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STUDY OF L-BAND UTILIZATION BY MSAT

SUB-TASK 2. SPACE SEGMENT CONCEPTS AND COSTING

PREPARED FOR

Communications Research Centre
Department of Communications

Submitted by:

TELESAT CANADA

FINAL

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MSAT Engineering Support Contract
DSS CONTRACT FILE 01SM. 36001-2-2568
TASK NO. 18

OUTLINE

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1.0 INTRODUCTION

The purpose of this study is to assess the impact on the MSAT space segment design and cost of operating all or part of the satellite communications payload in L-Band (1.5 GHz) rather than UHF (800 MHz). The results are expressed in terms of system capacity and cost, compared with the UHF system described in the MSAT Business Proposal.

For this purpose, three basic space segment configurations are chosen. First, a two-beam and a four-beam system are analyzed, using the same antenna coverage as was assumed for the UHF system. Even though the 2-beam system antenna mass is significantly reduced, the higher RF power requirement, and decreased HPA efficiency, imply a significant reduction in system capacity.

An alternative plan is to combine a four-beam L-Band payload with the two-beam UHF payload, described in the MSAT Business Proposal, on a common spacecraft. Although the result is a larger, more expensive spacecraft, the sharing of bus subsystems and reflectors by both transponders provides economy of scale.

A third plan is to operate dedicated UHF and L-Band satellites simultaneously. The capacity of such a system is simply the sum of the baseline UHF capacity and that of the L-band satellite described in the first plan, above. In each case, the configurations and performance requirements are outlined in section 2.0. In section 3.0, the capabilities of candidate spacecraft are assessed, and the capacity, in terms of active carriers, is calculated.

The result of the analysis is that the L-band capacity is rather small, under the performance assumptions of the baseline UHF system. Consequently, an alternative scenario was introduced, in an attempt to improve the prospects of an L-band system. An investigation was made to identify which parameters of system performance could be varied in order to reduce the required spacecraft downlink EIRP, thereby increasing communications capacity. The result, as shown in section 2.2., is a range of EIRP values, from 13.6 dBW, corresponding to fixed or transportable high-gain ground antennas, to a full mobile requirement of 32.5 dBW.

Furthermore, since 10-year spacecraft life provides an improved economic position of the system, this service life was chosen for the alternate scenario whereas seven years was retained for the primary scenario. To accommodate an L-band payload together with the 2-beam UHF system requires a spacecraft larger than the PAM-D or PAM-D2 class candidates considered for the 7-year cases.

As shown in section 3.3., this scenario has the potential of providing considerable capacity in L-band, depending upon the choice of performance parameters. To address the question of the relative cost of L-band versus UHF in the dual-band approach, the proportion of resources required in each configuration is calculated, as shown in section 3.4.

Finally, estimates of the program cost and cost disbursements (cash flows) are described in section 4.0. In general, the space segment implementation is conducted in the same fashion as the baseline UHF system, described in the MSAT Business Proposal, except that the Canadian satellite is launched one year after the American one. Spacecraft prices are estimated on the basis of comparison with the baseline UHF satellites.

2.0 SATELLITE SYSTEM DESCRIPTION

2.1 System Implementation Plans

Three distinct plans are chosen for implementation of an L-Band MSAT space segment. The selection, shown in Table 2.1.1, serves to enable a direct comparison with the UHF 2- and 4-beam systems described in the MSAT Business Proposal.

TABLE 2.1.1 IMPLEMENTATION PLANS

Plan	Coverage (Beams)	Spacecraft Type
1	2 L-Band or 4 L-Band	PAM-D or PAM-D2
2	2 UHF/4 L-Band (Dual-Band)	PAM-D2 or Larger
3	2 or 4 UHF and 2 or 4 L-Band	PAM-D or PAM-D2 and PAM-D or PAM-D2

In each case, the spacecraft type selected for determining system capacity is similar to the corresponding UHF configuration. Because of the limited capacity of dual-band PAM-D2 class spacecraft, larger configurations are also considered for this case. The combination of 2 UHF and 4 L-band beams was chosen because the two systems could share the same antenna reflectors.

A list of general requirements for implementation is shown in table 2.1.2. These apply to all optional plans and, except for the L-band communication frequencies, are the same as those adopted for the baseline UHF system. Although the assumption is that spectrum will be equally shared with the American operator, this may not be practical for a dual-band system.

TABLE 2.1.2 IMPLEMENTATION REQUIREMENTS

ITEM	DESCRIPTION
No. Satellites	1 Canadian, 1 USA
S/C Procurement	Joint with US operator
Satellite Operation	Separate
Coverage	Canada/CONUS/Alaska/Territorial waters
Communications Freq.	L-Band (1.65/1.55 GHz) UHF (820/870 MHZ)
Backhaul Freq.	Ku-Band (13/11 GHz)
Spectrum Sharing	Equal with US system
Modulation	DMSK/PELPC, ACSSB
Channel Spacing	5 kHz

In this case, it is assumed that the same amount of UHF spectrum is used as in the Business Proposal configuration, and the remaining payload resources are used to provide L-band communications. Spectrum used in L-band is therefore determined by the number of active carriers which these resources can provide.

2.2 Communication Performance Scenarios

The first approach adopted for implementing an L-band MSAT system assumes identical communication performance to that of the UHF system. This implies that the mobile link has availability equal to that at UHF, assuming the same antenna aperture of the ground terminal. Although this results in higher ground terminal antenna gain, the higher path and shadowing losses at L-band imply a net increase of 5.8 dB in downlink EIRP if equal availability is to be ensured. Consequently, whereas the UHF payload operates at 26.5 dBW EIRP/carrier, the L-band system requires 32.3 dBW to provide equal link performance. This set of requirements is summarized as Scenario I in Table 2.2.1.

An alternate approach to an L-band system is to relax the path availability constraints, by reducing the fade margin, or increase ground terminal gain. This has the advantage of reducing the penalty imposed on the system capacity by the characteristics of the L-band link.

To illustrate the effect on capacity of varying the ground terminal characteristics a range of EIRP values was addressed as shown in Scenario II, Table 2.2.1. Here, 13.6 dBW corresponds to fixed or transportable high-gain ground antennas, placed so that shadowing loss does not occur. 32.5 dBW represents fully mobile low-gain antennas, requiring high fade margin. In addition, capacities are calculated for spacecraft with 10-year service life.

TABLE 2.2.1 PERFORMANCE REQUIREMENT SCENARIOS

Requirement	UHF Baseline	L-BAND SCENARIOS	
		I	II
EIRP/Carrier (dBW)	26.5	32.3	13.6 - 32.5
Service Life (yr)	7	7	1 0

3.0 SPACECRAFT CONCEPTUAL DESIGN

3.1 Communications Subsystem Description

3.1.1 L-Band Payload Design Considerations

The basic requirement for the design of the L-band communications payload is that the system concept remain the same as that of UHF. As shown in Figure 3.1.1, the functional form of the payload is the same, under the assumption of separate transmit and receive antennas.

The major impact of the conversion in frequency results from the 5.8 dB increase in EIRP per carrier. This translates into a factor of about 3.8 in power. Consequently, whereas the UHF system requires 1.16 W per carrier, L-band will require in the order of 4.4 W, if all other design parameters remain the same.

In fact, the actual figure will be slightly higher than 4.4 W, due to a small drop in antenna net gain. This is caused by the fact that the downlink frequency at L-band is lower than the uplink frequency, and the antenna is assumed to be optimized for the average frequency. This assumption applies if the transmit and receive beams share the same reflector. However, if transmit and receive antennas are separate, they can be optimized independently, providing .4dB improvement in gain, and up to 10% improvement in capacity. Table 3.1.1 is a brief summary of L-band antenna parameters. Whereas the gain of the UHF antenna is 25.8 dBi, the L-band antenna gain is only 25.4 dBi, so that the L-Band power per carrier is 4.93 W.

Added to the increased power per channel is the reduction in HPA efficiency from 24% at UHF to 20% at L-band. This will demand in the order of 20% more DC power per beam from the spacecraft.

