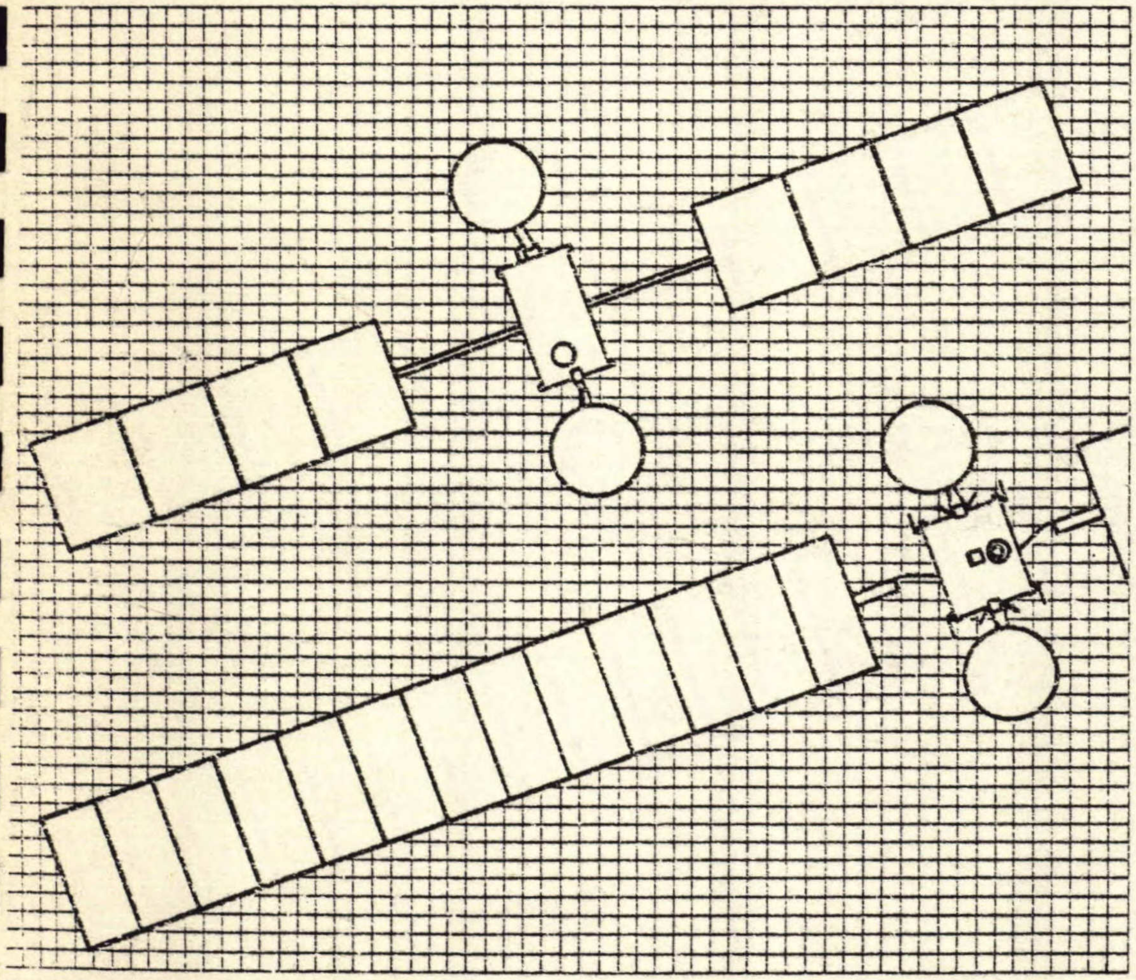
DIRECT BROADCASTING SATELLITE SYSTEM CONCEPTS



FINAL REPORT

Spar Aerospace Limited

Space & Electronics Group

Satellite & Aerospace Systems Division

Submitted to:

Department of Communications, Ottawa

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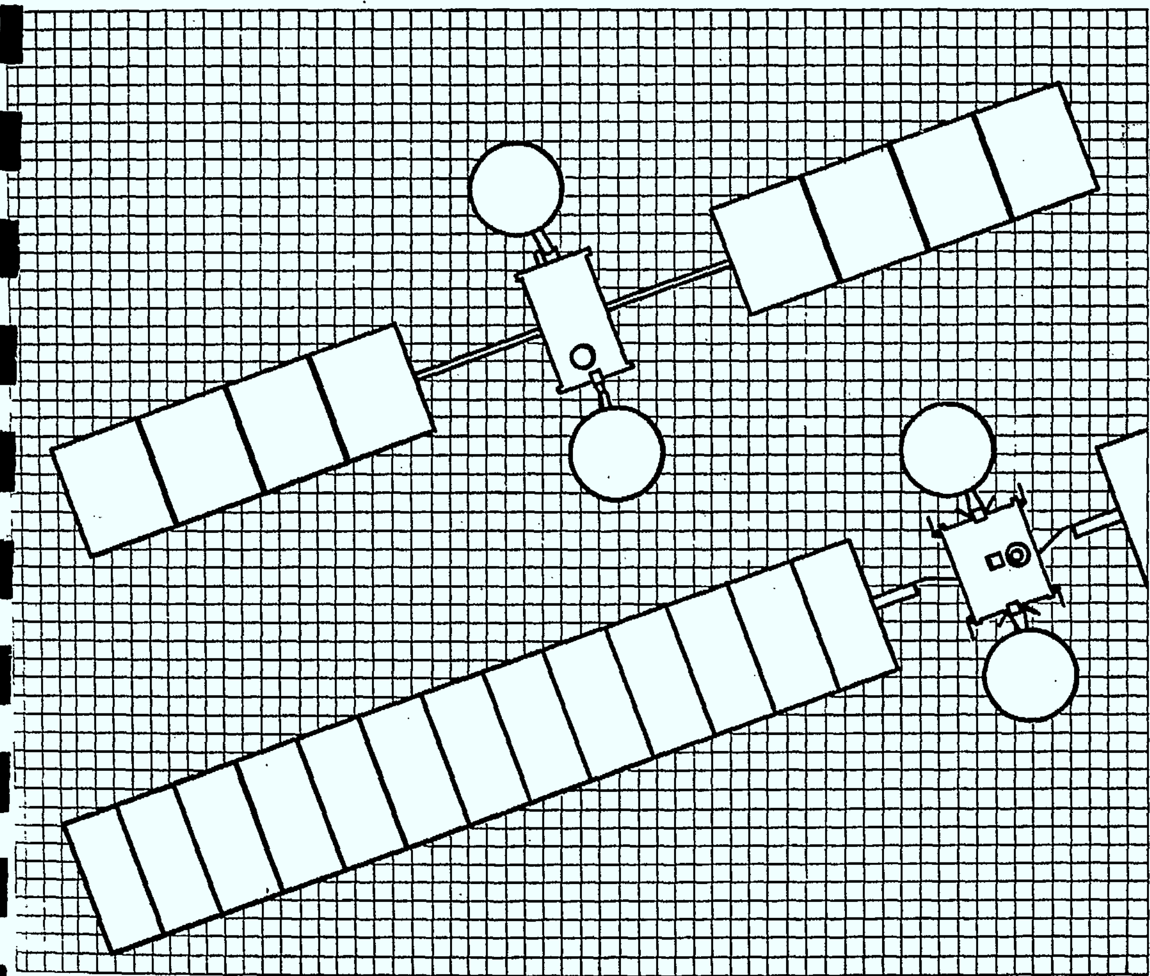

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2. CANADIAN

DIRECT BROADCASTING SATELLITE

SYSTEMS CONCEPT STUDY

FINAL REPORT

RML-009-82-65

Prepared for: The Department of Communications
Ottawa, Canada

Contract Serial Number: OST81-00167

DSS File Number: 15ST 36100-1-0288

SPAR Project Number: 5009-A

November 23, 1982

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Gouvernement du Canada
Ministère des Communications

DOC CONTRACTOR REPORT DOC-CR-SP -82-065

DEPARTMENT OF COMMUNICATIONS - OTTAWA - CANADA

SPACE PROGRAM

TITLE: DBS SATELLITE SYSTEM CONCEPTS STUDY

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DEPARTMENT OF SUPPLY AND SERVICES CONTRACT NO: OST 81-00167

DOC SCIENTIFIC AUTHORITY: H.R. RAINE
1981/82

CLASSIFICATION:

Canada

DBS SYSTEM CONCEPTS STUDY

1. INTRODUCTION AND SUMMARY

This study is complementary to a Direct Broadcasting Satellite System Modelling Study (Ref.) performed by SPAR for the Department of Communication in 1981.

In that study a range of possible high and low EIRP systems were examined for feasibility and cost.

System Parameters

This study examines in a more detail a range of system models differing mainly in the use of 2 or 3 orbit locations rather than 1 or 2 orbit locations previously considered. A phased increase in system capacity from an initial 8 channels per beam to about double this amount was also given as a criteria for system model selection.

Coverage and Polarization

To more accurately define antenna design requirements, sets of polygons were provided by DOC, representing both 6 and 4 beam possible coverage requirements. Based on current DOC studies of circular and linear polarization for direct broadcasting, circular polarization was selected for both up and down link antennas.

Within the communications subsystem, studies were performed to establish antenna and repeater configurations for each system model considered, supported by weight, power, and performance budgets.

TWTAs

A survey of medium to high power travelling wave tubes (TWTs) and their associated electronic power conditioners (EPCs) was conducted to determine technical characteristics as well as cost and availability. Three suppliers AEG Telefunken, Thompson CSF and Hughes appear capable, and interested in providing suitable TWTs, however the source of suitable EPCs is not clear in all cases.

Antenna Concepts

Transmit antennas using linear to circular polarization (CP) conversion at the reflector surface were a novel feature resulting from the antenna study. This spatial polarizer approach holds promise of achieving circular polarization purity superior to current multi horn shaped beam antennas which use polarizers in each individual horn. The use of linearly polarized feed horns permitted by this approach is believed to simplify the antenna design and testing program as it can draw directly on SPARs experience with linearly polarized multihorn antennas.

Dual mode antennas which are more difficult to design,and sacrifice gain relative to single mode antennas, were selected on the basis of system studies. These studies show that, for up to 6 channels per beam such as for European and US DBS systems, a single mode antenna was optimium while for 8 channels per beam or beyond, as required by this study, dual mode was optimium.

Ref. 1 Direct Broadcast System Modelling Study June 81
DSS Contract # 21st 36100-0-0866
Serial # 0ST80-00134

System Models Studied

Although the study required consideration of 4 and 6 beam coverage from only 2 orbit locations, it became clear during the system model selection process, that 6 beams from 2 orbit locations was a poor option, limited in growth due to frequency plan considerations, and impracticaly difficult to implement as a transitional system to a 3 orbit 6 beam system. The study subsequently dropped the 2 orbit 6 beam models from further consideration and looked only at the two discrete cases of, 2 orbit 4 beams, and 3 orbit 6 beams.

2 orbit 4 beam Selected System

The spacecraft which match the respective models have a close functional resemblance to each other as they each provide two beams oppositely polarized, service adjacent coverage areas.

For the 2 orbit 4 beam case, the selected system model employs 2 operating satellites, one at 100°W providing 2 transmit beams of 8 channels each for Eastern Canada coverage, and one at 130°W providing 2 beams of 8 channels each for Western Canada coverage. A third satellite acts as an orbiting spare for both satellites, but could also provide additional capacity for either East or West coverage, but not both simultaneously. This capacity would have to be preempted in the event of a catastrophic failure of either operating satellite. The system capacity can be doubled to 64 channels (16 per coverage area) by launching 2 additional satellites, one East and one West for a total of 4 operating. One orbiting spare satellite in conjunction with satellite subsystem redundancy is estimated to provide an adequate level of channel availability. All satellites are of identical design which requires the carriage of additional channel filters and requires a transmit antenna which can provide the required beam coverage from either orbit location (reconfigurable). The receive beams cover all of Canada on both senses of polarization.

3 orbit 6 beam Selected System

For the 3 orbit 6 beam case, the selected system model employs 3 operating satellites, each providing 2 oppositely polarized transmit beams of 8 channels each corresponding to East, Central, or Western coverage. A fourth satellite acts as an orbiting spare, or could provide additional capacity for the beam coverage areas corresponding to one of the three assigned orbit locations. The system capacity can be doubled to 96 channels (16 per beam) from an initial 48 channel (8 per beam) by launching 3 additional spacecraft, one at each orbit location. A system of 6 operating satellites is estimated to require 2 spare satellites to maintain an adequate level of channel availability. As in the 4 beam case, all operating and spare satellites are assumed identical. The transmit antenna must be adaptable in orbit to any one of the three coverage requirements, and the repeater must provide the additional channel filters and switching to accommodate the different channel assignment corresponding to each orbit location.

The smaller individual angular sizes of the 6 beams relative to the 4 beams requires less prime power per channel from the spacecraft. This can either be translated into more channels per beam for a given launcher/spacecraft size, or into a smaller launcher/spacecraft size for the minimum 8 channel per beam requirement. In either case the result is a modest reduction in cost per channel for the six beam system. This cost advantage is more than offset by the 33% increase in the number of spacecraft required to implement the initial system; 3 operating plus 1 spare for the 6 beam system versus 2 operating plus 1 spare for the 4 beam system (4 total vs 3 total).

To establish a base for costing of both high and low EIRP systems, spacecraft buses were chosen to match the power and weight demands of the corresponding 16 channel communications payloads.

HIGH EIRP
Payload
Weight and Power

In the high EIRP category, the payload power and weight requirements of up to 6.5 Kw and 350 Kg can be met within the design envelop of the BAe LSAT communications satellite bus. No other spacecraft constructor is known to have a bus of this capability in active development. By using the LSAT bus at the upper limit of its capability, it is believed that the cost effectiveness of the spacecraft should be shown to its best advantage. As LSAT was conceived primarily for various high power and weight communications missions, it can accommodate the required antennas and high power components with modest changes to the bus. Although the basic LSAT is designed to match the Ariane launcher which inserts the spacecraft into geosynchronous transfer orbit, it was considered prudent to consider a STS (shuttle) launch into low earth orbit as well. There is however, no commitment at this time to develop the necessary perigee motor and shuttle attachment to put the s/c in geosynchronous transfer orbit. The stowed configuration of the relatively conventional high EIRP spacecraft does however respect the envelop constraints of both a dedicated Ariane launch and a horizontal berth in the shuttle bay although the details of attachment and perigee motor are not available.

Bus selection

Spacecraft

Configuration

Low EIRP
Payload Weight
and Power

For the selected low EIRP system model there are several spacecraft bus candidates either committed or in the planning stage. The payload power and weight requirements of up to 2.7 Kw and 240 Kg could be met by the LSAT bus, but with a cost penalty because of under-utilization. The Eurosatellite TV SAT/TDF-1 is also a committed spacecraft program with DBS payload capabilities in the required range. The Hughes Intelsat VI spacecraft bus is a possibility but no decision has been made by Hughes to compete for the DBS market with this design. RCA Americom has submitted a filing to FCC for permission to construct DBS Satellites in the payload power and weight range of interest.

Bus Candidates

As the market for DBS develops, both in the USA and elsewhere, spacecraft constructors such as TRW, AeroFord and GE will undoubtedly offer competitive designs in this payload range. As the 3 axis spacecraft is considered the leading competitor for the DBS market, and because of RCAs record for cost effective design, their bus concept was selected (as representative of the genre) for this configuration study.

Bus Selection

Spacecraft Configuration

The resulting stowed configuration is compatible with a vertical mounting position in the shuttle bay, using a liquid perigee motor concept that is however not part of any committed program. Although the s/c weight requirements are marginally beyond the PAM A perigee motor capability, it is still considered a possibility for a horizontal position in the shuttle, albeit with increased launch costs. The stowed s/c configuration is also within the envelop of both upper and lower positions for a shared Ariane IV launch. As the s/c requires just over half of the launcher capability, a launch companion with complementary weight requirements would have to be found.

2 Satellite Launch

The deployed configuration for both high and low EIRP s/c are very similar and use essentially the same antenna concepts in either 6 beam or 4 beam versions.

NB

2. System Modelling

To establish the feasibility of various sytem implementations, frequency and polarization plans were produced as well as communications subsystem block diagrams. In this way, system level aspects of interference, repeater redundancy, and spacecraft replenishment could be determined, and used as part of the ultimate screening and selection process. For the parameters given, sets of communications payload weight and power budgets were derived which were subsequently matched to available spacecraft/launcher capabilities.

2.1 Evolution of DBS Models

The combination of system parameters (models) to be studied for both high and low EIRP systems are shown as solid lines in the study option tree Fig. 2.1-1. Coverage areas for both 4 beam and 6 beam options were defined by polygons supplied by DOC at the beginning of the study. Two orbit locations, 100^{o}W and 130^{o}W, were also defined although it was recognized that these were representative and not final assignments. The number of 8 channels per beam was stated as the minimum acceptable size of an initial DBS system, with a growth capability to double this number by the launch of additional spacecraft.

An assumption of the study was that all spacecraft in a proposed implementation plan should be identical. The main implication of this assumption is that each spacecraft must carry full sets of multiplexing filters, switches and adaptable antennas, so that any spacecraft can operate in either assigned location. It is conceivable that limited interchangeability might be acceptable initially, for example, only the later spacecraft used to expand the system would be designed for full interchangeability. During the system modelling phase of the study, as reported later in this section, it became clear that the 2 orbit 6 beam models could not meet the growth re-requirement because of the frequency plan limitations, and it also proved intractable as a transitional system to a 3 orbit 6 beam system. The 2 orbit 6 beam models were thus deleted from further consideration, by agreement with DOC, and 3 orbit 6 beam models were introduced as shown by the dotted lines in Fig. 2.1-1. Additional system models which provide greater initial and ultimate channel capacity were studied briefly. These systems, giving 9 or 10 channels per beam initially and 18 or 20 channels per beam ultimately, correspond to 36 and 40 channel frequency plans. Such plans appear acceptable on a systems basis and may lead to more efficient use of bus power and weight capabilities, and the possible use of spare channels rather than switched redundancy to achieve reliability. This technique is described more fully in section 3.4.

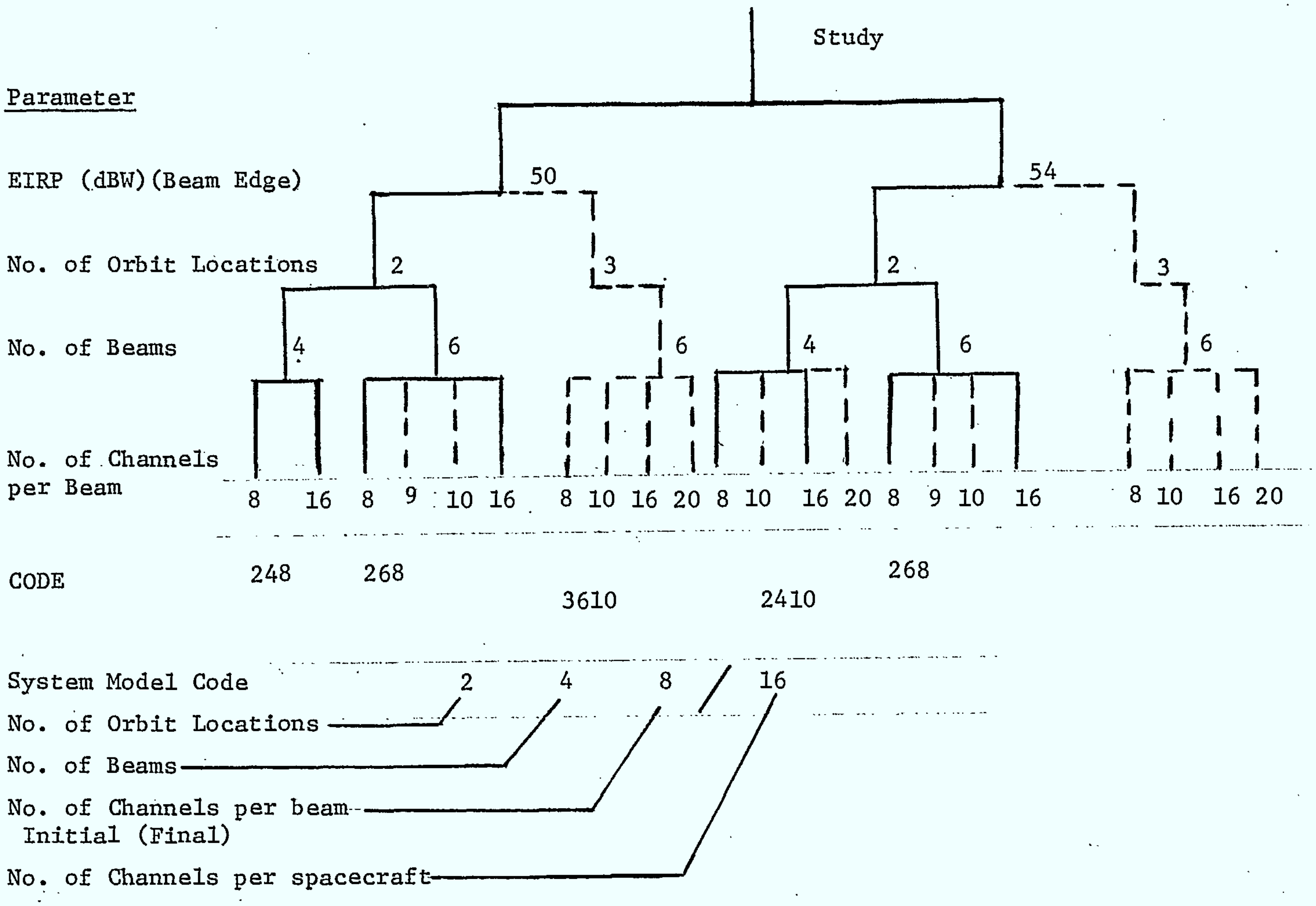


FIGURE 2.1-1 SYSTEMS MODELS CONSIDERED

Original SOW

Developed during Study

2.2. Selection of System Parameters and Models

2.2.1 4 Beam and 6 Beam Systems

Assuming the block assignment method of allocating DBS orbit and spectrum resources, Canada is assigned between 2 and 6 orbit locations and the full 500 MHz spectrum at each location. The maximum number of channels in a plan is not greater than 40, using both polarizations, based on adjacent cross polar channel interference limits. Other plans using 32 and 36 channels are attractive for 4 and 6 beam systems because of the easy division of capacity into beams and spacecraft. Since we assume that all channels in a coverage area must be of the same polarization from a single orbit location, the maximum number of channels available to any viewer is 20, 18, or 16 corresponding to one polarization of the plan. If these constraints were relaxed simultaneously, then in principle the number of channels available to all viewers would increase greatly. For example, if each orbit location produced a beam covering all Canada, then the number of channels available to all viewers would be 240 = 6 (maximum number of orbit locations) x 40(maximum number of channels in a plan).

Apart from the fact that some viewers could not see all satellites, such a scheme would be enormously wasteful of spacecraft resources because these 240 channels would have to serve all identified audience groupings such as time zones, language, provincial boundaries etc. Radiated power falling outside the addressed audience is then a waste of expensive satellite resources. This is the fundamental argument for beams shaped quite accurately to perceived audience boundaries. At the other extreme, from an orbit/spectrum resource rather than a spacecraft point of view, a small beam, uses up orbit-spectrum just the same as a large beam. Which resource is of greatest current value is a basic question.

2.2.1.1 4 Beam Models

We consider first, 4 beam system models in which an orbital position at 100^{o}W longitude provides transmit coverage to Eastern Canada on 2 oppositely polarized beams and an orbital position at 130^{o}W longitude provides coverage to Western Canada on 2 oppositely polarized beams. A dual polarized receive beam covers all of Canada that is visible from the assumed orbit locations. (The Eastern part of Newfoundland cannot be covered from the 130^{o}W location for example).

System implementations corresponding to 32, 36 and 40 channel plans are shown in the following figures 2.2.1.1-1 to 2.2.1.1-3. The spacecraft/beam capacities chosen satisfy the initial and growth requirements with a minimum number of spacecraft and can fully develop the capacity of the orbit/frequency plan.

Many other implementations are possible using smaller or larger capacity spacecraft but they all suffer from some combination of four factors:

- Higher cost because of the large number of spacecraft required
- Unuseable spectrum because of awkward increments of capability
- Excessive initial capacity and resulting higher front end cost
- Inadequate initial capacity

SYSTEM IMPLEMENTATION AND GROWTH

2 ORBIT 4 BEAM

MODEL: 24 8(16)/16

32 CHANNEL

HIGH OR LOW EIRP

TABLE GIVES NUMBER OF CHANNELS PER BEAM

S/C LAUNCH NUMBER \ BEAM NUMBER	1	2	3	4	
1			⊕ 8	⊖ 8	
2	⊕ 8	⊖ 8			
	8	8	8	8	PHASE 1 8 CH/BEAM
3			⊕ 8	⊖ 8	
4	⊕ 8	⊖ 8			
	16	16	16	16	PHASE 2 16 CH/BEAM
5 SPARE					

⊕ RHC POLARIZATION ⊖ LHC POLARIZATION

FOR

1) SATISFIES INITIAL CAPACITY REQUIREMENT OF 8 CH/BEAM
2) GROWTH IS SIMPLE
3) FREQ. PLAN CAN BE FULLY DEVELOPED
4) HIGH EIRP REQUIREMENTS WITHIN DESIGN ENVELOP OF BAE L SAT
5) LOW EIRP REQUIREMENTS WITHIN DESIGN ENVELOP OF RCA DBS

AGAINST

1) POWER SYSTEM CHANGES TO L SAT REQUIRED

FIGURE 2.2.1.1-1

SYSTEM IMPLEMENTATION AND GROWTH

2 ORBIT 4 BEAM — MODEL: 24 9(18)/18

36 CHANNEL PLAN — HIGH OR LOW EIRP

TABLE GIVES NUMBER OF CHANNELS PER BEAM

S/C LAUNCH NUMBER \ BEAM NUMBER	1	2	3	4	
1			⊕ 9	⊖ 9	
2	⊕ 9	⊖ 9			
	9	9	9	9	PHASE 1 9 CH/BEAM
3			⊕ 9	⊖ 9	
4	⊕ 9	⊖ 9			
	18	18	18	18	PHASE 2 18 CH/BEAM
5 SPARE					

⊕ RHC POLARIZATION   ⊖ LHC POLARIZATION

FOR

1) EXCEEDS INITIAL CAPACITY REQUIREMENT OF 8 CH/BEAM.

2) GROWTH IS SIMPLE

3) FREQUENCY PLAN CAN BE FULLY DEVELOPED

4) HIGH EIRP REQUIREMENTS WITHIN LSAT CAPABILITY

AGAINST

1) LOW EIRP REQUIREMENTS MARGINALLY EXCEED RCA DBS CAPABILITY CONSIDER REDUCTION IN % ECLIPSE OPERATION

FIGURE 2.2.1.1-2

SYSTEM IMPLEMENTATION AND GROWTH

2 ORBIT 4 BEAM
40 CHANNEL PLAN

MODEL: 24 10(20)/20
HIGH OR LOW EIRP

TABLE GIVES NUMBER OF CHANNELS PER BEAM

S/C LAUNCH NUMBER \ BEAM NUMBER	1	2	3	4	
1			⊕ 10	⊖ 10	
2	⊕ 10	⊖ 10			
	10	10	10	10	PHASE 1 10 CH/BEAM
3			⊕ 10	⊖ 10	
4	⊕ 10	⊖ 10			
	20	20	20	20	PHASE 2 20 CH/BEAM
5 SPARE					

⊕ RHC POLARIZATION ⊖ LHC POLARIZATION

FOR

1) EXCEEDS INITIAL CAPACITY REQUIREMENT OF 8 CH/BEAM
2) GROWTH IS SIMPLE
3) FREQUENCY PLAN CAN BE FULLY DEVELOPED

AGAINST

1) HIGH EIRP REQUIREMENTS MARGINALLY EXCEED LSAT POWER CAPACITY. CONSIDER SMALL REDUCTION IN BEAM EDGE EIRP.
2) LOW EIRP REQUIREMENTS EXCEED RCA DBS CAPABILITY. CONSIDER REDUCTION IN % ECLIPSE OPERATION AND COVERAGE TO 90% OF LARGEST BEAM.

FIGURE 2.2.1.1-3

An example, from among many, of a model exhibiting some of these characteristics is given in fig. 2.2.1.1-4.

System reliability and replenishment studies reported later in this section show that an initial implementation of a 2 operating spacecraft can be adequately protected by one spare. If this spare is launched it can be used to increase the capacity at either, but not both orbit locations, or as a rapidly available spare in the event of a catastrophic failure of an operating spacecraft. The full system which requires 4 operating spacecraft can also be adequately protected by a single spare.

For the high EIRP case, the payload power and weight demands were subsequently determined to be marginally within the design envelope of the L SAT Ariane IV bus/launcher combination. The L SAT power and weight capacity has been taken as a practical upper bound on the size of any spacecraft required by a system model.

The choice of spacecraft bus to match the low EIRP models was considered open and not constrained to any particular bus. Subsequent investigation showed that a spacecraft concept by RCA Astroelectronics, supporting an RCA Americom DBS filing to FCC, was very close to the required size.

2.2.1.2 6 Beam Models

The model first considered provides Eastern Canada coverage with 3 beams from an Eastern orbit location of 100°W and Western Canada coverage with 3 beams from a Western orbital location of 130°W.

A system implementation which achieves the initial objective of 8 channels per beam with the minimum number of spacecraft (2) must have 24 channels per spacecraft. This is a large number and although the TWTAs are individually lower in power than the equivalent 4 beam models, the total power is marginally beyond the capabilities of L SAT for the high EIRP case.

If this were the only impediment, some accommodation could be made in EIRP or eclipse operation. A more compelling reason for rejecting this model comes from frequency plan and growth considerations. Recalling that adjacent beams from one orbit location must be cross polarized, we see that for 3 beams from one location, 2 of the beams must be of the same polarization and thus must divide the channels available in one polarization (half) of the frequency plan. This limits the number of channels per beam to 8, 9 or 10 corresponding to 32, 36 or 40 channel frequency plans. At least half of the channels with the polarization of the middle beam of the trio, are effectively not available unless a much different and smaller spacecraft is considered for growth. Accepting these drawbacks then, figure 2.2.1.2-1 shows the most likely 2 spacecraft implementation for high EIRP using a 32 channel plan, and figure 2.2.1.2-2 shows an alternative 4 spacecraft implementation for high or low EIRP using a 40 channel plan.

SYSTEM IMPLEMENTATION AND GROWTH

2 ORBIT 4 BEAM

MODEL: 24 6(18)/12

36 CHANNEL

HIGH OR LOW EIRP

TABLE GIVES NUMBER OF CHANNELS PER BEAM

S/C LAUNCH NUMBER \ BEAM NUMBER	1	2	3	4	
1			⊕ 6	⊖ 6	
2	⊕ 6	⊖ 6			PHASE 1 6 CH/BEAM
3			⊕ 6	⊖ 6	
4	⊕ 6	⊖ 6			PHASE 2 12 CH/BEAM
5			⊕ 6	⊖ 6	
6	⊕ 6	⊖ 6			
	18	18	18	18	PHASE 3 18 CH/BEAM
7,8 SPARE					

⊕ RHC POLARIZATION ⊖ LHC POLARIZATION

FOR

1) HIGH EIRP S/C IS WITHIN CAPABILITY OF L SAT AIV

2) ORDERLY GROWTH

3) FULLY DEVELOPED FREQUENCY PLAN

AGAINST

1) PHASE 1 DOES NOT MEET INITIAL 8 CH/BEAM OBJECTIVE

2) 6 OPERATING SPACECRAFT REQUIRED FOR FULL DEVELOPMENT PLUS 2 SPARE

FIGURE 2.2.1.1-4

SYSTEM IMPLEMENTATION AND GROWTH

2 ORBIT 6 BEAM — 32 CHANNEL PLAN

MODEL 268/24 — LOW EIRP

TABLE GIVES NUMBER OF CHANNELS PER BEAM

S/C LAUNCH NUMBER \ BEAM NUMBER	1	2	3	4	5	6	
1				⊕ 8	⊖ 8	⊕ 8	
2	⊕ 8	⊖ 8	⊕ 8				
	8	8	8	8	8	8	PHASE 1 8 CH/BEAM
3 SPARE							

⊕ RHC POLARIZATION ⊖ LHC POLARIZATION

FIG. 2.2.1.2-1

FOR

1) MEETS INITIAL REQUIREMENT OF 8 CH/BEAM.

AGAINST

1) HIGH EIRP REQUIREMENTS ARE MARGINALLY BEYOND L-SAT A IV CAPACITY.

2) NO GROWTH IN CAPACITY POSSIBLE FOR 4 OF THE 6 BEAMS (1,3,4,6) GROWTH IN 2 BEAMS (2,5) REQUIRES LAUNCH OF 2 SMALLER SIZE SPACECRAFT (8 CH VS 24 CH CAPACITY).

SYSTEM IMPLEMENTATION AND GROWTH

2 ORBIT 6 BEAM
40 CHANNEL PLAN

MODEL 265 (10)/15
HIGH OR LOW EIRP

TABLE GIVES NUMBER OF CHANNELS PER BEAM

S/C LAUNCH NUMBER \ BEAM NUMBER	1	2	3	4	5	6	
1				⊕ 5	⊖ 5	⊕ 5	
2	⊕ 5	⊖ 5	⊕ 5				
	5	5	5	5	5	5	PHASE 1 5 CH/BEAM
3				⊕ 5	⊖ 5	⊕ 5	
4	⊕ 5	⊖ 5	⊕ 5				
	10	10	10	10	10	10	PHASE 2 10 CH/BEAM
5							
SPARE							

⊕ RHC POLARIZATION ⊖ LHC POLARIZATION

FOR

AGAINST

1) DOES NOT MEET INITIAL CAPACITY REQUIREMENT.

2) NO GROWTH IN CAPACITY POSSIBLE FOR 4 OF 6 BEAMS (1,3,4,6). GROWTH IN 2 BEAMS (2, 5) REQUIRES SMALLER SIZE SPACECRAFT (5 CH VS 15 CH CAPACITY).

FIG. 2.2.1.2-2

Although the 2 orbit 6 beam models have a serious flaw for ultimate orbit/spectrum exploitation, perhaps they could function in a transitional system in which capacity is added to the system by launching spacecraft into a third orbital location. Here we identify two cases:

i) the initial 2 orbit 6 beam model spacecraft are allowed to run out their design life and are replaced by the next generation 3 orbit 6 beam model spacecraft.

ii) the initial spacecraft must be changeable in orbit to operate in the final system

The first case treats the two systems as discrete and neither spacecraft design is affected by the other except for likely similarity in frequency plan and beam coverage.

The second case seems the most likely as it makes more efficient use of orbiting capacity in responding to increased traffic demand well within the design life of the first generation spacecraft. Design requirements on the first generation spacecraft are severe if it is to make efficient use of spacecraft resources in both systems.

For example, as shown in figure 2.2.1.2-3 the initial 24 channel spacecraft serving 3 coverage areas must be rearranged to cover 2 areas with 12 channels each. This requires antenna reconfiguration complexity even greater than 2 orbit 6 beam case, because now a third orbit location must be considered.

Multiplexing filters must also be carried to accommodate all possible orbital/system assignments. Note that an awkward half capacity sized spacecraft would be required for full development of the orbit.

Other possible implementations are given in figures 2.2.1-2 - 4 to 6, each with a different combination of good and bad features as noted. Some characteristics are common to any system growing from 2 to 3 orbit locations, namely that viewers in one third of the coverage areas must repoint their antennas to look at a new orbit location. Also by example, in the notes accompanying figure -4, some viewers will have to change polarization.

As all 2 orbit 6 beam models considered have problems of system growth and complex communications payload requirements as transitional systems, they were deleted from further consideration by agreement with the design authority.

SYSTEM IMPLEMENTATION AND GROWTH

2 ORBIT 6 BEAM TO 3 ORBIT 6 BEAM

36 CHANNEL PLAN HIGH OR LOW EIRP

MODEL: 26 8/24

TABLE GIVES NUMBER OF CHANNELS PER BEAM

S/C LAUNCH NUMBER \ BEAM NUMBER	1	2	3	4	5	6	
1				⊕ 8	⊖ 8	⊕ 8	
2	⊕ 8	⊖ 8	⊕ 8				PHASE 1 8 CH/BEAM
3			⊕ 12	⊖ 12			
	⊕ 12	⊖ 12			⊕ 12	⊖ 12	PHASE 2 12 CH/BEAM
4	⊕ 6	⊖ 6					
5			⊕ 6	⊖ 6			
6					⊕ 6	⊖ 6	
	18	18	18	18	18	18	PHASE 3

⊕ RHC POLARIZATION ⊖ LHC POLARIZATION

FOR

1) MEETS INITIAL 8 CH/BEAM REQUIREMENT

AGAINST

1) COMPLEX ANTENNA AND REPEATER RECONFIGURATION REQUIRED.
2) HIGH EIRP REQUIREMENTS ARE BEYOND CAPABILITY OF L-SAT.
3) PHASE 3 IS AWKWARD AS IT REQUIRES 1/2 SIZE S/C PROVIDING 12 CHANNELS (6 PER BEAM).

FIGURE 2.2.1.2-3

2 ORBIT 6 BEAM TO 3 ORBIT 6 BEAM DEVELOPMENT

36 CHANNEL PLAN HIGH OR LOW EIRP MODEL 266/18

TABLE GIVES NUMBER OF CHANNELS PER BEAM

S/C LAUNCH NUMBER \ BEAM NUMBER	1	2	3	4	5	6	
1				⊕ 6	⊖ 6	⊕ 6	
2	⊕ 6	⊖ 6	⊕ 6				PHASE 1 6 CH BEAM
	⊕ 9	⊖ 9			⊕ 9	⊖ 9	
3			⊕ 9	⊖ 9			
	9	9	9	9	9	9	PHASE 2 9 CH BEAM
4					⊕ 9	⊖ 9	
5	⊕ 9	⊖ 9					
6			⊕ 9	⊖ 9			
	18	18	18	18	18	18	PHASE 3 18 CH BEAM

⊕ RHC POLARIZATION ⊖ LHC POLARIZATION

FIGURE 2.2.1.2-4

FOR

1) PLAN CAN BE FULLY DEVELOPED IC, ALL CHANNELS HAVE ONE POLARIZATION IN ONE ZONE FROM ONE ORBIT LOCATION.
2) 6 CHANNEL PER BEAM PARTIAL SERVICE CAN BE STARTED WITH 2 S/C.

AGAINST

1) DOES NOT MEET INITIAL CAPACITY REQUIREMENT OF 8 CH/BEAM.
2) ONLY AREAS 1 AND 2 DO NOT CHANGE EARTH STATION POLARIZATION OR POINTING - 3 POINTING, 4 POINTING AND POLARIZATION, 5 AND 6 POLARIZATION (ASSUMING 2 ORIGINAL ORBIT LOCATIONS RETAINED).
3) 3 BEAM TO 2 BEAM ANTENNA AND MULTIPLEXING RECONFIGURATION REQUIRED INCLUDING POLARIZATION CHANGE.
4) HIGH EIRP MODEL IS BEYOND L SAT AIV CAPACITY (MARGINAL).

SYSTEM IMPLEMENTATION AND GROWTH

2 ORBIT 6 BEAM TO 3 ORBIT 6 BEAM DEVELOPMENT

40 CHANNEL PLAN HIGH OR LOW EIRP MODEL 265/15

TABLE GIVES NUMBER OF CHANNELS PER BEAM

S/C LAUNCH NUMBER \ BEAM NUMBER	1	2	3	4	5	6	
1				⊕ 5	⊖ 5	⊕ 5	
2	⊕ 5	⊖ 5	⊕ 5				
3			⊕	⊖ 7			
	⊕ 8	⊖ 7			⊕ 8	⊖ 7	
	8	7	8	7	8	7	45 CH BEAMS
4					⊕ 7	⊖ 8	
5			⊕ 7	⊖ 8			
6	⊕ 7	⊖ 8					
	15	15	15	15	15	15	90 CH BEAMS

⊕ RHC POLARIZATION ⊖ LHC POLARIZATION

FOR

EACH ORBIT CAN PROVIDE 40 CHANNELS (20 CH/BEAM) FOR A 2 BEAM SATELLITE, FOR A TOTAL OF 120 CH BEAMS.

AGAINST

1) COMPLEX ANTENNA AND REPEATER CONFIGURATION REQUIRED

2) DOES NOT MEET INITIAL 8 CH/BEAM REQUIREMENT

3) THE NEXT STEP TO FILL THE ORBIT TO CAPACITY IS AWKWARD AS IT WOULD REQUIRE 3 SMALLER (2/3 SIZE) SATELLITES PROVIDING 5 CH/BEAM FOR EACH OF 2 BEAMS.

FIGURE 2.2.1.2-5

SYSTEM IMPLEMENTATION AND GROWTH

2 ORBIT TO 3 ORBIT 6 BEAM

36 CHANNELS HIGH OR LOW EIRP

MODEL 264/12

TABLE GIVES NUMBER OF CHANNELS PER BEAM

S/C LAUNCH NUMBER \ BEAM NUMBER	1	2	3	4	5	6	
1				⊕ 4	⊖ 4	⊕ 4	PHASE 1 4 CH/BEAM
2	⊕ 4	⊖ 4	⊕ 4				
3			⊕ 6	⊖ 6			
	⊕ 6	⊖ 6			⊕ 6	⊖ 6	
	6	6	6	6	6	6	PHASE 2 6 CH/BEAM
4					⊕ 6	⊖ 6	
5	⊕ 6	⊖ 6					
6			⊕ 6	⊖ 6			
	12	12	12	12	12	12	PHASE 3 12 CH/BEAM
7					⊕ 6	⊖ 6	
8	⊕ 6	⊖ 6					
9				⊕ 6	⊖ 6		
	18	18	18	18	18	18	PHASE 4 18 CH/BEAM

⊕ RHC POLARIZATION ⊖ LHC POLARIZATION

FOR

1) PLAN CAN BE FULLY DEVELOPED I.E. ALL CHANNELS HAVE ONE POLARIZATION TO ONE ZONE FROM ONE ORBIT LOC. ACTION.

2) 4 CHANNEL PER BEAM PARTIAL SERVICE CAN BE STARTED WITH 2 S/C.

AGAINST

1) ONLY AREAS 1 AND 2 DO NOT CHANGE EARTH STATION POLARIZATION OR POINTING, ASSUMING 2 ORIGINAL ORBITS RETAINED.
3-CHANGES POINTING
4-POINTING AND POLARIZATION
5-POLARIZATION
6-POLARIZATION

2) S/C SIZE AVAILABLE CANNOT SUPPORT 18 CH AT HIGH EIRP. MODEL APPLIES TO LOW EIRP ONLY.

3) 3 BEAM TO 2 BEAM ANTENNA AND MULTIPLEXING RECONFIGURATION REQUIRED INCLUDING POLARIZATION CHANGES.

4) PHASE 1 PROVIDES ONLY 4 CHANNELS PER BEAM.

FIGURE 2.2.1.2-6

As 2 orbit 4 beam model spacecraft transitioning to 3 orbit 6 beam use, pose even greater system and communications payload problems, they were similarly not analyzed in detail, by agreement with the design authority.

2.2.1.3 3 Orbit 6 Beam Models

These models require spacecraft operating at 3 orbit locations, corresponding to East, Central and West coverage areas. Each spacecraft provides a pair of oppositely polarized transmit beams for adjacent coverage areas, and one all Canada dual polarized receive beam.

For this study an indeterminate mid position between East (100^{o}W) and West (130^{o}W) locations has been taken for the central coverage assignment.

A system implementation and growth plan is shown in figure 2.2.1.3-1 which meets the initial 8 channel per beam, and the growth requirement to double this amount. This model used a 32 channel plan but other implementations are possible as shown in figure 2.2.1.3-2 and 3 using 36 and 40 channel plans respectively.

All of these systems have adequate initial capacity and good growth characteristics. The main disadvantage of all 3 orbit systems is the cost of the additional spacecraft required to initiate the system compared to a 2 orbit system.

When selecting a spacecraft bus to match the payload demands of the 3 orbit 6 beam models, two approaches are considered:

i) Select as close a match as possible with the expectation that the resulting spacecraft will be cheaper to build and launch than the corresponding 2 orbit 4 beam models, because of its lower power and weight requirements.

ii) Use the same spacecraft for both 4 and 6 beam models and turn the lower per channel power and weight demands of the 6 beam models into more channels per spacecraft relative to a 4 beam spacecraft.

Approach ii) has been selected because no significant cost saving or breakpoint could be found in the choice of spacecraft to match the 6 beam requirements relative to the 4 beam. The cost comparison between systems is simplified a little by the use of a common spacecraft bus between 4 and 6 beam systems.

SYSTEM IMPLEMENTATION AND GROWTH

3 ORBIT LOCATION WITH 6 BEAM COVERAGE

MODEL: 36 8/16

32 CHANNEL PLAN

HIGH OR LOW EIRP

TABLE GIVES NUMBER OF CHANNELS PER BEAM

S/C LAUNCH NUMBER \ BEAM NUMBER	1	2	3	4	5	6	
1					⊕ 8	⊖ 8	
2			⊕ 8	⊖ 8			
3	⊕ 8	⊖ 8					
	8	8	8	8	8	8	PHASE 1 8 CH/BEAM
4					⊕ 8	⊖ 8	
5			⊕ 8	⊖ 8			
6	⊕ 8	⊖ 8					
7, 8 SPARES	16	16	16	16	16	16	PHASE 2 16 CH/BEAM

⊕ RHC POLARIZATION ⊖ LHC POLARIZATION

FOR

1) MEETS INITIAL CAPACITY REQUIREMENT OF 8 CH/BEAM
2) GROWTH IS SIMPLE
3) ORBIT/SPECTRUM CAN BE FULLY DEVELOPED
4) HIGH EIRP REQUIREMENTS ARE WITHIN DESIGN ENVELOPE OF L SAT

AGAINST

1) REQUIRES A MINIMUM OF 3 SPACECRAFT FOR INITIAL SYSTEM
2) FULL SYSTEM OF 6 SPACECRAFT REQUIRES 2 SPARES

FIGURE 2.2.1.3-1

SYSTEM IMPLEMENTATION AND GROWTH

3 ORBIT LOCATION   6 BEAM SYSTEM   MODEL: 36 9/18

36 CHANNEL   HIGH OR LOW EIRP

TABLE GIVES NUMBER OF CHANNELS PER BEAM

S/C LAUNCH NUMBER \ BEAM NUMBER	1	2	3	4	5	6	
1	⊕ 9	⊖ 9					
2					⊕ 9	⊖ 9	
3			⊕ 9	⊖ 9			
	9	9	9	9	9	9	PHASE 1 8 CH/BEAM
4	⊕ 9	⊖ 9					
5					⊕ 9	⊖ 9	
6			⊕ 9	⊖ 9			
	18	18	18	18	18	18	PHASE 2 18 CH/BEAM
7, 8 SPARES							

⊕ RHC POLARIZATION   ⊖ LHC POLARIZATION

FOR

1) EXCEEDS INITIAL CAPACITY REQUIREMENT OF 8 CH/BEAM
2) GROWTH IS SIMPLE
3) ORBIT/SPECTRUM CAN BE FULLY DEVELOPED
4) HIGH EIRP REQUIREMENTS ARE WITHIN DESIGN ENVELOPE OF L SAT

AGAINST

1) REQUIRES A MINIMUM OF 3 SPACECRAFT FOR INITIAL SYSTEM
2) FULL SYSTEM OF 6 SPACECRAFT REQUIRES 2 SPARES

FIGURE 2.2.1.3-2

SYSTEM IMPLEMENTATION AND GROWTH

3 ORBIT LOCATION 6 BEAM SYSTEM MODEL: 36 10/20

40 CHANNEL HIGH OR LOW EIRP

TABLE GIVES NUMBER OF CHANNELS PER BEAM

BEAM NUMBER / S/C LAUNCH NUMBER	1	2	3	4	5	6	
1	⊕ 10	⊖ 10					
2					⊕ 10	⊖ 10	
3			⊕ 10	⊖ 10			
	10	10	10	10	10	10	PHASE 1 10 CH/BEAM
4	⊕ 10	⊖ 10					
5					⊕ 10	⊖ 10	
6			⊕ 10	⊖ 10			
	20	20	20	20	20	20	PHASE 2 20 CH/BEAM
7, 8 SPARES							

⊕ RHC POLARIZATION ⊖ LHC POLARIZATION

FOR

1) EXCEEDS INITIAL CAPACITY REQUIREMENT OF 8 CH/BEAM
2) GROWTH IS SIMPLE
3) ORBIT/SPECTRUM CAN BE FULLY DEVELOPED
4) HIGH EIRP REQUIREMENTS ARE WITHIN DESIGN ENVELOPE OF L SAT

AGAINST

1) REQUIRES A MINIMUM OF 3 SPACECRAFT FOR INITIAL SYSTEM
2) FULL SYSTEM OF 6 SPACECRAFT REQUIRES 2 SPARES

FIGURE 2.2.1.3-3

2.2.1.3 <u>3 Orbit 6 Beam Models</u> cont'd....

The high EIRP system selected thus uses the growth version of the L SAT meeting the payload requirements of up to 4.6 kw DC power and 310 kg weight.

This spacecraft can be launched by dedicated Ariane or by the shuttle using an adaptation of the large motor of the IUS as a perigee stage.

The low EIRP system model selected is based on a spacecraft described by RCA Americom in a DBS filing to FCC. The payload power and weight requirements of up to 2.0 kw and 240 kg are within the capability of this spacecraft concept. The spacecraft may occupy either upper or lower position for a shared Ariane launch. It may also be launched by shuttle, horizontally mounted on an uprated PAM-A as perigee stage, or upright in the shuttle using a liquid perigee propulsion system.

2.2.2 Antenna Polarization

Studies performed for DOC by Miller Communications (1) and CAL (2) and SPAR (3). Have examined the question of linear and circular polarization (CP) for the direct broadcasting system from system interference, spacecraft antenna conceptual, and spacecraft current practice perspectives.

From the studies cited, no single overriding argument in favour of linear or circular polarization can be found. For example from the system study, downlink circular polarization is preferable on an interference basis particularly if one orbit serves a wide longitudinal area. Antenna reconfiguration concepts are feasible in either LP or CP although they may be more difficult in CP than LP. Sidelobe performance appears comparable in both CP and LP. Main beam cross polar discrimination for multi horn shaped beams is one performance area which favours LP over CP, the current state of the art being 25 - 27 dB for CP and 32 - 33 dB for LP.

Considering: i) the precedent that has been set for ITU regions 1 and 3 in the use of CP, albeit for simple elliptical coverage,

ii) the freedom from polarization adjustment in CP home receivers without significant CP cost penalty,

iii) the possibility of improvement in the state of the art for cross polar discrimination in multi horn shaped beam antennas,

iv) that the choice of polarization for feeder links (UP links) may wish to be treated independently of down links.

v) that as an exercise to explore the boundaries of feasible spacecraft concepts, this study should consider the most demanding choice of polarization.

Circular polarization was chosen for both transmit and receive antennas.

References

1. Study of the Linear or Circular Polarization for 12 GHz Broadcasting Satellite Service, Phase 1 Final Report March 19, 1982.

2. Reconfigurable Satellite Antenna Design for Direct Broadcasting Satellite Service, September 1981.

3. Study of Linear and Circular Polarization for 17/12 GHz Antennas of the Direct Broadcasting Satellite, May 1982.

2.2.3 System Reliability and Replenishment

This evaluation was performed in order to determine the achievable reliability and life of a multiple satellite DBS system under different conditions and review, at the system level, the effectiveness of the 16/24 payload redundancy scheme which was initially preferred based on the payload reliability analysis detailed in section 3.4.

The following assumptions are implied in the evaluation:

- Mission probability of success objective 0.5 to 0.7 at 7 years.
- L-Sat spacecraft bus
- STS launches with 0.98 probability of success
- 7 year life for each satellite
- balanced traffic loading between different orbital slots
- increasing traffic pattern consistent with system capacity
- not more than 2 satellites operating simultaneously in each orbital location

2.2.3.1 Two Orbit Four Beam Model

A five satellite system is considered with two simultaneous initial launches followed by three additional launches with one of them being for an in-orbit spare satellite. Two traffic patterns are included (top portion of the figures)

1. 32 channels increasing to 48 then 64 (16 ch/sat)
2. 24 channels increasing to 36 then 48 (12 ch/sat)

a. Payload Redundancy

Figure 2.2.3-1 shows the system reliability for three different payload configurations 16/16, 16/20 and 16/24 with traffic pattern #1. It can be seen that a 16/16 payload configuration (i.e. no protection) will not meet the mission requirements (typically 0.5 to 0.7 at 7 years), the 16/20 configuration will provide up to 6 years with better than 0.80 probability of success and 7 years with better than 0.55. The 16/24 configuration will provide 7 years with a probability of 0.85.

It would appear that the 16/20 configuration will be the most cost effective since it will accommodate a substantial traffic loading (64 channels at end of life) with high probability, degrading only in the last year to 0.55, while the 16/24 configuration, in spite of the significant increase in cost, will only achieve a limited improvement in the last 2 years. Subsequent evaluations are therefore based solely on the 16/20 configuration to determine the influence of other system parameters.

b. Traffic Loading

Figure 2.2.3-2 shows that with full loading of up to 64 channels, the probability drops to 0.55 at end-of-life. It can be seen however that a reduced traffic of 48 channels can be provided with a 0.85 probability of success.

c. Launch Scenario

Figs. 2.2.3-3 and 2.2.3-4 show that no real improvement in end-of-life reliability is achieved by deferring the launch of the in-orbit spare satellite. Moreover, as the launch of the spare is deferred, the system probability of success decreases down to 0.62 with a launch deferred till year 5.

2.2.3.2 Three Orbit Six Beam Model

An eight satellite system is evaluated with three initial launches followed by one a year. Two traffic patterns are selected arbitrarily to assess the impact of the reduced loading on system reliability.

1. 48 channels increasing to 96 channels (16 ch/sat) - fully loaded
2. 36 channels increasing to 72 channels (12 ch/sat) - partially loaded

A single in orbit spare provides a probability of only 0.36 of meeting the full traffic requirement, and thus two in orbit spares were judged necessary to meet the mission requirement, which is taken as typically 0.5 to 0.7 at 7 years. Furthermore, since the six active satellite launches extend over a long period of time --4 years assumed -- little time is left to construct and launch an additional spacecraft should any launch failure occur. If a second spare is planned for the six satellite system, the effect of a launch failure would be less catastrophic and contingency action easier.

1. Traffic Loading

Figure 2.2.3-5 shows that the full traffic requirement (16 channels per active satellite) can be achieved for 7 years with a probability of 0.70. It can be seen that a reduced traffic loading will improve the system probability of success but only towards the end-of-life, as the system reliability in the early years is controlled by that of the spacecraft bus.

2. Launch Scenario

Figures 2.2.3-5 and 2.2.3-6 show that little improvement to the overall system reliability profile can be achieved by deferring the launch of the spare. It would appear, however, that if the traffic loading is reduced, some improvement may be obtained by the earlier launch of the spares.

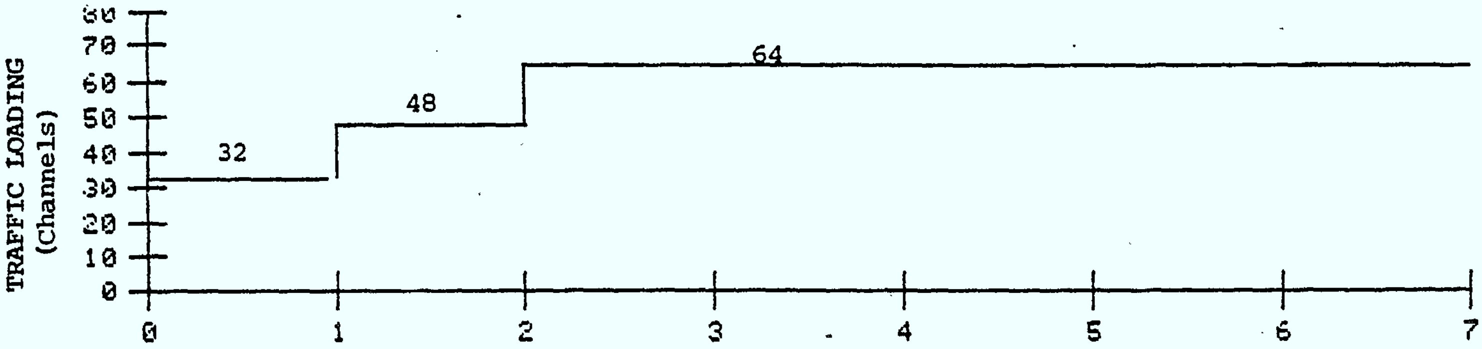
2.2.3.3 Summary and Conclusions

- The 16/20 payload configuration appears most adequate to meet the increasing traffic requirement with confidence in a cost effective way. The reliability improvement at the payload level, originally expected from a higher redundancy level such as 16/24, appears severely reduced at the system level due to the effect of the spacecraft bus on the overall probability of success of the mission.

- The four-beam, two-location system can accommodate, with 5 satellites up to 64 channels for 7 years with 0.55 probability, and 48 channels with 0.85 probability. No improvement is achieved by deferring the launch of the in-orbit spare.

- The six-beam, three-location system can provide with 8 satellites up to 96 channels for 7 years with 0.70 probability. A reduced traffic loading would provide higher reliability provided that the in-orbit spares are launched earlier. This is due to the fact that the multiple satellite system reliability is initially Bus controlled.

- Further evaluations could be done to determine an optimum replenishment scheme for any particular configuration.



