Sharing Studies Between MSS, Fixed and Mobile in the Frequency Band 1-10 GHz (Final Report)

July 5, 1993

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Executive Summary

The Department of Communications has requested Telesat to perform a frequency sharing study between MSS and Fixed and Mobile services in the 1-10 GHz band. This study is divided into four tasks. The requirements of each task are summarized below:

Task 1 Review in light of WARC-92, various sharing studies and CCIR reports. Extract and tabulate MSS versus Fixed and Mobile inter-service sharing conclusions.

Task 2 Determine relevancy of the sharing studies to the post-WARC situation, taking into account the WARC-92 allocations to mobile-satellite. A prospective on actual Canadian requirements and implementation time frames should also be included.

Task 3 Consider the issue of introducing the new mobile-satellite service allocations into existing fixed and mobile bands, in particular at 2 GHz and determine sharing possibilities between mobile-satellite, both GSO and non-GSO, fixed and mobile services, including in particular, both FPLMTS personal and vehicular terminals.

Task 4 Assess the technical feasibility of using spectrum at 2.5 GHz for future MSS requirements and possible timeframe for such use.

A number of documents are summarized in Section 2, as required in Task 1, with results and conclusions extracted regarding the sharing possibilities between the MSS and the fixed and mobile services. The recommendations of the various papers are quite similar. Mobile satellite earth terminals need to maintain a minimum distance from fixed earth stations for co-frequency operation. Also, transmitting fixed stations need a minimum off-axis angle from the GSO to facilitate sharing. WARC-92 did not include any new operational

limits on fixed earth stations or mobile satellite earth terminals. The current restrictions of Article 27 still apply to transmitting fixed or mobile stations, of course, but if more restrictive limitations are to be placed on fixed earth stations, they would have to be imposed by administrations on a national basis. For MSS use in Canada, both the DOC and FCC would have to incorporate these restrictions if it was desired to improve the co-frequency shareability of the band as MSAT coverage will include the U.S. as well as Canada.

Sharing between MSS and MS, particularly FPLMTS does not seem feasible on a co-frequency basis as cumulative interference from hundreds of FPLMTS base stations in urban areas would likely cause excessive interference into the MSS uplink.

Sharing between bidirectional MSS systems such as the Iridium system and geostationary MSS systems such as MSAT or Inmarsat does not appear to be an issue as the band allocated for bidirectional MSS use has such a severe mobile terminal power limit that the band would probably not be used by the MSAT system or Inmarsat in the near future.

Telesat's views on how mobile satellite technology may progress in the future are presented in Section 3. Views are presented on both spacecraft and earth segment technology. Changes in spacecraft technology can result in more users being supported per unit of bandwidth. Additionally, improved spacecraft technology could also improve the attractiveness of the mobile earth terminals allowing them to be smaller and less expensive and this may increase user demand. Another factor which could result in increased user demand is a reduction in the user service charges due to changes in the spacecraft technology.

It is expected that the goals of the second generation system will be to increase the system capacity, lower the unit cost to the subscribers, allow for the introduction of new services, and improve technical performance such as increased satellite EIRP and satellite

G/T. These goals could be achieved in at least three ways: A larger satellite (more power available) could make use of more bandwidth. A larger antenna and/or more complicated beam network could be implemented which would provide smaller satellite beams. On-board processing equipment would improve the link performance of the communication systems. In addition, more advanced modulation techniques could be used which would allow more users per unit of bandwidth.

More advanced technology may be introduced eventually, such as on-board processing. The use of on-board processing would increase the number of users that the satellite could support as the downlink noise would be de-coupled from the uplink noise. On-board processing would also give the system increased interconnect flexibility in assigning channels to spot beams. This is expected to be of importance as the MSAT system uses a greater number of smaller beams. It is possible that on-board processing would be used in the second generation MSAT system.

Changes in earth segment technology can also affect the requirement for MSS spectrum. In addition to improvements in power or bandwidth efficiency, improvements to the earth segment such as smaller size and improved features could serve to increase user demand for MSS. Improvements in vocoder technology, modulation and coding, and network control technology are likely to lead to improved spectrum efficiency.

As GPS equipment becomes more widely used, the addition of position location ability to MSS terminals is likely to become so inexpensive that virtually all mobile terminals will have this feature. With position location ability it will be feasible to implement band sharing schemes such as those requiring mobile earth terminals to stay out of the coordination area of a fixed station.

The first generation MSAT satellite is expected to be launched in mid 1994. The satellite life will probably be 12-14 years. Depending on how well the satellite ages, the second generation MSAT satellite will likely be planned to be launched 10-12 years after the first satellite. This assumes that there is not a faster build-up of the MSAT market than can be handled by the first generation satellite, requiring the launch of a second first generation satellite to supplement the capacity of the first satellite.

It is possible that the proposed non-geostationary mobile satellite systems may not be implemented in the proposed time frames. Technology development is an issue that could delay implementation. For example, the non-geostationary mobile satellite systems that plan to use a constellation of many satellites require technology development as well as improvements in the speed with which satellites are built, tested, and launched. Also, the software to control a large constellation of satellites with multiple beams per satellite is a very challenging task. As well as technology problems, large complicated non-geostationary satellite systems are expensive and may face financing problems. In addition to these concerns, licensing and regulatory problems for a world-wide system are likely to occur as approval would be needed from the government of each country in which it will offer service.

The need for spectrum to satisfy Canadian needs will be affected by at least three factors. The first factor is the number of Canadians choosing to use mobile satellite services. The second is the introduction of advanced services requiring more spectrum than basic voice or low-rate data. Although it is possible that the MSAT system would use more advanced modulation techniques allowing transmission of more bits per second in a given bandwidth, these techniques usually require more power and the system may not be able to afford it, especially if service to handheld terminals is desired. Another factor affecting spectrum utilization is the satellite frequency reuse factor which may change from generation to generation and will be different for each mobile satellite system.

The analysis for Task 3, in Section 4, determines the sharing possibilities between the MSS service and the fixed and the mobile service. Interference between MSS systems and both the FS and MS systems is studied for two different types of MSS systems; IRIDIUM, a Low Earth Orbit (LEO) satellite based system, and MSAT, a Geosynchronous Orbit (GSO) satellite based system. The MS system under study is the FPLMTS system. Interference is analysed for both directions, from the MSS systems into the terrestrial and FPLMTS systems and from the terrestrial and FPLMTS systems into the MSS systems.

The results indicate that sharing between the FS and the MSS at 2 GHz would be difficult. Interference from the IRIDIUM mobiles and the MSAT mobiles into the terrestrial stations would require that the mobiles be beyond the radio horizon in order for sharing to be possible. In addition, the interference from the terrestrial stations into the IRIDIUM and MSAT satellites would be more than acceptable.

Sharing between the FPLMTS and the MSS at 2 GHz would also be very difficult. Interference from the IRIDIUM and MSAT systems would reduce the maximum range of operation the FPLMTS mobiles could operate from their base stations to an impractical range. Interference from the FPLMTS terminals would also require a large separation distance between the FPLMTS terminals and the IRIDIUM and MSAT mobiles.

There are many operating and planned mobile satellite systems which use the conventional L-band (1.6 GHz uplink, 1.5 GHz downlink) for their mobile terminal-satellite links. This band is heavily used and frequency coordination between different systems are challenging tasks. WARC 92 has allocated new spectrum for the mobile satellite services (MSS). Region 2 gets a total of 114.5+111.5 MHz of new primary allocation and 40+40 MHz allocation at frequency bands below 3 GHz for MSS. Among these new allocations, the band 2500-2520 MHz downlink and 2670-2690 MHz uplink are allocated to MSS world-wide on a primary basis effective on January 1st, 2005.

Using assumptions based on present technologies, the analysis for Task 4 addresses the feasibility of using the spectrum around 2.5 GHz for MSS. Based on the results of this analysis, providing voice and data mobile satellite services seems feasible in this frequency band. However, the 2.5 GHz band seems less attractive than the L-band for satellite systems that intend to provide services to handheld terminal with omni-directional antenna due to the higher free space path loss in the S-band.

The analysis shows that it seems technically feasible to provide mobile satellite voice and data services at S-band to vehicle mounted terminals. The study indicates that if the gain and hence cost of the vehicle mounted antenna is to remain the same as those at L-band, the capacity of an S-band system of comparable size to a L-band system would be 2.8 times less.

S-band is also less attractive than L-band to systems with handheld terminals employing omni-directional antenna, e.g. a LEO-based system, since the terminal antenna gain cannot be increased to compensate for the increased path loss in the S-band.

1. INTRODUCTION

The Department of Communications has requested Telesat to perform a sharing study between MSS and Fixed and Mobile services in the 1-10 GHz band. This study is divided up into four tasks. The requirements of each task are specified below:

Task 1 Review in light of WARC-92, various sharing studies and CCIR reports. Extract and tabulate MSS versus Fixed and Mobile inter-service sharing conclusions.

Task 2 Determine relevancy of the sharing studies to the post-WARC situation, taking into account the WARC-92 allocations to mobile-satellite. A prospective on actual Canadian requirements and implementation time frames should also be included.

Task 3 Consider the issue of introducing the new mobile-satellite service allocations into existing fixed and mobile bands, in particular at 2 GHz and determine sharing possibilities between mobile-satellite, both GSO and non-GSO, fixed and mobile services, including in particular, both FPLMTS personal and vehicular terminals.

Task 4 Assess the technical feasibility of using spectrum at 2.5 GHz for future MSS requirements and possible timeframe for such use.

Section 2 provides a review of the sharing studies as required by Task 1. Section 3 determines the relevancy of the sharing studies reviewed in Task 1 in light of WARC-92 as required by Task 2. Section 4 analyses the sharing possibilities at 2 GHz between the MSS, Fixed and Mobile services as required by Task 3. Section 5 assesses the feasibility of using spectrum at 2.5 GHz for future MSS requirements as required by Task 4 and Section 6 lists the references used for this study.

2. TASK 1 - DOCUMENT REVIEW

2.1 Document: A Study of the Magnitude of Potential Interference Between the Mobile Satellite Service and the Fixed and/or Mobile Services in the Bands 1427-1525 and 1700-2500 MHz, CAL Report 0596-10001, October 1990

This document examines the possibility of frequency sharing between the mobile satellite service and the fixed or mobile services. Using a model based on the proposed MSAT design, current ground terminal specifications, and the technical outline of the Future Public Land Mobile Telecommunication System (FPLMTS), intersystem interference was analysed.

Calculations were performed for interference between the following systems: MSAT and Terrestrial Radio Relay (TRR), MSAT and FPLMTS, aircraft and FPLMTS, and FPLMTS and LMSS. The conclusions indicate that the only service feasible for sharing is the MSAT forward link with the TRR in the bands 1427-1525 MHz and 1900-2450 MHz.

In these bands, if the TRR has at least a 7° offset from the GSO then a TRR degradation of no greater than 3 dB would result. An offset of at least 22.5° would provide a degradation of at most 0.5 dB. Interference from the TRR to the MSAT mobile terminal would occur when in close proximity, but, this should be acceptable as the mobile is expected to leave the interfering environment relatively rapidly.

2.2 Document: A Study of the Feasibility of Mobile Satellite Services Sharing Spectrum with the Terrestrial Fixed Service, CAL Report 0646-10002, June 1991

This document establishes spectrum sharing conditions based on the regulatory provisions for both the MSS and fixed services, and Data

Relay Satellites (DRS) and fixed services. It also proposes several changes for the ITU Radio Regulations for Articles 27 and 28.

Table 2.1 indicates the interference scenarios considered and typical methods of preventing unacceptable interference.

Mobile Satellite Downlink	From Satellite to Terrestrial Stations	Limitations on satellite power flux density at various elevation angles
	From Terrestrial Stations to Mobile Earth Stations	Coordination of frequency assignments for earth stations located in the coordination areas of terrestrial transmitters
Mobile Satellite Uplink	From Mobile Earth Stations to Terrestrial Stations	Coordination of frequency assignments for earth stations located in the coordination areas of terrestrial receivers and power limits
	From Terrestrial Stations to Satellites	Limits on terrestrial transmitter power, EIRP and antenna pointing

Table 2.1: Interfering Scenarios and Prevention Methods

This study concludes that sharing between MSAT and TRR should be feasible at TRR angles of 15° off the GSO provided the TRR employ 4.0 m antennas with the first sidelobes at least 30 dB down from the boresight gain. Operation at 5° and 10° is feasible provided that the

TRR power can be increased by 2.4 dB and 1.2 dB respectively and up to 0.5 dB of degradation in satellite performance is acceptable.

Suggested modifications to Article 28, Section 2557 are as follows:

> -147.4 dB(W/m^2) in any 4 kHz band for angles between 5 and <10° above the horizontal plane.
>
> -144.9 dB(W/m^2) in any 4 kHz band for angles between 10 and <15° above the horizontal plane.
>
> -140.5 dB(W/m^2) in any 4 kHz band for angles =>15° above the horizontal plane.

Polarization and activity factors are not included in the above values.

This study also recommends that Article 27 should be changed to include a statement that transmitting stations operating in the 2.1 GHz band within 15° of the GSO be equipped with antennas at least 4.0 m in diameter and with first sidelobes at least 30 dB down from the boresight gain.

Operation of MSAT co-channel with the TRR should be permitted using spot beams that limit the PFD to -140.5 dBW/m^2 at the 15° elevation angle to the horizon.

In addition, if a LMSS terminal is to be operated co-channel with MSAT then it is recommended that it be inhibited from transmitting when terrestrial interference results in severe degradation in the LMSS signalling channel. This may be embedded in the link protocol or part of the terminal signalling sequence.

2.3 Document: Feasibility Study of Spectrum Sharing between LEO/MSS and GSO/MSS and Fixed Services and FPLMTS, Telesat Canada, 25 April 1991

This document performs interference analysis for co-frequency same and reverse direction operation modes. Interference between LEO/MSS systems and GSO/MSS systems, LEO/MSS and fixed systems, and between LEO/MSS systems and future public land mobile telephone systems (FPLMTS) is analysed. The LEO systems chosen are IRIDIUM and ORBCOMM. However, the system parameters of ORBCOMM were modified to represent the operation at L-band. The following GSO/MSS systems were studied: MSAT, INMARSAT II and III, ZENON, and EUTELSAT II.

Table 2.2 summarizes the sharing results for the IRIDIUM system with GSO/MSS systems and Table 2.3 summarizes the sharing results for the IRIDIUM system with fixed systems and FPLMTS. The "Sharing Conditions" codes are defined as follows:

0 Interference in this scenario seems marginally acceptable.

1 Interference in this scenario is severe but additional protection can be provided by geographical separation.

2 Interference in this scenario is severe but IRIDIUM satellite can turn off the outer beams to alleviate the problem.

3 Interference in this scenario is severe but IRIDIUM satellite can monitor the activity in the shared frequency band and uses only the least active frequency slot.

x Interference in this scenario is severe and the proposed interference reduction techniques are not likely to be effective.

IRIDIUM's Frequency	Interference Scenarios From	To	Sharing Condition	Remark
1.6 GHz	IRD mobile	GSO satellite	0	Sharing could be feasible if the IRIDIUM system can protect itself. Best scenario.
	IRD satellite	GSO satellite	0	
	GSO mobile	IRD mobile	1	
	GSO mobile	IRD satellite	3	
1.5 GHz	IRD mobile	GSO mobile	1	Sharing is not feasible
	IRD satellite	GSO mobile	x	
	GSO satellite	IRD mobile	x	
	GSO satellite	IRD satellite	2,3	
1.6/1.5 GHz Same Direction	IRD mobile	GSO satellite	0	Sharing is not feasible
	IRD satellite	GSO mobile	x	
	GSO mobile	IRD satellite	3	
	GSO satellite	IRD mobile	x	
1.6/1.5 GHz Reverse Direction	IRD mobile	GSO mobile	1	Sharing could be feasible if IRIDIUM can provide protection for itself & the GSO system
	IRD satellite	GSO satellite	2	
	GSO mobile	IRD mobile	1	
	GSO satellite	IRD satellite	2,3	

Table 2.2: Summary of Interference between the IRIDIUM System and GSO/MSS System

	Interference Scenarios From	To	Sharing Condition	Remark
Share with Fixed System	IRD mobile	Fixed System	1	Sharing may be feasible only if IRIDIUM can protect it self and also the fixed system receiver
	IRD satellite	Fixed System	x	
	Fixed System	IRD mobile	1	
	Fixed System	IRD satellite	2,3	
Share with FPLMTS	IRD mobile	FPLMTS	1	Sharing is not feasible
	IRD satellite	FPLMTS	0	
	FPLMTS	IRD mobile	1	
	FPLMTS	IRD satellite	x	

Table 2.3: Summary of Interference between the IRIDIUM System and Fixed System and FPLMTS

2.4 Document: DOC's LEO Spectrum Sharing Study, Phase 2, Telesat Canada, 21 January 1992

This document is a result of a second phase study, with the first phase as described in section 2.3. The phase 2 study consists of a review of a number of CCIR documents on LEOs below 3 GHz, a sharing analysis on the uplink between ORBCOMM and STARNET systems with existing terrestrial systems using the 148-149.9 MHz frequency band, and an assessment of the effect of interference from GSO based mobiles on the capacity of the IRIDIUM system if they were to share the same spectrum.

The reviewed documents discuss a number of methods for the IRIDIUM system to facilitate sharing with RDSS and GSO MSS. These include pulse blanking, dynamic interference detection and avoidance, turning off outer beams which intersect the GSO orbit, and dynamic time and geographical channel assignment. However, turning off the second ring of beams may also be required to provide sufficient isolations towards the GSO.

A number of methods for increasing the isolation from IRIDIUM mobiles into fixed services have been evaluated and include:

- Due to IRIDIUM's TDMA format, the satellite will only transmit 4.33% of the time, thus reducing the interference power by 13.6 dB.
- Antenna isolation will increase due to the diffraction of the beams over the earth's surface.
- IRIDIUM satellite will only remain in the mainlobe of a terrestrial antenna for a short period of time. Only one satellite will transmit towards a given point at a time.

Considering the above additional isolation and that fixed services have large margins, the percent of time interference from IRIDIUM satellites will occur is small and would not likely be a problem for fixed service receivers. However, geographic separation between the IRIDIUM mobile and the fixed service is required. In the other direction, interference from the fixed service into IRIDIUM satellites remains a problem.

Comments are also made on the prospect of using a -154 dBW/m^2/4kHz PFD limit for the IRIDIUM satellite. This limit cannot be met anywhere on the earth's surface. A peak PFD of -131 dBW/m^2/4kHz is required due to the low gain of the handheld terminals. The -154 dBW/m^2/4kHz would render the IRIDIUM system impractical.

The effect of interference avoidance techniques on the capacity of the IRIDIUM system is analysed and summarized in Table 2.4.

Interference Avoidance Technique	Effect on Capacity
Dynamic interference avoidance and detection	Less spectrum available for IRIDIUM to use. Cannot be reclaimed by adjacent satellite since same interference will occur.
Turning off outer beams of IRIDIUM satellite	Little effect on the capacity since there is sufficient overlapping coverage between adjacent satellites. However, this may not be possible if all outer beams have to be shut down. This would then result in gaps in coverage.
Dynamic time and geographical channel assignment	This technique will add complexity to the LEO system. It may not be applicable to the GSO MSS scenarios since there are several GSO MSS systems. If a frequency band is not used by one GSO system in a particular region then it will be used by another system.

Table 2.4: Effects of Interference Avoidance on IRIDIUM System

2.5 Document: JIWP/17, Mobile Satellite Services at L-Band, Inmarsat

This document demonstrates that sharing between MSS and other services in the L-band is in general feasible provided certain technical or operational measures are undertaken by the MSS and non-MSS systems. The analysis assumes that the MSS could be allocated on co-primary basis with other existing and planned services in the following bands:

MSS downlink	1450 - 1530 MHz
	1559 - 1564 MHz
MSS uplink	1610.0 - 1626.5 MHz
	1660.5 - 1670 MHz
	1670 - 1710 MHz
	1710 and above

This document suggests that any MSS allocation should be entirely or predominantly on a world-wide basis assuring consistency across all three ITU regions. Cases where sharing with other services is not possible might be resolved by allocating such services on a specific national or regional basis with co-primary status for the MSS.

The sharing analysis in this document provides the following results and conclusions with main beam antenna coupling, and co-coverage assumed.

MSS Downlink Band : 1429-1530 MHz

For interference from the fixed services (FS) into the MSS, an additional isolation of 160 dB to 200 dB, depending on the type of FS considered, is required. This results in minimum separation distances of between 35 km and 150 km. Interference to the FS earth stations from the MSS satellite would require an additional isolation of 3 dB to 20 dB for protection depending on the type of FS system. The following methods of protection would make sharing possible:

- percentage of time where an MSS mobile earth station(MES) would be susceptible to main beam coupling is expected to be very low.
- it may be expected that MSS MES would be sufficiently separated from the FS networks or shielding will be provided by natural or artificial obstacles.

- active power control to reduce high EIRP levels.
- dynamic channel and geographical channel assignment.
- percentage of time MSS MES receives interference from FS would be small since MES is most likely moving across the FS link.
- appropriate PFD limits could be developed for MSS downlink transmissions in the extended MSS allocations to protect the FS.
- implementation of spot beam MSS satellite systems will reduce the possibility of main beam coupling.

MSS Uplink Band : 1660.5-1670 MHz

Interference from the FS into the MSS is acceptable, however, interference from the MSS into the FS would require the following measures to permit sharing.

- Regulatory steps should be taken to ensure that FS transmit earth station antennas depoint from the GSO direction by 5°.
- main beam coupling may also be reduced by the use of spot beam MSS satellite systems.
- The duty cycle of MSS MES emissions is very low and therefore, the percentage of time of interference would be low.
- Use of frequency allocation by location techniques.

MSS Uplink Band : 1710 MHz & Above

The following measures would be required to allow sharing between MSS and MS (cellular) services:

- significant blockage would exist in the path between MSS MES and the MS MES.
- duty cycles for both services are small and so the percentage of time when both are active would be very low.
- maximum density of MESs located in the vicinity of MS coverage area will in general be very low.

- future use of narrow spot beam MSS satellite and lower EIRP levels will reduce interference into MS MSS receivers.

2.6 Document: CCIR Report - Technical and Operational Bases for the World Administrative Radio Conference 1992, Section 8.1.4.2.2

This document discusses the system characteristics for GSO/MSS systems and a number of other systems. The feasibility of sharing between GSO mobile satellite systems and systems in other services in the range of 1-3 GHz is analysed and some of the results are summarized in Table 2.5.

Service with which sharing is considered	Mobile satellite transmission direction	
	Earth-to-space	space-to-Earth
Fixed radio relay	Moderate	Moderate
Mobile	Moderate-Poor	Moderate-Poor
FSS	Moderate-Poor	Moderate-Poor

Table 2.5: Feasibility of sharing between GSO/MSS systems and other services in 1-3 GHz range

The sharing conditions in Table 2.5 are defined as follows:

Good — For diverse mobile satellite systems, sharing is possible between stations located in the same or nearby geographic area or geostationary orbit locations.