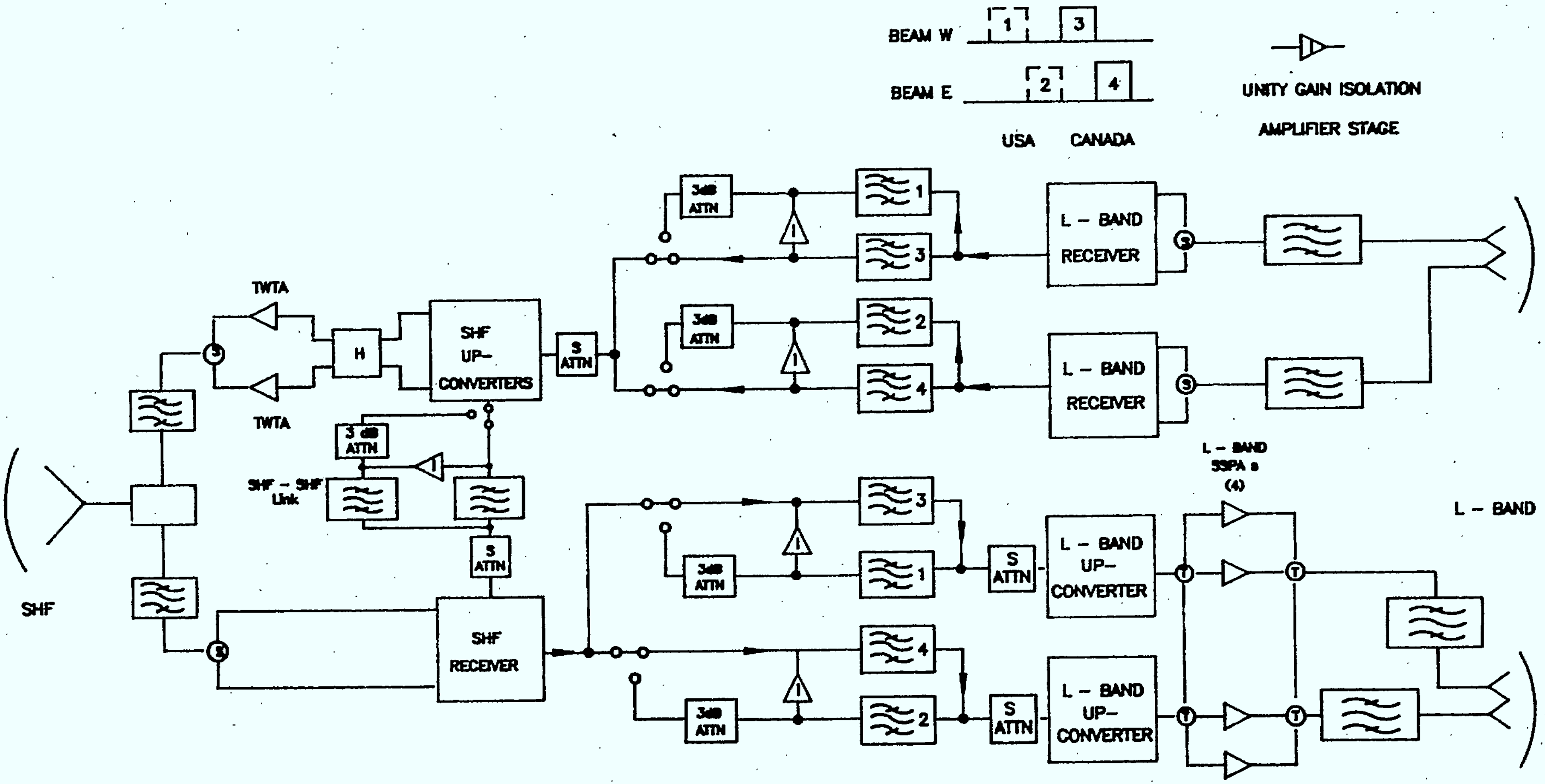


Fig. 3.1.1-

MSAT 2 BEAM FUNCTIONAL BLOCK DIAGRAM

TABLE 3.1.1. L-BAND ANTENNA PARAMETERS

Transmit	
Aperture Diameter (m)	2.64
Boresight Gain (dBi)	30.0
EOC gain (dBi)	27.0
Losses (dB)	1.6
Net EOC Gain (dBi)	25.4
Receive	
Boresight Gain (dBi)	30.3
EOC Gain (dBi)	27.3
Losses (dB)	2.0
Net EOC Gain (dBi)	25.3

TABLE 3.1.2 2-BEAM AMPLIFIER POWER

EIRP/Carrier (dBW)	32.3
Antenna net EOC Gain (dBi)	25.4
No. Active Carriers/Beam	23
Output RF Power/Beam (W)	113.4
Power/Carrier (W)	4.93

Whereas the impact of L-band on power is detrimental, the overall impact on mass is favourable. To retain the same 2-beam coverage as the baseline UHF system, the reflector size reduces to 2.64 m, thereby providing an estimated 32.5 kg mass saving. Even though the HPA and thermal control systems increase in size, due to increased HPA power and reduced efficiency, this increase is small compared to the reduction in antenna mass.

This mass reduction can generally be traded for increased power from the spacecraft. However, as will be seen in sections 3.2 and 3.3, Scenario I configurations become power-limited on PAM-D and PAM-D2 class spacecraft, and little capacity increase is achieved.

The result of these changes in transmit performance is a significant reduction in capacity, for a given level of spacecraft resources. As shown in Table 3.1.2, the power available from a PAM-D class spacecraft allows up to 113.4 W RF per beam, which is capable of providing only 23 simultaneous carriers per beam.

Similar remarks apply to the 4-beam L-band system. In this case, the 5.0 m reflector used for the 2-beam UHF is sufficient to provide 4-beam L-band coverage with a net EOC transmit gain of 28.4 dBi. However, because of a higher number of components, and a larger power requirement (see section 3.2) the 4-beam L-band payload resource requirements exceed the capability of a PAM-D class spacecraft. Consequently, this configuration must be implemented on a larger spacecraft, such as PAM-D2 class.

The acceptability of the 5.0 m reflectors for 4-beam L-band coverage allows a dual-band system to be implemented on a single spacecraft, such that a 2-beam UHF and a 4-beam L-band payload share a pair of 5.0 m reflectors. The resulting saving in mass, and consequent increase in capacity on a given spacecraft, promises to favour the dual-band approach over dedicated satellites.

3.1.2 Payload Design Parameters

An L-band 2-beam payload, shown in Figure 3.1.1, may be implemented on a PAM-D class spacecraft with power and mass budgets contained in Table 3.1.3.

In each case, 15% contingency has been added to the power and mass estimates.

TABLE 3.1.3 2-BEAM, L-BAND PAYLOAD POWER/MASS BUDGETS

Power (W) (2x23 Carriers)	
L-Band SSPAS (20% efficiency)	1134
L-Band Transponder & Local Oscillator	35
SHF TWTA	20
SHF Transponder & Local Oscillator	11
Contingency (15%)	180
Total	1380
Mass (kg)	
2 X 2.6 m dia Reflectors & Support	25.0
L-Band SSPA's (4)	22.8
Miscellaneous Transponder Equipment	12.9
SHF TWTA's	4.8
SHF Antenna & Misc.	10.5
Power Converter & TCIU	11.0
Thermal Control	54.8
Harness	9.0
Contingency (15%)	22.6
Total	173.4

Miscellaneous transponder equipment includes:

Reference Oscillator:	3 kg
Local Oscillator:	1.25 kg/beam
Other Components:	3.7 kg/beam

Corresponding budgets for a 4-beam L-band payload are shown in Table 3.1.4.

TABLE 3.1.4 4-BEAM L-BAND PAYLOAD POWER/MASS BUDGETS

Power (W) (4x33 Carrier)	
L-Band SSPA's (20% Efficiency)	1620.0
L-Band Transponder & Local Oscillators	70.8
SHF TWTA	75.7
SHF Transponder & Local Oscillator	10.4
Contingency (15%)	266.5
Total	2043.4
Mass (kg)	
2X 5.0 m Reflectors & Support	46.0
Feeds	11.5
L-Band SSPA's (8)	36.8
Miscellaneous Transponder Equipment	22.8
SHF TWTA'S	6.0
SHF Antenna & Miscellaneous	10.5
Power Converter & TCIU	15.0
Thermal Control	82.0
Harness	18.0
Contingency (15%)	37.3
Total	285.9

In the dual-band cases, no specific budget is provided for L-band although the same unit masses and power consumption values are used where applicable. It is assumed, for the comparative study, that the 2-beam UHF payload is similar to the MSAT Business Proposal version, and that the L-band transponder will use the balance of resources afforded by the candidate spacecraft. This implies that the full 2MHz of UHF spectrum is used, and the L-band spectrum used corresponds to the designated carrier capacity.

The UHF payload assumed for dual-band systems in this study is designed to accommodate 99% of the peak busy-hour channel requirement. Consequently the SSPA's used in the 2-beam system must be capable of 105W RMS RF power corresponding to 90 active carriers per beam. Whereas the Business Proposal UHF spacecraft power subsystem was sized for the average busy-hour demand, the dual-band spacecraft is designed to supply sufficient power for 99% of the peak demand. A summary of the 2-beam UHF payload budgets for a dual-band system is shown in Table 3.1.5.

