FINAL REPORT

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UHF/SHF/L-Band Spacecraft Trade Offs & Budgets

Prepared for:
Department of Communications
Ottawa, Ontario

DSS Contract Reference 13SR36100-4-0565

RCA

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Aerospace and Government
Government and Commercial Systems Division
RCA Limited
Ste-Anne-de-Bellevue, Quebec

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RCA

FOREWORD

This report describes work carried out under contract No. 13SR. 36100-4-0565 for Department of Communications. Mr. H. Werstiuk of the Communications Research Centre was the project officer.

Two transponder configurations were investigated. The first was a single band UHF spacecraft with the proviso that the complete UHF band be translated to 7 GHz for transmission to the ground where all signal processing was to take place. All signals were then assembled at 8GHz for transmission to the spacecraft. The signal band is then translated back to the UHF band for broadcast to the mobile field units. The UHF transponder was sized to fully occupy the payload of a 3-axis stabalized spacecraft suitable for launch on a 3914 Thor Delta vehicle.

The second transponder configuration was similar in the UHF band but some of the capacity of the spacecraft was assigned to an L-band service for ships and aircraft in the arctic region.

Two draft reports were submitted for the two transponder configurations. These are now assembled into a final report as Part I and Part II respectively except that the trade-off calculations for the two payloads are combined in Part III of this report.

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PART I

UHF/SHF PAYLOAD

I-1.0 INTRODUCTION

Part I describes work carried out on some aspects of a proposed UHF/SHF spacecraft for Canadian Government communication needs.

Three tasks were to be undertaken as listed below.

Task 1: To assist the design authority in developing satellite transponder configurations which will meet the requirements of the anticipated traffic characteristics of the UHF Communication System.

Task 2: To carry out transponder payload tradeoffs for a few selected transponder configurations developed in Task 1. Weight and power tradeoffs will be carried out as a function of operating frequency, antenna gain, EIRP/Channel, No. of channels, DC to RF efficiency and eclipse capability.

Task 3: Based on tradeoffs carried out in Task 2, furnish transponder block diagrams including weight and power estimates.

I-2.0 REQUIREMENTS FOR THE UHF/SHF SATELLITE CONFIGURATION

Some of the requirements, as furnished by the design authority, are reproduced below. Some of these, particularly the frequency bandwidths were modified during the course of the work. Other requirements, such as the need to consider the 3914 launch vehicle only, were introduced during meetings with the Project Officer. A full list of the requirements is not included here but these have been fully considered and satisfied whenever possible.

I-2.0 Requirements for Bandwidth

- Preliminary indications are that the satellite should be sized to support approximately 80 FDMA simultaneous voice equivalent 25 KHz channels. Allowing for guard bands, at least 50 KHz is required for each channel. Hence the minimum required bandwidth is 4 MHz for both the uplink and downlink.

- Some allowance will have to be made for growth and to allow two satellites to operate simultaneously on a non-interference basis.

- A wideband link (about 15 MHz) will be required for Spread-Spectrum multiplex access for DND.

- Bandwidth allowance will be required for Data Retransmission Platforms (DRP's) and for possible Emergency Position Indicating Radio Beacons (EPIRB's) in the allocated bands.

- A tentative frequency plan is shown in Figure I-1

I-2.3 <u>Available Spectrum from Radio Regulations</u>

- <u>UHF</u>

for mobiles (uplink and downlink) 240 - 328.6 MHz and 335.4 to 399.9 MHz.

for DRP's (uplink) 401 to 403 MHz

for EPIRB's (uplink) 406 to 406.1 MHz

- <u>SHF</u>

Option 1 downlink 3.7 to 4.2 GHz: uplink 5.925 to 6.425 GHz

Option 2 downlink 7.25 to 7.75 GHz: uplink 7.9 to 8.4 GHz

Option 3 downlink 11.7 to 12.2 GHz: uplink 14.0 to 14.5 GHz

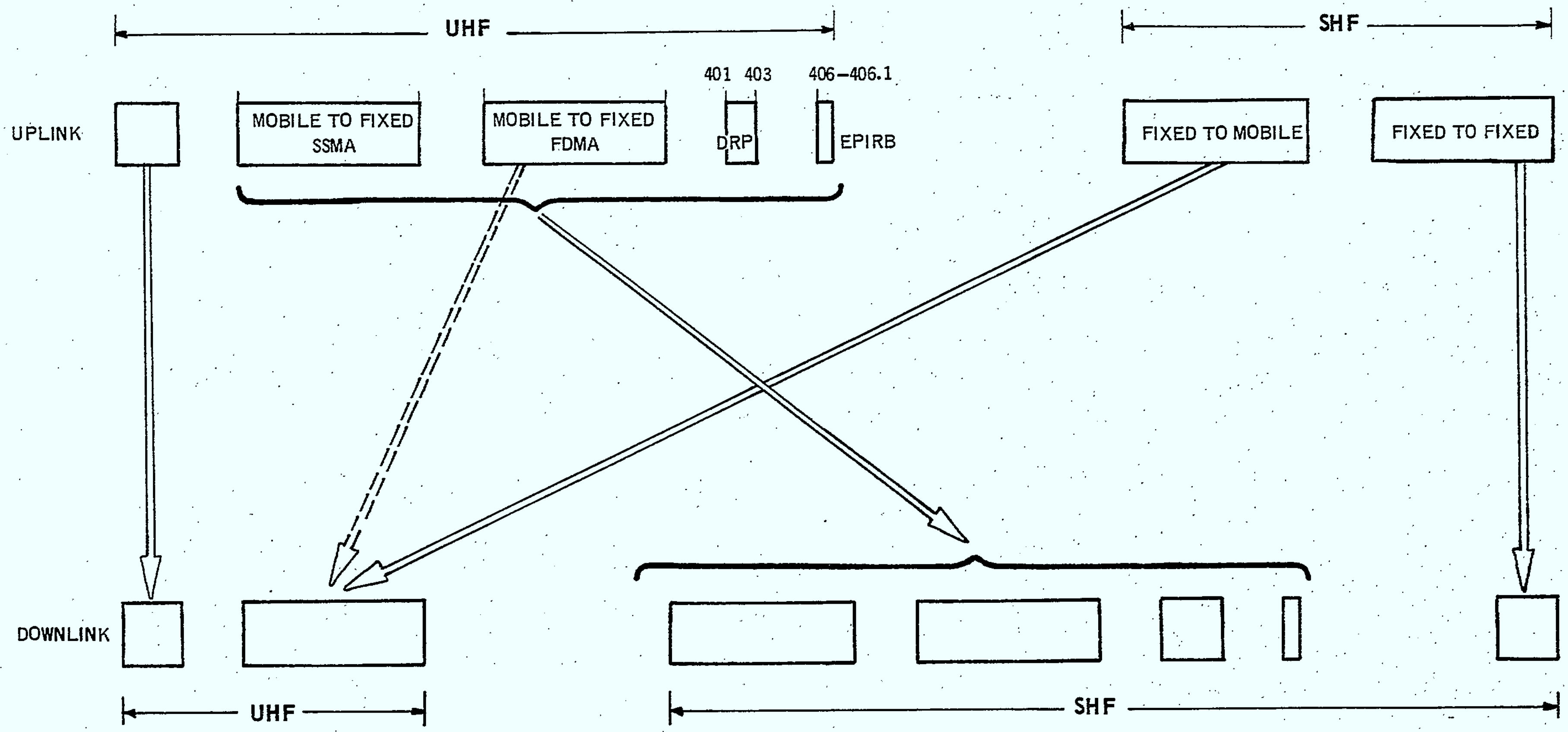


Figure I–1 Tentative frequency plan for UHF/SHF transponder

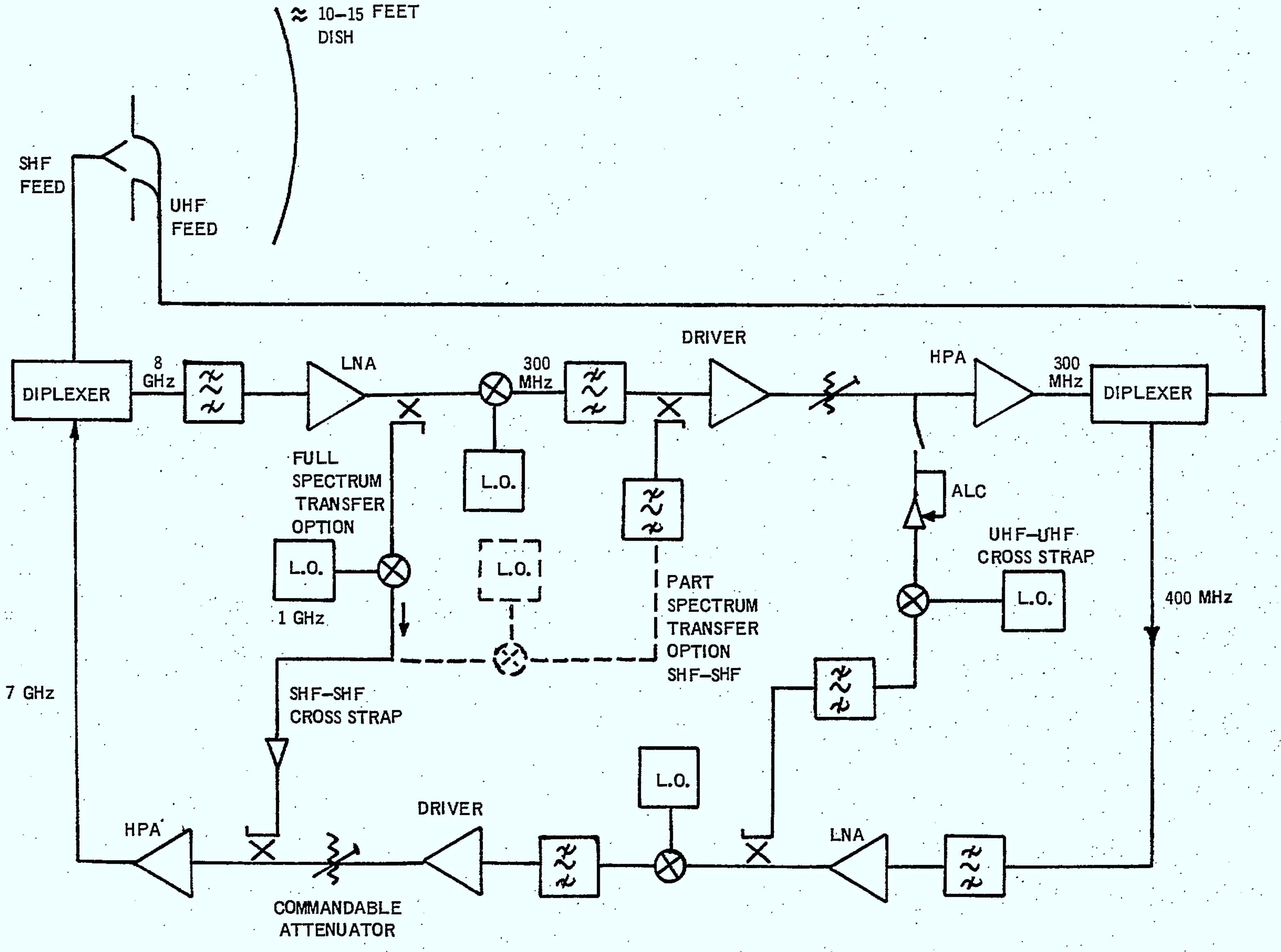


Figure I-2 Tentative block diagram for UHF/SHF transponder

I-2.4 Other Constraints

DND is likely to require some interoperability between the Canadian system and the U.S. system. This requirement is likely to be that DND UHF ground stations should be able to operate on the U.S. FLEETSAT system. (This is to allow access to satellite communications for DND mobiles when they are outside the coverage of the Canadian system, provided such arrangements can be negotiated with the U.S.) This requirement can be met by proper design of the mobile stations.

I-2.5 Preliminary Conclusions

Preliminary Conclusions	Bandwidth Requirements
UHF uplink	5 MHz for FDMA, 15 MHz for SSMA, each satellite
UHF downlink	5 MHz for FDMA, each satellite
SAF uplink	20 MHz for each satellite
SHF downlink	20 MHz for each satellite

I-3.0 EVOLUTION OF TRANSPONDER CONFIGURATION

The block diagram of Figure I-2 presented by the design authority was examined to determine the implications resulting from introducing redundancy. The diagram was also examined to determine the best method of implimenting the cross strapping without having excessive multipath problems due to looping through alternate paths.

The first modification to Figure I-2 (shown in Figure I-3) resulted in the elimination of active gain from the central cross strapping section. This is accomplished by putting a 3 dB hybrid

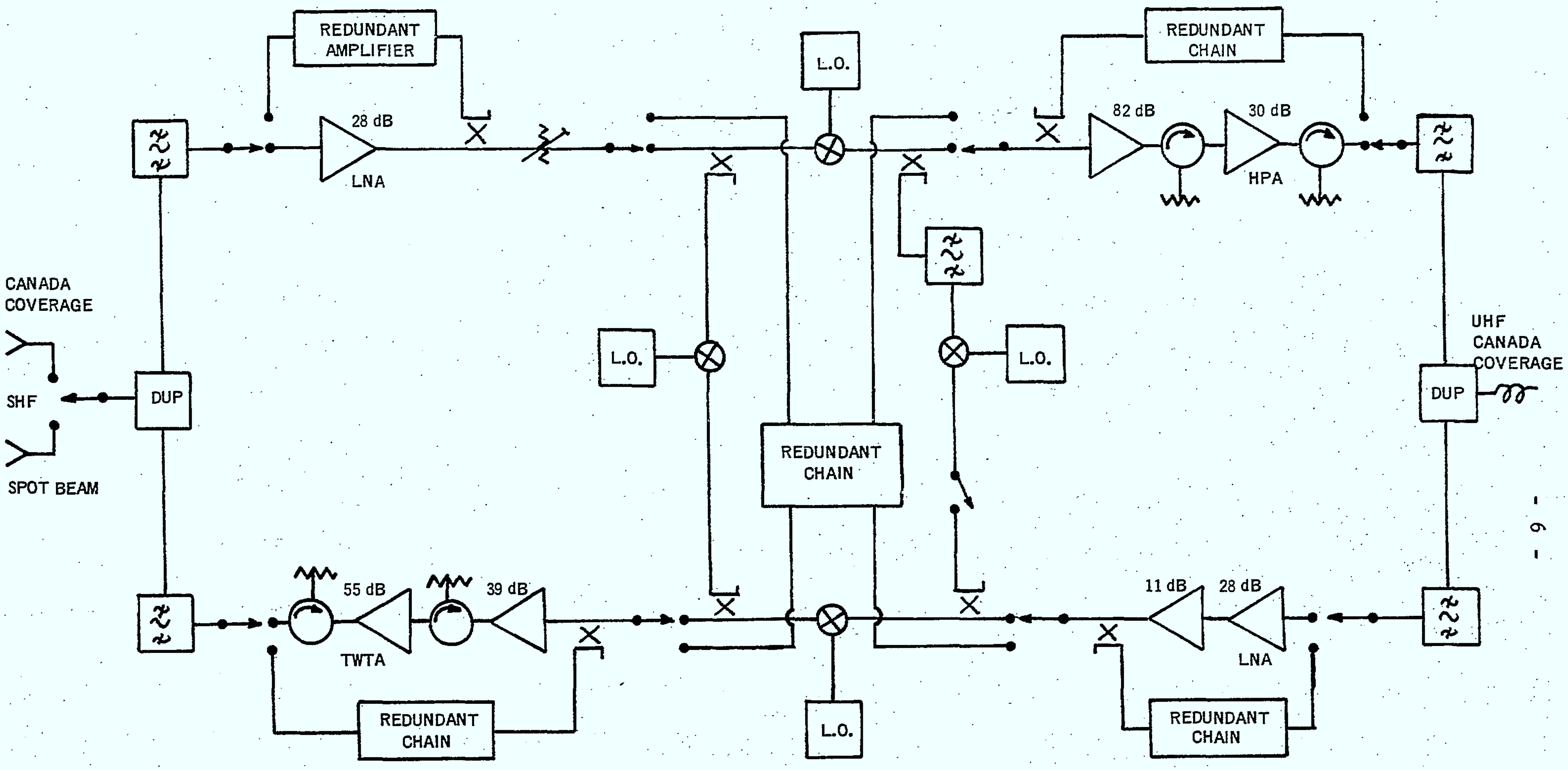


Figure I–3 Block diagram No. 1A for UHF/SHF transponder at each of the four corners of the central section and assuming that each of the mixers in each of the four sides has the same conversion loss. In this way the cross strapped signal has the same signal strength as the direct through path. The central section still has active elements consisting of mixers and local oscillators. One method of providing redundancy shown in Figure I-3 is to switch in a redundant box in the event of failure of one of the primary units. This results in five redundant assemblies and a total of eight switches.

The active elements can be completely removed from the cross strapping section (as shown in Figure I-4) by making the UHF to SHF chain double conversion. That is the uplink frequency of about 380 MHz is translated to the downlink frequency of about 300 MHz. Cross strapping is then accomplished without any further change of frequency or power level. The central cross over section is completely passive and nonredundant resulting in less complex redundancy switching.

The section of the transponder containing the UHF transmitter is shown in Figure I-4 with a total gain of 105 dB. This is sufficient gain so that the thermal noise in the transmitter chain in the receive band is unacceptably high and may dominate the output filter design. This is alleviated by raising the power level of the cross over section by moving some of the gain in the two transmitter legs to the two receiver legs as shown in Figure I-5. Other approachs such as a filter after the driver amplifier would alleviate the problem and make the configuration of Figure 4 more acceptable.