Moderate — Technical standards may be needed to enable sharing between stations located in nearby-to-distant geographic areas or orbit locations and the capacity for mobile satellite systems would likely be quite limited.

Poor — Sharing is impractical, i.e., little if any useful capacity would be obtained for mobile satellite systems even with large distance or orbital separations between stations.

Sharing considerations for feeder links and inter-satellite links are also addressed in this document. The problem areas in the MSS/FSS interference scenario for 6/4 GHz global systems are as follows:

- interference from space-to-Earth feeder links of MSS from the FSS.
- interference into FSS from Earth-to-space feeder links of MSS.

Sharing can be made possible by careful coordination measures and joint operating agreements. The following are typical measures used:

- adjustment of uplink power and downlink carrier EIRP.
- general frequency coordination, including appropriate carrier spacing and types of carriers that can be transmitted in certain parts of the band.
- consideration of relocation of one of the satellites by a small amount if possible.

Considering the predicted usage and the frequency re-use factors resulting from the use of spot beam spacecraft antennas, the estimated total spectrum requirement for the year 2010 is given in Table 2.6. A minimum requirement of 88.8 MHz and a likely requirement of 164.1 MHz in each direction is predicted.

Service	Minimum Requirement MHz	Likely Requirement MHz
AMS(R)S	14.5	17.5
Other AMSS	15.0	18.0
LMSS	41.3	87.6
MMSS	17.0	40.0
Distress and Safety	1.0	1.0

Table 2.6: Spectrum Requirements of the MSS in the 1-3 GHz band in each direction for the year 2010

It is proposed that new frequency allocations should be on a world-wide basis, be near existing allocations, provide equal up and downlink spectrum, and for LEO systems, if necessary, include some spectrum capable of bidirectional use.

2.7 Document: JIWP/.. , Mobile Satellite Services at Around 2.5/2.6 GHz, Inmarsat

This document analyses the S-band sharing scenarios for the MSS. The bands studied are:

MSS Space-to-Earth: 2500-2550 MHz
MSS Earth-to-Space: 2640-2690 MHz

The results of the sharing analysis for the FS are summarized in Table 2.7.

Service	MSS Downlink Sharing	MSS Uplink Sharing
FS	- feasible if scanning techniques are used for frequency allocation or frequency allocation by location are used - FS receive antennas depoint from the GSO by 5°	- feasible if FS transmit antennas depoint from the GSO by 5°

Table 2.7: Summary of Sharing possibilities for MSS around 2.5/2.6 GHz

2.8 Document: 8D/49-E (Canada), Draft New Report, Intersections of Radio Relay Antenna Beams with the Geostationary Orbit used by Space Stations in the Mobile Satellite Service, 10 December 1991

This document outlines the required orbit avoidance to ensure that the main lobe of a fixed station antenna would not intersect the geostationary orbit. Table 2.8 summarizes the results for frequencies in the range of 1-3 GHz.

Frequency Range (GHz)	D/λ	G_0 (dB)	G_1 (dB)	ψ_0 (Deg)	ψ_m (Deg)
1.6	16	32	20.0	4.7	4.5
2.0	20	34	21.5	3.5	3.5
2.6	26	36	23.0	2.8	2.9

Table 2.8: Required Orbit Avoidance for Various Frequencies

Where

- D = antenna diameter
- λ = wavelength
- G_0 = gain of main lobe
- G_1 = gain of first sidelobe
- ψ_0 = 3 dB beamwidth of the main lobe
- ψ_m = the point on the main lobe where the gain is equal to that of the first sidelobe

2.9 Document: 8D/48-E (Canada), Draft New Report, Sharing Between LEO MSS and GSO MSS Employing Spot Beams Around 1.6 GHz, 9 December 1991

This document looks at the interference from a LEO satellite system (IRIDIUM) into a GSO satellite (MSAT). The calculations show that the interference of the IRIDIUM MESs into a GSO MSS, on a timed averaged basis, would be excessive at the GSO satellite receiver.

Interference from the IRIDIUM satellites into a GSO satellite receiver would be excessive for the single entry, antipodal case. If the outer beams of the IRIDIUM satellite were shut off when they illuminated the GSO, interference from the IRIDIUM satellites probably would not be sufficient to exceed the GSO satellite's interference criterion.

Allowing high levels of interference, it has been shown that a GSO satellite would have difficulty sharing with and IRIDIUM MSS network without some type of coordination. In addition, some type of coordination would be required for IRIDIUM satellites to share with GSO MESs.

2.10 Document: Addendum 1 to Document JIWP92/17E, Mobile Satellite Services at L-Band - Proposed Report Elements, Inmarsat, 4 March 1991

This document proposes a number of changes to the CCIR JIWP Report. Table 2.9 summarizes the interference paths for the FS and MS where the MSS allocations are as follows:

space-to-earth 1450-1530 MHz & 1559-1564 MHz
earth-to-space 1610-1626.5 MHz & 1660.5-1750 MHz

Table 2.9 also includes the technical or operational measures which may be generally considered in promoting sharing of MSS with non-MSS services.

Other Service	Non-MSS Service Case	MSS Service Case
	MSS Uplink Band	
FS	MSS TXES -> FS RXES - short term interference - low geographical density of MSS MESs - MSS MES antenna discrimination - FABL in MSS uplink - Spot beam MSS satellites/ low EIRP MESs - site shielding of RXES - natural/artificial path shielding/blockage - spread spectrum mod. - high link margin in FS	FS TXES -> MSS RXSS - limited no. of interference situations - FS TXES antenna EIRP/ pointing restriction to GSO - spot beam MSS satellites
MS	MSS TXES -> MS MS RXES - short term interference - MSS MES antenna discrimination - disjoint service areas - FABL in MSS uplink - Spot beam MSS satellites/ low EIRP MESs - spread spectrum mod. - natural/artificial path shielding/blockage	MS TX BS -> MSS RXSS - single entry interference acceptable - MS BS TXES antenna discrimination to GSO - spot beam MSS satellites - spread spectrum mod.

	MSS Downlink Band	
FS	MSS TXSS -> FS RXES - limited no. of interference situations - FS antenna pointing restriction to GSO - narrow spot beam MSS sat. - PFD limits on MSS satellite EIRP - high link margin in FS	FS TXES -> MSS RXES - short term interference - spatial separation of services - use of FABL - use of MSS MES scanning systems - spot beam MSS satellites
MS	MSS TXSS -> MS MS RXES - interference marginal - MS BS RXES antenna discrimination to GSO - PFD limits on MSS satellite EIRP - narrow spot beam MSS sat. - disjoint service areas - spread spectrum mod.	MS TXES -> MSS RXES - interference marginal or excessive - separated service areas - short term interference - spatial separation of services - use of FABL - use of MSS MES scanning systems - spot beam MSS satellites - spread spectrum mod.

Table 2.9: Example L-Band Sharing Scenarios

2.11 Document: IWP-8/15-USA-6 (USA), Possibilities for Frequency Sharing Between Mobile Satellite Services using Geostationary Satellites and Other Services in the Approximate Range 1-3 GHz, 12 October 1990

This document discusses the sharing possibilities between a GSO mobile satellite system and other services.

Sharing between the MSS using narrowband channels and space services such as the FSS, BSS, METSAT, and Space Research services would require homogeneity of power density levels, large orbital separations, use of directional MSS earth station antennas, and may require interleaving of channels. MSS sharing with these services would require severe design and operating constraints on MSS systems using the 1-3 GHz band.

Sharing with Terrestrial Services may be summarized as follows:

Interference Interaction	Typical Method of Preventing Unacceptable Interference
	Mobile Satellite Downlink
From satellites to terrestrial stations	Limitation on satellite PFD produced on Earth surface at various arrival angles
From terrestrial stations to MESs	Coordination of frequency assignments for earth stations located in the coordination areas of terrestrial receivers
	Mobile Satellite Uplink
From MESs to terrestrial stations	Coordination of frequency assignments for earth stations located in the coordination areas of terrestrial receivers and power limits
From terrestrial stations to satellites	Limits on terrestrial transmitter power, EIRP, and antenna pointing

The results for sharing between the MSS and the Fixed Service (Radio Relay systems) indicate that uplink or downlink sharing is not possible in the same area, but is feasible in adjacent areas through application of coordination methods. These include EIRP limits, antenna pointing limits, and spot beam satellite antennas.

2.12 Document: IWP 8/15 CAN 1 IWP 9/6 CAN 7 (Canada), Sharing Between Fixed Networks and Geostationary Mobile Satellite Networks in Band 9, 8 November 1990

This document discusses the sharing possibilities between Canadian fixed radio relay systems for the 1.4, 1.8, and 2.1 GHz bands with the MSAT geostationary mobile satellite network. The results indicate that sharing is possible between mobile satellite networks and fixed networks, provided reasonable constraints are placed on both services. These constraints may include PFD limits, EIRP limits on the fixed station transmitters in the direction of the GSO, fixed network antenna depointing limits, and off-axis antenna discrimination.

Geographic or frequency separation would be required for the mobile earth stations to alleviate the interference situation. This would be feasible if multi-beam satellites are used with a small portion of the available spectrum in each beam.

2.13 Document: IWP 8/15 CAN 2.2 (Canada), Sharing Between FPLMTS Personal Stations and Mobile-Satellite, 2 November 1990

This document describes the results from sharing studies between FPLMTS and the proposed MSAT satellite system. Systems in the general frequency range between 1427 MHz and 2690 MHz were studied.

The results indicate that sharing between mobile satellite and FPLMTS personal stations may not be practical on the uplink due to cumulative effects of emissions from the FPLMTS terminals. On the downlink, the terrestrial component of the mobile satellite system would require geographic or frequency separation. The use of spot beam satellite antennas offers the possibility of reducing some terrestrial constraints to manageable proportions.

2.14 Document: WARC-92/96 (Canada), Sharing Between Mobile Satellite and Fixed and Mobile, 25 April 1991

The purpose of this document is to outline specific technical and operational measures and constraints which would facilitate sharing between the MSS and in particular, the fixed service.

This document proposes a number of changes to the CITEL Report. These amendments include satellite PFD limits of -154 dBW/m^2 at 0° to 5° and up to -144 and -136 dBW/m^2 at greater than 25° to 30° in a 4 kHz band. In addition, terrestrial stations may avoid use of satellite spectrum segment in the coverage area of a satellite antenna beam. Limits may also be placed on the terrestrial transmitter power, EIRP, and antenna pointing within 4° to 6° towards the GSO.

Annex 1 contains text cut from a number of other documents which have been reviewed in the previous sections. The techniques for improving sharing, in addition to the above techniques, are as follows:

- appropriate selection of modulation, error-correction, multiple access and channel allocation method in order to avoid interference.
- frequency assignment by location
- non-overlapping coverage areas
- orbital separation and geographical separation
- spot beam design for the satellites
- satellite and earth station discrimination
- earth station site shielding

2.15 Document: Report of IWP 8/14 to IWP 8/15, WARC-92 Preparation, September 1990

This document discusses the system characteristics for a number of mobile satellite services and sharing possibilities between them. The following techniques are proposed to improve sharing:

- reduction in spectrum occupancy by data compression and acceptance of more interference.
- use of real-time knowledge about other systems in a frequency band and institution of control mechanisms that adapt frequency use at particular instants in time.
- geographic differences in traffic loading.
- time-of-day differences in traffic loading.
- antenna off-axis performance
- use of orthogonal polarization
- channel interleaving
- geographical isolation

Sharing between the LMSS and other services in the 1-3 GHz band in the same service area may present major design constraints upon the proposed LMSS.

Significant possibilities for harmful interference exist between MSS and the fixed service. This may be alleviated by avoiding pointing the main lobe of fixed station antennas towards the GSO orbit.

2.16 Document: 8D/29-E (USA), Sharing Between Main Beam Downlink LEO and Uplink GSO Satellites in the 1-3 GHz Allocations, 21 November 1991

This study investigates the possibility of avoiding interference from the line-of-sight mainbeam coupling of downlink emissions from a LEO satellite with a receiving GSO satellite. The results show that interference can be avoided by shutting down LEO cells which would possibly illuminate the GSO.

2.17 Document: Report of IWP 8/13 to IWP 8/15, WARC 92 Preparation, 12 July 1990

This document discusses the system requirements and the services that will be offered by the FPLMTS. Sharing between the FPLMTS and other services is also discussed. The conclusions indicate that sharing between the FPLMTS and fixed services and possibly other services is possible, where suitable geographic separation between the services, or where neither service requires the total allocated bandwidth. In addition, adaptive channel assignment by the FPLMTS would increase the sharing possibility.

3. TASK 2 - RELEVANCY OF SHARING STUDIES - POST WARC-92

3.1 Document Commentary

This section determines the effect of the final acts of WARC-92 on the relevancy of the sharing study documents reviewed in Task 1 (Section 2). The documents are considered in the same order as they were presented in Task 1. A summary of new allocations made to MSS between 1-3 GHz at WARC-92 is presented in Appendix 1.

3.1.1 Document: A Study of the Magnitude of Potential Interference Between the Mobile Satellite Service and the Fixed and/or Mobile Services in the Bands 1427-1525 and 1700-2500 MHz, CAL Report 0596-10001, October 1990

This study examined interference between MSS and FS and MS. The Canadian MSAT system was assumed for the MSS system in the interference calculations.

The study apparently did not consider the effect to MSS earth station interference into Fixed service receivers. Similarly, the study did not consider the effect of MSS earth station interference into FPLMTS receivers. Interference from fixed services into the MSS uplink will produce unacceptable degradation unless the FS antennas are offset about 7 degrees or more. There were no new restrictions on FS stations imposed by WARC-92 in bands shared with MSS. The bands in which MSS was allocated on a co-primary basis with FS in Region 2 are:

1492-1525 MHz
2160-2200 MHz
2483.5-2500 MHz

Note that the U.S. put a footnote stating that in the U.S., the band 1492-1525 MHz is allocated to Fixed and Mobile services on a primary basis. The U.S. footnote should not affect the issue of MSS sharing with the Fixed and Mobile services in Canada.

Interference from the FPLMTS into the MSAT system was considered in the study. The interference on the MSAT uplink was reasonable, with a maximum of about 1 dB C/N degradation. However, the study assumed that MSAT uplink coverage would include only Canada and as the new MSAT design has beams covering both Canada and the U.S. simultaneously, the contribution to the interference from U.S. cities would likely make the total C/N degradation unacceptable.

MSS (space-to-Earth) was added to the band 2120-2160 MHz on a secondary basis in Region 2 sharing it with the Fixed and Mobile services which have a primary allocation. Therefore, the MSAT downlink is not permitted to cause harmful interference to the Fixed or Mobile services. Therefore sharing is not an issue as the fixed or mobile services do not have to protect the MSS service.

From the study interference from the MSAT downlink into FPLMTS terminals would cause a range reduction of 15% indoors or 24% outdoors. This appears to be harmful interference. The following band was allocated to MSS (space-to-Earth) and MS on a co-primary basis and have been designated by WARC-92 as being intended for FPLMTS implementation:

2160-2200 MHz

MSS (space-to-Earth) was added to the band 2483.5-2500 MHz on a primary basis in Region 2. Fixed and mobile services were allocated to this band previously on a co-primary basis. Other services having a primary allocation in this band are Radiodetermination satellite (space-to-Earth) and Radiolocation. The use of this band by the mobile satellite service is subject to the coordination and notification procedures of COM5/8. For MSS, this downlink band is paired with the 1610-1626.5 MHz uplink band. Due to the severe restriction placed on mobile earth terminals by footnote 731X, it is likely that geostationary MSS systems will not use this band, so that sharing may not be an issue as long as the restriction remains.

3.1.2 Document: A Study of the Feasibility of Mobile Satellite Services Sharing Spectrum with the Terrestrial Fixed Service, CAL Report 0646-10002, June 1991

Although this document does not explicitly define the frequency bands that it is addressing, it seems to be concerned with the same frequency bands addressed by the report of Section 3.1.1. Therefore, the comments made in Section 3.1.1 concerning the new allocations in WARC-92 also apply to this document.

This study also addressed the interference condition from FS stations into MSAT earth stations and from MSAT earth stations into terrestrial stations.

This study used the parameters of the Canadian MSAT system in its interference calculations. It calculated technical constraints on the systems that are sharing the band to facilitate sharing.

For MSS sharing with the FS service in the MSS downlink direction, satellite pfd restrictions were calculated. There were no such restrictions imposed by WARC-92 in the bands considered by this report.

For MSS sharing with the FS service in the MSS uplink direction, restrictions on the FS earth station antenna size and offset angle from the GSO were calculated to give specified C/N degradations. At WARC-92, there were no such limits placed on terrestrial systems.

The study also examined interference from MSAT mobile terminals into fixed stations. The study calculated the minimum separation between a fixed station and a MSAT mobile to achieve the desired interference protection. It assumed that the MSAT mobile would be inhibited from transmitting if inside this area. WARC-92 did not contain any limitations on the MSS mobile terminals or requirements that the systems implement a mobile terminal inhibit capability.

3.1.3 Document: Feasibility Study of Spectrum Sharing between LEO/MSS and GSO/MSS and Fixed Services and FPLMTS, Telesat Canada, 25 April 1991

The only MSS spectrum allocated at WARC-92 that could be used for the Iridium system, (i.e. bidirectional allocation) was the band 1613.8-1626.5 MHz in which the Earth-to-space allocation is primary and the space-to-Earth allocation is secondary. Footnote 731X states that the use of this band by the MSS in the E-S direction is subject to the coordination and notification procedures of Resolution COM 5/8. A mobile earth terminal cannot produce an EIRP density in excess of -15 dBW/4 kHz in the part of the band used by systems operating in accordance with Footnote 732 (i.e. Glonass). In other parts of the band, the power density limit on the mobile terminal is -3 dBW/4 kHz. Stations of the MSS shall not cause harmful interference to or claim protection from stations in the aeronautical radionavigation service, stations operating under Footnote 732.

3.1.4 Document: DOC's LEO Spectrum Sharing Study, Phase 2, Telesat Canada, 21 January 1992

Parts of this document deals with LEO systems below 1 GHz which is not relevant to this study.

Some CCIR documents on LEOs below 3 GHz are studied. One paper deals with means that the Iridium system (1.6 GHz) could use to share the band. It looks at the Iridium system capability to scan its frequency band to determine which frequencies are unused. It also comments that the Iridium systems could turn off its outer satellite beams to avoid main beam coupling interference into GSO MSS satellites. This strategy is unaffected by the outcome of WARC-92.

There were no constraints placed on LEO MSS systems to implement such schemes. However, MSS space-to-earth service has been allocated on a secondary basis in the band allocated to the MSS Earth-to-space on a primary basis. Therefore, the Iridium system would not be permitted to cause harmful interference to any MSS service using this band in the Earth-to-space direction.

Another paper looks at the resulting C/I values between geostationary MSS systems (Inmarsat) and non-geostationary MSS systems (Iridium). Excessive interference is predicted into Inmarsat satellites and into the Inmarsat mobile terminals. No specific interference relief techniques are specified except to say the Inmarsat mobile terminals must be separated at least 100 km from Iridium mobiles. Inmarsat aeronautical mobile terminals need to be separated by at least 300 km. The band allocated by WARC-92 to bidirectional MSS use has a restriction on the mobile earth terminals radiated power that is so severe that Inmarsat might not use this band. Therefore, sharing may not be an issue.

This study also examined interference from the Iridium system into Fixed services. However, the band allocated for bidirectional mobile satellite service for the Iridium system at WARC-92 is not allocated to the fixed service.

3.1.5 Document: JIWP/17, Mobile Satellite Services at L-Band, Inmarsat

This document only considers geostationary MSS systems.

The analysis assumed in this report assumes sharing on a co-Primary basis between MSS and other services in the bands:

MSS downlink	1450-1530 MHz
	1559-1564 MHz
MSS uplink	1610.0-1626.6 MHz
	1660.5-1670 MHz
	1670-1710 MHz

1710 MHz and above.

The outcome of WARC-92 is that MSS was allocated on a co-primary basis with Fixed and Mobile services in Region 2 in the band 1492-1525 MHz. There was no MSS allocation in the frequency band 1559-1564 MHz. There was a world-wide allocation to MSS in the frequency band 1610-1626.5 MHz on a co-primary basis with other services already assigned to this band. There was no allocation in the frequency band 1660.5-1675 MHz. There was an allocation to MSS in the frequency band 1675-1710 MHz on a co-primary basis with the existing services in this band.

This document evaluated the interference scenarios between MSS and other services already allocated to these bands. For the most part, WARC-92 did not place restrictions on the MSS for most bands. For example for downlink MSS in the 1492-1525 MHz there are no pfd limits.

For the MSS uplink band 1610-1626.5, the document does not suggest any power limitations on the mobile terminal, but at WARC-92, METs operating in this band were limited to radiating EIRP densities of -3 dBW/4 kHz or less and in parts of the band used by systems operating in accordance with Footnote 732 (Glonass), the METs were limited to -15 dBW/4 kHz. Both of these limits may prevent Inmarsat or MSAT use of the band.

The document also looks at sharing between the MSS and the mobile cellular service. There have been allocations made at WARC to MSS above 1710 MHz in bands shared with mobile services. Most of these bands have been designated at WARC-92 for implementation of the FPLMTS.

There was no MSS allocation in the band 1710-1930 MHz.

In the band 1930-1970 MHz, MSS is allocated on a secondary basis. The fixed and mobile services are co-primary. It is not likely that

MSS would use this band as they would not be protected from interference.

MSS has a primary allocation along with the fixed and mobile services in the band 1970-2010 MHz.

MSS has a secondary allocation in the band 2120-2160 MHz. The fixed and mobile services have primary allocations. Again, MSS is not likely to be implemented in this band.

MSS has a co-primary allocation along with the fixed and mobile services in the band 2160-2200 MHz.

The recommendations made by this document between MSS and mobile services all involve operational strategies. WARC-92 did not impose any such strategies in any bands allocated to MSS.

3.1.6 Document: CCIR Report - Technical and Operational Bases for the World Administrative Radio Conference 1992, Section 8.1.4.2.2

This document presented sharing possibilities between GSO/MSS systems and other services and ranked them as from moderate to poor. The document does not discuss sharing techniques between MSS and MS or FS. The results of WARC-92 should not affect the results of this study.

3.1.7 Document: JIWP/.. , Mobile Satellite Services at Around 2.5/2.6 GHz, Inmarsat

This document analyses the S-band sharing scenarios for the MSS. The bands studied are:

MSS Space-to-Earth: 2500-2550 MHz
MSS Earth-to-Space: 2640-2690 MHz

WARC-92 allocated MSS to the band 2500-2520 MHz on a co-primary basis in the space-to-Earth direction. MSS was also allocated to the band 2670-2690 MHz on a co-primary basis in the Earth-to-space direction.

The document suggests that the band 2500-2520 MHz could be shared between MSS and FS if the FS antennas are kept at least 5 degrees away from the GSO. There was no such restriction placed on FS stations at WARC-92. Other techniques suggested for sharing include keeping the METs out of the coordination range of the FS stations by using frequency scanning for free channels or assigning channels to METs based on knowledge of the FS station locations. These techniques were not imposed by WARC-92.