TABLE 3.1.5 2-BEAM UHF (DUAL-BAND) PAYLOAD
POWER/MASS BUDGETS

Power (W) (2x90 Carriers)	
2 UHF SSPA's at 24% efficiency	875.0
UHF transponder & local oscillators	35.4
SHF TWTAs	89.5
SHF transponder & local oscillator	10.4
Contingency (15%)	151.5
Total	1161.8
Mass (kg)	
2 reflectors & support	46.0
2 feed horns & support	11.5
4 SSPA's	19.2
Transponder & local oscillators	12.9
SHF TWTA (2)	6.5
SHF transponder & antenna	10.5
Power converter & TCIU	11.0
Thermal Control	45.6
Harness	9.0
Contingency (15 %)	25.8
Total	198.0

3.2 Candidate Spacecraft Resources

3.2.1 MSAT Spacecraft Characteristics

The characteristics of an MSAT spacecraft which distinguish it from a fixed-service type have been analyzed at length in previous studies. In general, there are four main areas of distinction.

1. Eclipse Coverage: Because the eclipse period traffic is expected to be no more than 25% of the design level of the transponder, batteries need only supply about 50% of the daylight power requirements of the payload. This represents a saving of 22.5 kg per kW of payload DC power.

2. HPA Efficiency: Most manufacturers include payload thermal control equipment in the bus. The amount required is calculated assuming the use of C-band or Ku-band TWTA's with 35-40% efficiency. Since the current MSAT design uses UHF or L-band solid state amplifiers having efficiencies in the order of 20-24%, the thermal control requirement is normally included in the payload mass estimate, and must be removed from the bus.

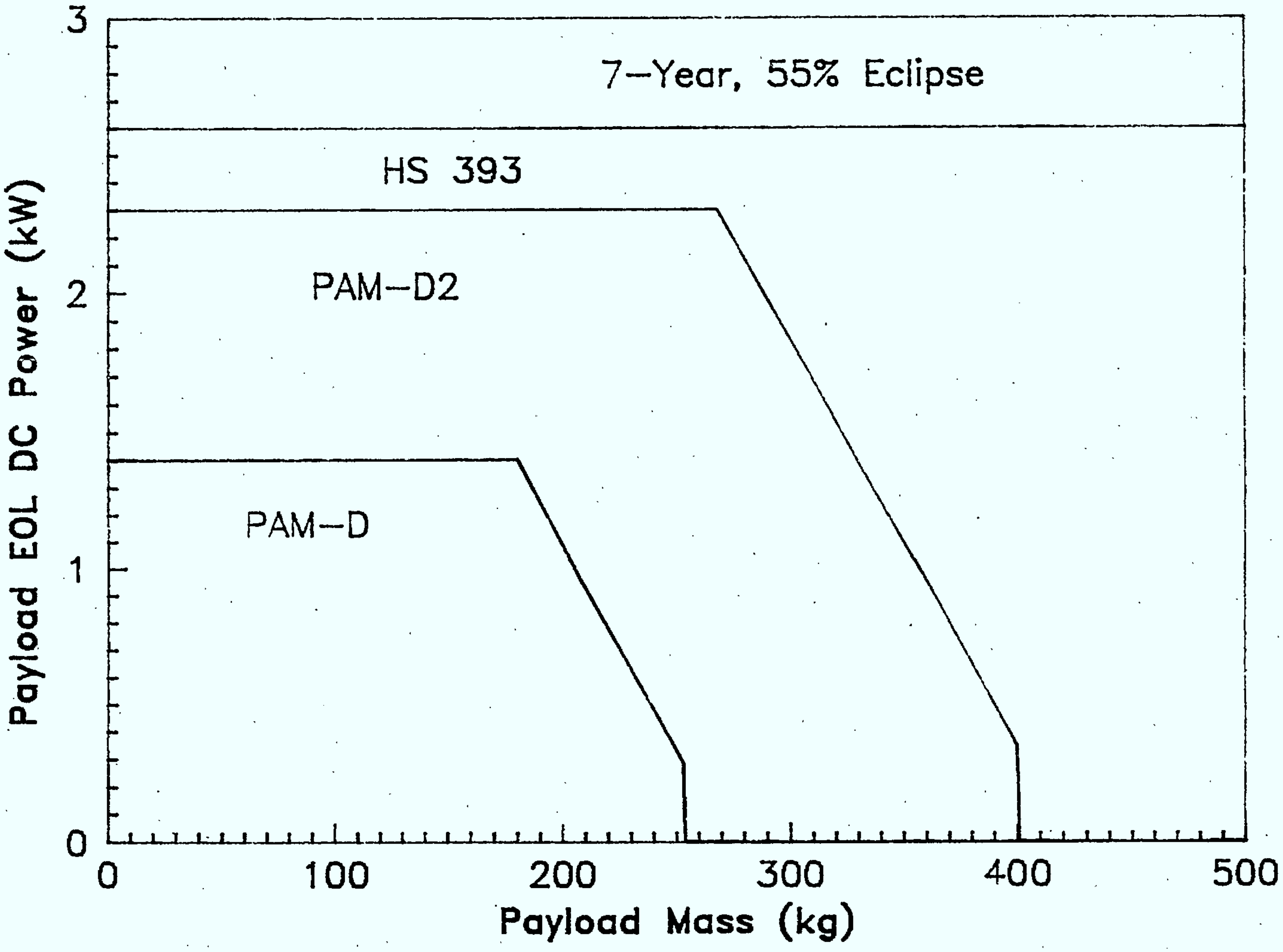
3. Life: Although most current spacecraft are designed to accommodate 10 years stationkeeping propellant, MSAT, under Scenario I, requires only 7 years of operation. The discarded 3 years propellant may be sacrificed in favour of payload, allowing 15% penalty for mechanical modifications. This represents a saving of 10-12 kg/year for PAM-D class spacecraft, and 18-20 kg/year for PAM-D2 class candidates.

4. Contingency: The conventional approach to conceptual design of a payload on a given spacecraft is to estimate the payload mass and power and compare it to the manufacturer's advertised payload capability envelope. The difference, in mass and power, resulting from the comparison is regarded as the implementation margin. However, in the case of MSAT, the payload size is a continuum, within a range, and the design is estimated as the maximum number of carriers accommodated by a given spacecraft. Since this is calculated from the intersection of a payload resource requirement function and a spacecraft capability envelope, it is necessary that the design reserve sufficient margin a priori. Consequently, a standard contingency factor of 2% GTO mass is removed from each advertised payload envelope, including any margin already held by the manufacturer.

3.2.2 Scenario I Spacecraft

Prime candidates for MSAT spacecraft in Scenario I are in the PAM-D and PAM-D2 classes. The capabilities of 3-axis stabilized spacecraft in these classes, in terms of payload mass and power, are shown as envelopes in Figure 3.2.1. Also shown in the figure is the envelope for a HS 393 spacecraft of 31% STS occupancy, included for comparison with PAM-D2 class. Note that, although the mass capability of the spinner is considerable, its power limit is not far beyond that of the PAM-D2 class 3-axis spacecraft.

