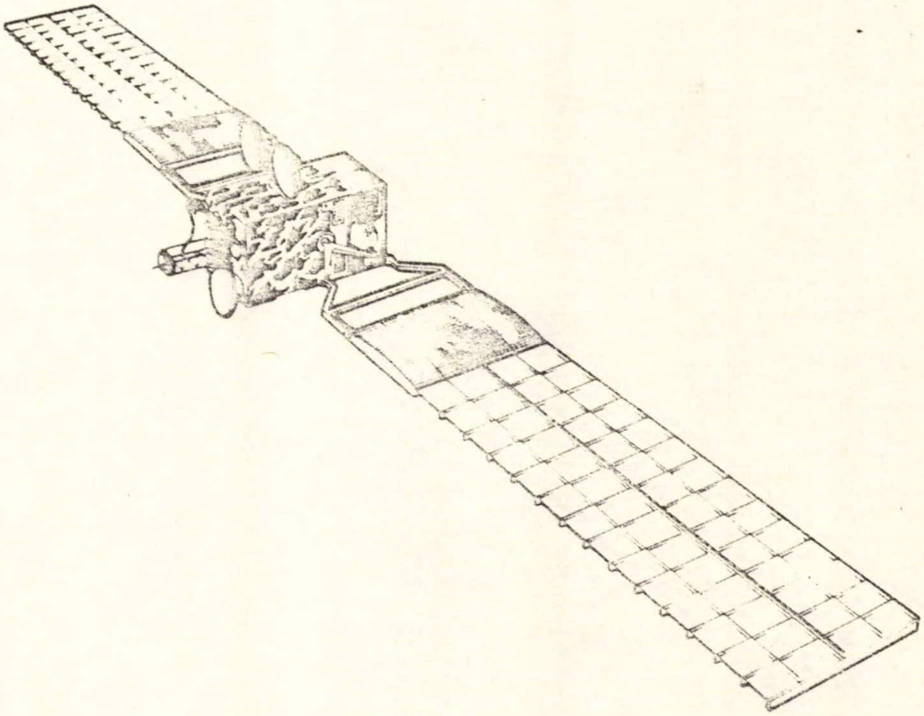
Direct Broadcasting Satellite System Modelling

FINAL REPORT



SUBMITTED TO:

Department of Communications, Ottawa

Spar Aerospace Limited
Space & Electronics Group

Satellite
Systems
Division

SPAR

DOC-CR_SP-81-035

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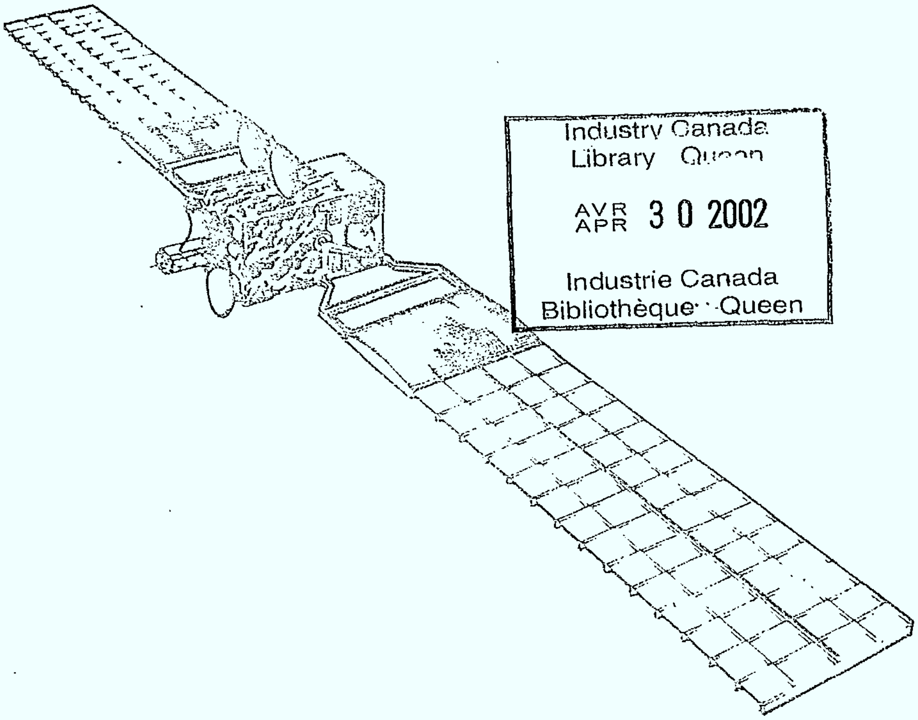

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DOC CONTRACTOR REPORT

DEPARTMENT OF COMMUNICATIONS - OTTAWA - CANADA

SPACE PROGRAM

TITLE: DIRECT BROADCASTING SATELLITE SYSTEM MODELLING

AUTHOR(S): SPAR AEROSPACE LTD.

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DIRECT BROADCAST
SYSTEM MODELLING STUDY

FINAL REPORT

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DIRECT BROADCAST SATELLITE SYSTEM MODELLING STUDY

SUMMARY

1. Summary

This study examines a range of possible system models using satellites with relatively high EIRP (58 dBW) or low EIRP (53 dBW), and with either 6 or 4 beam coverage. A reasonable match is found between the associated communications payload power and weight demands and the capabilities of available or feasible launcher - spacecraft combinations. The features of several systems have been compared for technical performance, flexibility, growth, and compatibility with World Administrative Radio Conference (WARC) objectives. A cost comparison shows a clear advantage of lower EIRP over higher EIRP systems, and a modest cost advantage of 4 beam over 6 beam systems. Transition problems from an interim DBS system based on Anik-C are discussed, as well as uplink implementation, and means of achieving multichannel national coverage. Finally, recommendations are made for future system studies to support DOC preparations for RARC 83 and to refine technical options. Improvement in cost modelling is also identified as an important area for future work.

2. Purpose and Scope of Study

This study was originally intended as an in-depth follow on to a parametric DBS study carried out by Spar for DOC in 1978/79. In examining the number and range of system variables fixed by DOC for this study, it was apparent that a wide ranging study was still required, with in-depth work being possible only after an initial selection process. This study thus became an attempt to bound technically feasible spacecraft options and to establish a basis for system comparisons using first order rather than refined analysis.

The leading technical parameters fixed by DOC are given in Table 1.

ITEM	VALUE
EIRP	53 and 58 dBW (Boresight)
Number of beams	
Down	4 and 6
Up	1
Channels per beam	4 and 8
Orbit location(s)	105°W or 105° and 140°W
Eclipse operation	0 and 50%
Polarization	circular
Frequency Band	
Up	17.3 - 17.8 GHz
Down	12.2 - 12.7 GHz

Table 1 System Parameters

The number of discrete cases to be examined can be appreciated from the option tree shown in Fig. 1. Some of the cases judged trivial or extreme were ignored by agreement with DOC at the outset of the study, however, 12 of the possible 16 cases were still of interest and were investigated.

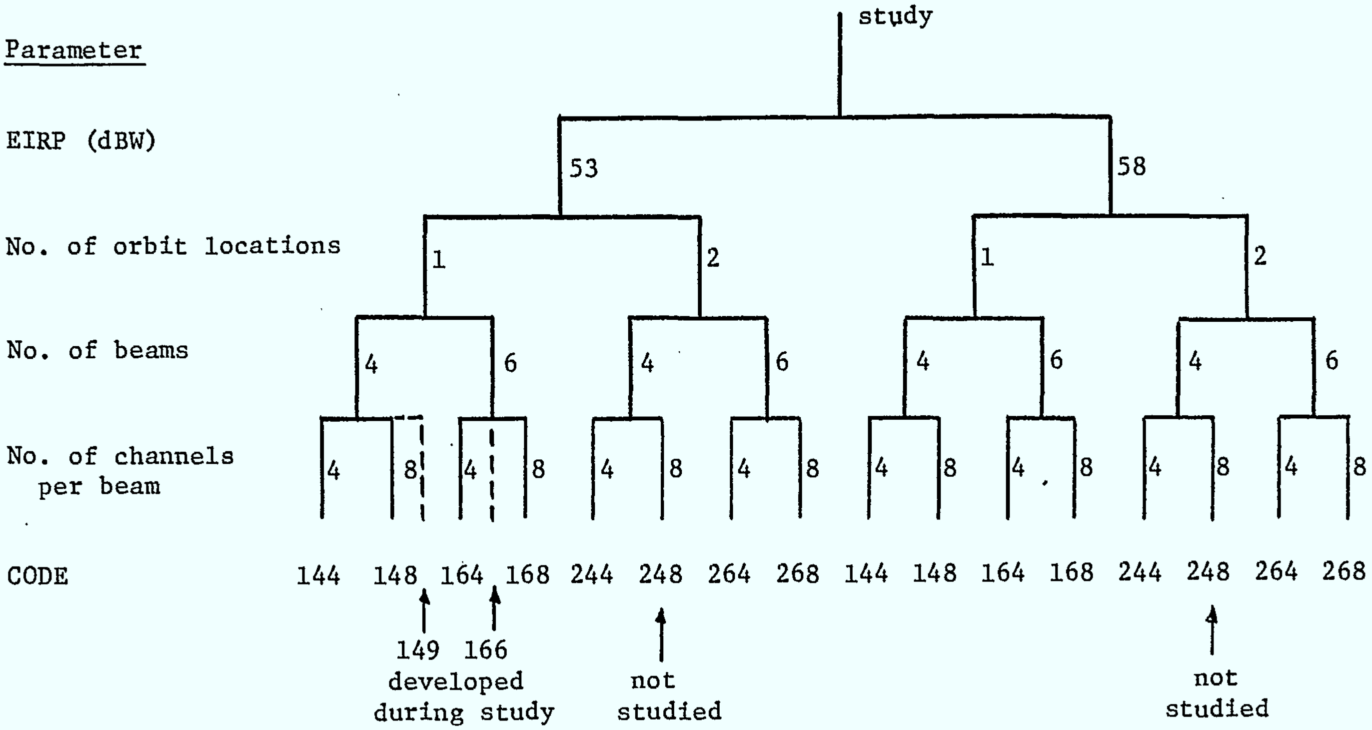


Fig. 1 System Models Included in Study

During the study, 2 cases of particular interest were added, for a total of 14, with 0 and 50% eclipse operation treated as a minor subset of each case. This figure also shows a 3 digit code which is a short form of identification of the many possible system configurations. The first digit is the number of orbit locations (1 or 2), the second, the number of beams (4 or 6), and the third, the number of channels per beam (4 or 8).

Other factors to be considered in the study were:

- Available launchers - STS and Ariane.
- Transition problems from interim DBS on Anik-C to full DBS.
- Flexibility and growth.
- Uplink arrangements for regional and national coverage.
- Interference (C/I)
- Costs

3. Study Approach

The steps in the study are given in Table 2 and are explained as follows.

- Develop frequency and polarization plans for each model.
- Communications Subsystems block diagrams.
- Communications Subsystem:
    - power estimate
    - weight estimate
- Generate and update payload weight and power availability graphs for candidate spacecraft/launcher combinations.
- Search for reasonable match between payload demand and spacecraft/launcher capabilities.
- Tabulation of selected system models.
- Develop cost data base for spacecraft and launchers.
- Compare system models.

Table 2 Study Approach

The first element was the development of frequency and polarization plans for each combination of number of beams (4 and 6) and channels per beam (4 and 8). The resulting plans are summarized in Fig. 2 and cover from 24 to 48 channels from a single orbit location.

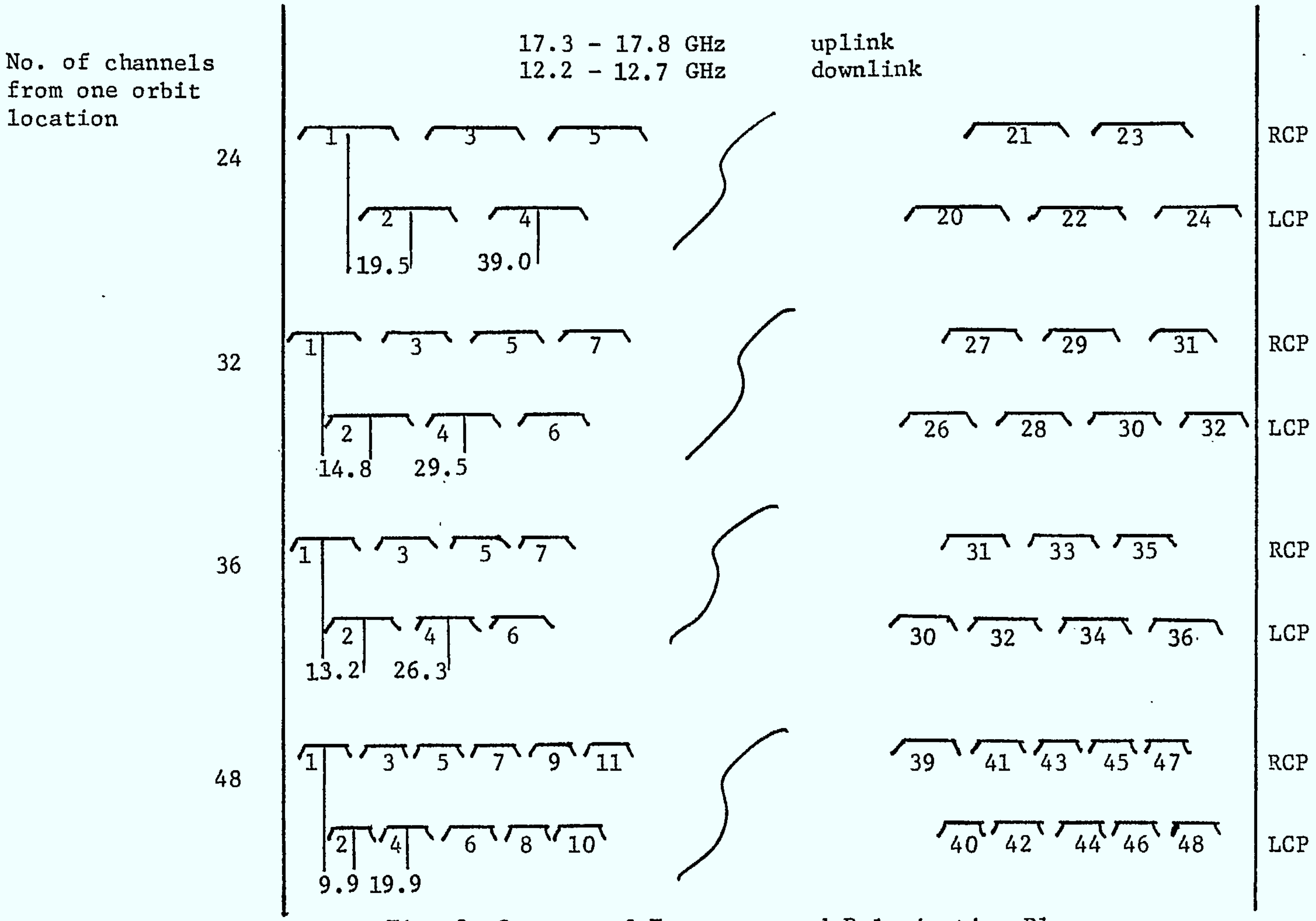


Fig. 2 Summary of Frequency and Polarization Plans

The key principles used in deriving the plans were: i) Full use of the available 500 MHz spectrum at each orbit location ii) Alternating polarization between adjacent beams. The basic planning assumption is that a given coverage area receives all its channels from one orbit location and of one polarization. The proposed assignment of channels to beams, as shown by example in Fig. 3, considered both system interference and problems of repeater and antenna design and performance.

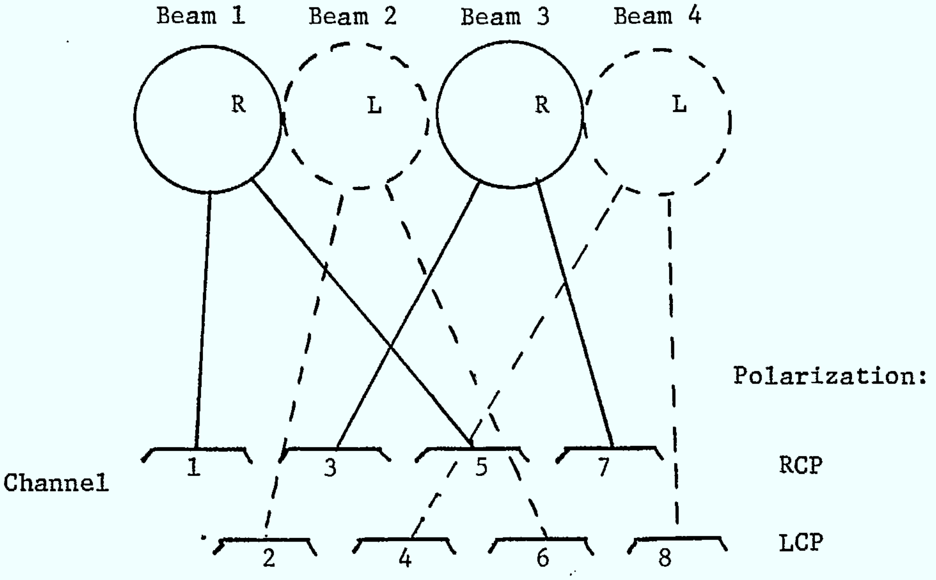


Fig. 3 Channel Assignment to Beams

Assuming that the highest practical degree of antenna beam shaping would be required to efficiently match coverage areas, the largest reflector (≈8.5 ft. dia.) was chosen consistent with spacecraft launcher constraints. It is noted parenthetically that the requirement for circular polarization denied the option of a space efficient, overlapped gridded reflector commonly used for linear polarization.

The required number of channels (16 to 48) from one orbit location can be achieved with one large spacecraft, or a number of smaller ones. The presence of relatively fixed overhead items such as telemetry and command in all spacecraft designs, tends to make the larger spacecraft more efficient in terms of available payload. However, a better match between service demand and growth in system capacity, favours multiple smaller spacecraft over a single large spacecraft. The ability to share a single spare spacecraft among 2 or more identical spacecraft reduces the total channel capacity required in orbit, compared to a simple duplication or doubling of capacity required for a single large spacecraft model. For these reasons then, system models up to 4 spacecraft per orbit location were considered for some of the system models. The resulting number of channels per spacecraft is included as part of the system identity code. For example the code 164/12 refers to a single orbit location model with six beams, 4 channels per beam, and 12 channels per spacecraft (2 operating spacecraft).

Fig. 4 shows the complete range of system models considered for 53 dBW EIRP. For 58 dBW, a similar range of system models was considered except for 3 cases which required very large single spacecraft implementations. (Total 31 models)

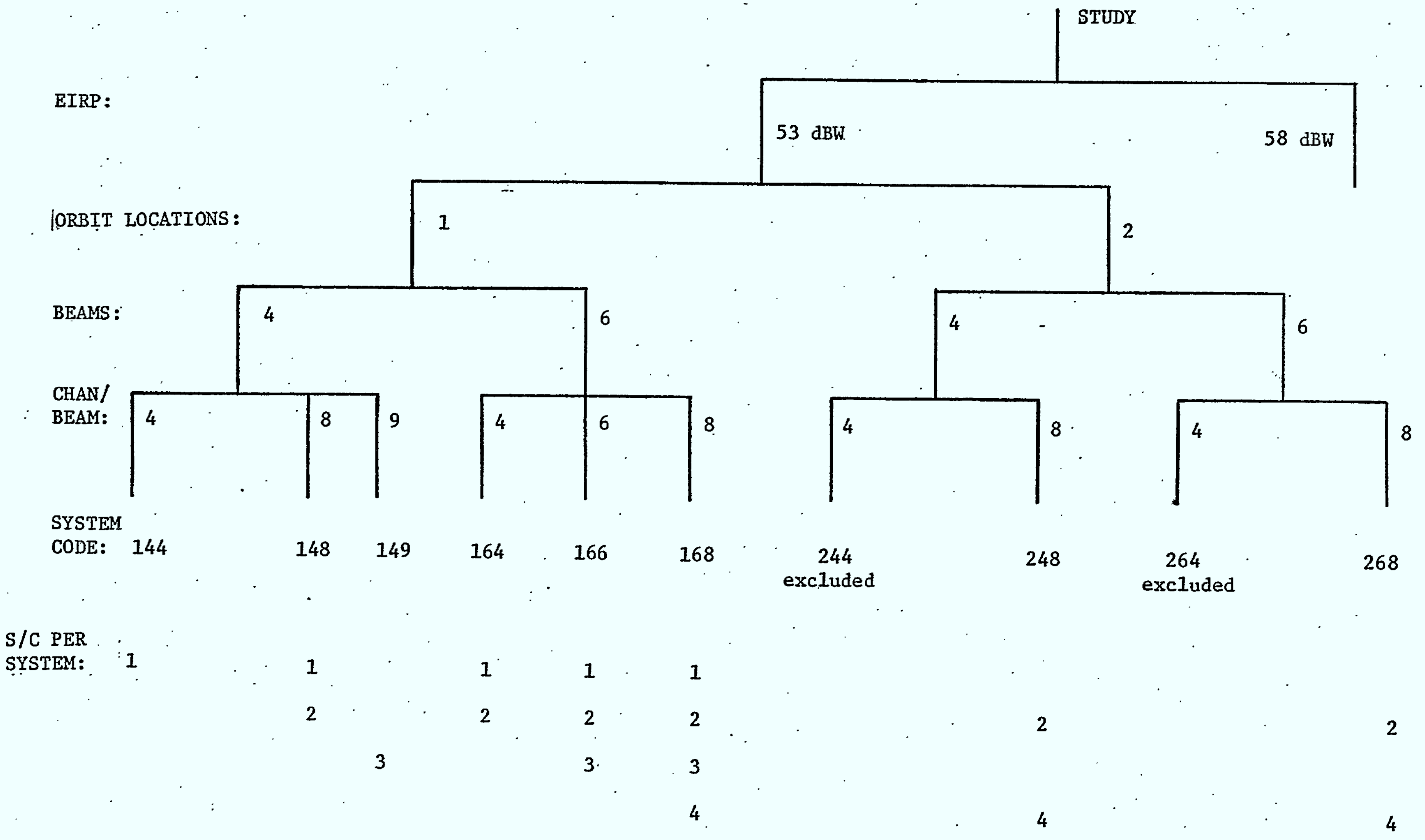


Fig. 4 53dBW System Models Included in Study

For each significantly different communications subsystem a block diagram was prepared, 7 complete and 5 in draft form. Fig. 5 is one sample, showing the 4 beam, 8 channel per beam, 16 channel per spacecraft model (Code 148/16). These diagrams help in the establishment of antenna/repeater configuration, weight and interface.

Tables 3.1 to 3.4 in the main report give communication weight break down for all spacecraft models. To estimate the TWTA weight, a graph of weight as a function of power was prepared (Fig. 6) using scaling rules similar to the previous DBS study updated by available data points. It should be noted that the actual availability of TWTAs at different power levels is very limited and the continuum is assumed only for comparison purposes.

A summary of payload weight and power for all models at summary both EIRP levels is shown in Table4A and B.

The full range of payload weight and power demands for all system models are plotted in Fig. 7. Note that the 58dBW and 53dBW models fall into two distinct areas. This is not surprising considering that the power demand for a given 58dBW model is 3 times (5dB) higher than the comparable 53dBW model.

4. Eclipse Operation

The study required that 0% and 50% eclipse operation be examined, with any significant break point between to be identified. No significant technical break point in this range could be found, when determining the relationship between power subsystem weight as a function of eclipse capability, and the weight available for the communications payload. An examination of the single orbit location models however shows that for an assumption of full service in all beams up to 1 a.m. local standard time, no eclipse outage will occur, if 38% eclipse power is available. The technique requires the turning down of channels in the East beams after 1 a.m. local time, which thereby reduces the total spacecraft power system demand to 38% of normal sunlit conditions.

Fig. 8 shows a 4 beam single orbit location case in further detail. The 38% eclipse power capacity can then be treated as a break point between no eclipse operation and full eclipse operation, which gives full channel capacity up to 1:00 a.m. local standard time. In practice the assignment of eclipse channel capacity to beams would be flexible so that some Eastern channels could operate later than 1:00 a.m. with correspondingly fewer Western channels operating through eclipse at earlier local times.

5. Two Orbit Location Eclipse Operation

Using the 4 beam model as an example, it can be seen from Fig. 8 that the 105° satellite position serving the Eastern beams provides full operation past 1:00 a.m. local standard time except for the small portion of Ontario in the Central time zone. The 140°W satellite

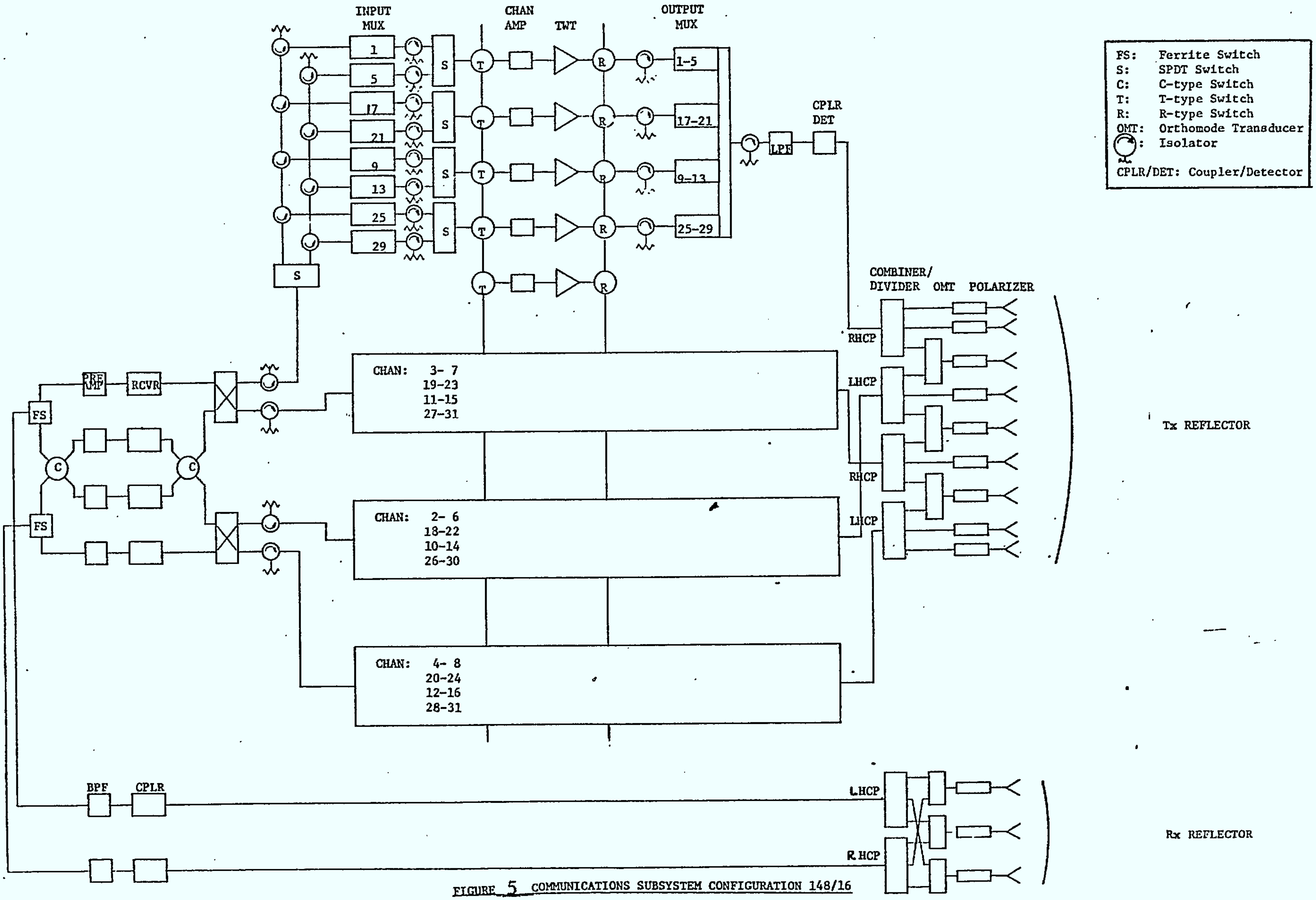
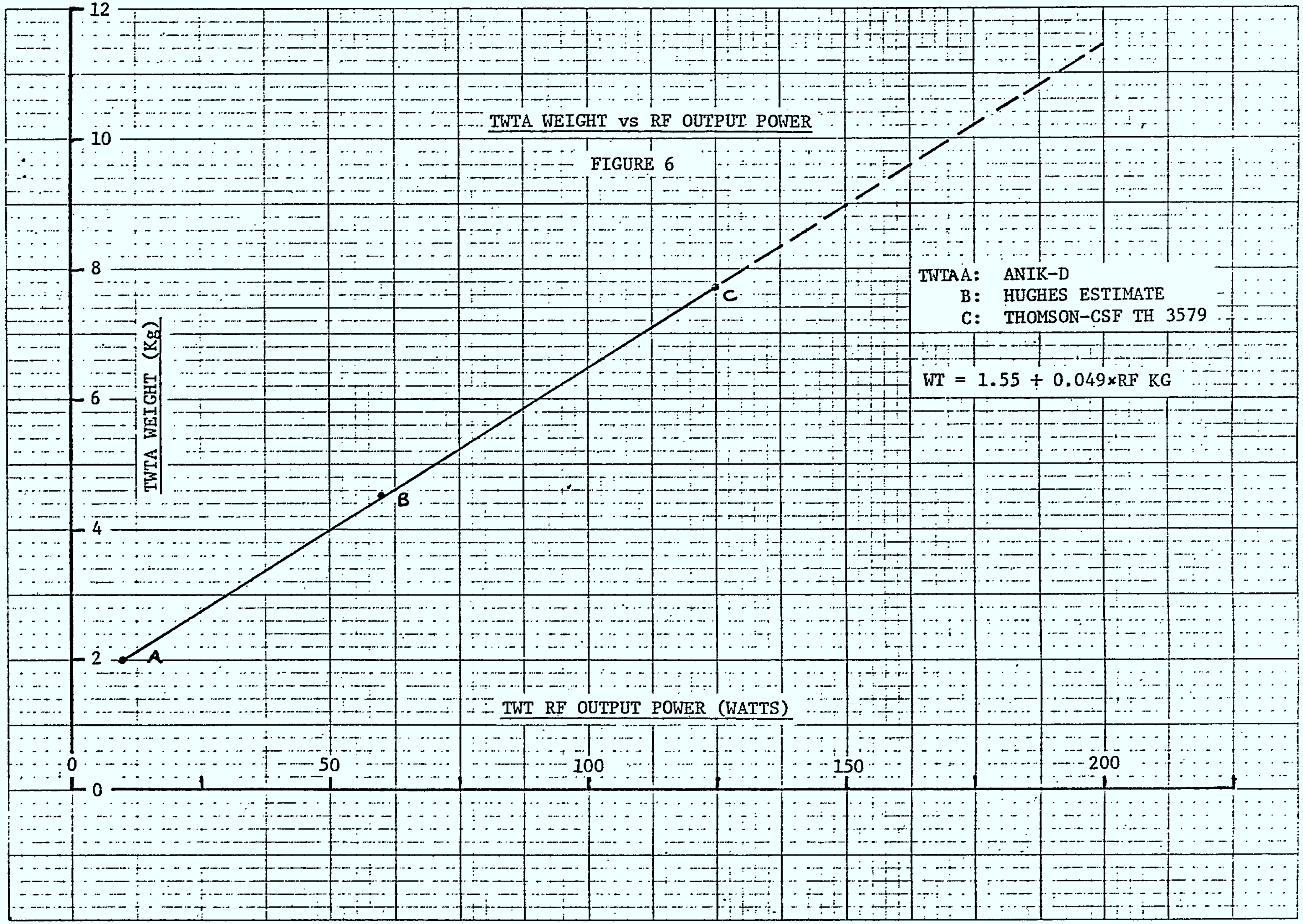


