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STUDY OF L-BAND UTILIZATION BY MSAT

SUB-TASK 1. SYSTEMS CONCEPTS

FINAL

STUDY OF L-BAND UTILIZATION BY MSAT

SUB-TASK 1. SYSTEMS CONCEPTS

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SYSTEMS CONCEPTS

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0. INTRODUCTION

There are two objectives of this study. The first one is to assess the potential impact of changing the MSAT frequency of operation from the UHF band (821-825 MHz and 866-870 MHz) to L-band (1645.5-1660.5 MHz and 1544-1559 MHz). The second objective is to examine the potential impact of adding L-band capability to the MSAT system. This can be done by either operating a UHF/L-band dual-band system or having two separate, but colocated spacecraft, one with an L-band payload and the other with the UHF payload as in the baseline system. In the dual-band case, the payload resources (power and mass) are first used to carry the UHF payload, with the excess resources being used to carry an L-band payload.

This report is one of five sub-task reports, each appearing under a separate cover, comprising the L-band study. The salient points and conclusions of the study will be summarized in the report entitled "Overall Summary".

This sub-task report specifies the system parameters that will be impacted by the change to L-band in order to allow the impacts on space and earth segments to be worked out in detail.

All system aspects not directly addressed in this report are assumed to be the same as for the Telesat Business Proposal submitted in March 1985.

For the purposes of this study, three alternative plans were defined. These are summarized below along with the reference plan for comparison. (A complete description of the reference plan is the subject of the Business Proposal of March 1985.)

Reference Plan:

- Canada/US cooperative system
- 2 satellites: one Canadian owned, the other US owned[1]
- 2 UHF beams, 1 SHF beam
- 50% frequency sharing with the USA
- 5 kHz channel spacing
- North-American coverage
- First and second generation
- PAM-D spacecraft

Alternative Plan 1:

- Canada/US cooperative system
- 2 satellites: One Canadian owned, the other US owned.
- Operating frequencies: L-band
  - 1645.5 to 1660.5 MHz uplink
  - 1544 to 1559 MHz downlink
- 50% spectrum sharing with the USA
- 5 kHz channel spacing
- With SHF feederlink

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[1] Both satellites should be placed such that each can provide coverage to most of the intended service area (both Canada and U.S.) in case of back up. Telesat currently believes that orbital re-use is not likely to be practicable at least for the first generation as this would require highly directive antennas and a sophisticated tracking system. Hence no orbital spacing is specified.

- First and second generations
- PAM-D spacecraft

Alternative Plan 2:

- Canada/US cooperative system
- 2 satellites: one Canadian owned, one US owned
- Dual band payload - assume all UHF with excess payload resource used on L-band
- Operating frequencies:
  - L-band:
    1645.5 to 1660.5 MHz uplink
  - 1544 to 1559 MHz downlink
  - UHF:
    821 to 825 MHz uplink
  - 866 to 870 MHz downlink
- 50% spectrum sharing with the USA
- 5 kHz channel spacing
- With SHF feederlink
- First and second generation
- PAM-DII spacecraft

Alternative Plan 3:

- Canada/US cooperative system
- 4 satellites: 2 L-band, 2 UHF
- Operating frequencies:
  - L-band:
    1645.5 to 1660.5 MHz uplink
  - 1544 to 1559 MHz downlink
  - UHF:
    821-825 MHz uplink
  - 866-870 MHz downlink
- 50% sharing with the USA
- 5 kHz channel spacing
- With SHF feederlink
- First and second generations
- PAM-D spacecraft

1. ASSUMPTIONS

There are two parts to this study. The first is a direct comparison between L-band and UHF systems in order to assess the impact of changing the frequency band of operation. The second part is a study aimed at presenting a cost improved (higher system capacity) L-band system whereby trade-offs may be made. The following assumptions govern the first part of the study.

i) In order to make a fair comparison between UHF and L-bands, the same link performance has to be maintained, ie. same availability for two-way mobile-to-SHF base communication. Since L-band experiences more propagation attenuation, maintaining the same availability as for UHF, implies increased propagation margins.

ii) An attempt should be made to change as few things in the system as possible. Hence, the SHF links (uplink in the forward direction and downlink in the reverse direction) are assumed unchanged.

iii) The beam coverage area is preserved. This means that the spacecraft antenna gain for L-band is the same as for UHF. Hence, the spacecraft antenna diameter is reduced. In this study, the spacecraft L-band G/T is assumed to be the same as that of the UHF system. However, it is noted that the losses in the spacecraft antenna system might be slightly higher at L-band than at UHF, thus resulting in a slightly reduced G/T.

iv) The dimensions of the vehicular antenna are maintained the same as for UHF, therefore the gain increases. Frequency considerations alone would suggest an increase in the receive gain of 5 dB, however, increased losses (including pointing losses due to the narrower beams) whittle down this increase to approximately 3.3 dB.

2. BEAM CONFIGURATIONS

Various beam configurations may be considered for the MSAT L-band Alternative Plans Numbers 1, 2 and 3. The more important characteristics of some of these beam configurations are delineated below.

2.1 Alternative Plan 1

2.1.1 Configuration 1

This is a 2 beam configuration with the beam size the same as that of the reference UHF beams. Two spacecraft are required, one for each country. By employing commandable filters, each satellite is capable of backing up the other satellite. No frequency reuse is possible for this case. The beam configuration is shown in Figure 2.1.

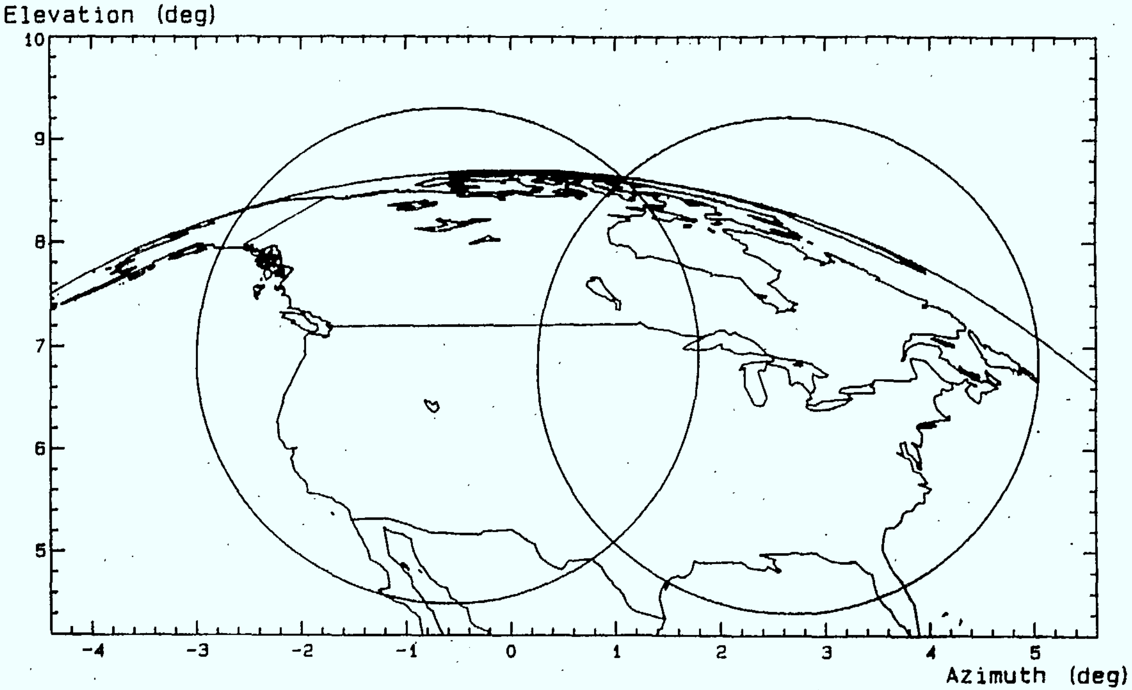


FIGURE 2.1: L-band Configuration 1

2.1.2 Configuration 2

This is a four shaped-beam configuration where the beam sizes and dispositions are similar to those of the optional system described in the business proposal. Two spacecraft are employed, one for each country. Since each beam covers both Canada and the U.S., joint sparing and partial lease back of capacity is possible without re-orienting the spacecraft. Frequency reuse is possible between the first and fourth beams. The beam configuration is shown in Figure 2.2.

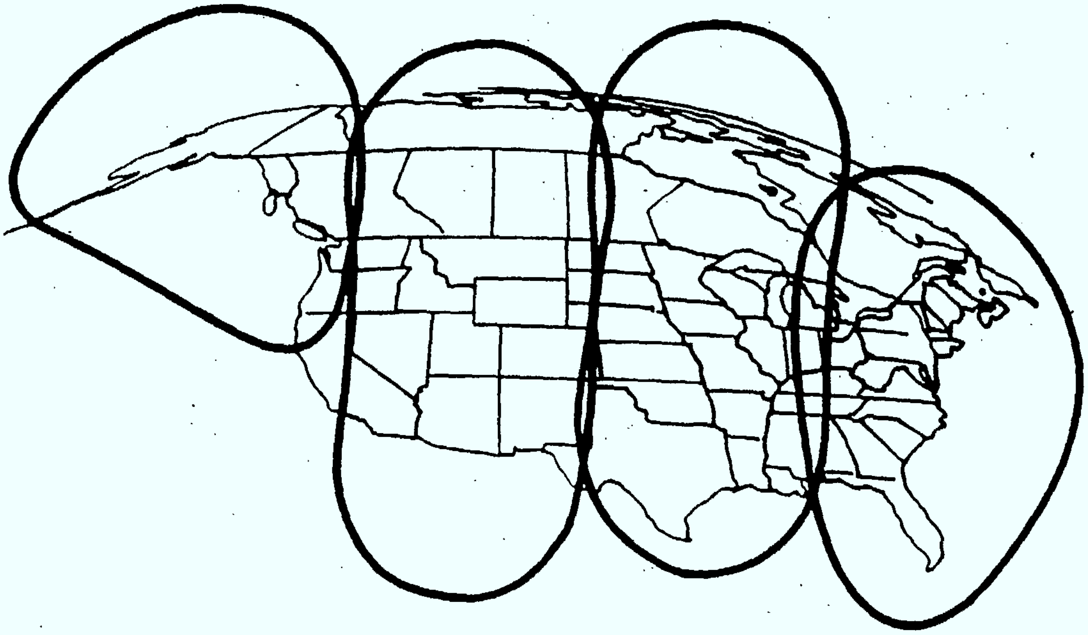
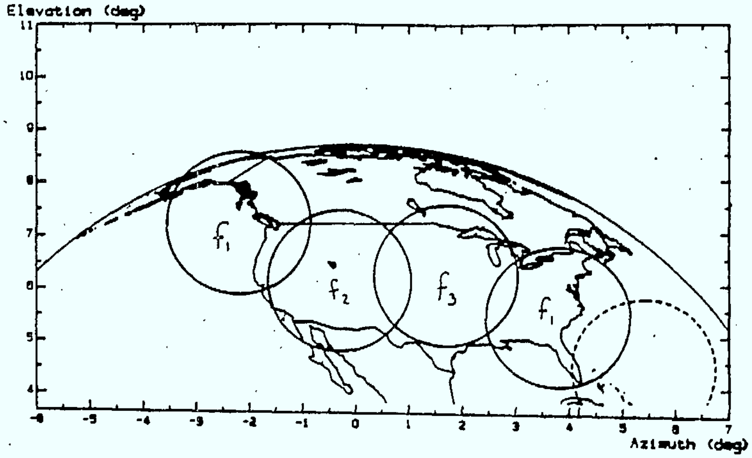


Figure 2.2: L-band Beam Configuration 2

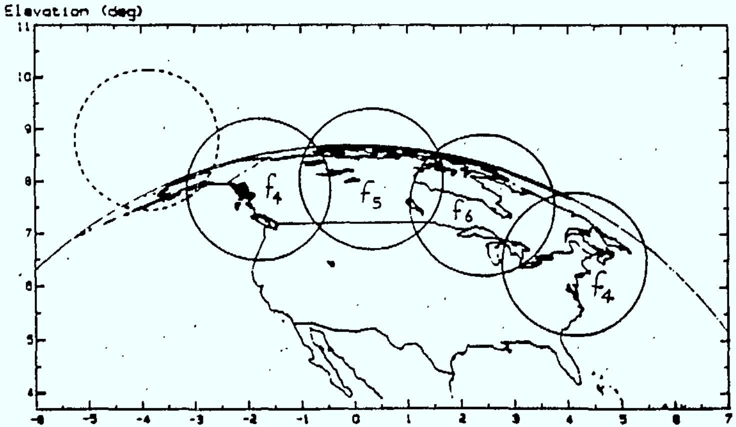
2.1.3 Configuration 3

This configuration has two operational spacecraft, one for Canada, and one for the U.S. Each spacecraft generates five beams, four of which are activated to cover each respective country (only four sets of transponders are provided). Either the left-most or the right-most beam is inactive depending on whether the satellite is used for Canadian or the U.S. coverage (see Figure 2.3). For each country the frequencies can be reused between beams 1 and 4.