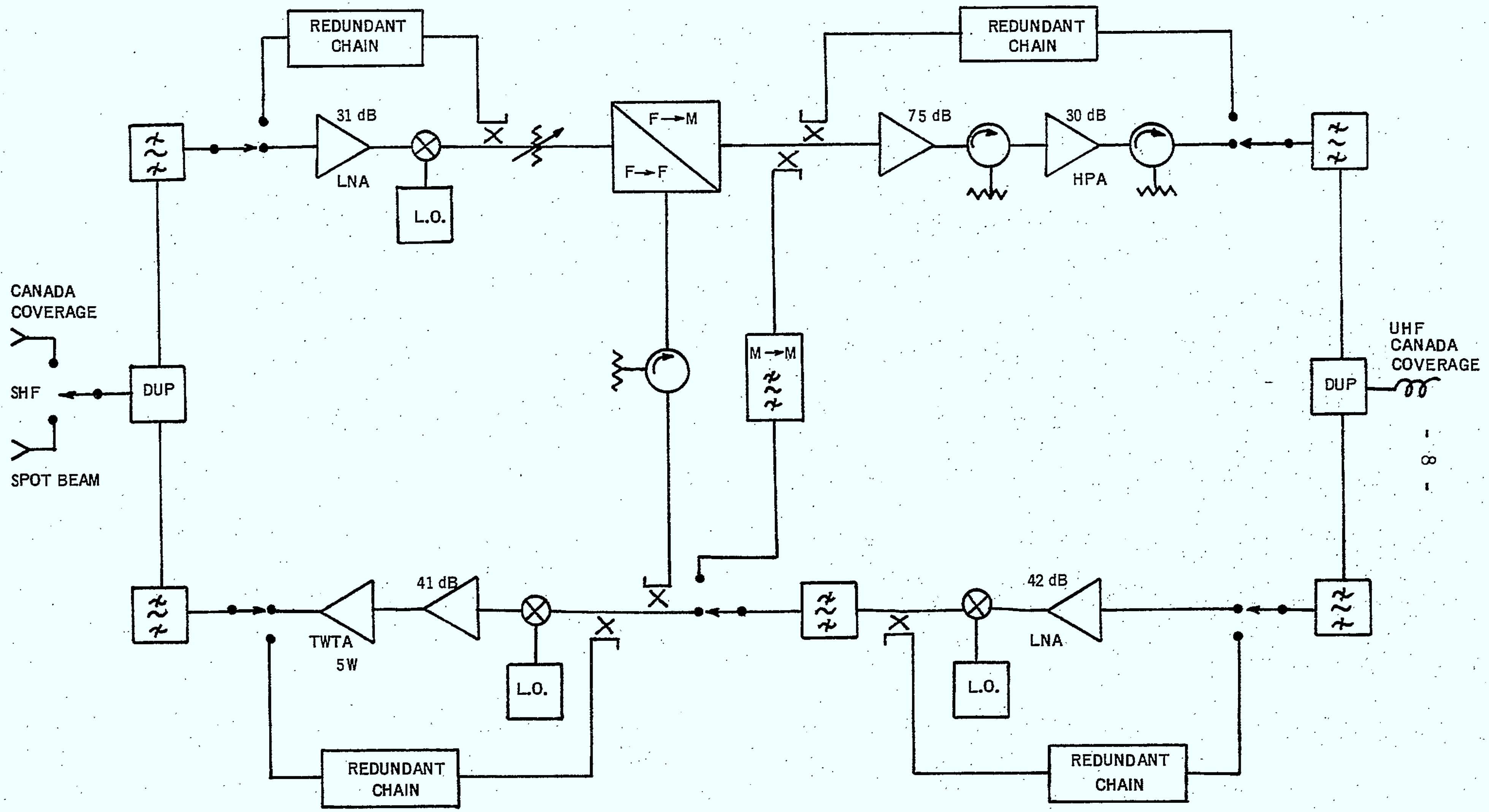


Figure I–4 Block diagram No.2 for UHF/SHF transponder

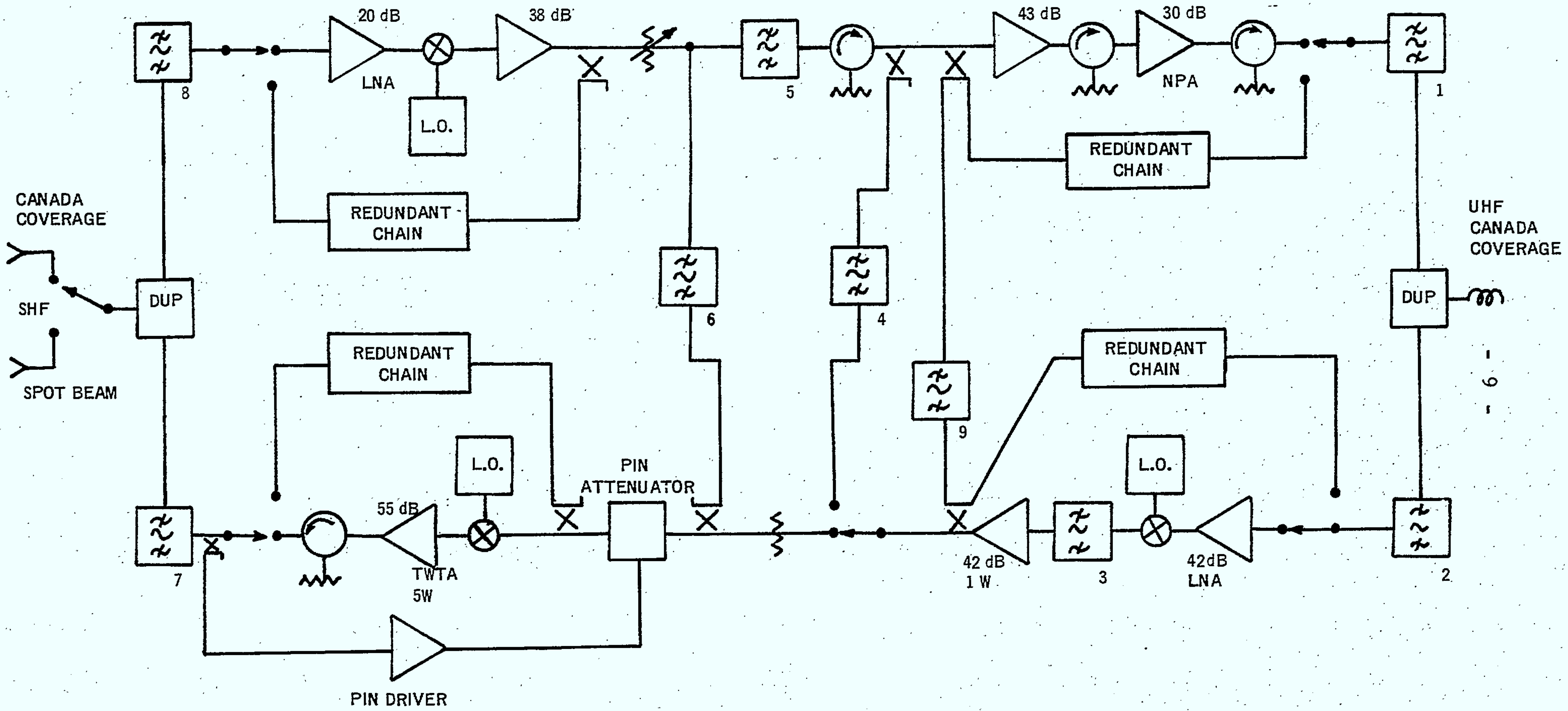


Figure I–5 Block diagram No. 2A for UHF/SHF transponder

Some additional changes are also shown in Figure I-5 namely the addition of filter number 9 for a narrow band of UHF to UHF traffic and the addition of a PIN diode attenuator and its redundant driver. This attenuator is controlled by the output power of the TWTA in such a way that the TWTA is never allowed to get too close to saturation.

Figure I-6 shows the final version of the transponder block diagram developed during the course of this study. There is a slight rearrangement of the filters 4 and 5 resulting in the elimination of filter number 4. In addition it has been recognized, by the addition of filter number 10, that a significant filter problem exists after the SHF to UHF mixer in the SHF receiver. The multipath problem in the cross strapped section has been examined. In the cases examined, the combination of filter separation and directivity of the hybrid junctions reduced the multipath signal to a low level and it is felt that no intractable problems of this nature are likely to occur.

In Figures I-7 to I-9 signal levels are included on the block diagram of Figure I-6. A low power signal of 18 dBW on the UHF downlink and -143 dBW/m^2 on the UHF uplink is used to illustrate the signal levels. In the SHF link an uplink field strength of -98.5 dBW/m^2 has been assumed for a low power channel for the purpose of setting the signal levels in the transponder. Other flux densities could be used with only minor implications on the spacecraft power and weight budget.

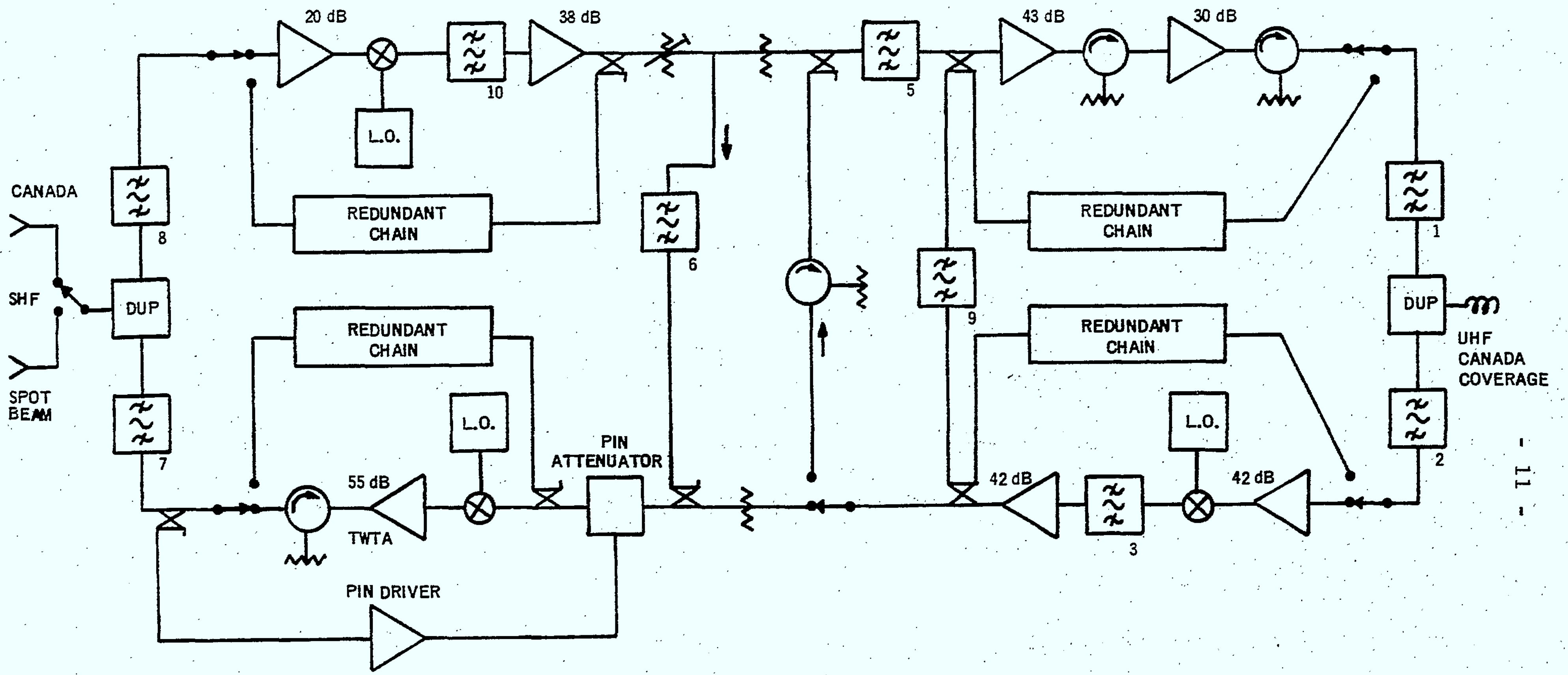


Figure I–6 Block diagram No. 2B for UHF/SHF transponder (Final version)

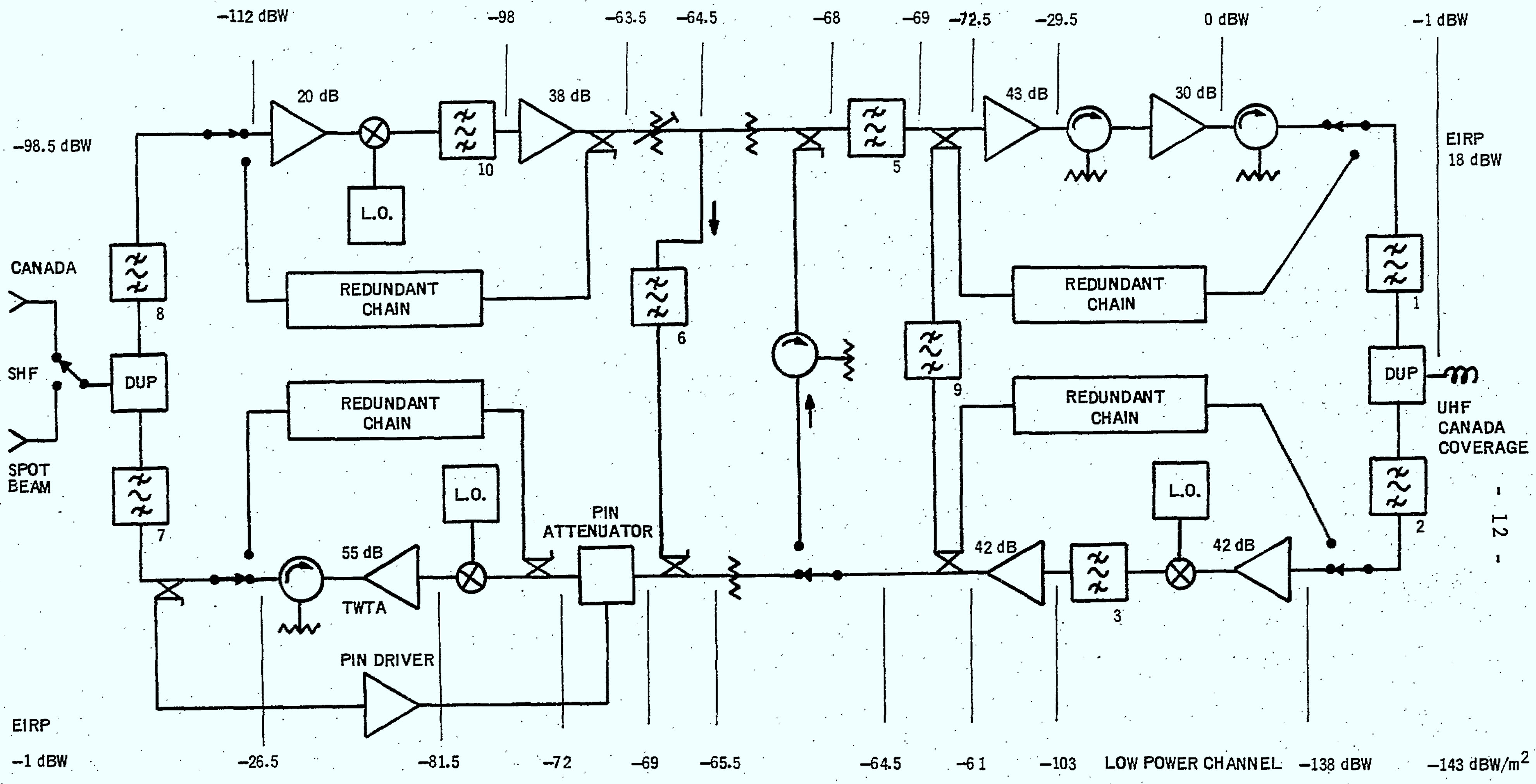


Figure I-7 Block diagram No. 2B for UHF/SHF transponder. Canada coverage 1 kW and 100 ft. antenna at SHF (no interference).

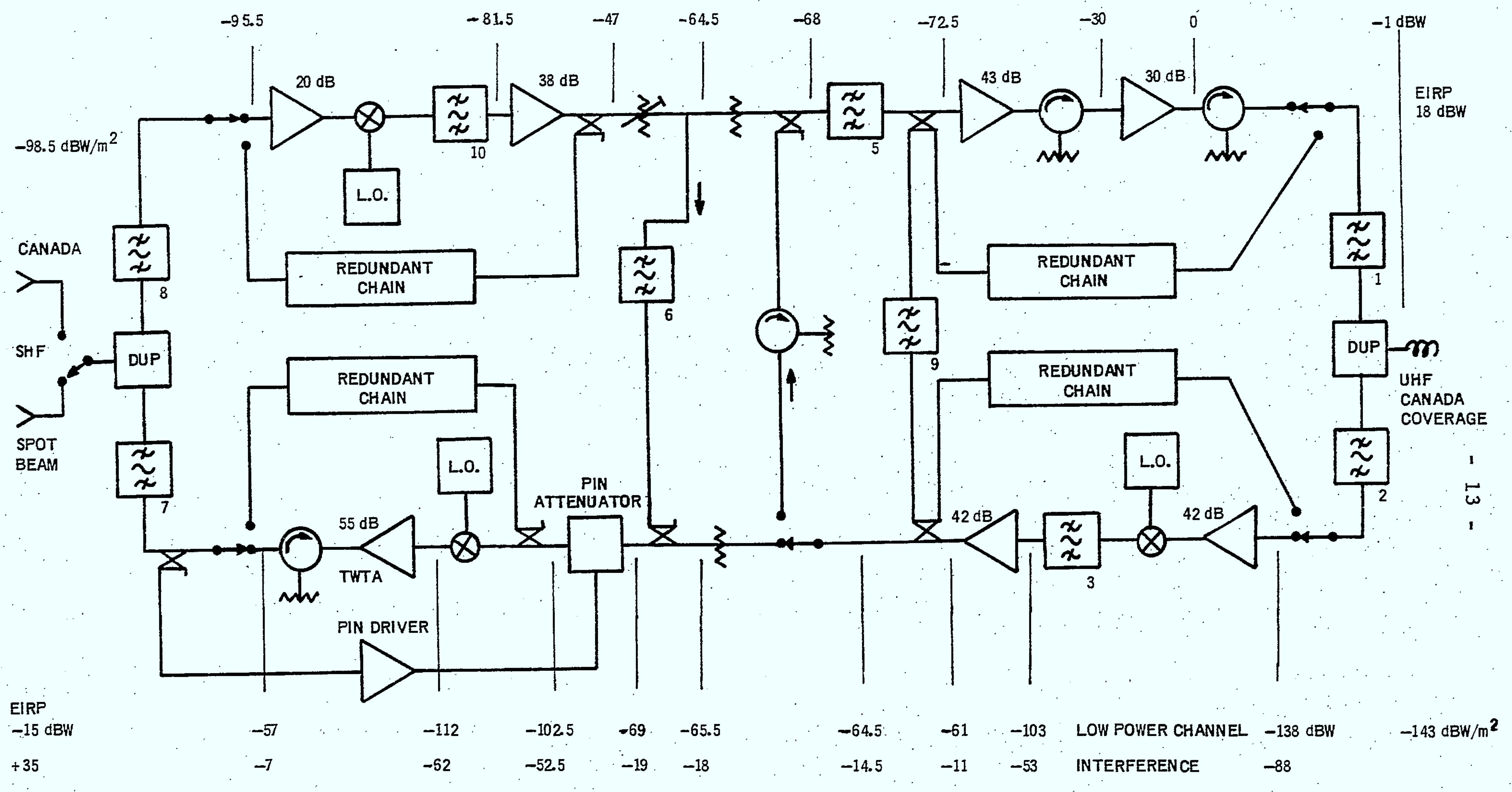


Figure I–8 Block diagram No. 2B for UHF/SHF transponder spot beam (UHF interference 50 dB above one low power channel)

