) > 48
   o8(j) = -6 ;
   end;

   if s9(j) < 2
   o9(j) = TxEIRPMaxC;
elseif s9(j) < 7
   o9(j) = 33-25*log10(s1(j));
elseif s9(j) < 9.2
   o9(j) = 12;
elseif s9(j)< 48
   o9(j) = 36 - 25*log10(s1(j));
else s9(j) > 48
   o9(j) = -6 ;
   end;

   if s10(j) < 2
   o10(j) = TxEIRPMaxC;
elseif s10(j) < 7
   o10(j) = 33-25*log10(s1(j));
elseif s10(j) < 9.2
   o10(j) = 12;
elseif s10(j)< 48
   o10(j) = 36 - 25*log10(s1(j));
else s10(j) > 48
   o10(j) = -6 ;
   end;


end;
o11 = o1 + o2 + o3 + o4 + o5 + o6 + o7 + o8 + o9 + o10;
```

```
plot(o11)
xlabel ('time steps')
ylabel ('Io/No')
title (' 10 Interferes 10 degree orbital separation')
```

**VITA**

**Justin Smith** received a BS degree in electrical engineering from George Mason University in 1996. The research for this paper was done as a requirement for a MS in electrical engineering from Virginia Tech .