The document suggests that the band 2670-2690 MHz could be shared between MSS and FS if the FS antennas are kept at least 5 degrees away from the GSO. Again, this type of limitation was not imposed by WARC-92.

3.1.8 Document: 8D/49-E (Canada), Draft New Report, Intersections of Radio Relay Antenna Beams with the Geostationary Orbit used by Space Stations in the Mobile Satellite Service, 10 December 1991

This document calculates the antenna GSO off-axis angle for an FS station. It does not calculate any interference values or make reference to sharing techniques. The results of WARC-92 would not change anything in this document.

3.1.9 Document: 8D/48-E (Canada), Draft New Report, Sharing Between LEO MSS and GSO MSS Employing Spot Beams Around 1.6 GHz, 9 December 1991

This document looks at the interference from a LEO satellite system (Iridium) into a GSO satellite (MSAT).

The results of WARC-92 assigned only one band bidirectionally which could be used by the Iridium system. This band contains a mobile terminal EIRP density limit which effectively precludes the MSAT system from using this band. Therefore, the results of this document have been made effectively irrelevant by WARC-92.

3.1.10 Document: Addendum 1 to Document JIWP92/17-E, Mobile Satellite Services at L-Band - Proposed Report Elements, Inmarsat, 4 March 1991

This document presents Inmarsat views concerning L-band mobile satellite allocations. In the document Inmarsat called for world-wide allocations for MSS to facilitate interoperability between MSS and AMSS. For the most part, allocations made to this band at WARC-92 were world-wide and generic (MSS rather than MMSS or LMSS or AMSS). Exceptions are:
1492-1525 MHz allocation to MSS in Region 2 only, other regions have no mobile satellite allocations of any kind.
1525-1530 MHz and 1626.5-1631.5 MHz allocation to MSS in Region 2 and 3, in Region 1 allocated to MMSS primary and LMSS secondary.
1675-1710 MHz allocated to MSS in Region 2 only.
1930-1970 MHz and 2120-2160 MHz allocated to MSS secondary in Region 2 only.
1970-1980 MHz and 2160-2170 MHz allocated to MSS in Region 2 only.

Another comment made in this document was that MSS allocations could be made co-primary on a national or regional basis. At WARC-92 only one band had a footnote added stating that the band was limited to operation within national boundaries: 2655-2670 MHz (until January 1 2005, the band 2655-2690 MHz).

This paper also presents table of results showing additional isolation required between MSS and various other services to allow sharing. Another table presents technical constraints and operating procedures which could be used to facilitate sharing. For the most part, WARC-92 did not impose technical restrictions on services or impose operational procedures which had to be followed. Exceptions are the band in which GLONASS will operate which has mobile terminal EIRP density limits.

3.1.11 Document: IWP-8/15-USA-6 (USA), Possibilities for Frequency Sharing Between Mobile Satellite Services using Geostationary Satellites and Other Services in the Approximate Range 1-3 GHz, 12 October 1990

This document discusses the sharing possibilities between a GSO mobile satellite system and other services.

This document presents a table of separation distances required between fixed stations and mobile earth terminals. The results of WARC-92 would not change this.

The report also calculated EIRP density limits which would have to be placed on fixed transmitting stations to limit interference into MMSS telephone channels. WARC-92 did not place such constraints on fixed services. The documents also discusses off-axis angles for fixed transmitting stations to avoid interference into MSS satellites. WARC-92 did not place any limitations on fixed stations.

This document commented on sharing between AMSS and aeronautical mobile services and concludes that it would be impractical to share the band. Nothing in WARC-92 would likely change this result.

3.1.12 Document: IWP 8/15 CAN 1 IWP 9/6 CAN 7 (Canada), Sharing Between Fixed Networks and Geostationary Mobile Satellite Networks in Band 9, 8 November 1990

This document discusses the sharing possibilities between Canadian fixed radio relay systems for the 1.4, 1.8, and 2.1 GHz bands with the MSAT geostationary mobile satellite network. The results indicate that sharing is possible between mobile satellite networks and fixed networks, provided reasonable constraints are placed on both services. These constraints may include pfd limits, EIRP limits on the fixed station transmitters in the direction of the GSO, fixed network antenna depointing limits, and off-axis antenna discrimination.

WARC-92 did not place any new constraints on fixed services or mobile satellite services in the bands in which they were allocated on a co-primary basis.

3.1.13 Document: IWP 8/15 CAN 2.2 (Canada), Sharing Between FPLMTS Personal Stations and Mobile-Satellite, 2 November 1990

This document describes the results from sharing studies between FPLMTS and the proposed MSAT satellite system. Systems in the general frequency range between 1427 MHz and 2690 MHz were studied.

The results indicate that sharing between mobile satellite and FPLMTS personal stations may not be practical on the uplink due to cumulative effects of emissions from the FPLMTS terminals. On the downlink, the terrestrial component of the mobile satellite system would require geographic or frequency separation. There were no restrictions placed on either of these two services by WARC-92 to improve shareability.

3.1.14 Document: WARC-92/96 (Canada), Sharing Between Mobile Satellite and Fixed and Mobile, 25 April 1991

The purpose of this document is to outline specific technical and operational measures and constraints which would facilitate sharing between the MSS and in particular, the fixed service.

The document proposes technical constraints to facilitate sharing between MSS and FS including satellite pfd limits and fixed transmitting station EIRP limits and off-axis angles to the GSO. WARC-92 did not put any of these constraints in any of the bands shared by FS and MSS.

3.1.15 Document: Report of IWP 8/14 to IWP 8/15, WARC-92 Preparation, September 1990

This document discusses the system characteristics for a number of mobile satellite services and sharing possibilities with other services. Sharing mechanisms mentioned are the usual geographical separation between mobile terminals and fixed stations and off-axis pointing of the fixed station antennas from the GSO. There is nothing in the results of WARC-92 which would change the results of this document.

3.1.16 Document: 8D/29-E (USA), Sharing Between Main Beam Downlink LEO and Uplink GSO Satellites in the 1-3 GHz Allocations, 21 November 1991

This study investigates the possibility of avoiding interference from the line-of-sight mainbeam coupling of downlink emissions from a LEO satellite with a receiving GSO satellite. The results show that interference can be avoided by shutting down LEO cells which would possibly illuminate the GSO.

The results of WARC-92 assigned only one band bidirectionally which could be used by the Iridium system. This band contains a mobile terminal EIRP density limit which effectively precludes MSAT from using this band. Therefore, the results of this document have been effectively made irrelevant by WARC-92.

3.1.17 Document: Report of IWP 8/13 to IWP 8/15, WARC 92 Preparation, 12 July 1990

This document discusses the system requirements and the services that will be offered by FPLMTS. Sharing between the FPLMTS and other services is also discussed. The document provides parameters for FPLMTS to be used in sharing studies. It discusses in a qualitative manner the possibility that FPLMTS base stations could be provided with information about local conditions to facilitate sharing. This document does not give any specific information concerning sharing between MSS and FPLMTS. There is nothing in the results of WARC-92 that would change the results presented by this document.

3.1.18 Summary

The papers in this section examined how mobile satellite service could share with other services if they were allocated to the same band. The recommendations of the various papers are quite similar. Mobile satellite earth terminals need to maintain a minimum distance from fixed earth stations for co-frequency operation. Also, transmitting fixed stations need a minimum off-axis angle from the GSO to facilitate sharing. WARC-92 did not include any new operational limits on fixed earth stations or mobile satellite earth terminals. The current restrictions of Article 27 still apply to transmitting fixed or mobile stations, of course, but if more restrictive limitations are to be placed on fixed earth stations, they would have to be imposed by administrations on a national basis. For MSS use in Canada, both the DOC and FCC would have to incorporate these restrictions if it was desired to improve the co-frequency shareability of the band as MSAT coverage will include the U.S. as well as Canada.

Sharing between MSS and MS, particularly FPLMTS does not seem feasible on a co-frequency basis as cumulative interference from hundreds of FPLMTS base stations in urban areas would likely cause excessive interference into the MSS uplink.

Sharing between bidirectional MSS systems such as the Iridium system and geostationary MSS systems such as MSAT or Inmarsat does not appear to be an issue as the band allocated for bidirectional MSS use has such a severe mobile terminal power limit that the band would probably not be used by the MSAT system or Inmarsat in the near future.

3.2 Technology Progress

This section presents Telesat's views on how mobile satellite technology may progress in the future. This discussion is mainly limited to factors which have the potential of affecting the spectrum requirements of the system. The view presented here will be oriented towards the Canadian situation. Both geostationary mobile satellite systems and non-geostationary mobile satellite systems will be considered. The Canadian MSAT system will be assumed to be the sole geostationary mobile satellite service operator in Canada as this is expected to be the situation for the foreseeable future. For non-geostationary mobile satellite systems we will assume that the Iridium system will be implemented. Although there have been other non-geostationary satellite systems proposed using the same frequency band as the Iridium system, it is probably the most advanced from a planning, technical, and financial standpoint.

The next two sections will discuss advances in spacecraft and earth segment technology.

3.2.1 Spacecraft

The advancement of spacecraft technology may have an effect on Canada's requirements in the future for MSS spectrum. Changes in spacecraft technology can result in more users being supported per unit of bandwidth. Additionally, improved spacecraft technology could also improve the attractiveness of the mobile earth terminals allowing them to be smaller and less expensive and this may increase user demand. Another factor which could result in increased user demand is a reduction in the user service charges due to changes in the spacecraft technology.

The second generation MSAT system might not use a geostationary satellite. The MSAT system operator may choose to use a low-earth orbit constellation or some other non-geostationary concept to provide service in the next generation. It is also possible that the success of other proposed mobile satellite systems may be such that the MSAT system would no longer be economically viable. However, for the purposes of this study, it is assumed that there will be a second generation MSAT system and that it will use one or more geostationary satellites.

It is expected that the goals of the second generation system will be to increase the system capacity, lower the unit cost to the subscribers, allow for the introduction of new services, and improve technical performance such as increased satellite EIRP and satellite G/T. These goals could be achieved in at least three ways: A larger satellite (more power available) could make use of more bandwidth. A larger antenna and/or more complicated beam network could be implemented which would provide smaller satellite beams. On-board processing equipment would improve the link performance of the communication systems. In addition, more advanced modulation techniques could be used which would allow more users per unit of bandwidth.

To take advantage of reduced signal bandwidth, narrower channels in the satellite transponders would be needed. For MSAT, the current system design uses 6 kHz channels. It may be possible to reduce this value in the second generation system, but narrower channels will require higher performance components such as more stable oscillators both on the satellite and in the subscriber terminals.

The decision to incorporate a new technology into a spacecraft is based mainly on its cost effectiveness. Also, as satellite operators have a large investment in their space segment, the equipment used must also be highly reliable. Many operators therefore prefer to use technology that has already been successfully employed on other programs.

More advanced technology may be introduced eventually, such as on-board processing. The use of on-board processing would increase the number of users that the satellite could support as the downlink noise would be de-coupled from the uplink noise. On-board processing would also give the system increased interconnect flexibility in assigning channels to spot beams. This is expected to be of importance as the MSAT system uses a greater number of smaller beams. It is possible that on-board processing would be used in the second generation MSAT system.

For non-geostationary, low-earth-orbiting satellite systems with a large number of satellites (for example, Iridium), the introduction of a completely new and different generation of satellites might pose a problem. Launching the entire second generation constellation near the end of the service life of the first generation is probably impractical as this would require much of the satellite control hardware to be doubled in addition to potentially wasting satellite resources. It is more likely that the second generation would be implemented by replacing each retiring first generation satellite with a second generation one. However, it may not be practical to do the replacement one satellite or several satellites at a time. As the system control software would be based on a certain satellite characteristic, changing the characteristics of only a few of the satellites would likely cause algorithm problems. However, as most non-geostationary low-earth-orbiting satellite systems have a constellation consisting of several planes of satellites, introduction of the second generation system might be done more easily by replacing an entire plane of satellites at a time. This might simplify the changes to the control algorithms if each plane were handled separately. However, replacement of a plane of satellites at a time would require that the coverage of the plane would remain the same so that gaps in coverage would not occur.

Capacity could be increased from one generation to the next by increasing the number of beams per satellite, increasing the power per satellite or increasing the number of satellites in each plane of the constellation. Changes to the beam patterns of the satellites or to the number of satellites per plane would cause complications to the control software. Increasing the size of the satellites, i.e. more power per satellite while keeping other characteristics the same should not significantly change the control software.

3.2.2 Earth Segment

Changes in earth segment technology can also affect the requirement for MSS spectrum. In addition to improvements in power or bandwidth efficiency, improvements to the earth segment such as smaller size and improved features could serve to increase user demand for MSS.

Improvements in vocoder technology will continue to be made which will allow toll-quality speech to be offered using lower data rates. This will result in improved spectrum efficiency. However, it is not expected that acceptable speech quality would be developed from vocoders operating below 2400 bps by the time of the second generation MSAT system.

Improvements are likely to be made to modulation and coding used by the mobile earth terminals. Although there would likely be a penalty in power to be paid by going to higher modulation schemes, integrated modulation and coding techniques such as trellis modulation may be introduced requiring higher levels of terminal complexity.

Future trends in mobile communications are expected to continue the move towards smaller, more portable terminals. Mobile satellite terminals will probably also follow this trend, but it is unlikely that the first generation geostationary MSS will offer handheld terminals for anything except low data rate communications as the power that the handheld terminals could generate would be too small. Supporting these types of terminals in a satellite environment would require so much power that the service would likely be quite expensive.

Improvements in network control technology are likely to occur over the first generation of mobile satellite systems. As GPS equipment becomes more widely used, the addition of position location ability to MSS terminals is likely to become so inexpensive that virtually all mobile terminals will have this feature. With position location ability it will be feasible to implement band sharing schemes such as those requiring mobile earth terminals to stay out of the coordination area of a fixed station. Modifications to the network control software will make this type of scheme feasible.

3.2.3 Future Mobile Satellite Services

The goal of the MSAT system is to offer voice and data communications to most of the locations in Canada and the U.S. where cellular service is not available. The Iridium system will be able to offer voice and data services to all parts of the world.

It is expected that in second generation mobile satellite systems, the main service offering will remain to be basic voice and/or fairly low-rate data. This is likely to be true for the MSAT system or Iridium system.

Advanced services such as medium rate data and compressed video may be offered in a limited manner on future MSS systems. As these services require more bandwidth than basic voice service, they would be more expensive.

ISDN-type services at 64 kbps are possible in future mobile satellite generations, however, this type of service would likely not be offered as a basic service, as it would require too much bandwidth and would limit the number of users.

Other applications include multimedia applications in which voice, text, graphics, music, etc. are offered in a single service. This may be a minor service offering on the MSAT system in the future, but due to the bandwidth required, it is likely to be quite expensive.

There appears to be increasing demand today for personal communications, i.e. communications capability with handheld terminals. The initial development of this has been the cellular phone and the cordless telephone. In the future, the concept will be carried further with the introduction of the FPLMTS systems. Personal communications services may also be offered in the future using satellite SHF systems.

The Iridium service was designed from the outset to offer service to handheld terminals. Although the MSAT system and some of the proposed non-geostationary MSS systems are not intended to strictly offer personal communications service (as opposed to simple basic voice and data service to mobile users), the recent fast growth in the personal communication field will likely eventually entice them to offer services that meet the demand (i.e. handheld terminals).

The MSAT system, however, will not be able to offer voice service to such terminals in the first generation system, only low-rate data. If the MSAT operator were to offer hand-held voice service in future generations, the system would have to compensate for the loss in antenna gain of the mobile terminal. In addition, as handheld terminals would be held near the subscriber's head, less power would be radiated for safety reasons. The loss in system gain could be compensated for by increasing the gain of the satellite antenna, using on-board processing, and reducing the satellite noise temperature.

However, there is an alternative method that could be used on the MSAT first generation system to offer service to handheld terminals without changing the MSAT space segment. If FPLMTS base stations are used together with mobile satellite earth terminals, subscribers could use a FPLMTS handheld terminal which transmits to a nearby base station which would be connected to the satellite terminal which would then transmit to the satellite. This would be particularly useful for operation at remote sites. It is expected that some service of this type will be offered on the first generation MSAT system.

3.3 Implementation Time Frames

The first generation MSAT satellite is expected to be launched in mid 1994. The satellite life will probably be 12-14 years. Depending on how well the satellite ages, the second generation MSAT satellite will likely be planned to be launched 10-12 years after the first satellite. This assumes that there is not a faster build-up of the MSAT market than can be handled by the first generation satellite, requiring the launch of a second first generation satellite to supplement the capacity of the first satellite. Note that the Canadian and U.S. MSAT operators are working closely together, so that there will be the opportunity for each to lease satellite capacity from the other operator. However, it is expected that the Canadian MSAT operator is more likely to lease capacity to the U.S. operator as the U.S. has more potential MSS customers.

It is unlikely that significant Canadian MSS traffic would be carried by Inmarsat as they do not have a licence to offer LMSS in Canada or the U.S. However, Canadian MSS traffic may be carried by the Iridium system if it gets a licence from the DOC.

It is possible that the proposed non-geostationary mobile satellite systems may not be implemented in the proposed time frames. Technology development is an issue that could delay implementation. For example, the non-geostationary mobile satellite systems that plan to use a constellation of many satellites require technology development as well as improvements in the speed with which satellites are built, tested, and launched. Also, the software to control a large constellation of satellites with multiple beams per satellite is a very challenging task. As well as technology problems, large complicated non-geostationary satellite systems are expensive and may face financing problems. In addition to these concerns, licensing and regulatory problems for a world-wide system are likely to occur as approval would be needed from the government of each country in which it will offer service.

3.4 Canadian Spectrum Requirement

This section will discuss Canada's future needs for MSS spectrum. The spectrum assigned to MSS in Region 2 could be used by the MSAT system, Inmarsat, the Iridium system, or any other geostationary or non-geostationary mobile satellite system to provide MSS to Canada. Note that the Iridium system can only use spectrum that has an allotment in both the space-to-Earth direction and Earth-to-space direction under the proposed system design. Of course, any MSS system offering service in Canada would require a licence from DOC.

Part of the demand for mobile satellite services may be fulfilled by systems operating below 1 GHz such as the proposed Orbcomm system. However, as the type of service that it is proposing features low rate data and very low cost terminals, it is expected that the impact of a system like this on the need for L-band spectrum will be small.

The need for spectrum to satisfy Canadian needs will be affected by at least three factors. The first factor is the number of Canadians choosing to use mobile satellite services. The second is the introduction of advanced services requiring more spectrum than basic voice or low-rate data. Although it is possible that the MSAT system would use more advanced modulation techniques allowing transmission of more bits per second in a given bandwidth, these techniques usually require more power and the system may not be able to afford it, especially if service to handheld terminals is desired. Another factor affecting spectrum utilization is the satellite frequency reuse factor which may change from generation to generation and will be different for each mobile satellite system.

Appendix 2 presents a list of the current MSS allocations between 1 GHz and 3 GHz.

3.4.1 Forecast

The following estimate of Canadian MSS spectrum requirements is taken from Reference 1.

By the year 2000, the number of MSAT subscribers is estimated to be 300,000-450,000.

The current forecast is that 40% of the subscribers will use voice services and that 60% of the subscribers will use data services.

This corresponds to 120,000-180,000 subscribers using voice services and 180,000-270,000 subscribers using data services.

It is expected that demand for FPLMTS terminals will be 3,000,000-6,000,000 by 2010. Satellite technology using an MSS band is expected to capture 10% of this market, which means that 300,000-600,000 terminals will use the MSAT system by 2010.

The total Canadian requirement for MSS spectrum in the year 2000 is estimated to be 23 MHz-33 MHz. Assuming a frequency reuse factor of 1.33 on the satellite, the spectrum requirement is then 17 MHz-25 MHz.

For FPLMTS using the MSAT system, the spectrum required is 30 MHz-60 MHz in the year 2010. Assuming a frequency reuse factor of 2.0 (second generation satellite), the spectrum requirement becomes 15 MHz-30 MHz.

3.5 Sharing Strategies Post WARC-92

This section will examine the sharing strategies between MSS, FS, and MS that are relevant with the new allocations of WARC-92.

MSS, FS, and MS were allocated on a co-primary basis in the following bands:

1492-1525 MHz	only in Region 2
1675-1690 MHz	only in Region 2
1700-1710 MHz	only in Region 2
1970-1980 MHz	only in Region 2
1980-2010 MHz	world-wide
2160-2170 MHz	only in Region 2
2170-2200 MHz	world-wide
2483.5-2520 MHz	world-wide
2670-2690 MHz	world-wide

The above bands are allocated to MSS, MS, and FS on a co-primary basis. However, there may be other co-primary services in the above bands.

The Canadian implications of an MSS, FS, MS co-primary allocation only in Region 2 are that if MSS has not been allocated in Region 1 and Region 3 as well, then Inmarsat might not implement any MSS service in that band as they have a world-wide mandate and tend to make their satellites common in a given generation. This would then simplify sharing somewhat for FS and MS.

Sharing between MSS, FS, and MS will not been considered for bands in which MSS is secondary or FS and MS is secondary as the secondary allocation is not entitled to protection from interference.

Of the above shared bands the following bands have been designated by WARC-92 as intended for the FPLMTS:

1970-2010 MHz
2160-2200 MHz

The frequency bands of the first generation MSAT satellite are effectively fixed now. Therefore the new MSS allocations at WARC-92 cannot be used by the MSAT system before the second generation system.

The amount of new spectrum allocated for MSS service at WARC-92 that could be used to provide mobile satellite service would depend on the existing use of this band and power levels radiated towards GSO. However, some bands such as those used by FPLMTS may not be shareable on a co-frequency basis and would require dividing the spectrum between the two services. Since FPLMTS seems to be advancing quickly towards the implementation stage and given that the MSAT system could not use this band before its second generation, it is likely that FPLMTS could take most of the band. This would depend partly on the success of the FPLMTS.

Most of the sharing studies examined previously concluded that FS and MSS could share the band provided that FS antennas were pointed off the GSO by some minimum angle. Therefore, some restrictions on FS transmit power towards the GSO is likely to be needed if the band is to be shared on a co-frequency basis.

The sharing studies also concluded that sharing with the FPLMTS were not be possible on the uplink due to the cumulative effect of urban areas. Therefore, it is likely that sharing between MSS and FPLMTS would be possible only by assigning dedicated bands to each of them.

4. TASK 3 - SHARING BETWEEN THE MSS AND FIXED AND MOBILE SERVICE AT 2 GHz

4.1. Interference between Mobile Satellite Service (MSS) and Fixed Service (FS)

Interference between MSS systems and the fixed service will be studied for two different types of MSS systems; IRIDIUM, a Low Earth Orbit (LEO) satellite based system, and MSAT, a Geosynchronous Orbit (GSO) satellite based system. Interference will be analysed in both directions, from the MSS systems into the terrestrial system and from the terrestrial system into the MSS systems. The interference analysis calculations will be based on a frequency of 2 GHz and are shown in Sections 4.1.1 and 4.1.2. A discussion of the results is provided in Section 4.1.3.

