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FINAL REPORT

Communications Subsystem Feasibility Study

- UHF and 4/6 GHz Payloads
- UHF and 12/14 GHz Payloads

Prepared for:

Department of Communications

Ottawa, Ontario

DSS Contract Reference PL36100-4-0947

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

SUMMARY

This report covers work carried out on payload trade-off studies for the UHF multipurpose spacecraft. Mr. H. Werstuik of the Communications Research Centre was the project officer.

Two payload configurations were investigated, the first a hybrid spacecraft combining UHF with twelve channels in the 4/6 GHz communications band, and the second combining UHF with five to seven channels in the 12/14 GHz space communications band.

The first configuration, described in Part I, required a twelve channel transponder with EIRP and ground coverage compatible with ANIK so that the hybrid spacecraft could provide a direct replacement for the ANIK spacecraft without adjustments to the ground segment and without any degradation to the system performance. In addition, certain improvements were required, notably in provision of a redundant battery.

The UHF portion of the payload was required to support 80 carriers with an "acceptable" level of intermodulation noise. On the uplink, the traffic included spread spectrum multiple access (SSMA), frequency division multiple access (FDMA), as well as signals from data retransmission platforms (DRP), and emergency position indicating radio beacons (EPIRB). The whole UHF uplink band is translated to 4 GHz and relayed to a communications control terminal (CCT) using one of the twelve channels at 4 GHz as a "backhaul" channel.

All signal processing, power leveling, frequency shifting and decoding is performed at the CCT. In addition, those calls destined for the national telephone network make connection at this location. The return messages, fixed to mobile, are assembled at the CCT and transmitted to the spacecraft on one of the twelve 6 GHz channels. The whole band is then translated to 300 MHz and broadcast to the ground.

Protection against intentional interference has been incorporated on the UHF uplink by providing a very large dynamic range and ALC action so that the transponder can neither be damaged nor saturated. On the 6 GHz uplink, protection is incorporated by providing spatial discrimination on the uplink for the backhaul channel.

A significant problem has been to develop an antenna concept that would give the required ground coverage with minimum degradation in 4 GHz EIRP due to the addition of the UHF antenna and the 6 GHz receive spot beam. The selected configuration is a deployable mesh parabolic reflector with an accurate solid center section used for the 6 GHz spot beam and the 4/6 GHz Canada wide beam. The latter uses only a part of the solid portion of the reflector, and the feed for this beam is directed towards the side of the aperture to minimize blockage from the feed structure. A turnstile, with parasitic reflecting elements, is used for the UHF feed. This feed also minimizing blockage for the Canada wide beam.

Intermodulation noise, generated by passive metallic elements that are normally considered linear, was an important problem. Based on a study of the proposed frequency plan and information obtained from industrial sources on state-Of-the-art construction, it was concluded that the system requirements could just be met by a single UHF antenna with transmit and receive signals separated by a duplexer.

The trade-off studies showed that, on a 3-axis stabilized spacecraft sized at 2000 lbs. for a 3914 Thor-Delta launch vehicle, the minimum UHF capability could be met. The UHF eclipse capability must be reduced to about 50% while still maintaining full capability at 4/6 GHz throughout eclipse to meet the minimum required UHF capability in sunlight.

The second configuration described in Part II substituted a number of 20 watt TWTA's at 12/14 GHz for the 12 channels at 4/6 GHz. The 12/14 GHz traffic consists of four TWTA's devoted to multiple channel per carrier (MCPC) telephony plus two TWTA's carrying single channel per carrier (SCPC) for thin route traffic. A seventh TWTA, plus a redundant unit, is used for the UHF backhaul. The UHF transponder for this configuration is essentially identical to that configured for the 4/6 GHz configuration.

Trade-off studies on the second configuration showed that the minimum UHF capability could be met, provided the 12/14 GHz traffic is reduced along with the UHF traffic during eclipse.

A number of other studies have been carried out on the UHF multipurpose spacecraft. A previous feasibility study on contract no. 13SR36100-4-0565 resulted in a final report entitled "UHF/SHF/L-Band Spacecraft Trade-Offs and Budgets". This report covers two other payload configurations, namely a purely UHF spacecraft with one SHF backhaul channel and a hybrid configuration combining an L-band capability compatible with Aerosat and Marisat with the UHF payload.

Another related study is the concurrent payload implementation study under contract no. PL36100-4-2008. That study investigated hardware availability and implementation problems associated with the two configurations described in this report.

Two other related studies covered the power subsystem of the spacecraft bus under contract no. PL36100-4-0959 and TT&C and TT&C aspects of the UHF spacecraft under contract no. PL36100-4-0969.

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PART I

UHF PLUS 4/6 GHz

PAYLOAD CONFIGURATION

I-1.0 REQUIREMENTS

I-1.1 Functional Requirements

The functional requirements of the payload are to provide voice, data, and facsimile communications services to mobile and transportable UHF stations, and to receive transmissions from data retransmission platforms and emergency beacons. In addition, the payload should provide communications service in the 6 and 4 GHz common carrier band compatible in performance with that provided by the Telesat ANIK satellites and in accordance with the guidelines of Appendix A.

I-1.2 Payload Configuration

The payload should be compatible with the weight, space, and physical constraints imposed by a 3 axis stabilized spacecraft launched by a Thor Delta 3914 vehicle (2,000 lbs. in transfer orbit). The transponder for the two services should be arranged so that one channel of the 6/4 GHz transponder is used as one half of a transmission path between a mobile UHF user and one or more fixed stations normally called Communications Control Terminals (CCT). This configuration takes advantage of the statistics that most of the traffic flows between mobile and fixed terminals and not mobile to mobile. It is less costly in terms of spacecraft resources to use spectrum space and RF power at 6/4 GHz to establish links with high performance fixed terminals rather than to use relatively scarce UHF spectrum space and RF power to establish such links with fixed terminals. This configuration also allows flexibility at the large earth terminal in dealing with jamming threats.

I-1.3 Coverage

The system for 6/4 GHz service should provide polarization, EIRP, and G/T in accordance with Appendix A and in addition should provide a spot beam for reception at 6 GHz as protection against uplink jamming.

For calculations the jammer may be assumed to have a 30 foot dish with 10 KW of CW power at any frequency. The UHF service should cover all of the Canadian land mass, including as much of the Arctic islands as can be seen from geosynchronous orbit slots between 114°W and 124°W longitude. In addition, the coastal waters between 40°W and 140°W and north of 49°N latitude should be covered.

I-1.4 4/6 GHz Common Carrier Service

Eleven channels each 40 MHz between centers is required for this service. The quality of the channel should be compatible with ANIK. The usable bandwidth per channel is nominally 36 MHz. The twelfth channel in the 4/6 GHz band is to be used as a backhaul channel for the UHF traffic.

I-1.5 UHF Services

The following services are to be provided in the UHF band:

(i) A 15 MHz band for spread spectrum multiple access (SSMA) reception from mobile and transportable UHF terminals.

(ii) A minimum of 15 MHz is required for frequency division multiple access (FDMA) to and from mobile and transportable UHF terminals.

(iii) A 2 MHz band for direct UHF/UHF communications between mobile and transportable UHF terminals.

(iv) A 2 MHz band for direct SHF/SHF traffic for housekeeping functions between different communications control terminals.

(v) A 2 MHz band for data relay platform (DRP) reception (401-403 MHz)

(vi) A 0.1 MHz band (406-406.1 MHz) for reception of emergency position indicating radio beacons (EPIRB).

The satellite should be sized to support approximately 80 FDMA simultaneous voice equivalent channels of 25 KHz each on the UHF downlink. Allowing guard bands, a minimum spacing of 50 KHz is required between channels.

I-1.6 Redundancy

The channel used for the UHF backhaul should have a redundant TWTA. No single point failures should exist among the transponder active elements. The 4/6 GHz common carrier band is protected by one of the remaining eleven channels being unused and acting as backup in the event of failure of one of the operating channels.

I-1.7 Eclipse

The 4/6 GHz common carrier band must be maintained fully operational during eclipse. Eclipse operation of UHF is a parameter of the study with values ranging from 25% to 100%. The eclipse service should be maintained with 66% depth of discharge with two out of three batteries operational.

I-1.8 Station Keeping Fuel

On orbit station keeping fuel shall be budgeted at 6 years. The tanks shall be maintained at the size presently used on SATCOM in anticipation that spacecraft margin remaining at the time of launch and/or growth in launch vehicle capability will allow the hydrazine tanks to carry more than the budgeted 6 years fuel load.

I-1.9 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-2.0 COMMUNICATIONS PAYLOAD OPERATION

Referring to the block diagram Figure I-1 and ignoring for the moment the detailed operation of redundant chains, the operation of the system is as described in the following sections. The various modes of operation are outlined in Table I-1 with references to Figure I-1 and to the text.

I-2.1 6/4 GHz Operation

Under normal conditions signals originating anywhere within the coverage provided by the combined 6/4 GHz antenna are picked up by the feedhorn and fed to the 6/4 GHz redundant receiver converter (CRX1) via an orthocoupler combiner network, a switch (CSW1), a latching circulator, a command extraction filter, and an input filter. Under jamming conditions, signals are received from the spot beam feedhorn and fed to the receiver via an attenuator (CATT13) and filter (CFL1). The orthocoupler combiner network in conjunction with the feedhorn array, provides 6 GHz beam shaping and part of the required isolation between transmit and receive antenna ports. The command extraction filter (CFL2) performs the feed function of attenuating the command signal before entering the communications receiver, and providing an interface to the command receiver for normal on station operation. The input filter (CFL3) defines the passband of the communications receiver and prevents out of band received spurious signals from being retransmitted or from degrading the performance of the receiver.

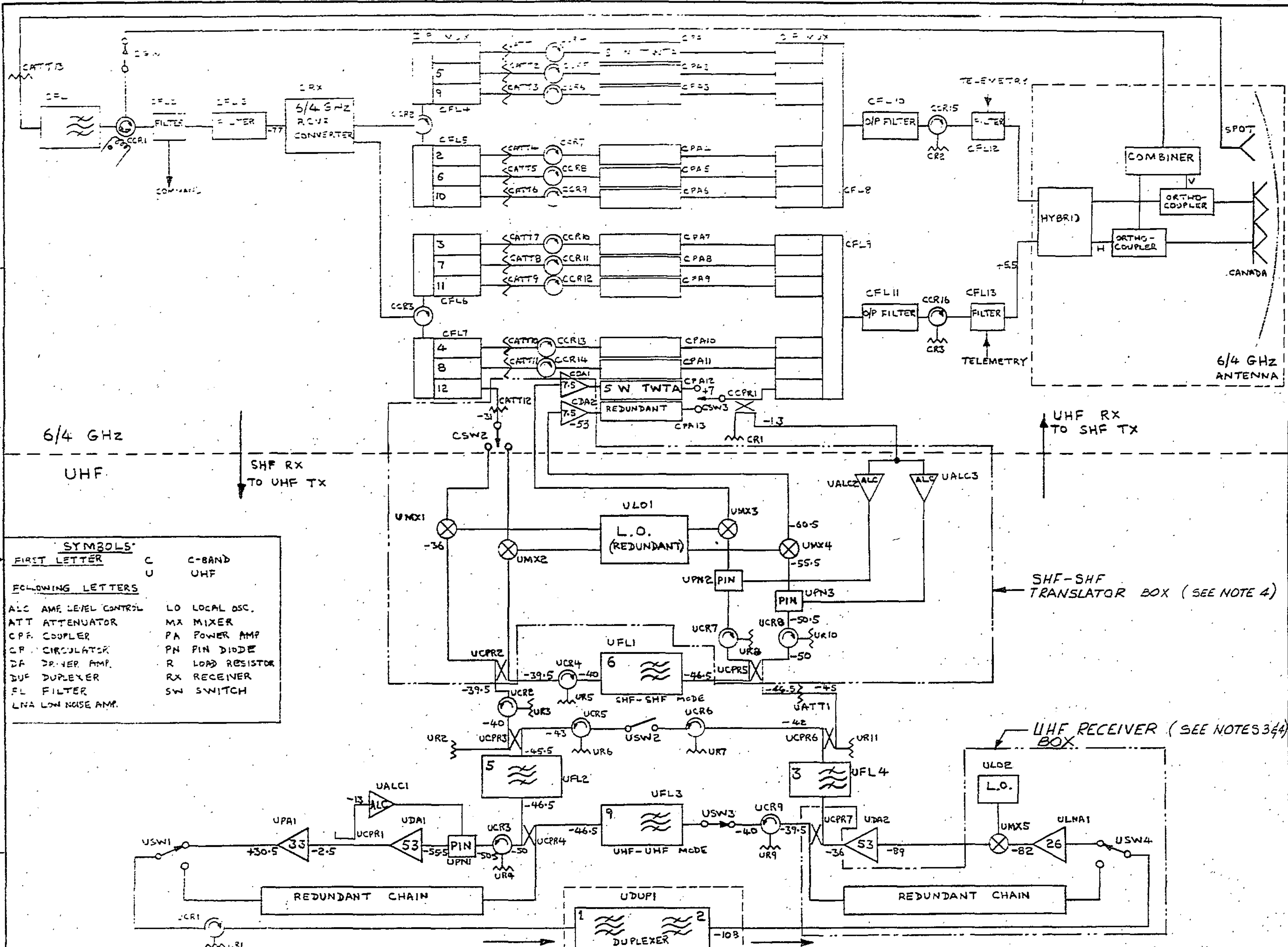
Following the receiver converter, the input band is separated into 12 individual channels by the input multiplexers. Except for channel 12, each multiplexer filter is followed by a fixed level adjusting attenuator, an isolator, and a 5 watt TWTA. The TWTA outputs are collected together in groups of six by the output multiplexers and fed to the two transmit ports of the antenna. The hybrid, in conjunction with the orthocoupler and feedhorn array produce a shaped beam at 4 GHz to give Canadian coverage.

Two jamming threat possibilities are considered. In the first, it is assumed that a few jammers concentrate on the channel dedicated to UHF back haul and SHF/SHF communications. The jammers are assumed to be in the ocean areas and their signals enter the transponder via the Canada wide antenna beam.

TABLE I-1

SUMMARY OF SERVICES

MODE	Elements Involved	Paragraph Reference
6/4 GHz Traffic	CRX1, CPA1-11	I-2.1
Mobile to fixed	ULNA1, UFL4, CPA12	I-2.2.1
Fixed to mobile	CRX1, UFL2, UPA1	I-2.2.2
Fixed to fixed	CRX1, UFL1, CPA12	I-2.2.2
Mobile to mobile normal mode	ULNA1, UFL3, UPA1	I-2.2.1
Mobile to mobile backup mode	ULNA1, USW2, UPA1	I-2.2.1
UHF Interference	UALC2, UPN2, CPA12	I-2.2.1
6 GHz Interference	CCR1, CFL1, CSW1	I-2.1



REVISIONS

AP. BY L.A. Kuys DATE 17 MAR 1975	O
MINOR REVISIONS AP. BY L.A. Kuys DATE 12 MAR 1975	1
CHANNELS RE-NUMBERED. UFL4 RELOCATED. UHF ANTENNA WAS QUAD HELIX. CCR1 SWITCHING CIRCULATOR SYMBOL ADDED. AP. BY L.A. Kuys DATE 17 APRIL 1975	2
UHF RECEIVER & SHF SHF TRANSLATOR IDENTIFIED. MAY 6/75 JP FEKEN	3

NOTES

(1) LEVELS SHOWN IN dBm PER SINGLE VOICE CHANNEL

(2) [A] AMPLIFIER WITH A dB GAIN

3) [illegible]

4) SEE DWG [illegible] FOR [illegible]

Figure I-1

WORKMANSHIP TO BE IN ACCORDANCE WITH RCA LIMITED WORKMANSHIP STANDARDS	VARIATIONS ON FINISHED DIMENSIONS UNLESS OTHERWISE MARKED		
	BASIC DIMENSIONS	2 PLACE DECIMALS	3 PLACE DECIMALS
	UP TO 6	± .02	± .005
	ABOVE 6 TO 24	± .03	± .010
	ABOVE 24	± .05	± .015

BLOCK DIAGRAM UHF–6/4 GHz MULTIPURPOSE SATELLITE

FIRST MADE FOR 3500-T/4 USED ON

DRAWN BY J.P. FEKEN MAY 6/75 CHECKED BY

DESIGNED BY COMMODITY CODE

RCA LIMITED

CODE IDENT NO 95311 SIZE C 2542202

NEXT ASSY

2542202

I-2.1 6/4 GHz Operation - Continued

To circumvent this, the latching circulator is reversed (counterclockwise in the diagram) so that the jamming signal is passed through CFL1 which passes channel 12, and is largely absorbed by CATT13 and subsequently reradiated by the spot beam.

The input match of CFL1 and the isolation of CCR1 at the jamming frequency limit the degree of suppression of the jamming signal to about 25 dB. Signals from one of the CCT's enter the transponder via the spot beam horn and pass in the opposite direction through filter CFL1 to reach the receiver. At the same time the regular channels 1-11 coming from the wide area beam are reflected by CFL1 and pass back through CCR1 and thence to the receiver with only a small loss in performance. A more careful evaluation of the system of telecommand may show that the command extraction filter may better be placed before or after CFL1 than in its present location. The second possibility assumes several jammers covering many channels so that normal operation is impossible on any channel. To circumvent this, switch CSW1 is opened so that now only signals originating within the spot beam may reach the receiver via CATT13 and CFL1. In this mode the attenuator serves to reduce the receiver sensitivity and thus improves its resistance to overload.

I-2.2 UHF Operation

I-2.2.1 Mobile to Fixed Direction

UHF signals originating anywhere within the defined coverage area are received by the UHF antenna which functions as both a transmitting and receiving antenna(1).

From the antenna the received signals are separated from the transmitted signals by the duplexer (UDUP1) and passed via a switch to the low noise amplifier (ULNA1). This amplifier has enough gain so that the noise of succeeding stages has a negligible effect on the overall noise figure. The local oscillator (UL02) and mixer (UMX5) translate the incoming frequency band downward by 72 MHz and the resulting band is amplified

---

Note (1) (The feasibility of this approach compared to separate transmitting and receiving antennas depends upon the degree of non-linearity exhibited by the duplexer and other passive components carrying high currents or operating in high field regions of the antenna. The subject of intermodulation in passive components is discussed elsewhere in this report.)

I-2.2.1 Mobile to Fixed Direction – Continued

by the driver amplifier (UDA2). The signals then pass into a 3 dB splitter (UCPR7) which performs the dual function of combining redundant chains without switching and provides two isolated outputs. One output passes the translated input spectrum via a circulator (UCR9) to a 2 MHz wide filter (UFL3) which passes the UHF/UHF signal band directly to the UHF transmit chain and reflects all other signals to the isolator where they are absorbed by a termination (UR9). The other output of the 3 dB splitter feeds another splitter (UCPR6) which divides the power unequally into two isolated outputs. The higher level output goes through a circulator (UCR6) and thence to a normally open switch (USW2) where the signals are reflected and subsequently absorbed by a termination UR7. By ground command the switch may be closed to provide a direct path for UHF to UHF communications for the complete UHF spectrum.

This mode of operation is considered a back-up to the normal 6/4 GHz back haul operation. The lower level output is further reduced by an attenuator (UATT1) and then split into two redundant paths by the 3 dB coupler UCPR5. From this point the signals pass through an isolator (UCR7), an electrically controllable attenuator (UPN2) and then an upconverting mixer (UMX3) which translates the UHF spectrum to channel 12 in the 4 GHz band by the addition of a fixed frequency (ULO1). The signal level is then boosted by amplifier (CDA1) and the 5W TWTA (CPA12). The TWTA selector switch (CSW3) is followed by a coupler (CCPR1) which samples and detects the output signal before it is combined with the 5 other channels in the output multiplexer (CFL9). The detected channel 12 output is DC amplified (UALC2) and used to control the variable attenuator so that the operating power level of the 5W TWTA remains below saturation during attempted jamming of the UHF uplink.

I-2.2.2 Fixed to Mobile Direction

6 GHz signals originating within the normal Canada coverage beam, or the spot beam under threat conditions, are amplified and converted to 4 GHz channel 12 in the input multiplexer (CFL7). Following the attenuator (CATT12) and the redundancy switch (CSW2), the 4 GHz signal band is translated to the UHF transmit band in a mixer (UMX1) by the subtraction of the same fixed local oscillator frequency used to upconvert the received UHF spectrum to the 4 GHz band. The down-converted signals then are passed to a 3 dB splitter which performs the dual function of combining the redundant paths and providing two isolated

I-2.2.2 Fixed to Mobile Direction - Continued

outputs. One output passes the signal band through a circulator (UCR4) to a filter (UFL1) which passes a 2 MHz band containing the SHF/SHF signals, and reflects all other signals back through the isolator which are then absorbed by a termination (UR5). The other output passes the signal band via a circulator (UCR2) to a coupler (UCPR3) which feeds a UHF filter (UFL2). This filter passes the UHF FDMA transmit band and reflects all other signals which are then absorbed by the circulators and terminations. The output of filter UFL2 is combined with the output of UFL3 (UHF/UHF direct channels) in a coupler (UCPR4) which feeds the UHF driver amplifier (UDA1) via a circulator (UCR3) and an electrically controllable attenuator (UPN1). The output of the driver amplifier is sampled and detected by a coupler (UCPR1) and subsequently DC amplified by UALC1 and used to drive the variable attenuator. The automatic level control thus formed protects the final UHF power amplifier (UPA1) from overdrive either accidentally through the normal 6 GHz uplink or by intentional jamming through the UHF uplink. In the latter case a switch (USW3) may be commanded open to eliminate the direct UHF/UHF path. The regular signal path culminating in the 4 GHz downlink is protected from overload by the automatic level control circuit around the TWTA as described in the mobile to fixed operation. Following the redundancy switch (USW1) and circulator (UCR1), the high power UHF signals pass through the transmitting filter of the duplexer to the antenna. The function of the duplexer is to combine transmit and receive paths into a single antenna port while isolating transmitter and receiver. To achieve this, the transmit filter must attenuate transmitter noise and intermodulation at the receive band, well below the receiver basic noise, and the receive filter must attenuate the transmit band to protect the low noise amplifier against overload.