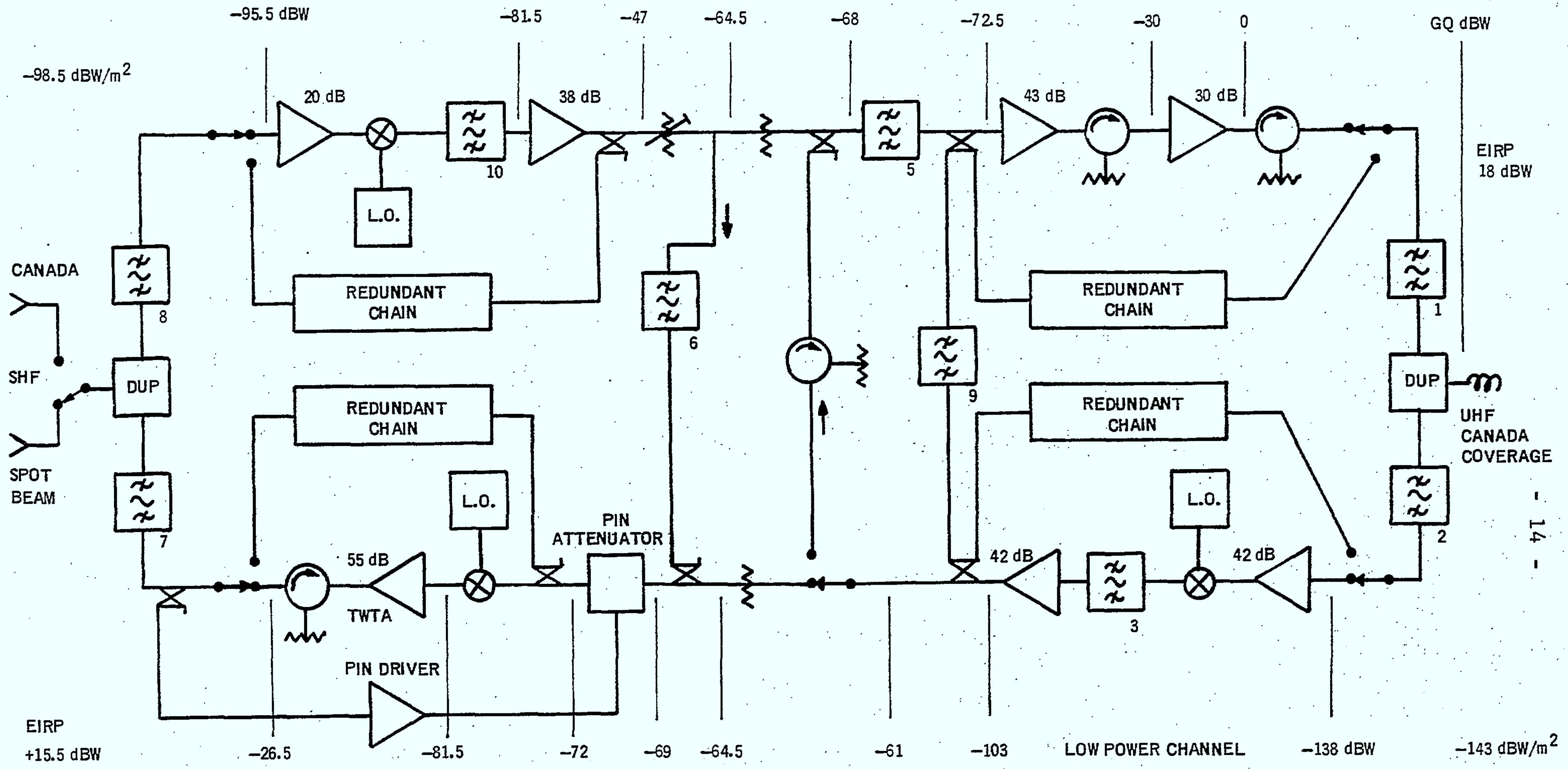


Figure I-9 Block diagram No. 2B for UHF/SHF transponder spot beam with 1 kW and 100 ft. antenna at SHF (SHF interfacing)

Figure I-7 shows the signal levels for the condition of no interference. The SHF antenna provides Canada coverage and the switched attenuator in the SHF receive leg is shown in its low attenuation state. Figure I-8 shows the signal levels when the satellite is experiencing UHF interference 50 dB above one low power channel. The interfering signal enters the UHF receiver and attains a level of -11 dBW at the output of the UHF receiver. All elements of the UHF receiver chain must have a large enough power handling capability to handle this power level in an essentially linear manner. In the SHF transmitter chain the interference is the dominant signal and the PIN diode leveling circuit maintains it at about the -7 dBW level. The desired signal is suppressed by about 30 dB. To recover some of the signal strength on the SHF downlink the antenna is switched to spot beam coverage. At the same time the switched attenuator in the SHF receive chain is switched to its high attenuation state so that signal levels in the UHF downlink transmitter are maintained constant.

In Figure I-9 the signal levels are shown when SHF interference is encountered. The SHF antenna is switched to spot beam and at the same time the attenuator switched to the high attenuation state. The interference is assumed to be outside the coverage area of the spot beam and therefore does not enter the SHF receiver.

It is recognized that a high power interference signal could pass through filter number 9 and jam the high power UHF transmitter.

This would have to be prevented by appropriate AGC action. This would have some impact on the spacecraft resources but the requirement has not been considered at this time.

I-4.0 FILTER REQUIREMENTS

The block diagram of Figure I-6 was examined to determine a reasonable manner in which the various filters could be located in the UHF band so as to provide the various services required and, on the other hand, avoid interaction between the filters. The various filters and their locations in the transponder are shown, with numbers, in Figure I-6. The services required are SSMA of about 15 MHz, FDMA with a minimum of 15 MHz, UHF to UHF of about 2 MHz permenantly connected plus a back up UHF to UHF connection for FDMA in case of a failure in the SHF section of the transponder. In addition, a narrow band SHF to SHF connection of 1-2 MHz is required.

In addition to these communications services the bands 401 to 403 Mhz for data retransmission platforms and 406 to 406,1 MHz for emergency position indication by radio beacon service are to be received by the satellite at UHF, translated to SHF and relayed to the central control terminal. These two services along with the SSMA traffic do not appear in the return link from SHF to UHF.

A tentative assignment of frequency and bandwidth for all services and the associated UHF filters are shown in Figure I-11. The filter center frequency and bandwidth are listed in Table I-1.

The most critical filters are the input and output filters at both UHF and SHF. The output filters must reduce emissions from the

TABLE I-1 - TENTATIVE FILTER PARAMETERS

Filter No.	Center Freq. mHz	Useable BW MHz
1	314	28
2	388	36
3	317	34
5	314	28
6	297	1
7	7300	120
8	8000	120
9	327	1
10	311	34

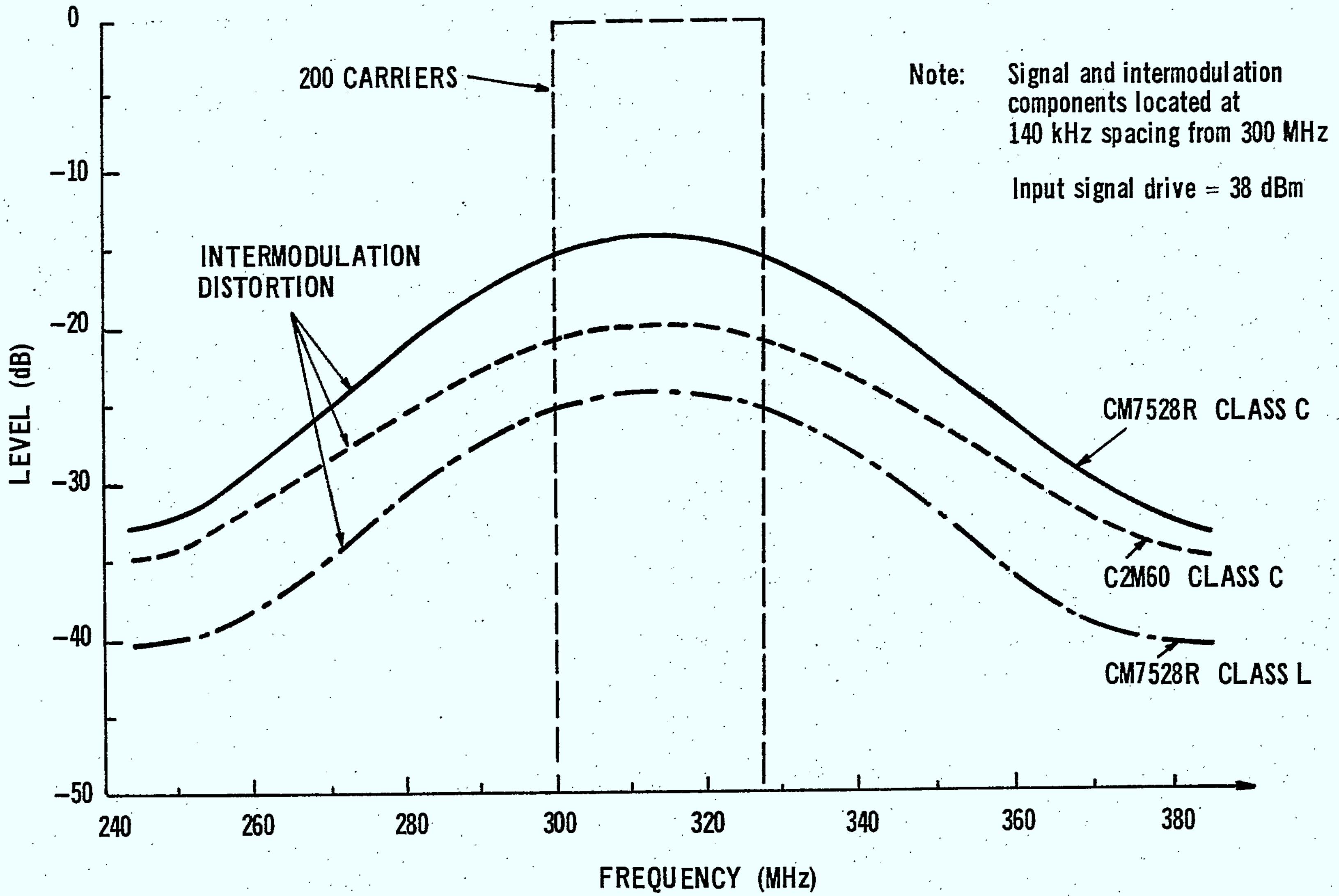


Figure I-10 Intermodulation noise spectrum calculated from measured amplifier nonlinearity characteristics

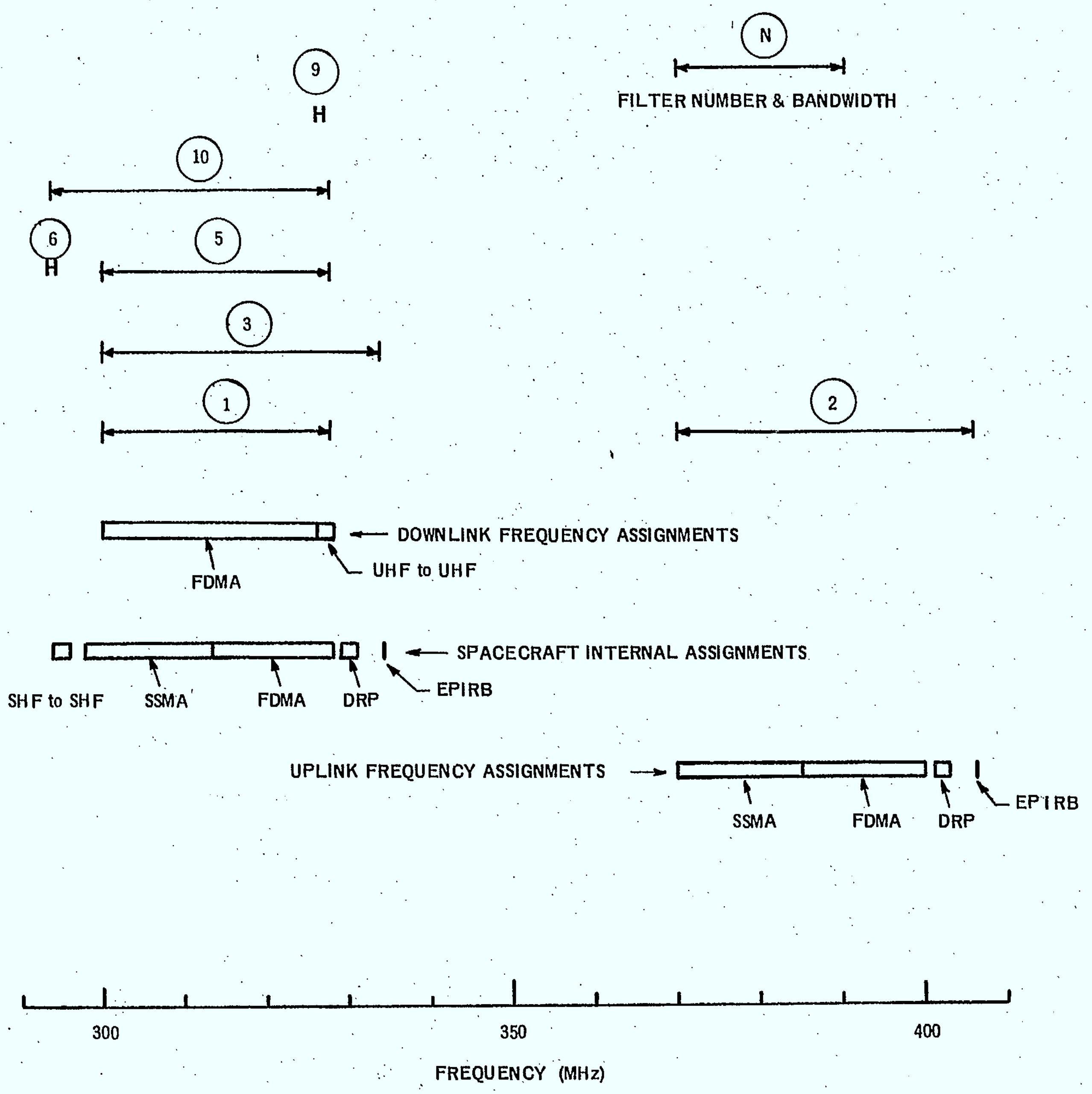


Figure I-11 Tentative frequency bandwidths in the UHF band

transmitter in the receive band to a level well below the thermal noise of the receiver. A level 10 dB below thermal noise has been selected as maximum acceptable level. This causes a degradation in C/N in the uplink of about 0.5 dB which is about the maximum that can be tolerated at least in the UHF uplink.

The input filter is required to protect the receiver from the Transmitted signal. The criteria is that the residual transmitter signal in the receiver should be well below the saturation level of the receiver. Under these conditions the intermod produced by the transmitter signals in the receiver are low and the gain of the receiver is not affected.

Calculations of the isolation required from the input and output filters at both UHF and SHF are summarized in Table I-2. The minimum total input and output filter isolation is calculated which may be divided between the input or output filter and the diplexer as required.

TABLE I-2 - FILTER ISOLATION CALCULATIONS

UHF Output Filters

Receiver thermal noise (25 kHz F=2d6)	-128 dBM
Reduce all Transmitter signals Receive band to	-138 dBM
Transmitter thermal noise figure	10dB
Transmitter thermal noise power	-120 dBm
Amplifier gain	72 dB
Transmitter noise at transmitter output	-48 dBm
Transmitter intermod C/I	15 dB
Small carrier power level	29 dBm
Intermod power (worst channel)	14 dBm
Decrease in Intermod from transmit to receive band at 370 mHz (see Figure I-10)	17 dB
Intermod in receive band (transmitter output)	-3 dBm
Transmitter spurious at transmitter output	-75 dBm
Required reduction in thermal noise	90 dB
Required reduction in intermod power	135 dB
Required reduction in spurious	63 dB
Minimum total output filter isolation in receive band	135 dB

continued

SHF Output Filter

Receiver thermal noise power	-125 dBm
Reduce all transmitter signals in receive band to	-135 dBm
Trasmitter thermal noise figure	30 dB
Transmitter thermal noise power	-100 dBm
Amplifier gain	55 dB
Transmitter noise power at transmitter output	-45 dBm
Transmitter intercept point	12 dBW
C/ (2 carriers) 2 x (12 - 26.5)	77 dB
**Degradation for 100 carriers	42 dB
C/1 (100 carriers) worst case	35 dB
Carrier level	-26.5 dBw
Intermod Power	-61.5 dBw 31.5 dBm
Decrease in Intermod from transmit to receive band	30 dB
Intermod power (receive band)	-61.5 dBm
Transmitter spurious at transmitter output	-75 dBm
Required reduction in thermal noise	90 dB
Required reduction in intermod power	73.5 dB
Required reduction in spurious	60 dB
Minimum total output filter isolation in receive band	90 dB

** Westcott R.J. Investigation of multiple FM/FDM comes through a satellite FWT operating near to saturation Proc. IEE Vol, 114, No. 6, June 1967, P8 726-740

continued

UHF Input Filter

Reduce transmitter signals in transmit band
well below saturation level of receiver front end

LNA intercept point	10 dBm
Transmitter signal power at output of LNA	-10 dBm
LNA gain	42 dB
Transmitter signal power at input of LNA	- 52 dBm
Transmitter output power	50 dBm
Minimum total input filter isolation in transmit band	102 dB

SHF Input Filter

Intercept point on Receiver LNA	-15 dBm
Transmitter signal power at LNA output	-35 dBm
LNA gain	20 dB
Transmitter signal power at LNA input	-55 dBm
Transmitter output power	23 dBm
Minimum total input filter isolation at transmit band	78 dB

