Telesat

Télésat Canada

TASK NO. 20B
MSAT LINK BUDGET OPTIMIZATION
TASK REPORT

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TASK REPORT

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LINK BUDGET OPTIMIZATION
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1.0 INTRODUCTION

In its continued effort towards planning and implementation of a communication satellite system for provision of mobile service (MSAT), the Federal Department of Communications (DOC) commissioned a series of technical tasks, under the umbrella of the Engineering Support contract, to study specific aspects relating to the basic MSAT system concept.

This task report aims at consolidating and updating the link budgets pertaining to the MSAT system. The link budgets used by Telesat have been presented in various reports and memoranda, such as the Commercial Viability Study (CVS) report [1] and the Business Proposal Appendix B of March 1985 [2]. Since then, Telesat has revised its MSAT concept and issued a new business proposal to include the use of frequencies at around 1600 MHz (generally referred to as L-Band frequencies). A comparison of UHF and L-band for use as MSAT operating frequencies was documented in a Telesat report to DOC [3], and various L-band budgets were worked out. In this report, all the pertinent link budgets (both for UHF and L-Band systems) are presented under one cover.

A considerable amount of work including modulation study, payload and unit development, and link simulation has been done and will continue to be done by the Communication Research Centre (CRC), Telesat, and SPAR to further characterize the MSAT channel. As better information thus becomes available, revisions will be made in the link budgets. The link budgets can, therefore, be considered as "living" or evolving budgets. A recent study by Bell-Northern Research Ltd. (BNR) reported on the subjective evaluation of the voice quality of various modulation methods hitherto proposed for use in MSAT. The results of this study provide a better method of establishing link performance criteria. Further, the study suggests that MTS requirements should be treated differently from MRS requirements.

There are two possible business arrangements for realization of the MSAT services. The first is a joint Canada/U.S.A. cooperative concept, and the other is a stand-alone Canadian domestic system. The cooperative system, which is the preferred system, is a joint venture agreement between Telesat as the Canadian operator and a U.S. operator, whereby joint system development, procurement, launch arrangements and mutual satellite sparing can be implemented. However, each country will own and operate its own satellite and ground segment network including a central control station (CCS). The main advantage of this mode of operation is the elimination of the requirement for in-orbit or ground-based spare satellites by either Canada or the U.S. This joint operation, along with the sharing of non-recurring development costs through joint procurement, results in significant cost savings for both Telesat and the U.S. operator.

It should be reiterated that the current link budgets are based on Telesat's baseline system viewpoint as it stands today based upon Canadian needs in the context of a cooperative system approach, and the current state of the relevant technology. Changes in the baseline may be effected to appropriately respond to technology improvements, as the planning for MSAT progresses to the point of implementation. Also, assuming a Canada/U.S. cooperative system, the final system design will include U.S. requirements and, to this extent, can only be developed once the FCC has selected the U.S. licencee(s).

Although link budgets exist for most of the twelve proposed U.S. systems, they are preliminary and differ in many respects. As such, and since there is no way of knowing which one of the twelve applicants will be selected, their link budgets have not been used to modify Telesat's.

In Section 2, Telesat's current service concept is briefly reviewed. In Section 3, the link budgets for various services are provided. As a justification for the various values of C/N_0 chosen, a discussion of the BNR tests results on subjective voice quality is presented. To obviate any confusion that might exist regarding the service quality of MSAT compared to terrestrial services, it is briefly explained that the UHF fading statistics at 99% probability are equivalent to measured fades in rural areas under the 90% temporal/90% spatial availability criterion sometimes used for terrestrial services.

A brief review of some of the representative link budgets submitted by the U.S. applicants to the FCC is given in Section 4. Finally, in Section 5, several critical areas of concern are discussed. An early resolution of these concerns is imperative if MSAT is to meet its already tight schedule.

2.0 CURRENT MSAT SERVICE CONCEPT

2.1 Introduction

The MSAT system concept previously considered consists of one or two satellites scheduled for launch sometime around 1990, to be placed in geostationary orbit (GEO) at a nominal longitude of between 106 and 113°W. It was intended to provide communication services to mobile and transportable terminals operating in the Ultra-High Frequency (UHF) band at 800 MHz with a backhaul in the Super-High Frequency (SHF) band at 13 GHz (uplink) and 11 GHz (downlink). If the 13/11 GHz backhaul frequencies are unavailable, the 14/12 GHz frequencies may be used. This MSAT concept has been revised to include service at 1600 MHz (L-band) in addition to the UHF service.

Two service scenarios have been considered: One where the satellite system provides service to both Canada and the U.S.A., and the satellites are procured jointly by Canada and the U.S.A; and the other where the satellite system provides service to Canadian users only. This latter system would only be considered in case of failure to realize a Canada/U.S. cooperative arrangement. In the Canada/U.S. cooperative systems, each country owns one satellite which provides service to its own users, but with sufficient built-in capability to act as spare in restoring service to the other nation in the event of a failure. However, the systems are configured such that, even in the event of a failure, all billings and user control are still the responsibility of the parent country. For the stand-alone Canadian system, there would be two satellites in orbit, one operational and one spare. The spare satellite, however, can be activated to carry some traffic in cases of mass/power limited spacecraft such that the total capacity approaches the spectrum limit. The loading degree of the spare satellite is dependent upon the spacecraft reliability and the level of system redundancy demanded by various sectors of MSAT market.

The system will be available to all customers at all times. Even during the eclipse period, the system will accommodate virtually all the expected traffic.

2.2 The Dual-Band Concept

In order to make the MSAT system economically viable, the exiguous amount of spectrum that can realistically be hoped for at UHF must be supplemented by additional spectrum at other bands. It is assumed that spectrum will be made available at L-band, both to increase the system user capacity for the first generation and for growth in second and future generations. However, L-band suffers an extra 5 to 6 dB of excess path loss relative to UHF due to increased shadowing and multipath loss [3]. L-band would, therefore, appear to be particularly suited for applications where high fade margins are not necessary and where high-gain directional antennas may be employed. These include transportable or fixed services, aeronautical mobile and maritime mobile services, and land mobile services to areas of low foliage blockage such as the Prairies and the Northwest Territories and Arctic.

In its current baseline service concept, Telesat has defined two basic classes of service. The first class involves service to land mobile terminals operating under light to moderate shadowing[1], and is often referred to as "true mobile service". Because of the more manageable shadowing losses at UHF compared to L-band, this service is provided at UHF. A satellite carrier level of 26.5 dBW was found to be suitable for service to typical mobile radio users (see Section 3). On the other hand, L-band will be used in areas with no shadowing, or

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1 In heavily shadowed areas, acceptable voice quality cannot be achieved unless extremely high satellite EIRP's are allocated. This would, however, drastically penalize the system user capacity for a given size spacecraft bus.

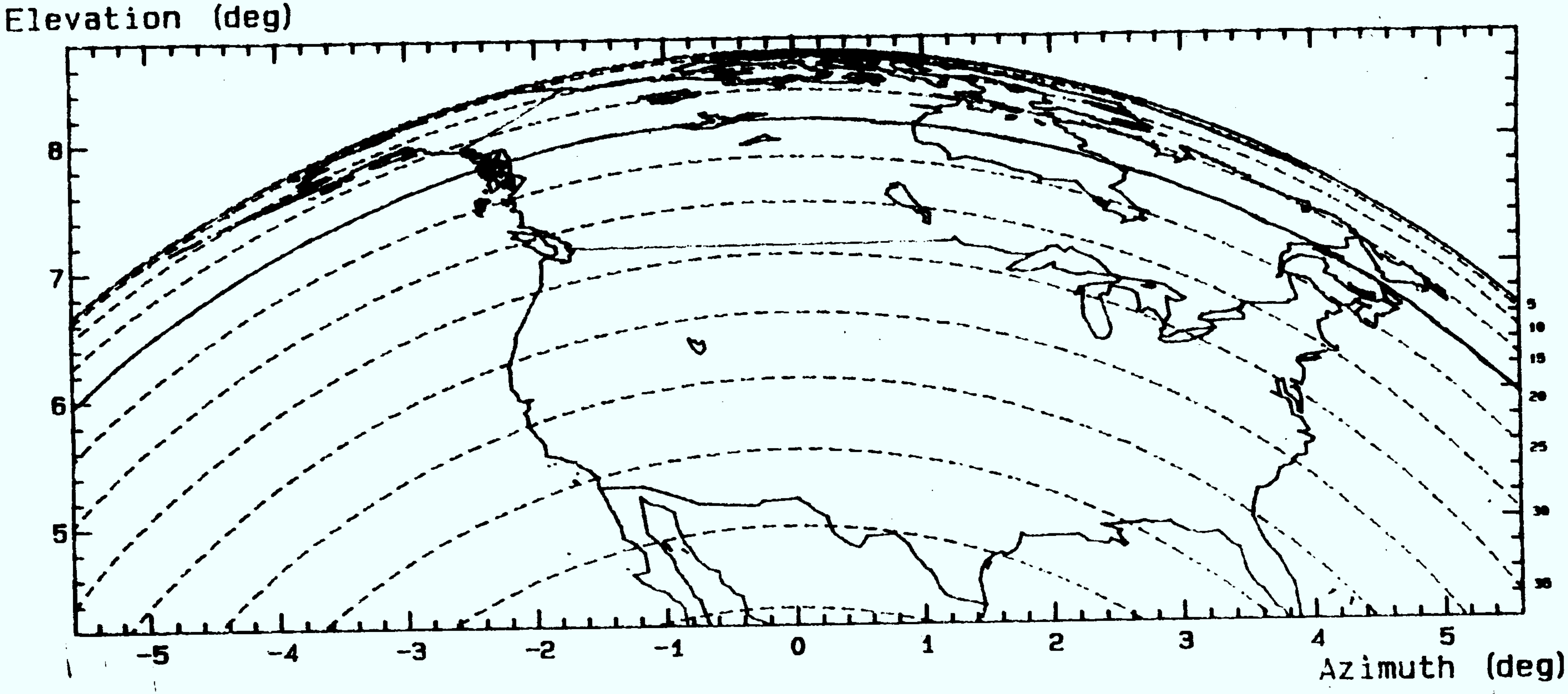
only light shadowing. An L-band satellite carrier level of 28.5 dBW was established to yield similar subjective performance to UHF service for no to light shadowing situations.

2.3 Service Area

The target service area for the Canadian MSAT service includes all of Canada's land mass and coastal waters up to the 200 nautical mile limit. Since a great majority of MSAT potential users are concentrated in areas with elevation angles greater than 20 degrees, a primary service area for true mobile applications (communication while the vehicle is moving) is defined to be limited to areas with elevation angles greater than 20°. Figure 2.1 shows the elevation angles for a satellite at 106.5°W. Note that most of the major areas (with the exception of Newfoundland) have elevation angles greater than 20°. Figure 2.2 shows the major vegetation areas of Canada. It can be seen that a significant portion of the primary area is forested and will hence require large propagation margins (due to shadowing). For the secondary service area including extremities of the coverage area, it is assumed that special measures, such as using higher-gain antennas (12 dBi) and in extreme cases operating primarily in a portable mode, could be required to combat the adverse propagation effects. This would allow the system to provide a truly ubiquitous service.

For the Canada/U.S. cooperative systems, each satellite must be capable of backing up the other one. The coverage area in a back-up mode must include the other satellite's service area. For Canada, this means that in the back-up mode the coverage area is all of Canada and the contiguous United States (CONUS) and Alaska.

The coverage area is illuminated by a number of UHF and L-band beams. The proposed baseline consists of two UHF beams and four L-band beams. The backhaul consists of one SHF beam. For



ELEVATION ANGLE CONTOURS; SATELLITE LONGITUDE 106.5 W

Figure 2.1

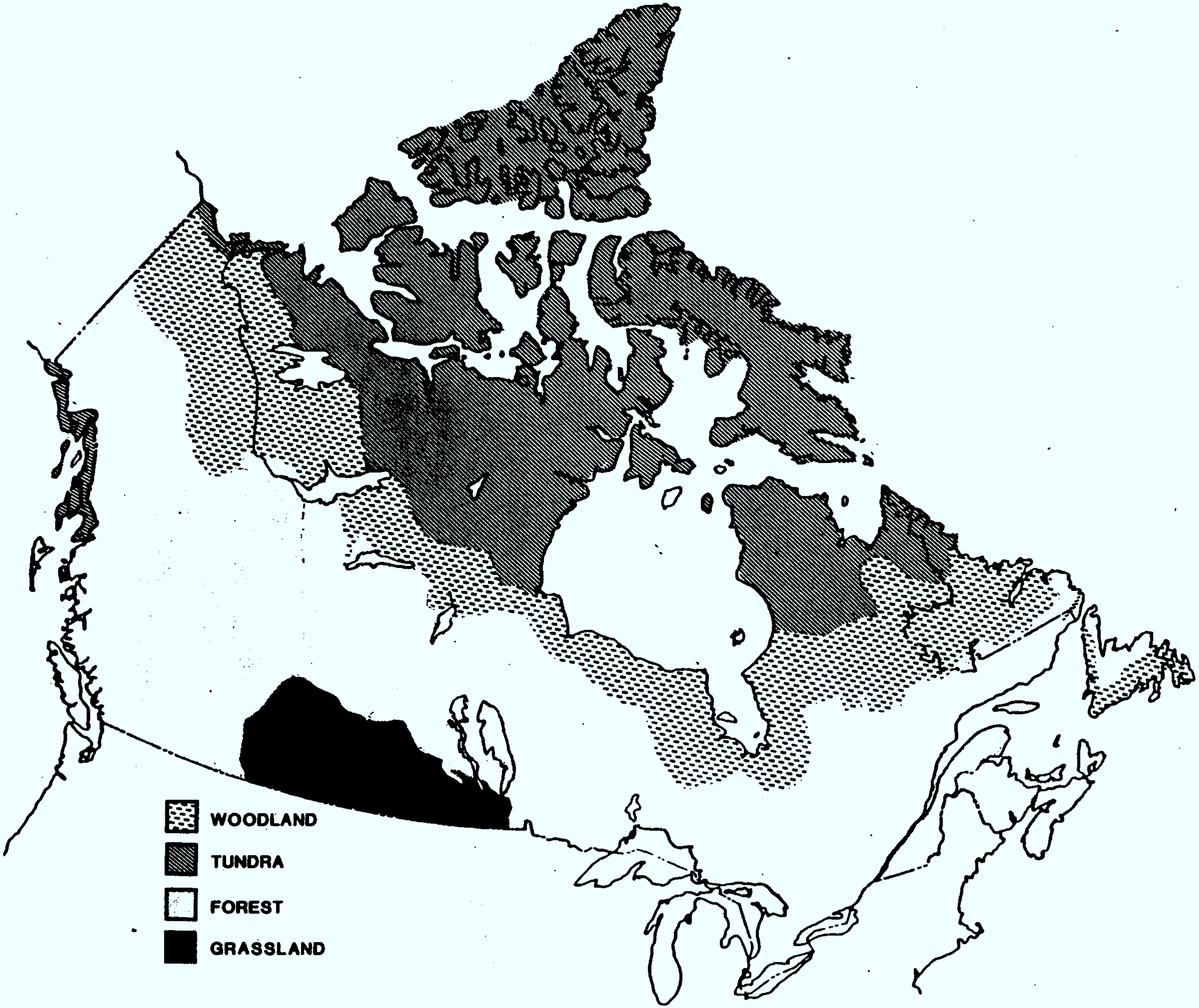


Figure 2.2: Canada's Major Vegetation Areas

the Canada/U.S. system, separate UHF frequencies are proposed for Canada and the U.S. and the same is true for L-band frequencies. However, in case of a single spacecraft failure, the other satellite can be commanded to respond to the operational frequencies of the failed spacecraft[1]. This can conceptually be accomplished through provision of a series of commandable bandpass filters and the associated hardware on-board the spacecraft. Depending on the loading of each spacecraft, and the available excess power, such a sparing scenario could provide full back-up capability, with reduced link margins being necessary under full load conditions.

2.4 Types of Services

Communication services within urban centres and surrounding areas are readily available. MSAT is intended to be used primarily in rural and remote regions where the wide-area coverage and extended range are required and terrestrial services are generally not available. Typical applications for MSAT can be found in the following market sectors: trucking, mineral exploration, forestry, law enforcement, coastal and in-land shipping, light aircraft communications, national paging, environmental sensing, remote monitoring and control of utilities, and emergency relief.

There are basically four major types of services that have been identified as potential applications for MSAT during the initial service introduction phase. These are:

- Mobile Radio Service
- Mobile Telephone Service
- Data Service
- Paging Service

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1 The satellite may have to be relocated in order to optimize for North American coverage. However, this may pose some problems since it would take 3 to 10 days to change the S/C location.

The above merely lists the major potential services for MSAT and is by no means exhaustive. Other new and/or enhanced services could be identified as the first-generation system is developed and implemented.

2.4.1 Mobile Radio Service (MRS)

This service provides voice communication primarily between a mobile terminal and a base station and between mobile terminals. It is intended primarily for private communication between mobiles and base stations belonging to the same organization. Mobile dispatch service is a typical example. It is assumed here that a base station can be patched to the Public Switched Telephone Network (PSTN) on an individual line basis if required but they are not normally connected to the PSTN. Most of the communication between MRS terminals is anticipated to fall within a single UHF beam. However, there is a small requirement for some mobile terminals to access UHF base stations or other mobile terminals which belong to another UHF beam. Although the interbeam traffic for L-band is higher than that of UHF (since there are more beams) it is still expected to be a very small fraction of the total traffic.