4.1.1 Interference from MSS into FS

4.1.1.1 Acceptable Interference Levels into the FS

Interference levels from both IRIDIUM and MSAT MSS systems into the terrestrial fixed service are considered in this section. Acceptable interference levels for the terrestrial system are based on a Radio-Relay Committee proposal, "Interference Objectives & Coordination Criteria 3700-4200 MHz/5925-6425 MHz Between the FSS and FS using Digital Modulation", July 1992. There are no current interference objectives set for the 2 GHz band and so the assumptions used for C-band will be adopted in the following analysis. Terrestrial station parameters are obtained from the Standard Radio System Plan, SRSP 301.9 Issue 2.

A hypothetical reference circuit of 6500 km is assumed which consists of 24 sections with 144 hops, and each section is composed of 6 hops. The two-way availability is set at 99.98% which translates to a 0.02% unavailability. The unavailability or outage time is divided evenly between propagation and equipment loss, or 0.01% for each. The total 1-way propagation outage allowance is therefore:

Total Propagation Outage Allowance(1-way) = 1576 seconds/year
The Propagation Outage Allowance per hop = 10.96 seconds/year

The interference objectives state that earth station interference shall be limited to:
a) 10% of the one-way HRC propagation outage time, or 157.6 seconds, and
b) 30% of the HRC interference allowance in any section, or 47.3 seconds.

For IRIDIUM, the number of satellites and beams which will be visible to a given section may exceed one, but only one cell will be active over a particular section at a time. Interference into a section will therefore only be from one IRIDIUM beam at a time.

The frequency re-use pattern assumed for the terrestrial system is such that the same frequency is used by every second terrestrial station. A maximum of four out of seven terrestrial stations could then use the same frequency in a given section. The amount of allowable outage seconds for both objectives (a) and (b) can then be reduced by a factor of 4 to obtain a per hop allowable outage. Objective (a), which covers the entire one-way link, could also be further reduced by a factor of 5 due to the five times frequency re-use pattern used by the IRIDIUM beams. The allowable outages would then be 7.88 seconds and 11.83 seconds for objectives (a) and (b) respectively. A worst case analysis will be performed and so the 7.88 seconds allowable outage for interference from objective (a) will be used in the following calculations. The terrestrial station interference to thermal noise ratio can then be calculated as follows:

For partial transponder (multiple carrier narrowband operation) interference,

$$I/N = 10 \times \log\left(\sqrt{\frac{10.96 + 7.88}{10.96}} - 1\right) + 10\log\left(\frac{\text{Partial Transponder BW}}{\text{Usable Transponder BW}}\right)$$

or

$$I/N = -10 \text{ dB, whichever is greater}$$

For IRIDIUM, using a partial transponder bandwidth of 41.67 KHz and a usable bandwidth of 30 MHz, the calculated I/N = -33.64 dB. The I/N that will be used is I/N = -10 dB since it is the larger value. The I/N = -10 dB represents a lower limit of 2 seconds of outage.

For interference from the MSAT satellite, the same allowable outages are assumed for objectives (a) and (b). Both outages may again be reduced by a factor of 4 due to the frequency re-use pattern of the terrestrial system. The frequency re-use for the MSAT satellite is assumed to be two times and so the allowable outage for objective (a) may be further reduced by a factor of 2. The allowable outages/hop would then be 19.7 seconds and 11.83 seconds for objectives (a) and (b) respectively. Assuming a worst case analysis, 11.83 seconds of allowable outage from objective (b) is used to calculate the I/N ratio. The partial transponder I/N, with a partial transponder bandwidth of 7 KHz and a usable transponder bandwidth of 30 MHz, can be calculated as follows:

$$I/N = 10 \times \log\left(\sqrt{\frac{10.96 + 11.83}{10.96}} - 1\right) + 10 \log(7 \text{ KHz}/30 \text{ MHz})$$
$$= -39.87 \text{ dB}$$

The I/N value to be used in the calculations, as for the IRIDIUM case, will be -10 dB since a lower limit of 2 outage seconds is employed.

The maximum allowable interference level from each satellite into the hypothetical reference circuit may then be calculated using the thermal noise floor of the receivers as follows:

$$I = I/N + N$$

Where N = Thermal noise floor (dBm)
I = Maximum allowable interference level (dBm)

Table 4.1 illustrates the maximum allowable interference levels from the satellites and mobile terminals for four different types of digital receivers.

Receiver	Thermal Noise Floor (dBm)	Maximum Allowable Interference Level (dBm)
Rockwell MDR4102 45 MB/s 64 QAM	-100.77	-110.77
Farinon LR4-2000 6.3 MB/s QPSK	-102.95	-112.95
Farinon DM2-2A-45 45 MB/s QPSK	-95.37	-105.37
Farinon DM2-2A-12 12 MB/s 2-QAM	-103.70	-113.70

Table 4.1: Maximum Allowable Interference into Terrestrial Stations for Different Receivers

4.1.1.2 Maximum Power Flux Density Levels at FS

In order to establish whether interference levels into the fixed service would be harmful or not, maximum allowable levels must be set. This can be done by calculating the maximum power flux density levels at the terrestrial stations from the MSS satellites for various elevation angles.

The maximum possible interference level is given by:

$$I_{max}(dBm) = EIRP_{sat}(dBW) - L_p + 30 + G_r - Disc \qquad \text{Eqn 4.1}$$

The value of 30 in the right hand side of equation 1.1 is used to convert dBW to dBm. Rearranging to solve for $EIRP_{sat}$ gives:

$$EIRP_{sat}(dBW) = I_{max}(dBm) - 30 + L_p - G_r + Disc \qquad \text{Eqn 4.2}$$

The flux density per 4 KHz at the terrestrial station from the satellite is given by:

$$FD_{max} = EIRP_{sat} - L_p + 10 \log\left(\frac{4\pi f^2}{c^2}\right) - 10 \log\left(\frac{BW}{4\ KHz}\right) \qquad \text{Eqn 4.3}$$

The maximum flux density per 4 KHz in order not to exceed the given interference level is then found by substituting equation 4.2 into equation 4.3.

$$FD_{max} = I_{max} - 30 - G_r + Disc + 10 \log\left(\frac{4\pi f^2}{c^2}\right) - 10 \log\left(\frac{BW}{4\ KHz}\right)$$

Where

FD_{max}	=	maximum flux density in $dBW/m^2/4KHz$
I_{max}	=	maximum allowable interference in dBm
$EIRP_{sat}$	=	EIRP of the satellite in dBW
L_p	=	Path loss (dB)
	=	92.5 + 20 log(freq. in GHz) + 20 log(D in km)
G_r	=	Maximum gain of terrestrial antenna in dBi
	=	35.91 dBi for 12 foot antenna @ 2 GHz
Disc	=	Discrimination of terrestrial antenna
f	=	Frequency = 2 GHz
c	=	speed of light = 3×10^8 m/s
BW	=	Terrestrial station bandwidth
	=	10 MHz for MDR4102 receiver
	=	7 MHz for LR4-2000 receiver
	=	29.65 MHz for DM2-2A-45 receiver
	=	7 MHz for DM2-2A-12 receiver

Table 4.2 illustrates the maximum allowable flux density requirements for various elevation angles for each of the four terrestrial receiver types. The calculations assume that the satellite is along the same azimuth that the terrestrial station is pointing so that the off-axis angle is only due to the elevation angle. In most

cases, the azimuth will not be the same resulting in a larger off-axis angle and a larger maximum allowable power flux density.

Elevation Angle (Deg.)	MDR4102 PFD ($dBW/m^2/4KHz$)	LR4-2000 PFD ($dBW/m^2/4KHz$)	DM22A-45 PFD ($dBW/m^2/4KHz$)	DM22A-12 PFD ($dBW/m^2/4KHz$)
0	-183.19	-183.82	-182.51	-184.57
2	-183.19	-183.82	-182.51	-184.57
5	-174.19	-174.82	-173.51	-175.57
10	-165.19	-165.82	-164.51	-166.57
15	-165.19	-165.82	-164.51	-166.57
20	-158.19	-158.82	-157.51	-159.57
25	-157.52	-158.15	-156.84	-158.90
30	-156.86	-157.49	-156.18	-158.24

Table 4.2: Maximum Power Flux Densities at Various Elevation Angles

Based on the antenna pattern given in SRSP 301.9, Table 4.2 gives the maximum power flux density at the earth's surface in a 4 KHz band. The Radio Regulations RR2566 states that the power flux density limits should be -152 dBW/m^2 in any 4 KHz band for angles of arrival between 0° and 5°. This limit applies for the frequency range 3400-4200 MHz and other higher frequency ranges as listed in RR2567. RR2557 specifies a maximum power flux density limit of -154 dBW/m^2 in any 4KHz band for the same arrival angles. This limit is valid for the frequency bands defined in RR2559 which was modified at WARC-92. These ranges include 2025-2110 MHz and other ranges around 2 GHz. The calculated limits for 0° elevation angle in Table 4.2 are around -183 $dBW/m^2/4KHz$ which is about 31 dB lower than the radio regulation limits. This additional isolation is to be provided by the isolation of the receive antenna of the terrestrial station.

4.1.1.3 Interference Levels from IRIDIUM Satellites

Information based on the IRIDIUM system is obtained from the FCC filing, December 1990, and the Minor Amendment submitted to the FCC, August 1992.

A program has been developed to determine the interference levels from the IRIDIUM satellites based on the off-axis angle from the terrestrial station to the satellites. The receive antenna pattern is based on the antenna pattern given in the Standard Radio System Plan, SRSP 301.9. Given a terrestrial station located at 75°W longitude and 45°N latitude, the best and worst case off-axis angles are computed for every minute and for a period of one day. The terrestrial station is assumed to be pointing east with an elevation of 0°. Given the maximum interference levels calculated in Section 4.1.1.1, the percentage of time that this maximum interference level is exceeded is computed.

Based on the current information about the IRIDIUM system, the satellite transmits for about 40% of the time. The amount of time which the maximum interference level is exceeded is therefore weighted by 40%. The interference level from the satellite is calculated using equation 4.1 with the following parameters:

$EIRP_{sat}$	=	EIRP from the IRIDIUM satellite
	=	27.7 dBW for elevation angle 0°-20°
	=	24.5 dBW for elevation angle 20°-33°
	=	22.0 dBW for elevation angle 33°-52°
	=	19.5 dBW for elevation angle 52°-90°
L_p	=	Path loss (dB)
	=	92.5 + 20 log(freq. in GHz) + 20 log(D in km)
D	=	Distance between satellite and terrestrial station in km (varies with elevation angle)
satellite altitude	=	780 km
Earth radius	=	6378 km
IRIDIUM BW	=	41.67 KHz

The results of the IRIDIUM satellite interference are shown in Table 4.3 and the plots are shown in Figures 4.1 to 4.4. The percentage of time that the maximum allowable interference level is exceeded is shown for the best case (largest off-axis angle) and the worst case (smallest off-axis angle) possibilities. Both cases include a 40% weighting factor to account for the percentage of time each cell is active. Note that the acceptable time percentage is 0%, i.e. the maximum allowable interference should not be exceeded.

Receiver System	% Time Interference Level Exceeded Best Case	% Time Interference Level Exceeded Worst Case
Rockwell MDR4102 45 MB/s 64 QAM	0.17	40.00
Farinon LR4-2000 6.3 MB/s QPSK	0.70	40.00
Farinon DM2-2A-45 45 MB/s QPSK	0.00	39.22
Farinon DM2-2A-12 12 MB/s 2-QAM	1.09	40.00

Table 4.3: Percent of Time Maximum Allowable Interference into a Terrestrial Station is Exceeded from IRIDIUM Satellites

Figure 4.1: Interference Level from IRIDIUM Satellite into Terrestrial Station Rockwell MDR4102 Receiver

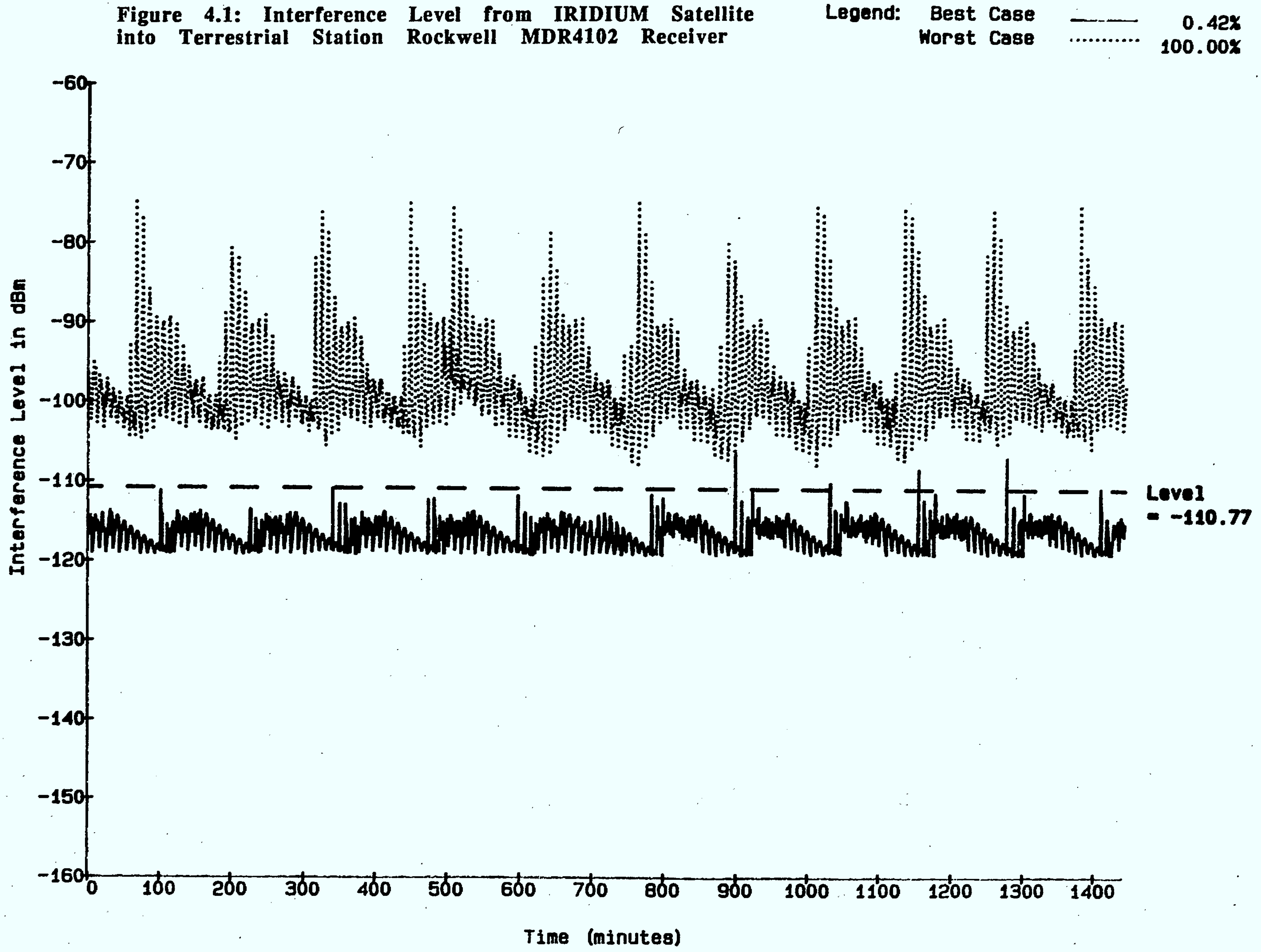


Figure 4.2: Interference Level from IRIDIUM Satellite into Terrestrial Station Farinon LR4-2000 Receiver

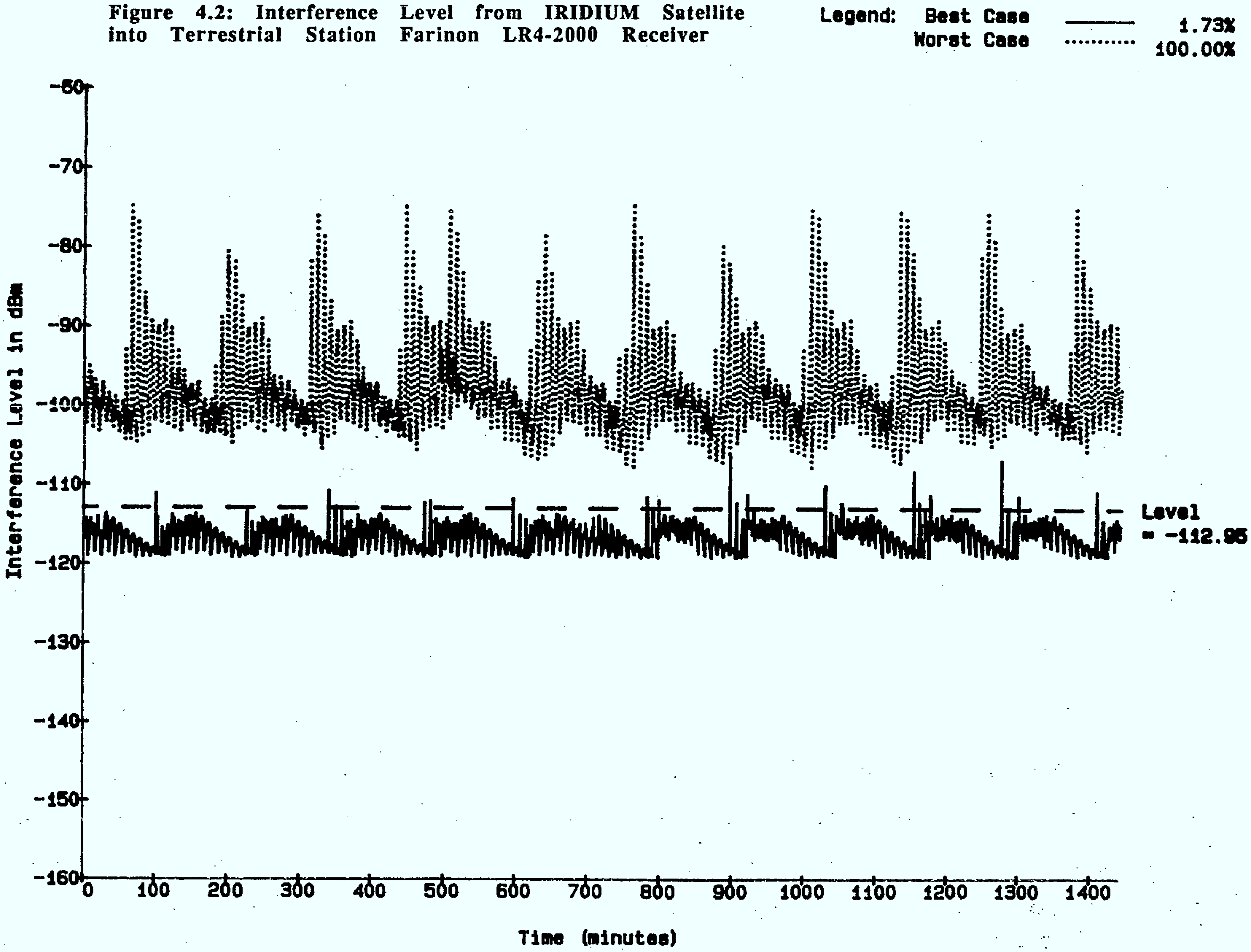


Figure 4.3: Interference Level from IRIDIUM Satellite into Terrestrial Station Farinon DM2-2A-45 Receiver