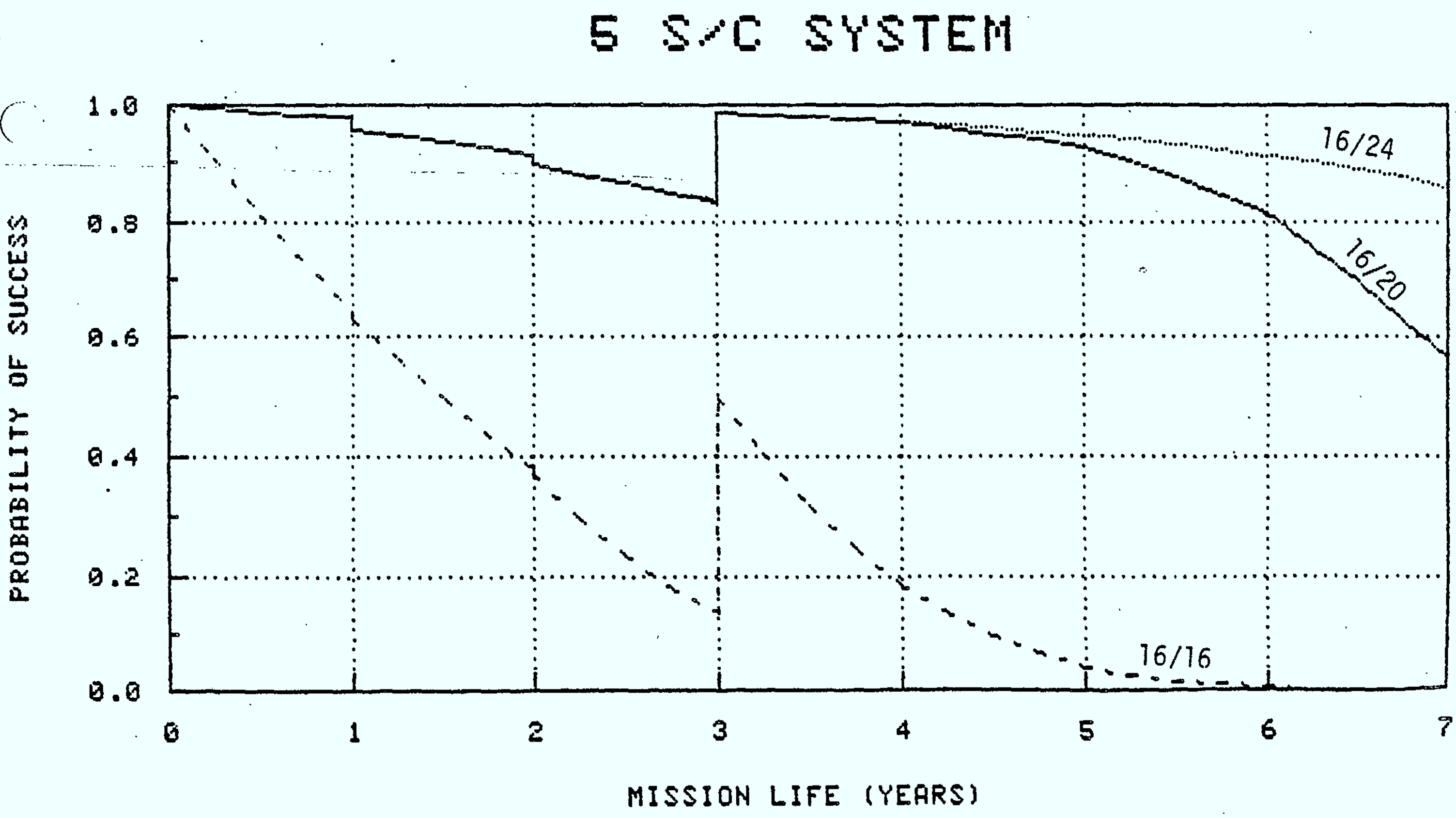


Fig. 2.2.3_1 5-Satellite System Reliability-Effect of Payload Configuration Launches at 0, 0, 1, 2, 3 Years

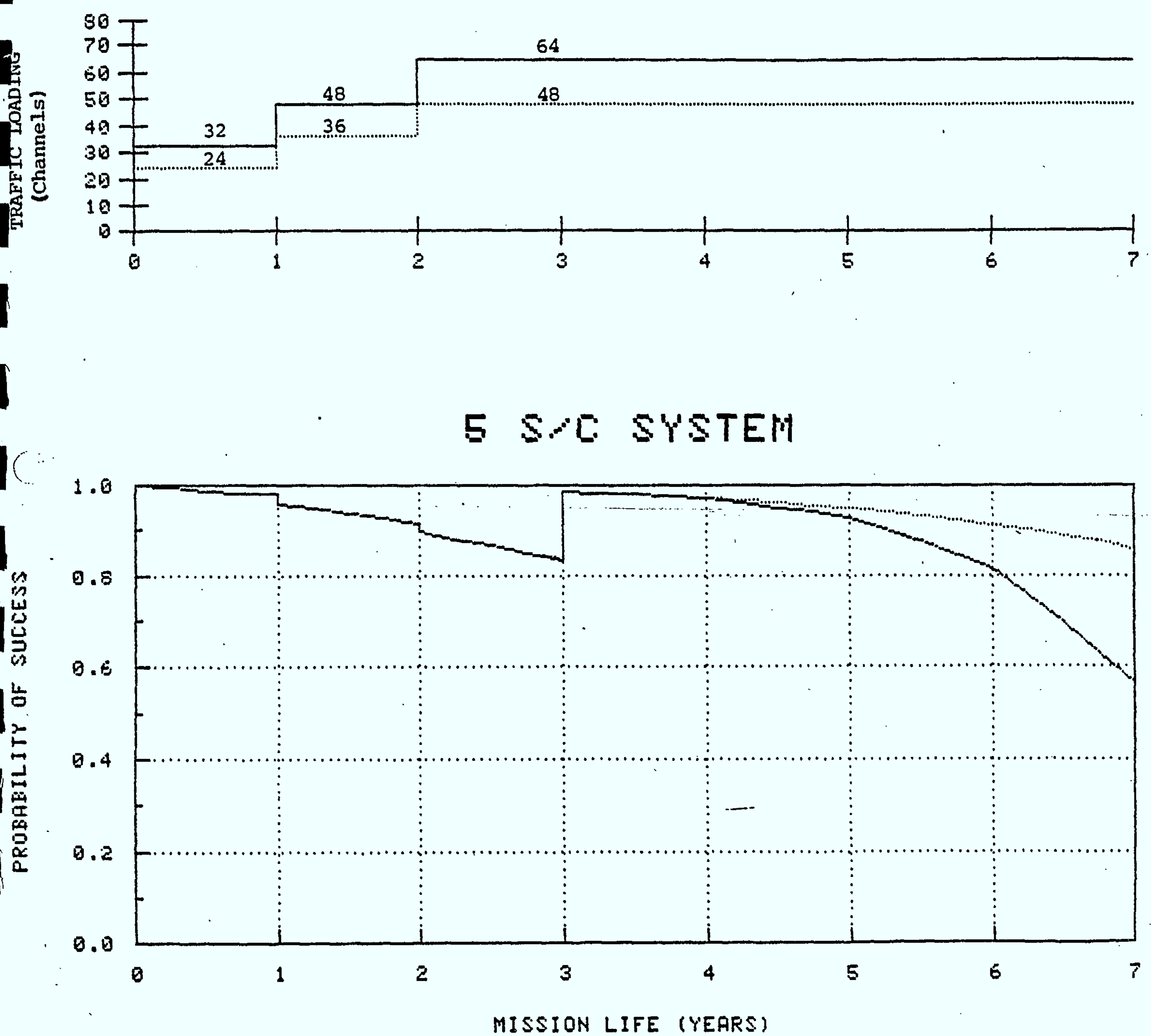
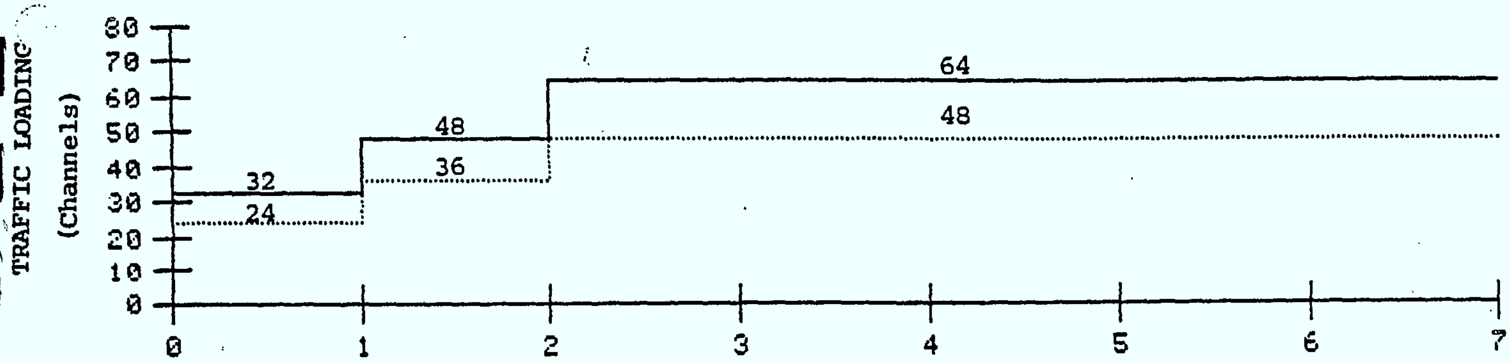


Fig. 2.2.3.2 5-Satellite System Reliability with launches at: 0,0,1,2,3 years



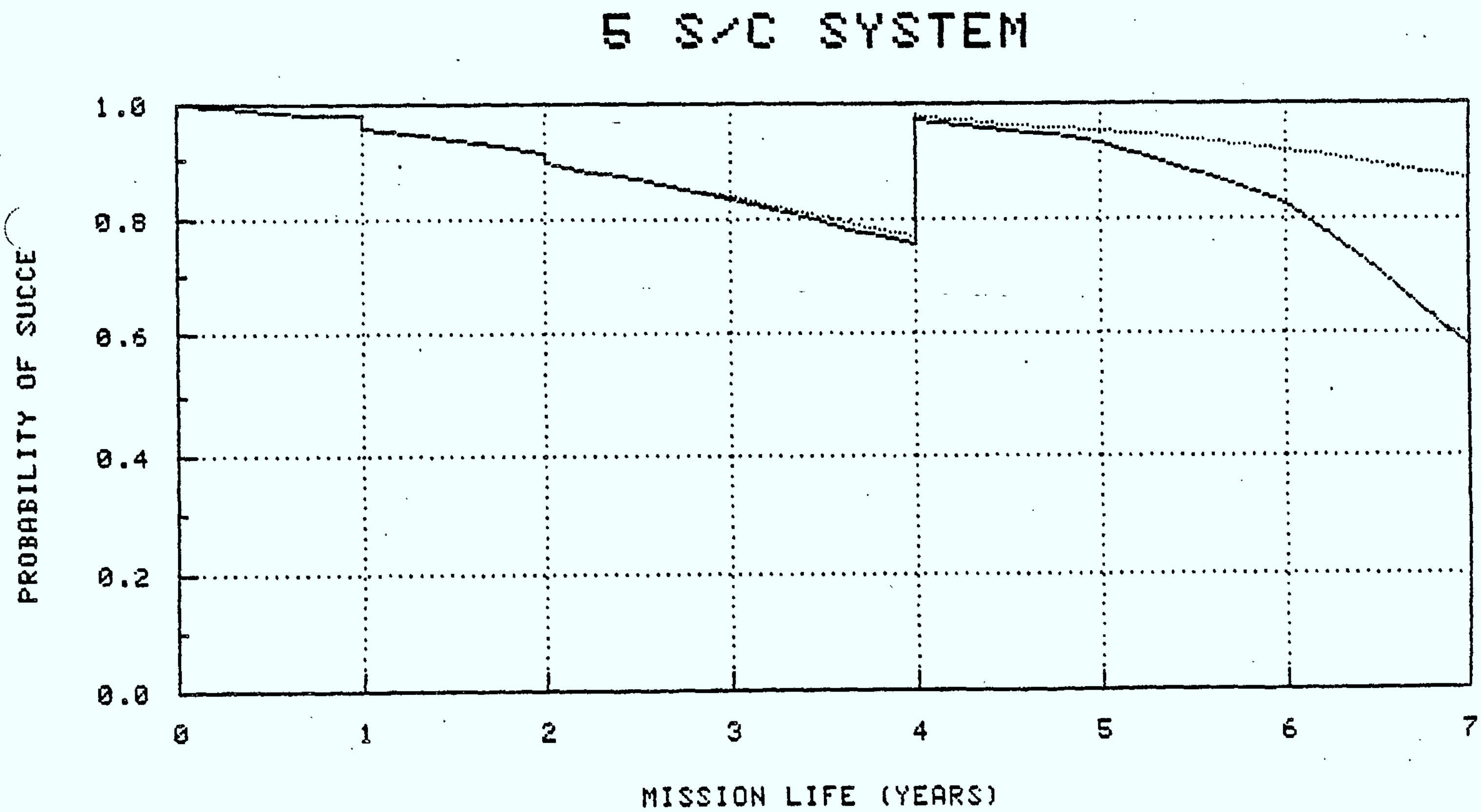
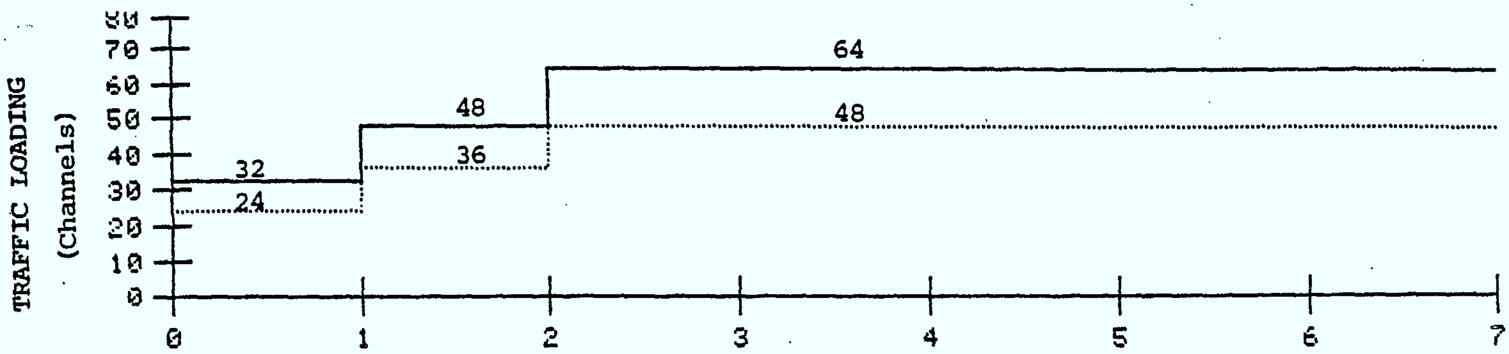


Fig. 2.2.3.3 5-Satellite Systems Reliability-Launches at: 0,0,1,2,4 years



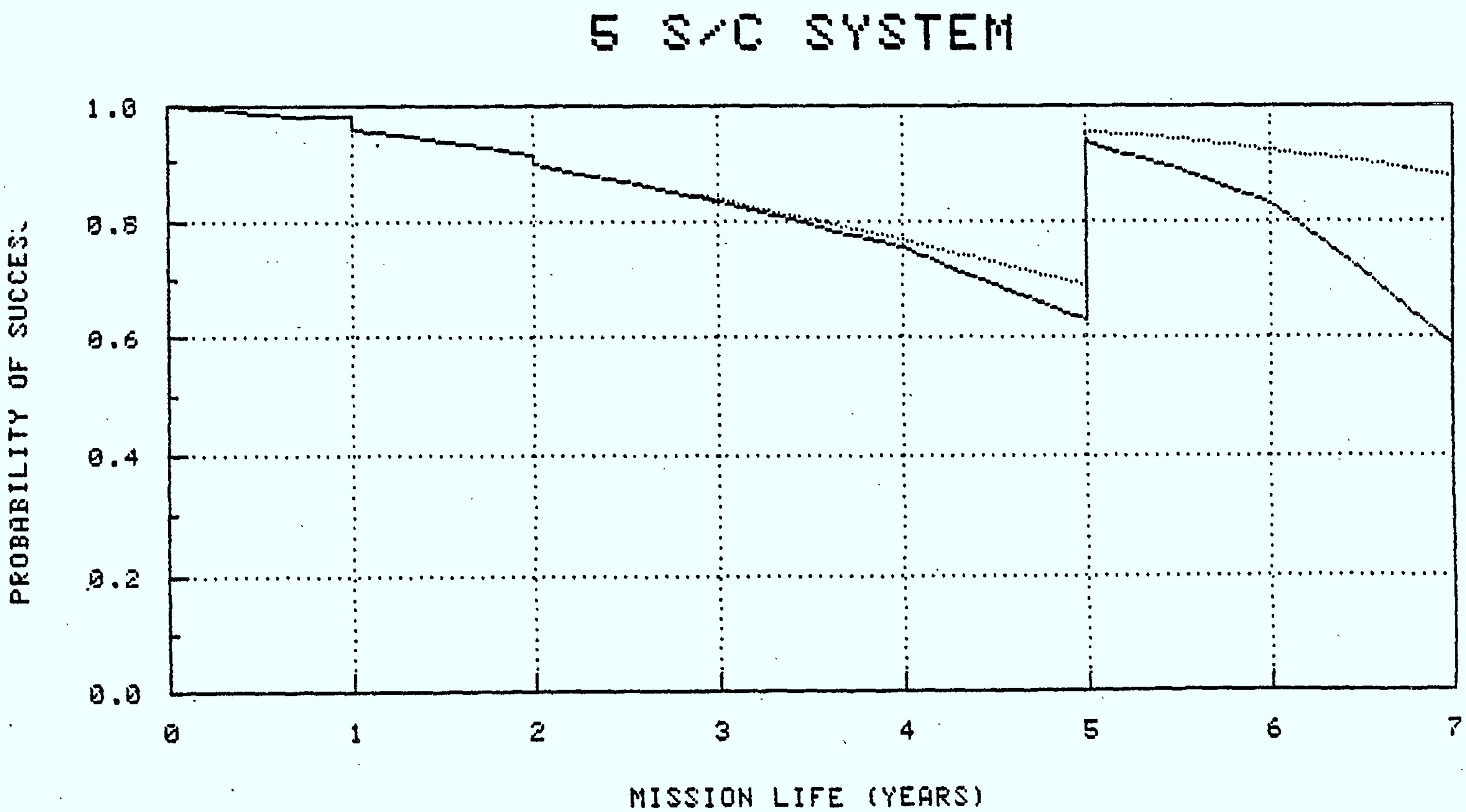
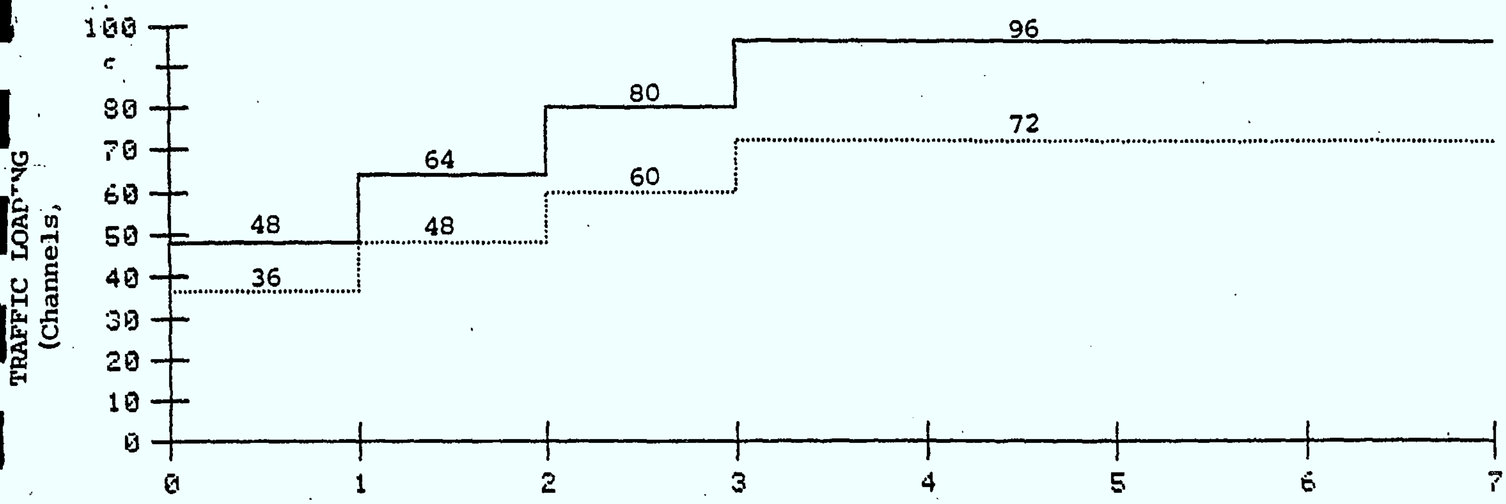


Fig. 2.2.3.4 5-Satellite System Reliability-Launches at 0,0,1,2, 5 years



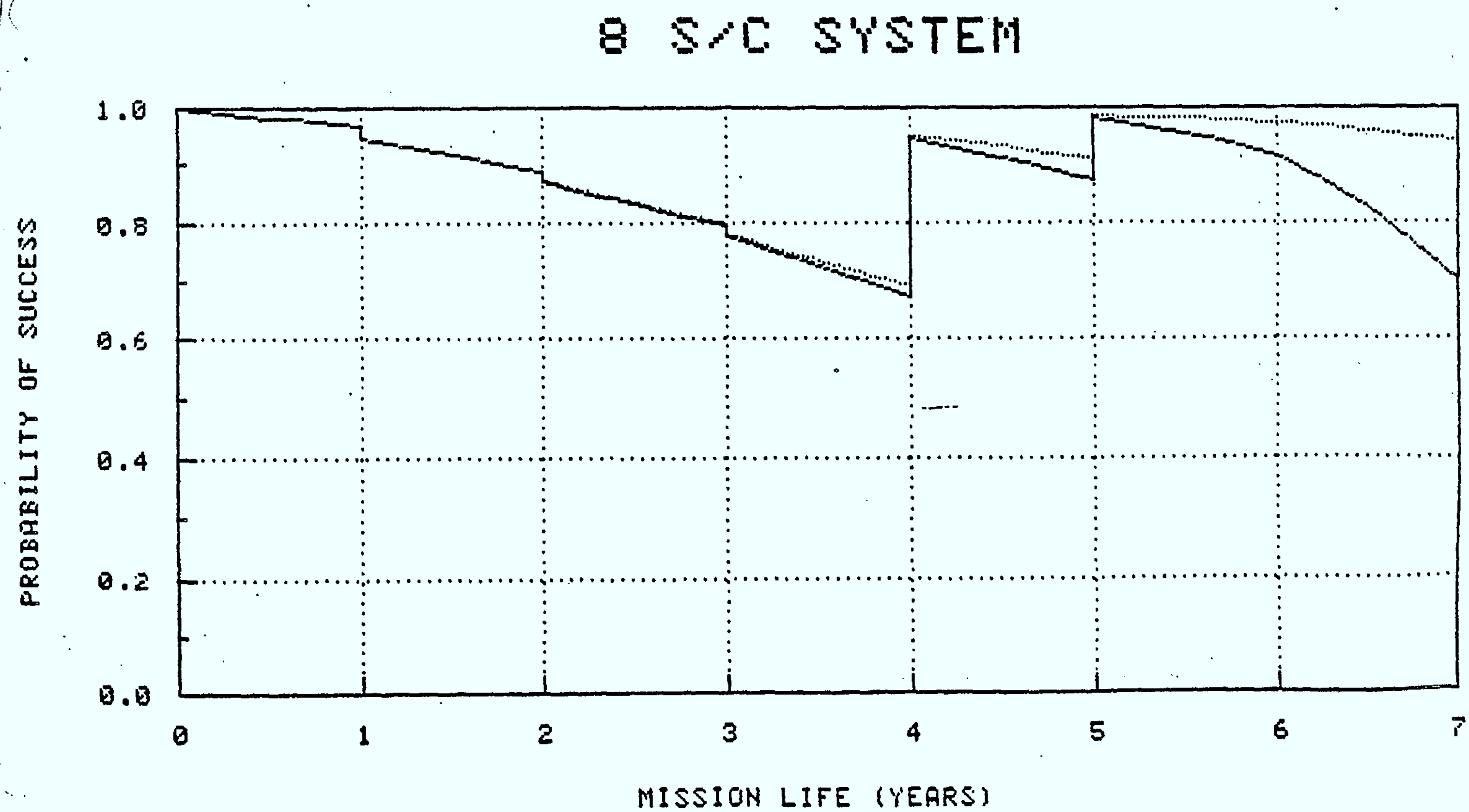
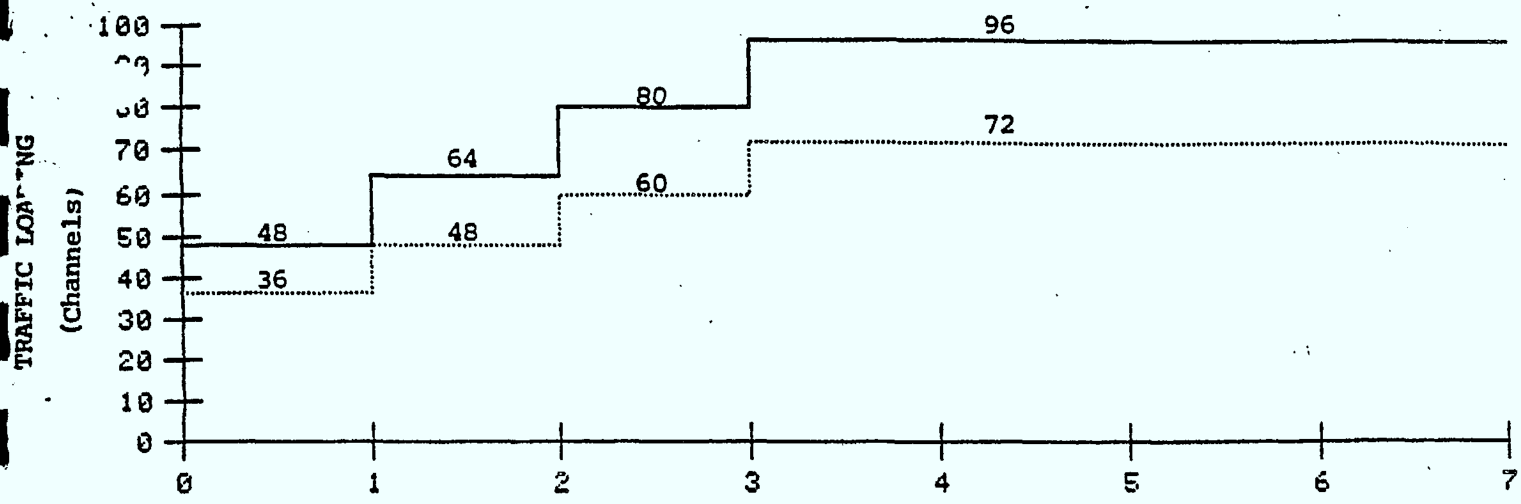


Fig. 2.2.3.5 8-Satellite System Reliability - Launches at: 0,0,0,1,2,3,4,5 years



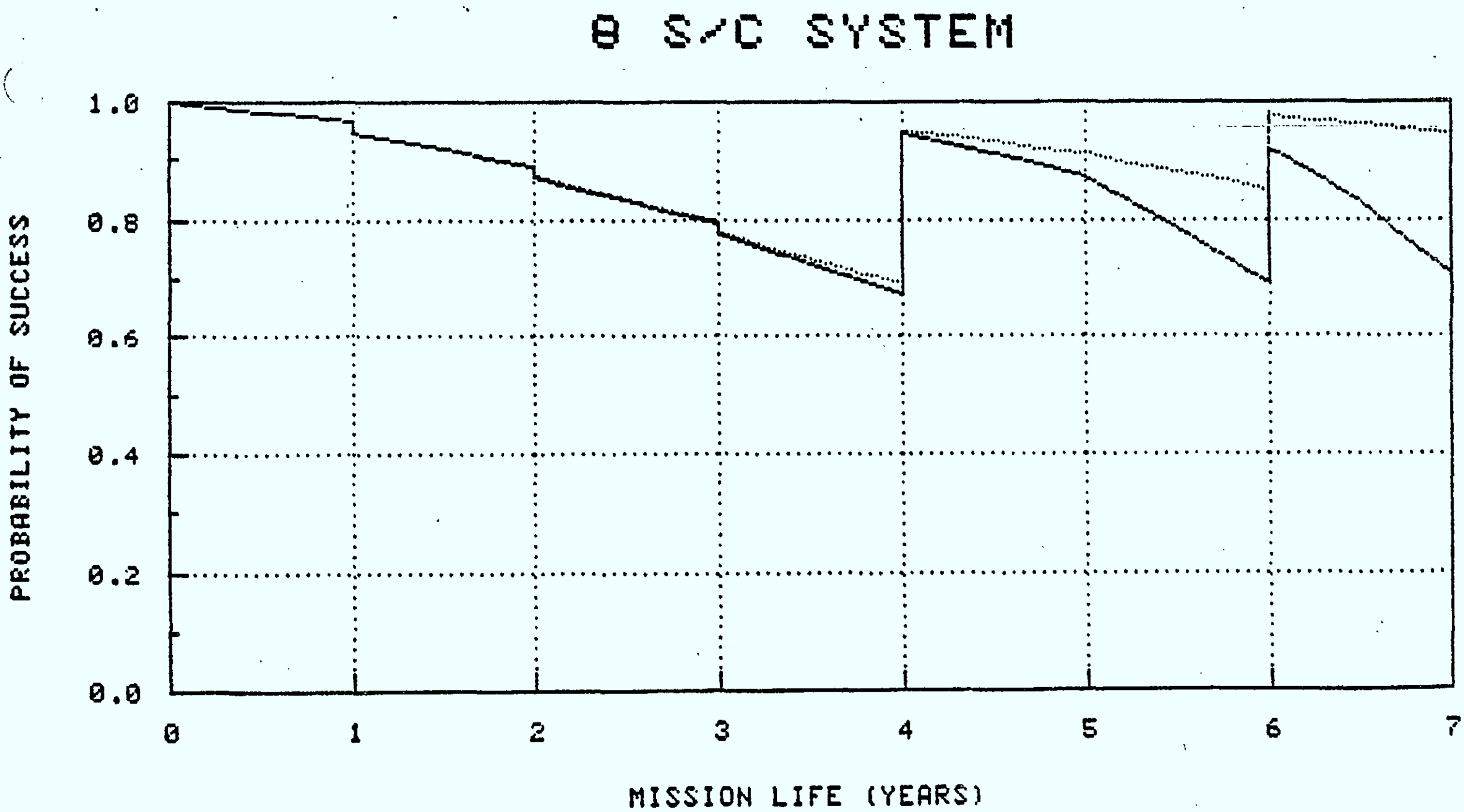


Fig. 2.2.3.6. 8-Satellite System Reliability - Launches at 0,0,0,1,2,3,4, 6 years

2.2.4 RARC Planning Considerations

An objective of the present system concepts study is to identify any major system constraints associated with the Canadian First Draft Proposals for RARC 83. With the system conceptual design work completed no such major constraints have been identified. A discussion on the system technical parameters used in this study and those of the Canadian First Draft Proposals is considered useful and presented below.

Modulation:

Frequency modulations has been assumed in this study and the First Draft Proposals.

Signal-to-Noise:

This parameter was not examined in this study.

Carrier-to-Noise:

This parameter was not examined in this study.

RF Bandwidth

The conceptual design is based on 18 MHz channel bandwidth. If the channel bandwidth were to be increased to 21 MHz as suggested by the First Draft Proposals a reduction of the total number of channels possible within the available 500 MHz spectrum should be expected due to increased interference effects.

Based on 18 MHz RF bandwidth a 40 channel plan is possible within the 30 dB aggregate carrier-to-interference constraint. An increase of BW to 21 MHz would probably limit the total number of channels to 36 instead of 40 for the same C/I. Some impact on multiplexer design is also anticipated but it is not expected to be a serious one.

Protection Ratio

It has been shown in this study that an aggregate $C/I \gtrsim 30$ dB is possible based on an adjusted protection ratio mask described in subsection 3.2. This mask is derived from the one defined in the WARC-77 Final Acts Documents by prorating the frequency scale in the ratio of the RF bandwidths: 18/27. The validity of this approach should be examined by subjective picture quality tests.

Inter-Service Interference

This subject was not covered in the present study.

Characteristics of Receiving Earth Stations

In the area of interference evaluation from adjacent orbital stations a 1m antenna and the WARC-77 receiving antenna characteristic have been assumed by this study. This is in agreement with the First Draft Proposals.

Type of Polarization

Circular polarization in uplink and downlink has been assumed in agreement with the current Canada's position described in the First Draft Proposals.

This topic is covered in subsection 2.2.2 of this study.

Satellite Antenna Characteristics:

Antenna Beam Shapes Used in Planning:

This subject is receiving considerable attention in a number of separate studies. In this study a shaped beam approach has been followed as described in subsection 4.2.3 and Appendix A.

Satellite Transmitting and Receiving Antennas

The antenna conceptual design part of this study has addressed the questions of crosspolarization discrimination (XPD) and sidelobe levels of the satellite antennas. No major conflicts exist between the findings of this study and the First Draft Proposals. XPD performance of 27 to 30 dB appears to be realisable for circular polarization. The intrasystem interference evaluation performed in this study shows that 27 dB XPD for both the transmit and receive satellite antennas is adequate in satisfying the carrier-to-interference objective of 30 dB.

Minimum Satellite Antenna Beamwidths

The antenna design undertaken in this study led to a reflector size of 75 inches. The upper limit of reflector size compatible with the present spacecraft conceptual design is approximately 90 inches. Different designs, presumably, could contain practical reflector sizes to the limit of the launcher dynamic envelope.

Antenna Pointing Accuracy

Preliminary examination of antenna pointing error in the present conceptual design indicated that total pointing errors of the order of $\pm$ 0.15 degree must be considered unless some method of RF tracking is employed. In this

Antenna Pointing Accuracy(cont'd)

conceptual design antenna gain values have been adjusted for a pointing error of $\pm$ 0.15 degree. The gain "reduction" due to pointing error exceeds 1 dB which makes it quite significant. The question of antenna pointing accuracy and possible use of RF tracking appears to merit a separate system optimization study.

Transmitting Earth Stations:

This topic was examined under the previous DBS study (Direct Broadcast System Modeling Study, DSS Contract OST80-00134). The only aspect of transmit earth station characteristics used in this study was the crosspolarization discrimination of the antenna. As part of the interference analysis an XPD of 30 dB has been assumed based on the 14 GHz INTELSAT V 10m antenna specifications.

Battery Power Required During Eclipse Periods:

The use of Nickel-Hydrogen batteries has been assumed in the present conceptual design.

Satellite EIRP

Two EIRP values have been used as the bases of the conceptual design: 54 dBw and 50 dBw at Edge of Coverage. TWT power required to satisfy this EIRP ranges from 40 w to 170 w RF.

2.2.5 Eclipse Operation

Considered below are the power requirements for system to provide service to 1:00 a.m. local standard time during eclipse. It is assumed that the system operates from two orbital locations at 100° and 130°W and that the western beams are serviced from the western orbital location while the eastern beams are serviced from the eastern location. Six and four beam systems are considered.

Eclipse power requirements are expressed as a percentage of full operation power and include the power required by the active TWTA's plus standby power for the remaining TWTA's. The standby power is necessary for heaters used to maintain the TWTA within permissible temperature limits and full or partial filament operation. Arbitrarily, the amount of standby power is assumed to be 15% of the full operation power of the TWTA.

The occurrence of eclipse in terms of local time at the westernmost service area covered by the satellite is shown in Figures 2.2.5-1 and 2.2.5-2 for the 100°W and 130°W orbital locations respectively. The beginning of eclipse in terms of local standard time at each service area and the necessary percent power to provide service to 1:00 a.m. is given in Figures 2.2.5-3 and 2.2.5-4. This power is only what is required by the active TWTA's.

The total eclipse power requirements including standby power are summarized below.

SIX BEAM SYSTEM

WESTERN ORBITAL SLOT

One beam operated 78% of the eclipse time and it is on standby for the other 22% of the time.

Two beams are on standby for the full eclipse duration.

$$\text{Eclipse Power} = (\underbrace{78 + 22 \times 0.15}_{\text{1 beam}} + \underbrace{2 \times 100 \times 0.15}_{\text{2 beams}}) \div 3 = 37.1\% \text{ Avg./Beam}$$

EASTERN ORBITAL SLOT

All three beams are on standby for the full eclipse duration.

$$\text{Eclipse Power} = 3 \times 100 \times .15 \div 3 = 15\%$$

2.2.5 Eclipse Operation(cont'd)

FOUR BEAM SYSTEM

WESTERN ORBITAL SLOT

One beam operates 78% of the eclipse time and it is on standby 22% of the time.

One beam is on standby for the full eclipse duration.

Eclipse Power = (78 + 22 x 0.15 + 100 x .15) ÷ 2 = 48.2%

EASTERN ORBITAL SLOT

Two beams are on standby for the full eclipse duration.

Eclipse Power = 15%

In the conceptual spacecraft design covered in Sections 4.4 and 4.5 50% eclipse power has been included.

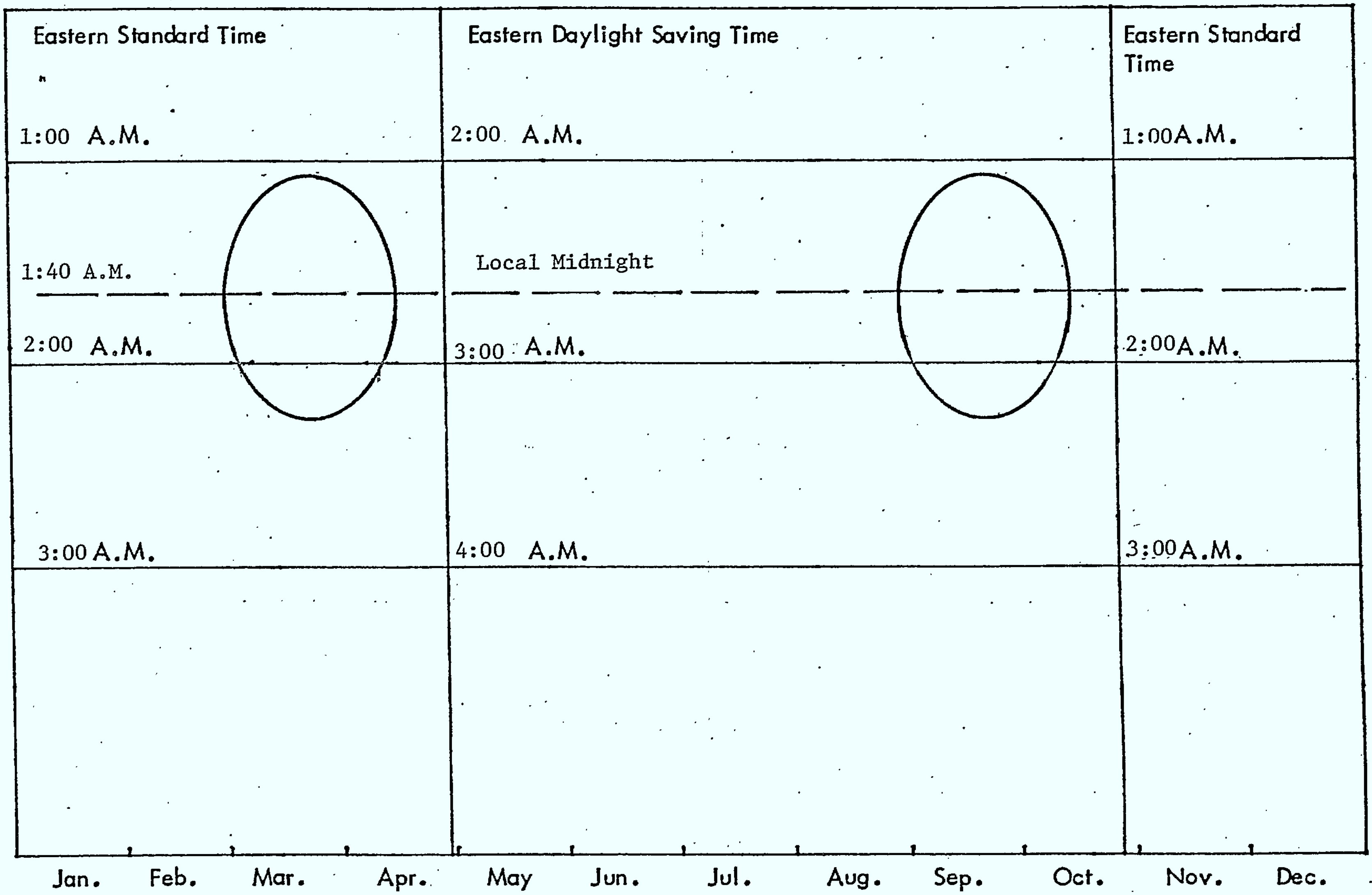


Figure 2.2.5.1 Eclipse Occurence and Duration Throughout a Year at Eastern Time Zone & 100º W Satellite Orbital Slot.

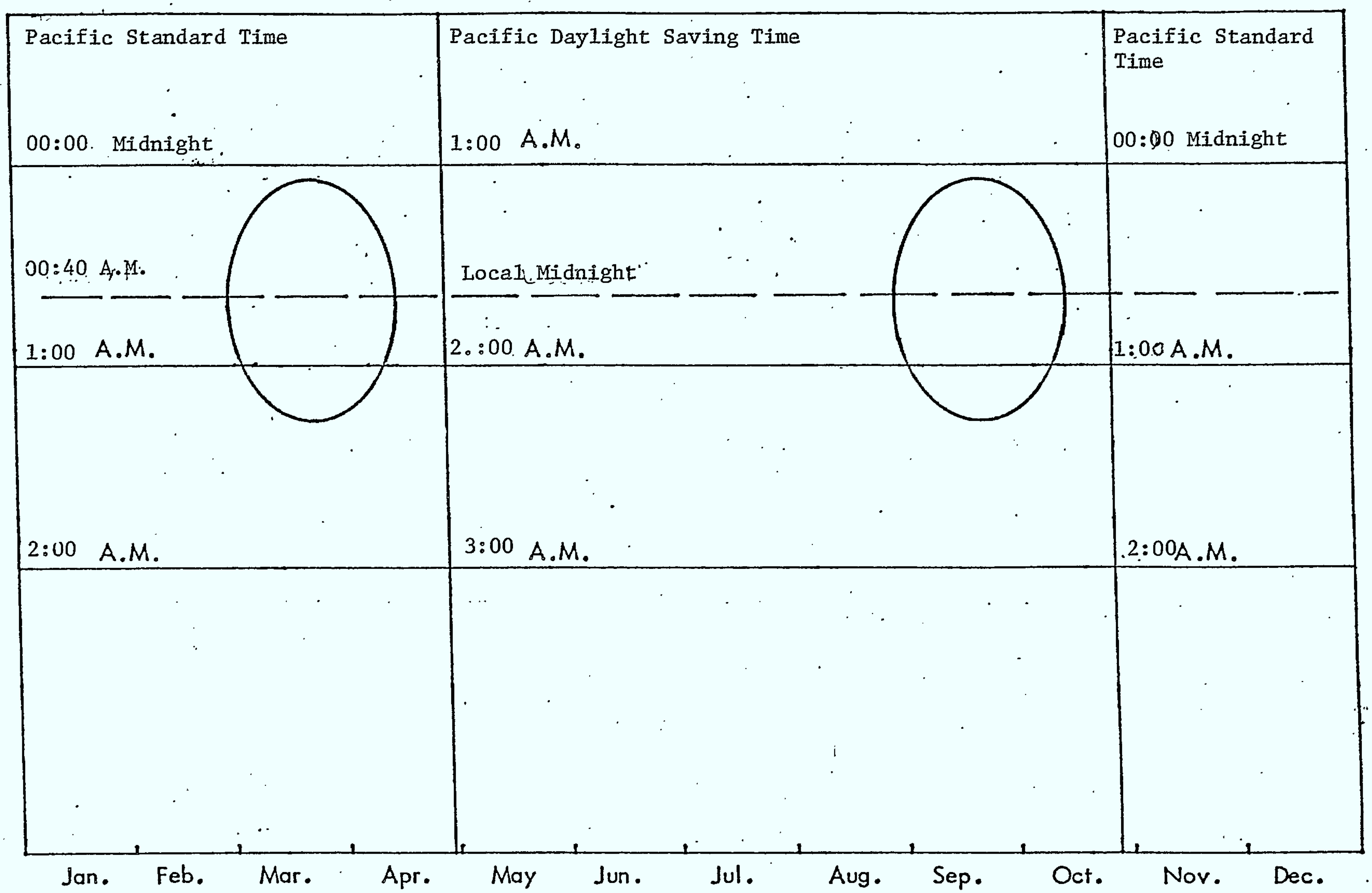
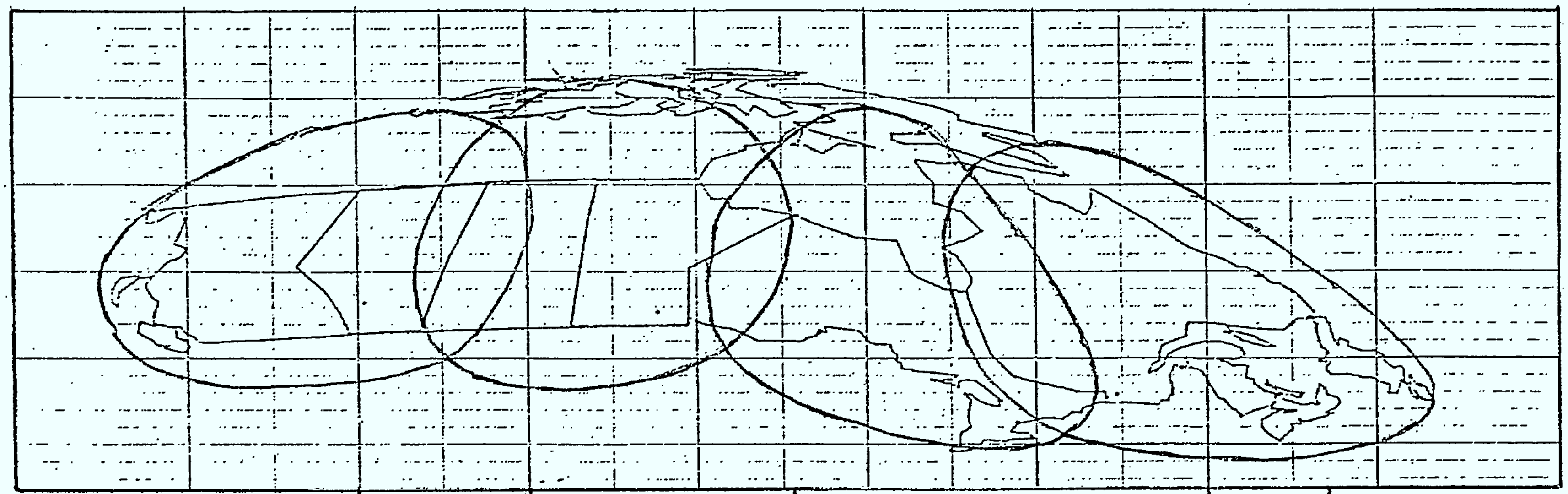


Figure 2.2.5.2 Eclipse Occurence and Duration Throughout a Year at PacificTime Zone & 130° W Satellite Orbital Slot.

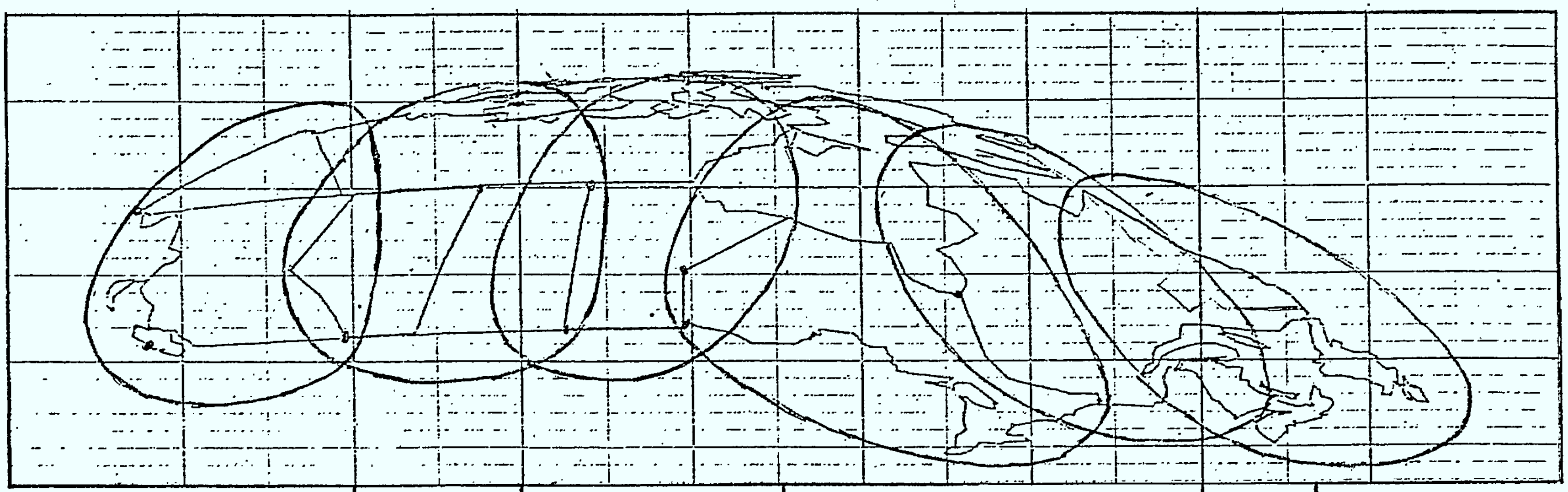


TIME ZONE:	PACIFIC	MOUNTAIN	CENTRAL	EASTERN	ATLANTIC	NFLD
LOCAL STANDARD TIME ECLIPSE BEGINS:	00:04	01:04	02:04	01:04	02:04	02:34

	1	2	3	4
% OF NORMAL BEAM LOAD REQUIRED FOR OPERATION TO 1 AM LOCAL STANDARD TIME:	78%	0%	0%	0%
% OF TOTAL SYSTEM LOAD:	39%	0%	0%	0%

WESTERN SATELLITE AT 130°W (beams 1–2); EASTERN SATELLITE AT 100°W (beams 3–4)

Figure 2.2.5.3 ECLIPSE OPERATION LOAD FOR 4 BEAM SYSTEMS



TIME ZONE:	PACIFIC	MOUNTAIN	CENTRAL	EASTERN	ATLANTIC	NFLD
LOCAL STANDARD TIME ECLIPSE BEGINS:	00:04	01:04	02:04	01:04	02:04	02:34

	1	2	3	4	5	6
% OF NORMAL BEAM LOAD REQUIRED FOR OPERATION TO 1 AM LOCAL STANDARD TIME:	78%	0%	0%	0%	0%	0%
% OF TOTAL SYSTEM LOAD:	26%	0%	0%	0%	0%	0%

WESTERN SATELLITE AT 130°W — EASTERN SATELLITE AT 100°W

Figure 2.2.5.4 ECLIPSE OPERATION LOAD FOR 6 BEAM SYSTEMS

(TWO ORBITAL LOCATIONS)

2.3 Anik-C to DBS Transition

A very important factor which determines the degree to which an interim (11.7-12.2 GHz) DBS service can become successful in Canada is the extent of compatibility of the TVRO terminals with a (12.2-12.7 GHz) DBS system. Differences between Anik C and DBS receive frequency bands and probably polarization difference preclude direct compatibility of receiving stations. However, it would seem feasible to arrange for a simple modification of Anik C TVRO terminals to permit operation with a future DBS system. Anik C receiving terminals should, therefore, be designed so that they can be readily changed for operation using the DBS reception band and polarization.

A comparison between key technical characteristics of the Anik C system and DBS system are furnished in the following table in order to evaluate the transitional problems.

Parameters	Anik C	DBS
Uplink Frequency Band, GHz	14.-14.5	17.3-17.8
Downlink Frequency Band, GHz	11.7-12.2	12.2-12.7
Polarization	linear	circular*
EIRP at the Edge of Coverage Area, dBW	47	50-54
Number of Downlink Beams	4 to 2	4 or 6
Number of Uplink Beams	1	1*
RF Signal Bandwidth, MHz	54	20*

*Assumed as a likely parameter for Canada.

This report examines the transitional problems from Anik C to a DBS system. Two possible models for orbital positions are considered (a) four beams, two orbit locations, (b) six beams, three orbit locations. It is expected that the Government of Canada will apply for orbital locations close to those assumed in the report, for a Canadian DBS system.

In what follows, the first section examines the general problem of transition from interim DBS (Anik C) to a DBS system, when either model (a) or (b) is chosen for the DBS system. Satellite EIRP is, then, considered and it is pointed out that in the costs study the sum of the satellite EIRP and the receiving terminal G/T should be considered in design of a future DBS system.

Finally, DBS receive terminals and feeder links are described and the transitional problems from an interim Anik C DBS system to a DBS system are addressed from a technical compatibility point of view. Although there are differences in frequency band, EIRP and possibly in polarization, it appears feasible to plan for an orderly transition of service without interruption of programming and without excessive costs.

2.3.1 Four Beams, Two Orbital Positions vs. Six Beams Three Orbital Locations

There are two suggested scenarios for a future DBS system which are briefly discussed below:

a) Four beams, two orbital locations:

Each satellite would cover half of the country, two beams for the eastern coverage and the other two to cover the Western region. The satellite covering the Eastern region would probably be positioned at about 100°W. This would prevent satellite eclipse before 1:00 a.m. in the areas served, compatible with acceptable elevation angle constraints. A broadcaster in the east (or west) would require only one uplink antenna to distribute program(s) in the same region. In the case of a national broadcasting uplink from certain areas in the extreme east of Canada, e.g. St. John's, a terrestrial link or double hopping would be required since the Western satellite positioned probably at about 135°W may not be able to cover that part of the country.

b) Six beams, 3 orbital positions:

In this model three beams would cover half of the country. For eastern coverage, two beams would be from the satellite positioned probably at about 85° W and the third beam from a satellite located at about 100°W. The elevation angle in this scenario is higher for viewers in Atlantic provinces where heavy rain fall occurs and as a result, this model would provide a smaller outage time due to a rainy atmosphere. Furthermore the chance of shielding the view of the antennas by a building or any other obstructions would be reduced. The broadcaster, however, would require an additional uplink antenna pointed to the second satellite. He would also utilize more channels in order to broadcast the same number of program(s) as in the two orbital positions case (six channels versus four for full country service). In this model, the third satellite would probably be positioned at about 135° W.

2.3.2 Satellite EIRP Consideration

In the selection of the antenna size there are two factors which determine an upper bound on the size, that is, cost and practical considerations such as ease of installation and operation. The reflector cost is the primary factor determining the antenna costs with the size also determining to a large extent the costs for mount and installation.

From a practical and operational standpoint the larger antenna sizes will result in higher mispointing losses, and increased wind and ice loading on the structure. Consideration must also be given to the esthetic impact and available space especially in urban/suburban areas. In addition, an investigation of the present state of the art of LNA's at 12 GHz and a reasonable projection of development trends indicates that a practical temperature achievable in high volume production, in the near future is about 230°K (NF= 2.5dB).

Taking these factors into consideration, a DBS system with high EIRP is more attractive to the viewers than the one with low EIRP. However, the cost of space segments would be considerably greater for a DBS with higher EIRP. This suggests that in the design of a DBS system both the satellite EIRP and receiving terminal G/T should be considered in order to minimize the total cost of the system.

2.3.3 DBS Receive Terminals

DBS receive terminals consist of three major subsystem components: an antenna, an outdoor electronic unit (ODU) and an indoor unit (IDU). For a given figure of merit G/T of a receive terminal, the principle parameters which determine this value are the antenna gain and the noise figure of the outdoor unit, comprised of a low noise amplifier and/or a down converter/pre-amplifier unit.

A cost optimization trade-off is possible in the selection of antenna size (gain) and ODU noise figure to achieve a desired performance. However, if the receiver noise figure used is the lowest practical and cannot be significantly improved without large expenditures of money, then improvements in terminal performance would most economically be achieved by increasing the antenna size.

In the receiver unit, the ODU is presently seeing very significant design development, hence, it is difficult to forecast accurately cost and performance over the next few years. Low noise amplifiers with one or two stages of amplification using Gallium-Arsenide Field Effect Transistors (GaAsFET) are presently approaching a noise figure of less than 3 dB, and are expected to approach 2 dB in the next decade.

The IDU essentially comprises the second stage of the down conversion or tuner, with filtering/amplification and a demodulator/remodulator. The unit also houses an addressable decoder. The latter can be controlled from a central point to allow the subcriber to view only those programs he has ordered.

2.3.4 Conversion of Interim TVRO terminals to a DBS System

Two approaches may be considered in conversion of interim DBS receiving terminals to a future DBS system. In the first approach, the DBS terminals are initially designed to operate over both the Anik C 11.7-12 GHz band and a future DBS 12.2-12.7 GHz band. This approach may mot be possible at this time due to the fact that the performance of a DBS TVRO terminal would be inferior if it were designed to operate over a 1 GHz band as opposed to the 500 MHz band designed either for Anik C or a future DBS system. That is, the LNA matching circuitry, the input transition as well as the GaAsFET devices and the antenna feed structure can be designed and biased for much better performance in terms of the system noise figure and the antenna characteristics over a 500 MHz operational bandwidth than a 1 GHz bandwidth.

SED of Saskatchewan is currenly developing a feed and an LNA which will operate within 11.7-12.7 GHz band. The maximum noise figure (NF) across the 1 GHz band was measured to be 3.2 dB. The price of each unit is expected to be high in the beginning, but as the market grows it should drop sharply to a few hundred dollars. SED's TVRO can easily be converted to circular polarization when it is necessary and viewers can switch either to left or right sense of CP reception.

In the second approach, however, the DBS TVRO terminals would be designed for operation in the 11.7 -12.2 GHz band such that they could, at a later date, be readily converted for operation in the 12.2-12.7 GHz band. This approach has the following advantages:

a) It provides for the lowest cost and the simplest terminal for the initial service.

b) It permits an optimum design of the terminal for the initial service.

c) It permits the latest technology and hardware to be employed (e.g. LNA) at the time the transfer to 12.2-12.7 is made.

d) It permits the "conversion kit" to be designed after the system parameters have been selected by RARC 83.

In the conversion process of receive station, the front end (i.e. antenna feed and first down conversion stage) of TVRO terminals seems to be the only major parts which would have to be retrofitted with proper hardware due to the shift in the receive frequency band and changing polarization from linear to circular.

This could be accomplished by either replacing the entire outdoor unit (antenna, feed and first down converter) or by retrofitting the antenna feed and the outdoor electronics with appropriate hardware. The cost of this conversion would, therefore, be considerably less (about 1/2) than the cost of a new DBS terminal.

Effects of differences in channel bandwidth and channel spacing on the IDU should also be considered in the design of the IDU.

It should be noted here that in the beginning when the DBS traffic is low and the adjacent channels are not used, the change from linear polarization (LP) to circular polarization (CP) may not be necessary in ther interim transition of TVRO terminals to a DBS system and they could operate for an interim time with a 3 dB polarization loss. This is due to the higher EIRP of the DBS satellite which would compensate for the polarization loss of the TVRO terminals. This is especially applicable to the case of a DBS system with high EIRP (54 dBW at the edge of coverage area), however, for a DBS system with a low EIRP (50 dBW) there could be a problem for the viewers near the edge of coverage zone. As the DBS traffic grows, unacceptable interference from adjacent cross-polarized channel would adversely affect the LP receivers and eventually the LP feeds would need to be replaced or retrofitted to CP feeds in a convenient time. Employing CP feed from the beginning in the interim DBS (Anik C) is not possible due to low EIRP characteristics of Anik C, unless one is prepared to go to a larger dish which is considerably more expensive, conspicuous and harder to mount.

2.3.5 Feeder Links

In the countries with a single beam coverage the channels of the DBS satellite can be accessed from anywhere within the country. A similar capability for countries with a multibeam coverage requires a careful planning of national feeder links. There are two types of channels for multibeam countries: regional channels accessible only from within its corresponding downlink service area and national channels accessible from inside and/or outside its corresponding downlink service area. If direct access to national channels is required from anywhere within the country, a country-wide uplink service area is needed. If direct access is required from only one or few national broadcasting centers whose locations are known, one uplink service area for each national center needs to be planned. If the locations are not known a country-wide uplink service area may still be needed for planning purposes.

National channels can either be accessed directly using feeder links to broadcasting satellites or indirectly by using a satellite in the fixed satellite service or a terrestrial microwave network for the distribution of the national programs to regional centers of the broadcasting satellite systems. Probably, this will be the case when one of the satellites is positioned at about 135°W and it may not cover some parts of Canada, in the East.

2.3.6 Conversion of Transmitting Stations

Differences in frequency band and polarization would require a major modification of Anik C uplink stations for DBS transmission. A requirement for modification to operate simultaneously at both 14 and 18 GHz may not be desirable because of technical difficulties, and the likelihood that an Anik C and a DBS spacecraft would not be colocated in orbit. Although the main antenna reflector could be designed initially for operation up to 17.8 GHz, an entirely new antenna feed and HPA would be required. Retrofitting Anik C feeder links, however, would cause down time periods as long as a month. During this period the broadcaster could lose the monthly fee from the viewers, advertising revenue and possibly some of his market due to a lengthy interruption of this program. Furthermore, not all the viewers would be prepared to repoint their TVRO terminals to a DBS satellite.

Multibeam torus antennas aimed at different satellites might be used by a broadcaster. However, the specified aperture size of a torus antenna depends on the designed field of view and it becomes very large for large separation between satellites. Furthermore, the look angle of the reflector varies with the station location and, therefore, the mount structure can be totally different from one location to the other. This makes the mount and the feed horn fixture almost useless for other locations. The initial installation, antenna erection and alignment phases of torus are also significantly more complicated than those of conventional dishes with comparable sizes. In addition, the use of torus in place of multiple conventional parabolic dishes is only cost effective if more than two satellites are simultaneously being accessed from a single site. In view of the above discussion and the possible use of Anik C as an interim DBS until late 1980's, makes the investment of a torus unattractive at this time.

The most likely approach for going to DBS system is that regional and national transmitting sites developed for Anik C would be augmented by the addition of separate antennas and HPA's for the DBS service. This plan has an advantage that there would not be any interruption on service continuity. The broadcaster could continue transmitting programs on both Anik C and the DBS system (at some added cost) until the majority of viewers have transferred to the DBS system. This transitional period to a future DBS system may take as long as six months.

2.3.7 Conclusion

The most acceptable transitional scheme from the interim DBS (Anik C) to a future DBS system would likely be as follows:

1) Anik C interim DBS system starts sometime in 1983;

2) receiving stations readily adaptable to future DBS technical characteristics (RARC 83) are installed. At the same time, transmitting earth stations would be developed;

3) A DBS system using 12.2-12.7 GHz band could start as early as 1987. During about half a year overlapping period, some programs would be carried simultaneously on Anik C and the DBS. Anik C receivers would be adapted to the DBS band (and possibly polarization) and repointed during this time.

This general scheme and the transitional problem, referred to earlier are essentially the same for both low or high EIRP and for both low or high EIRP and for two or three orbital position models.

3. Communications Subsystem Analyses

3.1 Frequency and Polarization Plans

The frequency plans developed in this section are only those which satisfy the scope of system configurations as set out by the Statement of Work and subsequent redirection resulting from the findings of this study. The initial intent was to examine systems of only two orbital stations. This plan, however, allows only up to a maximum of possibly 10 channels per service area in the case of six beam system. To overcome this limitation, systems of three orbital stations had to be considered for six beam systems.

The system characteristics considered in the development of frequency plans are the following:

a) Required Channel Bandwidth: 18 MHz.

b) System Capacity Growth Plan: Initial capacity of 8 channels per service area (beam). Ultimate capacity of 16 channels per beam.

c) Number of Orbital Stations: 2 or 3.

d) Intrasystem Interference: Aggregate C/I 30 dB based on an adjusted protection ratio mask as presented in Section 3.2.

In addition, the following design considerations have been used in the frequency plan development:

e) Number of spacecraft per orbital station.

f) Commonality of design for all spacecraft in the system.

g) Low loss, versatile output multiplexers.

Based on these general objectives specific frequency and polarization plans have been developed for the range of system contained in Table 3.1.1 and are presented in Tables 3.1.2 to 3.1.7. To satisfy the need of all the system configurations considered three basic Channel Frequency Plans are required for 32, 36 and 40 channels each. Figures 3.1-1, 3.1-2 and 3.1-3 contain these plans.

3.1 Frequency and Polarization Plans (cont'd)

The spectrum division to accomodate the required frequency plans is based on the assumption that all 500 MHz of spectrum is available to each orbital station for the transmission of identical TV channels of 18 MHz bandwidth. Transmission over this band of other services such as HDTV (High Definition TV), Telidon and Radio is possible with some modifications to the repeater and to the frequency plan in the case of Telidon and Radio.Transmission of HDTV is possible within the proposed frequency plans as presented in Section 3.6. The portion of the spectrum required for transmission of Telidon and Radio is expected to be small, hence such spectrum allocation will not affect the validity of the conclusions drawn from the present spectrum division.