Communication to the other UHF (L-band) beam(s) or to SHF base stations will be established on a full-duplex basis. It is possible to use half-duplex for mobile-to-mobile or mobile-to-UHF base communications within a beam. The baseline scenario adopted here, however, is full-duplex operation for all circuits for channel estimates. This does not preclude use of half-duplex terminals with push-to-talk. Mobile-to-base station traffic is intended to operate in a single hop mode whereas the mobile-to-mobile traffic will likely be double hop via the central control station or a gateway.

2.4.2 Mobile Telephone Service (MTS)

This service is intended to provide direct access to and from the PSTN by the mobile terminal users via SHF gateway stations.

It can also provide voice communication between two mobile users, however, this is expected to be a very small requirement. All MTS circuits are planned to operate in a full duplex mode. Mobile-to-PSTN traffic is all single hop whereas mobile-to-mobile traffic is likely to be double hop via the gateway. A numbering plan for the mobile vehicles will be necessary. Whereas this numbering plan does not have to be the same as that of the PSTN, a mobile calling into the PSTN will dial in the same way as any other customer in the terrestrial network would.

2.4.3 Data Service

Data services are possible within the nominal 5 kHz channels. These services include mobile data transmission service (MDTS) which provides a communication path for transfer of data between a mobile terminal and a base station; and the Data Acquisition and Control Service (DACS) which facilitates the transfer of sensor data information from data collection platforms to base stations, and the transmission of control messages in the opposite direction. Police forces or resource exploration teams could use MDTS while remote data collection and industrial monitoring and control are applications of DACS.

2.4.4 Paging Service

Paging service provides a one-way message from a base station to a mobile paging receiver. It can be provided by a simple single-channel per UHF (L-band) beam. It should be noted that the paging channel requires more power than that required by the other services in order to provide communication to typical paging units which are significantly compact and have low G/T. However, one paging channel can support a very large number of paging units. Requirements for this service have not yet been fully identified and quantified.

2.5 Quality of Service

For the purposes of system sizing, the peak busy-hour blocking rate for voice communication channels assumed at the satellite end-of-life (or system saturation point) is no worse than 15%. This does not include the increase in traffic due to the blocked callers trying again. However, the actual blocking rate over much of the satellite life is expected to be considerably better than this level.

In the absence of better information on the performance of the modulation methods proposed for MSAT, a "threshold" value of C/N_o was chosen that was believed to be acceptable. Based on measured and simulated propagation data, availabilities could be worked out as the percentage of locations for which the overall faded signal would maintain a C/N_o value higher than the threshold. Based on a threshold C/N_o of 39 dB-Hz, the two-way availability objectives targetted for the voice communications at UHF was 95% for a single hop, and 85% for a double hop in a true mobile mode and over a large portion of the total service areas. If terminals are operated in a fixed or portable mode, significantly better availabilities can be expected.

However, tests on subjective voice quality of the modulation schemes proposed for MSAT in a mobile fading environment have been conducted by BNR and the results are now available. These results can now replace the availability method which has been used heretofore as a design aid. The objective for the subjective voice quality is a mean opinion score of "fair" (under faded conditions) where quality has been categorized as bad, poor, fair, good or excellent.

Although the BNR subjective voice quality tests are the ultimate criteria of system performance, the results so obtained indicate that the system design based on the design aid of a percentage availability is quite close to that based on mean opinion scores.

3.0 RECOMMENDED LINK BUDGETS

3.1 Propagation

Telesat's system design has used the propagation data presented by Butterworth [4, 5]. These data are processed on an overall basis (i.e. long-time statistics) giving a single curve of the cumulative distribution of the fade considering all the locations travelled. For the UHF design, a value of close to 99% for a single link was chosen, leading to fades of around 13 dB. However, in some of the terrestrial mobile services, the data presented were processed a little differently. The data are first processed for short-term (within one second) temporal variation, then these one-second levels are processed for spatial variation. The design of some of these systems have been based on a 90% temporal and 90% spatial variation. This has resulted in some confusion, leading some to conclude that MSAT has been designed using a far more stringent criterion (99%) compared to the criterion used for terrestrial mobile (90%/90%). However, a careful comparison of these two criteria shows that they are essentially equivalent. Vogel [6] has plotted the statistics based on both temporal and spatial variation and also the statistics based on overall processing on the same graph (see Figure 3.1). In the figure, the right-most curve represents the overall processing (equivalent to Butterworth's data). If a link availability of 99% is desired, the overall statistics indicate a 12 dB fade as can be seen from the figure. For the 90% temporal/90% spatial variation, the curve labelled P = 90% will be used. This is the temporal variation. The vertical axis in this case represents spatial variation. It is seen, therefore, that the level of fade corresponding to 90% temporal/90% spatial variation is 13 dB. This compares surprisingly well with the 12 dB fade based on 99% overall statistics, and Butterworth's figure of 13 dB.

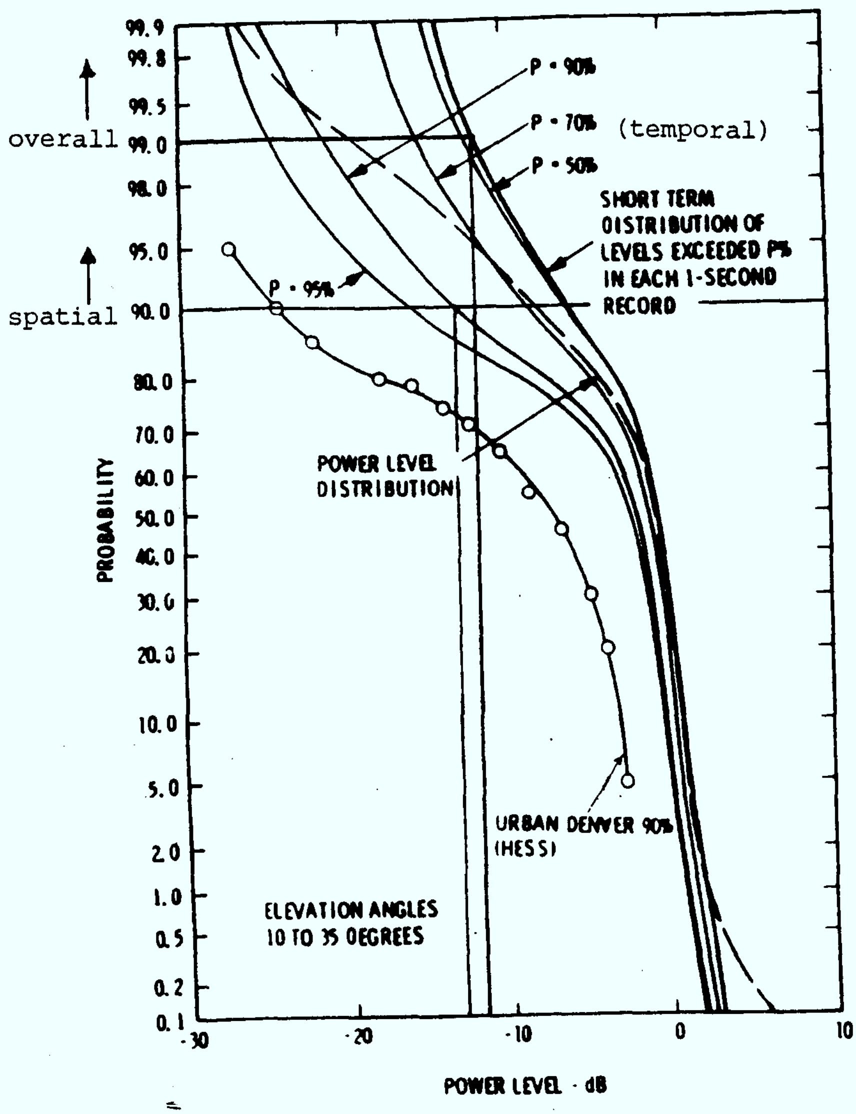

Figure 3.1: Equivalence of overall statistics and temporal/spatial statistics criteria (figure from ref. 6)

3.2 Definition and Assumptions

It is worthwhile at this point to define the terminology of forward and return (reverse) links. In the primary mode of operation, the forward link is established from an SHF base station or gateway, via the satellite, to the UHF (or L-band) mobile or transportable terminal. The return link (sometimes also called the reverse link) is established from the UHF or L-band mobile or transportable terminal, via the satellite, to the SHF base station or gateway. Hence the forward link is an SHF-UHF (or SHF-L-band) link whereas the return link is an UHF-SHF (or L-band-SHF) link.

The base stations and gateways are assumed to be equipped with a 3.5 m diameter paraboloidal reflector. The UHF mobile terminal has a high gain (8 dBic receive gain, 7.5 dBic transmit gain) antenna and the L-band mobile terminal has an antenna with a receive gain of 10.4 dBic and a transmit gain of 11.4 dBic [1,3]. The transportable terminal (sometimes referred to as field portable, FP) antenna gains are 12 dBic receive and 11.5 dBic transmit for UHF and 17 dBic receive and 17.5 dBic transmit for L-band. The spacecraft has two 5 m diameter reflectors which are used for both UHF and L-band. The UHF net EOC gain is 25.8 dBic while the L-band net EOC gain is 28.4 dBic. The spacecraft also has an SHF antenna with a net EOC gain of 25.2 dBi.

3.3 Subjective Voice Quality

Bell-Northern Research Ltd. conducted a series of voice quality subjective evaluations for the DOC in 1985 [7]. The study evaluated the voice quality of amplitude companded single sideband (ACSSB) and 2.4 kb/s linear predictive coding/differential minimum shift keying (LPC/DMSK) which were proposed for MSAT, and also included narrow band frequency modulation (NBFM) familiar to most mobile users as a reference.

The tests were conducted with varying levels using standard techniques and in a fading environment by using CRC's satellite link simulator.

The general conclusion of the study was that whereas LPC/DMSK received relatively poor rating by the particular subjects used, ACSSB was found to be suitable over a range of carrier-to-noise density ratios. LPC/DMSK therefore should be used by customers interested more in speech intelligibility and/or security than "naturalness". More work with 4.8 kb/s multipulsed LPC may eventually yield voice quality approaching that of ACSSB. Based on these findings, our link budgets are based on operation with ACSSB.

The BNR voice quality tests can be used to establish the required power per channel in a typical fading environment. In Figure 3.2, the subjective quality rating by radio subjects of ACSSB with fading is shown. Three curves (from ref. [3]) are given for the case with no fading, with light fading ($K = -10$, $\sigma = 1$ dB) on which Telesat's baseline design is based, and medium fading ($K = -10$, $\sigma = 2$ dB). The fading characterized by these parameters is typical of rural land around Ottawa. The abscissa is the carrier-to-noise density ratios while the ordinate is the mean opinion score (MOS) ranging from "bad" (1.0) to "excellent" (5.0). If a rating of "fair" (mean opinion score of 3.0) is used as the criterion of acceptability, then in a light fading environment a link design with an unfaded C/N_0 of 50.3 dB-Hz would be suitable. In the unfaded case, this gives a rating close to "good". It is interesting to note, however, that for the unfaded case, a "fair" score is obtained for a C/N_0 of around 44 dB-Hz. The value of 39 dB-Hz used as a threshold in the earlier analysis results in a score close to "poor". It is important to note that this is true if this value of C/N_0 is maintained all the time. If this value occurs only occasionally, the rating would not be quite so low. Due to the graceful degradation of ACSSB, if a threshold must be chosen not to be exceeded beyond a certain percentage

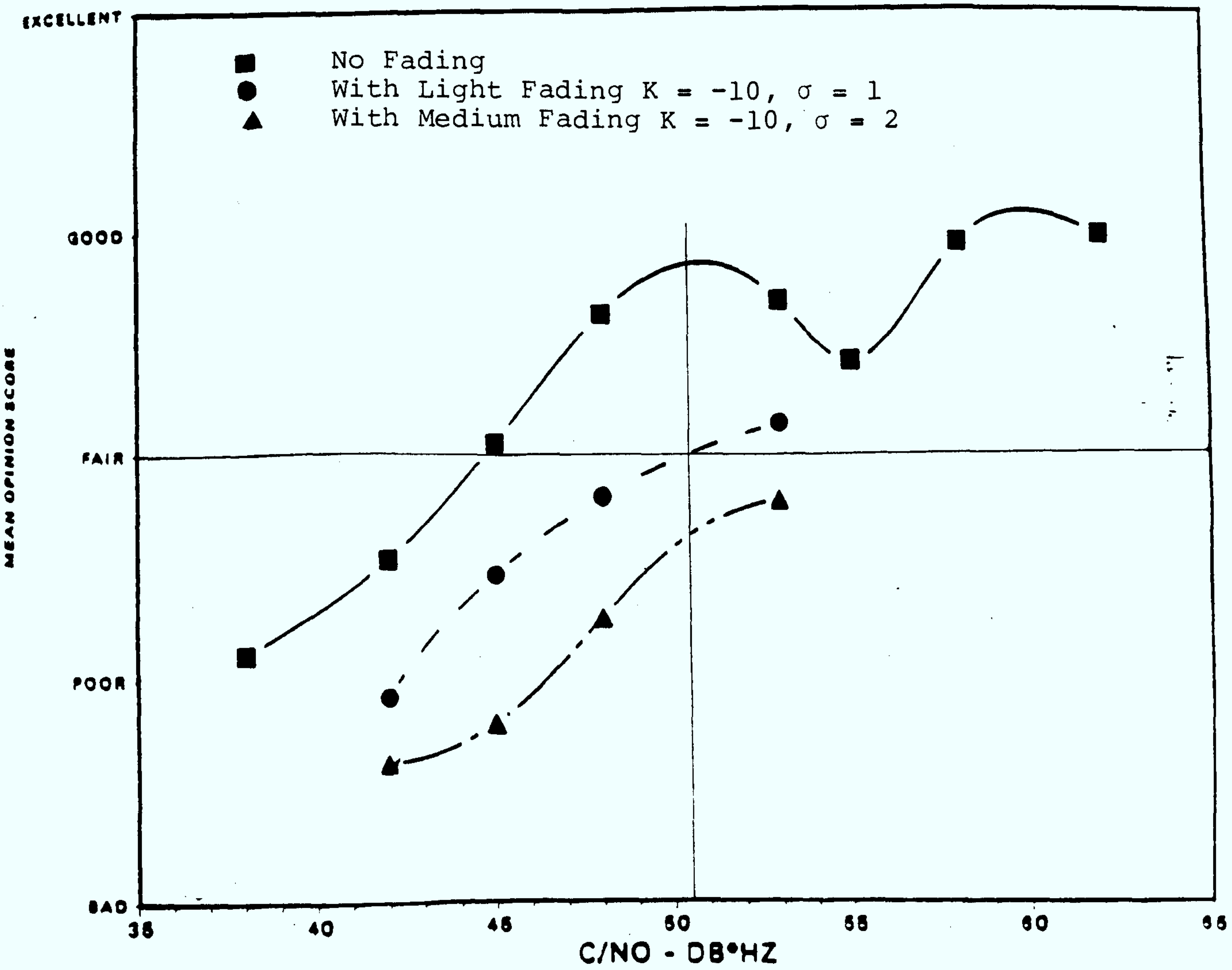

Figure 3.2 : Subjective Quality of ACSSB With Fading (Radio Subjects)