1-3.0 FREQUENCY PLAN

The requirements outlined in section I-1.0 place certain restrictions on the frequency plan. The basic UHF frequency plan is shown in Figure I-2. The UHF uplink has SSMA between 370 and 385 MHz, FDMA between 385 and 400 MHz, signals from Data Retransmission Platforms (DRP) between 401 and 403 MHz and signals from Emergency Position Indicating Radio Beacons (EPIRB) between 406 and 406.1 MHz. This is translated by 72 MHz to the 300 MHz region, i.e., SSMA between 298 and 313 MHz, FDMA between 313 and 328 MHz, DRP between 329 and 331 MHz and EPIRB between 334 and 334.1 MHz. This is done so that cross-strapping between the mobile to fixed link and the fixed to mobile link can be accomplished at the same frequency and the same power level. A small segment of the FDMA band, namely that between 326 and 328 MHz is assigned to mobile to mobile service (UHF to UHF) and is coupled directly to the UHF transmitter amplifiers provided the switch USW3 is closed. The remaining FDMA from 313 to 226 MHz is used for mobile to fixed service and is routed along with the DRP and EPIRB to the communication control terminal (CCT) via the 4 GHz transmitter. The mobile to mobile segment (326 to 328 MHz) is not removed from the rest of the spectrum and gets transmitted at 4 GHz to the CCT. The signals from the 6 GHz uplink are translated, first to 4 GHz by the main 6 GHz receiver and then to 300 MHz. The internal spacecraft assignments for these signals are shown in Figure I-2. They consist of an FDMA spectrum from 300 to 326 MHz and an SHF to SHF segment (also FDMA) from 331.5 to 333.5 MHz. The SHF to SHF traffic is coupled into the spectrum routed to the 4 GHz receiver and is fitted in between the DRP and the EPIRB segments. The UHF downlink frequency spectrum consists of an FDMA spectrum from 300 to 326 MHz and the UHF to UHF segment from 326 to 328 MHz. The SHF to SHF segment from 331.5 to 333.5 MHz has been removed by the internal filtering.

The routing of the various signal bands in the cross strapped 300 MHz portion of the transponder is illustrated in Figure I-3. The signals that appear in the UHF uplink are shown along with the frequency limits after translation to the 300 MHz band. The spectrum from the 6 GHz uplink and that going to the 4 GHz downlink are labelled with the frequency limits pertaining to the 300 MHz band. The make-up of signals in the four legs of the transponder (two uplink and two downlink) are illustrated in Figure I-3 for the case where the switch USW3 is closed.

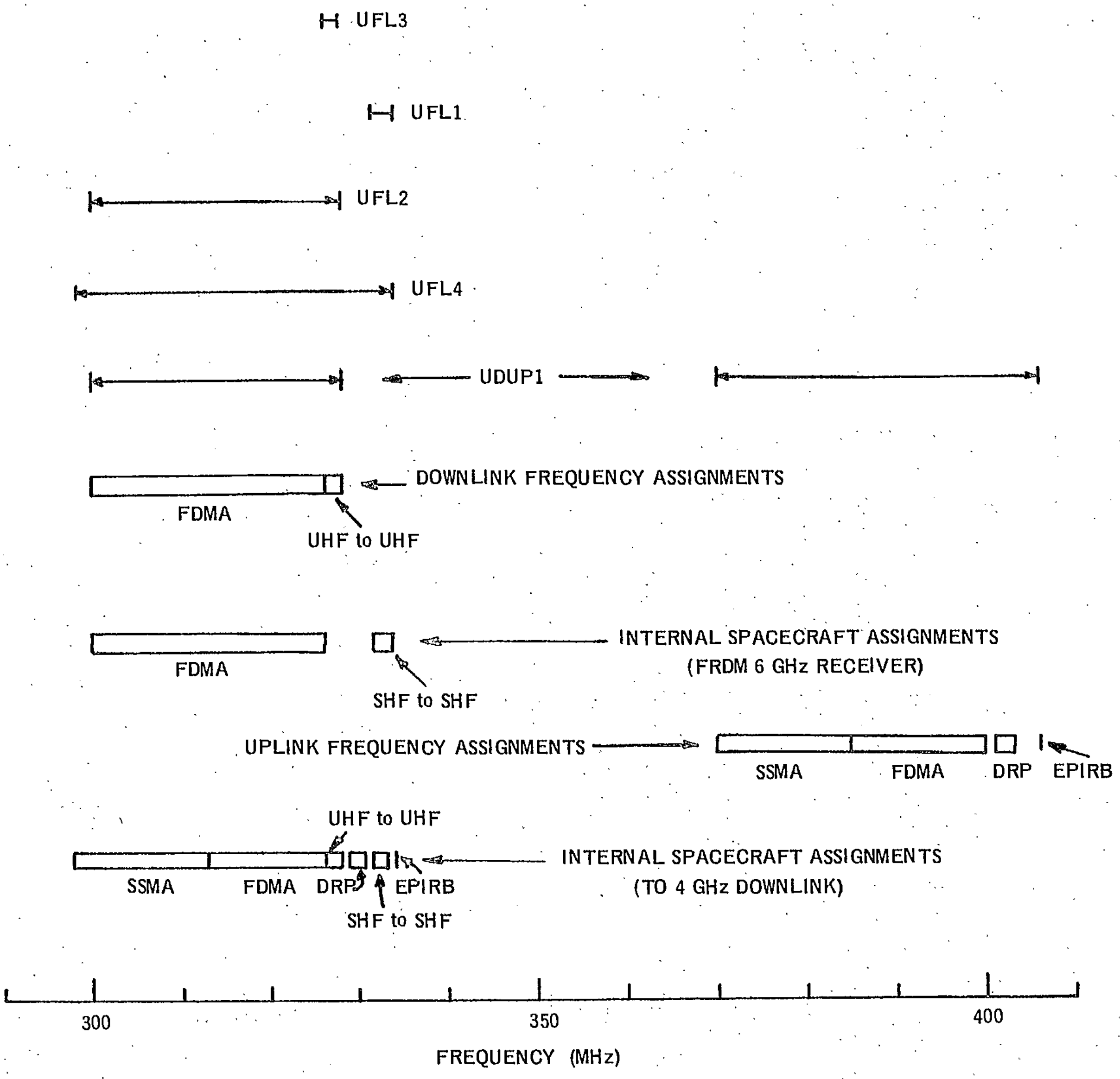


Figure I–2 Tentative frequency plan in the UHF band

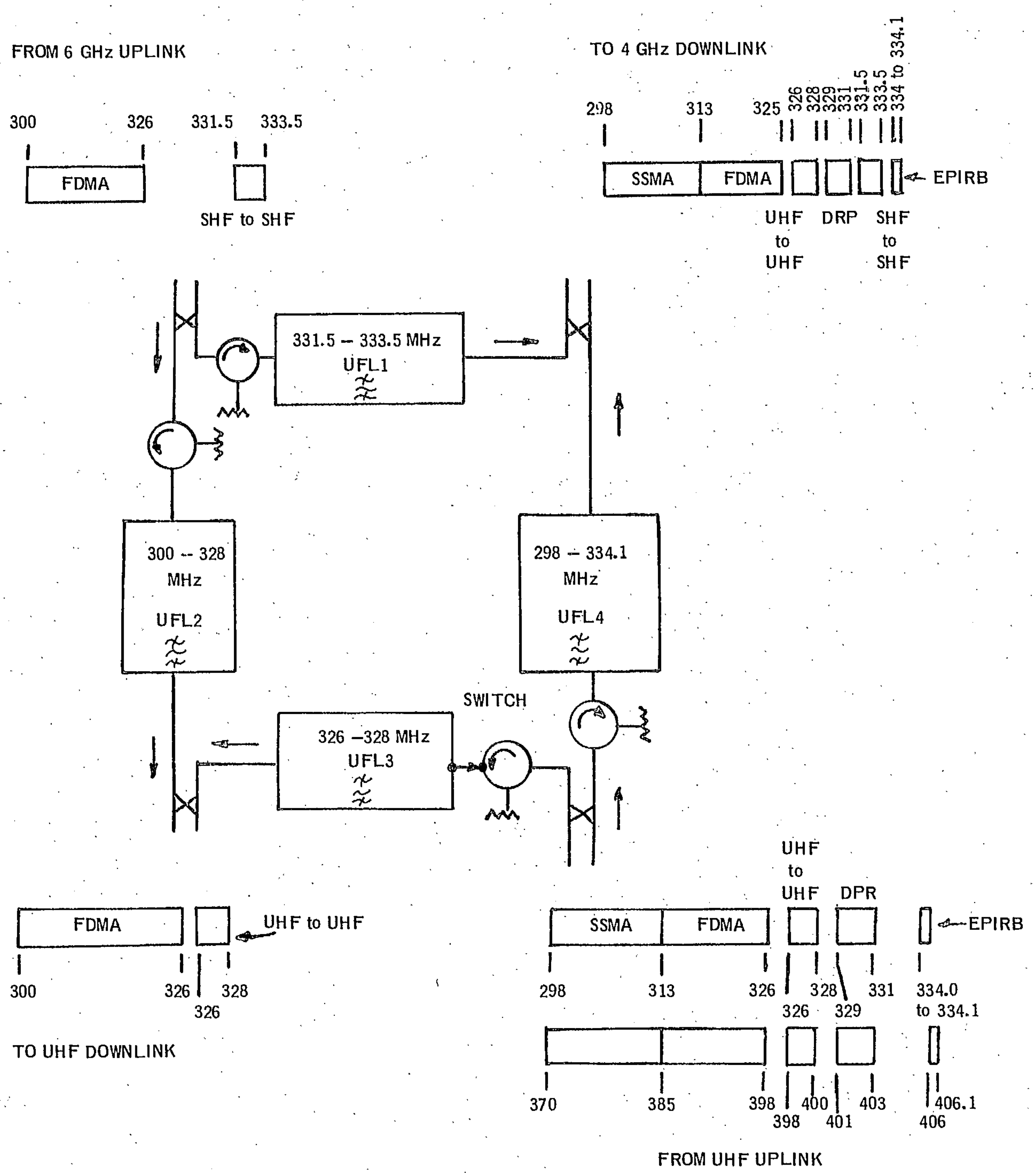


Figure I–3 Routing of signals in the UHF cross-over network

I-3.0 FREQUENCY PLAN - Continued

It should be noted in Figures I-2 and I-3 that the filter UFL2 bandwidth is specified as 300-328 MHz to cover the full UHF down link frequency band. This is done so that if a direct UHF to UHF link is not required or is jammed out, the switch USW3 can be opened and the full FDMA uplink band from 375-400 MHz and the full downlink band from 300-328 MHz can be used for mobile to fixed services. The filter UFL3 is isolated from the direct mobile to fixed and fixed to mobile paths even for operation in the passband of this filter by the use of hybrid couplers and isolators as combining elements.

I-4.0 UHF FILTERS

In the frequency band 300 to 400 MHz, free-space wavelength is of the order of 35 inches. Such a long wavelength tends to make the filter structures big and therefore necessitates a critical trade-off between electrical performance and the physical size and weight.

A survey of the presently used filters in the frequency range under consideration indicated the following structures.

a) MIC Structures

b) Inter-Digital Structures

   i) Quarter-Wave Coupled

   ii) Comb-line Structures

c) Helical Resonator Filters

d) Coaxial-Structures

I-4.1 MIC Structures

Primary advantage of using MIC structures is the reduction in size by virtue of using low-loss substrates with high dielectric constants. At UHF frequencies however use of a substrate material like Tamtron 5038 or TiO_2 with $E_r = 60$, the size of a $\lambda/2$ disc-resonator is still $\approx$ 3", which is quite large. Further considerations of copper losses and the basic thermal instability of dielectric materials rule out MIC structures

I-4.2 Inter-Digital (ID) Structures

These structures are widely used at UHF frequencies - especially on ground-based equipment including earth terminals for communications satellite. A typical ID structure is shown in Figure I-4. There are two basic types that are commonly used:

i) Quarter-Wave Coupled Filters

ii) Comb-Line Filters

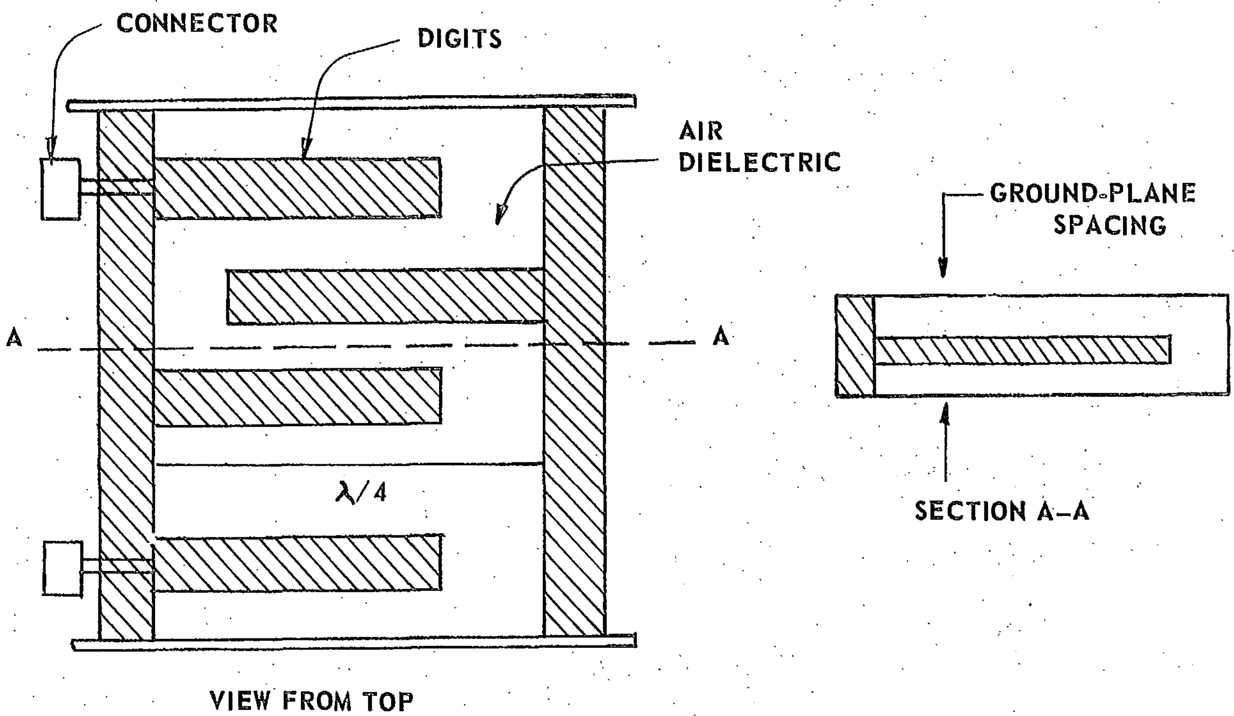


Figure I-4 Typical quarter wavelength coupled inter-digital structure

I-4.2 Inter-Digital (ID) Structures - Continued

In the quarter wave coupled structures, length of each digit is approximately $\lambda/4$ which for the present application amounts to about 8 inches. With a ground plane spacing of between $\frac{1}{2}$ to 1", it is readily feasible to realize unloaded Q's of the order of 1000. This is based on hardware experience on filters for Earth stations.

For comb-line structures, transmission lines or the filter digits are capacitively loaded at the end to reduce the size to approximately $\lambda/8$ or 4 inches. This reduction insize is achieved at the expense of higher losses. It is estimated that the achievable Q_o with this structure will be around 500.

Table I-2 summarizes the size and weight for these two types. An alternative weight is provided for both types using Graphite Fiber Epoxy composite (GFEC) rods. This was done on the assumption that use of GFEC rods only introduce a minimum of risk but results in significant weight saving. Table I-3 summarizes the expected response for the various UHF filters used in the proposed system assuming ID structures. This type is used as the baseline for this study. These can readily be realized using Invar, Al, GFEC or some hybrid combination.

I-4.3 Helical Resonator Filters

At UHF, it is possible to realize inductances (L's) using semi-lumped structures like helices. Such a structure enclosed in a capacity can be made to resonate at a given frequency by virtue of its L and capacitance between the helical windings. Reasonable Q's (500 to 1000) are achievable in moderate sizes. Thermal stability depends upon the material and the choice of design. This type is a potential design candidate. It is somewhat difficult to realize using Invar as the basic material.

I-4.4 Coax Structures

This is similar to ID structures except that round-rods in enclosed space are used as the resonant cavities. Coupling is achieved via slots between these cavities. Such designs can realize Q's of 1000 or more (up to 1500) depending upon the choice of the design. These types are also potential candidates for UHF filtering - especially where insertion loss is critical.

TABLE I-2

WEIGHT ESTIMATE - UHF FILTERS

$\frac{\lambda}{4}$ Coupled Inter-digital Filter ($Qo \geq 1000$)

Parts	Qty	Material and Dimension	Lot - Lbs.
Rods	9	Invar (hollow) .3" Dia; .050" thick or GFEC -.3" Dia.	.89 or .30
Middle Sections	2	Aluminum	.07
Top Cover	1	"	.35
Bottom Cover	1	" "	.32
Stiffners		"	.05
Connectors	2	OSM	.065
TOTAL WEIGHT		1.7lbs. using Invar rods 1.1lbs. using GFEC rods	

$\frac{\lambda}{8}$ Coupled Comb-line Filter ($Qo \geq 450$)

Parts	Qty	Material and Dimension	Lot- Lbs.
Rods	9	Hollow Invar or GFEC	.445 or .12
Middle-Section	1	Al	.07
Top Cover	1	"	.175
Bottom Cover	1	"	.16
Stiffners		"	.03
Connectors	2	OSM	.065
Discs to load Resonators	9	Invar or GFEC	.057 or .015
TOTAL WEIGHT		1.0lbs. using Invar rods 0.65lbs. using GFEC rods	

I-4.5 Filter Parameters

Basic parameters of the UHF filters required by the UHF transponder are listed in Table I-3. The function of each filter can be obtained by referring to Section I-2.0 and Figure I-1.

TABLE I-3

EXPECTED PERFORMANCE - UHF FILTERS

Filter Type	Center Frequency MHz	Minimum Required Bandwidth MHz	Estimated No. of Sections "n"	Insertion Loss at f_o in dB Assumes $\frac{\lambda}{4}$-coupled Structure with a Q_o = 1000
Transmit Filter - UDUP1	314	28	9	.6
Receive Filter - UDUP2	388	36	8	.5
Band-Select Filter - UFL1	332.5	2	5	4.3
Band-Select Filter - UFL2	314	28	7	.45
Band-Select Filter - UFL3	327	2	6	5.6
Mixer Filter - UFL4	316	36.1	7	.4

I-5.0 ANTENNA SUBSYSTEM FOR THE UHF PLUS 4/6GHz HYBRID SPACECRAFT

I-5.1 Introduction and Summary of Requirements

The basic antenna requirement of the hybrid satellite system capable of providing the required service for Canadian public and military operations can be summarized as follows:

a) In the 3.7-4.2GHz band, a Canada wide transmit shaped beam is required, covering edge located cities such as, St. John's and Dawson by approximately 27.5dB gain with an East-West polarized signal at the satellite in the 109 +5° orbital slot. The antenna must have two independent inputs for this operation to separate the 6 odd and 6 even numbered channels by approximately 30dB isolation. The above requirement is compatible with the final EIRP requirement of 34dBw at the contour, when 6.5dBw power enters into the antenna port. Under these conditions, the performance in this band is identical to Telesat's present performance with Anik satellite.

b) In the 5.925-6.425GHz band, a Canada wide receive beam is required communicating with the same area as defined for the 4GHz band operation. The antenna must provide North-South polarization and all 12 channels may be received at one single terminal. In order to make the performance of this beam also compatible with Anik's, the antenna must have an edge gain of approximately 26dB or more, providing at least $-81 dBW/m^2$ flux density at contour.

c) One of the receive transponder channels in the 6GHz frequency band must be connectable to an approximately 1.6° wide spot beam directed to 55°N, 110°W. This beam must be linearly polarized with either N-S or E-W polarization and must have as low as possible sidelobe levels toward oceanic areas. No gain requirements are specified for this beam, but its beamwidth is compatible with a peak gain of approximately 40dB.

d) In the 370 - 406.1MHz uplink and 300 - 328MHz downlink (300 - 406.1MHz UHF Frequency band), a circularly polarized antenna is required with approximately 19dB edge gain over Canada. The above gain figure represents an approximately 20° circular cross-section beam directed toward the Winnipeg region. The transmit and receive operation can be provided by either one antenna with a diplexer or with two independent antennas.

1-5.1 Introduction and Summary of Requirements - Continued

e) For the tracking, telemetry and control of the spacecraft, the antenna farm must include a TTC antenna which has a down and uplink frequency band and two modes of operation in each frequency band.

In the following, a brief description of a possible antenna farm is given. The antenna configuration assumes a three axis stabilized spacecraft, such as the Satcom bus, which can be launched by the Delta 3914 vehicle. From the point of view of the antenna design, one of the major characteristics of the launch vehicle is that it has an 84 inch dynamic envelope shroud diameter. Beyond this diameter, elements of the antenna farm must be deployable. The basic characteristic of the bus is that it has a rectangular top deck of 64 in. x 48 in. Ideally, all waveguide and tower connections must fall within this area.

1-5.2 4 GHz Band Public Operation

This function is utilizing an offset fed paraboloid reflector of 60 inch nominal projected aperture diameter with a focal distance between 36 in. and 44 in. The projected aperture diameter is achieved by using the outer region of a circularly symmetrical paraboloid with 84 in. diameter and the above stated focal length.

The 4GHz performance can be achieved if the utilized part of the paraboloid is illuminated by a pair of horns, directed toward the center of the projected aperture, have 4.6 in. NS and 3.2 in. EW aperture, and fed inphase through a Magic Tee. Alternatively, the horns can be pulled away from the paraboloid (axial defocussing) and can be fed through a 90° hybrid. For this configuration, the EW aperture of the horn can be slightly reduced in order to increase the field at the crossover of the two component beams. It may be mentioned that axial defocussing is effective for relatively small F/D ratios. Alternatively, the EW dimension of the aperture can be slightly reduced for the same effect. Among these manipulations, only the axial defocussing does not change the spillover efficiency of the antenna, but deterioration of spillover efficiency in the latter cases is tolerably small.