As can be seen from the figure, the beams covering each country do not extend far into the other, hence simultaneous coverage of the other country is not possible except for areas close to the border. Hence lease-back of capacity is very limited. For joint sparing, therefore, a third (spare) spacecraft is necessary.



a) U.S. Coverage

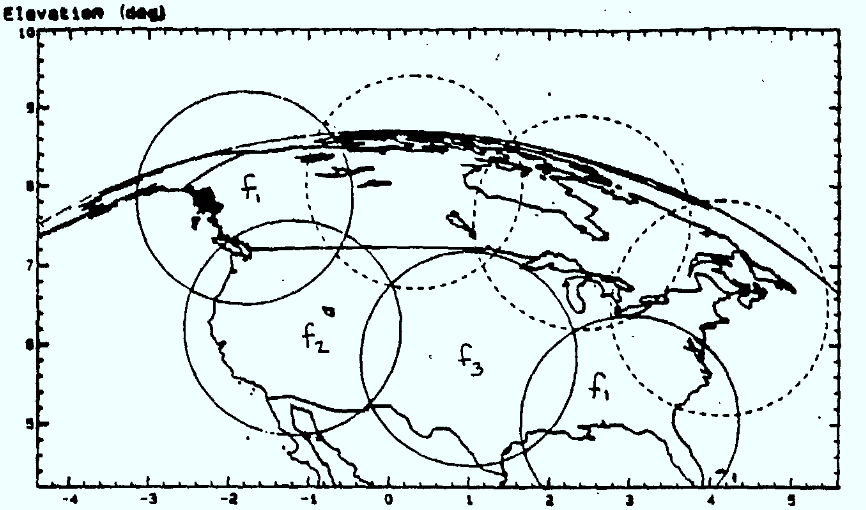


b) Canadian Coverage

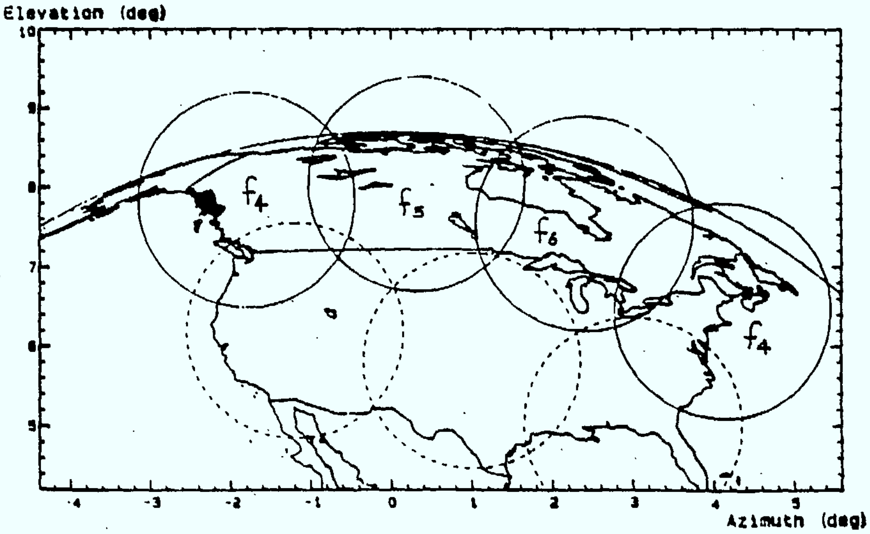
Figure 2.3: L-band Beam Configuration 3

2.1.4 Configuration 4

In this configuration, each of the two identical spacecraft has four beams covering either Canada or the U.S. as shown in Figure 2.4. In addition, three feeds are provided which form three more inactive beams (shown dotted in Figure 2.4). A network of variable power dividers is provided. By varying the power division, the appropriate beams can be selected to cover either U.S. or Canada. Also, by dividing the power equally between the Canadian and U.S. feeds, composite beams can be formed thus allowing joint sparing, (Fig. 2.4c). Frequency reuse is possible as in the above two scenarios.

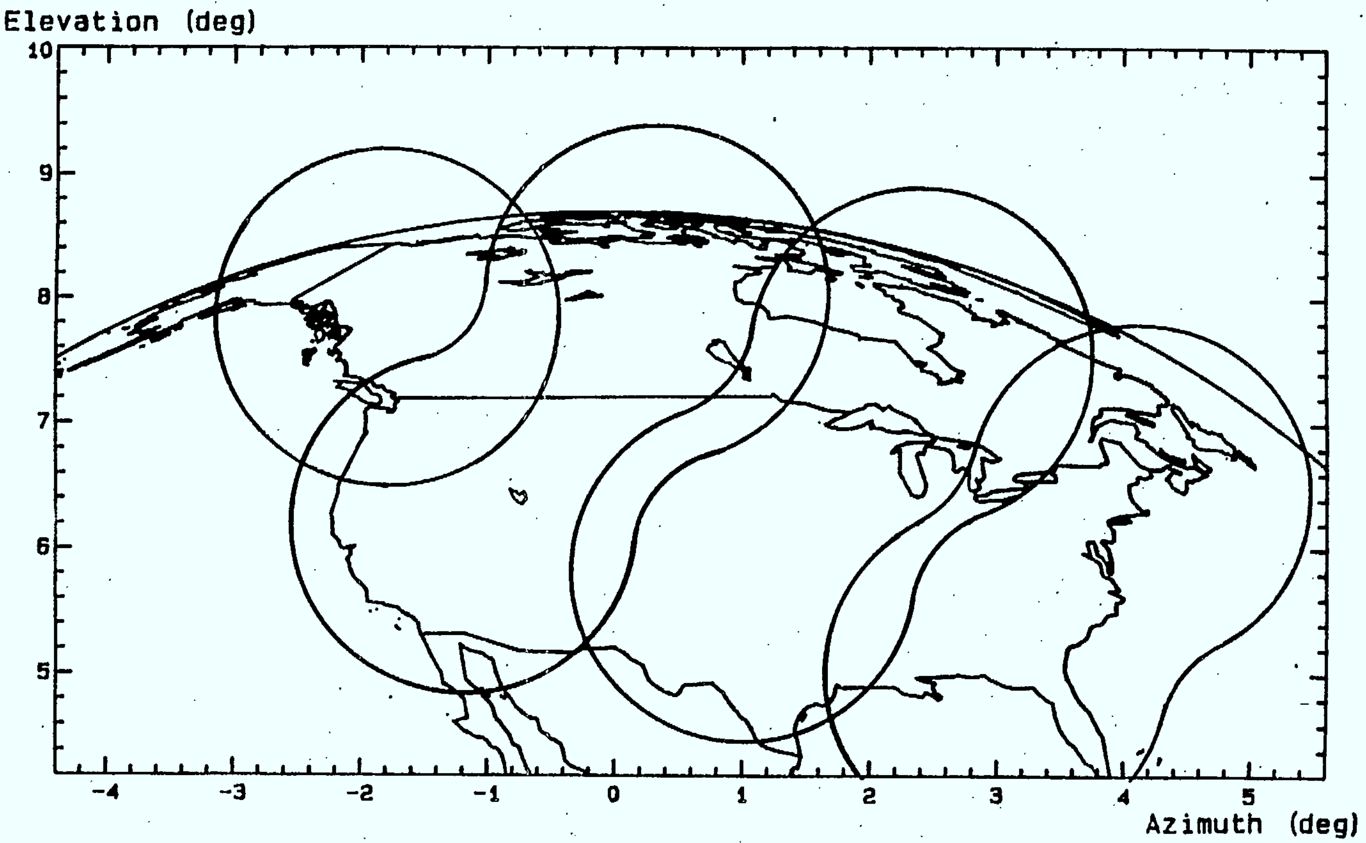


a) U.S. Coverage



b) Canadian Coverage

Figure 2.4: L-band Beam Configuration 4



c) Joint Sparing Mode Beam Configuration

Figure 2.4 Continued

Table 2.1

Summary of Characteristics of the Beam Configurations For Alternative Plan 1

Selection Criteria	Configuration 1	Configuration 2	Configuration 3	Configuration 4
No. of Beams	2	4 shaped	4 active (1 switchable)	4 active (3 switchable)
Beam Size (°)	4.9	-	2.7	2.7
EOC Gain (dBi)	25-26	27-28	30-31	30-31
CAN/US S/C Similarity	Identical	Identical	Identical	Identical
Joint Sparing	Feasible (reduced capacity or performance limited to the extent of simultaneous coverage)	Feasible	Feasible (one separate spare required)	Feasible (reduced capacity or performance)
Partial lease back Capacity	Feasible (limited to the extent of simultaneous coverage)	Feasible	Very limited (CAN/US border only)	Feasible (with power dividers)
Simultaneous Coverage	Adequate	100%	Very limited	100%
Frequency Reuse	None	33%	33%	33%
Power Amplifier Rating	TBD	TBD	TBD	TBD
No. of Spacecraft	2	2	3	2
Bus Type	TBD	TBD	TBD	TBD

2.2 Alternative Plan 2

Alternative Plan 2 is a Canada/U.S. cooperative system where each of the satellites is dual band (UHF/L-band).

2.2.1 Configuration 1

The UHF portion consists of two beams as in the preferred system described in the Business Proposal. The L-band segment consists of four shaped beams as in configuration 2 of Alternative Plan 1.

2.2.2 Configuration 2

This configuration is a combination of the two UHF beams of the Business Proposal and the L-band four-active beams (three inactive beams) system of configuration 4, Alternative Plan 1.

2.2.3 Configuration 3

This configuration combines the four shaped UHF beam system (optional system of the Business Proposal) and the L-band system in configuration 2, Alternative Plan 1.

2.2.4 Configuration 4

The final configuration in this Alternative Plan combines the four shaped UHF beam system and the L-band system of configuration 4, Alternative Plan 1.