Channel spacings have been derived by the following method:

Available Spectrum	: 500 MHz
Guard Band as per WARC 79 Based on 55 dBW EOC EIRP	: 13 MHz
Number of Channels N	: 40
	: 36
	: 32

Channel spacing: $\frac{500 - 13}{N+1}$ for cross-polarized channels

$\frac{500 - 13}{N+1}$ X 2 for co-polarized channels

3.1 Frequency and Polarization Plans (cont'd)

	40 CH PLAN	36 CH PLAN	32 CH PLAN
Cross-polarized Channel spacing	11.9 MHz	13.2 MHz	14.8 MHz
Co-polarized Channel spacing	23.8 MHz	26.3 MHz	29.5 MHz

The resulting channel frequency plans are shown in Figures 3.1.1, 3.1.2 and 3.1.3.

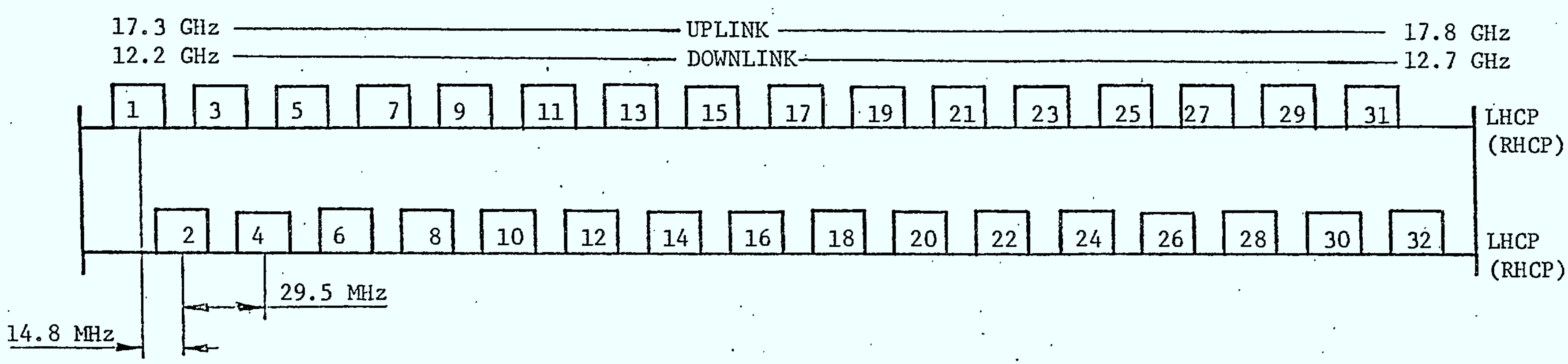


FIGURE 3.1.1 32 CHANNEL FREQUENCY PLAN

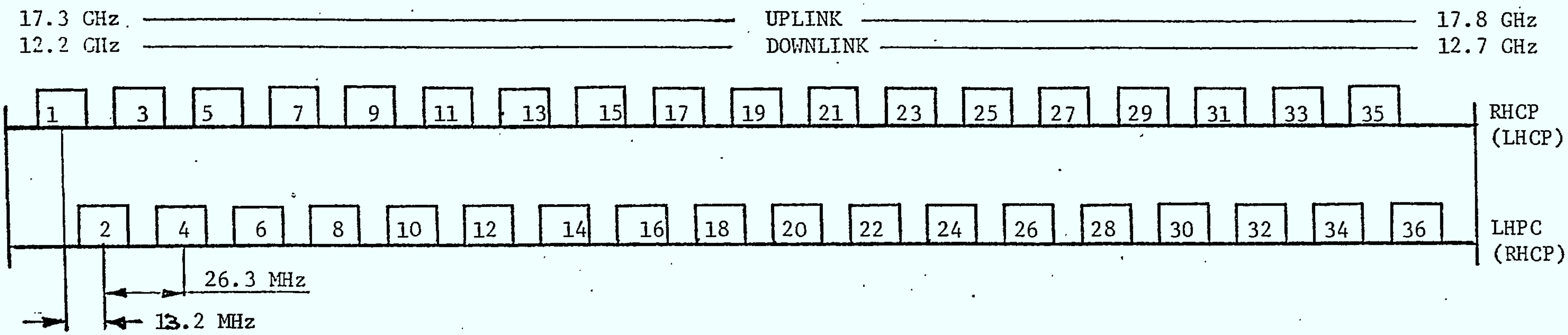


FIGURE 3.1.2 36 CHANNEL FREQUENCY PLAN

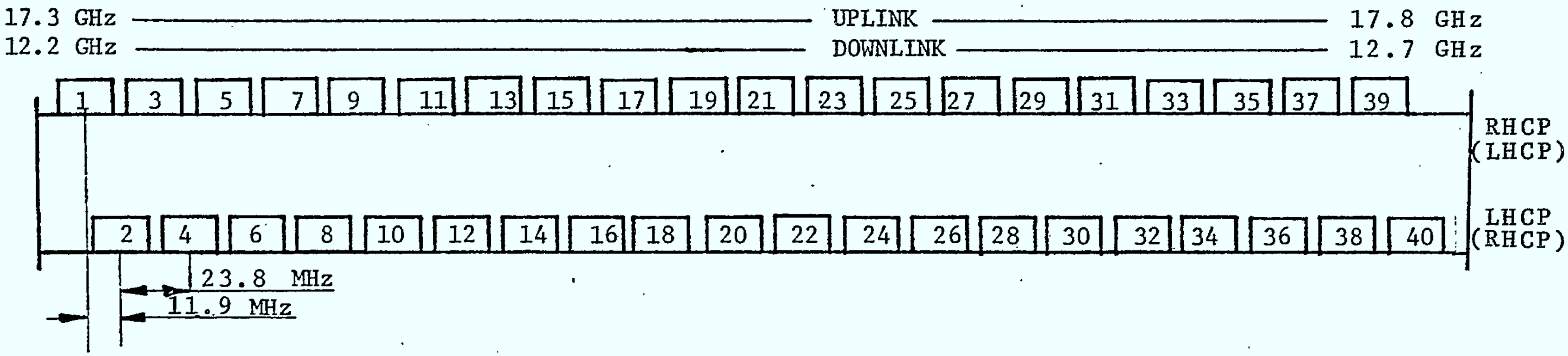


FIGURE 3.1.3 40 CHANNEL FREQUENCY PLAN

NUMBER OF ORBITAL STATIONS	NUMBER OF BEAMS IN SYSTEM	NUMBER OF CHANNELS PER BEAM	NUMBER OF CHANNELS PER ORBITAL STATION	NUMBER OF CHANNELS PER POLARIZATION	FREQUENCY PLAN REQUIRED	NUMBER OF SPACECRAFT FOR FULL SYSTEM
2	4	16	32	16	32 channel	4,8
	6	8*	24	16	32 channel	2,4
		9*	27	18	36 channel	2
		10*	30	20	40 channel	2,4
3	6	16	32	16	32 channel	6,12

* This system configuration cannot provide the required ultimate capacity of 16 channels per beam.

TABLE 3.1.1 REQUIRED FREQUENCY PLAN FOR FULLY GROWN SYSTEM

ORBITAL STATION	130° W			100° W	
BEAM	1	2		3	4
POLARIZATION	RHCP	LHCP		RHCP	LHCP
SC1W	1 - 5 9 - 13 17 - 21 25 - 29	2 - 6 10 - 14 18 - 22 26 - 30	SC1E	1 - 5 9 - 13 17 - 21 25 - 29	2 - 6 10 - 14 18 - 22 26 - 30
SC2W	3 - 7 11 - 15 19 - 23 27 - 31	4 - 8 12 - 16 20 - 24 28 - 32	SC2E	3 - 7 11 - 15 19 - 23 27 - 31	4 - 8 12 - 16 20 - 24 28 - 32

TABLE 3.1.2 - FREQUENCY AND POLARIZATION PLAN FOR CONFIGURATION 2416/16

ORBITAL STATION	130° W			100° W	
BEAM	1	2		3	4
POLARIZATION	RHCP	LHCP		RHCP	LHCP
SC1W	1 - 9 - 17 - 25	2 - 10 - 18 - 26	SC1E	1 - 9 - 17 - 25	2 - 10 - 18 - 26
SC2W	3 - 11 - 19 - 27	4 - 12 - 20 - 28	SC2E	3 - 11 - 19 - 27	4 - 12 - 20 - 28
SC3W	5 - 13 - 21 - 29	6 - 14 - 22 - 30	SC3E	5 - 13 - 21 - 29	6 - 14 - 22 - 30
SC4W	7 - 15 - 23 - 31	8 - 16 - 24 - 32	SC4E	7 - 15 - 23 - 31	8 - 16 - 24 - 32

TABLE 3.1.3 - FREQUENCY AND POLARIZATION PLAN FOR CONFIGURATION 2416/8

ORBITAL STATION	WESTERN			CENTRAL			EASTERN	
BEAM	1	2		3	4		5	6
POLARIZATION	RHCP	LHCP		RHCP	LHCP		RHCP	LHCP
SC1W	1 – 5 9 – 13 17 – 21 25 – 29	2 – 6 10 – 14 18 – 22 26 – 30	SC 1C	1 – 5 9 – 13 17 – 21 25 – 29	2 – 6 10 – 14 18 – 22 26 – 30	SC 1E	1 – 5 9 – 13 17 – 21 25 – 29	2 – 6 10 – 14 18 – 22 26 – 30
SC2W	3 – 7 11 – 15 19 – 23 27 – 31	4 – 8 12 – 16 20 – 24 28 – 32	SC 2C	3 – 7 11 – 15 19 – 23 27 – 31	4 – 8 12 – 16 20 – 24 28 – 32	SC 2E	3 – 7 11 – 15 19 – 23 27 – 31	4 – 8 12 – 16 20 – 24 28 – 32

TABLE 3.1.4 – FREQUENCY AND POLARIZATION PLAN FOR CONFIGURATION 3616/16

TABLE 3.1.4 – FREQUENCY AND POLARIZATION PLAN FOR CONFIGURATION 3616/16

ORBITAL STATION	WESTERN			CENTRAL			EASTERN	
BEAM	1	2		3	4		5	6
POLARIZATION	RHCP	LHCP		RHCP	LHCP		RHCP	LHCP
SC1W	1-9-17-25	2-10-18-26	SC 1E	1-9-17-25	2-10-18-26	SC 1E	1-9-17-25	2-10-18-26
SC2W	3-11-19-27	4-12-20-28	SC 2E	3-11-19-27	4-12-20-28	SC 2E	3-11-19-27	4-12-20-28
SC3W	5-13-21-29	6-14-22-30	SC 3E	5-13-21-29	6-14-22-30	SC 3E	5-13-21-29	6-14-22-30
SC4W	7-15-23-31	8-16-24-32	SC 4E	7-15-23-31	8-16-24-32	SC 4E	7-15-23-31	8-16-24-32

TABLE 3.1.5 - FREQUENCY AND POLARIZATION PLAN FOR CONFIGURATION 3616/8

TABLE 3.1.5 - FREQUENCY AND POLARIZATION PLAN FOR CONFIGURATION 3616/8

ORBITAL STATION	130° W				100° W		
BEAM	1	2	3		4	5	6
POLARIZATION	RHCP	LHCP	RHCP		RHCP	LHCP	RHCP
SCW	1	2	3	SCE	1	2	3
	5	6	7		5	6	7
	9	10	11		9	10	11
	13	14	15		13	14	15
	17	18	19		17	18	19
	21	22	23		21	22	23
	25	26	27		25	26	27
8 CH/BEAM	29	30	31		29	30	31
9 CH/BEAM	33	34	35		33	34	35
10 CH/BEAM	37	38	39		37	38	39

TABLE 3.1.6 - FREQUENCY AND POLARIZATION PLAN FOR CONFIGURATIONS 268/24, 269/27, 2610/30

TABLE 3.1.6 - FREQUENCY AND POLARIZATION PLAN FOR CONFIGURATIONS 268/24, 269/27, 2610/30

ORBITAL STATION	130° W				100° W		
BEAM	1	2	3		4	5	6
POLARIZATION	RHCP	LHCP	RHCP		RHCP	LHCP	RHCP
SC1W — 8 CH/BEAM	1 9 17 25	2 10 18 26	3 11 19 27	SC1E	1 9 17 25	2 10 18 26	3 11 19 27
SC1W — 10 CH/BEAM	33	34	35		33	34	35
SC2W — 8 CH/BEAM	5 13 21 29	6 14 22 30	7 15 23 31	SC2E	5 13 21 29	6 14 22 30	7 15 23 31
SC2W — 10 CH/BEAM	37	38	39		37	38	39

TABLE 3.1.7 - FREQUENCY AND POLARIZATION PLAN FOR CONFIGURATIONS 268/12 and 2610/15

TABLE 3.1.7 - FREQUENCY AND POLARIZATION PLAN FOR CONFIGURATIONS 268/12 and 2610/15

3.2 Intrasystem Interference

The following interference analysis covers only the intrasystem interference and applies to system configurations considered in this study. Any external interference resulting from other systems is assumed to be considered elsewhere and has been omitted.

Three system configurations are considered necessary to cover the range of possibilities:

a) 4 Beams, 2 orbit locations - 16 channels/beam

b) 6 Beams, 2 orbit locations -
   - 8 channels/beam
   - 9 channels/beam
   - 10 channels/beam

c) 6 Beams, 3 orbit locations - 16 channels/beam

In case b) the analysis is carried to an ultimate capacity of 10 channels/beam which is considered a practical limit to the allowable channel separation.

The system parameters which determine the level of interference in the system are described below.

Figure 3.2.1 gives the Interference Protection ratio resulting from the carrier frequency separation. This characteristic is based on the WARC 79 recommendations and has been adjusted for the narrower channel bandwidth for Region 2. The original characteristic was derived from a channel bandwidth of 27 MHz. The "adjusted" characteristic has been derived by prorating the frequency scale of the original at the ratio of 18 ÷ 27. The validity of this approach has been assumed without supporting analysis.

Antenna cross-polarization discrimination (XPD) figures have been derived from WARC '79 where available otherwise other sources have been used as indicated below. Two interference calculations have been performed to show sensitivity to the satellite antennas XPD of which realisable limits have yet to be defined.

Antenna	XPD Values	
	Set #1	Set # 2
Ground Uplink	30dB (INTELSAT V)	30dB (INTELSAT V)
Spacecraft Uplink	33dB (assumed)	27dB (INTELSAT V)
Spacecraft Downlink	33dB (WARC '79)	27dB (INTELSAT V)
Individual Receiver	25dB (WARC '79)	25dB (WARC '79)
Total System XPD	22.9dB	20.9dB

Set #1 antenna parameters are mainly based on WARC '79 objectives for Region 2. The ground uplink and individual receiver antenna XPD is expected to remain as shown. The spacecraft transmit and receive antenna XPD are considered somewhat optimistic for circularly polarized shaped beam antenna. In addition, it might not be necessary to burden the spacecraft antenna design with very stringent XPD requirements while the individual receiver antenna is effectively controling the system XPD. The sensitivity of system XPD to satellite XPD is illustrated by set #2 which uses more conservative but realizable spacecraft XPD values.

The copolar angular discrimination of the satellite transmit and the individual reception antennas are the only ones which enter the interference calculations. The WARC '79 reference patterns of Figure 3.2.2 and 3.2.3 have been assumed for this purpose. If 1m diameter individual reception antenna is assumed the copolar angular discrimination towards other satellite positions is as follows:

15^{o} orbital arc spacing = 32 dB

20^{o} orbital arc spacing = 35 dB

30^{o} orbital arc spacing = 38 dB

The transmit satellite antenna has been assumed to provide conservatively, 5 dB discrimination into copolarized adjacent beams and 0 dB discrimination into adjacent crosspolarized beams.

Interference occurrence situations encountered in the three system configurations considered in this study are shown in Figures 3.2.4, 3.2.5, and 3.2.6. The only significant interference components considered here are:

a) Co-channel

b) Adjacent co-polarized channels

c) Adjacent cross-polarized channels

All other interference components have negligible effect and have been omitted.

The resulting interference values are presented in Tables 3.2.1, 3.2.2, 3.2.3 and 3.2.4.

The agregate C/I for the system presented in Table 3.2.3 and 3.2.4 indicate that the 30 dB objective is met in all cases of orbital station spacing of 20° or greater. The effect of the relaxed satellite antenna XPD (Set #2) is almost insignificant in the cases of 4 Beam, 2 orbit location and 6 beam, 3 orbit location systems. The total C/I degradation in the case of the 6 beam, 2 orbit location system is significant and in the order of 1.5 dB. This increased sensitivity of the latter system configuration does not cause the aggregate C/I to fall below the 30 dB objective, hence it is not expected to drive the satellite antenna XPD objective upwards.

The conclusions to be drawn from this interference analysis are that all the selected frequency plans, antenna parameters and system configurations can satisfy the interference performance objectives to a satellite spacing of about 17°. Interference becomes marginal at 15° spacing although it might be still acceptable.

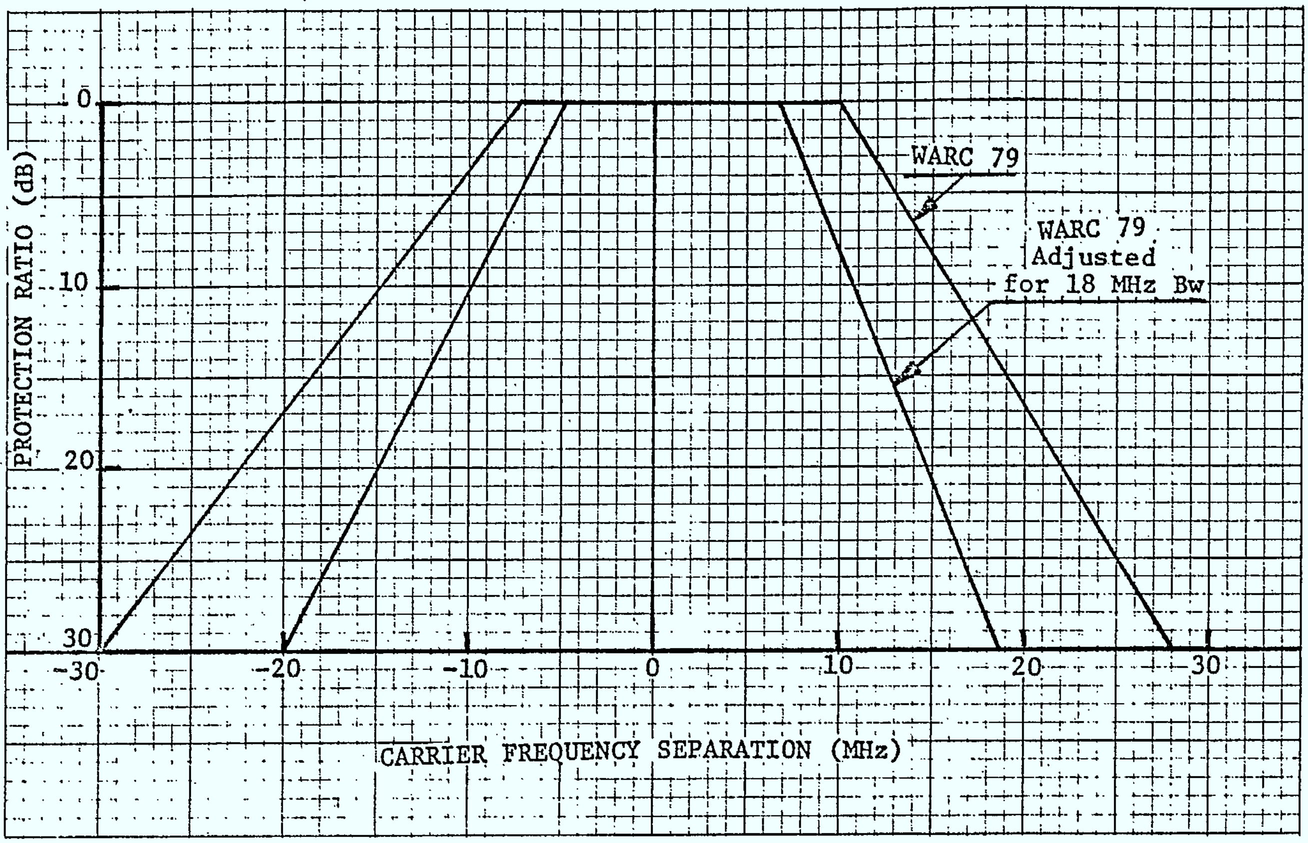


Figure 3.2.1 Interference Protection Ratio

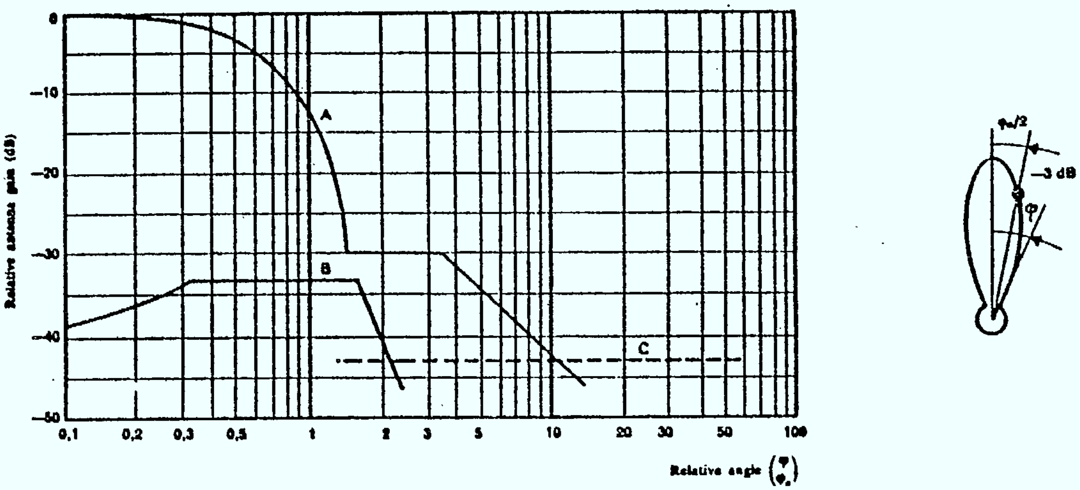


Figure 3.2.2 Reference Pattern for Satellite
Transmit Antenna (WARC '79)

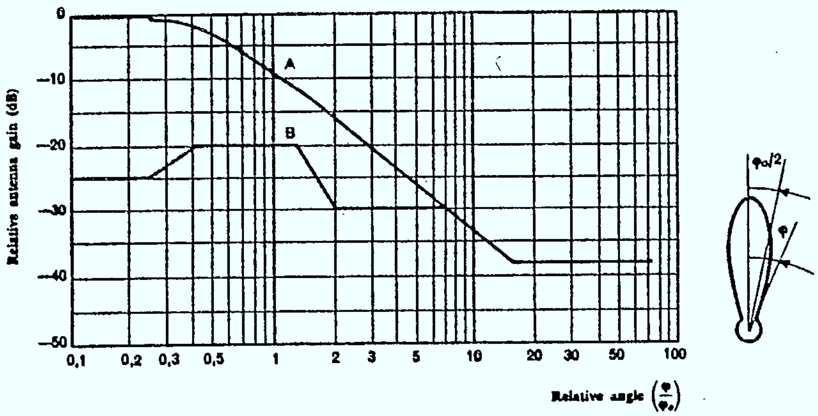
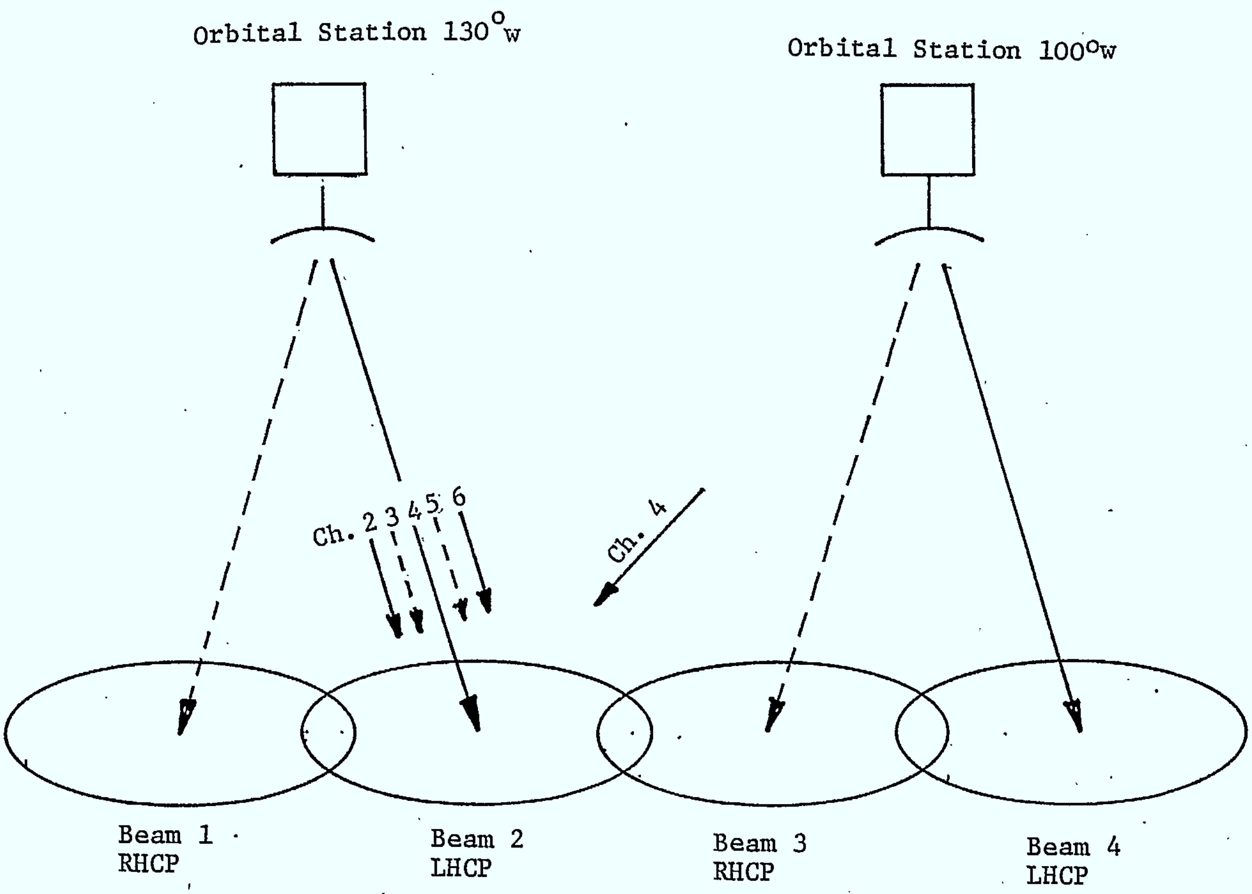


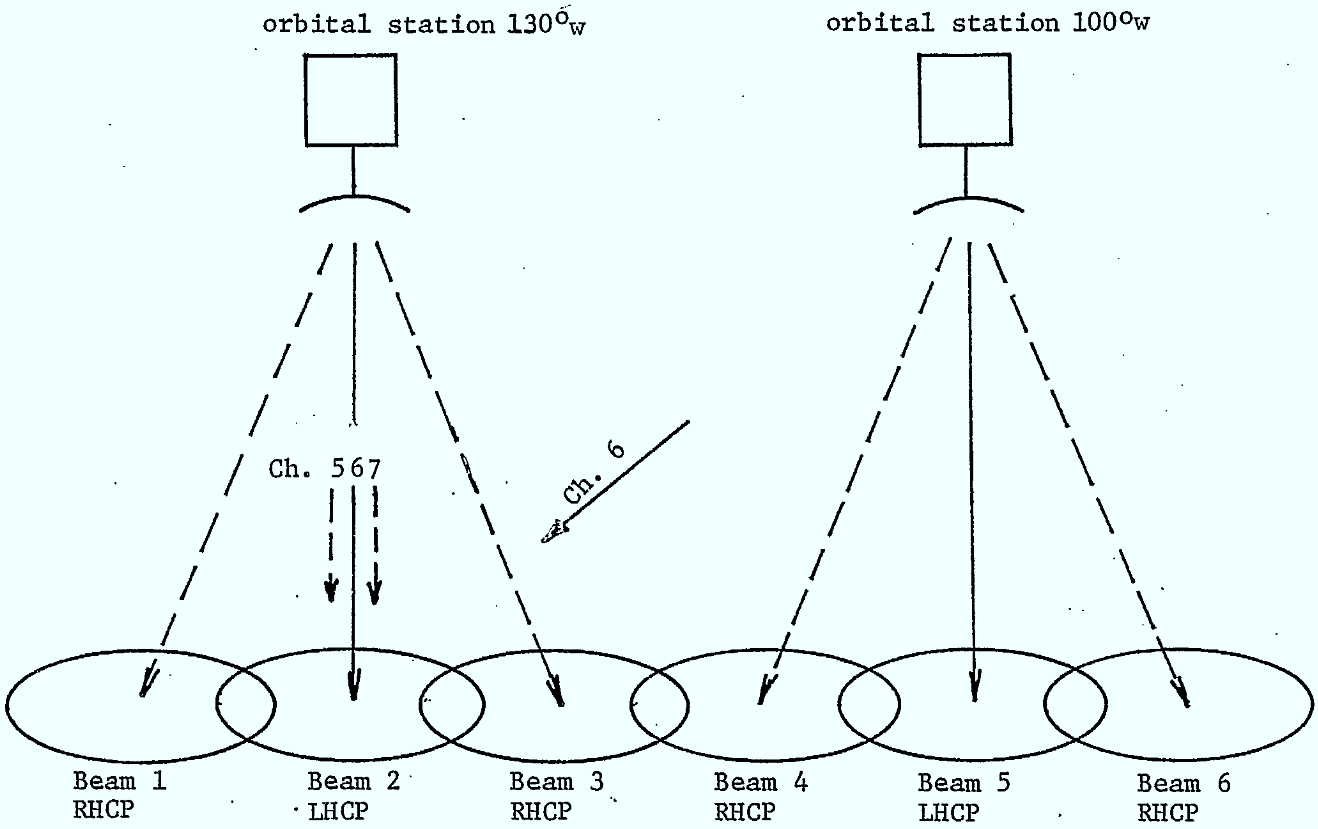
Figure 3.2.3 Reference Pattern for Individual Reception
Antenna (WARC '79)



Example of Interference (worst case)

Victim Channel	: Ch. 4, Beam 2
Interfering Channels	:
- within same orbital location	: Ch. 3 and 5 adjacent crosspolarized from Beam 1
	Ch. 2 and 6 adjacent copolarized from within same Beam
- from other orbital location	: Ch. 4 cochannel copolarized from Beam 4

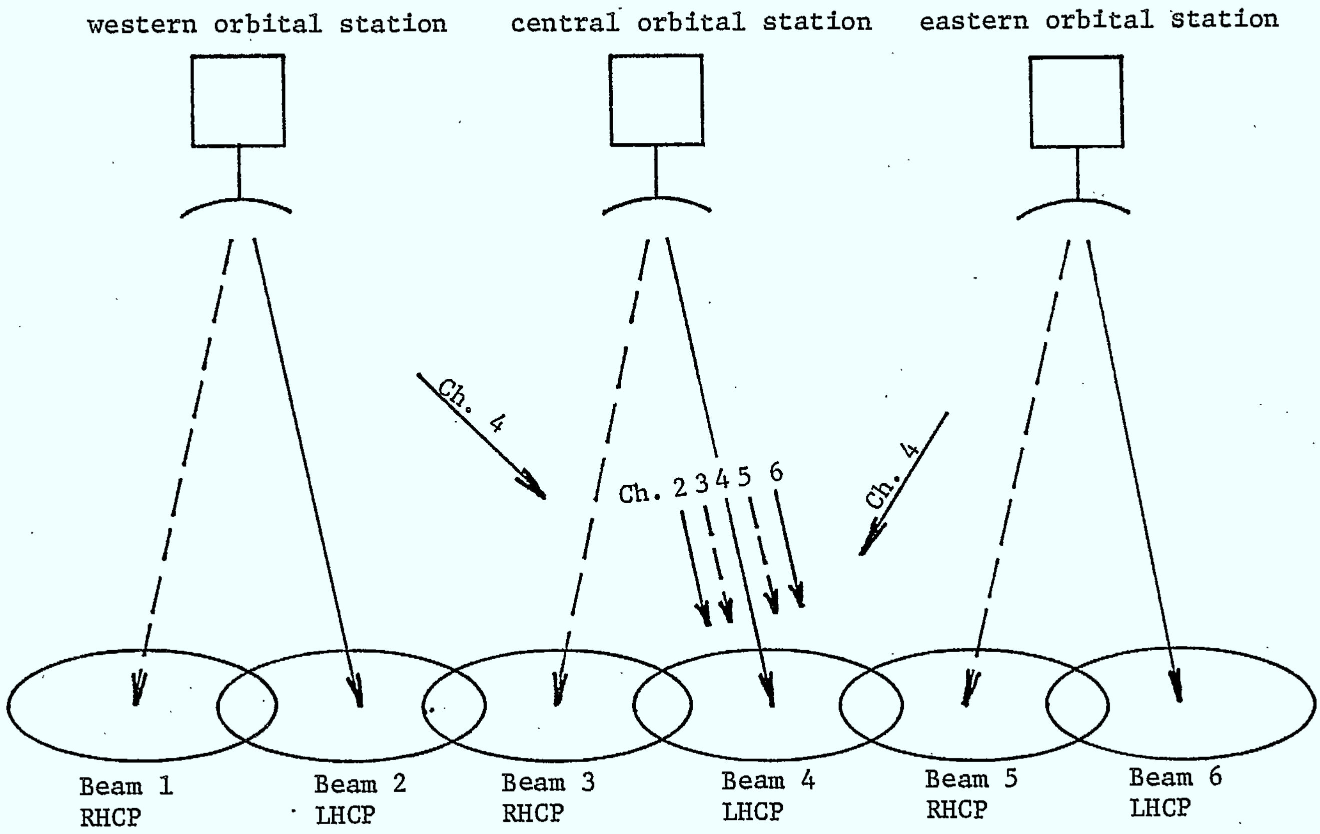
FIGURE 3.2.4 OCCURRENCE OF INTERFERENCE IN 4 BEAM, 2 ORBITAL LOCATION SYSTEM



example of interference(worst case)

Victim channel	:	Ch.6 in Beam 2
Interfering channels		
- within same orbital location	:	Ch.5 and 7 adjacent cross-polarized from beams 1 and 3
		Ch.4 and 8 are not used in this frequency plan
- from other orbital location	:	Ch.6 Cochannel copolarized from Beam 5

FIGURE 3.2.5 OCCURRENCE OF INTERFERENCE IN 6 BEAM, 2 ORBITAL LOCATION SYSTEM



Example of Interference(worst case)

Victim Channel	:	Ch. 4 in beam 4
Interfering Channels		
- within same orbital location	:	Ch. 3 and 5 adjacent crosspolarized from Beam 3
		Ch. 2 and 6 adjacent copolarized from within same beam
- from other orbital location	:	Ch. 4 from Beams 2 and 6

FIGURE 3.2.6 OCCURRENCE OF INTERFERENCE IN
6 BEAM, 3 ORBITAL LOCATION SYSTEM

	40 Channel Frequency Plan	36 Channel Frequency Plan	32 Channel Frequency Plan
Crosspol Frequency Spacing	11.94 MHz	13.2 MHz	14.8 MHz
Frequency Spacing Improvement	14 dB	16.5 dB	20 dB
Total System XPD	22.9 dB	22.9 dB	22.9 dB
C/I due to 2 Crosspol Entries	33.9 dB	36.4 dB	39.9 dB
Copol Frequency Spacing	23.8 MHz	26.3 MHz	29.5 MHz
Frequency Spacing Improvement	37 dB	42 dB	48 dB
Antenna Angular Discrimination	5 dB	5 dB	0 dB
C/I due to 2 Copol Entries	39 dB	44 dB	45 dB
Total C/I (4 entries)	32.7 dB	35.7 dB	38.7 dB

TABLE 3.2.1 <u>C/I ASSOCIATED WITH ONE ORBITAL LOCATION BASED ON SET #1 ANTENNA CHARACTERISTICS</u>

	40 Channel Frequency Plan	36 Channel Frequency Plan	32 Channel Frequency Plan
Crosspol Frequency Spacing	11.94 MHz	13.2 MHz	14.8 MHz
Frequency Spacing Improvement	14 dB	16.5 dB	20 dB
Total System XPD	20.9 dB	20.9 dB	20.9 dB
C/I due to 2 Crosspol Entries	31.9 dB	34.4 dB	37.9 dB
Copol Frequency Spacing	23.8 MHz	26.3 MHz	29.5 MHz
Frequency Spacing Improvement	37 dB	42 dB	48 dB
Antenna Angular Discrimination	5 dB	5 dB	0 dB
C/I due to 2 Copol Entries	39 dB	44 dB	45 dB
Total C/I (4 entries)	31.1 dB	33.9 dB	37.1 dB

TABLE 3.2.2 C/I ASSOCIATED WITH ONE ORBITAL LOCATION BASED ON SET #2 ANTENNA CHARACTERISTICS

	4 BEAM – 2 ORBIT LOCATIONS SYSTEM	6 BEAM – 3 ORBIT LOCATIONS SYSTEM	6 BEAM – 3 ORBIT LOCATIONS SYSTEM	6 BEAM – 2 ORBIT LOCATIONS SYSTEM		
				8 CH/BEAM	9 CH/BEAM	10 CH/BEAM
SATELLITE SEPARATION	30^{o}	15^{o}	20^{o}	30^{o}	30^{o}	30^{o}
RECEIVER ANTENNA DISCRIMINATION	38 dB	32 dB	35 dB	38 dB	38 dB	38 dB
TRANSMIT ANTENNA DISCRIMINATION	0 dB	0 dB	0 dB	5 dB	5 dB	5 dB
C/I DUE TO COCHANNEL FROM ADJACENT SATELLITE (S)	38 dB (ONE ENTRY)	29 dB (TWO ENTRIES)	32 dB (TWO ENTRIES)	43 dB (ONE ENTRY)	43 dB (ONE ENTRY)	43 dB (ONE ENTRY)
C/I FROM OWN ORBITAL LOCATION	38.7 dB	38.7 dB	38.7 dB	39.9 dB	36.4 dB	33.9 dB
AGGREGATE C/I	35.3 dB	28.6 dB	31.2 dB	38.2 dB	35.5 dB	33.4 dB

TABLE 3.2.3 SUMMARY OF INTRASYSTEM C/I INCLUDING ALL CONTRIBUTORS BASED ON SET #1 ANTENNA CHARACTERISTICS

	4 BEAM - 2 ORBIT LOCATIONS SYSTEM	6 BEAM - 3 ORBIT LOCATIONS SYSTEM	6 BEAM - 3 ORBIT LOCATIONS SYSTEM	6 BEAM - 2 ORBIT LOCATIONS SYTEM		
				8 CH/BEAM	9 CH/BEAM	10 CH/BEAM
SATELLITE SEPARATION RECEIVER ANTENNA DISCRIMINATION TRANSMIT ANTENNA DISCRIMINATION	30° 38 dB 0 dB	15° 32 dB 0 dB	20° 35 dB 0 dB	30° 38 dB 5 dB	30° 38 dB 5 dB	30° 38 dB 5 dB
C/I DUE TO COCHANNEL FROM ADJACENT SATELLITE (S) C/I FROM OWN ORBITAL LOCATION	38 dB (ONE ENTRY) 37.1 dB	29 dB (TWO ENTRIES) 37.1 dB	32 dB (TWO ENTRIES) 37.1 dB	43 dB (ONE ENTRY) 37.9 dB	43 dB (ONE ENTRY) 34.4 dB	43 dB (ONE ENTRY) 31.9 dB
AGGREGATE C/I	34.5 dB	28.4 dB	30.8 dB	36.7 dB	33.8 dB	31.6 dB

TABLE 3.2.4 SUMMARY OF INTRAYSTEM INTERFERENCE INCLUDING ALL CONTRIBUTORS BASED ON SET #2 ANTENNA CHARACTERISTICS

3.3 Block Diagram Development

Key repeater block diagrams were generated to support the weight and power estimates, verification of channel multiplexing concepts and redundancy schemes. Initially six diagrams were produced covering all the different families of the system models developed for use in the selection of models for conceptual design. Specifically these diagrams correspond to the models indicated by a block in Figure 3.3.1.

The important features of the repeater configuration developed are listed:

a) Receiver redundancy is identical in all models. A four-for-two redundancy scheme has been used and it is achievable by two ferrite input switches and two C-type switches. The receiver outputs are connected to the input multiplexers via 3dB hybrids for increased reliability in contrast to use of switches.

b) Full capacity input multiplexers are used in these models where two or more spacecraft share one orbital location. This scheme provides increased operational flexibility of channel assignments and permits a common repeater design to satisfy the full growth plan including spare satellites.

c) The output multiplexers involve duplexers, quadruplexers and pentaplexers. The channel assignment flexibility is achieved here by using wideband filters capable of handling more than one channel(non simultaneously) as required by the specific configuration. This approach provides low multiplexing loss as well as low weight and increased reliability by eliminating selectable dual multiplexers.

d) Channel amplifier and TWTA redundancy is shown for single ring redundancy and mainly 5 for 4 sparing.

e) Antenna configurations shown in Figure 3.3.2 to 3.3.7 apply to the pre-conceptual design phase and are based on the previous DBS study. As a result of the conceptual design the antenna configuration has been changed into the form of Figures 3.3.8 and 3.3.9 which represent the conceptual design models. The dual mode antenna has been retained in the design models based on preliminary trade-off examination during the design phase. Similar trade-offs have not been performed on the remaining models.

Of the attached eight block diagrams the first six annotated as "selection models" apply to the initial model development phase and are partially obsolete in the antenna area as pointed out above. Figures 3.3.8 and 3.3.9 represent the conceptual design models. They have been derived from the original block diagrams in all aspects except antennas.

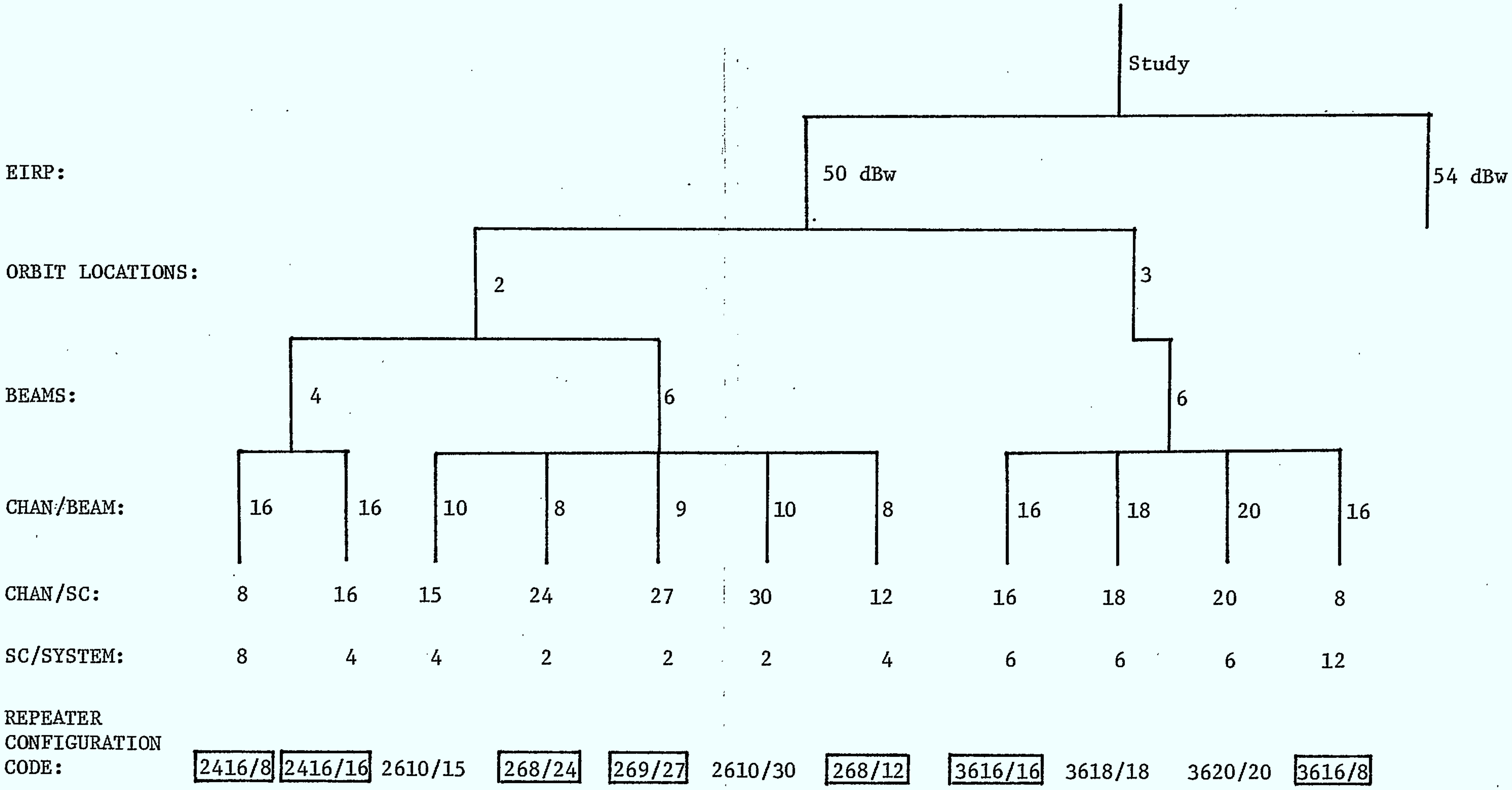


FIGURE 3.3.1 REPEATER CONFIGURATIONS DEVELOPED

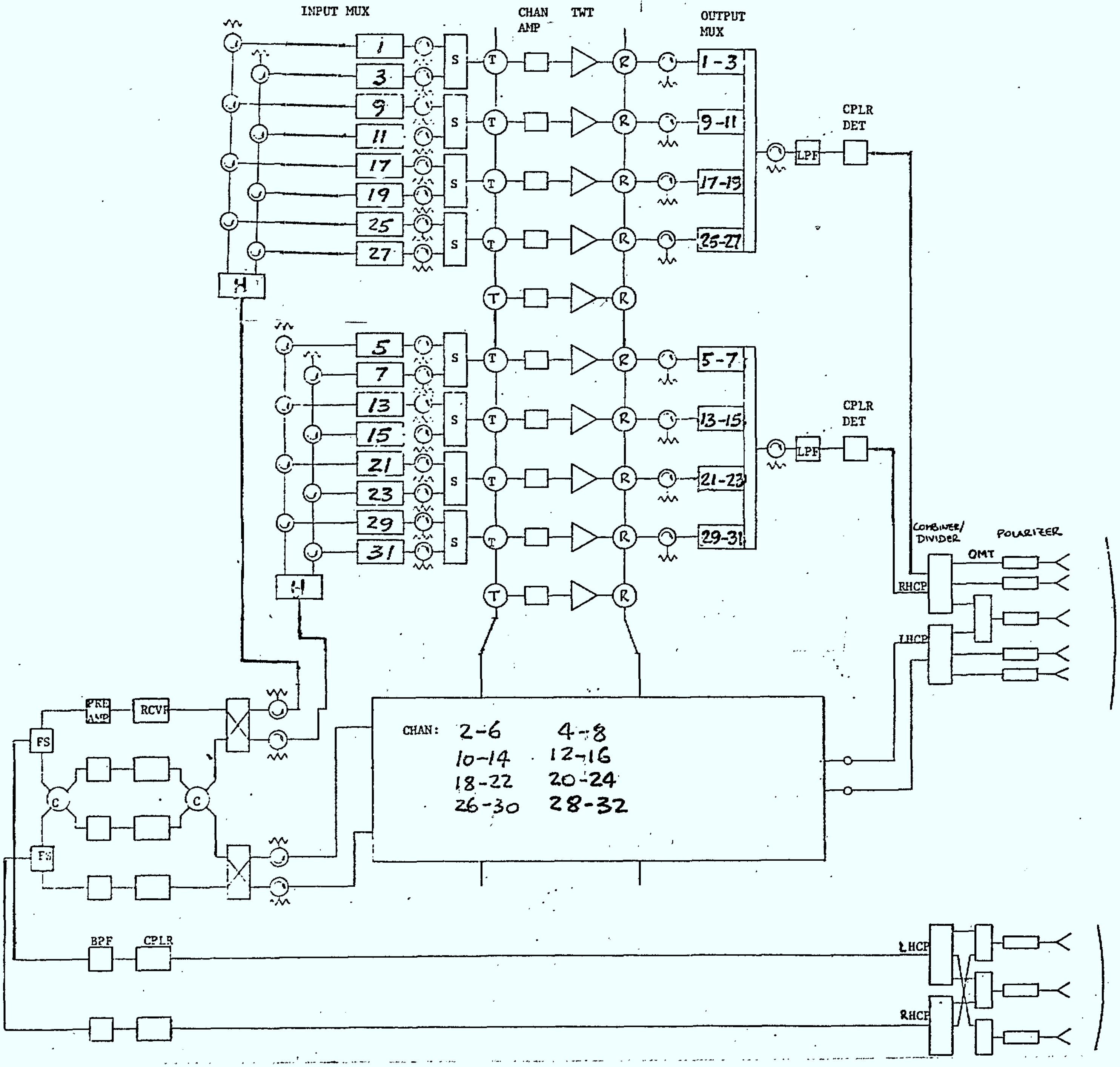


FIGURE 3.3.2 REPEATER CONFIGURATION 2416/16 (SELECTION MODEL)

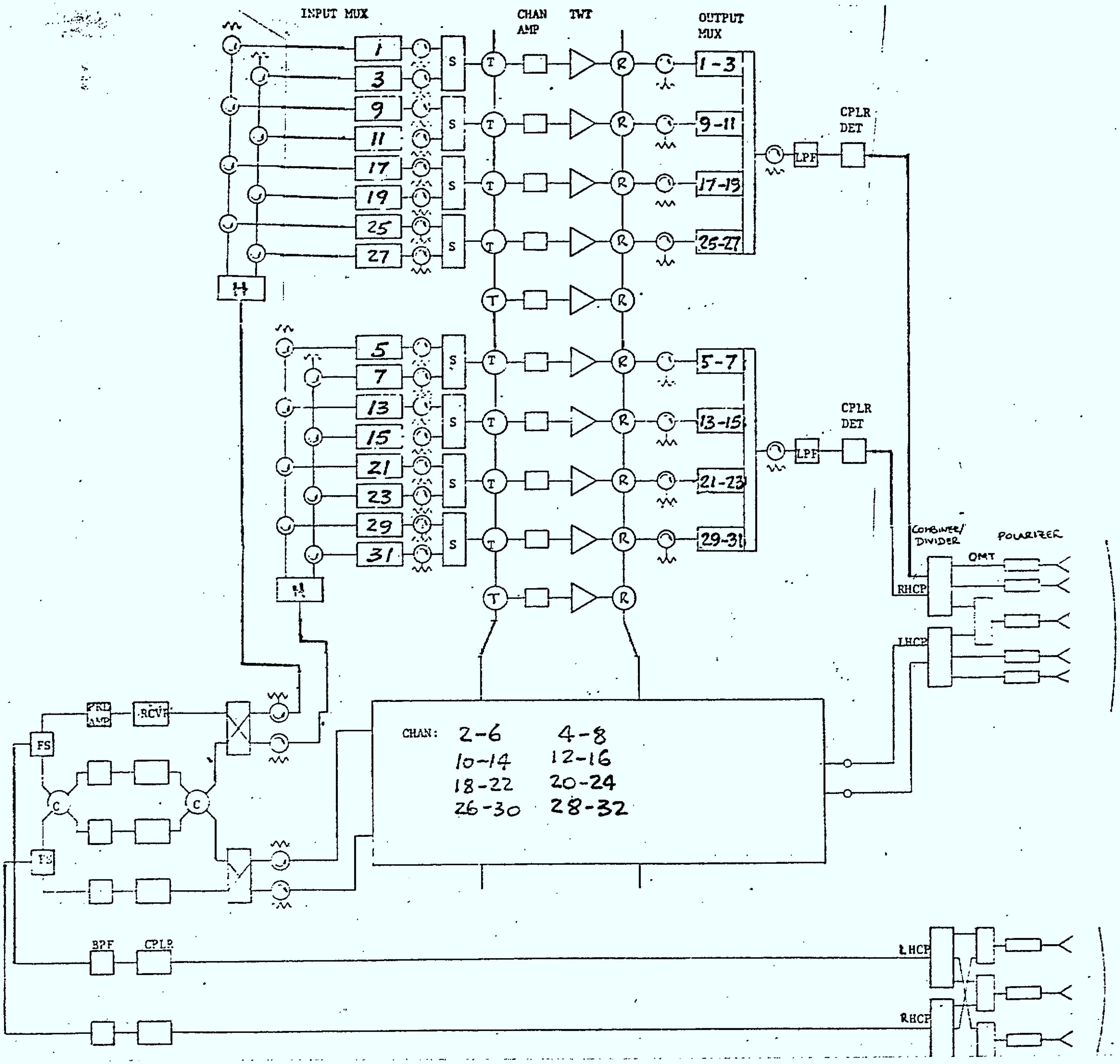


FIGURE 3.3.3 REPEATER CONFIGURATION 3616/16 (SELECTION MODEL)

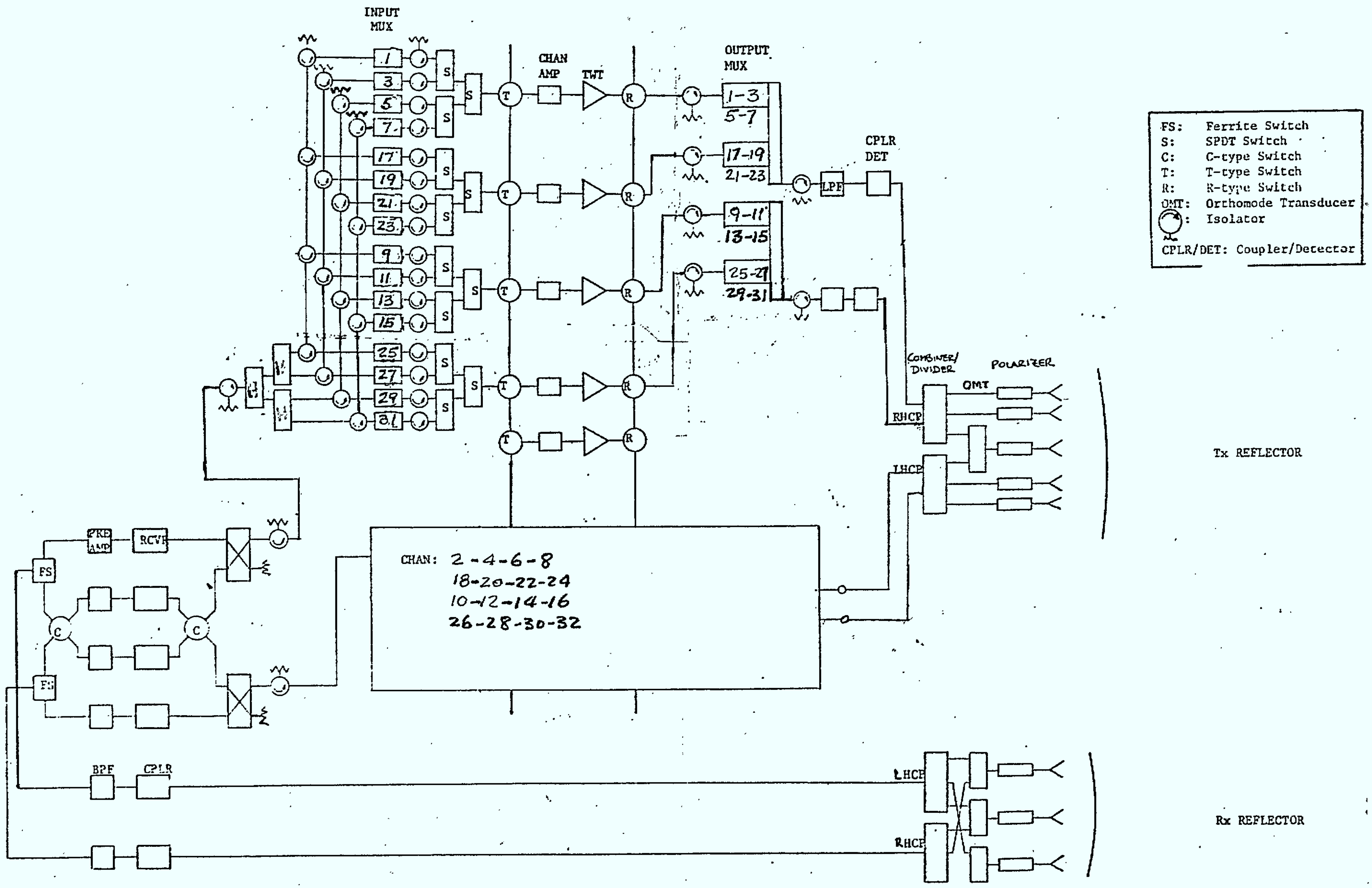


FIGURE 3.3.4 REPEATER CONFIGURATION 2416/8 & 3616/8 (SELECTION MODEL)

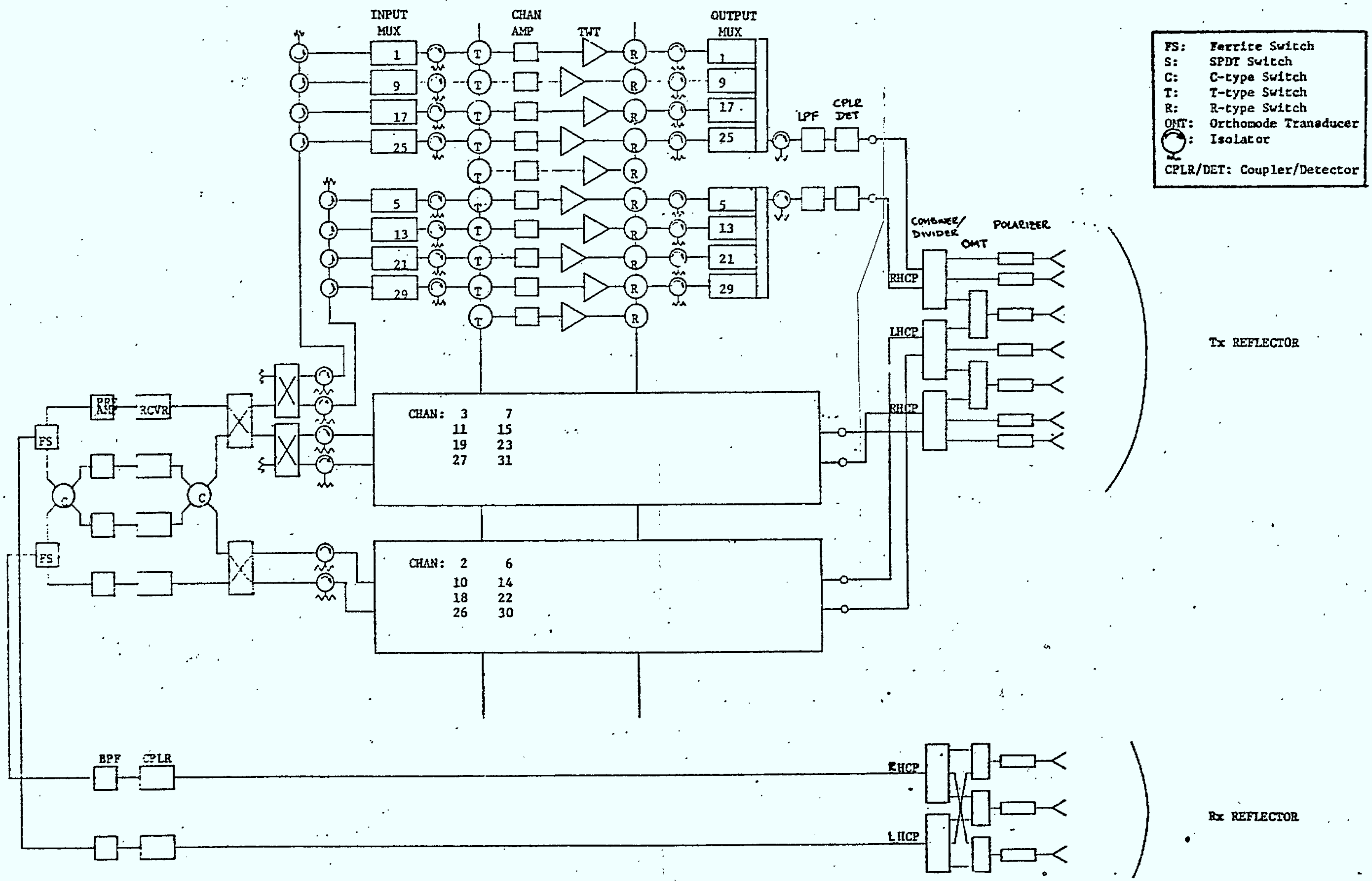


FIGURE 3.3.5 REPEATER CONFIGURATION 268/24 (SELECTION MODEL)