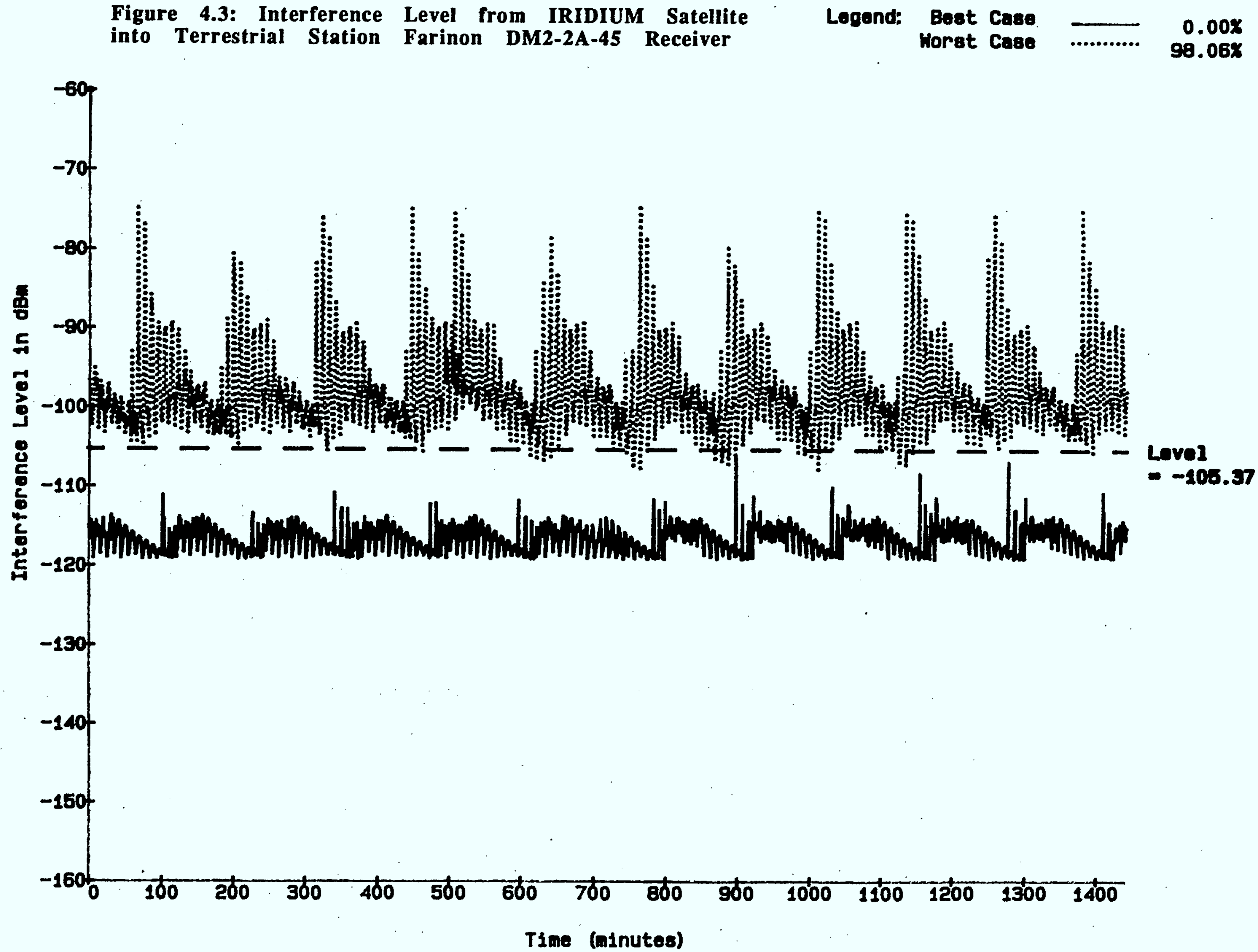
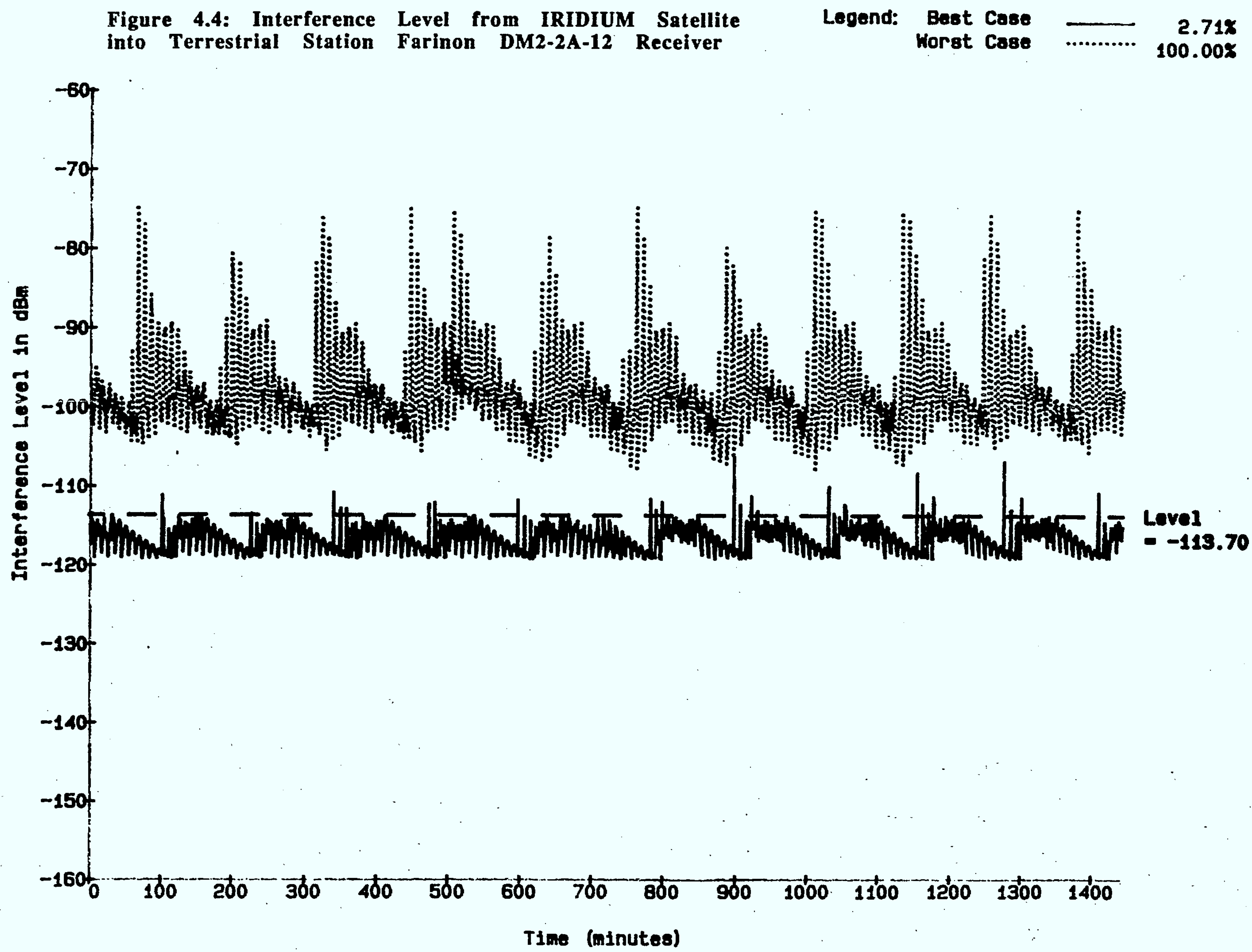


Figure 4.4: Interference Level from IRIDIUM Satellite into Terrestrial Station Farinon DM2-2A-12 Receiver



4.1.1.4 Interference Levels from IRIDIUM Mobiles

Interference from the IRIDIUM mobile terminals into the terrestrial station must also be considered. The maximum allowable interference levels into the terrestrial receivers are the levels as calculated in section 4.1.1.1. Rather than calculating the percentage of time the interference level will be exceeded, the minimum separation distance between the mobile terminal and the terrestrial station will be calculated in order that the interference level is acceptable. The IRIDIUM mobile only transmits for approximately 1/10 of the time in each TDMA frame, therefore the EIRP of the mobile is reduced by 10 log(1/10), or 10 dB, to account for this. The interference level from the IRIDIUM mobile is calculated as follows assuming only one interfering mobile terminal:

$$I = EIRP_{mob} - 10 - L_p + 30 + G_{terr} - Disc \qquad \text{Eqn 4.4}$$

Where

I	=	Interference level in dBm
$EIRP_{mob}$	=	EIRP of the IRIDIUM mobile in dBW
	=	6.0 dBW
G_{terr}	=	Maximum gain of terrestrial antenna in dBi
	=	35.91 dBi
Disc	=	Discrimination of terrestrial antenna towards mobile in dB
L_p	=	path loss between the mobile and the terrestrial station in dB

The equations used for the path loss, L_p, are the long-term propagation, mode 1, basic transmission loss for the radio climatic zone A. These formulas are based on the propagation model that was adopted at the Special Joint Meeting (SJM) of the CCIR in 1971 which preceded the WARC-ST (1971). Details of the SJM model are given in Section 4 of Annex 10-1 of the "Report of the SJM". The equations used are valid for 1-10 GHz over land (Zone A) and are shown below:

$L_p(20\%)$	=	$104.45 + 20 \log d + 20 \log(f/4)$	for $d \leq 90$ km
	=	$-228 + 190 \log d + 20 \log(f/4)$	for $90 < d \leq 160$ km
	=	$14 + 80 \log d + 20 \log(f/4)$	for 160 km $< d$

Where

$L_p(20\%)$ = basic transmission loss exceeded for all but 20% of the time, in dB

d = path length in km

f = frequency in GHz

The minimum path length that is required to ensure the maximum interference level is not exceeded can then be calculated by substituting the path loss equations into equation 4.4 and solving for d, giving:

$$d = 10^{(EIRPmob-10+Gterr-Disc-I+30-104.45-20\log(f/4))/20}$$

if d>90 km then,

$$d = 10^{(EIRPmob-10+Gterr-Disc-I+30+228-20\log(f/4))/190}$$

if d>160 km then,

$$d = 10^{(EIRPmob-10+Gterr-Disc-I+30-14-20\log(f/4))/80}$$

Using the maximum interference levels as calculated in section 4.1.1.1 for the four typical terrestrial receiver types, a frequency of 2 GHz, and a mobile terminal EIRP of 6.0 dBW, the minimum separation distances are shown in Table 4.4 assuming there is only one interfering mobile terminal. The separation distances are calculated for various azimuths away from the main beam of the terrestrial station for each of the receiver types.

Azimuth from main beam (deg)	Min D (km) I =-110.77 dBm	Min D (km) I =-112.95 dBm	Min D (km) I =-105.37 dBm	Min D (km) I =-113.70 dBm
0	138	142	129	143
2	138	142	129	143
3	133	137	125	138
4	129	132	120	133
5	124	127	116	128
10	111	114	104	115
20	102	105	96	106
30	100	103	94	104
40	99	101	93	102
50	97	100	91	101

Table 4.4: Minimum Required Separation Distances between IRIDIUM Mobiles and Terrestrial Stations

4.1.1.5 Interference Levels from MSAT Satellites

Interference levels from the MSAT satellite into the fixed service should also not exceed the maximum interference levels into the terrestrial station as calculated in section 4.1.1.1. The interference levels from the MSAT satellite are calculated using equation 4.1. The calculations use the same parameters as for the IRIDIUM satellite except for the following modified parameters:

- Satellite EIRP
  - 6.4 kbps voice = 30.46 dBW
  - 4.8 kbps data = 30.16 dBW
- Satellite Altitude = 35786 km
- MSAT bandwidth = 7 KHz

The interference level from the MSAT satellite into four typical terrestrial receivers have been calculated for various elevation angles and are shown in Table 4.5. The difference between the received interference level (3rd column) and the maximum allowable interference level are shown in the last four columns for each of the receivers. Positive numbers indicate that interference would be unacceptable.

4.1.1.6 Interference Levels from MSAT Mobiles

The same procedure is used for calculating interference levels from the MSAT mobiles to the terrestrial stations as was used with the IRIDIUM mobiles in section 4.1.1.4. The four typical terrestrial receivers have the same maximum interference levels as calculated in section 4.1.1.1. The minimum separation distances are calculated and shown in Table 4.6. The calculations assume an MSAT mobile EIRP of 14.65 dBW.

System	Elevation Angle(Deg)	I level (dBm)	MDR4102 I = -110.77	LR4-2000 I = -112.95	DM22A-45 I = -105.37	DM22A-12 I = -113.70
6.4 kbps Voice	0	-94.85	15.92	18.10	10.52	18.85
	2	-94.80	15.97	18.15	10.57	18.90
	5	-103.73	7.04	9.22	1.64	9.97
	10	-112.62	-1.85	0.33	-7.25	1.08
	15	-112.50	-1.73	0.45	-7.13	1.20
	20	-119.39	-8.62	-6.44	-14.02	-5.69
	30	-120.52	-9.75	-7.57	-15.15	-6.82
4.8 kbps Data	0	-95.15	15.62	17.80	10.22	18.55
	2	-95.10	15.67	17.85	10.27	18.60
	5	-104.03	6.74	8.92	1.34	9.67
	10	-112.92	-2.15	0.03	-7.55	0.78
	15	-112.80	-2.03	0.15	-7.43	0.90
	20	-119.69	-8.92	-6.74	-14.32	-5.99
	30	-120.82	-10.05	-7.87	-15.45	-7.12

Table 4.5: Interference Levels from MSAT Satellite into Terrestrial Station

Azimuth from main beam (deg)	Min D (km) I = -110.77 dBm	Min D (km) I =-112.95 dBm	Min D (km) I = -105.37 dBm	Min D (km) I =-113.70 dBm
0	153	158	144	159
2	153	158	144	159
3	148	152	139	153
4	143	147	134	148
5	138	141	129	143
10	123	127	116	128
20	113	116	106	117
30	112	115	104	116
40	110	113	103	114
50	108	111	101	112

Table 4.6: Minimum Separation Distance Required between MSAT Mobiles and Terrestrial Stations

4.1.2 Interference from FS into MSS

In order that interference from the FS into the MSS may be determined as acceptable or not, the allowable interference criteria must be established. In the following sections, interference into the MSS will be considered acceptable if the interference level is less than 6% of the noise level, ie. 10 log(0.06) or 12.2 dB less than the noise level.

4.1.2.1 Interference from FS into IRIDIUM Satellites

The noise level for the IRIDIUM satellite may be determined using the following equation:

$$N = k + T_{sys} + 10\log(B) \qquad [dBW]$$

Where

k = Boltzman's constant = -228.6 dBW/Hz/K
T_{sys} = Receive system noise temperature in dBK
B = Bandwidth in Hz

From the IRIDIUM FCC filing,

T_{sys} = 500 K = 26.98 dBK
B = 41.67 KHz

Therefore the noise level is given by:

$$N = -228.6 + 26.98 + 10\log(41.67\ \text{KHz})$$
$$= -155.42\ \text{dBW}$$

The maximum allowable interference into the IRIDIUM satellite is therefore -155.42 - 12.2 = -167.62 dBW

The maximum EIRP from the terrestrial transmitter must not exceed 55 dBW as stated in SRSP 301.9. For this analysis, the EIRP for the mainlobe will be assumed to be 40 dBW. Away from the mainlobe, the EIRP will be reduced by the discrimination of the antenna as given in SRSP 301.9.

The received power at the IRIDIUM satellite is calculated as follows:

$$P_{rx} = EIRP_{terr} - Disc(El) - L_a - L_p + G_{sat} + Q_{fact}$$

Where

$EIRP_{terr}$	=	EIRP of terrestrial station in dBW = 40 dBW
Disc(El)	=	Discrimination of terrestrial antenna in dB as a function of elevation angle El in Degrees
L_a	=	absorption loss = 0.3 dB
L_p	=	path loss in dB
	=	92.5 + 20 log(D) + 20 log(f)
G_{sat}	=	Gain of IRIDIUM satellite in dBi = 23.9 dBi
D	=	path length in km
f	=	frequency in GHz = 2 GHz
Q_{fact}	=	Q-factor
	=	10 log(IRIDIUM BW/Terrestrial BW)
	=	10 log(41.67 KHz/7 MHz) = -22.25 dB

Refer to Figure 4.5 to further illustrate the path length calculation. The path length, D, is calculated as follows:

$$a = \sin^{-1}\left(\frac{R}{R+H}\sin(90+El)\right)$$

$$b = 180 - a - (90+El)$$

$$d_1 = (H+R)\sin(b)$$

$$D = \frac{d_1}{\sin(90-El)}$$

The satellite is assumed to be along the same azimuth as the terrestrial station antenna is pointing. The elevation angle is therefore the only factor involved in the transmit antenna discrimination calculation. If the azimuths are not the same then the off-axis angle would be larger than the elevation angle and the discrimination would be larger, reducing the amount of interference. Table 4.7 illustrates the interference from the terrestrial station into the IRIDIUM satellite at various elevation angles. The right column shows the amount by which the received interference level exceeds the maximum allowable interference into the IRIDIUM satellite. All of the numbers are positive which would indicate that sharing would not be possible.

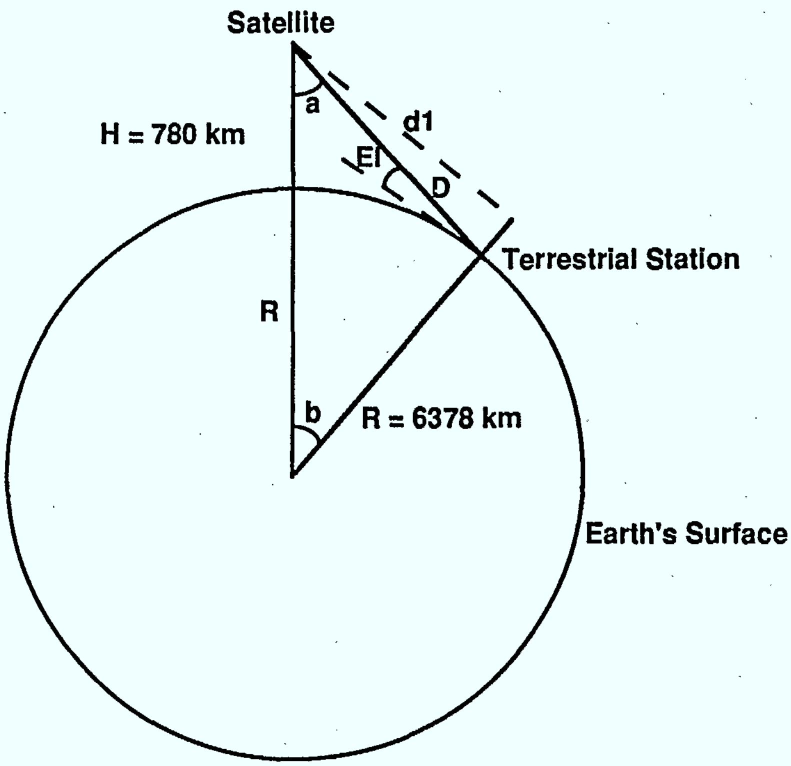


Figure 4.5: Calculation of Path Length

Elevation Angle (Deg)	Path Length (km)	Path Loss (dB)	Tx. Antenna Disc. (dB)	Satellite Gain (dBi)	Received Power (dBW)	Intf above thresh (dB)
0	3249	168.76	0.00	23.90	-127.41	40.21
2	3034	168.16	0.00	23.90	-126.81	40.81
5	2741	167.28	9.00	23.90	-134.93	32.69
10	2325	165.85	18.00	23.90	-142.50	25.12
15	1994	164.51	18.00	23.90	-141.17	26.45
20	1732	163.29	25.00	22.60	-148.25	19.37
30	1364	161.22	26.33	22.60	-147.50	20.12

Table 4.7: Interference from Terrestrial Station into IRIDIUM Satellite at Various Elevation Angles

4.1.2.2 Interference from FS into IRIDIUM Mobiles

Interference from terrestrial stations into IRIDIUM mobile terminals must also be considered. The threshold of acceptable interference into the mobile terminals is calculated using the same method as the interference into the IRIDIUM satellite. The interference must not exceed 6% of the noise level. For the IRIDIUM mobile terminals, the bandwidth is 41.67 KHz and the system noise temperature is given as 250 K in the FCC Minor Amendment. The noise level is then given by:

$$N = -228.6 + 10\log(250) + 10\log(41.67\text{ KHz})$$
$$= -158.42\text{ dBW}$$

The maximum interference level is then given by:

$$I_{max} = -158.42 - 12.2 = -170.62\text{ dBW}$$

The interference level from the terrestrial station into the IRIDIUM mobile is calculated as follows:

$$I = EIRP_{terr} - Disc - L_p + 30 + G_{mob} - Q_{fact} \quad \text{Eqn 4.5}$$

Where

I = Interference level in dBm

Q_{fact}	=	10 log(IRIDIUM mobile BW/Terrestrial BW)
	=	10 log(41.67 KHz/7 MHz)
	=	-22.25 dB
G_{mob}	=	Gain of mobile antenna = 1 dBi
$EIRP_{terr}$	=	EIRP of terrestrial station = 40 dBW
Disc	=	Discrimination of terrestrial antenna
L_p	=	path loss as calculated in section 4.1.1.4

Substituting the path loss equations into equation 4.5 and solving for the minimum separation distance, d, between the mobile terminal and the terrestrial station, gives:

$$d = 10^{(EIRPterr-Disc+Gmob-Qfact-I+30-104.45-20\log(f/4))/20}$$

if d>90 km then,

$$d = 10^{(EIRPterr-Disc+Gmob-Qfact-I+30+228-20\log(f/4))/190}$$

if d>160 km then,

$$d = 10^{(EIRPterr-Disc+Gmob-Qfact-I+30-14-20\log(f/4))/80}$$

Table 4.8 illustrates the minimum separation distance between the mobile terminal and the terrestrial station in order that interference into the IRIDIUM mobile terminal will not exceed the maximum allowable interference.

Azimuth from Main Beam (Deg.)	Minimum Separation Distance (km)
0	439
5	339
10	261
15	261
20	214
25	210
30	206
35	202
40	198
50	190

Table 4.8: Minimum Separation Distance Required between IRIDIUM Mobile terminals and Terrestrial Stations

4.1.2.3 Interference from FS into the MSAT Satellite

The same method, as used in section 4.1.2.1 to calculate the allowable interference into IRIDIUM satellites, is used to calculate the allowable interference into the MSAT satellite. The noise level is calculated as a function of the bandwidth, system noise temperature, and Boltzman's constant. The maximum allowable interference is 6% of this noise level or 12.2 dB less than the noise level. The bandwidth and system noise temperature of the MSAT satellite are as follows:

$$B = 7 \text{ KHz}$$

$$T_{sys} = 30 \text{ dBK}$$

Therefore the noise level is given by,

$$\begin{aligned} N &= K + T_{sys} + 10 \log B \\ &= -228.6 + 30 + 10 \log 7000 \\ &= -160.15 \text{ dBW} \end{aligned}$$

The maximum allowable interference level is then

$$I_{max} = N - 12.2 \text{ dB} = -172.35 \text{ dBW}$$

Table 4.9 illustrates the interference levels from the terrestrial station into the MSAT satellite. The calculations assume an MSAT satellite antenna gain of 32.7 dBi, an MSAT bandwidth of 7 KHz, and a satellite altitude of 35786 km. The right column illustrates the amount the received interference is above the maximum allowable interference into the MSAT satellite.

Elevation Angle (Deg)	Path Length (km)	Path Loss (dB)	Tx. Antenna Disc. (dB)	Received Power (dBW)	Intf above thresh (dB)
0	41679	190.92	0.00	-148.52	23.83
2	41457	190.87	0.00	-148.47	23.88
5	41127	190.80	9.00	-157.40	14.95
10	40586	190.69	18.00	-166.29	6.06
15	40061	190.57	18.00	-166.17	6.18
20	39554	190.46	25.00	-173.06	-0.71
30	38612	190.25	26.33	-174.19	-1.84

Table 4.9: Interference from Terrestrial Station into MSAT Satellite at Various Elevation Angles

4.1.2.4 Interference from FS into MSAT Mobiles

Interference from terrestrial stations into MSAT mobile terminals must also be considered. The threshold of acceptable interference into the mobile terminals is calculated such that the interference must not exceed 6% of the noise level, or, interference must be 12.2 dB less than the noise. For the MSAT mobile terminals, the bandwidth is 7 KHz and the system noise temperature is given as 320 K. The noise level is then given by:

$$N = -228.6 + 10\log(320) + 10\log(7\ \text{KHz})$$
$$= -165.1\ \text{dBW}$$

The maximum interference level is then,

$$I_{max} = -165.1 - 12.2 = -177.3\ \text{dBW}$$

The minimum separation distance between the terrestrial station and the MSAT mobile is calculated using the same method as in section 4.1.2.2 with

$$Q_{fact} = 10\log(\text{MSAT mobile BW/Terrestrial BW})$$
$$= 10\log(7\ \text{KHz}/7\ \text{MHz})$$
$$= -30.0\ \text{dB}$$

G_{mob} = Gain of mobile antenna = 0 dBi

Table 4.10 illustrates the minimum separation distance between the MSAT mobile terminal and the terrestrial station in order that interference into the mobile terminal will not exceed the threshold.

Azimuth from Main Beam (Deg.)	Minimum Separation Distance (km)
0	414
5	319
10	246
15	246
20	201
25	198
30	194
35	190
40	186
50	179

Table 4.10: Minimum Separation Distance Required between MSAT Mobile terminals and Terrestrial Stations

4.1.3 Discussion

Interference from the IRIDIUM satellites into the terrestrial stations would exceed the allowable limit for 40% of the time as a worst case and around 1% of the time as a best case. 0% is only achieved for the best case using the Farinon DM2-2A-45 receiver. If the IRIDIUM mobile communicated with the highest satellite all of the time, the best case results could be achieved and interference may be considered acceptable. For this to occur, the IRIDIUM satellite would have to switch off its outer beams and the adjacent satellites would have to use its outer beams to provide complete coverage. The percentage of time that acceptable interference would be exceeded will be somewhere between the best case and worst case figures. In regions of higher latitude (ie. Canada), the percentage of time acceptable interference would be exceeded would probably be closer to the best case figures due to more overlapping of the satellite beams.