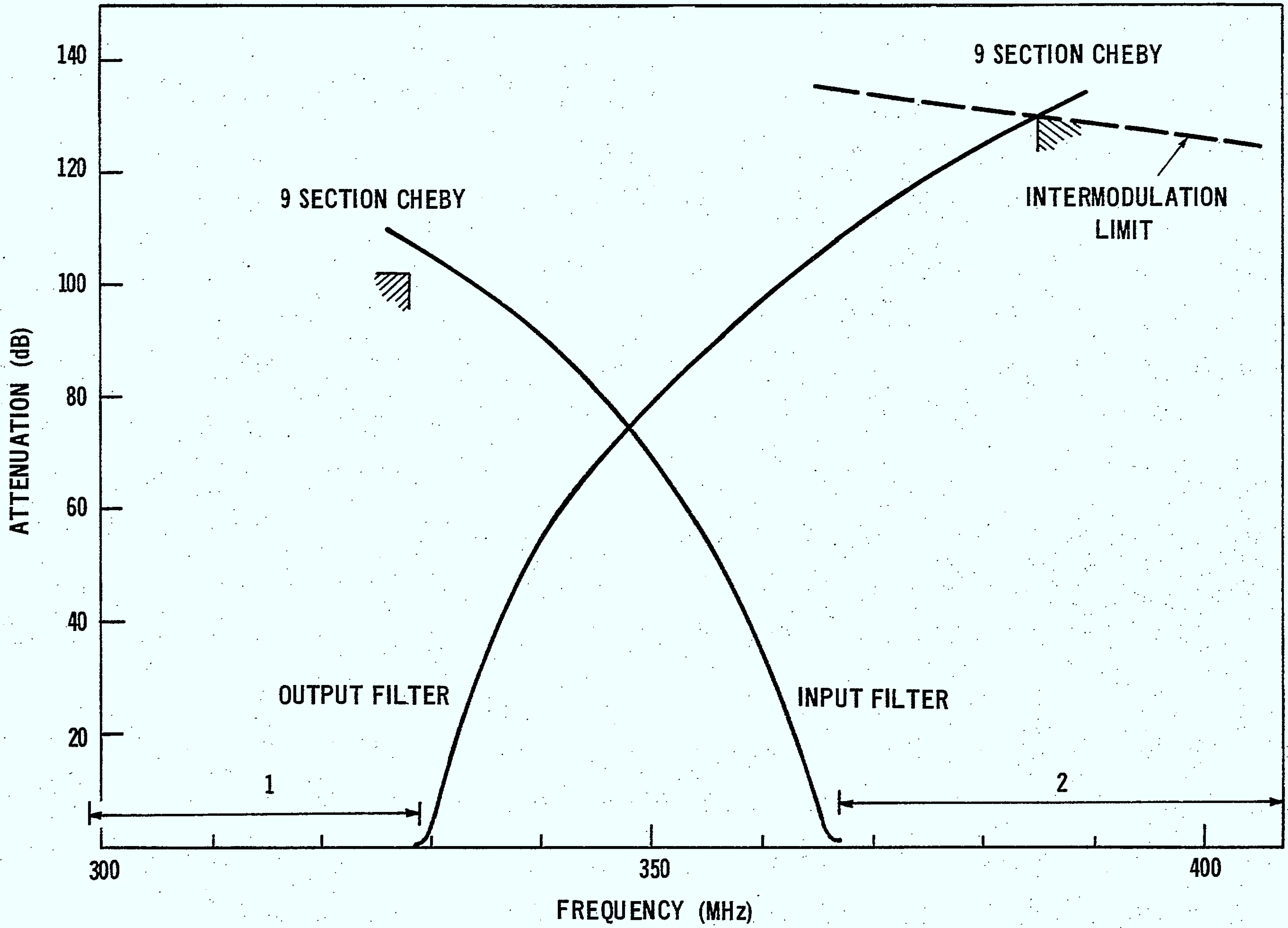


Figure I–12 Required characteristics of the input and output filters at UHF

I-5.0 ANTENNA CONFIGURATION

Considerable attention was directed towards the antenna configuration to meet the requirements. These requirements are rather stringent. The antenna was required to transmit and receive on each of three beams namely

1. Canada coverage at UHF
2. Canada coverage at SHF
3. Spot beam at SHF

Two basic configurations were considered (a) A single parabolic reflector with a complex feed assembly providing all the above three beams and (b) a quad helix for UHF with a smaller reflector in the center of the quad helix to provide the two SHF beams. The latter has been found less favourable because to provide the desired UHF gain of 19 dB it would be necessary to deploy the quad helix in two directions, namely moving the helices to give the correct spacing and then extending the helices. By contrast the parabolic reflector requires only one deployment mechanism (the outer rim of the parabola is a fold out mesh structure). The necessity to provide three feeds for the reflector instead of only two for case (a) above is an added complication. Apertures will have to be cut in the solid central reflector for the earth sensors etc., but this would not alter the performance by any significant amount.

Gain and beam width are presented as a function of diameter for UHF in Figure I-13 and for SHF in Figure I-14. The cross section of the parabola with feed is shown in Figure I-15 while the plan view is

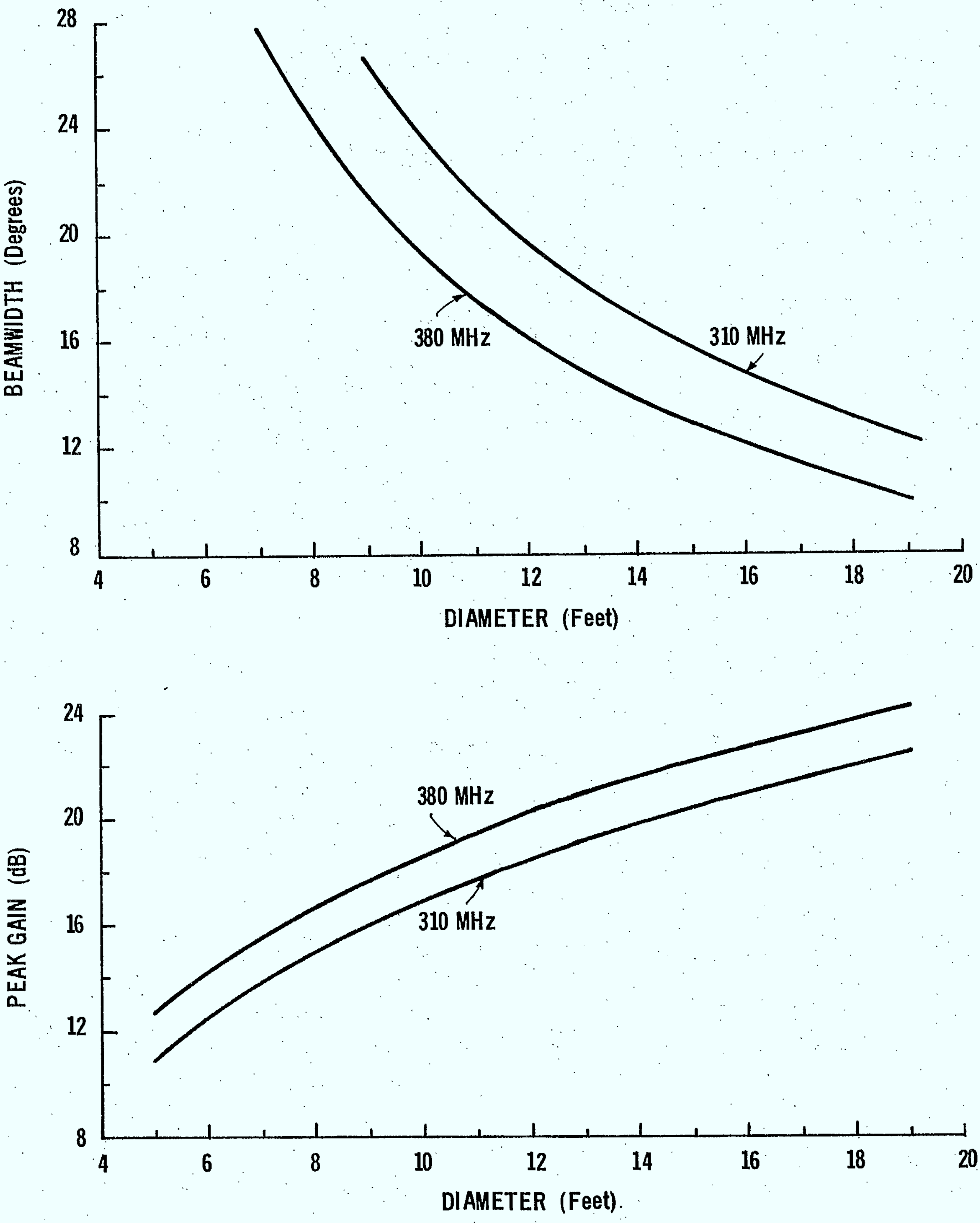


Figure I-13 Beam width and gain of a UHF parabolic reflector versus diameter

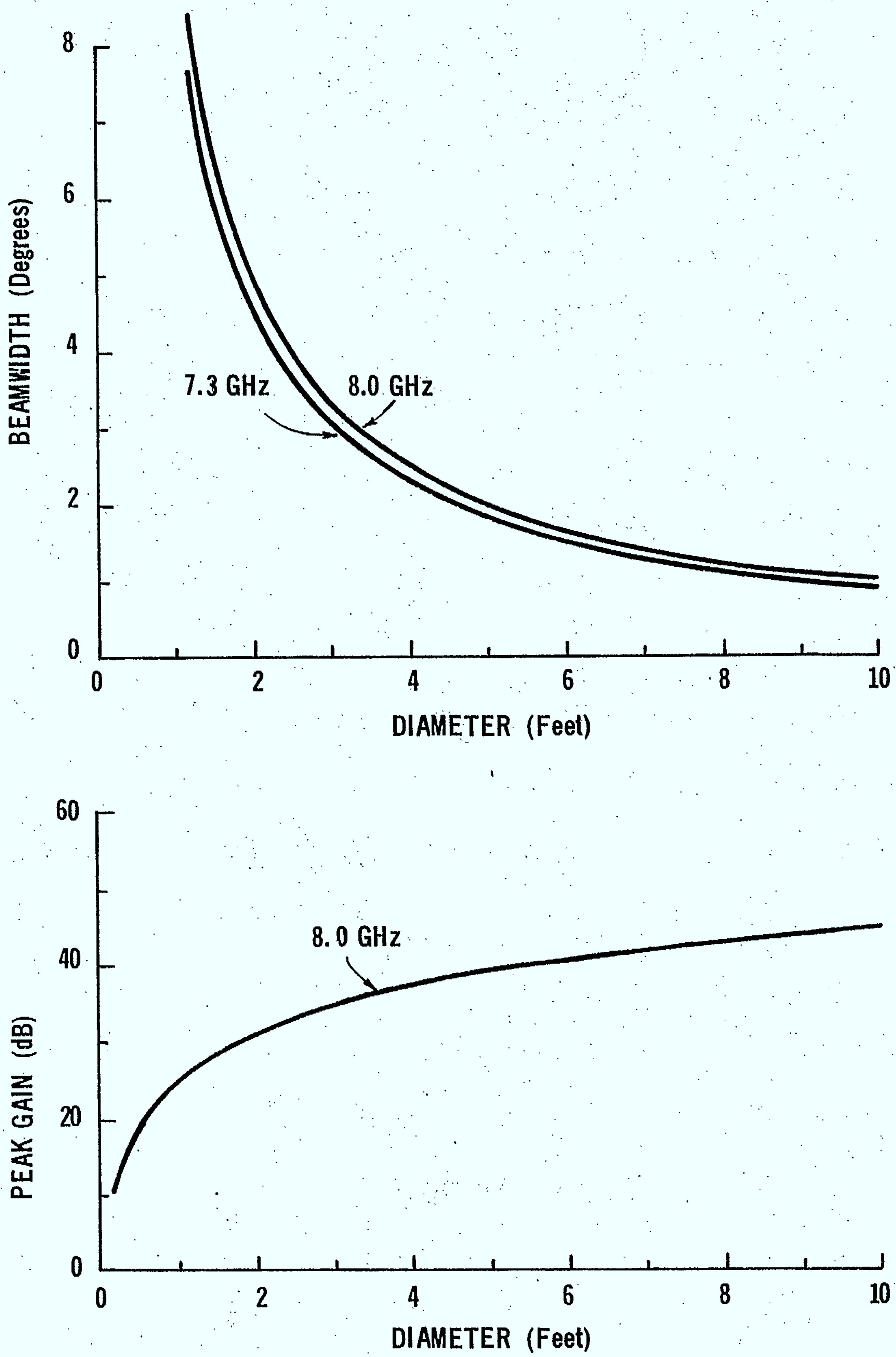


Figure I–14 Beamwidth and gain of an SHF antenna versus diameter given in Figure I-16. An f/d of about .25 is shown for UHF, .5 for SHF spot beam and much larger for SHF Canada coverage.

A quadrifilar helix is shown for the UHF feed and an array of horns for SHF (Figure I-17). The array is fed with a Bulter matrix (Figure I-18) so that for the Canada coverage beam the reflector is illuminated off axis. In this way the blockage of the feed assembly is avoided. To provide a spot beam the signal is fed to only one of the feed horns giving symmetric illumination out to about 7 ft diameter (switching arrangements are nct shown).

The quadrifilar helix is a four wire helix with a length about equal to the diameter. It radiates circular polarization. In Figure I-17 the length is somewhat shorter than the diameter. This is necessary to increase the diameter so that it will enclose the horn assembly. Depending upon the size of the horn assembly this may not be an acceptable solution as the polarization purity degrades as the length to diameter ratio departs from optimum. In addition the quadrifilar antenna is a resonant structure and requires a separate helix for transmit and receive. This may be an advantage because it will provide additional isolation between transmit and receive.

Table I-3 Antenna parameters

Antenna type	deployed parabola
Antenna diameter	13 feet
UHF gain over all Canada	19 dB
SHF gain over all Canada	26 dB
SHF peak spot beam gain	42 dB
UHF Polorization	Circular
SHF Polorization	Linear
Weight	55 lbs.