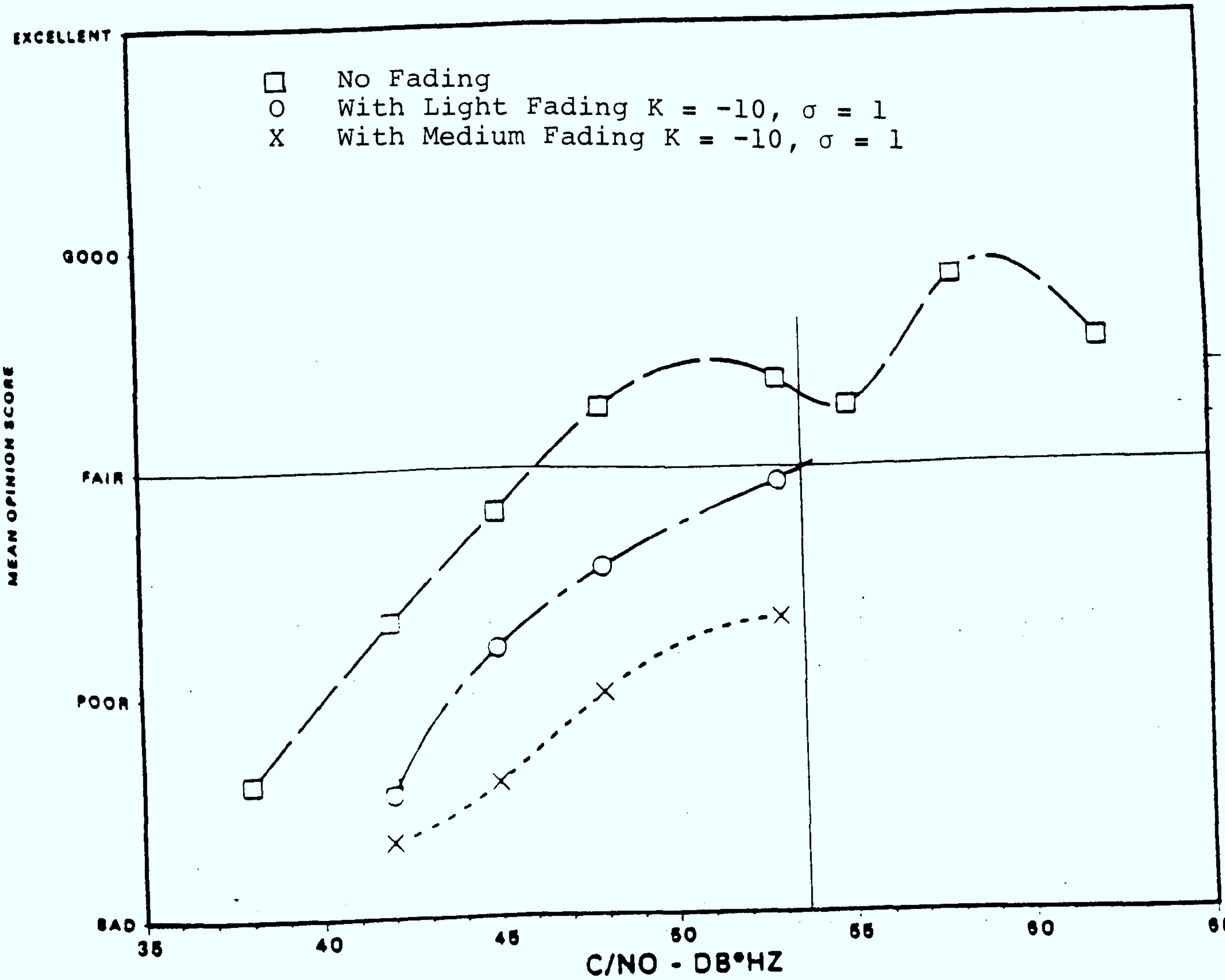

Figure 3.3 : Subjective Quality of ACSSB With Fading (Telephone Subjects

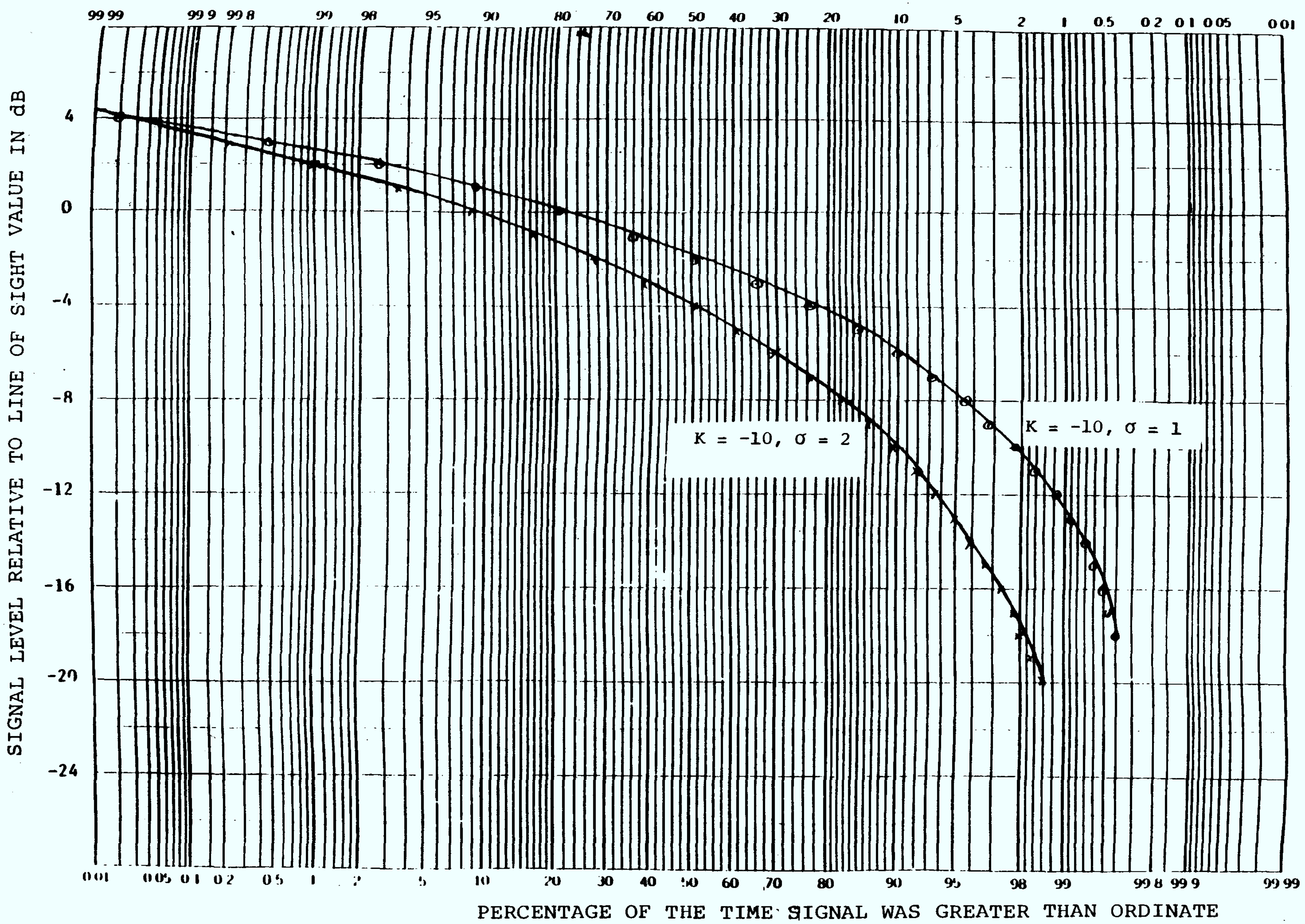

Figure 3.4 Cumulative Probability Distribution Functions of Fades

of the time, a C/N_o value close to 42 dB-Hz may be suitable. This will mean that the availabilities quoted in the CVS and L-Band reports are somewhat optimistic.

In Figure 3.3, the subjective quality rating of ACSSB by telephone subjects is shown for the same three cases as in Figure 3.2. It is apparent that these subjects tended to give lower opinion scores than radio subjects for the same C/N_o values. For a light fading case, a "fair" rating is obtained with an unfaded C/N_o of 53.5 dB-Hz.

From both Figures 3.2 and 3.3, comparing the "fair" score C/N_o's for faded and unfaded cases, it would appear that the light fading case corresponds to an average fade of 6 to 7 dB. It should be noted also that for both telephone (MTS) users and radio (MRS) users in a medium fading environment, a mean opinion score of 3.0 or "fair" cannot be obtained for reasonable C/N_o values.

Figure 3.4 shows the cumulative distribution functions of the fades for the light fading ($K = -10$, $\sigma = 1$) and medium fading ($K = -10$, $\sigma = 2$) situations shown in Figures 3.2 and 3.3.

3.4 Link Budgets

3.4.1 UHF System

Table 3.1 presents the link budgets that would be suitable for the MRS service. The total unfaded carrier-to-noise density ratio in the forward link is 50.4 dB-Hz for the mobile terminal, and in the reverse link the total C/N_o is 51.2 dB-Hz. These C/N_o values are compatible with the values derived from the BNR test results in the last section.

The system noise distribution for the forward and reverse links are as follows:

TABLE 3.1

2-Beam Canada/US (MRS Service)
Link Calculations UHF-SHF

M = Mobile
FP = Field Portable

PARAMETER	UNIT	FORWARD LINK		REVERSE LINK
		3.5m		3.5m
UPLINK		M	FP	M or FP
Satellite G/T	dB/K	-3.0		-2.0
Uplink EIRP/ Voice Act. Carr.	dBW	40.1		11.1
Path Loss	dB	206.8		182.8
Total IPBO/Transp.(Av. Pwr)	dB	N/A		12
Req'd. Flux Density/Voice Carr.	dBW/m^2	-122.8		-151.9
C/No Thermal	dB-Hz	58.9		54.9
Noise Bandwidth	kHz	3		3
C/N Thermal	dB	24.1		20.1
DOWNLINK				
Req'd EIRP/Voice Act. Carr.	dBW	26.5		8.6
Req'd Total OPBO	dB	N/A		7
Path Loss	dB	183.2		205.8
Receive Terminal G/T	dB/K	-19.1	-15.1	25.9
C/No Thermal	dB-Hz	52.8	56.8	57.3
Noise Bandwidth	kHz	3.0		3
C/N Thermal	dB	18.0	22.0	22.5
INTERFERENCE (C/I)				
Intermod & Energy Spread				
Uplink	dB	32		25
Downlink	dB	22		25
Interbeam Co-channel				
Uplink	dB	-		-
Downlink	dB	-		-
Other Sources				
Uplink	dB	32		-
Downlink	dB	-		29
Total Interference	dB	21.2		21.2
Total Unfaded C/N	dB	15.6	17.5	16.4
Total Unfaded C/No	dB-Hz	50.4	52.3	51.2

System Noise Distribution (2-Beam UHF MRS Service)

	Forward Link (to mobile)	Return Link
Uplink Noise	14%	43%
Downlink	58%	24%
Satellite (Intermod)	23%	14%
Others	5%	19%
Total C/N (dB)	15.6	16.4

In the forward link, the total unfaded C/N_o for the service to a UHF transportable terminal is 52.3 dB-Hz which provides voice quality that is significantly better than fair in the unfaded case. Further, the fades experienced by transportable terminals should be considerably less than those experienced by mobile terminals. (It is estimated by interpolation that, in the fading case, a mean opinion score of 3.0 may be obtained with a C/N_o of about 48 dB-Hz.) It is possible to reduce the required downlink EIRP to a transportable terminal to 22.5 dBW in order to maintain the same unfaded C/N_o of 50.4 dB-Hz. This can be done either by adjusting the uplink power from the base station under DAMA control or by channelizing the transponder to separate low-level and high-level carriers.

We note here that in Table 3.1 and subsequent tables, we have assumed a nominal noise bandwidth of 3 kHz. This was used in the past since it was sufficient for the modulation schemes previously considered, including LPC/DMSK and ACSSB. The current ACSSB modem developed at CRC uses transparent tone in-band (TTIB) and has a bandwidth of 3.9 kHz. The eventual noise bandwidth cannot be determined at this time. However, this only affects the C/N ratio and does not really affect the link budgets.

TABLE 3.2

2-Beam Canada/US (MTS Service)
Link Calculations UHF-SHF

M = Mobile

FP = Field Portable

PARAMETER	UNIT	FORWARD LINK		REVERSE LINK
		3.5m		3.5m
UPLINK		M	FP	M of FP
Satellite G/T	dB/K	-3.0		-2.0
Uplink EIRP/ Voice Act. Carr.	dBW	43.1		16.1
Path Loss	dB	206.8		182.8
Total IPBO/Transp.(Av. Pwr)	dB	N/A		12
Req'd. Flux Density/Voice Carr.	dBW/m^2	-119.8		-148.9
C/No Thermal	dB-Hz	61.9		59.9
Noise Bandwidth	kHz	3		3
C/N Thermal	dB	27.1		25.1
DOWNLINK				
Req'd EIRP/Voice Act. Carr.	dBW	29.5		8.6
Req'd Total OPBO	dB	N/A		7
Path Loss	dB	183.2		205.8
Receive Terminal G/T	dB/K	-19.1	-15.1	25.9
C/No Thermal	dB-Hz	55.8	59.8	57.3
Noise Bandwidth	kHz	3.0		3
C/N Thermal	dB	21.0	25.0	22.5
INTERFERENCE (C/I)				
Intermod & Energy Spread				
Uplink	dB	32		25
Downlink	dB	24		25
Interbeam Co-channel				
Uplink	dB	-		-
Downlink	dB	-		-
Other Sources				
Uplink	dB	35		-
Downlink	dB	-		29
Total Interference	dB	23.1		21.2
Total Unfaded C/N	dB	18.3	20.0	17.9
Total Unfaded C/No	dB-Hz	53.1	54.8	52.7

In Table 3.2, the link budgets are presented for MTS service. Since the required unfaded C/N_o for MTS service was determined to be 53.5 dB-Hz, adjustments have been made to get a total C/N_o close to this value. Two changes have been made in the forward link to try to achieve this. First, the uplink SHF EIRP has been increased by 3 dB. This can easily be obtained by increasing the output power per carrier from the base station HPA's. This also affects the uplink carrier-to-interference ratio due to adjacent satellite, increasing it by 3 dB. The uplink intermodulation and energy spread is assumed to remain constant[1]. The second change is an increase in the required downlink EIRP per carrier to 29.5 dBW. This in turn increases the downlink carrier-to-intermodulation[2] power ratio for the MTS carriers. Since there is now a mixture of different-level carriers, which would tend to increase the intermodulation level, it is assumed that the C/IM ratio for the MTS carriers will be 24 dB instead of 25 dB. (Note that the C/IM for MRS may drop slightly.) The actual value that should be used will have to be determined by simulation.

In the reverse link, the uplink thermal C/N_o has been increased to 25.1 dB by boosting up the mobile terminal EIRP by 5 dB. The overall unfaded C/N_o hence becomes 52.7 dB-Hz. The link appears to be interference- dominated as opposed to the forward link (to the mobile terminal) which is downlink thermal noise dominated. This is clearly shown in the system noise distribution table below.

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1 Note that the uplink energy spread C/I_o for the MRS service might decrease slightly due to the increased MTS uplink power.

2 It should be pointed out that the instantaneous intermodulation power will have a statistical distribution. Numbers specified refer to values that will be met for 99% of the time.

System Noise Distribution (2-Beam UHF MTS Service)

	Forward Link (to mobile)	Return Link
Uplink Noise	13%	19%
Downlink	54%	35%
Satellite (Intermod)	27%	19%
Others	6%	27%
Total C/N (dB)	18.3	17.9

3.4.2 L-Band System

The BNR subjective voice quality tests were conducted at UHF (800 MHz) and assumed channel spacings of 5 kHz. No test results are currently available at L-Band (1600 MHz). However, it is possible to use interpolation to estimate the expected subjective quality of ACSSB at L-band. In Figure 3.5, the fading statistics for UHF and L-band are compared. Specifically, the L-band light shadowing statistics are shown along with the statistics for UHF light fading and UHF medium fading. From the figure, the L-band (light fading) curve falls between those of UHF light and medium fading being somewhat closer to the medium fading curve for deeper fades. It is reasonable to expect, therefore, that the subjective quality results for ACSSB at L-band would lie somewhere between the result for UHF light and medium fading. Figure 3.6 shows the interpolated estimate for subjective quality at L-band[1]. Again using a MOS of 3.0 ("fair") as the criterion of acceptability, for an L-band link in a light fading environment, an overall unfaded C/N_o of 53.4 dB-Hz would be required.

---

1 This interpolation is based solely on the depth of fades occurring at L-band. However, the subjective quality at L-band might be a little worse due to the increased rapidity of fades and the higher phase fluctuations at L-band compared to UHF. Further, the increased frequency drifts and doppler shifts might have an effect on the voice quality [8].

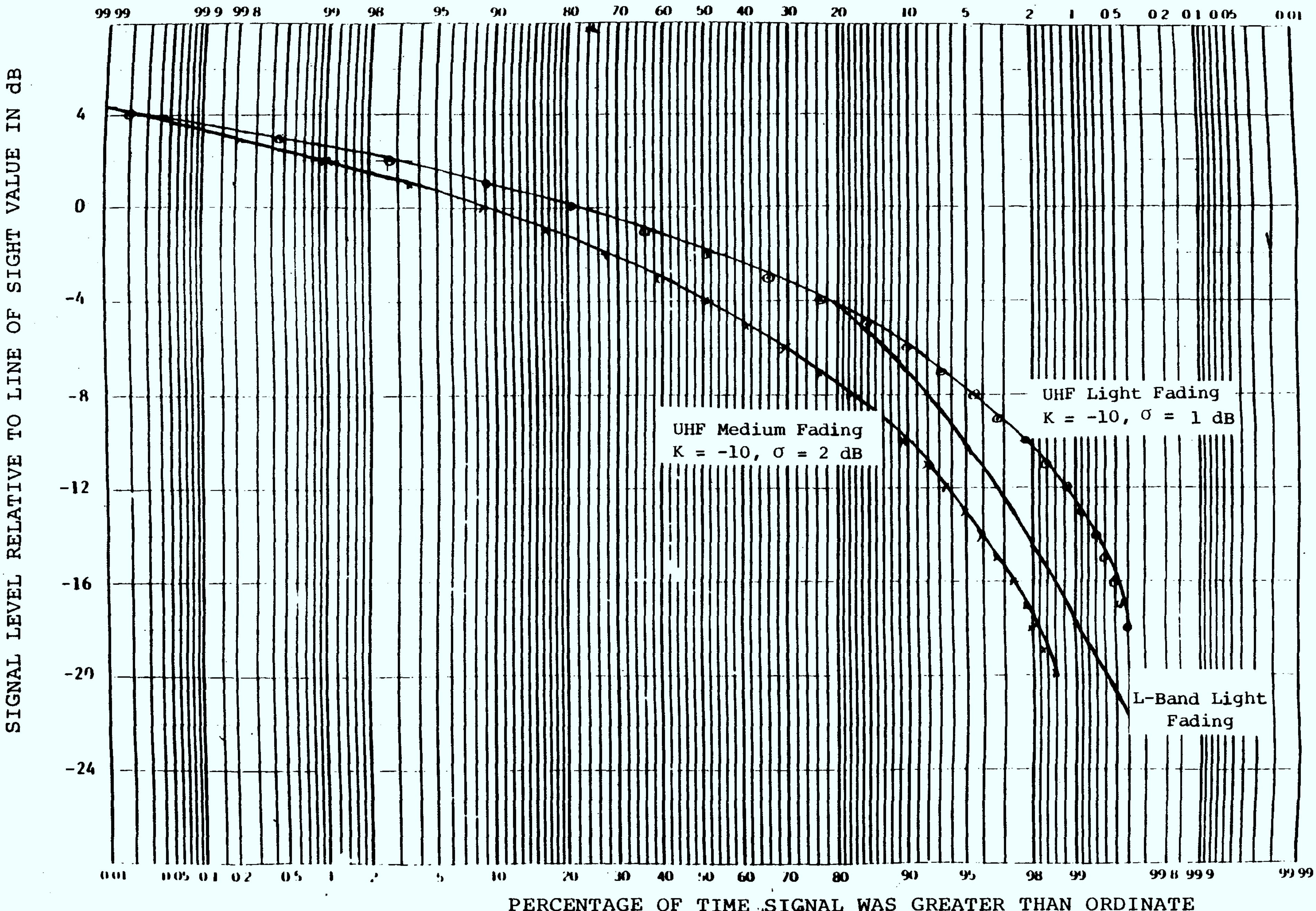

Figure 3.5 Comparison of UHF and L-Band Fading Statistics

Table 3.3 presents the link budgets for the L-band system. These are assumed to be for the MRS service only. The total unfaded C/N_o in the forward link is 52.3 dB-Hz and in the reverse link the total C/N_o is 52.9 dB-Hz. These values are slightly lower than those estimated above. An attempt to realize an overall C/N_o of 53.4 dB-Hz would lead to very high required L-band EIRP's both from the satellite and the mobile terminal since the links will become essentially interference limited. The voice quality achievable with the overall C/N_o's in the table is around 2.9 MOS.