FIG 3.2.1 SCENARIO I S/C PAYLOAD ENVELOPES



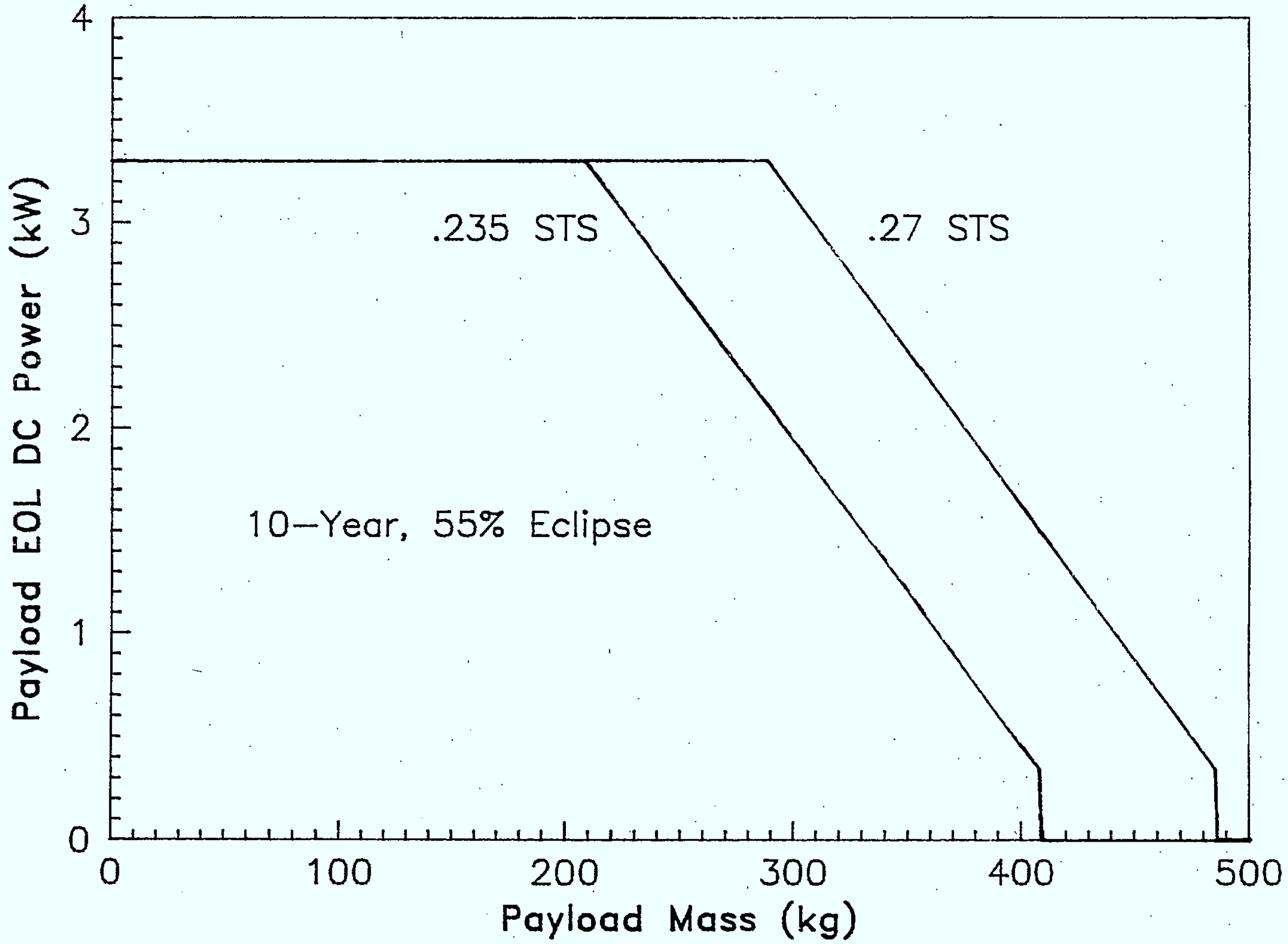
3.2.3 Scenario II Spacecraft

The requirement, in the alternate scenario, to increase service life to 10 years places a significant constraint upon the spacecraft capability. Consequently, it was necessary to abandon PAM-D2 class spacecraft from candidacy for a dual-band system. (It would still, however, be a candidate for a dedicated L-band satellite).

To exceed the capabilities of the PAM-D2 class of spacecraft involves venturing into the realm where most manufacturers are likely to propose integral upper stages. Although it is expected that separate commercial stages in this class will be available in the MSAT time frame, spacecraft-supplied stages are expected to provide cost advantages to the purchaser.

For these reasons, two candidate 3-axis spacecraft, of about 23.5% and 27% STS occupancy, were selected to represent candidates in this class, and their payload envelopes are shown in Figure 3.2.2. It should be noted that, although the payload envelopes represent 3-axis type spacecraft, there are spin-stabilized models in this class with comparable performance.

FIG. 3.2.2 SCENARIO II S/C PAYLOAD ENVELOPES



3.3 Communication Capacity Summaries

3.3.1 Scenario I

Considering payload design parameters discussed in section 3.1, and the spacecraft capability envelopes described in section 3.2, capacities, in terms of active carriers, were calculated for all optional configurations. Plan 1 capacities are shown in Table 3.3.1, compared with the capacities of comparable UHF configurations, as stated in the MSAT Business Proposal. Also shown are resource requirements, corresponding to the capability of each candidate spacecraft.

Of particular note is the fact that the L-band capacities are all significantly lower than those of their UHF counterparts. As explained in Section 3.1.1, however, optimization of separate transmit and receive reflectors could provide up to 10% increase in the capacity figures.

The capacities of dual-band options are listed in Table 3.3.2. The 2-beam UHF system is also shown, so that the total system capacity can be derived. Capacities of Plan 3 options are simply the sums of the applicable capacities in Table 3.3.1.

TABLE 3.3.1 PLAN 1 SPACECRAFT CAPACITIES
(EIRP = 32.3 dBW/Carrier)

CONFIGURATION	* 2 UHF	2 L-BAND	2 L-BAND	*4 UHF	4 L-BAND
S/C Class	PAM-D	PAM-D	PAM-D2	PAM-D2	PAM-D2
Payload Mass (kg)	198	173	216	323	286
Payload Power (W)	926	1380	2300	788	2043
Active Carriers/Beam	90	23	39	69	33
TOTAL CARRIERS	180	46	78	276	132

* MSAT Business Proposal, Appendix D

TABLE 3.3.2 PLAN 2 SPACECRAFT CAPACITIES

(EIRP = 32.3 dBW/Carrier)

CONFIGURATION	2 UHF	2 UHF/4 L-BAND	2 UHF/4 L-BAND
S/C Class	PAM-D	PAM-D2	HS 393
Payload Mass (kg)	198	310	366
Payload Power (W)	1162	1675	2600
UHF Active Carriers/Beam (99%)	90	90	90
L-Band Active Carriers/Beam	-	7	23
TOTAL CARRIERS	180	208	272

In the table, the mass and power figures are the totals for the combined payload, and the total carrier figure is the sum of the UHF and L-band capacities. This arrangement illustrates the incremental capacity effect of the dual-band approach in Scenario I.

3.3.2 Scenario II

The basic approach of adding L-band transponder equipment to the 2-beam UHF payload is retained in Scenario II. However, in this case the spacecraft capability envelopes are different, corresponding to large spacecraft with 10 year nominal service life. Furthermore, the design must be presented for a range of EIRP levels, corresponding to a range of power-per-carrier values.

The results are shown in Table 3.3.3, in terms of active L-band carriers per beam. Clearly, the L-band capacity for mobile communications (30.5-32.5 dBW) is still small even for large spacecraft, if 10 years of life is required . However, reducing required EIRP provides a dramatic increase in capacity, with little change in required resources.

TABLE 3.3.3

SCENARIO II SPACECRAFT CAPACITIES

S/C CLASS	.235 STS			.27 STS		
EIRP (dBW)	ACTIVE CARRIERS/BEAM	MASS (kg)	POWER (W)	ACTIVE CARRIERS/BEAM	MASS (kg)	POWER (W)
13.6	104	322	1610	275	362	2195
21.5	50	320	1640	133	359	2233
26.5	22	320	1640	57	358	2254
28.5	15	320	1640	38	357	2259
30.5	10	320	1640	25	357	2263
32.5	6	320	1640	16	356	2265

3.4 Dual-Band Payload Resource Allocation

The proportion of spacecraft resources demanded by each payload of a dual-band design is a useful parameter for estimating the cost impact of implementing an additional payload. Although the definition of "resources" is somewhat subjective, a straightforward figure-of-merit is the product of payload mass and power.

The dual-band configurations addressed in this study contain a shared antenna reflector system. In this case, it can be argued that the allocation of reflector resources is the same as that for the balance of the payload mass and power. Subtracting the reflector mass from the total payload mass, the resource allocation for each payload is simply the mass-power product divided by the sum of the products for the two frequency bands. The results for Scenario I are shown in Table 3.4.1.

TABLE 3.4.1 SCENARIO I RESOURCE ALLOCATION

S/C CLASS	PAM-D2		31% STS HS393	
P/L Mass (kg)	310		366	
Reflector Mass (kg)	53		53	
Repeater Mass (kg)	257		313	
P/L Power (kW)	1.675		2.60	
BAND	UHF	L	UHF	L
Repeater Mass (kg)	145	112	145	168
P/L Power (kW)	1.162	0.513	1.162	1.438
Resources (Mass X Power)	168.5	57.5	168.5	241.6
Resource Fraction	.75	.25	.41	.59

In Scenario II, a variety of performance requirements are considered. However, the amount of resources used by the payload is insensitive to this variation, hence average values are used. The results are shown in Table 3.4.2.

TABLE 3.4.2

SCENARIO II RESOURCE ALLOCATION

S/C CLASS	.235 STS		.27 STS	
P/L Mass (kg)	320		358	
Reflector Mass (kg)	53		53	
Repeater Mass (kg)	267		305	
P/L Power (kW)	1.64		2.244	
BAND	UHF	L	UHF	L
Repeater Mass (kg)	145	122	145	160
P/L Power (kW)	1.162	0.478	1.162	1.082
Resources (Mass X Power)	168.5	58.3	168.5	173.1
Resource Fraction	.74	.26	.49	.51

4.0 SPACE SEGMENT COST

4.1 Program Cost Description

This section describes the estimation of space segment program costs for the various L-band MSAT system options. In order to justly compare costs with those of the baseline UHF system, the costing rationale is preserved from the MSAT Business Proposal, except that the launch of the Canadian satellite is delayed by one year relative to the U.S. satellite.