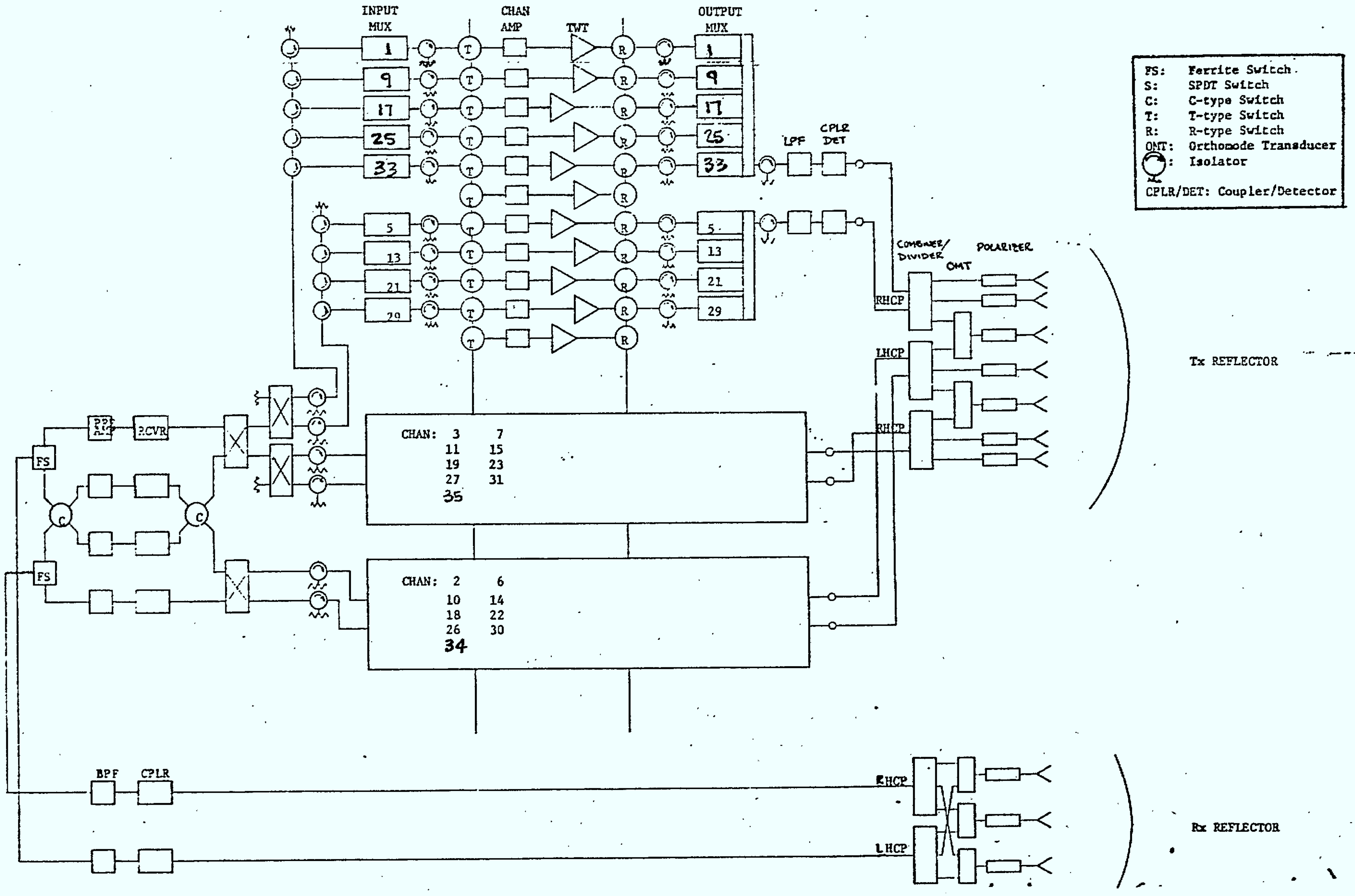


FIGURE 3.3.6 REPEATER CONFIGURATION 269/27 (SELECTION MODEL)

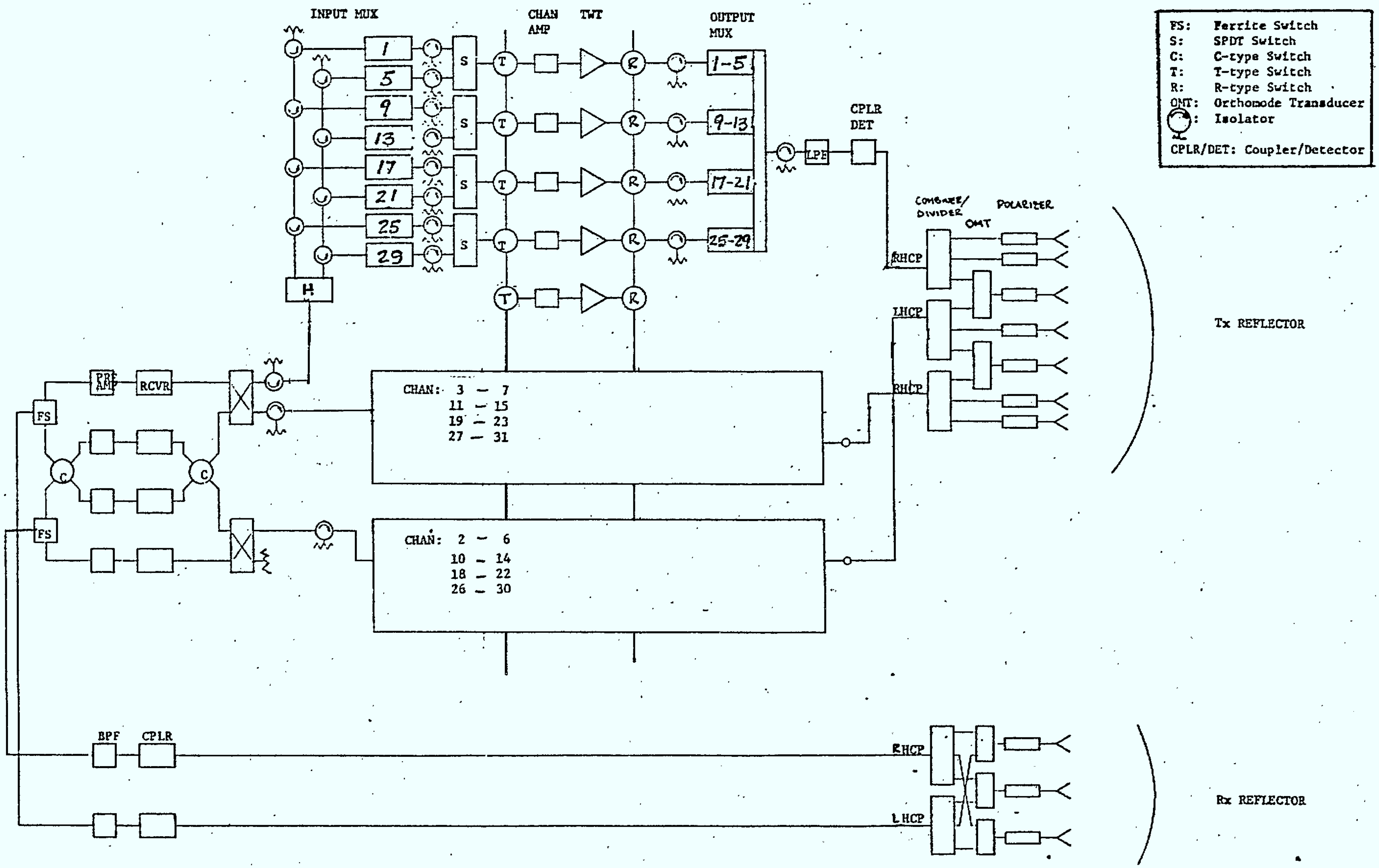


FIGURE 3.3.7 REPEATER CONFIGURATION 268/12 (SELECTION MODEL)

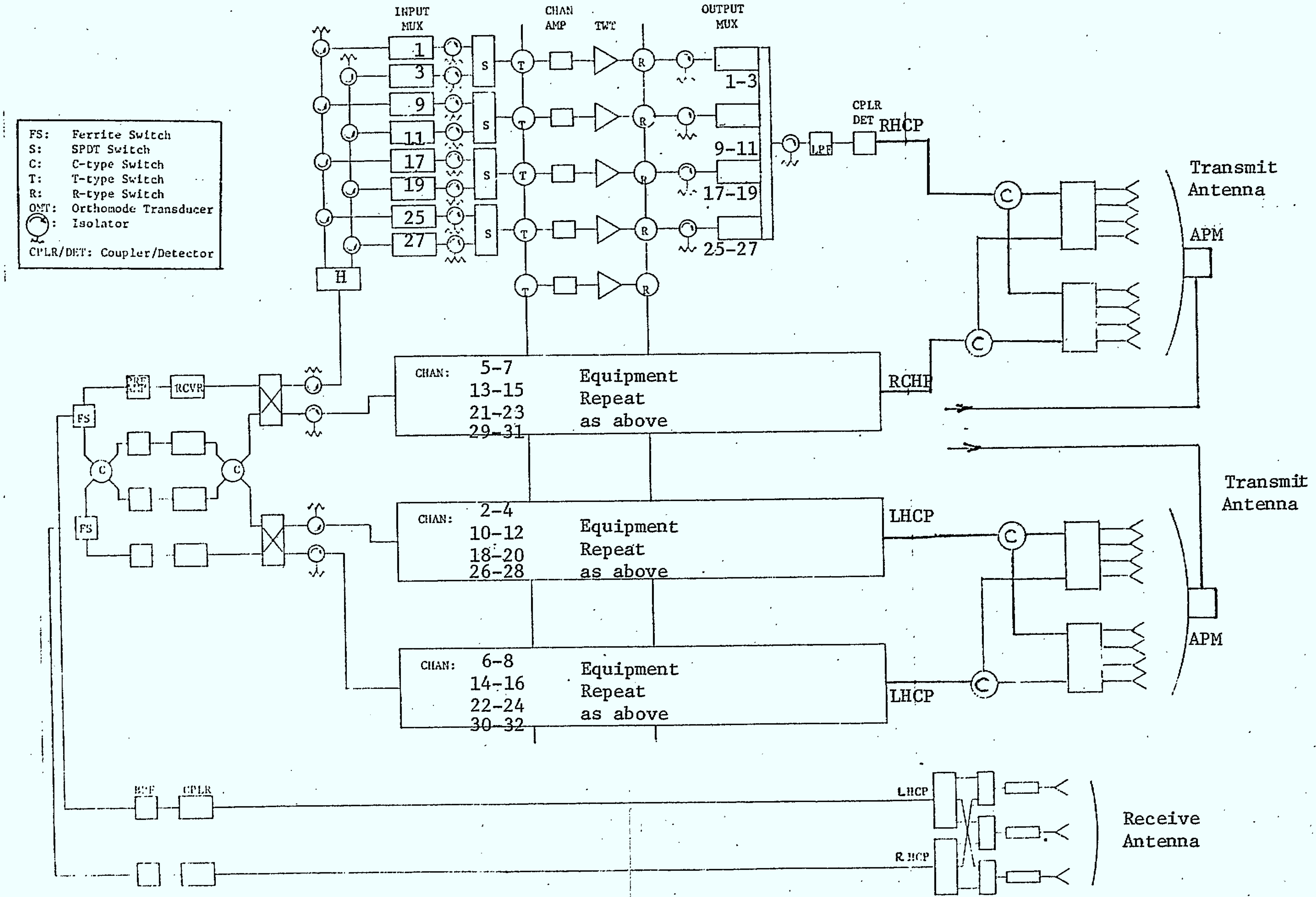


FIGURE 3.3.8 Repeater Configuration of Four Beam Two Orbit Location System (2416/16) Design Model

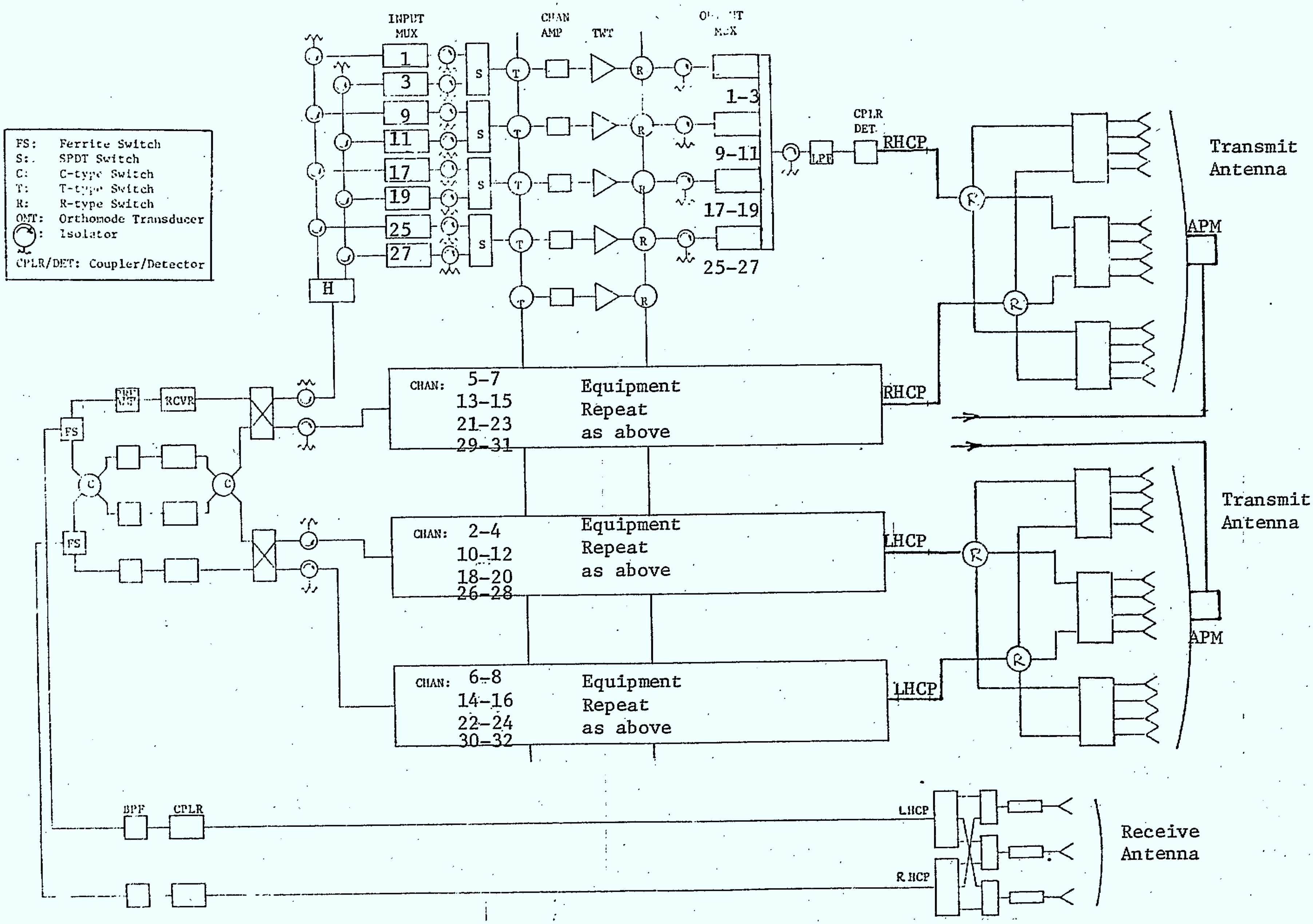


FIGURE 3.3.9 Repeater Configuration of Six Beam Three Orbit Location System (3616/16) Design Model

3.4 Reliability Analysis and Redundancy

3.4.1 Introduction

A reliability analysis was performed as required for the DBS System Concepts Study. This involved an examination of the six identified TWTA transmitter configurations of the DBS payload.

3.4.2 DBS Transmitter Reliability Assumptions

The transmitter reliability analysis presented herein is restricted to a consideration of the TWTA's and the waveguide switches only. All other reliability aspects of the payload were considered common to all configurations and were therefore not included.

a) Configuration

The following assumptions were made concerning the payload configurations.

- o Single ring protection switching with limited flexibility in using standby TWTA's.
- o Double ring protection switching with high flexibility in using standby TWTA's.

A total of six payload configurations as shown in Table 1 of the attachment have been analyzed. Excluding the non-redundant arrangement, these configurations have been divided into the following two groups.

i) Single Ring - In this group, the outputs of the operational and standby TWTA's are connected to a common waveguide ring which can be accessed by activating a "T" type waveguide switch. There are, however, constraints on the degree of interchangability of the operational and standby TWTA's based on the number and location of the standby TWTA's around the ring.

For configuration (b), only two of the four TWTA's in each quadrant can be spared simultaneously with a total of four standby TWTA's available for the sixteen TWTA's. In configuration (c), again only two of the four TWTA's in each quadrant can be spared simultaneously with a total of eight standby TWTA's available. In configuration (d), three of the four TWTA's in each quadrant can be spared simultaneously with a total of eight standby TWTA's available.

ii) <u>Double Ring</u> - In this group, the I/O of the operational and standby TWTA's are connected to two independent waveguide rings. By careful selection of the appropriate T-switches, four out of four TWTA's in each quadrant can be spared simultaneously. In configuration (e), there are a total of four standby TWTA's available and configuration (f) provides a total of eight standby TWTA's.

It should be noted that this double ring configuration requires twice as many T-switches and additional waveguide and associated flanges. This creates an increase in weight over the single ring version as well as requiring additional labour and cost. All transmission paths have an additional loss due to an extra T-switch.

b) Failure Rates

The following assumptions were made in reference to the failure rates utilized in this analysis.

- TWT - 12 GHz, 50W tube based on ANIK C and higher powered matrix tubes.
  It is represented by an increasing failure rate with a Weibull distribution after the application of appropriate derating factors assuming a 10% increase in the stress factor for this category of higher power TWT's. The failure rate value used for the redundant standby TWT is taken as 10% of the failure rate used for the operational TWT.
- EPC - Model based on ANIK C/D design with a power scaling factor. It is represented by a constant failure rate of 700 FITS.
- T-Switch - Model based on ANIK C type R-switch.
  It is represented by a constant failure rate of 170 FITS.

Figure 3.4.1 shows a plot of the failure rate distributions for the above items.

3.4.3 DBS Transmitter Reliability Analysis

Probability of success distributions were obtained for each of six payload configurations and are shown in figure 3.4.2. Table 3.4.2 shows a comparison between the eight and ten year values for each configuration.

The above computations were performed using a complex Markov chain program applied as necessary for each of the six configurations.

3.4.4 DBS Reliability Assessment

With the available data, a relative assessment was made of the six payload configurations and is summarized in Table 3.4.3.

Configuration (a) presents an unacceptable low level of reliability and hence it is clear that redundancy is required. Configurations (b) and (c) provide an improvement over (a), however, configuration (d) seems to achieve a high level of reliability with high flexibility and relatively low complexity and switching weight.

Configuration (e) of the double ring arrangement suffers from a similar level of reliability (@ 8 yrs) as its single ring counterpart (b) due to the unreliability from doubling the number of waveguide switches. However configuration (f) overcomes this limitation and achieves a high level of reliability but at the cost of high complexity and switching weight.

From the above, it seems that configuration (d) gives the most attractive balance of reliability, flexibility and complexity.

For the first generation true DBS where pressure on the spectrum resource may not be extreme, some consideration may be given to the use of non powered spare channels in place of switched hardware redundancy, in a manner directly analagous to the first generation C Band domestic satellites. In the ANIK A, Westar and SATCOM satellites, no switched TWTA redundancy was used, thus in ANIK A and Westar 1, hardware for 12 channels was provided but the spacecraft design and system capacity was based on the availability of any 10 of the 12 channels. Similarly SATCOM 1 provided 24 channels but the spacecraft was designed to support 22 at the end of life. As a system matures and demand for spectrum increases, this valuable resource can no longer be used for protection, and conventional switched hardware redundancy must be used. In the present DBS as an example, it may be possible to use a 36 or 40 channel plan rather than a minimum 32 channel plan. The advantage of this approach to redundancy is that switching with its losses and reliability hazard is eliminated, and TWTAs are assigned uniquely to channels, which improves their efficiency.

TABLE 3.4.1

PAYLOAD CONFIGURATIONS ANALYZED

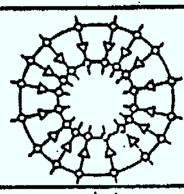
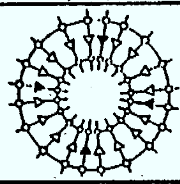
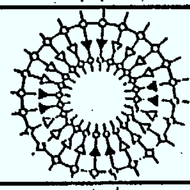
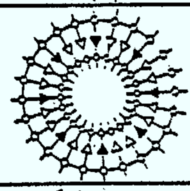
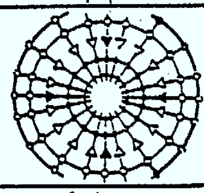
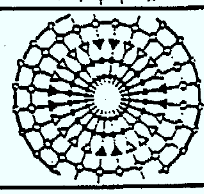
CONFIGURATION		DESCRIPTION	DRAWING
NON REDUNDANT	a)	No Standby TWTA's $(16/16)_{SINGLE}$	
SINGLE RING REDUNDANCY	b)	4 Standby TWTA's $(16/20)_{SINGLE}$ 1 Standby for 4 Operational	
	c)	8 Standby TWTA's $(16/24)_{SINGLE}$ 2 Standby for 4 Operational	
	d)	8 Standby TWTA's $(16/24)_{SINGLE}$ 1 Standby for 2 Operational	
DOUBLE RING REDUNDANCY	e)	4 Standby TWTA's $(16/20)_{DOUBLE}$ No Constraint	
	f)	8 Standby TWTA's $(16/24)_{DOUBLE}$ No Constraints	

TABLE 3.4.2

PAYLOAD CONFIGURATION PROBABILITY OF SUCCESS

CONFIGURATION		DESCRIPTION	P_s 8 YEARS	P_s 10 YEARS
NON REDUNDANT	a)	No Standby TWTA's $(16/16)_{SINGLE}$	0.007	0.002
SINGLE RING REDUNDANCY	b)	4 Standby TWTA's $(16/20)_{SINGLE}$ 1 Standby for 4 Operational	0.411	0.065
	c)	8 Standby TWTA's $(16/24)_{SINGLE}$ 2 Standby for 4 Operational	0.597	0.154
	d)	8 Standby TWTA's $(16/24)$ SINGLE 1 Standby for 2 Operational	0.684	0.214
DOUBLE RING REDUNDANCY	e)	4 Standby TWTA's $(16/20)_{DOUBLE}$ No Constraint	0.410	0.063
	f)	8 Standby TWTA's $(16/24)_{DOUBLE}$ No Constraint	0.916	0.472

TABLE 3.4.3

PAYLOAD CONFIGURATION ASSESSMENT

CONFIGURATION			RELIABILITY (P_S @ 8 Yrs)	FLEXIBILITY	SWITCHING ΔW_T (~lbs)
NON REDUNDANT		a)	V. LOW (0.007)	NONE	NONE (0)
SINGLE RING REDUNDANCY		b)	MED (0.411)	LOW (2/4 per quad)	LOW (2)
		c)	MED (0.597)	MED (2/4 per quad)	LOW (4)
		d)	HIGH (0.684)	HIGH (3/4 per quad)	LOW (4)
DOUBLE RING REDUNDANCY		e)	MED (0.410)	HIGH (4/4 per quad)	HIGH (26)
		f)	V. HIGH (0.916)	V. HIGH (4/4 per quad)	HIGH (32)

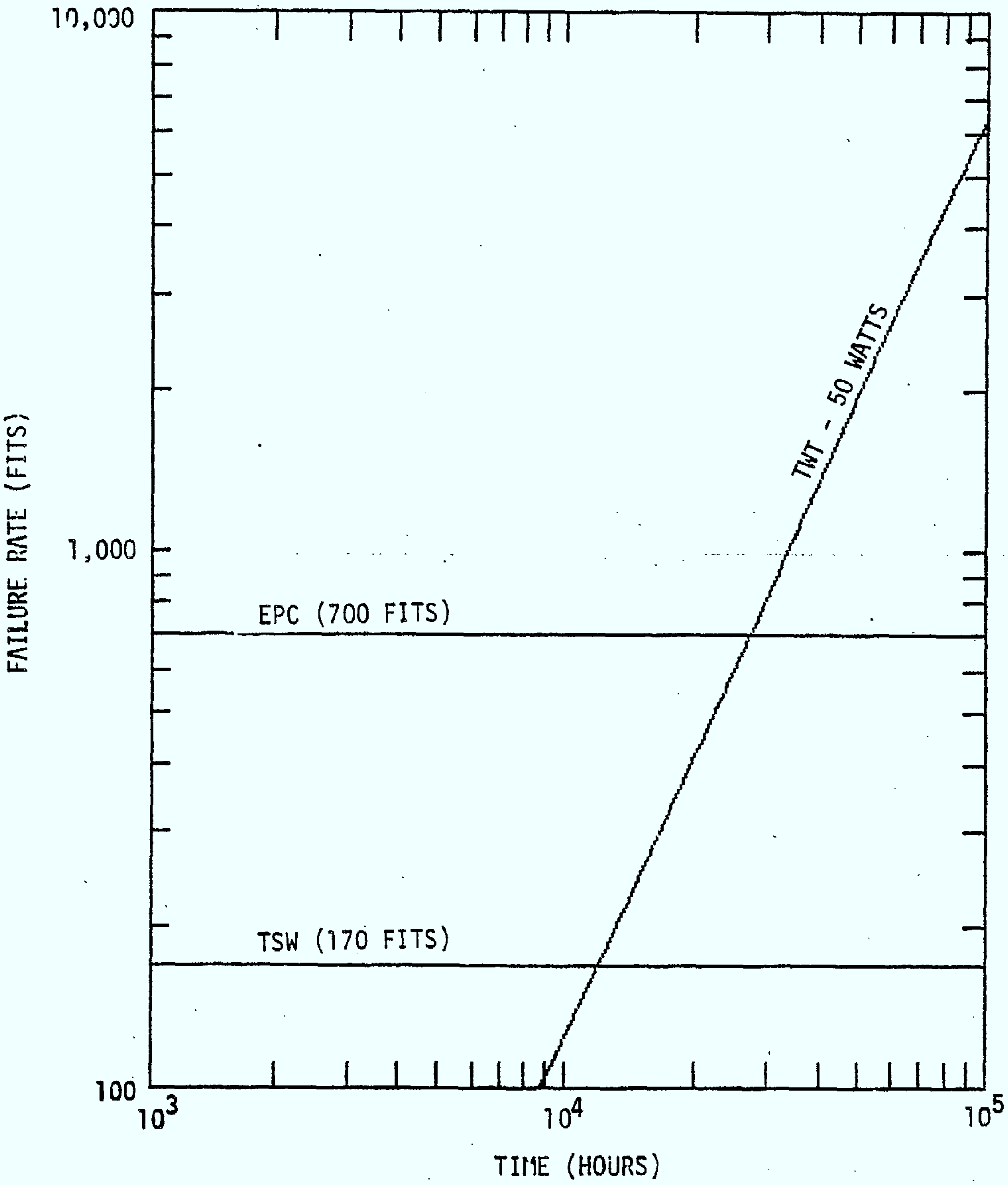


Figure 3.4.1 FAILURE RATE DISTRIBUTION

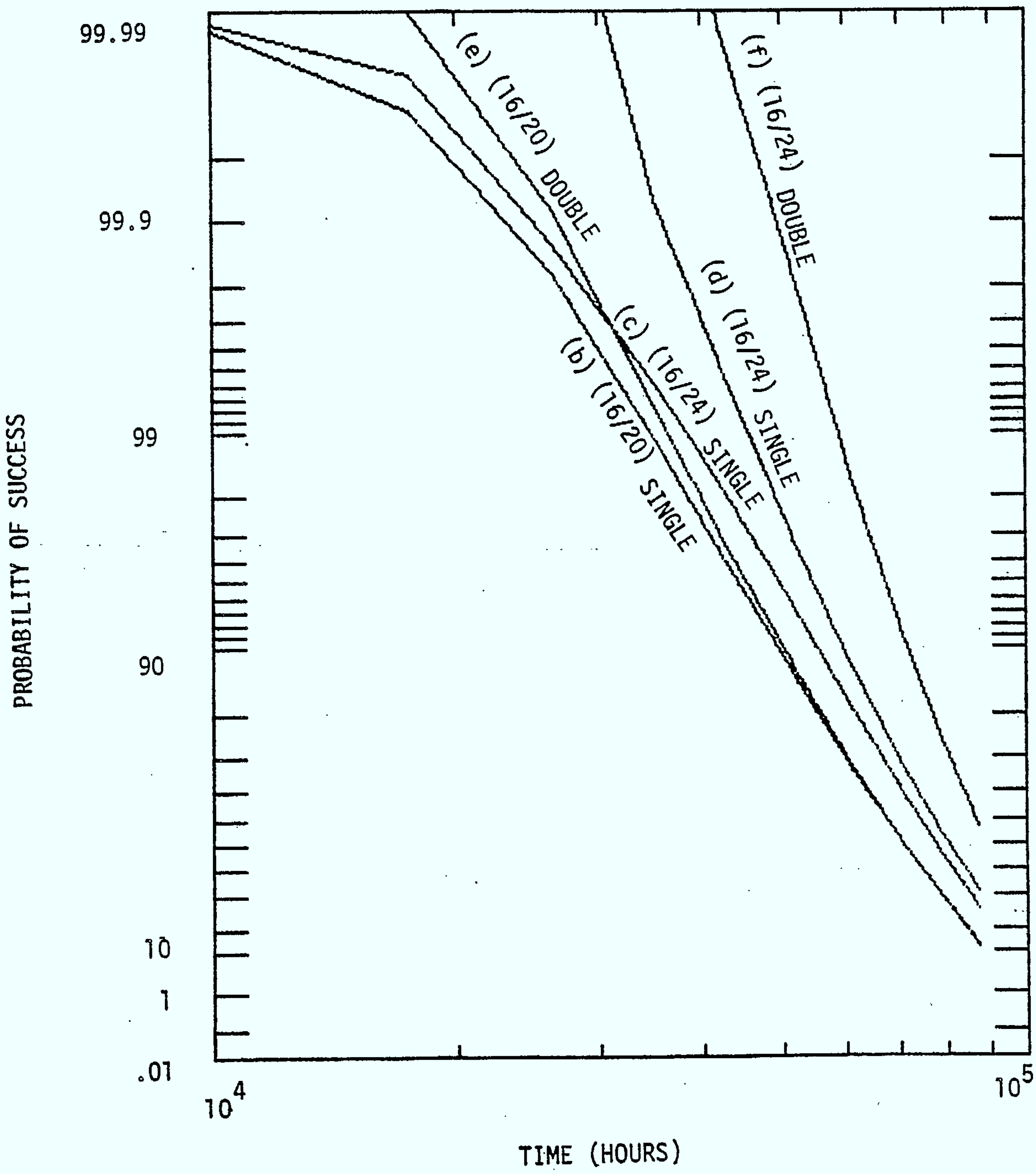


Figure 3.4.2 PAYLOAD CONFIGURATIONS PROBABILITY OF SUCCESS

3.5 Mass and Power Budgets

This section contains mass and power budgets for all the communications subsystem configurations developed in this study. The material has been updated as part of the conceptual design process, and significant differences might exist from previous reports and presentations to the Scientific Authority.

The conceptual design models presented here to greater detail than the remaining models establish the basis of mass and power estimates that were used in all other models. The assumption has been made here that the antenna system related structures would be similar to the design models. On the basis of low or high EIRP, mass for structures of 15 to 17.3 Kg have been used respectively. All other repeater mass and power assumptions apply equally to all models.

Transponder Equipment:

The mass estimate of the transponder equipment(without TWTA's) presented in Table 3.5.1 is derived mainly from the previous DBS study with updated mass estimates in the areas of input and output multiplexers and channel amplifiers.

TWTA's:

Mass and power estimates for the TWTA's presented in Tables 3.5.2 and 3.5.3 have been based on the TWTA survey of section 4.2.1. Figure 3.5.1 shows a comparison of the TWTA mass used in this study to that used in the previous DBS study.

TWT's of 50 watts output and over have been assumed to be of the collector radiator type. The 38 watt TWT shown is conduction cooled and this accounts for the abrupt step in the mass distribution.

Thermal Control Hardware:

Thermal control hardware consists of heat spreader plates for the TWT and EPC and heat conduction brackets for the output multiplexers. The mass estimates for this hardware are based on distributed heat sources as described in Section 4.2.5.

Antennas and Support Structures:

Mass estimates in this area are based on the spacecraft configurations of the conceptual design. Two 75 inch apperture, deployable transmit antennas have been selected for the design. The antennas are equipped with multiple feeds to allow operation from two or three orbital locations. Table 3.5.4 shows mass estimates for 6 and 4 beam transmit antennas.

The receive antenna uses an 18 inch reflector for all Canada uplink and it is common for 6 and 4 beam systems. Table 3.5.5 contains the mass breakdown.

Antenna Tiedowns and Tower:

The mass associated with stowed antenna tiedowns, telemetry and command antenna and tower, has to be included as part of the payload. Estimates have been produced for the high EIRP(L-SAT) and low EIRP(RCA) bus configurations considered in the designs. A mass breakdown is presented in Table 3.5.6.

Mass and power budgets for the design models have been generated for 100% coverage of the largest beam to cover the limit of payload demands. Alternate budgets for 90% coverage of the largest beam are also presented for a broader base for comparison and ultimate selection of a suitable system. For example an interesting comparison emerges between 100% coverage 16 channel spacecraft and 90% coverage 20 channel spacecraft. The extension of the design boundaries to 20 channel systems (3620/20 and 2420/20) was included to provide this kind of option. Tables 3.5.7 and 3.5.8 contain the payload mass and power summaries for 50 and 54 dBw EIRP over 100% and 90% coverage of the largest beam.

Updated mass and power summaries for the models considered in the selection are presented in Tables 3.5.9 and 3.5.10. They are all based on 100% coverage of the largest beam. Figure 3.5.2 gives a concise summary of the payload mass and power demands of all models based on 100% coverage.

UNIT	UNIT WEIGHT (KG)	NUMBER OF UNITS	TOTAL WEIGHT (KG)
COUPLER	0.045	2	0.09
W/B FILTER	0.20	2	0.40
W/G FERR. SWITCH(FS)	0.185	2	0.37
W/G TRANS. SWITCH(C)	0.23	1	0.23
FET PREAMP	0.27	4	1.08
RECEIVER	1.60	4	6.40
COAX TRANS. SWITCH(C)	0.10	1	0.10
COAX SPDT SWITCH(S)	0.055	16	0.88
HYBRID	0.045	6	0.27
COAX ISOL/CIRC.	0.030	72	2.16
CHANNEL FILTER	0.25	32	8.00
COAX "T" SWITCH	0.14	20	2.80
CHANNEL AMPLIFIER	0.80	20	16.00
W/G "R" SWITCH	0.25	24	6.00
W/G ISOLATOR	0.085	20	1.70
QUADRUPLEXER	0.94	4	3.76
HARMONIC FILTER	0.07	4	0.28
COUPLER/DETECTOR	0.045	4	0.18
COAX CABLES	0.032/1'cable	145	4.64
WIRE HARNESS	0.25/TWTA+2	20	7.00
W/G+BRACKETS+HARDW.	0.10/Filter	48	4.80
TRANSPONDER TOTAL EXCLUDING TWTA's			67.1

TABLE 3.5.1 TRANSPONDER WEIGHT BREAKDOWN FOR MODELS 2416/16 AND 3616/16

	Units	6 Beam Model		4 Beam Model	
		54 DBW EIRP	50 DBW EIRP	54 DBW EIRP	50 DBW EIRP
Antenna Gain (Worst Beam EOC)	dB	34.5	34.5	33.3	33.3
Output Losses	dB	1.5	1.5	1.5	1.5
TWT Output	dBW	21.0	17.0	22.2	18.2
	W	126	50	166	66
EPC Efficiency	%	87	85	87	85
TWT Efficiency	%	48	47	48	47
DC Power/TWTA	W	302	125	398	165
TWT Mass	kg	3.0	2.0	3.5	2.0
EPC Mass	kg	4.0	2.5	4.8	2.7
TWTA Mass	kg	7.0	4.5	8.5	4.7

TABLE 3.5.2 TWTA Mass and Power Budgets - Indicated EIRP Over 100% of Largest Service Area

	Units	6 Beam Model		4 Beam Model	
		54 DBW EIRP	50 DBW EIRP	54 DBW EIRP	50 DBW EIRP
Antenna Gain (Worst beam 90% cov.)	dB	35.7	35.7	34.5	34.5
Output Losses	dB	1.5	1.5	1.5	1.5
TWT output	dBW	19.8	15.8	21.0	17.0
	W	95	38	126	50
EPC Efficiency	%	87	85	87	85
TWT Efficiency	%	48	47	48	47
DC Power/TWTA	W	227	95	302	125
TWT Mass	kg	2.6	1.4	3.0	2.0
EPC Mass	kg	3.5	2.0	4.0	2.5
TWTA Mass	kg	6.1	3.4	7.0	4.5

TABLE 3.5.3 TWTA Mass and Power Budgets - Indicated EIRP over 90% of Largest Service Area

COMPONENT	6 BEAM SYSTEM	4 BEAM SYSTEM
75" REFLECTOR + THERMAL	11.1 Kg	11.1 Kg
REFLECTOR SUPPORT STRUCTURE	1.2	1.2
ANTENNA POSITION MECHANISM(APM)	3.9	3.9
FEED + SUPPORT + THERMAL	6.8	4.6
INTERFACE HARDWARE	0.2	0.2
TOTAL ANTENNA WEIGHT	23.2 Kg	21.0 Kg

TABLE 3.5.4 TRANSMIT ANTENNA WEIGHT BREAKDOWN

COMPONENT	ALL CANADA
18" REFLECTOR + THERMAL	0.9 Kg
REFLECTOR SUPPORT STRUCTURE	0.5
FEED + SUPPORT + THERMAL	2.4
INTERFACE HARDWARE	0.1
TOTAL ANTENNA WEIGHT	3.9 Kg

TABLE 3.5.5 RECEIVE ANTENNA WEIGHT BREAKDOWN

COMPONENT	L-SAT BUS	RCA DBS BUS
FRONT TIEDOWNS:		
- Brackets	0.90 Kg	0.90 Kg
- Tubes	0.46	0.46
- Pyros	0.54	0.54
- Hardware	0.09	0.09
SIDE SNUBBERS:		
- Brackets	1.36	1.36
- Tubes	0.68	0.68
- Pyros	0.54	0.54
- Hardware	0.09	0.09
TOWER:		
- Main Structure	6.80	4.53
- Support Tube	3.17	3.17
- Hinge	0.45	0.45
- T &C Antenna	0.90	0.90
- Coax Cables + Hardware	0.65	0.65
Thermal Hardware	0.68	0.68
TOTAL WEIGHT	17.3 Kg	15.0 Kg

TABLE 3.5.6 ANTENNA TIEDOWNS AND TOWER WEIGHT BREAKDOWN

	6 Beam System				4 Beam System			
	100% Coverage of Largest Beam		90% Coverage of Largest Beam		100% Coverage of Largest Beam		90% Coverage of Largest Beam	
	3616/16	3620/20	3616/16	3620/20	2416/16		2416/16	
Mass:								
Transponder:								
Equipment	67.1	78.6	67.1	78.6	67.1		67.1	
Thermal Control	8.5	10.2	10.9	13.1	11.0		8.5	
TWTAs	90.0	108.0	68.0	81.6	94.0		90.0	
Antennas	50.3	50.3	50.3	50.3	45.9		45.9	
Antenna Tie Down & Tower	15.0	15.0	15.0	15.0	15.0		15.0	
Total Payload Mass (kg)	230.9	262.1	211.3	238.6	233.0		226.5	
Power:								
TWTAs	2000	2500	1520	1900	2640		2000	
Other Equipment	76	92	76	92	76		76	
Total Payload Power (W)	2076	2592	1596	1992	2716		2076	

TABLE 3.5.7 Payload Mass and Power Summary 50 DBW EIRP

	6 Beam System				4 Beam System			
	100% Coverage of Largest Beam		90% Coverage of Largest Beam		100% Coverage of Largest Beam		90% Coverage of Largest Beam	
	3616/16	3620/20	3616/16	3620/20	2416/16		2416/16	2420/20
<u>Mass</u>:								
Transponder:								
Equipment	67.1	78.6	67.1	78.6	67.1		67.1	78.6
Thermal Control	19.5	23.4	14.7	17.6	25.6		19.5	23.4
TWTAs	140.0	168.0	122.0	146.4	170.0		150.0	180.0
Antennas	50.3	50.3	50.3	50.3	45.9		45.9	45.9
Antenna Tiedowns & Tower	17.3	17.3	17.3	17.3	17.3		17.3	17.3
Total Payload Mass (kg)	294.2	337.6	271.4	310.2	325.9		299.8	345.2
<u>Power</u>:								
TWTAs	4832	6040	3632	4540	6368		4832	6040
Other Equipment	76	92	76	92	76		76	92
Total Payload Power (W)	4908	6132	3708	4632	6444		4908	6132

TABLE 3.5.8 Payload Mass and Power Summary 54 DBW EIRP

	6 BEAM SYSTEMS						4 BEAM SYSTEMS	
	3616/16	3616/18	2610/30	268/24	2610/15	268/12	2616/16	2416/8
MASS:								
Transponder:								
Equipment	67.1	47.9	96.8	81.3	62.2	53.0	67.1	47.9
Thermal Control	8.5	4.3	15.3	12.8	7.7	6.4	11.0	5.5
TWTS's	90.0	45.0	162.0	135.0	81.0	67.5	94.0	47.0
Antennas	50.3	50.3	50.3	50.3	50.3	50.3	45.9	45.9
Ant. Tiedowns&Tower	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
TOTAL PAYLOAD(Kg)	230.9	162.5	339.4	294.4	216.3	192.2	233.0	161.3
POWER:								
TWTS's	2000	1000	3750	3000	1875	1500	2640	1320
Other Equipment	76	44	132	108	72	60	76	44
TOTAL PAYLOAD(W)	2076	1044	3882	3108	1947	1560	2716	1364

TABLE 3.5.9 PAYLOAD MASS AND POWER SUMMARY

50 dBw EIRP over 100% of largest beam

	6 BEAM SYSTEMS						4 BEAM SYSTEMS	
	3616/16	3616/8	2610/30	268/24	2610/15	268/12	2416/16	2416/8
MASS:								
Transponder:								
Equipment:	67.1	47.9	96.8	81.3	62.2	53.0	67.1	47.9
Thermal Control	19.5	9.8	35.1	29.3	17.6	14.6	25.6	12.8
TWTA's	140.0	70.0	252.0	210.0	126.0	105.0	170.0	85.0
Antennas	50.3	50.3	50.3	50.3	50.3	50.3	45.9	45.9
Antenna Tiedowns/Tower	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3
TOTAL PAYLOAD(Kg)	294.2	195.3	451.5	388.2	273.4	240.2	325.9	208.9
POWER:								
TWTA's	4832	2416	9060	7248	4530	3624	6368	3184
Other Equipment	76	44	132	108	72	60	76	44
TOTAL PAYLOAD POWER(W)	4908	2460	9192	7356	4602	3684	6444	3228

TABLE 3.5.10 PAYLOAD MASS AND POWER SUMMARY

54 dBw EIRP Over 100% of largest Beam

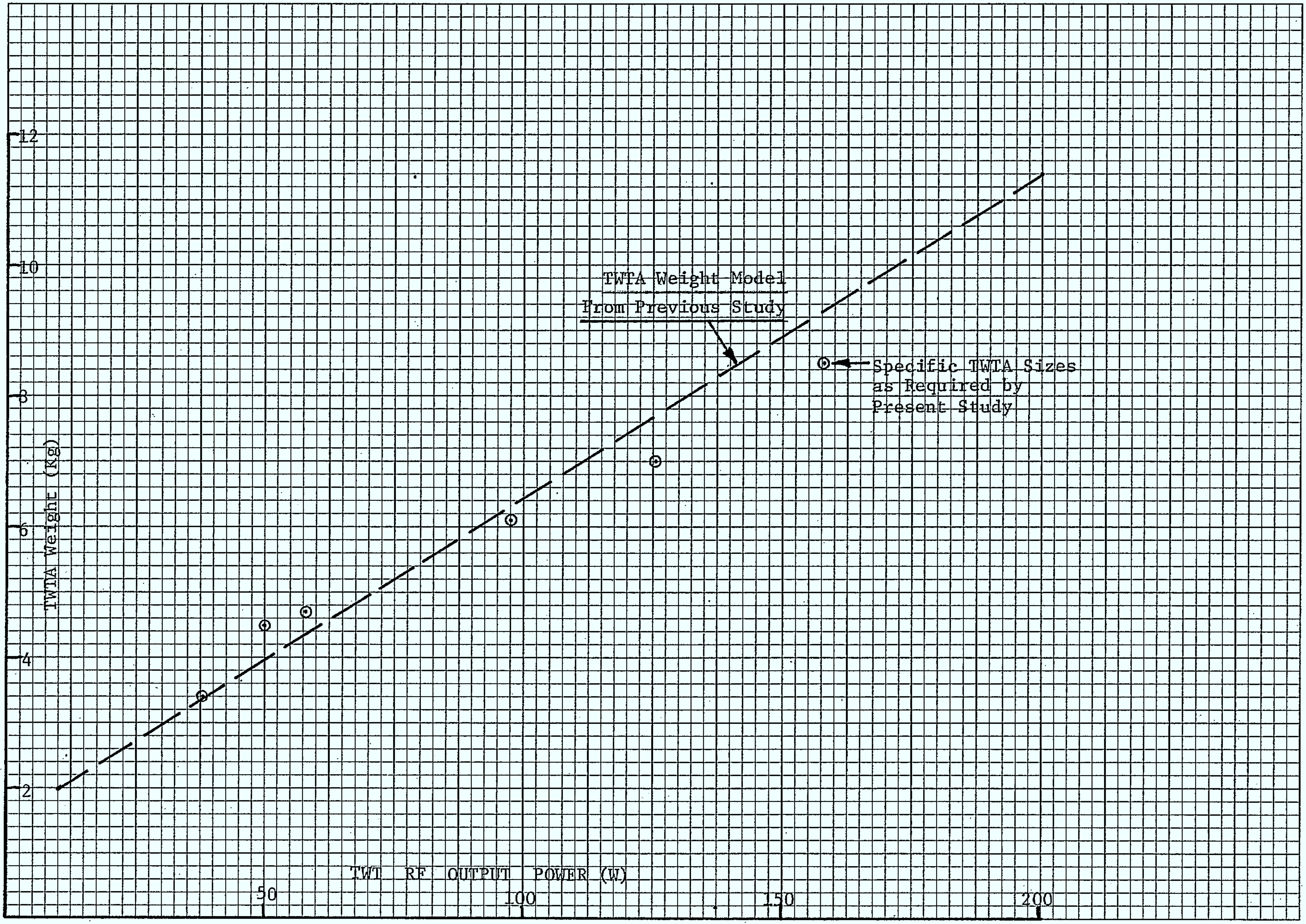


FIGURE 3.5.1 TWTA WEIGHT AS A FUNCTION OF RF POWER

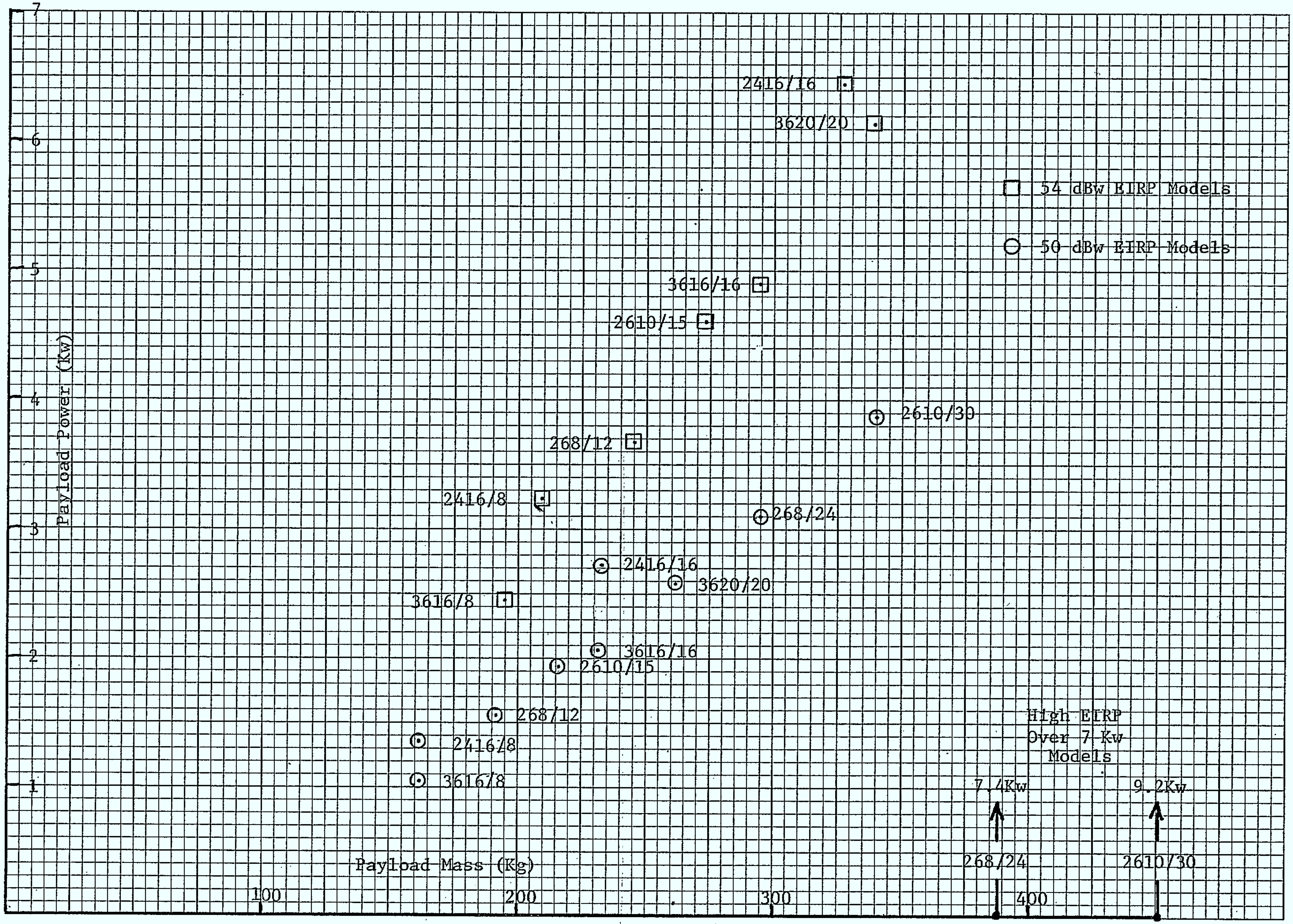


FIGURE 3.5.2 PAYLOAD MASS AND POWER DEMANDS

3.6 Provision for Alternative Services and Onboard Switching

The repeater configurations of Section 3.3 represents the simplest case of TV transmission directly from an uplink channel to the corresponding downlink channel. In an actual DBS system it might be necessary to provide other services such as Telidon, Radio and high definition TV(HDTV). In addition it might be desirable to provide on board switching capability which would allow one uplink channel to be transmitted over more than one beam.

Transmission of Other Services:

The transmission of other services if required to be on a continuous basis would be best achieved by dedicated input and output filters, channel amplifiers and TWTA's and should be included in the overall frequency plan and spectrum allocation of the system. This approach might require additional channels to be handled, hence increase the multiplexing level to pentaplexers from quadruplexers in the design cases of 2416/16 and 3616/16 systems.

Occasional transmission of other services could time-share the spectrum with regular TV transmission to achieve maximum spectrum utilization. This approach would require additional input channel filter for the wider based HDTV signal but might not require additional input filters for narrower band Telidon or Radio signals. Figure 3.6.1 shows a method of transmitting HDTV on time-sharing basis with regular TV transmission. Depending on the required bandwidth of HDTV signal one channel of HDTV would displace 3 to 5 TV channels. The weight penalty of this arrangement is approximately 0.5 Kg per HDTV channel.

Onboard Switching

The distribution of one uplink channel into more than one beams through onboard switching would invariably lead to separate frequency translation and amplification of the switched channel(s). This would increase the complexity and weight of the transponder at the benefit of reduced uplink channel capacity of the feeder stations. The attractiveness of such scheme diminishes as the number of orbital locations increases and the number of beams covered by a spacecraft decreases. For the conceptual design systems the uplink channel reduction that is possible for national channels is only one-to-one while for one orbital location 6 beam system is 6-to-1. Figure 3.6.2 shows a method of multiple frequency conversion which allows distribution of one uplink channel into three beams. The weight penalty per frequency converter is approximately 1.8 Kg.

An alternate implementation method could use the principle of double conversion wherein amplification of each channel is performed at a common intermediate frequency (IF). This intermediate frequency is then up converted to the appropriate channel by different mixers and local oscillators for each beam. (Except for one beam which operates normally.) For a full double conversion repeater in which every channel is converted to a common IF, it is possible to connect any uplink channel to any dowlink channel either on a one to one basis or a multiple basis as for national coverage. Although feasible, this extremely flexible repeater is probably not justifiable. The double conversion of only national channels does not seem to offer any advantage over the multiple single conversion repeater which is therefore the preferred configuration.

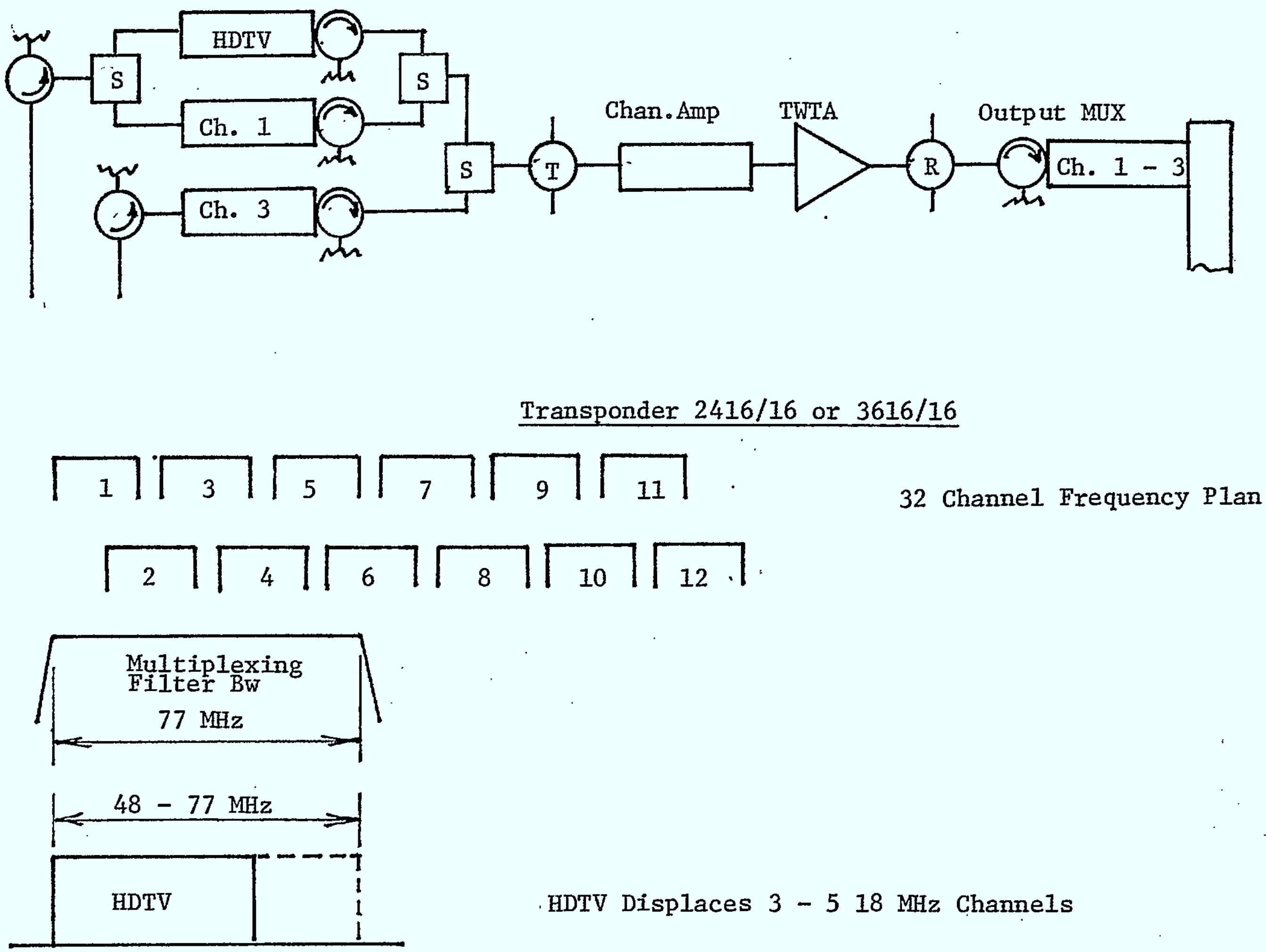


FIGURE 3.6.1 TRANSMISSION OF HIGH DEFINITION TV

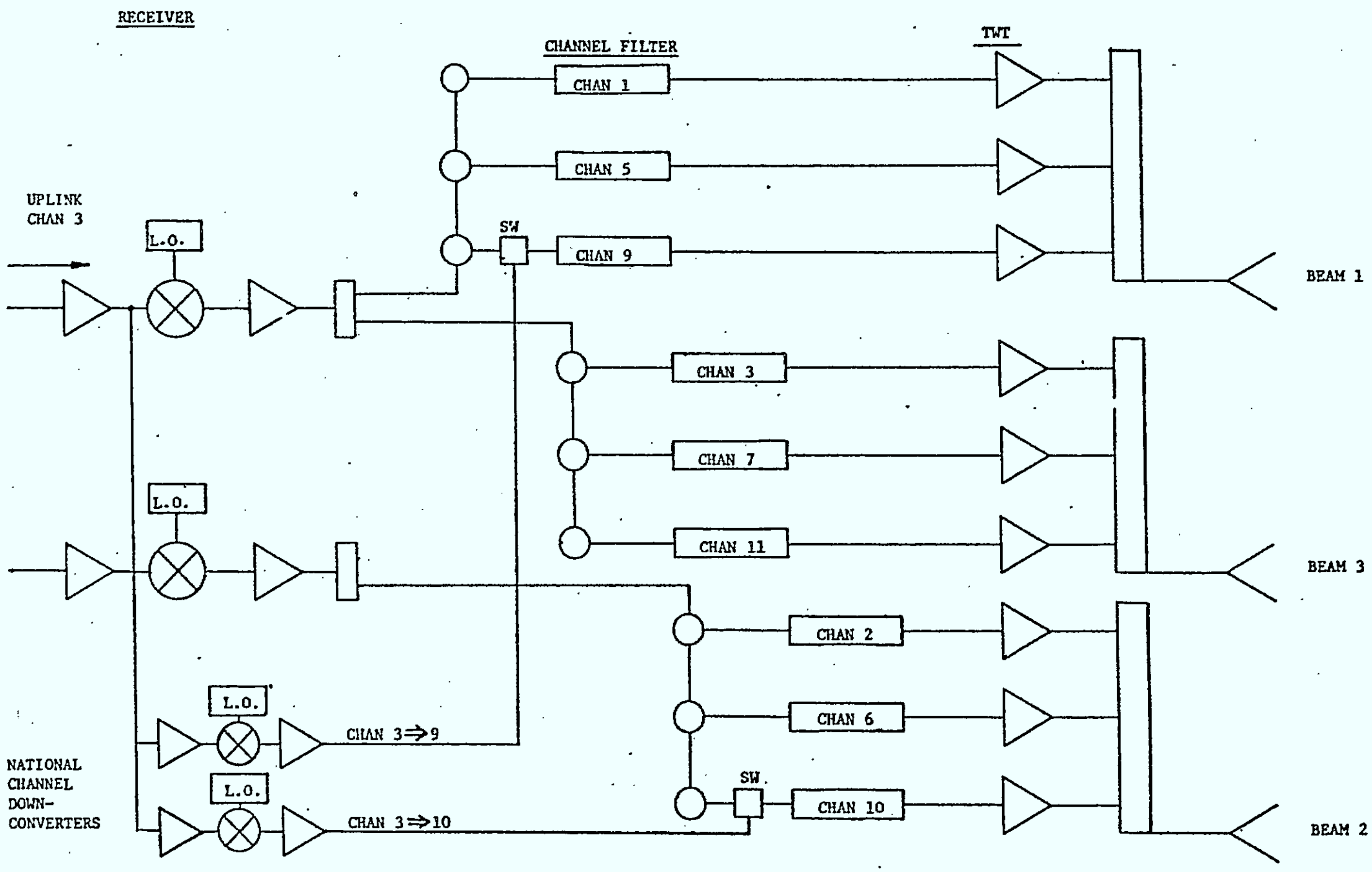


FIGURE 3.6.2 EXAMPLE OF ONBOARD SWITCHING - MULTIPLE SINGLE CONVERSION

3.7 Two Television Channels per TWT

The present study has been based on transmission of one television channel per TWT. In this section the implication of an alternate operational mode of the system with two television channels per TWT are examined.

Transmission of two TV signals per TWT has been field tested and used by satellite system operators such as RCA Americom, Intelsat and Telesat. Acceptable performance has been achieved by appropriate TWT back-off, group delay preequalization at uplink and in the case of RCA Americom by color crosstalk cancellation through Alternate Line Delay(ALD) signal processing. From the existing literature (ref. 1&2) on the subject; it seems that the most serious effect of simultaneous transmission of two TV signals through a TWT is the color subcarrier crosstalk which appears as a periodic variation of chrominance (color breathing) at the difference frequency between the two subcarriers. Group delay preequalization reduces this effect by approximately one half and it is practiced by all three companies mentioned above. The amount of TWT back-off varies amongst these companies from 5dB to 7.5dB (referenced to single carrier saturation) per carrier at the TWT output. In the systems that do not use signal processing,color crosstalk effects are evident although not known how objectionable. The RCA system through its Alternate Line Delay processing is reported to have eliminated the subjective effects of color crosstalk. Luminance crosstalk has not received equal attention in the literature, perhaps, because it is considered a lesser problem than chrominance effects. It has been reported, however, that at some degree of TWT back-off serious image overlap(ghosting) might be present and can be improved by additional back-off.

The entire subject of picture quality and the means of achieving it in a two-for-one transmission mode is considered to be beyond the scope of this study. Assuming that acceptable transmission quality is possible at some TWT back-off near the 5dB per carrier reported by Telesat the following analysis examines some of the important differences between the two systems under the topics of:

- System Complexity
- Frequency Plan
- Performance
- Power and Weight Requirements

3.7.1 System Complexity

Transmission of two TV channels per TWT would involve some additional constraints on the make up of the system and its operation.