The L-band link budgets of Table 3.3 were based on expected service quality close to that at UHF. This implies a required EIRP per L-band carrier of 32.3 dBW. Such a high required EIRP leads to a very low system capacity for practical-sized spacecraft [2]. By accepting a lower service quality (lower system availability or higher system outage or lower MOS), the burden on the spacecraft power can be lessened. Table 3.4 depicts the link budgets for an L-band link with reduced availability. The noise distribution for this link is given below alongside that of the true mobile service.

System Noise Distribution For L-Band True Mobile Service and Service With Reduced Availability

	True Mobile Service		Service with Reduced Availability	
	Forward Link	Reverse Link	Forward Link	Reverse Link
Uplink Noise	22%	16%	15%	32%
Downlink Noise	35%	35%	56%	28%
Satellite (IM)	36%	20%	24%	16%
Others	7%	28%	5%	23%
Total C/N (dB)	17.5	18.1	15.8	17.2

The major change in these budgets is the reduction of the required EIRP per carrier from 32.3 dBW to 28.5 dBW, assuming the same earth terminal receive G/T of -15.8 dB/K. The resulting overall

TABLE 3.3

4 L-Band Beams Canada/U.S.
Link Budgets L-Band→SHF Service to Mobile

PARAMETER	UNIT	FORWARD LINK	REVERSE LINK
UPLINK		3.5m SHF Ant. to Mobile	Mobile to 3.5m SHF Ant.
Satellite G/T	dB/K	-3.0	0.3
Uplink EIRP/ Voice Act. Carr.	dBW	40.1	20.7
Path Loss	dB	206.8	188.7
Total IPBO/Transp.(Av. Pwr)	dB	N/A	12
Req'd. Flux Density/Voice Carr.	dBW/m^2	-122.8	-142.2
C/No Thermal	dB-Hz	58.9	60.9
Noise Bandwidth	kHz	3	3
C/N Thermal	dB	24.1	26.1
DOWNLINK			
Req'd EIRP/Voice Act. Carr.	dBW	32.3	8.6
Req'd Total OPBO	dB	N/A	7
Path Loss	dB	188.2	205.8
Receive Terminal G/T	dB/K	-15.8	25.9
C/No Thermal	dB-Hz	56.9	57.3
Noise Bandwidth	kHz	3	3
C/N Thermal	dB	22.1	22.6
INTERFERENCE (C/I)			
Intermod & Energy Spread			
Uplink	dB	32	25
Downlink	dB	22	25
Interbeam Co-channel			
Uplink	dB	-	-
Downlink	dB	-	-
Other Sources			
Uplink	dB	32	-
Downlink	dB	-	29
Total Interference	dB	21.2	21.2
Total Unfaded C/N	dB	17.5	18.1
Total Unfaded C/No	dB-Hz	52.3	52.9

TABLE 3.4

4 Beams Canada/U.S.
Link Budgets L-Band → SHF with Reduced Availability

PARAMETER	UNIT	FORWARD LINK	REVERSE LINK
UPLINK		3.5m SHF Ant. to Mobile	Mobile to 3.5m SHF Ant.
Satellite G/T	dB/K	-3.0	0.3
Uplink EIRP/ Voice Act. Carr.	dBW	40.1	16.7
Path Loss	dB	206.8	188.7
Total IPBO/Transp.(Av. Pwr)	dB	N/A	12
Req'd. Flux Density/Voice Carr.	dBW/m^2	-122.8	-143.9
C/No Thermal	dB-Hz	58.9	56.9
Noise Bandwidth	kHz	3	3
C/N Thermal	dB	24.1	22.1
DOWNLINK			
Req'd EIRP/Voice Act. Carr.	dBW	28.5	8.6
Req'd Total OPBO	dB	N/A	7
Full Load EIRP/Transponder (edge of coverage)	dBW	TBD	TBD
Path Loss	dB	188.2	205.8
Receive Terminal G/T	dB/K	-15.8	25.9
C/No Thermal	dB-Hz	53.1	57.3
Noise Bandwidth	kHz	3	3
C/N Thermal	dB	18.3	22.6
INTERFERENCE (C/I)			
Intermod & Energy Spread			
Uplink	dB	32	25
Downlink	dB	22	25
Interbeam Co-channel			
Uplink	dB	-	-
Downlink	dB	-	-
Other Sources			
Uplink	dB	32	-
Downlink	dB	-	29
Total Interference	dB	21.2	21.2
Total Unfaded C/N	dB	15.8	17.2
Total Unfaded C/No	dB-Hz	50.6	52.0

C/N_o's are 50.6 dB-Hz and 52.0 dB-Hz for the forward and reverse links respectively. Given the same fading environment, this would correspond to about a 60% increase in the system outage. Alternatively, the expected voice quality is an MOS of approximately 2.7 and 2.9 for the forward and reverse links respectively. It should be pointed out, however, that this service would be most suited to applications where shadowing is a minimum and hence the fades are not as deep. This includes mobile service in areas with low foliage such as grasslands as in the Prairies and North West Territories, aeronautical and maritime mobile services. For such areas, it is expected that acceptable voice quality (MOS of 3.0) would be achieved with an overall C/N_o of around 50 dB-Hz.

For the transportable service, it is assumed that the site is chosen such that there is a clear line of sight to the satellite, hence the hefty propagation margin associated with shadowing is not required. Multipath fading is the only source of excess path loss. Since the transportable terminal has a 17 dBic gain antenna, the multipath fade should be in the order of 2 to 3 dB. Since the terminal is fixed while in use, this fade will be constant in the short term. Hence, the curve for transportable service is expected to be parallel to that of the no fading situation and shifted by 2 or 3 dB to the right. With this, a mean opinion score of "fair" should be obtained for an overall C/N_o of 47 to 48 dB-Hz for transportable service (see Figure 3.6).

Using the above target values of overall C/N_o, the link budgets for the L-band transportable service have been calculated as shown in Table 3.5. The overall C/N_o's are 48 dB-Hz and 49.3 dB-Hz for the forward and reverse links. The system noise is distributed as shown below.

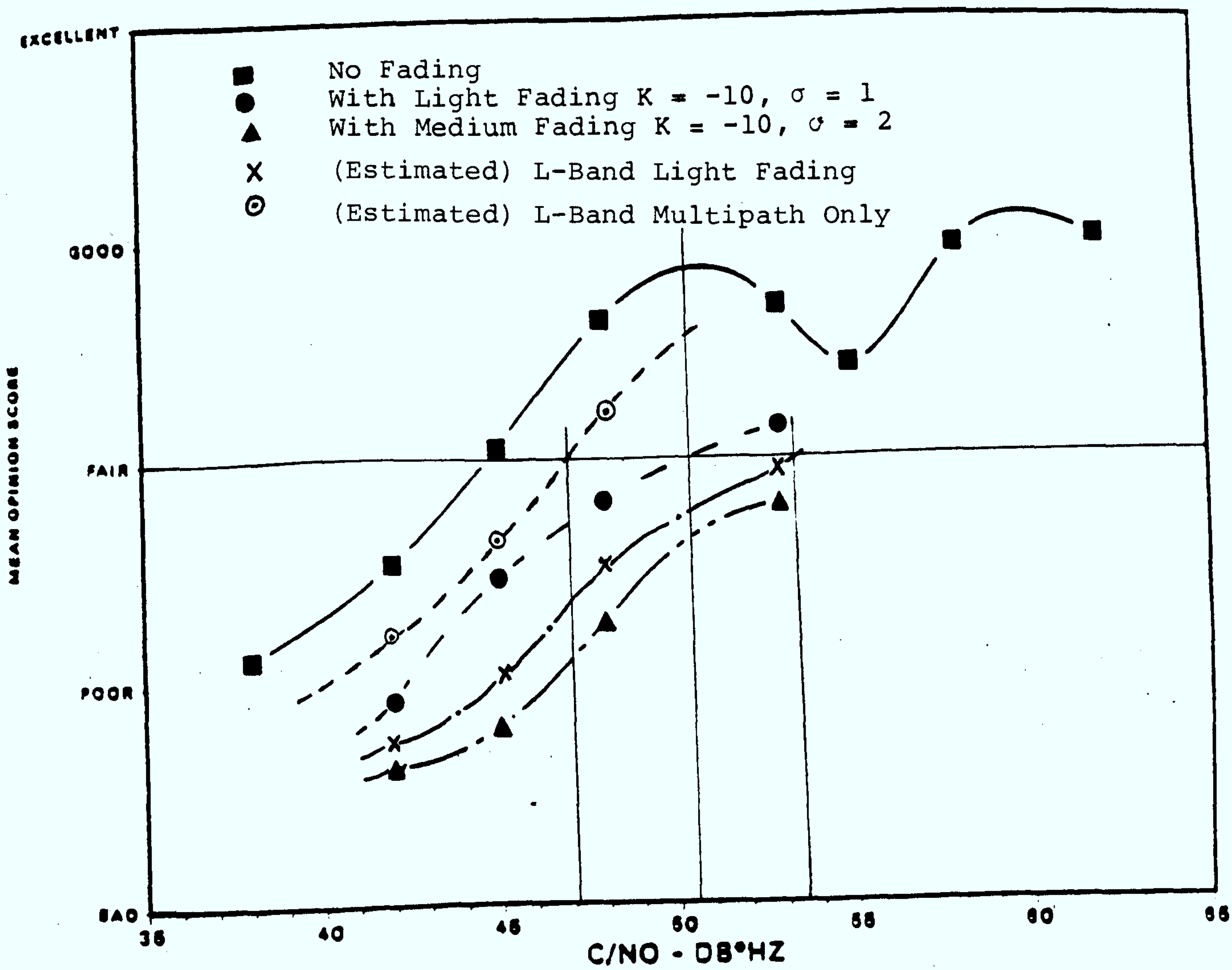

Figure 3.6: Estimation of L-Band Performance With Light Fading

System Noise Distribution (L-Band Transportable Service)

	Forward Link	Return Link
Uplink Noise	8%	48%
Downlink	76%	28%
Satellite (Intermod)	13%	9%
Others	3%	15%
Total C/N (dB)	13.2	14.5

Both the L-band and SHF downlink EIRP's (for the forward and reverse links respectively) have been reduced accordingly. It should be noted that for L-band, the carrier destined to a transportable service has an EIRP of 18.9 dBW compared to 28.5 dBW for that destined to a mobile terminal. If both these types of carriers have to share the same transponder, extreme care should be exercised in their respective locations in order to avoid excessive intermodulation levels.

TABLE 3.5

4 Beams Canada/U.S.
Link Budgets L-Band-SHF For Transportable Service

PARAMETER	UNIT	FORWARD LINK	REVERSE LINK
UPLINK		3.5m SHF Ant. to Transportable St.	Transportable St. to 3.5m SHF Ant.
Satellite G/T	dB/K	-3.0	0.3
Uplink EIRP/ Voice Act. Carr.	dBW	40.1	12.3
Path Loss	dB	206.8	188.7
Total IPBO/Transp.(Av. Pwr)	dB	N/A	12
Req'd. Flux Density/Voice Carr.	dBW/m^2	-122.8	-148.3
C/No Thermal	dB-Hz	58.9	52.5
Noise Bandwidth	kHz	3	3
C/N Thermal	dB	24.1	17.7
DOWNLINK			
Req'd EIRP/Voice Act. Carr.	dBW	18.9	6.0
Req'd Total OPBO	dB	N/A	7
Path Loss	dB	188.2	205.8
Receive Terminal G/T	dB/K	-10.1	25.9
C/No Thermal	dB-Hz	49.2	54.7
Noise Bandwidth	kHz	3	3
C/N Thermal	dB	14.4	20.0
INTERFERENCE (C/I)			
Intermod & Energy Spread			
Uplink	dB	32	25
Downlink	dB	22	25
Interbeam Co-channel			
Uplink	dB	-	-
Downlink	dB	-	-
Other Sources			
Uplink	dB	32	-
Downlink	dB	-	26.4
Total Interference	dB	21.2	20.6
Total Unfaded C/N	dB	13.2	14.5
Total Unfaded C/No	dB-Hz	48.0	49.3

4.0 REVIEW OF LINK BUDGETS SUBMITTED BY U.S. APPLICANTS

In response to the U.S. Federal Communications Commission (FCC) Notice of Proposed Rule Making (NPRM) [9], twelve applicants filed for permission to construct and operate a mobile satellite service (MSS) system. The applications came in a variety of types ranging from those giving detailed comprehensive descriptions to some with barely enough information for one to understand the structure of the intended system. From reviewing all the applications, several shortcomings or concerns were apparent. These include:

1. Overly optimistic antenna gains and antenna patterns.
2. Errors in G/T calculations.
3. Hastily assembled link budgets often ignoring UHF and L-band propagation margins completely.
4. Too optimistic or unworkable frequency reuse schemes such as polarization diversity only or orbit reuse while still employing close to omni-directional vehicular antennas.
5. New or critical technology as well as the economic feasibility of some items such as very "quiet" satellite LNA's (Noise Figure of 0.8 dB) and high power SSPA's.

Based on a preliminary review of the twelve applications to the FCC, six were selected for a more detailed study to assess the similarity, or otherwise, of their link budgets to Telesat's. These were the six that appeared to Telesat to have included enough details in their applications to enable a meaningful comparison, and/or have enunciated a readiness to share the spectrum and a willingness to cooperate with Telesat in sharing spacecraft non-recurring costs as well as having a mutual sparing scheme. The link budgets for the following six applicants are examined below: Hughes, McCaw Space Technologies, Mobilesat Corporation, North American Mobile Satellite Service, Omninet, and Skylink.

4.1 Hughes Communications Mobile Satellite Service (HCMSS)

Hughes uses UHF for communication to land mobile and L-band for communication to transportable terminals and air mobile terminals. The UHF mobile terminal antenna gain is assumed to be 5 dBic while the L-band transportable terminal antenna gain is 22 dBic and the air mobile antenna gain is 12 dBic. Representative link budgets are given in Table 4.1 for the UHF link and Table 4.2 for the L-band link for transportables. Any obvious error found is pencilled in. For example in Table 4.2(b) the downlink noise temperature has not accounted for rain noise which is an additional 2 dB. Table 4.3 shows the link summary including corrections. Some of the salient observations about the Hughes link budgets are:

"Toll quality" for mobile telephone is defined as subjective signal-to-noise ratio of 27 dB or more in a 300 to 3000 Hz bandwidth. For mobile dispatch, "communication quality" is defined as a subjective signal-to-noise ratio of 20 dB or more in a 300 to 3000 Hz bandwidth. In the link budgets, however, the minimum nominal C/N is quoted as 16 dB while the minimum faded communication quality is quoted as 8 dB. There is no attempt to relate these two. Note, however, that their unfaded C/N_o objective of 50.8 dB-Hz (16 dB C/N) is compatible with Telesat's design. The design calls for a 5m SHF base station antenna compared to Telesat's 3.5 m. Whereas this will not affect the uplink EIRP (because the HPA power can be increased), it will have an effect on the adjacent satellite interference which Hughes has not included in their link budgets. Hughes analyzed the expected interference from a terrestrial mobile transmitter and concluded that there will be no harmful UHF interference from the satellite since it was 49 dB below the satellite noise floor. It should be noted however that they did not consider that there is a multiplicity of these transmitters. All that is needed is 75,000 terrestrial mobiles to double the satellite noise.

The fading loss of 6 dB assumed for high latitude is too low in the light of results obtained by Butterworth [4] and Vogel [6]. It appears that these were all the link budgets could afford.

Another point to be noted is the apparently high SSPA efficiency of 40% assumed by Hughes, compared to the 24% that Telesat believes currently achievable based on measurements of the prototypes developed by SPAR.