The surface of the reflector for this operation can be solid or an N-S polarized grid deposited on a kevlar reflector, such as in the Satcom antenna. The advantage of the second method is that it provides the optimum size and shape reflector which acts only on the 4GHz vertically polarized signal.

More than 2 horns can also be used for the 4GHz band operation. However, such systems require more complicated feed circuits and the performance improvement is very small.

I-5.2 **4 GHz Band Public Operation - Continued**

Justification for the use of 3 horns for the 4GHz operation can be considered only in conjunction with the 6 GHz band operation. This will be discussed later.

Figure I-5 shows a configuration of the antenna for this operation which meets the requirements listed in Section I-5.1. Table I-4 shows the details of the calculated performance. The performance calculation was based on efficiency factors defined relative to the directivity of the antenna. The directivity of the antenna was assumed to be identical to the directivity of the Anik antenna using the same aperture size.

I-5.3 **6GHz Band Public Operation**

There are two basic differences in the operations in this frequency band relative to the 4GHz band operation. First, the center frequency is 1.56 times higher, thus directivity of the component beams tend to be larger if the same horns and reflector aperture are used for this band. Second, the horns are stacked in the H plane which tends to separate the beam centers even more.

There are several techniques to compensate the above effects. If the same horns are used for the 4 and 6GHz band operations, then the axial defocussing widens the 6GHz component beam more than the 4GHz component beam on two counts: first, the phase center of the horn is deeper in the horn for this band; second, the quadratic path length error in the aperture of the paraboloid corresponds to larger phase error in this band because of the higher frequency. An alternative method is to use a smaller EW dish size for this frequency band. For instance, if the EW size of the dish is reduced to approximately 60/1.56 = 38 in., then the E-W size of the component beam remains comparable to the 4GHz size of the component beam and splitting of the shaped beam can be avoided. The dish size reduction requires the use of E-W polarized grided reflector, supported by the same Kevlar structure as employed for the 4GHz operation.

A further alternative is the reduction of the E-W horn size, mentioned earlier. In all the above cases, the 6GHz horns are added inphase.

When the same horns are used for 4 and 6GHz, an orthogonal coupler must be included for each horn. In order to avoid excessive radius of curvature in the connecting (square) waveguide, these orthogonal couplers must be placed at the throat of the horns and from there, separate waveguides come down to the top deck (WR137 for the 6GHz band, half height WR229 for the 4GHz band).

It may be mentioned that an alternative, separate configuration of horns can also be used to obtain the required 6GHz performance. In this case, no orthogonal couplers are employed, the 4GHz horns are operated in a focal point configuration as previously, and the 6GHz horns are operated in a Cassegrainian configuration.

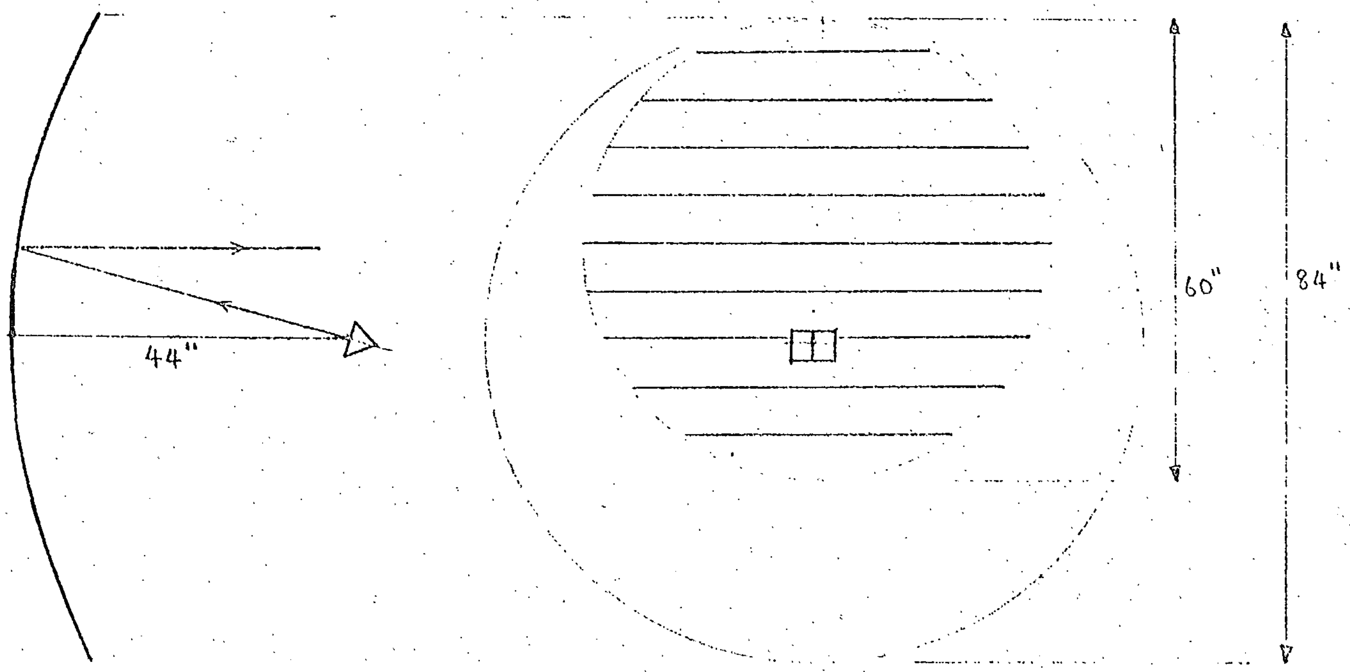


Fig. I-5 Reflector geometry for 4 GHz band operation.

TABLE I-4

CALCULATED ANTENNA EFFICIENCY COMPONENTS RELATIVE TO DIRECTIVITY OF SHAPED BEAM AND RESULTANT EIRP FOR THE 4 GHz BAND OPERATION

	3.72 GHz		4.16 GHz	
	Anik	Proposed	Anik	Proposed
η_S	0.68	0.61	0.68	0.61
η_P	0.20	0.20	0.20	0.20
η_Δ	0.12 (0.04" rms)	0.03 (0.02" rms)	0.14	0.04
η_X	0.15	0.15	0.15	0.15
η_L	0.15	0.19	0.15	0.19
η_{scan}	0.25	0.20	0.25	0.20
η_Γ	0.10	0.10	0.10	0.10
η_{block}	-	0.15	-	0.15
η_{DIR}	1.65	1.63	1.67	1.64
D_M	30.57	30.57	30.90	30.90
G_M	28.92	28.94	29.23	29.26
G_O	35.47	35.47	36.44	36.44
P_M(dBW)	7.4	7.4	7.4	7.4
α_{MUX}	0.5	0.5	0.5	0.5
P_{out} (dBW)	6.9	6.9	6.9	6.9
$EIRP_{MAX}$	35.82	35.84	36.13	36.16
$EIRP_{MIN}$ (E.O.C.)	34.32	34.34	34.63	34.66

I-5.3 6GHz Band Public Operation - Continued

The Cassegrainian subreflector is grided, orthogonal to the 4GHz polarization and its shape can be selected to give optimum shaped beam at 6GHz when illuminated by the (near field) horns. 2,3 or 4 horns can be selected for the 6GHz band in this case, resulting in considerable flexibility. The Cassegrainian subreflector has to be constructed as a double grid or parallel plate system in order to achieve 30dB or more isolation between receive and transmit horns. Since the scanning properties of Cassegrainian optics are more limited than focal point optics, the ideal pattern shape for Canada would require a 4 way power divider and 4 horns plus the Cassegrainian grid. For exchange, 2 orthogonal couplers are eliminated. Although the 6GHz performance of this sytem is slightly higher than for the common 4/6 GHz horn based system, the added complexity may not justify the improvement. However, it has to be noted for a particular advantage of this configuration: boresighting of the 4 and 6GHz beams can be made independently.

Figure I-6 shows the antenna configuration for the case when common horns are used and the 6GHz performance is optimized by reducing the 6GHz aperture size for the EW polarization employing EW grid on the paraboloid.

Table I-5 exhibits the details of calculated performance using the same method as in Table I-4 . Table I-6 gives the definition of the symbols used.

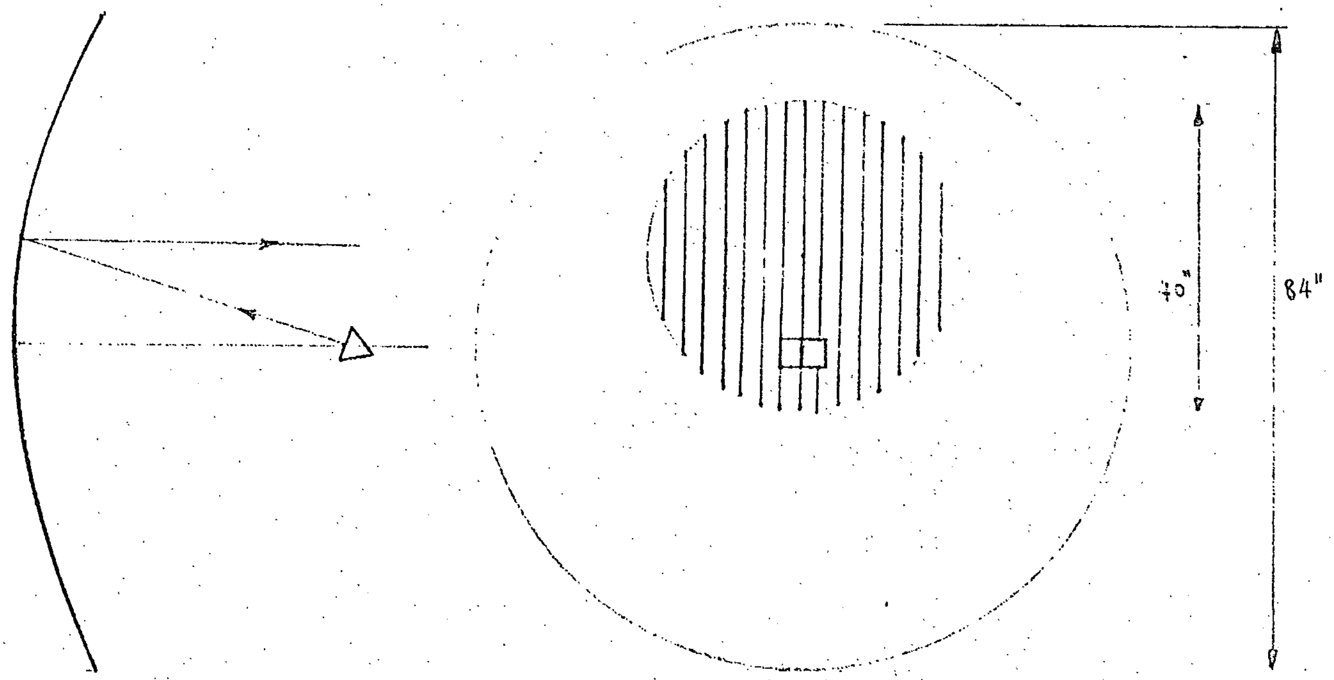


Fig. I-6 Reflector geometry for 6 GHz band operation.

TABLE I-5

CALCULATED ANTENNA EFFICIENCY COMPONENTS RELATIVE TO DIRECTIVITY OF SHAPED BEAM FOR THE 6 GHz BAND OPERATION

	5.945 GHz	
	Anik	Proposed
η_S	0.53	0.56
η_P	0.30	0.30
η_Δ	0.28	0.07
η_X	0.15	0.15
η_L	0.20	0.25
η_{scan}	0.30	0.25
η_Γ	0.10	0.10
η_{block}	-	0.15
η_{DIR}	1.86	1.83
D_M	30.17	30.17
G_M	28.31	28.34
G_O	39.54	39.54

TABLE I-6

DEFINITION OF SYMBOLS

η_A	=	aperture efficiency
η_S	=	spill-over
η_P	=	phase error
η_X	=	cross polarization loss
η_Δ	=	surface error
η_L	=	waveguide and horn losses
η_{scan}	=	feed scan loss
η_Γ	=	mismatch loss
η_{block}	=	aperture blockage
η_m	=	mesh loss
P_M	=	output of TWT assumed to be 5.5 W
α_{MUX}	=	multiplexer loss
P_{out}	=	net power out for input into antenna feed system
$EIRP_{MIN}$	=	edge of cover EIRP, assumed edge gain loss is 1.5 dB
G_O	=	maximum gain of 100% efficient antenna
G_M	=	peak gain
D_M	=	maximum directivity

I-5.4 6 GHz Band Spot Beam Operation

For the 6GHz band spot beam operation, the full available 84 in. diameter for which no deployment is necessary is utilized. Selection of N-S polarization has the advantage that the N-S dimension of the radiating horn can be minimized, thus the horn can be moved as close as possible for the already used dual horns in order to minimize boresight direction difference. On the other band, E-W polarization can be handled by an E-W grid, which does not interfere with the optimum shaping of the N-S polarized 6GHz Canada wide beam.

In order to optimize the communication for the 6GHz band public channels E-W polarization will be assumed in the following. The spot beam horn requires

$$\frac{60}{84} \times \frac{3950}{6175} = .458$$

times smaller aperture size than the optimum horn dimension for the 4GHz band operation. However, in the E plane of the horn, a further reduction can be introduced at the expense of a slight deterioration of spillover efficiency. Figure I-7 shows a number of ways the spot beam horn can "coexist" with the 4/6GHz band dual horns.

Figure I-7a shows a layout when a dual horn as previously described is used for the 4/6GHz band public operation and a separate horn for the 6GHz spot beam. In this arrangement, the boresight of the spot beam can be selected freely in the E-W direction but there will be an approximately 2.55°N-S boresight difference between the center of the spot beam and the center of the 4GHz band shaped beam. That may be useful to reduce radiation toward the ArcticOcean, but otherwise such a situation may not be tolerable.

Typically, the Canada coverage beam has its symmetry plane about 1.1° North of Calgary. Thus, a station south of Calgary will be about 1.4° away from the center of the spot beam. Since the spot beam has approximately .82° NS half beamwidth, a station for such conditions will be about 9dB below the peak of the beam. That may be compensated by higher EIRP at the ground, but the EIRP at the satellite will be highly pointing error dependent. Thus, configurations corresponding to Figure I-7a require some compensation to move or widen the beam in the direction of the North.

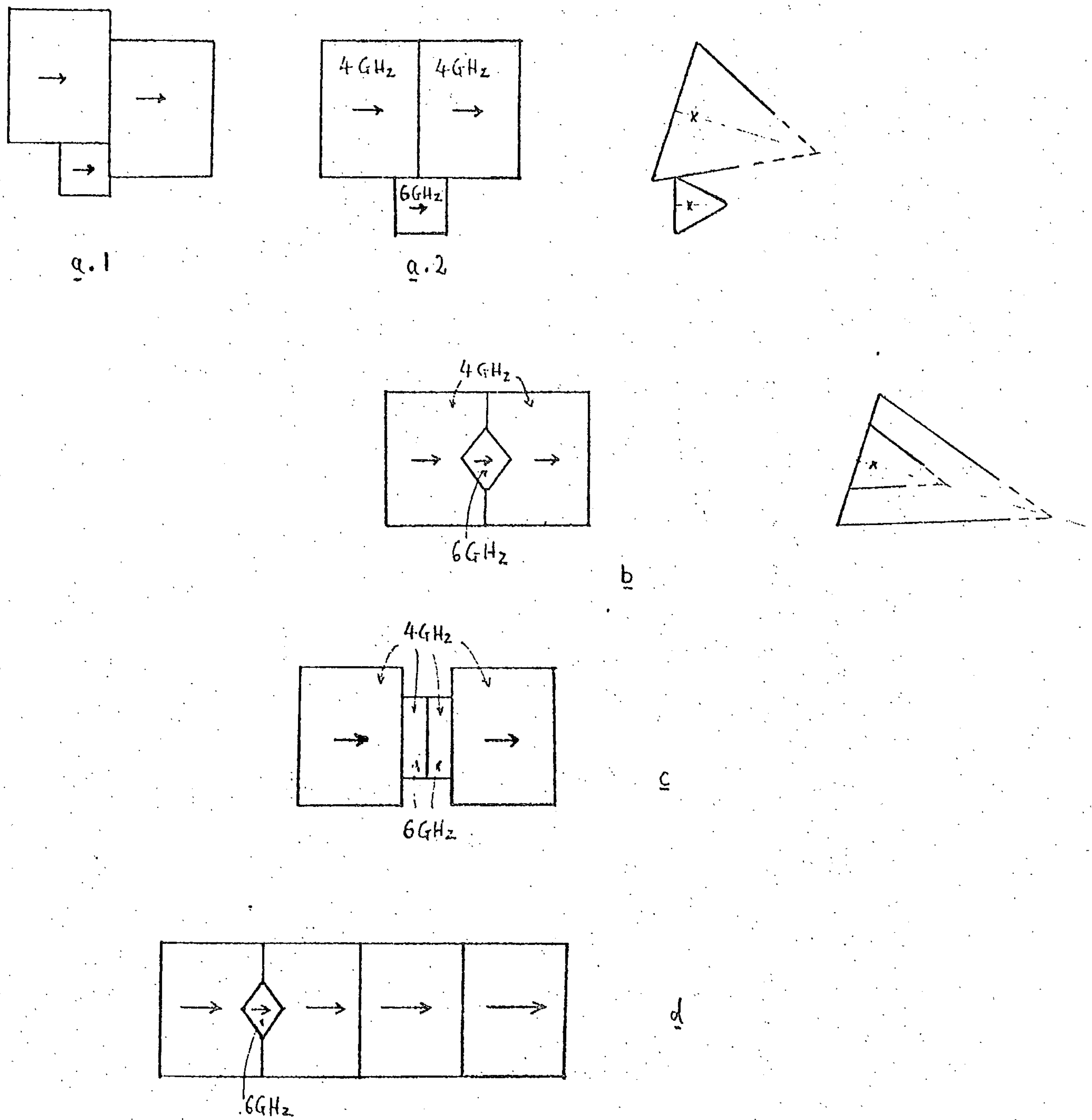


Fig. I-7 Possible horn configuration for E-W polarized spot beam.

1-5.4 6GHz Band Spot Beam Operation - Continued

One such method is to split the reflector as shown in Figure I-8 and tilt the lower half until its focal point coincides with the phase center of the spot beam horn. This method reduces the peak gain of the spot beam by an amount proportional to the tilt. A reasonable compromise is probably a 1.7 times N-S widening of the spot beam at which point the peak almost coincides with a Calgary South station and only 2.3dB gain is sacrificed instead of the previously occurring 9dB. Note that the beam widening technique described above does not significantly influence the sidelobe levels in the E-W direction. Furthermore, the 4/6 GHz public operation remained unaffected.

Figure I-7b shows a configuration in which the N-S boresight error is eliminated, but the E-W positioning freedom is lost. Also, the inserted diagonal horn tends to separate the 4/6 GHz beams slightly. This effect is practically eliminated in the configuration shown in Figure I-7c where the spot beam horn itself is split and it is also reused for the 4GHz band operation. This arrangement is unfortunately too complicated (requires two additional orthogonal couplers and two 4GHz power splitters) and still does not solve the E-W boresighting problem.

The arrangement shown in Figure I-7d offers a solution for no N-S boresight error, approximately right E-W location of the spot beam and requires no splitting of the dish. Instead, now the added complexity is in the required additional two power splitters at both 4 and 6GHz. Although the spot beam performance is best of the four considered configurations, this system is still fairly complex. On that basis, the a1 configuration with the split dish seems to be the best compromise. It may be mentioned in this configuration the shape of the spot beam is controllable by both the phase and amplitude distribution in the aperture of the 84 inch diameter reflector. The phase distribution is introduced by "splitting" the reflector into two and tilting its lower half relative to the upper half. This introduces a linear phase error and corresponding beam widening toward the North. The amplitude distribution is introduced by the variation of the wire density in the edge region of the reflector. This technique was used in the past to achieve sidelobe levels in the 25 to 30dB region at the cost of a slight reduction of aperture efficiency through dish transparency. The increased dish transparency has only second order effect on the antenna gain .3 to .5dB reduction), but it has primary control on the fine detail of aperture illumination function and, thus on the achievable sidelobe level. In the present case, not all sidelobes, but only those which do not fall to land areas have to be minimized. Furthermore, the sidelobe optimization can be made for the small frequency band corresponding to one or a few transponder bandwidths. Table I-7 shows the calculated efficiency and gain for the 6GHz band spot beam operation with circular beam cross-section. When the N-S beam widening is introduced, the peak gain has to be reduced by ~2.3dB.

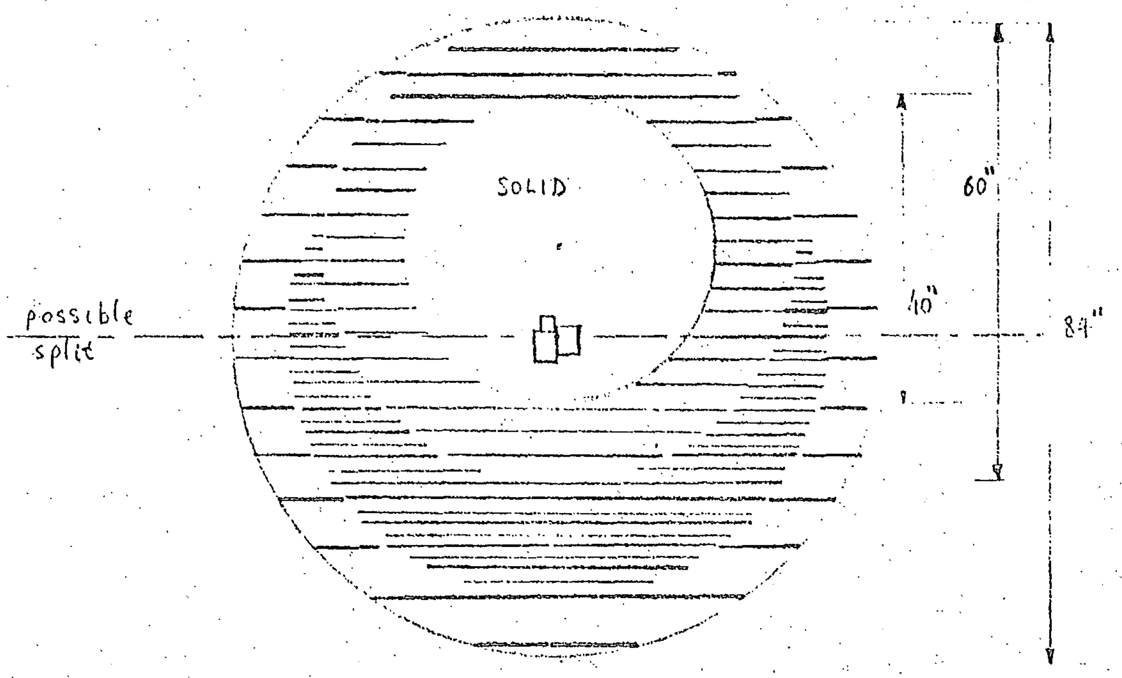


Fig. I-8 Superimposed geometry for 4/6 GHz band public and 6 GHz band spot beam operation.