Table 2.2

Summary of Characteristics of the Beam Configurations For Alternative Plan 2

Selection Criteria	Configuration 1	Configuration 2	Configuration 3	Configuration 4
No. of Beams (UHF; L-band)	2; 4	2; 4, 3 swt.	4 shaped, 4 shaped	4 shaped; 4 act. 3 swt.
Beam Size (°)	4.9; shaped	4.9; 2.7	- -	- -;2.7
EOC Gain (dBi)	25-26; 27-28	25-26, 30-31	27-28	27-28, 30-31
CAN/US S/C Similarity	Identical	Identical	Identical	Identical
Joint Sparing	Feasible (reduced capacity or performance limited to the extent of simultaneous coverage)	Feasible	Feasible	Feasible
Partial lease back Capacity	Feasible (limited to the extent of simultaneous coverage)	Feasible	Feasible	Feasible (with power dividers)
Simultaneous Coverage	Adequate	Adequate	100%	100%
Frequency Reuse	None; 33%	None; 33%	33%	33%
Power Amplifier Rating	TBD	TBD	TBD	TBD
No. of Spacecraft	2	2	2	2
Bus Type	TBD	TBD	TBD	TBD

2.3 Alternative Plan 3

Alternative Plan 3 is a Canada/U.S. cooperative system whereby each country is served by two satellites - one a dedicated UHF satellite and the other a dedicated L-band satellite. The UHF satellite can be either a two-beam or four-beam configuration, whereas the L-band satellite can be any of the four configurations of the Alternative Plan 2. However, if the L-band beam configuration 3 of Plan 1 is used here, there will be a total of five spacecraft; in all other cases, there is a total of four spacecraft.

2.4 Implementation Scenarios

For this study, two implementation scenarios were selected. Scenario I allows for direct comparison with the baseline UHF systems of the Business Proposal. Hence only two-and four-beam configurations are selected. The spacecraft size identified for system capacity determination is similar to that of the corresponding UHF configuration. Because of the limited capacity of the dual-band PAM-DII class spacecraft, larger size buses may be considered for this case. The service life considered was seven years for comparison with the Business Proposal. Table 2-3 summarizes Scenario I.

Scenario II is an alternative approach to realizing an L-band system, whereby certain system parameters may be changed. These may include a relaxation in the link availabilities corresponding to reduced fade margins. This has an impact of reducing the spacecraft power penalty imposed by required higher margins, and hence allows a higher system capacity for a given spacecraft. In addition the spacecraft service life may be assumed to be 10 years. This will impact the economic analysis. See Sub-Task 4 report.

Table 2-3: Scenario I. Implementation Plans

Plan	No. of Beams	Spacecraft Type	Service Life (yr.)	Link Availability
1	2 L-band or	PAM-D or	7	Similar to UHF
	4 L-band	PAM-DII	7	,,
2	2 UHF/4 L-band	PAM-DII or larger (dual-band)	7	,,
3	2 or 4 UHF	PAM-D or	7	,,
	2 or 4 L-band	PAM-DII	7	,,

3. PROPAGATION AND SYSTEM AVAILABILITY

For the Alternative Plan 1, (Change UHF to L-band) of the L-Band study, four configurations were defined in the last chapter. The first and most logical configuration to start with is the two-beam one where the beam sizes are the same size as the reference UHF beams. This chapter presents a preliminary analysis necessary for the specification of the required satellite EIRP per carrier, as well as the L-band uplink mobile terminal EIRP.

3.1 Propagation

Excess path loss in the satellite-to-vehicular terminal link is due mainly to two phenomena: shadowing by terrain obstacles (principally foliage), and multipath fading. This excess path loss is expected to be higher at L-band than at UHF, mostly due to increased foliage attenuation with frequency. Figure 3.1(a) (from Ref(1)) shows the cumulative distribution functions of the fade for an L-band (1542 MHz) link, while Figure 3.1(b) shows the distribution functions for a UHF (870 MHz) link. In Figure 3.1(a), which is for an elevation angle of approximately 20°, a curve has been drawn showing the combining of the forested and farmland data. The curves in Figure 3.1(b) are average curves. Figure 3.1(c) shows simulated results for different percentages of shadowed areas. It can be seen that Figure 3.1(a) corresponds to approximately 15% shadowed areas.

Comparing the L-band data to UHF data, there appears to be 4-5 dB more propagation attenuation at L-band than at UHF for the availabilities of interest.

It should be mentioned that different antennas were used for UHF and L-band: conical log spiral for UHF and a crossed-drooping dipole for L-band. These antennas have different radiation patterns and could influence the differences. However, since foliage loss is the dominating factor in excess path loss, the difference in antenna patterns is not expected to make a significant difference in the total loss. Experiments conducted later by the Communications Research Centre, using the same antenna type for both frequency bands and along the same roads found virtually the same results as shown in Figures 3.1(a) and 3.1(b) [3] (See Figure 3.2).

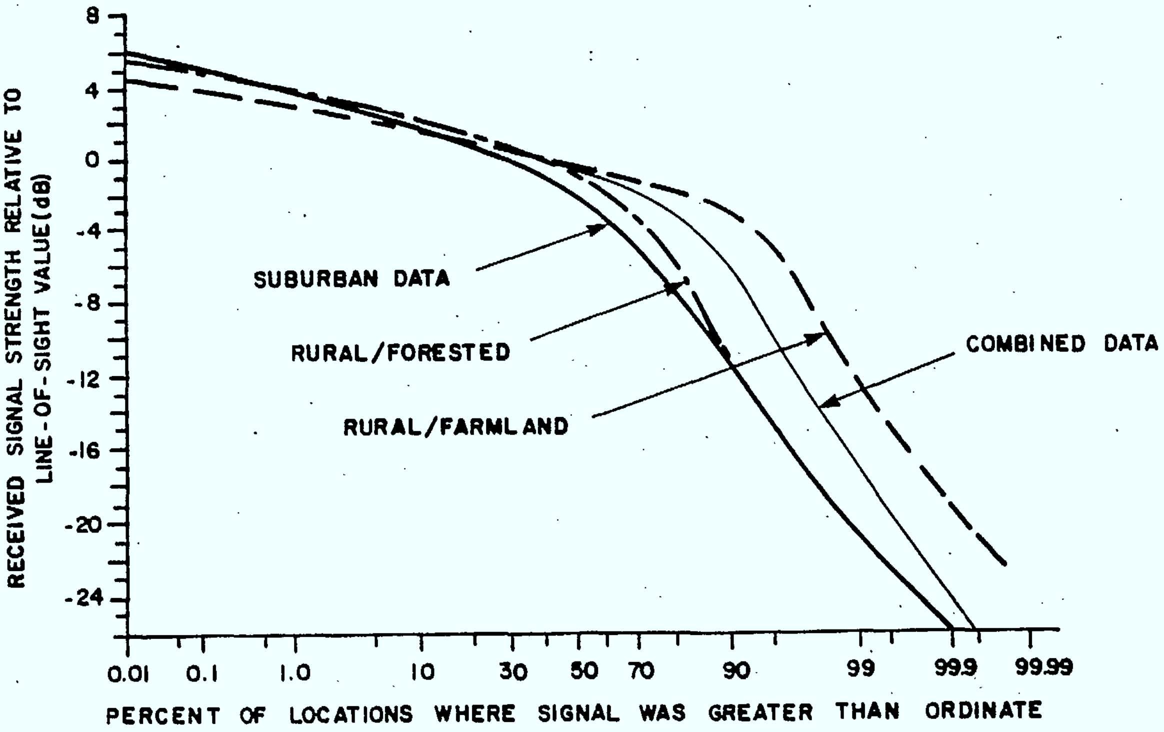


Figure 3.1(a): L-band (1542 MHz) signal strength distribution functions (recorded in June 1983)

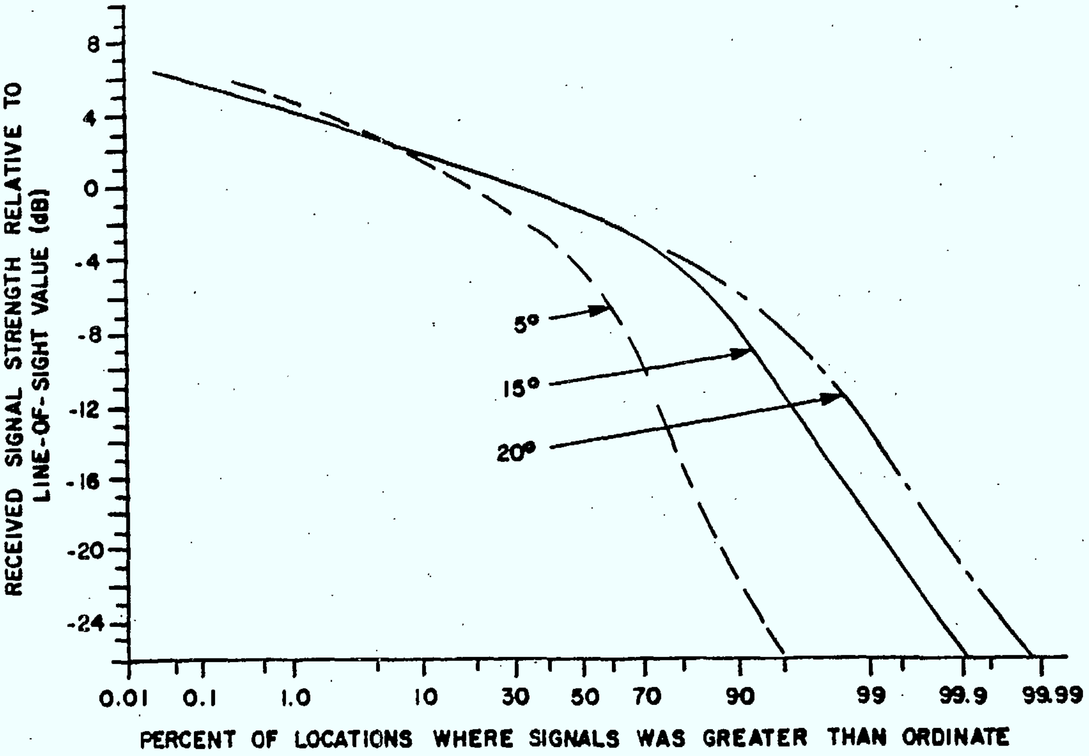


Figure 3.1(b): UHF (870 MHz) signal strength distribution functions (recorded in June 1983).