(FROM HUGHES' FILING TO THE FCC)

TABLE 4.1(a): SPACECRAFT TO LAND MOBILE TERMINAL LINK ANALYSIS
KU BAND TO UHF

Links	Performance	
	Nominal	Faded, Communications Quality
Uplink		
HPA power, dBW	0.0	0.0
E/S antenna gain, dB	55.0	55.0
Path loss, dB	-207.5	-207.5
Spacecraft antenna gain, dB	28.0	28.0
Residual fading loss, dB*	0.0	-0.5
Bandwidth, dBHz	35.0	35.0
Noise temperature, dBK	30.0	30.0
C/N_{up}, dB	39.1	38.6
Downlink		
SSPA power, dBW	26.3	26.3
Power loss, dB	-1.0	-1.0
Spacecraft antenna gain, dB	29.0	29.0
EIRP, dBW	54.3	54.3
N, number of channels	400	400
-10 log N, dB	-26.0	-26.0
Backoff, dB	0.0	0.0
Uplink drive loss, dB	0.0	-0.5
EIRP/channel, dBW	28.3	27.3
Path loss, dB	-182.5	-182.5
Fading loss, dB	-0.5	-6.0**
E/S antenna gain, dB	5.0	5.0
Bandwidth, dB-Hz	35.0	35.0
Noise temperature, dBK	25.0	25.0
C/N_{down}, dB	18.9	12.9
C/IM, dB	30.0	30.0
C/N total, dB	18.9	12.9
C/N min, dB	16.0	8.0
Margin, dB	2.9	4.9

*After uplink power control.
**-6.0 dB for high latitudes.
-5.0 dB for low latitudes.

(FROM HUGHES' FILING TO THE FCC)

TABLE 4.1(b): LAND MOBILE TERMINAL TO SPACECRAFT LINK ANALYSIS
UHF TO KU BAND

Links	Performance	
	Nominal	Faded, Toll Quality
Uplink		
SSPA power, dBW	10.0	10.0
E/S antenna gain, dB	5.0	5.0
Path loss, dB	-182.5	-182.5
Spacecraft antenna gain, dB	29.0	29.0
Fading loss, dB	0.0	-6.0*
Bandwidth, dB-Hz	35.0	35.0
Noise temperature, dBK	28.3	28.3
C/N_{up}, dB	26.8	20.8
Downlink		
TWTA power, dBW	14.8	14.8
Power loss, dB	-2.0	-2.0
Spacecraft antenna gain, dB	28.0	28.0
EIRP, dBW	40.8	40.8
N, number of channels	800.0	800.0
-10 log N, dB	-29.0	-29.0
Backoff, dB	-5.0	-5.0
Uplink drive loss, dB	0.0	-6.0*
EIRP/channel, dBW	6.8	0.8
Path loss, dB	-206.5	-206.5
Rain fade loss, dB	0.0	-5.0
E/S antenna gain, dB	54.0	54.0
Bandwidth, dB-Hz	35.0	35.0
Noise temperature, dBK	24.0	26.0
C/N_{down}, dB	23.9	10.9
C/IM, dB	26.0	26.0
C/N total, dB	22.1	10.5
C/N min, dB	16.0	10.0
Margin, dB	6.1	0.5

*-6.0 dB for high latitudes.
-5.0 dB for low latitudes.

(FROM HUGHES' FILING TO THE FCC)

TABLE 4.2(a): SPACECRAFT TO TRANSPORTABLE TERMINAL LINK ANALYSIS
KU BAND TO L BAND (22 dB E/S ANTENNA GAIN)

Links	Performance: Nominal	Performance: Faded, Toll Quality
Uplink		
HPA power, dBW	0.0	0.0
E/S antenna gain, dB	55.0	55.0
Path loss, dB	-207.5	-207.5
Spacecraft antenna gain, dB	28.0	28.0
Residual fading loss, dB*	0.0	-0.5
Bandwidth, dB-Hz	35.0	35.0
Noise temperature, dBK	30.0	30.0
C/N_{up}, dB	39.1	38.6
Downlink		
SSPA power, dBW	17.7	17.7
Power loss, dB	-1.4	-1.4
Spacecraft antenna gain, dB	29.0	29.0
EIRP, dBW	45.3	45.3
N, number of channels	662.0	662.0
-10 log N, dB	-28.3	-28.3
Backoff, dB	0.0	0.0
Uplink drive loss, dB	0.0	-0.5
EIRP/channel, dBW	17.0	16.5
Path loss, dB	-187.5	-187.5
Fading loss, dB	0.0	2.0
E/S antenna gain, dB	22.0	22.0
Bandwidth, dB-Hz	35.0	35.0
Noise temperature, dBK	25.0	25.0
C/N_{down}, dB	19.6	17.6
C/IM, dB	25.0	25.0
C/N total, dB	19.6	17.6
C/N min, dB	16.0	10.0
Margin, dB	3.6	7.6

*After uplink power control.

(FROM HUGHES' FILING TO THE FCC)

TABLE 4.2(b): TRANSPORTABLE TERMINAL TO SPACECRAFT LINK ANALYSIS
L BAND TO KU BAND (22 dB E/S ANTENNA GAIN)

Links	Performance: Nominal	Performance: Faded, Toll Quality
Uplink		
HPA power, dBW	0.0	0.0
E/S antenna gain, dB	22.0	22.0
Path loss, dB	-187.5	-187.5
Spacecraft antenna gain, dB	29.0	29.0
Fading loss, dB	0.0	-2.0
Bandwidth, dB-Hz	35.0	35.0
Noise temperature, dBK	26.0	26.0
C/N_{up}, dB	31.1	29.1
Downlink		
TWTA power, dBW	14.8	14.8
Power loss, dB	-2.0	-2.0
Spacecraft antenna gain, dB	28.0	28.0
EIRP, dBW	40.8	40.8
N, number of channels	732.0	732.0
-10 log N, dB	-29.6	-29.6
Backoff, dB	-5.0	-5.0
Uplink drive loss, dB	0.0	-2.0
EIRP/channel, dBW	7.2	5.2
Path loss, dB	-206.5	-206.5
Rain fade loss, dB	0.0	-5.0
E/S antenna gain, dB	54.0	54.0
Bandwidth, dB-Hz	35.0	35.0
Noise temperature, dBK	24.0	24.0
C/N_{down}, dB	24.3	17.3
C/IM, dB	26.0	26.0
C/N total, dB	23.5	17.0
C/N min, dB	16.0	8.0
Margin, dB	7.5	9.0

(FROM HUGHES' FILING TO THE FCC)

TABLE 4.3 MOBILE SATELLITE LINK SUMMARY, dB

Link	C/N_{up}	C/N_{down}	C/IM	C/N_{total}	C/N_{min}	Margin
Ku to UHF	38.6	12.9	30.0	12.9	8.0	4.9
UHF to Ku	20.8	10.9	26.0	10.5	10.0	0.5
Ku to Ku	~~37.1~~ 38.6	~~19.1~~ 17.1	26.0	~~19.0~~ 17.1	10.0	~~9.0~~ 7.1
Ku to L (12 dB antenna gain)	~~38.6~~	~~17.1~~ 16.7	25.0	~~17.1~~ 16.7	8.0	~~9.1~~ 8.7
Ku to L (22 dB antenna gain)	38.6	17.6	25.0	17.6	10.0	7.6
L to Ku (12 dB antenna gain)	29.1	~~17.3~~ 15.3	26.0	~~17.0~~ 15.1	10.0	~~7.0~~ 5.1
L to Ku (22 dB antenna gain)	29.1	~~17.3~~ 15.3	26.0	~~17.0~~ 15.1	~~8.0~~ 10.0	~~9.0~~ 5.1

4.2 McCaw Space Technologies, Inc.

McCaw proposes to use 20 UHF beams to cover the U.S., Canada, Mexico and the Carribean and two L-band beams to cover South America. The spectrum is divided into 250 kHz channels and two of these are "roving" channels switchable to selected beams. It is interesting to note also that 10% of the spectrum is used for guard bands.

The UHF mobile terminal antenna gain is assumed to be 5 dBic, while for the L-band the gain is assumed to be 10 dBic. For both UHF and L-band, the uplink signal is assumed to be right-hand circularly polarized (RHCP) while the downlink is left-hand circularly polarized (LHCP). This will no doubt complicate the mobile terminal design.

Representative link budgets for both the UHF link and L-band link are given in Tables 4.4(a) and 4.4(b) respectively. McCaw believes that a minimum C/N_o of 45 dB-Hz in a 5 kHz channel is adequate to support acceptable quality 2.4 kb/s digital voice and data at 2.4 kb/s using GMSK and a high rate FEC coding scheme (end-to-end BER of 10^{-5}). They also assume that adequate voice quality using ACSSB can be achieved for this C/N_o value of 45 dB-Hz. For the UHF link shown (Table 4.4(a)) however, we note that overall link C/N_o is 50.2 dB-Hz and 51.5 dB-Hz for the forward and reverse links respectively which match Telesat's overall numbers.

The gateway is assumed to have a 5.5 m SHF antenna compared to Telesat's 3.5 m. For the L-band link (Table 4.4(b)) the overall link C/N_o are 47.5 dB-Hz and 47.1 dB-Hz for the forward and reverse links respectively. Whereas these may be adequate for thin-route (fixed) rural communications they are clearly too low if mobile service is ever intended. Of particular note should be the use of an L-band to L-band link. The (L-band) gateway has an antenna with 3.0 m diameter.

McCaw has only discussed interference qualitatively. The intermodulation C/IM_o values of 58.9 dB-Hz used for all links (up and down) appears rather optimistic compared to Telesat's. Also, only a 0.5 dB degradation is allowed for all other interferences (ACI, etc.)

Another major point of departure from Telesat's design is the use of a large spacecraft reflector (11 m diameter compared to Telesat's 5.0 m).

(From McCaw's Filing to the FCC)

Table 4.4(a): <u>TYPE 1 MOBILE ANTENNA LINK PERFORMANCE - UHF</u>

MOBILE TO GATEWAY LINK			GATEWAY TO MOBILE LINK		
UPLINK			**UPLINK**		
Frequency	0.823	GHz	Frequency	14.25	GHz
Mobile Antenna Gain	5.0	dBi	Gateway Antenna Dia	5.5	m
Cable and Other Losses	0.5	dB	Gateway Tx Antenna Gain	55.7	dBi
Polarization Loss	0.5	dB	Feed & Other Losses	2.0	dB
Transmitter Power	0.500	Watt	Tx Power/Carrier	0.500	Watt
Uplink EIRP/Channel	1.0	dBW	Uplink EIRP/Channel	50.7	dBW
Free Space Loss	182.4	dB	Free Space Loss	207.1	dB
S/C Antenna Gain (EOC)	34.3	dBi	S/C Antenna Gain (EOC)	25.0	dBi
Losses	1.0	dB	Losses	1.0	dB
S/C Receive Noise Temp	400.0	K	S/C Receive Noise Temp	630.0	K
S/C G/T (EOC)	7.3	dB/K	S/C G/T (EOC)	-4.0	dB/K
Boltzmann Constant	-228.6	dBJ/K	Boltzmann Constant	-228.6	dBJ/K
UPLINK C/No	54.5	dBHz	UPLINK C/No	68.2	dBHz
DOWNLINK			**DOWNLINK**		
Frequency	11.95	GHz	Frequency	0.868	GHz
S/C Antenna Gain (EOC)	25.0	dBi	S/C Antenna Gain (EOC)	34.3	dBi
Losses	1.5	dB	Losses	1.5	dB
TWTA Saturation Power	30.0	Watts	SSPA Saturation Power	25.0	Watts
S/C Saturation EIRP	38.3	dBW	S/C Saturation EIRP	46.8	dBW
S/C Output Backoff	3.0	dB	S/C Output Backoff	2.5	dB
No. of Carriers/Xponder	900		No. of Carriers/Xponder	45	
S/C EIRP/Carrier	5.7	dBW	S/C EIRP/Carrier	27.7	dBW
Free Space Loss	205.6	dB	Free Space Loss	182.8	dB
Gateway Antenna Dia	5.5	m	Mobile Antenna Gain	5.0	dBi
Gateway Rx Gain	54.2	dBi	Mobile Rx Noise Temp	400.0	K
Gateway Rx Noise Temp	250.0	K	Cable and Other Lossess	0.5	dB
Pointing & Other Losses	0.5	dB	Polarization Loss	0.5	dB
Gateway Receive G/T	29.7	dB/K	Mobile Rx G/T	-22.0	dB/K
Boltzmann Constant	-228.6	dBJ/K	Boltzmann Constant	-228.6	dBJ/K
DOWNLINK C/No	58.4	dBHz	DOWNLINK C/No	51.5	dBHz
UPLINK C/No	54.5	dBHz	UPLINK C/No	68.2	dBHz
DOWNLINK C/No	58.4	dBHz	DOWNLINK C/No	51.5	dBHz
Intermod C/IMo	58.9	dBHz	Intermod C/IMo	58.9	dBHz
COMPOSITE C/No	52.0	dBHz	COMPOSITE C/No	50.7	dBHz
Degradation (ACI, etc)	0.5	dB	Degradation (ACI, etc)	0.5	dB
LINK C/No	51.5	dBHz	LINK C/No	50.2	dBHz
MINIMUM REQD C/No	45.0	dBHz	MINIMUM REQD C/No	45.0	dBHz
OVERALL LINK MARGIN	6.5	dB	OVERALL LINK MARGIN	5.2	dB

(From McCaw's Filing to the FCC)

Table 4.4(b): **TYPE 2 MOBILE ANTENNA LINK PERFORMANCE (L-BAND)**

USER TO GATEWAY LINK			GATEWAY TO USER LINK		
UPLINK			**UPLINK**		
Frequency	1.6	GHz	Frequency	1.6	GHz
User Antenna Gain	10.0	dBi	Gateway Antenna Dia	3.0	m
Cable and Other Losses	0.5	dB	Gateway Tx Antenna Gain	31.8	dBi
Polarization Loss	0.5	dB	Feed & Other Losses	2.0	dB
Transmitter Power	1.000	Watt	Tx Power/Carrier	0.500	Watt
Uplink EIRP/Channel	9.0	dBW	Uplink EIRP/Channel	26.7	dBW
Free Space Loss	188.4	dB	Free Space Loss	188.4	dB
S/C Antenna Gain (EOC)	27.3	dBi	S/C Antenna Gain (EOC)	27.3	dBi
Losses	1.0	dB	Losses	1.0	dB
S/C Receive Noise Temp	460.0	K	S/C Receive Noise Temp	460.0	K
S/C G/T (EOC)	-0.3	dB/K	S/C G/T (EOC)	-0.3	dB/K
Boltzmann Constant	-228.6	dBJ/K	Boltzmann Constant	-228.6	dBJ/K
UPLINK C/No	48.8	dBHz	UPLINK C/No	66.6	dBHz
DOWNLINK			**DOWNLINK**		
Frequency	1.55	GHz	Frequency	1.55	GHz
S/C Antenna Gain (EOC)	27.3	dBi	S/C Antenna Gain (EOC)	27.3	dBi
Losses	1.5	dB	Losses	1.5	dB
Saturation Power	70.0	Watts	Saturation Power	70.0	Watts
S/C Saturation EIRP	44.3	dBW	S/C Saturation EIRP	44.3	dBW
Number of Carriers	45		Number of Carriers	45	
Carrier Output Backoff	36.5	dB	Carrier Output Backoff	19.5	dB
S/C EIRP/Carrier	7.7	dBW	S/C EIRP/Carrier	24.7	dBW
Free Space Loss	187.9	dB	Free Space Loss	187.9	dB
Gateway Antenna Dia	3.0	m	User Antenna Gain	10.0	dBi
Gateway Rx Gain	31.2	dBi	User Rx Noise Temp	400.0	K
Gateway Rx Noise Temp	250.0	K	Cable and Other Lossess	0.5	dB
Pointing & Other Losses	0.5	dB	Polarization Loss	0.5	dB
Gateway Receive G/T	6.7	dB/K	User Rx G/T	-17.0	dB/K
Boltzmann Constant	-228.6	dBJ/K	Boltzmann Constant	-228.6	dBJ/K
DOWNLINK C/No	55.1	dBHz	DOWNLINK C/No	48.4	dBHz
UPLINK C/No	48.8	dBHz	UPLINK C/No	66.6	dBHz
DOWNLINK C/No	55.1	dBHz	DOWNLINK C/No	48.4	dBHz
Intermod C/IMo	58.9	dBHz	Intermod C/IMo	58.9	dBHz
COMPOSITE C/No	47.6	dBHz	COMPOSITE C/No	48.0	dBHz
Degradation (ACI, etc)	0.5	dB	Degradation (ACI, etc)	0.5	dB
LINK C/No	47.1	dBHz	LINK C/No	47.5	dBHz
MINIMUM REQD C/No	45.0	dBHz	MINIMUM REQD C/No	45.0	dBHz
OVERALL LINK MARGIN	2.1	dB	OVERALL LINK MARGIN	2.5	dB

4.3 Mobilesat Corporation

Mobilesat has proposed a system with one large UHF beam to cover all of Continental U.S. and Canada, and three smaller beams to cover Alaska and the islands. The L-band system has 11 beams. The spacecraft antenna gain quoted appears to be too high for the beam coverage area shown. Also, there might not be sufficient isolation between the Alaska and North American beams even with orthogonal polarization.

The UHF mobile terminal antenna gain is assumed to vary from 4 dBic to 10 dBic while for L-band, the gain is either 6 dBic or 13 dBic depending on whether the antenna is fixed or steered. In their system, all receive beams are orthogonally polarized to the transmit beams which will complicate the mobile terminal design.