TABLE I-7

CALCULATED ANTENNA EFFICIENCY COMPONENTS RELATIVE TO 100% EFFICIENT ANTENNA FOR 6 GHz SPOT BEAM OPERATION

(D = 84 in.)

η_A	0.35
η_S	0.76
η_X	0.10
η_P	0.18
η_Γ	0.10
η_Δ	0.35
η_m	0.18
η_L	0.10
η_{block}	0.10
η_{tot}	2.22
G_O	42.61
G_M	40.39

1-5.5 UHF Band Operation

If the UHF band operation is achieved by one antenna, then this device must have $\pm 16.3\%$ relative bandwidth around a center frequency of 349MHz. Within this overall band, the transmit band represents $\pm 4.56\%$ relative bandwidth around a center frequency of 313.7MHz and a receive band of $\pm 4.48\%$ relative bandwidth around a center frequency of 388.67MHz.

At the center of the transmit frequency band, the wavelength is λ_{To}=95.63 cm= 37.65in. Thus, the shroud diameter of 84 in. represents 2.230 λ_{To}. If this aperture is utilized by a conventional tapered aperture distribution, the 3dB beamwidth of the obtained beam will be only about 33° and the corresponding directivity 15.8dB.

In actual practice, the maximum possible gain will be even less, because of spillover and ohmic losses relative to the above directivity figure. From this, it follows that the desired 19 dB gain cannot be achieved by an aperture radiator which stays within the dynamic envelope of the shroud. In order to obtain more gain either a volume radiator or a larger aperture radiator must be employed.

The specified mission requires the same circular polarization, for both the transmit and receive operation. The simplest possible "volume" radiator in this case is a single wire travelling wave helix. The diameter of such a helix must be about .3λ at the center frequency. If such a helix must be used for transmit as well as for receive, then this diameter must be provided at 349 MHz, yielding .3 x 33.84 in. = 10.15 in. The gain of such a helix increases with its length but in practice, it is difficult to obtain more than 14-15 dB gain. Furthermore, the associated ground plane diameter is increasing as the length of the helix increases. A more efficient utilization of the used volume can be achieved if the number of windings on cylindrical surface supporting the helices is increased. For instance, with a 4 winding helix, a peak gain of 17 dB can be achieved using a total length of approximately 3 wavelengths (101.5 in.) and a variable pitch angle, conical shaped ground plate for maximum gain and optimum sidelobe level. Such a helix can be mounted in the middle of the spacecraft top deck (84 in. reflector) and would produce a practically axially symmetrical beam down to the 12 dB point of the beam, a sidelobe level in the order of 18 dB and an axial ratio of better than .25 dB within the 3 dB contour of the beam. The 3 dB beamwidth of such an antenna is about 29°. The disadvantage of this device is that it would block the radiation of the 4 and 6 GHz horns and would require an axial deployment mechanism, capable not only for the 101.5 in. extension but also to maintain the delicate variable pitch angle geometry. These difficulties already rule out such a device, but its length would cause further difficulties on account of the shadow, which the helix causes on the solar panels.

I-5.5 UHF Band Operation - Continued

The above difficulties can be reduced and the gain increased if more than one helix element is used in an array. With two elements on the East and West side of the 84 in. diameter reflector 3 dB additional gain can be achieved and the rf blockage can be eliminated. Furthermore, the sun blockage can also be eliminated if the beginning of the solar panel is not closer than 60 in. from the center of the spacecraft. (This is compatible with the present Satcom solar panel configuration). The trouble with this configuration is that its coverage is elliptical in the wrong direction (EW) and it requires not only an axial deployment but also a sideway deployment and the deployment must cover not only the very long helices but also their very large conical ground plates. Even under these conditions, the shape of the ground plates will not be ideal unless they penetrate into the cylindrical space represented by the contour of the 84 in. diameter reflector. Although the interference between the UHF and 4/6 GHz band antennas can be minimized by using a very thin ground cone, some blockage will occur.

To reduce the complexity of the helix to be deployed, their size can be reduced and their number increased. This generally increases the total weight and present additional packaging problems but the gain can be slightly increased. Three or four element arrays can be visualized, but due to symmetry considerations and interference with the solar panels, probably only 4 element array is worth further consideration. Such an array can produce 23 dB gain if helix length and ground cone size is not limited. For the present case, an N=4 element array with w=2 windings, $t/\lambda_{T_o} = 2.7$(101.65 in.) element length, $l/\lambda_{T_o} = 1.91$ (71.91 in.) element spacing, $d/\lambda_{T_o} = 1.69$ (63.62 in.) ground cone diameter can be considered which yields a peak gain of 19.75 dB. This ground plate size is still too large. A reduction to $d/\lambda_{T_o} = 1$ (37.65 in.) results in a peak gain of 19 dB.

Electrically, the above described array is an acceptable solution. It is exhibited in Figure I-9. It has the advantage of an axial symmetrical beam with a 3 dB beamwidth of 20°, an axial ratio of better than .5 dB and no rf blockage on the main reflector.

Mechanically, the above arrangement can be realized with considerable difficulties. The helices must be sideways as well as axially deployed, including their ground cones. The beginning of the solar panel must be further than about 100 in. from the center of the spacecraft. In order to make the weight of the deployed helices tolerable, their lowest resonant frequency falls below 1 Hz and may have some effect on station keeping operations.

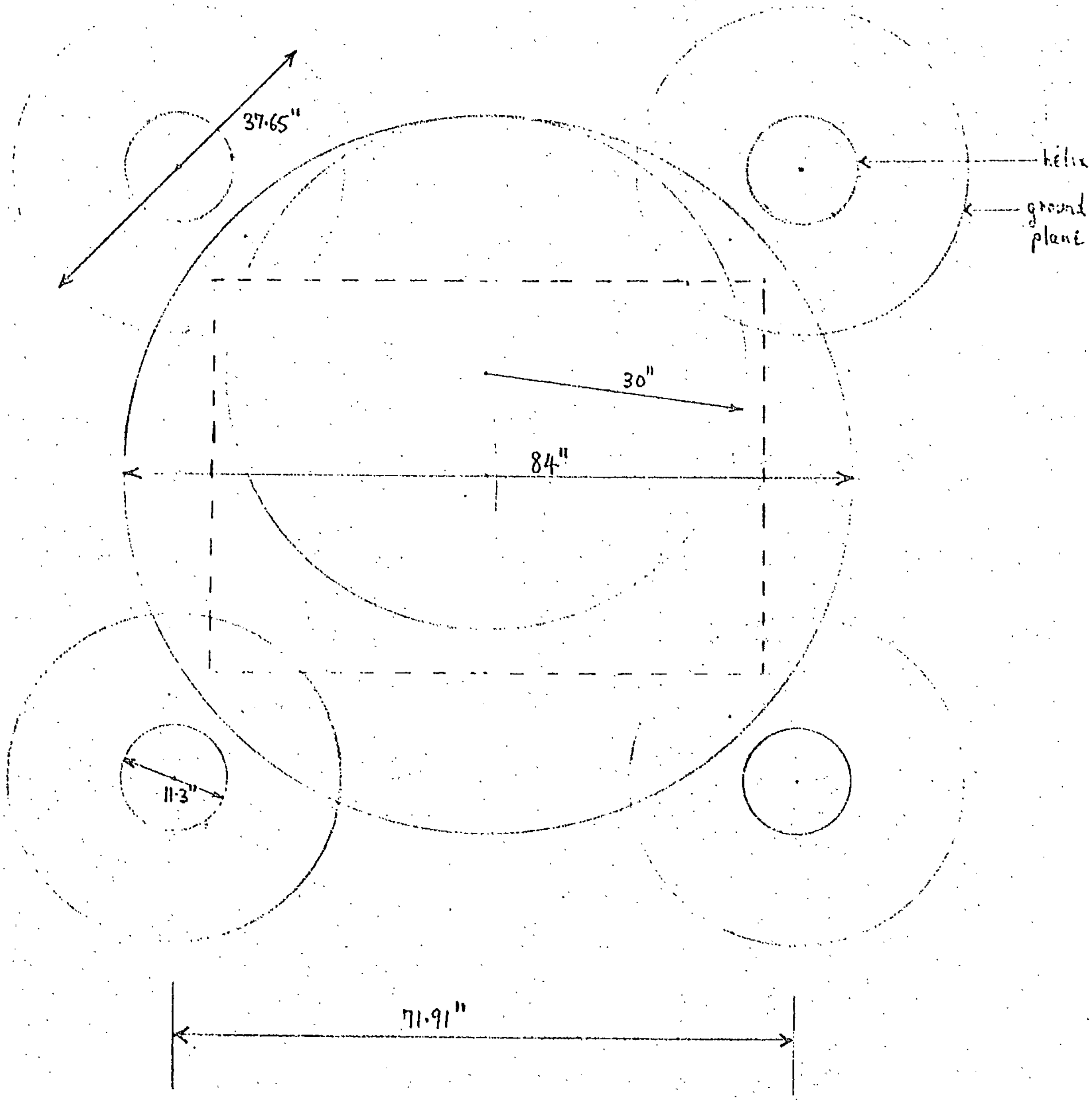


Fig. I-9 Layout of an UHF antenna using a quad helix array.

I-5.5 UHF Band Operation - Continued

A completely different alternate to provide 19 dB UHF frequency band gain is based on the use of extending the already provided 84 in. diameter paraboloid. Assuming that the basic paraboloid is extended by a mesh or wire surfaced paraboloid which is focal point fed by a CP turnstile feed, a gain in the order of 19 dB can be achieved with relatively small mechanical difficulty. Table I-8 shows the efficiency, gain and beamwidth characteristics for 144 in. and 156 in. diameter extensions. In the latter case, the maximum gain is 19.49 dB with a beamwidth of 21.8°. Assuming that a Canada coverage requires an 8° wide EW beam, the edge gain for this condition will be 19.09 dB (See Table I-8).

This antenna has a very small interference to the calculated performance of the 4/6 GHz antennas, through some blockage, but this interference is fairly small. It is assumed that the antenna is fed by a four element turnstile, quadrature fed to obtain circular polarization and two such turnstiles are used in 90° endfire condition feeding its beam toward the reflector. (See Figure I-10). The complete configuration is shown in Figure I-11. Notice that the dish now also has to have vertical wires but their separation corresponds to the UHF band (about 2 in.), thus they practically do not reflect the 6 GHz band signals.

In an integrated design, the focal distance of the paraboloid reflector has to be selected in such a manner that the depth of the deployed dish is not excessively large. For a very deep paraboloid, the surface of the reflector and its weight are relatively large compared to the aperture area. At the same time, the directivity of the turnstile feed is not very large, thus a fairly large aperture angle is desirable. The selected focal distance of approximately 40 in. results in an angle slightly below 90°, which is a good compromise. That requires a feed tower of slightly larger than 40 in., which must support the turnstile elements forming a 16.2 in. x 16.2 in. cross-section, 8.12 in. high box.

When the outer part of the reflector is folded, it must leave the inside 22.8 in. diameter space unobstructed for the turnstile feed, 4/6 GHz band horns, orthogonal couplers, five connecting waveguides and their supporting structure. The projected length of the hinged support elements at the circumference of the reflector is 36 in., even for the 156 in. deployed diameter case, thus these elements can be comfortably folded to the tower without covering its top, where the TTC antenna must be situated.

TABLE I-8

CALCULATED ANTENNA EFFICIENCY COMPONENTS OF TURNSTILE-FED PARABOLOID FOR UHF OPERATION

Paraboloid	144 in.	156 in.
A	1.70 dB	1.80 dB
S	0.19 dB	0.18 dB
P	0.05 dB	0.05 dB
A (0.25" rms)	0.03 dB	0.03 dB
m (mesh loss)	0.08 dB	0.08 dB
block	0.03 dB	0.02 dB
L	0.15 dB	0.15 dB
Γ	0.10 dB	0.10 dB
tot	2.33 dB	2.41 dB
G_o	21.21 dB	21.90 dB
G_M	18.88 dB	19.49 dB
$\Theta_{3\ dB}$	23^o	21.8^o

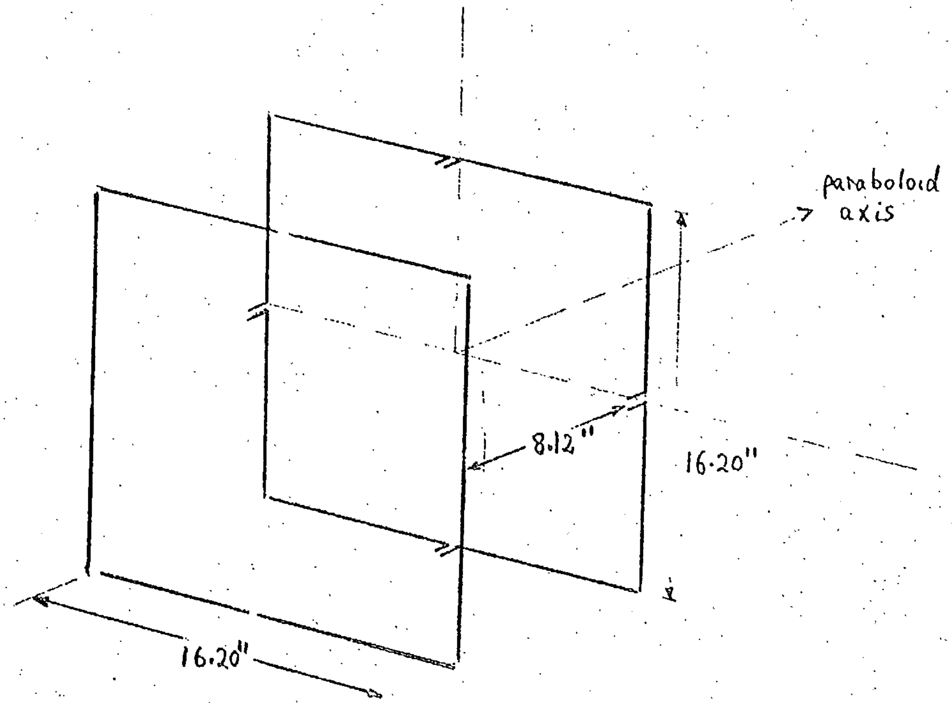


Fig. I-10 Layout of the turnstile feed for paraboloid reflector type UHF antenna.

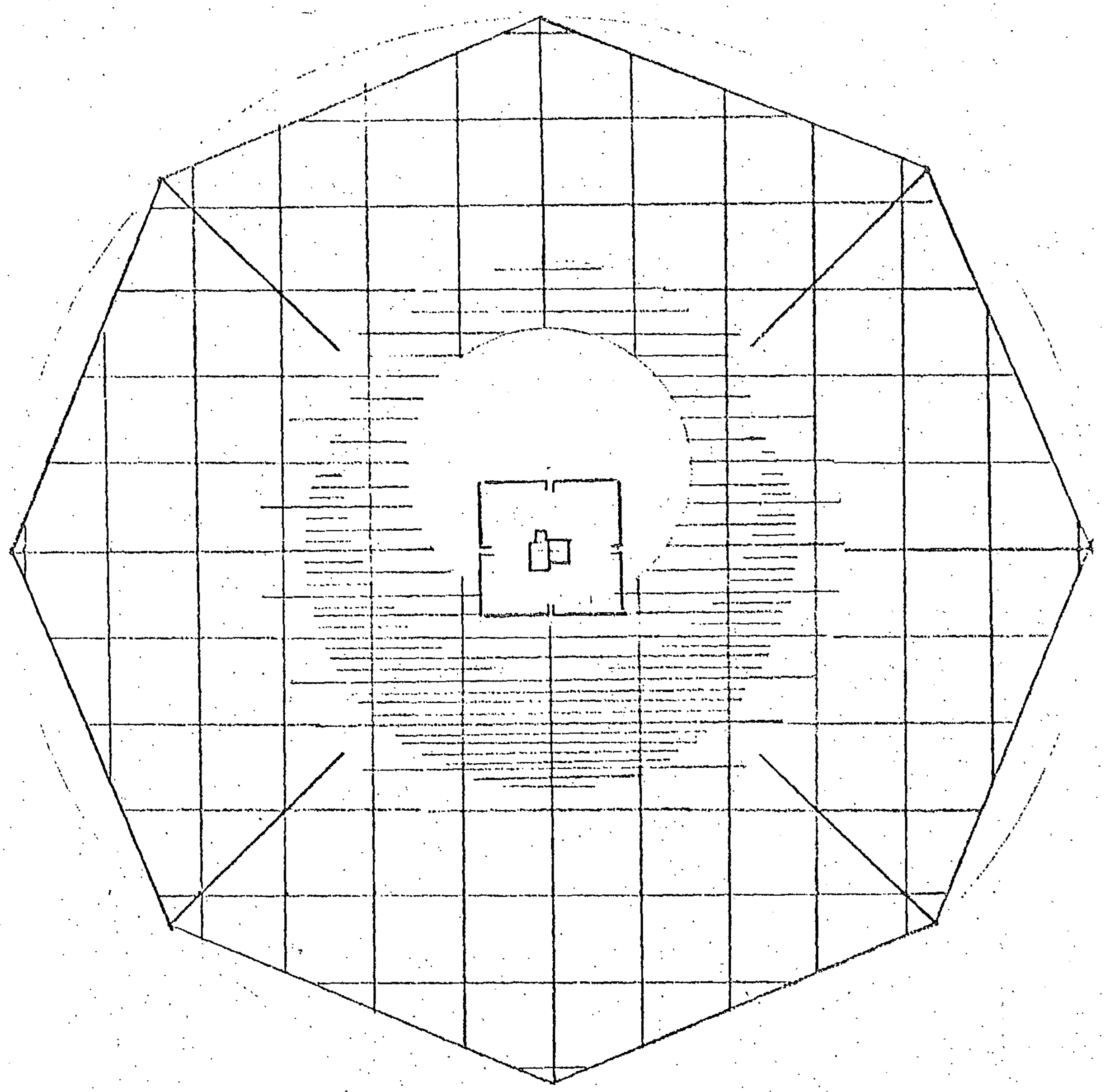


Fig. I-11 Overall configuration of the antenna system using deployable paraboloid for UHF operation.

I-5.6 TTC Antenna

The TTC antenna is selected identical to the SATCOM satellite. This antenna is the combination of a resonant biconical helix for the spinning mode operation and an endfire resonant helix for the on-station cardioid pattern operation.

This antenna is quite small for the 4/6 GHz band operation and can be mounted on top of the feed supporting tower. It remains unobstructed during the spinning mode since the folded reflector ribs do not reach that height. After the satellite is in station, the endfire mode of the antenna is used, which remains independent of other antenna functions.

I-5.7 Earth Sensors

A pair of redundant earth sensors have to be integrated with the antenna farm. These will be mounted on small pedestals on the top deck of the satellite, close to the South edge of the spacecraft. They will be raised close to the surface of the paraboloid so that their clear field of view requires only small holes (approximately 3 in. diameter) in the surface of the reflector. These holes have negligible effect on the overall performance of the antenna.

I-5.8 Overall Configuration and Weight

Figure I-12 shows the overall mechanical configuration of the antenna system using the deployable paraboloid antenna.

Table I-9 gives a preliminary weight budget associated with these elements.

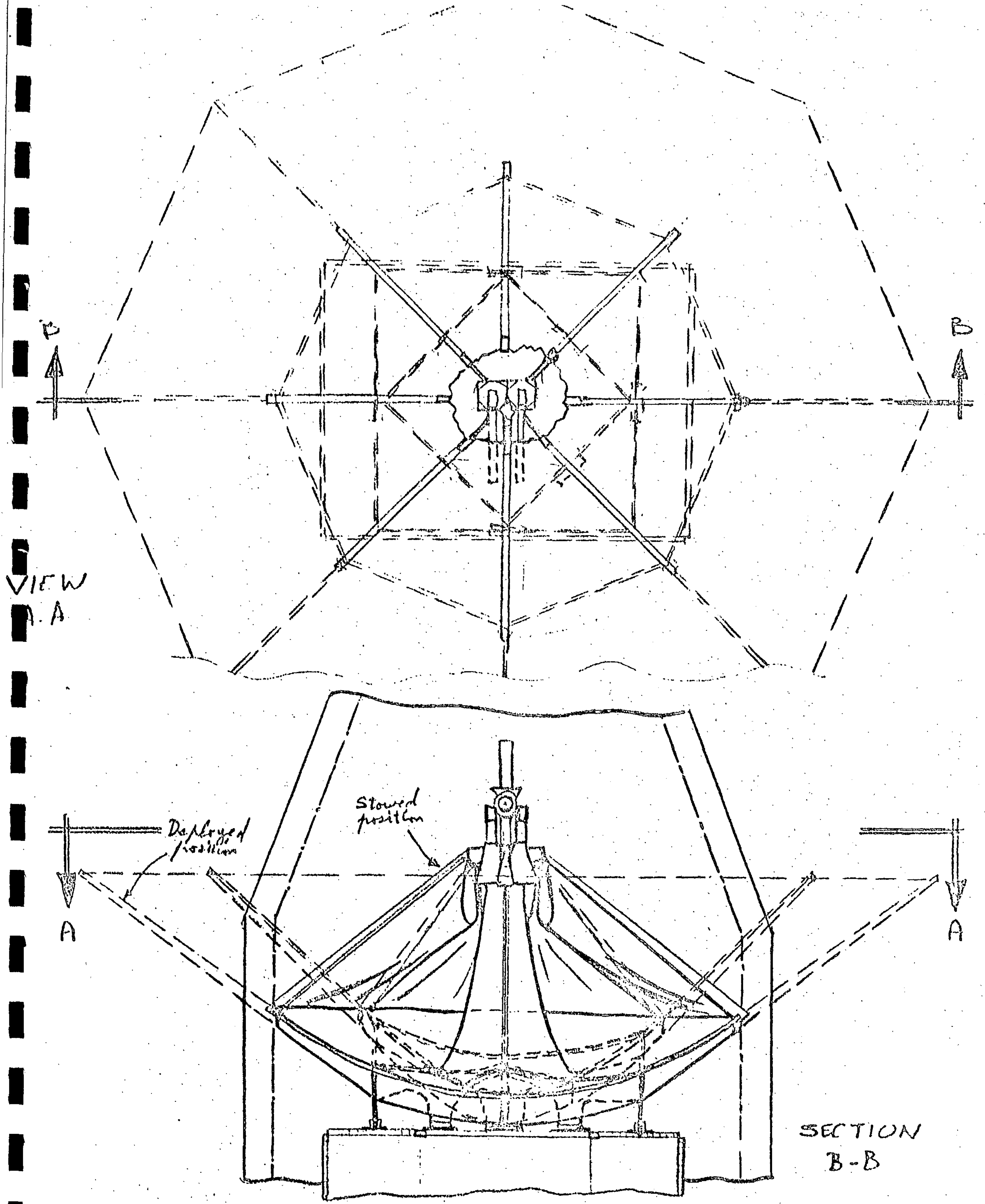


Fig. I-12 Mechanical layout of the antenna system using deployable paraboloid.