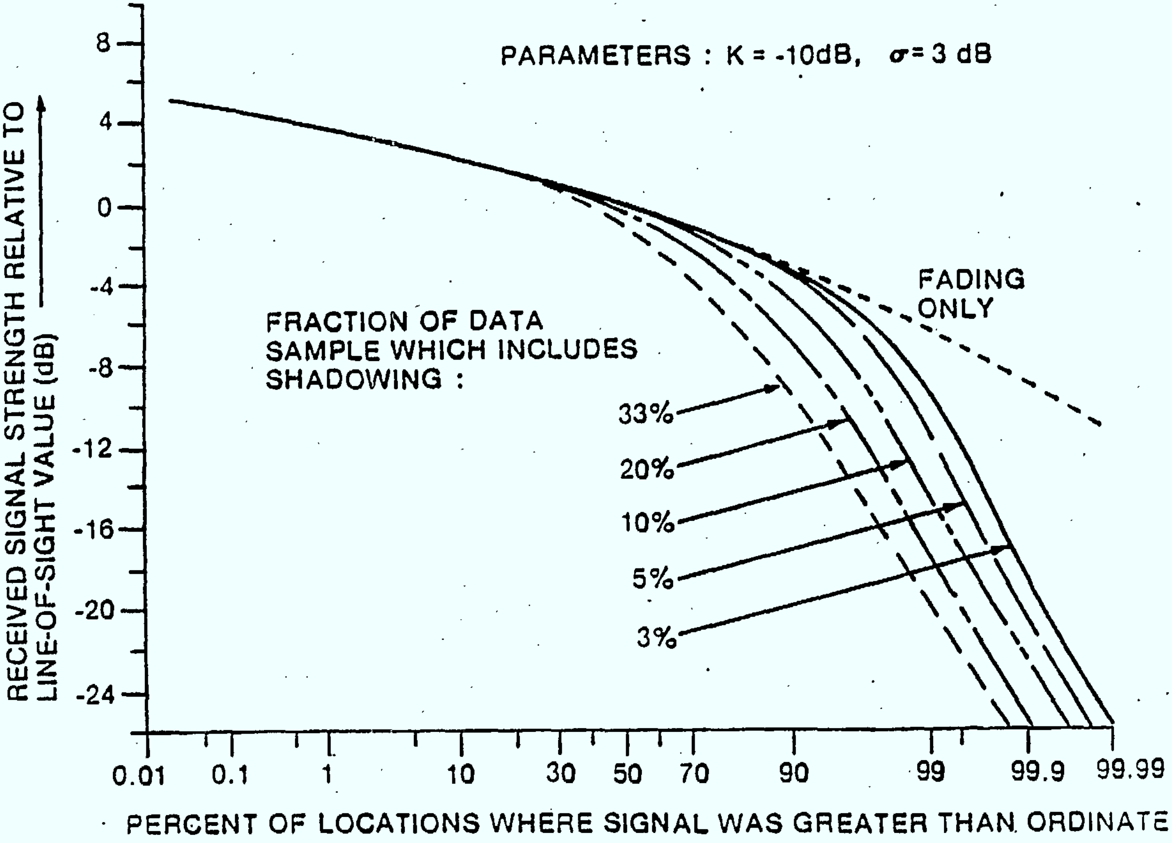


Figure 3.1(c) L-band Simulation Data For Different Percentage of Shadowed Areas

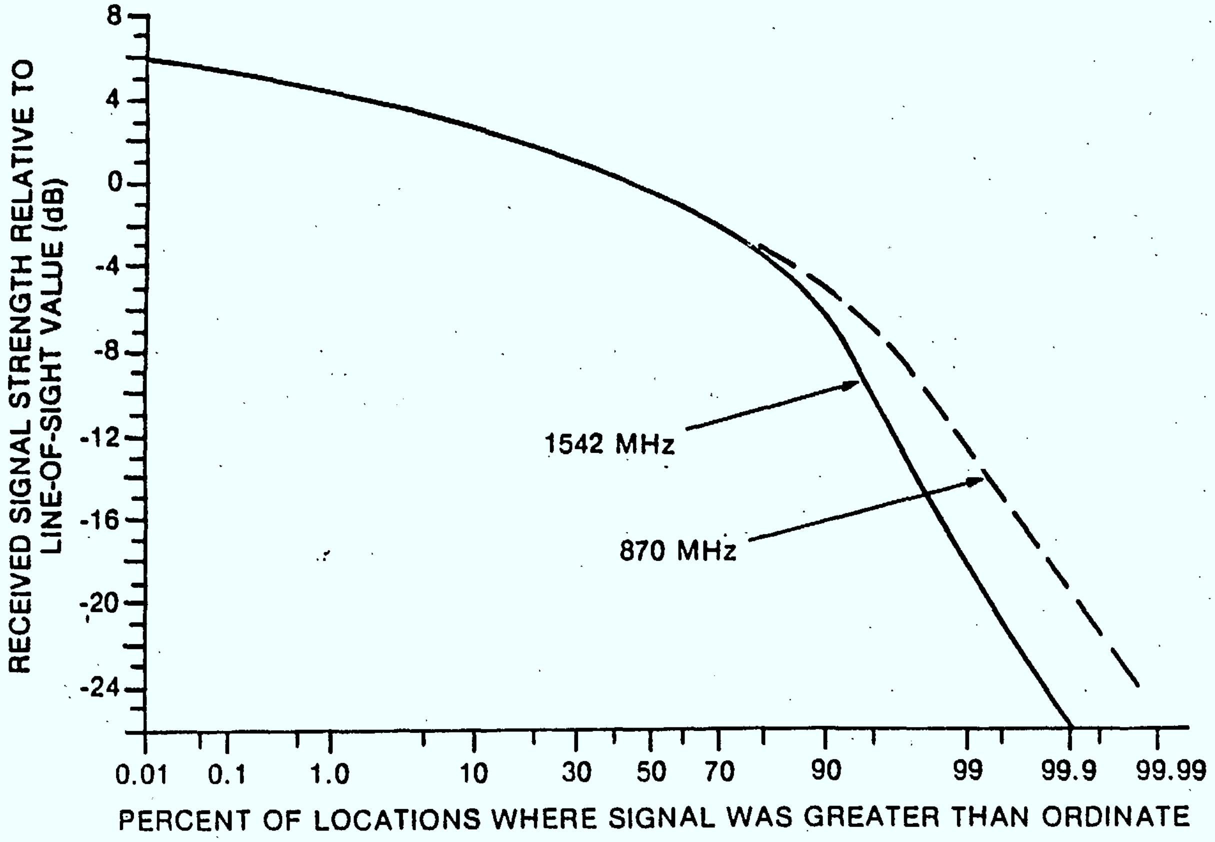


Figure 3.2: Comparison of L-band and UHF Fading Data

3.2 System Availability

The propagation statistics in Figure 3.1, together with the appropriate SHF fading statistics were used as inputs to a link simulation computer program to come up with the expected performance of each desired link in terms of system availabilities. As it was mentioned earlier, the reference UHF case is taken to be the two-beam configuration. Thus the L-band case considered here is also a two-beam configuration and for elevation angles greater than or equal to 20°.

The cumulative distributions of the received total carrier-to-noise plus interference or C/(N+I) ratio for the forward link (SHF→L-band) are plotted in Figure 3.3 for different values of unfaded downlink thermal C/N ratio. The unfaded uplink thermal carrier-to-noise (C/N) ratio is kept constant at 24.1 dB, and the interference budget is kept constant as well. The corresponding cumulative distributions for the reverse link (L-band→SHF) are plotted in Figure 3.4 for three different values of unfaded uplink thermal C/N ratio, keeping the unfaded downlink thermal C/N ratio constant at 22.6 dB. The fourth curve in Figure 3.4 is for a case in which the unfaded downlink (SHF link) thermal C/N ratio was allowed to increase to 25.6 dB.

To obtain the total two-way link availabilities, one has to combine the forward and reverse link availabilities. This was done for two values of the total C/(N+I) ratio, corresponding to "minimum quality" and "normal quality" of the received signal. The results are shown in Table 3.1.

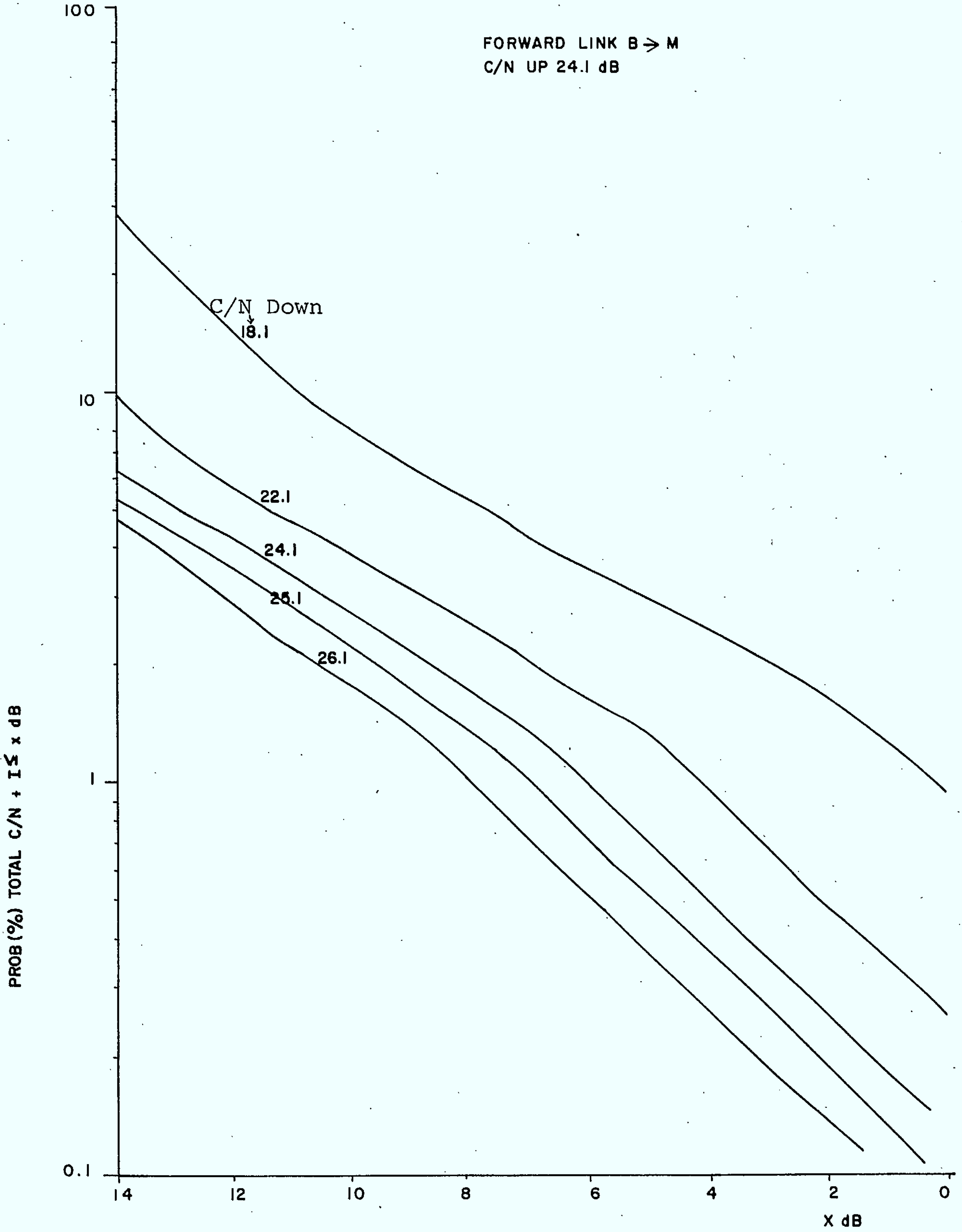


Figure 3.3: Cumulative distributions of the received C/N + I for the forward link