Representative link budgets (CONUS coverage) for both UHF and L-band are given in Tables 4.5 a) and b). Mobilesat has set a C/N_o objective of 50.3 dB-Hz which is compatible with Telesat's. The gateway is assumed to have an antenna with a diameter of 3.0 m, but at the Network Operating Centre the antenna has a diameter of 10.0 m.

Only a 0.5 dB downlink degradation is allowed due to uplink noise. No margin seems to be provided for fading and blockage.

The UHF and L-band mobile terminal receive noise temperature of 22.1 dB (162 K) appears unrealistically low. Also the noise figures of 0.8 dB for the UHF and L-band mobile receiver as well as the satellite (space-qualified) LNA would appear overly optimistic.

The link budgets presented do not show the effect of interference although in the filing, Mobilesat states that its effect has been considered and it expects to achieve high quality performance despite these effects.

TABLE 4-5(a)

SYSTEM PERFORMANCE CHARACTERISTICS (THERMAL NOISE ONLY)

MOBILE-TO-GATEWAY PATH

	Mobile-to-Satellite UHF (CONUS)	Mobile-to-Satellite L-Band (CONUS)	Satellite-to-Gateway Ku-Band (CONUS)
Carrier-to-Noise Density, dB-Hz	50.3	50.3	50.3
Degradation Allowance, dB(1)	9.6	9.6	0.5
Link C/No Required, dB-Hz	59.9	59.9	50.8
Propagation Loss, dB, Typical	182.4	188.4	205.6
Margin + Loss	--	--	4.0
Antenna Receive Gain, Average, dBi	27.4	32.1	49.5(3)
Receive Noise Temp, dB	26.6	26.1	26.3
Required EIRP, dBW(2)	12.9	13.7	8.6
Antenna Transmit Gain, dBi	10.0	13.0	28.9
Transmitter Power, dBW (average) (for standard equiv. circuit)(5)	2.9	0.7(mobile)	-20.3
Transmitter Output Losses, dB and/or Coupling Losses	1.0	1.0	2.8
Transmitter Power dBW (Watts)	3.9 (2.5)	1.7 (1.5)	-17.5

(1) 0.5 dB downlink degradation due to uplink noise
(2) Boltzmann's constant = -228.6 dBW/Hz/K
(3) 10 foot gateway antennas
(4) 14 foot gateway antennas
(5) Power at antenna

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(Extracted from Mobilesat's Filing to the FCC)

TABLE 4-5(b)

SYSTEM PERFORMANCE CHARACTERISTICS (THERMAL NOISE ONLY)

GATEWAY-TO-MOBILE PATH

	Gateway-to Satellite Ku-Band (CONUS)	Satellite-to-Mobile UHF (CONUS)	Satellite-to-Mobile L-Band (CONUS)
Carrier-to-Noise Density, dB-Hz	50.3	50.3	50.3
Link Degrad. Allowance, dB(1)	9.6	0.5	0.5
Link C/N_o Required, dB-Hz	59.9	50.8	50.8
Propagation Loss, dB, Typical	207.0	182.8	187.9
Margin + Loss	4.0	--	--
Antenna Receive Gain, Average, dBi	30.1	10.0	13.0
Receive Noise Temp, dB	27.9	22.1	22.1
Required EIRP, dBW(2)	40.1	17.1	19.2
Antenna Transmit Gain, dBi	50.9(3)	26.9	30.8
Transmitter Power, dBW(6)	-10.8	-9.8	-11.6
Transmitter Output Losses, and/or Coupling Losses, dB	--	1.8	4.5
Transmitter Power dBW (Watts)	--	-8.0	-11.1

(1) 0.5 dB downlink degradation due to uplink noise
(2) Boltzmann's constant = -228.6 dBW/Hz/K
(3) 10 foot gateway antennas
(4) 14 foot gateway antennas
(5) More power is required for UHF link
(6) At antenna

Doc. 2529Z

4.4 North American Mobile Satellite, Inc.

North American Mobile Satellite (NAMS) proposes a system with four UHF beams covering CONUS and Canada, and a beam each for Hawaii and the Caribbean. It should be noted here that from the coverage diagrams, it appears that the Canadian maritime provinces will not have adequate coverage. Two types of mobile terminal antennas are considered—a low-gain antenna (6 dBic) and a medium-gain antenna (10 dBic for UHF and 12 dBic for L-band).

Representative link budgets are given in Table 4.6 for the UHF system and Table 4.7 for the L-band system. These budgets are only for ACSSB modulation. NAMS believes that for ACSSB service using syllabic companding, a C/N_o of 46 to 50.3 dB-Hz would be acceptable.

NAMS intends to use C-band for the feederlinks which is different from Telesat's proposal to use Ku-band. Also, the use of a fairly large spacecraft antenna (10 m diameter reflector) is a major departure from Telesat's design. Another salient point in NAMS' design is the use of reverse band operation, (i.e. uplink and downlink frequency reversal) between Canada and the U.S. so that each country has the full 4 MHz of spectrum. This proposal, however, means that the mobile terminal has to be able to reverse the frequency directions in case of sparing by the other country's satellite. As a result, the mobile terminal design will be quite complicated.

The link budgets given contain quite a few arithmetic errors, for example the number of carriers is given as 1.00 dB instead of 0 dB (1 carrier).

(From NAM'S FILING TO THE FCC)

Table 4.6a): UHF Forward Link

NAMSAT LINK ANALYSIS () () () () () () () () () () () () ()			Gateway Up-Mobile Down HYBRID	AM-CSSB
GATEWAY UPLINK				
Bandwidth	kHz		4.50	
HPA P.O.	Watts		10.00	
Output Backoff	dB	))	6.00	
Freq.	GHz	))	5.90	
E.S.Diam.	Meters		3.50	
Ant. Eff.	%	))	0.65	
E.S.Gain	dB		44.72	
Losses	dB		1.00	
E.S.EIRP	dBW	))	47.72	
Number Carriers		)	12.00	
E.S.EIRP/Carrier	dBW		36.93	
Sat Ant Gain(EOC	dB		26.50	
NoiseTemp	degK	))	290.00	
Sat. G/T(EOC)	dB-K		-1.12	
Path Loss	dB		199.72	
BoltzmanKonst	dBW/K		228.60	
C/No-up	dB		64.69	
DOWNLINK TO MOBILE	866 MHz		Mid-Gain	Low-Gain
Sat D.C.Power	Watts		290.00	290.00
RF Eff.	%		60.00	60.00
RF P.O.	Watts		174.00	174.00
Output Backoff	dB	))	3.70	3.70
Peak Sat AntGain	dB		34.00	34.00
Losses	dB		2.00	2.00
EIRP(EOC)	dBW	))	47.71	47.71
Number Carriers per Chan		)	180.00	90.00
Voice Activity' Factor			0.40	0.40
Sat EIRP/Carrier	dBW		29.13	32.14
Freq.	GHz	))	0.87	0.87
E.S.Gain	dB		10.00	6.00
NoiseTemp	degK	))	400.00	400.00
E.S. G/T	dB-K		-16.02	-20.02
Path Loss	dB		183.06	183.06
BoltzmanKonst	dBW/K		228.60	228.60
C/No-down	dB-Hz		58.65	57.66
Downlink Fade	dB		5.00	5.00
C/Ndown	dB		17.12	16.13
C/Nup	dB		28.16	28.16
C/Ntot-therm	dB		16.79	15.87
C/Im	dB	))	28.00	28.00
C/Xpol	dB	))	26.00	26.00
C/Iax	dB	))	50.00	50.00
C/Ntotal	dB		16.01	15.23
Required C/No	dB-Hz		49.80	49.80
Margin(+5dB fade)	dB		2.74	1.96

(FROM NAM'S FILING TO THE FCC)

Table 4.6b): UHF Reverse Link

NAMSAT LINK ANALYSIS — MOBILE UP -GATEWAY DOWN

<> <> <> <> <> <> <> <> <> <> <> <> <> — HYBRID AM-CSSB

MOBILE UP		822 MHz	Mid-Gain	Low-Gain
HPA P.O.	Watts		10.00	12.00
Output Backoff	dB	>>	1.00	1.00
Ant Gain	dB		10.00	6.00
Losses	dB		1.60	1.60
EIRP(EOC)	dBW	>>	14.40	11.19
Number Carriers			1.00	1.00
ES EIRP/Carrier	dBW		13.40	10.19
Freq.	GHz	>>	0.82	0.82
Sat Gain(EOC)	dB		30.00	30.00
NoiseTemp	degK	>>	300.00	300.00
Sat G/T	dB-K		5.23	5.23
Path Loss	dB		182.60	182.60
BoltzmanKonst	dBW/K		228.60	228.60
Bandwidth	kHz		3.50	3.50
C/No-up	dB		64.63	61.42
Fade	dB		5.00	5.00
Faded C/No	dB		59.63	56.42
DOWNLINK to GATEWAY				
HPA P.O.	Watts		10.00	10.00
Output Backoff	dB	>>	3.70	3.70
Peak Sat AntGain	dB		31.00	31.00
Losses	dB		1.00	1.00
EIRP(EOC)	dBW	>>	33.30	33.30
Number Carriers	per Chan	>	1200.00	1000.00
Voice Activity	Factor		0.40	0.40
Sat EIRP/Carrier	dBW		6.49	7.28
Freq.	GHz	>>	3.69	3.69
E.S.Diam	Meters		3.50	3.50
Ant.Eff.	%		0.65	0.65
E.S.Gain	dB		40.67	40.67
LNA NoiseTemp	degK	>>	80.00	80.00
Addtnl Noise	degK	>>	50.00	50.00
E.S. G/T	dB-K		20.67	20.67
Path Loss	dB		195.64	195.64
BoltzmanKonst	dBW/K		228.60	228.60
C/No-down	dB		60.12	60.91
C/Ndown	dB		24.68	25.47
C/Nup	dB		19.19	15.98
C/Ntot-therm	dB		18.11	15.52
C/Im	dB	>>	28.00	28.00
C/Xpol	dB	>>	26.00	26.00
C/Iax	dB	>>	50.00	50.00
			##########	##########
Faded C/Ntotal	dB		17.09	14.93
C/No Req.	dB		49.80	49.80
Margin(C/Ntotal-C/Nreq)			2.73	0.57

(FROM NAM'S FILING TO THE FCC)

Table 4.7a): L-Band Forward Link

NAMSAT LINK ANALYSIS			Gateway Up-Mobile Down	
()()()()()()()()()()()()()			HYBRID	AM-CSSB
GATEWAY UPLINK				
Bandwidth	kHz		3.50	
HPA P.O.	Watts		10.00	
Output Backoff	dB	>>	6.00	
Freq.	GHz	>>	5.90	
E.S.Diam.	Meters		3.50	
Ant. Eff.	%	>>	0.65	
E.S.Gain	dB		44.72	
Losses	dB		1.00	
E.S.EIRP	dBW	>>	47.72	
Number Carriers		>	8.00	
E.S.EIRP/Carrier	dBW		38.69	
Sat Ant Gain(EOC	dB		26.50	
NoiseTemp	degK	>>	290.00	
Sat. G/T(EOC)	dB-K		-1.12	
Path Loss	dB		199.72	
BoltzmanKonst	dBW/K		228.60	
C/No-up	dB		66.45	
DOWNLINK TO MOBILE		1555MHz	Mid-Gain	Low-Gain
Sat D.C.Power	Watts		400.00	400.00
RF Eff.	%		60.00	60.00
RF P.O.	Watts		240.00	240.00
Output Backoff	dB	>>	3.70	3.70
Peak Sat AntGain	dB		34.00	34.00
Losses	dB		2.00	2.00
EIRP(EOC)	dBW	>>	49.10	49.10
Number Carriers	per Chan	>	150.00	70.00
Voice Activity	Factor		0.40	0.40
Sat EIRP/Carrier	dBW		31.32	34.63
Freq.	GHz	>>	1.56	1.56
E.S.Gain	dB		12.00	6.00
NoiseTemp	degK	>>	300.00	350.00
E.S. G/T	dB-K		-12.77	-19.44
Path Loss	dB		188.13	188.13
BoltzmanKonst	dBW/K		228.60	228.60
C/No-down	dB-Hz		59.01	55.66
Downlink Fade	dB		5.00	5.00
C/Ndown	dB		18.57	15.21
C/Nup	dB		31.01	31.01
C/Ntot-therm	dB		18.33	15.10
C/Im	dB	>>	28.00	28.00
C/Xpol	dB	>>	26.00	26.00
C/Iax	dB	>>	50.00	50.00
C/Ntotal	dB		17.26	14.56
Required C/No	dB-Hz		49.80	49.80
Margin(+5dB fade)	dB		2.90	0.20

(FROM NAM'S FILING TO THE FCC)

Table 4.7b): L-Band Reverse Link

NAMSAT LINK ANALYSIS			MOBILE UP -GATEWAY DOWN HYBRID	AM-CSSB
MOBILE UP		1657 MHz	Mid-Gain	Low-Gain
HPA P.O.	Watts		15.00	25.00
Output Backoff	dB	>>	0.50	0.50
Ant Gain	dB		12.00	6.00
Losses	dB		1.40	1.40
EIRP(EOC)	dBW	>>	18.86	15.08
Number Carriers			1.00	1.00
ES EIRP/Carrier	dBW		18.36	14.58
Freq.	GHz	>>	1.66	1.66
Sat Gain(EOC)	dB		31.00	31.00
NoiseTemp	degK	>>	300.00	300.00
Sat G/T	dB-K		6.23	6.23
Path Loss	dB		188.69	188.69
BoltzmanKonst	dBW/K		228.60	228.60
Bandwidth	kHz		3.50	3.50
C/No-up	dB		64.50	60.72
Fade	dB		5.00	5.00
Faded C/No-up	dB		59.50	55.72
DOWNLINK to GATEWAY				
HPA P.O.	Watts		10.00	10.00
Output Backoff	dB	>>	3.70	3.70
Peak Sat AntGain	dB		31.00	31.00
Losses	dB		1.00	1.00
EIRP(EOC)	dBW	>>	33.30	33.30
Number Carriers	per Chan	>	1400.00	1000.00
Voice Activity	Factor		0.40	0.40
Sat EIRP/Carrier	dBW		5.82	7.28
Freq.	GHz	>>	3.69	3.69
E.S.Diam	Meters		3.50	3.50
Ant.Eff.	%		0.65	0.65
E.S.Gain	dB		40.67	40.67
LNA NoiseTemp	degK	>>	80.00	80.00
Addtnl Noise	degK	>>	50.00	50.00
E.S. G/T	dB-K		20.67	20.67
Path Loss	dB		195.64	195.64
BoltzmanKonst	dBW/K		228.60	228.60
C/No-down	dB		59.45	60.91
C/Ndown	dB		24.01	25.47
C/Nup	dB		19.06	15.28
C/Ntot-therm	dB		17.86	14.88
C/Im	dB	>>	28.00	28.00
C/Xpol	dB	>>	26.00	26.00
C/Iax	dB	>>	50.00	50.00
Faded C/Ntotal	dB		16.88	14.37
C/No Req.	dB		49.80	49.80
Margin(C/Ntotal-C/Nreq)			2.52	0.01

4.5 Omninet Corporation

The system proposed by Omninet has 12 UHF beams per satellite to cover both the U.S. and Canada and uses two satellites. Polarization reversal is assumed between the two satellites. For example, of the seven beams covering Canada, three are from one satellite and they are right-hand circularly polarized, while the other four beams are from the second spacecraft and are left-hand circularly polarized. This will require that the mobile terminal be equipped with the capability to change polarization, in case it has to transmit to the other satellite. The use of both orthogonal polarization and orbit reuse is doubtful in light of the current vehicular antenna technology. It is felt that the isolation provided by these antennas is not sufficient to allow polarization diversity. Further, orbital reuse will require sophisticated antenna beam steering mechanisms. However, the UHF and L-band mobile terminal antenna gains are both assumed to be 5 dBic. Another two satellites each provide 17 L-band beams covering CONUS, Alaska and Hawaii. For L-band, the transmit and receive are orthogonally polarized which adds to the mobile terminal complication.

Representative link budgets for ACSSB are given in Tables 4.8 and 4.9 for the UHF forward and reverse links respectively. L-band budgets are similar to these. Omninet believes that a C/N_o value of 47.0 dB-Hz is sufficient for ACSSB voice, digital LPC voice, and GMSK data. This differs considerably from the value assumed by Telesat. In determining this C/N_o value, Omninet has taken 2 to 3 dB multipath fading into account. This is a bit optimistic based on measured propagation results [4 - 6]. Omninet argues that the composite C/N_o value derived by assuming additive noise and interference is rather pessimistic. Results of their channel simulation studies indicate for example a "true composite" C/N_o of 51 dB-Hz instead of 47.6 dB-Hz (see Table 4.8), resulting in a 3 dB system margin. However, if one has to compare with Telesat's design, the comparison has to be based on the same method of computing the composite C/N_o i.e. 47.6 dB-Hz vs. 50.2 dB-Hz. The transponder C/I_o (intermod) value of 60 dB-Hz appears rather high.

The gateway is assumed to have a 5.0 m SHF antenna compared to Telesat's 3.5 m. The satellite antenna gains and G/T appear to be too high. Also, a fairly large spacecraft antenna (9.1 m) is employed compared to Telesat's 5.0 m antenna. Some arithmetic errors in the budgets are pencilled in.