TABLE I-9

PRELIMINARY WEIGHT BUDGET FOR UHF/4 & 6 GH ANTENNA SYSTEM

4 & 6 GH Subsystem:	Lbs.
Main Reflector	18
Support Tower & Bracket	10
Feed Horns	2
Waveguides (3 X WR137 + 2 X WR229½H)	6
Orthro-Couplers (2 Off)	2
Underdeck Components & W/G	6
Thermal Hardware	3
Sub Total (1)	47

UHF (1st Alternative)	
Extendible Booms (8 Off)	5
Reflecting Mesh (17,600 in^2)	6.3
Feed System & Wiring	2
Support Brackets at Tower	2
Springs, Hinges, & Shock Absorbers	3
Pyrotechnics Controls & Strings	3
Sub Total (2)	21.3

UHF (2nd Alternative)	
Extendible Booms for Radial Deployment (4 Off)	4
Supporting Structure (TRW Type) (4 Off)	16
Coax Runs and/or Wiring	2
Ground Plates (4 Off 30" Dia.)	4
Support Brackets for Stowed Position (4 Off)	2
Spring, Hinges, and Shock Absorbers	2
Pyrotechnics, Controls & Strings	3
Radiating Elements (4 Off)	4
Sub Total (3)	37

	Lbs.
Total (1 & 2)	68.3
10% Contingency & Hardware	6.8
Grand Total (1 & 2)	75.1
Total (1 & 3)	84
10% Contingency & Hardware	8.4
Grand Total (1 & 3)	92.4

I-6.0 INTERMODULATION PRODUCTS GENERATED IN "LINEAR" COMPONENTS

It has been the experience for other UHF spacecraft that intermodulation (hereinafter abbreviated to IM) products are generated by the multicarrier output spectrum in the receive band due to spacecraft hardware whenever there is a metal to metal contact that has not been solidly welded together. Though the process is not properly understood, it appears to be due to moisture and other contaminants entering the contact area and changing the metal to metal contact into a weakly rectifying junction. Other causes that have been observed are nonlinear materials, oxide layers and corrosion.

Spacecraft carrying UHF transponders are prone to this phenomenom because of the very high gain within the transponder. Transponders for the 4/6 GHz band generally have gains of only about 100 dB whereas UHF transponder gains are in the 140 - 150 dB range. This extra gain internal to the spacecraft means that IM in the UHF transponder must be suppressed an extra 40 - 50 dB below that in a standard 4/6 GHz transponder.

Information* was obtained on the IM problems experienced in two previous spacecraft; LES-6 built by Lincoln Labs and already in orbit, and FLTSATCOM presently under construction by TRW.

The lowest order IM product appearing in the receive band of LES-6 was the 19th. This is a very high order but gave trouble because of spring fingers used to connect the front and back surfaces of the cavity backed slots used as radiating elements. They had great difficulty on the ground keeping the IM generated by these spring contacts down to an acceptable level. However, when the satellite was in orbit, the IM disappeared within 5 minutes after the transponder was turned on. Thus it required a combination of vacuum and power to clean up the contacts and make them truly linear.

In the case of FLTSATCOM the transmit and receive bands are close enough so that even the 3rd order IM products can appear in the receive band. The main problem units are those that are subjected to high field strengths, namely the duplexer, coaxial connectors, the feed and thermal blankets around the feed. The mesh reflector is fully welded at every contact and gives no problem. In addition it shields the spacecraft from the UHF radiation and prevents IM generation in bolted points on the spacecraft body. Also, in the multicarrier situation it has been observed by TRW that individual IM products decreased compared to the two-tone case.

* Private communication from Mr. Berg of Lincoln Labs, Lexington Mass., and Mr. Becker of TRW, Redondo Beach, Calif.

I-6.0 INTERMODULATION PRODUCTS GENERATED IN "LINEAR" COMPONENTS – Continued

TRW were not able to build a duplexer with sufficient linearity to meet their requirements and had to add a separate receive antenna to isolate the receiver from the transmitter IM.

For the UHF Multipurpose spacecraft it is necessary to establish if a duplexer can be utilized or if the IM is such that separate antennas will be required. From TRW it is determined that a state-of-the-art duplexer will generate IM 160 dB below each of two 40 watt carriers, that is, the IM level is -144 dBW. It was also determined that in the worst case, when the carrier level was changed, the C/I may change one dB per dB rather than the expected 2 dB per dB. Thus at the one watt power level the C/I ratio becomes, at a minimum, 176 dB and the IM level -176 dBW. In addition the IM level would become -186 dBW for 5th order and -196 dBW for 7th order etc.

The above numbers are expected levels for two-tone tests. For multicarrier operation it is necessary to determine the increase in IM level from the single IM product level. The actual situation expected in the UHF multi-purpose spacecraft is illustrated in Figure I-13. It is seen that for low power channels the 7th order is the lowest order in the FDMA segment of spectrum while 5th order is the lowest order in the SSMA frequency band. In addition, if the high power channels are located in the centre of the band (between 314 and 316 for example), the lowest IM products generated by high power channels are 11th and 9th orders in the FDMA and SSMA receive bands respectively.

For equally spaced carriers the IM products appear at equally spaced locations but the number of IM products increases from one for the product furthest away in frequency of a given order (i.e. at 412 MHz for 7th order), to the number of products that occur at the middle of the band. This number has been estimated by counting the number of products appearing in the first 5 frequency positions (beginning at 412 MHz for 7th order for example) and then generating an infinite series on that basis. The series (written in APL) and the resulting sequence of the first 30 numbers is as follows:

```
      +\1,N+¯1↓0,N←⍳30
1  2  5   10   17   26   37   50   65   82   101   122   145
      170  197  226  257  290  325  362  401  442
      485  530  577  626  677  730  785  842  901
```

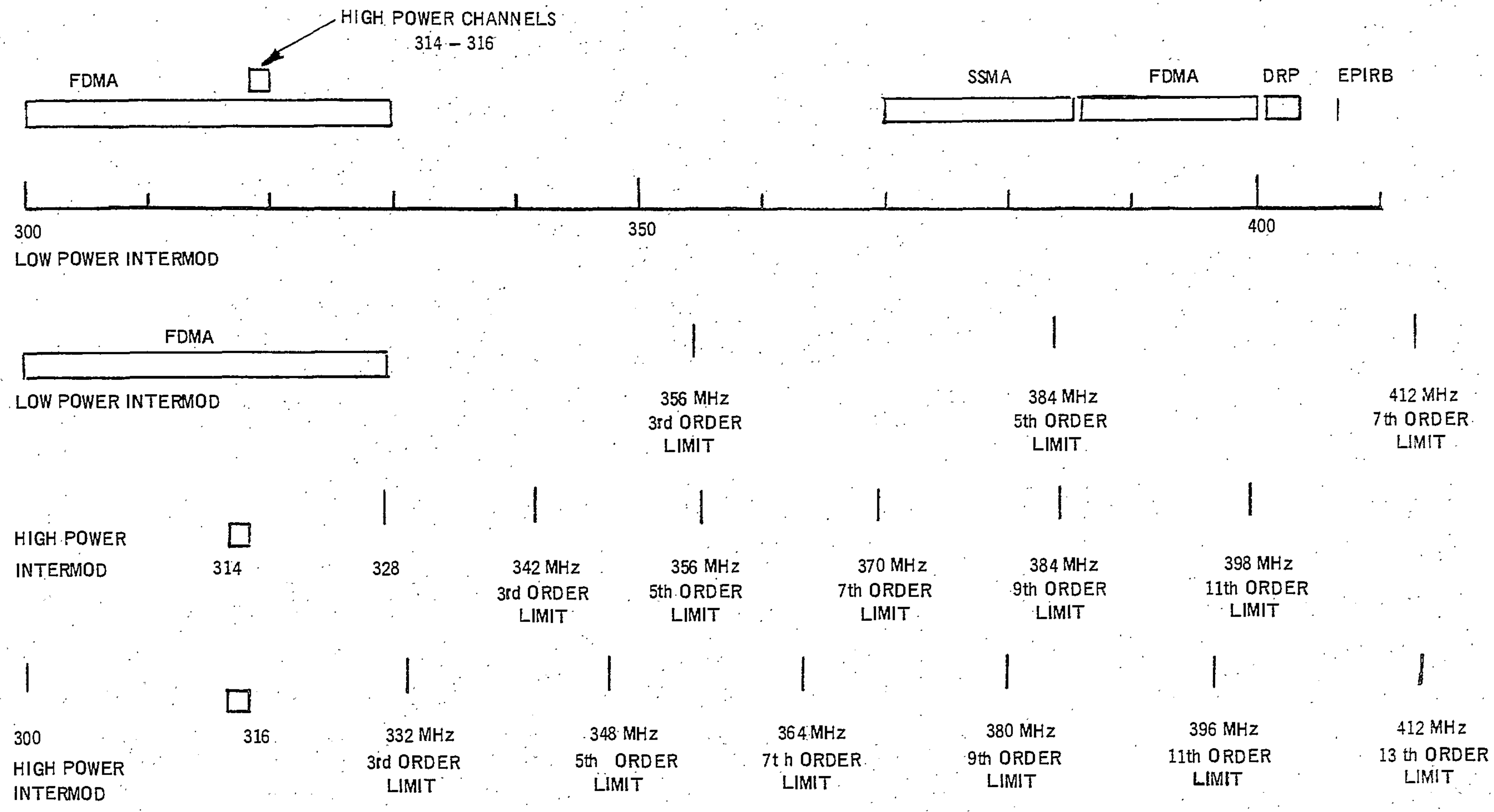


Figure I–13 Frequency range of passive intermodulation products up to the 13th order

INTERMODULATION PRODUCTS GENERATED IN "LINEAR" COMPONENTS -Continued

The number of products generated by this series is high, because the series does not level out as the middle of the band is reached. However, some of the products have a higher power level than the product measured with a two-tone test. For this reason the numbers generated by the sequence and used as multipliers are thought to give a reasonable representation of the multicarrier IM level.

On the basis of the above sequence the multicarrier IM levels at various frequencies and condition are listed in table I-10. As an example the IM level for 5th order, 20 tones is calculated from the 1 watt 2 tone 5th order IM level of -186 dBW by applying the appropriate multiplier from the above sequence. The appropriate multiplier is determined by reference to Figure I-13. At 385 MHz the fifth order does not occur and the tenth equispaced interval (1.5 MHz each) occurs at 370 MHz. At the tenth location the multiplier is 82 = 19 dB which increases the IM level to -167 dBW. These levels are considered to be conservative estimates in that the true levels are expected to be lower than those given. In all cases the IM level is below the uplink thermal noise level of -157 dBW in a 25 kHz bandwidth. An additional IM margin occurs because the carriers are not equally spaced as assumed here. When the carriers are randomly spaced the average improvement is equal to the ratio of utilized to occupied bandwidth. In the present instance eighty carriers of 25 kHz each utilize 2 MHz but are spread over a total bandwidth of 28 MHz a ratio of 11.5 dB. While, this is the average improvement the worst channel will be considerably poorer with an improvement that may not exceed 6 dB. Considering all these factors the single antenna approach is considered to be feasible and is the approach that has been adopted in this report. In the parallel implementation study the implications of this approach as far as technical risk and schedule are concerned will be examined.

TABLE I-10

ESTIMATED INTERMODULATION LEVELS IN THE RECEIVE BAND DUE TO PASSIVE ELEMENTS

	40 watts	10 W			1 watt		
		single product	370 MHz	385 MHz	single product	370 MHz	385 MHz
I (2 tone) 3rd	-144dBW	-156dBW			-176dBW		
I (2 tone) 5th					-186dBW		
I (2 tone) 7th					-196dBW		
I (2 tone) 9th		-186dBW					
I (2 tone) 11th		-196dBW					
I (20 tone) 5th						-167dBW	
I (20 tone) 7th						-167dBW	-170dBW
I (4 tone) 9th			-166dBW				
I (4 tone) 11th			-166dBW	-176dBW			

I-7.0 WEIGHT AND POWER BUDGETS

The weight and power budget shown in table I-11 is based on the block diagram of figure I-1. The total weight for the transponder excluding the HPA is 46.3 lbs. To this is added 75.1 lbs. for the antenna complex and 87 lbs for one half of the SATCOM transponder weight. To bring the total to 208.4 lbs.* These weights are based on actual SATCOM weights for the 4/6 GHz components and upon catalogue data as well as direct contact with suppliers wherever possible for the UHF components.

* This weight would be increased by an estimated 9.5 lbs if a separate redundant spot beam receiver were considered necessary to satisfy the mission requirements.

Table I-11

UHF/SHF WEIGHT BREAKDOWN

A. UHF COMPONENTS

UNIT	Number	Weight (oz) Per Unit	Weight (oz) Total	Power (Watts)
UDUP 1 - UHF Duplexer	1	36	36	
USW 1, 4 - UHF Switch	2	8	16	
ULNA 1, 2 - UHF LNA) UMX 5, 6 - UHF/UHF Mixer) ULO 2, 4 - UHF/UHF L.O.) UDA 2, 4 - UHF Driver Ampl.)	2	30	60	11
UDA 1, 3 - UHF Driver Ampl.	2	8	16	10
UCPR 2 to 7 - UHF 3 dB Hybrid	6	2	12	
UFL 1 to 4 - UHF Filter	4	18	72	
UCR 2 to 10 - UHF Isolator	9	2.5	20	
USW 2, 3 - UHF FE Switch	2	2.5	5	
UPN 1 to 4 - UHF Pin Diode Atten.) UALC 1 to 4 - UHF Pin Diode Level Control)	4	8	32	2
UCPR 1, 8 - UHF Coupler	2	4	8	
UPA 1, 2 - UHF Power Ampl.	2	Subject to tradeoff		
UCR 1 - UHF Output Isolator/Termination	1	25.6	25.6	
UATT 1 - UHF Atten.	1	0.25	0.25	
UMX 1 to 4 - UHF/SHF Mixer	4	8	32	
ULO 1 - UHF/SHF L.O. (redundant)	1	33	33	3
UR 2 to 12 - UHF Termination	11	0.25	3.3	
PT & C Unit	1	80	80	3
Coax Plumbing	1	48	48	
Wiring Harness	1	6	6	
Brackets & Hardware	1	24	24	
RF 1 Enclosure & Hardware	2	14	28	

B. SHF COMPONENTS

UNIT		Number	Weight (oz) Per Unit	Weight (oz) Total	Power (Watts)
CSW 1	6 GHz Switch	1	12	12	
CCR 1	6 GHz Circulator	1	12	12	
CFL 1	6 GHz Filter	1	8	8	
CSW 2, 3	4 GHz Switch	2	7	14	
CDA 1, 2	4 GHz Ampl.	2	3	6	1
CPA 13	4 GHz TWTA (spare)	1	56	56	
CCPR 1	4 GHz Coupler	1	2	2	
CATT 12,13	Atten.	2	0.25	0.5	
CR	4 GHz Termination	1	0.25	0.25	

		Weight	Power
	Sub-Total	673 oz.	
		= 42.1 lb.	30
	Margin (10%)	4.2	
	Antenna Complex	75.1	
		121.4 lbs.	30
	½ SATCOM	87.0	209
TOTAL (excluding UHF Power Amplifier)		208.4 lbs.	239 Watts

I-8.0 TRADE-OFF CALCULATIONS

I-8.1 General

The objective of the trade-off studies is to fully utilize the available capacity of the RCA SATCOM Bus which is sized for the 2000 lb. launch capability of the 3914 launch vehicle. The payload related weight is determined from the SATCOM weight budgets including that portion of the battery and the solar array which is proportional to power and is used to power the payload. This total payload weight (Wp) may then be divided up as desired between array, battery, antenna and transponder hardware. The variable, used to bring the payload weight up to maximum, has been taken as the UHF capacity in terms of the number of simultaneous carriers at 18 dBW each.

The payload weight can be divided into a fixed portion and a portion which is proportional to power namely, the array, battery and the UHF power amplifier. These latter are represented by a total weight coefficient K_T (lbs/watt) for the purposes of calculation. The contributions to K_T must be weighted by the fraction of power used by the UHF power amplifier in the case of its coefficient and by the fractional eclipse load in the case of the battery. In addition, the array can supply more power when charging current is not required. Thus slightly different array coefficients are used for the fractional eclipse power than for the remainder of the array power.

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.

I-8.2 Weight Coefficients

The weight and power specifications of the battery, solar array and the UHF power amplifier have been examined to determine the coefficients that are most appropriate for use with the SATCOM bus as modified by the requirements outlined in Section I-1.0. As a basis for establishing the magnitude of the coefficients the data will be used as presented in the RCA proposal, dated December 12, 1974, to Telesat for a 24 Channel Spacecraft. Specifically the data of Table 2.6-2, 2.6-1, and 2.1-3 will be utilized. These are reproduced here as Table I-12, I-13, and I-14 respectively.

TABLE I-12

POWER SUBSYSTEM COMPONENT SUMMARY
(From 24 Channel Proposal)

Component	Key Features	Electrical Parameters	Physical Data
Solar Array	Single-axis sun orientation -150° C to +55° C temp. range Initial max. power: 890 watts @ 35.5 volts Min. power @ 7 years: 655 watts @ 35.5 volts	8369 2 x 4 cm N-on-P 1 Ω cm cells 88 parallel strings of 95 series cells 12-mil fused silicon cover glass Diode isolation between circuits	Total area - 82 square feet Total weight - 70 pounds 0.25 inch honeycomb substrate Doni's (all particles) 4×10^{14} for ... yr life Trapped electron and protons - NASA SP 3024 Solar flare protons - Comsat CL-0-69
Solar Array Drive	Gearless dc motor drive Clock rate controlled servo Array velocity speed trim	24 Power slip rings - rated 10.3 amperes 7 Signal slip rings - rated 2.0 amperes 4 Brushes on power slip ring 2 Brushes on signal slip ring	Drive Assembly Weight: 11.2 lb Electronics Weight: 5.6 lb Power: 11.1 w
Solar Array Deployment	Deployment energy: torsion springs Rotary hydraulic damper 6-point support during launch Redundant release squibs	Squib firing	Weight - 6.4 pounds
Battery	3 nickel-cadmium batteries 0 to +10° C temp. range Reconditioning cycle prior to eclipse	45.9 ampere-hour total capacity 15.3 ampere-hour cells 59% max. discharge with 22 TWTAs	Size - 12.2 x 5.2 x 5.6 inches Total weight - 99.8 pounds 2 modules per battery 11 cells per module
Power Supply Electronics	Essential and non-essential buses Over-current detection Fused outputs Battery reconditioning circuits	+24.5 to +35.5 volt range, both buses +24.5 to +29 volts during eclipse Withstand 100% overload before operation Discharge each cell to 0.05 volt, then fully charge at C/10 rate during battery reconditioning	Size - 11 x 7.9 x 7.6 inches Total weight - 13.1 pounds
Charge Regulator	3 primary regulators 3 backup regulators	C/60: 0.28 ± 0.05 amp/batt. - during 100% sun C/20: 0.7 + 0.5 amp/batt. - during eclipse season C/10: 1.4 + 0.10 amp/batt. - during reconditioning cycle	Located in the power supply electronics
Shunt Control	Redundant shunt controller amplifiers with redundant failure detectors for each amp. Distributed dissipators Automatic switchover to standby unit	Limits load bus to +35.0 ± 0.5 volts 30 shunt transistors 3 parallel transistors per shunt section	Amplifiers and detectors located in the power supply electronics Dissipator total weight - 2.3 pounds
Electrical Harness	Selected wire redundancy Redundant return lines Separate redundant pyrotechnic lines Separated grounds	Twisted power wiring Shielded twisted wiring - cmd, signal lines 50-500 kHz Coaxial cables 500 kHz Shielded twisted pyrotechnic lines Single Point Star Ground	Total weight - 34.5 pounds Wire size - AWG #26 min, AWG #18 max
Total Weight: Power System 208.5 lbs Harness 34.5 lbs			

TABLE I-13

OPERATIONAL ORBIT POWER REQUIREMENTS
(From 24 Channel Proposal)

Subsystems	End of 7 Years			
	Solstice		Equinox	
	Winter	Summer	Day	Eclipse
Transponders (RCVR +22 TWTAs)	503.6 watts	503.6 watts	503.6 watts	503.6 watts
Command, Ranging, & Telemetry	17.4 watts	17.4 watts	17.4 watts	17.4 watts
Attitude Control & Propulsion	16.1 watts	16.1 watts	13.6 watts	13.6 watts
Power	56.3+ watts	56.3+ watts	101.3++ watts	32.4 watts
Thermal	54.0 watts	26.6 watts	54.0 watts	23.0 watts
Harness	11.5 watts	11.5 watts	11.5 watts	11.5 watts
TOTAL	658.6 watts	631.5 watts	701.4 watts	601.5 watts
TOTAL FOR 24 TWTAs	706.7 watts	676.3 watts	749.2 watts	648.4 watts

+ Includes Trickle Charge
++ Includes Charging at C/20 Rate

TABLE I-14

WEIGHT AND POWER SUMMARY
(From 24 Channel Proposal)

Subsystem	Weight (lb.)	Avg. Power (watts)	Comments
Structure	100.3	-	5% of transfer orbit weight.
Thermal Control	17.7	23 - 54	Heater power varies with season.
Propulsion (RCS)	39.2	0.6	Pressure transducer power.
Power	208.5	32 - 56	11.1 watts required for array drive. Power system losses and shunt dissipation vary with load, life, and season.
Attitude Control	57.9	16.1	Additional 12 watts for gyro during stationkeeping only.
Command, Ranging, and Telemetry	28.3	17.4	48 watts total in transfer orbit.
Harness	34.5	11.5	Cable ohmic loss.
Communications			
Transponders	183.5	503.6	22 channels; 547.8 watts for 24 channels early in life.
Antennas	54.9	-	Includes CR&T antennas.
Apogee Motor Case	62.2	-	Case sized for 2190-lb. transfer weight.
Balance, Brackets, and Misc.	18.6		
Spacecraft Margin	25.0		
Total S/C Dry Weight	830.6		
Reaction Control Propellant	190.0		6½ year stationkeeping capability.
Apogee Motor Expendables	904.4		
Launch Vehicle Adapter	75.0		MCD-D 3721A, with Telemetry Package.
Total Transfer Orbit Weight	2000.0		Delta 3914

I-8.2 Weight Coefficients - Continued

In Table I-12, the solar array, the power supply electronics, and the shunt control have been identified as the power dependent parts of the solar array, making the total solar array weight equal to 85.4 lbs. The total battery weight is only the battery at 99.8 lbs. as very little electronics is associated with the batteries. The remaining items in Table I-12 are considered fixed so that the total power dependent portion of the power subsystem is 85.4 + 99.8 = 185.2 lbs. From Table I-14 the total payload related weight can be obtained as the transponder at 183.5 lbs. plus the antenna at 54.9 lbs. plus the portion of the 185.2 lbs. of the power subsystem that is used by the payload. This fraction is obtained from the summer solstice conditions in Table I-13 as 185.2 x 503.6 ÷ 631.5 = 148 lbs. In addition the Table I-14 shows a $6\frac{1}{2}$ year station keeping fuel budget. To meet the present requirements this must be reduced by $\frac{1}{2}$ year to 6 years at the rate of 19.2 lbs/year. This extra weight is then available for payload. The total payload weight then becomes 396 lbs.* using the SATCOM bus and the requirements of the present mission. This assumes there is no effect of the payload on the SATCOM Bus. Some contingency is carried in the spacecraft margin of 25 lbs. listed in Table I-14 and retained implicitly in the weight coefficients used in this study.