In brief, the price of the L-band spacecraft is estimated by comparison with the UHF spacecraft. Using a standard set of program cost components, a summary of capital costs is prepared for each configuration. The corresponding disbursements over program life are then calculated, to enable economic analysis to be performed.

Assumptions adopted for the costing exercise are listed in Table 4.1.1

TABLE 4.1.1 COSTING ASSUMPTIONS

1. 2 spacecraft: one Canadian, one U.S.
2. Joint procurement
3. Competitive, fixed price contract
4. Separate ownership and operation
5. Contract signature (kick-off) 3Q, 1986
6. STS launch
7. Canadian satellite launched 2Q, 1991
8. Quarterly payment schedule.

Table 4.1.2 is a description of all capital cost components used in this study, along with some of the quantities used in the calculations. A more detailed description of these costs is found in the MSAT Business Proposal, Appendix D. Spacecraft price estimation is discussed in section 4.2.

TABLE 4.1.2

SPACE SEGMENT CAPITAL COST COMPONENTS

COMPONENT	DEFINITIONS	CALCULATION
SPACECRAFT CONSTRUCTION	Supplier Price	Payments before Launch
INCENTIVE PAYMENTS	Nominal Performance	12% of total S/C Price
UPPER STAGE	Supplier Price	Standard Formula
LAUNCH VEHICLE	NASA STS Price	Standard Formula
LAUNCH SITE SUPPORT	Supplier Price, including integration performance	STS: 2M per launch
CAPITALIZED ENGINEERING	S/C Procurement and launch Manpower, Travel and Living.	
INSURANCE	Coverage of all capital costs (above)	10% of Capital costs
MISSION CONTROL	Control System Upgrade, Computer Equipment, Antennas	
SATELLITE OPERATIONS	Stationkeeping equipment and start-up engineering	Includes limited motion TT&C antenna in back-haul frequency band

4.2 Spacecraft Price Estimates

Analogous to the price estimation procedure adopted for the UHF configurations, the prices of the L-band spacecraft are calculated as increments to the prices of fixed service spacecraft. The prices are estimated in 4th quarter 1984 U.S. dollars (MUS'84), and converted to Canadian 3rd Quarter 1986 dollars (MCD'86) using an exchange rate of 1.30.

Scenario I prices are shown in Table 4.2.1, broken down between fixed-service price, payload increment, and total MSAT spacecraft price in MUS'84 and MCD'86. All prices are for 2 units purchased under one contract. Note that the incremental cost of the UHF payload (primarily due to the large reflectors) tends to decrease on large spacecraft, since these are priced to accommodate more expensive payloads.

TABLE 4.2.1 SCENARIO I SPACECRAFT PRICES

MUS'84 (MCD'86)

S/C CLASS	PAM-D	PAM-D2	.31 STS
* FSS Price (2)	95	110	130
PAYLOAD INCREMENT			
* 2 UHF	20	20	15
2 L-band	5	5	-
4 L-band	-	24	20
2 UHF/4 L-band	-	40	30
SPACECRAFT			
2 L-band	100 (146)	115 (168)	-
4 L-band	-	134 (196)	-
2 UHF/4L-band	-	150 (219)	160 (234)

* MSAT Business Proposal, Appendix D

In the dual-band cases, sharing of the reflectors is traded off against the added complexity of integrating two payloads with separate feed systems.

The scaling of incremental cost is further revealed in the dual-band estimates for Scenario II, shown in Table 4.2.2. Here, the effect of a larger spacecraft is to reduce the incremental cost, such that the total price increase is insignificant.

TABLE 4.2.2 SCENARIO II SPACECRAFT PRICES

MUS'84 (MCD'86)

S/C CLASS	.235 STS	.27 STS
FSS Price (2)	120	125
PAYLOAD INCREMENT		
2 UHF	15	14
4 L-band	10	9
2 UHF/4 L-band	25	23
SPACECRAFT		
2 UHF/4 L-band	145 (212)	148 (216)

Because the resource requirements are insensitive to the performance levels of the various Scenario II options for each spacecraft class, spacecraft prices are assumed to be constant.

4.3 Capital Cost Summaries

Based upon the assumptions and breakdown of section 4.1, and the spacecraft prices of section 4.2, program cost summaries were prepared for each implementation plan. Scenario I costs are listed in Tables 4.3.1 and 4.3.2, and Scenario II costs in Table 4.3.3. Appropriate UHF system costs are shown in Table 4.3.1 for comparison. Costs are quoted in MCD'86 for the Canadian share of a joint procurement of 2 spacecraft.

TABLE 4.3.1 PLAN 1 SPACE SEGMENT CAPITAL COSTS

COMPONENT	COSTS MCD' 3Q'86				
Configuration	*2-UHF	2-L	2-L	*4-UHF	4-L
Spacecraft Type	PAM-D	PAM-D	PAM-D2	PAM-D2	PAM-D2
Spacecraft Cost	84	73	84	102	98
Incentives (12%)	10	9	10	13	12
Upper Stage	11	9	11	13	11
Launch Vehicle	27	27	34	39	37
Launch Site Support	3	3	3	3	3
Capitalized Engineering	5	5	5	5	5
Insurance (10%)	14	13	15	17	17
Mission Control	5	3	3	5	3
Satellite Operations	4	4	4	4	4
Contingency (5%)	8	7	8	10	9
TOTAL	169	152	177	210	198

* MSAT Business Proposal, Appendix D

TABLE 4.3.2 PLAN 2 SPACE SEGMENT CAPITAL COSTS

COMPONENT	COSTS MCD' 3Q '86	
Configuration	2 UHF/4L	2 UHF/4L
Spacecraft Type	PAM-D2	HS 393
Spacecraft Cost	110	117
Incentives (12%)	13	14
Upper Stage	11	3
Launch Vehicle	40	38
Launch Site Support	3	3
Capitalized Engineering	5	5
Insurance (10%)	18	18
Mission Control	3	3
Satellite Operations	4	4
Contingency (5%)	10	10
TOTAL	216	214

A point to note in Table 4.3.1 involves upper stage costs. The real price of PAM upper stages decreases with time because the expected price increases more slowly than inflation. Since the L-band systems assume launch deferment relative to the UHF systems, the 1986 upper stage prices are slightly less.

In Table 4.3.3, concerning dual-band spacecraft of larger than PAM-D2 class, it is important to remember that the integral upper stages used in these configurations provide some cost advantage over the PAM-D2 stage. Furthermore, it is assumed that the upper stage price is insensitive to spacecraft size, over this limited range.

TABLE 4.3.3 SCENARIO II SPACE SEGMENT CAPITAL COSTS

COMPONENT	COSTS MCD'3Q'86	
Configuration	2 UHF/4L	2UHF/4L
Spacecraft Type	.235 STS	.27 STS
Spacecraft Cost	106	108
Incentives (12%)	13	13
Upper Stage	9	9
Launch Vehicle	38	44
Launch Site Support	3	3
Capitalized Engineering	5	5
Insurance (10%)	17	18
Mission Control	3	3
Satellite Operations	4	4
Contingency (5%)	10	10
TOTAL	207	216

4.4 Program Cost Disbursements

The disbursements of space segment program costs (cash flows) are provided as input to economic and financial analysis of the overall system. Typical payment schedules for spacecraft and launch costs, and typical cash outlay profiles for engineering costs, are used to provide a composite capital costs flow, on a quarterly basis, from contract signature (kick-off) to satellite commissioning, according to the schedule of Table 4.4.1. This schedule differs from that of the MSAT Business Proposal only in that the Canadian satellite is launched one year later than the American one.

All space hardware payments, except spacecraft, are inflated according to NASA - published inflation projections. Because the spacecraft price and payment schedule is fixed in the contract, the price is inflated only up to kick-off. Engineering costs are incurred in Canada, and therefore carry an average 6% inflation corresponding to the CPI escalation rate.

TABLE 4.4.1

MSAT IMPLEMENTATION SCHEDULE

EVENT	DATE
Kick-Off (Contract Signature)	3Q, 1986
First delivery	1Q, 1990
Launch	2Q, 1991
Commissioning	4Q, 1991

Cash flows for all cases discussed above are contained in Tables 4.4.2 to 4.4.8. All figures are in Canadian millions; the summary numbers are in MCD'86, while the cash flows are in real-year MCD.

(NOTE: See Tables 4.4.2 - 4.4.8 Appended)

5.0 SUMMARY & CONCLUSIONS

The overall impact of changing the MSAT communication frequency from UHF to L-band is a reduction in capacity, in terms of active carriers. Although mass is saved, due to smaller antennas required for equal coverage, the increase in path loss and decrease in HPA efficiency results in a net drop in carrier capacity on a given spacecraft.

This observation, however, applies only under the assumption that performance requirements remain the same as those adopted for the UHF system, described in the Business Proposal. If performance requirements are relaxed, by varying the user terminal capability, substantial improvements in capacity are realized.