FIGURE 5 COMMUNICATIONS SUBSYSTEM CONFIGURATION 148/16



TWTA WEIGHT vs RF OUTPUT POWER

FIGURE 6

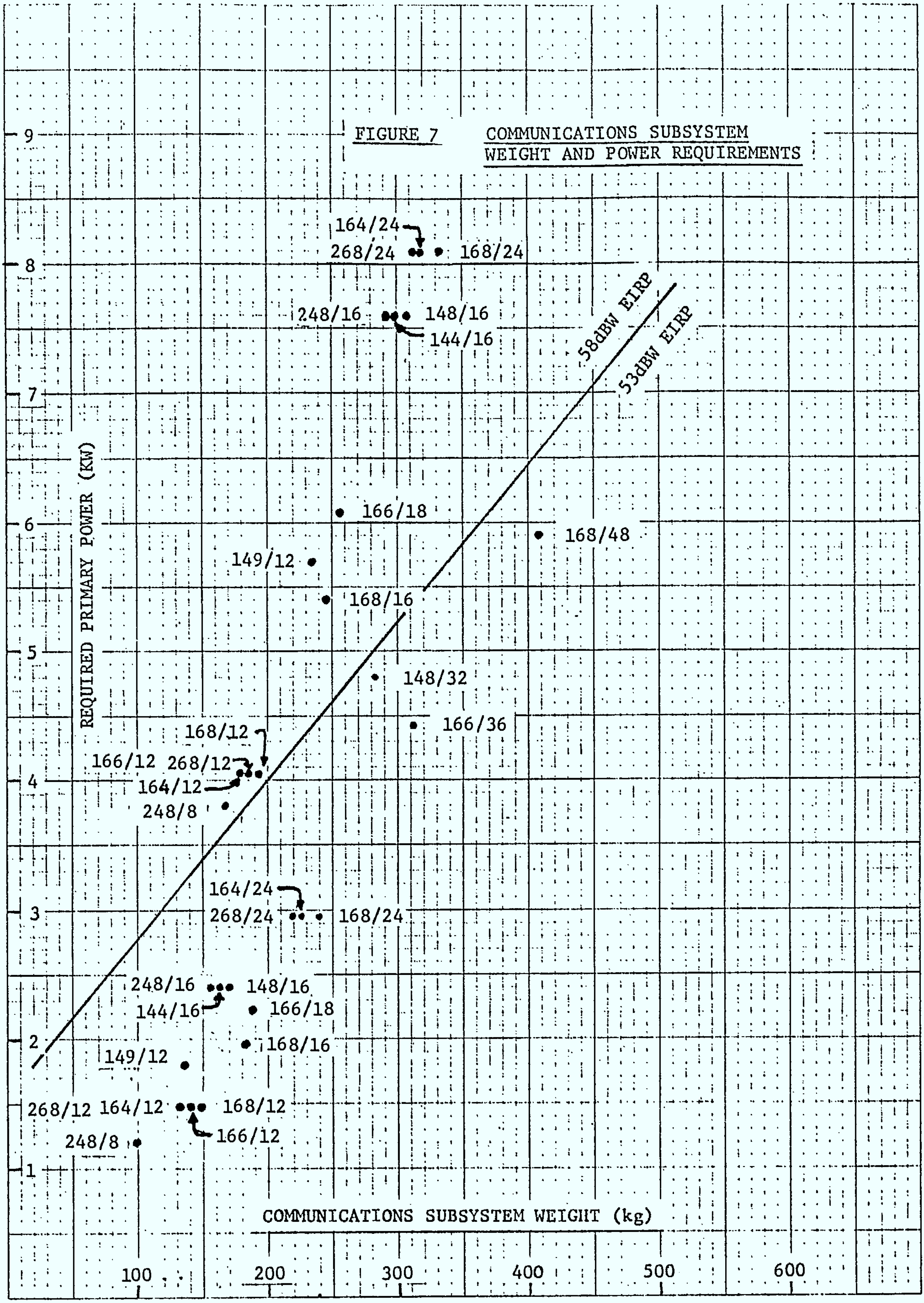
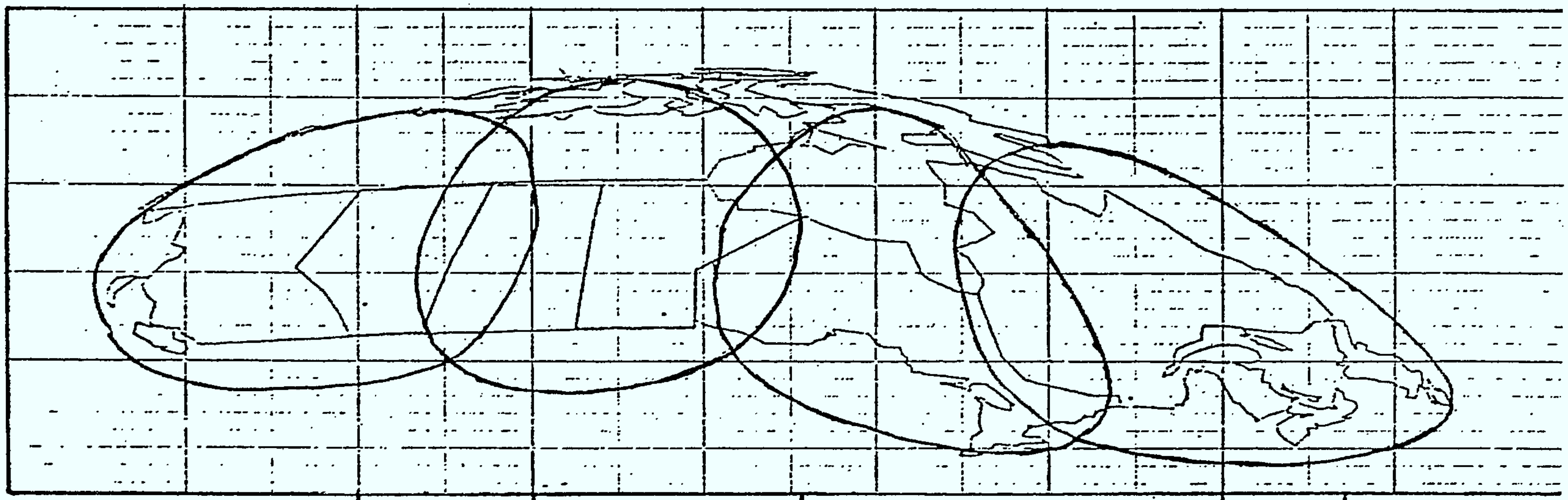


FIGURE 7 COMMUNICATIONS SUBSYSTEM WEIGHT AND POWER REQUIREMENTS



TIME ZONE:	PACIFIC	MOUNTAIN	CENTRAL	EASTERN	ATLANTIC	NFLD
LOCAL STANDARD TIME ECLIPSE BEGINS:	22:24	23:24	00:24	01:24	02:24	02:54

	1	2	3	4
% OF NORMAL BEAM LOAD REQUIRED FOR OPERATION TO 1 AM LOCAL STANDARD TIME:	100%	50%	0%	0%
% OF TOTAL SYSTEM LOAD:	25%	12.5%	0%	0%

FIGURE 8. ECLIPSE OPERATION LOAD FOR 4 BEAM SYSTEMS
(ONE ORBITAL LOCATION AT 105°W)

COMMUNICATIONS SUBSYSTEM WEIGHT AND PRIMARY POWER SUMMARY

COMM S/S CONFIGURATION	168/24	168/16	168/12	166/18	166/12	164/24	164/12	148/16	149/12	144/16	268/12	268/24	248/16	
TRANSPONDER (kg)	69.1	57.8	50.7	53.7	44.8	55.7	38.8	48.7	44.4	41.0	39.2	55.7	40.6	
ANTENNA SYST. (kg)	34.0	34.0	34.0	34.0	34.0	34.0	34.0	30.0	30.0	300	28.0	28.0	26.0	
TWTAs (kg)														
53 dBw	135.0	90.0	63.0	99.0	63.0	135.0	63.0	90.0	63.0	90.0	67.5	135.0	90.0	
TOTAL WEIGHT (kg) for 53 dBw	238.1	181.8	147.7	186.7	141.8	224.7	135.8	168.7	137.4	161.0	134.7	218.7	156.6	
PRIMARY POWER (w)														
6 BEAM: 123 w/chan	2952	1968	1476	2214	1476	2952	1476	———	———	———	1476	2952	———	
4 BEAM: 150 w/chan	———	———	———	———	———	———	———	2400	1800	2400	———	———	2400	
TWTAs (kg) 58 dBw	228.0	152.0	106.4	167.2	106.4	228.0	106.4	228.0	159.6	228.0	114.0	228.0	228.0	
TOTAL WEIGHT (kg) for 58 dBw	331.1	243.8	191.7	254.9	185.2	317.7	179.2	306.7	234.0	299.0	181.2	311.7	294.6	
PRIMARY POWER (w)														
6 BEAM: 338 w/chan	8112	5408	4056	6084	4056	8112	4056	———	———	———	4056	8112	———	
4 BEAM: 475 w/chan	———	———	———	———	———	———	———	7600	5700	7600	———	———	7600	

TABLE 4A COMMUNICATIONS SUBSYSTEM WEIGHT AND PRIMARY POWER SUMMARY

COMMUNICATIONS SUBSYSTEM WEIGHT AND PRIMARY POWER SUMMARY

COMM S/S CONFIGURATION	148/32	168/48	166/36	248/8										
TRANSPONDER (kg)	72.3	103.2	79.4	29.1										
ANTENNA SYST. (kg)	30.0	34.0	34.0	26.0										
TWTAs (kg)														
53 dBw	180.0	270.0	198.0	45										
TOTAL WEIGHT (kg) for 53 dBw	282.3	407.2	311.4	100.1										
PRIMARY POWER (w)														
6 BEAM: 123 w/chan	—	5904	4428	—										
4 BEAM: 150 w/chan	4800	—	—	1200										
TWTAs (kg) 58 dBw				114.0										
TOTAL WEIGHT (kg) for 58 dBw				169.1										
PRIMARY POWER (w)														
6 BEAM: 338 w/chan				—										
4 BEAM: 475 w/chan				3800										

TABLE 4B COMMUNICATIONS SUBSYSTEM WEIGHT AND PRIMARY POWER SUMMARY position serving the Western beams provides full service past 1:00 a.m. local time except for the Pacific Time Zone which has full capacity up to 0:44 a.m. System models using the two orbit locations specified in this study could conceivably be treated as not requiring eclipse capability.

6. Development of Spacecraft/Launcher Weight and Power Availability

Having thus far developed a range of communications payload weight and power demands, the next step was to develop a set of weight and power availability graphs for several spacecraft/launcher candidates. Some of this information was updated from the 1978/79 Spar DBS study which considered a generalized 3 axis stabilized spacecraft design (GPB) for PAM-D class launches (≈1000 pounds in final orbit) and a larger version (x GPB) for PAM-A class launch (≈2000 pounds in final orbit). Variants of these designs to match Ariane and half Ariane (Sylda) capacity were also considered as were the British Aerospace L-SAT and the Hughes Leasat.

As seen from Fig. 9 the range of available weight for communications plus power subsystems is nearly continuous. System models requiring power and weight in the IUS or dedicated shuttle launch category have not been examined for two reasons; a) the lack of performance and cost data on a spacecraft of this size, b) a belief that such system implementations are unlikely because of initial cost, and flexibility reasons.

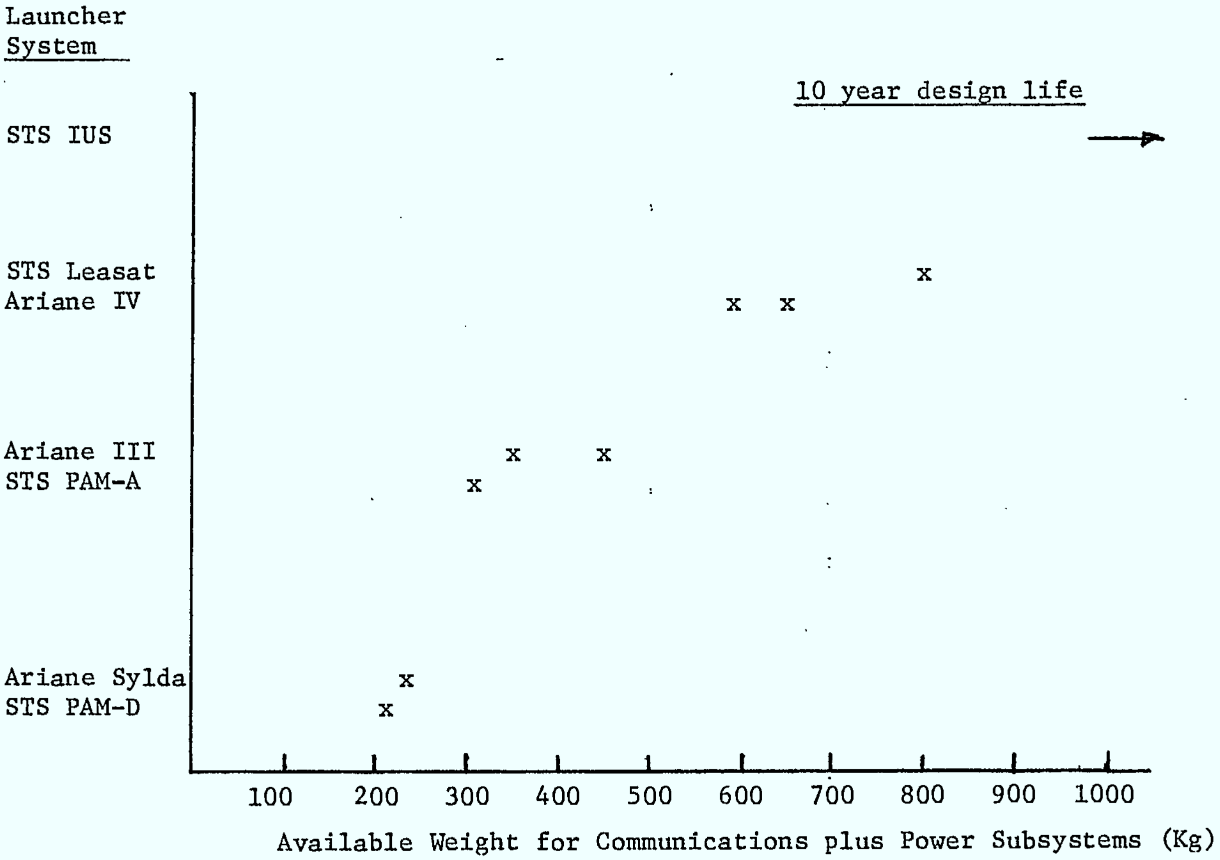


Fig. 9 Available Weight for Various Launcher Systems

Fig. 10 shows a representative communications payload weight and power availability graph for one spacecraft launcher combination. Any point to the left of a given curve represents an allowable combination of communications weight and power.

Increasing mission lifetime or increasing eclipse capability is seen to reduce the allowable combination of communications weight and power. A close match between payload demand and spacecraft capability can be found by the graphical method of overlaying the payload demand plot on each of the spacecraft candidate availability graphs in turn. It is believed that within a tolerance of ± 10% of an exact weight match, a compromise could be worked out for any single point design. A summary of feasible systems is given in Table 5, using this selection criteria.

7. Comparison of System Models

A list of 8 criteria was initially proposed (Table 6) to evaluate system models, however in consultation with the scientific authority it was agreed that most of the factors were related to a shorter list of criteria:

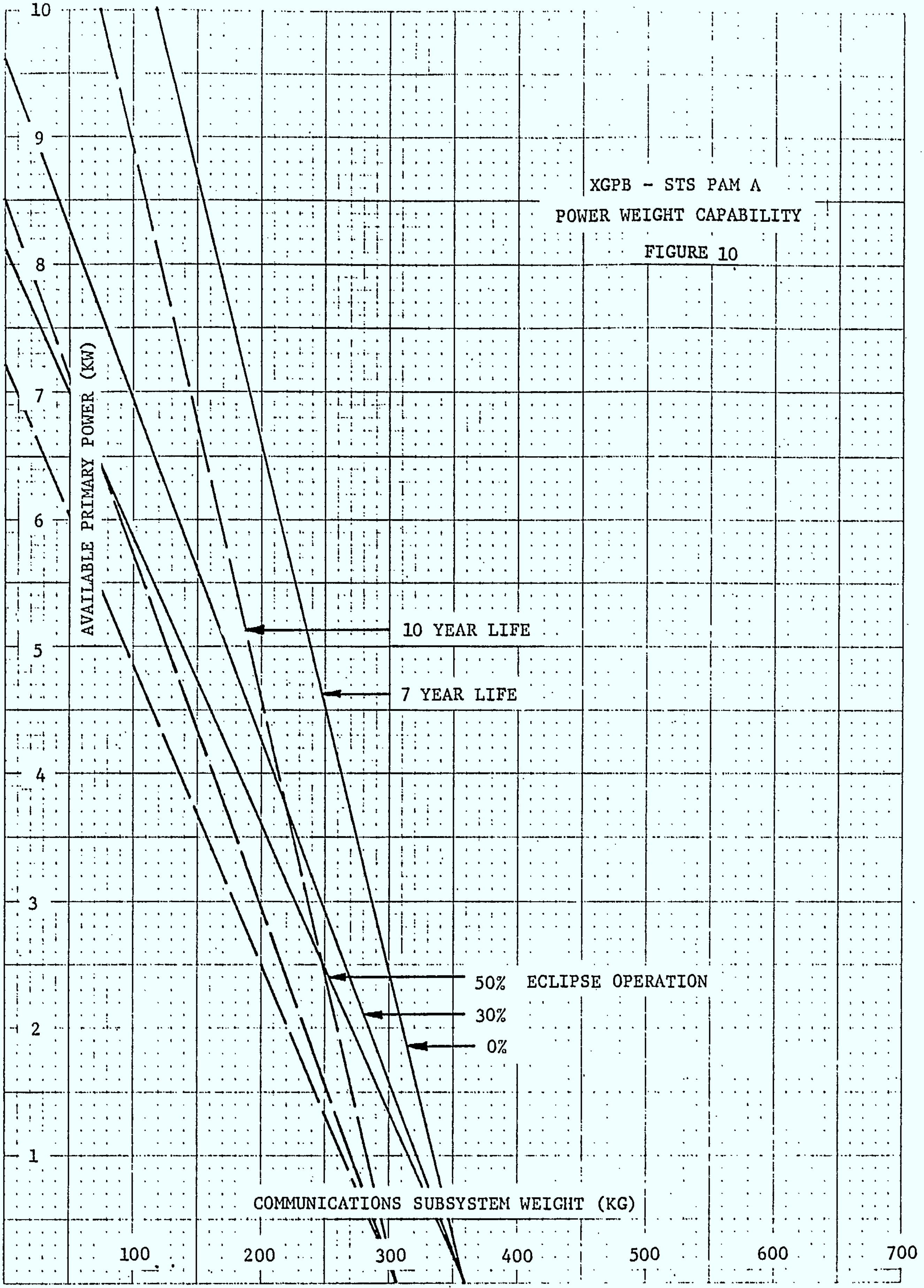
i) Cost
ii) Growth
iii) WARC Compatibility

	Long list	Short list
1.	Match to Launcher/Spacecraft	
2.	Growth capability	- Cost
3.	In Orbit protection and sparing	- Growth
4.	Eclipse capability	- WARC Compatibility
5.	WARC 79 Compatibility	
6.	Transitional problems - interim Anik C to DBS	
7.	Uplink flexibility	
8.	Cost	

Table 6 Criteria for Comparison of Systems

8. Spacecraft Cost

Spacecraft costs as given in Table 7 are part historical and part speculative. For Anik-D and Intelsat V, the historical values have been adjusted to 1981 economic conditions and Canadian dollars. The



XGPB - STS PAM A

POWER WEIGHT CAPABILITY

FIGURE 10

TABLE 5 SPACECRAFT LAUNCHER SUITABILITY SUMMARY

			OPTIMIZED 3 AXIS SPACECRAFT										REFERENCE SPACECRAFT							
													L-SAT (3 AXIS)				LEASAT (SPINNER)			
		Launcher	PAM-D		Ariane Sylda		PAM-A		Ariane III		Ariane IV		Ariane III		Ariane IV		15' Array		30' Array	
		DC Power Level	2 KW → 8 KW										4.5 to 6 KW		6 to 8 KW		Up to 2KW		2 to 4 KW	
		EIRP (dBW)	53	58	53	58	53	58	53	58	53	58	53	58	53	58	53	58	53	58
4 BEAM SYSTEMS	1 Orbit Loc.	148/32							O				O							
		148/16	O		O					X		X				X			O	
		149/12	O					X		X				X			O			
		144/16	O		O			X		X						X			O	
	2 Orbit Loc.	248/16	O		O					X						X			O	
		248/8		X		X		X									O			X
6 BEAM SYSTEMS	1 Orbit Loc.	168/48									O				O					
		168/24					O			X		X				X			O	
		168/16	O		O			X						X			O			
		168/12	O			X		X									O			X
		166/36							O				O							
		166/18	O		O					X				X					O	
		166/12	O			X		X									O			X
		164/24					O			X		X				X			O	
		164/12	O			X		X									O			X
	2 Orbit Loc.	268/24			O		O			X		X				X			O	
		268/12	O			X		X									O			X

NOTE TO TABLE 5: The Anik-C/PAM-D is power limited to 6 channels at 53dBw and is below the minimum capacity spacecraft considered in this study (12)

SPACECRAFT	LAUNCHER	SPACECRAFT DRY WEIGHT (Kg)	SPACECR COST ($M Can
ANIK-D GPB	STS - PAM D	513	47
INTELSAT V XGPB	STS - PAM A	809	58
LEASAT	STS	1640	59
L-SAT XGPB	ARIANE III	1031	67
L-SAT XGPB	ARIANE IV	1696	Not Available

TABLE 7 SPACECRAFT COST (1981 $ CAN)

LAUNCHER	LAUNCHER CAPABILITY (DRY WEIGHT) (Kg)	LAUNCH COST ($M Can)
STS - PAM D	513	16.0
STS - PAM A	809	28.9
STS OPTIMISED (LEASAT)	1640	22.6
ARIANE SYLDA	534	33.7
ARIANE III	1031	60.3
ARIANE IV	1696	Not Available

TABLE 8 LAUNCH COST (1981 $ CAN)

L-SAT and LEASAT figures are based on best available data, adjusted to 1981 Canadian dollars. The trend is to lower cost per unit of dry spacecraft weight with increasing spacecraft size.

9. Launch Costs

Launch costs (normalized to 1981 Canadian dollars) are compared in Table 8. These figures are based on current data but must be used cautiously if comparing possible launches by Ariane or shuttle in the 1987 period. Proponents of the Ariane launcher claim that STS charges are artificially low and will certainly rise dramatically after an initial honeymoon period. They have additionally stated a long term policy of competitiveness with the shuttle.

Within the shuttle family, little difference in cost per unit of dry spacecraft weight exists for PAM-D and PAM-A upper stages, however the shuttle optimized LEASAT offers a much lower cost per unit of dry spacecraft weight. This configuration can support communication payloads with large weight, and with power requirements up to nearly 4 KW DC.

10. Total Space Segment Costs

For each system model a total cost has been developed assuming one spare spacecraft plus launch, and using the spacecraft and launcher costs just presented. A useful comparison of cost may be based on a cost per channel per year as shown in the last column of Table 9a and b. The higher cost of the high EIRP models relative to the low EIRP can be seen both in total cost and cost per channel year. The average cost per channel year of a 58dBW system is 70% higher than a 53dBW system, (1.64 vs. 0.97 M$), corresponding to 551 vs. 326 M$ for 48 channel systems.

The average cost per channel of a 4 beam system is 34% higher than a 6 beam system at the high EIRP level, and 16% at the lower EIRP level.

Considering that 50% more channels are required in a 6 beam system than a 4 beam system for the same number of channels per service area, there is an 11% cost advantage for the 4 beam system at the high EIRP level, and 23% at the low EIRP level.

11. Growth

System growth is considered in two parts. The first is growth to the maximum system capacity specified for this study, which is a minimum of 16 channels (4 beams x 4 channels per beam) and a maximum of 48 channels (6 beams x 8 channels per beam). Comparison between system models is mainly qualitative considering the following points:

i) A gradual implementation using more than one spacecraft more closely matches installed capacity with growth in demand. This could be treated as deferred cost even though the total cost might be higher than a single operating spacecraft system.

ii) Sharing of a spacecraft between 2 or more operating spacecraft is flexible and efficient.

SYSTEM DESCRIPTION	SYSTEM CODE	SPACECRAFT-LAUNCHER REQUIRED	SPACECRAFT COST $M	LAUNCH COST $M	TOTAL COST PER S/C $M	NUMBER OF S/C PER SYSTEM + ONE SPARE	TOTAL COST PER SYSTEM $M	COST/CHANNEL PER YEAR (7 YEAR LIFE) $M
4 BEAM SYSTEM								
ONE ORBITAL LOCATION								
8 channels/beam	148/32	L-SAT - AR III	67	60.3	127.3	2	254.6	1.137
	148/16	GPB - PAM D	47	16.0	63.0	3	189.0	0.844
9 channels/beam	149/12	GPB - PAM D	47	16.0	63.0	4	252.0	1.000
4 channels/beam	144/16	GPB - PAM D	47	16.0	63.0	2	126.0	1.125
TWO ORBITAL LOCATIONS								
8 channels/beam	248/16	GPB - PAM D	47	16.0	63.0	3	189.0	0.844
	248/8	GPB - PAM D	47	16.0	63.0	5	315.0	1.406
6 BEAM SYSTEM								
ONE ORBITAL LOCATION								
8 channels/beam	168/48	L-SAT - AR IV	Not Available	Not Available	---	2	---	---
	168/24	XGPB - PAM A	58	28.9	86.9	3	260.7	0.776
	168/16	GPB - PAM D	47	16.0	63.0	4	252.0	0.750
	168/12	GPB - PAM D	47	16.0	63.0	5	315.0	0.938
6 channels/beam	166/36	L-SAT - AR III	67	60.3	127.3	2	254.6	1.010
	166/18	GPB - PAM D	47	16.0	63.0	3	189.0	0.750
	166/12	GPB - PAM D	47	16.0	63.0	4	252.0	1.000
4 channels/beam	164/24	XGPB - PAM A	58	28.9	86.9	2	173.8	1.035
	164/12	GPB - PAM D	47	16.0	63.0	3	189.0	1.125
TWO ORBITAL LOCATIONS								
8 channels/beam	268/24	XGPB - PAM A	58	28.9	86.9	3	260.7	0.776
	268/12	GPB - PAM D	47	16.0	63.0	5	315.0	0.938

TABLE 9A COST PER CHANNEL-YEAR COMPARISON FOR 53 dBw EIRP SYSTEMS

SYSTEM DESCRIPTION	SYSTEM CODE	SPACECRAFT-LAUNCHER REQUIRED	SPACECRAFT COST $M	LAUNCH COST $M	TOTAL COST PER S/C $M	NUMBER OF S/C PER SYSTEM + ONE SPARE	TOTAL COST PER SYSTEM $M	COST/CHANNEL PER YEAR (7 YEAR LIFE) $M
4 BEAM SYSTEM								
ONE ORBITAL LOCATION								
8 channels/beam	148/32	exceeds AR.IV capability				2		
	148/16	L-SAT - AR III	67	60.3	127.3	3	381.9	1,705
9 channels/beam	149/12	L-SAT - AR III	67	60.3	127.3	4	509.2	2,021
4 channels/beam	144/16	L-SAT - AR III	67	60.3	127.3	2	254.6	2,273
TWO ORBITAL LOCATIONS								
8 channels/beam	248/16	L-SAT - AR III	67	60.3	127.3	3	381.9	1.705
	248/8	XGPB - PAM A	58	28.9	86.9	5	434.5	1.940
6 BEAM SYSTEM								
ONE ORBITAL LOCATION								
8 channels/beam	168/48	exceeds AR.IV capability				2		
	168/24	L-SAT - AR IV	Not Available	Not Available	---	3	---	---
	168/16	L-SAT - AR III	67	60.3	127.3	4	509.2	1.515
	168/12	XGPB - PAM A	58	28.9	86.9	5	434.5	1.293
6 channels/beam	166/36	exceeds AR.IV capability				2		
	166/18	L-SAT - AR III	67	60.3	127.3	3	381.9	1.515
	166/12	XGPB - PAM A	58	28.9	86.9	4	347.5	1.379
4 channels/beam	164/24	L-SAT - AR IV	Not Available	Not Available				
	164/12	XGPB - PAM A	58	28.9	86.9	3	260.7	1.552
TWO ORBITAL LOCATIONS								
8 channels/beam	268/24	L-SAT - AR IV	Not Available	---	---	3	---	---
	268/12	L-SAT - PAM A	58	28.9	86.9	5	434.5	1.293

TABLE 98 COST PER CHANNEL-YEAR COMPARISON FOR 58dBw EIRP SYSTEMS

The second growth factor considers system sizes above that given in the study, up to perhaps 18 channels per coverage area. For such growth, single orbit position models are not feasible, unless spectrum reuse through polarization or beam spatial isolation is used. Although partial reuse may be possible by improvements in antenna technology such as beam spatial isolation, this factor is not considered at this time, thus 2 or more orbit locations are required for expansion.

The 2 orbit models considered in this study are adaptable to expansion. Although the specific system interference levels have not been calculated, it is believed that satisfactory levels can be achieved. The repeater and antenna implementation will be more complex but still remains feasible.

None of the two orbit models are directly applicable to 3 or more orbit location models, however it is believed that no major system or technical problems would prevent adaptation of the 2 orbit models to such a system. A key objective to be considered in any adaptation is the desireability of keeping all spacecraft designs identical to reduce the total system cost.

12. WARC Compatibility

To establish frequency and polarization plans for this study a TV channel bandwidth of 18 MHz was specified versus 27 MHz for the WARC 77 Region 1 and 3 plan. For calculation of system interference levels, antenna characteristics were as given in the CCIR reference specifications. Two cases of channel protection ratio masks were considered; one was scaled in frequency to correspond to the reduced channel bandwidth (18 MHz) which is anticipated for Region 2. Using this more favourable protection ratio mask, only the single orbit location, 48 channel model can be considered incompatible with anticipated WARC objectives for Region 2. In this model it is necessary to assign adjacent copolar channels within a coverage area, which results in a carrier to interference ratio (C/I) just below the target 30dB.

13. Uplink Arrangements

The single uplink beam specified for the study has good flexibility as it provides access to all channels from all coverage areas. Intra regional, interregional and national beam coverage can thus be developed readily from any location. The main uplink penalty is in the number of earth terminal transmitters required for each national channel; one per coverage area. It appears feasible to consider satellite repeater configurations which give multi beam down link coverage for single uplink illumination of the satellite. This configuration could also provide regional subdivisions as well as national if required.

14. Transition from an Interim Anik C to a Full DBS System

Transitional problems from an interim Anik C DBS system to a full DBS system have been considered only from the technical compatibility point of view. Although there are differences in polarization, EIRP and frequency bands, it appears feasible to plan for an orderly transition of service without massive obsolescence, and startup costs.

15. Recommendations for Future Studies

Three main areas of work are recommended for continuing study:

i) Carry out system studies in support of RARC 83 preparations
ii) Studies to develop and refine technical options
iii) Refine cost modelling

In the technical area, the antenna subsystem merits special mention for several reasons:

First it is a major determinant in the physical arrangement of the spacecraft and its accommodation with the launcher.

Second, the interface with the repeater is complex and has a major effect on achievable gains and losses.

Third, system performance is strongly dependent on antenna performance in the areas of beam coverage optimization, sidelobe control, and polarization isolation. The choice of linear or circular polarization for a DBS system should also be critically examined from the spacecraft antenna point of view.

Fourth, the economy of using identical spacecraft for different orbit locations depends on antenna reconfiguration capability.

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Fourth, the economy of using identical spacecraft for different orbit locations depends on antenna reconfiguration capability.

1.0 INTRODUCTION

This report covers a System Modeling Study for a Canadian Direct Broadcast Satellite System. The study was conducted by the Satellite Systems Division of SPAR Aerospace Limited for the Department of Communications under Contract serial # OST80-00134.

The scope of the study was defined by the Scientific Authority through the requirements and parameters outlined below. The recommendations of WARC 79 for Region 2 were also to form part of performance requirements unless otherwise provided by the Design Authority.

a)	EIRP:	53 dBW and 58 dBW on axis
b)	Orbit Location:	A total system from 105°W and a split system from 105°W and 140°W
c)	Number of Beams:	4 and 6
d)	Number of Channels per Beam:	4 and 8
e)	Frequency Band:	17.3 - 17.8 GHz Uplink 12.2 - 12.7 GHz Downlink
f)	Polarization:	Circular
g)	TV Channel Bandwidth:	18 MHz FM
h)	Interference:	30 dB C/I
i)	Eclipse Operation:	0 and 50%
j)	Uplink Arrangement:	At least 50% regional programming channels and the remaining for national programming
k)	On-Board Switching:	Propose method allowing any uplink channel to be transmitted simultaneously to all beams.

The objective of this study was to generate a number of system models which would satisfy the given system parameters in the most effective way. These models would form the basis for detail frequency plan derivation, weight and power demand estimates and selection of suitable Bus/Launcher combinations. To achieve this objective, the system models of Figure 1.1 were generated.
The methodology used in the study can be described briefly in terms of the following tasks:

1) Generated frequency and polarization plans to accommodate all system models.

2) Generated block diagrams of most of the system models.

1.0 (continued)

3) Prepared weight and power estimates of all models.

4) Generated Bus/Launcher weight and power capability information.

5) Examined match of model weight and power demands to Bus/Launcher capability.

The model family tree of Figure 1.1 is symmetrical on the EIRP, hence, the 58 dBW branch is identical to the 53 dBW which is shown. System models 244 and 264 have been omitted from this study since such system capacities can be more effectively implemented from one orbital location.