Interference from the IRIDIUM mobiles into the FS would make sharing difficult. The minimum separation distance between the IRIDIUM mobile and the terrestrial station would have to be at least about 130 km along the same azimuth as the mainlobe of the terrestrial station. This distance is reduced as the azimuth moves away from the mainlobe, but distances are still in excess of a feasible sharing distance. Separation distances must be over 90 km even at an azimuth of 50° away from the mainlobe.

Interference levels from the MSAT satellite into the FS would be unacceptable at low elevation angles from the terrestrial stations to the satellites. The results indicate that interference levels would exceed the allowable levels at elevation angles below and around 15° for both the 6.4 kbps voice and 4.8 kbps data carriers. However, elevation angles to the MSAT satellite would normally exceed 15° for most areas where terrestrial stations are located in Canada. In addition, off-axis angles to the MSAT satellite would increase if the terrestrial station was not pointing along the same azimuth towards the MSAT satellite. This would be the case for most terrestrial stations since most point in an easterly or westerly direction. Taking these factors into account, there may be hope for sharing between the GSO satellite and the FS. However, as mentioned below, interference from the terrestrial station into the the MSAT satellite would make sharing difficult.

Interference from the MSAT mobiles into the terrestrial station would be unacceptable. Interference levels would exceed those from the IRIDIUM mobiles due to the increased EIRP levels. The results indicate that the minimum separation distance between the MSAT mobiles and the terrestrial stations would have to be at least 140 km along the main beam azimuth of the terrestrial station. This is clearly not a feasible sharing condition.

The results indicate that interference from the FS into the MSS would be unacceptable and sharing would be difficult. Interference levels from the terrestrial station into the IRIDIUM satellite would be

20 dB above the allowable levels even at 30° elevation angle towards the satellite. Interference levels into the MSAT satellite would only become acceptable for elevation angles over 20°. This assumes that the MSS satellite lies along the azimuth of the terrestrial station. In most cases, this would not occur and the the off-axis angle would be larger than the elevation angle. This would provide more antenna discrimination and therefore increase the possibility of sharing. The radio regulation RR2502 states that the direction of maximum radiation from a transmitter in the fixed or mobile service should be at least 2° away from the geostationary-satellite orbit for frequencies from 1 to 10 GHz and EIRPs exceeding 35 dBW. With a terrestrial station EIRP of 40 dBW, a 30° elevation angle does not provide sufficient discrimination to reduce the interference to an acceptable level into the IRIDIUM satellite.

Interference levels from the terrestrial stations into the IRIDIUM and the MSAT mobiles would make sharing difficult. The results indicate that the minimum separation distance between the terrestrial station and both the IRIDIUM and MSAT mobiles would have to be over 414 km along the azimuth of the main beam of the terrestrial station.

4.2. Interference Between Mobile Satellite Service (MSS) and Mobile Service (MS)

Interference, in the 2 GHz band, between the MSS and the MS will be considered with IRIDIUM, a LEO based MSS, and MSAT, a GSO based MSS. The mobile service under consideration will be the Future Public Land Mobile Telecommunication Service (FPLMTS). Interference will be considered for both the personal and vehicular FPLMTS terminals. In the following sections, interference will be calculated for both directions, from the MSS into the MS and from the MS into the MSS. Information on the FPLMTS system was obtained from the CCIR document IWP 8/13-54.

Telesat has previously completed a study involving the sharing between IRIDIUM and the FPLMTS systems in the 2 GHz band. The calculations and conclusions are listed in the "Feasibility Study of Spectrum Sharing Between LEO/MSS and GSO/MSS and Fixed Services and FPLMTS" report submitted to the Department of Communications, April 25, 1991. This report analysed the sharing between IRIDIUM and the FPLMTS using the original IRIDIUM satellite configuration of 77 satellites. A similar method will be used in this report with the appropriate modifications to represent the 66 satellite configuration and the new transmission characteristics.

4.2.1 Allowable Interference into FPLMTS

The amount of allowable interference into the FPLMTS terminals remains the same as discussed in the previous study. The indoor office environment path loss and the outdoor line-of-sight free space loss are obtained from the CCIR document IWP 8/13-54. These formulas are valid for 2 GHz and are shown in equations 4.6 and 4.7.

Indoor:	$L_i(r)$ =	$21.0 + 35 \log(r)$	[dB]	Eqn 4.6
Outdoor:	$L_o(r)$ =	$38.5 + 20 \log(r)$	[dB]	Eqn 4.7

Where r is the range in metres of the mobile from its base. The maximum range is 67m for indoor and 133m for outdoor personal mobiles, which corresponds to maximum pathlosses of 85 dB and 81 dB respectively.

For these given ranges, the maximum allowable interference from satellite systems for both indoor and outdoor terminals are calculated assuming 10% of the maximum allowable interference is acceptable, and are given by:

Indoor: $I_{allowable} = -98.0 + 10 \log(r^{-3.5} - 10^{-6.4})$ [dBW]
Outdoor: $I_{allowable} = -107.5 + 10 \log(r^{-2.0} - 10^{-5.45})$ [dBW]

The path loss equation 4.7 is used for the vehicular FPLMTS terminal as well as being used for the outdoor personal mobile. Assuming a 10 dBW EIRP, a noise level of -152 dBW, a 14 dB shadowing margin, a 15 dB fade margin, and a 3 dBi vehicular antenna gain, the minimum received carrier level is -54.5 - 20 log(r). The allowable interference into the vehicular terminal can then be calculated, assuming a required C/(N+I) of 13 dB, and is given by:

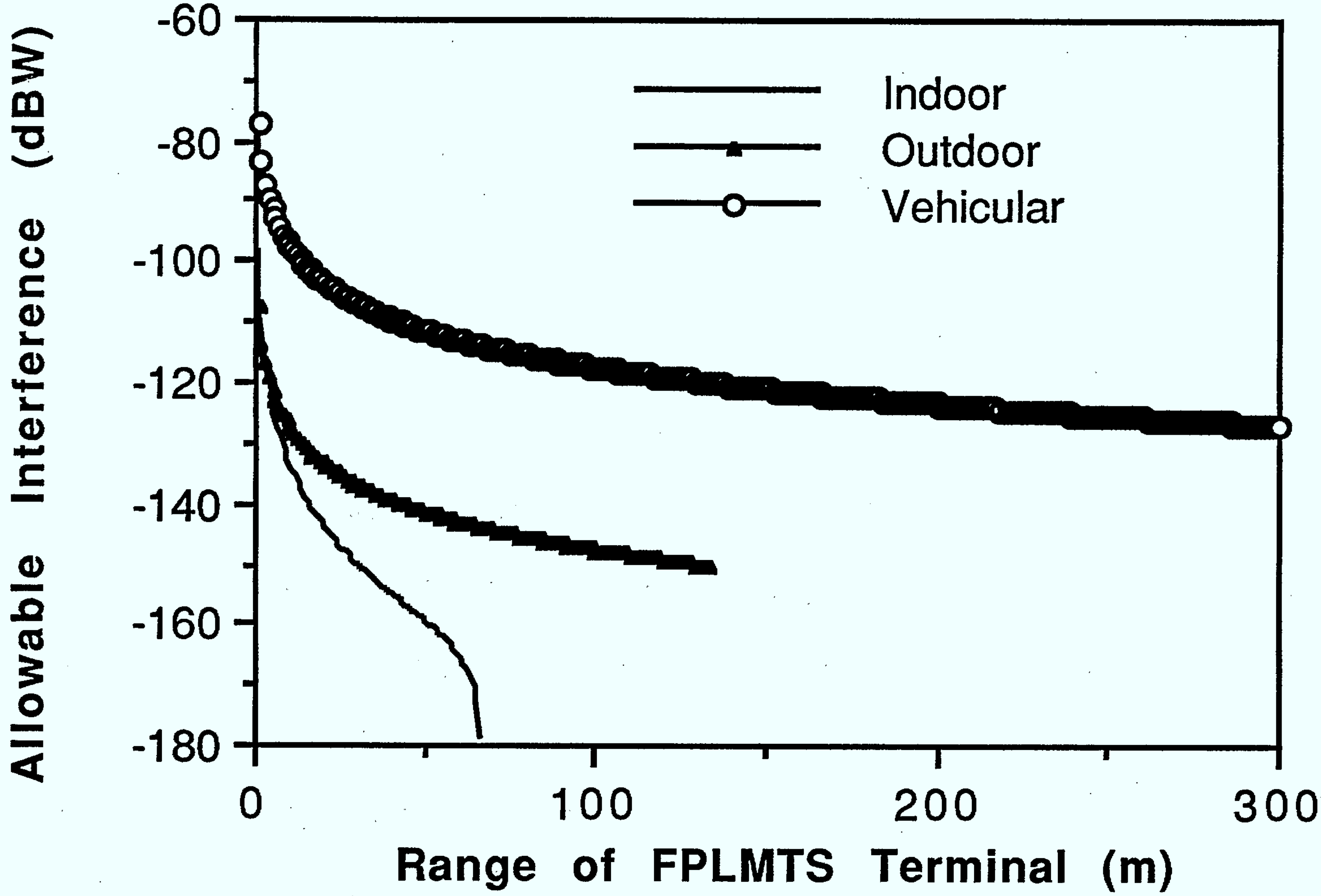
Vehicular: $I_{allowable} = -77.5 + 10 \log(r^{-2.0} - 10^{-8.45})$ [dBW]

Table 4.11 illustrates the allowable interference levels for various ranges for each of the FPLMTS terminals. Figure 4.6 illustrates graphically the allowable interference levels into the FPLMTS terminals.

4.2.2 Allowable Interference into MSS

In order to determine whether the interference received by the MSS is acceptable or not, the maximum allowable interference must be determined. Table 4.12 illustrates the maximum allowable interference into both the IRIDIUM and MSAT systems.

Figure 4.6: Allowable Interference into FPLMTS Terminals



Allowable interference levels into the MSS have been calculated for two different cases. The middle column illustrates the figures for a 0.5 dB degradation in the C/N due to interference and the last column illustrates the figures for a 1.0 dB degradation.

	Range (m)	Total Inter. (dBW)	Allowable Inter. (dBW)
Indoor	10	-123.0	-133.0
	25	-137.1	-147.1
	50	-149.3	-159.3
	67	-168.9	-178.9
Outdoor	25	-125.5	-135.5
	50	-131.5	-141.5
	100	-137.7	-147.7
	133	-140.3	-150.3
Vehicular	50	-101.5	-111.5
	100	-107.5	-117.5
	250	-115.5	-125.5
	500	-121.5	-131.5

Table 4.11: Allowable Interference Levels into the FPLMTS Terminals

For the interference into the IRIDIUM satellite and mobiles, a required E_b/N_0 of 6.1 dB is given in the Minor Amendment to the FCC filing and the occupied bandwidth per channel is given as 31.5 KHz. The required C/N is then calculated as follows:

$$\begin{aligned} \text{Required C/N} &= E_b/N_0 + 10 \log R - 10 \log BW \\ &= 6.1 + 10 \log(50 \text{ kbps}) - 10 \log(31.5 \text{ KHz}) \\ &= 8.1 \text{ dB} \end{aligned}$$

The minimum carrier levels of -148.5 dB for the satellite and -151.5 dB for the mobiles are given in the link budget for the uplink and downlink with shadowing in the Minor Amendment to the FCC filing.

Allowable interference into IRIDIUM satellite

Required C/N (dB)	8.1	8.1
Acceptable C/(N+I) (dB)	7.6	7.1
Minimum C (dBW)	-148.5	-148.5
Maximum I (dBW)	-165.7	-162.5

Allowable interference into IRIDIUM mobile

Required C/N (dB)	8.1	8.1
Acceptable C/(N+I) (dB)	7.6	7.1
Minimum C (dBW)	-151.5	-151.5
Maximum I (dBW)	-168.7	-165.5

Allowable interference into MSAT satellite

Required C/N (dB)	13.0	13.0
Acceptable C/(N+I) (dB)	12.5	12.0
Minimum C (dBW)	-147.2	-147.2
Maximum I (dBW)	-169.3	-166.1

Allowable interference into MSAT mobile

Required C/N (dB)	13.0	13.0
Acceptable C/(N+I) (dB)	12.5	12.0
Minimum C (dBW)	-152.1	-152.1
Maximum I (dBW)	-174.2	-171.0

Table-4.12 Allowable Interference into MSS Systems

For interference into the MSAT system, a required C/N of 13 dB is assumed and the minimum carrier level, C, is calculated as follows:

$$C = C/N + N \quad [dBW]$$

Where

N	=	Noise level in dBW = K + T_{sys} + BW
K	=	Boltzman's constant = -228.6 dBW/Hz/K
T_{sys}	=	System noise temperature in dBK
	=	30 dBK for MSAT satellite
	=	10 log(320 K) = 25.1 dBK for MSAT mobile
BW	=	10 log(bandwidth) = 10 log(7 KHz) = 38.5 dB-Hz

4.2.3 Interference Between IRIDIUM and FPLMTS

Table 4.13 illustrates the potential interference from both the IRIDIUM system and the FPLMTS. The potential interference takes into account three adjustment factors in addition to the EIRP and path losses. These adjustment factors include the ratio of the bandwidths (Q-factor) , number of interferers (DF factor), and a time factor (P factor).

The Q-factor is defined as

$$\text{Q-factor} = 10 \log\left(\frac{\text{Victim Bandwidth}}{\text{Interferer Bandwidth}}\right).$$

Where

IRIDIUM BW	=	41.67 KHz
FPLMTS		
Indoor BW	=	50 KHz
Outdoor BW	=	50 KHz
Vehicular BW	=	25 KHz

The IRIDIUM system uses a 60 ms TDMA frame for transmitting both satellite and mobile transmissions. Four slots are assigned for the satellite transmissions and four are also assigned for mobile transmissions. An additional slot is used for a framing time slot. The satellite and mobile transmissions are assumed to be 50% of the time for each. The potential interference level from the satellite and

Potential interference from IRIDIUM satellite into FPLMTS terminal

	Indoor FPLMTS terminal	Outdoor FPLMTS terminal	Vehicular FPLMTS
10 log Q (dB)	0.8	0.8	-2.2
10 log DF (dB)	0.0	0.0	0
10 log P (dB)	-3.0	-3.0	- 3
EIRP (dBW)	27.7	27.7	27.7
Losses (dB)	165.8	165.8	165.8
Potential interference (dBW)	-140.3	-140.3	-143.3

Potential interference from IRIDIUM mobile into FPLMTS terminal

	Indoor FPLMTS terminal	Outdoor FPLMTS terminal	Vehicular FPLMTS
10 log Q (dB)	0.6	0.8	-2.2
10 log DF (dB)	10 log m	10 log m	10 log m
10 log P (dB)	-3.0	-3.0	-3.0
EIRP (dBW)	6.0	6.0	6.0
Losses (dB)	f(d)	f(d)	f(d)
Potential interference (dBW)	10 log m + 3.8 - f(d)	10 log m + 3.8 - f(d)	10 log m + 0.8 - f(d)

Potential interference from FPLMTS terminal into IRIDIUM satellite

	Indoor FPLMTS terminal	Outdoor FPLMTS terminal	Vehicular FPLMTS
10 log Q (dB)	-0.8	-0.8	2.2
10 log DF (dB)	10 log n	10 log n	10 log n
10 log P (dB)	0.0	0.0	0
EIRP (dBW)	-25.0	-17.0	10
Losses (dB)	165.8	165.8	165.8
Potential interference (dBW)	10 log n - 191.6	10 log n - 183.6	10 log n - 153.6

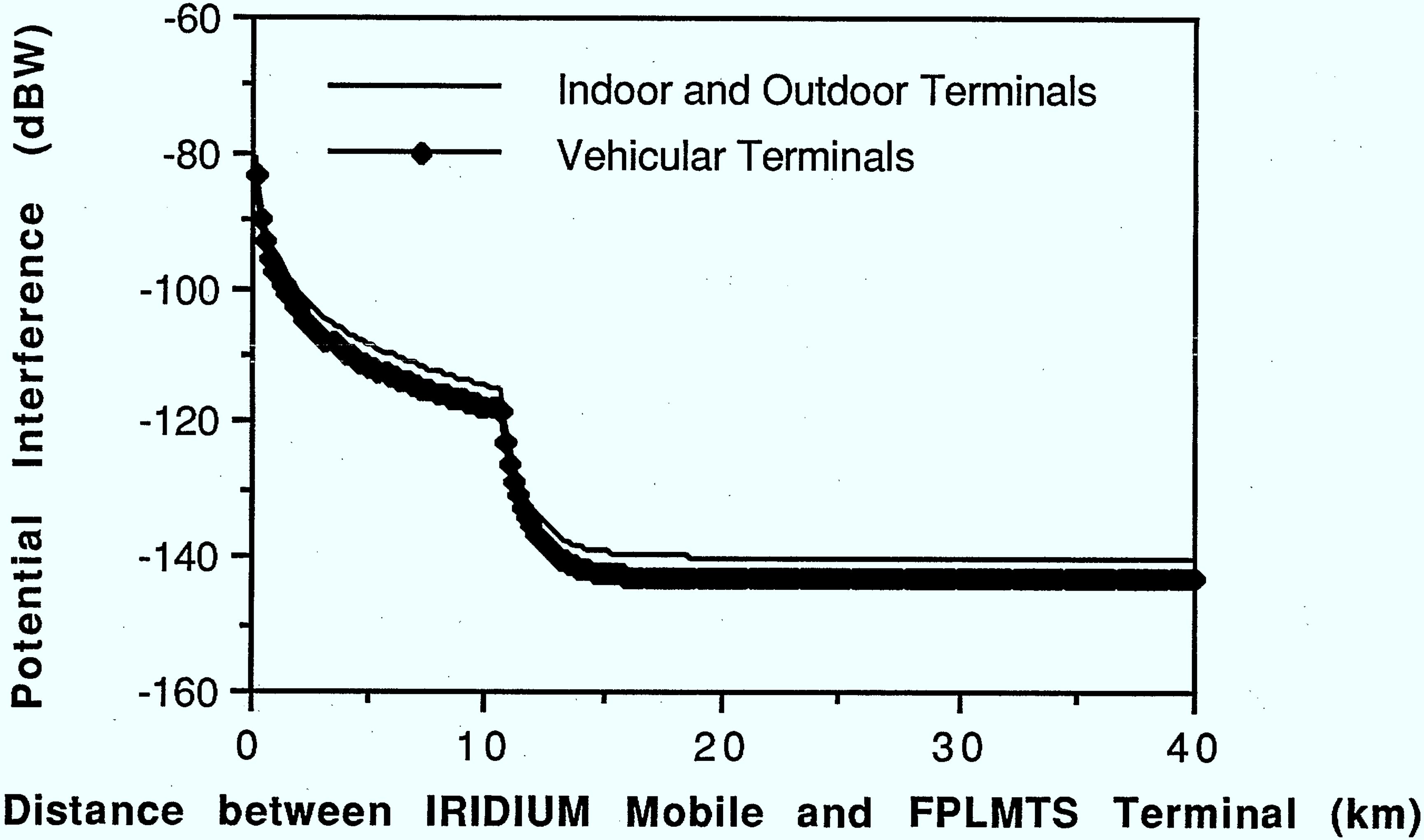
Potential interference from FPLMTS terminal into IRIDIUM mobile

	Indoor FPLMTS terminal	Outdoor FPLMTS terminal	Vehicular FPLMTS
10 log Q (dB)	-0.8	-0.8	2.2
10 log DF (dB)	10 log n	10 log n	10 log n
10 log P (dB)	0.0	0.0	0.0
EIRP (dBW)	-25.0	-17.0	10.0
Losses (dB)	f(d)	f(d)	f(d)
Potential interference (dBW)	10 log n - 25.8 - f(d)	10 log n - 17.8 - f(d)	10 log n + 12.2 - f(d)

f(d) in dB is the loss between an IRIDIUM mobile and an FPLMTS terminal,
d is in kilometers, EIRPs and losses are at 2 GHz,
n is the number of FPLMTS terminals, and m is the number of IRIDIUM mobiles.

Table-4.13 Potential Interference between FPLMTS and IRIDIUM systems

Figure 4.7: Potential Interference into FPLMTS Terminals from IRIDIUM Satellite and Mobiles



mobiles may then be reduced by this time factor of 3 dB, 10 log(50%). The FPLMTS mobiles could transmit for 100% of the time and so a 0 dB time factor is used for potential interference from the FPLMTS terminals.

4.2.3.1 Interference from IRIDIUM System

The total interference into the FPLMTS terminals comes from both the IRIDIUM satellite and the IRIDIUM mobiles. If the potential interference from the IRIDIUM satellite and mobiles are added together, the total potential interference into the FPLMTS would be as follows for the indoor, outdoor and vehicular terminals:

Indoor and Outdoor:

$$I_{potential} = 10\log[10^{-14.03} + m(10^{+0.38-f(d)/10})]$$

Vehicular:

$$I_{potential} = 10\log[10^{-14.33} + m(10^{+0.08-f(d)/10})]$$

Figure 4.7 illustrates the potential interference from the IRIDIUM system, both satellite and mobile terminals, into the FPLMTS indoor, outdoor, and vehicular terminals. It is assumed that there is only one interfering IRIDIUM mobile terminal, that is m = 1, and the height of both the FPLMTS and IRIDIUM mobile terminals is 1.5m.

4.2.3.2 Interference from FPLMTS System

If the potential interference from n indoor FPLMTS terminals or n outdoor FPLMTS terminals into the IRIDIUM satellite is set equal to the allowable interference, then the maximum allowable number of FPLMTS terminals would be as shown in Table 4.14.

C/N-C(N+I)	Maximum no. of indoor terminals	Maximum no. of outdoor terminals	Maximum no. of vehicular terminals
0.5 dB	389	61	0
1.0 dB	812	128	0

Table 4.14: Maximum Number of FPLMTS Terminals Allowable for Interference into IRIDIUM Satellite

If the potential interference from the FPLMTS terminals is set equal to the allowable interference into the IRIDIUM mobiles, with the number of FPLMTS terminals, m, set equal to 1, then the minimum distance, d, between the IRIDIUM mobile and the FPLMTS terminal would be as shown in Table 4.15.

C/N-C(N+I)	Minimum distance for indoor FPLMTS (km)	Minimum distance for outdoor FPLMTS (km)	Minimum distance for vehicular FPLMTS (km)
0.5 dB	13.0	15.0	45.0
1.0 dB	12.4	14.0	38.8

Table 4.15: Minimum Separation Distance between FPLMTS Terminals and IRIDIUM Mobiles

4.2.4 Interference Between MSAT and FPLMTS

The potential interference from the MSAT system into the FPLMTS system and from the FPLMTS system into the MSAT system is shown in Table 4.16. The potential interference includes factors which take into account the ratio of the bandwidths, the number of interfering transmitters, and the percentage of time the interferer is transmitting. All MSAT and FPLMTS transmitters are assumed to be able to transmit 100% of the time, which gives a 0 dB time factor (10 log P). The Q-factors are as defined for Table 4.13 with the bandwidth of 7 KHz used for both the MSAT satellite and mobiles.