The power available from three batteries with a total weight of 99.8 lbs. can also be calculated using the data of Tables I-12 and I-13 and some additional data on cell voltage versus fractional discharge. This is done (Table I-15) for two cases as a comparison, for all three batteries discharged to 59% and for two of the three batteries carrying the load to a depth of discharge of 66%. The second is required by the present mission giving a battery coefficient of .242 lbs./watt.

The array coefficient can also be calculated. This is done on the basis of the power load for both summer solstice and equinox and the most pessimistic coefficients are used. During equinox the array produces more power because the sun's rays are normal to the array but the spacecraft load is also higher mainly because the battery charging current is higher, making solar array power about as critical at equinox as at summer solstice. Using figures from Table I-13 and the appropriate charge rates, the following coefficients are obtained.

*The SATCOM Bus has been budgeted for station keeping fuel assuming an eight year life and near maximum average rate of inclination buildup. For most launch dates therefore, no modification to the total payload weight is anticipated.

TABLE I-15

AVAILABLE POWER FROM THE BATTERIES IN ECLIPSE

$$P = \frac{V \times n \times (DOD)}{t} C$$

P = available power in W
V = average cell voltage during discharge in V
n = number of series connected cells
DOD = depth of discharge, (assuming initially fully charged batteries) full charge = 1
t = maximum discharge time in hrs.
C = battery charge in AH

1. 3 batteries @ 15.3 AH

$C = 3 \times 15.3 = 45.9$ AH

If V = 1.23V, n = 22, DOD = 0.59 and t = 1.2 hrs.

$P_1 = \frac{1.23 \times 22 \times 0.59}{1.2}$ 45.9 = 610.7W available from the battery terminals

Note: $V_{Bus} = 1.23 \times 22 - 0.86 = 27.06 - 0.86 = 26.2V$

Thus $P_{1Bus} = \frac{45.9 \times 0.59}{1.2} \times 26.2 = 591.3W$ available from the bus

Weight Coefficient $= \frac{99.8}{591.3} = .169$ lbs./watt

2. 2 batteries @ 15.3 AH, C = 30.6 AH

If V = 1.155, n = 22, DOD = 0.66 and t = 1.2 hrs.

$P_2 = \frac{1.155 \times 22 \times 0.66}{1.2}$ 30.6 = 427.6W available from the battery terminals

Note: $V_{Bus} = 1.155 \times 22 - 0.91 = 25.41 - .91 = 24.5V$

Thus $P_{2Bus} = \frac{30.6 \times 0.66}{1.2} \times 24.5 = 412.3W$ available from the bus

Weight Coefficient $= \frac{99.8}{412.3} = .242$ lbs./watt

I-8.2 Weight Coefficients - Continued

Summer solstice

Daylight power	631.5 watts
Battery charging	30.4 watts
Useful power	601.1 watts
$K_1 = 85.4 \div 601.1$ =	.142 lbs./watt
$K_2 = 85.4 \div 631.5$ =	.135 lbs./watt

Equinox

Daylight power	701.4 watts
Battery charging	80.5 watts
Useful power	620.9 watts
$K_1 = 85.4 \div 620.9$ =	.138 lbs./watt
$K_2 = 85.4 \div 701.4$ =	.122 lbs./watt

Summer solstice coefficients are used since they are most stringent.

The UHF power amplifier coefficient has been calculated from specifications for the 42 watt AB amplifier built for FLTSATCOM. This amplifier has 60 dB gain, has an overall efficiency of 34%, and weighs 6 lbs. including the power conditioning function. The total dissipation is 81.5 watts giving a coefficient of $6 \div 81.5 = .074$. To allow for a redundant unit this coefficient is doubled to .148.

I-8.3 Analysis

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.

$$P_{RF} = EFF \times P_s$$

$$P_H = (1 - EFF) \times P_s$$

$$W_T = K_4 \times P_H = K_4\ (1 - EFF)\ P_s$$

The heat dissipation "P_H" in the output power amplifier must include the power to the drive circuits. Thus "EFF" in the above equations is the overall efficiency including the driver stages and the power conditioning, if it is used.

I-8.3 Analysis - Continued

Under eclipse conditions when the UHF capability is reduced, it is assumed that the battery drain is controlled by reducing the number of active channels in the system. In this way the total drive level is reduced which reduces the output RF power and consequently the DC power drain from the battery. However, the DC to RF efficiency does not remain constant as the amplifier is backed off with the result that any specific RF eclipse capability in the UHF band, such as 50%, requires more than 50% battery load, compared to that required for 100% UHF capability, to provide the necessary DC drive power. This has been simulated in the calculation by using measured results on a single stage class C amplifier* at 300 MHz. Correction factors, normalized to an arbitrary maximum operating point, have been determined for output power and efficiency from these measured results. They are listed in Table I-16.

TABLE I-16

BACK-OFF CHARACTERISTICS OF A CLASS C TRANSISTOR AMPLIFIER

Relative RF Output Power	Relative Efficiency
1	1
.795	.921
.609	.855
.451	.77
.327	.68
.229	.594
.15	.496
.097	.41
.062	.349
0	0

Using Table I-16 and linear interpolation between points, the eclipse battery ratio for UHF operation can be calculated for any specified RF eclipse capability. For example, if an RF eclipse channel capacity of .609 is required, then the fractional battery power of .609 ÷ .855 = .713 is required. The value .713 becomes E_T, the UHF eclipse battery load, while the value .609 is the UHF eclipse channel capacity.

*R. G. Harrison and H.J. Moody "A Study of Low Intermodulation Transistor Power Amplifiers", RCA Ltd. Report No. FXC65-2 May 1974, Performed under Contract No. PZ.36001-3929 for the Communications Research Centre, Ottawa, Ontario.

I-8.3 Analysis - Continued

The total weight coefficient for the array, battery and UHF power amplifier can be formulated by weighting the individual coefficient by the fraction of power associated with each. Thus:

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

The battery ratio E_B is the ratio of the total eclipse load to the total sunlight load.

The sunlight load is $PTot = Ps + P_R + P_L$ and,

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 relative values of P_S, P_R, and P_L.

Finally,

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

Thus we have E_B depending upon P_s, and P_s depending upon E_B. This can be solved by a trial and error approach using the computer. Finally the prime power P_s is converted to radiated power using the assumed total conversion loss. This is nominally budgeted at 6 dB (Table I-17), but will vary depending upon the assumed output stage efficiency. Finally, the total radiated power is converted to the number of channels at an EIRP of 18 dBW.

The coefficients and parameters used in the trade-off calculations are listed in Table I-18.

TABLE I-17

DC TO RADIATED RF CONVERSION LOSSES

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

TABLE I-18

WEIGHT AND POWER COEFFICIENTS USED IN THE CALCULATIONS

Array #/eclipse watt	K_1 = .142 lbs./watt
Array #/sunlight watt	K_2 = .135 lbs./watt
Battery #/watt	K_3 = .242 lbs./watt
Redundant Transmitter	K_4 = .148 lbs./watt dissipation
UHF/SHF Receiver Prime Power	P_R = 30 watts
4/6 GHz Prime Power	P_L = 209 watts
UHF/SHF Weight Less Transmitter	W_R = 142.1 lbs.
4/6 GHz Transponder Weight (½ SATCOM)	W_L = 87 lbs.
UHF Transmitter Weight	W_T lbs.
Full Payload Capacity of Bus	W_P = 396 lbs.
UHF Transmitter Prime Power in Sunlight	P_S watt
UHF Transmitter Prime Power in Eclipse	P_e watts
UHF Eclipse Load	$E_T = \frac{P_e}{P_s}$
4/6 GHz Eclipse Capability	E_L
Battery Eclipse Ratio (ratio of eclipse load to sunlight load)	E_B
Total Weight Coefficient Including Array, Battery and Transmitter	K_T
UHF Power Amplifier Efficiency	EFF

I-8.4 Trade-Off Results

The number of RF channels (at 18 dBW) has been calculated as a function of efficiency and for various values of fractional eclipse capability (specified in both channel capacity and battery load). The results are plotted in Figure I-14. In the event that the efficiency of the output amplifier can be maintained in the backed off condition, then the channel capacity becomes equal to the battery load and figures for battery load can be used for channel capacity. It is evident from Figure I-14 that 77 channels at 18 dBW can be supported in sunlight for 50% UHF eclipse channel capacity and 35% efficiency for the UHF power amplifier. During eclipse, 50% capability gives 38 channels. A total loss from the power amplifier to the antenna of 1.5 dB has been assumed (Table I-16), and this combined with the 19 dB antenna gain requires 0.5 dBw output power per channel to give the standard EIRP of 18 dBW. Thus the 77 channels require a total RF power of 86.5 watts.

Corresponding to the curves of Figure I-14, the weight of the UHF power amplifier is plotted in Figure I-15. In figure I-16 the weight of the batteries and array required for total communications payload are presented. It is seen that, as the amplifier efficiency increases, the amplifier weight decreases while the battery and array weight increase, keeping the total weight constant. Also, in Figure I-17, the DC prime power required for the power amplifier and the total power required by the communications payload is shown. These powers increase slowly as the power amplifier efficiency increases.

Additional calculations have been made showing the sensitivity of number of channels to antenna gain (at constant antenna weight) and to increases in the estimated weight at constant antenna gain. The results are shown in Figure I-18. It is seen that at a UHF amplifier efficiency of 35% a 10 lb. weight increase decreases the channel capacity by 8 channels, while an increase of one dB in the antenna gain increases the channel capacity by 16 channels. Thus an increase in antenna gain is advantageous if it can be obtained for less than 20 lbs. per dB.

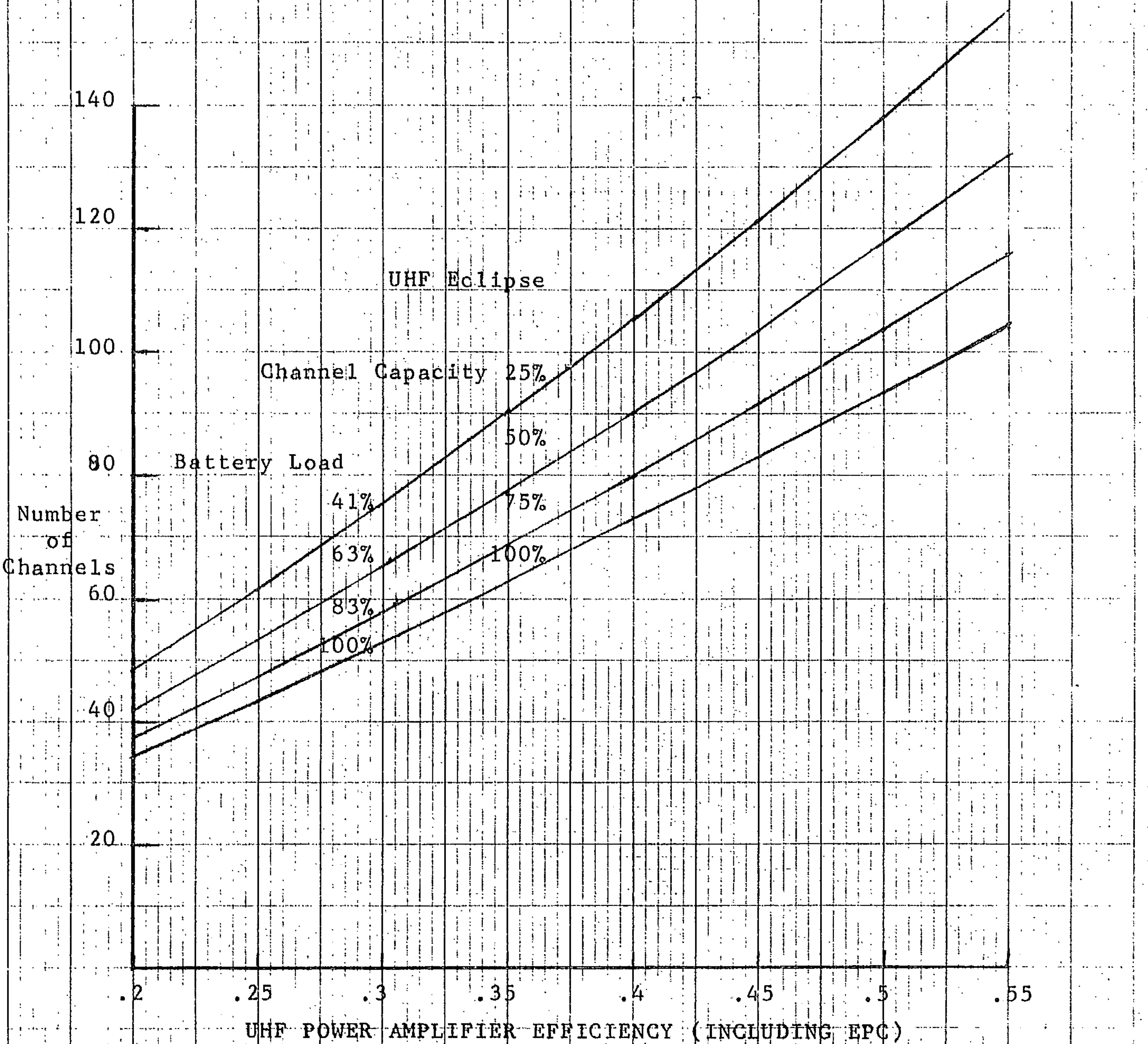


Figure I-14 Number of UHF channels with 100% 4/6 GHz eclipse operation

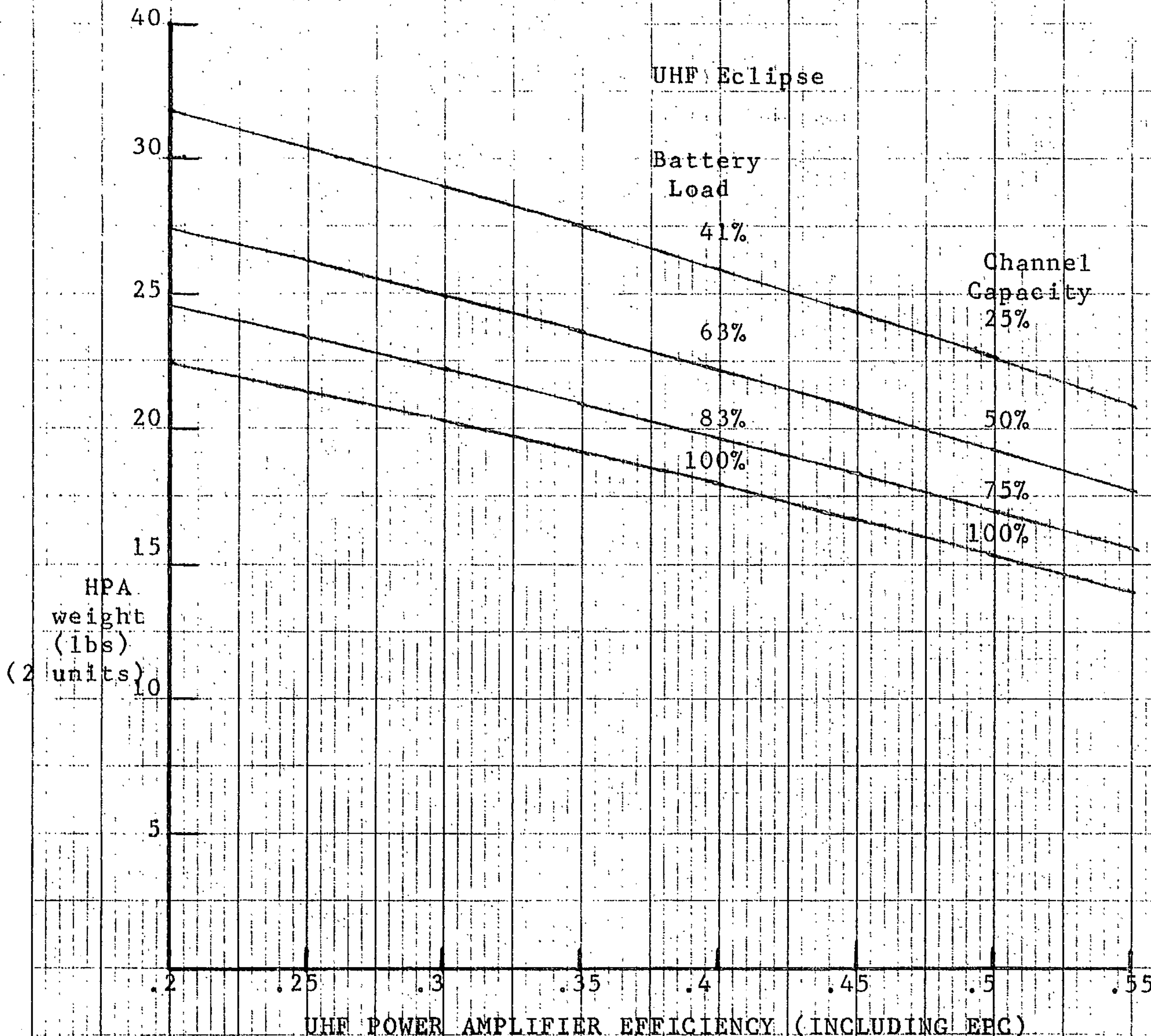


Figure I-15 UHF power amplifier weight for 100% 4/6 GHz eclipse

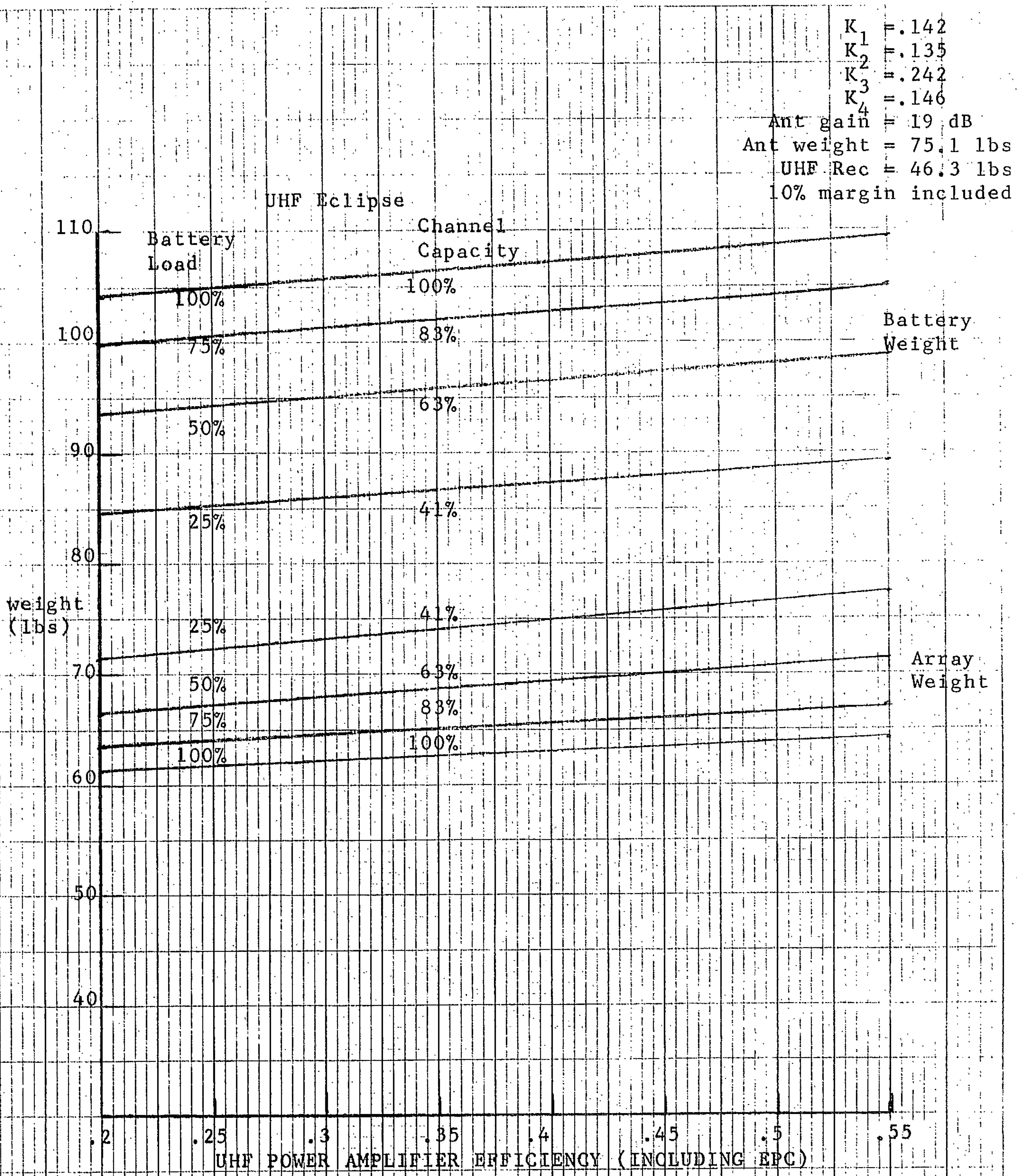


Figure I-16 Battery and array weight required to power the total communications payload. (100% 4/6 GHz eclipse)