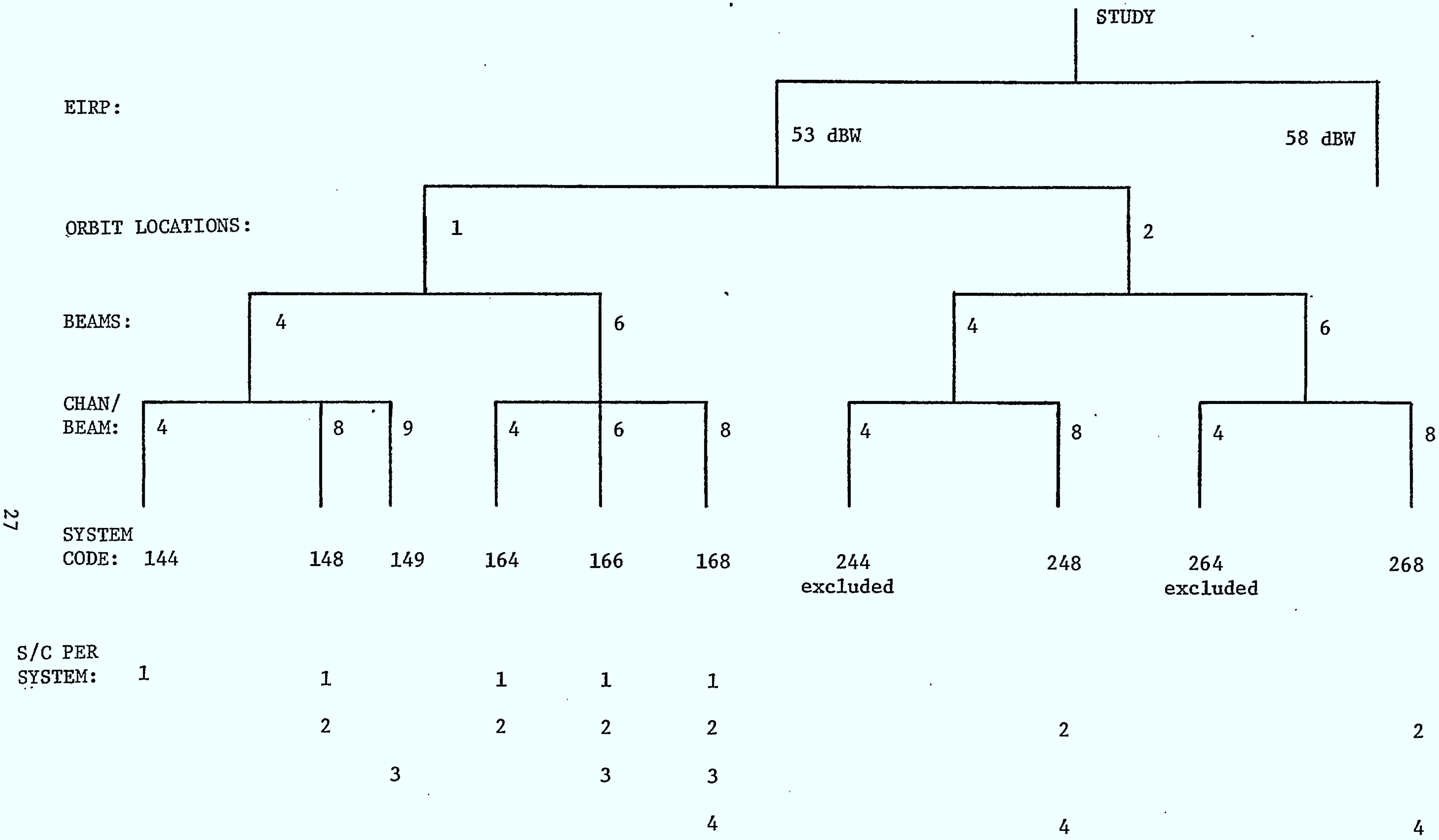


FIGURE 1.1 SYSTEM MODELS INCLUDED IN STUDY

2.0 FREQUENCY PLANS

2.1 General

The frequency plans examined in this study have been selected to satisfy the system models specified in the Statement of Work. As it can be imagined, these plans are not thought to be unique. Alternate plans could possibly be generated to satisfy the requirements of the candidate system models.

Table 2.1, colums 1 to 3 contain top level parameters of the systems required to be studied. Column 6 indicates the number of channels which are necessary in a frequency plan to accommodate a specific system. The approach here has been to assume that the entire 500 MHz band (minus the end guard bands) can be dedicated to a specific system (the resulting frequency plans are depicted in Figures 2.1 to 2.4). This approach has the advantage of generating a parametric examination of channel spacing ranging from the relatively easy to implement 24 channel plan to the most difficult case of the 48 channel plan. Frequency plans with fewer than 24 channels are considered particularly wasteful and have not been used in this study. Instead, in those cases where fewer than 24 channels are required a suitable larger frequency plan has been adopted. Specifically, there are three cases which fall into this category and they are discussed below:

a) The One Orbital Location, 4 beam, 4 channels/beam system:

This system can be considered as one half of the 8 channel/beam system system. Hence the 32 channel plan has been adopted to allow expansion to full system if required or share the frequency plan with another spectrum user. Refer to Table 2.15 for specific frequency plan.

b) The Two Orbital Location, 4 beam, 8 channel/beam system:

This system requires only 2 of the 4 eight channel groups available in a 32 channel plan. It is possible to assign the remaining 2 eight channel groups to another spectrum user.

c) The Two Orbital Location, 6 beam, 8 channel/beam system:

In this case 24 channels are required per location with 16 channels in one polarization and 8 channels in the other polarization. Because of this assymmetry a 32 channel plan has to be used to accommodate the 16 channels of one polarization. Hence, one group of 8 channels remains unused and could be assigned to another user. Refer to Table 2.18 for specific frequency plan.

2.0 2.1 (continued)

In Table 2.1 some apparent irregularities in the "number of channels per beam" column have been introduced to satisfy certain needs which became evident during the course of the study. The 6 channels per beam case was introduced as a fall-back plan in the event that the 48 channel plan is not adopted or it proves particularly difficult to implement. The 9 channel per beam case was introduced to allow an orderly division of the 4 beam, 8 channels/beam system over 3 spacecraft. Column 6 contains the number of frequencies required to satisfy the needs of each one of the models. Channel spacing has been derived as follows:

Available Band : 500 MHz

Guard Band as per WARC 79 : 13 MHz
Based on 55dBw EOC EIRP

Number of Channels N : 48
36
32
24

$$\text{Channel spacing} = \frac{500 - 13}{N + 1} \quad \text{Crosspolarized channels}$$

$$= \frac{500 - 13}{N + 1} \times 2 \quad \text{Copolarized channels}$$

	48 CHAN PLAN	36 CHAN PLAN	32 CHAN PLAN	24 CHAN PLAN
Crosspolarized Channel spacing	9.9 MHz	13.2 MHz	14.8 MHz	19.5 MHz
Copolarized Channel spacing	19.9 MHz	26.3 MHz	29.5 MHz	39.0 MHz

From these four basic plans, specific frequency plans have been generated for all the communications subsystem necessary to satisfy the requirements of Table 2.1. In these specific frequency plans channel assignments per beam and per spacecraft has been made in an optimum way towards achieving the following system objectives:

a) Minimize intrasystem interference

b) Permit Common spacecraft design where more than one spacecraft are required per system

c) Allow graceful growth

d) Achieve minimum loss in the output multiplexer.

The type of features which help achieve objectives (a), (b), (c), and (d) are common to all frequency plans hence one example would suffice to demonstrate the point. For example Table 2.5 shows a 48 channel plan used for a 6 beam, 8 channels/beam system carried on 2 spacecraft. In order to minimize intrasystem interference the channel assignment within one beam does not contain adjacent copolarized channels. Instead adjacent copolarized channels are used two beams away where a greater degree of interference protection is provided by the spacecraft antenna angular discrimination. Channel assignment per spacecraft is such as to enable a common TWT and common output filter to carry either of 2 frequencies such as for example channel 1 or 7. The spacecraft is also equipped with 2 sets of input filters, command selectable, to allow it to transmit either group of frequencies. These features of spacecraft commonality provide wide system flexibility and enhance sparing. This channel assignment provides an additional advantage in allowing the use of wideband output filters with their greatly reduced insertion loss as compared to narrow, single channel filters. Graceful growth or degradation is achieved by providing partial capacity to each service area (beam) from each spacecraft. Systems requiring more than one spacecraft can be implemented in stages up to full system or if a spacecraft is lost partial capacity is maintained at all service areas.

The spacecraft commonality and graceful growth can be better achieved in systems from one orbital location. Common antenna design for spacecraft of two orbital locations is expected to be at least difficult to implement. Partial coverage of all service areas is also outside the capability of a multiple location system.

2.2 Intrasystem Interference

The intrasystem interference examined below deals with the occurrence of interference from adjacent crosspolarized and copolarized channels. For example, channel 5 is subjected to interference from channels 4 and 6 with opposite polarization and from channels 3 and 7 with same polarization. In the worst case, four significant interference exposures or entries would occur as explained above. The effect of exposures from channels of greater spacing than this is considered negligible and omitted from this analysis. As required by the Design Authority no allowance for external interference has been included in this study.

The interference conditions differ between one and two orbital location systems, hence, separate analyses are provided. Carrier-to-Interference ratios used in this analysis could be actual, as it is the case where no frequency separation improvement has been applied, or <u>effective</u> for those cases where frequency separation improvement has been applied. No distinction is necessary to be made between these two cases, however, the meaning will be clear from the context. The total Carrier-to-Interference (C/I) presented below is the effective C/I and directly relates to the 30dB C/I objective set by the Design Authority and WARC 79.

One Orbital Location System

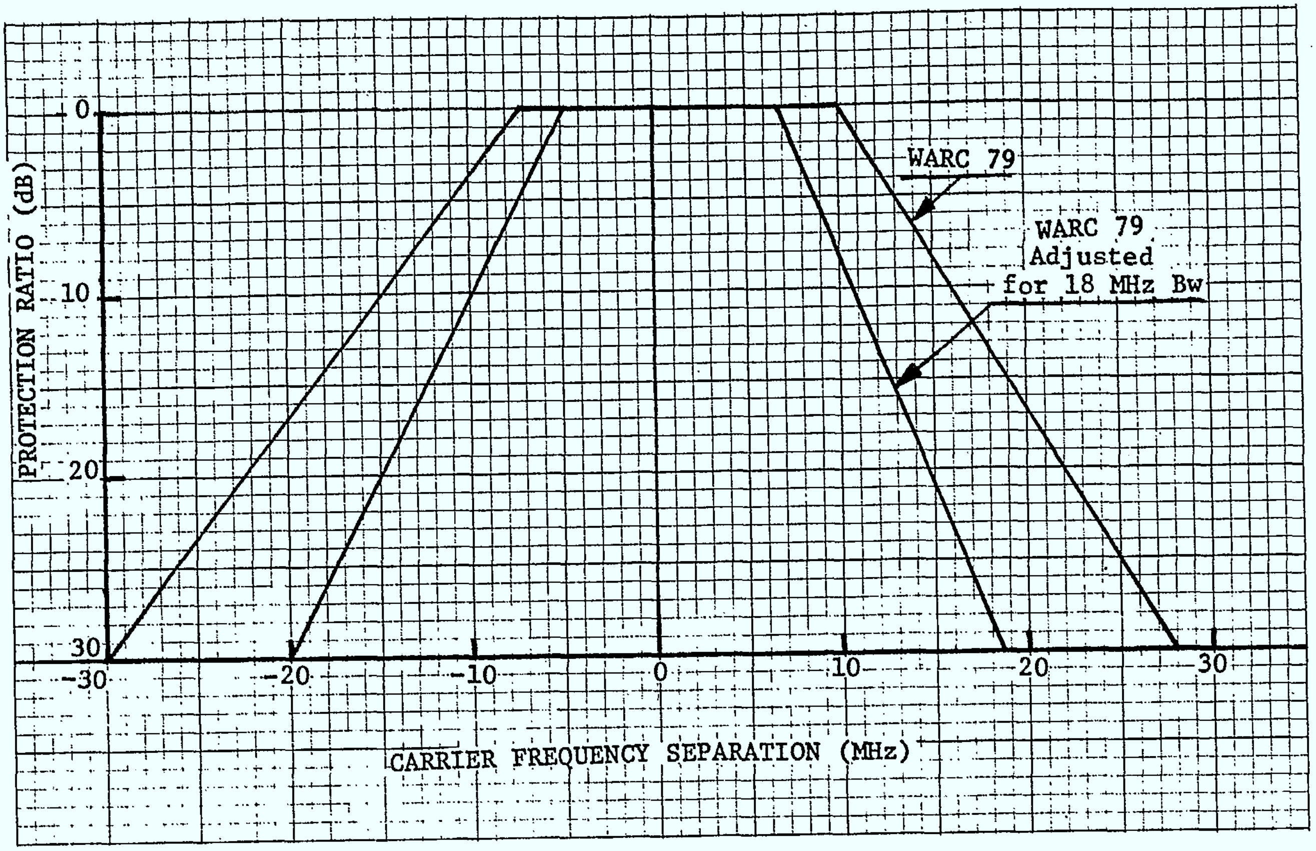
For the purpose of this analysis the following antenna system parameters have been used. The source of information is also listed for reference.

		GROUP 1	GROUP 2
Ground Uplink Antenna XPD	=	30dB INTELSAT V	30dB INTELSAT V
Spacecraft Uplink Antenna XPD	=	33dB WARC 79	27dB INTELSAT V
Spacecraft Downlink Antenna XPD	=	33dB Assumed	27dB INTELSAT V
Domestic Receive Antenna XPD	=	25dB WARC 79	25dB WARC 79
Total System XPD	=	22.9dB	20.9dB

Spacecraft Downlink Antenna Spacial Discrimination at Adjacent Copolarized Beam = 15dB WARC 79 Antenna Pattern

Group 1 antenna parameters are primarily based on WARC 79 objectives for Region 2. In this group, the spacecraft antenna XPD (Cross-Polarization Discrimination) is considered somewhat optimistic for circularly polarized, shaped beam antennas. As an indication of what might be considered realizable the INTELSAT V specification is shown in Group 2. The calculations of C/I, however, are based on Group 1 values to be consistent with WARC 79 objectives. If desired, the total C/I values in Table 2.2 could be lowered by 1-2dB to provide a more conservative view of the interference effect.

For completeness, two parallel calculations of C/I have been made and are presented in Table 2.2. The column labeled WARC 79 uses the WARC 79 Protection Ratio mask without any adjustment for the narrow channel bandwidth of 18MHz. The column labeled "Adjusted WARC 79" uses the same mask as WARC 79 except that the frequency separation scale has been adjusted for the narrower bandwidth of Region 2 at the ratio of 18 ÷ 27. This approach sets the interference level on the same basis between systems using different video bandwidths and peak deviations.



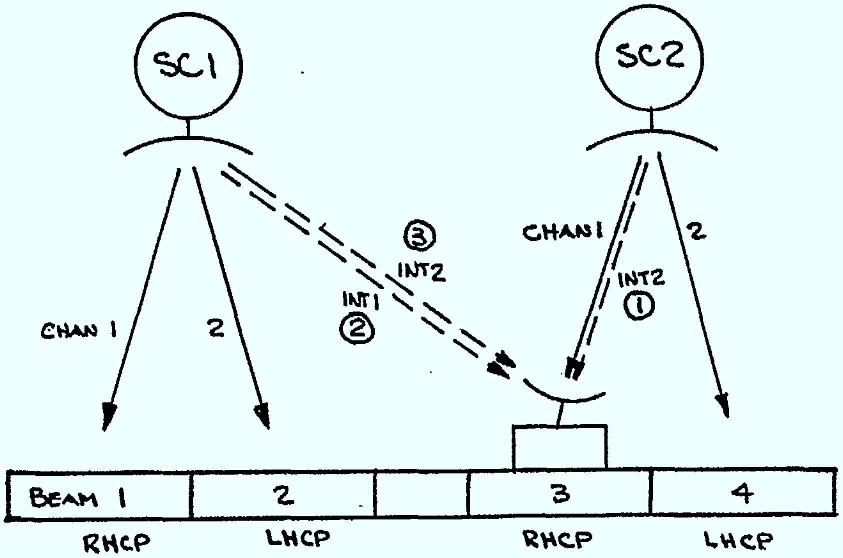
Two Orbital Location System

In this type of system the interference conditions are somewhat different from those of the one orbital location system and require a separate analysis. There are even additional differences between the four and six beam systems requiring a separate treatment.

Table 2.3 and 2.4 contain summaries of the occuring interference components described below. Both the 4 beam and 6 beam cases use the 32 channel frequency plan.

2.0 2.2 (continued)

4 Beam System:



In the worst case, there are three interference components as defined in above diagram and described below:

Component ①: Crosspolarized adjacent channel interference identical to that of one orbital location 32 channel plan except that only one exposure is involved.

Component ②: Copolarized Co-channel interference between the frequency re-use areas of the system.

Assumed Parameters:

Domestic Antenna Discrimination
at 8° from axis = 25dB
at 20° from axis = 35dB

Satellite Antenna Discrimination
at 0.7 Beamwidth from axis = 10dB

Component ③: Crosspolarized Adjacent channel interference between the frequency re-use areas of the system.

Assumed Parameters:

Domestic Antenna XPD
at 8° from axis = 30dB
at 20° from axis = 35dB.

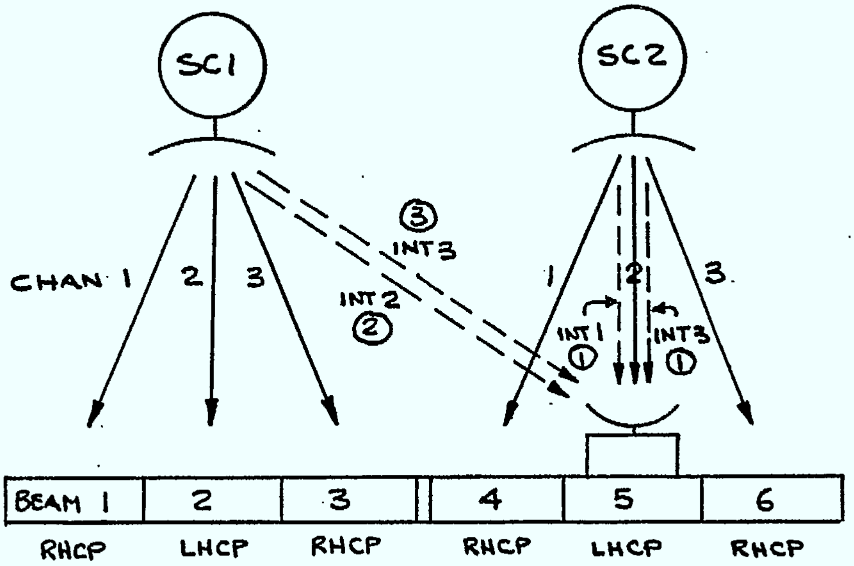
2.0 2.2 (continued)

Satellite Antenna XPD = 33dB

Total Antenna XPD
at 8° from axis = 28.2dB
at 20° from axis = 30.9dB

Frequency spacing improvement
WARC 79 = 9dB
Adjusted WARC 79 = 20dB

6 Beam System:



In the worst case there are three interference components as identified in above diagram and described below:

Component 1: Crosspolarized adjacent channel interference identical to that of one orbital location 32 channel plan.

Component 2: Copolarized co-channel interference between the frequency reuse areas of the system.

Assumed Parameters:

Domestic Antenna Discrimination
at 8° from axis = 25dB
at 20° from axis = 35dB

Satellite Antenna Discrimination
at 0.7 Beamwidth from axis = 13dB.

2.0 2.2 (continued)

Component 3: Crosspolarized adjacent channel interference
identical to that of 4 Beam system,
component 3.

The total C/I calculated on the basis of the WARC 79 protection ratio mask indicate that all cases except for the 24 channel plan are marginal to poor in intra-system interference (refer to Tables 2.2, 2.3, 2.4). The Adjusted WARC 79 method, however, indicates that all cases except for the 48 channel one are at least 4dB better than the 30dB C/I objective. The 48 channel plan falls short from meeting the 30dB objective. However, it is still considered a possible plan involving greater technical difficulty than the other plans.

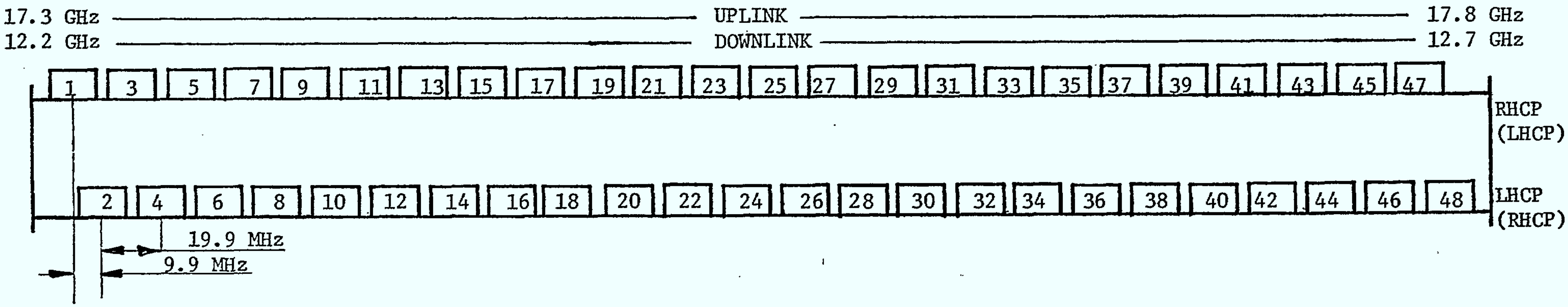


FIGURE 2.1 48 CHANNEL FREQUENCY PLAN

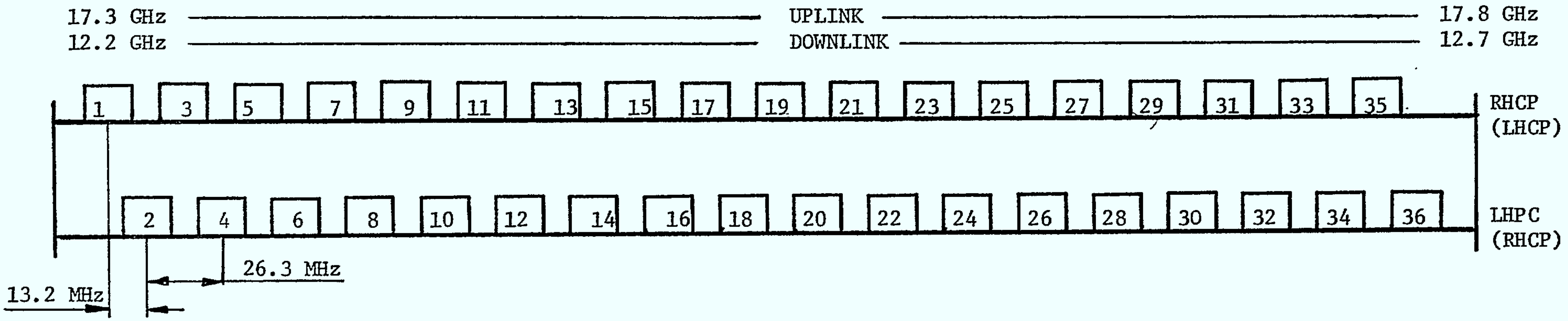


FIGURE 2.2 36 CHANNEL FREQUENCY PLAN

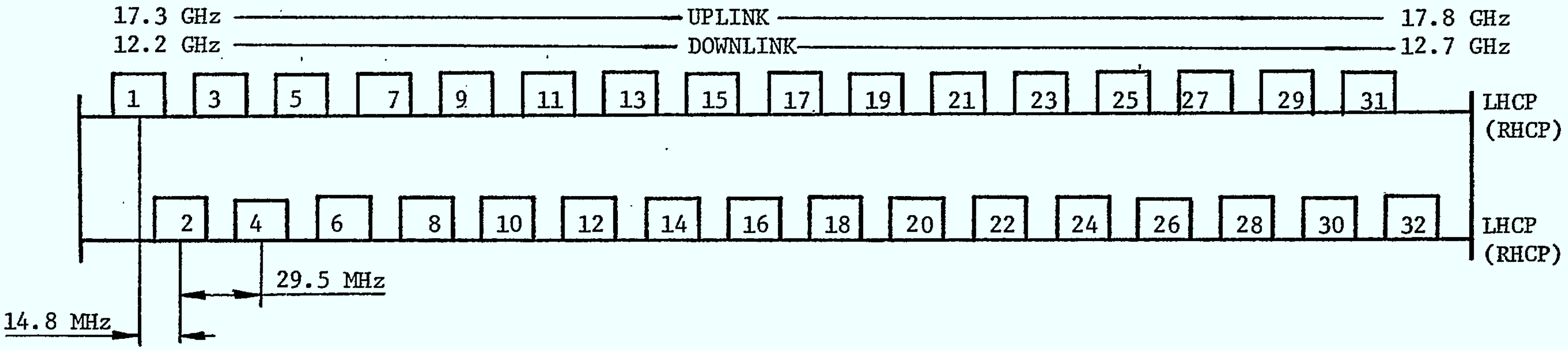
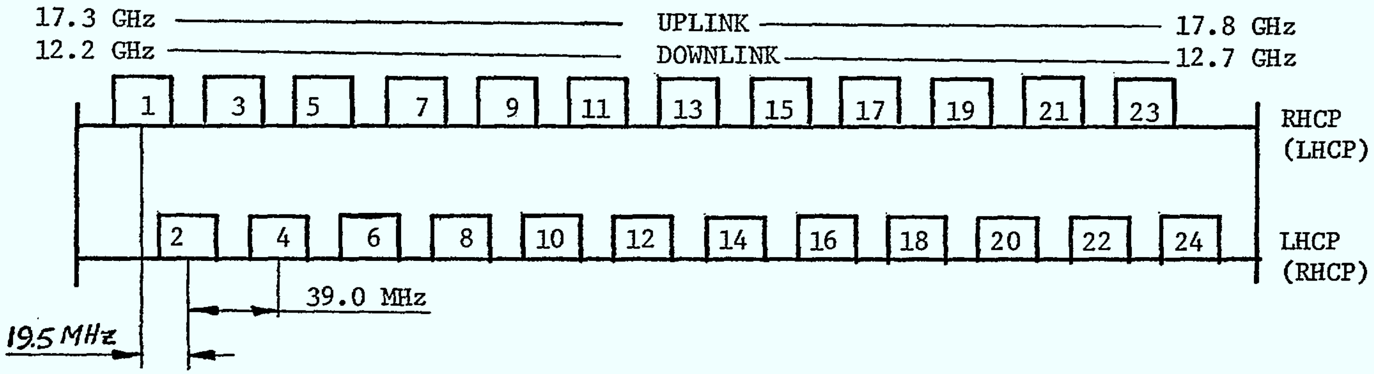


FIGURE 2.3 32 CHANNEL FREQUENCY PLAN



<u>FIGURE 2.4</u> <u>24 CHANNEL FREQUENCY PLAN</u>

ORBITAL LOCATIONS	NUMBER OF BEAMS	NUMBER OF CHANNELS PER BEAM	TOTAL NUMBER OF CHANNELS	NUMBER OF CHANNELS PER POLARIZATION	NUMBER OF FREQUENCIES REQUIRED (BASIC PLAN)	NUMBER OF SPACECRAFT FOR FULL SYSTEM
1	6	8	48	24	48	1, 2, 3, 4
	6	6	36	18	36	1, 2, 3
	6	4	24	12	24	1, 2
	4	8	32	16	32	1, 2, $\boxed{3}$
	4	9	36	18	36	3
	4	4	16	8	32	1
2	6	8	24/Location	16	32	2, 4
	4	8	16/Location	8	16	2, 4

TABLE 2.1 FREQUENCY PLAN UTILIZATION

	48 Channel Frequency Plan		36 Channel Frequency Plan		32 Channel Frequency Plan		24 Channel Frequency Plan	
	WARC 79	Adjusted WARC 79	WARC 79	Adjusted WARC 79	WARC 79	Adjusted WARC 79	WARC 79	Adjusted WARC 79
Crosspol Frequency Spacing	9.9 MHz	9.9 MHz	13.2 MHz	13.2 MHz	14.8 MHz	14.8 MHz	19.5 MHz	
Frequency Spacing Improvement	1.5 dB	9 dB	7 dB	16.5 dB	9 dB	20 dB	16 dB	
Total System XPD	22.9 dB	22.9 dB	22.9 dB	22.9 dB	22.9 dB	22.9 dB	22.9 dB	
C/I due to 2 Crosspol Entries	21.4 dB	28.9 dB	26.9 dB	36.4 dB	28.9 dB	39.9 dB	35.9 dB	
Copol Frequency Spacing	19.9 MHz	19.9 MHz	26.3 MHz	26.3 MHz	29.5 MHz	29.5 MHz	39.0 MHz	
Frequency Spaceing Improvement	17 dB	> 30 dB	27 dB	> 30 dB	30 dB	> 30 dB	> 30 dB	
Antenna Angular Discrimination	15 dB	15 dB	15 dB	15 dB	15 dB	15 dB	15 dB	
C/I due to 2 Copol Entries	29 dB	> 42 dB	39 dB	> 42 dB	42 dB	> 42 dB	> 42 dB	
Total C/I (4 entries)	20.7 dB	> 28.7 dB	26.6 dB	> 35.3 dB	28.7 dB	> 37.8 dB	> 34.9 dB	≫ 35 dB

TABLE 2.2 INTRA SYSTEM CARRIER-TO-INTERFERENCE

(ONE ORBITAL LOCATION SYSTEM)

Interference Component	WARC 79		Adjusted WARC 79	
	SATELLITE SPACING		SATELLITE SPACING	
	8°	20°	8°	20°
Component ① C/I (same as in Table 2.2 except only one exposure)	31.9 dB	31.9 dB	42.9 dB	42.9 dB
Component ②				
Domestic Antenna Spacial Discrimination	25 dB	35 dB	25 dB	35 dB
Satellite Antenna Spacial Discrimination	10 dB	10 dB	10 dB	10 dB
C/I	35 dB	45 dB	35 dB	45 dB
Component ③				
Total Antenna Crosspol Discrimination	28.2 dB	30.9 dB	28.2 dB	30.9 dB
Frequency Spacing Improvement	9 dB	9 dB	20 dB	20 dB
C/I	37.2 dB	39.9 dB	48.2 dB	50.9 dB
Total C/I	29.4 dB	31.1 dB	34.2 dB	40.4 dB

TABLE 2.3 INTRA SYSTEM CARRIER-TO-INTERFERENCE FOR 4 BEAM SYSTEM
(TWO ORBITAL LOCATION SYSTEM)

Interference Component	WARC 79 SATELLITE SPACING 8°	WARC 79 SATELLITE SPACING 20°	Adjusted WARC 79 SATELLITE SPACING 8°	Adjusted WARC 79 SATELLITE SPACING 20°
Component 1 C/I (same as in Table 2.2)	28.9 dB	28.9 dB	39.9 dB	39.9 dB
Component 2				
Domestic Antenna Spacial Discrimination	25 dB	35 dB	25 dB	35 dB
Satellite Antenna Spacial Discrimination	13 dB	13 dB	13 dB	13 dB
C/I	38 dB	48 dB	38 dB	48 dB
Component 3				
System Spatial and Crosspol Discrimination	28.2 dB	30.9 dB	28.2 dB	30.9 dB
Frequency Spacing Discrimination	9 dB	9 dB	20 dB	20 dB
C/I	37.2 dB	39.9 dB	48.2 dB	50.9 dB
Total C/I	27.9 dB	28.5 dB	35.6 dB	39.0 dB

TABLE 2.4 INTRA SYSTEM CARRIER-TO-INTERFERENCE FOR 6 BEAM SYSTEM

(TWO ORBITAL LOCATION SYSTEM)

ORBITAL STATION	105° W					
BEAM	1	2	3	4	5	6
POLARIZATION	RHCP	LHCP	RHCP	LHCP	RHCP	LHCP
SC #1	1 - 13 25 - 37	2 - 14 26 - 38	3 - 15 27 - 39	4 - 16 28 - 40	5 - 17 29 - 41	6 - 18 30 - 42
SC #2	7 - 19 31 - 43	8 - 20 32 - 44	9 - 21 33 - 45	10 - 22 34 - 46	11 - 23 35 - 47	12 - 24 36 - 48

ONE ORBITAL LOCATION
6 BEAMS
8 CHANNELS/BEAM
2 SC PER SYSTEM
OR
1 SC PER SYSTEM

TABLE 2.5 FREQUENCY PLAN FOR CONFIGURATION 168/24 & 168/48

ORBITAL STATION	105° W					
BEAM	1	2	3	4	5	6
POLARIZATION	RHCP	LHCP	RHCP	LHCP	RHCP	LHCP
SC #1	1 - 19 - 37	2 - 20 - 38	3 - 21 - 39	4 - 22 - 40	5 - 23	6 - 24
SC #2	7 - 25 - 43	8 - 26 - 44	9 - 27 - 45	10 - 28 - 46	11 - 29	12 - 30
SC #3	13 - 31	14 - 32	15 - 33	16 - 34	17 - 35 - 41 - 47	18 - 36 - 42 - 48

ONE ORBITAL LOCATION
6 BEAMS
8 CHANNELS/ BEAM
3 SC PER SYSTEM

TABLE 2.6 FREQUENCY PLAN FOR CONFIGURATION 168/16

ORBITAL STATION	105° W					
BEAM	1	2	3	4	5	6
POLARIZATION	RHCP	LHCP	RHCP	LHCP	RHCP	LHCP
SC #1	1 - 19 - 37	2 - 20 - 38	15 - 21 - 39	16 - 22 - 40	5 - 35 -	6 - 36 -
SC #2	7 - 25 - 43	8 - 26 - 44	3 - 27 - 45	4 - 28 - 46	11 - 23 -	12 - 24 -
SC #3	13 - 31 -	14 - 32 -	9 - 33 -	10 - 34 -	17 - 29 - 41 - 47	18 - 30 - 42 - 48

NOTE: This frequency plan has the same channel assignment per beam as that of Table 2.6. The channel assignment per spacecraft has been changed to reduce input multiplexing losses.