Alternatively, implementing both UHF and L-band systems on common spacecraft could provide cost benefits, due to resource sharing. It is expected that the MSAT reflectors represent a significant component of the payload cost. Since these can operate at both frequencies, this major cost item will be incurred only once in a dual-band system.

Examination of space segment cost for each configuration shows that L-band systems tend to be less expensive, primarily due to lower antenna costs. However, these savings are generally accompanied by reduced system capacity.

Under the assumption that performance requirements are preserved from the Business Proposal (Scenario I), a comparison of capacity and cost for the three alternate implementation plans is as shown in Table 5.1.

TABLE 5.1 SCENARIO I CAPACITY AND COST

PLAN	BEAM CONFIGURATION	SPACECRAFT CLASS	CARRIER CAPACITY	SPACE SEGMENT COST (MCD '86)
1	2 UHF	PAM-D	180	169
	2 L-BAND	PAM-D	46	152
		PAM-D2	78	177
	4 UHF	PAM-D2	276	210
	4 L-BAND	PAM-D2	132	198
2	2 UHF/4 L-BAND	PAM D2	208	216
		HS 393	272	214
3	2 UHF, 2 L-BAND	2 x PAM-D	226	321
		or		
		1 x PAM-D		
		1 x PAM-D2	258	346
	4 UHF, 4 L-BAND	2 x PAM-D2	408	408

The cost impact of implementing a dual-band system rather than a single-band one is partly determined from the relative resource utilization by each frequency band.

An estimate of the resource allocation for the various dual-band configurations shows splits which favour UHF, on smaller spacecraft, and L-band on larger ones. A summary of these figures is shown in Table 5.2, for both Scenarios I and II.

TABLE 5.2 DUAL-BAND RESOURCE ALLOCATION

CONFIGURATION	PAM-D2	HS 393	.235 STS	.27 STS
UHF Resource Fraction	.75	.41	.74	.49
L-Band Resource Fraction	.25	.59	.26	.51

This information may be used, in conjunction with market and performance data, to assess the relative economics of providing L-band capacity in the space segment.

TABLE 4.4.2

2-BEAM L-BAND PAM-D
SPACE SEGMENT PROGRAM COSTS

<VERSION 31/05/85 D.SHOWALTER>

CAPITAL COSTS

CURRENCY $MCD 3Q 1986
EXCHANGE RATE 1.30

COMPONENT	TYPE	COST	DESCRIPTION
Spacecraft	MSAT2	73.0	Launched:1 Procured:2
Incentives		8.8	12.0% Of Spacecraft
Upper Stage	PAMD	9.4	GTO Mass: 1270.0kg
Launch Vehicle	STS	26.5	Cargo Mass:4619.8kg
Launch Site Supp.		2.9	$2MUS Per Launch (STS)
Cap. Engineering		5.0	Procurement: JOINT
Insurance		12.6	10.0% Of Above Costs
Mission Control		2.6	Operation: SEPARATE
Sat. Operations		3.7	Lifetime: 7.0yr
Contingency		7.2	5% Of Total
Total		151.7	

SCHEDULE

BASE DATE 4Q 1984
KICK-OFF DATE 3Q 1986

SPACECRAFT	DELIVERY	LAUNCH	EOL	STAGE COST
1	1Q 1990	2Q 1991	2Q 1998	14.5
2	3Q 1990	2Q 1991	2Q 1998	12.3

TABLE 4.4.2 (CONTD) 2-BEAM L-BAND PAM-D

Program Cost Disbursements PAGE 1

Dates (QUART)	3/1986	4/1986	1/1987	2/1987	3/1987	4/1987	1/1988	2/1988	3/1988	4/1988
Events	KICK									
Spacecraft	10.3	12.9	12.1	10.1	7.9	5.9	4.3	3.1	2.2	1.5
Incentives										
Upper Stage										1.7
Launch Vehicle									3.1	
Launch Site Supp										
Cap. Engineering	.2	.2	.2	.2	.2	.7	.2	.2	.2	.2
Insurance										
Mission Control									.2	.2
Sat. Operations										
Annual Totals	10.5	13.1	12.3	10.3	8.1	6.6	4.5	3.3	5.7	3.7

TABLE 4.4.2 (CONTD) 2-BEAM L-BAND PAM-D

Program Cost Disbursements PAGE 2

Dates (QUART)	1/1989	2/1989	3/1989	4/1989	1/1990	2/1990	3/1990	4/1990	1/1991	2/1991
Events					DELIVR					LAUNCH
Spacecraft	1.0	.7	.5	.3	.2					
Incentives										
Upper Stage	1.0	1.0	1.0	1.0	1.0	1.0	2.5	2.5	.9	.9
Launch Vehicle	3.2		5.6		5.8		8.2		8.5	
Launch Site Supp										3.2
Cap. Engineering	.3	.3	.3	.3	.3	.3	.3	.3	.3	1.0
Insurance										14.0
Mission Control	.2	.3	.3	.3	.3	.3	.3	.3	.3	.3
Sat. Operations			.6	.6	.6	.6	.6	.6	.6	.6
Annual Totals	5.7	2.2	8.2	2.4	8.2	2.1	11.8	3.6	10.6	20.0

TABLE 4.4.2 (CONTD) 2-BEAM L-BAND PAM-D

Program Cost Disbursements PAGE 3

Dates (QUART)	3/1991	4/1991	4/1991
Events		COMMIS	TOTALS
Spacecraft			73.0
Incentives		8.8	8.8
Upper Stage			14.5
Launch Vehicle			34.4
Launch Site Supp			3.2
Cap. Engineering			6.2
Insurance			14.0
Mission Control			3.1
Sat. Operations			4.7
Annual Totals		8.8	162.0
Contingency (5%)			8.1
TOTAL			170.1

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                           TABLE 4.4.3
                           -----------
                        2-BEAM L-BAND PAM-D2
                     SPACE SEGMENT PROGRAM COSTS
================================================================================
                  <VERSION 31/05/85  D.SHOWALTER>

                          CAPITAL COSTS
                          -------------
                       CURRENCY $MCD 3Q 1986
                       EXCHANGE RATE    1.30

     COMPONENT          TYPE       COST          DESCRIPTION
    ------------------------------------------------------------------
    Spacecraft          MSAT2      84.0     Launched:1   Procured:2
    Incentives                     10.1     12.0% Of Spacecraft
    Upper Stage         PAMD2      11.3     GTO Mass:   1500.0kg
    Launch Vehicle      STS        33.9     Cargo Mass:6073.0kg
    Launch Site Supp.               2.9     $2MUS Per Launch (STS)
    Cap. Engineering                5.0     Procurement: JOINT
    Insurance                      14.7     10.0% Of Above Costs
    Mission Control                 2.6     Operation: SEPARATE
    Sat. Operations                 3.7     Lifetime:   7.0yr
    Contingency                     8.4     5% Of Total
    ------------------------------------------------------------------
    Total                         176.6


                            SCHEDULE
                            --------
                       BASE DATE        4Q 1984
                       KICK-OFF DATE    3Q 1986

    SPACECRAFT   DELIVERY     LAUNCH        EOL        STAGE COST
    ------------------------------------------------------------------
        1        1Q 1990     2Q 1991      2Q 1998        17.5
        2        3Q 1990     2Q 1991      2Q 1998        14.7

================================================================================
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TABLE 4.4.3 (CONTD) 2-BEAM L-BAND PAM-D2

Program Cost Disbursements PAGE 1

Dates (QUART)	3/1986	4/1986	1/1987	2/1987	3/1987	4/1987	1/1988	2/1988	3/1988	4/1988
Events	KICK									
Spacecraft	11.9	14.9	13.9	11.6	9.1	6.8	5.0	3.5	2.5	1.7
Incentives										
Upper Stage									.4	1.8
Launch Vehicle									3.9	
Launch Site Supp										
Cap. Engineering	.2	.2	.2	.2	.2	.7	.2	.2	.2	.2
Insurance										
Mission Control									.2	.2
Sat. Operations										
Annual Totals	12.1	15.1	14.1	11.8	9.3	7.5	5.2	3.8	7.2	4.0

TABLE 4.4.3 (CONTD) 2-BEAM L-BAND PAM-D2

Program Cost Disbursements PAGE 2

Dates (QUART)	1/1989	2/1989	3/1989	4/1989	1/1990	2/1990	3/1990	4/1990	1/1991	2/1991
Events					DELIVR					LAUNCH
Spacecraft	1.2	.8	.5	.4	.2					
Incentives										
Upper Stage	1.2	1.2	1.2	1.2	1.2	1.2	3.0	3.0	1.1	1.1
Launch Vehicle	4.1		7.2		7.5		10.5		10.9	
Launch Site Supp										3.2
Cap. Engineering	.3	.3	.3	.3	.3	.3	.3	.3	.3	1.0
Insurance										16.5
Mission Control	.2	.3	.3	.3	.3	.3	.3	.3	.3	.3
Sat. Operations			.6	.6	.6	.6	.6	.6	.6	.6
Annual Totals	7.0	2.5	10.0	2.7	10.0	2.3	14.6	4.1	13.1	22.7