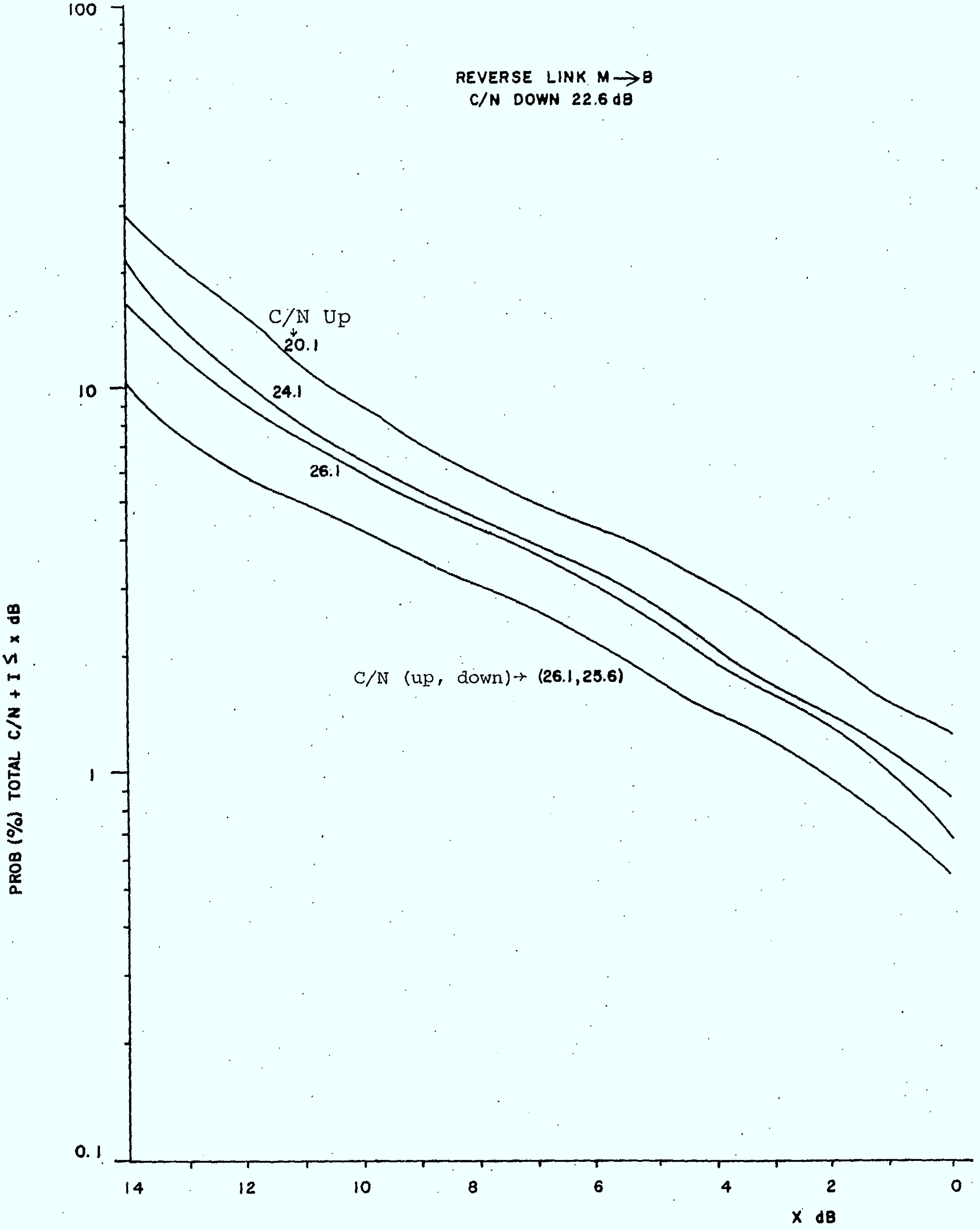


Figure 3.4: Cumulative Distributions of the Received Total C/N + I for the reverse link

For the reference UHF case, the total two-way system availability was 98.4% for minimum quality and 96.1% for normal quality [4]. It is apparent from Table 3-1 that availabilities for the L-band links are clearly too low to match those of the equivalent UHF links. Increasing the uplink thermal C/N ratio beyond 26.1 dB in the reverse link will not lead to a significant improvement.

Table 3.1: Total System Availabilities

Forward-link C/N$_{up}$ = 24.1 dB, Reverse-link C/N$_{down}$ = 22.6 dB

FL C/N down (dB)	Type of Link	System Availability (%)					
		Minimum Quality for RL C/N up (dB)			Normal Quality for RL C/N up (dB)		
		20.1	24.1	26.1	20.1	24.1	26.1
18.1	M→B	97.0	97.8	98.0	94.8	96.0	96.2
	B→M	97.5	97.5	97.5	95.6	95.6	95.6
	M↔B	94.6	95.4	95.6	90.6	91.8	92.0
22.1	M→B	97.0	97.8	98.0	94.8	96.0	96.2
	B→M	99.0	99.0	99.0	97.9	97.9	97.9
	M↔B	96.0	96.8	97.0	92.8	94.0	94.2
24.1	M→B	97.0	97.8	98.0	94.8	96.0	96.2
	B→M	99.5	99.5	99.5	98.6	98.6	98.6
	M↔B	96.5	97.3	97.5	93.5	94.7	94.9
25.1	M→B	97.0	97.8	98.0	94.8	96.0	96.2
	B→M	99.6	99.6	99.6	98.9	98.9	98.9
	M↔B	96.6	97.4	97.6	93.8	94.9	95.1
26.1	M→B	97.0	97.8	98.0	95.8	96.0	96.2
	B→M	99.7	99.7	99.7	99.2	99.2	99.2
	M↔B	96.7	97.5	97.7	94.1	95.2	95.6

M→B = Mobile-to-base station

B→M = Base station-to-mobile

M↔B = Two-way base-to-mobile

FL C/N down = Forward downlink thermal C/N

RL C/N up = Reverse uplink thermal C/N

If the assumptions in Chapter 1 are to be held, it appears that the best two-way availability that can be achieved for L-band mobile service is of the order of 97.7%, and this is achievable only at considerably high satellite EIRPs. This availability is still lower than that of the equivalent UHF link[1].

The only other way to increase the availability is to change assumption (ii) in Chapter 1 and increase the reverse downlink (SHF link) thermal C/N ratio. Changing this C/N ratio from 22.6 dB to 25.6 dB results in a reverse link availability of 98.5% for a total two-way availability of 97.5%. Increasing C/N down beyond that will not yield much improvement since the intermodulation noise becomes a limiting factor.

However, this increase in SHF link C/N to 25.6 dB means either doubling of the TWT power rating or forces the SHF base stations to use 5 m antennas.

In order to avoid too high EIRPs, our recommendation at this stage would be to adopt for study a link with forward downlink thermal C/N ratio of 22.1 dB, and reverse thermal C/N of 26.1 dB, and accept the reduced availability[1].

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[1] It should be noted that the fading results used here were for antennas with directivities around 5 dBi, whereas assumption (iv) in Chapter 1 allows for higher antenna directivities. It is recognised that with higher directivities for mobile antennas, the multipath fade will be somewhat reduced. With the L-band link budgets recommended here, a somewhat higher availability than that calculated above may be achieved. However, since the attenuation by foliage is the dominant factor for availabilities of interest, the reduction in fade margin may not be significant.

4. L-BAND GROUND SEGMENT ANTENNAS

4.1 Introduction

In this chapter, the impact of changing the MSAT frequency from UHF (821-825 MHz and 860-870 MHz) to L-band (1645.5-1660.5 and 1544-1559 MHz) on G/T of vehicular antenna is examined. First the impact of using an L-band omni-directional antenna is discussed and then the desired characteristics of a steerable phased array antenna are given.

It is shown that a simple azimuthally omni-directional antenna could not be used at L-band unless either the satellite EIRP/carrier is increased significantly or a reduced fade margin is accepted. For a steerable phased array antenna, the calculated G/T is about -15.8 dB/K which is only an improvement of about 3.3 dB over its UHF counterpart of the same physical size. Since the downlink free space loss at L-band is 5 dB greater than UHF-band, the satellite EIRP per carrier at L-band should be increased at least by about 1.7 dB for the same service availability and capacity as in UHF-band. This is based only on consideration of free space loss and ignores the additional propagation loss at L-band, which as was seen in the last chapter is significant.

Note that the number of elements in a L-band phased array antenna is significantly greater than that of the UHF array and, therefore, the associated cost is expected to be higher.

4.2 Omni-Directional Antenna

Assume that it is feasible to design a simple single element azimuthally omni-directional antenna with a minimum directivity of 10 dBic. A minimum directive gain of 10 dBic is required since there is 5 dB difference in free space loss between L-band and UHF downlink frequencies. If we assume that there would be only 1 dB network loss due to the duplexer, and ignoring the additional propagation loss at L-band over UHF-band, the mobile terminal would have the same performance as in the UHF when satellite EIRPs per carrier in the two cases are identical.

The beamwidth of the antenna could be determined from:

$$G_D = K/\phi_\theta \phi_\phi$$

where G_D is the peak directivity of the antenna, K is a constant, and ϕ_θ and ϕ_ϕ are the 3 dB beamwidths in elevation and azimuth, respectively. For an omni-directional antenna $\phi_\phi = 360°$. In addition, we assume that $K \simeq 30{,}000$. Substituting these values in the above equation results in $\phi_\phi \simeq 8°$. Note that this value of 3 dB beamwidth in elevation could result in a significant amount of antenna pointing loss. For example, a possible vehicle tilt of ±2° from the zenith due to road condition (i.e. road slope less than 4%) could cause as much as 1 dB pointing loss: Note also that the same omni-directional antenna design might not be possible to use everywhere in Canada due to excessive pointing loss caused by change of elevation angle.

From the above discussion it is clear that a simple omni-directional antenna could not be used in L-band if the traffic capacity and the satellite EIRP per carrier are to remain the same as UHF.

It is worth mentioning that it could be possible to employ a non-steerable L-band antenna with pseudo omni-directional characteristics if a circular (or polygon) array is designed with each element(s) of the array covering only a sector of the space. The number of the elements in the array depends on the choice of the 3 dB beamwidth in elevation and the gain variation in azimuth. Table 4.1 shows the probable number of elements in the array for different values of 3 dB beamwidth in elevation plane when the maximum gain ripple in azimuth is limited to about 2 dB.

4.3 Array Configuration at L-Band

The relationship between antenna directive gain, G_D, and its half power beam width is given by:

$$G_D = 4\pi \eta A/\lambda^2 \approx K/\phi_o^2$$

where the factor K can vary slightly for different classes of antennas and for high efficiency antennas is approximately 4 x 10^4. λ is the wavelength of the RF signal, A is the array area, and η is the antenna efficiency. It is assumed that the antenna has identical 3 dB beamwidth in azimuth and elevation planes. The antenna directive gain at L-Band (1550 MHz) for an aperture of 70cm x 70cm (the same physical size as the one assumed for UHF operation) is about 21.2 dBic when an aperture efficiency of 80% is assumed.

To avoid the formation of grating lobes when the beam is steered, the spacing between individual antenna element in the array cannot significantly exceed a half wavelength. With such spacing, the number of array elements, N, is given by:

Table 4.1: Number of elements in a circular array for an omni-directional coverage.

3 dB BW in Elevation (deg.)	3 dB BW in Azimuth (deg.)	No. of Elements
40	47	9
30	63	7
25	75.7	6
20	95	5

Note, the maximum directivity is assumed to be 12 dBic. The gain ripple in azimuth is limited to 2 dB.

$$N = 4Lx \cdot Ly/\lambda^2$$

where Lx and Ly are the aperture dimensions. For a square array, the number of array elements becomes:

$$N = 4L^2/\lambda^2 \simeq 10^4/\phi_o^2$$

Table 4.2 shows the required number of array elements for different antenna beamwidths, as well as their respective 1 dB beamwidths. Note that the number of elements increases as the directive gain increases and it would be at least 35-40 elements for a L-band antenna with an aperture size of 70 cm x 70 cm. Table 4.3 lists the desired characteristics of such an antenna and its expected power gain. These design goal objectives are believed to be within the reach of the phased array designers. However, its cost would be higher than the UHF design and is an area which requires detailed assessment.