ONE ORBITAL LOCATION
6 BEAMS
8 CHANNELS/BEAM
3 SC PER SYSTEM

TABLE 2.7 FREQUENCY PLAN FOR CONFIGURATION 168/16 (PLAN B)

ORBITAL STATION	105° W					
BEAM	1	2	3	4	5	6
POLARIZATION	RHCP	LHCP	RHCP	LHCP	RHCP	LHCP
SC #1	1 - 25	2 - 26	3 - 27	4 - 28	5 - 29	6 - 30
SC#2	7 - 31	8 - 32	9 - 33	10 - 34	11 - 35	12 - 36
SC#3	13 - 37	14 - 38	15 - 39	16 - 40	17 - 41	18 - 42
SC#4	19 - 43	20 - 44	21 - 45	22 - 46	23 - 47	24 - 48

ONE ORBITAL LOCATION
6 BEAMS
8 CHANNELS/BEAM
4 SC PER SYSTEM

TABLE 2.8 FREQUENCY PLAN FOR CONFIGURATION 168/12

ORBITAL STATION	105° W					
BEAM	1	2	3	4	5	6
POLARIZATION	RHCP	LHCP	RHCP	LHCP	RHCP	LHCP
SC #1	1 - 25	2 - 26	21 - 27	22 - 28	5 - 47	6 - 48
SC #2	7 - 31	8 - 32	3 - 33	4 - 34	11 - 29	12 - 29
SC #3	13 - 37	14 - 38	9 - 39	10 - 40	17 - 35	18 - 36
SC #4	19 - 43	20 - 44	15 - 45	16 - 46	23 - 41	24 - 42

NOTE: This frequency plan has the same channel assignment per beam as that of Table 2.8. The channel assignment per spacecraft has been changed to reduce input multiplexing losses.

ONE ORBITAL LOCATION
6 BEAMS
8 CHANNELS/BEAM
4 SC PER SYSTEM

TABLE 2.9 FREQUENCY PLAN FOR CONFIGURATION 168/12 (PLAN B)

ORBITAL STATION	105° W					
BEAM	1	2	3	4	5	6
POLARIZATION	RHCP	LHCP	RHCP	LHCP	RHCP	LHCP
SC#1	1 13 25	2 14 26	3 15 27	4 16 28	5 17 29	6 18 30
SC#2	7 19 31	8 20 32	9 21 33	10 22 34	11 23 35	12 24 36

ONE ORBITAL LOCATION
6 BEAMS
6 CHANNELS/BEAM
2 SC PER SYSTEM
OR
1 SC PER SYSTEM

TABLE 2.10 FREQUENCY PLAN FOR CONFIGURATION 166/18 & 166/36

ORBITAL STATION	105° W					
BEAM	1	2	3	4	5	6
POLARIZATION	RHCP	LHCP	RHCP	LHCP	RHCP	LHCP
SC#1	1 19	2 20	3 21	4 22	5 23	6 24
SC#2	7 25	8 26	9 27	10 28	11 29	12 30
SC#3	13 31	14 32	15 33	16 34	17 35	18 36

ONE ORBITAL LOCATION
6 BEAMS
6 CHANNELS/BEAM
3 SC PER SYSTEM

TABLE 2.11 FREQUENCY PLAN FOR CONFIGURATION 166/12

ORBITAL STATION	105° W					
BEAM	1	2	3	4	5	6
POLARIZATION	RHCP	LHCP	RHCP	LHCP	RHCP	LHCP
SC #1	1 19	2 20	15 33	4 22	5 23	18 36
SC #2	7 25	8 26	3 21	10 28	11 29	6 24
SC #3	13 31	14 32	9 27	16 34	17 35	12 30

NOTE: This frequency plan has the same channel assignment per beam as that of Table 2.11. The channel assignment per spacecraft has been changed to reduce input multiplexing losses.

ONE ORBITAL LOCATION
6 BEAMS
6 CHANNELS/BEAM
3 SC PER SYSTEM

TABLE 2.12 FREQUENCY PLAN FOR CONFIGURATION 166/12 (PLAN B)

ORBITAL STATION	105° W					
BEAM	1	2	3	4	5	6
POLARIZATION	RHCP	LHCP	RHCP	LHCP	RHCP	LHCP
SC#1	1 13 7 19	2 14 8 20	3 15 9 21	4 16 10 22	5 17 11 23	6 18 12 24

ONE ORBITAL LOCATION
6 BEAMS
4 CHANNELS/BEAM
1 SC PER SYSTEM

TABLE 2.13 FREQUENCY PLAN FOR CONFIGURATION 164/24

ORBITAL STATION	105° W					
BEAM	1	2	3	4	5	6
POLARIZATION	RHCP	LHCP	RHCP	LHCP	RHCP	LHCP
SC#1	1 13	2 14	3 15	4 16	5 17	6 18
SC#2	7 19	8 20	9 21	10 22	11 23	12 24

ONE ORBITAL LOCATION
6 BEAMS
4 CHANNELS/BEAM
2 SC PER SYSTEM

TABLE 2.14 FREQUENCY PLAN FOR CONFIGURATION 164/12

ORBITAL STATION	105° W			
BEAM	1	2	3	4
POLARIZATION	RHCP	LHCP	RHCP	LHCP
SC#1	1 - 17 9 - 25	2 - 18 10 - 26	3 - 19 11 - 27	4 - 20 12 - 28
SC#2	5 - 21 13 - 29	6 - 22 14 - 30	7 - 23 15 - 31	8 - 24 16 - 32

NOTE: For a 4 channel/beam system (144/16) either of the SC #1 or SC #2 frequency groups can be used.

ONE ORBITAL LOCATION
4 BEAMS
8 CHANNELS/BEAM
2 SC PER SYSTEM
OR
1 SC PER SYSTEM

TABLE 2.15 FREQUENCY PLAN FOR CONFIGURATION 148/16 & 148/32

ORBITAL STATION	105° W			
BEAM	1	2	3	4
POLARIZATION	RHCP	LHCP	RHCP	LHCP
SC#1	1 - 13 - 25	2 - 14 - 26	3 - 15 - 27	4 - 16 - 28
SC#2	5 - 17 - 29	6 - 18 - 30	7 - 19 - 31	8 - 20 - 32
SC#3	9 - 21 - 33	10 - 22 - 34	11 - 23 - 35	12 - 24 - 36

ONE ORBITAL LOCATION
4 BEAMS
9 CHANNELS/BEAM
3 SC PER SYSTEM

TABLE 2.16 FREQUENCY PLAN FOR CONFIGURATION 149/12

ORBITAL STATION	140° W				105° W		
BEAM	1	2	3		4	5	6
POLARIZATION	RHCP	LHCP	RHCP		RHCP	LHCP	RHCP
SC #1	1 - 9 5 - 13 17 - 25 21 - 29	2 - 10 6 - 14 18 - 26 22 - 30	3 - 11 7 - 15 19 - 27 23 - 31	SC #2	1 - 9 5 - 13 17 - 25 21 - 29	2 - 10 6 - 14 18 - 26 22 - 30	3 - 11 7 - 15 19 - 27 23 - 31

TWO ORBITAL LOCATION
6 BEAMS
8 CHANNELS/BEAM
2 SC PER SYSTEM

TABLE 2.17 FREQUENCY PLAN FOR CONFIGURATION 268/24

ORBITAL STATION	140° W				105° W		
BEAM	1	2	3		4	5	6
POLARIZATION	RHCP	LHCP	RHCP		RHCP	LHCP	RHCP
SC#1	1 - 9 17 - 25	2 - 10 18 - 26	3 - 11 19 - 27	SC#3	1 - 9 17 - 25	2 - 10 18 - 26	3 - 11 19 - 27
SC#2	5 - 13 21 - 29	6 - 14 22 - 30	7 - 15 23 - 31	SC#4	5 - 13 21 - 29	6 - 14 22 - 30	7 - 15 23 - 31

TWO ORBITAL LOCATIONS
6 BEAMS
8 CHANNELS/BEAM
4 SC PER SYSTEM

TABLE 2.18 FREQUENCY PLAN FOR CONFIGURATION 268/12

ORBITAL STATION	140° W			105° W	
BEAM	1	2		3	4
POLARIZATION	RHCP	LHCP		RHCP	LHCP
SC#1	1 - 5 9 - 13	2 - 6 10 - 14	SC#2	1 - 5 9 - 13	2 - 6 10 - 14
	17 - 21 25 - 29	18 - 22 26 - 30		17 - 21 25 - 29	18 - 22 26 - 30

TWO ORBITAL LOCATIONS
4 BEAMS
8 CHANNELS/BEAM
2 SC PER SYSTEM
OR
4 SC PER SYSTEM

TABLE 2.19 FREQUENCY PLAN FOR CONFIGURATION 248/16 & 248/8

2.0 2.3 Uplink Arrangements

One Orbit Location

The origination of at least 50% of the channels assigned to a beam, from within that beam, defines a regional uplink with a minimum capacity of 2 channels. This corresponds to a 4 channel per beam system model. For an 8 channel per beam system model, this minimum uplink capacity would be 4 channels. Increases in the number of channels in a beam increase the regional earth station capacity on a one for one basis for programs originating within the beam. Likewise for each program transmitted to another beam one more uplink is required.

National coverage puts more difficult demands on up link station. The beam configurations defined in this study all use a single uplink beam covering all Canada, thus any regional station can transmit to any other beam by chosing the appropriate frequency and polarization. Any regional station, then, can produce a National beam, or more correctly National coverage by transmitting the same information on all beams (i.e. 4 or 6 depending on the model). A National station will similarly need 4 or 6 transmitters for each National channel. To produce even two simultaneous National coverage channels (for example one English and one French language) will require up to 12 transmitters, each operating at a different channel frequency. As it is becoming evident from the above, the total number of transmitters per system is a function of the point of uplink origin of channels hence it can be affected greatly by the ratio of regionals to national channels. Table 2.20 in the form of two examples shows the effect on the total number of transmitters required as the assignment of channels is varied between national and regional.

Two Orbit Locations

It should be kept in mind that in a 2 orbit location system, the most Easterly regional stations may not be able to see the Westernmost satellite and thus cannot broadcast directly into the Western half of Canada. Any uplink station which can see both satellite locations will be capable of originating inter-regional and National coverage, however, two separate antennas will be required.

Repeater Configuration Effects on National Coverage

The foregoing discussion of uplinks assumed a single conversion satellite repeater configuration. This arrangement puts a burden on the stations originating national coverage because one transmitter is required for each spot beam making up the total coverage. This number of transmitters is multiplied again by the number of separate national programs.

Several ideas for simplifying national coverage have been considered, all aimed at reducing the number of uplink transmitters.

Common Downlink Channel

The same downlink frequency band is assigned to all spot beams to produce full or national coverage. This creates a difficult repeater/antenna design problem, but conceptually is possible. A single uplink transmitter would thus provide national coverage, however there is a serious frequency and polarization planning problem. For example, all frequency and polarization plans considered in this study use orthogonal polarization, alternated between beams, so that only a single polarization is assigned to each spot beam. This simplifies both the ground receiving station and the satellite transmitting antenna. If a single downlink channel is used for national coverage then one of two things must happen:

i) An all Canada downlink of one polarization is produced which requires that the receivers in half the coverage area must be capable of receiving both polarizations.

ii) A downlink is produced using two polarizations alternating between beams which precludes the use of the channel(s) adjacent to the national channel. For all but the lowest capacity systems, the numerically adjacent channels are too close for separation by filtering in the receiver.

Multiple Conversion

This concept would use a single uplink channel for each national program, and would convert this frequency band to a different channel in each downlink spot beam to give full national coverage. This scheme has no effect on the downlink beam and channel assignment process - it would also be possible to select by ground command, either the normal repeater configuration or the multiple conversion configuration. Selected channels in each beam may then be switched to either the normal receiver output for regional use or to the appropriate offset receiver output for national use.

Two repeater implementations appear feasible. The first shown in Figure 2.5 uses the principle of single conversion but has available a different conversion frequency for each beam.

2.0 2.3 (continued)

The second implementation uses 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 downlink 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.

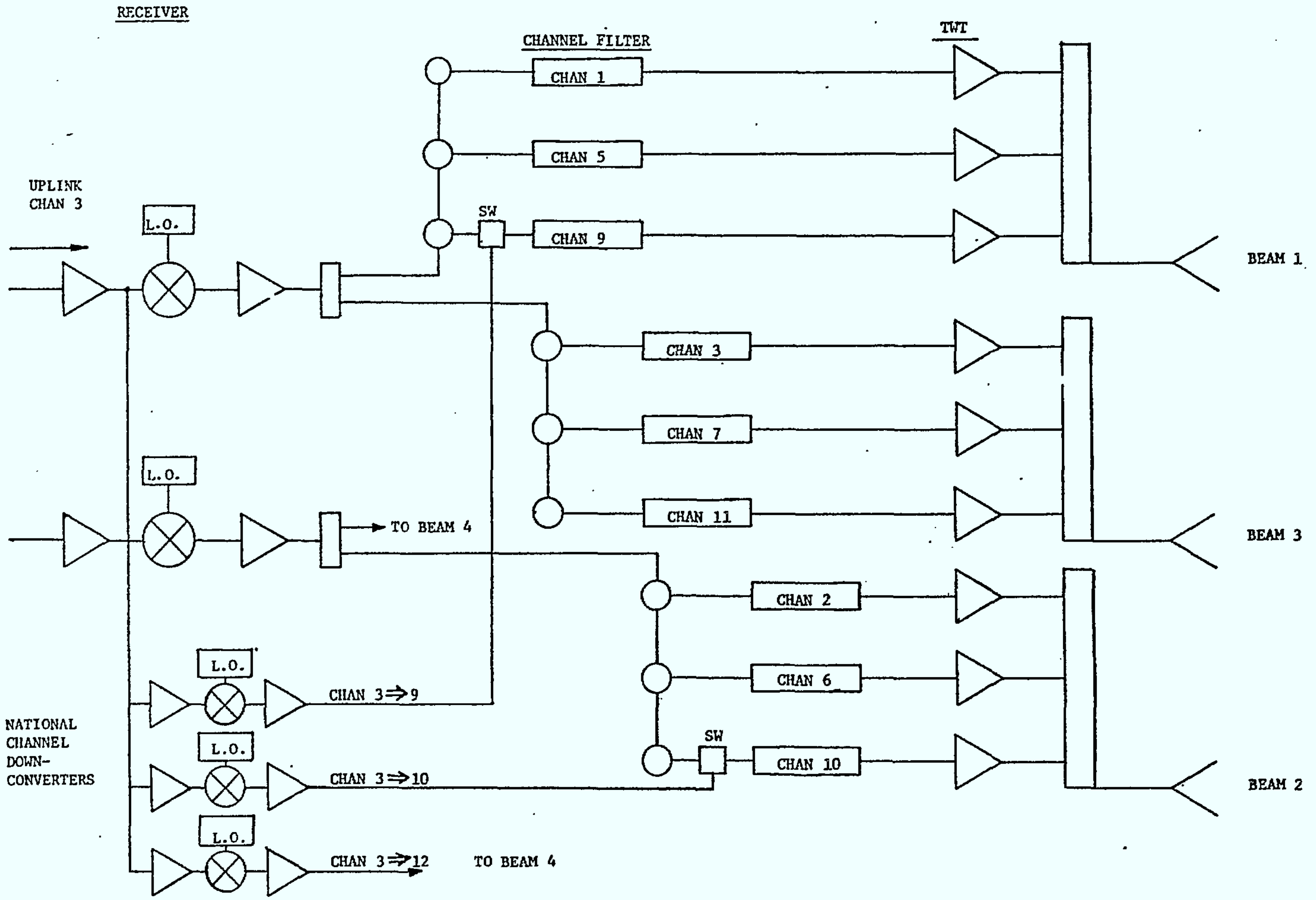


FIGURE 2.5 MULTIPLE SINGLE CONVERSION – 4 BEAM SYSTEM

SYSTEM	REGIONAL CHANNELS	REQUIRED TRANSMITTERS FOR REGIONAL CHANNELS	NATIONAL CHANNELS	REQUIRED TRANSMITTERS FOR NATIONAL CHANNELS	TOTAL TRANSMITTERS PER STATION	TOTAL TRANSMITTERS PER SYSTEM
Smallest System 4 Beams 4 Chan/Beam	2	2	2	6	8	32
	3	3	1	3	6	24
	4	4	0	0	4	16
Largest System 6 Beams 8 Chan/Beam	4	4	4	20	24	144
	6	6	2	10	16	96
	7	7	1	5	12	72
	8	8	0	0	8	48

TABLE 2.20 EARTH STATION UPLINK CAPACITY

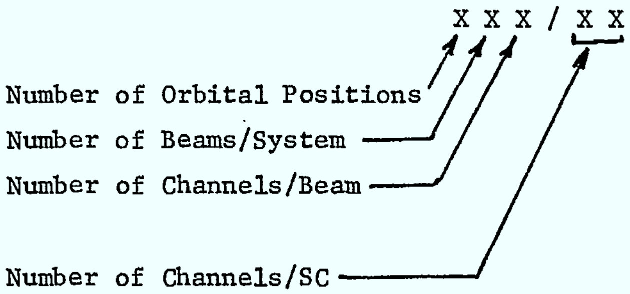
3.0 COMMUNICATIONS SUBSYSTEMS

3.1 General

This section deals with electrical configurations, as well as weight and power estimates of the communications subsystems studied. The number of models included in this study is shown in Figure 3.1. This model tree of Figure 3.1 is symmetrical on the EIRP with the exception of very large systems exceeding the launch capability of ARIANE IV. These systems are the 32, 36 and 48 channel ones. Systems such as these might still be possible to launch by STS-IUS. Tables 3.5 and 3.6 contain a complete listing of all systems covered in the study and their respective weight and primary power summary.

Throughout this and subsequent sections a need exists for a brief model designation code which would replace the complete functional description of each system. The following code has been generated for this purpose:

COMM SUBSYSTEM CODE



Example: Comm S/S 168/16 corresponds to:

1 Orbital position
6 Beams/System
8 Channels/Beam
16 Channels/SC (3 SC/System)

3.2 Communications Subsystems Configurations

A number of communications subsystem block diagrams have been generated to support the weight and power estimates and allow verification of the frequency plan concepts. A total of twelve block diagrams were produced in sketched form and were used in the study. Seven of these diagrams representing Key configurations have been drawn and included in this report. The included diagrams cover the range of configuration variations among the systems such as: a) 6, 4, 3 and 2 beam antenna systems, b) Single and dual mode antenna feeds, c) Division of one system into 2, 3 and 4 spacecraft and d) A range of system channel capacities of 12, 16, 18 and 24 per spacecraft.

3.0 3.2 (continued)

Some of the main communications subsystem features are as follows:

1. Receiver configuration and redundancy is identical in all systems. There is a four-for-two receiver chain redundancy switchable by the two input Ferrite Switches and the two C-type switches. Each pair of receiver outputs is connected directly to a 3dB Hybrid thus increasing the system reliability by eliminating the output switch.

2. In those cases where the total system consists of more than one spacecraft switchable input filters are used to allow any spacecraft to carry any group of channel frequencies thus improving system protection flexibility and allowing common design of spacecraft including the spare.

3. Spare TWT's and channel amplifiers have been included to a level of 15-20% of capacity dependent on the system configuration. The redundancy scheme has not been studied for its effect on system reliability or whether it is possible to protect widely spaced channels across the frequency range. Its inclusion here is intended only as an indication of a protection scheme and include an appropriate weight contribution in the system weight estimates.

4. The output mulitplexer required by the various systems range from the 4 channel size to the case where no output mux is required at all (system 168/12). Generally, channel assignments per beam have been selected to allow use of widest possible bandwidth in the output filter thus reducing the output loss.

   There are some cases where a dual mode antenna is used instead of output mulitplexers. This arrangement has been arbitrarily selected at this stage. Eventually, actual trade-offs should be examined before a final selection of approach is made.

3.3 Antenna Concepts

A number of alternate antenna system schemes have been reviewed:

1. Single Reflector with Duplex Feed

   This system would involve a very complex feed especially in combination with multiple beam and beam shaping. The complexity of such scheme is expected to be further aggravated by difficulties in making polarizers and OMT's (Orthomode Transducers) which would cover the frequency band 12.2 to 17.8 GHz. In general, this is a difficult scheme that should be avoided.

3.0 3.3 (continued)

2. Separate Transmit and Receive Reflectors

This system would greatly reduce the feed complexity as compared to the previous scheme and might allow greater beam shaping range by increased number of feedhorns. Because of the all-Canada uplink requirement a much smaller receive reflector could be used.

3. Separate Receive, RHCP Transmit and LHCP Transmit Reflectors

This scheme simplifies further the transmit feed and eliminates the need for OMT's. The requirement for three reflectors, however, increases the antenna deployment complexity and most likely would make this the heaviest of all three schemes.

Scheme 1 appears to be particularly complex and contains considerable risks in combining operation over a rather wide frequency range and high power levels over receive feed elements. On the positive side, it is doubtful whether it would offer a weight advantage over scheme 2 when the extra components and support bracketry are compared to the separate receive reflector.

In scheme 3 the second transmit reflector does not seem to be well justified. Further examination might prove this scheme to be quite wasteful.

From this casual examination it appears that scheme 2 has certain advantages in that it avoids the risks of scheme 1 and the expected weight of scheme 3. Weight and gain estimates have been based on scheme 2 and it has also been incorporated into the subsystem block diagram.

Antenna gain estimates for 8 ft. transmit reflector and 3 ft. receive reflector have been derived from past designs and they are as follows:

4 Beam Coverage:	37dB on axis 34dB EOC
6 Beam Coverage:	38.5dB on axis 35.5dB EOC
Uplink Beam:	27dB EOC.

3.0 3.3 (continued)

Weight estimates for the selected antenna scheme are contained on Table 3.4. Component weights have been derived mainly from past designs. The areas where significant weight variances might occur are the reflector deployment mechanism and support structures. It should be noted that no weight allowance has been made for an antenna feed tower. Instead, it has been assumed that the feed could be mounted on the spacecraft main structure in such a way that reflector deployment would complete the required antenna configuration.

3.4 Communications Subsystem Weight Estimates

The unit weights contained on Tables 3.1, 3.2 and 3.3 were derived to the greatest extent possible from past designs with suitable adjustment wherever necessary. Mainly, they are the same weight as those used in the previous study except that some have been updated. The same approach has been used for antenna component weights contained on Table 3.4.

The source of TWTA weight estimates is somewhat more complicated than the rest of the transponder/antenna components. This is due mainly to lack of TWTA's of power outputs corresponding to those derived in Subsection 3.5. The information on TWTA weights available to us at the time of the study was limited to the following two cases:

1. A Hughes EDD weight estimate for a hypothetical 60W TWTA = 4.5 kg.
2. A weight estimate based on the Thomson-CSF TWT TH 3579 120-150W equipped with a hypothetical EPC from the previous DBS study = 7.6 kg for TWTA.

A third case was added by taking the Anik-D TWTA of 11W and 2 Kg. These three cases have been plotted to generate Figure 3.2 which showed the following simple relationship between RF output and TWTA weight:

$$\text{TWTA weight} = 1.55 + 0.049 \times R_F(W) \text{ Kg}$$

This relationship was used to extrapolate the weight of only the 190 W TWTA. In fact, some additional margin was added to the weight estimate of this TWTA by using the corresponding weight of a 200 W TWTA which is 11.4 Kg. Weights for the other TWTA's have been assigned on the basis of the available single point estimates. For both the 45 and 60 W cases a common weight has been assigned equal to that of the Hughes estimate for a 60 W TWTA. For the 135 W case the Thomson-CSF TWTA weight estimate of 7.6 Kg has been used. This approach provides a close fit between the estimates of the 60 and 135 W TWTA and the weight model of Figure 3.2. The assumed weight estimate for the 45 W TWTA is considerably more conservative and hence significantly above the weight model. This might be justified by reasoning that the gap between available TWT's of 30 and 120 W power could lead to new development aimed somewhere in the 60-70 watt range.

3.0 3.5 Communications Subsystem Power Estimates

The total power requirements for any model have been assumed to be identical to the power requirements of the TWTA's alone. Receivers and channel amplifiers have power requirements in the order of 0.5 to 1.5% of the total hence it has been omitted. The TWTA D.C. power requirements have been derived as follows:

Example:

Antenna Gain Ga = 38.5dB on axis

Transponder Output Losses Lo = 1.2dB (common to all systems)

TWTA O/P = EIRP - Ga + Lo dBw
= 53 - 38.5 + 1.2 = 15.7dBw
≡ 37.2 W

TWTA O/P (including 0.5dB margin) ≡ 41.7 W

Round-off power
to next 5 watt level : 45W

TWTA efficiency = 40%

Hence, primary power required = $\frac{45W}{.40}$ = 123 w/channel

Number of Beams	Antenna Gain	53dBW EIRP		58dBW EIRP	
		RF Power	DC Power	RF Power	DC Power
6	38.5dB	45W	123W	135W	338W
4	37dB	60W	150W	190W	475W

The total primary power requirements for any system is the per channel power times the total number of channels contained in the system. Power required to charge batteries for eclipse operation has not been added to the total power requirements. It is assumed that the power subsystem is designed for adequate power during solstice when the sun angle accounts for approximately 7% lower power input to the solar arrays.The corresponding 7% increase at equinox is considered adequate power excess for battery charging.

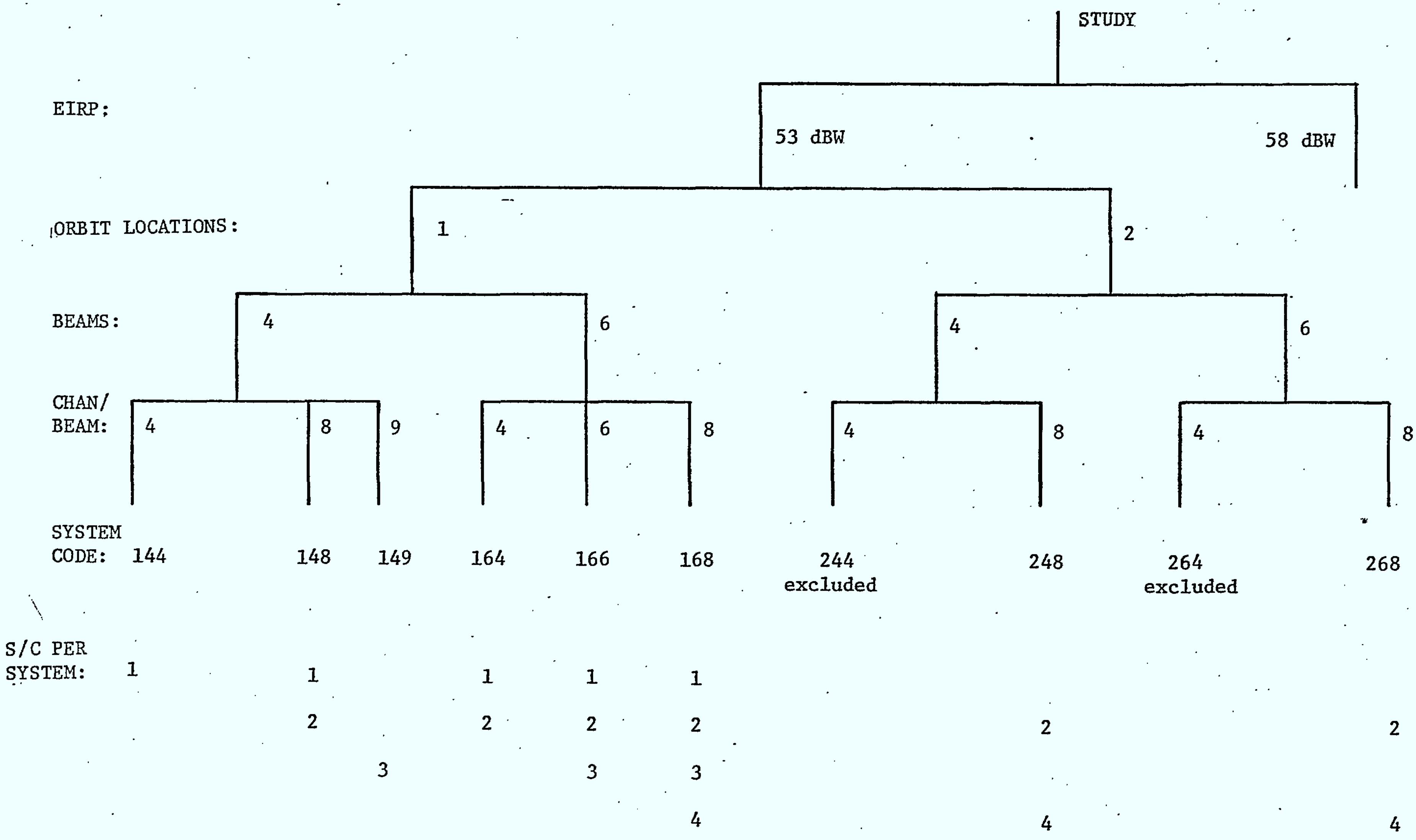
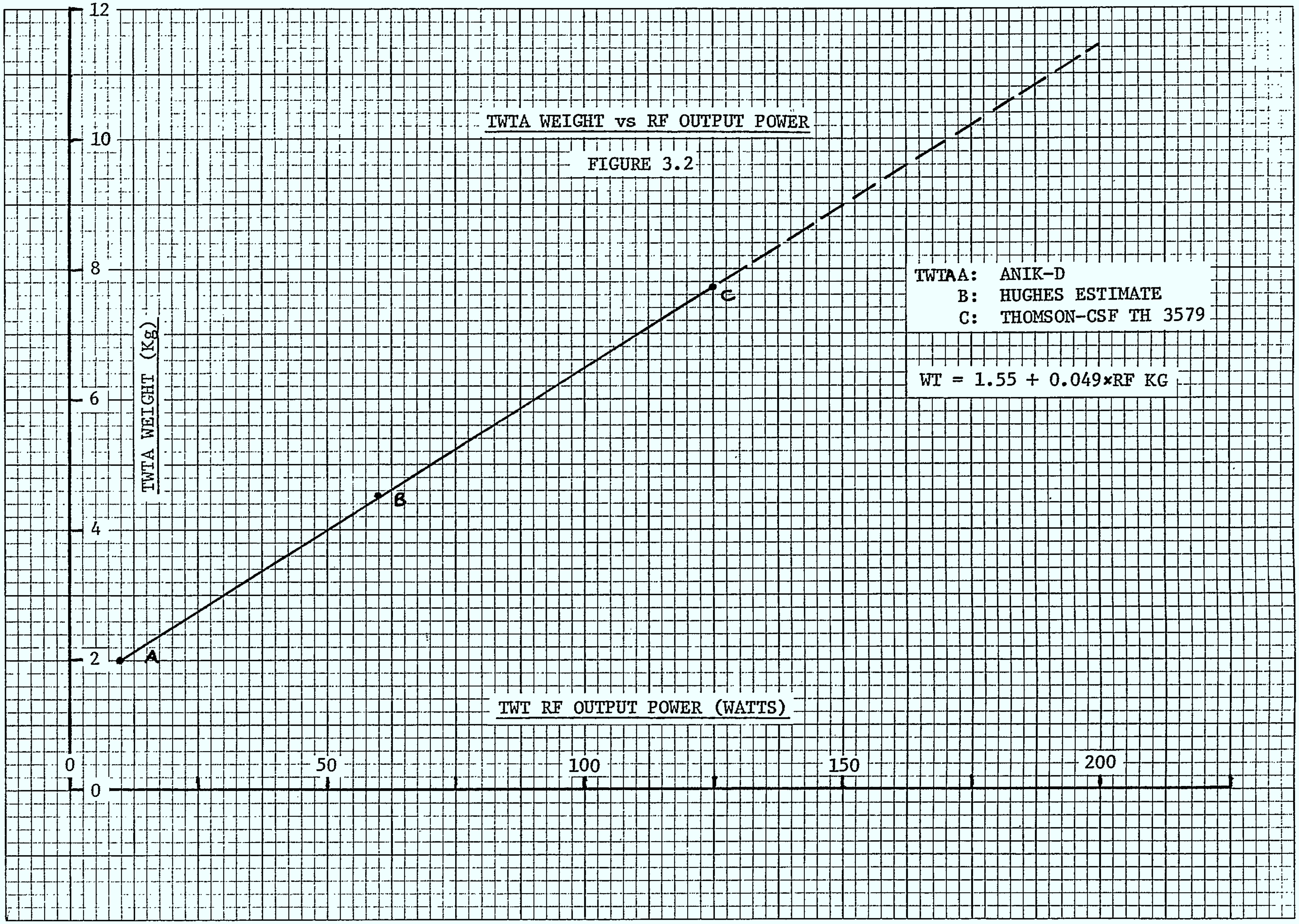