TABLE 4.4.3 (CONTD) 2-BEAM L-BAND PAM-D2

Program Cost Disbursements PAGE 3

Dates (QUART)	3/1991	4/1991	4/1991
Events		COMMIS	TOTALS
Spacecraft			84.0
Incentives		10.1	10.1
Upper Stage			17.5
Launch Vehicle			44.1
Launch Site Supp			3.2
Cap. Engineering			6.2
Insurance			16.5
Mission Control			3.1
Sat. Operations			4.7
Annual Totals		10.1	189.4
Contingency (5%)			9.5
TOTAL			198.9

TABLE 4.4.4

4-BEAM L-BAND PAM-D2
SPACE SEGMENT PROGRAM COSTS

<VERSION 31/05/85 D.SHOWALTER>

CAPITAL COSTS

CURRENCY $MCD 3Q 1986
EXCHANGE RATE 1.30

COMPONENT	TYPE	COST	DESCRIPTION
Spacecraft	MSAT4	98.0	Launched:1 Procured:2
Incentives		11.8	12.0% Of Spacecraft
Upper Stage	PAMD2	11.4	GTO Mass: 1700.0kg
Launch Vehicle	STS	36.7	Cargo Mass:6620.3kg
Launch Site Supp.		2.9	$2MUS Per Launch (STS)
Cap. Engineering		5.0	Procurement: JOINT
Insurance		16.6	10.0% Of Above Costs
Mission Control		2.6	Operation: SEPARATE
Sat. Operations		3.7	Lifetime: 7.0yr
Contingency		9.4	5% Of Total
Total		198.1	

SCHEDULE

BASE DATE 4Q 1984
KICK-OFF DATE 3Q 1986

SPACECRAFT	DELIVERY	LAUNCH	EOL	STAGE COST
1	1Q 1990	2Q 1991	2Q 1998	17.7
2	3Q 1990	2Q 1991	2Q 1998	14.9

TABLE 4.4.4 (CONTD) 4-BEAM L-BAND PAM-D2

Program Cost Disbursements PAGE 1

Dates (QUART)	3/1986	4/1986	1/1987	2/1987	3/1987	4/1987	1/1988	2/1988	3/1988	4/1988
Events	KICK									
Spacecraft	13.9	17.3	16.2	13.5	10.6	7.9	5.8	4.1	2.9	2.0
Incentives										
Upper Stage									.4	1.8
Launch Vehicle									4.2	
Launch Site Supp										
Cap. Engineering	.2	.2	.2	.2	.2	.7	.2	.2	.2	.2
Insurance										
Mission Control									.2	.2
Sat. Operations										
Annual Totals	14.1	17.5	16.5	13.8	10.8	8.6	6.0	4.4	8.0	4.3

TABLE 4.4.4 (CONTD) 4-BEAM L-BAND PAM-D2

Program Cost Disbursements PAGE 2

Dates (QUART)	1/1989	2/1989	3/1989	4/1989	1/1990	2/1990	3/1990	4/1990	1/1991	2/1991
Events					DELIVR					LAUNCH
Spacecraft	1.4	.9	.6	.4	.3					
Incentives										
Upper Stage	1.2	1.2	1.2	1.2	1.2	1.2	3.0	3.0	1.1	1.1
Launch Vehicle	4.4		7.8		8.1		11.4		11.8	
Launch Site Supp										3.2
Cap. Engineering	.3	.3	.3	.3	.3	.3	.3	.3	.3	1.0
Insurance										18.5
Mission Control	.2	.3	.3	.3	.3	.3	.3	.3	.3	.3
Sat. Operations			.6	.6	.6	.6	.6	.6	.6	.6
Annual Totals	7.5	2.7	10.7	2.8	10.7	2.4	15.5	4.2	14.0	24.6

TABLE 4.4.4 (CONTD) 4-BEAM L-BAND PAM-D2

Program Cost Disbursements PAGE 3

Dates (QUART)	3/1991	4/1991	4/1991
Events		COMMIS	TOTALS
Spacecraft			98.0
Incentives		11.8	11.8
Upper Stage			17.7
Launch Vehicle			47.7
Launch Site Supp			3.2
Cap. Engineering			6.2
Insurance			18.5
Mission Control			3.1
Sat. Operations			4.7
Annual Totals		11.8	210.9
Contingency (5%)			10.5
TOTAL			221.4

TABLE 4.4.5

2UHF/4L-BAND PAM-D2
SPACE SEGMENT PROGRAM COSTS

<VERSION 31/05/85 D.SHOWALTER>

CAPITAL COSTS

CURRENCY $MCD 3Q 1986
EXCHANGE RATE 1.30

COMPONENT	TYPE	COST	DESCRIPTION
Spacecraft	MSAT4	109.5	Launched:1 Procured:2
Incentives		13.1	12.0% Of Spacecraft
Upper Stage	PAMD2	11.4	GTO Mass: 1900.0kg
Launch Vehicle	STS	39.5	Cargo Mass:7167.6kg
Launch Site Supp.		2.9	$2MUS Per Launch (STS)
Cap. Engineering		5.0	Procurement: JOINT
Insurance		18.2	10.0% Of Above Costs
Mission Control		2.6	Operation: SEPARATE
Sat. Operations		3.7	Lifetime: 7.0yr
Contingency		10.3	5% Of Total
Total		216.2	

SCHEDULE

BASE DATE 4Q 1984
KICK-OFF DATE 3Q 1986

SPACECRAFT	DELIVERY	LAUNCH	EOL	STAGE COST
1	1Q 1990	2Q 1991	2Q 1998	17.7
2	3Q 1990	2Q 1991	2Q 1998	14.9

TABLE 4.4.5 (CONTD) 2UHF/4L-BAND PAM-D2

Program Cost Disbursements PAGE 1

Dates (QUART)	3/1986	4/1986	1/1987	2/1987	3/1987	4/1987	1/1988	2/1988	3/1988	4/1988
Events	KICK									
Spacecraft	15.5	19.4	18.1	15.1	11.8	8.9	6.5	4.6	3.2	2.3
Incentives										
Upper Stage									.4	1.8
Launch Vehicle									4.6	
Launch Site Supp										
Cap. Engineering	.2	.2	.2	.2	.2	.7	.2	.2	.2	.2
Insurance										
Mission Control									.2	.2
Sat. Operations										
Annual Totals	15.7	19.6	18.4	15.4	12.0	9.6	6.7	4.9	8.7	4.5

TABLE 4.4.5 (CONTD) 2UHF/4L-BAND PAM-D2

Program Cost Disbursements PAGE 2

Dates (QUART)	1/1989	2/1989	3/1989	4/1989	1/1990	2/1990	3/1990	4/1990	1/1991	2/1991
Events					DELIVR					LAUNCH
Spacecraft	1.5	1.1	.7	.5	.3					
Incentives										
Upper Stage	1.2	1.2	1.2	1.2	1.2	1.2	3.0	3.0	1.1	1.1
Launch Vehicle	4.7		8.4		8.7		12.2		12.7	
Launch Site Supp										3.2
Cap. Engineering	.3	.3	.3	.3	.3	.3	.3	.3	.3	1.0
Insurance										20.1
Mission Control	.2	.3	.3	.3	.3	.3	.3	.3	.3	.3
Sat. Operations			.6	.6	.6	.6	.6	.6	.6	.6
Annual Totals	8.0	2.8	11.4	2.8	11.4	2.4	16.4	4.2	14.9	26.3

TABLE 4.4.5 (CONTD) 2UHF/4L-BAND PAM-D2

Program Cost Disbursements PAGE 3

Dates (QUART)	3/1991	4/1991	4/1991
Events		COMMIS	TOTALS
Spacecraft			109.5
Incentives		13.1	13.1
Upper Stage			17.7
Launch Vehicle			51.3
Launch Site Supp			3.2
Cap. Engineering			6.2
Insurance			20.1
Mission Control			3.1
Sat. Operations			4.7
Annual Totals		13.1	229.0
Contingency (5%)			11.5
TOTAL			240.5