Table 4.4 gives the noise budget and overall G/T of the phased array antenna. Note that the overall G/T is -15.8 dB/K which is only about 3.3 dB greater than that of the UHF antenna assumed in CVS. However, the downlink free space loss in L-band is 5 dB greater than in the UHF band. That is, for the same traffic capacity and service availability as UHF band, the satellite EIRP/carrier should be increased by 1.7 dB. This is based on the assumption that multipath or foliage losses are identical in the two bands. The experimental results by CRC, however, indicates that this assumption is not valid. This means that for the availability of interest, a further increase in EIRP/carrier would be required at L-Band to compensate for increased foliage losses. However, off-setting this to some degree is the reduced multipath fading resulting from the increased antenna directivity.

Table 4.2: Required number of elements in an L-band phased array antenna for different antenna beamwidths.

3 dB, BW°	1 dB BW°	Directive gain(dBic)	Number of Elements in array
10	2.9	46	100
15.5	4.3	22	45
17.4	5	21	35
20	5.8	20	25
25	7.2	18	16
30.4	8.6	16	11
35.1	10.1	15	8
40.9	11.5	13	6

Table 4.3: Expected Characteristics of an L-Band steerable phased array antenna for mobile application.

Parameters	Values	Note
Total aperture area	70cm x 70cm	
Frequency Range	1544 MHz to 1660.5 MHz	
Directivity	21.2 dB (Rx), 22.2 dB (Tx)	
Scan Loss	4 dB	1
Feeder Loss	1 dB	
Loss of Phase Shifters Network	2.5 dB	2
Duplexer Loss	1 dB	
Polarization Loss	1.1 dB	
Mismatch Loss	0.2 dB	
Pointing Loss	1 dB	3
Total loss	10.8 dB	
Rx gain	10.4 dB	

Notes

1. Loss due to beam scanning down to elevation angle of about 20°.
2. It could be a conservative value by as much as 0.8-1 dB.
3. Corresponding to 5° of pointing error due to a four-bit phase-shifter.

4.4 Transportable/Fixed/Portable Antennas

As a final note, an L-band antenna for base station and/or transportable/portable/fixed applications could easily be designed to compensate for the differential free space loss between the two bands. That is, the transmit gain and the receive G/T would be 6 dB and 5 dB, respectively, greater than the UHF design given in CVS.

4.4.1 Transportable/Fixed Antenna

This will be used for thin route type of application. A Yagi or a helix seem to be good candidates. They can be ruggedly constructed and they are relatively inexpensive antennas. If a helix is used, its size would be about 0.8m (Gain = 18dBic).

4.4.2 Portable (Suitcase) Type Antenna

Its mechanical design criteria would dictate the choice of the antenna. In addition to portability of the whole transmit/receive system by a person on foot, wind drag and the antenna ruggedness should be considered. The candidate antennas seem to be collapsible Yagi or helix, cavity backed crossed dipole or microstrip arrays. A trade-off study between the antenna gain and available power on the portable terminal should be carried out to determine if a smaller antenna gain can be tolerated. Note that a smaller antenna gain could be desirable in order to reduce the antenna pointing loss.

4.5 Summary

Use of an omni-directional antenna at L-band for a truly mobile service impacts severely the spacecraft power resource if the large fade margins for foliage are to be maintained. A steerable phased array antenna with G/T of about -15 to -16 dB/K seems to be achievable when the physical size of the array is kept the same as the UHF design. However, the cost is expected to be higher than the UHF design since the number of elements would be about four times greater.

Table 4.4: Noise budget and G/T of an L-band phased array antenna for mobile application.

Parameters	Values
LNA noise temperature (NF = 2 dB)	170 K
Antenna noise temperature	150 K*
Noise temperature due to losses	210 K
Total noise temperature	421 K
Antenna gain	10.4 dB
G/T	-15.8 dB/K

* About 30 K is due to the atmospheric absorption and the remaining is due to the other sources such man made noise.

5. SATELLITE EIRP AND EARTH SEGMENT PARAMETERS

5.1 L-Band Mobile Service

Due to the increased frequency in the forward path downlink, there is a 5 dB increase in the free space loss. As seen in the last chapter, assuming the same physical aperture for the vehicular antenna, the increase in gain for the L-band vehicular antenna over its UHF counterpart is 3.3 dB. The resulting L-band vehicular antenna figure of merit, G/T, is -15.8 dB/K. From the above two items, the L-band downlink has a 1.7 dB deficit compared to the UHF one. Further, the availability considerations in Chapter 3 led to a recommendation to use a downlink thermal C/N ratio of 22.1 dB compared to 18.0 dB for the UHF, a difference of 4.1 dB. Hence, the satellite EIRP per channel should be increased by 5.8 dB in order to maintain a reasonable though somewhat reduced, overall link availability for L-band. Since the UHF EIRP per channel was 26.5 dBW/carrier, the required L-band EIRP per carrier would be 32.3 dBW.

From Chapter 3, the uplink (L-band) thermal C/N ratio for the reverse link was suggested to be 26.1 dB, which is 6 dB greater than that of UHF. Further, there is a 6 dB increase in the free space loss due to the increase in frequency (from 823 MHz to 1653 MHz). The beam coverage area for L-band is the same as for UHF, hence the satellite receive gain does not increase. Therefore, the additional free space and propagation losses on the uplink have to be compensated for fully by increasing the mobile terminal uplink EIRP. Thus, the uplink EIRP per channel of the L-band mobile terminal should be increased to 23 dBW which is 12 dB above the UHF requirements. This corresponds to an RF output power of approximately 14.8 W. It is worth mentioning that the L-band antennas for base station and portable applications could easily be designed to compensate for the differential path loss in L-band and, therefore the output power per carrier would be about the same as for UHF.

The recommended link budgets for both the forward and reverse links are shown in Table 5.1.

Table 5.2 summarizes the L-band vehicular terminal characteristics, and also the spacecraft L-band EIRP. Included in the table for comparison are the corresponding UHF parameters.

Table 5.1
Link Calculations 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	-2.0
Uplink EIRP/ Voice Act. Carr.	dBW	40.1	23.0
IPBO/Carrier	dB	N/A	TBD
Total No. of Carriers/Beam		TBD	TBD
Equiv. # of Act. Channels/Beam		TBD	TBD
Total IPBO/Transp.(Av. Pwr)	dB	N/A	12
Req'd. Flux Density/Voice Carr.	dBW/m^2	-122.8	-139.9
Saturating Flux Density	dBW/m^2	N/A	TBD
Full Load Flux Density	dBW/m^2	TBD	TBD
Req'd Saturating C/T	dBW/K	TBD	TBD
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
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	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

Table 5.2: Comparison of Some Parameters of L-Band and UHF Systems

	L-Band	UHF
Ground Segment		
Transmit gain, dBic	11.4	7.5
Transmit EIRP/carrier, dBW	23.0	11.0
Transmit Power, Watts	14.8	2.24
Receive gain, dBic	10.4	8
Receive noise figure, dB	2	2
Receive G/T, dB/K	-15.8	-19.1
Space Segment		
Transmit EIRP/carrier, dBW	32.3	26.5

5.2 L-Band Transportable (Fixed) Service

In Chapter 3, it was shown that L-band mobile service requires a hefty propagation margin in the order of 17 to 18 dB to maintain the same order of service availability as was assumed in the baseline UHF system. The dominant phenomenon is shadowing by terrain obstacles, principally foliage. This leads to the conclusion that L-band would be particularly suited to fixed-type or transportable services. For such a service the site is chosen such that a clear line of sight exists to the satellite, i.e. there is no shadowing. Multipath fading is hence the only source of excess path loss.

Figure 5.1 shows an extrapolation of the fade distribution curve to estimate the multipath only case. It is seen that for 99% of the locations, the multipath loss is less than or equal to 4 dB[1], while for both multipath and shadowing, the corresponding figure is roughly 17 dB. Hence there is a 13 dB advantage for the fixed service; or for cases where no blockage occurs.

The antenna for fixed/transportable application is designed to have transmit gain and receive G/T which are 6 dB and 5 dB, respectively, greater than the corresponding values for the UHF base stations assumed in the commercial viability study. Thus, the G/T is -10.1 dB/K. This is 5.7 dB higher than the L-band mobile service G/T. Table 5.3 summarizes the L-band transportable/fixed service terminal characteristics. (The table assumes 2 L-band beams.)

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[1] Results of simulation studies at Telesat indicate a multipath loss of the order of 2 dB [5].

Included in the table, for comparison, are the corresponding L-band vehicular terminal parameters.

From the above, it follows that for a two-way link availability of 97%, the required satellite L-band EIRP per carrier to the transportable station is 13.6 dBW. The recommended link budgets for both the forward and reverse links are shown in Table 5.4.

Note that these link budgets are for the purpose of comparison to the mobile service only. One would not for example design a reverse link with uplink thermal C/N only 13.1 dB while the downlink thermal C/N is 22.6 dB. The link would be optimized to accommodate a higher C/N in the uplink and a somewhat reduced thermal C/N on the downlink to save a bit of power on the spacecraft.

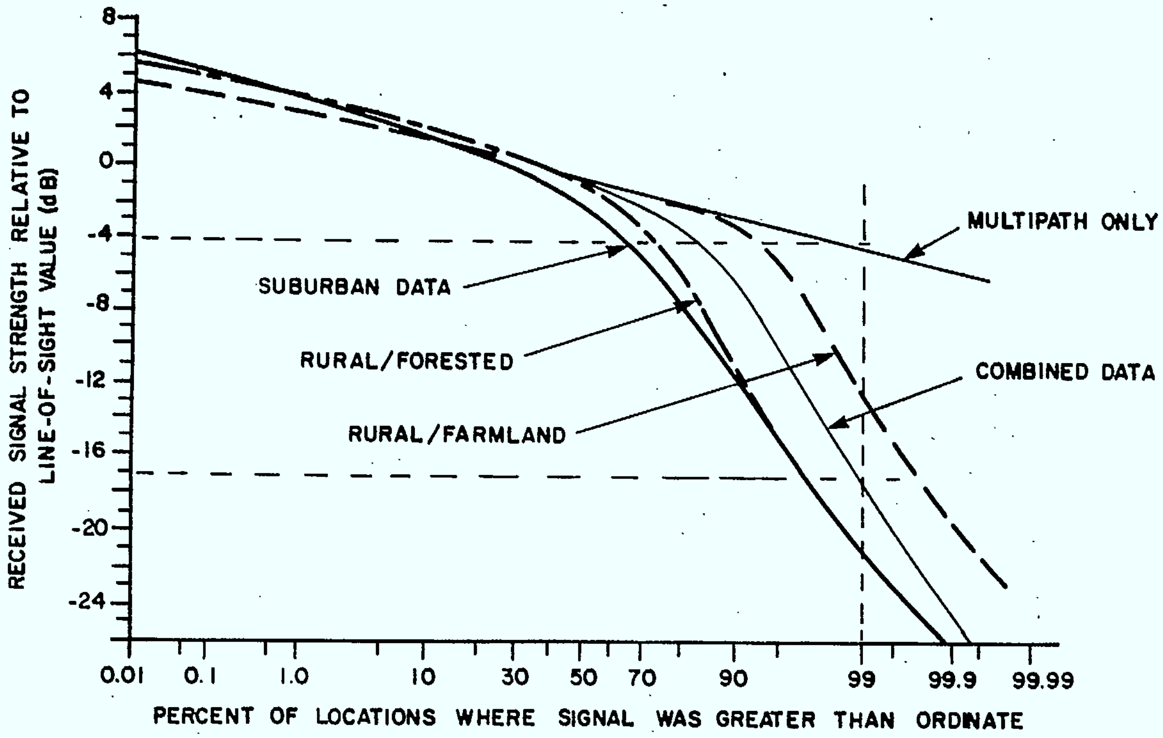

Figure 5.1: L-band (1542 MHz) signal strength distribution functions (recorded in June 1983).