(From OMNINET'S FILING TO THE FCC)

Table 4.8 Forward Link Parameters

(a) Ku-Band Feeder-Link Uplink Parameters

G/S antenna diameter	5.0	m
Antenna gain	54.0	dB
Transmit line loss	2.0	dB
Transmitted power/carrier	- 12.1	dBW
EIRP per channel	39.9	dBW
Free space loss	206.8	dB
Satellite G/T	- 2.5	dB/K
	59.2	dBHz
Resultant C/N_o	59.2	dBHz
Gateway C/I_o	60.0	dBHz
Composite C/N_o	56.6	dBHz

(From OMNINET'S FILING TO THE FCC)

Table 4.8 (b) ASCB LINK PERFORMANCE
UHF SATELLITE-TO-MOBILE LINK BUDGET

Thermal Noise	
Edge of Coverage EIRP per Carrier	26.2 dBW */
Activity Factor	4.0 dB
Free Space Loss (40,000km)	183.2 dB
Mobile Antenna Gain	5.0 dBi
Rec. System Temp. (408°K)	26.1 DBK
G/T	-21.1 dB/K
Clear Sky C/N_o	54.5 dBHz
Margins:	
Polarization Loss	0.5 dB
Antenna Pointing Loss	0.5 dB
Resultant Thermal C/N_o	53.5 dBHz
Other Noise Source	
Transponder C/I_o	60.0 dBHz
Inter-satellite X-Pol C/I_o	55.3 dBHz
Inter-satellite CO-Pol C/I_o	52.3 dBHz
Intra-satellite X-Pol C/I_o	55.3 dBHz
Intra-satellite CO-Pol C/I_o	80.3 dBHz
Composite C/N_o **/	47.6 dBHz
True Composite C/N_o	51.0 dBHz

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*/ Saturated XPDR EIRP = 47.8 dBW EOC, 92 equal channels, 2.0 dB output backoff.

**/ The pessimistic additive noise and interference assumption results in a 6 dB loss. In fact, as shown in Appendix C, the results of channel simulation studies indicate no more than 2.5 dB of loss for the amount of interferences shown above. In the following tables, the values of Composite C/N_o which are based on channel simulation studies are referred to as True Composite C/N_o.

(From OMNINET'S FILING TO THE FCC)

Table 4.8 (c) UHF ACSB SYSTEM MARGIN
GATEWAY-TO-SATELLITE-TO-MOBILE

UHF Downlink Composite C/N_o	47.6 dBHz
Feeder-link Uplink C/N_o	56.6 dBHz
Total End-to-End C/N_o	47.1 dBHZ
UHF Downlink True Composite C/N_o	51.0 dBHz
Feeder-Link Uplink C/N_o	56.6 dBHz
Total End-to-End C/N_o	50.0 dBHz
Required End-to-End C/N_o	47.0 dBHz
System Margin	3.0 dB

(From OMINET'S FILING TO THE FCC)

Table 4.9 Reverse Link Parameters

(a) ACSB LINK PERFORMANCE
UHF MOBILE-TO-SATELLITE LINK BUDGET

Thermal Noise	
Mobile Transmitter	7.8 dBW (6 watts)
Circuit Loss	1.5 dB
Antenna Gain	5.0 dBi
Mobile EIRP per Channel	11.3 dBW
Free Space Loss	182.8 dB
Edge of Coverage G/T	4.0 dB/K
Clear Sky C/N_o per Carrier	~~60.1~~ dBHz 61.1
Margins:	
Polarization Loss	0.5 dB
Antenna Pointing Loss	0.5 dB
Resultant Thermal C/N_o	~~61.1~~ dBHz 60.1
Other Noise Sources	
Inter-satellite X-pol, C/I_o	55.3 dBHz
Inter-satellite Co-Pol, C/I_o	52.3 dBHz
Intra-Satellite X-pol, C/I_o	55.3 dBHz
Intra Satellite Co-Pol, C/I_o	80.3 dBHz
Composite C/N_o	48.9 dBHz
True Composite C/N_o	57.0 dBHz

(From OMNINET'S FILING TO THE FCC)

Table 4.9 (b)

Composite C/No for the UHF Satellite Feeder-Link Downlink

Ku band EIRP per carrier	9.9	dBW
Activity Factor	4.0	dB
Space Loss	206.0	dB
Ground Station G/T (5M)	+28.6	dB/K
C/N_o	65.1	dBHz
C/I_o	58.0	dBHz
Composite C/N_o	57.2	dBHz

Table 4.9 c) UHF SYSTEM MARGIN

MOBILE-TO-SPACECRAFT-TO-GATEWAY

Mobile-to-Satellite Link	48.9 dBHz
Satellite-to Gateway Link	57.2 dBHz
Total End-to-End C/N_o	48.3 dBHz
UHF Uplink True Composite C/N_o	57.0 dBHz
Feeder-Link Downlink C/N_o	57.2 dB
Total True End-to-End C/N_o	54.1 dB
Required End-to-End C/N_o	47.0 dBHz
System Margin	7.1 dB

4.6 Skylink Corporation

Skylink proposes to cover the U.S. and Canada with two UHF beams and also use 8 L-band beams to provide added coverage to the U.S. The UHF mobile terminal antenna gain is assumed to be 5 dBic for elevation angles between 15° and 50°, while two services are envisaged at L-band, one requiring 12 dBic gain antennas, the other requiring 19 dBic gain antennas. For L-band, both orbital reuse and crosspolarization between sub-bands are proposed. It is very questionable if orbital reuse can be achieved with only 12 dBic ground segment antennas. Further crosspolarization would require the mobile terminals to change from LHCP to RHCP as they roam into adjacent beams. Depending on the antenna type used, this may necessitate using two antennas.

Representative link budgets are given in Tables 4.10 and 4.11 for both the UHF and L-band systems. Skylink did not present their link budgets in the normal tabular form. The budgets in Tables 4.10 and 4.11 are grouped here in this tabular form for ease of comparison with Telesat's budgets. The outbound link corresponds to the forward link while the inbound link corresponds to the return link.

Skylink proposes to use either ACSSB or LPC with two phase rectangular spectrum manipulation (RSM) modulation for voice, while using RSM for channel acquisition and data transmission. The target for both voice and data is a total C/N_0 of 51 dB-Hz which is quite close to Telesat's objective for ACSSB voice.

The backhaul hub (SHF base stations or gateway) will have a 5.0 m parabolic antenna while UHF hub terminals will be equipped with 3.0 m antennas. (Note that Skylink allows UHF-UHF half duplex channels.)

The UHF LNA noise temperature of 75 K used for both the satellite and mobile terminal appears somewhat optimistic. For L-band, the LNA noise temperatures assumed are 90 K and 80 K for the satellite and mobile terminal respectively. Very high SSPA efficiencies are assumed -- 32.5% for the PA and 100% for the EPC. Also, the value of carrier-to-intermod ratio of 28 dB used is rather high considering that there is a 6 dB difference in the levels of carriers to mobiles and base stations.

(Assembled from Skylink's Filing to the FCC)

TABLE 4-10

Remote (UHF) to Satellite to Base Station Link

Uplink	Inbound	Outbound
E/S EIRP	11.4 dBW	47.3 dBW
Path Loss	183.1 dB	207.8 dB
Atmospheric Att.	0.1 dB	0 dB
S/C Ant. Gain	25.6 dBic	25 dBi
Receive Diplexer Loss	1.3 dB	0.5 dB
Receive Misc. Loss	0.3 dB	0.5 dB
Ant. Effective Temp.	168 K	290 K
LNA Noise Temp.	75 K	275 K
Sys. Temp.	281 K	565 K
G/T Sat.	- 0.5 dB/K	-3.5 dB/K
C/N_o Up	56.3 dB Hz	64.6 dB Hz
Downlink		
Power Output	-11.1 dBW	4.9 dBW
S/C Ant. Gain	25 dBic	26.1 dBic
Transmit Diplexer Loss	0.5 dB	1 dB
Transmit Misc. Loss	0.5 dB	0.5 dB
EIRP/Channel	12.9 dBW	29.5 dBW
Path Loss	206.2 dB	183.6 dB
Atmospheric Att.	0 dB	0.1 dB
E/S Ant. Gain	52.5 dBi	6. dBic
Pointing Loss	1 dB	0.5 dB
Polarization Loss	0.1 dB	0.4 dB
Receive diplexer loss	1.5 dB	1.0 dB
Sky Temperature	35 K	100 K
Feedline Loss	0 dB	1 dB
Receive Misc. Loss	0.3 dB	0.3 dB
LNA Temperature	275 K	75 K
Sys. Temp.	400 K	263 K
G/T	23.6 dB/K	-21.4 dB/K
C/N_o	58.9 dB Hz	53.0 dB Hz
C/N_o thermal total	54.4 dB Hz	52.7 dB Hz
C/I Uplink	21.2 dB	25.7 dB
C/I Downlink	18.2 dB	17.5 dB
Transponder IM Ratio	28 dB	28 dB
BW 2500 Hz	34 dB Hz	34 dB Hz
C/I_o Uplink	55.2 dB Hz	59.7 dB Hz
C/I_o Downlink	52.2 dB Hz	51.5 dB Hz
C/IM	62 dB Hz	62 dB Hz
C/N_o Overall	48.7 dB Hz	48.5 dB Hz

(Assembled from Skylink's Filing to the FCC)

TABLE 4-11

Remote (L-band) to Satellite to Base Station

Uplink	Inbound	Outbound
E/S EIRP	18.0 dBW	47.3 dBW
Path Loss	189.2 dB	207.8 dB
Atmospheric Attenuation	0.1 dB	0.1 dB
S/C Antenna Gain	30.6 dBic	25 dBi
Receive Diplexer Loss	1.3 dB	0.5 dB
Receive Misc. Loss	0.5 dB	0.5 dB
Ant. Effective Temperature	200 K	290 K
LNA Noise Temperature	90 K	275 K
System Temperature	321 K = 25.1 dBK	565 K = 27.5 dBK
G/T Sat.	3.7 dB/K	-3.5 dB/K
C/N_0 Up	61 dB Hz	64.5 dB Hz

Downlink	Inbound	Outbound
Power Output/Channel	-11.1 dBW	1.9 dBW
S/C Ant. Gain	25 dBic	30.1 dBic
Transmit Diplexer Loss	0.5 dB	1 dB
Transmit Misc. Loss	0.5 dB	0.7 dB
EIRP/Channel	12.9 dBW	30.3 dBW
Path Loss	206.2 dB	188.7 dB
Atmospheric Attenuation	0.1 dB	0.1 dB
E/S Antenna Gain	52.5 dBi	12 dBi
Pointing Loss	1.0 dB	0.5 dB
Polarization Loss	0.1 dB	0.3 dB
Receive Diplexer loss	1.5 dB	1.4 dB
Sky Temperature	35 K	60 K
Feedline Loss	0 dB	0.5 dB
Receive Misc. Loss	0.3 dB	0.2 dB
LNA Temperature	275 K	80 K
System Noise Temperature	400 K	238 K
G/T_{BS}	23.6 dB/K	-14.6 dB/K
C/N_0	58.9 dB Hz	55.5 dB Hz
C/N_0 Total Thermal	56.8 dB Hz	55.0 dB Hz
C/I Uplink	22.5 dB	25.7 dB
C/I Downlink	18.8 dB	18.5 dB
Transponder IM Ratio	28 dB	28 dB
BW 2500 Hz	34.0 dB Hz	34.0 dB Hz
C/I_0 Uplink	56.5 dB	59.7 dB Hz
C/I_0 Downlink	52.8 dB Hz	52.5 dB Hz
C/IM	62 dB Hz	62 dB Hz
C/N_0 Overall	49.9 dB Hz	50.0 dB Hz

5.0. CRITICAL AREAS OF CONCERN

In the course of the development of the MSAT system concept and its refinement, several assumptions about the expected performance were made, or implied. The system performance then determines the user capacity, ie. the number of users that the system can accommodate. The ultimate success of MSAT will depend on the extent to which the assumed performance can be achieved and how the users will accept the performance bounds thus defined. Among the many uncertain areas, there are a handful that appears to Telesat to be crucial to the system design and optimisation. These areas of concern which pertain either to technology that is inchoate (such as narrowband modulation techniques) or situations that are not well understood, such as the true interference situation, must be addressed immediately in order for MSAT to meet its already tight schedule. Some of the major issues are briefly described below. This is by no means meant to be an exhaustive enumeration of the critical issues.

5.1 Spacecraft-Related Areas

In the spacecraft area, as far as the communication payload is concerned, there are two issues that are of concern: the antenna and SSPA performances. The antenna gain and radiation pattern are of particular concern since the gain will influence the power requirement from the high power amplifiers and the radiation pattern will affect the intended coverage. The concern stems mainly from the dual-band nature of the payload. The current concept adopted by SPAR entails a cluster of thirteen (13) dual-band horns whereby the L-band horns are placed inside the UHF horns. The possibility of generating two circular UHF beams along with the four shaped L-band beams using this concept should be clearly demonstrated. The actual transmit gain obtainable by these antennas has not been established. For example, SPAR's latest presentation (SPAR/Telesat Interface meeting No. 3 of March 6, 1986) shows the net UHF transmit gain as 24.4 dBic whereas in their Tenth Progress Review of February 7, 1986 the same gain is shown as 23.4 dBic. Even considering that we now have a separate transmit/receive with beam forming network (BFN loss is only 0.4 dB), these gains contrast sharply with the gain (25.8 dBic) assumed by Telesat based on SPAR's Phase B Twelfth Progress Review of March 2, 1984. If these lower gains are adopted, there will be a severe reduction in the system user capacity assuming the same spacecraft size is maintained. Alternatively, to maintain the same capacity, larger spacecraft will be called for. Either way, the economic viability of the system will have to be re-evaluated.

The solid-state (high) power amplifier (SSPA) needs to be more carefully characterized. SPAR is now quoting efficiencies of 28% and 24% for the UHF and L-band SSPA's respectively which is expected to be achieved with linearisers. These efficiencies and the accompanying mass penalty due to the linearisers need to be demonstrated. Another area of uncertainty is how the efficiency of these amplifiers change when not operating at the (optimal) design points. This could be significant when the SSPA have to carry the U.S. traffic (in the back-up mode) over which Telesat will have no control. The measured transfer characteristic of the SSPA seems to indicate a nonlinear device. The input/output transfer characteristics of a linear device when plotted on a logarithmic scale should have a unity slope with the intercept indicating the gain. In Figure 5.1, it appears that the slope over a significant portion of the plot is 3 dB to 1 dB. The effect of this nonlinearity is not clear and steps should be taken to clarify the situation.

The measured carrier power-to-third-order intermodulation power ratio of the SSPA can be as low as 17 to 19 dB. It appears to be optimized at the operating point of 50 W output power. This seems to suggest that the system performance would be considerably worse when the system is not fully loaded. Telesat's

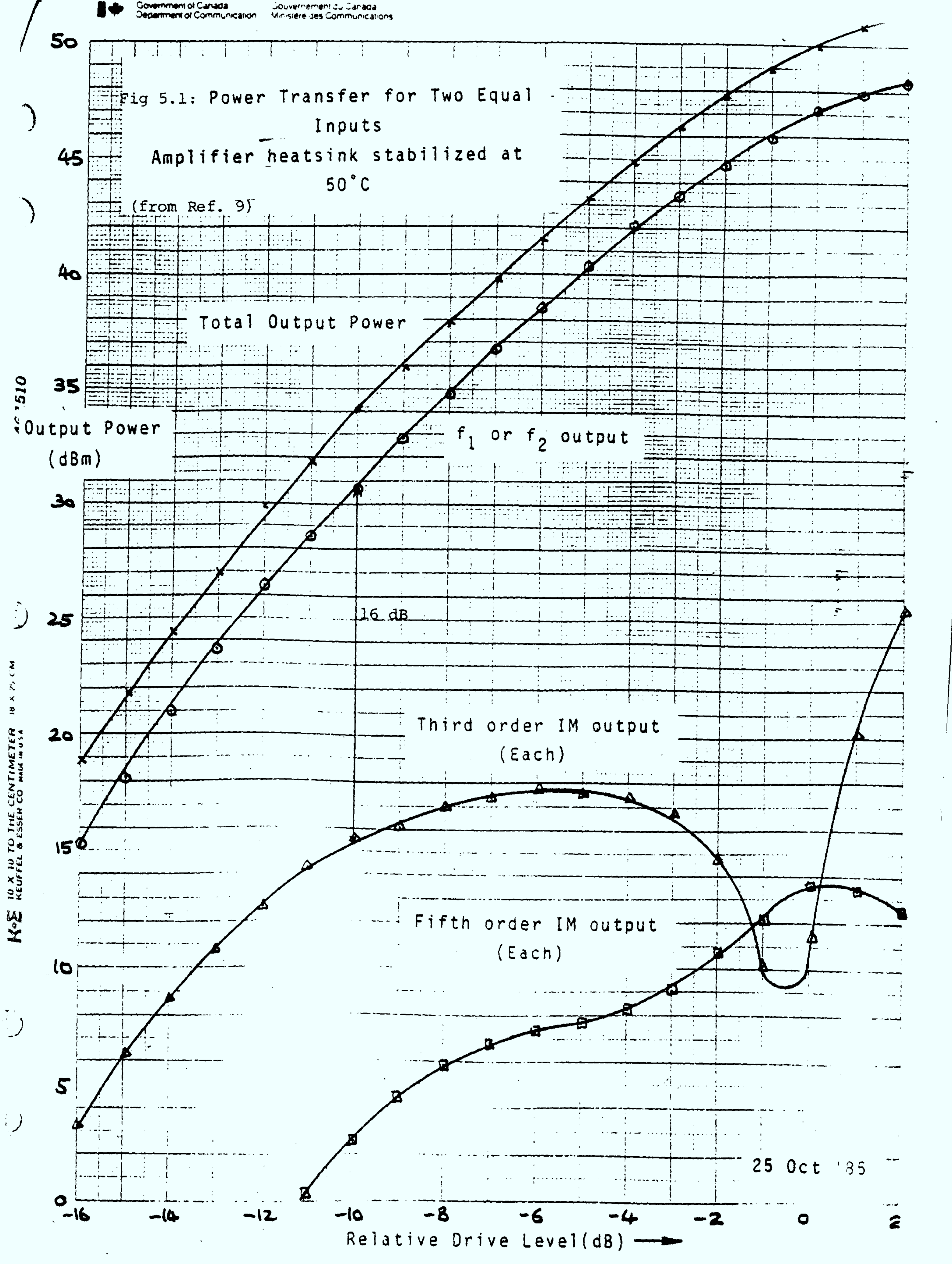
Fig 5.1: Power Transfer for Two Equal Inputs
Amplifier heatsink stabilized at 50°C
(from Ref. 9)
Total Output Power
Output Power (dBm)
f1 or f2 output
16 dB
Third order IM output (Each)
Fifth order IM output (Each)
25 Oct '85
Relative Drive Level(dB)
50
45
40
35
30
25
20
15
10
5
0
-16
-14
-12
-10
-8
-6
-4
-2
0
2
K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM KEUFFEL & ESSER CO. MADE IN U.S.A.