Signal Processing, such as ALD, would increase the complexity of the uplinking station by the addition of processing equipment in one of two TV channels sharing a single TWT and require assignment coordination so that only one of the two channels is ALD processed. The individual reception terminal would also have to be equipped with processing equipment and means of recognition of the ALD processed channels.

Group Delay Preequalization would further increase the complexity of the uplink station. This is required with or without processing.

Uplink Flux Density Equalization would be required between two uplink stations supplying the same TWT.

Output Multiplexer Filters at the transponder would likely be required to provide better isolation at the intermodulation product frequencies. This could result in increased output losses and payload weight.

EIRP per Channel would be limited towards the low EIRP end by practical limits of available TWT sizes. For example, if a 4 Beam, 50 dBw model were to be implemented in the two-for-one operational mode the required TWT to carry two 50 dBw carriers would be as a minimum 210W size. This is based on 2 dB total output back-off(5 dB back-off per carrier) which represents the most optimistic case. At a more realistic, 3 dB back-off, the required TWT size is 260W.

Repeater Configuration Changes required for two-for-one operation involve additional SPDT switches and power combiners at the input mux output and possibly input filter channel frequency reassignment. For example, repeater configuration 2416/16 in figure 3.3.8 would require one SPDT switch per input mux channel output and a power combiner per two channel filters to produce combined output for one TWT. The SPDT switches are required to provide optional operation of one TV channel per TWT.

3.7.2 Frequency Plan

Two-for-one transmission used presently by satellite operating companies is intended to increase spectrum utilization by transmitting two TV signals within one 36 MHz channel. This scheme requires special IF filters at the receiver to separate the channels prior to demodulation. Such filters are considered to be beyond the price range of an inexpensive domestic receiver. The spectrum constraints are not such in a DBS system to require serious consideration of this frequency spacing, hence the frequency plans described in this report are assumed to apply in the two-for-one transmission scheme. Channel spacing within one TWT can then be that of one or two copolar channels (eg. Ch. 1 to 3 or 1 to 5) with due attention given to the intermodulation product frequencies to maintain acceptable interference levels. For example, in the repeater configuration of figure 3.3.8 it might be advantageous to combine channels 1 and 5 and protect channel 9 instead of combining channels 1 and 3 and protecting channel 5. The former arrangement would involve lower output loss due to the wider bandwidth and should be preferred.

3.7.3 Performance

The crosstalk effects described earlier represent, perhaps, the most serious problem in two-for-one transmission. Reduction of these crosstalk effects has a serious impact on the dowlink EIRP of the system by imposing an approximate upper limit of 52 dBw for the 6 Beam system and 50 dBw for the 4 Beam system assuming the use of existing 230-260W TWT's.

Two-carrier per TWT operation would have a profound effect on the DC to RF efficienty of the repeater. For single-carrier operation this efficiency is in the order of 40%. For two-carrier operation the efficiency at saturation decreases to 28%. The effect of back-off further decreases the efficiency to 25% and 20% for 2 dB and 3 dB total output back-off respectively. For a power intensive DBS system this reduction of the efficiency is intolerable.

3.7.4 Power and Weight Requirements

The implication of the reduced DC to RF efficiency described above is that a two-for-one system would require 26% increase in DC power per dB of total output back-off over its equivalent EIRP single carrier per TWT system. For a 16 channel repeater (2416/16, fig. 3.3.8) of 50 dBw EIRP the DC power requirements and its corresponding power subsystem weight are compared in Table 3.7.4-1.

	Single Carrier per TWT	Two-Carrier per TWT	
		2dB TOBO	3dB TOBO
Channel RF Power (W)	66	66	66
DC to RF efficienty (%)	40	25	20
DC power per Channel (W)	165	264	330
DC power per Repeater (W)	2640	4224	5280
Power Subsystem weight including (kg) batteries	220 (12W/kg)	352 (12W/kg)	440 (12W/kg)

Table 3.7.4-1 Comparison of DC Power requirements and corresponding Power Subsystem Weight

3.7.4 Power and Weight Requirements(cont'd)

The repeater weight increase would be mainly affected by TWTA weight increase due to poor utilization of the required TWT size. Any other changes such as addition of switches and power combiners and possibly increase in size of output filters are small and can be neglected. Reduction in the number of mux filters and channel amplifiers if the system is designed to operate in a dedicated two-for-one mode would tend to cancel some of the TWTA weight increase. To simplify the comparison process it is assumed that the same repeater (2416/16), 50 dBw) is implemented in two-for-one transmission mode whereby 10 high power TWTA's replace the present 20 low power TWTA's. The TWTA and thermal control hardware weight comparison resulting is presented in Table 3.7.4-2.

	Single-Carrier per TWT	Two-Carrier per TWT	
		2dB TOBO	3dB TOBO
Channel RF Power (W)	66	66	66
TWTA Size (W)	66	209	263
TWTA Weight (kg)	4.7	10.4	11.5
Thermal Control (kg)	0.55	2.2	2.9
Number of TWTA's	20	10	10
Total TWTA Weight (kg)	94	104	115
Total Thermal Weight (kg)	11	22	29
Total Weight (kg)	105	126	144

Table 3.7.4-2 Comparison of TWTA and Thermal Control hardware weight

3.7.4 Power and Weight Requirements(cont'd)

The total weight difference resulting from the above comparisons is 153 kg and 259 kg for the 2dB and 3dB total output back-off (TOBO) respectively. Compared to a reference repeater plus power subsystem weight of 453 kg (single channel per TWT) they represent increases of 33% and 57% respectively.

References:

1. "Cancellation of Visible Color Crosstalk Between Two TV Signals by use of Alternate Line Delay"

   L. Abbott, RCA Review, Sept. 1980.

2. "Parameter Tradeoffs for Transmitting Two Television Channels per Transponder"

   L. Abbott, G.W. Beakley and W. T. Rowse, RCA Review, Sept. 1980.

4. Spacecraft Conceptual Designs

4.1 Launch Vehicle Consideration

DBS is to be launched by the Space Transportation System (STS) from Kennedy Space Centre or by the Ariane 4 expendable launch vehicle from the Guiana Space Centre. The spacecraft shall therefore be designed to meet the most constraining requirements of both launch vehicles (weight, envelope, environment requirements).

4.1.1 Space Transportation System

A typical STS geosynchronous mission sequence consists of injecting the spacecraft with an upper stage from the STS parking orbit (300 km) into transfer orbit and achieving the final orbit with the spacecraft propulsion system.

In the STS launch mode the spacecraft will be mated to a Perigee Kick Stage System (PKSS) and the combination installed on a cradle in the Orbiter Cargo Bay.

The Cargo Bay envelope has the following dimensions:

length	18.288m	(60 feet)
diameter	4.572m	(15 feet)

Given that the STS launch performance is about 30,000 kg, the S/C weight and external dimensions are not constrained by an STS launch configuration.

4.1.2 Ariane 4

The Ariane launch vehicle is capable of injecting the spacecraft directly into a geosynchronous transfer orbit. The spacecraft will be mated to the third stage via an adapter.

Six Ariane 4 versions are available, providing the following performance in a geosynchronous transfer orbit:

AR 40	:	1900KG	AR 42L	:	3200KG
AR 42P	:	2600KG	AR 44LP	:	3700KG
AR 44P	:	3000KG	AR 44L	:	4200KG

Each version can be accommodated with various fairings in a dedicated launch configuration or with a SPELDA structure (in addition to the fairing) in a dual launch configuration. The payload envelopes of these configurations are shown in Figure 4.1.2-1.

The Ariane payload envelope will drive the stowed configuration of the spacecraft.

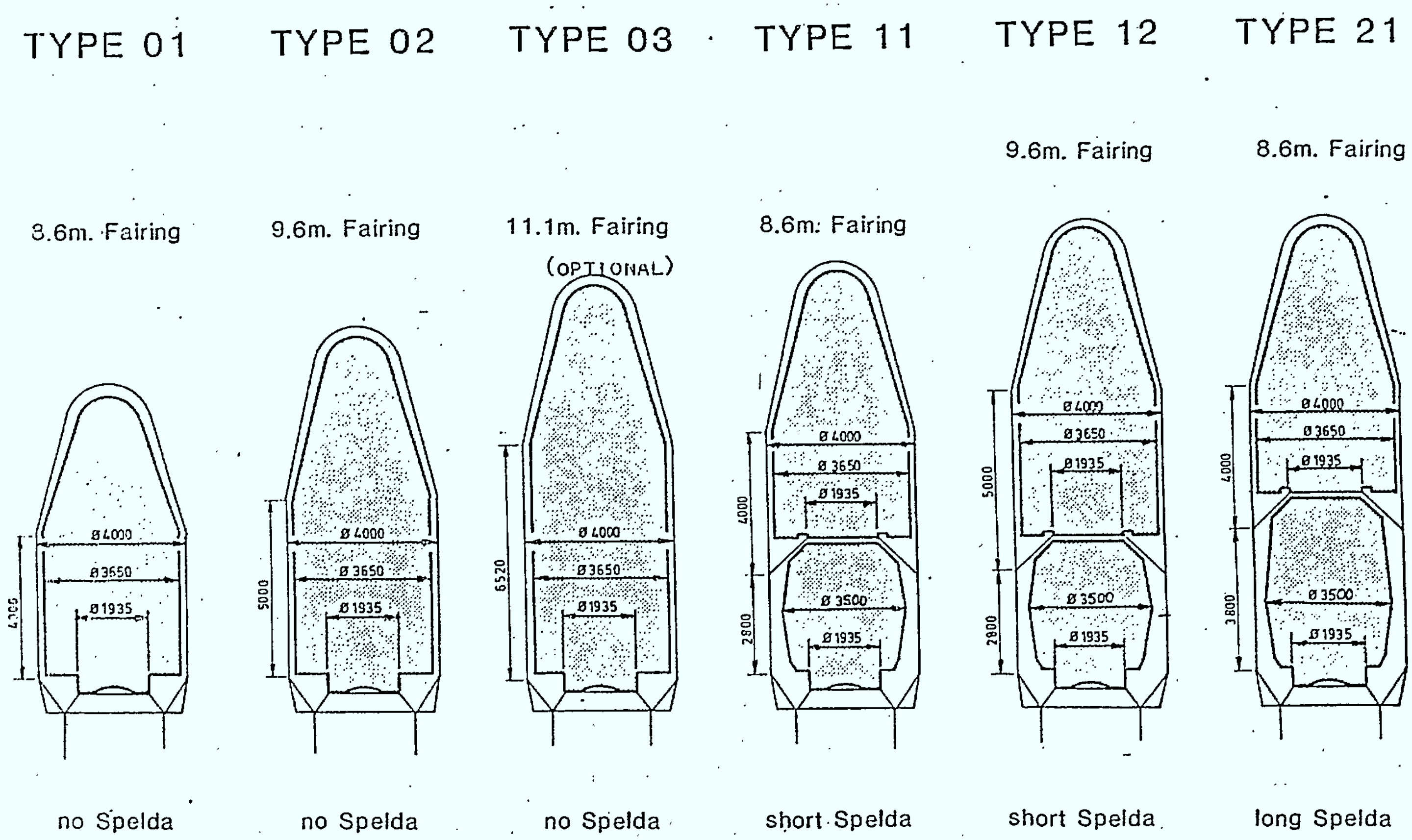


Figure 4.1.2-1: Ariane 4 Fairing Configurations

4.2 Communications Payload Elements

The section deals with the lower level studies conducted on major payload elements in support of the spacecraft conceptual design. Due to the power intensive nature of the system particular emphasis was placed on the TWTA's, transmit antenna and output multiplexers.

A TWTA survey was conducted to determine availability status, performance , likely suppliers as well as rate of production and cost of suitable units. This task was achieved and the findings of the survey are presented in subsection 4.2.1. The survey was conducted by TELESAT under contract to SPAR.

A significant amount of conceptual design work was performed on the satellite transmit antenna. The scope of this work was to examine a feasible antenna design which could satisfy the objectives of the present conceptual design in the areas of:

a) High beam efficienty

b) Reconfigurability for design commonality of spacecraft

c) Dual mode operation

d) Conformance to launcher envelope constraints

e) Conformance to XPD and sidelobe objectives

The adopted antenna design has addressed all of the above objectives and has satisfied the needs of the overall spacecraft design. The satellite receive antenna has also been examined under this study. The full study report is attached as Appendix A.

Selected cases of input and output multiplexers have been analyzed to establish requirements for filter design and resulting performance. A summary of the multiplexer analysis is presented in subsection 4.2.2. The results confirm that the multiplexing methods used by the configurations developed are suitable and would present no special problems in implementation.

Performance specifications for the receivers and channel amplifiers have been developed to satisfy the conceptual design objectives. The required performance of these specifications is considered achievable without any serious risks.

The thermal aspects of the conceptual design have been examined and the results presented in subsection 4.2.5. Comparison between the use of heat pipes and thermal doublers has led to the selection of the latter approach on the basis of weight advantage and simplicity.

4.2.1 TWTA SURVEY

The Travelling Wave Tube Amplifier (TWTA) is a key payload element and is usually a major controlling factor in determining satellite life expectancy. The advent of the Direct Broadcast Satellite (DBS) has resulted in the need for the development of a new class of long life, high power TWTA's. The design characteristics of these tubes are such that expected operational lifetime should be similar to the currently available dispenser cathode TWT's used in Ku-Band Communications Satellites. High power TWTA's, with lower life expectancy, have already been successfully operated on satellites. The Canadian Hermes Satellite used a 200 Watt Ku-Band tube to prove the effectiveness of direct broadcast operation in this frequency band. In Europe, Eurosatellite is currently manufacturing Direct Broadcast Satellites for France and Germany for launch in 1985. Thomson CSF and AEG Telefunken are producing TWT's in the 200 Watt power range in support of this program.

In the case of a Canadian DBS, alternate system designs lead to a requirement for a medium power TWTA with an RF output of between 50 and 75 Watts and a high power tube with an output of between 120 and 150 Watts. For the purposes of this study, TWTA's have been reviewed from three candidate suppliers, AEG Telefunken (AEG), Hughes Electron Dynamics Division (HEDD) and Thomson CSF (ThCSF). Although the review concerns primarily the TWT, as the EPC design tends to be bus dependent, dimensions and weight estimates are provided for a typical EPC design in each of power ranges considered.

4.2.1 MEDIUM POWER TWTA

Candidate Medium Power TWT'S

No long life space qualified TWT exists in the RF output power range 50 to 75 Watts. Such a tube could either be developed from a stretched version of existing qualified 30 Watt Ku-Band tubes or from a scaled down version of the high power direct broadcast tubes currently in production. The latter approach would be expected to produce a lower risk product. This power/frequency range falls outside the capability of oxide cathodes and all candidate tubes have dispenser cathodes. Collector cooling could be either by conduction or radiation depending on the requirements of the spacecraft thermal design. Characteristics and design heritage of TWT's that could be provided by the three manufacturers are shown in Table 4.2.1.1.1.

AEG Telefunken's most likely approach would be to develop their tube from the TDRSS TL12030 and the TV-SAT TL12260 designs. The conduction and radiation versions would both use the TL12260 gun and integrated pole piece structure delay line. The conduction cooled version will use the TL20030 three stage collector while the radiation cooled version would use the five stage collector developed for their TV-SAT, TDF1 tube. An efficiency of 48% is estimated for both designs. AEG would use their standard type B dispenser cathode with a tapered helix construction to maximise efficiency.

HEDD could offer a conduction cooled design based on their 50 Watt 874H tube used on the Space Shuttle for communications and radar in the 13.7 to 15.2 GHz frequency range. Frequency scaling of the RF circuit and an increase of cathode diameter would be required as well as repackaging the tube for the satellite application. If a radiation cooled version was required, the collector could be derived from the 100 Watt 294H tube developed for the Japanese Broadcasting Satellite. The Shuttle application of the 874H does not have the stringent lifetime requirements necessary for DBS operation. In view of the current TWT designs being manufactured by HEDD, it is expected that they would modify the 874H cathode by changing from a type B to a type M design.

The coated M cathode shows a good potential for stable long life performance but this has yet to be verified and only limited life data is available. The 874H requires EPC voltages in the order of 7kV which requires careful EPC design.

The third manufacturer ThCSF could offer a conduction cooled design based on their Th3626 Telecom 1 tube and a radiation cooled version based on the Th3579 developed for BS2. Modifications would include the reduction of the gun diameter and collector scaling. The conduction cooled tube would have two collectors and an estimated efficiency of 43% while the radiation cooled version would have four collectors with efficiency increased to 48%. ThCSF would use their standard S-type dispenser cathode and their design would encorporate a tapered helix for efficiency optimisation.

PARAMETER	AEG	HEDD	ThCSF
<u>Previous Experience</u>			
Conduction cooled	TL12030 TDRSS	874H Space Shuttle	Th3626 Telecom 1
Radiation cooled	TL12260 TV-SAT	294H JBS	Th3579 BS2
Cathode Type	Matrix-B	Matrix-M	Matrix-S
Helix	Tapered	Uniform	Tapered
<u>Collectors</u>			
Conduction cooled	3	3	2
Radiation cooled	5	3	4
<u>Efficiency</u>			
Conduction cooled	48	46	43
Radiation cooled	48	46	48
Cathode Voltage	5.7 kV	7.1 kV	5.0 kV

TABLE 4.2.1.1.1

MEDIUM POWER TWT - POTENTIAL TWT CHARACTERISTICS

Proposed Characteristics of Study TWTA

For the purposes of this study typical performance and interface characteristics of a medium power TWTA in the 50 to 75 Watt class are as shown in Tables 4.2.1.1.1 and 4.2.1.1.2 and in Figures 4.2.1.1.1 to 4.2.1.1.2 inclusive.

PARAMETER	UNITS	VALUE
RF Output Power	Watts	50 to 75
Saturated Gain	dB	48
AM/PM Transfer Coefficient	°/dB	4.5
TWT Efficiency	%	46 to 48
EPC Efficiency	%	85

TABLE 4.2.1.1.2

STUDY MEDIUM POWER TWTA - ELECTRICAL CHARACTERISTICS

PARAMETER	UNITS	VALUE
Mass (Conduction Cooled)		
TWT		1.4
EPC	kg	3.0
TWTA		4.4
Mass (Radiation Cooled)		
TWT		2.0
EPC	kg	3.0
TWTA		5.0
Dimensions		
TWT		See Figures 4.2.1.1.1, 4.2.1.1.2
EPC	mm	350x150x150
Thermal		
Thermal Model		See Figure 4.2.1.1.3
TWT Baseplate		-15 to +85
Collector:		
conduction	°C	100 maximum
radiation		300 maximum
EPC		-15 to 50

TABLE 4.2.1.1.3

STUDY MEDIUM POWER TWTA - MECHANICAL AND THERMAL INTERFACE DATA

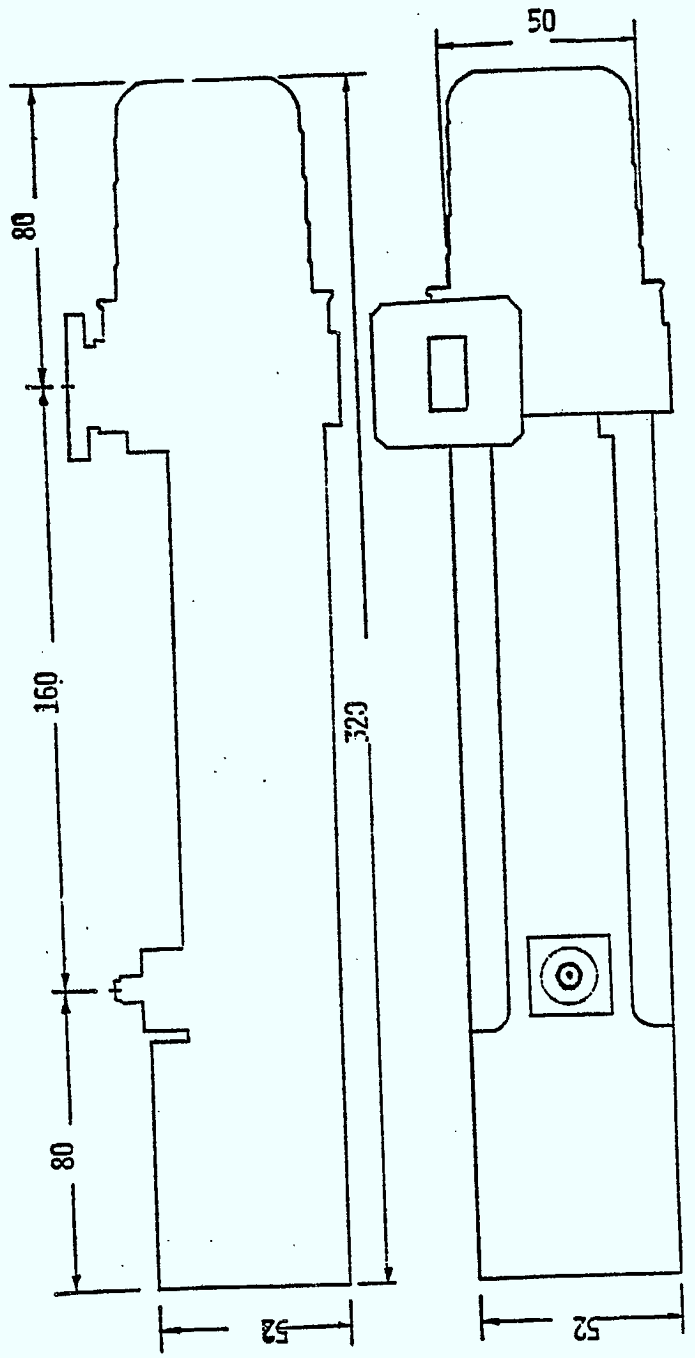


FIGURE 4.2.1.1.1 MEDIUM POWER RADIATION COOLED TWT

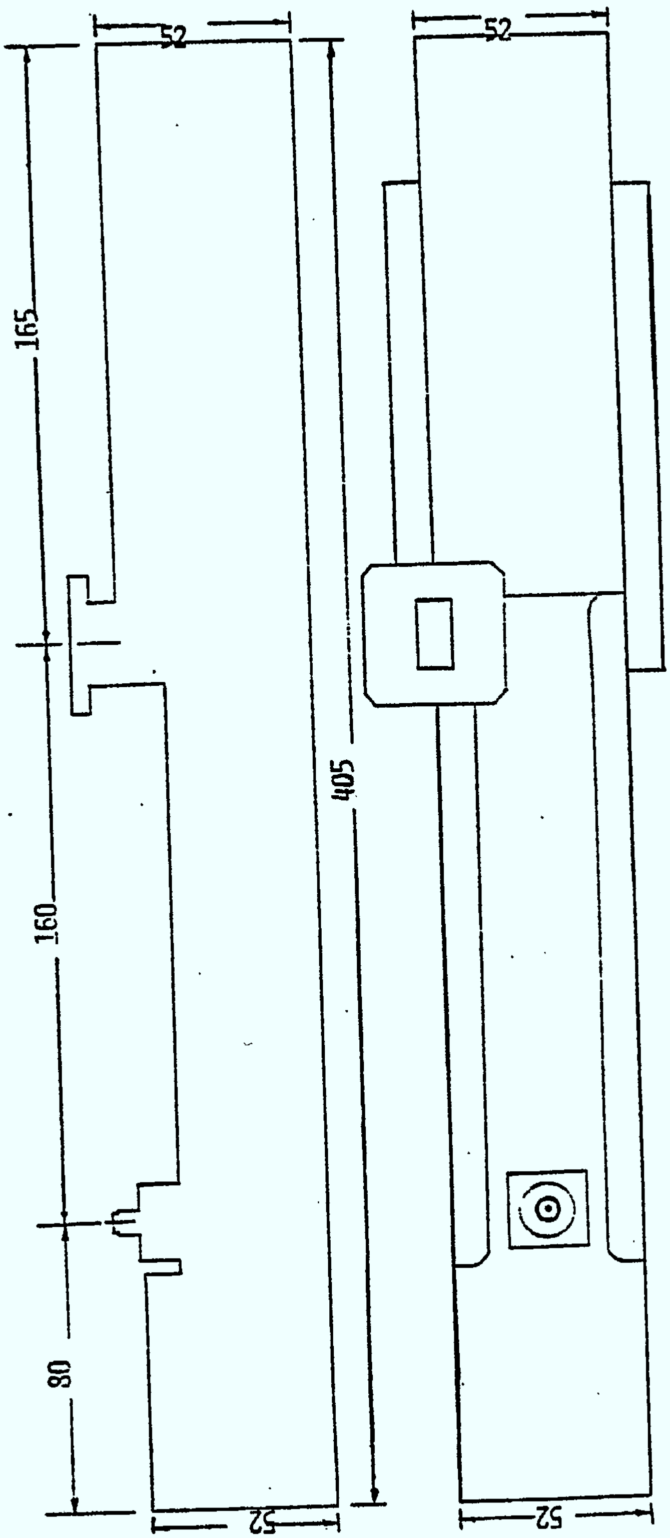
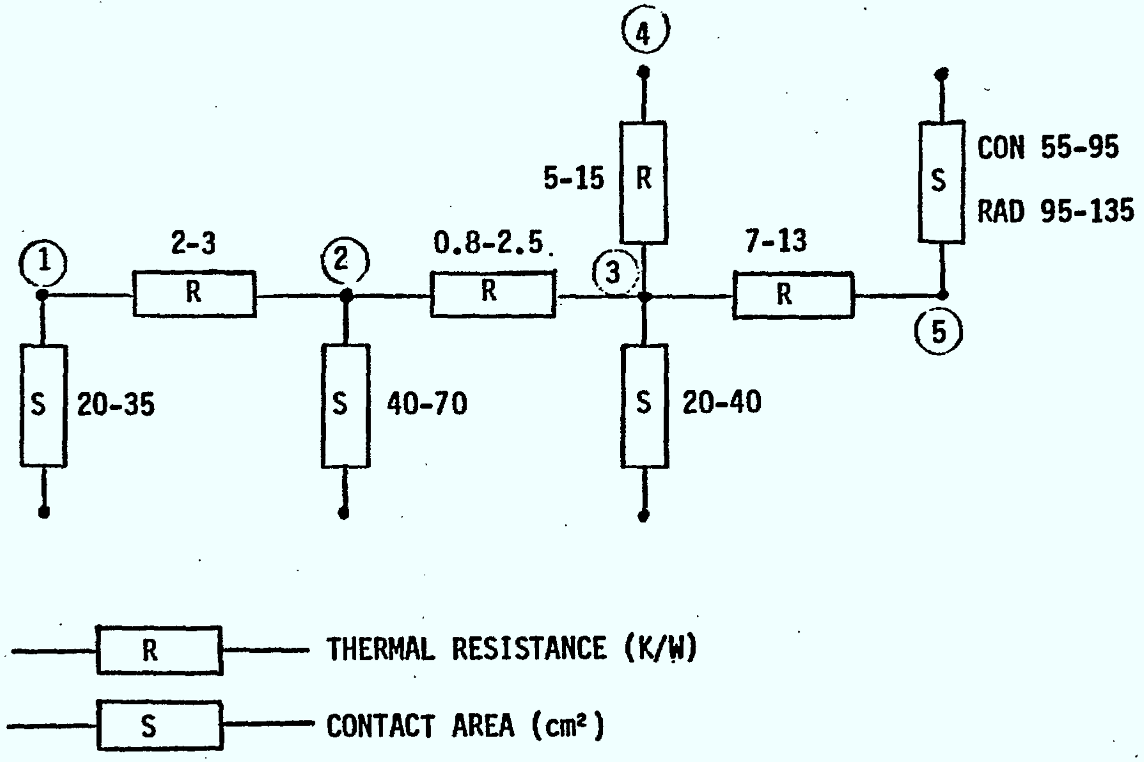


FIGURE 4.2.1.1.2 MEDIUM POWER CONDUCTION COOLED TWT



NODE 1 - GUN

NODE 2 - Delayline Input

NODE 3 - Delayline output

NODE 4 - Waveguide Flange

NODE 5 - Collector

FIGURE 4.2.1.1.3 MEDIUM POWER TWT - THERMAL MODEL

4.2.1.2 HIGH POWER TWTA (120 to 150 WATTS)

Candidate High Power TWT's

The development status of TWT's in this high power range is better than the medium power tubes discussed. Table 4.2.1.2.1 summarises the characteristics of tubes most closely matching the study requirements from the three tube manufacturers. In this power range, only radiation cooled designs are considered.

AEG Telefunken has considerable development experience with the 260 Watt TL12260 TWT which will be qualified for the TV-SAT, TDF-1 Direct Broadcast Satellite applications. This is a five collector design using AEG's Matrix-B cathode and has an overall efficiency in the range 46 to 48%.

HEDD is carrying out an internally funded development program for a 200 Watt Ku-Band tube designated the 899H. The design uses technology developed from the 50 Watt Space Shuttle 874H tube and the 100 Watt 294H tube developed for the Japanese Broadcast Satellite. The 899H has three collectors and an estimated overall efficiency of 46%. In line with their current approach, HEDD has selected the coated M type dispenser cathode for this application. As stated previously, this cathode has an excellent long life potential but little supporting life test data.

Thomson CSF are the co-supplier of TWT's in the 200 Watt power range for the French TDF-1 and the German TV-SAT DBS program. The Th3619 has four collectors, a Matrix-S cathode and has an overall efficiency in excess of 50%.

PARAMETER	AEG	HEDD	ThCSF
Previous Experience			
	TL 12260 260W Being qualified for TV-SAT & TDF-1 DBS.	New development tube 899H 200W Uses technology of 50W 874H Space shuttle tube and 294H 100W JBS tube	Th3619 230W Being qualified for TV-SAT & TDF-1 DBS application.
Cathode Type	Matrix-B	Matrix-M	Matrix-S
Cathode Loading	750 mA/cm^2	540 mA/cm^2	800 mA/cm^2
Cathode Voltage	7.5 kV	8.5 kV	7.0 kV
Helix	Tapered	Uniform	Tapered
Collector	5	3	4
Collector Cooling	Radiation	Radiation	Radiation
Overall Efficiency	46-48%	46%	50%

TABLE 4.2.1.2.1

HIGH POWER TWT - POTENTIAL TWT CHARACTERISTICS

Proposed Characteristics of Study TWTA

Interface data, considered representative of a TWTA in the 120 to 150 Watt class is shown in Tables 4.2.1.2.2 and 4.2.1.2.3 and in Figure 3-1 and 3-2. The EPC for the TV-SAT, TDF-1, program is being manufactured by AEG Telefunken and has a weight of 8.0 to 8.5 kg. For the high power 120-150 Watt tube it is estimated that an EPC could be developed with a mass of 6.0 kg.

PARAMETER	UNITS	VALUE
RF Output Power	Watts	120 to 150
Saturated Gain	dB	55
AM/PM Transfer Coefficient	°/dB	5
TWT Efficiency	%	48
EPC Efficiency	%	87

TABLE 4.2.1.2.2

STUDY HIGH POWER TWTA - ELECTRICAL CHARACTERISTICS

PARAMETER	UNITS	VALUE
<u>Mass</u>		
TWT		3.0
EPC	kg	6.0
TWTA		9.0
<u>Dimensions</u>		
TWT		see Figure 4.2.1.2.1
EPC	mm	350x165x150
<u>Thermal</u>		
TWT Baseplate		-10 to +70
Collector	°C	300 maximum
EPC		-15 to 50

TABLE 4.2.1.2.3

STUDY HIGH POWER TWTA - MECHANICAL AND THERMAL INTERFACE DATA

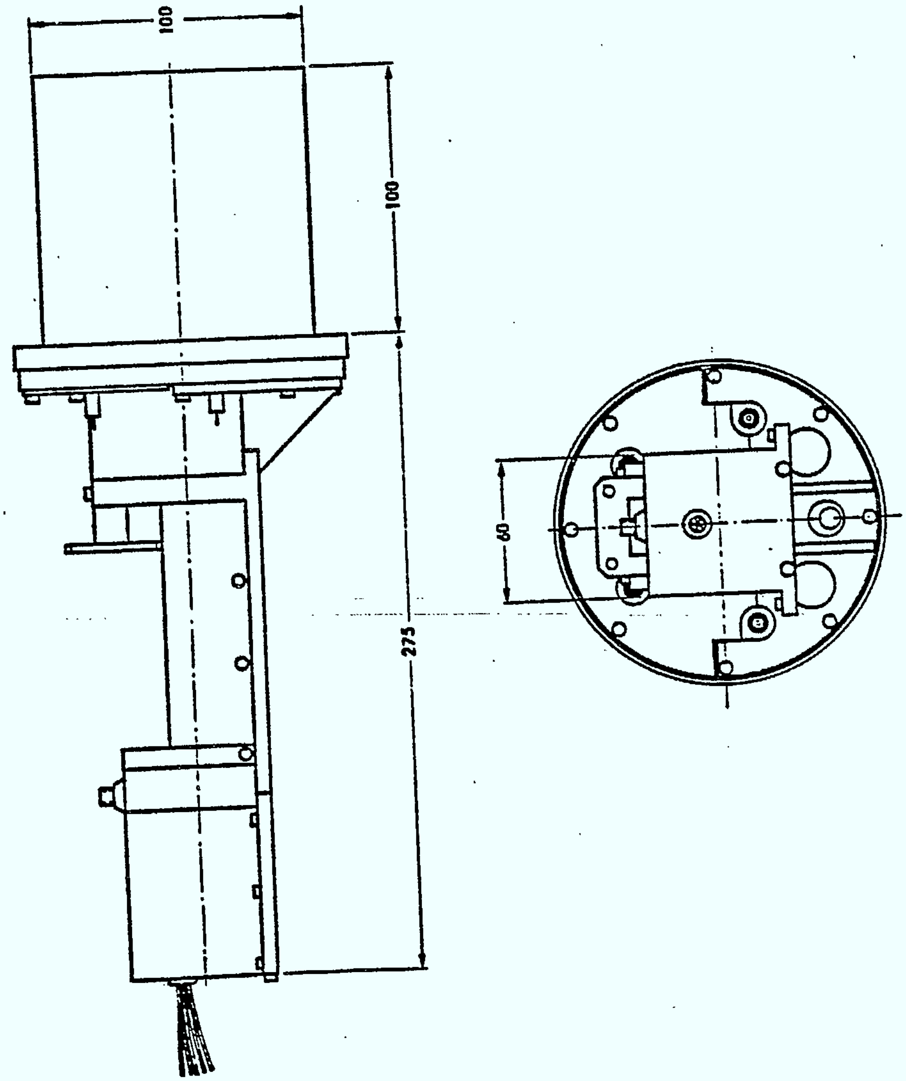
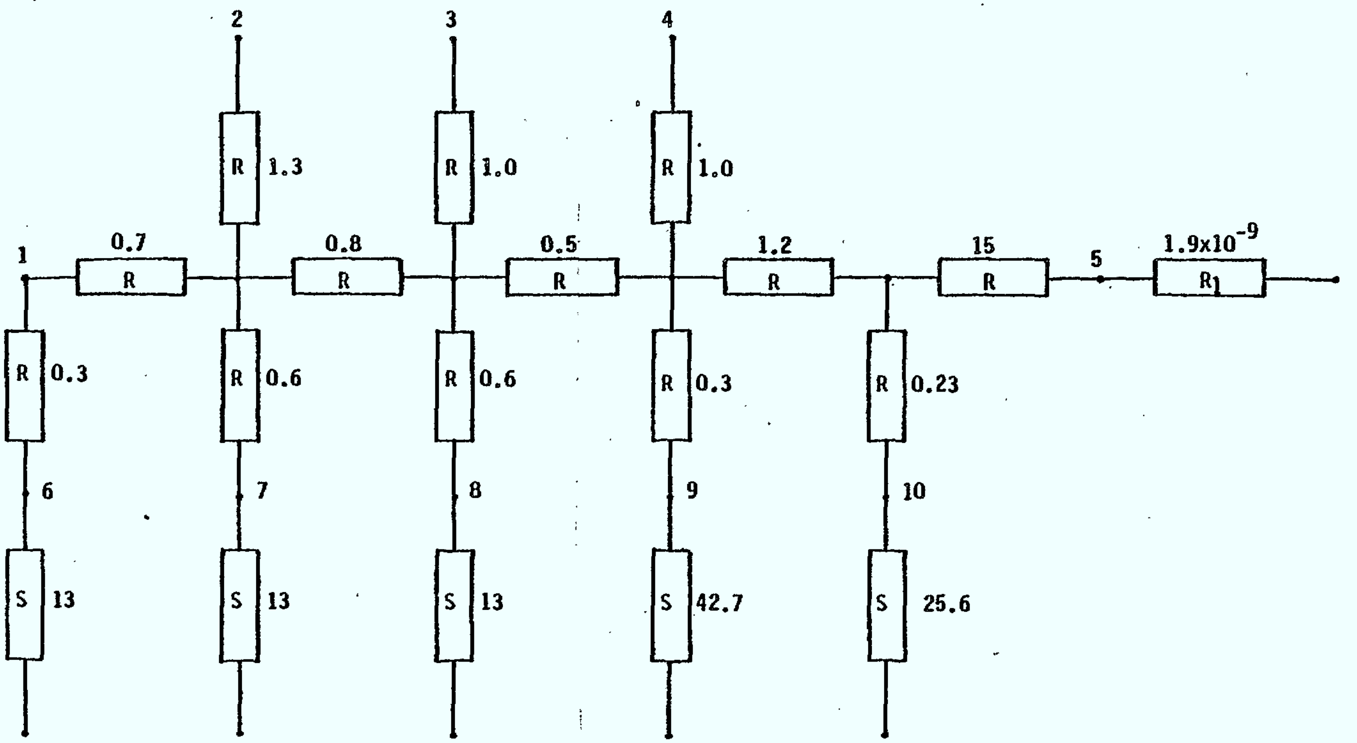


FIGURE 4.2.1.2.1 HIGH POWER RADIATION COOLED TWT



R — THERMAL RESISTANCE (K/W)

S — CONTACT AREA (cm²)

R1 — RADIOSITY (W/K4)

NODE 1 - Electron Gun
NODE 2 - Helix Input
NODE 3 - Helix Center
NODE 4 - Helix Output
NODE 5 - Collector

NODE 6 - ELECTRON GUN AREA
NODE 7 - HELIX INPUT AREA
NODE 8 - HELIX CENTER AREA
NODE 9 - HELIX OUTPUT AREA
NODE 10 - COLLECTOR BASEPLATE

FIGURE 4.2.1.2.2 HIGH POWER TWT - THERMAL MODEL

4.2.1.3 OPERATIONAL REQUIREMENTS

Operational Bandwidth

In order to meet typical DBS TWT requirements, tubes in the power and frequency ranges considered in this study can readily meet a 200 MHz specification. If a lower yield and hence higher price is acceptable, tubes could be selected with a 400 MHz operational range.

Eclipse Operation

Unlike most communications satellites, the high RF power required for a Direct Broadcast satellite usually results in the need to power down a significant number of channels during eclipse periods. There are four possible operating modes that could be used to reduce demand on the satellite batteries.

i) Filament On, High Voltage On, RF Drive Off:

In this mode of operation, TWTA the input power would be expected to drop by approximately 50% between saturated drive and no drive conditions. Measurements on a 200 Watt TWTA showed that under no-drive conditions, the d.c. input power decreased to 46% of the level measured with saturated drive.

ii) Filament On, High Voltage Off:

The satellite bus must provide the heater power of between 5 and 8 Watts and any keep-alive circuits within the EPC. Due to the absence of electron cooling, the cathode temperature will increase by typically 20°C above its nominal value under these operating conditions. However, as this occurs for only a small percentage of the overall lifetime of the TWTA,the impact on tube life will be small (typically 1,000 hours out of the 80,000 hours expected lifetime.)

iii) Filament On (reduced power), High Voltage Off:

This mode offers a small power saving advantage over (ii) at the expense of a greater disturbance of the cathode operating conditions.

iv) Filament Off, High Voltage Off:

This operational mode would result in minimum power demand, as the only power demand would be for any keep alive circuits within the EPC, but would result in maximum stress to the TWTA during the repeated on/off cycles. Manufacturers typically have data to support a total number of switching cycles of around 1,000, but it is to be expected that there would be a certain life reduction as the number of switching cycles increases beyond this value. There is limited life data to quantify this effect.

Discussions with a TWT vendor have shown that, if the satellite bus is unable to support TWTA operation under no RF drive condition, the preferred mode of operation during eclipse is to leave the filament voltage on and turn the high voltage off. The tube manufacturer concerned considered that the impact of the increased cathode temperature would be acceptable in view of the small percentage of the total operating time involved.

4.2.1.4 CONCLUSIONS

In the case of the medium power TWT, although no existing qualified design exists, all three TWT vendors reviewed could develop suitable tubes using existing technology. One possible exception is the HEDD M-type cathode. Although HEDD are currently producing Ku-Band tubes with this type of cathode, the long term performance has yet to be demonstrated by extensive life tests. For this power range, both conduction and radiation cooled designs are feasible. The high power tube design is, in the case of the two European suppliers, in a reasonable state of design maturity. It is to be expected that HEDD will also be actively competing in this expanding DBS market. For both classes of tube, the conservative design approach being adopted by the manufacturers should lead to tube having comparable lifetime to the lower power Ku-Band tubes currently available.

Both power ranges of TWT's would have typical operating bandwidths of 200MHz although selection of tubes with operating bandwidths as high as 400MHz would be possible.

During eclipse operation, the preferred operational mode is to leave the TWTA fully on and to turn off the RF drive. As this is unlikely to be acceptable in terms of satellite battery size, an acceptable compromise is to switch off the high voltage supplies and leave the filament running at its nominal level.

In view of the criticality of these amplifiers to the DBS program, dual procurement should be seriously considered to minimise schedule risk and to provide some protection against in-orbit problems. Such an approach has been followed for the TV-SAT, TDF-1 satellites.

4.2.2 Input and Output Multiplexer Review

From all possible configurations, three (3) cases, each representing the most difficult of its type, are chosen for detailed investigation.
Case No. 1 is the 40 channel plan, 23.8 MHz spacing, 18 MHz usable band and corresponds to configuration 2610/30.
Case No. 2 is the 32 channel plan, 29.5 MHz spacing, 18 MHz usable band and corresponds to configuration 2416/8.
Case No. 3 is the 32 channel plan, 29.5 MHz spacing, 18 MHz usable band and corresponds to configuration 268/12.
In the last case, two types of output multiplexers were analysed; the first configuration is using a near-contiguous 4 channels multiplexer while the other is the more usual non-contiguous diplexer pair which implied that the antenna feed has to be reconfigured for two inputs.

In all others, non-contiguous approach is used.
The filter type for the output mux is 4-pole dual mode elliptic, in all cases. The input multiplexer configuration is the well-proven circulator channel-dropping approach, which avoids any adjacent channel interferences. 8-pole DMQE filter are needed in case No. 1 while 6-pole DMQE are used in cases No. 2 and No. 3.

Input Mux Key Features

Filter: 8-pole dual mode quasi elliptic
and 6-pole dual mode quasi elliptic
Waveguide, mode: Thin wall circular, TE113
Material: High purity invar (.020 wall) for good thermal stability.
Circulator/Isolator: Waveguide design WR75

Output Mux Key Features

Filter:	4-poledual mode elliptic
Wageguide, Mode:	Invar Circular, TE113
Material:	High purity invar
Manifold:	Aluminum, WR75
Circulator/Isolator:	Waveguide WR75, high power
Configuration:	Mostly non-contiguous multiplexing except case no. 3 where near-contiguous is proposed.

Performance Parameters

A summary of the major performance parameters is given for each case. Estimated mass and dimensions are also given in the tables. Brackets are not included in the weight estimates. Also it is assumed that the output mux filters are placed 8 cm (_ 3.0") apart. This value is approximate; the actual spacing is determined in the final design.

Alternative Designs

The output multiplexer features shown are not necessarily final. The final design of the output multiplexer will depend on the TWTA power level selected, the antenna design, and the frequency plan adopted. When these system factors are finalized, an evaluation of alternative multiplexer designs and materials will be required. For example:

- Use of TE115 Mode
- Use of TE001 Mode
- Use of aluminum or silver possibly temperature compensated
- Use of heat pipes

Case #1 Input Multiplexer Filter Parameter:	27 channels 18 MHz usable band 23.8 MHz spacing 8-pole DMQE BW= 24.2 MHz QU= 10000 RL= 25 dB	
PARAMETER	COMPUTED	BUDGET
Isolation (dB) CF(1) ± 14.8 MHz	28	20
Loss Variation (dB) CF ± 9 MHz	.81	1.4
Gain Slope (dB/MHz) CF ± 9 MHz	.3	.5
Group Delay (ns) CF ± 9 MHz	24	36
Midband Loss (of filter alone)	1.7	2.0

Note (1): CF Centre frequency of filter

Weight per channel *: .357Kg (.785 lbs)

Total weight (27 filters): 9.65 Kg (21.2 lbs)

Dimension : 200 x 5 x 25cm

* Includes: Circulator, filter, isolator

Case #2 and case #3

Input Multiplexer

Filter Parameter: 6-pole DMQE
BW =22 MHz
QU =10000
RL =25 dB

32 and 24 channels
18 MHz usable band
29.5 MHz spacing

PARAMETER	COMPUTED	BUDGET
Isolation (dB)		
CF[(1)] ± 20 MHz	27	20
CF ± 29.5 MHz	44	40
Loss Variation (dB) CF ± 9 MHz	.39	0.8
Gain Slope (dB/MHz) CF ± 9 MHz	.13	.3
Group Delay (ns) CF ± 9 MHz	11.6	20
Midband Loss (dB) (filter alone)	1.4	1.7

Note (1): CF: Centre frequency of filter

* Weight per channel: .307 Kg (.677 lb)

* includes: circulator, filter, isolator

Total weight (32 filters): 9.86 Kg (21.7 lbs) case #2
(24 filters): 7.39 Kg (16.3 lbs) case #3

Dimension: 250 x 5 x 20 cm case #2
180 x 5 x 20 cm case #3

Case #1 Output Multiplexer Filter Parameter: 4-pole elliptic BW =43 MHz QU =10000 RL =20 dB		27 channels 18 MHz usable band 23.8 MHz spacing
PARAMETER	COMPUTED	BUDGET
Isolation (dB) CF(1) ± 35 MHz CF ±> 40 MHz	 18 26	 10 25
Loss Variation (dB) CF ± 9 MHz	.04	.10
Group Slope (dB/MHz) CF ± 9 MHz	.012	.020
Group Delay (ns) CF ± 9 MHz	.77	2
Midband Loss (dB) (filter alone)	.46	.6

Note (1): CF: Centre frequency of filter
*Weight per quadruplexer: .94 Kg (2.07 lb)
** Weight per pentaplexer: 1.14 Kg (2.49 lbs)
Total weight (27 filters): 5.91 Kg (13 lbs)
Dimension: 200 x 5 x 15 cm
* Includes: 5 isolators, 4 filters, 1 manifold
** Includes: 6 isolator, 5 filters, 1 manifold

Case #2		32 channels
Output Multiplexer		18 MHz usable band
Filter Parameter:	4-pole Elliptic	29.5 MHz spacing
	BW = 105 MHz	
	QU = 10000	
	RL = 20 dB	

PARAMETER	COMPUTED	BUDGET	APPLICABLE TO
Isolation (dB)			
CF(1) ± 98 MHz	37	25	
CF ± 110 MHz	27	25	
Loss Variation (dB)			
CF ±35.25 MHz	.08	.15	Ch.1,7(2)
CF ±55.25 MHz	.24	.50	
Gain Slope (dB/MHz)			
CF ±35.25 MHz	.003	.015	Ch.1,7(2)
CF ±55.25 MHz	.049	.100	
Group Delay (ns)			
CF ±35.25 MHz	1.2	3	Ch.1,7(2)
CF ±55.25 MHz	5.2	10	
Midband Loss (dB)			
of CH5	.19	.5	Ch.3,5
of CH7	.28	.5	Ch.1,7

Case #2 (Cont'd.)

Notes:

(1) CF Centre frequency of filter

(2) Performance for Ch #3 & 5 is better

* Weight per diplexer: .53 Kg (1.16 lb)

Total weight (8 filters): 2.1 Kg (4.6 lbs)

Dimension: 60 x 5 x 15 cm

* Includes: 3 isolators, 2 filters, 1 manifold

Case #3

Ouput Multiplexer

Filter Parameter: 4-pole Elliptic
BW =77 MHz
QU =10000
RL =20dB

24 channels
18 MHz usable band
29.5 MHz spacing

PARAMETER	COMPUTED	BUDGET	APPLICABLE TO
Isolation (dB) CF ± 79.5 MHz CF ± 85 MHz	39.5 27	20 25	
Loss Variation (dB) CF ± 29.5 MHz CF ± 38.5 MHz	.03 .17	.1 .3	Ch.1,5
Gain Slope (dB/MHz) CF ± 29.5 MHz CF ± 38.5 MHz	.008 .020	.015 .040	Ch.1,5
Group Delay (ns) CF ± 29.5 MHz CF ± 38.5 MHz	2.3 4.8	5 8	Ch.1,5
Midband Loss (dB) of Ch 5	.28 .31	.6 .6	Ch.3 Ch.1,5

Note(1): CF Centre frequency of filter

N.B.: One contiguous quadruplexer

* Weight per quadruplexer: .95 Kg (2.10 lbs)

Total weight: 2.8 Kg (6.2 lbs)

Dimension: 90 x 5 x 15 cm

* includes: 5 isolators, 4 filters, 9 manifold

Case #3

Output Multiplexer

Filter Parameter: 4-pole Elliptic
BW = 83 MHz
QU = 10000
RL = 20 dB

24 channels
18 MHz usable band
29.5 MHz spacing

PARAMETER	COMPUTED	BUDGET	APPLICABLE TO
Isolation (dB) CF[(1)] ± 79.5 MHz CF ± 90 MHz	 28.4 28	 20 25	
Loss Variation (dB) CF ± 29.5 MHz CF ± 38.5 MHz	 .03 .11	 .1 .2	Ch.1,5
Gain Slope (dB/MHz) CF ± 29.5 MHz CF ± 38.5 MHz	 .005 .020	 .015 .040	Ch.1,5
Group Delay (ns) CF ± 29.5 MHz CF ± 38.5 MHz	 1.72 4.0	 3 75	Ch.1,5
Midband Loss (dB) of Ch 5	.25 .28	.5 .5	Ch.3 Ch.1,5

Note (1): CR Centre frequency of filter

N.B: Two non contiguous diplexers

* Weight per diplexer: .53 Kg (1.2 lb)

Total weight estimate is 3.1 Kg (6.8 lbs)

Dimension: 90 x 5 x 15

* includes: 3 isolators, 2 filters, 1 manifold

All others system configurations will give similar or better performance due to the fact that the cases chosen here are assumed to be the worst.

4.2.3 Antennas

A complete report on studies of circularly polarized DBS antennas done as part of this study is given in Appendix A.

The study selected the largest area beam with the most complex shape for the 6 beam coverage case. This limited the amount of detailed computation to be done in arriving at a suitable system configuration and reasonably accurate gain values. These results were then extended to cover all beams in both 4 and 6 beam configurations.

The selected system uses 2 separate deployed transmit reflectors one RCP and one LCP with a single all Canada coverage dual polarized receive antenna.

Dual mode transmit antennas were selected, based on comparison of single mode/contiguous multiplexers and dual mode/non contiguous multiplexer options.

The transmit antennas are made reconfigurable by the provision of separate feed horn assemblies in each polarization for each possible orbital location (2 or 3). For each orbit location, the reflectors are moved by command in orbit to reposition the focal points close to the middle of the appropriate feed clusters.

The transmit antenna employs a novel linear to circular spatial polarizer concept using a corrugated surface on the reflector. This allows the use of linearly polarized feed horn arrays with the advantages of flexibility in beam optimization using well established design techniques

If the technique for generating CP proves to be unsatisfactory, then polarizers would be required in each feed horn. More square or circular horns would be required for a given degree of beam shaping than for the equivalent rectangular horn array, thus increasing the feed network complexity. A single reflector downlink option seems unlikely on the basis of the polarization purity achievable in a dual mode CP antenna. The matter of single mode versus dual mode antennas is in turn closely linked with the ultimate channel capacity of the planned system, and the feasibility of contiguous output multiplexers for 8 or more high power channels. Should such a multiplexer prove satisfactory, both single reflector and two reflector transmit antenna options would have to be evaluated for performance and weight.

4.2.4 Receivers and Channel Amplifiers

The requirements for receivers and channel amplifiers have been reviewed and the following performance specifications have been developed to satisfy the present conceptual design. Although there is no existing design of such receiver, projection from 14 GHz receivers indicate that the required performance is achievable.

Receiver:

o Operating Frequency Band:	
Input:	17.3-17.8 GHz
Output:	12.2-12.7 GHz
o Gain/Frequency Response :	55± 1dB (across band)
o Intermodulation(2 tone) :	40dB at -30dBw total output
o Gain Stability :	1dB peak to peak
o Gain Slope :	0.01dB/MHz
o Noise Figure :	4.5dB
o Intelligible Crosstalk :	$-200 + 20 \log f_m$
o Translation Frequency :	5100 MHz
o Frequency Stability :	± 5 ppm
o Temperature Range :	0 - 50°C full performance
o Mission Life :	8 yrs.
o Unit Weight :	1.6 Kg
o DC Power :	6 W

Channel Amplifier:

- o Operating Frequency Band : 12.2-12.7 GHz
- o Gain : 25 to 45dB with ALC
- o Gain/Frequency Response : 0.25dB p-p over any 20 MHz
- o Gain Slope : 0.01dB/MHz
- o Output Level : -20dBw with input varying from -45 to 65 dBw
- o Intermodulation : -5dBw intercept point
- o Intelligible Crosstalk : $-200 + 20 \text{ Log } f_m$
- o Noise Figure : 10dB
- o Temperature Range : 0-50°C full performance
- o Mission Life : 8 yrs.
- o Unit Weight : 0.8 Kg
- o DC Power : 4 W

4.2.5 Thermal Design

The objectives of thermal design at this level of system definition are to examine conceptual approaches to the problem of heat removal from the system and determine the weight of necessary heat pipes, thermal doublers etc. so that it can be included in the payload weight budgets.

Preliminary comparisons of required hardware weight between a scheme involving heat pipes and an alternate using only thermal doublers indicated that for this application the thermal doubler approach provides a clear weight advantage. The example used for this comparison was the highest dissipation case encountered of 160 W total dissipation through the panel. Lower dissipation cases are expected to compare even better versus heat pipes. This rather unexpected result was attributed to the fact that the heat dissipation sources are distributed amongst the TWT body, EPC and a number of locations along the output circuit. Had the total heat source been concentrated at one location the heat pipe approach would have emerged as the preferred approach from the weight point of view.

On the basis of simplicity of design and weight advantage the thermal doubler approach has been adopted here. The thermal hardware weight budgeted in all configurations is based on a simplified approach using 1 mm thick aluminum thermal doubler over an area corresponding to 0.035 w/cm^2 radiation capability for 50°C unit baseplate temperature. The 50°C baseplate temperature applies to the EPC operating temperature range. TWT's can be operated to 70°C, hence this generalized approach is expected to provide safe estimates of thermal hardware weight.

Table 4.2.5.1 contains a heat dissipation breakdown in terms of Collector Radiator, TWT body, EPC and output circuit comprising all the RF components from the TWT output to the antenna connections. The purpose of this breakdown was to generate estimates of through-the-panel heat dissipation for all the TWT sizes used in this study. The thermal doubler weight estimates are based on the total dissipation through-the-panel contained in this table.

4.2.5 Thermal Design(cont'd)

As a byproduct of the thermal design work a guide was generated to allow quick computation of thermal doubler size when the heat source footprint dimensions and baseplate temperature limit are known. Unfortunately, in our case where equipment layouts and unit mounting areas are not defined, application of the method described in the guide would have led to different answers depending on the mounting area assumptions. The usefulness of this guide can be considerable in a more advanced phase of design where unit mounting areas are known or are in the process of being defined. In anticipation of using this guide in the next phase of system definition it is appended to this report as Appendix B, entitled "Transponder Thermal Parameter Evaluation Technique".

	6 BEAM MODEL		4 BEAM MODEL	
	54 dBw EIRP	50 dBw EIRP	54 dBw EIRP	50 dBw EIRP
100% Coverage of Largest Beam:				
DC Power/TWTA (w)	302	125	398	165
Dissipation: (w)				
TWT - Radiator	91	38	120	50
- Body	46	19	60	25
EPC	39	19	52	25
Output Circuit	37	15	48	19
Total Through Panel (w)	122	53	160	69
90% Coverage of Largest Beam:				
DC Power/TWTA (w)	227	95	302	125
Dissipation:				
TWT - Radiator	68	N/A	91	38
- Body	34	43	46	19
EPC	30	14	39	19
Output Circuit	28	11	37	15
Total Through Panel (w)	92	68	122	53

TABLE 4.2.5.1 TWTA AND OUTPUT CIRCUIT HEAT DISSIPATION SUMMARY

4.3 Communications Payload Configuration

The system models selected for conceptual design, contain 4 and 6 beam repeater configurations with high and low EIRP TWTA's. Sixteen-channel repeaters were chosen in both cases from practical spacecraft/launcher match considerations and the objective for 8 channels/beam initial system capacity.

The repeaters are essentially identical between the 4 and 6 beam systems except in TWTA size where a higher power TWTA is required by the 4 beam case and the transmit antenna feed which has to accommodate operation from three orbital locations for the 6 beam system versus the two orbital locations for the 4 beam system. Block diagrams of the two different repeater configurations are contained in figures 4.3.1 and 4.3.2. A description of the main features of the adopted design follows.

Receive Antenna

The receive antenna consists of a single reflector of 18 inch apperture and dual polarization feed with three-horn stack. Feed polarizers are used to convert the circularly polarized signal to linearly polarized prior to recombination through the 3-way combiner to a common output per polarization.

This antenna is fixed to the spacecraft without any stearing capability. Construction is expected to be of GEFEC and Kevlar except for the feed which would be aluminum.

Receivers

Four-for-two receiver reduncancy has been included in the design, with switching capable of assigning either of the redundant (inner two) receivers to either polarization side. The primary receivers (outer two) are connected directly to the ferrite switch for low input loss. Construction of these units would be MIC similar to existing 14/12 GHz designs.

The receivers are preceeded by a bandpass filter and a test coupler. The bandpass filter has been included to satisfy any potential requirement for input filtering to be defined at some later time.

Input Multiplexers

The input multiplexers are equipped with two banks of channel filters to enable the repeater to handle either half of the frequency plan. In a fully expanded system (16 channels per beam) where two spacecraft are colocated all channels are received by each of the repeaters and directed to the input of the channel filters through power splitters. The commandable SPDT switch at the output of each pair of filters can then be used to select either channel for transmission through the repeater.

Input Multiplexers(cont'd)

The input filters would be 6 to 8 pole dual mode quasi elliptic depending on the frequency plan to be adopted. Construction would be thin wall invar of circular cross-section.

Channel Amplifiers and TWTA's

The present design is based on 5- for -4 single ring redundancy in channel amplification. This redundancy scheme provides a desirable option as confirmed by reliability analysis of various options in subsection 3.4 and replenishment plans of subsection 2.2.3.

Channel amplifiers are required to provide additonal gain and automatic level control(ALC) to the TWT input signal. ALC is considered a necessary feature to provide a constant input to the TWT during uplink signal fading or low EIRP uplink from transportable stations. These units are expected to be of similar construction to the receivers.

TWTA's for the design models could vary in RF power as described in subsection 3.5. Units providing 50w RF or over are expected to be equipped with collector radiators to allow direct radiation of heat to space. Additional features of the candidate TWTA designs are described in subsection 4.2.1.

Output Multiplexers

Output multiplexing involves four quadruplexers capable of handling two adjacent co-polarized channels in each filter. Thus allowing the selected channel from the input mux to be fed to the antenna without switching.

The adopted multiplexing option requires dual mode antenna feeds. An alternate method employing octaplexers and single mode antenna feeds would also provide the same system operational flexibility. Preliminary comparison between these two options showed that the net EIRP of the system would be the same in either options. The net antenna gain reduction associated with dual mode operation is estimated to be approximately equal to the additonal loss incurred in the octaplexers due to narrower filter bandwidth and extra multiplexing loss. The choice of the present design approach has been based on technical judgement between the anticipated difficulties associated with the development and production of contiguous octaplexers and difficulties involved in the optimization process of dual mode antennas.

The proposed multiplexers would use 4-pole elliptic filters. Construction would be of invar for the filters and aluminum manifolds.

Transmit Antenna

The repeater uses two transmit antennas of 75 inch apperture mounted one each on the east and west sides of the spacecraft. The reflectors are deployable and equipped with one-plane steering mechanism to allow focusing of the antenna on a dedicated beam-feed for each of the orbital locations. Conversion of linear to circular polarization is achieved by a spatial reflector surface polarizer. Each reflector handles one sense of polarization. Hence the two beams required for each orbital location are separately generated on each of the antennas.

Each antenna feed is fixed to the spacecraft and consists of 2 or 3 horn clusters corresponding to the 2 or 3 orbital locations. The feeds produce linear polarization. Two R-type switches are required per antenna to allow selection of the applicable feed for a particular orbital location.