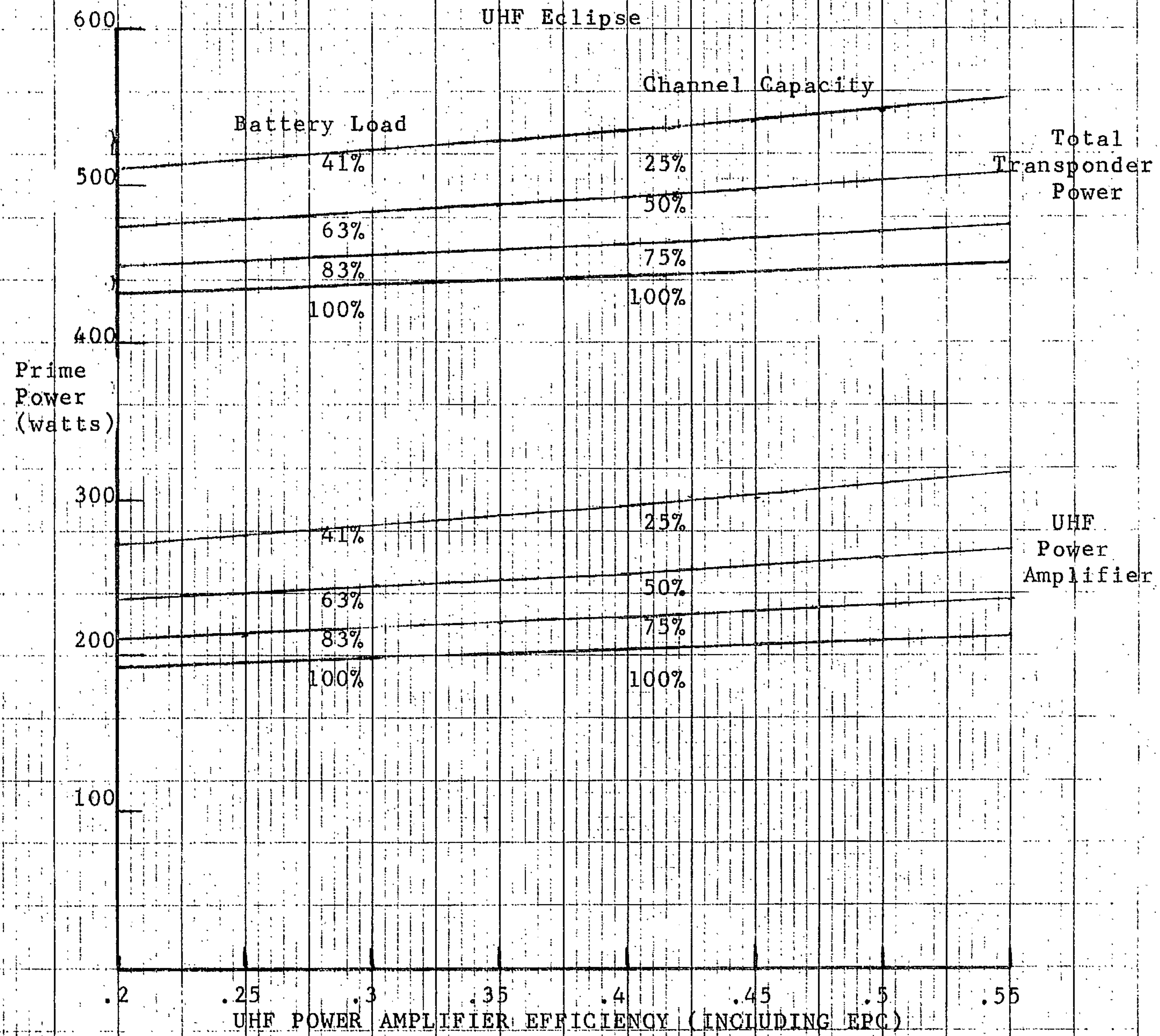


Figure I-17 Prime power requirements for the UHF power amplifier and the total communications payload. 100% 4/6 GHz eclipse

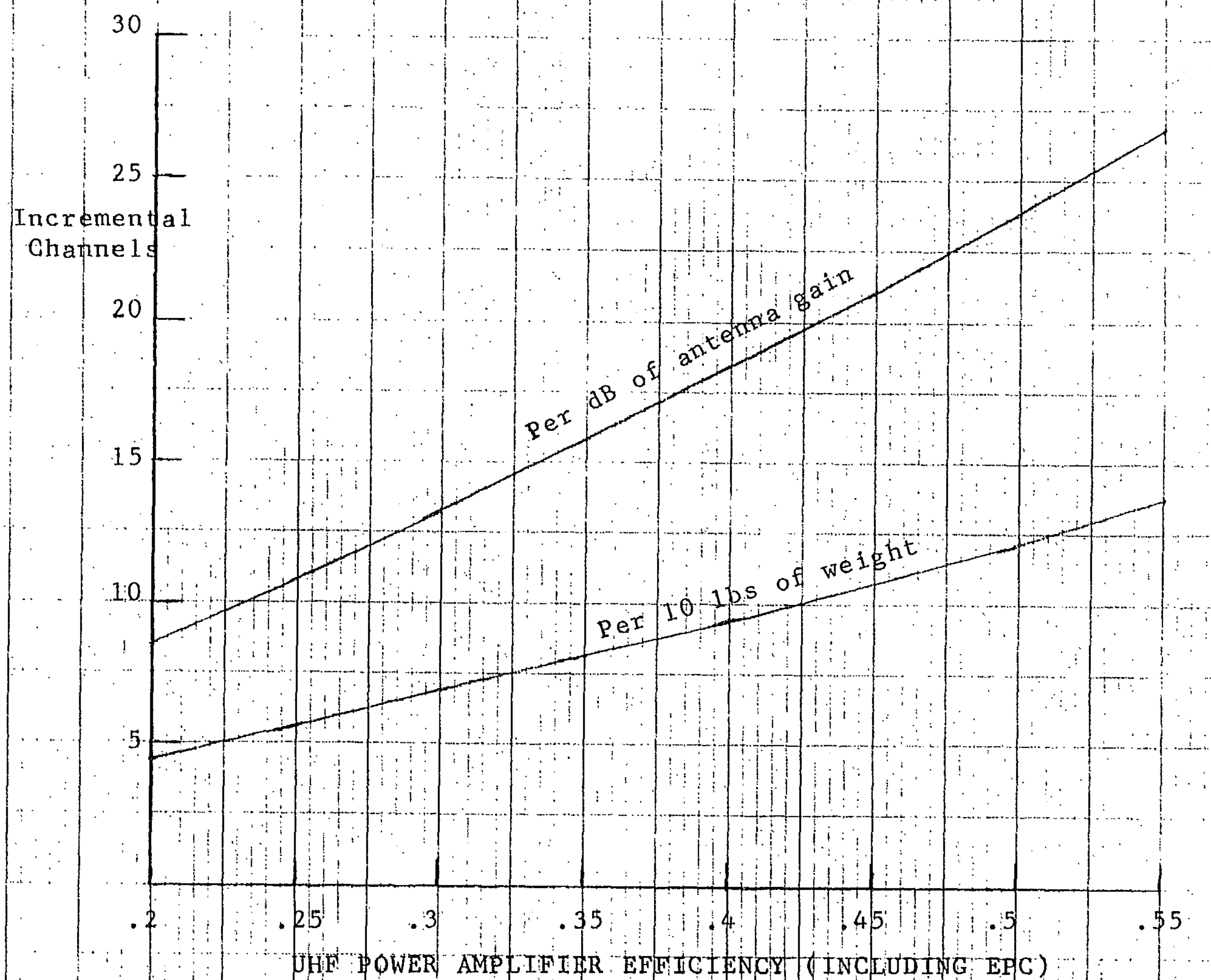


Figure I-18 Increase in number of UHF channels for 1 dB increase in antenna or 10 lbs decrease in the payload weight estimate. (50% UHF eclipse and 100% 4/6 GHz eclipse)

PART II

UHF PLUS 12/14 GHz

PAYLOAD CONFIGURATION

II-1.0 REQUIREMENTS

The requirements for the 12/14 GHz transponder have been supplied by the contracting agency in the form of guidelines and are reproduced in Appendix B. These are in addition to all the UHF requirements and the general requirements on redundancy, batteries, launch vehicle, etc., outlined in Section I-1.0.

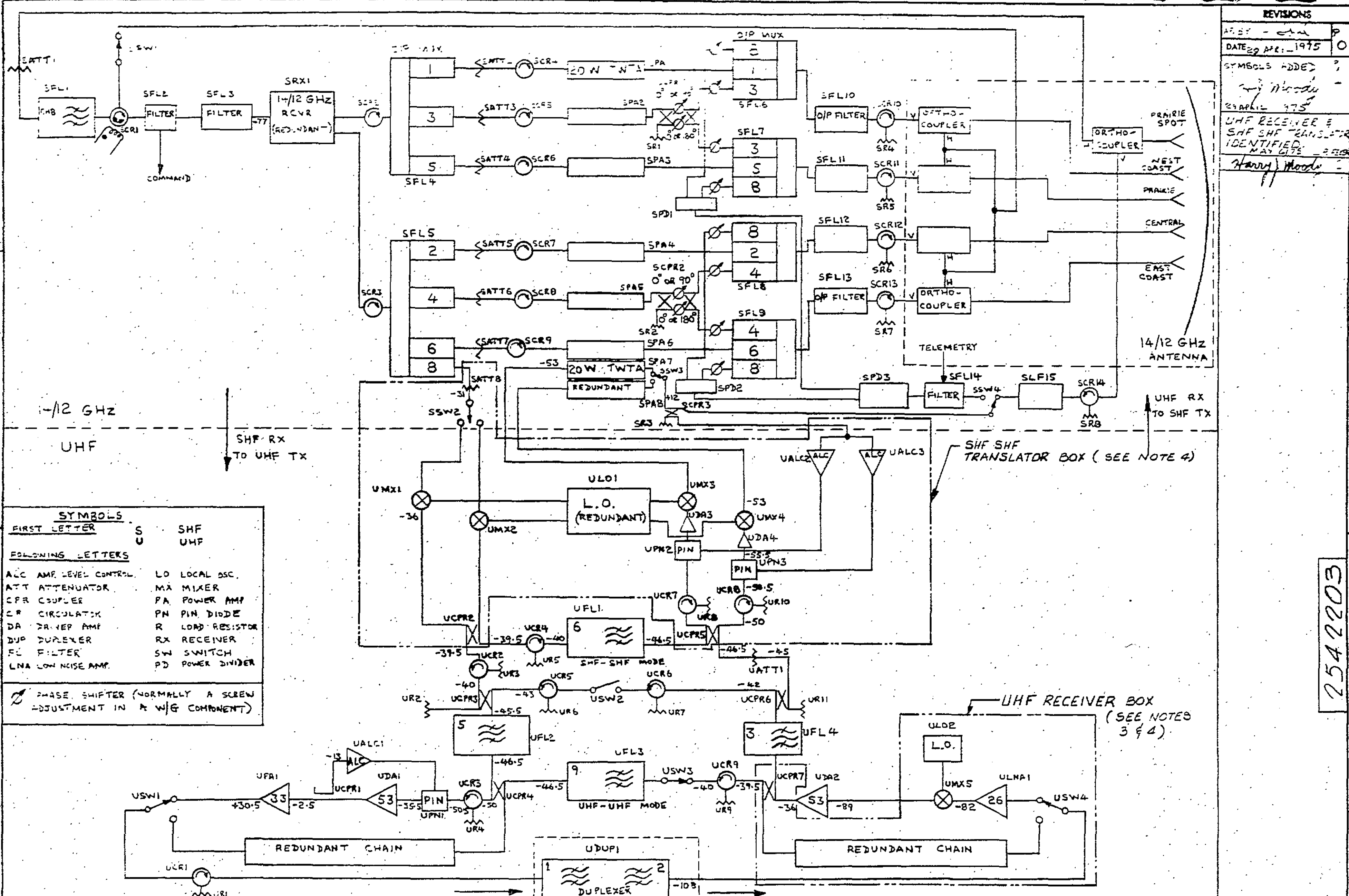
II-2.0 TRANSPONDER DESCRIPTION

II-2.1 Configuration A

This configuration, shown in Figure II-1, has 7 TWTA's operating at 20 watts of RF power. Four of these TWTA's are used to provide multi-channel per carrier (MCPC) service to each of four 2° x 2° spot beams across the width of Canada. Two channels are used to provide single channel per carrier (SCPC) service with the power from each channel split between one pair of the four beams. The remaining TWTA along with its redundant unit are used for the UHF backhaul channel.

The two channels used for SCPC service also serve as back-up for the MCPC service. For example, if the TWTA in Channel 1 failed, then the TWTA in Channel 3 would be switched so that all its power was radiated in the west coast spot beam. Similarly if Channel 5 TWTA failed the Channel 3 TWTA would be fully switched to the prairie spot beams. This switching action is accomplished by means of two 90° hybrids and two latching ferrite phase shifters, one located in each arm between the two hybrids. One phase shifter has stable phase shift positions of 0 and 90°, while the other has 0 and 180°. The configuration obeys the following switching table for power division between outputs A & B.

Phase Shifter 2	Phase Shifter 1: 0°	Phase Shifter 1: 90°
0°	A = 0 B = 1	$A = \frac{1}{2}$ $B = \frac{1}{2}$
180°	A = 1 B = 0	$A = \frac{1}{2}$ $B = \frac{1}{2}$



NOTES

(1) LEVELS SHOWN IN dBm REF SINGLE VOICE CHANNEL
(2) [A ▷] AMPLIFIER WITH A dB GAIN
(3) UDA2 & UDA2 REDUNDANT ARE NOT INCLUDED IN UHF RECEIVER BOX
(4) SEE DWG 2563192 FOR LAYOUT

Figure II-1

BLOCK DIAGRAM UHF–14/12 GHz MULTIPURPOSE SATELLITE

WORKMANSHIP TO BE IN ACCORDANCE WITH RCA LIMITED WORKMANSHIP STANDARDS	VARIATIONS ON FINISHED DIMENSIONS UNLESS OTHERWISE MARKED		
	BASIC DIMENSIONS	2 PLACE DECIMALS	3 PLACE DECIMALS
	UP TO 6	± .02	± .005
	ABOVE 6 TO 24	± .03	± .010
	ABOVE 24	± .06	± .015

FIRST MADE FOR 3500–T/4 USED ON

DRAWN BY J.P. FEKEN MAY 6/75 CHECKED BY

DESIGNED BY COMMODITY CODE

RCA LIMITED C 2542203

II-2.1 Configuration A - Continued

To provide a Canada wide receive beam, the four spot beam horns are fed with orthocouplers and the horizontally polarized received signals are combined in phase to provide a composite $2^{\circ} \times 8^{\circ}$ beam. A spot beam for both transmit and receive of the UHF backhaul on Channel 8 is provided by a fifth horn positioned between the west coast and prairie horn. To provide a Canada wide transmit beam for the UHF backhaul channel, the power from the TWTA is split four ways and combined with the other signals in each of the four output multiplexers. Channel 7 is unused in this configuration to provide a separation between Channels 6 and 8 which are multiplexed together in one of the output multiplexers. Adjustable phase shifters are provided in some of the feed lines. These phase shifters are adjusted before launch to optimize the composite antenna patterns for the combined beams.

The G/T specification for a $2^{\circ} \times 8^{\circ}$ beam is -8 dB. This is equivalent to a noise temperature of 36 dB or 4000°K. To meet this noise temperature, it may not be necessary to have gain at the 14 GHz uplink frequency. An image recovery mixer similar to that built for CTS having a noise figure of 5 dB and a conversion loss of 5 dB followed by a FET amplifier with a noise figure of 5.5 dB* should meet the G/T specification. Being able to operate without an amplifying stage at 14 GHz has some advantages. Not only is weight and power saved, but existing hardware would favour a TDA as the front end amplifier. However, in this application the TDA would limit the dynamic range needed in the event of interference at the 14 GHz uplink frequency.

If a 14 GHz RF stage is required to meet the G/T specification, then it would be advantageous to develop a single stage FET amplifier. With such an amplifier, the G/T figure would easily be met and the dynamic range is great enough to handle any expected level of interference. The weight and power budgets have been developed to include this single stage FET or TDA amplifier at 14 GHz.

* Presently being measured at 11.8 GHz on FET amplifiers that have not been optimized for noise figure.

II-2.2 Configuration B

Two block diagrams have been developed for Configuration B, shown in Figure II-2 and II-3. Neither of these are entirely satisfactory. A major concern in Configuration B has been the double multiplexing both on the input and output multiplexers. That is, channels are separated and recombined using the same filters. At different frequencies, the filters are different lengths so that the shorter filters do not reach from the separating manifold to the combining manifold. Extending the filter by a short length of waveguide does not rectify the situation since, for frequencies outside the passband of the filter, the filter appears as a short which may not appear at the optimum location for some filters.

The problem has been solved for the input multiplexer by recombining the channels using a 3 dB hybrid. There is a loss of 3 dB which must be made up by additional gain. Since there is no power loss, this additional gain can be obtained with only a small weight penalty.

For the output multiplexer, two solutions have been considered. The first, shown in Figure II-2, uses hybrids for recombining for the output multiplexers as well as the input multiplexers. The power loss is avoided by providing eight feed horns to the antenna and thus radiating all the energy. The horns are fed in pairs with each pair providing a dog-bone shaped pattern in the far field. This system is satisfactory for Channels 1 to 8, but it is not certain that it provides a Canada wide beam for Channel 10. In Figure II-2, Channel 10 is shown power divided by four and multiplexed in with Channels 1, 7, 2, and 8. However, the hybrids between horns introduce a 90° phase shift so that at the output of the eight horns the phase alternates between 0° and 90°. The type of beam that this would produce in the far field is uncertain. An alternative approach is shown in Figure II-3. Four horns are provided, each fed by a three port multiplexer. The problem of separating and recombining in the output multiplexers described above is solved by dividing each filter into two halves with one half attached to the separating manifold and the other half attached to the combining manifold. If a five section output filter would normally be used, it might be replaced by two halves of three sections each. The two halves of each filter are connected by short lengths of straight waveguide of appropriate length and possibly a waveguide isolator if required. A sketch of an output multiplexer is shown in Figure II-4. This approach presents some possible design and schedule risks.