Table 5.3: Comparison of Some Parameters of L-Band Mobile and Transportable Fixed Services

	L-Band Mobile	L-Band Transportable
Ground Segment		
Transmit gain, dBic	10.4	17.5
Transmit EIRP/carrier, dBW	23.0	10.0
Transmit Power, Watts	14.8	0.2
Receive gain, dBic	10.4	17.0
Receive noise figure, dB	2.0	2
Receive G/T, dB/K	-15.8	-10.1*
Space Segment		
Transmit EIRP/carrier, dBW	32.3	13.6

* The same assumption regarding the noise temperature of the antenna has been used as in the CVS.

Table 5.4(a)

Link Calculations L-Band-SHF For Transportable Service (2 L-Band Beams)

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	-2.0
Uplink EIRP/ Voice Act. Carr.	dBW	40.1	10.0
IPBO/Carrier	dB	N/A	TBD
Total No. of Carriers/Beam		TBD	TBD
Equiv. # of Act. Channels/Beam		TBD	TBD
Total IPBO/Transp.(Av. Pwr)	dB	N/A	12
Req'd. Flux Density/Voice Carr.	dBW/m^2	-122.8	-152.9
Saturating Flux Density	dBW/m^2	N/A	TBD
Full Load Flux Density	dBW/m^2	TBD	TBD
Req'd Saturating C/T	dBW/K	TBD	TBD
C/No Thermal	dB-Hz	58.9	47.9
Noise Bandwidth	kHz	3	3
C/N Thermal	dB	24.1	13.1
DOWNLINK			
Req'd EIRP/Voice Act. Carr.	dBW	13.6	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	-10.1	25.9
C/No Thermal	dB-Hz	43.9	57.3
Noise Bandwidth	kHz	3	3
C/N Thermal	dB	9.1	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	8.7	12.1

Table 5.4(b)

Link Calculations L-Band-SHF For Transportable Service (4 L-Band Beams)

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	7.7
IPBO/Carrier	dB	N/A	TBD
Total No. of Carriers/Beam		TBD	TBD
Equiv. # of Act. Channels/Beam		TBD	TBD
Total IPBO/Transp.(Av. Pwr)	dB	N/A	12
Req'd. Flux Density/Voice Carr.	dBW/m^2	-122.8	-152.9
Saturating Flux Density	dBW/m^2	N/A	TBD
Full Load Flux Density	dBW/m^2	TBD	TBD
Req'd Saturating C/T	dBW/K	TBD	TBD
C/No Thermal	dB-Hz	58.9	47.9
Noise Bandwidth	kHz	3	3
C/N Thermal	dB	24.1	13.1
DOWNLINK			
Req'd EIRP/Voice Act. Carr.	dBW	13.6	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	-10.1	25.9
C/No Thermal	dB-Hz	43.9	57.3
Noise Bandwidth	kHz	3	3
C/N Thermal	dB	9.1	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	8.7	12.1

6. L-BAND LINK WITH REDUCED AVAILABILITY

Having finished the first part of the L-band study which was to compare L-band to UHF on an equal basis, the next step is to try to modify the design in order to come up with a viable L-band system. One possible area of modification is the system availability. It is shown, in this chapter, that accepting an availability which is about 3% lower than that considered earlier (chapter 3) leads to a significant reduction in the required satellite power per carrier, thus resulting in a considerable increase in the system user capacity.

Several values of satellite EIRP per carrier are given corresponding to different possible earth segment G/T's.

6.1 Link Analysis

In the first part of this L-band study, it was shown that L-band mobile service required a considerable propagation margin (in the order of 17 to 18 dB) to maintain the same order (though somewhat reduced) of service availability as was assumed in the baseline UHF system and assuming heavy blockage by foliage, etc. The required EIRP per carrier was shown to be 32.3 dBW leading to a total system capacity of only 6,000 users (see chapter 7), for a PAM-D size spacecraft compared to 35,000 users for the baseline UHF system. The resulting cost penalty for using L-band as opposed to UHF is Cd$68 million NPV. [See "Market Study and Economic Analysis", one of the reports of this study].

Before dismissing L-band as an unviable band for mobile service, one has to attempt some "fine-tuning" of the system design to find out if indeed an L-band system can be operable, and under what conditions. This is important as the L-band offers a potential of 15 MHz additional spectrum. As a first step in this fine-tuning process, we have examined the effect of reducing the system availability in order to alleviate the burden on the spacecraft power.

The two-way system availabilities are worked out for different values of uplink and downlink thermal C/N ratios using the procedure explained in chapter 3. Again, the SHF link characteristics are maintained constant. The availabilities are tabulated in Table 6.1.

From the table, it is seen that if we reduced the overall system availability to 94.0%, the required downlink thermal C/N in the forward link would be 17.1 dB and that of the uplink in the reverse link would be 22.1 dB. This compares very favourably with the corresponding values of 22.1 dB and 26.1 dB, respectively, for 97% availability which were calculated earlier.

The implication of this reduction in the downlink C/N requirement in the forward link is to reduce the satellite EIRP if the earth station G/T is held constant. The practical (easily realizable) vehicular G/T is not identified at this stage and will be one of the subjects of the ground segment future studies. Hence the required EIRP per carrier is given for several possible G/T values. See Table 6.2 and Figure 6.1.

The reduction in satellite EIRP requirements will lead to a sizeable increase in the system user capacity for a PAM-D size spacecraft. The required uplink EIRP per channel of the L-band mobile terminal decreases to 19 dBW from 23 dBW.

Table 6.1: Total System Availabilities

Forward-link C/N_{up} = 24.1 dB, Reverse-link C/N_{down} = 22.6 dB

FL C/N down (dB)	Type of Link	System Availabilities (%)							
		Minimum Quality for RL C/N up (dB)				Normal Quality for RL C/N up (dB)			
		20.1	22.1	24.1	26.1	20.1	22.1	24.1	26.1
17.1	M→B	97.0	97.3	97.8	98.0	94.8	95.5	96.0	96.2
	B→M	96.6	96.6	96.6	96.6	93.9	93.9	93.9	93.9
	M↔B	93.7	94.0	94.5	94.7	89.0	89.7	90.1	90.3
18.1	M→B	97.0	97.3	97.8	98.0	94.8	95.5	96.0	96.2
	B→M	97.5	97.5	97.5	97.5	95.6	95.6	95.6	95.6
	M↔B	94.6	94.9	95.4	95.6	90.6	91.3	91.8	92.0
22.1	M→B	97.0	97.3	97.8	98.0	94.8	95.5	96.0	96.2
	B→M	99.0	99.0	99.0	99.0	97.9	97.9	97.9	97.9
	M↔B	96.0	96.3	96.8	97.0	92.8	93.5	94.0	94.2
24.1	M→B	97.0	97.3	97.8	98.0	94.8	95.5	96.0	96.2
	B→M	99.5	99.5	99.5	99.5	98.6	98.6	98.6	98.6
	M↔B	96.5	96.8	97.3	97.5	93.5	94.2	94.7	94.9
25.1	M→B	97.0	97.3	97.8	98.0	94.8	95.5	96.0	96.2
	B→M	99.6	99.6	99.6	99.6	98.9	98.9	98.9	98.9
	M↔B	96.6	96.9	97.4	97.6	93.8	94.4	94.9	95.1

M→B = Mobile-to-base station
B→M = Base station-to-mobile
M↔B = Two-way base-to-mobile
FL C/N down = Forward downlink thermal C/N
RL C/N up = Reverse uplink thermal C/N

The recommended link budgets for both the forward and reverse links are shown in Table 6.3.

Table 6.2: Required Satellite EIRP Per Carrier For Different Values of Vehicular Antenna G/T

Vehicular Antenna Transmit Gain, dBic	Vehicular Antenna G/T, dB/K	Satellite EIRP dBW
17.2	-10	21.5
12.2	-15	26.5
10.2	-17	28.5
8.2	-19	30.5
6.2	-21	32.5

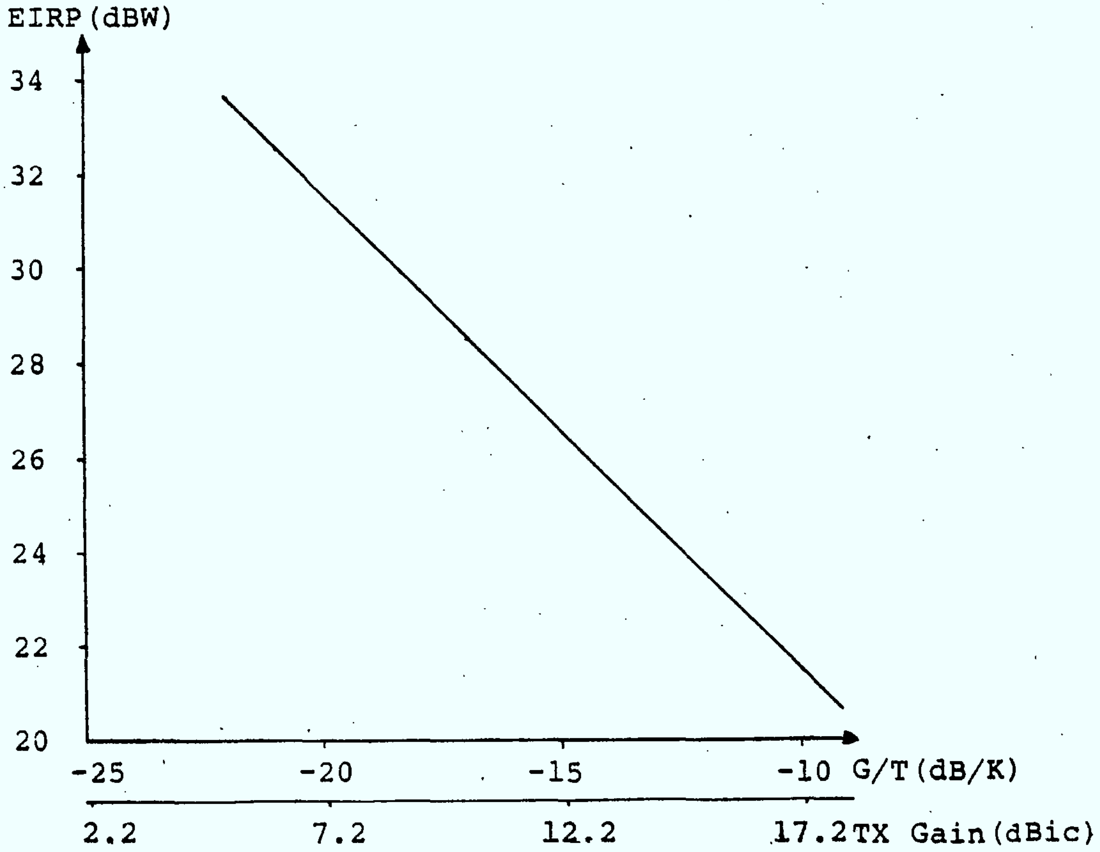

Figure 6.1: Variation of Satellite EIRP With E.S. G/T

Table 6.3(a)
Link Calculations L-Band → SHF with Reduced Availability (2 L-Band Beams)