FIGURE 3.1 SYSTEM MODELS INCLUDED IN STUDY



TWTA WEIGHT vs RF OUTPUT POWER

FIGURE 3.2

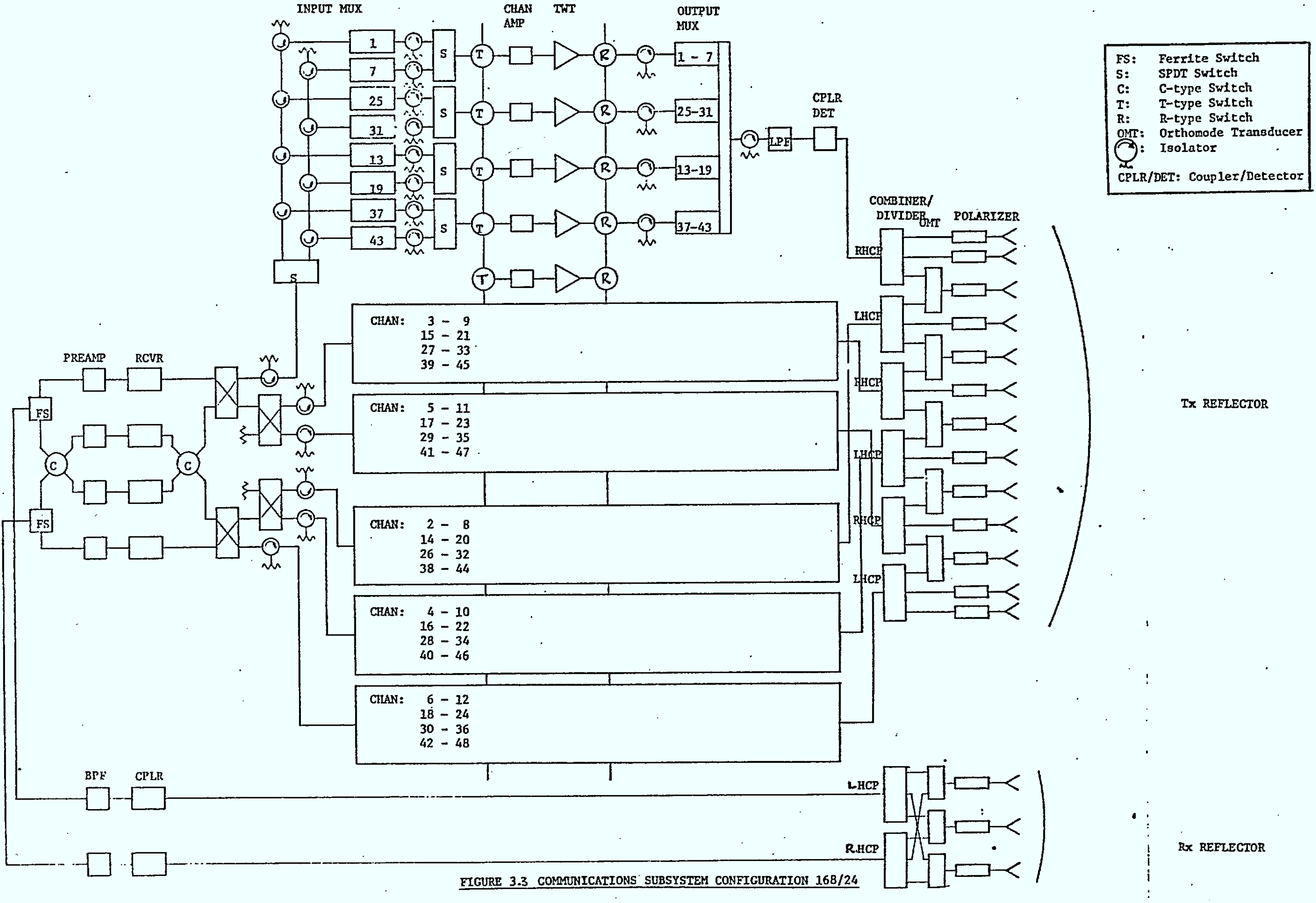


FIGURE 3.3 COMMUNICATIONS SUBSYSTEM CONFIGURATION 168/24

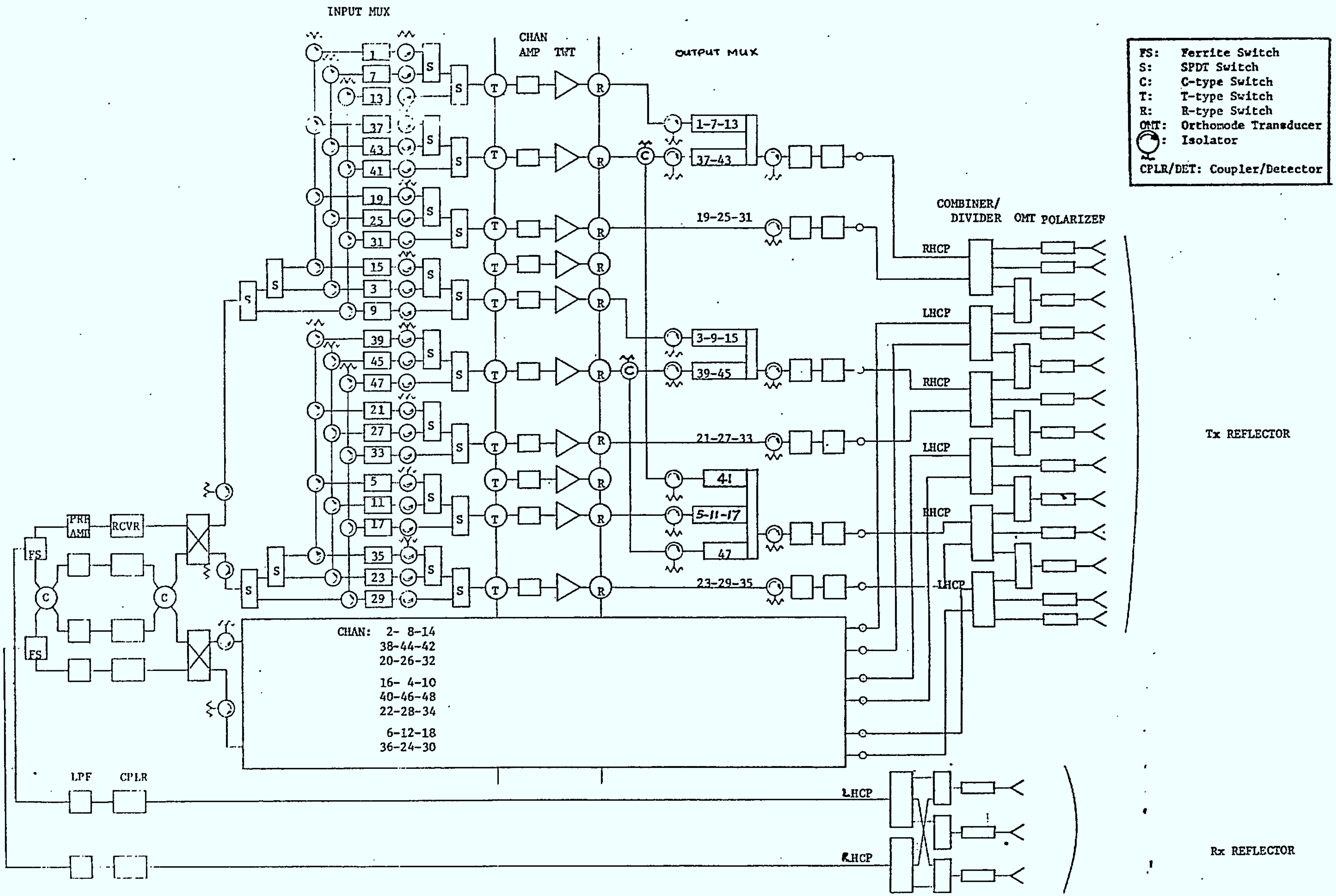


FIGURE 3.4 COMMUNICATIONS SUBSYSTEM CONFIGURATION 168/16

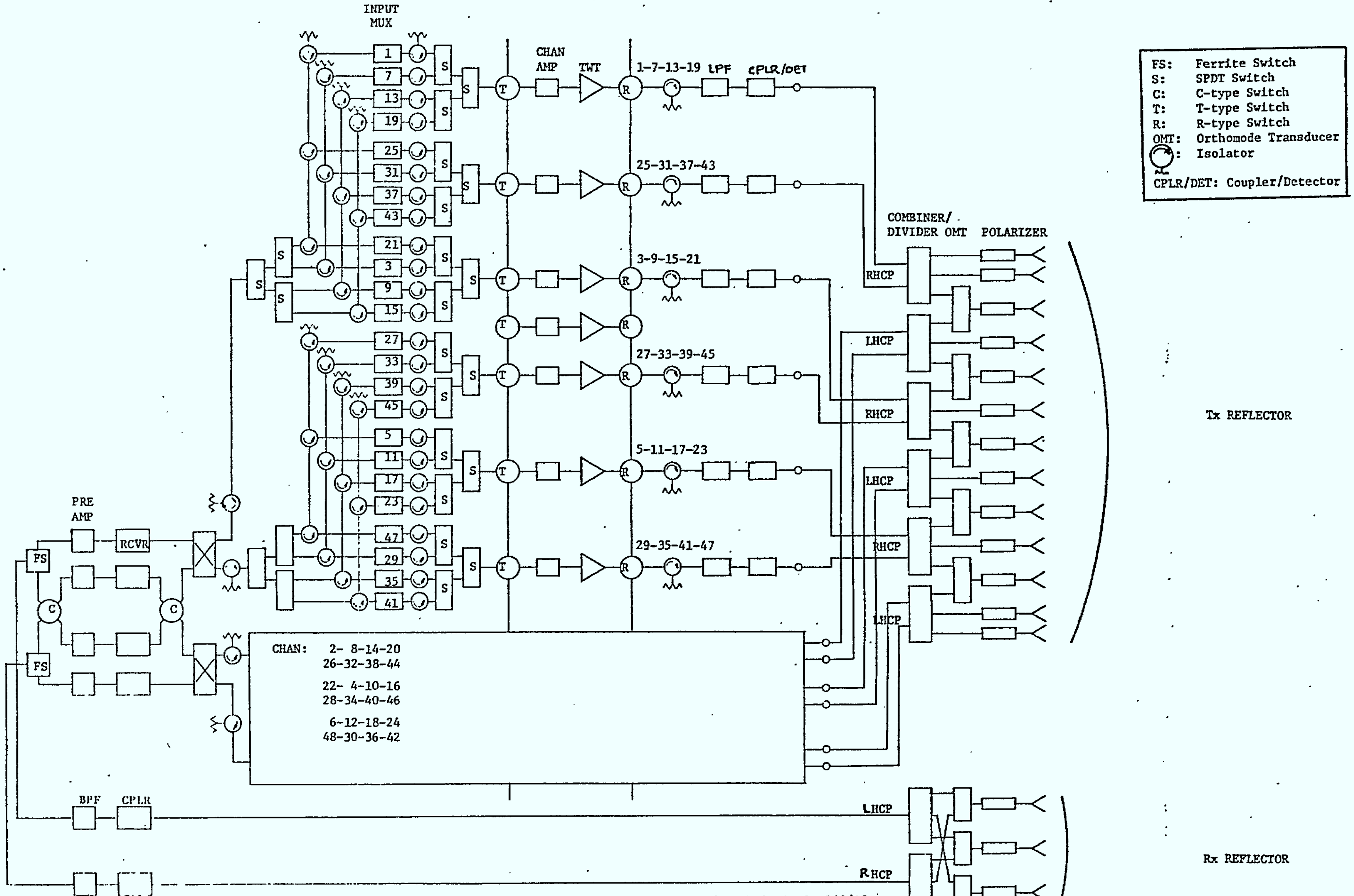


FIGURE 3.5 COMMUNICATIONS SUBSYSTEM CONFIGURATION 168/12

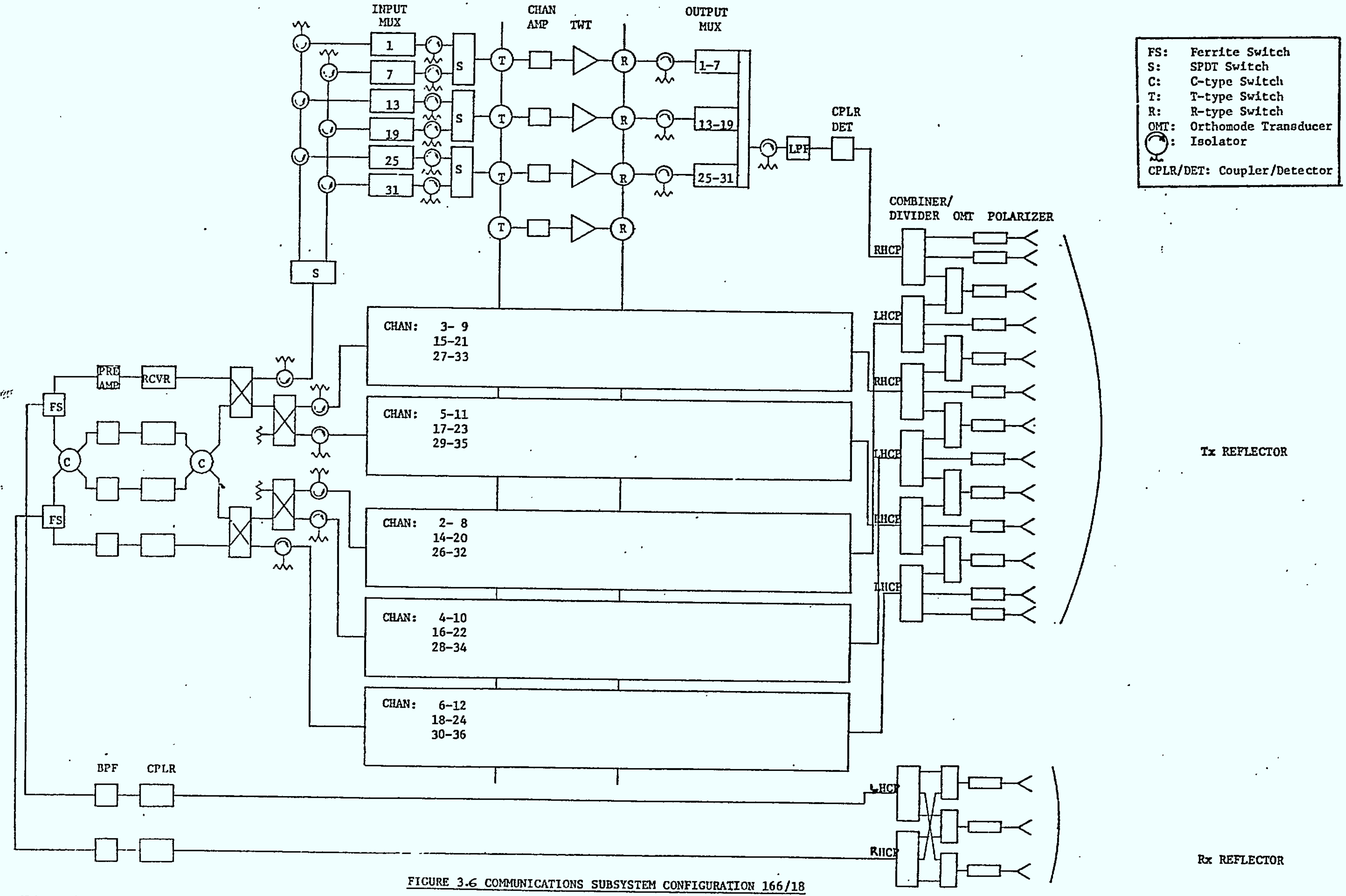


FIGURE 3.6 COMMUNICATIONS SUBSYSTEM CONFIGURATION 166/18

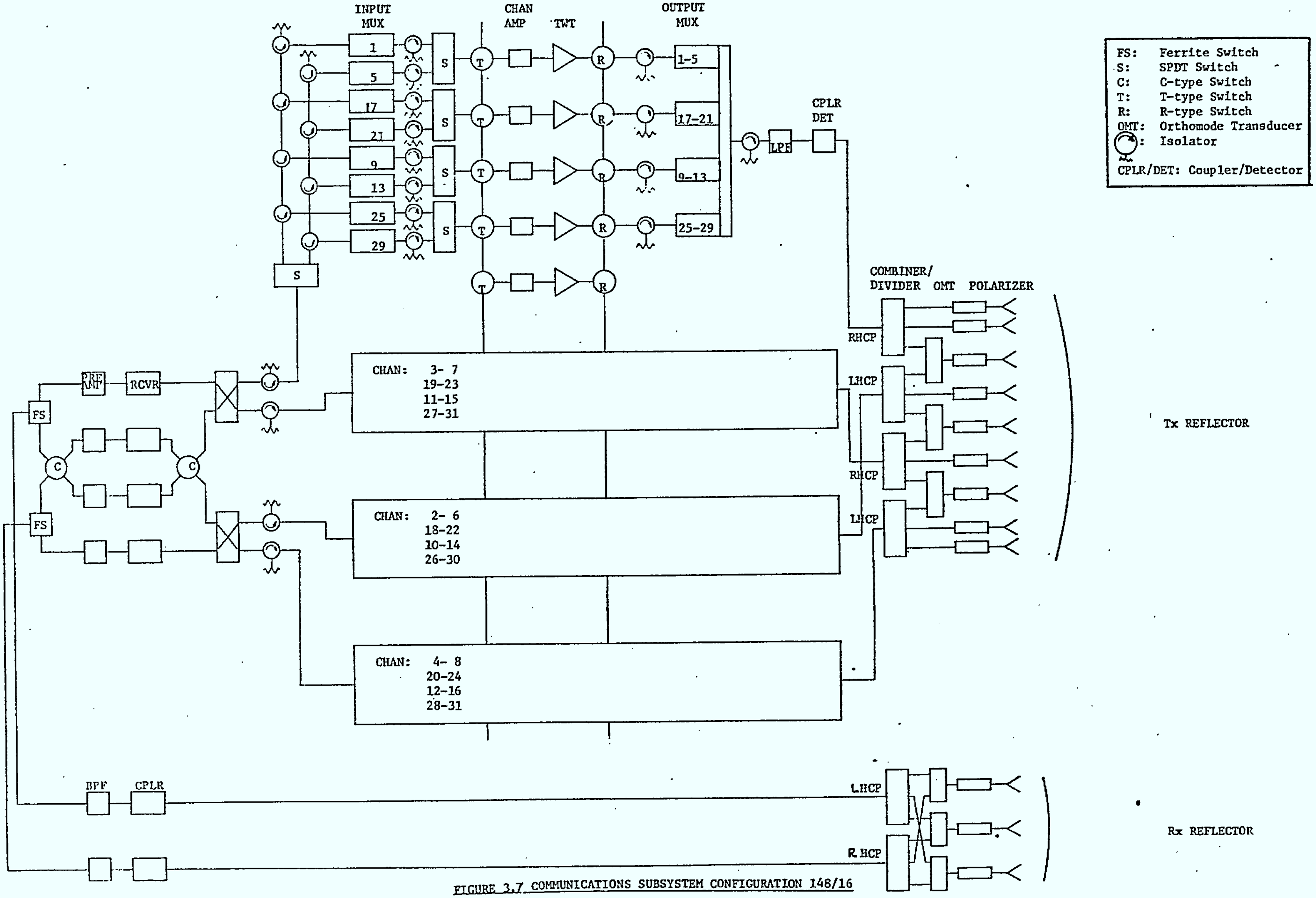


FIGURE 3.7 COMMUNICATIONS SUBSYSTEM CONFIGURATION 148/16

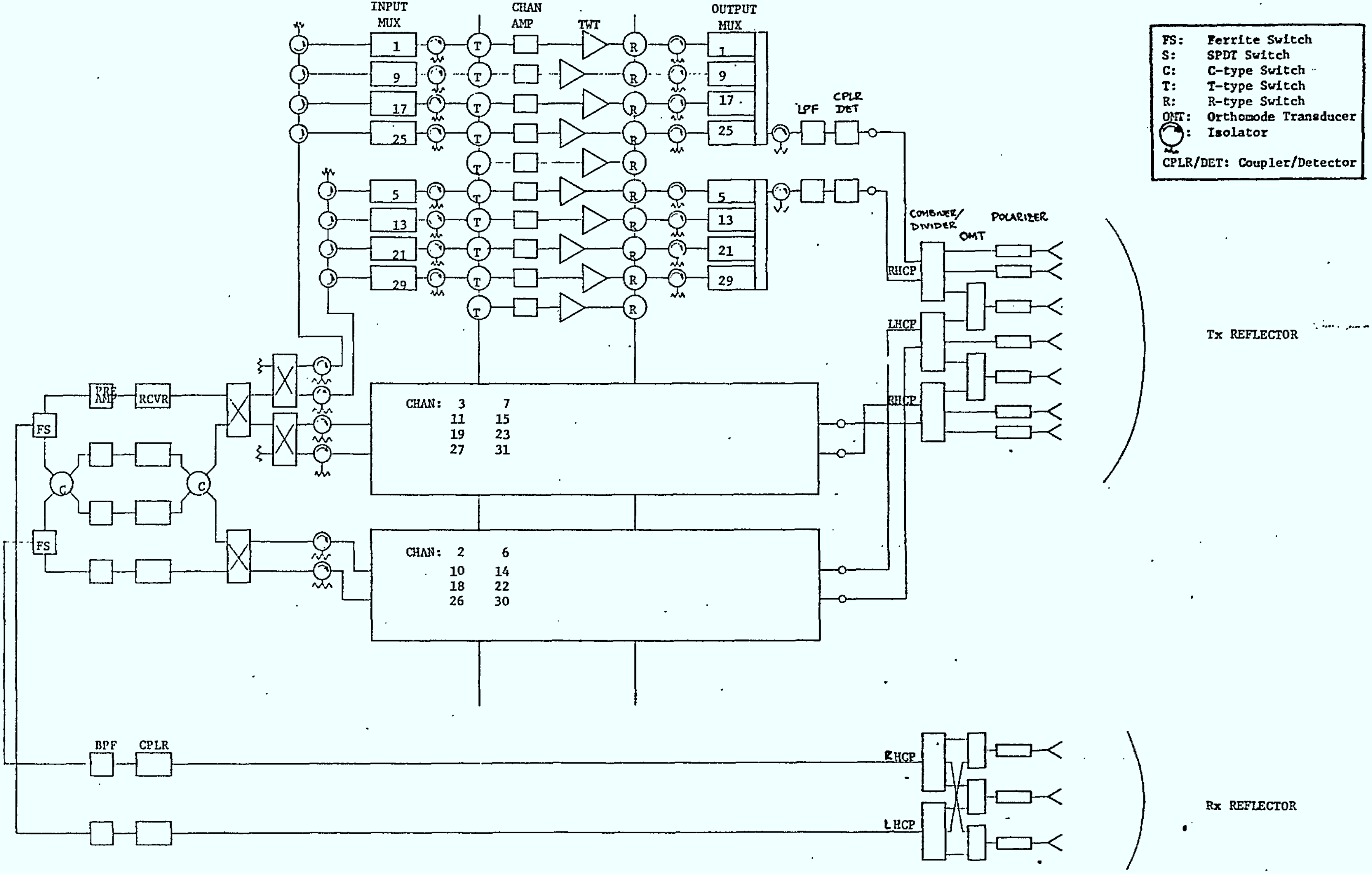


FIGURE 3.8 COMMUNICATIONS SUBSYSTEM CONFIGURATION 268/24

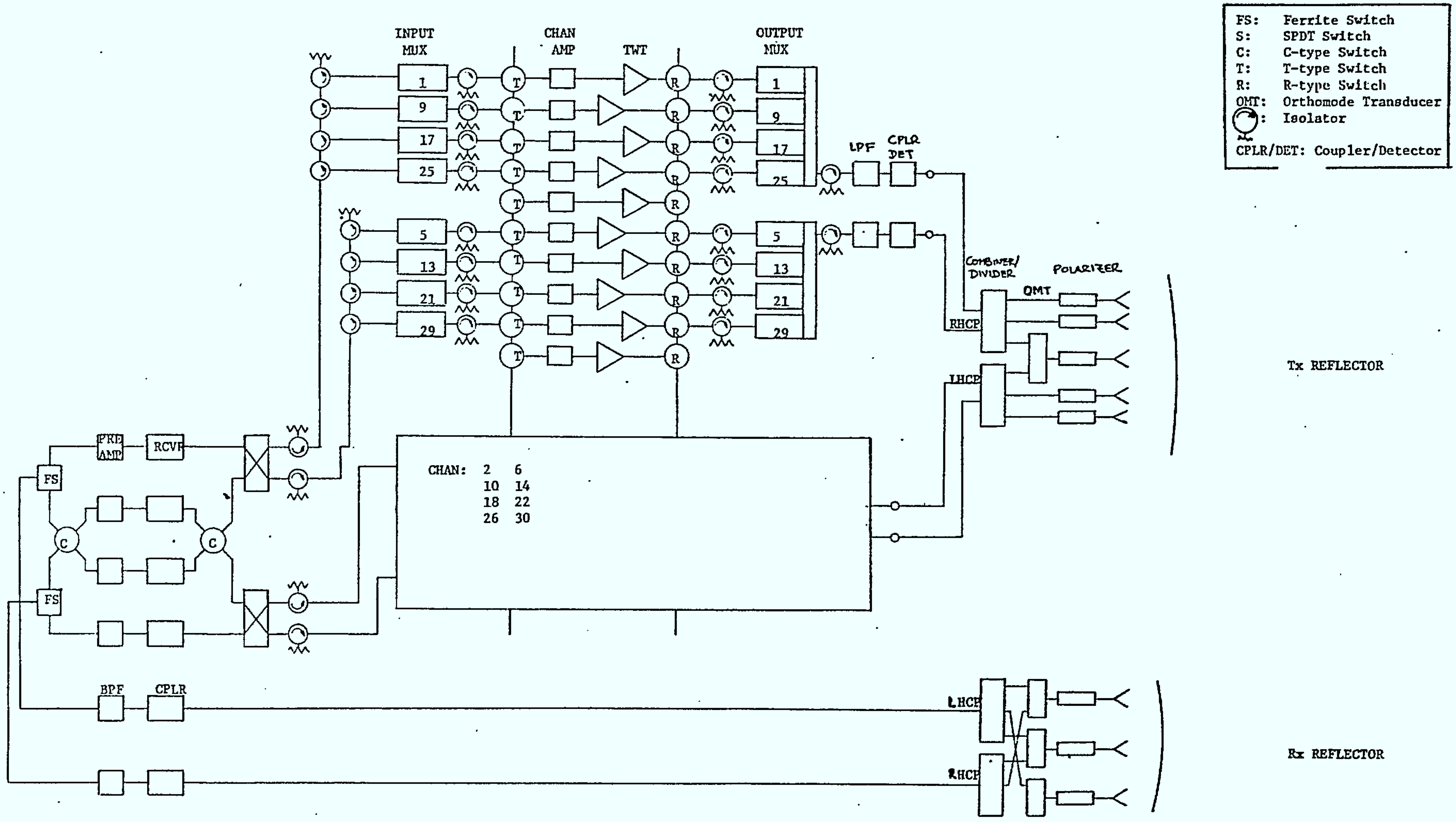


FIGURE 3.9 COMMUNICATIONS SUBSYSTEM CONFIGURATION 248/16

COMMUNICATIONS SUBSYSTEM CONFIGURATION		168/24		168/16		168/12		166/18		166/12		164/12	
UNIT	UNIT WEIGHT (KG)	NUMBER OF UNITS	TOTAL WEIGHT (KG)	NUMBER OF UNITS	TOTAL WEIGHT (KG)	NUMBER OF UNITS	TOTAL WEIGHT (KG)	NUMBER OF UNITS	TOTAL WEIGHT (KG)	NUMBER OF UNITS	TOTAL 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		} 8.67		8.67		8.67				8.67
COOLED 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	30	1.65	40	2.20	48	2.64	24	1.32	32	1.76	16	0.88
HYBRID	0.045	4	0.18	2	0.09	2	0.09	4	0.18	2	0.09	2	0.09
COAX ISOLATOR	0.030	102	3.06	100	3.00	100	3.00	78	2.34	76	2.28	52	1.56
COAX CIRCULATOR	0.030												
CHANNEL FILTER	0.15	48	7.20	48	7.20	48	7.20	36	5.40	36	5.40	24	3.60
COAX "T" SWITCH	0.14	30	4.20	20	2.80	14	1.96	22	3.08	14	1.96	14	1.96
CHANNEL AMPLIFIER	0.20	30	6.00	20	4.00	14	2.80	22	4.40	14	2.80	14	2.80
TWT		30		20		14		22		14		14	
EPC		30		20		14		22		14		14	
W/G "R" SWITCH	0.25	30	7.50	22	5.50	14	3.50	22	5.50	14	3.50	14	3.50
W/G ISOLATOR	0.085	24	2.04	20	1.70	12	1.02	18	1.53	12	1.02	12	1.02
OUTPUT MUX/CHAN	0.10	24	2.40	20	2.00	12	1.20	18	1.80	12	1.20	12	1.20
W/G ISOLATOR	0.06	6	0.36	6	0.36	6	0.36	6	0.36	6	0.36	6	0.36
HARMONIC FILTER	0.07	6	0.42	6	0.42	6	0.42	6	0.42	6	0.42	6	0.42
COUPLER/DETECTOR	0.045	6	0.27	6	0.27	6	0.27	6	0.27	6	0.27	6	0.27
COAX CABLES	0.032/1'cable	204	6.53	180	5.76	190	6.08	174	5.57	150	4.80	106	3.39
WIRE HARNESS	0.25/TWTA+2	30	9.50	20	7.00	14	5.50	22	7.50	14	5.50	14	5.50
W/G + BRACKETS + HARDW.	0.10/Filter	72	7.20	68	6.80	60	6.00	54	5.40	48	4.80	36	3.60
TRANSPONDER W/O TWTA'S			69.10		57.77		50.71		53.74		44.83		38.82
			Note 1										

Note 1: Weight includes Group Delay equalizers of 1.9 Kg total weight.

TABLE 3.1 TRANSPONDER WEIGHT ESTIMATE EXCLUDING TWTAs

COMMUNICATIONS SUBSYSTEM CONFIGURATION		148/16		149/12		144/16		268/12		268/24		248/16	
UNIT	UNIT WEIGHT (KG)	NUMBER OF UNITS	TOTAL WEIGHT (KG)	NUMBER OF UNITS	TOTAL WEIGHT (KG)	NUMBER OF UNITS	TOTAL WEIGHT (KG)	NUMBER OF UNITS	TOTAL WEIGHT (KG)	NUMBER OF UNITS	TOTAL WEIGHT (KG)	NUMBER OF UNITS	TOTAL WEGHT (KG)
COUPLER	0.045												
W/B FILTER	0.20												
W/G FERR. SWITCH (FS)	0.185												
W/G TRANS. SWITCH (C)	0.23		8.67		8.67		8.67		8.67		8.67		8.67
COOLED FET PREAMP	0.27												
RECEIVER	1.60												
COAX TRANS. SWITCH (C)	0.10												
COAX SPDT SWITCH (S)	0.055	20	1.10	32	1.75	—	--	15	0.83	—	—	—	—
HYBRID	0.045	2	0.09	2	0.09	2	0.09	2	0.09	4	0.18	2	0.09
COAX ISOLATOR	0.030	68	2.04	76	2.28	36	1.08	51	1.53	54	1.62	36	1.08
COAX CIRCULATOR	0.030												
CHANNEL FILTER	0.15	32	4.80	36	5.40	16	2.40	24	3.60	24	3.60	16	2.40
COAX "T" SWITCH	0.14	20	2.80	14	1.96	20	2.80	15	2.10	30	4.20	20	2.80
CHANNEL AMPLIFIER	0.20	20	4.00	14	2.80	20	4.00	15	3.00	30	6.00	20	4.00
TWT		20		14		20		15		30		20	
EPC		20		14		20		15		30		20	
W/G "R" SWITCH	0.25	20	5.00	14	3.50	20	5.00	15	3.75	30	7.50	20	5.00
W/G ISOLATOR	0.085	16	1.36	12	1.02	16	1.36	12	1.02	24	2.04	16	1.36
OUTPUT MUX/CHAN	0.10	16	1.60	12	1.20	16	1.60	12	1.20	24	2.40	16	1.60
W/G ISOLATOR	0.06	4	0.24	4	0.24	4	0.24	3	0.18	3	0.18	2	0.12
HARMONIC FILTER	0.07	4	0.28	4	0.28	4	0.28	3	0.21	3	0.21	2	0.14
COUPLER/DETECTOR	0.045	4	0.18	4	0.18	4	0.18	3	0.14	3	0.14	2	0.09
COAX CABLES	0.032/1'Cable	148	4.74	148	4.74	96	3.07	111	3.55	144	4.61	96	3.07
WIRE HARNESS	0.25/TWTA+2	20	7.00	14	5.50	20	7.00	15	5.75	30	9.50	20	7.00
W/G + BRACKETS + HARDW.	0.10/Filter	48	4.80	48	4.80	32	3.20	36	3.60	48	4.80	32	3.20
TRANSPONDER W/O TWTAS			48.70		44.41		40.97		39.22		55.65		40.62

TABLE 3.2 TRANSPONDER WEIGHT ESTIMATE EXCLUDING TWTAs

COMMUNICATIONS SUBSYSTEM CONFIGURATION		148/32		168/48		166/36		248/8		164/24			
UNIT	UNIT WEIGHT (KG)	NUMBER OF UNITS	TOTAL WEIGHT (KG)	NUMBER OF UNITS	TOTAL WEIGHT (KG)	NUMBER OF UNITS	TOTAL WEIGHT (KG)	NUMBER OF UNITS	TOTAL WEIGHT (KG)	NUMBER OF UNITS	TOTAL WEIGHT (KG)	NUMBER OF UNITS	TOTAL WEGHT (KG)
COUPLER	0.045												
W/B FILTER	0.20												
W/G FERR. SWITCH (FS)	0.185												
W/G TRANS. SWITCH (C)	0.23		8.67		8.67		8.67		8.67				
COOLED FET PREAMP	0.27												
RECEIVER	1.60												
COAX TRANS. SWITCH (C)	0.10												
COAX SPDT SWITCH (S)	0.055	--		--		—		8					
HYBRID	0.045	2	0.09	2	0.09	2	0.09	2	0.09				
COAX ISOLATOR	0.030	68	2.04	102	3.06	78	2.34	36	1.08				
COAX CIRCULATOR	0.030	--		--		—		--					
CHANNEL FILTER	0.15	32	4.80	48	7.20	36	5.40	16	2.40				
COAX "T" SWITCH	0.14	40	5.60	60	8.40	44	6.16	10	1.40				
CHANNEL AMPLIFIER	0.20	40	3.00	60	12.00	44	8.80	10	2.00				
TWT													
EPC													
W/G "R" SWITCH	0.25	40	10.00	60	15.00	44	11.00	10	2.50				
W/G ISOLATOR	0.085	32	2.72	48	4.08	36	3.06	8	0.68				
OUTPUT MUX/CHAN	0.10	32	3.20	48	4.80	36	3.60	8	0.80				
W/G ISULATOR	0.06	8	0.48	12	0.72	12	0.72	4	0.24				
HARMONIC FILTER	0.07	8	0.56	12	0.84	12	0.84	4	0.28				
COUPLER/DETECTOR	0.045	8	0.36	12	0.54	12	0.54	4	0.18				
COAX CABLES	0.032/1'Cable	230	7.36	350	11.20	250	8.00	60	1.92				
WIRE HARNESS	0.25/TWTA+2	40	12.00	60	17.00	44	13.00	10	4.50				
W/G + BRACKETS + HARDW.	0.10/Filter	64	6.40	96	9.60	72	7.20	24	2.40				
TRANSPONDER W/O TWTA'S			72.28		103.20		79.42		29.14		55.65		
		Note 2		Note 2		Note 2		Note 2			Note 3		

Note 2: Number of small components is not an exact count.