TABLE 5.1

2-Beam Canada/US (MRS Service)
Link Calculations UHF-SHF

M = Mobile
FP = Field Portable

PARAMETER	UNIT	FORWARD LINK		REVERSE LINK
		3.5m		3.5m
UPLINK		M	FP	M or FP
Satellite G/T	dB/K	-3.0		-2.0
Uplink EIRP/ Voice Act. Carr.	dBW	40.1		11.1
Path Loss	dB	206.8		182.8
Total IPBO/Transp.(Av. Pwr)	dB	N/A		12
Req'd. Flux Density/Voice Carr.	dBW/m^2	-122.8		-151.9
C/No Thermal	dB-Hz	58.9		54.9
Noise Bandwidth	kHz	3		3
C/N Thermal	dB	24.1		20.1
DOWNLINK				
Req'd EIRP/Voice Act. Carr.	dBW	26.5		8.6
Req'd Total OPBO	dB	N/A		7
Path Loss	dB	183.2		205.8
Receive Terminal G/T	dB/K	-19.1	-15.1	25.9
C/No Thermal	dB-Hz	52.8	56.8	57.3
Noise Bandwidth	kHz	3.0		3
C/N Thermal	dB	18.0	22.0	22.5
INTERFERENCE (C/I)				
Intermod & Energy Spread				
Uplink	dB	32		25
Downlink	dB	18		25
Interbeam Co-channel				
Uplink	dB	-		-
Downlink	dB	-		-
Other Sources				
Uplink	dB	32		-
Downlink	dB	-		29
Total Interference	dB	17.7		21.2
Total Unfaded C/N	dB	14.4	15.7	16.4
Total Unfaded C/No	dB-Hz	49.2	50.5	51.2

link budgets have so far assumed a carrier-to-intermodulation ratio of 22 dB. To assess the effect of 18 dB C/IM, the link budgets for the two-beam UHF system are given in Table 5.1 assuming this value of C/IM. From the table, it appears that the total unfaded carrier-to-noise power ratio drops to 14.4 dB from 15.6 dB, i.e. a decrease of 1.2 dB for communication between a base station and a mobile terminal. For communication to a transportable terminal, the decrease is 1.8 dB.

The cumulative distribution of the received total carrier-to-noise plus interference power ratio (C/(N + I)) for the forward link is plotted in Figure 5.2 for the two values of downlink C/IM i.e. 18.0 dB and 22.0 dB.

It is clear, from Figure 5.2, that for low values of the fade assuming a C/IM of 18 dB has a considerable effect on the total C/(N + I). However, as the fade increases the difference diminishes. For fades which yield a total C/(N + I) of around 7.2 dB (threshold corresponding to 42 dB-Hz $C/(N_o + I_o)$), the difference between assuming the two values of C/IM is only 0.2 dB in order to achieve the same availability. Stated another way, for otherwise identical links, the link with a C/IM of 18.0 dB yields a lower availability than the one with a C/IM of 22.0 dB by about 0.2%. It should be stressed that although the availability is not significantly affected around the threshold point, an 18 dB intermodulation ratio has a significant effect for links at near-no-fade situations, so all efforts should exerted to try to achieve a C/IM of 22.0 dB. From the point of view of subjective quality, the link with a C/IM of 18.0 dB would achieve a mean opinion score of 2.9 compared to 3.0 for the link with a C/IM of 22.0 dB.

5.2 Earth Terminals

In order to keep the satellite power requirements at a reasonable level, Telesat's design is based on the use of high-gain vehicular

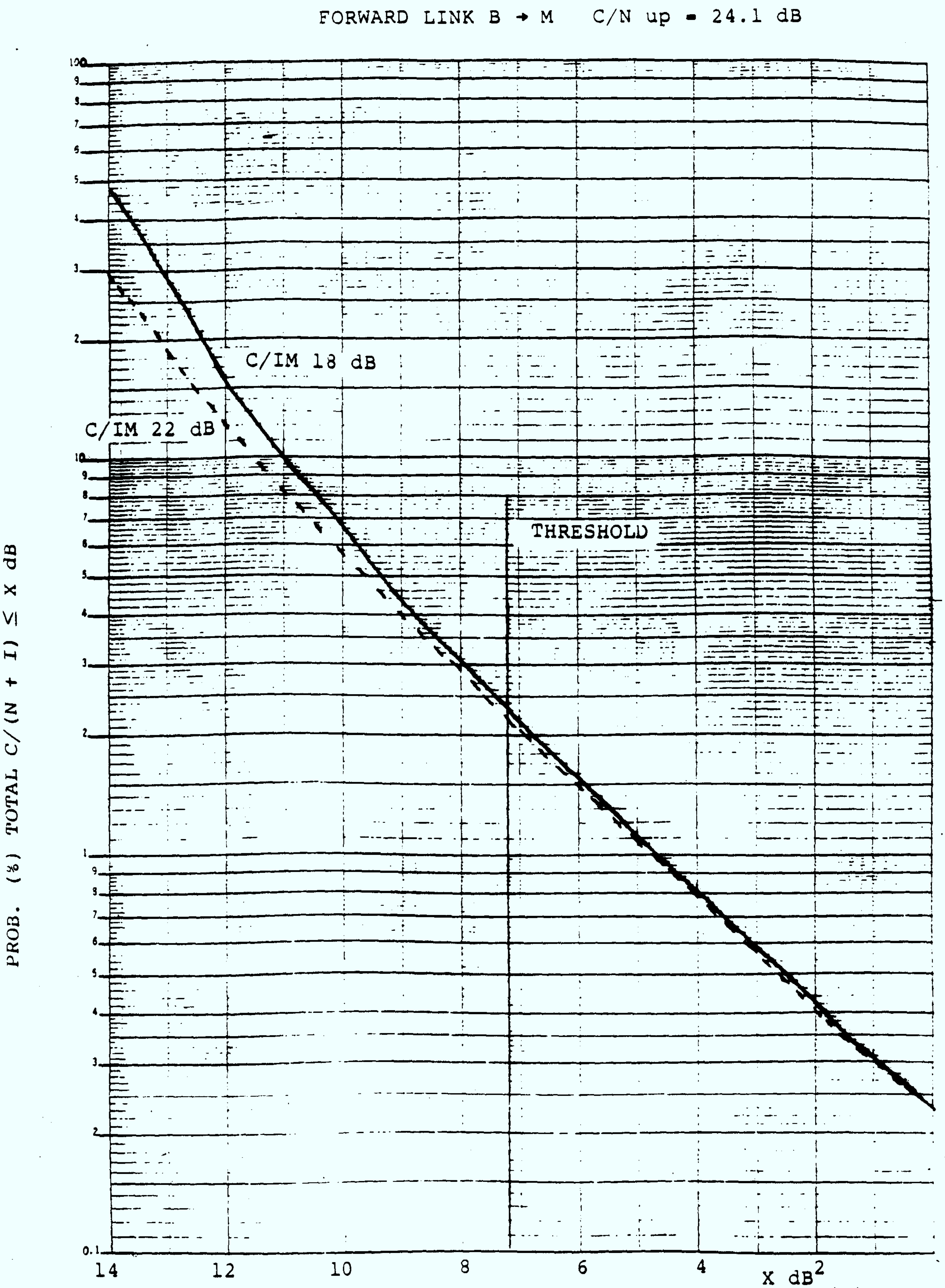

Figure 5.2: Cumulative Distribution of the Forward-Link C/(N + I) for the SHF-UHF Link

antennas (8 dBic for UHF and 10.4 dBic for L-band). The timely availability and user acceptability of these high-gain antennas is not yet determined. Moreover, although there are reasons to believe that the cost of these antennas may eventually drop to an acceptable level by the time MSAT service is introduced, present cost estimates for an electronically steered phased array antenna are still over $1,000 at UHF and over $1,500 at L-band. Reduction of this cost will largely depend on the market realization, and can be significantly affected by the extent to which the Canadian and U.S. systems use the same technology.

Of more concern, however, is the manner in which the vehicular terminal antenna will be steered to keep pointing toward the satellite as the vehicle changes direction since the antenna beam is narrow. The design of a suitable pointing mechanism with an acceptable accuracy is believed to be no small engineering feat. If an electronically steered phased array antenna is used, a beacon from the satellite may be used to help in the location of the satellite direction, but this requires a beacon receiver in the terminal. Alternatively the terminal may work by monitoring a signalling channel. However, this can only work while the terminal is in the passive mode unless an extra receiver for the signalling channel is included. If mechanically steered antennas are used, the sensing mechanism may call for a magnetic compass, a gyroscope or a combination of both. The magnetic compass, though potentially inexpensive may suffer from inaccuracies caused by local magnetic anomalies.

5.3 Interference

In Section 3, it was seen that interference was a significant contributor to link degradation, and hence deserves close scrutiny. It appears that the amount of interference may have been slightly underestimated which is definitely cause for concern because this will affect the subjective quality of the received signal.

Since there are no output filters in the spacecraft, out-of-band intermodulation has to be addressed to see if it may pose any problems.

The link budgets so far considered have not accounted for any passive intermodulation (PIM). Although the design has been modified to incorporate separate transmit/receive antennas in an attempt to minimize PIM, a complete look at the problem is warranted. This issue has been addressed a in DOC contract to industry and the results should be available soon.

Another area of concern is the adjacent satellite interference in the SHF feederlink. If the frequency of operation at SHF is 13 GHz, interference from terrestrial microwave radio systems will affect MSAT and the level of this interference will have to be determined. If operation is at 14 GHz, then interference from fixed satellite (Ku-band) services will have to be considered. The values used in the link budgets were estimated assumed 2° orbital spacing of satellites. However, situated in the orbital arc targetted for MSAT (106°W to 113° W longitude), are following operating or planned Ku-band satellites: Gstar II 105° W, Anik C1 107.5° W, Anik C2 110° W, Morelos I 113.5° W, Morelos II 116.5° W. It is clear that any attempt to place MSAT in this arc will result in at best 1 1/2° spacing. In light of this, it is apparent that the interference level assumed in the link budgets might be quite optimistic. One thing is clear, however: The 1 1/2° spacing will definitely preclude the use of 1.8 m diameter SHF base station antennas. Another concern is the intermodulation interference from the fixed satellite service uplink stations.

Since the consideration of use of L-band for MSAT is relatively new, potential interference between MSAT and other satellite systems operating at L-band, such as INMARSAT, Aerosat etc., has not been looked at. Also for L-band, even though there are four beams, it is currently assumed that frequency reuse will not be utilized for the first generation, and hence the link budgets have not included any co-channel interference. It is believed that if frequency reuse were employed, the antennas can provide no better than about 20 dB co-channel interference protection.

5.4 Other Concerns

Among the other concerns about the design of the MSAT system is the effect of interference at 800 MHz emanating from the terrestrial conventional trunked radio and cellular mobile systems, given the large number of terminals that are expected. A study of this problem by SPAR [11] concluded that tighter specifications have to be imposed on the MSAT satellite receiver including better linearity of the LNA.

As pointed out in Section 3, no subjective quality test of ACSSB was made at L-band and thus the acceptability of ACSSB voice at this band is still uncertain. Assuming that ACSSB with TTIB is the modulation of choice, the increased doppler spreads and frequency drifts at L-band will cause the width of the notch to be nearly doubled. This makes it doubtful if 5 kHz channel spacing can still be used at L-band without degradation in performance. Further, the wider notch will mean that a higher level of pilot power will be required to maintain the same C/N for the pilot. This potential increase in the EIRP per carrier has not yet been reflected in the link budgets. The effect on the subjective quality at L-band due to the increased rapidity of fades and the higher phase fluctuations at L-band compared to UHF is still uncertain. Another question that is still unanswered is what happens to the pilot during intervals when speech is absent? The satellite power estimates were predicated on voice activation whereby no power is transmitted during intersyllabic pauses in speech.

One factor that affects the system design is the proportion of the total traffic (airtime) that is initiated by the mobile user. This ratio which ultimately determines the traffic intensity (erlangs per user) depends on the type of application of the radio; for instance, it is different for Special Industrial Radio and Mobile Telephone Service. Another critical factor is the split of the conversation time between the mobile user and the base station. Both of these factors can only be determined from a thorough market definition. In the absence of this, a 50/50 split was assumed in the studies so far. There is some concern that the traffic may be (for some applications) mainly from the base station to mobile users. This would change the UHF power requirements assumed as well as have a significant effect on the number of UHF signalling channels required.

The traffic calculations used for the system sizing have assumed Erlang B formulation. It should be mentioned here that for MSAT, the fundamental assumptions used in deriving the Erlang B loss formula of the blocked calls are not strictly valid since there is no provision for alternate routing. That is, a majority of the blocked callers will hang up and try again, and keep trying until their calls go through. As a result, the busy-hour load would be higher than the assumed level under Erlang B formulation utilized in the design. However, the system analyzed in Telesat's study so far is engineered to reach the maximum capacity close to the expected end-of-life and only during the busy hours. Moreover, since the busy hours of the individual beams are not simultaneous and most of the beams enjoy some level of overlap, one could reason that efficient schemes of traffic sharing between the beams which are bound to emerge over the first few years of system implementation and traffic experimentation would ultimately increase the system's efficiency beyond the level understood at this point in time and could easily compensate for the extra traffic load imposed on the system by the blocked callers.

A blocking rate of 15% was chosen in order to maximize the traffic carrying capacity of the system within the bus size and power limitations. MTS, especially, may require a higher grade of service (eg. cellular radios are rated at 2% blocking rate). If then we still wish to maintain an overall average grade of service of 15%, that of MRS would have to be reduced to approximately 18%. These grades of service are indeed very low and may be considered by a number of users as being unacceptable. Besides user inconvenience, such low grades of service will result in an abnormally high call reattempts which would place high demands on the signalling channels. Further, only two channel groups have been considered for the communications channels. In practice, more channel groups may be required due to different grades of service required. For instance, in addition to MRS and MTS groups, special short message data services will require a separate channel group. Also some dedicated channels may be demanded for such applications as emergency, law enforcement which might require priority.

Although it does not directly affect the link budget, the issue of system control needs to be finalized. The subject of the MSAT DAMA is extensively studied in the companion task report of this contract (see Task 19 report). However, a few issues are still outstanding. Among these are the final choice of the most appropriate protocol(s) to use in the signalling channels, and transmission of data messages (both long and short). The numbering plan is an issue that demands a significant amount of attention. Studies have so far indicated a preference for a dedicated network planning area (NPA) or area code for MSAT. The availability of this is being explored. For a joint backup system for Canada and the U.S., a joint DAMA backup is considered. The exact format of this and its implication has not been addressed since it will be affected at least in part by the DAMA system adopted by the U.S. operator once he is selected by the FCC.

The issue of the location of the signalling channels in the MSAT band has not yet been resolved. Upward compatibility between the first and subsequent generations has to be carefully examined as this will influence sub-band selection and the location of signalling channels in those sub-bands. Since the mobile terminals are expected to have a lifetime in the order of 10 to 15 years, their design will have to accommodate changes from the first to second generation.

Finally as explained earlier, the fade statistics were based on "long term" averaging. The effect of having no constraint on the short-term shadowing has to be assessed especially if data transmission becomes increasingly important.

5.5 Conclusions

This section has pointed out some outstanding issues the solutions to which are needed in order to finalize and optimize the system. The list is by no means exhaustive but it serves to show that tests and further developmental work must be carried out in order to steer MSAT towards implementation at the start of the next decade. It is suggested that DOC and Telesat move quickly to arrange for a pre-launch experiment to check out some of the parameters used. It would be preferable if the experiment involved the use of a satellite to at least check the the effect of the delays. It might be possible to use Anik C for uplink and downlink at Ku-band with an "UHF backhaul" from the Ku-band receive station to a mobile vehicular terminal.

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