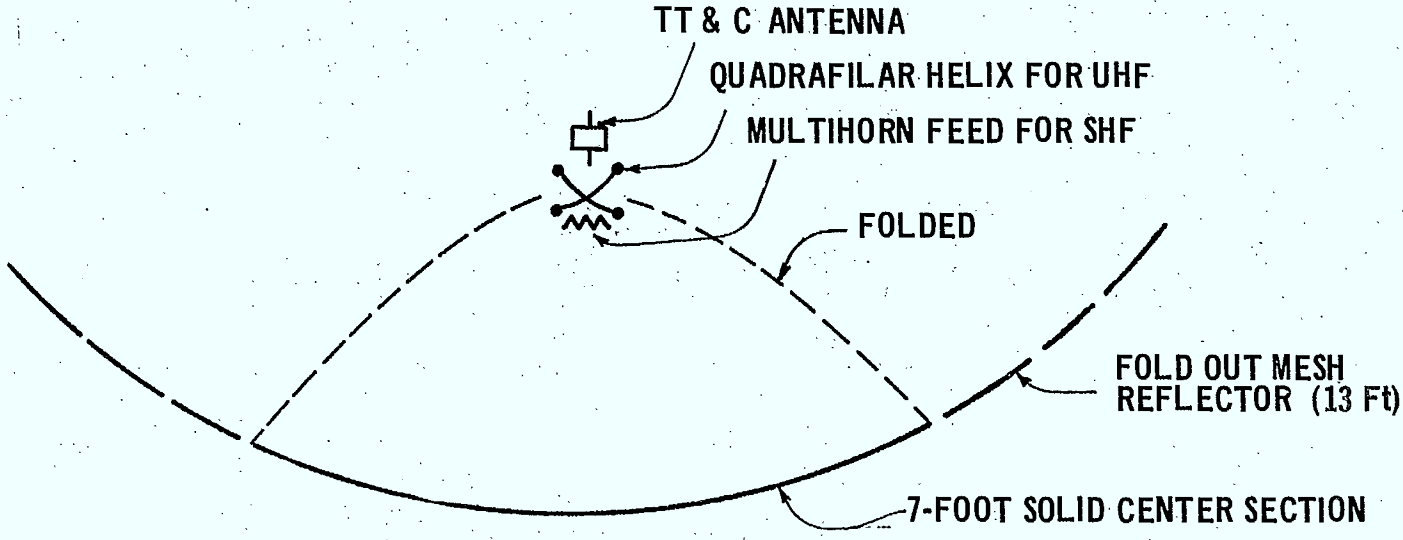


Figure I–15 Cross section of dualband reflector antenna

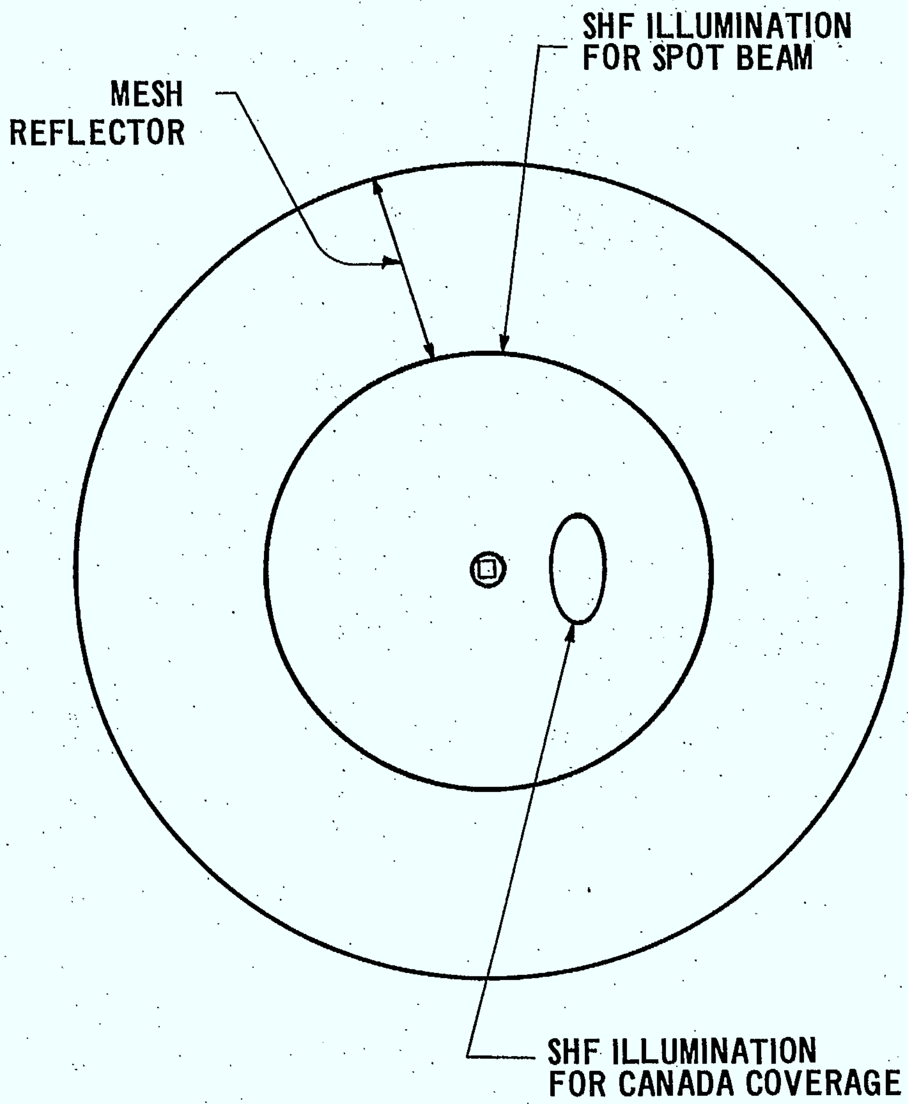


Figure I–16 Plan view of dualband reflector antenna

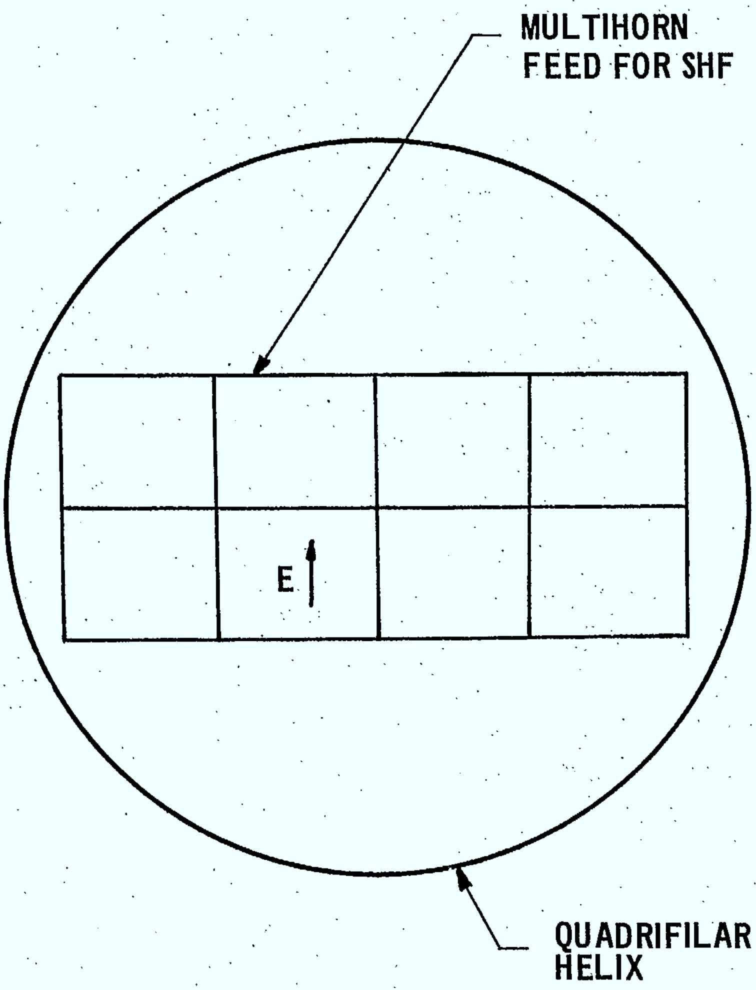


Figure I–17 Detail of feed structure

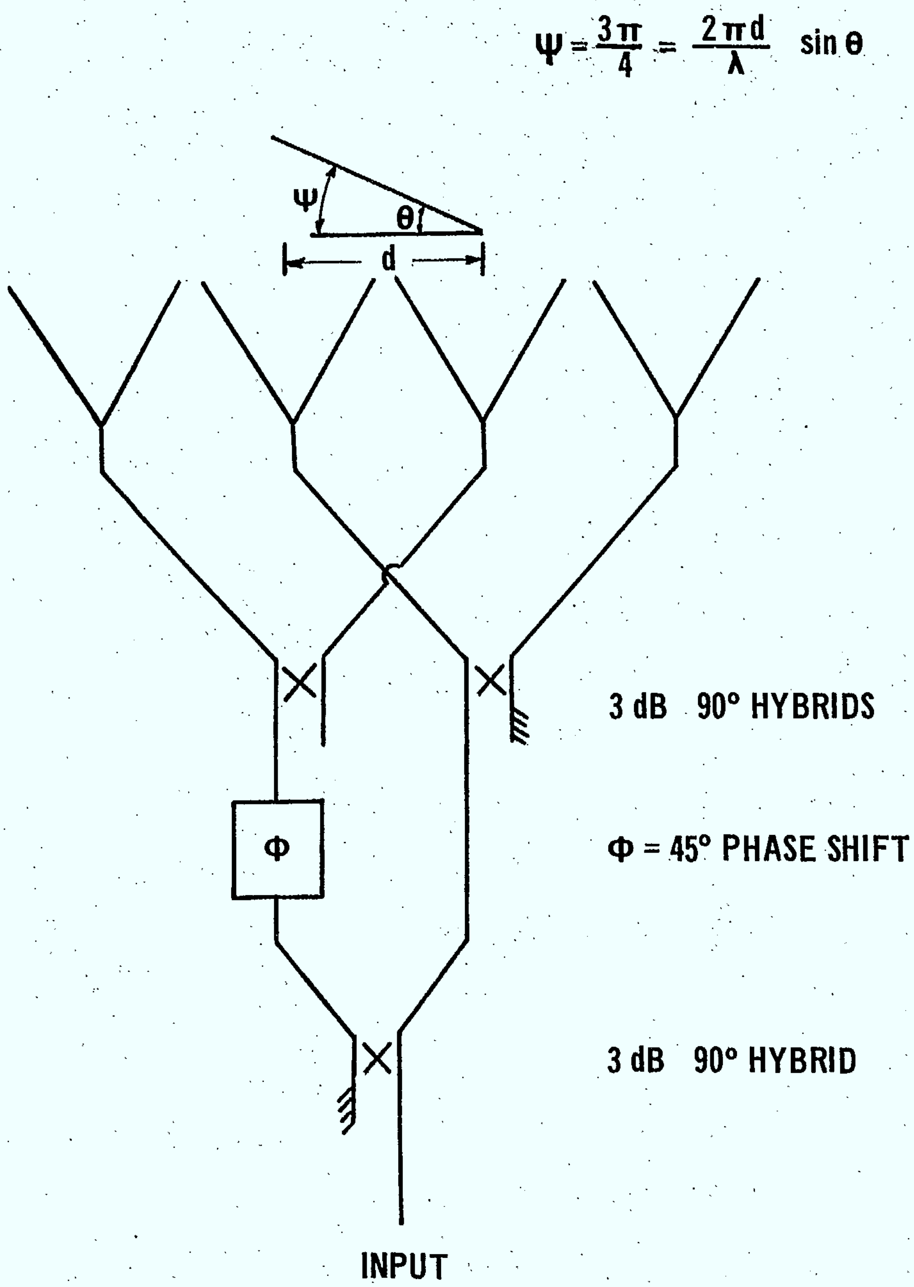


Figure 1–18 Butler matrix feed for a four-horn array

I-6.0 WEIGHT AND POWER

The weight and power estimates are given in Table I-4. The UHF amplifier weight and power figures are based on commercially available units of appropriate noise and power level. Filter weights are based on comb type filter structures fabricated from GFEC material. Some resources are alloted to power conditioning. This is required because power from the spacecraft swings between array voltage and battery voltage. It has been assumed that the high power UHF amplifier can work between these limits and no power conditioning has been included for this unit.

TABLE I-4 - WEIGHT AND POWER ESTIMATES

	Unit Weight (oz)	Number	Total Weight (oz)	Power (Watts)
- UHF LNA	12	2	24	1
- IW UHF Amp	40	2	80	16
- UHF mp	10	2	20	2
- UHF driver	40	2	80	16
- HPA & EPC		To be determined		
- SHF L A	15	2	30	1
- SHF TWTA	80	2	160	20
- UHF/UHF mixer	8	2	16	-
- UHF/SHF mixer	8	2	16	-
- SHF/UHF mixer	8	2	16	-
- UHF/UHF L.O.	8	2	16	1
- UHF/SHF L.O.	16	2	32	1
- SHF/UHF L.O.	16	2	32	1
- UHF hybrid	2	6	12	
- SHF direct Coupler	2	1	2	
- UHF switch	6	3	18	
- SHF switch	4	3	12	
- command attenuator	8	1	8	
- attenuator pads (UHF)	1	4	4	
- UHF isolators	8	8	64	
- SHF isolators	3	6	18	
- UHF filters	16	9	144	
- SHF filters	4	2	8	
- PIN modulator	6	1	6	
- PIN driver	8	2	16	1
- Antenna and feed	55x16	1	880	
- Cables and connectors	48	1	48	
- misc Hardware	5x16	1	80	
- Power, telemetry and Command (PTC)	6.5x16	1	104	6
			1946 oz = 121.6 lbs.	66 W

PART II

UHF/SHF/L-BAND PAYLOAD

II-1.0 Introduction

Part II describes work carried out to define an L-band addition to the UHF/SHF transponder configuration. The basic UHF/SHF transponder is described in Part I and should be read in conjunction with this part to obtain a full understanding of the complete transponder configuration..

II-2.0 L-band requirements

The following pages provided by the project officer, specify the L-band portion of the transponder. Included is a task description of the three tasks covered by this portion of the contract and included in this report.

UHF/SHF/L-BAND TRANSPONDER

1. Purpose

To provide a domestic coverage AEROSAT and MARISAT compatible service to air and ship mobiles, in addition to the UHF/SHF services provided by the UHF/SHF transponder concept.

2. Frequency Plan

Figure II-1 attached. L-band frequency assignments are proposed to be in the 1 MHz band which is shared between Aeronautical and Maritime services. (i.e., 1644 - 1645 MHz uplink and 1542.5 - 1543.5 MHz downlink)

3. Assumptions

(a) Frequency plan - see Figure II-1.

(b) L-band coverage $4^{\circ} \times 8^{\circ}$ beam (i.e., 29 dB peak gain, 26 dB gain at edge of coverage).

(c) Polarization for L-band is RHC, UHF/SHF Polarizations remain the same as in the UHF/SHF transponder.

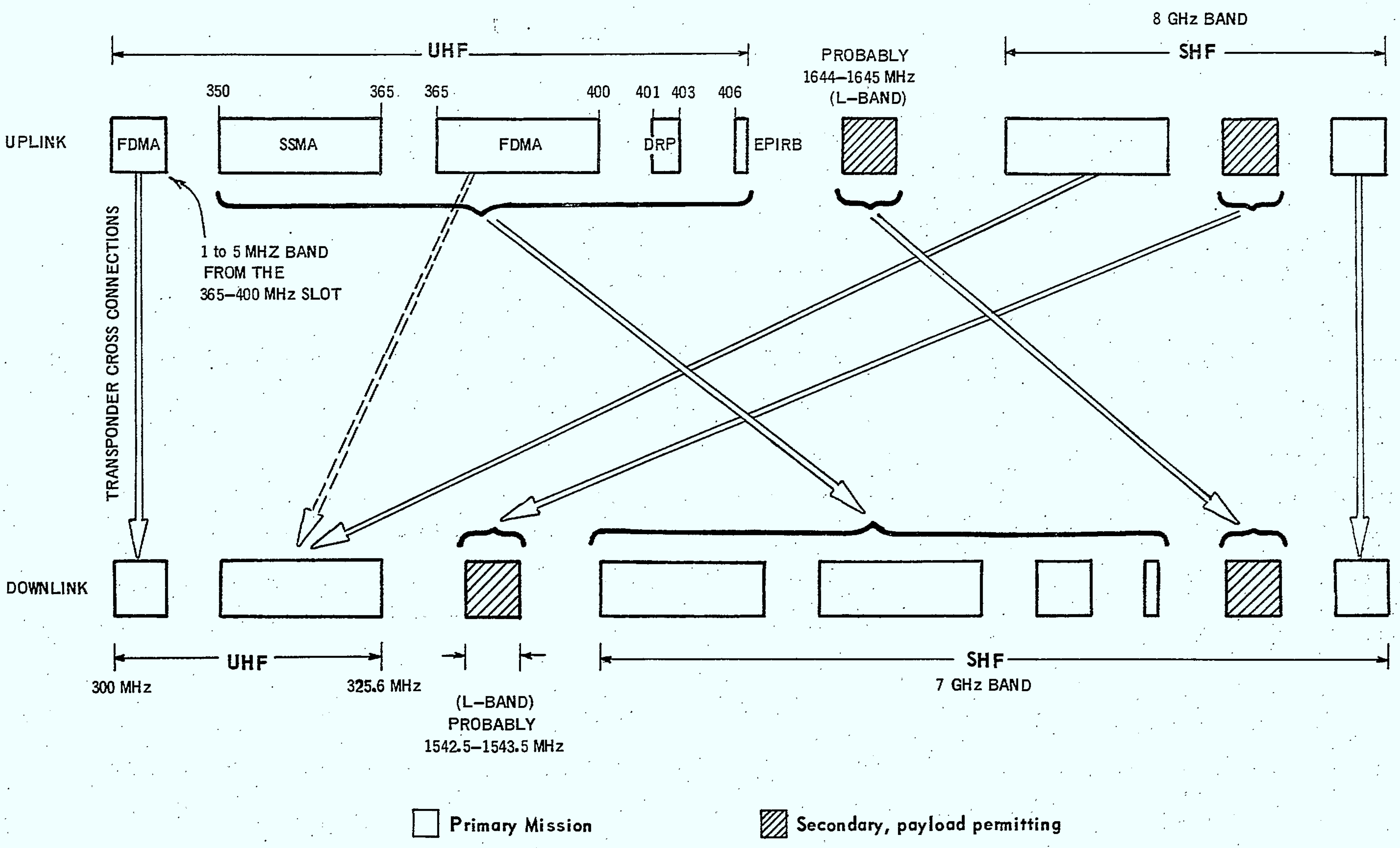


Figure II-1 Tentative frequency plan – UHF/SHF/L-Band transponder

(d) Spacecraft L-band RF losses from the TWT to the antenna are 1.5 dB.

(e) Fixed station parameters: 30' parabolic, 100^{o}K noise temp, 100 watt TWT.

4. Technical Parameters

4.1 Forward Channels (fixed to mobile)

		Aeronautical	Maritime
1.	Require space to mobile c/No dBhz	43	51
2.	Mobile noise Temp ^{o}K	1000	500
3.	Mobile antenna gain dB	4	23
4.	Margin at L Band dB	5	5
5.	Free space loss L-band dB	188.4	188.4
6.	Required space to mobile L-band EIRP dBW (edge of coverage)	33.8	19.8
7.	Satellite SHF	1000	1000
8.	Satellite SHF net antenna gain dB	29	29
9.	Required fixed to space c/No dBHz	63	71
10.	Free space loss at SHF (8GHz) dB	202.6	202.6
11.	Margin at SHF dB	3	3
12.	Required EIRP at SHF (dBW)	41	49
13.	For fixed gain transponder required ground station EIRP	63	49
14.	SHF flux density at satellite (dBW/m)	-100	-114

4.2 Return Channels (mobile to fixed)

		Aeronautical	Maritime
1.	Number of return channels	2	2 to 5
2.	Overall C/No required	44 dB-Hz	53 dB-Hz
3.	Satellite L-band Rx noise temperature	1000^{0}K	1000^{0}K
4.	Gain of the satellite L-band antenna (edge of Canada)	26 dB	26 dB
5.	Margin at L-band	5 dB	5 dB
6.	Mobile EIRP	23 dBW	37 dBW
7.	L-band flux at satellite	-140 dBW/m^2	-126 dBW/m^2
8.	Mobile-to-space C/No	53.5 dB-Hz	67.5 dB-Hz
9.	Ground station antenna gain (SHF)	54 dB	54 dB
10.	Ground station Rx temperature	100^{0}K	100^{0}K
11.	SHF margin	3 dB	3 dB
12.	Required space-to-fixed C/No	44.5 dB-Hz	53.5 dB-Hz
13.	Required space-to-fixed EIRP	-13 dBW	-4 dBW

5. Contract Task

(a) Modify the UHF/SHF transponder to accommodate the L-band requirement. This involves the installation of L-band antenna feeds, receiver, cross-strapping of the L-band to the SHF, and the addition of a L-band TWT (redundant). Assuming an L-band antenna gain of about 26 dB edge gain, the TWT power is as shown in the chart below.

	Aeronautical	Maritime
Number of channels	1	1 to 4
EIRP/channel	33.5 dBW	19.5 dBW
L-band gain (edge of coverage)	26 dB	26 dB

RF losses	1.5 dB	1.5 dB
RF watts/channel	7.9	.32
Total Rf (one aeronautical, four maritime		9.2 watts
TWT power (2 dB backoff)		15 watts

(b) Determine the weight and power budgets for this new configuration.

(c) Determine if this new transponder can be accommodated in a typical 3914 3-axis bus. Also determine the remaining UHF capacity for various eclipse capability (100%, 50%, 25%) assuming:

(1) L-band portion has full eclipse capacity.

(2) L-band portion has no eclipse capacity.

II-3.0 Transponder configuration with L-band addition

Two ways have been identified for including the L-band capability into the UHF/SHF transponder. Block diagrams of transponders illustrating these two methods are shown in Figures II-2 and II-3.

L-band traffic from aircraft or marine vehicles is received by the L-band antenna and after frequency translation in the spacecraft is radiated at 7GHz. It is then received by the central control station and routed to its destination. The return message retraces the path from the central station to the SHF receiver on the spacecraft whence it is radiated at L-band. There is no requirement for traffic between L-band and UHF.

Figure II-2 shows the L-band portion of the transponder connected into the SHF receiver just after the low noise amplifier and into the SHF transmitter just before the TWTA. Thus the SHF to L-band path and the L-band to SHF return both have single conversion frequency translations.