Potential interference from MSAT satellite into FPLMTS terminal

	Indoor FPLMTS terminal	Outdoor FPLMTS terminal	Vehicular FPLMTS
10 log Q (dB)	8.5	8.5	5.5
10 log DF (dB)	0.0	0.0	0
10 log P (dB)	0.0	0.0	0
EIRP (dBW)	30.5	30.5	30.5
Losses (dB)	190.9	190.9	190.9
Potential interference (dBW)	-151.9	-151.9	-154.9

Potential interference from MSAT mobile into FPLMTS terminal

	Indoor FPLMTS terminal	Outdoor FPLMTS terminal	Vehicular FPLMTS
10 log Q (dB)	8.5	8.5	5.5
10 log DF (dB)	10 log m	10 log m	10 log m
10 log P (dB)	0.0	0.0	0.0
EIRP (dBW)	14.7	14.7	14.7
Losses (dB)	f(d)	f(d)	f(d)
Potential interference (dBW)	10 log m + 23.2 - f(d)	10 log m + 23.2 - f(d)	10 log m + 20.2 - f(d)

Potential interference from FPLMTS terminal into MSAT satellite

	Indoor FPLMTS terminal	Outdoor FPLMTS terminal	Vehicular FPLMTS
10 log Q (dB)	-8.5	-8.5	-5.5
10 log DF (dB)	10 log n	10 log n	10 log n
10 log P (dB)	0.0	0.0	0
EIRP (dBW)	-25.0	-17.0	10
Losses (dB)	190.9	190.9	190.9
Potential interference (dBW)	10 log n - 224.4	10 log n - 216.4	10 log n - 186.4

Potential interference from FPLMTS terminal into MSAT mobile

	Indoor FPLMTS terminal	Outdoor FPLMTS terminal	Vehicular FPLMTS
10 log Q (dB)	-8.5	-8.5	-5.5
10 log DF (dB)	10 log n	10 log n	10 log n
10 log P (dB)	0.0	0.0	0.0
EIRP (dBW)	-25.0	-17.0	10.0
Losses (dB)	f(d)	f(d)	f(d)
Potential interference (dBW)	10 log n - 33.5 - f(d)	10 log n - 25.5 - f(d)	10 log n + 4.5 - f(d)

f(d) in dB is the loss between an MSAT mobile and an FPLMTS terminal,
d is in kilometers, EIRPs and losses are at 2 GHz,
n is the number of FPLMTS terminals, and m is the number of MSAT mobiles.

Table-4.16 Potential interference between FPLMTS and MSAT systems

The number of FPLMTS terminals is defined by n and the number of MSAT mobiles is defined by m.

4.2.4.1 Interference from MSAT System

Since the MSAT system employs two different frequency bands, the interfering scenarios would be between the MSAT mobile and the FPLMTS terminal, and between the MSAT satellite and the FPLMTS terminal.

If the potential interference from the MSAT satellite is set equal to the allowable interference into the FPLMTS terminals then the maximum range, r, between the FPLMTS terminal and its base would be 33.7m, 158.4m, and 6.8 km for the indoor, outdoor, and vehicular terminals respectively.

Table 4.16 illustrates the potential interference from the MSAT mobile terminals into the FPLMTS terminals, and is given by:

for Indoor and Outdoor:

$$I_{potential} = 10 \log m + 23.2 - f(d)$$

for Vehicular:

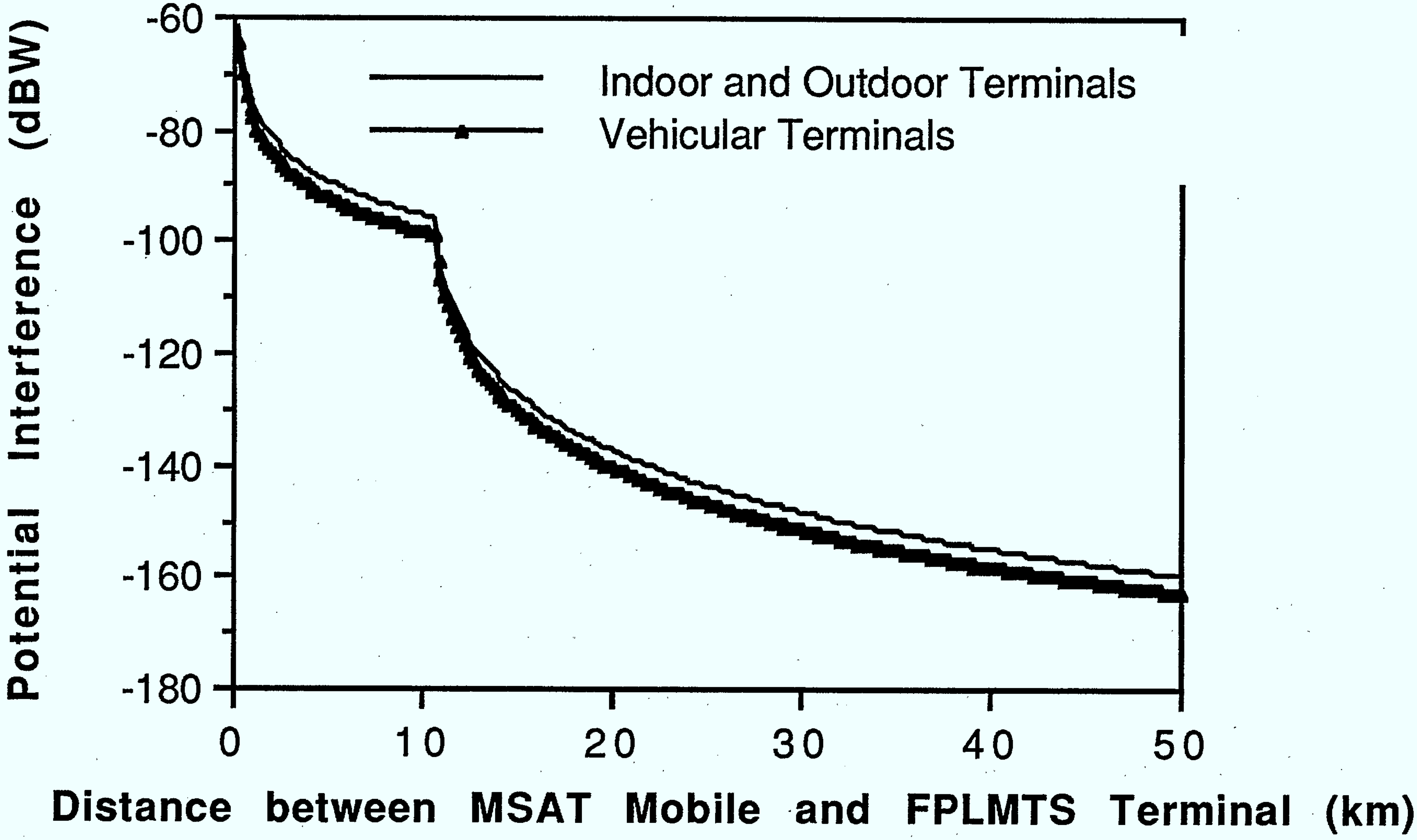
$$I_{potential} = 10 \log m + 20.2 - f(d)$$

Figure 4.8 illustrates graphically the potential interference versus the separation distance between the FPLMTS terminal and the MSAT mobile. Both MSAT and FPLMTS terminals are assumed to be 1.5m in height.

4.2.4.2 Interference from FPLMTS Terminals

If the potential interference from n FPLMTS terminals into the MSAT satellite is set equal to the allowable interference into the MSAT satellite then the maximum number of FPLMTS terminals, n, would be as shown in Table 4.17.

Figure 4.8: Potential Interference into FPLMTS Terminals from MSAT Mobile



C/N-C(N+I)	Maximum no. of indoor terminals	Maximum no. of outdoor terminals	Maximum no. of vehicular terminals
0.5 dB	323,593	51,286	51
1.0 dB	676,082	107,151	107

Table 4.17: Maximum Number of FPLMTS Terminals Allowable for Interference into MSAT Satellite

If the potential interference from an FPLMTS terminal into an MSAT mobile is set equal to the allowable interference into the MSAT mobile then the minimum distance, d, between them would be as shown in Table 4.18.

C/N-C(N+I)	Minimum distance for indoor FPLMTS (km)	Minimum distance for outdoor FPLMTS (km)	Minimum distance for vehicular FPLMTS (km)
0.5 dB	12.5	14.4	40.6
1.0 dB	12.0	13.6	35.2

Table 4.18: Minimum Separation Distance between FPLMTS Terminals and MSAT Mobiles

4.2.5 Discussion

The results in Figures 4.6 and 4.7 indicate the interference into the FPLMTS terminals from the IRIDIUM satellite and mobile would be severe for the indoor and outdoor terminals while it would be less severe into the vehicular terminals.

If the IRIDIUM mobile is separated by more than about 15 km from the indoor or outdoor FPLMTS terminals, interference would be mainly due to the IRIDIUM satellite at a level of about -140 dBW. This interference level would limit the indoor FPLMTS terminal to a maximum range of about 16m from its base station. The maximum range for the outdoor terminal would be limited to about 42m. The range of the vehicular terminals would not be limited at all with a potential interference of about -143 dBW when the separation between the IRIDIUM mobile and vehicular terminal is more than 17 km.

When the separation between the IRIDIUM mobile and the FPLMTS terminals is reduced to 5 km, the potential interference into the indoor and outdoor terminals is increased to -109 dBW and -111 dBW for the vehicular terminals. These potential interference levels would reduce the maximum ranges between the FPLMTS terminals and their bases to about 2m for the indoor and outdoor terminals and 48m for the vehicular terminals. These maximum limits on the range of FPLMTS terminals would clearly make the system not feasible to operate.

Interference from the MSAT mobiles into the FPLMTS terminals would reduce the maximum ranges of the FPLMTS terminals even more than the IRIDIUM mobiles. This is due to the increased EIRP levels in the MSAT mobiles.

Interference from the FPLMTS terminals into the IRIDIUM satellite would be severe. Table 4.13 illustrates that the maximum number of interfering indoor FPLMTS terminals would be 389 for a 0.5 dB degradation in the C/N due to interference and 812 for a 1.0 dB degradation. As mentioned in the first report, the expected number of active terminals for the Ottawa area would be about 2400 assuming a population of 600,000, 20% of the population using FPLMTS, and a busy hour traffic of 0.02 E per user. The allowable number of interferers would not be sufficient to handle the possible number of interferers. Likewise for the outdoor and vehicular terminals, the number of allowable interfering terminals is less than the number for indoor terminals. In the case of the vehicular terminals, no interferers would be acceptable.

Interference from the FPLMTS terminals into the IRIDIUM mobiles would also put an impossible sharing condition on the two systems. The minimum distance between the IRIDIUM mobile and the FPLMTS terminals would have to be about 13km, 15km, and 45km for the indoor, outdoor, and vehicular terminals respectively for a 0.5 dB degradation in C/N due to interference. These distances would be reduced slightly to 12.4km, 14km, and 38.8km for a 1.0 dB degradation.

Interference from the FPLMTS terminals into the MSAT satellite would not be as severe as into the IRIDIUM satellite. The maximum number of indoor interfering terminals would be 323,593 for a 0.5 dB degradation in the C/N due to interference. Assuming that one of the MSAT beams covers a quarter of the population of Canada, the total number of possible users would be 25,000,000/4 = 6,250,000 people. Assuming again that 20% of the population would use the FPLMTS terminals and a busy traffic hour of 0.02 E per user, the possible number of interferers would be 25,000. This means that interference should not be a problem into the MSAT satellite except from the vehicular terminals where very few interferers would be allowed. This is mainly due to the much higher EIRP levels of the vehicular terminals.

Interference from the FPLMTS terminals into the MSAT mobiles would also be a limiting sharing factor. The minimum separation distances between the FPLMTS terminals and the MSAT mobiles would be slightly less than those with the IRIDIUM mobiles. However distances would still be about 12.5km, 14.4km, and 40.6km for the indoor, outdoor, and vehicular terminals respectively for a 0.5 dB degradation in C/N due to interference.

4.3 Conclusions

Sharing between the FS and the MSS at 2 GHz would be difficult. Interference from the IRIDIUM mobiles and the MSAT mobiles into the terrestrial stations would require that the mobiles be beyond the radio horizon in order for sharing to be possible. In addition, the interference from the terrestrial stations into the IRIDIUM and MSAT satellites would be more than acceptable.

Sharing between the FPLMTS and the MSS at 2 GHz would also be very difficult. Interference from the IRIDIUM and MSAT systems would reduce the maximum range of operation the FPLMTS mobiles could operate from their base stations to an impractical range. Interference from the FPLMTS terminals would also require a large separation distance between the FPLMTS terminals and the IRIDIUM and MSAT mobiles.

5. TASK 4 - FEASIBILITY STUDY OF USING 2.5 GHz BAND FOR MSS

5.1 INTRODUCTION

There are many operating and planned mobile satellite systems which use the conventional L-band (1.6 GHz uplink, 1.5 GHz downlink) for their mobile terminal-satellite links. This band is heavily used and frequency coordination between different systems are challenging tasks. WARC 92 has allocated new spectrum for the mobile satellite services (MSS). Region 2 gets a total of 114.5+111.5 MHz of new primary allocation and 40+40 MHz allocation at frequency bands below 3 GHz for MSS. Among these new allocations, the band 2500-2520 MHz downlink and 2670-2690 MHz uplink are allocated to MSS world-wide on a primary basis effective on January 1st, 2005.

Using assumptions based on present technologies, the following analysis addresses the feasibility of using the spectrum around 2.5 GHz for MSS. Based on the results of this analysis, providing voice and data mobile satellite services seems feasible in this frequency band. However, the 2.5 GHz band seem less attractive than the L-band for satellite systems that intend to provide services to handheld terminal with omni-directional antenna due to the higher free space path loss in the S-band.

5.2 METHODOLOGY

Link analysis for the voice and data services will be carried out to determine the power requirement assuming that these services are to be provided, at S-band, by an MSAT-type GSO system to vehicle mounted terminals and by an IRIDIUM-type LEO system to handheld terminals. The new power requirement will then be compared with the present power requirement for the same voice carrier over the

MSAT satellite. To limit the scope of the study, the 6.4 kbps digital voice carrier with C/N threshold level of 9.0 dB and three hypothetical data carriers - 4.8 kbps and 2.4 kbps data carriers on the reverse link and a 56 kbps forward link - are to be investigated.

An overall link margin of 4 dB is assumed for the S-band operation in this analysis. This is the same link margin used for MSAT.

5.3 SYSTEM CONFIGURATION

Figures 1a and 1b show the GSO and LEO system configuration under study, respectively. For the data services, the forward link carrier will be a continuous 56kbps TDM carrier. Whereas the mobile terminals will access the satellite on the reverse link through either 4.8 or 2.4 kbps carrier. 6.4 kbps SCPC/DAMA carrier is proposed for the voice service. Section 5.3.1 below briefly describes the communication system parameters of the satellites. The carrier parameters and the terminal characteristics are described in Section 5.3.2 and 5.3.3, respectively.

5.3.1 Satellite Communication System Parameters

The communication systems of the satellites in this analysis are assumed to be the same as those of MSAT and IRIDIUM except that S-band, instead of L-band, will be used for the user links. Since the service area is to be kept the same, increasing frequency from 1.5 GHz to 2.5 GHz band would not result in any change in the satellite antenna gain. There might be a slight increase in the LNA noise temperature in the satellite receive system but this increase is insignificant as compared to the total system noise temperature. Thus, for all practical purposes, we can assume that the S-band satellite antenna transmit gain and the satellite G/T remain the same as those of the L-band systems. The feeder links for the GSO system is at Ku-band and for the LEO system, Ka-band is used.

The satellite transmit antenna gain and G/T values at the edge of coverage as well as the path lengths are listed below:

	GSO	LEO
S-band Transmit Antenna Gain (dBi)	31	8
S-band Antenna G/T (dB/K)	2.7	-19
Feeder Link Antenna G/T (dB/K)	-3.6	-10
User Link Frequency (Up/Down in GHz)	2.68/2.51	2.68/2.51
Feeder Link Frequency (Up/Down in GHz)	13.1/10.8	30/20
Path Length to Hub Station (km)	38300	850
Path Length to Mobile Terminal (km)	40300	850

Table 5.1: Satellite Parameters

5.3.2 Carrier Parameters

The parameters for the voice and data carriers are summarized below. The 56kbps carrier is the forward link TDM carrier.

Carrier	Mod.	Bit Rate	FEC Rate	Noise BW	Threshold C/N
Voice	BPSK	6.4kbps	7/8	7.0 kHz	9.0 dB
2.4kbps data	BPSK	2.4kbps	1/2	2.6 kHz	7.5 dB
4.8kbps data	BPSK	4.8kbps	1/2	5.3 kHz	7.5 dB
56kbps data	BPSK	56kbps	1/2	62.0kHz	7.7 dB

Table 5.2: Carrier Parameters

5.3.3 Terminal Characteristics

This study addresses two types terminal, one for each of the two types of orbit : vehicle mounted terminal for GSO system and handheld terminal for LEO system. As above, the transmit antenna gain and the receive G/T of the terminals are assumed to be the same as those used in MSAT and IRIDIUM. The reason for this assumption is not, however, to keep the beams size (hence coverage area) the same but it is a technical one which is explained below.

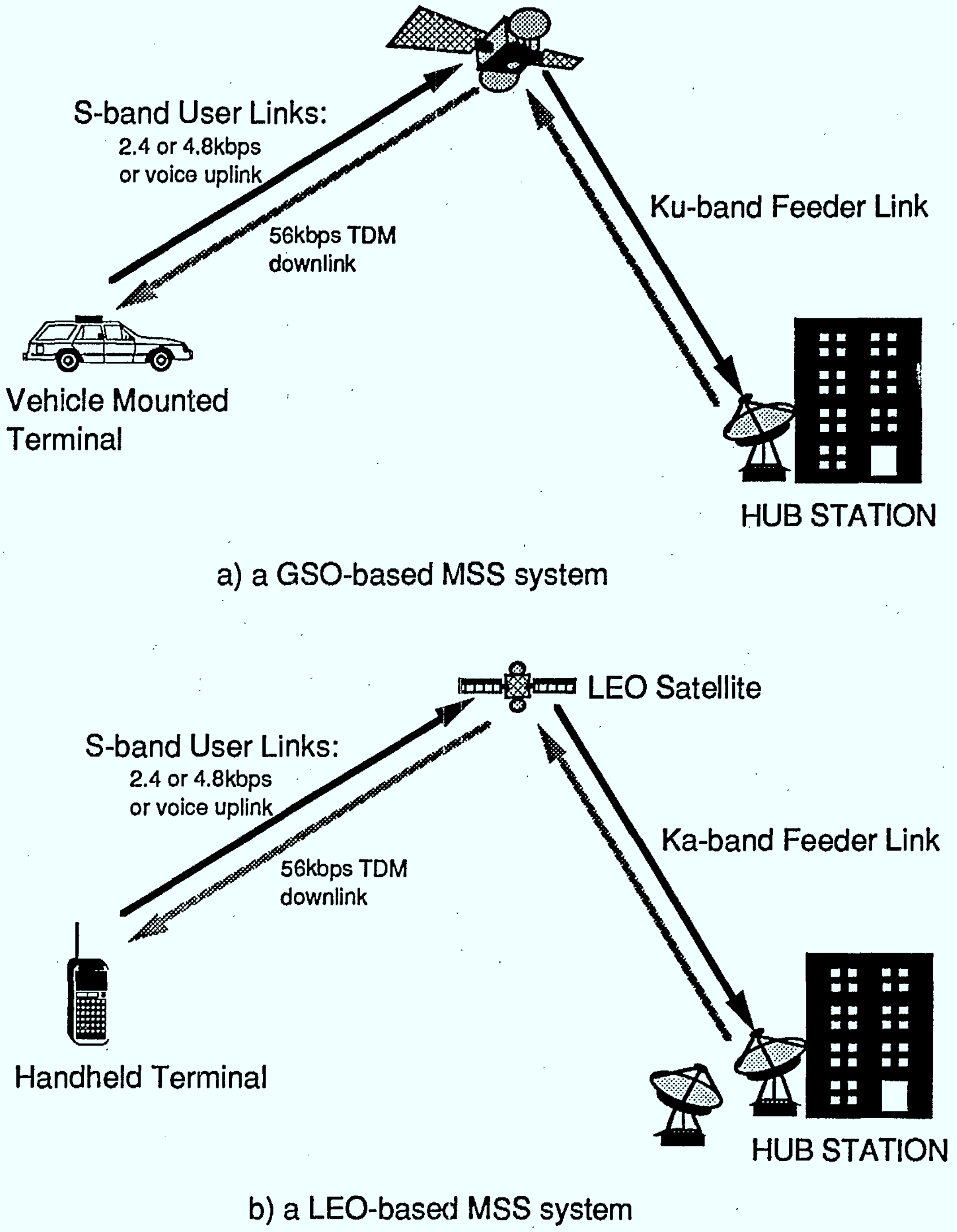
The directivity of antennas of the aperture type (e.g. parabolic dish and phase array antennas) is proportional to the square of the operating frequency; but the size and not the gain of a half-dipole or array of dipoles, for example, would depend on the frequency of operation. Thus, the gain of a half-dipole antenna used in handheld terminals would be about that of an isotropic antenna at any frequency. This study assumes that the antenna gain for the handheld terminal is -1 dBi.

It is envisaged that the antenna of a vehicle mounted terminal would be some kind of phase array. Moving from L-band to S-band and keeping the antenna size the same to increase the gain would result in more costly antenna since more radiating elements and phase shifters would be required. To keep the same number of elements and phase shifter and hence cost of the antenna, the antenna size would be reduced and the gain remain the same as that at L-band.

The following table lists the terminal's antenna gain and G/T.

	Vehicle Mounted Terminal	Handheld Terminal
Transmit Gain (dBi)	9.5	-1.0
Receive G/T (dB/K)	-16.0	-26.75

Table 5.3: Terminal Antenna Gain and G/T



	Voice *	Data
Forward Link	6.4kbps SCPC	56kbps TDM
Reverse Link	6.4kbps SCPC	1.2 or 2.4kbps SCPC

* Voice Service is not available for handheld terminals

Figure 5.1: Configuration for MSS systems

5.4. ANALYSIS

5.4.1 Interference Assumptions

The following tables list the carrier-to-interference ratios for the three proposed carrier types. Note that the downlink carrier-to-intermodulation noise ratios are computed based on the assumption that the NPR is 16 dB and that voice activation reduces the intermodulation noise level by 3 dB.