Note 3: Total weight is assumed to be same as that of 268/24 which is similar configuration.

TABLE 3.3 TRANSPONDER WEIGHT ESTIMATE EXCLUDING TWTAs

	UNIT	UNIT WEIGHT (kg)	NUMBER OF UNITS (4 BEAM)	TOTAL WEIGHT (kg)
Tx FEED	Horn	0.075	18	1.35
	Polarizer	0.045	18	0.81
	OMT	0.045	3	0.135
	Power Divider	0.180	4	0.72
	Horn Bracketry	0.680	1 Set	0.680
	Feed Bracketry	0.910	1 Set	0.910
	W/G	2.700	1 Set	2.70
	Tx FEED TOTAL		-	7.305
Rx FEED	Horn	0.056	6	0.336
	Polarizer	0.034	6	0.204
	OMT	0.034	3	0.102
	3 to 1 Combiner	0.135	2	0.270
	Horn Bracketry		Set	0.227
	Feed Bracketry		Set	0.303
	W/G		Set	0.900
	Rx FEED TOTAL			2.34
	8' Reflector	9.0		9.0
	Deployment & Support	5.7		5.9
	3' Reflector	2.7		2.7
	REFLECTOR TOTAL			17.6
	ANTENNA TOTAL			27.3
	Contigency			+ 10%
	TOTAL BUDGET			30 Kg

TABLE 3.4 ANTENNA WEIGHT ESTIMATE

(FOUR BEAM CASE SHOWN)

COMMUNICATIONS SUBSYSTEM WEIGHT AND PRIMARY POWER SUMMARY

COMM S/S CONFIGURATION	168/24	168/16	168/12	166/18	166/12	164/24	164/12	148/16	149/12	144/16	268/12	268/24	248/16	
TRANSPONDER (kg)	69.1	57.8	50.7	53.7	44.8	55.7	38.8	48.7	44.4	41.0	39.2	55.7	40.6	
ANTENNA SYST. (kg)	34.0	34.0	34.0	34.0	34.0	34.0	34.0	30.0	30.0	300	28.0	28.0	26.0	
TWTAs (kg) 53 dBw	135.0	90.0	63.0	99.0	63.0	135.0	63.0	90.0	63.0	90.0	67.5	135.0	90.0	
TOTAL WEIGHT (kg) for 53 dBw	238.1	181.8	147.7	186.7	141.8	224.7	135.8	168.7	137.4	161.0	134.7	218.7	156.6	
PRIMARY POWER (w)														
6 BEAM: 123 w/chan	2952	1968	1476	2214	1476	2952	1476	———	———	———	1476	2952	———	
4 BEAM: 150 w/chan	———	———	———	———	———	———	———	2400	1800	2400	———	———	2400	
TWTAs (kg) 58 dBw	228.0	152.0	106.4	167.2	106.4	228.0	106.4	228.0	159.6	228.0	114.0	228.0	228.0	
TOTAL WEIGHT (kg) for 58 dBw	331.1	243.8	191.7	254.9	185.2	317.7	179.2	306.7	234.0	299.0	181.2	311.7	294.6	
PRIMARY POWER (w)														
6 BEAM: 338 w/chan	8112	5408	4056	6084	4056	8112	4056	———	———	———	4056	8112	———	
4 BEAM: 475 w/chan	———	———	———	———	———	———	———	7600	5700	7600	———	———	7600	

TABLE 3.5 COMMUNICATIONS SUBSYSTEM WEIGHT AND PRIMARY POWER SUMMARY

COMMUNICATIONS SUBSYSTEM WEIGHT AND PRIMARY POWER SUMMARY

COMM S/S CONFIGURATION	148/32	168/48	166/36	248/8										
TRANSPONDER (kg)	72.3	103.2	79.4	29.1										
ANTENNA SYST. (kg)	30.0	34.0	34.0	26.0										
TWTAs (kg)														
53 dBw	180.0	270.0	198.0	45										
TOTAL WEIGHT (kg)	282.3	407.2	311.4	100.1										
for 53 dBw														
PRIMARY POWER (w)														
6 BEAM: 123 w/chan	—	5904	4428	—										
4 BEAM: 150 w/chan	4800	—	—	1200										
TWTAs (kg)				114.0										
58 dBw														
TOTAL WEIGHT (kg)				169.1										
for 58 dBw														
PRIMARY POWER (w)														
6 BEAM: 338 w/chan				—										
4 BEAM: 475 w/chan				3800										

TABLE 3.6 COMMUNICATIONS SUBSYSTEM WEIGHT AND PRIMARY POWER SUMMARY

4.0 SPACECRAFT-LAUNCHER WEIGHT AND POWER CAPABILITY

The available payload weight and power from a given spacecraft Bus/Launch vehicle combination is provided in this section.

The data provided is generally an update of the information provided in Spar Report R.972 and deals with the following four classes of spacecraft:

Class 1 - PAM-D/Ariane SYLDA
Class 2 - PAM-A/Ariane III
Class 3 - Ariane IV
Class 4 - STS optimized.

Class 1 - PAM-D/Ariane SYLDA

The spacecraft bus used for this class is the GPB (General Purpose Bus) and is based on the design studies performed by Spar including the Canadian Domestic Bus (CDB) proposed for the MUSAT spacecraft which included a major portion of Anik-D equipment.

Class 2 - PAM-A/Ariane Dedicated

Two spacecraft buses are considered for this class:

a) X GPB; based on the GPB but sized to accomode the greater capabilities of the PAM-A/Ariane launch vehicles - this was the selected bus from the previous study Spar R.972.

b) L-Sat; based on published data received during recent presentations by British Aerospace (BAe) to both Spar and DOC.

Class 3 - Ariane IV

L-Sat is again considered in this class based on the published data from BAe. The X GPB was also considered in this class by extrapolating again from the GPB and XGPB designs.

Class 4 - STS optimized

One spacecraft bus system is considered for this class; the HAC Leasat type with a deployable solar drum. This is based on published data for a 15 ft spacecraft using a hydrazine system and in house estimates for the weight and power effects of adding up to a 15 ft deployable drum solar array, providing a 4 kW solar array, and estimates for the weight of reducing eclipse capability to 50%, 30% and 0%.

4.0 (continued)

For each of the spacecraft systems investigated above, the available weight for the communications payload and the power subsystem was derived by subtracting the total weight of each of the remaining subsystems, the fuel requirements and the spacecraft system margin from the allowable launch weight. The results are shown in Table 4.1 for each spacecraft system, however, in the case of L-Sat and Leasat, a complete subsystem breakdown was not available and communications/ power subsystem available weights were provided directly.

	CLASS 1		CLASS 2			CLASS 3		CLASS 4
SUBSYSTEM	GPB-PAM-D	GPB SYLDA	XGPB-PAM-A	XGPB-ArIII	LSat ArIII	XGPB-ARIV	LSat-ArIV	DEP.LEASAT
CT&R & Omni	27	27	34	34		39		
ACS	32	32	39	43		52		
RCS	19	19	29	34		43		
Structure	61	61	95	104		136		
Thermal	23	23	32	32		41		
Harness	24	24	29	32		36		
AKM	30	29	64	64		73		
Balance Weights	5	5	7	7		9		
Bus Total	221	220	329	350		429		
RCS - 7 years	123	127	186	230		295		
RCS - 10 years	164	167	248	313		394		
Margin Philosophy	10% Dry +	2% RCS	20% Dry +	5% RCS		20%/5%		
Margin - 7 years	58	60	184	234		294		
- 10 years	55	57	174	222		280		
AKM expendables	567	499	880	956		1206		
Comms/Power weight available								@4Kw/50%
- 7 years	279	295	358	530	442	676	759	506*
- 10 years	241	257	306	459	360	591	660	363* Kg
TOTAL S/C Weight	1247 Kg	1200 Kg	1937 Kg	2300 Kg	2300 Kg	2900 Kg	2900 Kg	

* Comms. subsystem weight only.

TABLE 4.1 SPACECRAFT SUBSYSTEM SUMMARY - AVAILABLE PAYLOAD/POWER SUBSYSTEM WEIGHT

Communications Payload/Power Subsystem Weight

Given the allowable weight for the communications payload and Power subsystem weight, from Table 4.1, tradeoffs can be performed between the communications payload weight and total spacecraft power.

For L-Sat and Leasat, the tradeoff curves were provided directly and required only extrapolation for the Leasat deployable solar drum. For the GPB and XGPB the following assumptions were made for the power subsystem:

i) 30 watts/kg at BOL for the solar array

ii) 68% BOL power at 7 or 10 years EOL

iii) 28 watts/kg for the remainder of the power subsystem using Ni-H batteries (at 50% eclipse operation and 80% DOD).

For each spacecraft system, tradeoff curves have been plotted providing total spacecraft power versus communications subsystem weight for each of the following operational conditions.

- 10 year mission life
  - 50% eclipse operation
  - 30% eclipse operation
  - 0% eclipse operation

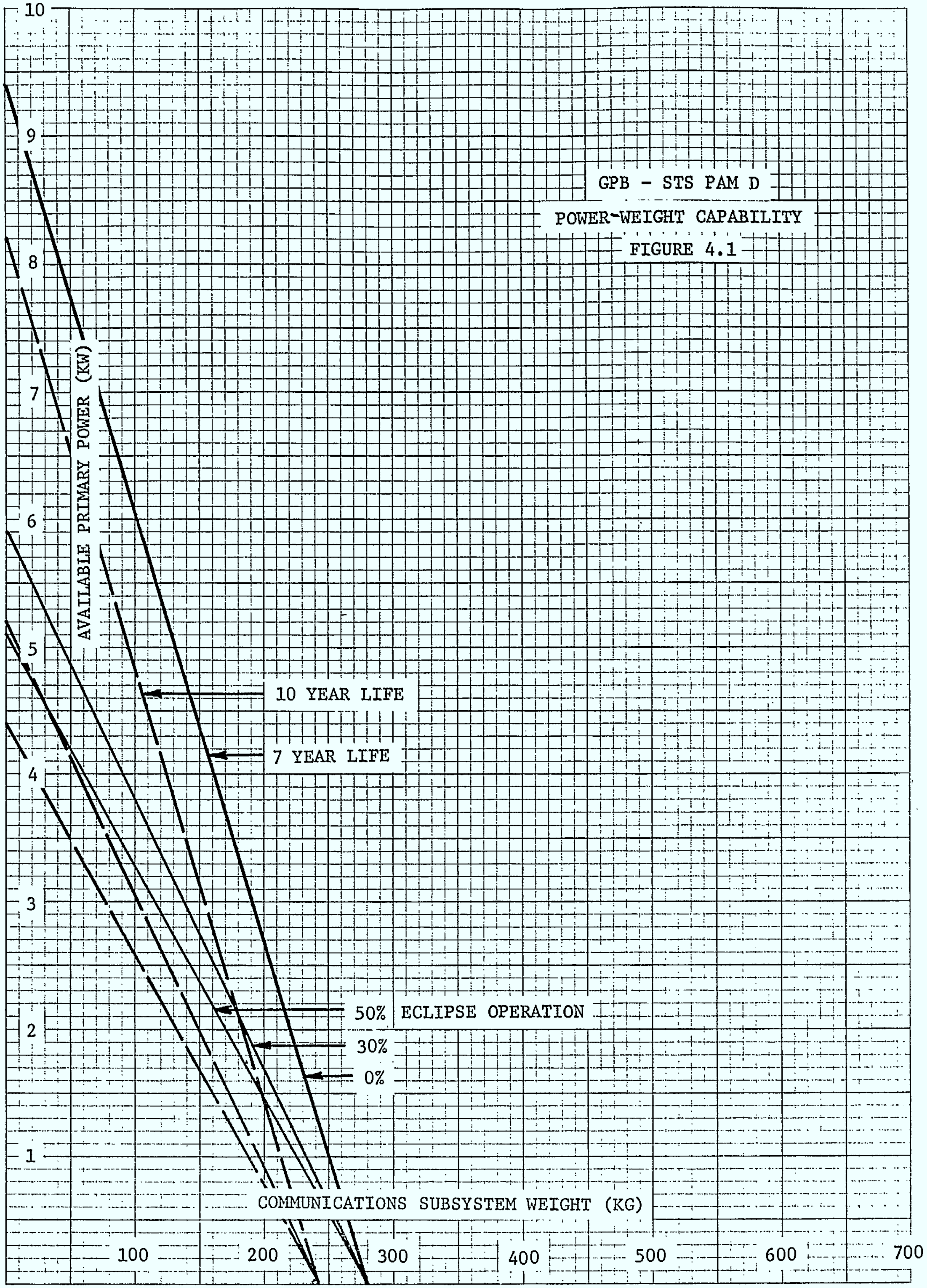
- 7 year mission life
  - 50% eclipse operation
  - 30% eclipse operation
  - 0% eclipse operation

The resulting tradeoff curves are provided as follows:

Figure 4.1	GPB with STS/PAM-D
Figure 4.2	GPB with Ariane/SYLDA
Figure 4.3	XGPB with STS/PAM-A
Figure 4.4	XGPB with Ariane III
Figure 4.5	XGPB with Ariane IV
Figure 4.6	L-Sat with Ariane III
Figure 4.7	L-Sat with Ariane IV
Figure 4.8	Deployable Leasat with STS.

Composite graphs containing Class 1, 2 and 3 bus/launcher tradeoff information.

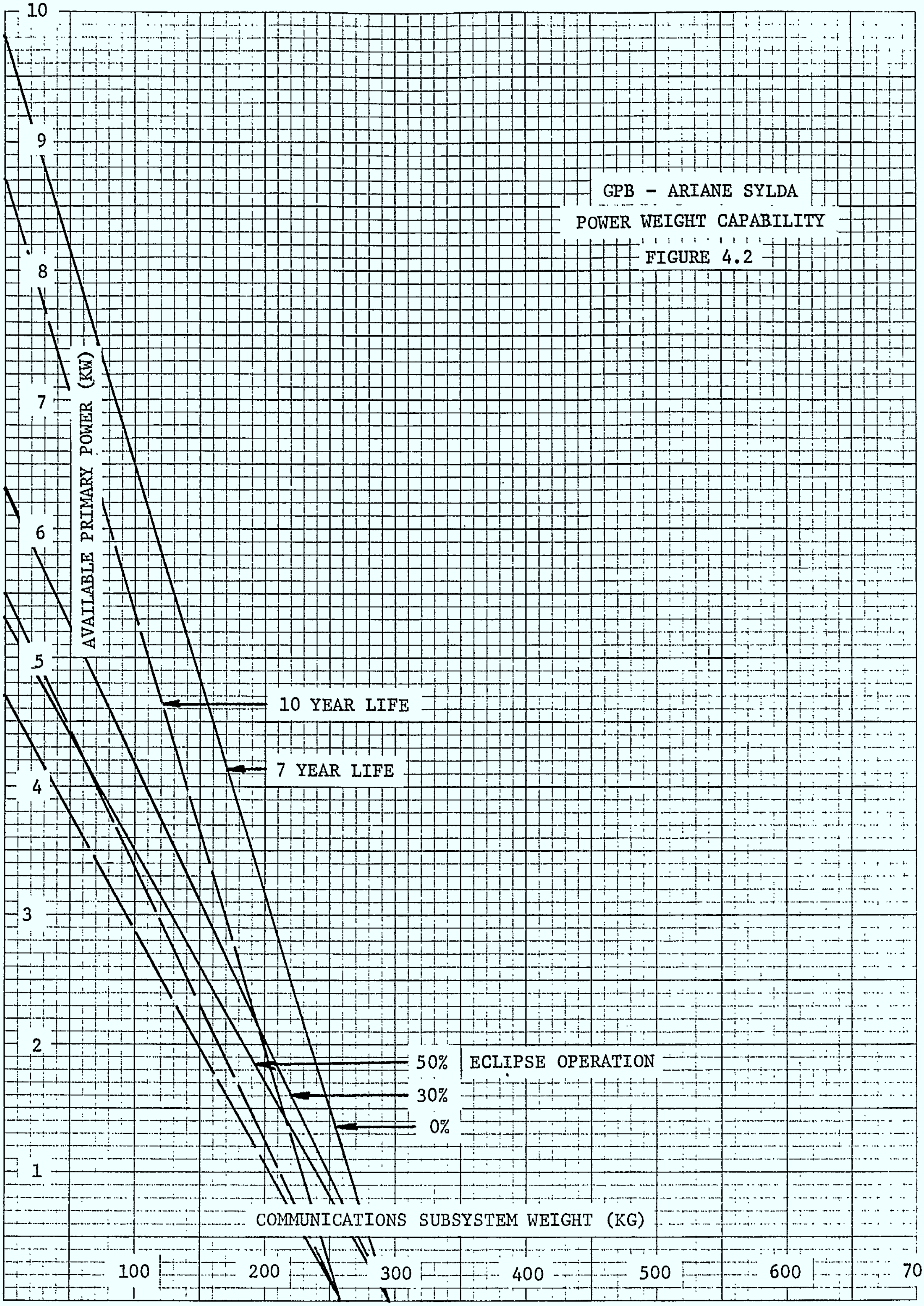
Figure 4.9	Based on 7 year life and 50% eclipse operation
Figure 4.10	Based on 7 year life and 30% eclipse operation
Figure 4.11	Based on 7 year life and 0% eclipse operation