Figure II-3 shows the L-band portion of the transponder connected in at the UHF transmit frequency. Thus the SHF to L-band link and the L-band to SHF return path both have double conversion frequency translations. This latter configuration (Figure II-3) would seem to be the least desirable because of the double frequency conversion and the addition of four of the relatively large size UHF filters. However, this arrangement causes the L-band signals to pass through both the commandable attenuator and the PIN attenuator

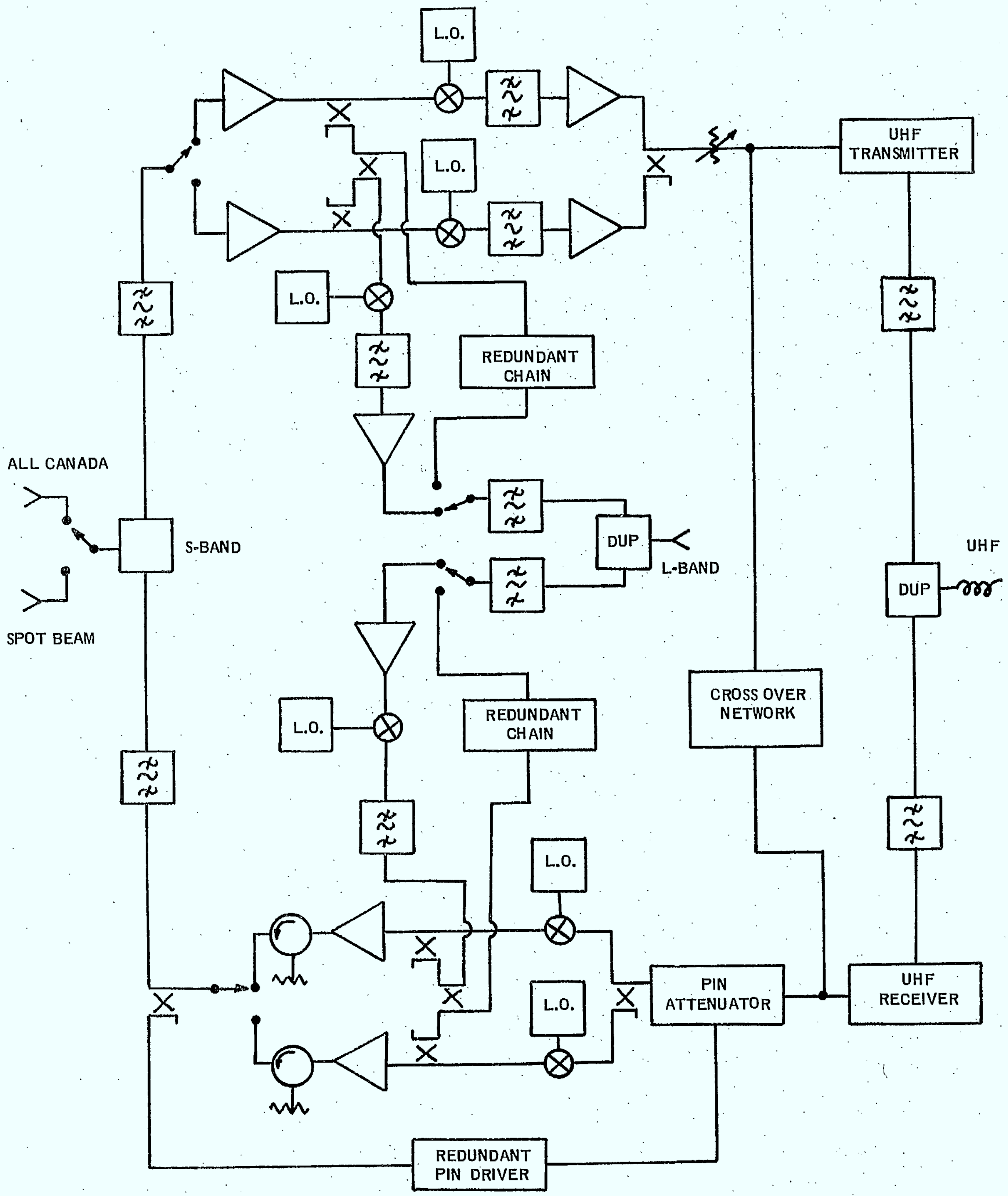


Figure II–2 Block diagram No. 3A for UHF/SHF/L-band transponder

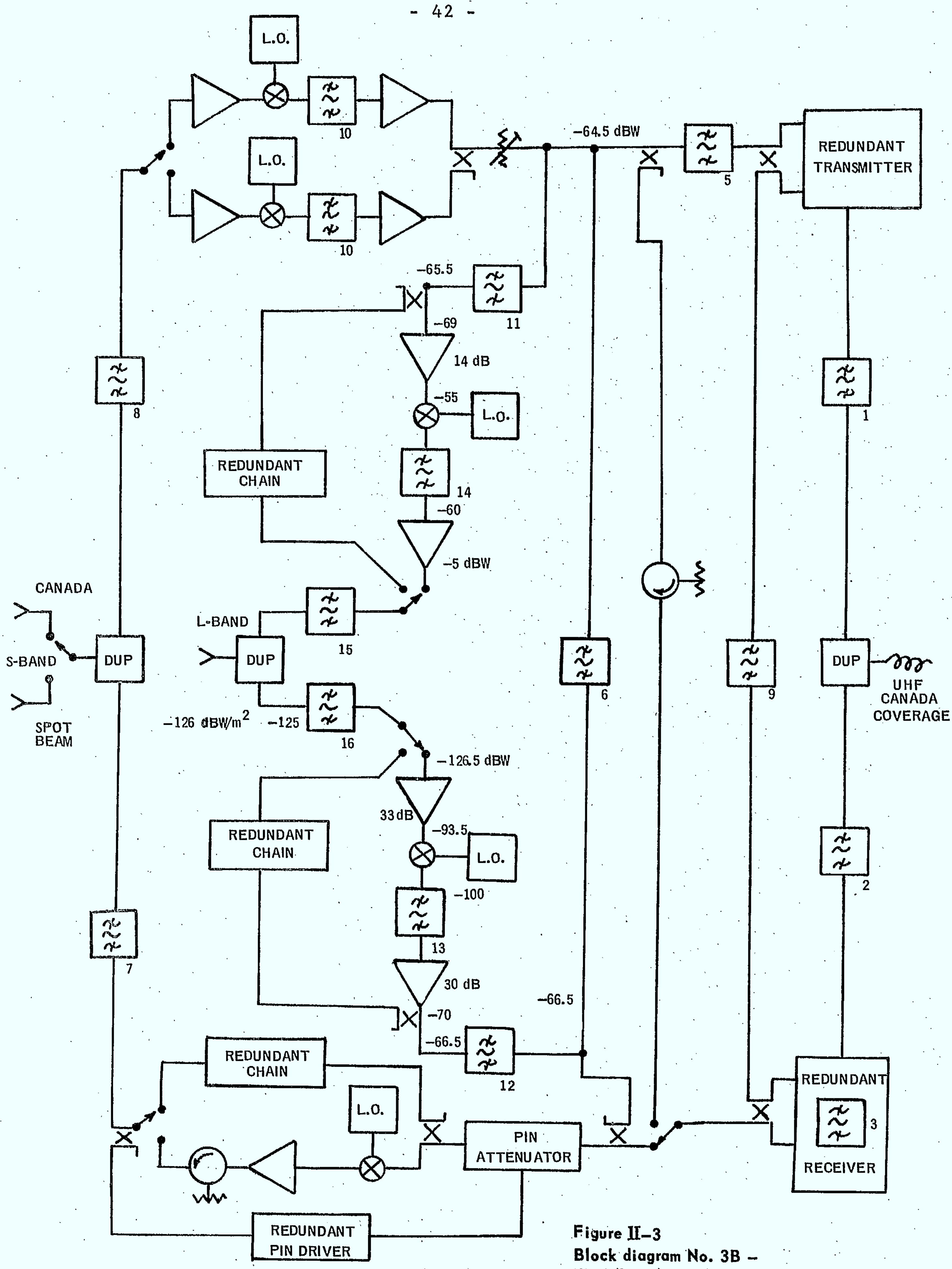
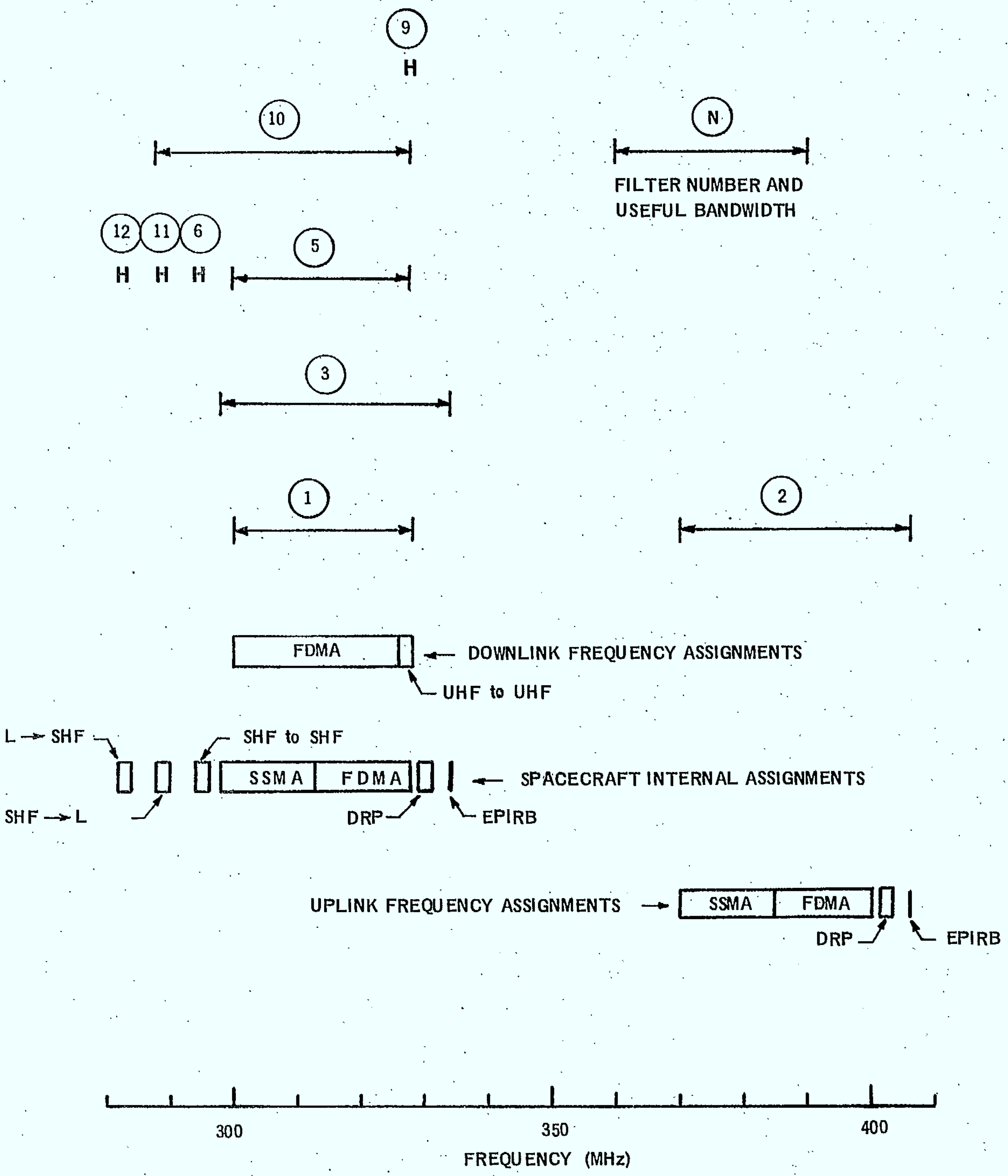


Figure II-3
Block diagram No. 3B – UHF/SHF/L-Band Transponder

and gives protection against L-band interference as well as UHF and SHF interference. On the other hand, if the configuration of Figure II-2 is used, then L-band interference would not only block L-band traffic but UHF to SHF and SHF to SHF traffic as well. Only UHF to UHF and SHF to UHF traffic would remain. If it is not required to maintain L-band service in the presence of large L-band interference then the UHF traffic can be protected from L-band interference by an AGC action in the L-band receiver. Another consideration is the effect of UHF interference on the L-band service. With the configuration of Figure II-2 the SHF ground transmitter would have to adjust the levels of all carriers destined for L-band, a requirement that does not occur with the configuration of Figure II-3. For these various reasons Figure II-3 is considered to be the prefered configuration.

II-4.0 Frequency Plan

This frequency plan is based on the assumption that the transponder of Figure II-3 is adopted. The frequency plan is shown in Figure II-4. It is the same as that included in the Part I of this report except for the addition of a narrow band of 1MHz for the L-band traffic. Only one filter (No. 10) needs to be changed from the UHF/SHF configuration. The additional traffic appears internally in the UHF band but is only radiated at L-band and SHF. An additional advantage of double conversion of the L-band traffic is that relatively narrow band filters can be utilized to separate the L-band traffic from the rest of the traffic.



FigureII–4 Tentative frequency plan in the UHF band

II-5.0 Antenna Configuration

The antenna configuration required for this spacecraft is extremely complex. Four separate antenna beams in three distinct frequency bands are required. Transmit and receive capability is required on all four beams. Three of the beams are provided by a 13 foot diameter parabola of revolution reflector with a focal point feed. The central portion of approximately seven foot diameter is a solid reflector while the outer 6 feet (3 foot radius) consists of a deployed mesh configuration. The facilities suggested for each of the four beams are described below (shown in Figure II-6).

(a) UHF - The full 13 foot diameter is illuminated by a quadri filar helix to provide circular polarization. A parabolic focal length of 3.25 feet is used giving an f/d ratio of 0.25. Because of the resonant nature of the quadrifilar helix separate helices for transmit and receive are considered necessary. The quadrifilar helix provides very good circular polarization over a full hemisphere and seems ideally suited for this application.

(b) SHF spot: - An aperture size of seven feet or slightly less is required for the SHF spot beam. This is provided by a focal point feed horn but the horm is aimed to one side to reduce distortions caused by the Canada coverage insert described in (c) below and by holes that must be cut in the solid central part of the reflector for station keeping functions.

(c) SHF Canada coverage:- This is provided by a specially formed insert set into the east (or west) side of the solid portion of the main reflector. A focal length of 2 feet has tentatively been selected for this insert. If the vertex of the insert is displaced from the vertex of the main reflector both axially and latterly, then the contour of the insert follows the contour of the main reflector that it replaces by a very small maximum error. There is also a blockage of the UHF and L-band aperture by the SHF horn for the insert. This blockage must be considered in optimizing the SHF Canada coverage antenna.

(d) L-band coverage: - Because L-band radiation must be circularly polarized a quadrifilar helix is used as the feed element. This provides a circularly symmetric illumination pattern and would provide a circular beam in the far field from a parabola of revolution reflector. To optimize the ground coverage at L-band and give the required $4^{\circ} \times 8^{\circ}$ beam, two quadrifilar helices are used appropriately spaced to illuminate the reflector over an area of approximately 7' x 13'. The gain and beam width of an L-band aperture is shown in Figure II-5 as a function of diameter. It is seen that almost the full 13 feet is required to give 4 degrees N-S beam width.

The basic concept for this antenna incorporates an insert with a shorter focal length for the SHF Canada coverage. Because of defocussing effects, the SHF spot beam illumination may not be able to fall on the area occupied by the insert. The SHF spot must then be squinted sideways (East-West) so that a portion of the SHF spot falls on the less accurate mesh portion of the reflector. At the same time a part of the accurate solid portion

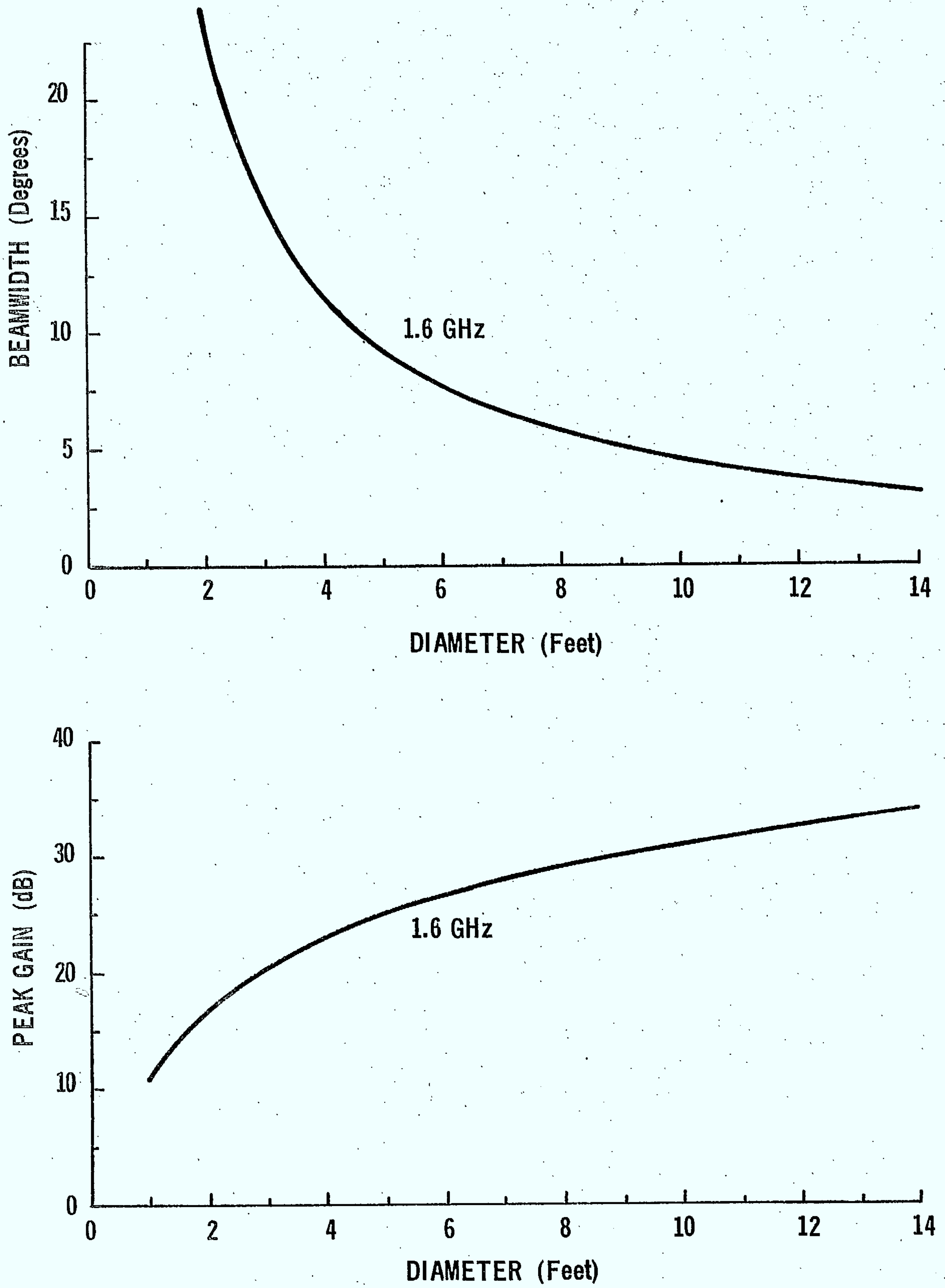


Figure II-5 Beamwidth and gain for an L-band antenna versus diameter of the reflector is not illuminated by SHF, only L-band and UHF. The principle objective of an optimized antenna configuration is to bring the SHF spot beam illumination close to the center of the reflector to utilize most of the accurate portion of the reflector. In this way the mesh portion can be less accurate and therefore have lower weight and cost.

This objective can be accomplished by placing the SHF Canada coverage inset on the east side of the main reflector. In this way the short dimension of the insert is along the radius of the main reflector and the long dimension along the circumference. The SHF spot illumination is now squinted west by the amount required to minimize degredation caused by illumination falling on the Canada coverage insert. Finally by careful selection of the contour of the insert the departure from the main reflector contour can be made smaller towards the center than towards the mesh so that the SHF spot beam illumination can overlap a portion of the insert without undue defocusing effects.