	56kbps		Voice	
FORWARD LINK	Up	Down	Up	Down
GSO System				
Adjacent Beam & Satellite	30	20	30	20
Intermodulation	25	19	25	19
LEO System				
Adjacent Beam & Satellite	∞	20	∞	20
Intermodulation	25	19	25	19

	2.4kbps		4.8kbps		Voice	
REVERSE LINK	Up	Down	Up	Down	Up	Down
GSO System						
Adjacent Beam & Satellite	20	30	20	30	20	30
Intermodulation	∞	19	∞	19	∞	19
LEO System						
Adjacent Beam & Satellite	20	∞	20	∞	20	∞
Intermodulation	∞	19	∞	19	∞	19

Table 5.4: Interference Assumptions

5.4.2 Results

The detailed link calculations for the various carrier types are given in Tables 5.6 to 5.11. The total link margin is set at 4 dB for all link. Since the terminal antenna gain is small thus the S-band links to and from the terminal are the limiting factors. As a result, we would be interested only in the power requirement at S-band. The power levels at S-band required on the uplink and downlink for the proposed carriers are summarized in the table below. For purpose of comparison, the actual power requirements for the MSAT voice carrier at L-band are also given in the last row of the table.

Carrier Type	System	Uplink EIRP (dBW)	Uplink RF Power (watts)	Downlink EIRP (dBW)	Downlink RF Power (watts)
2.4kbps Data	MSAT-Type GEO	9.70	1.02	-	-
	IRIDIUM-Type LEO	-1.10	0.92	-	-
4.8kbps Data	MSAT-Type GEO	12.70	2.04	-	-
	IRIDIUM-Type LEO	2.00	1.88	-	-
56kbps Data	MSAT-Type GEO	-	-	41.76	11.91
	IRIDIUM-Type LEO	-	-	20.36	13.68
Digital Voice	MSAT-Type GEO	16.40	4.78	35.06	2.55
	IRIDIUM-Type LEO	5.60	4.32	13.56	2.86
Digital Voice (L-band)	MSAT	12.3	1.86	30.6	0.91

Table 5.5: User-link Power Requirements

It can be seen from the above table that the space segment power requirement to provide voice and data services using a GSO-based satellite system seems achievable. However, the power required from the handheld terminal for the voice service in the LEO system is rather high. Assuming that the DC-to-RF efficiency is 25% then to provide 4.32 watts of RF power would require 17.28 watts of DC power. This requirement exceeds the capacity of most batteries of handheld size.

5.4.3 Capacity Comparison for L-band and S-band Systems

Assuming that the size of the satellites in the L-band and S-band are the same. The power output from the satellites would be similar. Table 5.5 shows that the downlink EIRP for a voice carrier is 30.6 dBW and 35.06 dBW for L-band and S-band GSO-based systems, respectively. Thus, in this case, there would be a reduction of 2.8 times (4.46 dB) in system capacity if S-band is used instead of L-band. The same conclusion would apply to LEO-based systems.

We have assumed that the S-band mobile terminal antenna gain remains the same as for that at L-band. Thus the 2.8 times reduction in capacity is the direct result of higher free space path loss of the S-band frequencies. For the vehicle mounted antenna operate in the GSO-based systems, the antenna size can be kept the same (but the cost will increase) as frequency increases to compensate for the increase in free space path loss. But for the handheld terminal with linear-type antenna, the effective gain would remain below isotropic level for all frequencies. As a result, S-band seems to be less attractive (than L-band) for LEO systems which is intended to serve handheld terminals.

5.5 CONCLUSIONS

The analysis shows that it seems technically feasible to provide mobile satellite voice and data services at S-band to vehicle mounted terminal. The study indicates that if the gain and hence cost of the vehicle mounted antenna is to remain the same as those at L-band, the capacity of an S-band system of comparable size to a L-band system would be 2.8 times less.

S-band is also less attractive than L-band to system with handheld terminals employing omni-directional antenna, e.g. a LEO-based system, since the terminal antenna gain can not be increased to compensate for the increase path loss in the S-band.

6. REFERENCES

1. Canadian Domestic MSS Spectrum Requirements for the Year 2000-2010, Canadian Preparatory Committee, WARC'92 Frequency Allocation Subcommittee, Mobile/Mobile Satellite Services Working Group, Document FASC-20, MWG 19 Rev. 2.

2. Standard Radio System Plan SRSP-301.9, Issue 2, Technical Requirements for line-of-sight radio systems operating in the fixed service in the band 1900-2290 MHz, Government of Canada, 9 November 1985.

3. AD HOC Group Sub-Committee D Radio-Relay Committee Proposal, Interference Objectives & Coordination Criteria 3700-4200 MHz/5925-6425 MHz Between the FSS and FS using Digital Modulation, July 1992.

4. MOTOROLA's IRIDIUM FCC Filing, December 1990.

5. MINOR AMENDMENT to MOTOROLA's IRIDIUM FCC Filing, August 1992

6. Feasibility Study of Spectrum Sharing Between LEO/MSS and GSO/MSS and Fixed Services and FPLMTS, Telesat Canada, 25 April 1991.

Appendix 1 - Changes to Article 8 from 1-10 GHz affecting MSS, FS, and MS

1492-1525 MHz Region 2
Mobile-Satellite (space-to-Earth) added as Primary
Footnote 722B added

1525-1530 MHz Region 1
Maritime Mobile-Satellite (space-to-Earth) added as Primary
Land Mobile-Satellite (space-to-Earth) added as Secondary
Footnote 723B added
Footnote 726A modified
Footnote 726X added

1525-1530 MHz Region 2
Mobile-Satellite (space-to-Earth) added as Primary
Footnote 726A modified
Footnote 726X added

1525-1530 MHz Region 3
Mobile-Satellite (space-to-Earth) added as Primary
Footnote 726A modified
Footnote 726X added

1530-1533 MHz Region 1
Footnote 723B added
Footnote 726X added
Footnote 726 deleted

1530-1533 MHz Regions 2 and 3
Footnote 726 deleted
Footnote 726C added
Footnote 726X added

1533-1535 MHz Region 1
Footnote 726B added
Footnote 726X added

1533-1535 MHz Regions 2 and 3
Footnote 726 deleted
Footnote 726C added
Footnote 726X added

1535-1544 MHz Regions 1,2, and 3
Footnote 726C added
Footnote 726X added

1544-1545 MHz Regions 1,2, and 3
Footnote 726X added

1545-1555 MHz Regions 1,2, and 3
Footnote 726X added

1555-1559 MHz Regions 1,2 and 3
Footnote 726X added
Footnote 730B added
Footnote 730C added

1610-1610.6 MHz Region 1
Mobile-Satellite (Earth-to-space) added as Primary
Footnote 731X added
Footnote 731A deleted
Footnote 731B deleted
Footnote 731D deleted

1610-1610.6 MHz Region 2
Mobile-Satellite (Earth-to-space) added as Primary
Footnote 731X added
Footnote 731B deleted
Footnote 731C deleted

1610-1610.6 MHz Region 3
Mobile-Satellite (Earth-to-space) added as Primary
Footnote 731X added
Footnote 731B deleted
Footnote 731C deleted

1610.6-1613.8 MHz Region 1
Mobile-Satellite (Earth-to-space) added as Primary
Footnote 731X added
Footnote 731A deleted
Footnote 731B deleted
Footnote 731D deleted

1610.6-1613.8 MHz Region 2
Mobile-Satellite (Earth-to-space) added as Primary

Footnote 731X added
Footnote 731B deleted
Footnote 731C deleted

1610.6-1613.8 MHz Region 3
Mobile-Satellite (Earth-to-space) added as Primary
Footnote 731X added
Footnote 731B deleted
Footnote 731C deleted

1613.8-1626.5 MHz Region 1
Mobile-Satellite (Earth-to-space) added as Primary
Mobile-Satellite (space-to-Earth) added as Secondary
Footnote 731X added
Footnote 731Y added
Footnote 731A deleted
Footnote 731B deleted
Footnote 731C deleted

1613.8-1626.5 MHz Region 2
Mobile-Satellite (Earth-to-space) added as Primary
Mobile-Satellite (space-to-Earth) added as Secondary
Footnote 731X added
Footnote 731Y added
Footnote 731B deleted
Footnote 731C deleted

1613.8-1626.5 MHz Region 3
Mobile-Satellite (Earth-to-space) added as Primary
Mobile-Satellite (space-to-Earth) added as Secondary
Footnote 731X added
Footnote 731Y added
Footnote 731B deleted
Footnote 731C deleted

1626.5-1631.5 MHz Region 1
Footnote 726X added

1626.5-1631.5 MHz Region 2 and 3
Maritime Mobile-Satellite deleted
Land Mobile-Satellite deleted
Mobile-Satellite (Earth-to-space) added as Primary
Footnote 726C added

Footnote 726X added
Footnote 726B deleted

1631.5-1634.5 MHz Region 1,2, and 3
Footnote 726C added
Footnote 726X added

1645.5-1646.5 MHz Region 1,2, and 3
Footnote 726X added

1656.5-1660 MHz Region 1,2, and 3
Footnote 726X added
Footnote 730B added
Footnote 730C added

1660-1660.5 MHz Regions 1,2, and 3
Footnote 726X added
Footnote 730B added
Footnote 730C added

1675-1690 MHz Region 2
Mobile-Satellite (Earth-to-space) added as Primary
Footnote 735A added

1690-1700 MHz Region 2
Mobile-Satellite (Earth-to-space) added as Primary
Footnote 735A added

1700-1710 MHz Region 2
Mobile-Satellite (Earth-to-space) added as Primary
Footnote 735A added

1930-1970 MHz Region 2
Mobile-Satellite (Earth-to-space) added as Secondary
Footnote 746A added

1970-1980 MHz Region 2
Mobile-Satellite (Earth-to-space) added as Primary
Footnote 746A added
Footnote 746U added
Footnote 746X added

1980-2010 MHz Region 1,2, and 3

Mobile-Satellite (Earth-to-space) added as Primary
Footnote 746A added
Footnote 746U added
Footnote 746X added

2120-2160 MHz Region 2
Mobile-Satellite (space-to-Earth) added as Secondary
Footnote 746A added

2160-2170 MHz Region 2
Mobile-Satellite (space-to-Earth) added as Primary
Footnote 746A added
Footnote 746U added
Footnote 746X added

2170-2200 MHz Region1,2, and 3
Mobile-Satellite (space-to-Earth) added as Primary
Footnote 746A added
Footnote 746U added
Footnote 746X added

2483.5-2500 MHz Region 1
Mobile-Satellite (space-to-Earth) added as Primary
Footnote 753 added
Footnote 753X added
Footnote 753E deleted

2483.5-2500 MHz Region 2
Mobile-Satellite (space-to-Earth) added as Primary
Footnote 753X added

2483.5-2500 MHz Region 3
Mobile-Satellite (space-to-Earth) added as Primary
Footnote 753X added

2500-2520 MHz Region 1
Broadcasting-Satellite deleted
Mobile-Satellite (space-to-Earth) added as Primary
Footnote 754 added
Footnote 754B added
Footnote 755A added
Footnote 760X added

2500-2520 MHz Region 2 and 3
Broadcasting-Satellite deleted
Mobile-Satellite (space-to-Earth) added as Primary
Footnote 754 added
Footnote 755A added
Footnote 760X added

2670-2690 MHz Region 1
Broadcasting-Satellite deleted
Mobile-Satellite (Earth-to-space) added as Primary
Footnote 764A added
Footnote 766 added

2670-2690 MHz Region 2
Broadcasting-Satellite deleted
Mobile-Satellite (Earth-to-space) added as Primary
Footnote 764A added
Footnote 766 added

2670-2690 MHz Region 3
Broadcasting-Satellite deleted
Mobile-Satellite (Earth-to-space) added as Primary
Footnote 764A added
Footnote 766 added

Footnotes

722B
Alternative allocation: in the United States of America, the band 1452-1525 MHz is allocated to the fixed and mobile services on a primary basis (See also No. 723).

723B
Additional allocation: in Belarus, the Russian Federation and Ukraine, the band 1429-1535 MHz is also allocated to the aeronautical mobile service on a primary basis exclusively for the purposes of aeronautical telemetry within the national territory. As of 1 April 2007, the use of the band 1452-1492 MHz is subject to agreement between the administrations concerned.

726A
The bands 1525-1544 MHz, 1545-1559 MHz, 1626.5-1645.5 MHz and 1646.5-1660.5 MHz shall not be used for feeder links of any

service. In exceptional circumstances, however, an earth station at a specified fixed point in any of the mobile-satellite services may be authorized by an administration to communicate via space stations using these bands.

726C

Additional allocation: in Argentina, Australia, Brazil, Canada, the United States, Malaysia and Mexico, the band 1530-1544 MHz is also allocated to the mobile-satellite (space-to-Earth) service, and the band 1626.5-1645.5 MHz is also allocated to the mobile-satellite (Earth-to-space) service, on a primary basis subject to the following conditions: maritime mobile-satellite distress and safety communications shall have priority access and immediate availability over all other mobile satellite communications operating under this provision. Communications of mobile-satellite system stations not participating in the global maritime distress and safety system (GMDSS) shall operate on a secondary basis to distress and safety communications of stations operating in the other mobile-satellite services.

726X
The use of the bands 1525-1559 and 1626.5-1660.5 MHz by the mobile-satellite services are subject to the application of the coordination and notification procedures set forth in Resolution COM5/8. In Regions 1 and 3 in the band 1525-1530 MHz coordination of space stations of the mobile-satellite services with respect to terrestrial services is required only if the power flux-density produced at the Earth's surface exceeds the limits in No. 2566. In respect of assignments operating in the band 1525-1530 MHz, the provisions of Section II, paragraph 2.2 of Resolution COM5/8 shall also be applied to geostationary transmitting space stations with respect to terrestrial stations.

730B
Alternative allocation: in Australia, Canada and Mexico, the band 1555-1559 MHz is allocated to the mobile-satellite (space-to-Earth) service, the band 1656.5-1660 MHz is allocated to the mobile-satellite (Earth-to-space) service, and the band 1660-1660.5 MHz is allocated to the mobile-satellite (Earth-to-space) and the radio astronomy services, on a primary basis.

730C

Alternative allocation: in Argentina and the United States, the band 1555-1559 MHz is allocated to the mobile-satellite (space-to-Earth) service, the band 1656.5-1660 MHz is allocated to the mobile-satellite (Earth-to-space) service, and the band 1660-1660.5 MHz is allocated to the mobile-satellite (Earth-to-space) and the radio astronomy services, on a primary basis subject to the following conditions: the aeronautical mobile-satellite (R) service shall have priority access and immediate availability over all other mobile-satellite communications within a network operating under this provision; mobile-satellite systems shall be interoperable with the aeronautical mobile-satellite (R) service; account shall be taken of the priority of safety-related communications in the other mobile-satellite services.

731X

The use of the band 1610-1626.5 MHz by the mobile-satellite service (Earth-to-space) and by the radiodetermination-satellite service (Earth-to-space) is subject to the application of the coordination and notification procedures set forth in Resolution COM5/8. A mobile earth station operating in either of the services in this band shall not produce an e.i.r.p. density in excess of -15 dBW/4 kHz in the part of the band used by systems operating in accordance with the provisions of No. 732, unless otherwise agreed by the affected administrations. In the part of the band where such systems are not operating, a value of -3 dBW/4kHz is applicable. Stations of the mobile-satellite service shall not cause harmful interference to, or claim protection from, stations in the aeronautical radionavigation service, stations operating in accordance with the provisions of No. 732 and stations in the fixed service operating in accordance with the provisions of No. 730.

731 Y

The use of the band 1613.8-1626.5 MHz by the mobile-satellite service (space-to-earth) is subject to the application of the coordination and notification procedures set forth in Resolution COM5/8.

735A

In the band 1675-1710 MHz, stations in the mobile-satellite service shall not cause harmful interference to, nor constrain the development of, the meteorological aids services (see Resolution COM 4/X) and the use of this band shall be subject to the provisions of Resolution COM5/8.

746X

The use of the band 1970-2010 MHz and 2160-2200 MHz by the mobile-satellite service shall not commence before 1 January 2005 and is subject to the application of the coordination and notification procedures set forth in Resolution COM 5/8. In the band 2160-2200 MHz coordination of space stations of the mobile-satellite service with respect to terrestrial services is required only if the power flux-density produced at the Earth's surface exceeds the limits in No. 2566. In respect of assignments operating in this band, the provisions of Section II, paragraph 2.2 of Resolution COM 5/8 shall also be applied to geostationary transmitting space stations with respect to terrestrial stations.

746U

In the United States of America, the use of the bands 1970-2010 MHz and 2160-2200 MHz by the mobile-satellite service shall not commence before 1 January 1996.

746A

The frequency bands 1885-2025 MHz and 2110-2200 MHz are intended for use, on a world-wide basis by administrations wishing to implement the future public land mobile telecommunications systems (FPLMTS). Such use does not preclude the use of these bands by other services to which these bands are allocated.

The frequency bands should be made available for FPLMTS in accordance with Resolution COM 4/4.

753X

The use of the band 2483.5-2500 MHz by the mobile-satellite and the radiodetermination-satellite services is subject to the application of the coordination and notification procedures set forth in Resolution COM 5/8. Coordination of space stations of the mobile-satellite and radiodetermination-satellite services with respect to terrestrial services is required only if the power flux-density produced at the Earth's surface exceeds the limits in No. 2566. In respect of assignments operating in this band, the provisions of Section II, paragraph 2.2 of Resolution COM 5/8 shall also be applied to geostationary transmitting space stations with respect to terrestrial stations.

753

Different category of service: in France, the band 2450-2500 MHz is allocated on a primary basis to the radiolocation service (see No. 425). Such use is subject to agreement with administrations having services operating or planned to operate in accordance with the Table of Frequency Allocations which may be affected.

760X
The allocation of the frequency band 2500-2520 MHz to the mobile-satellite service shall be effective 1 January 2005 and is subject to the application of the coordination and notification procedures set forth in Resolution COM 5/8. Coordination of space stations of the mobile-satellite service with respect to terrestrial services is required only if the power flux-density produced at the Earth's surface exceeds the limits in No. 2566. In respect of assignments operating in this band, the provisions of Section II, paragraph 2.2 of Resolution COM 5/8 shall also be applied to geostationary transmitting space stations with respect to terrestrial stations.

755A
In the band 2500-2520 MHz, the power flux-density at the surface of the Earth from space stations operating in the mobile-satellite (space-to-Earth) service shall not exceed -152 dB(W/m2/4 kHz) in Argentina, unless otherwise agreed by the administrations concerned.

754
Subject to agreement obtained under the procedure set forth in Article 14, the band 2520-2535 MHz (until 1 January 2005 the band 2500-2535 MHz) may also be used for the mobile-satellite (space-to-Earth), except aeronautical mobile-satellite, service for operation limited to within national boundaries. The coordination and notification procedures set forth in Resolution COM 5/8 apply. However, coordination of space stations of the mobile-satellite service with respect to terrestrial services is required only if the power flux-density produced by the station exceeds the limits in No. 2566.

764A
The allocation of the frequency band 2670-2690 MHz to the mobile-satellite service shall be effective from 1 January 2005. When introducing mobile-satellite systems in this band administrations shall take all necessary steps to protect the satellite systems operating in this band prior to 3 March 1992. The coordination of

mobile-satellite systems in the band shall be in accordance with Resolution COM 5/8.

766
Subject to agreement obtained under the procedure set forth in Article 14, the band 2655-2670 MHz (until January 2005 the band 2655-2690 MHz) may also be used for the mobile-satellite (Earth-to-space), except aeronautical mobile-satellite, service for operation limited to within national boundaries. The coordination and notification procedures set forth in Resolution COM 5/8 apply.

Appendix 2 - Frequency Bands Allocated to Mobile Satellite Service

Band (MHz)	Direction	Comments
1492-1525	space-to-Earth	MSS
1525-1530	space-to-Earth	MSS
1530-1533	space-to-Earth	LMSS - secondary to GMDSS
1533-1535	space-to-Earth	MMSS LMSS (secondary) limited to non-speech low-rate data
1535-1544	space-to-Earth	MMSS LMSS (secondary) limited to non-speech low-rate data
1544-1545	space-to-Earth	MSS limited to distress and safety communications
1545-1555	space-to-Earth	AMSS(R)
1555-1559	space-to-Earth	LMSS MSS (in Canada)
1610-1610.6	Earth-to-space	MSS - see Note 1
1610.6-1613.8	Earth-to-space	MSS - see Note 1
1613.8-1626.5	Earth-to-space	MSS - see Note 1 MSS space-to-Earth secondary
1626.5-1631.5	Earth-to-space	MSS - secondary to GMDSS
1631.5-1634.5	Earth-to-space	MMSS LMSS MSS in Canada but secondary to GMDSS
1634.5-1645.5	Earth-to-space	MMSS LMSS secondary MSS in Canada but secondary to GMDSS
1645.5-1646.5	Earth-to-space	MSS only for distress and safety communications
1646.5-1656.5	Earth-to-space	AMSS(R)
1656.5-1660	Earth-to-space	LMSS
1660-1660.5	Earth-to-space	LMSS
1675-1690	Earth-to-space	MSS - see Note 2
1690-1700	Earth-to-space	MSS - see Note 2
1700-1710	Earth-to-space	MSS - see Note 2
1930-1970	Earth-to-space	MSS secondary
1970-1980	Earth-to-space	MSS
1980-2010	Earth-to-space	MSS
2120-2160	space-to-Earth	MSS secondary

2160-2170	space-to-Earth	MSS
2170-2200	space-to-Earth	MSS
2483.5-2500	space-to-Earth	MSS but must accept harmful interference from ISM service
2500-2520	space-to-Earth	MSS
2520-2535	space-to-Earth	MSS but no AMSS limited to operation within national boundaries
2655-2670	Earth-to-space	MSS but no AMSS limited to operation within national boundaries
2670-2690	Earth-to-space	MSS

Note 1: Mobile earth terminals are limited to an EIRP density of -3 dBW/4 kHz in this band and cannot exceed -15 dBW/4 kHz in parts of the band used by systems operating under Footnote 732 (Glonass).

Note 2: Cannot cause harmful interference to or constrain development of meteorological or meteorological aids services

Discussion

The MSAT satellite will use the bands 1530-1559 MHz and 1631.5-1660.5 MHz. This provides 29 MHz for the uplink and 29 MHz for the downlink. These frequency bands are not shared with other non-mobile satellite services.

New bands allocated at WARC-92 which affect the mobile satellite service are 1525-1530 MHz and 1626.5-1631.5 MHz. These bands could provide 5 MHz of uplink and 5 MHz of downlink. These bands are not shared with other non-MSS services.

Also allocated to MSS were the bands 1492-1525 MHz and 1675-1710 MHz. These bands could be used to provide 35 MHz of uplink and 33 MHz of downlink. These bands are shared with the fixed and mobile services.

The bands 1970-2010 and 2160-2200 MHz were also allocated to MSS. These bands could be used for 40 MHz of uplink and 40 MHz of downlink. These bands are shared with the fixed and mobile services.

There are also allocations to the MSS in the bands 1930-1970 MHz and 2120-2160 MHz which could be used to provide 40 MHz of uplink and 40 MHz of downlink. However, these allocations are on a secondary basis and it is doubtful if the MSAT system would ever use these bands.

The bands 2483.5-2535 MHz and 2655-2690 MHz are also allocated to MSS. Both bands are shared with FS and MS, but the higher band is shared with other services such as FSS and BSS and the lower band must accept interference from the ISM services. It is not clear if this band would eventually prove useful for MSAT use.