GPB - STS PAM D

POWER-WEIGHT CAPABILITY

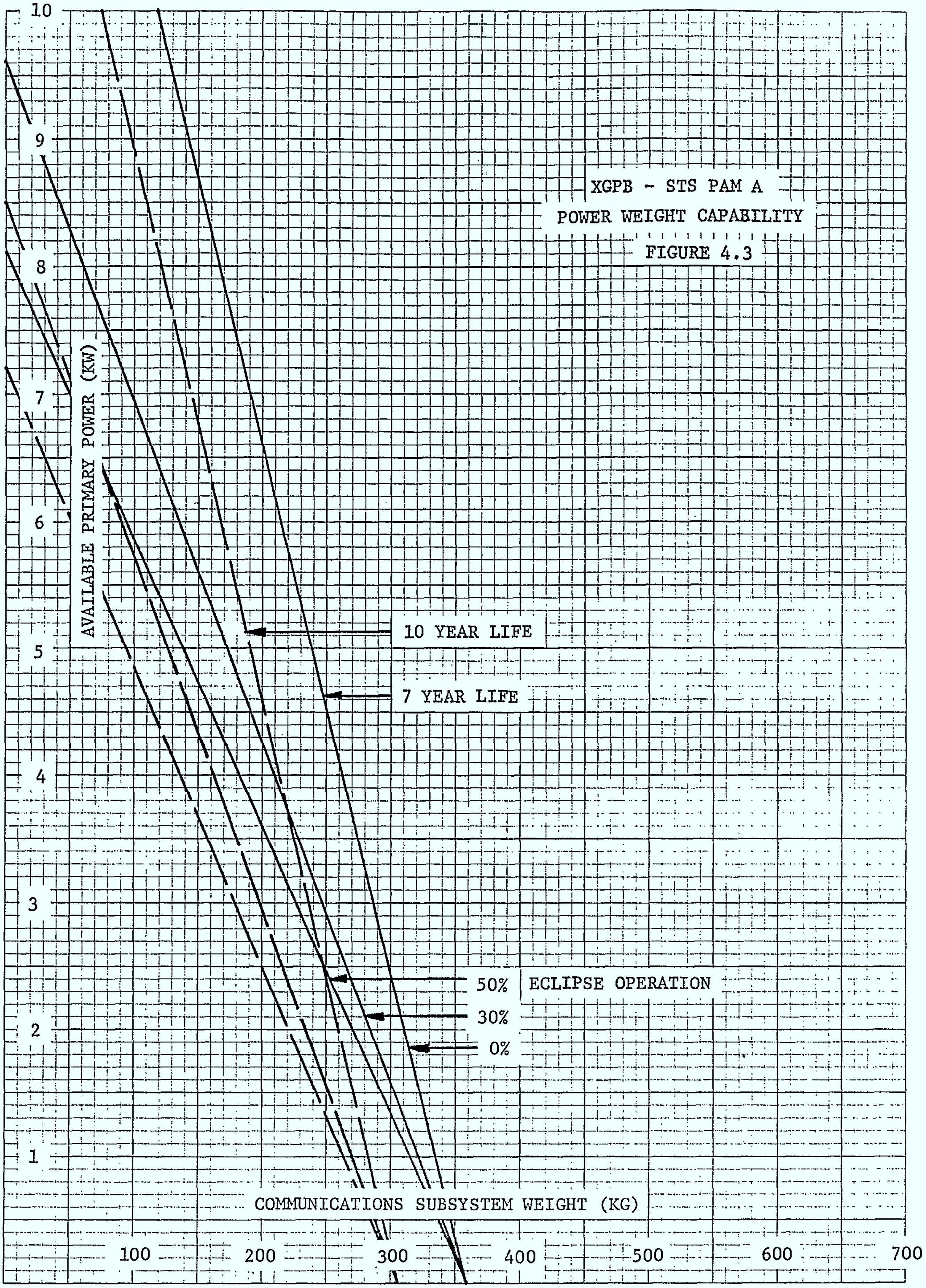
FIGURE 4.1



GPB - ARIANE SYLDA

POWER WEIGHT CAPABILITY

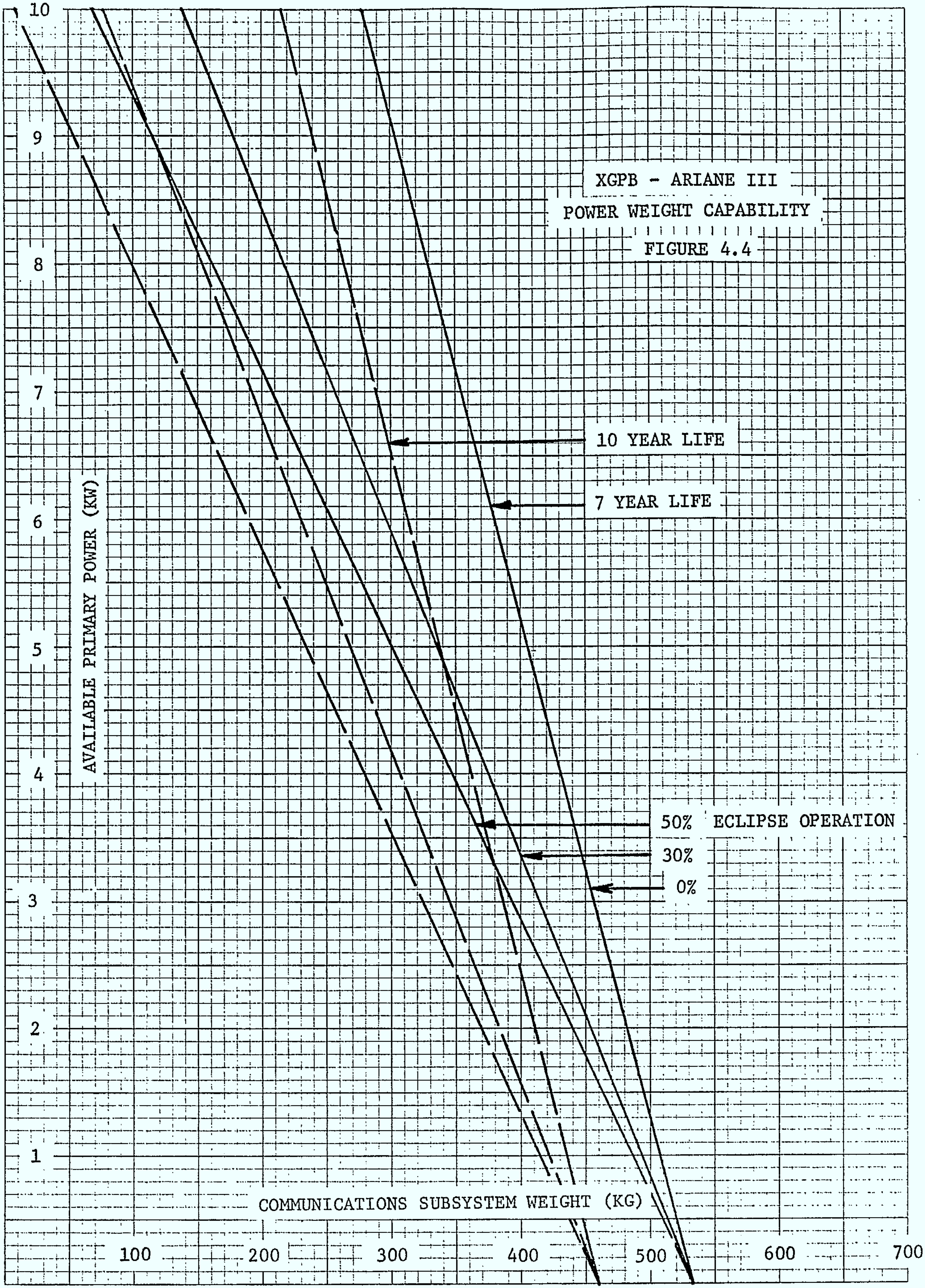
FIGURE 4.2



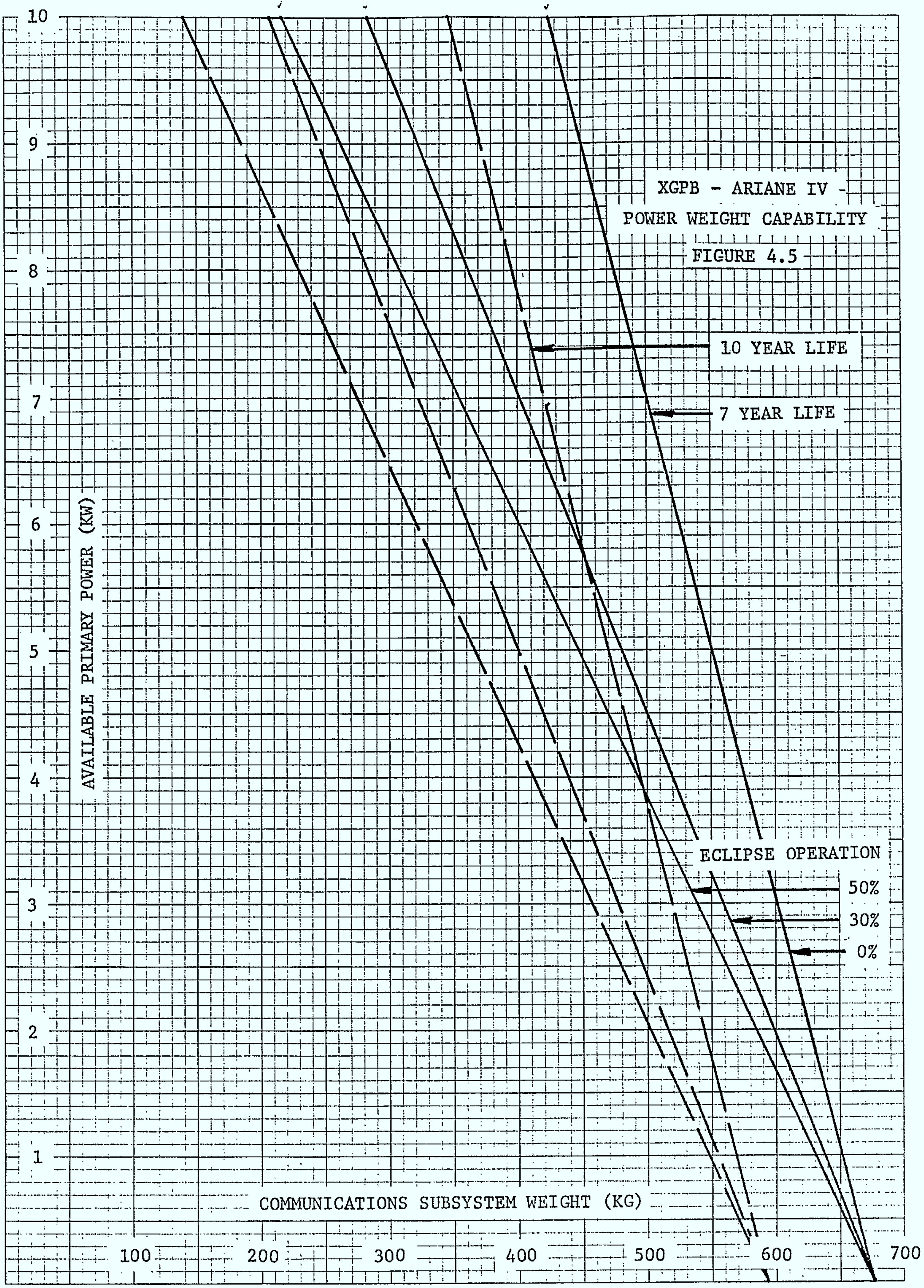
XGPB - STS PAM A

POWER WEIGHT CAPABILITY

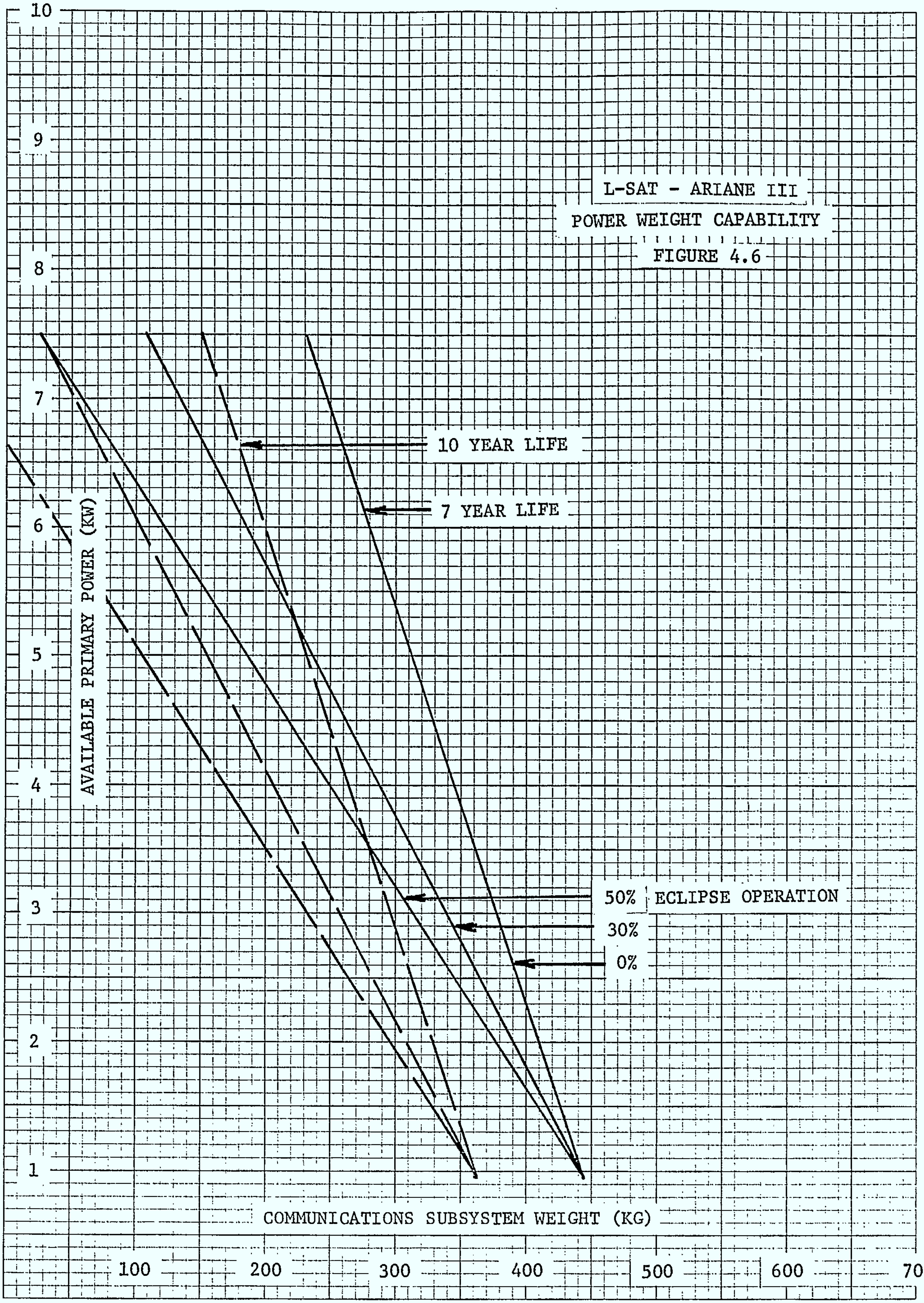
FIGURE 4.3



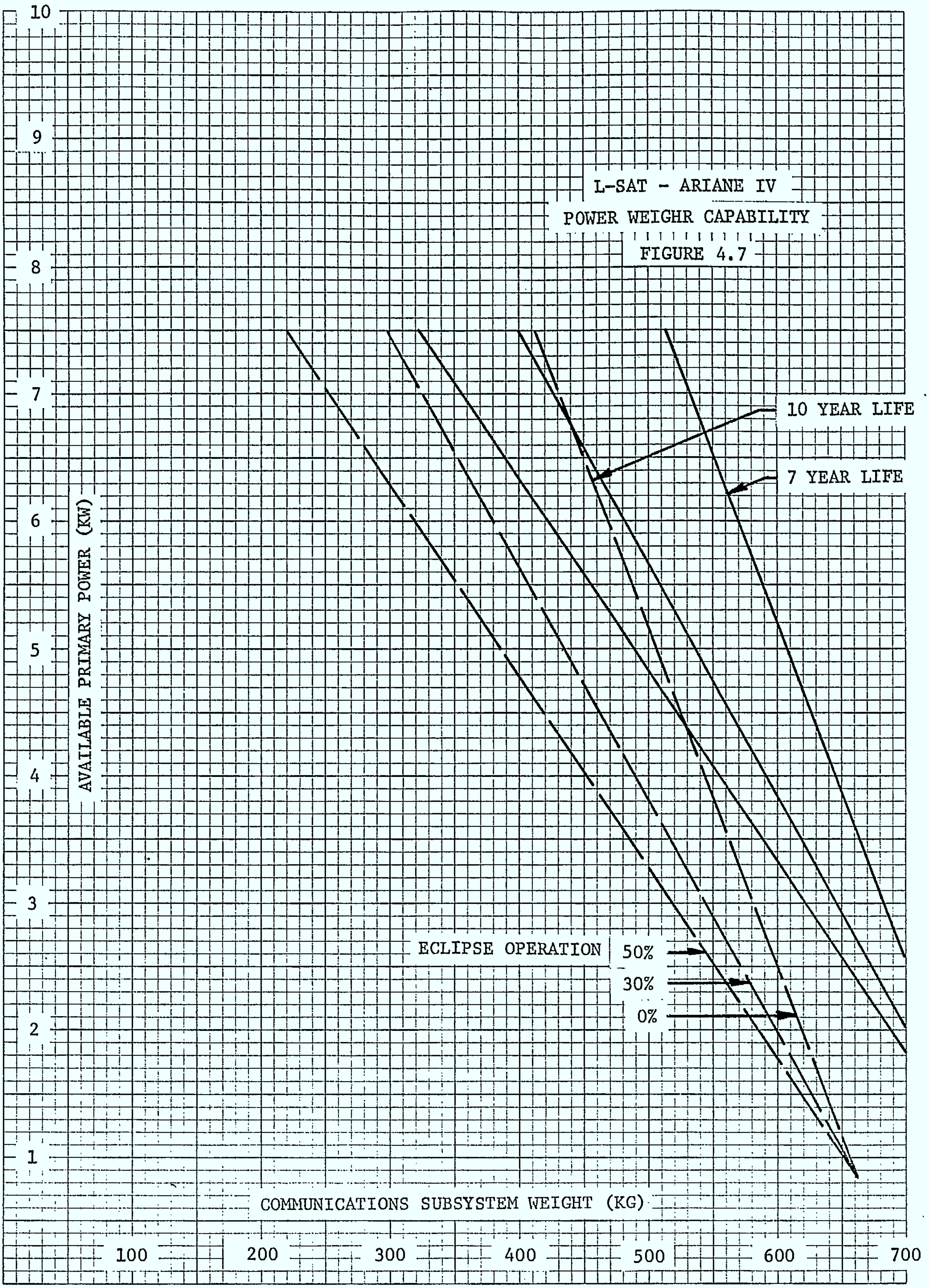
XGPB - ARIANE III
POWER WEIGHT CAPABILITY
FIGURE 4.4

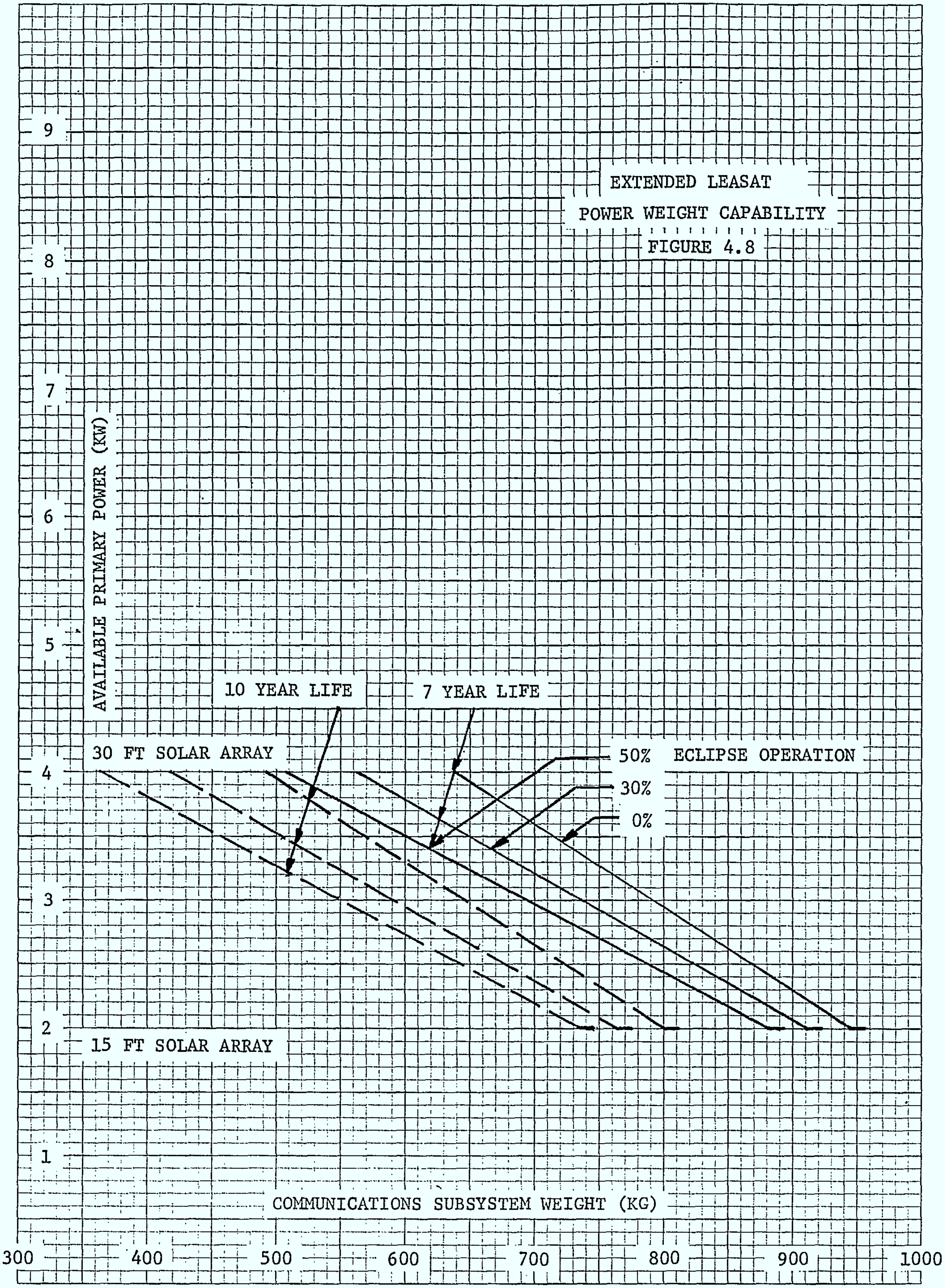


XGPB - ARIANE IV -
POWER WEIGHT CAPABILITY
FIGURE 4.5

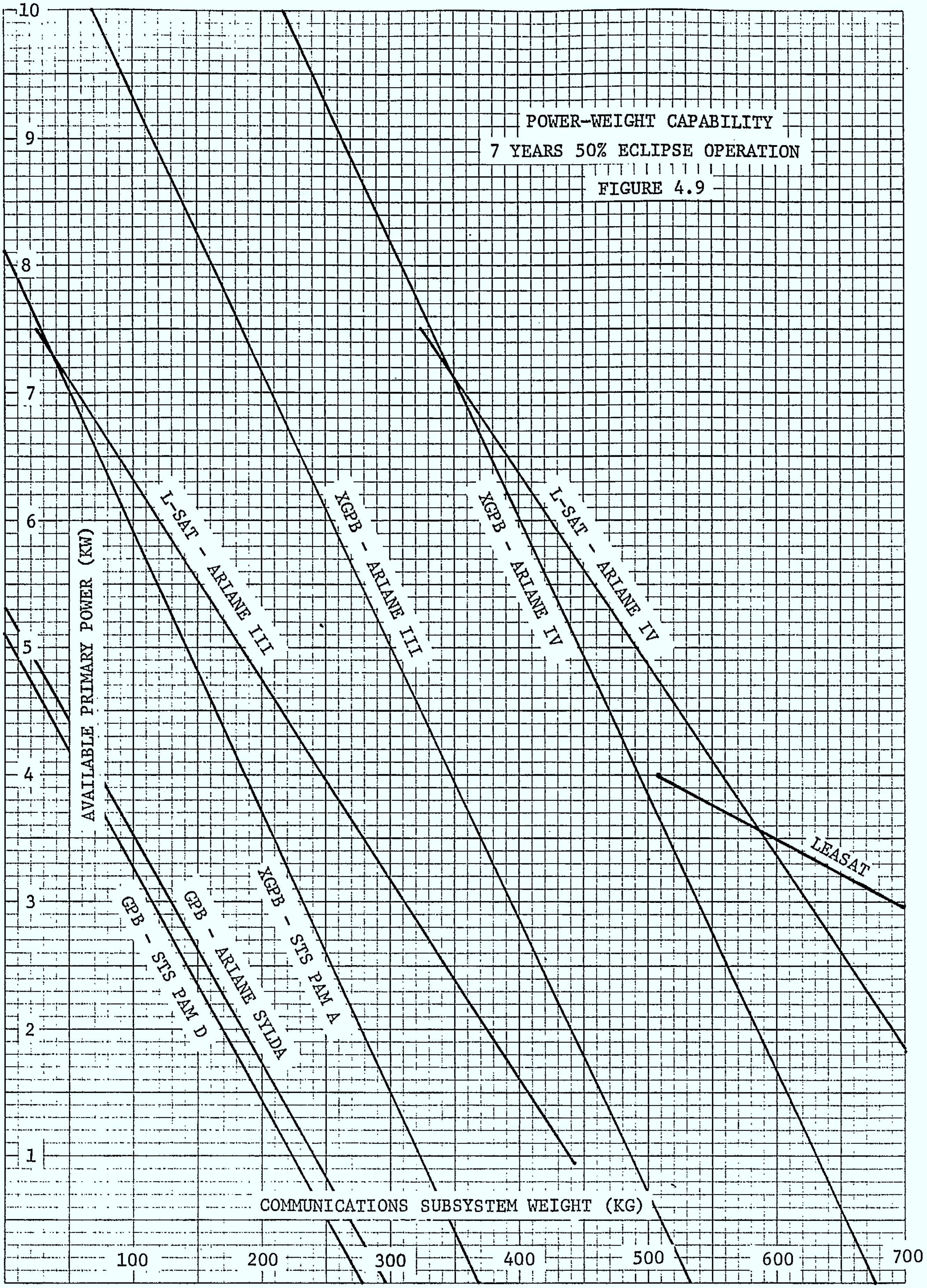


L-SAT - ARIANE III
POWER WEIGHT CAPABILITY
FIGURE 4.6


L-SAT - ARIANE IV
POWER WEIGHR CAPABILITY
FIGURE 4.7
10 YEAR LIFE
7 YEAR LIFE
AVAILABLE PRIMARY POWER (KW)
ECLIPSE OPERATION
50%
30%
0%
COMMUNICATIONS SUBSYSTEM WEIGHT (KG)
10
9
8
7
6
5
4
3
2
1
100
200
300
400
500
600
700



EXTENDED LEASAT
POWER WEIGHT CAPABILITY
FIGURE 4.8



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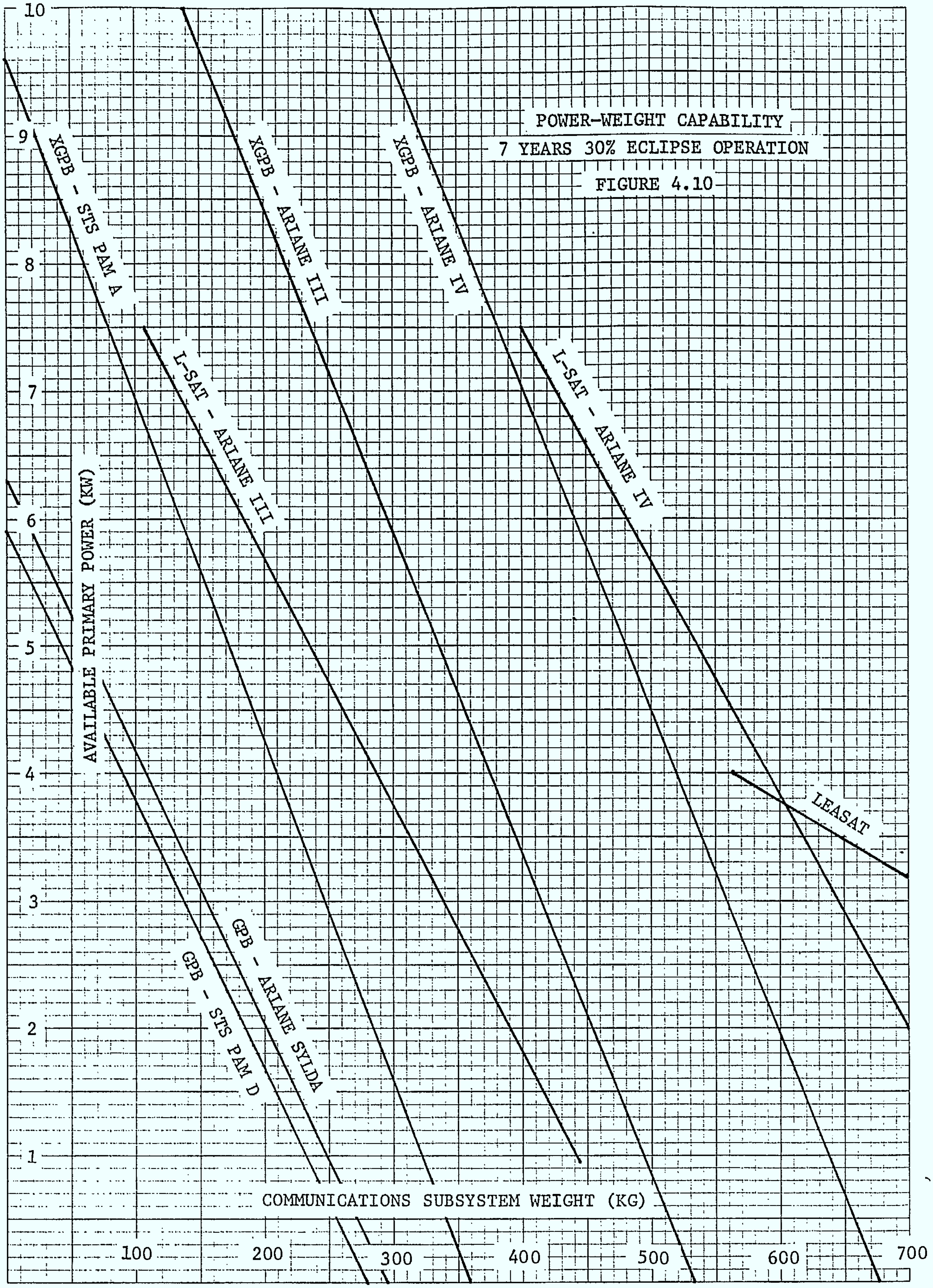
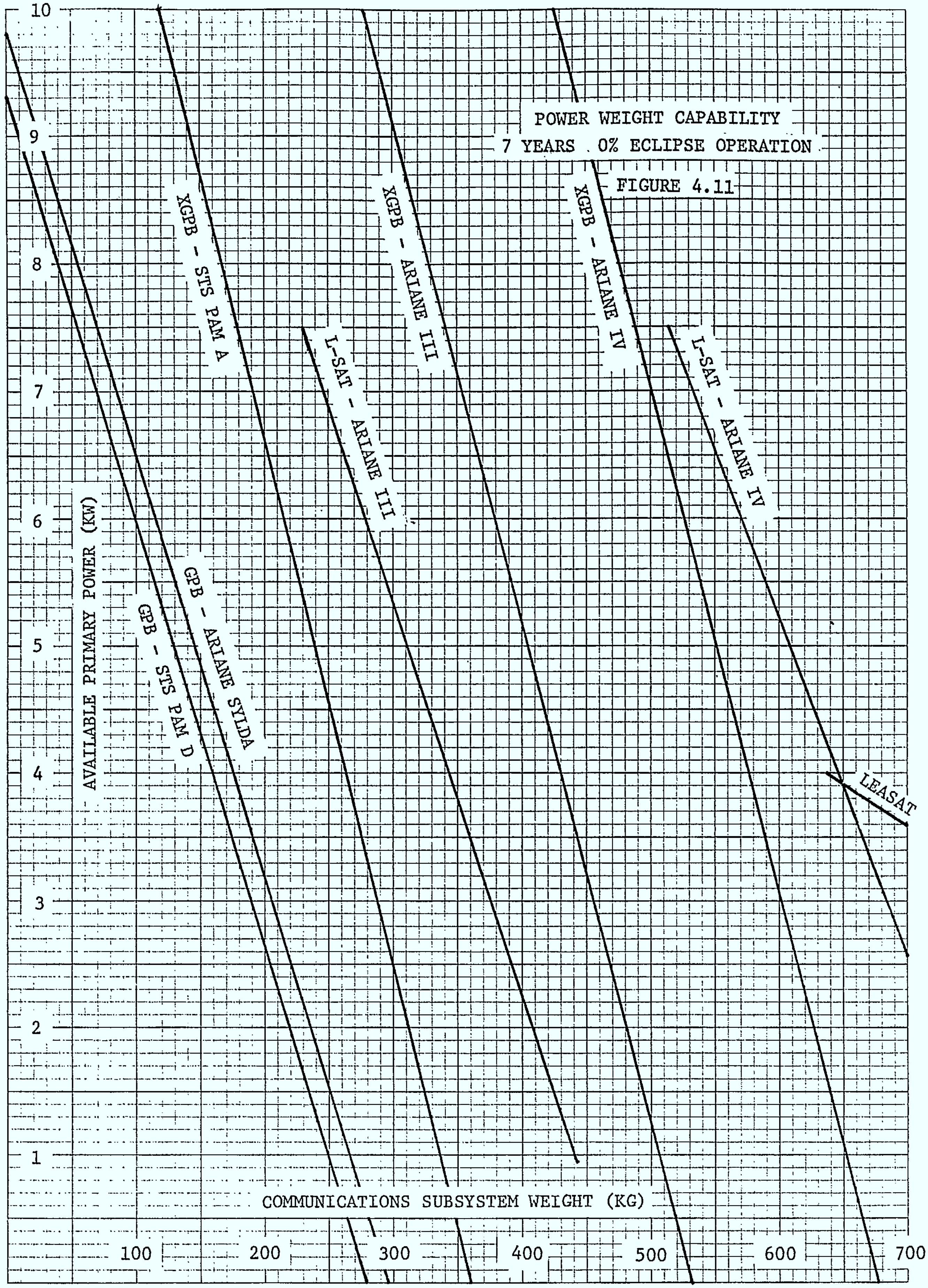


POWER-WEIGHT CAPABILITY
7 YEARS 30% ECLIPSE OPERATION
FIGURE 4.10



POWER WEIGHT CAPABILITY
7 YEARS 0% ECLIPSE OPERATION

FIGURE 4.11

Eclipse Operation:

As required by the study objectives eclipse operation is to be examined for 0% and 50% and determine any significant break-points within this range. Due to the simplified and continuous form of the weight/power model of the power subsystem break-points cannot be detected. An arbitrary mid range model of 30% eclipse operation has been introduced to improve the model flexibility. These three eclipse operation models are used in each of Power/Weight trade-off graphs contained in Fig 4.1 to 4.8.

In Fig. 4.12 and 4.13 an attempt is made to derive some measure of the power needs for eclipse operation in all beam to 1AM local standard time. Fig. 4.12 provides a scheme of eclipse operation of a 4 beam system from 105°W orbital location. Full beam operation is assumed to 1AM local standard time. This scheme involves full power for the duration of the eclipse for beam 1, full power for 36 minutes (1/2 of eclipse duration) for beam 2 and beams 3 and 4 shutdown. Such scheme would require an average load during eclipse of 37.5% of full system load. Similarly the 6 beam system shown in Fig. 4.13 would require 42% of full system load to provide eclipse operation to 1AM local standard time. Other eclipse operation schemes as required by programming objectives could be examined using available information in this report.

Figure 14 and 15 show the eclipse occurence and duration for satellites located at 105 and 140°W.

TIME ZONE:	PACIFIC	MOUNTAIN	CENTRAL	EASTERN	ATLANTIC	NFLD
LOCAL STANDARD TIME ECLIPSE BEGINS:	22:24	23:24	00:24	01:24	02:24	02:54

	1	2	3	4
% OF NORMAL BEAM LOAD REQUIRED FOR OPERATION TO 1 AM LOCAL STANDARD TIME:	100%	50%	0%	0%
% OF TOTAL SYSTEM LOAD:	25%	12.5%	0%	0%

FIGURE 4.12 ECLIPSE OPERATION LOAD FOR 4 BEAM SYSTEMS
(ONE ORBITAL LOCATION AT 105°W)

TIME ZONE:	PACIFIC	MOUNTAIN	CENTRAL	EASTERN	ATLANTIC	NFLD
LOCAL STANDARD TIME ECLIPSE BEGINS:	22:24	23:24	00:24	01:24	02:24	02:54

	1	2	3	4	5	6
% OF NORMAL BEAM LOAD REQUIRED FOR OPERATION TO 1 AM LOCAL STANDARD TIME:	100%	100%	50%	0%	0%	0%
% OF TOTAL SYSTEM LOAD:	16.7%	16.7%	8.3%	0%	0%	0%

FIGURE 4.13 ECLIPSE OPERATION LOAD FOR 6 BEAM SYSTEMS
(ONE ORBITAL LOCATION AT 105°W)

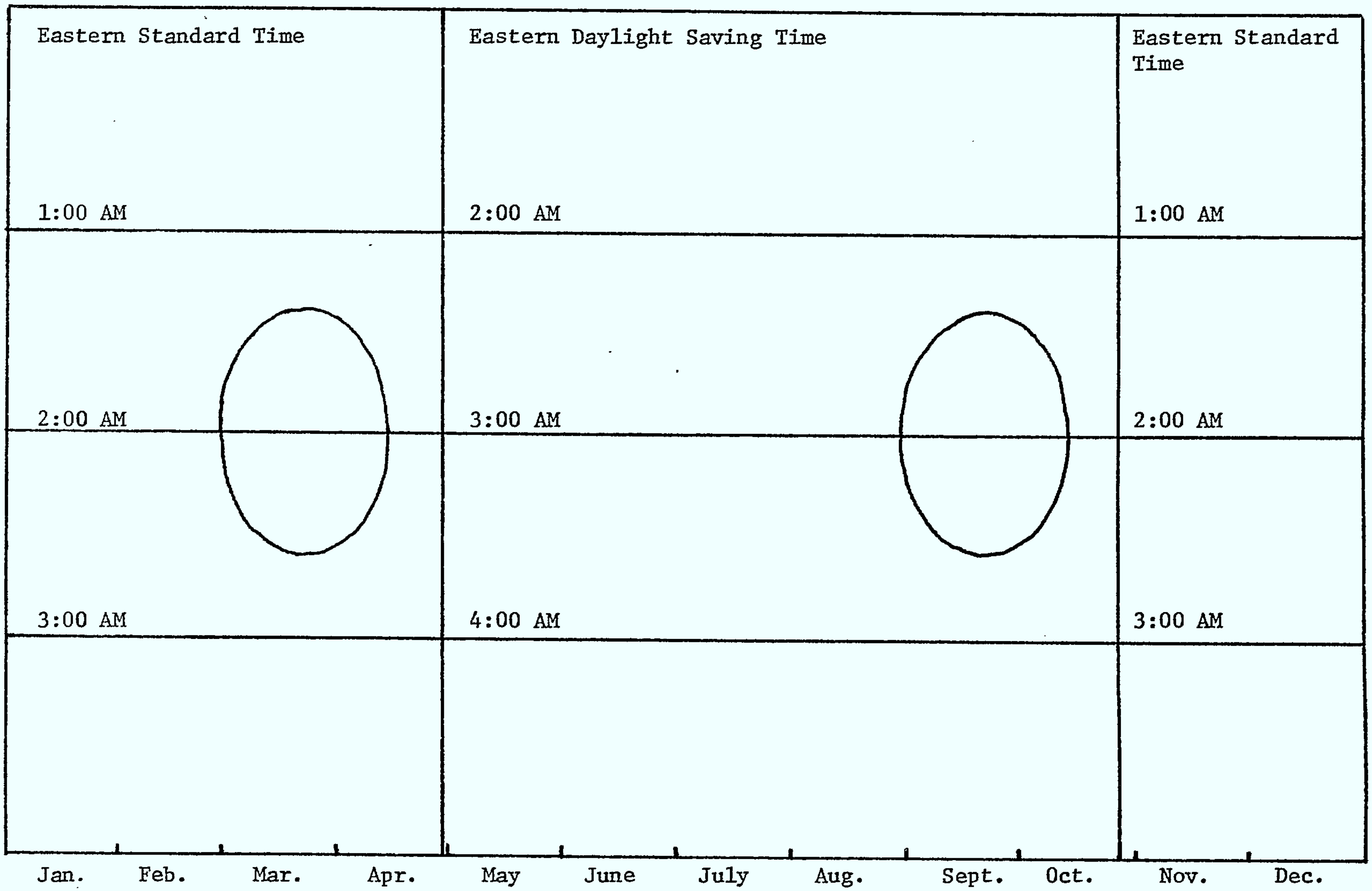


Figure 4.14 Eclipse Occurence and Duration Throughout a Year at Eastern Time Zone and 105°W Satellite Orbital Slot

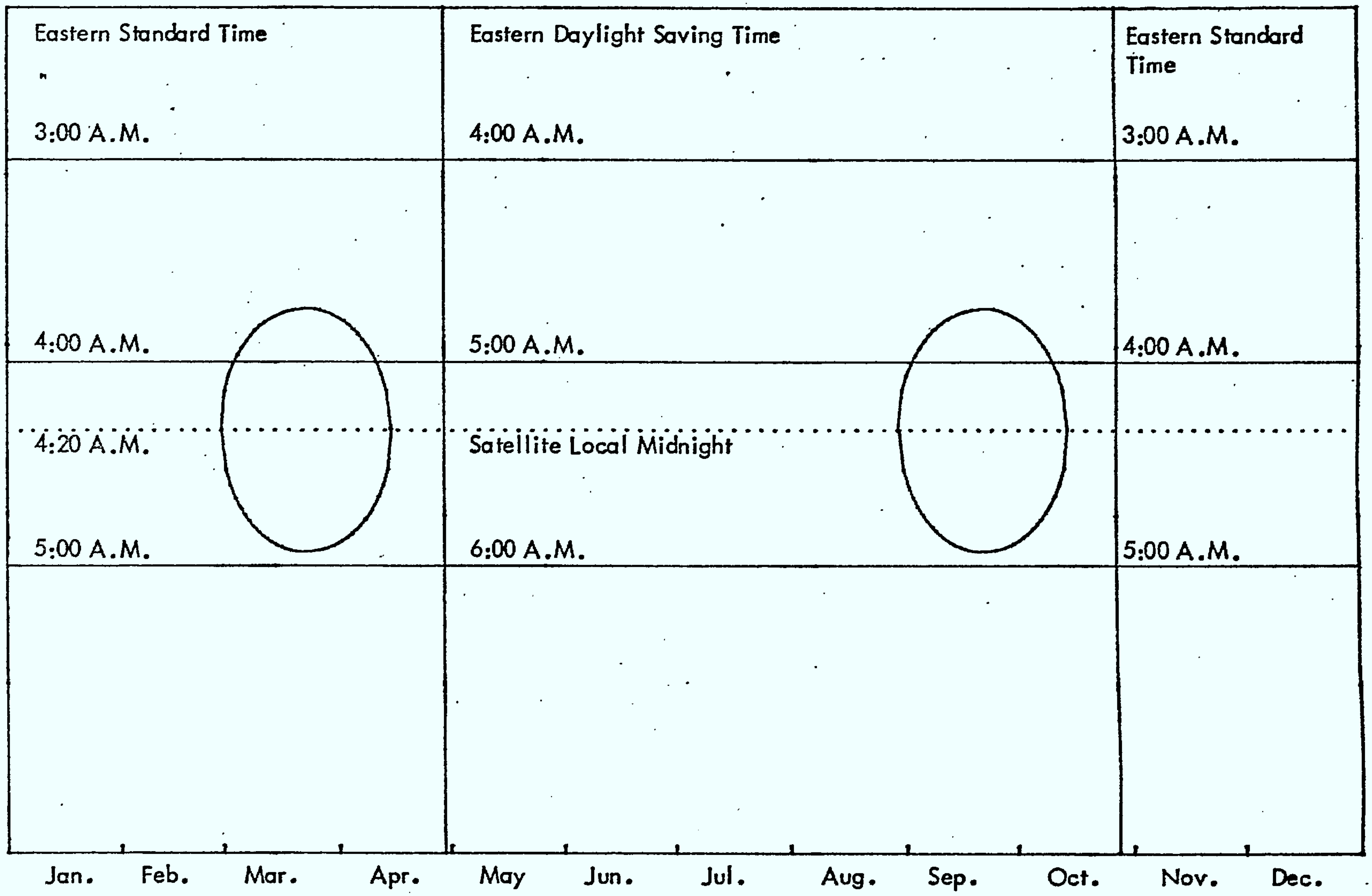


Figure 4.15 Eclipse Occurence and Duration Throughout a Year at Eastern Time Zone and 140°W Satellite Orbital Slot.

5.0 SELECTION OF SPACECRAFT-LAUNCHER COMBINATIONS

In Section 3.0 the power and weight requirements for each system have been generated and summarized on Tables 3.5 and 3.6. In Section 4.0 the power and weight capability trade off curves of each of the candidate Bus/Launcher combinations have been produced and are contained in Figures 4.1 to 4.11. In this section a selection is made of Bus/Launcher combinations to match the communications subsystem power and weight requirements.

Tables 5.1 and 5.2 contain a summary of suitable matches based on 7 year mission life and eclipse operation as indicated in 50, 30 and 0% columns. Similar suitability summaries can be produced for other mission life times. Seven year was selected as a reasonable target for high power TWTAs and it is sufficiently long to serve as a good comparison basis. The optimized 3-axis spacecraft referred to in Tables 5.1 and 5.2 are the generalized body stabilized buses described in Section 4.

The degree of fit for each match is shown by a decimal number (match factors) signifying the fraction of available weight which is demanded by the communications subsystem once the power has been matched. Hence, all match factors smaller than 1.0 indicate that margin is available while match factors larger than 1.0 indicate that subsystem weight/power demands exceed these available by the Bus/Launcher combination. Recognizing the risk in negative margin matches an absolute limit of 20% has been observed, hence no matches are shown above 1.2. On the positive margin side matches are shown down to quite small match factors. Quantifying the degree of fit between demands and availability is considered necessary for a fuller appreciation of the results of this study especially in the area of cost.