The concept is illustrated in the attached figures. Figure II-6 gives the plan view showing the location of the insert and the SHF spot beam illumination. Figure II-7 is a east-west section of the antenna showing the insert, the location of its apex and the feed elements. Figure II-8 gives two views of the L-band feed and the SHF spot beam feed horn. The L-band quadrifilar helices are dimensioned for half turn elements. This makes them quite small and gives maximum space for the SHF horn between. The UHF quadrifilar helices surround the L-band and SHF spot beam feeds and would be one quarter turn quadrifilar helices to give maximum space inside for the L-band and SHF. Finally Figure II-9 gives

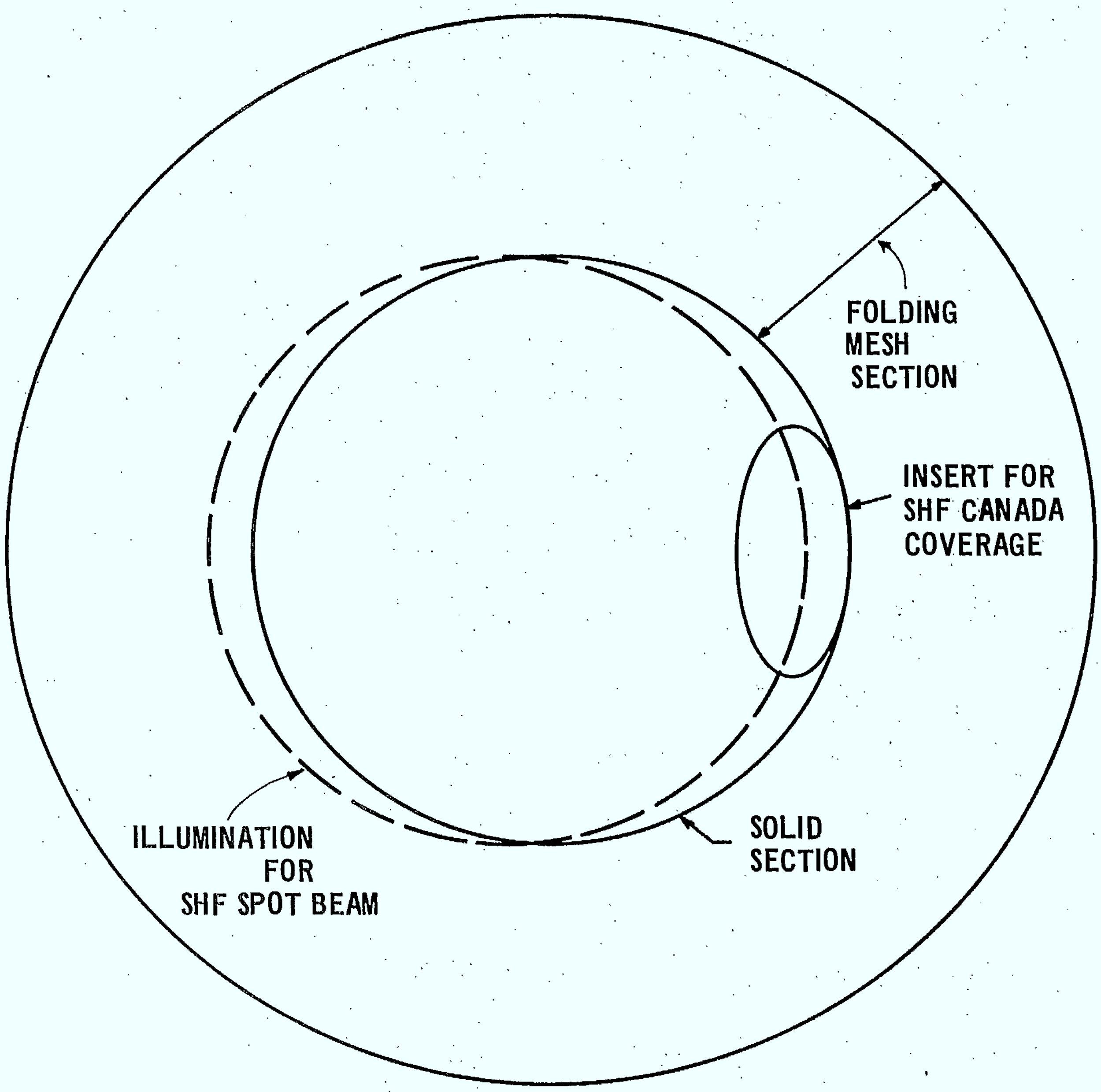


Figure II–6 **Plan view of UHF/SHF/L-band reflector antenna showing illumination areas**

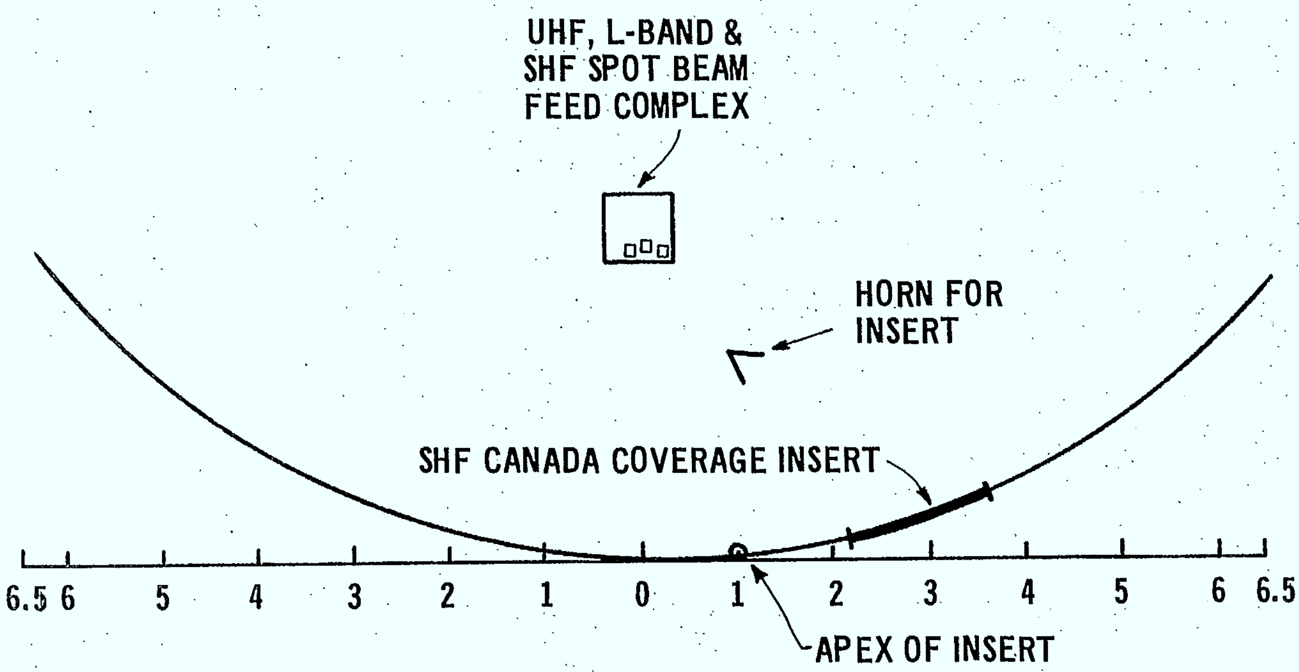


Figure II-7 East-west section of UHF/SHF/L-band showing location of insert and feed structure

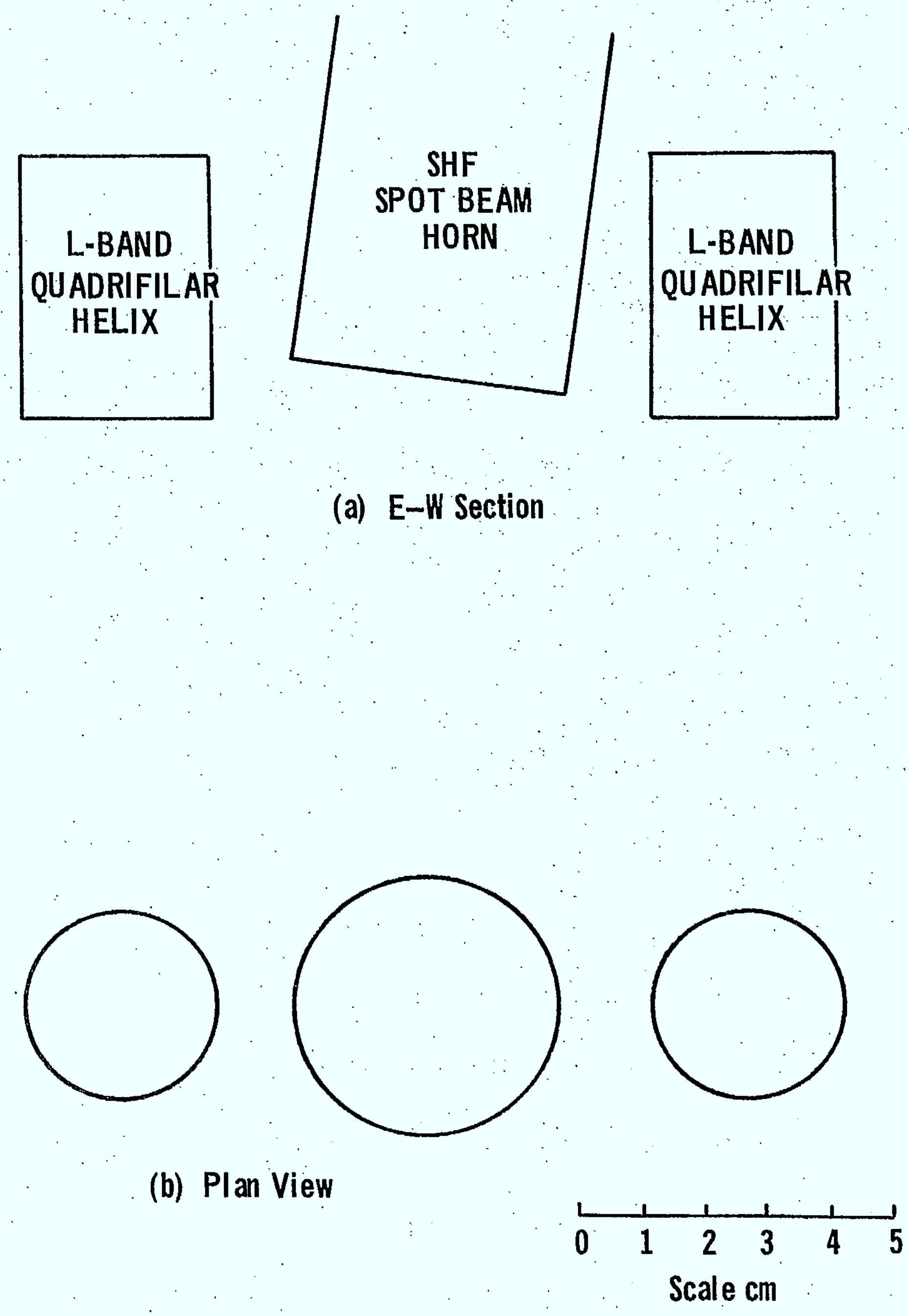
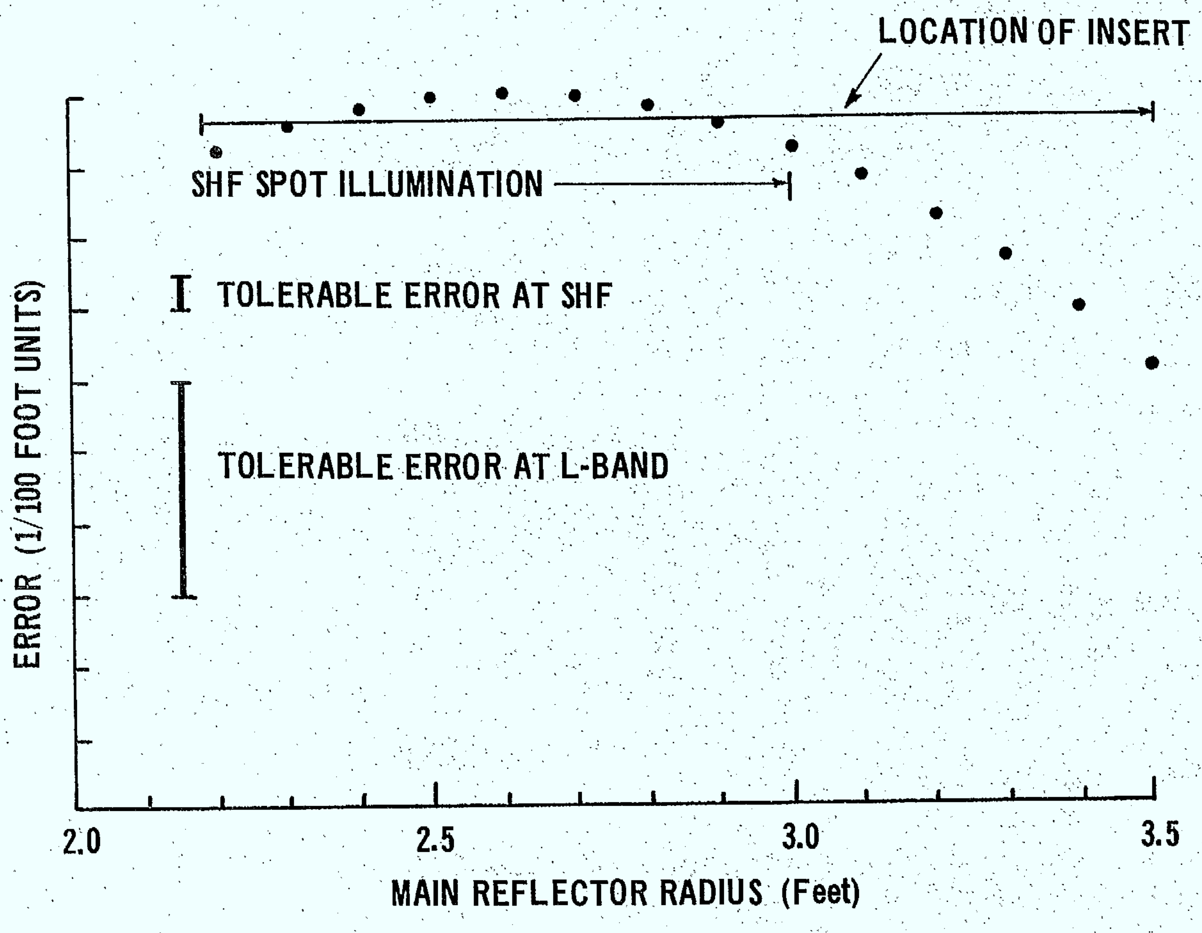


Figure II–8 Sketch of L-band and SHF spot beam feed complex



Lateral displacement 1 foot
Axial displacement 0.196 feet

Figure II–9 Difference between main reflector and insert contours along the east-west plane the difference between the main reflector with 3.25 foot focal length and the insert with 2 foot focal length along the east-west cut for the case where the apex of the parabola for the insert is displaced one foot laterally and .196 feet axially. This shows that the SHF spot beam illumination can overlap the insert to the 3 foot radius point without exceeding the tolerable error at SHF. Between 3 foot and 3.5 foot radius the error increased rapidly but does not exceed the tolerable limit for L-band at the worst location.

II-6.0 Weight and Power Budgets

The weight and power budgets for the L-band portion of the transponder are given in Table II-1. addition to the L-band feed weight,ten pounds has been added to the basic UHF/SHF antenna. An implementation margin of 15 lbs. has been added to apply specifically to the transponder. This is 10% of the transponder weight.

If L-band service is not required during eclipse the L-band portion can be turned off and the 83 watts of power used for the UHF service. No partial L-band service is possible.

Table II-1: L-Band Weight Budget (3B)

	Unit Weight OZ	Number	Table Weight OZ	Power Watts
UHF filters	16	3	48	-
UHF hybrids	2	2	4	-
L-band TWTA	112	2	224	45
UHF/L-band mixer	8	2	16	-
L-band/UHF mixer	8	2	16	-
L.O.	8	4	32	2
UHF Driver Amp.	5	2	10	1
L-band INA	6	2	12	2
L-band filters	12	3	36	-
UHF Amp	30	2	60	8
L-band antenna feed	32	1	32	-
L-band feed line	48	1	48	-
Cables and connectors	16	1	16	-
Misc. hardware	32	1	32	-
Power, Telemetry & Command (PTC)	30	1	30	2
			616 OZ 38.5 lbs.	60 Watts
UHF/Shf total with (19dB gain antenna and excluding the HPA)			121.6 lbs.	66 Watts
Margin			15 lbs.	-
Total			175.1 lbs.	126 Watts

PART III

TRADE-OFF ANALYSIS AND CALCULATIONS

III-1.0 UHF Capacity Analysis

The UHF capacity depends upon the antenna gain, the transmitter efficiency and the eclipse capability as well as the weight available to provide transmitter power. The capacity depends upon the efficiency in two ways: a) in providing RF power proportional to the efficiency for fixed prime power and b) in providing more weight for prime power with higher efficiency because the transmitter weight depends upon power dissipation rather than either RF or DC power.

Weight coefficient for the solar array and batteries are as follows:

Array #/eclipse watt	K_1= .127 lbs/watt
Array #/sunlight watt	K_2= .115 lbs/watt
Battery #/watt	K_3= .167 lbs/watt
Full payload capacity of Bus	K = 360 lbs/watt
Redundant transmitter	K_4= .128 lbs/watt dissipation
UHF/SHF receiver prime power	P_R= 66 watts
L-Band prime power	P_L= 83 watts
UHF/SHF weight less transmitter	W_R= 131.6 lbs.
L-Band weight (total)	W_L= 43.5 lbs.
UHF transmitter weight	W_T lbs.
UHF transmitter power in sunlight	Ps watts
UHF transmitter prime power in eclipse	Pe watts

UHF Eclipse capability	$E_T = \frac{Pe}{Ps} = 100\%, 75\%, 50\%, 25\%$
L-Band eclipse capability	$E_L = \quad = 100 \ \& \ 0\%$
Battery eclipse ratio (ratio of eclipse load to sunlight load)	E_B
Total weight coefficient including array, battery and transmitter	K_T
Transmitter stage efficiency	EFF

The transmitter weight is assumed proportional to dissipation. This is considered valid as a low power amplifier with 30 dB gain weighs only a few ounces.

$P_{RF} = EFF \times P_s$

$P_H = (1\text{-}EFF) \times P_s$

$W_T = K_4 \times P_H = K_4 \ (1\text{-}Eff) \ P_s$

$K_T = \frac{K_4 P_s}{PTot} \ (1 - EFF) + (1 - E_B) \times K_2 + E_B \times K_3 + K_1 \times E_B$

NOTE: - The heat dissipation "P_H" in the output power amplifier must include the power to the drive circuits. This has been taken as 1.5dB thus "Eff" in the above equations must be multiplied by

$10^{-.15} = .708$

Thus

$P_H = (1 - Eff \times .708) \ P_{DC}$

$K_T = \frac{K_4 P_s}{PTot} \ (1 - EFF \times .708) + K_2 \ (1 - E_B) + E_B \ (K_1 + K_3)$

The battery ratio E_B is related to the UHF eclipse capability

The sunlight load is $PTot = P_S + P_R + P_L$

The eclipse load is $E_T P_s + P_R + E_L P_L$

Thus $E_B = \frac{E_T P_S + P_R + E_L P_L}{P_S + P_R + P_L}$

This is a variable depending upon E_T and E_L and upon the ratios of P_S, P_R and P_L

Finally

$$P_S = (360 - W_R - W_L)\frac{1}{K_T} - P_R - P_L$$

Thus we have E_B depending upon Ps and Ps depending upon E_B. This can be solved by a trial and error approach using the computer. Finally, the prime power Ps is converted to radiated power using the assumed total conversion loss. This is 6dB for the case listed in Table III-1 but will vary depending upon the assumed output stage efficiency. Finally the total radiated power is converted to No. of channels at an EIRP of 18 dBW.