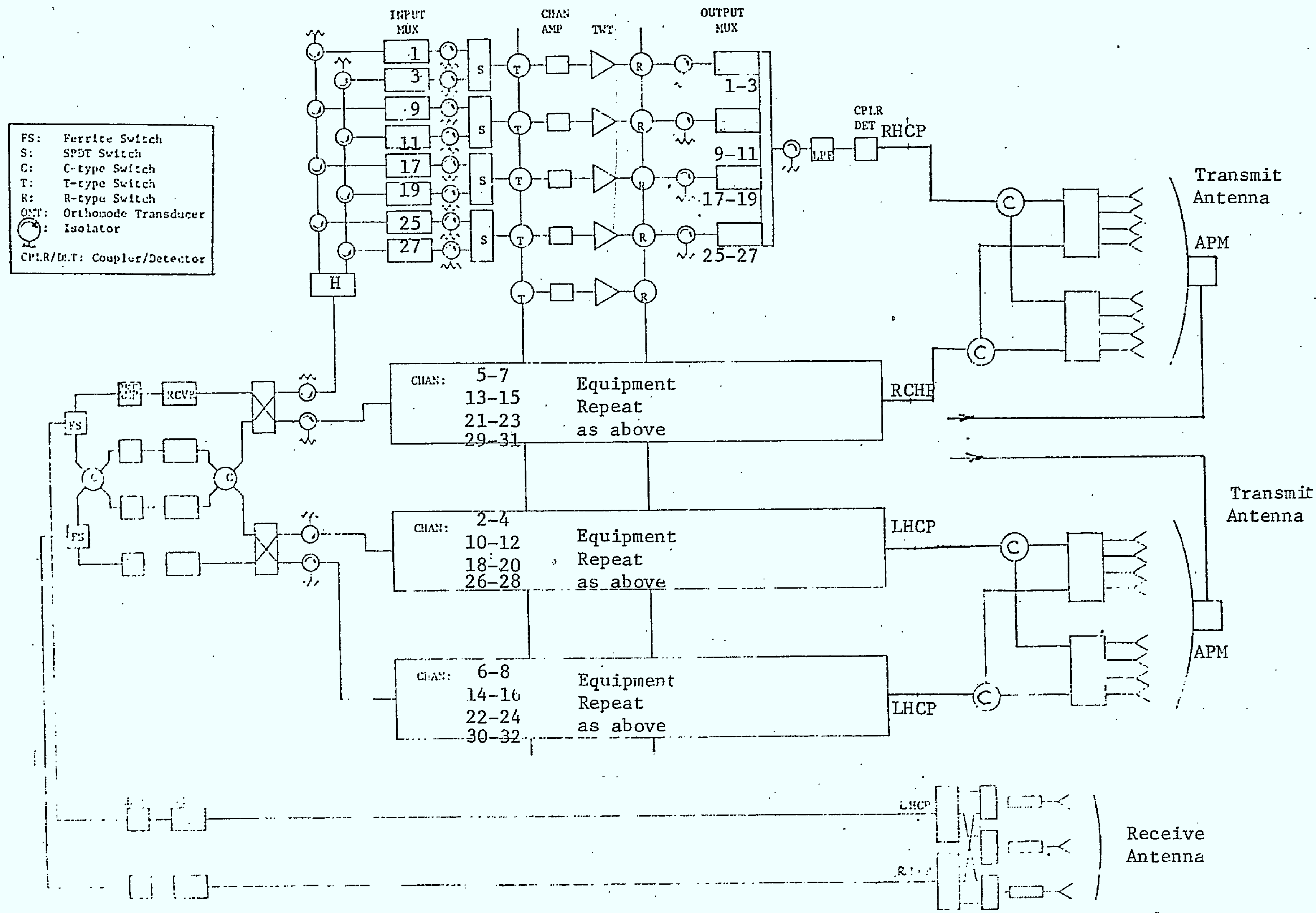


FIGURE 4.3.1 Repeater Configuration of Four Beam Two Orbit Location System (2416/16) Design Model

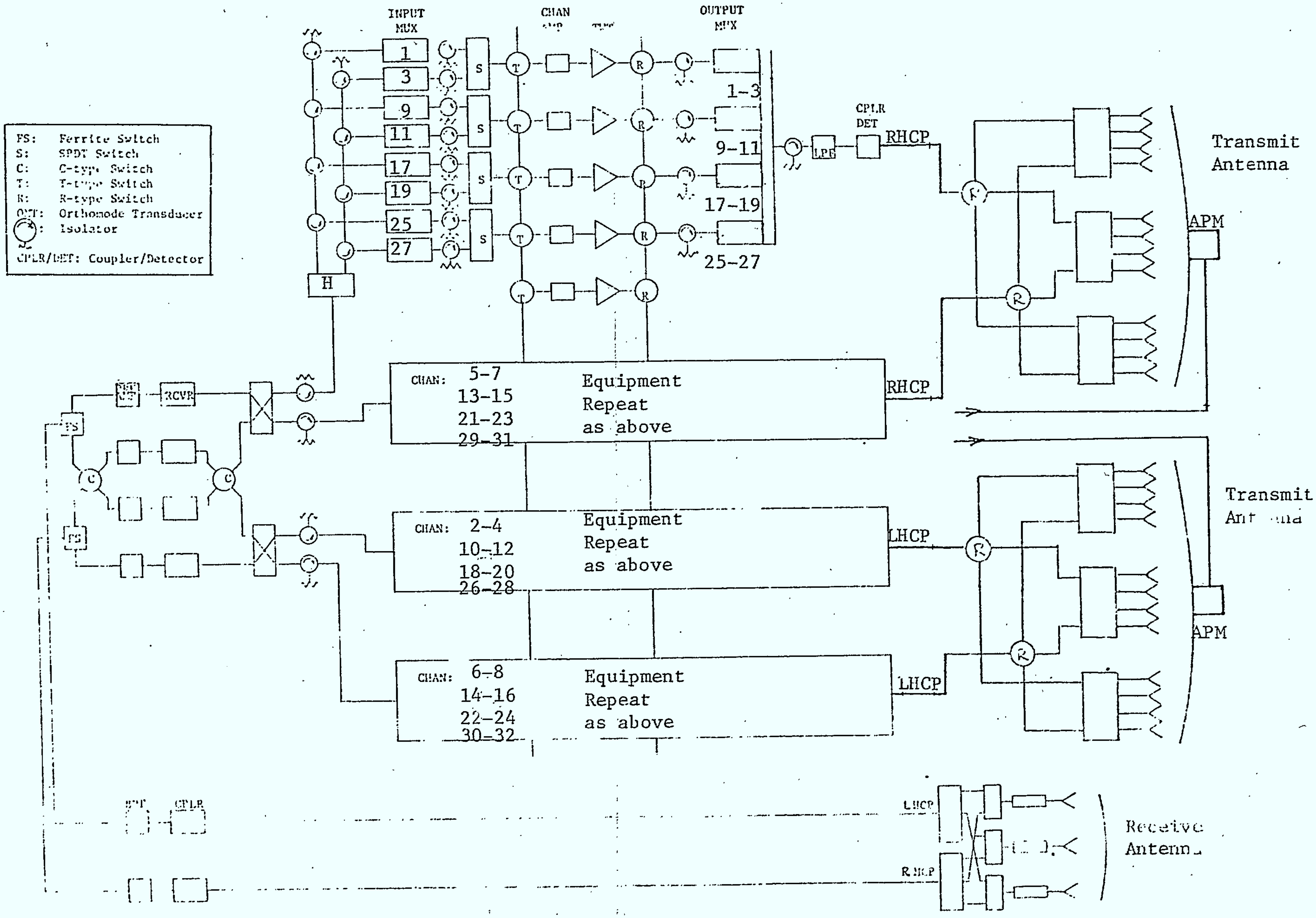


FIGURE 4.3.2 Repeater Configuration of Six Beam Three Orbit Location System (3616/16) Design Model

4.4 High EIRP Spacecraft

4.4.1 Launch and Operational Configuration Description

The High EIRP configuration of the DBS is based on the British Aerospace L-SAT bus. This bus is a very large, three axis stablized spacecraft with an on orbit weight capacity of greater than 1500 kilograms and power of more than seven kilowatts. The spacecraft is designed to be either shuttle or Ariane compatible. A bi-propellant engine is used both for a AKM and for on orbit station keeping.

Figure 4.4-1 shows the DBS payload mounted on the L-SAT Bus. In order to achieve the required power, 19 sections are used in each solar array, giving each wing a length of nearly 23 meters. The twin transmit antennas are mounted on the - x and + x sides of the spacecraft, and stowed along those sides. A deployable omni antenna is mounted on a small tower on the earth facing panel (-Z) and the 18 GHz antenna is also mounted on the -Z panel. The TWTS's are mounted along the - x and + x sides of the spacecraft, near the corners. The TWTA's radiate to the outside, so as to minimize the thermal impact.

Figure 4.4-2 shows the L-SAT configuration stowed in an Ariane IV fairing. No problems are expected with the fit. The omni antenna and the transmit antennas are the only payload deployables.

4.4.2 High EIRP Weight Budget

The Mass Budget for this DBS configuration is based on the April 1982 L-SAT configuration. Table 4.4-1 gives the mass summary. The principle changes occur in the structure, thermal, and power subsystems.

The structure requires some strengthing because of the extra batteries carried by the DBS spacecraft. The primary mass impact on the thermal subsystem is providing for the extra battery shunts. The TWTA are direct radiators so their thermal impact is not nearly as great as if they were inboard.

The greatest amount of extra mass is in the power subsystem and associated areas. The solar array is considerably larger than that of L-SAT, extra batteries are carried,

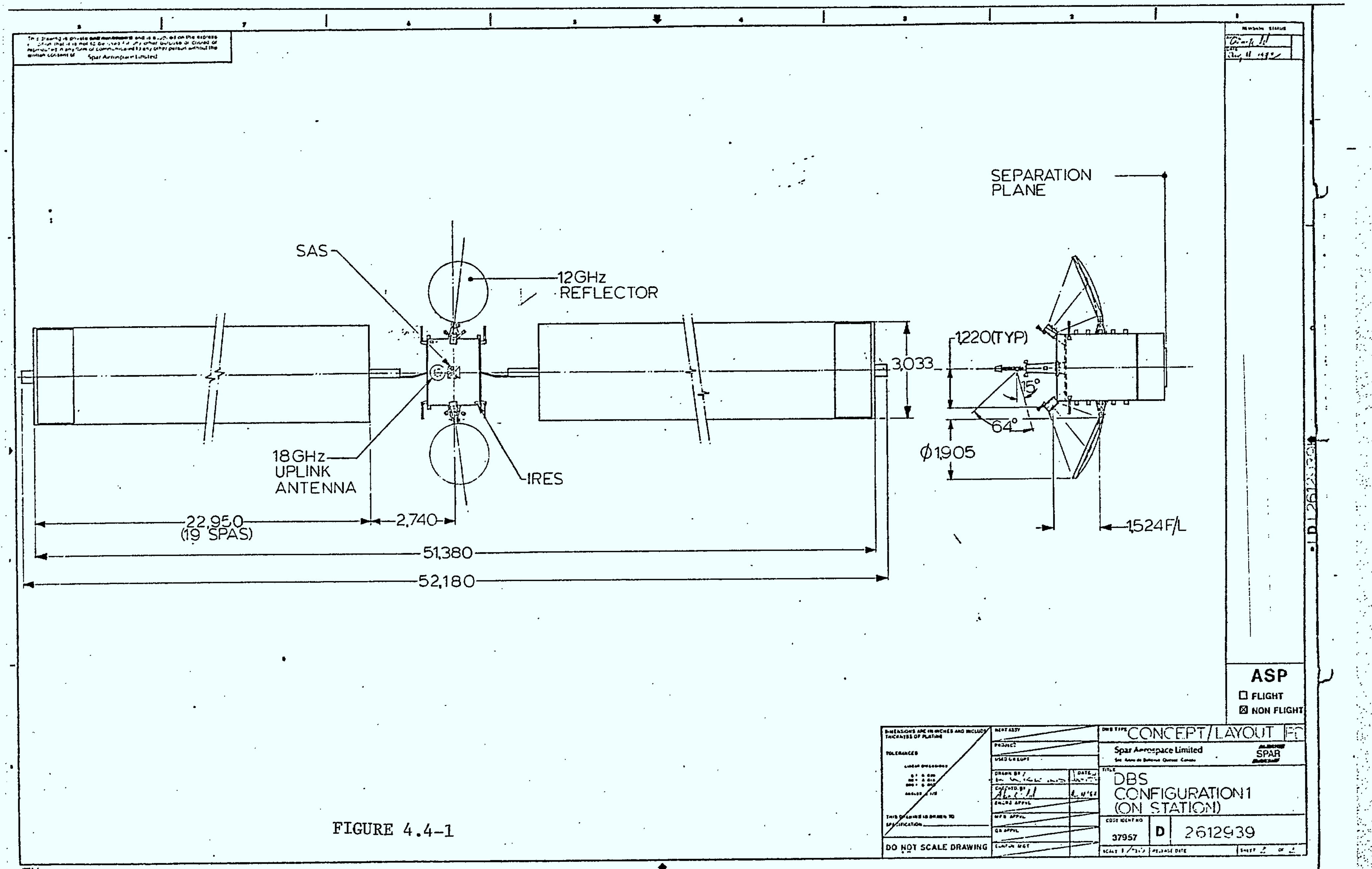

SAS
12GHz
REFLECTOR
SEPARATION
PLANE
1220(TYP)
3,033
15°
64°
ϕ1905
18GHz
UPLINK
ANTENNA
IRES
1524F/L
22,950
(19 SPAS)
2,740
51,380
52,180
ASP
FLIGHT
NON FLIGHT
CONCEPT/LAYOUT
Spar Aerospace Limited
SPAR
DBS
CONFIGURATION 1
(ON STATION)
37957
D
2612939
DO NOT SCALE DRAWING

FIGURE 4.4-1

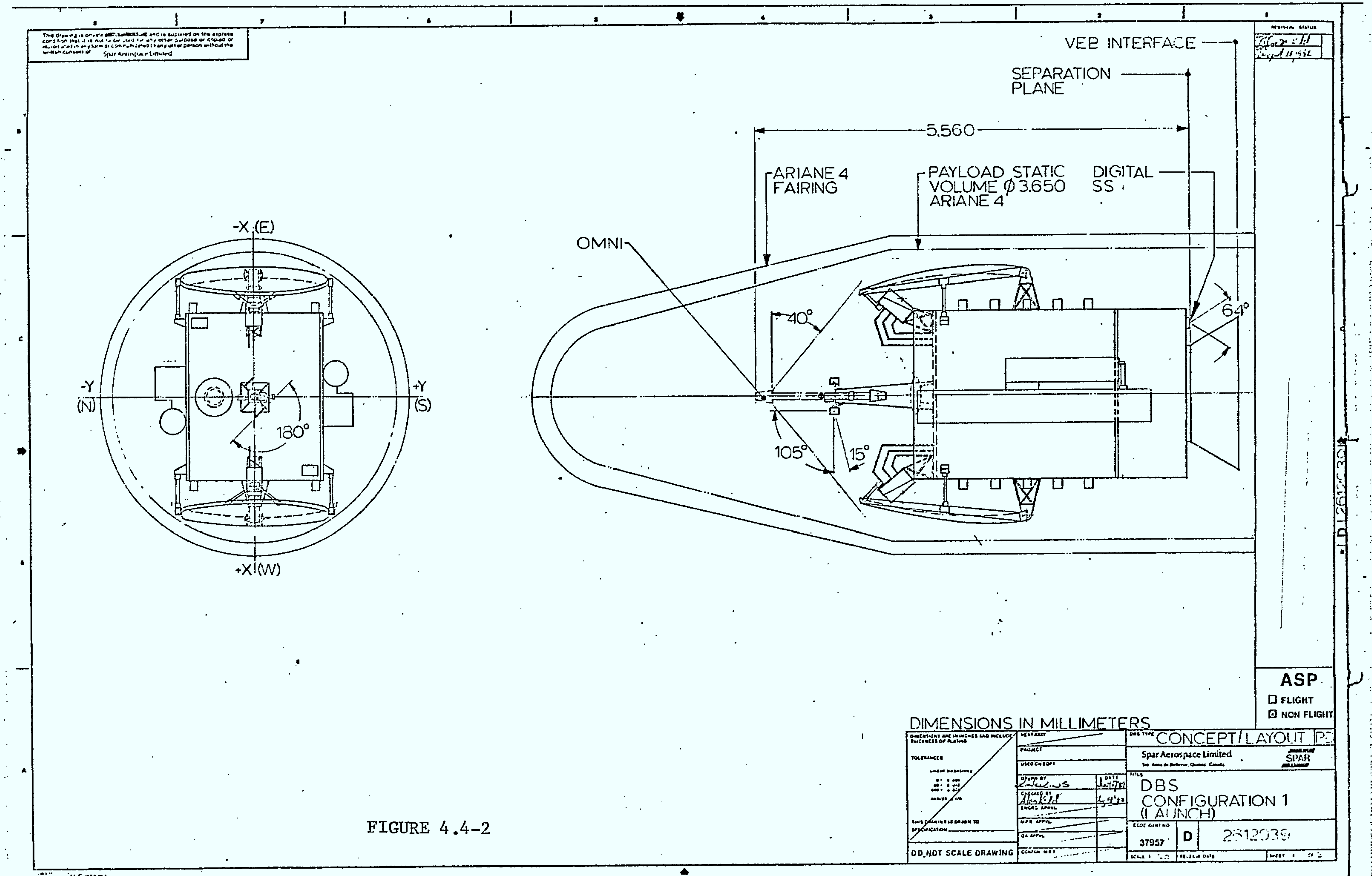

VEB INTERFACE
SEPARATION PLANE
5,560
ARIANE 4 FAIRING
PAYLOAD STATIC VOLUME ∅ 3,650 ARIANE 4
DIGITAL SS
OMNI
40°
64°
105°
15°
-X (E)
+X (W)
-Y (N)
+Y (S)
180°
ASP
FLIGHT
NON FLIGHT
DIMENSIONS IN MILLIMETERS
CONCEPT/LAYOUT
Spar Aerospace Limited
SPAR
DBS
CONFIGURATION 1
(LAUNCH)
37957
D
2612039
DO NOT SCALE DRAWING

FIGURE 4.4-2

TABLE 4.4.-1 MASS BUDGET - HIGH POWER CONFIGURATION

Subsystem	Mass	Comments
Structure	251	Strengthing of service module
Thermal	60	Extra battery shunts
A OCS	85	
Power	239	Impact of extra batteries
Electrical Distribution	53	Larger harness
Solar Array	256	19 SPA Array wing
TT&C	35	
CPS	120	Stretched tank
Balance	20	
Subtotal	1119	
Pressurants and Residuals	23	
Subtotal Bus	1142	
Payload Antennas	50	
Repeaters	276	
20% Margin	66	
Spacecraft Dry Mass	1534	

4.4.2 <u>High EIRP Weight Budget (cont'd)</u>

which in turn require extra shunts, discharge regulators and load inverters. It is also necessary to increase the size of the harness.

The remaining subsystems have masses very close to those of L-Sat. Table 4.4-2 gives the S/C launch weight for STS and Ariane launches.

4.4.3 High EIRP Power Budget

The power budget is again based on the April 1982 L-SAT configuration. The subsystems have all been assumed to have the same power consumption as L-SAT except for thermal and power, whose power budget has been increased. In the High Power configuration the Payload is alloted 6444 watts during sunlight and 3222 watts during eclipse. Table 4.4-3 shows the budget for the high power configuration in transfer orbit, and on station in eclipse and at solstice and Equinox. In order to calculate battery discharge and charge rates, four 50 Amp Hour Nickel Hydrogen batteries are assumed. All categories can be seen to have ample margin.

4.4.4 Launch Vehicle and Interface

4.4.4.1 Space Transportation System

The weight of the high EIRP spacecraft requires the use of the Upper Stage IUS first stage. The two will be mated and installed horizontally in the cargo bay.

The IUS first stage is presently under development, and will use the Solid Rocket Motor 1 of the Inertial Upper Stage with modified electronics and airborne support equipment.

Its lift capability to geosynchronous transfer orbit will be from 3175Kg to 6100Kg. It should be available as a spin and three axis stabilized configurations by early 1987.

The overall length (upper stage and spacecraft) in the cargo bay will be approximately 8.80m.

TABLE 4.4.-2 DBS LAUNCH WEIGHT(Kg) HIGH POWER CONFIGURATION

	STS	ARIANE
S/C DRY MASS	1534	1534
FUEL ON STATION(7 YEARS)	321	321
TRANSFER ORBIT, APOGEE FIRING STATION ACQUISITION	1700	1290
S/C TRANSFER ORBIT WEIGHT	3555	3145
LAUNCH ADAPTOR		43
PKM PROPELLANT (1)	6370	
PKM DRY MASS + CRADLE (1)	4500	
LAUNCH WEIGHT	14425	3188

(1): THE PERIGEE KICK MOTOR IS THE IUS FIRST STAGE (REF. TO PARAGRAPH 4.4.4.1)

TABLE 4.4.-3 POWER BUDGET - HIGH POWER CONFIGURATION

Subsystem	Transfer Orbit Sun	Transfer Orbit Eclipse	On Station Solstice	On Station Equinox	On Station Eclipse
BUS					
Thermal	1600	65	160	320	100
A OCS	213	90	128	128	128
Power	45	45	45	45	45
TT&C	46	46	46	46	46
Subtotal (Bus)	1904	246	379	539	319
Payload	-	-	6444	6444	3222
Total at Power I/F	1904	246	6823	6983	3541
LOSSES					
Battery Charging	500	-	50	500	-
Battery Discharge Reg.	-	22	-	-	318
Shunt Dumps	144	-	412	448	-
Harness	100	10	100	100	50
Subtotal (Losses)	744	32	562	1048	368
Total Power Req'd	2648	278	7385	8031	3909
Power Available from Array (EOL 7 yrs.)	-	-	8200	9100	-
Total Energy Req'd from Batteries (WH)		334			4691
Energy Available at 70% DOD (WH)		5338			5338
Margin			815	1069	647 (WH)
Margin %			11%	13%	14%

4.4.4.2 Ariane

A direct broadcast satellite of the given dimensions will require a dedicated launch short fairing.

The spacecraft will be installed on the third stage using the Ariane adapter 1194, as shown in Figure 4.4.4.2-1.

Based on present weight estimates the spacecraft is compatible with the Ariane 42L version (launch performance: 3200Kg).

A dual launch is not likely because of the large spacecraft weight.

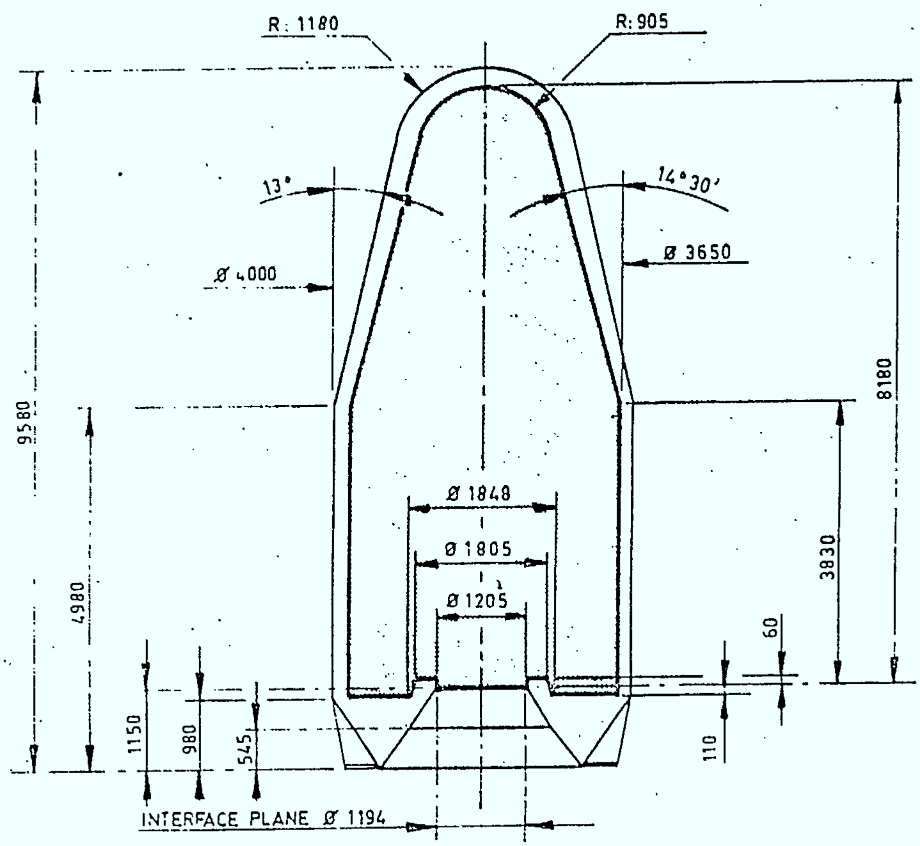


Figure 4.4.4.2-1: Dedicated Launch Short Fairing Envelope with Adapter 1194

4.5 Low EIRP Spacecraft

4.5.1 The Low EIRP version of the Canadian DBS is based on a proposed RCA Americom DBS satellite. This is a three axis stabilized bus with an on orbit weight of about 900 kilograms and power of 3.5 kilowatts. The spacecraft is designed to be shuttle compatible and use a liquid propulsion stage (LPS) as a PKM. (It is possible that RCA may use the LPS as an AKM also, but a solid AKM is used for this analysis). The proposed LPS uses a bi-propellant system of 10675N thrust and is fully guided from STS separation. Capabilities of the proposed LPS are still tentative since it is in a pre-development stage at RCA however it will have sufficient fuel capacity to inject at least 2100 Kg into geosynchronous with extra capability also being considered.

Figure 4.5-1 shows the spacecraft deployed in its on orbit configuration. The two transmit antennas deploy into position on the -x and +x sides on the spacecraft. The solar array is a rigid fold-out type which deploys on the -y and + y sides of the spacecraft. This 18 GHz uplink antenna is mounted on the earth facing panel and is uncovered when the transmit antennas deploy.

As Figure 4.5-2 shows, the RCA bus can also be accommodated in a Ariane IV fairing in a dual launch configuration. In order to achieve this fit, both payload transmit antennas are stowed on the -z face of the spacecraft.

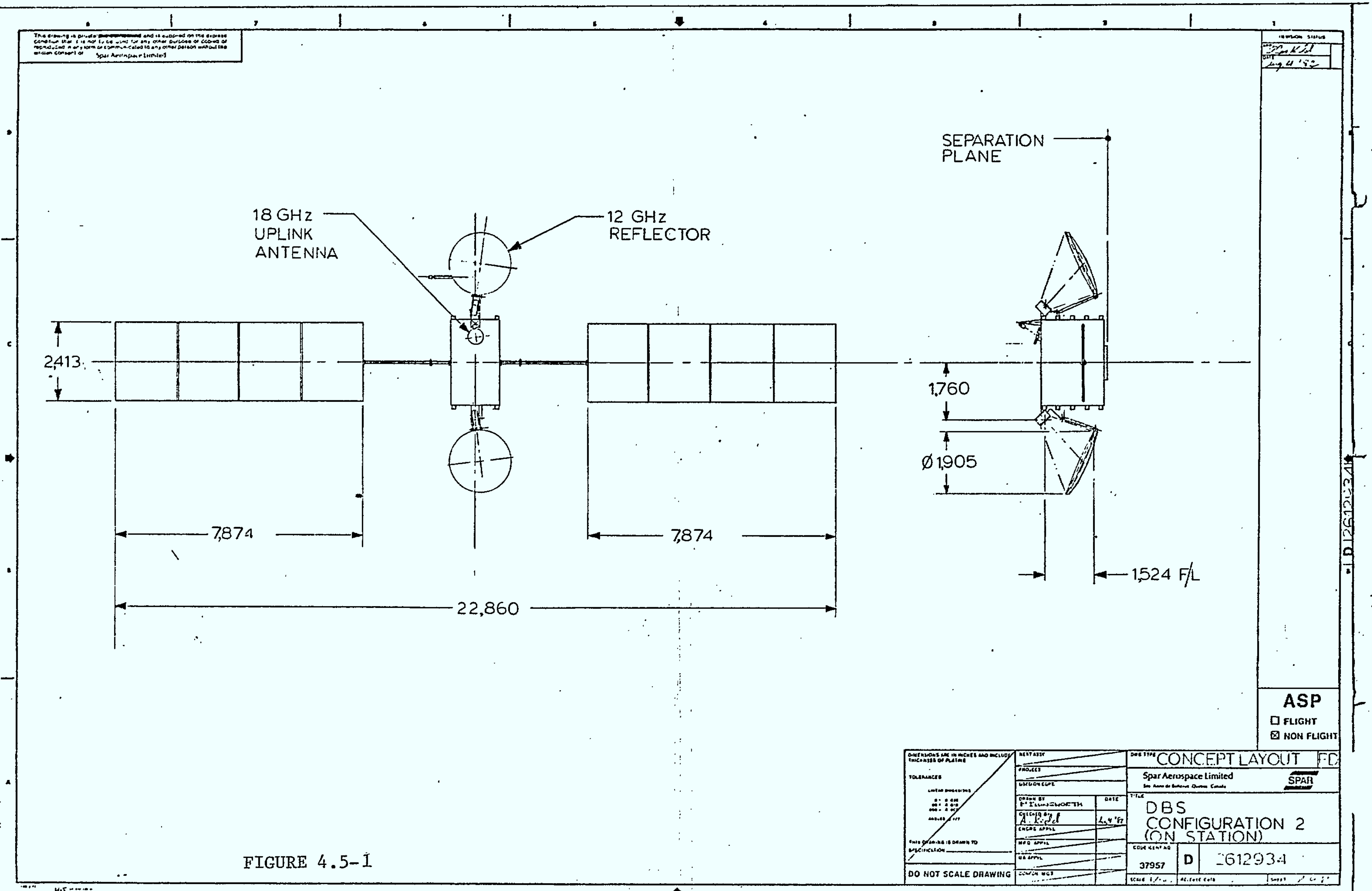
The attitude control system uses a pivoted momentum wheel for a momentum bias stabilization system. Station keeping may be performed using the bipropellant LPS or electro hydrazine thrusters. Trade off studies are still to be performed to resolve that question.

4.5.2 Low EIRP Weight Budget

The mass budget for this DBS configuration is based on the RCA Americom DBS filing. Table 4.5-2 gives the mass summary. The principle changes occur in the power subsystem which has reduced mass due to down sizing of the array. Allowance was made for the extra batteries needed to achieve 50% eclipse operation. Table 4.5-2 gives the S/C launch weight for STS and Ariane launches.

4.5.3 Low EIRP Power Budget

The power budget is also based on the RCA filing. The only changes made have been in the power and thermal subsystem to allow for extra battery charging and reduced total power. The power budget for the RCA bus based configuration is shown in Table 4.5-3. Note that there are two budgets for the high and low power extremes that can be flown on the RCA bus.



SEPARATION PLANE
18 GHz UPLINK ANTENNA
12 GHz REFLECTOR
2,413
1,760
Ø 1,905
7,874
7,874
1,524 F/L
22,860
ASP
FLIGHT
NON FLIGHT
CONCEPT LAYOUT
Spar Aerospace Limited
SPAR
DBS
CONFIGURATION 2
(ON STATION)
37957
D
2612934
DO NOT SCALE DRAWING

FIGURE 4.5-1

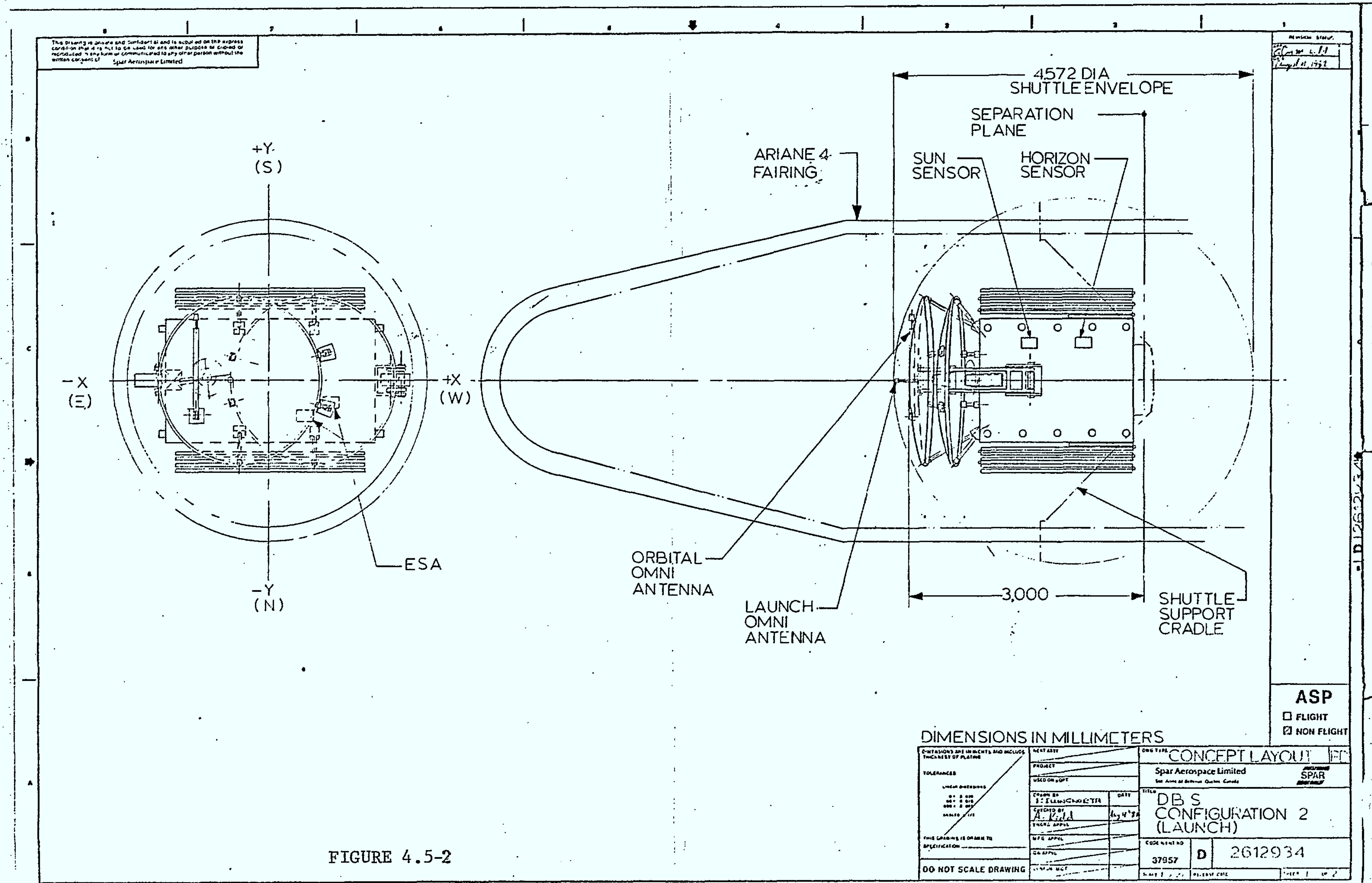

4572 DIA
SHUTTLE ENVELOPE
SEPARATION PLANE
ARIANE 4 FAIRING
SUN SENSOR
HORIZON SENSOR
+Y (S)
-Y (N)
-X (E)
+X (W)
ESA
ORBITAL OMNI ANTENNA
LAUNCH OMNI ANTENNA
3,000
SHUTTLE SUPPORT CRADLE
ASP
FLIGHT
NON FLIGHT
DIMENSIONS IN MILLIMETERS
CONCEPT LAYOUT
Spar Aerospace Limited
SPAR
DBS
CONFIGURATION 2
(LAUNCH)
37957
D
2612934
DO NOT SCALE DRAWING

FIGURE 4.5-2

TABLE 4.5-1 MASS BUDGET - LOW POWER CONFIGURATION

Subsystem	2 KW Mass (Kg)	2.7 KW	
Structure	144		
Thermal	33		
AOCS	40		
Power (Incl. array)	170	225	Battery added array downsized
Harness	20	30	Harness downsized
Mechanical Assemblies	35		
TT&C	24		
Propulsion	33		
AKM (burned out)	74		
Margin and Balance	56	62	
	629	700	
Payload Antennas	50	46	
Repeaters	181	187	
20% Margin	46	46	
Subtotal	277	279	
Spacecraft Dry Mass	906	979	

TABLE 4.5-2 DBS LAUNCH WEIGHT (KG)

LOW POWER CONFIGURATION

	STS		ARIANE	
OPTION	2 KW	2.7KW	2 KW	2.7 KW
S/C Dry Mass	906	979	906	979
Hydrazine + Pressurant (7 years)	224	242	224	242
AKM Expendables	1032	1115	808	873
Launch Adapter			48	48
Liquid Perigee Stage (LPS)	5750	5950		
S/C Launch Weight	7912	8286	1986	2142

TABLE 4.5-3a POWER BUDGET - LOW POWER CONFIGURATION (#1)

Subsystem	Solstice	Equinox	Eclipse
BUS			
Thermal	25	60	20
AOCS	65	65	65
Power	65	165	45
TT&C	25	25	25
Harness	20	20	10
Subtotal Bus	200	335	165
Payload	2076	2076	1076
Total Power Req'd	2276	2411	1241
Power Available from Array (EOL 7yrs.)	2400	2573	-
Total Energy Req'd from Batteries	-	-	1489(WH)
Energy Available at 70% DOD(WH) (2 X 30 AH)	-	-	1600(WH)
Margin	124	162	111

TABLE 4.5-3b POWER BUDGET - LOW POWER CONFIGURATION(#2)

Subsystem	Solstice	Equinox	Eclipse
BUS			
Thermal	30	70	25
AOCS	65	65	65
Power	80	190	60
TT&C	25	25	25
Harness	30	30	15
Subtotal Bus	220	380	190
Payload	2716	2716	1429
Total Power Req'd	2936	3096	1619
Power Available from Array(EOL 7yrs)	3600	3840	-
Total Energy Req'd from Batteries	-	-	1943
Energy Available at 70% DOD (WH) (2 X 40 AH)	-	-	1980
Margin	664	744	37

4.5.4 Launch Vehicle and Interfaces

4.5.4.1 Space Transportation System

The most suitable upper stage for the low EIRP spacecraft is the liquid perigee stage (bi-propellant propulsion system) installed vertically in the cargo bay via a specific cradle, as shown in Figure 4.5.4.1-1. It should be noted that RCA is evaluating the possibility of using a combined bi-propellant propulsion subsystem enabling final orbit achievement and on orbit maneuver.

The only reasonable alternative would be an uprated version of the PAM A upper stage (present performance: 1994 Kg). The spacecraft would be installed horizontally in the cargo bay as shown in Figure 4.5.4.1-2.

4.5.4.2 Ariane

The spacecraft will be mated to the third stage via an adapter (Arianespace or user's specific adapter).

Two launch configurations are possible (ref. Figure 4.1.2-1)

- a dedicated launch using the short fairing (8.6m)
- a dual launch under the long fairing (9.6m) above a short SPELDA structure (350 KG).

In a dedicated launch mode, both options can be launched either by Ariane 44LP (performance: 3700 Kg) or the Ariane 44L (performance: 4200 Kg) versions, depending on the flight companion.

Note: The short SPELDA envelope can be fitted either by a PAM D class (1140 Kg) or a PAM D II class (1400Kg) spacecraft.

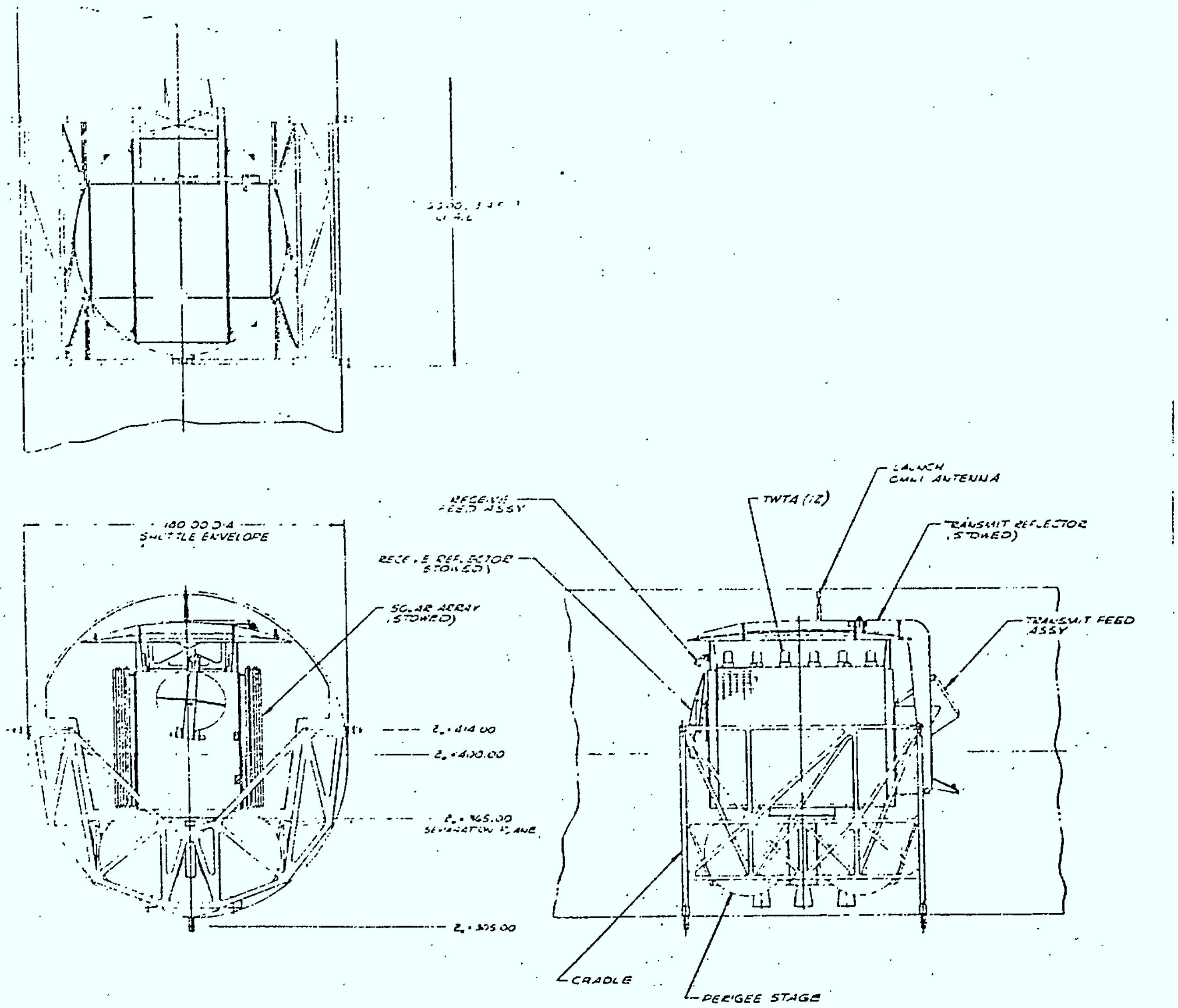
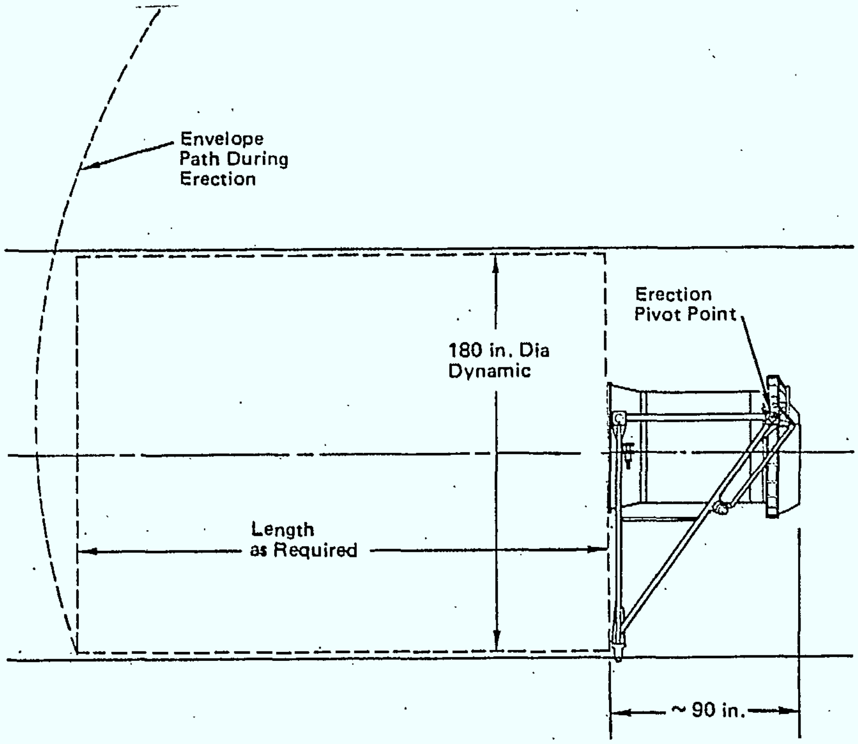


Figure 4.5.4.1-1 RCA Direct Broadcast Satellite
(STS Launch Configuration)



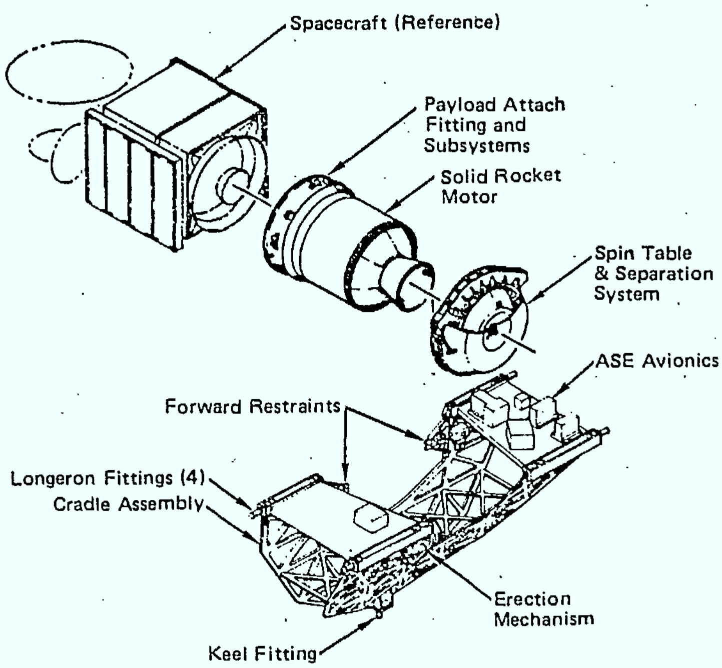


Figure 4.5.4.1-2: PAM A Upper Stage

5.0 Cost Estimates

Cost estimate for low and high EIRP system models presented in Table 5.0-1 are based on a 3 spacecraft initial implementation for the 4 beam, 2 orbit models, and a 4 spacecraft initial implementation for the 6 beam, 3 orbit models. The cost of the fully developed systems are based on a 5 spacecraft implementation for the 4 beam 2 orbit system, and an 8 spacecraft implementation for the 6 beam 3 orbit system.

To simplify cost comparisons between 4 and 6 beam models, the same spacecraft bus and payload costs are assumed for both; however the channel capacity per beam of the 6 beam spacecraft is increased from 8 to 10 relative to the 4 beam spacecraft, to reflect the lower power per channel requirements of the 6 beam design. Although the total cost of the 4 spacecraft 6 beam system is clearly higher than the 3 spacecraft 4 beam system, the cost per national channel is essentially the same for both. The cost per regional channel (channel beam) is 1.3 times (30% higher) that for the 4 beam system which approximates the inverse ratio of the number of beams (4/6). The cost per channel advantage of the six beam system is only relevant if a demand exists for the larger number of channel beams available.

Low EIRP vs High EIRP

The low EIRP systems cost approximately 75% of the high EIRP systems. This is surprisingly high considering that the low EIRP spacecraft are half the size of the high EIRP spacecraft, and the launch costs are also about one half as seen in table 5.0-1.

A cost comparison presented as part of the 1981 SPAR DBS study for DOC showed that the low EIRP systems were about 50% of the cost of the high EIRP systems.

Several factors combine to produce this narrowing of the price ratio.

(i) The low EIRP weight and power demands exceeded the STS PAM-D category S/C and moved into the PAM A category increasing launch costs.

(ii) The low EIRP S/C estimate contains a high non recurring element, characteristic of a stand alone program. Previous estimates assumed serial production with non recurring cost spread over more than one program.

(iii) The high EIRP S/C estimate contains a low non recurring element and a notably low recurring cost.

(iv) The program durations and content were assumed identical for both categories of S/C whereas in practice, program costs such as I&T would favour the smaller S/C.

System Model Description											
EIRP	Beams/ Orbits	Channels Per Beam	Code	Spacecraft & Launcher	S/C Cost	Launch Cost	S/C Per System	System Cost	Cost Per National Channel	Cost Per Channel Beam	Cost Per Ch. Beam Yr. (7Year Life)
Low 50 dBW	4 Beam 2 Orbit	Initial 8	248/16	RCA-DBS STS PAM A	99	38	3	411	51	13	1.8
		Final 16	2416/16		86	38	5	620	39	10	1.4
	6 Beam 3 Orbit	Initial 10	3610/20	RCA-DBS STS-PAM A	91	38	4	516	52	8.6	1.2
		Final 20	3620/20		80	38	8	944	47	7.9	1.1
High 54 dBW	4 Beam 2 Orbit	Initial 8	248/16	L-SAT Ariane IV	96	74	3	510	64	16	2.3
		Final 16	2416/16		87	74	5	805	50	13	1.8
	6 Beam 3 Orbit	Initial 10	3610/20	L-SAT Ariane IV	90	74	4	656	66	11	1.6
		Final 20	3620/20		82	74	8	1248	63	10	1.5

Table 5.0-1 System Costs (1982 M Can. $)

Program Schedule

The schedule shown in Figure 5.0-1 is assumed to be the same for both high and low power spacecraft and consists of an 18 month system definition and advanced development phase B, followed by a 42 month design, fabrication phase C and D. Phase E represents an initial 6 months in orbit maintenance period.

In practice, the duration of the program phases will vary for different spacecraft concepts, reflecting the maturity of the design, and external factors such as timing and resource allocation.

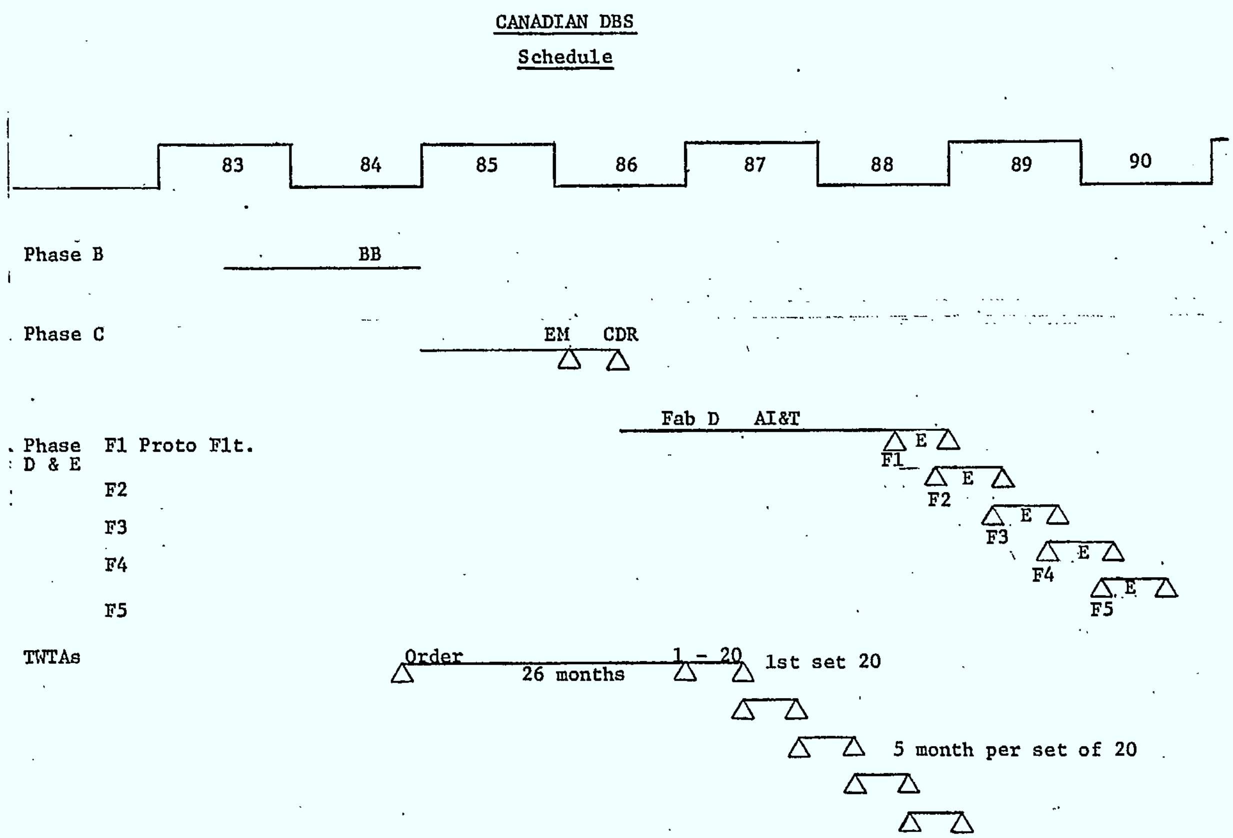


Figure 5.0-1 Program Schedule

Comparative Spacecraft Costs

A comparison of DBS cost per unit dry weight with other communications satellites is given in Table 5.0-2. Some points to note are:

(i) The unit cost of the low EIRP spacecraft, which includes a high non recurring element, is below Brasilsat which has a low non recurring cost associated with the serial production HS376 spacecraft bus.

(ii) The unit cost of the high EIRP DBS spacecraft is dramatically lower than M-Sat even though the same L-Sat bus is used. This is due primarily to the complex and experimental nature of the M-Sat program.

(iii) Incentive payments have been included in the calculation of costs for Anik D, Brasilsat and Intelsat V.

(IV) A low EIRP spacecraft program with non recurring costs spread over a larger production should approach the unit cost of the Intelsat V which is in the same weight category.

Program Qty	Spacecraft	Launcher	Spacecraft Dry Weight (Kg)	Spacecraft Cost M$	Cost per Kg of Dry S/C Weight ($1000)	Notes
2	ANIK D	Delta 3920	513	47	92	
2	Brasilsat	Ariane SYLDA STS-PAM D	513	58	112	(1)
15	Intelsat V	Atlas Centaur or Ariane	809	64	79	(2)
3	Low EIRP DBS (RCA)	Ariane IV SPELDA or STS-PAM A	980	99	101	(3)
3	High EIRP DBS (L-SAT)	Ariane IV or STS IUS-MI	1534	96	63	(4)
2	M-SAT	Ariane III	1160	193	166	(5)

Notes:
(1) Firm including approx. 10M headstart funds (selling)
(2) Historical numbers factored for inflation
(3) High non recurring - "Stand along bus quotation from RCA"
(4) Low non recurring (13M)
(5) M-Sat has high non recurring for bus and payload, and a high recurring payload

Table 5.0-2 Spacecraft Cost Comparison (1982 Can. $)

Table 5.0-3 provides launch costs per unit of dry spacecraft weight for a range of candidate launches. For comparison, a STS-PAM D launch is included, although all of the spacecraft considered in this report are beyond its capability. Points to note are:

(i) Launch costs are similar per unit weight

(ii) No major difference exists between STS and Ariane based launch costs per unit weight.

Launch Vehicle	Dry Mass	Cost (M $)	Cost/Kg (1,000 $)
STS/PAM A	810 Kg	37.6	46.4 K
STS/IUS	1534 Kg	73.6	47.9 K
AR IV (40)/RCA	850 Kg	47.36	49.9 K
AR IV (44P)/L-SAT	1534 KG	74.5	48.5 K
STS/PAM D II	660 Kg	28.1	42.5 K

AR IV prices based on present Ariane III prices.

STS prices do not include optional services.

Table 5.0-3 Launch Cost Comparison (1982 Can $)

5.1 High EIRP Spacecraft Cost

Spacecraft costs for high EIRP systems as presented in Table 5.1-1 include budgetary quotations from British Aerospace for recurring and non recurring costs of the L-SAT bus modified for maximum power operation. Payload, program management, integration and test estimates are based on current SPAR experience, with allowances for program complexity and duration. TWTA cost and delivery indications provided by Telesat Canada are based on discussions with potential TWTA suppliers and apply to a relatively small quantity (approx. 20). Reductions may be possible for larger orders.

5.2 Low EIRP Spacecraft Cost

Spacecraft costs for low EIRP systems as presented in Table 5.2-1 include budgetary estimates from RCA Astro Electronics for recurring and non recurring costs of a new medium power (2.5 Kw) DBS spacecraft bus, as conceived for a 6 channel high EIRP RCA Americom DBS system.

Payload, program management, integration and test estimates are based on current SPAR experience, with allowance for program complexity and duration. TWTA costs and delivery information provided by Telesat is based on discussions with potential suppliers and apply to relatively small quantities. Reductions may be possible for larger orders.

Program Qty	Spacecraft	Launcher	Spacecraft Dry Weight (Kg)	Spacecraft Cost M$	Cost per Kg of Dry S/C Weight ($1000)	Notes
2	ANIK D	Delta 3920	513	47	92	
2	Brasilsat	Ariane SYLDA STS-PAM D	513	58	112	(1)
15	Intelsat V	Atlas Centaur or Ariane	809	64	79	(2)
3	Low EIRP DBS (RCA)	Ariane IV SPELDA or STS-PAM A	980	99	101	(3)
3	High EIRP DBS (L-SAT)	Ariane IV or STS IUS-MI	1534	96	63	(4)
2	M-SAT	Ariane III	1160	193	166	(5)

Notes: (1) Firm including approx. 10M headstart funds (selling)
(2) Historical numbers factored for inflation
(3) High non recurring - "Stand along bus quotation from RCA"
(4) Low non recurring (13M)
(5) M-Sat has high non recurring for bus and payload, and a high recurring payload

Table 5.0-2 Spacecraft Cost Comparison (1982 Can. $)

SPACECRAFT ESTIMATE

CANADIAN DIRECT BROADCAST SATELLITE SYSTEM

HIGH EIRP (6.5 KW L-SAT BUS)

1982 CAN $M

Description	Non-Recurring		Total	Recurring		Total	
	Spar	Subcont.	Non-Recurring	Spar	Subcont.	Recurring	Grand Total
4 Beam (System 1)							
Programmatics	10		10	35		35	45
Payload	12		12	35		35	47
TWTA		2	2		29	29	31
Bus		24	24		140	140	164
Initial 2 Oper + 1 Spare	22	26	48	70	169	239	287
Final 4 Oper. + 1 Spare	22	26	48	105	282	306	437
6 Beam System							
Programmatics	10		10	41		41	51
Payload	12		12	45		46	58
TWTA		2	2		39	39	41
Bus		24	24		187	187	211
Initial 3 Oper + 1 Spare	22	26	48	86	226	313	361
Final 6 Oper. + 2 Spare	22	26	48	157	451	608	658

Table 5.1-1

SPACECRAFT ESTIMATE

CANADIAN DIRECT BROADCAST SATELLITE SYSTEM

LOW EIRP (2.5KW RCA DBS BUS)

1982 CAN $M

Description	Non-Recurring		Total	Recurring		Total	
	Spar	Subcont.	Non-Recurring	Spar	Subcont.	Recurring	Grand Total
4 Beam System (System 2)							
Programmatics	10		10	34		34	45
Payload	12		12	35		35	47
TWTA		3	3		22	22	25
Bus		46	46		135	135	181
Initial 2 Oper. + 1 Spare	22	49	71	69	156	226	298
Final 4 Oper. + 1 Spare	22	49	71	104	256	360	432
6 Beam System (System 4)							
Programmatics	10		10	40		41	51
Payload	12		12	46		46	58
TWTA		3	3		31	31	35
Bus		46	46		173	173	219
Initial 3 Oper. + 1 Spare	22	49	71	86	205	291	363
Final 6 Oper. + 2 Spare	22	49	71	157	407	564	636

Table 5.2-1

5.4 Preparation of a DBS Phase B Plan

To prepare a phase B plan at the major task and program milestone level will require 10 man weeks of senior staff effort, plus support, over a 6 week period.

This task requires inputs from program management and engineering skill centers, supported by planning, scheduling, estimating and manufacturing functions.

The output of this task would consist of preliminary planning documents covering the following:

Program plans
Milestone schedule
Definition of models and deliverables
Resource and facility demands
Work breakdown structure (2 levels)
Statement of work

The division of responsibility by skill area would be as follows:

Program Management

- o Coordination of efforts of all contributors
- o Preparation of preliminary planning documents
- o Liaison with customer

Engineering

- o System Engineering to define system requirements (payload and space-craft bus) and to assist program management in defining the need and function of spacecraft and subsystem models.
- o Integration and test engineering to identify test program needs and resources to support the test program (EGSE, MGSE etc.).
- o Hardware engineering to prepare make/buy decision matrix and to define long lead develpment items.

Estimate

Labour 375 hrs.	$28,263
T&L	344
Computing/Printing	296
Total	$28,903

using 1981 approved DSS rates - 12% escalation per year for a 1983 start.

6. Conclusions and Recommendations

The objectives of the study have been achieved by the development of a range of complete system models responsive to the tasks and parameters specified,and drawing on the background of DBS related studies performed by SPAR and other suppliers to DOC.

A 2 orbit 4 beam system was chosen for both high and low EIRP which is implemented by two operating spacecraft each providing 2 beams of at least 8 channels each for an initial service. A spare satellite would protect the two operating satellites and act as a step in the growth of capacity to double the initial amount, by the addition of a second satellite at each orbit location.

Spacecraft conceptual designs were developed for both EIRP levels, which were matched to suitable launcher combinations. To produce most reasonable cost estimates within the scope of this study, the spacecraft concepts were based on existing or advanced designs of responsible suppliers who provided budgetary estimates for the basic spacecraft without payload. Estimates for payload and integration were developed by SPAR and launch costs were based on best available information from the launching agencies. To simplify cost comparisons between 4 beam and 6 beam models the same spacecraft bus was used for both models.