From the possible matches indicated in Tables 5.1 and 5.2 some trends become evident. All the 53 dBw EIRP PAM-D systems are poorly matched. Also, poorly matched are all LEASAT cases as a result of the power limited nature of this spacecraft. In most cases good matches of 0.9 or 1.0 exist indicating most likely choices for further study in followon phases.

Subsequent to the selection of appropriate matches a comparison table was produced showing the Total Cost per System and Cost/Channel-year for each model. Models have been segregated along the EIRP line hence Table 5.3 contains models of 53 dBW EIRP while Table 5.4 contains models of 58 dBW EIRP. Spacecraft costs used in this comparison have been obtained from various sources. The cost of GPB and XGPB (PAM A) are based on Anik-D and INTELSAT V published figures. The L-SAT and LEASAT cost are speculative since no published figures exist. All cost figures have been adjusted for 1981 Canadian dollars. Launcher costs have been based on published figures from NASA and ARIANESPACE hence their validity is expected to be higher than that of the spacecraft costs. Spacecraft and launch costs are listed in Tables 5.5 and 5.6. The large discrepancies existing between ARIANE and STS costs leading to the belief that large scale cost adjustments should be anticipated by the time both of these systems become fully operational.

5.0 Cont'd.......

These launch cost discrepancies set a certain bias in the cost comparison picture tending to favour STS launched systems. To overcome this weakness in the comparison basis an additional comparison is made of cost/Kg of spacecraft dry weight as a function of total spacecraft weight based entirely on ARIANE launch cost and presented in Figure 3.2. This comparison, based on a common launch system, indicates a cost advantage for larger spacecraft. Similarly, a comparison based on solely STS launched systems would indicate some cost advantage for larger spacecraft resulting from flat launch costs and decreasing spacecraft cost with increasing size.

The cost advantage derived from the better cost effectiveness of larger spacecraft would be partly offset by the higher costs of sparing larger spacecraft. The sparing approach used in this study is to provide one spare spacecraft regardless of the number of spacecraft comprising the system. This approach would involve 100% spare hardware for one-spacecraft system and only 25% for a four-spacecraft system. Although not apparent from this level of comparison some optimum cost would be expected at the breakeven point resulting from decreasing overall costs for larger spacecraft and increasing overall costs with increasing percentage sparing. At this point it should be noted that the sparing approach of one spare spacecraft assumed for the two orbital location system involves serious risks in that a reconfigurable antenna to suit both locations might not even be possible. Should it be proven necessary to increase the spare spacecraft to two, the split system would suffer as a result an additional cost increase.

Although comparison and selection of systems based on Tables 5.3 and 5.4 might be risky, there is no doubt as to their usefulness in providing some insight into the general cost element of the various systems. For example, the average cost/channel-year is 16% higher for 4 beam than 6 beam systems for 53 dBW EIRP and it is 34% higher in the 58 dBW case. This is to be expected from the fact that 4 beam systems would require higher TWTA power for the same EIRP. The average cost/channel-year is 0.97 $M for 53 dBW EIRP and 1.64 $M for 58 dBW based on "all models" averages. Based on the "all systems" averages rough order of magnitude costs for a 48 channel system are $326M for 53 dBW and $551M for 58 dBW.

All system models covered in this study have been matched to one or more Bus/Launcher combinations. Adequate support information is available in this report to allow additional matches to be evaluated for different mission life and/or eclipse operation. Systems of other EIRPs than these used in this report can also be generated from information contained in this report. In general, the objectives of this study have been addressed to the fullest degree possible within the imposed study limitations.

SPACECRAFT	LAUNCHER	SPACECRAFT DRY WEIGHT (Kg)	SPACECRAFT COST ($M Can)	COST PER Kg OF DRY WEIGHT ($1000 Can)
ANIK-D GPB	STS - PAM D	513	47	92
INTELSAT V XGPB	STS - PAM A	809	58	72
LEASAT	STS	1640	59	35
L-SAT XGPB	ARIANE III	1031	67	65
L-SAT XGPB	ARIANE IV	1696	Not Available	--

TABLE 5.5 SPACECRAFT COST (1981 $ CAN)

LAUNCHER	LAUNCHER CAPABILITY (DRY WEIGHT) (Kg)	LAUNCH COST ($M Can)	LAUNCH COST PER Kg OF DRY WEIGHT ($1000 Can)
STS - PAM D	513	16.0	31.2
STS - PAM A	809	28.9	35.7
STS OPTIMISED (LEASAT)	1640	22.6	13.8
ARIANE SYLDA	534	33.7	63.1
ARIANE III	1031	60.3	58.5
ARIANE IV	1696	Not Available	--

TABLE 5.6 LAUNCH COST (1981 $ CAN)

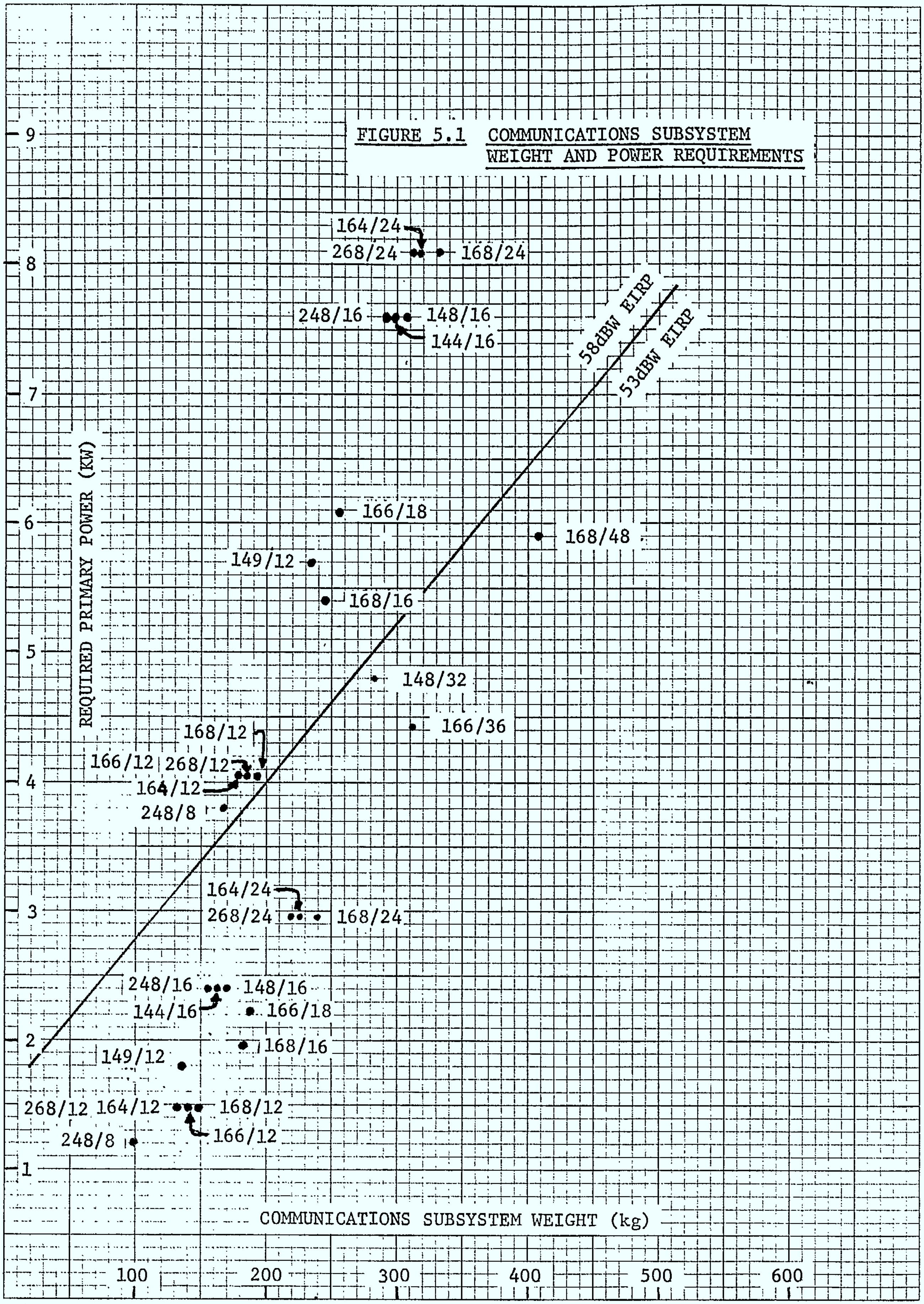


FIGURE 5.1 COMMUNICATIONS SUBSYSTEM WEIGHT AND POWER REQUIREMENTS

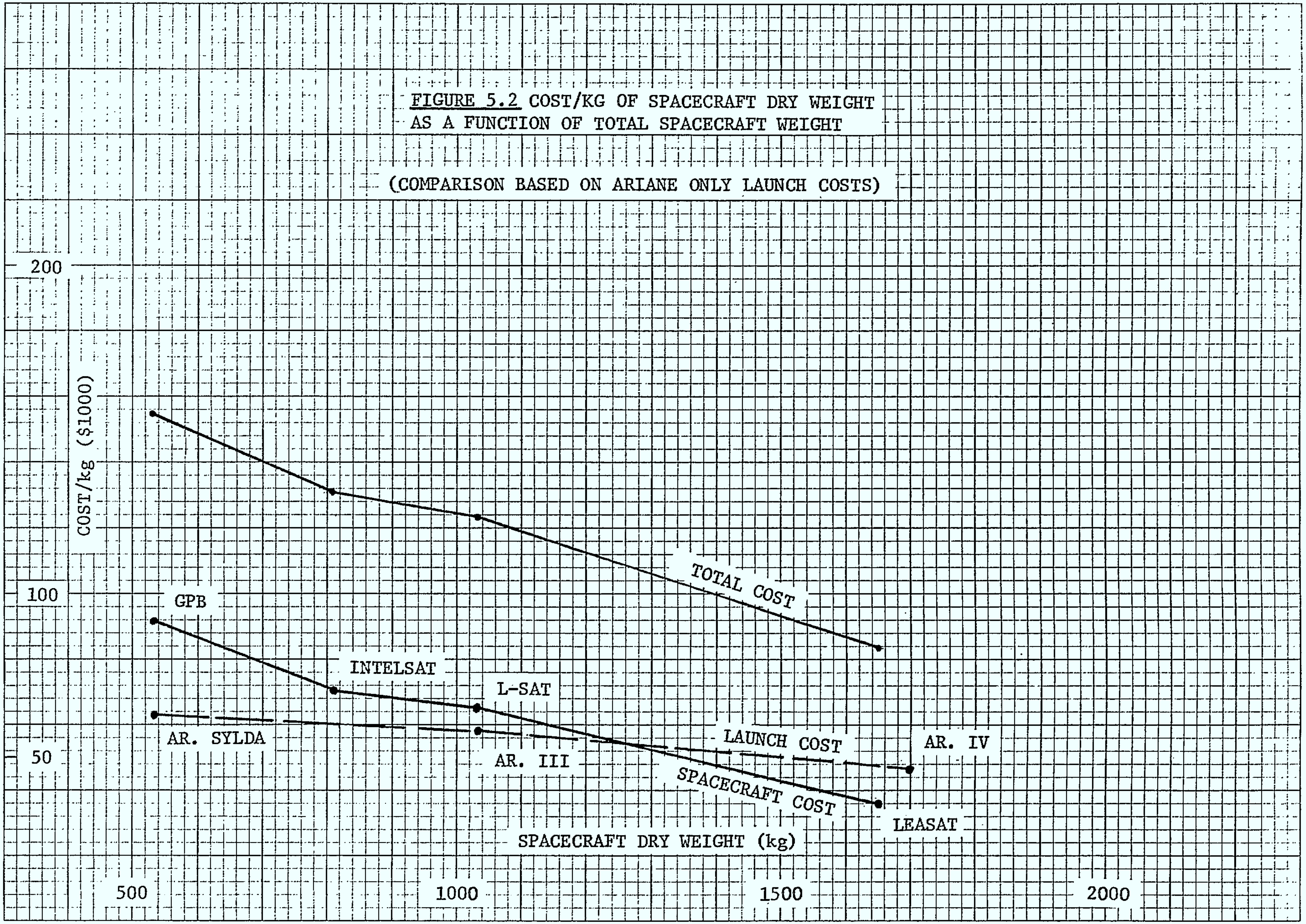


FIGURE 5.2 COST/KG OF SPACECRAFT DRY WEIGHT AS A FUNCTION OF TOTAL SPACECRAFT WEIGHT

(COMPARISON BASED ON ARIANE ONLY LAUNCH COSTS)

BASIS OF COMPARISON: 53dBw EIRP/7 YEAR LIFE

SPACECRAFT			OPTIMIZED 3-AXIS SPACECRAFT															REFERENCE SPACECRAFT L-SAT (3-AXIS)						REFERENCE SPACECRAFT LEASAT (SPINNER)					
LAUNCHER			STS-PAM D			ARIANE SYLDA			STS-PAM A			ARIANE III			ARIANE IV			ARIANE III			ARIANE IV			STS			STS		
SYSTEM DESCRIPTION	SC PER SYSTEM	COMM S/S CODE	50%	30%	0%	50%	30%	0%	50%	30%	0%	50%	30%	0%	50%	30%	0%	50%	30%	0%	50%	30%	0%	15' ARRAY			30' ARRAY		
																								50%	30%	0%	50%	30%	0%
4 BEAM SYSTEM																													
ONE ORBITAL LOCATION																													
8 channels/beam	1	148/32									1.1	0.9	0.7						1.1	0.9									
	2	148/16		1.0		1.0	0.9																				0.2		
9 channels/beam	3	149/12	0.7			0.6																		0.2					
4 channels/beam	1	144/16		1.0		1.0	0.9																				0.2		
TWO ORBITAL LOCATIONS																													
8 channels/beam	2	248/16		1.0		1.0	0.9																				0.2		
	4	248/8	0.5			0.4																		0.1					
6 BEAM SYSTEM																													
ONE ORBITAL LOCATION																													
8 channels/beam	1	168/48												1.1	1.0	0.9					0.9	0.8							
	2	168/24							1.0	1.0																	0.3		
	3	168/16		1.0		1.0	0.9																	0.2					
	4	168/12	0.7			0.6																		0.2					
6 channels/beam	1	166/36										0.9	0.8						1.2	1.0									
	2	166/18		1.1		1.0	1.0																				0.2		
	3	166/12	0.6			0.6																		0.2					
4 channels/beam	1	164/24							1.0	0.9																	0.3		
	2	164/12	0.6			0.6																		0.2					
TWO ORBITAL LOCATIONS																													
8 channels/beam	2	268/24						1.1	0.9	0.9																	0.3		
	4	268/12	0.6			0.6																		0.2					

TABLE 5.1 SPACECRAFT-LAUNCHER SUITABILITY SUMMARY

BASIS OF COMPARISON: 58dBw EIRP/7 YEAR LIFE

* Exceed 7.5kw power capability but have adequate weight available for larger solar arrays

SPACECRAFT			OPTIMIZED 3-AXIS SPACECRAFT															REFERENCE SPACECRAFT L-SAT (3-AXIS)						LEASAT (SPINNER)					
LAUNCHER			STS-PAM D			ARIANE SYLDA			STS-PAM A			ARIANE III			ARIANE IV			ARIANE III			ARIANE IV			STS 15' ARRAY			STS 30' ARRAY		
SYSTEM DESCRIPTION	SC PER SYSTEM	COMM S/S CODE	50%	30%	0%	50%	30%	0%	50%	30%	0%	50%	30%	0%	50%	30%	0%	50%	30%	0%	50%	30%	0%	50%	30%	0%	50%	30%	0%
4 BEAM SYSTEM																													
ONE ORBITAL LOCATION																													
8 channels/beam	1	148/32	Exceeds AR IV Capability																										
	2	148/16												0.9	1.0	0.8					1.0	0.8							
9 channels/beam	3	149/12									1.0	0.9	0.7						1.2	0.8									
4 channels/beam	1	144/16											1.2	0.9	0.9	0.7					1.0	0.7							
TWO ORBITAL LOCATIONS																													
8 channels/beam	2	248/16											1.2	0.9	0.9	0.7					0.9	0.7							
	4	248/8			1.0			0.9	0.9	0.7																	0.3		
6 BEAM SYSTEM																													
ONE ORBITAL LOCATION																													
8 channels/beam	1	168/48	Exceeds AR IV Capability																										
	2	168/24												1.0	1.1	0.9					1.2*	0.9*							
	3	168/16									1.0	0.9	0.7						1.1	0.8									
	4	168/12						1.1	1.0	0.9																	0.4		
6 channels/beam	1	166/36	Exceeds AR IV Capability																										
	2	166/18										1.0	0.8							0.9									
	3	166/12						1.0	1.0	0.8																	0.4		
4 channels/beam	1	164/24												1.0	1.0	0.9					1.1*	0.8*							
	2	164/12						1.0	1.0	0.8																	0.4		
TWO ORBITAL LOCATIONS																													
8 channels/beam	2	268/24												1.0	1.0	0.8					1.1*	0.8*							
	4	268/12						1.0	1.0	0.8																	0.4		

TABLE 5.2 SPACECRAFT-LAUNCHER SUITABILITY SUMMARY

SYSTEM DESCRIPTION	SYSTEM CODE	SPACECRAFT-LAUNCHER REQUIRED	SPACECRAFT COST $M	LAUNCH COST $M	TOTAL COST PER S/C $M	NUMBER OF S/C PER SYSTEM + ONE SPARE	TOTAL COST PER SYSTEM $M	COST/CHANNEL PER YEAR (7 YEAR LIFE) $M
4 BEAM SYSTEM								
ONE ORBITAL LOCATION								
8 channels/beam	148/32	L-SAT – AR III	67	60.3	127.3	2	254.6	1.137
	148/16	GPB – PAM D	47	16.0	63.0	3	189.0	0.844
9 channels/beam	149/12	GPB – PAM D	47	16.0	63.0	4	252.0	1.000
4 channels/beam	144/16	GPB – PAM D	47	16.0	63.0	2	126.0	1.125
TWO ORBITAL LOCATIONS								
8 channels/beam	248/16	GPB – PAM D	47	16.0	63.0	3	189.0	0.844
	248/8	GPB – PAM D	47	16.0	63.0	5	315.0	1.406
6 BEAM SYSTEM								
ONE ORBITAL LOCATION								
8 channels/beam	168/48	L-SAT – AR IV	Not Availabl	Not Available	—	2	—	—
	168/24	XGPB – PAM A	58	28.9	86.9	3	260.7	0.776
	168/16	GPB – PAM D	47	16.0	63.0	4	252.0	0.750
	168/12	GPB – PAM D	47	16.0	63.0	5	315.0	0.938
6 channels/beam	166/36	L-SAT – AR III	67	60.3	127.3	2	254.6	1.010
	166/18	GPB – PAM D	47	16.0	63.0	3	189.0	0.750
	166/12	GPB – PAM D	47	16.0	63.0	4	252.0	1.000
4 channels/beam	164/24	XGPB – PAM A	58	28.9	86.9	2	173.8	1.035
	164/12	GPB – PAM D	47	16.0	63.0	3	189.0	1.125
TWO ORBITAL LOCATIONS								
8 channels/beam	268/24	XGPB – PAM A	58	28.9	86.9	3	260.7	0.776
	268/12	GPB – PAM D	47	16.0	63.0	5	315.0	0.938

TABLE 5.3 COST PER CHANNEL-YEAR COMPARISON FOR 53 dBw EIRP SYSTEMS

SYSTEM DESCRIPTION	SYSTEM CODE	SPACECRAFT-LAUNCHER REQUIRED	SPACECRAFT COST $M	LAUNCH COST $M	TOTAL COST PER S/C $M	NUMBER OF S/C PER SYSTEM + ONE SPARE	TOTAL COST PER SYSTEM $M	COST/CHANNEL PER YEAR (7 YEAR LIFE) $M
4 BEAM SYSTEM								
ONE ORBITAL LOCATION								
8 channels/beam	148/32	exceeds AR-IV capability				2		
	148/16	L-SAT- AR III	67	60.3	127.3	3	381.9	1.705
9 channels/beam	149/12	L-SAT- AR III	67	60.3	127.3	4	509.2	2.021
4 channels/beam	144/16	L-SAT- AR III	67	60.3	127.3	2	254.6	2.273
TWO ORBITAL LOCATIONS								
8 channels/beam	248/16	L-SAT- AR III	67	60.3	127.3	3	381.9	1.705
	248/8	XGPB - PAM A	58	28.9	86.9	5	434.5	1.940
6 BEAM SYSTEM								
ONE ORBITAL LOCATION								
8 channels/beam	168/48	exceeds AR.IV capability				2		
	168/24	L-SAT- AR IV	Not Available	Not Available	---	3	---	---
	168/16	L-SAT - AR III	67	60.3	127.3	4	509.2	1.515
	168/12	XGPB - PAM A	58	28.9	86.9	5	434.5	1.293
6 channels/beam	166/36	exceeds AR.IV capability				2		
	166/18	L-SAT- AR III	67	60.3	127.3	3	381.9	1.515
	166/12	XGPB - PAM A	58	28.9	86.9	4	347.5	1.379
4 channels/beam	164/24	L-SAT- AR IV	Not Available	Not Available				
	164/12	XGPB - PAM A	58	28.9	86.9	3	260.7	1.552
TWO ORBITAL LOCATIONS								
8 channels/beam	268/24	L-SAT - AR IV	Not Available	---	---	3	---	---
	26S/12	L-SAT- PAM A	58	28.9	86.9	5	434.5	1.293

TABLE 5.4 COST PER CHANNEL-YEAR COMPARISON FOR 58dBw EIRP SYSTEMS

6. ANIK-C TO DBS TRANSITION

Timing

The introduction of a DBS system of the type considered in this study may follow an interim system provided by Anik-C. To evaluate transitional problems, a 1987 DBS implementation is assumed which will overlap the Anik-C system to at least 1989. Key technical characteristics of the two systems are compared in the following table.

	DBS	Anik-C
Uplink Frequency Band	17.3 - 17.8 GHz	14.0 - 14.5 GHz
Downlink Frequency Band	12.2 - 12.7 GHz	11.7 - 12.2 GHz
Polarization	Circular	Linear
Frequency Plan	24, 32, 36, 48	16 channel
EIRP (-3 dB)	50 - 55 dBw	46 dBw
No. of downlink beams	4, 6	4
No. of uplink beams	1	1
RF signal bandwidth	18 MHz	54 MHz

Receiving Stations

Differences between Anik-C and DBS receive frequency bands and polarization preclude direct compatibility of receiving stations with both systems. It would seem feasible and prudent however to arrange for a one way compatibility of Anik-C receiving stations with DBS. Thus, Anik-C receiving stations should be designed to change readily to the DBS reception band and polarization. The accommodation to the DBS frequency band should not be difficult if one assumes a double conversion receiver where a 500 MHz change in the first local oscillator frequency will bring the 12.2 - 12.7 GHz DBS band into the second IF frequency band. The switch from linear to circular should likewise not be difficult but may rule out some of the simpler LP feed approaches.

Even if a change from LP to CP is not done in the receiving station, it can still operate through a transitional period with a 3dB polarization loss. The higher EIRP of DBS will more than make up for the loss however only half of the DBS channels can be used. As the DBS traffic grows beyond half of the system capacity, unavailable and unacceptable interference from adjacent cross polarized channels will affect progressively more of the LP receivers.

Transmitting Stations

Differences in frequency band and polarization would make modification of Anik-C uplink stations for DBS transmission marginal. Although the main antenna reflector could be designed initially for operation up to 17.5 GHz, an entirely new antenna feed and HPA would be required. Modifications to operate simultaneously at both 14 and 17 GHz is unlikely because of technical difficulties, and the uncertainty that an Anik-C and a DBS spacecraft would be colocated in orbit.

A more likely scenario is that regional and central transmitting sites developed for Anik-C would be augmented by the addition of separate antennas and HPAs for the DBS service. As given elsewhere in this report regional stations are thus estimated as basic 2 channel systems expandable to 8 channels, and the central station as a basic 4 channel system expandable to 12 channels.

The relative ease of locating 17 GHz uplink stations will probably encourage different users to establish their own separate stations. Transportable uplink stations will no doubt be used for special purposes.

Relative scarcity of components for 17 GHz, particularly high powered amplifiers and other microwave devices will result in substantial cost premiums for all DBS earth stations.

A likely transitional scenario from an Anik-C interim to a full DBS system is as follows:

1) Anik-C interim DBS system starts 1983

2) Receiving stations readily adaptable to future DBS (RARC 83) technical characteristics are installed.

3) DBS system starts 1987 carrying some programs simultaneously on Anik-C and DBS.

4) Two year overlap period in which programming builds up on DBS and is gradually withdrawn on Anik-C. Low cost receivers for DBS only installed. Anik-C receivers are adapted to DBS and repointed or are replaced by new receivers as the customers decide.

This general scenario and the transitional problems referred to earlier are essentially the same for any of the DBS systems considered in this report. That is to say, differences in the number of beams, channels, and EIRP levels between DBS system models are not critical to transitional problems. Better coverage in EIRP and number of channels over parts of Canada, particularly the North, will none-the-less make DBS more attractive than Anik-C to many viewers.

7. UPLINK EARTH STATION

Station Description and Cost

In this section the cost and requirements of uplink earth station are examined. It has been assumed that there is only one type of earth station with varying requirements on the number of channels. Cost of components are based on existing 14GHz equipment and no allowance has been included for development and other costs associated with new design to cover the 17.3 - 17.8 GHz frequency band. Costs of buildings, roads and power have also been excluded.

Station costs presented on Figure 7.1 are in 1981 Canadian dollars. Included in these costs are the following equipment and service:

1. One 10 meter antenna per station
2. RF combining network to suit number of channels
3. 750W Klystron HPA
4. Exciters
5. Monitor, Alarm and Control System
6. TV monitoring system
7. Engineering Services
8. Program Management Services
9. Installation and Test Services
10. Station Documentation.

The cost of additional antenna for two orbital location system uplink would be in the order of $550K including a separate RF combining network.

The resulting cost model from Figure 7.1 for number of channels greater than 2 is:

Station Cost = 2.73 + 0.325 X (number of channels) $M

This cost model applies to one installation for the system size selected. For gradual system growth costs are expected to increase somewhat depending on the expansion pattern.

The antenna size and HPA output are based on available 14GHz sizes and represent the closest match possible at this time. As it will become evident in the uplink calculations smaller size antenna or lower HPA output could be used if available. Also, some tradeoff between antenna size and HPA output might be possible when 17GHz equipment becomes available. At this time any finer definition of antenna/HPA requirements cannot be translated into greater cost determination accuracy.

7. (continued)

Uplink EIRP Calculations

Derivation of uplink EIRP is based on the conditions of negligible effects of the uplink on the total system carrier-to-noise (C/N) under normal propagation conditions and up to 1dB degradation for some small percentage of time during which the uplink is undergoing fading. For this purpose the downlink C/N is assumed to be constant at 15dB. The uplink C/N which would cause 1dB degradation on the total system C/N is:

$$C/N = -10 \log [\log^{-1} (\frac{-14}{10}) - \log^{-1} (\frac{-15}{10})]$$

$$= 21\text{dB}$$

The percentage of time during which the system C/N would be allowed to degrade by 1dB to 14dB has been arbitrarily set to 0.05% annually. From available 19GHz fading statistics for Northern New Jersey (Reference 1) the fade depth corresponding to this annual probability is 9dB. This implies that for regions having similar fading distributions to that used above an unfaded C/N of 30dB is required in the uplink to limit system degradation to 1dB for not more than 0.05% of the time. The 30dB C/N objective causes less than 0.2dB degradation to the 15dB system C/N. The foregoing discussion deals solely with the effects of uplink fading and does not include degradations due to signal depolarization and downlink fading.

The EIRP required to achieve the above objective of 30dB C/N is determined as follows:

$$\frac{C}{N} = \text{EIRP} - \text{FSL} + G_A - \text{Lin} - \text{KTB} = 30\text{dB}$$

OR:

$$\text{EIRP} = 30 + \text{FSL} - G_A + \text{Lin} + \text{KTB} \qquad \text{dBw}$$

Where:

FSL = Free Space Loss = 209dB
G_A = Receive Antenna Gain = 27dB
Lin = Transponder Input Loss = 1dB
k = -228.6 dBw/Hz/K
B = Channel Bandwidth = 72.6dB - Hz (18MHz)
T = System Temperature = 29.1dB - K (817K)

hence:

$$\text{EIRP} = 30 + 209 - 27 + 1 + (-228.6 + 29.1 + 72.6)$$

$$= 86.1\text{dBw.}$$

7. (continued)

The EIRP produced by the assumed earth station antenna and HPA is the following:

$$EIRP = G_A + Pout - Lo \quad dBw$$

where:

G_A = Earth Station Antenna Gain
= 62dB (50% efficiency)
Pout = HPA output level
= 28.7dBw (750w)
Lo = Output loss = 3dB

hence:

$$EIRP = 62 + 28.7 - 3 \quad dBw$$
$$= 87.7dBw$$

The uplink EIRP is 1.6dB higher than what is required to satisfy the 30dB, C/N objective. This excess EIRP cannot, at this time, be used to reduce the costs since there is no information on what might be available at the time of implementation.

Reference 1: "19 and 28 GHz Propagation Considerations affecting satellite Communications Systems Design"

H.W. Arnold, D.C. Cox, H.H. Hafman and R.P. Leck

AIAA 1980 Communications Satellite Conference

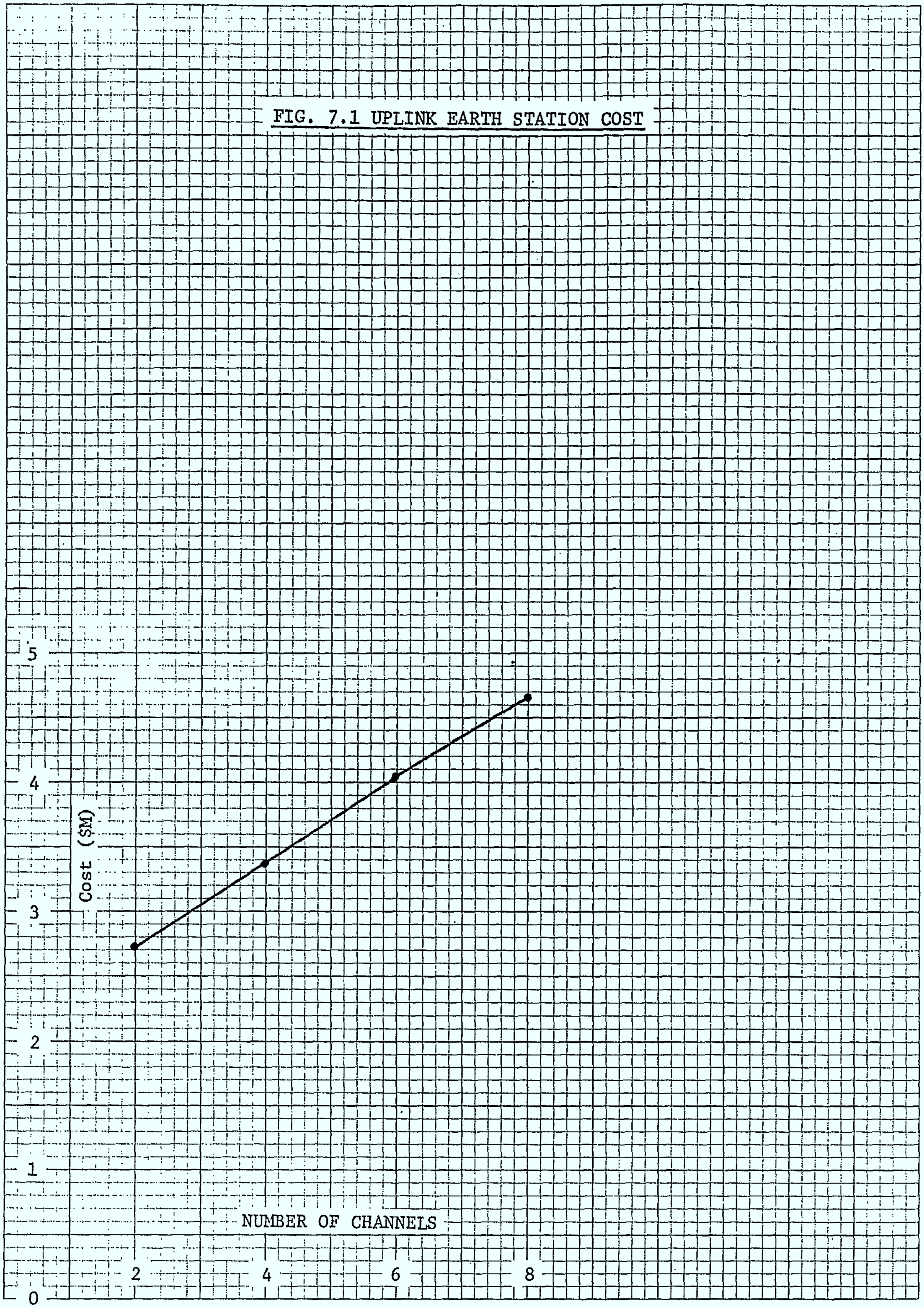


FIG. 7.1 UPLINK EARTH STATION COST