TABLE III-1

DC to Radiated RF Conversion Losses

Unit	Loss (dB)
EPC	.5
Output Stage	2.5
Driver Stages	1.5
Isolater	.25
Switch	.25
Output Filter	.5
Line Losses	.5
Total	6.0

UHF ANTENNA GAIN (dB)	Antenna Weight (lbs)	Trans Weight (lbs)	Redundant Transmitter Weight (lbs)	Transmitter Prime Power (Watts)	W = Power subsystem and baterries					
					100% eclipse		50% eclipse		25% Eclipse	
					W	Total	W	Total	W	Total
20	51	126.8	10.2	250	76	137.2	56	117.2	46.5	107.7
19	46	124.4	12.8	3.6	96	154.8	70	128.8	58.5	117.3
18	42	123.7	16.1	398	121	179	89	147	74	132
17	37	122.9	20.3	500	152	209.3	111	168.3	93	150.3
16	32.5	123.6	25.5	630	191	249	140	198	117	175
15	28.5	126.2	32.1	795	240	300.6	176	236.6	147	207.6
14	25	131.0	40.4	1000	313	368.4	222	287.4	185	250.4

TABLE III-2 - TRADE-OFF CALCULATIONS TO MINIMIZE PAYLOAD WEIGHT AS ANTENNA GAIN IS VARIED (FOR 100 CHANNELS AT 18 dBW)

III-2.0 TRADE-OFFS

The trade-offs performed in the UHF/SHF configuration are tabulated in Table II-2 and presented in Figures II-1 to III-2.

In Table III-2 the total weight of all power sensitive units, namely the high power amplifier, the eclipse batteries, the power subsystem and the antenna has been claculated as a function of antenna gain and percent of eclipse capability. It is evident that the highest antenna gain, up to the 20 dB considered, gives the lowert total weight. Reducing the eclipse capability also reduces the weight as expected.

These calculations have been based upon an efficiency of 56% (2.5 dB) for the output stage of the HPA. For output stages of different efficiencies the available capacity is shown in Figure III-1 assuming an antenna gain of 19 dB. These are calculated for different UHF eclipse capabilities from 25% to 100 The eclipse capabilities is specified in the number of 18 dBW channels but in reality it is DC power to the UHF transmitter. Because the backoff during eclipse would be obtained by cutting down on the number of channels loaded on the spacecraft, the UHF output amplifier would experience a reduction in efficiency during eclipse. Thus for less than 100% eclipse capability the average load on the spacecraft would of necessity be lower than shown in the graphs in this report.

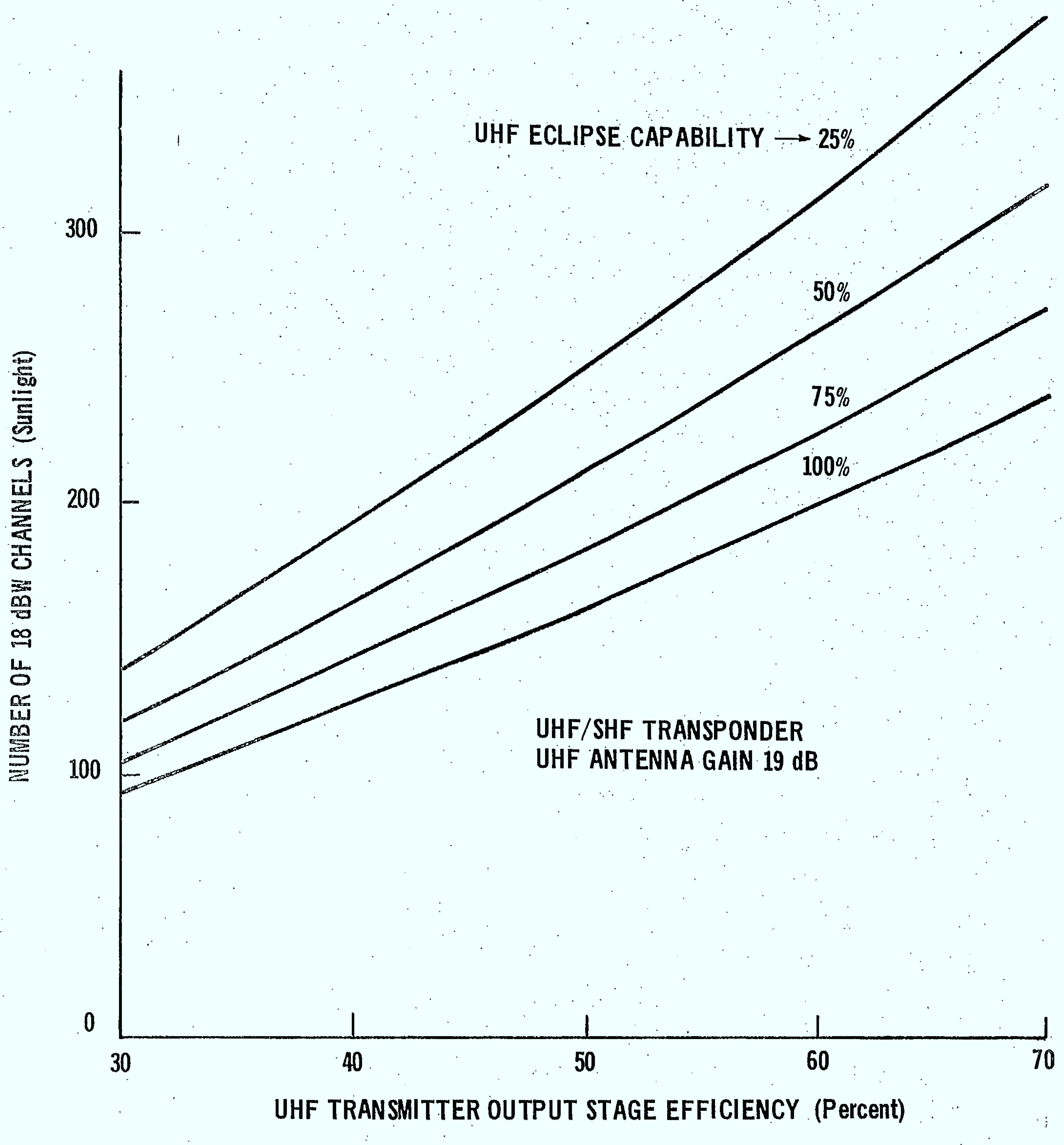


Figure III-1 UHF capacity of basic UHF/SHF transponder versus output stage efficiency and eclipse cabability

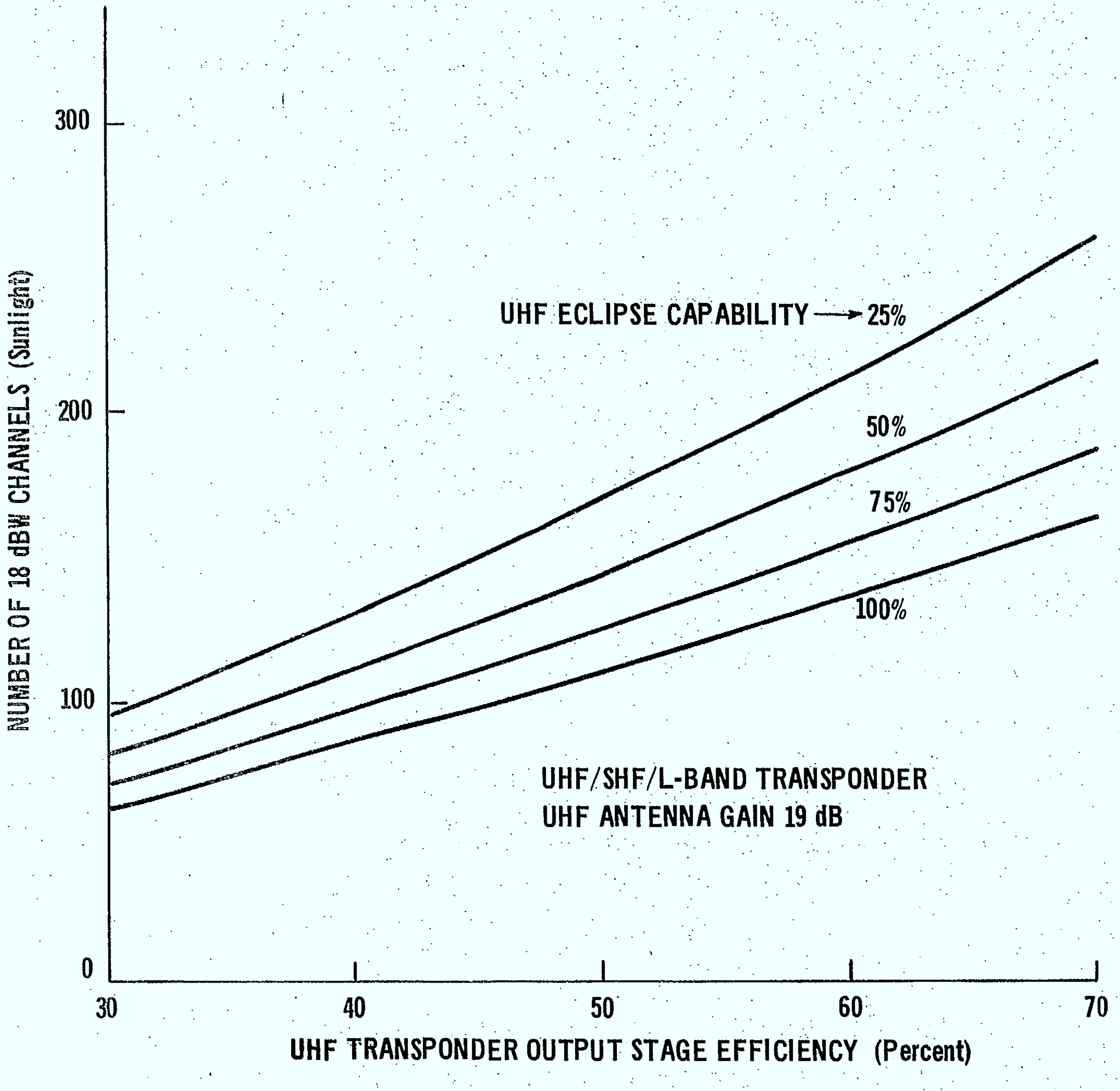


Figure III-2 UHF capacity with L-band capability operating during eclipse

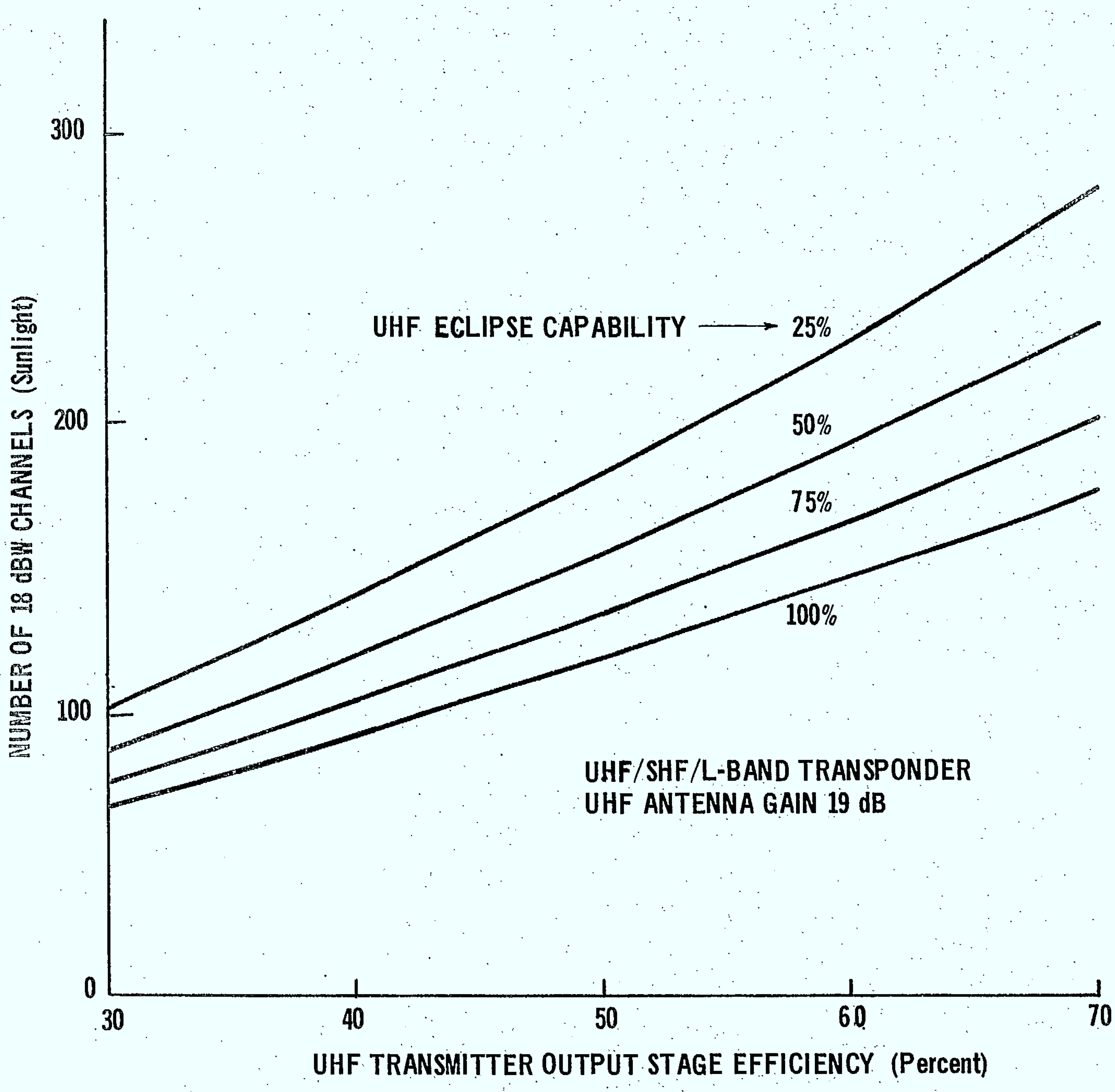


Figure III-3 UHF capacity with the L-band capability NOT operating during eclipse

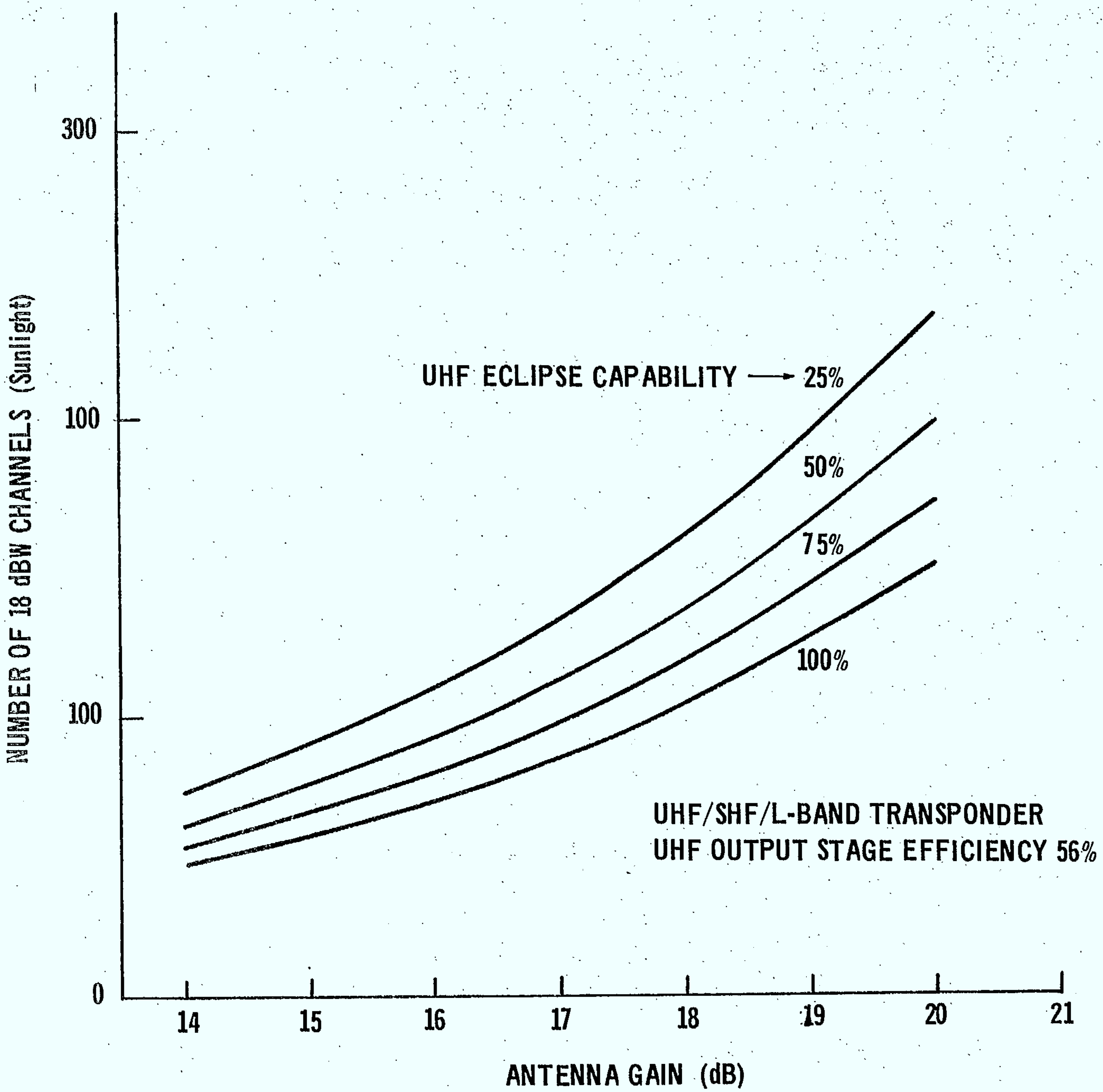


Figure III-4 UHF capacity with L-band capability operating during eclipse

The capacity of the UHF/SHF/L-band configuration has also been calculated. Figure III-2 shows the UHF capacity if the L-band transponder is left on during eclipse. The UHF sunlight capability is shown for 100%, 75%, 50% and 25% eclipse capability as a function of the UHF output stage efficiency.

Figure III-3 shows the sunlight capability if the UHF transmitter is sized on the assumption that the L-band capability will be turned off during eclipse. The final Figure (III-4) shows the UHF capability as a function of antenna gain in the case that L-band capability is maintained during eclipse.

III-3.0 Conclusions

It has been shown that a three axis stabilized bus on the 3914 launch vehicle has sufficient launch capability to include an L-band service capability. If 100% of the UHF capability and the L-band service are maintained during eclipse approximately 100 simultaneous carriers at UHF can be supported providing 18 dBW per carrier.

UHF/SHF/L-BAND SPACECRAFT TRADE
OFFS & BUDGETS: FINAL REPORT.