Topics for Further Study

Within the scope of this study, several subjects were addressed which are recommended for further study. Many of these are in the antenna area, as it is the unique interface between system level parameters such as polarization and coverage, and repeater hardware parameters such as TWTA power level and output multiplexer design.

- Analysis and experiments on LP to CP Spatial polarizers particularly corrugated paraboloidal surfaces. This should include an evaluation of this technique applied to multihorn shaped beam reconfigurable antennas.
- Coverage requirements study to minimize gain differences between beams. This could include the concept of primary and secondary coverage areas with different EIRP levels. The feasibility of antenna designs to produce beams weighted to favour primary areas could be treated separately or as part of this item.
- Establish trade off between single mode antennas with contiguous multiplexers, and dual mode antennas with non contiguous multiplexers, as a function of the number of channels per beam. This should consider requirements for antenna reconfigurability and high power operation of multiplexers and other RF components.
- Establish options and tradeoffs for antenna beam steering and define system configuration and requirements for a selected system.

APPENDIX A

DBS ANTENNA REPORT

1 INTRODUCTION AND PRELIMINARY CONSIDERATIONS

A preliminary study was done for an antenna system which will provide 6 beams, 2 from each one of three orbital locations, to cover Canada. The results are applied also to a system of 4 beams, 2 from each one of 2 orbital locations.

The eastern orbital location is at 100°W, the western at 130°W, and the middle location, to be used in the 6 beam system option, is between these two, not as yet specified.

All the beams will be at the frequency of 12.45 ± 0.25 GHz, and they will be circularly polarized; this polarization will be alternately right-hand and left-hand, to provide isolation between adjacent areas. In addition, for each beam, the even and the odd channels within the 500MHz frequency band will be fed separately, requiring a dual-mode network (i.e., two input ports) for each feed.

For the six beam system, it is assumed that there will be 4 satellites in orbit, one of them being used as a spare, so that it can be brought to any of the three orbital locations and be used to illuminate the two areas assigned to that location.

It is then desirable that the 4 satellites be identical and that each one of them can provide any of the three coverages, depending on the orbital location occupied.

This reconfigurability may be achieved by using a single stack of feed horns with a network providing three different excitation schemes for each polarization, or by using three different feed stacks for each hand of polarization and exciting only one of them for each orbit location. The first alternative would allow for the horn stack to be more compact, but would require a much more complex feed network with several variable power dividers, hence considerably increasing the weight of the system. Furthermore, the fact that each beam is excited by a dual-mode network, would greatly complicate the task of implementing good coverage of the different areas, from a common feed configuration. These considerations led to the choice of the second alternative mentioned above. This means that each satellite will carry six independent horn stacks with their respective feed networks, and only 2 of them will be utilized from each orbit location, one LHCP and one RHCP.

The use of one single reflector was considered and abandoned, from the considerations of Section 2. As a result, a 2 reflector system is proposed, one for each hand of circular polarization.

One antenna is mounted on the East side and the other on the West side of the satellite, hence the offset of the reflector will occur in the E-W direction, and the 3 independent feeds of each reflector will appear stacked principally in the direction of offset. (for geometry, see Fig. 1.1)

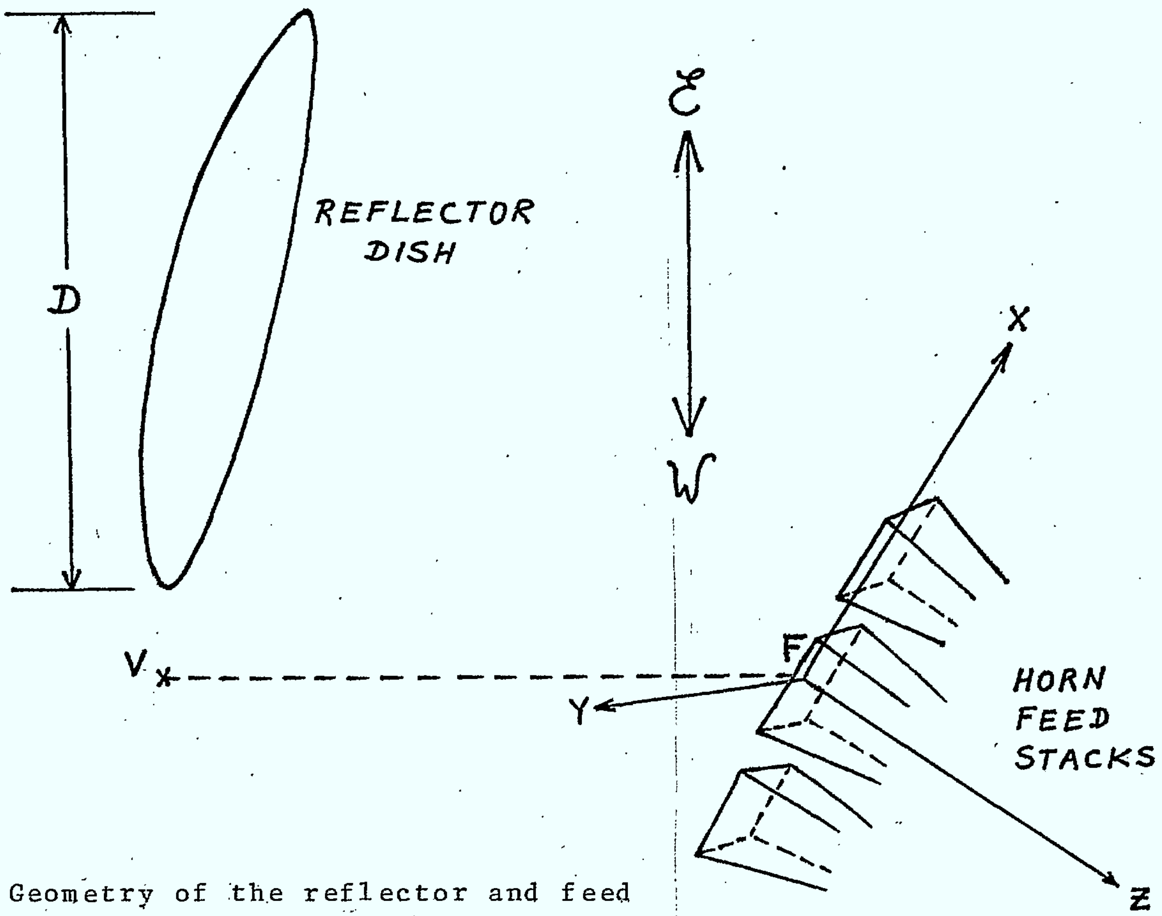


FIGURE 1.1 Geometry of the reflector and feed stacks for the downlink antenna, (eastern reflector), with identification of the coordinate system for the horns. V is the vertex and F the focal point (also used to represent the focal length) of the reflector.

It is noted here that this preliminary study was done for the beam which covers the Quebec region from the eastern orbit location, because this seems to be the most demanding of all six beams, in terms of the total number of square degrees to be covered, and the shape of the area of coverage. Estimations are made for the performance of the other five beams, based on this worst-case study, with an allowance given to the different sizes of the areas of coverage.

An antenna for the uplink beams (two circularly polarized beams, one LHCP and the other RHCP) was also designed, to operate at 17.55 $\pm$.25 GHz, and covering all of Canada.

2. CHOICE OF BASIC ANTENNA CONFIGURATION

2.1 Single Reflector Downlink

2.1.1 Concepts

The single reflector concept (as opposed to a two reflector design, to be considered later) has obvious attractions in terms of size and weight. Three different single reflector design options were therefore investigated. These are described in the sub-sections below. However, each option is found to have significant drawbacks, favouring finally the alternative approach described in Section 3 onwards.

Two general points may be made here:

a) The arguments against a single reflector are to some extent linked with the assumption that some form of dual mode network will be necessary. This in turn relates (as determined in previous studies) to the number of 'planned' channels.

'Planned' here implies available in the final, fully expanded system, although not necessarily implemented for an initial service. The number of 'planned' channels for Canadian system models is larger than the corresponding figure for some current U.S. DBS models.

b) Whichever of the satellite bus options is chosen, it appears that the only feasible mounting arrangement for a downlink reflector is deployed off the side of the bus. A single reflector thus has the disadvantage of unbalancing the spacecraft structure mechanically. The only advantage is a saving in weight of about 20 lb for an additional reflector and deployment system; the total feed system weight for the alternative 'dual reflector' downlink to be considered in Section 3 is at worst the same, or possibly slightly less than that of the single reflector design.

2.1.2 Single Solid Reflector, Polarizers in Horns

This is perhaps the most obvious configuration, but has important disadvantages as follows.

Polarization Purity Circularly polarized horn arrays tend to suffer from a fundamental cross-polar coupling effect. That is, the mutual coupling between adjacent RHCP are LHCP horns is much stronger than that between (say) horizontally and vertically polarized linearly polarized horns. Moreover, the solid reflector gives no opportunity to 'filter-out' the polarization impurities generated by the feed system. In principle some degree of compensation could be provided by intentionally 'detuning' the polarizers.

However, it seems very unlikely that this principle could be made to work for both modes of a dual mode antenna.

More detailed computations and experiments would be needed to fully quantify the arguments above and establish the actual levels of the polarization impurities. However, it is believed that a 33dB cross-polar isolation is totally impractical, and even a 27dB isolation extremely difficult for a solid reflector.

Beam Overlap If all feed horns for the solid reflector were to be operated on one polarization only, there would inevitably be substantial gaps between beams. A partial remedy is to use orthomode transducers for some horns, permitting these horns to be used simultaneously for a LHCP beam and the adjacent RHCP beam. The word 'partial' is used with good reason because this concept only allows a very quantised control of beam shape in the overlap regions. Each quantum step is achieved by exciting one horn of a neighbouring beam to augment the contours of a given beam. With only 3 or 4 feed horns per beam (as proposed for the dual reflector alternative to be discussed), the degree of pattern control available to attempt to fit a specified geographical coverage is extremely limited.

The 'beam overlap' penalty of the solid reflector/single feed system design for the specified DBS geographical coverage has not been quantified during the study. It seems likely however, that it could amount to a 1 dB or more gain degradation when only 3 or 4 horns per beam are used.

A larger number of horns would of course reduce the gain penalty, but increase feed system complexity and weight.

2.1.3 Dual Linearly Polarized Feed System, CP Polarizing Grid Incorporated in Reflector

In this scheme, the polarizer is a spatial type situated at the main reflector surface. In principle it consists of a grid of etched conductors orientated at 45° to the incident polarization and backed by a further, probably continuous, conducting surface at about $\lambda/8$ electrical spacing. In practice the spacing would be slightly different, being selected so as, in conjunction with the presence of a dielectric support medium, and appropriate grid geometry, to provide adequate bandwidth for the DBS downlink application. The inherent properties of this configuration may be summarized as follows:

a) The LHCP/RHCP coupling problem at the feed horns envisaged for the solid reflector antenna previously discussed is now eliminated. However, it is still not feasible to incorporate any form of spatial filter to remove the polarization impurities generated by the feed horn arrays, unless the latter is used only for horns which are not in the overlap region (and in consequence are excited on one polarization only).

b) The 'beam overlap' problem as discussed for the solid reflector remains.

c) Since the feed horns corresponding to the overlap regions have to operate in both linear polarizations simultaneously, 'high efficiency' loading techniques such as dielectric wedge inserts and bifurcations cannot be used.

2.1.4 Plane Gridded Subreflector, Separate 'HP' and 'VP' Feed Stacks, 'CP' Polarizing Grid Incorporated in Parabolic Reflector

Initially, this scheme appeared very attractive. The gridded subreflector conceptually takes on the role of a polarization filter separating the 'HP' and 'VP' linear polarizations and directing each to its individual feed array (Fig 2.1). The arrays for the RHCP and LHCP beams are thus geometrically separate and beam overlap is no longer a major consideration. Each feed stack can be designed for maximum efficiency for its own particular (linear) polarization.

The plane grid subreflector concept has been previously proposed in the context of a different space application. However, in the present case, its polarization filtering properties are a key feature in determining its suitability.

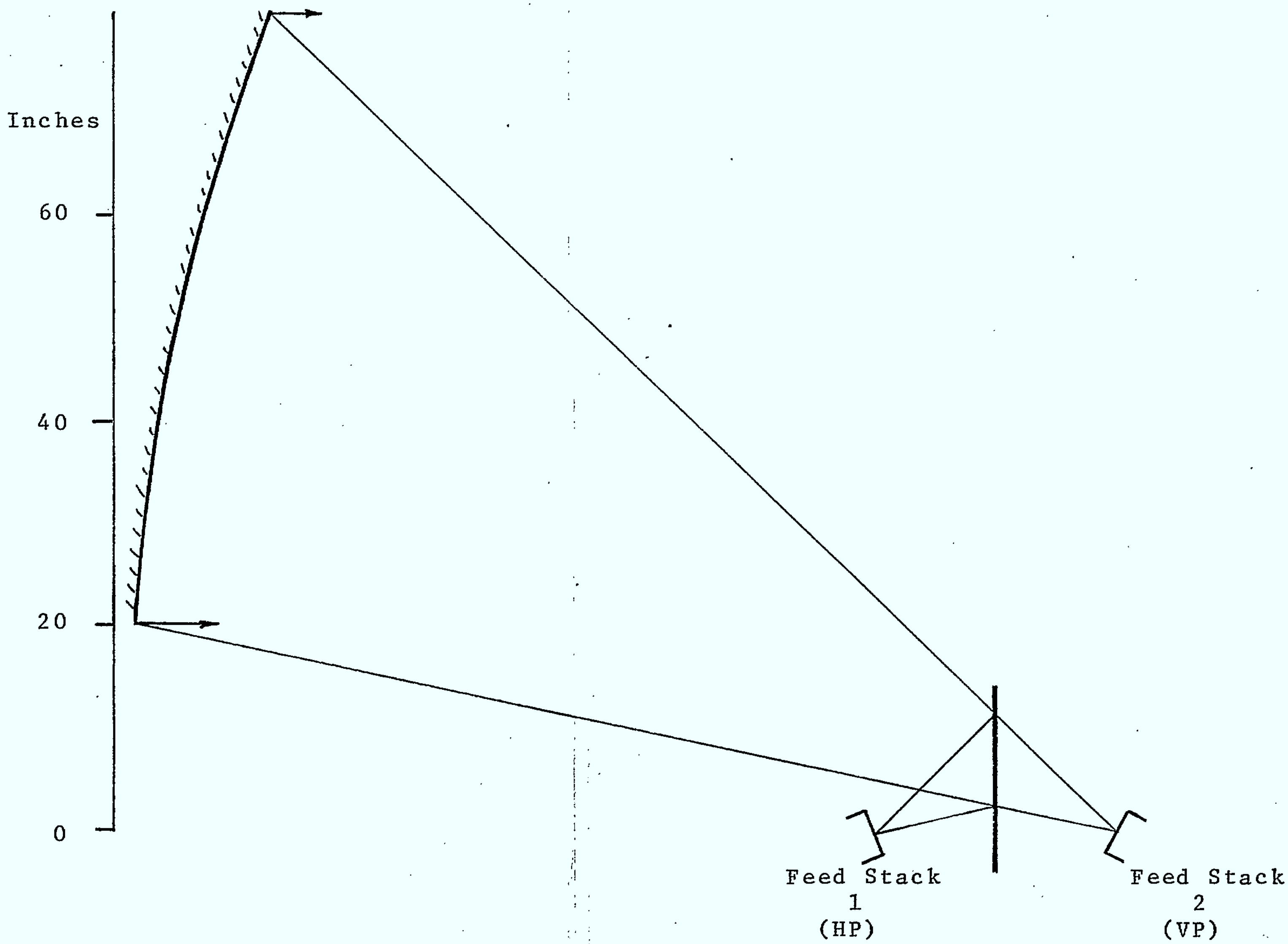


FIGURE 2.1 SINGLE REFLECTOR ANTENNA WITH PLANE GRIDDED SUBREFLECTOR

The basic concept of the gridded subreflector pre-supposes that it provides total reflection of the copolar fields of the inner feed system, whilst allowing the corresponding cross-polar energy to pass through the subreflector and be 'harmlessly' (i.e. in a direction which does not intercept the earth) radiated. Equally, the copolar fields of the outer feed system should pass straight through the subreflector to the main reflector. The cross-polar fields by way of constrast should be reflected from the outer surface of the grid, ultimately also be re-radiated 'harmlessly'.

To realize the behaviour described above, the grid must act as a near-perfect polarization filter. This implies certain limitations on grid conductor width and spacing, as well as dielectric constant of the grid support material. However, first an even more fundamental limitation must be considered. Namely, this is that the field lines generated by the two feed arrays must be at every point orthogonal to each other when projected onto the subreflector surface. The grid conductors may then be layed out in curved paths such that they are simultaneously parallel to the incident polarization of one feed system and orthogonal to that of the other.

This 'field orthogonality' condition will now be investigated analytically. For the purposes of analysis, the feed systems will be assumed to each launch 'pure' linear polarization. That is, they are assumed to generate zero cross-polar pattern as judged by the standard 'Ludwig third definition'. Less a pattern multiplier dependent on the spherical polar co-ordinates θ and ϕ, the radiated electric field is of the form.

$$\underline{E} = \cos(\phi - \phi_o)\,\underline{a}_\theta - \sin(\phi - \phi_o)\,\underline{a}_\phi \qquad \ldots\ldots(1)$$

Here ϕ_o is the nominal inclination of the polarization vector at the feed aperture. Conceptually as already stated we need to consider feed systems on either side of the subreflector. However, bearing in mind the geometrical symmetries of the problem in practice it suffices to consider the 'self orthogonality' of the polarization lines of one feed system as it is rotated about its own boresight axis, that is, as ϕ_o takes on the values of 0 and $\pi/2$ in eqn (1).

In terms of the x, y, z co-ordinate system of Fig. 2.2 and the tangential unit vector $\underline{a}_t$ depicted in that figure, it may be shown that

$$\underline{E} \cdot \underline{a}_y = \cos\theta \sin\phi \cos(\phi - \phi_o) - \cos\phi \sin(\phi - \phi_o) \qquad \text{......(2)}$$

$$\underline{E} \cdot \underline{a}_t = \cos\Psi \left[\cos\theta \cos\phi \cos(\phi - \phi_o) + \sin\phi \sin(\phi - \phi_o) \right] - \sin\Psi \sin\theta \cos(\phi - \phi_o) \qquad \text{......(3)}$$

Now the dot product

$$P = (\underline{E})_{\phi_o = 0} \cdot (\underline{E})_{\phi_o = \pi/2} \qquad \text{......(4)}$$

describes the degree of non-orthogonality (if any) between the nominally orthogonal fields. It may be shown that a 'worst case' occurs for $\phi = \pi/2$; we then get

$$P \approx -\tfrac{1}{2} \sin 2\Psi \sin\theta \qquad \text{......(5)}$$

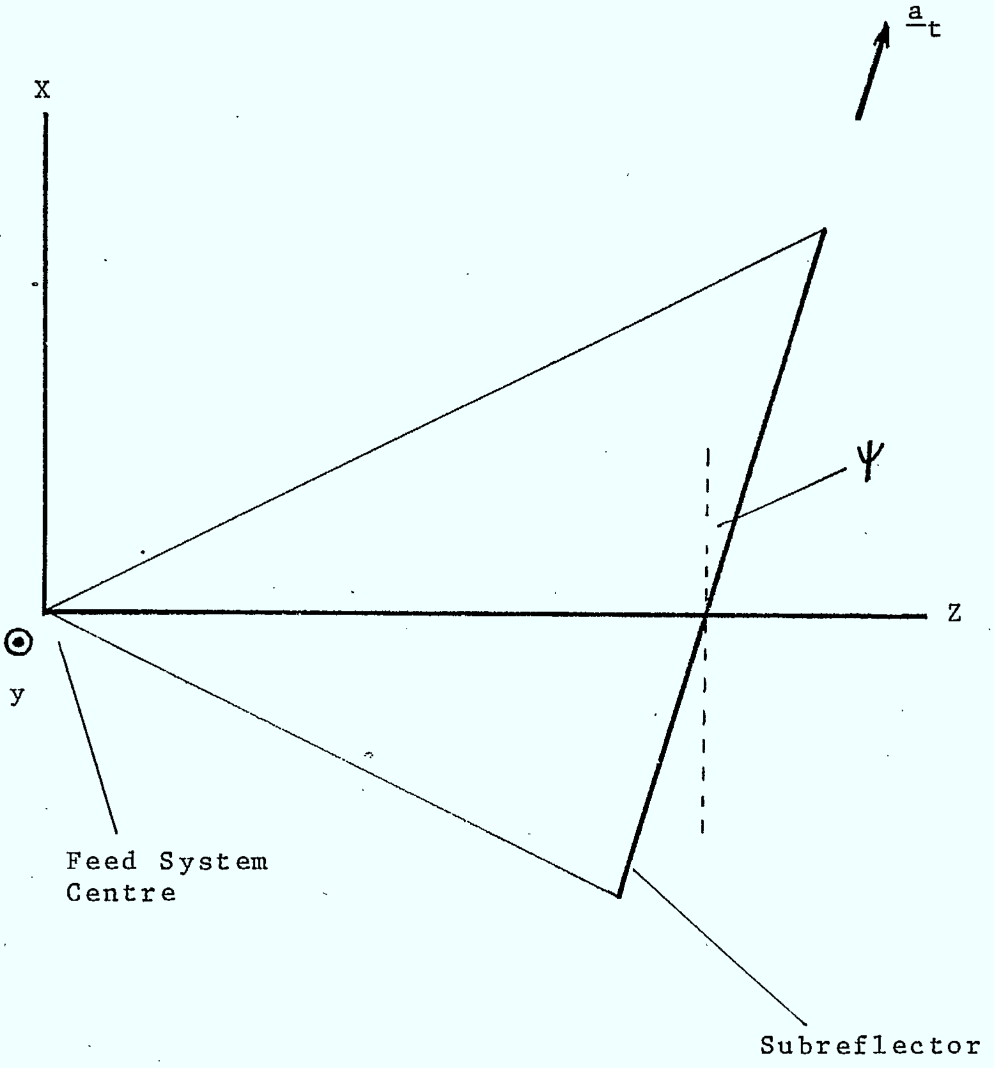


FIGURE 2.2 COORDINATE SYSTEMS FOR POLARIZATION CALCULATION

Clearly, non-orthogonality of polarization lines can only be avoided by selecting both Ψ (subreflector tilt relative to feed axis) and θ (feed system and offset paraboloid opening angle) small. Geometries which would achieve this are of too long a focal length to be practical.

2.2. Single Reflector Uplink

The single reflector/two reflector antenna trade-offs are quite different in the case of the uplink. The key features of the uplink application in this context are single mode, single beam operation for each polarization. The latter implies that beam overlap problems are non-existent.

The preferred uplink configuration to be described later in this report consists of a solid reflector fed by a horn array with individual polarizers for each feed horn. It is probable that the polarizers would have to be adjusted during the course of radiation contour measurements. However, this appears to be workable on the basis that there are only three polarizers, and (on the basis of symmetry) only two having independent adjustments

3 ANTENNA DESIGN RESULTS

Given the dimensions of the antenna and the power and phase distributions of the feed excitation, a computer program was used which evaluates the gain and phase at specified points in the area of coverage of the beam. This program was run repeatedly for different sets of input parameters, until an optimized design was achieved interms of the gain at the edge of the area of coverage.

The limited time budget allowed for this task was not sufficient for a complete optimization of the different designs, and hence the results presented here could be slightly bettered by a more intensive study.

3.1 Downlink Antennas

3.1.1 Unsteerable Versus Steerable (3 positons) Reflectors Options

The two main options to be considered are fixed reflectors or steerable reflectors. The first case has the feeds corresponding to the eastern most and the western most beams of each polarization displaced from the focus in the plane of offset, which introduces a cubic phase error across the aperture, with resulting beam shift, and gain and sidelobe level degradation. Only the central feed of each antenna will be centered on focus.

One of the main reasons for the loss in gain at the edge of coverage, when the feed is displaced from focus, is the mode shift, which becomes quite pronounced. This means that the patterns of the even and odd modes of excitation in each beam will display marked differences, and hence the common area of coverage will appear quite reduced. This mode shift is reduced by increasing the focal length of the reflector, for a fixed diameter.

For the case of the steerable reflectors, the focus can be relocated in each case to point to the center of the feed stack being used, and this eliminates the undesirable effects of an off focus feeding. As the steerability will be implemented around the axis of deployment of the reflectors, only a steering motor must be added to the fixed reflector system, but no extra hinge is introduced.

3.1.2. <u>Results For Fixed Reflectors</u>

With the fixed reflectors and the feed off focus, the following was adopted as the antenna geometry:

Focal Length: 100 in.

Reflector Diameter: 72 in., Circular.

Offset of Reflector Center from axis: 48 in., eastward.

Feed of 3 dielectric loaded horns, linearly polarized in the North-South plane.

The geometry and dimensions of the feed horn stack for the Quebec beam are shown in Fig. (3.1). The three horns are fed with equal power, and relative phases 0^o, $\pm 60^o$, $\mp 120^o$ (upper and lower signs refer to the two modes of excitation).

The beam produced by this geometry is centered 2.5^o East of the mechanical boresight of the antenna, with no displacement in the North-South plane, and it covers the desired area with a minimum gain, in both modes, of approximately 35.2 dB. The 36 dB contour also covers most of the area desired (96%).

It is estimated that further optimization of the feed geometry and excitation would add 0.5 dB to the minimum gain, bringing it up to around 35.7 dB, with a gain of 36.5 dB over most of the area of specified coverage.

3.1.3 <u>Steerable Reflectors, with Three Positions</u>

The same reflector and horn geometry were used, with the feed stack centered on focus, which would correspond to steerable reflectors. It is remarked that, comparing with the off focus case, the mode shift is decreased, and the area covered with both modes at a given gain level is increased (see Fig. (3.2)). It is estimated that an optimization procedure, in this case, of the geometry and excitation of the horns, would easily bring the minimum gain to the 36 dB level, which represents an improvement of .8 dB over the off focus case.

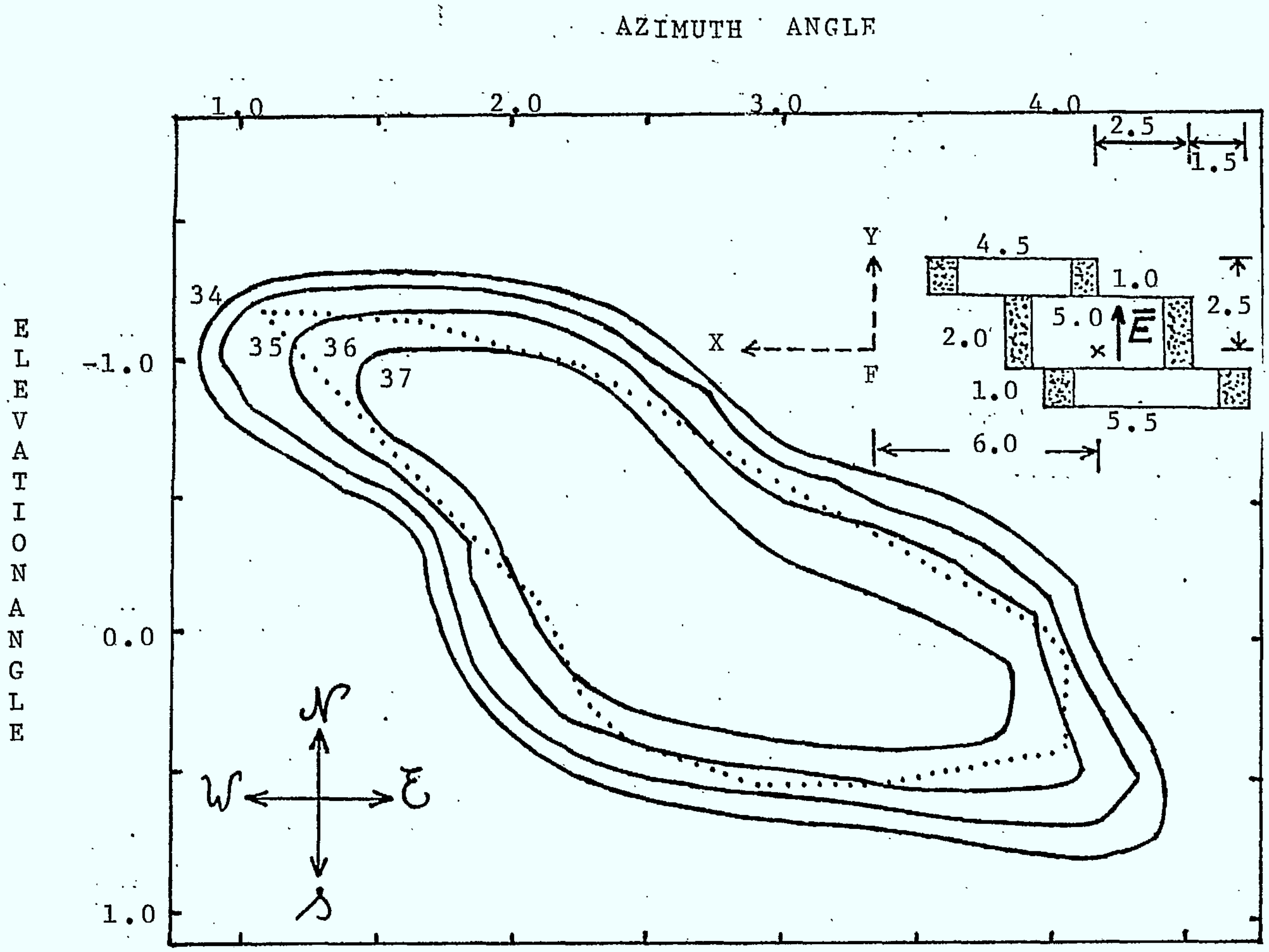


FIGURE 3.1a - COMPOSITE COVERAGE GAIN CURVES (IN dB) FOR BOTH MODES OF EXCITATION, FOR F = 100 in., D = 72 in., REFLECTOR CENTER OFFSET = 48 in., DIELECTRIC LOADED HORNS, DIMENSIONS IN INCHES, F IS THE FOCAL POINT. THE DOTTED CONTOUR IS THE DESIRED AREA OF COVERAGE. THE HORNS ARE FED WITH EQUAL POWER, AND WITH PHASES 0°, $\pm 60^\circ$, $\pm 120^\circ$ FOR THE TWO MODES.

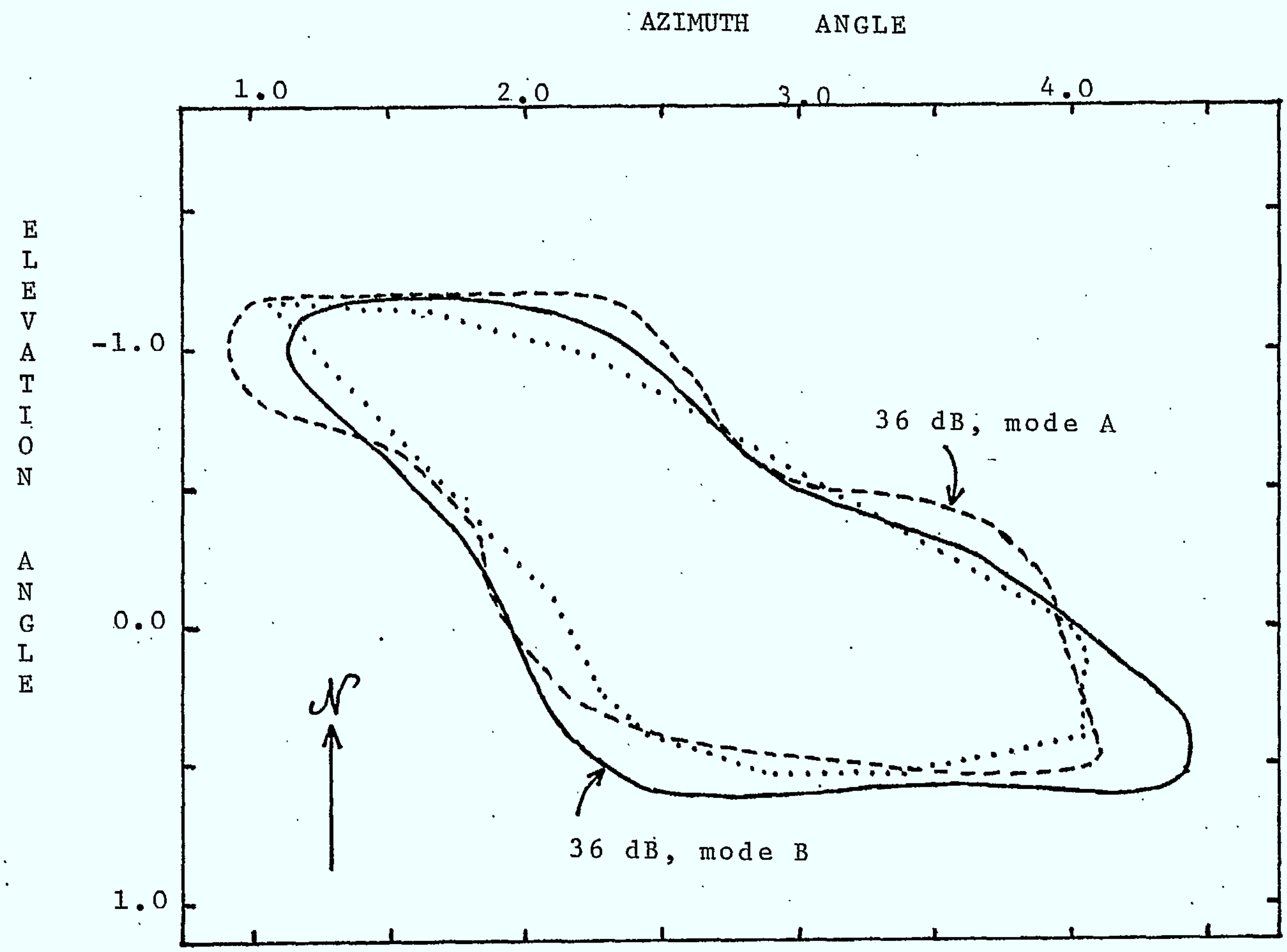


FIGURE 3.1b - 36 dB GAIN CONTOURS FOR THE TWO MODES OF EXCITATION OF THE ANTENNA OF FIGURE 3.1a, SHOWING THE MODE SHIFT THAT OCCURS.

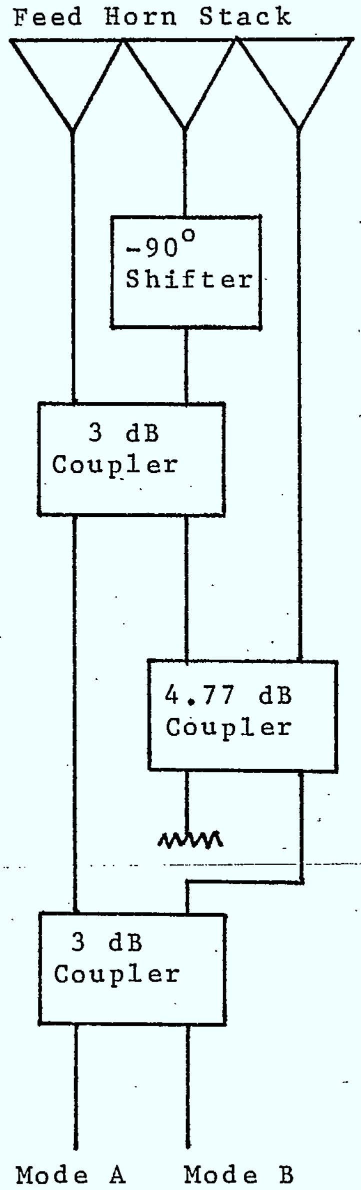


FIGURE 3.1c FEEDING NETWORK FOR THE ANTENNA OF FIGURE 3.1a. CONNECTING LINES ARE 0.375 in. x 0.75 in. RECTANGULAR WAVEGUIDE

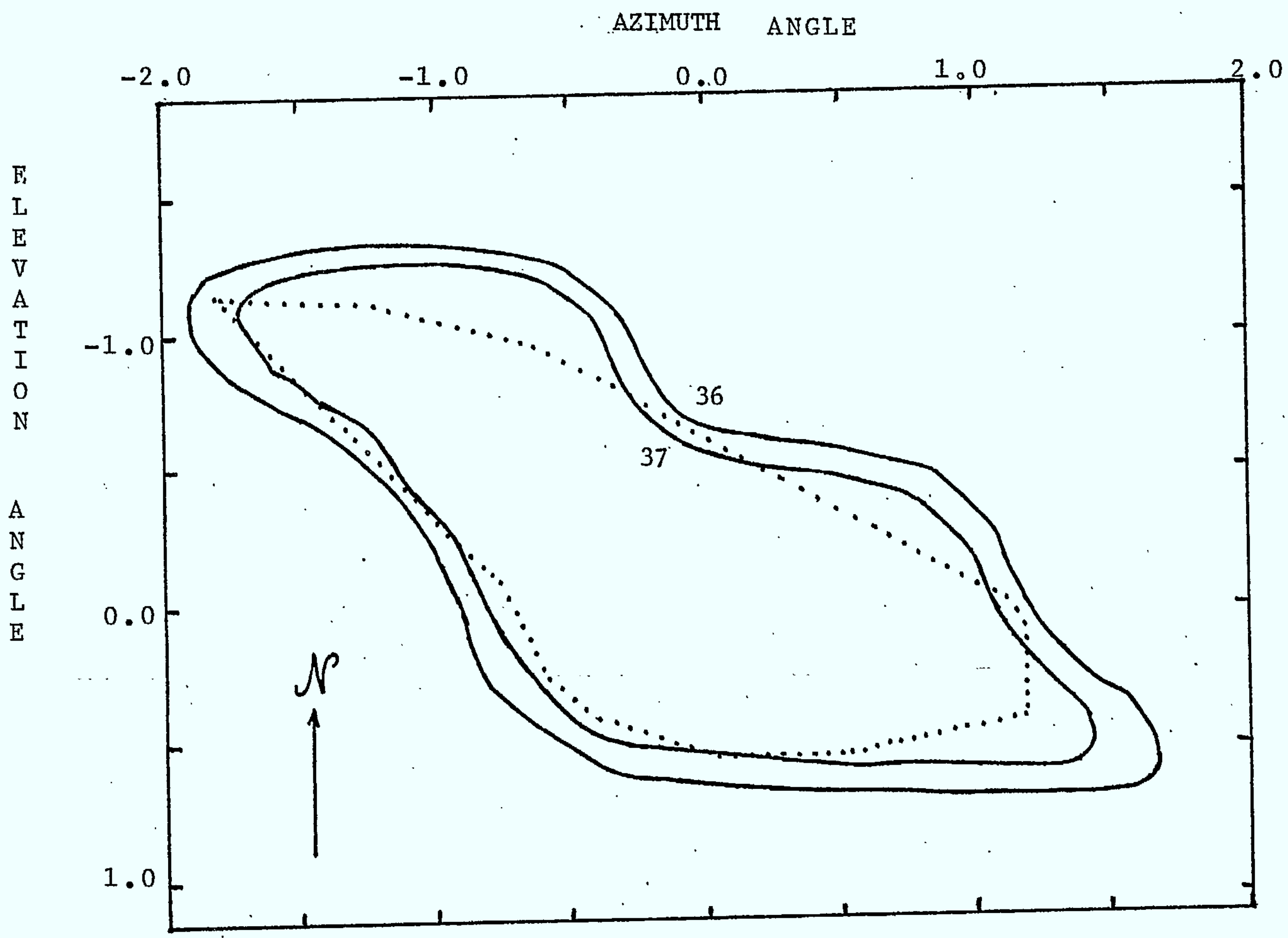


FIGURE 3.2a - COMPOSITE COVERAGE GAIN CONTOURS, IN dB, WHEN THE FEED STACK OF FIGURE 3.1a IS CENTERED AT THE FOCAL POINT.

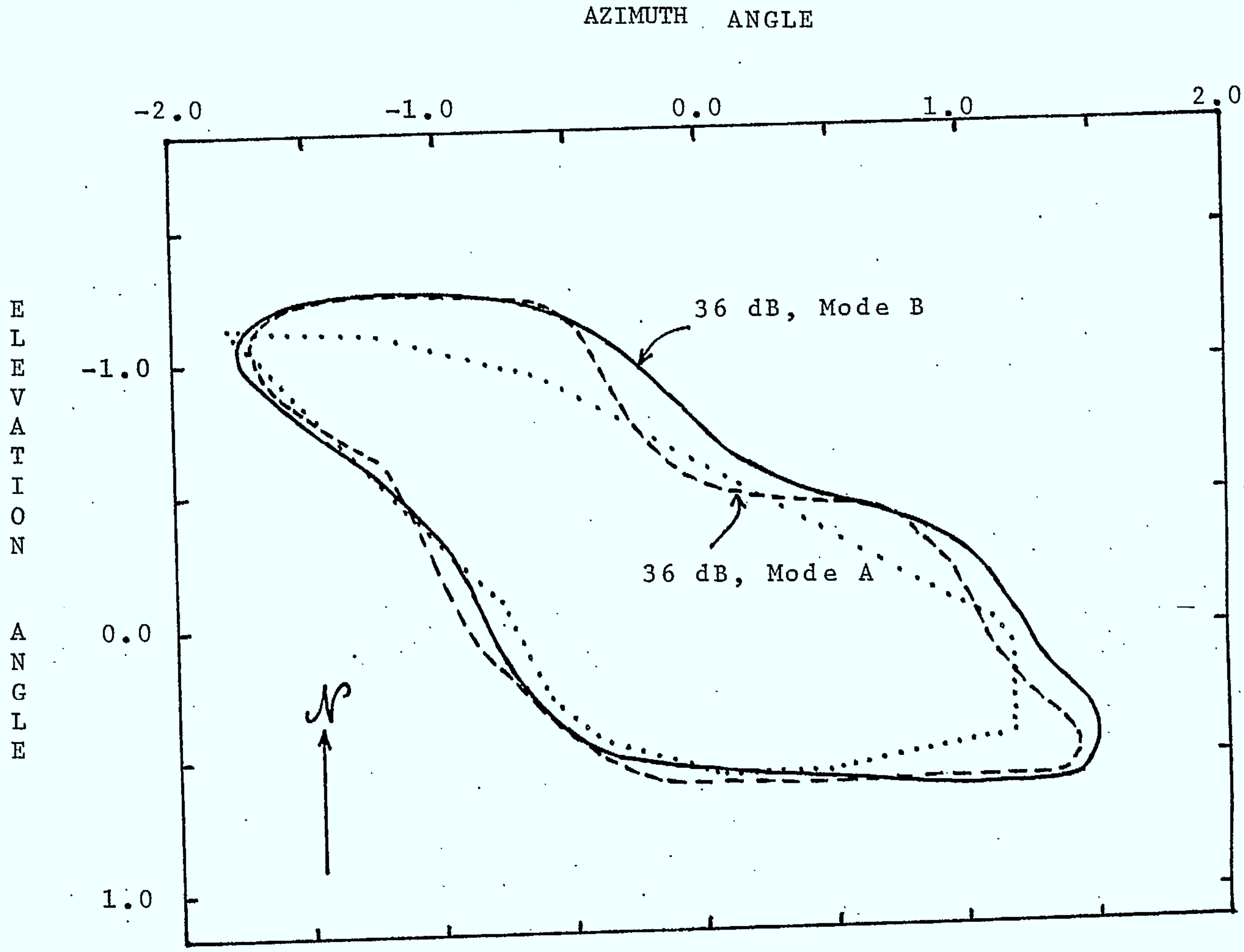


FIGURE 3.2b - 36 dB GAIN CONTOURS FOR THE TWO MODES OF EXCITATION OF THE ANTENNA OF FIGURE 3.2a, SHOWING THE MODE SHIFT.

This justifies the choice of the steerable over the fixed reflector antennas, and therefore that is the recommended concept.

Some refinements were then carried out for the steerable reflector option. The first step undertaken was to shorten the focal length of the paraboloid, in order to better fit the available space inside the launching vehicle. This also has the advantage of reducing the aperture dimensions of the feed horns, which are roughly proportional to the focal length.

Another advantage of the steerable system is apparent in that a much smaller focal length is allowed before the mode shift becomes unreasonably high. For the fixed reflector option, as the feed stack for the Quebec beam is centered off the focus, the mode shift is much higher, and much longer focal length is required. Hence, the focal length was decreased to F = 60 in. In an attempt to increase the gain, the diameter of the reflector was increased to 84 in. Also, as the three feeds are spaced in the plane of offset, linear polarization in that plane was chosen. As the horns are usually stacked principally in the E-plane, their H-plane dimensions are perpendicular to the direction of offset, and can then be increased without forcing adjacent feeds to be placed further apart. This allows us to use ordinary horns, instead of dielectric loaded horns, which were used before to decrease the H plane dimensions.

The use of ordinary instead of dielectric loaded horns is advisable, because it decreases the sidelobes in the H plane of the primary pattern, therefore increasing the spillover efficiency of the feed-reflector system. The feed will also be lighter, and no dielectric losses will have to be taken into account. In addition, it was concluded during this study that East-West stacking of the horns in each feed, with East-West polarization, yields the best spillover efficiency. The concomitant increase in gain, however, is partly offset by the fact that it proved to be quite harder to make the composite gain contours of the even and odd modes fit the specified area of coverage.

The best coverage achieved with this antenna was for

(Focal length: 60 in.

(Reflector diameter: 84 in., circular.

(Offset of reflector center from axis: 62 in., eastward.

(Feed of 3 ordinary horns, with East-West polarization, as displayed in Fig. (3.3). It is apparent that the East - West coverage of this beam is too narrow to cover the area specified at a level of around 36 dB. Several attempts were made to lengthen the E-W coverage, by appropriately changing the E-plane dimensions of the horns, but the individual beams due to each horn do not combine properly when the horn centers are separated any further. Different phasings and power splits among the three horns were tried, but did not result in any significant improvement. Consequently, a 4-horn feed was considered, with the same (East-West) plane of stacking.

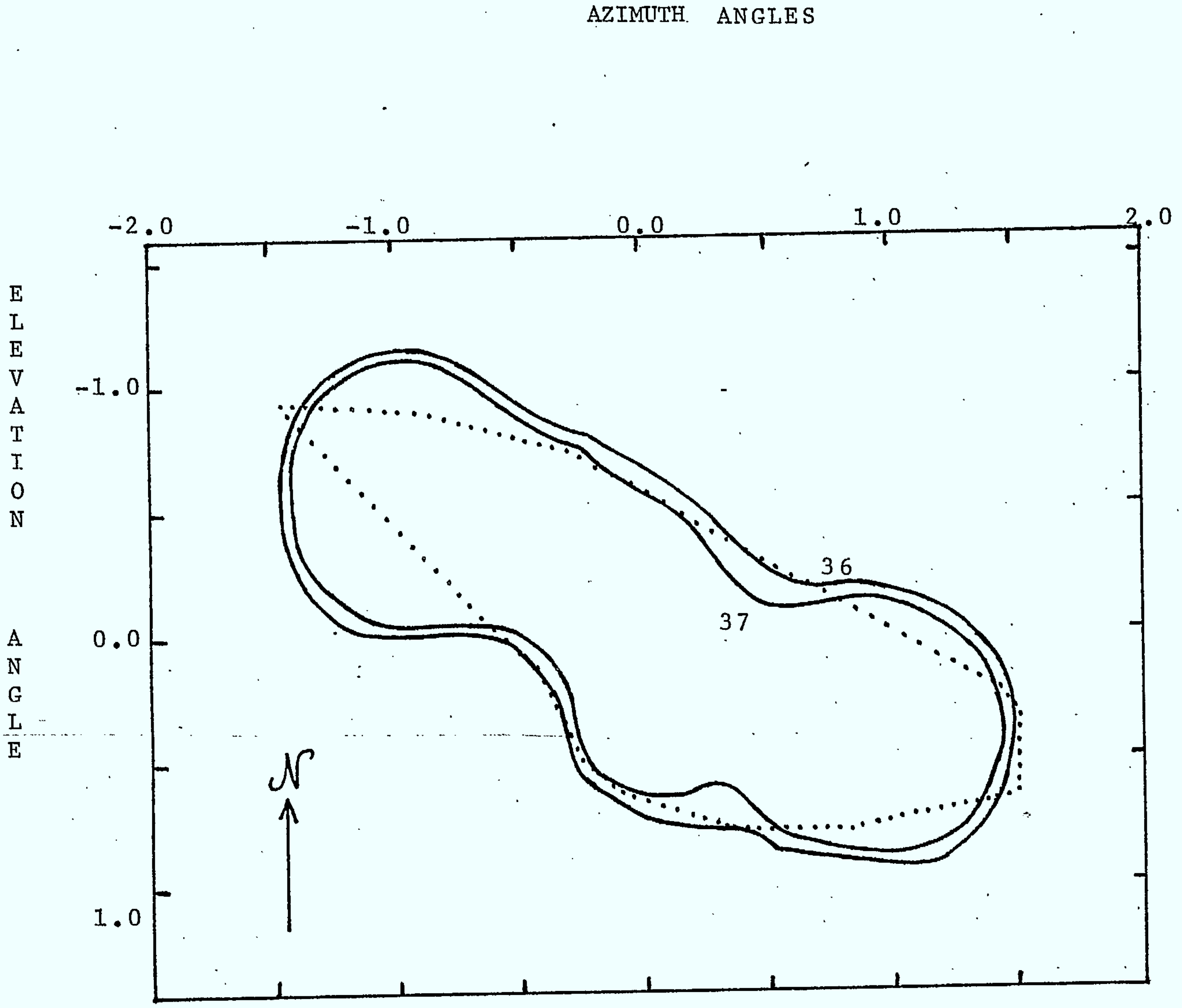


FIGURE 3.3 - COMPOSITE COVERAGE GAIN CONTOURS, IN dB, FOR BOTH MODES OF EXCITATION, FOR F = 60 in., D = 84 in., REFLECTOR CENTER OFFSET = 62 in., 3 HORN FEED.

As shown in Fig. (3.4), a minimum gain of 36 dB for both modes over the area of coverage was achieved, with 37 dB over most of that area.

3.1.4 Partial Steering

With the steerable reflector as described above, where each position has the focus around the center of the corresponding feed stack, the dimension of the feeds in the East-West plane is such that a rotation of about 4.3 degrees appears to be needed betweeen adjacent feeds. (*) The electrical boresight of the antenna will rotate by the same amount in the E-W plane.

Considering that the uplink antenna, which must cover all of Canada with one beam, will always be centered at roughly the middle of the country, from all three orbital locations, it follows that the angle by which the electrical boresight must change between adjacent positions is about 2.5 degrees only.

This means that the steerable antennas considered above actually over-rotate the beams in the E-W plane. This could be compensated only by having an uplink antenna which would also be steerable, so that it could be kept pointing towards the center of Canada from all locations.

* An accurate result is not available at the present time, since all 6 feed stacks must be designed in detail before a minimum separation between feeds can be specified.However, it seems almost certain that there is an over-rotation problem.

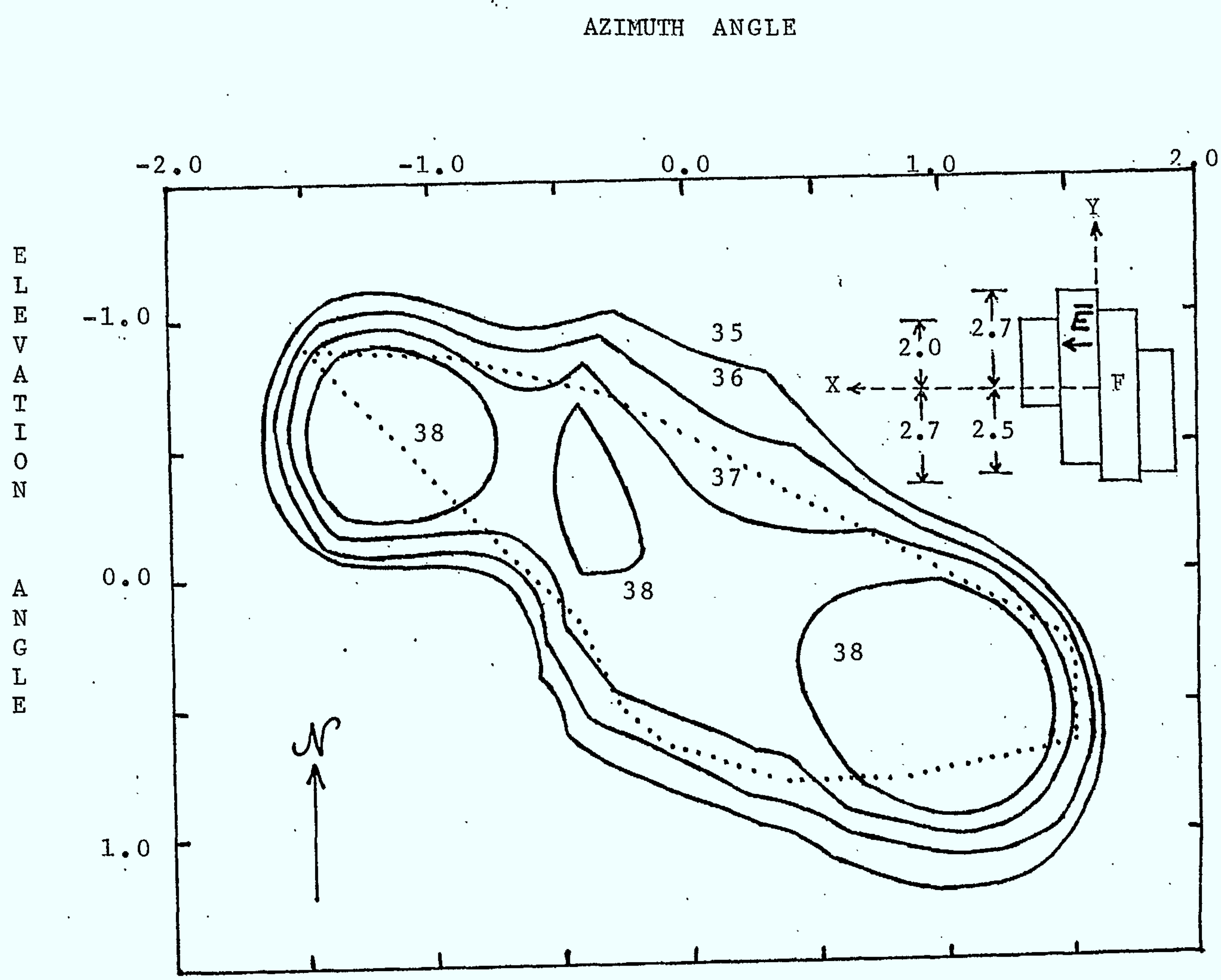


FIGURE 3.4 - COMPOSITE COVERAGE GAIN CONTOURS, IN dB, FOR BOTH MODES OF EXCITATION, FOR F = 60 in., D = 84 in., REFLECTOR CENTER OFFSET = 62 in., 4 HORN FEED, WITH EQUAL POWERS AND PHASES 70°, 45°, 72°, 135° FOR MODE A, 70°, -45°, -108°, -135° FOR MODE B. HORN APERTURE DIMENSIONS, RIGHT-TO-LEFT IN INCHES: 1.1 x 3.5, 1.1 x 4.9, 1.1 x 4.9, 1.1 x 2.5.

As such an extra mechanism is undesirable, an alternative solution is envisaged, which centers the middle feed stack on focus for the central beam, but doesn't quite center the inner and outer feed stacks for the Eastern and Western beams. Rather, the reflectors will be rotated just enough that the electrical boresight will be moved by 2.5^{o} in either direction. This means that the inner and outer feed stacks of each antenna will operate with a small offset from focus, estimated to be about 1 in. at this focal length. (see Fig. (3.5)).

A design was then conceived with the feed slightly off-focus. The reflector diameter was also decreased to 75 in., so that each individual beam of each one of the four horns would be widened, making it easier to combine them constructively to form the Quebec beam, by appropriately choosing the powers and phases of excitiation. The final design presented is then:

(Focal length: 60 in.
(Reflector diameter: 75 in., circular.
(Offset of reflector center from axis: 49.5 in., eastward.
(Feed of 4 ordinary horns, polarized in the plane of offset,

as depicted in Fig. (3.6). It is seen that this beam has a minimum gain of about 35.8 dB in the area of specified coverage, with most of the area (94%) covered with 37dB or higher.

Once more, the limited time allocated for this design didn't allow for all the possible optimizations to be carried through. An extra gain of at least 0.5 dB is to be expected from such a procedure, raising the minimum gain to about 36.3 dB.

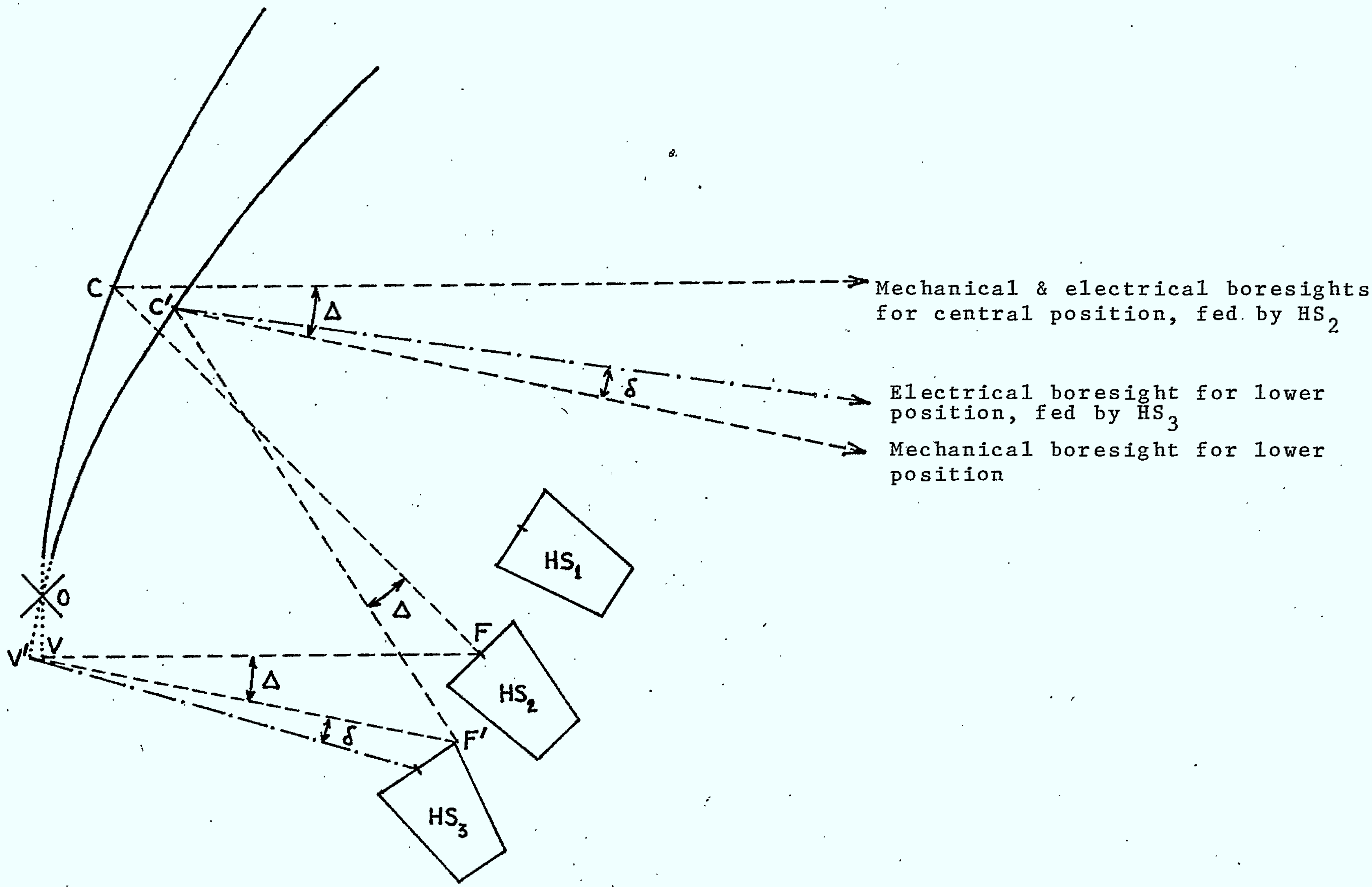


FIGURE 3.5 GEOMETRY OF THE PARTIAL STEERING MECHANISM (ANGLES Δ AND δ AND FEED STACKS HS_i ARE NOT DRAWN TO SCALE !). THE REFLECTOR ROTATES BY AN ANGLE Δ AROUND THE AXIS 0, BUT THE ELECTRICAL BORESIGHT ONLY ROTATES BY $\Delta - \delta$.