PARAMETER	UNIT			FORWARD LINK			REVERSE LINK
				3.5m SHF Ant. to Mobile			Mobile to 3.5m SHF Ant.
UPLINK							
Satellite G/T	dB/K			-3.0			-2.0
Uplink EIRP/ Voice Act. Carr.	dBW			40.1			19.0
IPBO/Carrier	dB			N/A			TBD
Total No. of Carriers/Beam				TBD			TBD
Equiv. # of Act. Channels/Beam				TBD			TBD
Total IPBO/Transp.(Av. Pwr)	dB			N/A			12
Req'd. Flux Density/Voice Carr.	dBW/m^2			-122.8			-143.9
Saturating Flux Density	dBW/m^2			N/A			TBD
Full Load Flux Density	dBW/m^2			TBD			TBD
Req'd Saturating C/T	dBW/K			TBD			TBD
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	21.5	26.5	28.5	30.5	32.5	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	-10.0	-15.0	-17.0	-19.0	-21.0	25.9
C/No Thermal	dB-Hz			51.9			57.3
Noise Bandwidth	kHz			3			3
C/N Thermal	dB			17.1			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			15.1			17.2

Table 6.3(b)
Link Calculations L-Band → SHF with Reduced Availability (4 L-Band Beams)

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
IPBO/Carrier	dB			N/A			TBD
Total No. of Carriers/Beam				TBD			TBD
Equiv. # of Act. Channels/Beam				TBD			TBD
Total IPBO/Transp.(Av. Pwr)	dB			N/A			12
Req'd. Flux Density/Voice Carr.	dBW/m^2			-122.8			-143.9
Saturating Flux Density	dBW/m^2			N/A			TBD
Full Load Flux Density	dBW/m^2			TBD			TBD
Req'd Saturating C/T	dBW/K			TBD			TBD
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	21.5	26.5	28.5	30.5	32.5	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	-10.0	-15.0	-17.0	-19.0	-21.0	25.9
C/No Thermal	dB-Hz			51.9			57.3
Noise Bandwidth	kHz			3			3
C/N Thermal	dB			17.1			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			15.1			17.2

6.2 Remarks

It is shown that by accepting an availability which is 3% lower than that assumed in the earlier part of this report, a reduction in the required satellite EIRP per carrier of about 5 dB results. This is a significant power reduction which can lead to a restoration of system user capacity to near the same level as that in the UHF baseline system. This would ultimately render an L-band system viable. Further areas of fine-tuning should be identified.

However, a few words of caution are worthwhile at this juncture.

(1) The same relaxation in availability can also be allowed in the UHF system resulting in lower UHF fade margins (satellite EIRP of 22.5 dBW) and hence higher capacity. This would allow a UHF system to operate at the spectrum limit, and is an area that merits further study.

(2) The propagation results used are for elevation angles of 20° or higher. For areas with lower elevation angles, higher margins may be required. Although a large part of the country will not suffer blockage (especially the Prairies and Northern Canada where there are no appreciable blockages due to trees) the parts that have large proportions of wooded areas are the potentially significant revenue-generating ones, e.g. Ontario and Québec. Further, there is some uncertainty in the available data.

(3) The availability given are for "minimum quality". For "normal quality" the corresponding availability

for transportable/fixed service is 89.7%. It is doubtful if "minimum quality" (threshold C/N_o = 39 dB-Hz) will be sufficient. Some sources have expressed doubt of even the so-called "normal quality" (threshold C/N_o of 42 dB-Hz). If a higher C/N_o value is indeed necessary for an acceptable quality, this will effectively reduce the system availabilities to well below 90% for the propagation paths assumed.

7.0 SYSTEM CAPACITIES

The system capacities in terms of the number of L-band users are given here for typical cases and a few representative spacecraft bus candidates. The approach taken in this study is to work out the number of active channels (number expected to be active for 99% of the time) that can be accommodated on a particular spacecraft bus. This is one of the subjects of the "Space Segment Concepts and Costing" sub-task report of this study. The number of active channels is used to calculate the number of assignable channels and hence the system user capacity using the computer programme developed for the CVS study. The assumptions relevant to this computation are similar to those made for capacity derivations in the CVS and Business Proposal. The key ones are:

- MTS 25%, MRS 75%
- 150 minutes per month per mobile → 0.011 erlang/user
- erlang B loss formula assumed
- no L-band to L-band cross patch
- full duplex for intra-beam mobile-to-mobile traffic
- LPC/DMSK for voice coding/modulation
- 5 kHz channel spacing
- voice activation used

This system user capacity is then used in the Economic Analysis section of the study. See sub-task report entitled, "Market Studies and Economic Analysis".

7.1 System Capacities For Plan 1

In Table 7.1, the system user capacities are given for an L-band only system. This is for a truly mobile

Table 7.1: L-Band System Capacities For Mobile Service

Spacecraft	No. of Beams	L-Band EIRP/Ch. (dBW)	Channels Per Beam		Total L-Band Capacity
			Active*	Assignable	
PAM-D	2	32.3	23	37	6,000
PAM-D II	2	32.3	39	70	13,000
PAM-D II	4	32.3	33	57	20,500

*Numbers in this column are for carriers active for 99% of the time assuming a voice activation factor of 40%.

service and for a two-way system availability of 97% which is comparable to that of the baseline UHF system. It is seen that a two-beam L-band system on a PAM-D size spacecraft (seven-year life) can accommodate only 6,000 users compared to the 35,000 users of the two-beam UHF system. This is a dramatic reduction in capacity which underscores the advantage of operating at UHF as opposed to L-band if comparable availability is required and significant foliage blockage is encountered. Even by using the larger PAM-DII size spacecraft, the capacity is only 13,000 users for two beams and 20,500 users if a four-beam system is used.

7.2 System Capacities for Plan 2

Table 7.2 gives the number of active and assignable channels as well as the L-band user capacity for a dual band system and two typical spacecraft buses. The dual band consists of a two-beam UHF payload and a four-beam L-band payload. The underlying assumption is that the spacecraft payload resources (mass and power) are first used to support the full UHF payload as in the Business Proposal and any extra resources are used to carry the L-band payload to the extent possible. The L-band capacity given here is for mobile (vehicular) service with an availability of 97%. The increase with reduced fade margins is given in Section 7.3.

From the table, it appears that the additional L-band capacity on an PAM-DII is a mere 1,000 users, and for an HS393 it is a few thousands more. This slight increase in capacity might not justify the extra cost of L-band addition as is evident from the sub-task report on "Market Studies and Economic Analysis" of this study. Hence L-band might be assigned for point-to-point fixed service only.

Table 7.2: L-Band User Capacities For Plan 2

Spacecraft Size	No. of Beams	L-Band EIRP/Ch. (dBW)	Channels Per Beam		Total L-Band Capacity
			Active	Assignable	
PAM-D II	2 UHF +4 L-Band	32.3	7	7	1,000
HS 393 (MM3) (1985 DATA)	2 UHF +4 L-Band	32.3	23	37	12,000

Note: The capacities in the last column do not include the UHF capacity.

7.3 System Capacities For System With Reduced Link Availability

Table 7.3 gives the L-band user capacity for the dual-band system for a system with reduced L-band link availability for the different EIRP values specified in Chapter 6. It should be noted that in all cases, the table identifies only the L-band capacity which is over and above the baseline UHF capacity of 35,000 users. For example, for an L-band EIRP of 28.5 dBW, the total dual-band capacity is 35,000 + 25,000 = 60,000 users if spacecraft with 27% STS occupancy is used. Four beams are assumed for L-band and two beams for UHF. Three spacecraft bus sizes are considered: PAM-DII, 23.5% STS and 27% STS. In all cases ten years lifetime is assumed.

It is seen that a PAM-DII spacecraft with ten years lifetime is so severely mass limited that it can handle no L-band users in addition to the UHF capacity. It should be understood that addition of an L-band package necessitates inclusion of a sizeable "overhead" (capacity-independent) mass. This includes such items as additional feeds and mechanisms to isolate them from the UHF feeds, wire harness, interfaces, etc. This will be explained in more detail in the chapter on the space segment.

Note that although a large user capacity is shown for the case with EIRP of 13.6 dBW, this case corresponds to a fixed or transportable service with high earth terminal gain antennas. Although the market to utilize such capacity may not exist, it might be possible to negotiate with the U.S. to sell them some of that capacity if they need it.

Table 7.3: L-Band user capacity for a dual-band system for link with reduced availability

L-band EIRP/carr. (dBW)	PAM-DII Capacity	0.235 STS			0.27 STS		
		Ch/beam		Capacity	Ch/beam		Capacity
		Active	Asg		Active	Asg	
13.6	–	104	212	84,500	275	596	244,000
21.5	–	50	91	34,000	133	276	111,000
26.5	–	22	34	11,000	57	106	40,500
28.5	–	15	23	7,000	38	68	25,000
30.5	–	10	13	3,000	25	40	13,000
32.5	–	6	6	1,000	16	24	7,200

Note: Capacity in this table does not include baseline UHF capacity.

8. CONCLUSIONS

The major impact of changing the MSAT frequency of operation from UHF to L-band is in the required satellite EIRP and, hence, the system user capacity for a given spacecraft size. In order to maintain nearly the same link quality (availability) as that assumed for UHF in the CVS, under the same assumed blockage conditions, the required EIRP per channel has to be increased by 5.8 dB to counter the increased propagation losses. This means that for the same spacecraft size as employed for the baseline UHF system, the L-band system user capacity decreases dramatically to 6,000 users compared to 35,000 users for UHF. That is, the L-band capacity is only about 17% of that of UHF. In the dual-band case using larger size spacecraft, only a modest L-band user capacity can be accommodated. This clearly underlines the preference of UHF over L-band. (The cost penalties are explained in Sub-task 4 of this study.) Further, operation at L-band would obviate the possibility of exploiting the large technology base available for vehicular terminals from the terrestrial systems, which also operate at UHF in just the adjacent bands.

Due to the increased frequency of operation from UHF to L-band, vehicular terminal antenna dimensions would be manageable. A microstrip phased-array of the same size as that assumed for UHF vehicular antenna would yield an acceptable gain and G/T. A further impact on the vehicular terminal is an increase in the required output power (14.8 watts for the L-band terminal compared to 2 watts for the UHF terminal), however this power level is considered acceptable.

Since the significant contributor to excess path loss is shadowing (multipath loss is only a few dB's), it follows that L-band would be particularly suited for fixed or transportable services. For such applications, the terminal site would be selected such that there would exist a clear line of sight between the terminal antenna and the satellite. Therefore, the lower required fade margin as well as a high terminal G/T would result in a modest required satellite EIRP for these services. It was shown that about 5 dB satellite power saving can be achieved if a 3% lower link availability could be accepted. This translates into a significant increase in the system user capacity for the same size of spacecraft. For example, for a two-way availability of 94%, a system capacity of around 40,000 users can be accommodated compared to only 6,000 users for a two-way availability of 97% (G/T = -15.8 dB/K).

It should be stressed that L-band transponders would appear to provide a most effective service for applications where high fade margins are not necessary, and where high gain directional antennas may be used. Typical examples of this type of application are:

a) Mobile service in areas of low foliage blockage, such as the Prairies and the North West Territories and Arctic.
b) Mobile service to customers who can select transmission times when blockage by foliage is minimal.
c) Transportable or fixed service applications where high gain antennas may be used.
d) Aeronautical mobile and maritime mobile services. (Note that equipment for these bands has been, or may be developed in the near future.)

For purposes of comparison with the UHF design, however, it should be pointed out that the same relaxation in link availability can also be allowed for the UHF system. This would result in lower fade margins, and hence required satellite EIRP per channel (22.5 dBW per channel). The resultant increase in the UHF system capacity would allow the system to operate at the spectrum limit. This is an area which merits further future study.

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