TABLE 4.4.6 (CONTD) 2UHF/4L-BAND HS393

Program Cost Disbursements PAGE 2

Dates (QUART)	1/1989	2/1989	3/1989	4/1989	1/1990	2/1990	3/1990	4/1990	1/1991	2/1991
Events					DELIVR					LAUNCH
Spacecraft	1.7	1.1	.8	.5	.3					
Incentives										
Upper Stage	.3	.3	.3	.3	.3	.3	.7	.7	.2	.2
Launch Vehicle	4.5		8.0		8.3		11.7		12.2	
Launch Site Supp										3.2
Cap. Engineering	.3	.3	.3	.3	.3	.3	.3	.3	.3	1.0
Insurance										19.4
Mission Control	.2	.3	.3	.3	.3	.3	.3	.3	.3	.3
Sat. Operations			.6	.6	.6	.6	.6	.6	.6	.6
Annual Totals	7.0	1.9	10.1	1.9	10.1	1.4	13.6	1.9	13.6	24.7

TABLE 4.4.6 (CONTD) 2UHF/4L-BAND HS393

Program Cost Disbursements PAGE 3

Dates (QUART)	3/1991	4/1991	4/1991
Events		COMMIS	TOTALS
Spacecraft			117.0
Incentives		14.0	14.0
Upper Stage			4.1
Launch Vehicle			49.2
Launch Site Supp			3.2
Cap. Engineering			6.2
Insurance			19.4
Mission Control			3.1
Sat. Operations			4.7
Annual Totals		14.0	221.0
Contingency (5%)			11.0
TOTAL			232.0

```
                              TABLE 4.4.7
                              -----------
                        DUAL-BAND SC II .235 STS
                      SPACE SEGMENT PROGRAM COSTS
=============================================================================
                     <VERSION 31/05/85   D.SHOWALTER>

                             CAPITAL COSTS
                             -------------
                         CURRENCY $MCD 3Q 1986
                         EXCHANGE RATE    1.30

   COMPONENT            TYPE      COST          DESCRIPTION
   ------------------------------------------------------------------
   Spacecraft           MSAT4    106.0    Launched:1   Procured:2
   Incentives                     12.7    12.0% Of Spacecraft
   Upper Stage          SCOTS      8.7    GTO Mass:   2090.0kg
   Launch Vehicle       STS       38.3    Cargo Mass:6931.2kg
   Launch Site Supp.               2.9    $2MUS Per Launch (STS)
   Cap. Engineering                5.0    Procurement: JOINT
   Insurance                      17.4    10.0% Of Above Costs
   Mission Control                 2.6    Operation: SEPARATE
   Sat. Operations                 3.7    Lifetime: 10.0yr
   Contingency                     9.9    5% Of Total
   ------------------------------------------------------------------
   Total                         207.2


                               SCHEDULE
                               --------
                         BASE DATE        4Q 1984
                         KICK-OFF DATE    3Q 1986

   SPACECRAFT   DELIVERY      LAUNCH          EOL      STAGE COST
   ------------------------------------------------------------------
       1        1Q 1990      2Q 1991      2Q 2001         12.4
       2        3Q 1990      2Q 1991      2Q 2001         12.4

=============================================================================
```

TABLE 4.4.7 (CONTD) DUAL-BAND SC II .235 STS

Program Cost Disbursements PAGE 1

Dates (QUART)	3/1986	4/1986	1/1987	2/1987	3/1987	4/1987	1/1988	2/1988	3/1988	4/1988
Events	KICK									
Spacecraft	15.0	18.7	17.6	14.6	11.4	8.6	6.3	4.5	3.1	2.2
Incentives										
Upper Stage										1.5
Launch Vehicle									4.4	
Launch Site Supp										
Cap. Engineering	.2	.2	.2	.2	.2	.7	.2	.2	.2	.2
Insurance										
Mission Control									.2	.2
Sat. Operations										
Annual Totals	15.2	19.0	17.8	14.9	11.7	9.3	6.5	4.7	8.1	4.2

TABLE 4.4.7 (CONTD) DUAL-BAND SC II .235 STS

Program Cost Disbursements PAGE 2

Dates (QUART)	1/1989	2/1989	3/1989	4/1989	1/1990	2/1990	3/1990	4/1990	1/1991	2/1991
Events					DELIVR					LAUNCH
Spacecraft	1.5	1.0	.7	.5	.3					
Incentives										
Upper Stage	.9	.9	.9	.9	.9	.9	2.1	2.1	.7	.7
Launch Vehicle	4.6		8.1		8.4		11.9		12.3	
Launch Site Supp										3.2
Cap. Engineering	.3	.3	.3	.3	.3	.3	.3	.3	.3	1.0
Insurance										19.0
Mission Control	.2	.3	.3	.3	.3	.3	.3	.3	.3	.3
Sat. Operations			.6	.6	.6	.6	.6	.6	.6	.6
Annual Totals	7.5	2.4	10.8	2.4	10.7	2.0	15.1	3.3	14.2	24.9

TABLE 4.4.7 (CONTD) DUAL-BAND SC II .235 STS

Program Cost Disbursements PAGE 3

Dates (QUART)	3/1991	4/1991	4/1991
Events		COMMIS	TOTALS
Spacecraft			106.0
Incentives		12.7	12.7
Upper Stage			12.4
Launch Vehicle			49.8
Launch Site Supp			3.2
Cap. Engineering			6.2
Insurance			19.0
Mission Control			3.1
Sat. Operations			4.7
Annual Totals		12.7	217.2
Contingency (5%)			10.9
TOTAL			228.0

TABLE 4.4.8

DUAL-BAND SC II .27 STS
SPACE SEGMENT PROGRAM COSTS

<VERSION 31/05/85 D.SHOWALTER>

CAPITAL COSTS

CURRENCY $MCD 3Q 1986
EXCHANGE RATE 1.30

COMPONENT	TYPE	COST	DESCRIPTION
Spacecraft	MSAT4	108.0	Launched:1 Procured:2
Incentives		13.0	12.0% Of Spacecraft
Upper Stage	SCOTS	8.7	GTO Mass: 2510.0kg
Launch Vehicle	STS	44.0	Cargo Mass:8043.5kg
Launch Site Supp.		2.9	$2MUS Per Launch (STS)
Cap. Engineering		5.0	Procurement: JOINT
Insurance		18.2	10.0% Of Above Costs
Mission Control		2.6	Operation: SEPARATE
Sat. Operations		3.7	Lifetime: 10.0yr
Contingency		10.3	5% Of Total
Total		216.3	

SCHEDULE

BASE DATE 4Q 1984
KICK-OFF DATE 3Q 1986

SPACECRAFT	DELIVERY	LAUNCH	EOL	STAGE COST
1	1Q 1990	2Q 1991	2Q 2001	12.4
2	3Q 1990	2Q 1991	2Q 2001	12.4

TABLE 4.4.8 (CONTD) DUAL-BAND SC II .27 STS

Program Cost Disbursements PAGE 1

Dates (QUART)	3/1986	4/1986	1/1987	2/1987	3/1987	4/1987	1/1988	2/1988	3/1988	4/1988
Events	KICK									
Spacecraft	15.3	19.1	17.9	14.9	11.7	8.7	6.4	4.6	3.2	2.2
Incentives										
Upper Stage										1.5
Launch Vehicle									5.1	
Launch Site Supp										
Cap. Engineering	.2	.2	.2	.2	.2	.7	.2	.2	.2	.2
Insurance										
Mission Control									.2	.2
Sat. Operations										
Annual Totals	15.5	19.3	18.1	15.1	11.9	9.5	6.6	4.8	8.8	4.2

TABLE 4.4.8 (CONTD) DUAL-BAND SC II .27 STS

Program Cost Disbursements PAGE 2

Dates (QUART)	1/1989	2/1989	3/1989	4/1989	1/1990	2/1990	3/1990	4/1990	1/1991	2/1991
Events					DELIVR					LAUNCH
Spacecraft	1.5	1.0	.7	.5	.3					
Incentives										
Upper Stage	.9	.9	.9	.9	.9	.9	2.1	2.1	.7	.7
Launch Vehicle	5.3		9.3		9.7		13.6		14.2	
Launch Site Supp										3.2
Cap. Engineering	.3	.3	.3	.3	.3	.3	.3	.3	.3	1.0
Insurance										20.0
Mission Control	.2	.3	.3	.3	.3	.3	.3	.3	.3	.3
Sat. Operations			.6	.6	.6	.6	.6	.6	.6	.6
Annual Totals	8.2	2.4	12.0	2.4	12.0	2.0	16.9	3.3	16.1	25.9

TABLE 4.4.8 (CONTD) DUAL-BAND SC II .27 STS

Program Cost Disbursements PAGE 3

Dates (QUART)	3/1991	4/1991	4/1991
Events		COMMIS	TOTALS
Spacecraft			108.0
Incentives		13.0	13.0
Upper Stage			12.4
Launch Vehicle			57.1
Launch Site Supp			3.2
Cap. Engineering			6.2
Insurance			20.0
Mission Control			3.1
Sat. Operations			4.7
Annual Totals		13.0	227.8
Contingency (5%)			11.4
TOTAL			239.2