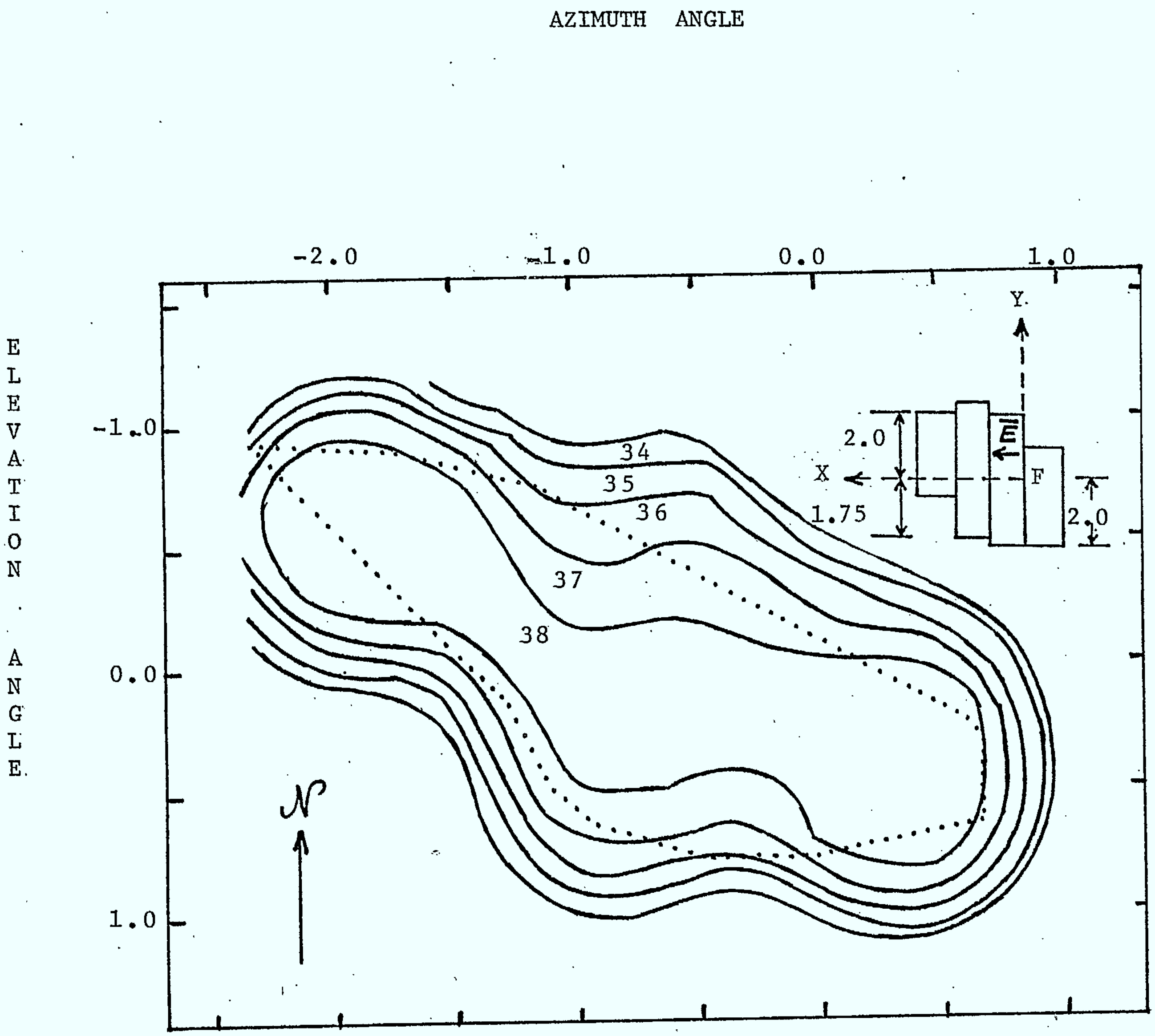


FIGURE 3.6a - COMPOSITE COVERAGE GAIN CONTOURS, IN dB, FOR BOTH MODES OF EXCITATION, WHEN F = 60 in., D = 75 in., REFLECTOR CENTER OFFSET = 49.5 in., 4 HORN FEED STACK, CENTERED SLIGHTLY OFF FOCUS. HORNS WITH EQUAL POWER, AND PHASES 0°, 15°, 60°, 130°, FOR MODE A AND 0°, -75°, -120°, -140° FOR MODE B. HORN APERTURE DIMENSIONS, IN INCHES, RIGHT-TO-LEFT: 1.16 x 3.0, 1.0 x 4.0, 1.0 x 4.0, 1.16 x 2.5.

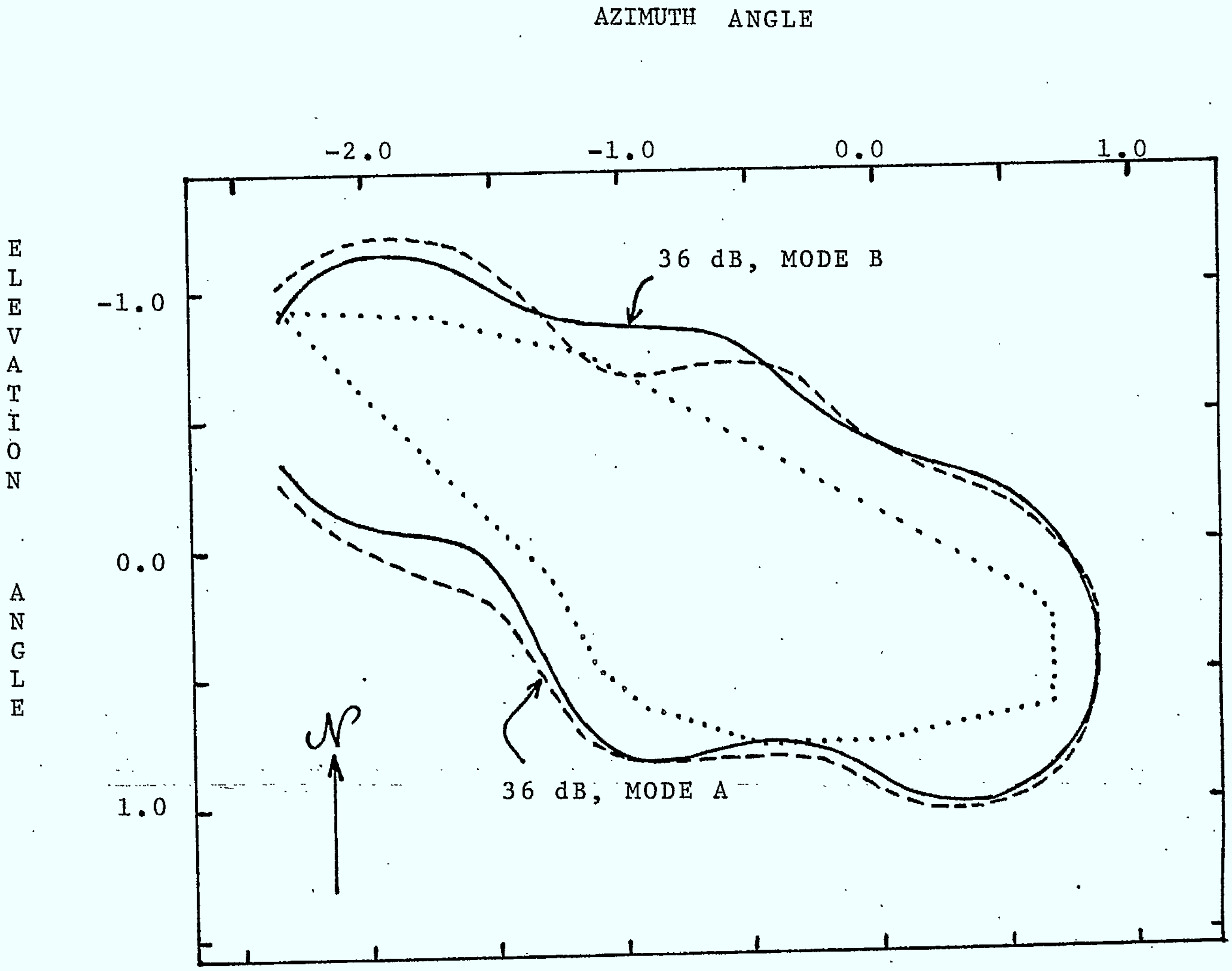


FIGURE 3.6b - 36 dB GAIN CONTOURS FOR THE TWO MODES OF EXCITATION OF THE ANTENNA OF FIGURE 3.6a, SHOWING THE MODE SHIFT.

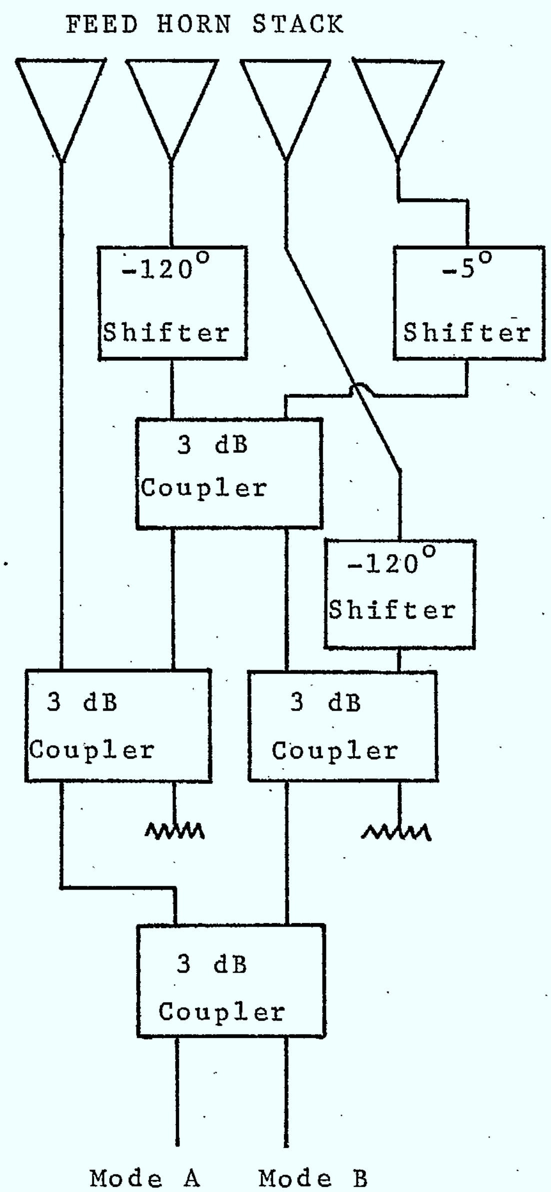


FIGURE 3.6c - FEEDING NETWORK FOR THE ANTENNA OF FIGURE 3.6a. CONNECTING LINES ARE 0.375 in. x 0.75 in. RECTANGULAR WAVEGUIDE.

3.1.5 Predicted Performance of Preferred Downlink Configuration

3.1.5.1 Gain Over Coverage

From the study done for the Quebec beam, conclusions may be extrapolated to the remaining beams, taking into account the different areas of coverage required.

The gain at the edge of coverage is expected to be inversly proportional to the area of coverage required, in square-degrees. The Quebec beam must cover 2.41 square-degrees. The remaining beams must cover the following:

Beam Description	Area of Coverage	Gain relative to the Quebec Beam
I-Maritime Provinces	1.06 sq. deg.	3.57 dB
II-Quebec	2.41 sq. deg.	0 dB
III-Ontario	1.70 sq. deg.	1.52 dB
IV-Manitoba-Sask.	1.35 sq. deg.	2.52 dB
V-Sask.-Alberta	1.36 sq.deg.	2.48 dB
VI-British Columbia	2.07 sq. deg.	0.66 dB

Beams I and II are to be covered from the Eastern Orbital Location (E.O.L.), and beams V and VI from the Western Orbital Location (W.O.L.). As to beams III and IV, they will be covered from the central location (C.O.L.), which has not been assigned as yet. An estimation was done of the areas of coverage required from the C.O.L. for those two beams, based on the areas viewed from the E.O.L. (III-2.27, IV-1.49) and the W.O.L. (III-1.30, IV-1.18), in square degrees.

Other factors to be considered are:

i) Implementation Margin: 0.4 dB. This includes mutual coupling effects which have not been taken into account in the modelling, inaccuracies in the feeding network implementation, and reflector irregularities.

ii) Pointing Error: could be as large as 0.15° in any direction. This brings the minimum gain for the Quebec beam in the steerable case to as little as 34.3 dB, i.e., a minimum gain loss of 1.5 dB.

It is estimated that an optimization process for the specified area of coverage, which would include 0.15° pointing error from the start, would reduce this loss by 25%, to about 1.1 dB.

For the fixed antenna system, it is also found that a worst direction pointing error of 0.15° brings about a loss of 1.2 dB in the minimum gain over the area of coverage. An optimization process, which would include the pointing error from the start, would reduce this loss to about 0.9 dB.

Considering a fixed region within the specified area of coverage, covering 90% of that area, the pointing error degradation of the minimum gain will be considered to be 1 dB.

TABLE 3.1

EXPECTED PERFORMANCE OF AN OPTIMIZED SIX BEAM ANTENNA SYSTEM

Beam	Minimum Gain Over Area of Coverage (dB)			Minimum Gain Over At Least 90% of The Area of Coverage (dB)	
	Basic Value	Including Implementation & feed network losses	Considering the worst case(0.15°) pointing error	Basic Value	Including Implementation, feed network, & 1 dB pointing error losses
I) FIXED ANTENNA SYSTEM					
I	39.2	38.4	37.5	40.0	38.2
II	35.7	34.9	34.0	36.5	34.7
III *	37.7	36.9	36.0	38.5	36.7
IV *	38.7	37.9	37.0	39.5	37.7
V	38.1	37.3	36.4	38.9	37.1
VI	36.3	35.5	34.6	37.1	35.3
II) STEERABLE (3 POSITIONS) ANTENNA SYSTEM					
I	39.8	39.0	37.9	41.0	39.2
II	36.3	35.5	34.4	37.5	35.7
III	37.8	37.0	35.9	39.0	37.2
IV	38.8	38.0	36.9	40.0	38.2
V	38.7	37.9	36.8	39.9	38.1
VI	36.9	36.1	35.0	38.1	36.3

* For these 2 beams, 0.5 dB were added for the fact that the respective feeds are centered on focus

(iii) Losses in the Feed Network: each feed network is expected to have between 30 and 50 inches of .75 in. x .375 in. waveguide. A quick estimation of the losses may be done by comparison with the ANIK-C satellite, where about 70 in. of waveguide at the feed led to 0.5 dB total loss. (The frequency was 4% lower than in the present case, but the guide dimensions were the same). A loss value of 0.4 dB is a conservative estimate, from this data.

From the considerations above, the following extra losses will be taken into account, and considered to be the same for all beams:

(Implementation losses: 0.4 dB
(
(Feed network losses: 0.4 dB
(
(Pointing error losses: 1.1 dB (steerable system)
(or 0.9 dB (fixed reflectors) for the minimum gain
(over the area of coverage, and 1 dB for the minimum
(gain over 90% of the area of coverage.

The expected performance of the system is presented in Table 3.1.

3.1.5.2 Sidelobe Performance

The detailed calculation of sidelobe distributions over a global disc for an antenna aperture of 80 wavelengths (as for the proposed DBS downlink configuration) is an extremely complex task. In relation to the usual 'within coverage' computer simulations, the number of integration points has to be increased in each of two dimensions in proportion to the increased geographical subtended angle, and simultaneously the number of computed pattern points has to be increased in each of two dimensions. For a Physical Optics computer program such as the one developed at SPAR for shaped beam antenna calculations, the computing time requirement for the basic 'within coverage' calculation is not insignificant. Global coverage calculations make very heavy demands on computing time and on contour plotting facilities.

For the purposes of the present limited study, an estimate of sidelobe performance will be made based on an extrapolation of the ANIK C data generated during the "Study of Linear and Circular Polarization for 17/12 GHz Antennas of the Direct Broadcasting Satellite (DBS)" (DOC contract no. 06ST. 36001-1-1603). In this context results for linear polarization are of most relevance to the present application, since the feed horns for the preferred configuration downlink antenna design are linearly polarized devices. Both measured and computed data is cited in the final report RML-009-82-89 for the 'Linear and Circular Polarization Study', for the ANIK C East beam. The first and second sidelobes are of about 18 dBi and 13 dBi level respectively in the North-South plane (narrow beam plane of shaped coverage). Marginally lower values pertain in the East-West plane (wide beam plane of shaped coverage).

To extrapolate these results to the present DBS downlink configuration, it will be assumed that the absolute level of the sidelobes is independent of number of feed horns or beam shape. That is since the ANIK C and DBS downlink reflectors are of similar size (72" and 75" diameter respectively) the 18 dBi and 13 dBi levels will be assumed to be maintained even though the 'on-axis' gain is somewhat greater for the DBS downlink case.

On this basis the first and second sidelobes for the DBS downlink are at -22 dB and -27 dB level respectively relative to the peak gain. If we compare the 'narrow beam plane' pattern with the 'WARC 77' recommended copolar reference pattern, it is evident that the first sidelobe of the antenna pattern is the limitation and this exceeds the WARC 77 '-30 dB plateau' by 8 dB. The first sidelobe peak will occur quite near the beginning of the plateau. Should it actually lie slightly outside the plateau (e.g. within the $12(\theta/\theta_o)^2$ region) the 8 dB figure would be reduced.

Overall, bearing in mind this and other uncertainties in the present estimation, it appears that the WARC 77 reference pattern will be exceeded by 8 dB $\pm$ perhaps 5 dB.

In the 'broad beam' plane the new 'shaped beam' copolar reference pattern to be submitted to RARC-83 by the CCIR will be assumed. The first sidelobe now intercepts the -25 dB reference plateau, and exceeds this by about 2 dB. The -35 dB plateau probably encompasses the fourth and fifth sidelobes, and is a lesser limitation.

Overall, therefore, the application of the WARC 77 reference pattern to the 'narrow beam plane' performance of the antenna leads to the most stringest limitation. The 'overshoot' of the antenna pattern relative to this reference pattern is considerable (8 dB $\pm$ 5 dB quoted above). However, it exists only in a narrow angular region perhaps 0.5^o wide.

It is relevant at this point to review the mechanisms of sidelobe generation present in a shaped beam antenna with particular consideration to any potential techniques for sidelobe reduction. This topic can be most readily approached by considering each horn of the feed array as generating a secondary pattern 'beamlet' of essentially pencil beam form and of a beamwidth less than that of the overall shaped antenna pattern.

The overall antenna sidelobe level is essentially a summation of the 'beamlet' sidelobe distributions. As such it is clearly dependent on the amplitude and phase excitation of the feed horns, which determines the relative amplitudes and phases involved in the summation. However, the feed horn excitations are specified in the course of optimizing the within coverage shaped beam pattern. Typically, perturbations in excess of 0.5 dB amplitude and 5° phase of the feed horn excitations cause serious degradations of the within coverage performance. To arrange for destructive addition of beamlet sidelobes is likely to require large perturbations, approaching 180° in phase in some cases. Hence adjusting the excitations of the feed array cannot be considered a viable means of reducing the sidelobe level.

Following the reasoning of the previous paragraph, it becomes evident that the only practical avenue to reducing antenna sidelobes is to reduce beamlet sidelobes. In a conventional single feed reflector antenna, increasing the feed horn aperture increases the illumination taper across the main reflector and in consequence reduces secondary pattern sidelobes. The only limitation is that antenna gain will tend to be slightly reduced. In a shaped beam antenna, the same change forces the distance between the centres of feed apertures to be increased. Hence the beamlets are scanned apart, and nulls appear within the shaped beam coverage region. To avoid undesirable consequences of this kind, individual feed horns of a shaped beam antenna usually are designed to provide no more than about 6 dB illumination taper across the reflector in the plane (s) in which they are stacked. To summarize, there are only extremely limited degrees of freedom available to reduce beamlet sidelobes by increasing feed horn aperture size in a typical shaped beam antenna in the plane of stack.

For an antenna such as ANIK C where the feeds are predominantly stacked in one plane (the East - West plane) only, it is in principle feasible to increase horn dimensions and hence reduce sidelobes in the orthogonal plane (North-South). For the DBS 'Quebec beam' studied the horns are stacked in a fashion which could more aptly be described as diagonal and it is doubtful if such a sidelobe suppression technique is feasible.

The final consideration entering into beamlet sidelobes is the coma effect resulting from displacing individual feed horns away from the focus of the parabolic reflector. Usually, feed displacements and coma are larger for a multi-beam antenna than for an antenna with a single shaped beam. However, with the 'partial steering' concept evolved for the DBS downlink antenna described in this report, off-axis displacements are minimized. The only avenue for further reduction of coma-related sidelobe generation is therefore to increase the focal length of the reflector. A factor of increase of perhaps 1.5 would be necessary to have any reasonable expectation of a tangible improvement. The mechanical repercussions of such a change are considerable.

3.1.5.3 Polarization Purity

The proposed DBS downlink uses two reflectors with spatial polarizers built into the reflecting surfaces. This concept allows individual linear polarizing grids to be employed in the vicinity of the apertures of the two feed arrays. Although it has not been feasible within the available time frame to investigate the design of these grids in detail, it appears that it should be possible to arrange that these do not constitute a significant limitation in performance, and pure linear polarization at the correct angle is incident on the spatial polarizers.

Grid Polarizer

The grid-type spatial polarizer uses parallel conductors etched on a dielectric which is itself backed by a conducting surface. The most advantageouse construction for reflection polarizers involves widely spaced conductors. The grid then behaves as a transmission line with dielectric loading adjacent to a short circuit. For incident polarization parallel to the grid conductors, there is a shunt inductive susceptance -B at the air/dielectric interface. For polarization perpendicular to the grid, the latter is essentially invisible at mirrowave frequencies.

A simplistic model of a grid polarizer would have grid conductors of 'ideal' reflection properties (e.g. $B = \infty$ for parallel incident polarization suspended in free space $\lambda/8$ above a conducting plane. For normal incidence, the worst case polarization impurity (or unwanted hand CP) generated would be at -36 dB level for a 12.2 GHz to 12.7 GHz band.

A dielectric sheet can be used as a support for the grid; the overall thickness of the grid/conducting plane sandwich for optimum performance is then reduced, although not by as much as $\sqrt{\varepsilon}$, where ε is the dielectric permittivity. The polarization purity properties are degraded to -33 dB at band edges for $\varepsilon = 2.3$.

Reducing the susceptance B results in an increased thickness of sandwich for optimum performance. Over a fairly wide range, B has little effect on polarization frequency sensitivity. However, for values of

$$B/Y_o = 1$$

or less (Y_o = free space conductance), the susceptance loading starts to compensate the frequency characteristic.

A solution of the latter type that has been investigated has 0.01" wide conducting strips spaced about 0.3" apart on a dielectric sheet of 2.3 permittivity. The thickness of the sheet is about 0.16". The level of unwanted hand CP generation is ideally -39 dB at band edges.

The results discussed so far apply to the case of normal incidence. For the proposed DBS configuration, incidence angles of up to 40° are involved. Incidence angle principally affects the effective path length across the sandwich. The resulting perturbations may be compensated by varying the thickness of dielectric. In practice this means that the dielectric would need to be N/C machined on both sides, the surfaces being nearly parabolic but nevertheless of slightly different shape on either side.

Manufacturing tolerances are a very important consideration with a grid type polarizer. The effect of an ± 0.001" variation of the ± 0.01" nominal conductor width of the compensated design is small. Surprisingly, so also is a ± 10% variation in dielectric permittivity. The dielectric thickness however is more critical. A ± 0.002" variation from 0.16" nominal generates unwanted hand CP at about -37 dB level at band centre.

Corrugated Surface Type

An alternative type of spatial polarizer is constructed by cutting parallel grooves about $\lambda/8$ deep in the reflecting surface. This concept might be preferred from mechanical considerations since no dielectric is involved. Electrically the principle of operation is similar to the grid polarizer. Thus, suppose the incident field is linearly polarized with polarization at 45° to the grooves. The component of linear polarization polarized parallel to the grooves will be reflected essentially from the top of the grooves, whereas the orthogonal component will penetrate to the bottom before being reflected, introducing the desired 90° phase shift.

Ideally, the frequency sensitivity of a corrugated surface polarizer is such that -36 dB unwanted hand CP is excited at DBS band edges. There has not been sufficient time during the study to explore to what extent if any the design could be 'compensated' to reduce frequency sensitivity.

The groove depth of the corrugated surface polarizer plays a similar role to the dielectric thickness for the grid-type polarizer. Thus $\pm$ 0.002" variation of groove depth again results in about -37 dB unwanted hand level. However, maintaining precise groove depths should be a more straight-forward matter from a mechanical point of view, since both surfaces determining the depth are machined from one side.

Factor Influencing Polarization Performance	Level of Unwanted Hand CP Relative to Wanted Hand CP
Inherent Performance of Spatial Polarizer, With Allowance For Manufacturing Tolerances	-31 dB
Direct Radiation From Linearly Polarized Feed Horns	-50 dB
Scattering of Wavefront Emerging From Reflector Off The Feed Horn Stack	-40 dB
Overall Polarization Purity	-30 dB

TABLE 3.2 SOURCES OF UNWANTED HAND CP FOR DOWNLINK ANTENNA

Overall Estimate of Downlink Polarization Purity

An overall estimate of the downlink polarization properties is given in Table 3.2. Adding together the individual contributions on a RSS basis leads to a prediction of -30 dB worst case unwanted hand CP level.

3.1.6 Extension to a 4 Beam - 2 Orbital Location System

In a manner similar to section 3.1.5., the performance of a system with 4 beams from 2 orbital locations may be estimated.

On the basis that the achievable gain at the edge of coverage is inversely proportional to the area to be covered, in square degrees, the following gains relative to the case of the Quebec beam in the six beam system apply:

Beam Description	Area of Coverage	Gain Relative to the Quebec Beam (6 beam system)
I-Quebec, Maritimes	2.39 sq. deg.	.04 dB
II-Ontario, Quebec	3.20 sq. deg.	-1.23 dB
III-Manitoba-Sask.	1.76 sq. deg.	1.37 dB
IV-Alberta-Brit.Col.	2.73 sq. deg.	- .54 dB

Considering implementation, waveguide, and pointing losses to have the same values as for the 6 beam system, the expected performance for the optimized antennas is given in the following Table, for steerable (2 positions) reflectors:

TABLE 3.2

EXPECTED PERFORMANCE OF AN OPTIMIZED
FOUR BEAM ANTENNA SYSTEM
(steerable (2 positions) reflectors)

Beam	Minimum Gain Over Area of Coverage (dB)			Minimum Gain Over at Least 90% of the Area of Coverage (dB)	
	Basic Value	With implementation & feed network losses	including the worst case (0.15^0) pointing error	Basic Value	With implementation, feed network, & 1 dB pointing error losses
I	36.3	35.5	34.4	37.5	35.7
II	35.1	34.3	33.2	36.3	34.5
III	37.6	36.8	35.7	38.8	37.0
IV	35.8	35.0	33.9	37.0	35.2

3.2 UPLINK ANTENNA

3.2.1 Proposed Configuration and Gain Performance

The uplink antenna will receive two beams, one left-hand circularly polarized and the other right-hand circularly polarized, at a frequency of 17.55 ± 0.25 GHz, from any point in Canada.

Its coverage area is all of Canada, and the proposed feed system consists of 3 circularly polarized square horns, centered on focus.

The dimensions of this antenna are:
(Focal length: 18 in.
(Reflector diameter: 18 in., circular
(Offset of the center of the reflector: 15 in., 9° from
(North, and the coverage gain contours are displayed in
(Figure 3.7a.

The minimum gain over the area of coverage, for both orbital locations, is about 29.2 dB. A worst case pointing error, 0.15° southward or northward, will entail an extra loss of 0.6 dB. Assuming 0.6 dB for implimentation and feed waveguide losses, the worst case minimum gain over the area of coverage from both orbital locations is placed at 28.0 dB. This value can most probably be raised to around 28.5 dB if a full scale optimization procedure were to be carried through.

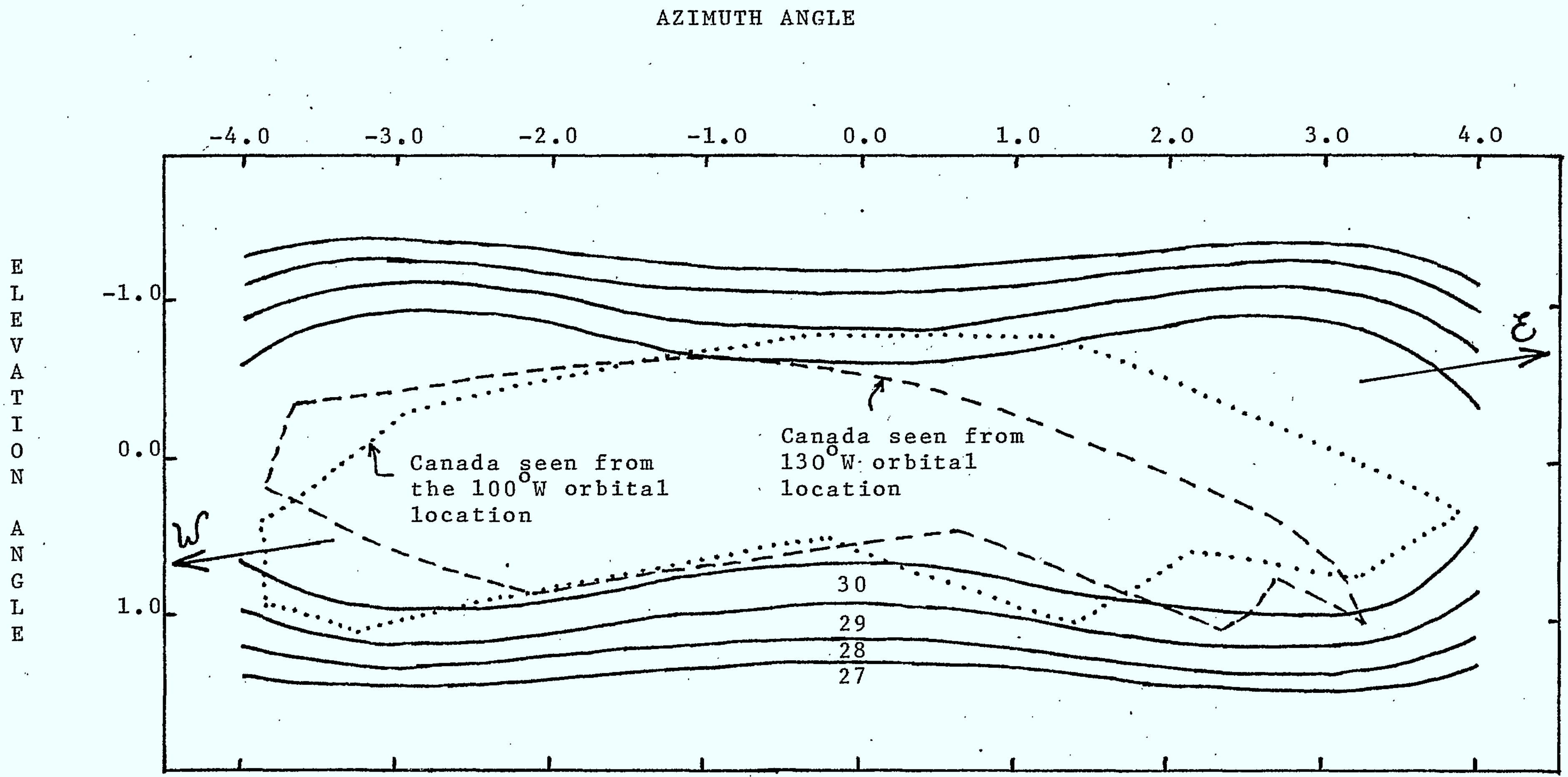


FIGURE 3.7a - GAIN CONTOURS, IN dB, FOR THE UPLINK ALL-CANADA ANTENNA. F = 18 in., D = 18 in., REFLECTOR CENTER OFFSET = 15 in., 3 SQUARE HORNS 1.3 in. x 1.3 in., STACKED IN AZIMUTH, CIRCULARLY POLARIZED (RHCP). THE REFLECTOR IS OFFSET ALONG A PLANE WHICH IS ROTATED CLOCKWISE BY 9° RELATIVE TO THE NORTH-SOUTH PLANE.

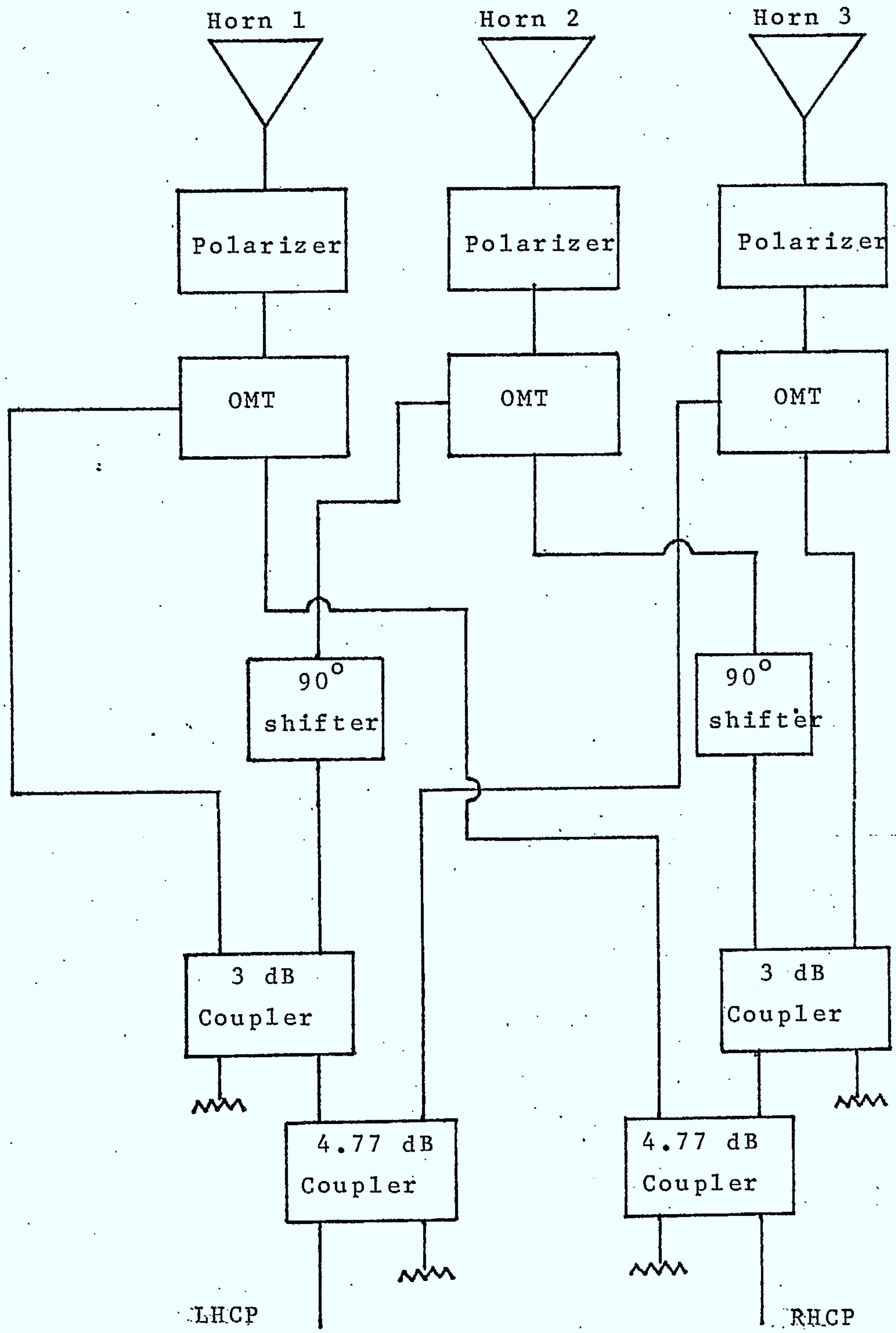


FIGURE 3.7b - FEEDING NETWORK FOR THE UPLINK ANTENNA (OMT = ORTHO-MODE TRANSDUCER)

3.2.2 Polarization Purity

3.2.2.1 Horn to Horn Coupling and Compensation Schemes

For the uplink antenna, the configuration as described above uses individual waveguide-type polarizers in each feed horn. As such, it is susceptible to a mechanism generating polarization impurities related to horn to horn coupling. Thus referring to Fig. 3.8 a), when two square pyramidal horns are placed side by side there will be substantial coupling for the component of polarization parallel to the x axis, but negligible coupling for the orthogonal polarization. The effect is to introduce an additional field vector, assigned the magnitude 2c in the figure, at the horn aperture. This vector unbalances the ideal circularly polarized nature of the excitiation.

The question now arises as to whether or not the depolarizing effect of the coupling can be compensated by 'detuning' the circular polarizer. It transpires that this is indeed possible: Instead of producing orthogonally polarized outputs of amplitudes

$$1 \text{ and } j$$

respectively it should be detuned to provide

$$1-c \text{ and } j(1+c)$$

For a pin-type polarizer with the pins aligned at 45^{o} to the x and y axes, the length of the pin loaded waveguide can in principle be varied to achieve this (assuming for the moment that 'c' is a real quantity). For a pin type polarizer with pins parallel to either the x or y axes, it is necessary to rotate the incident linear polarization slightly so that it no longer is incident at 45^o to the pins.

The arguments so far however assume one particular hand of circular polarization; specifically Fig. 3.8 a) and b) refer to LHCP. For a given polarizer and OMT (orthomode transducer) combination, if now the other port of the OMT is excited, the two linear vectors at the feed horn will (in the absence of horn to horn coupling) have the form

$$1 + c \quad \text{and} \quad -j \ (1 - c)$$

This statement holds irrespective of the orientation of the polarizer pins relative to the feed horn aperture axis x and y.

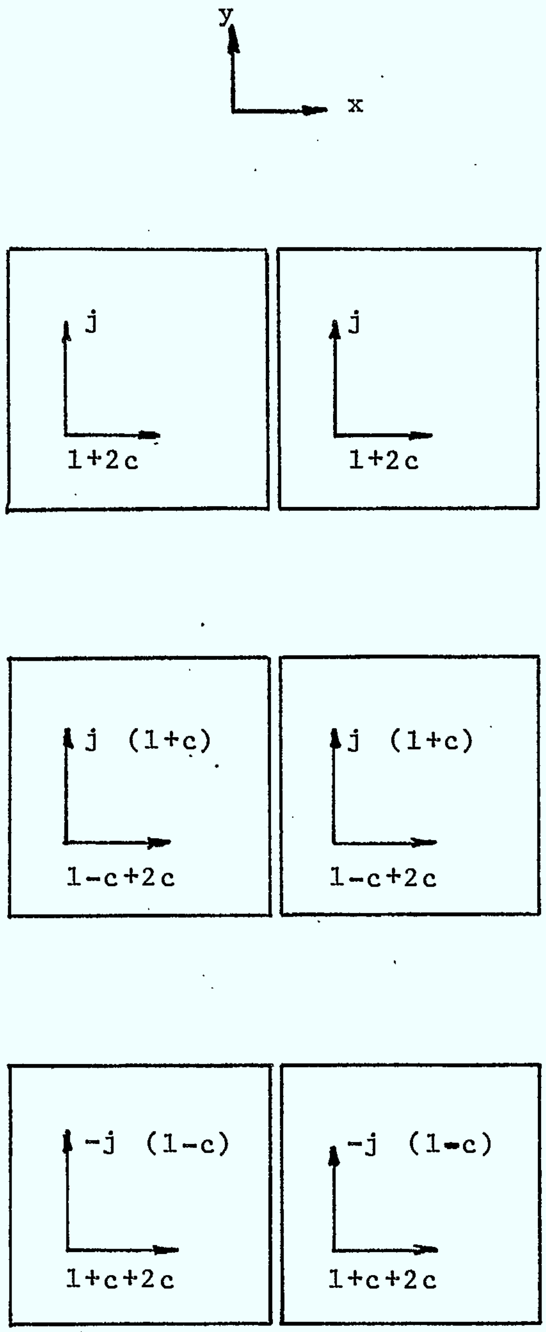
The final conclusion is that polarizer detuning which is beneficial for one hand of polarization is detrimental to the other hand when this is excited by the same polarizer/OMT units. Although the arguments that have been advanced are for one particular case (cophasal coupling) they appear to be valid quite generally. Hence polarizer detuning cannot be used to advantage for the proposed uplink antenna configuration.

3.2.2.2 Overall Estimate of Uplink Polarization Impurity

An overall estimate of the proposed uplink polarization properties is given in Table 3.4. Adding together the individual contributions on an RSS basis leads to a prediction of -25 dB worst case unwanted hand CP level. Should this latter figure not be considered adequate from a system point of view, an improvement could be had by going to two uplink reflectors with spatial polarizers. This approach would involve space and weight penalties in relation to the proposed approach.

Factor Influencing Polarization Performance	Level of Unwanted Hand CP Relative to Wanted Hand CP
Feed Horn Intrinsic Cross-Polarization (-28 dB primary Lobes Giving -33 dB off Axis Secondary Lobes)	-29 dB
Horn to Horn Coupling (-25 dB for E Plane Stacking and Linear Excitation Assumed)	-31 dB
Waveguide - type Polarizers (0.2 dB Axial Ratio Assumed)	-38 dB
Scattering of Wavefront Emerging from Reflector off the Feed Horn Stack	-35 dB
Intrinsic Depolarization of Solid Reflector	-39 dB
Direct Radiation from Feed Horns	-48 dB
Overall Polarization Purity	-25 dB

TABLE 3.4 SOURCES OF UNWANTED HAND CP FOR UPLINK ANTENNA



a) 2 identical CP horns with E plane coupling 2c (LHCP)

b) Horns compensated by detuning polarizers (LHCP)

c) Detuned polarizers excited for RHCP port

FIGURE 3.8 2 HORN CP ARRAY WITH HORN TO HORN COUPLING

4. CONCLUSIONS AND RECOMMENDATIONS

The foregoing study of the antenna system for the DBS satellites was done under rather limited time constraints, so that it was not possible to reach a fully optimized design.

However, predictions were made for the behavior of an optimized system, and some of the major possible concepts were analyzed.

The one-reflector option for the downlink antenna was considered and abandoned, in view of the considerations of section 2. It is then concluded that 2 reflectors will be used, one for each polarization (LHCP and RHCP).

A grid polarizer is used to generate the circular polarization, at the surface of each main parabolic reflector. The feeds are then linearly polarized (VP or HP). The alternative of using polarizers at the feed of the horns would entail the use of square horns, which would very much limit the extent to which a given specified area of coverage can be matched.

The existence of dual-mode feeding networks for the horns brought with it the problem of mode shifting, which considerably reduces the composite area of coverage of both modes, unless it is kept within certain limits. This led to the realization that a better gain could be achieved with the feed of each beam centered on focus. As the reflectors will have to be deployed, and that will be done around a north-south axis, the simple addition of an APM (Antenna Positioning Mechanism) will permit control over the position of the reflectors, with no need for an extra hinging mechanism.

It is then suggested that steerable (3 positions) reflectors be used, so that the geometry of the antenna can be optimized for each beam separately. A slight modification led to the partial steering concept, intended to compensate for an over-rotation problem of the fully steered reflectors (section 3.1.4).

The following is then recommended as the most suitable antenna system for DBS:

- DOWNLINK ANTENNAS (6 beam case)

i) 2 main reflectors, one in the eastern side and the other in the western side of the satellite, with an East-West offset from axis.

ii) Three separate and independent feed horn stacks for each reflector, spaced also in the East - West plane.

iii) The feeds are linearly polarized, and the circular polarization is achieved by means of a grid polarizer at the surface of the main reflectors, oriented at 45^{o} relative to the surface current lines on a solid reflector.

iv) The main reflectors are steerable around a North-South axis, with three positions which place the focus close to each one of the three feed stacks of each reflector.

v) The reflector dimensions are: $F \approx 60$ in., $D \approx 75$ in., offset of reflector's center from axis: 49.5 in.

vi) A similar concept would be used for a 4 beam system, where the reflectors would now be steerable between 2 positions.

- UPLINK ANTENNA

i) One solid reflector, offset in a direction which makes a 9° angle with North, eastward.

ii) The feed is made of three circularly polarized square horns, and receives independently LHCP and RHCP.

iii) The reflector dimensions are: F = 18 in., D = 18 in., offset of reflector's center from axis: 15 in.

APPENDIX B

TRANSPONDER THERMAL PARAMETER EVALUATION TECHNIQUE

APPENDIX B

TRANSPONDER THERMAL PARAMETER EVALUATION TECHNIQUE

The following procedure outlines a quick method to determine the thermal parameters involved in mounting a unit on the inboard side of the equipment panels of a three axis stabilized spacecraft. The required doubler thickness and radiating area can be sized for specific unit temperatures and power dissipations. In using this technique the unit is assumed to have a uniform baseplate temperature and be thermally decoupled from the inside of the spacecraft.
(Figure 1).

PROCEDURE

1) Decide on the maximum unit temperature in ^{o}C (T_u)
2) Calculate the unit mounting surface area in in^2 (A_u)
3) Get the surface area of the doubler associated with the unit in in^2 (A_d). When many similar units are mounted on the same region of a panel, as a first cut, assign each doubler an equal portion of the available space. Engineering judgement should be used if one of these units has a substantially larger power dissipation then the others. In this case a greater proportion of the available area should be assigned to the unit (Figure 2).
4) Calculate δ parameter

$$\delta = \sqrt{\frac{A_d}{A_u} + 1}$$

5) Calculate Q_{um}, the maximum allowable power dissipation of the unit to stay below the maximum unit temperature T_u when the doubler efficiency is set to 1.

$$Q_{um} = 3.66 \times 10^{-11} \varepsilon A_u (T_u + 273)^4 \delta^2 - Q_{sol} \quad [\text{Watts}]$$

where Q_{sol} is the solar heat input to the spacecraft panel directly opposite the unit and the doubler.
It is given as

$$Q_{sol} = .9 \alpha_s \cos\theta \; A_u \delta^2 \quad [\text{Watts}]$$

where: 0.9 is the solar constant in W/in^2, α_s is the solar absorptivity of the spacecraft panel directly opposite the units and the doubler (typically .1 for second surface mirrors).

θ is the angle between the panel normal and the direction of the solar heat input. (typically 67^o for the North or South side panels of a geosynchronous 3 axis stabilized spacecraft)

6) if Q_{um} is below the unit power dissipation then the configuration is not possible regardless of doubler thickness. Other parameters such as doubler area, unit power dissipation or allowable unit temperature must be modified in order to mount the unit on the spacecraft panel.

7) Assume a reasonable effective doubler thickness (t) in inches (.25" max.). The effective doubler thickness is the sum of the thicknesses of the doubler and both faces sheets.

8) Evaluate β parameter

$$\beta = \left[\frac{3.66 \times 10^{-11} \varepsilon \, (T_u + 273)^3}{Kt\pi} \left((2 A_u + A_d - 2\sqrt{A_u \, (A_d + A_u)} \right) \right]^{\frac{1}{2}}$$

where ε is the emissivity of the spacecraft panel exposed to space directly opposite the unit and the doubler, (typically .85 for second surface mirrors)

K is the conductivity of the doubler material in °C/W/in (typically 4°C/W/in for an aluminum doubler)

9) from Figure 3 obtain the doubler efficiency (η_d)

10) Calculate $Q_{um\eta}$ the maximum allowable power dissipation of the unit to stay below the maximum unit temperature decided in step 1.

$$Q_{um\eta} = 3.66 \times 10^{-11} \varepsilon \; A_u \; (T_u + 273)^4 \; (\eta_d (\delta^2 - 1) + 1) - Q_{sol}$$

11) If $Q_{um\eta}$ is below the unit power dissipation, then the configuration is not possible. If this is the case try increasing the doubler thickness assumed in step 7 thereby yielding a higher permissible unit power dissipation. If the configuration is possible, but a thinner doubler is considered more desirable, assume a thinner doubler and repeat steps 7 thru 11.

Appendix A outlines some of the assumptions and limitations of the method described above.

EXAMPLE

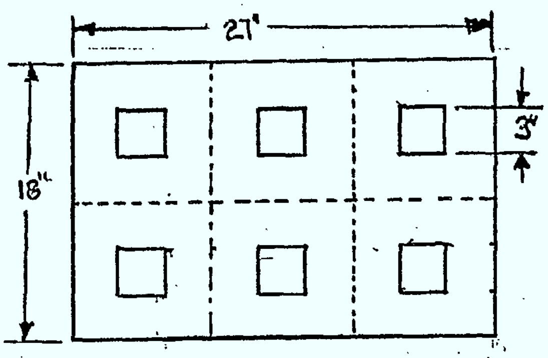
given - 6 units mounted inboard of South side panel
- unit maximum temperature is 100°C
- units have a uniform baseplate temperature
- unit power dissipation 38 watts each
- Exterior of panel has a second surface mirror thermally characterized by $\varepsilon = .85$
$\alpha_s = .1$
- Doubler is Aluminum
- Unit is decoupled from inside of spacecraft
- Unit and doubler have a view factor of unity to space
- Aluminum face sheets .010" thick each.

find - an adequate doubler thickness

Step (1) Maximum temperature is fixed at 100°C

(2) Unit mounting surface area is $3 \times 3 = 9$ in^2

(3)



doubler area is $9^2 - 3^2 = 72$ in^2

(4) $\delta = \sqrt{\frac{72}{9}+1}$

$= 3$

(5) $Q_{um} = 3.66 \times 10^{-11}$ (.85) (9) $(100+273)^4 9$ - (.9)(.1)(81) cos 6

= 48.78 - 2.85

= 45.93 watts

(6) $Q_{um} > 38$ watts therefore design is possible

(7) Assume .02" doubler, therefore effective doubler thickness is .02 + .01 + .01 = .04"

(8) $$\beta = \left[\frac{3.66 \times 10^{-11} (.85)(100 + 273)^3}{4(.04)\pi}(2.x9 + 72 - 2\sqrt{9(72+9)})\right] = .34$$

(9) get $\eta_d = .82$

(10) $Q_{um\eta} = 3.66 \times 10^{-11} (.85)(9)(100 + 273)^4 (.82(9-1) + 1) - 2.85 = 38.12$ watts

(11) $Q_{um\eta} > 38$ watts therefore design is adequate. Steps (7) to (11) may be repeated to optimize for a minimum doubler thickness.

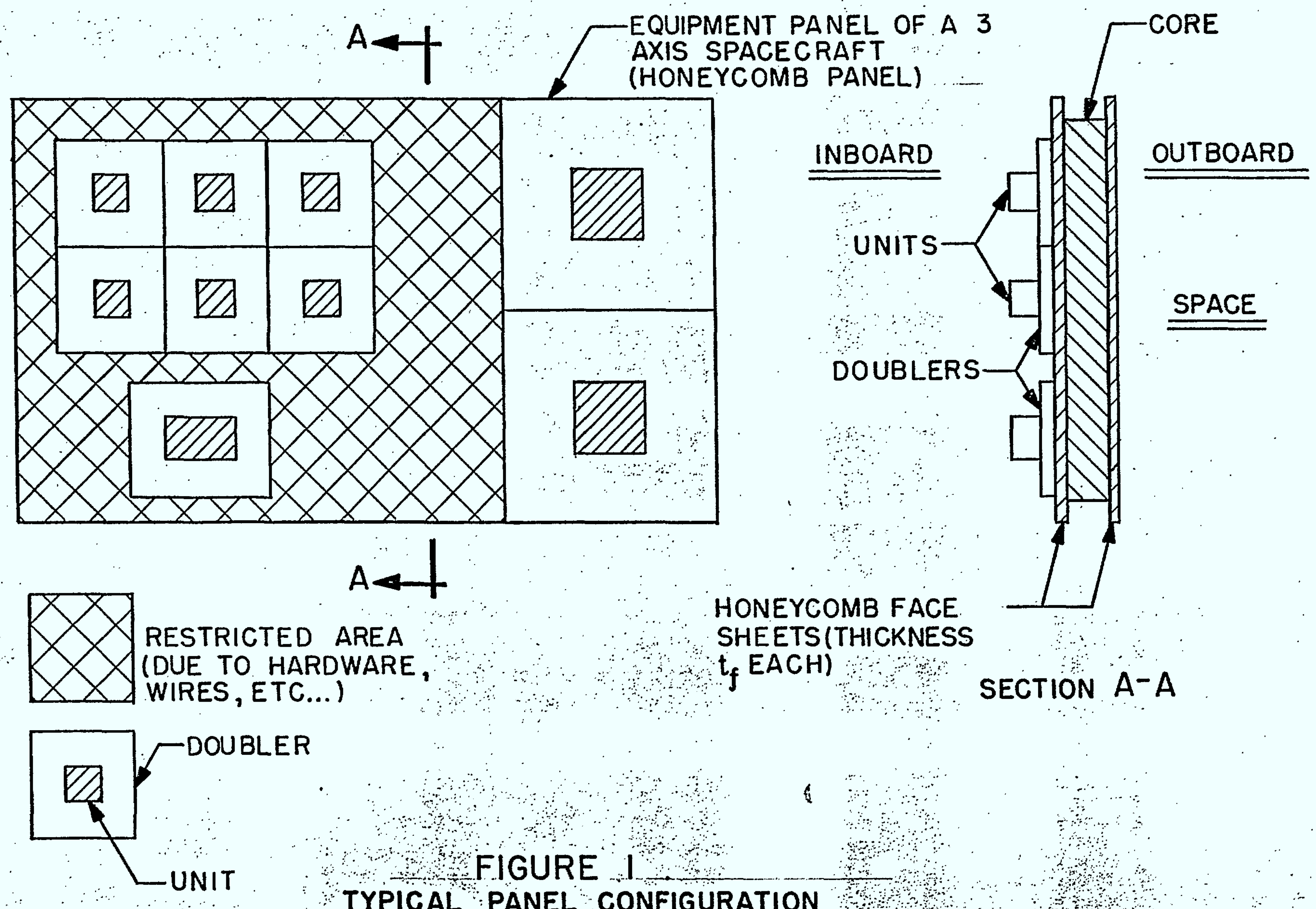


FIGURE 1
TYPICAL PANEL CONFIGURATION

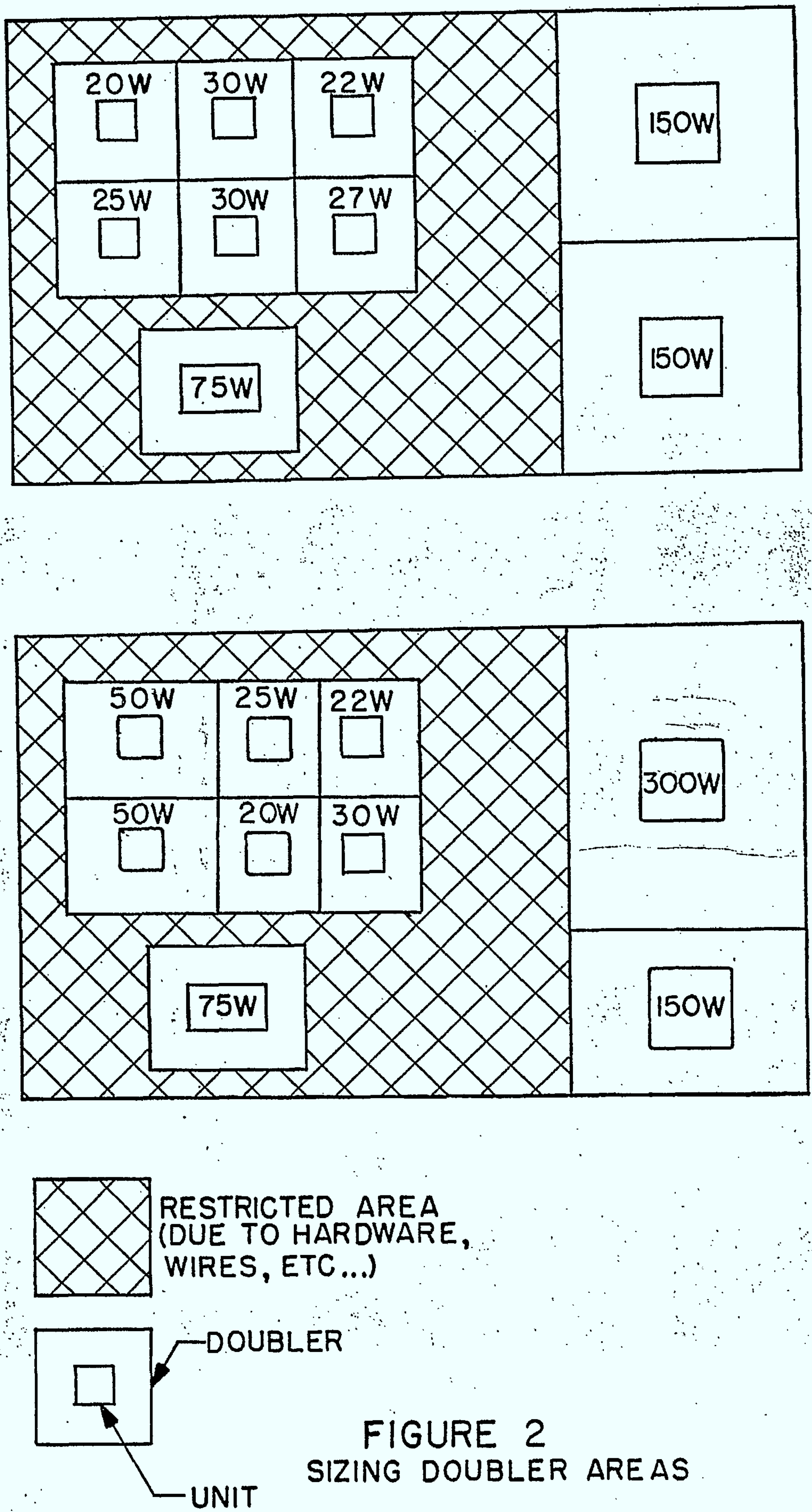
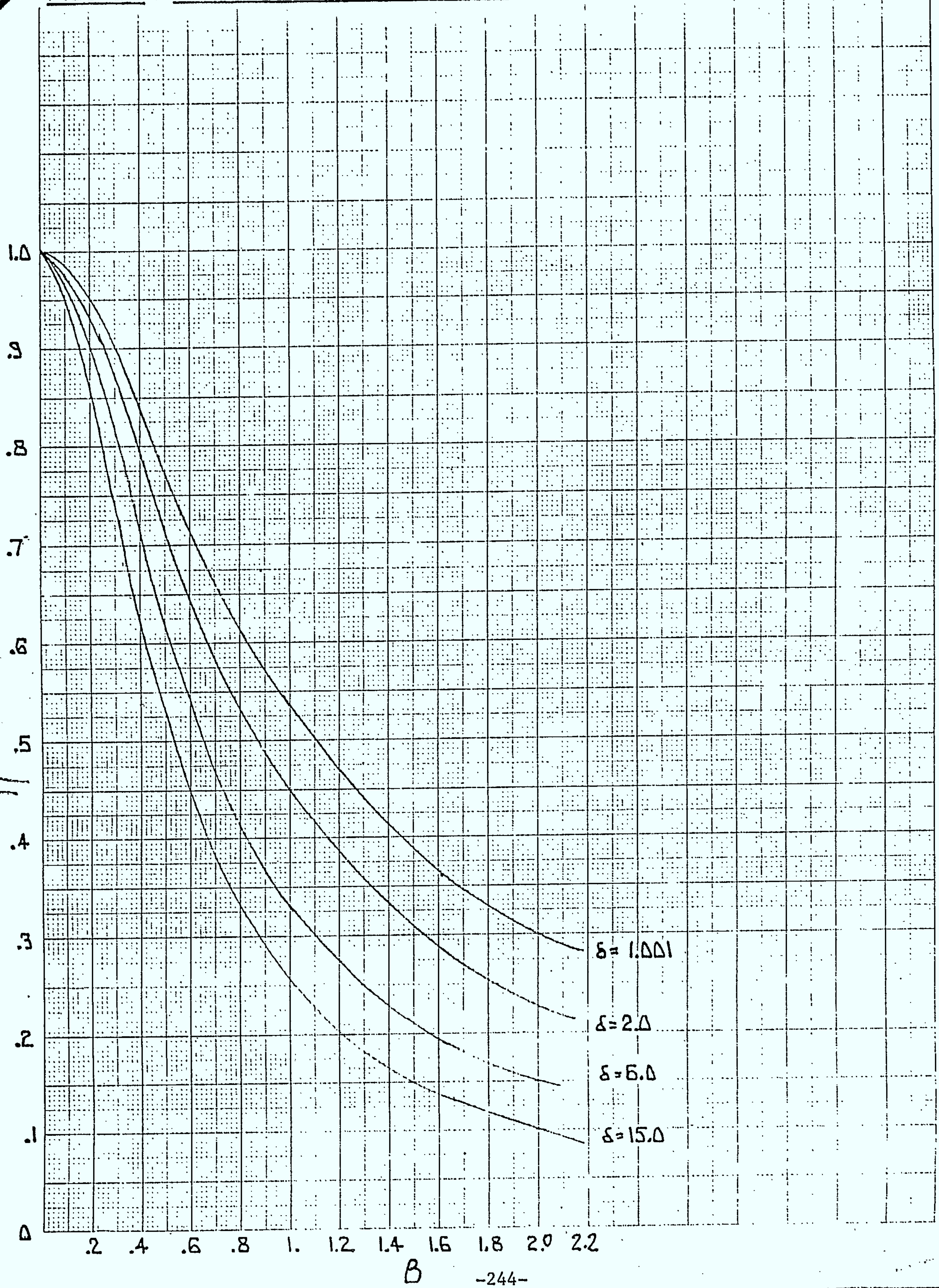


FIGURE 2
SIZING DOUBLER AREAS

FIGURE 3: DOUBLER EFFICIENCY AS A FUNCTION OF δ AND β



Assumptions and Limitation

1) Uniform unit baseplate temperature.
   If this condition is not met, use the conservative assumption that the overall unit baseplate temperature corresponds to the lowest temperature of the baseplate when the unit is at T_u.
2) Unit and doubler are thermally decoupled from the inside of the spacecraft.
   If need be this can be achieved by using lightweight multilayer metalized blanket insulation.
3) The solar heat input to the panel opposite the doubler is considered as a heat input to the unit.
   This conservative assumption greatly simplifies the analysis and results in the preceding closed form solutions.
4) Conductive resistance of honeycomb panel not accounted for in evaluating $Q_{um\eta}$
   Conductive resistances through honeycomb side panels of three axis stabilized spacecrafts are typically 3-4% of the overall coupling of the unit to space. They can therefore be neglected with relatively little effect on the accuracy of the overall coupling to space. This implies that honeycomb parameters such as cell size, foil thickness etc. are not required to investigate the thermal feasibility of placing a unit on the panel.
5) No lateral thermal conduction in the honeycomb core.
6) The analysis assumes a view factor of unity from the unit to space and from the doubler to space.

DATE DUE