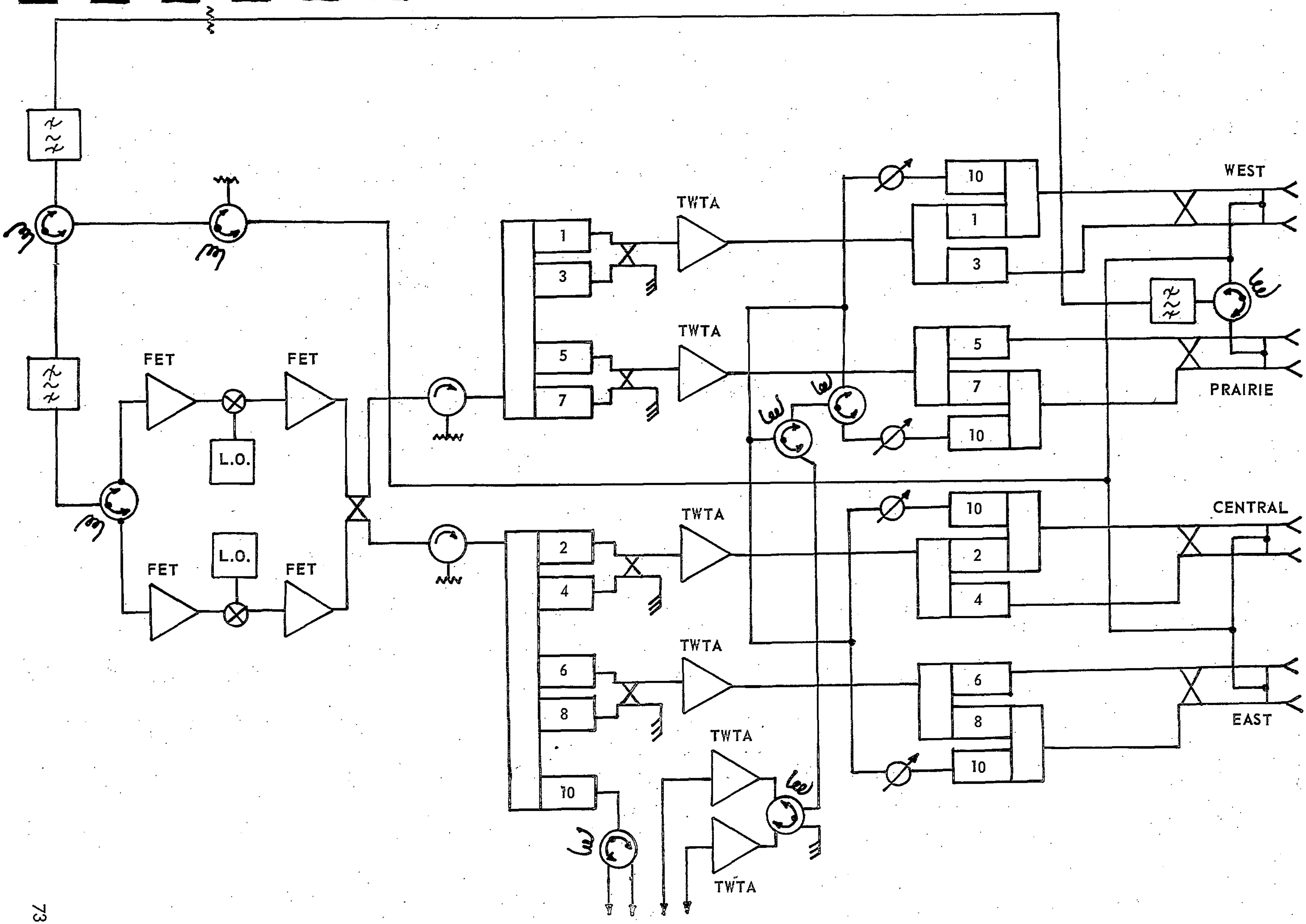


Figure II–2 A possible block diagram for Configuration B, 12/14 GHz/UHF Transponder

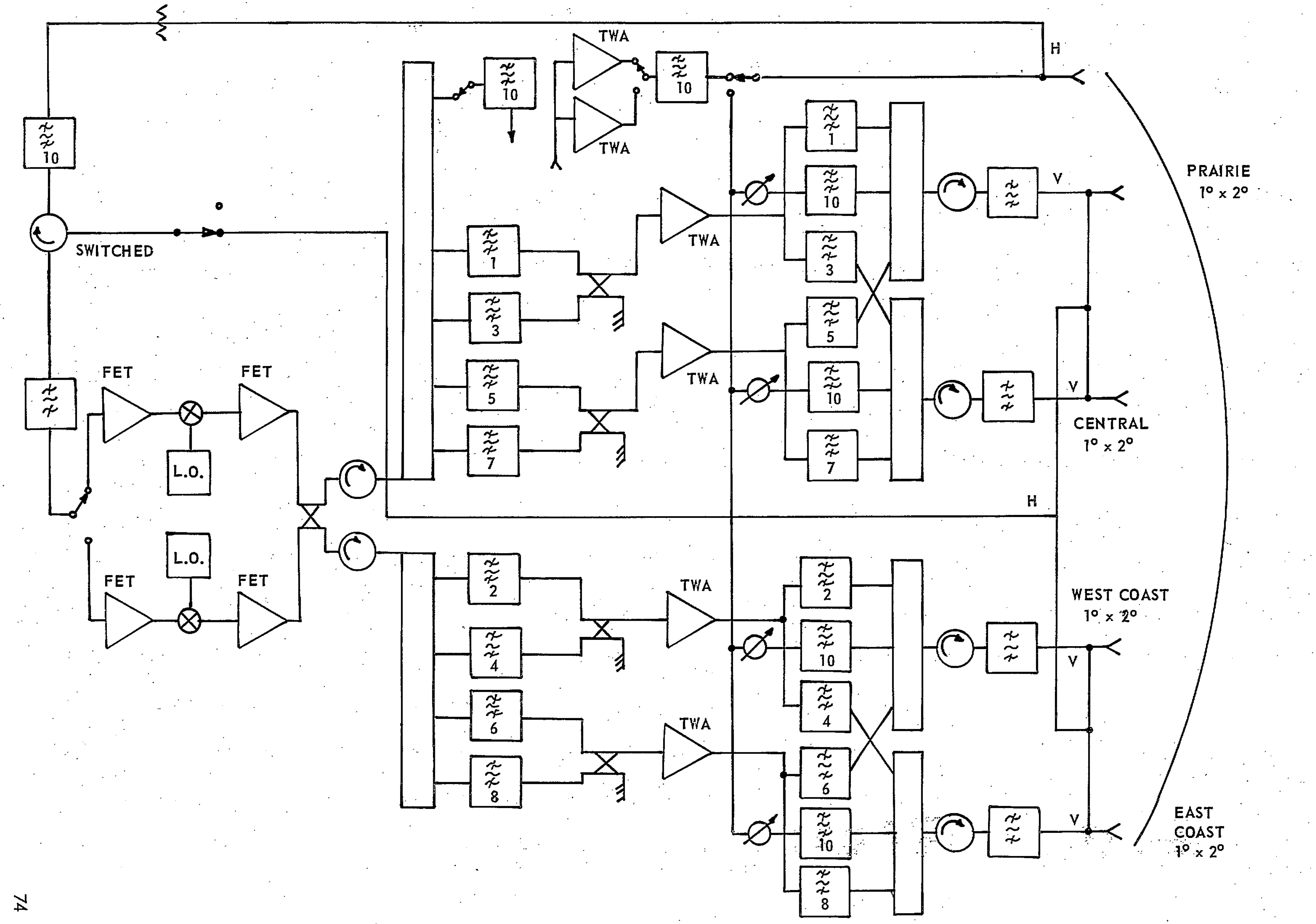


Figure II–3 Configuration B, 12/14 GHz/UHF Transponder – functional block diagram

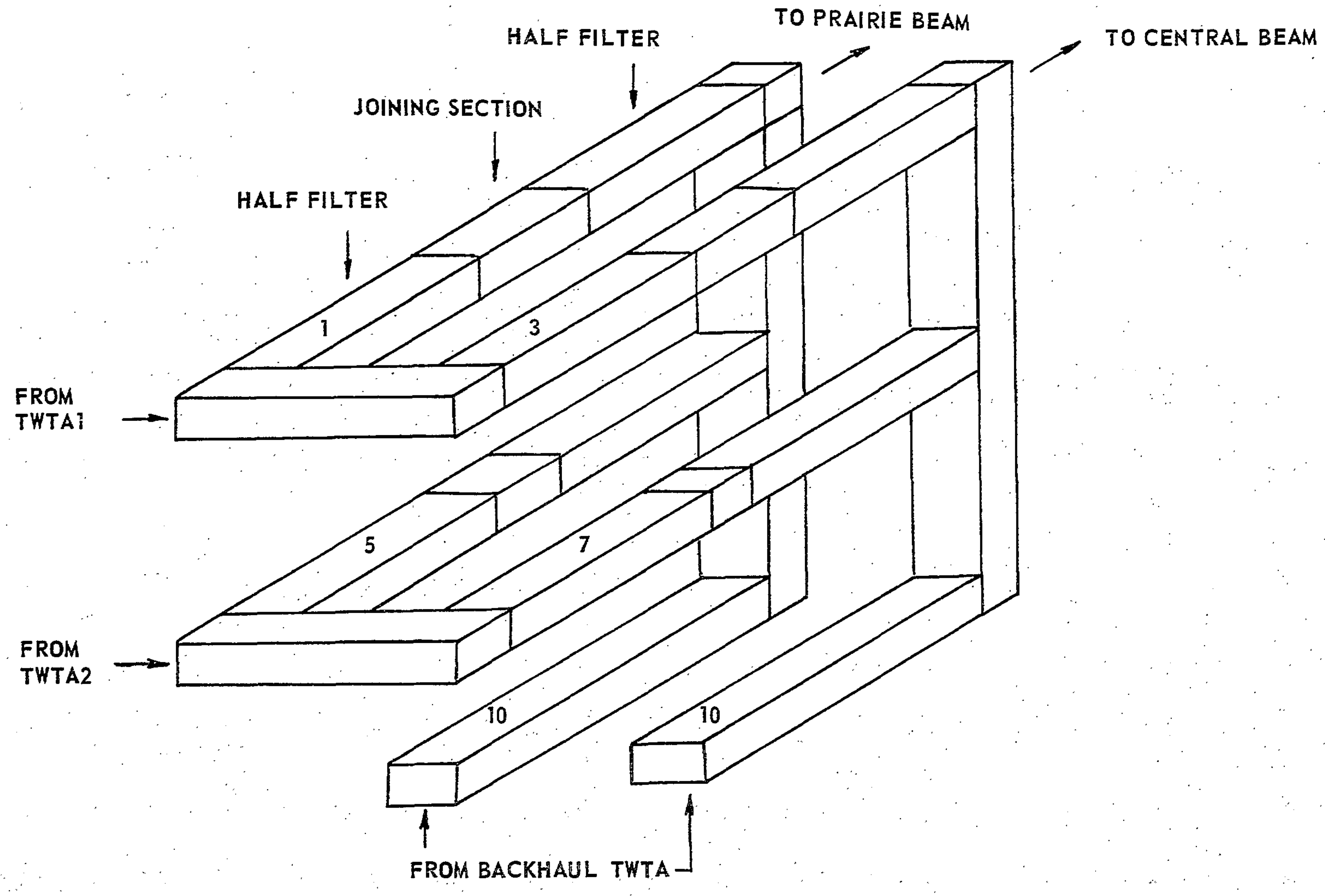


Figure II–4 A possible separating-recombining output multiplexer arrangement

II-2.2 Configuration B - Continued

The remaining parts of Configuration B are very similar to Configuration A. In the case of Figure II-3, the antenna is identical in concept to Configuration A antenna. The receiver and the spot beam receive arrangement for the backhaul spot beam is also identical to Configuration A. In the case of Figure II-2, the antenna is different, having 8 horns instead of 5, and some different arrangement is required for handling the backhaul channel for the Canada wide transmit beam.

II-3.0 FREQUENCY PLAN

One of the considerations used in establishing the frequency plan is that it should stand the test of time and be applicable to the majority of users. This is particularly true when commercial traffic is being introduced into a new frequency band. When introducing a new frequency band, a considerable amount of time and effort must be expended in designing both spacecraft and ground equipment and much of this design effort and equipment is wasted if the frequency plan is subsequently changed.

II-3.1 UHF Frequency Plan

The UHF frequency plan is identical to that presented in Part I of this report (Section I-3.0).

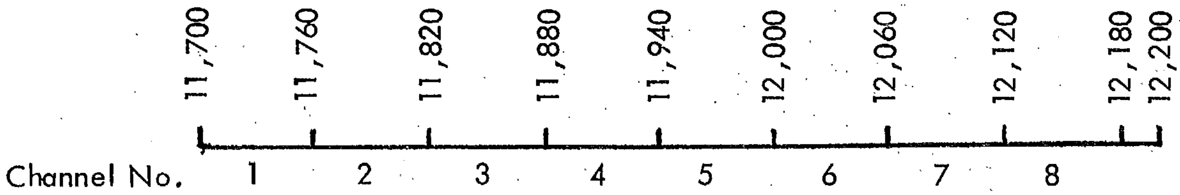
II-3.2 SHF Frequency Plan for Configuration A

The traffic model combined with the method of implementation presented in Section II-2.1 requires a total of eight transponder channels of which Number 7 is unused allowing Channels 6 and 8 to be multiplexed together. If all channels are made equal width the spacing between band centers becomes 60 MHz with a 20 MHz band remaining at the band edge for telemetry and command. Channels 7 and 8 do not need to be as wide as 60 MHz but it seems unreasonable to have a frequency plan with channels of different widths. For this reason eight channels of 60 MHz spacing as shown in Figure II-5 has been chosen for the frequency plan to be used with Configuration A.

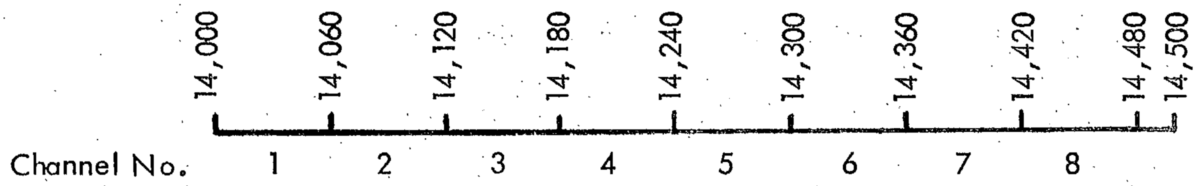
In the configuration proposed the Canada wide telemetry beam is obtained by using the backhaul power division and multiplexing arrangement. To do this it is necessary to make each of the Channel 8 filters 80 MHz wide to include the 20 MHz allocated to telemetry and command.

II-3.3 SHF Frequency Plan for Configuration B

For Configuration B, eight channels are required for communications traffic and an additional channel for the UHF backhaul which must be separated from Channel 8 by a buffer channel. Thus 10 channels in all are required. The 500 MHz available frequency band has been divided into 10 equal bands of 50 MHz each as shown in Figure II-6. The telemetry and command function can occupy the unused channel or alternately another band such as 2 GHz may be used.

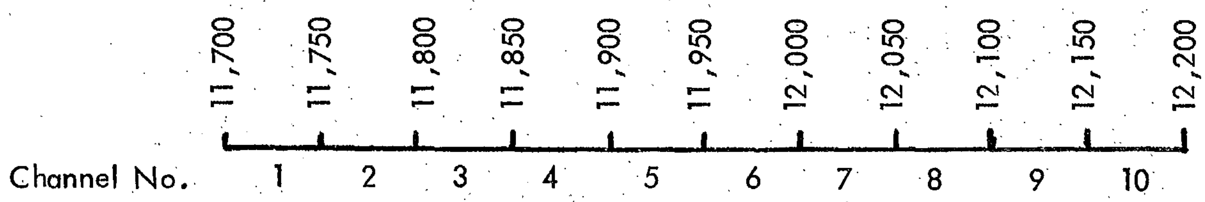


TRANSMIT BAND
(Frequencies in MHz)
Polarization Parallel to N-S Axis

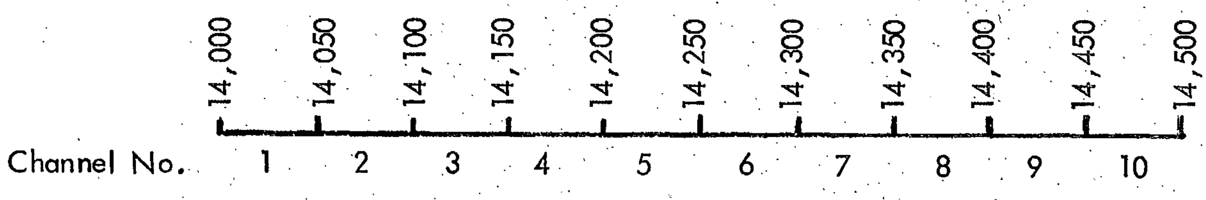


RECEIVE BAND
(Frequencies in MHz)
Polarization Orthogonal to N-S Axis

FIGURE II-5 FREQUENCY PLAN FOR CONFIGURATION A IN THE 12/14 GHz BAND



TRANSMIT BAND
(Frequencies in MHz)
Polarization Parallel to N-S Axis



RECEIVE BAND
(Frequencies in MHz)
Polarization Orthogonal to N-S Axis

FIGURE II-6 FREQUENCY PLAN FOR CONFIGURATION B IN THE 12/14 GHz BAND

II-4.0 ANTENNA SUBSYSTEM FOR THE UHF-12/14 GHz HYBRID SPACECRAFT

II-4.1 Summary of Requirements

The following requirements for the 12/14 GHz antenna combined with the UHF requirements of Section I-5.1 constitute the combined antenna requirements.

a) The downlink for the public operation will be in the 12 GHz frequency band. Two possible configurations are defined. Configuration A provides Qty. 4 spot beams with 2° wide beams centered at approximately 55°N, 120°W; 55°N, 104°W; 50°N, 85°W; 50°N, 66°W respectively. Each beam carries 2 transponders at a single input terminal. Configuration B provides Qty. 4 spot beams with 2° E-W and 1° N-S (dog-bone) shaped beams. In this case, each spot beam is associated with 2 isolated input terminals for the 8 transponder channels. Polarization will be linear. Since the relative frequency separation between up and downlink is small in this case, orientation of polarization is a relatively free parameter. The N-S polarization for the downlink, however, yields slightly better contour EIRP.

b) The uplink for the public communication in the SHF band will be centered around 14 GHz and requires a Canada wide beam. Coverage is either 2° x 8° or 1° x 8° for Configurations A and B respectively. Polarization is opposite to the downlink operation. The antenna must have 1 terminal for this operation.

c) A transmit spot beam for the SHF version of the hybrid satellite must be centered at 55°N, 110°W, have a beamwidth of 1° and as low as possible sidelobe level toward oceanic areas. The spot beam polarization can be identical or the same as for the public operation.

d) A receive spot beam corresponding to the transmit spot beam described under c) must also be available. The receive spot beam must have comparable characteristics to the transmit spot beam except that its polarization must be orthogonal to the transmit polarization.

II-4.2 12 GHz Band Public Operation

Configuration A

The requirement for this configuration is to provide four 2° wide spot beams for transmit operation.

The proposed solution requires a 35 in. diameter reflector fed by 4 horns (see Figures II-7 and II-8). Because the feeds and their connecting waveguides represent considerable blockage, this antenna is offset fed. The main electrical characteristics of the antenna for the 12 GHz operation is shown in Table II-1. It can be seen that a contour gain of approximately 35 dB is achievable with this system.

Configuration B

The requirement for this configuration is to provide four 1° NS by 2° EW beams for transmit operation.

This pattern coverage can be achieved by a total of eight horns illuminating a 70 in. diameter reflector as shown in Figures II-9 and II-10. The horns are approximately square and they are nearly in line. Each horn is fed by an orthocoupler. The eight transmit ports of the orthocouplers are brought down below the deck by eight WR75 waveguides and connected in pairs to four short slot hybrids. Thus, each of the eight short slot hybrid terminals corresponds to an independent 1° x 2° "dog-bone" pattern and they completely overlap each other in pairs.

Table II-2 shows the main electrical characteristics of the antenna for the 12 GHz operation. It can be seen that the improvement relative to the edge gain values in Table II-1 are a little less than 3 dB due to the larger effect of blockage, antenna surface inaccuracy and beam scan loss (in Configuration B, the outer beams are scanned by 1.5 Θ_3 from the center).

II-4.3 14 GHz Band Public Operation

For this (receive) operation, a Canada wide beam has to be provided resulting in a relatively low edge gain.

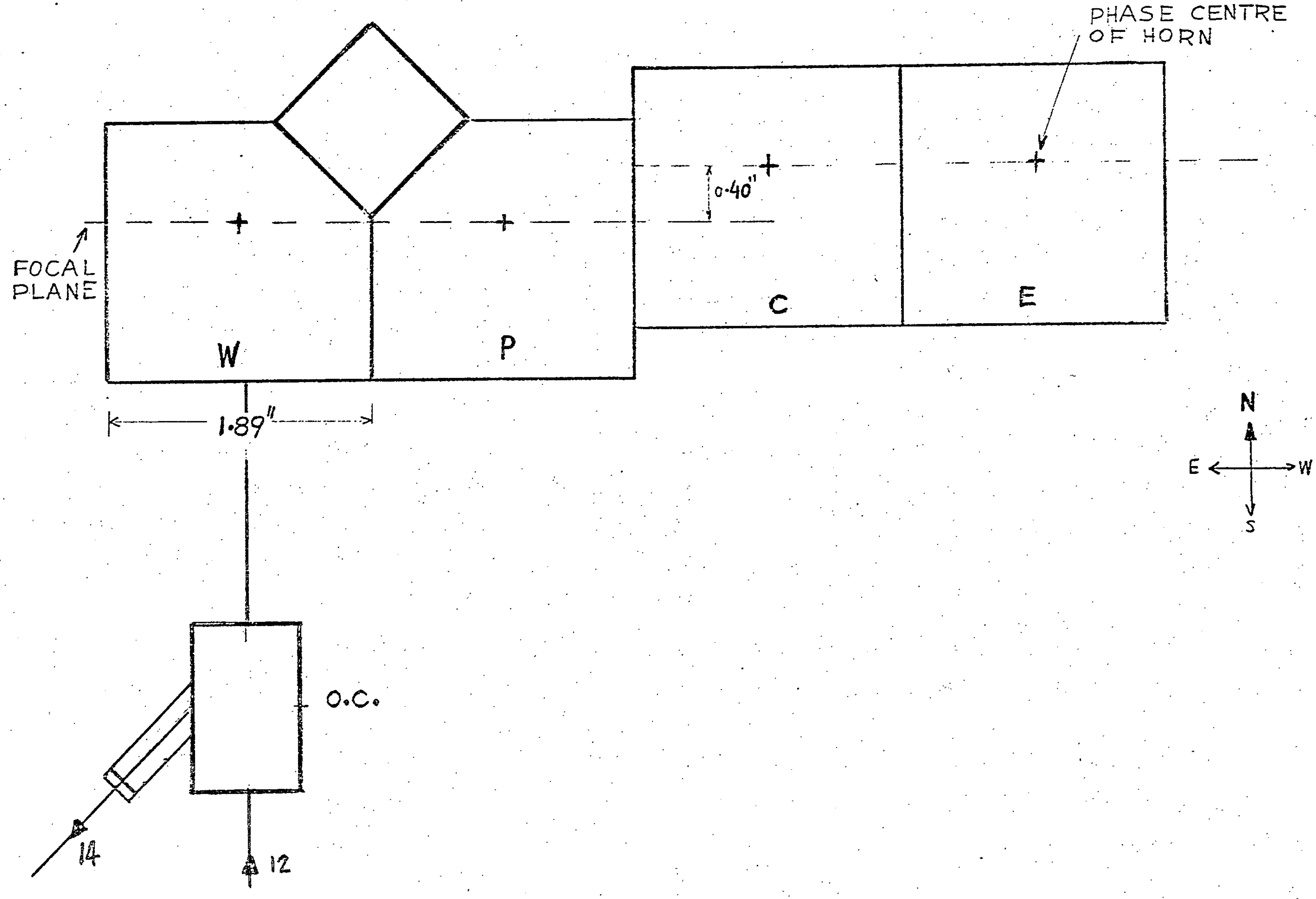


Fig. II-7 Feed horn layout for Configuration A.

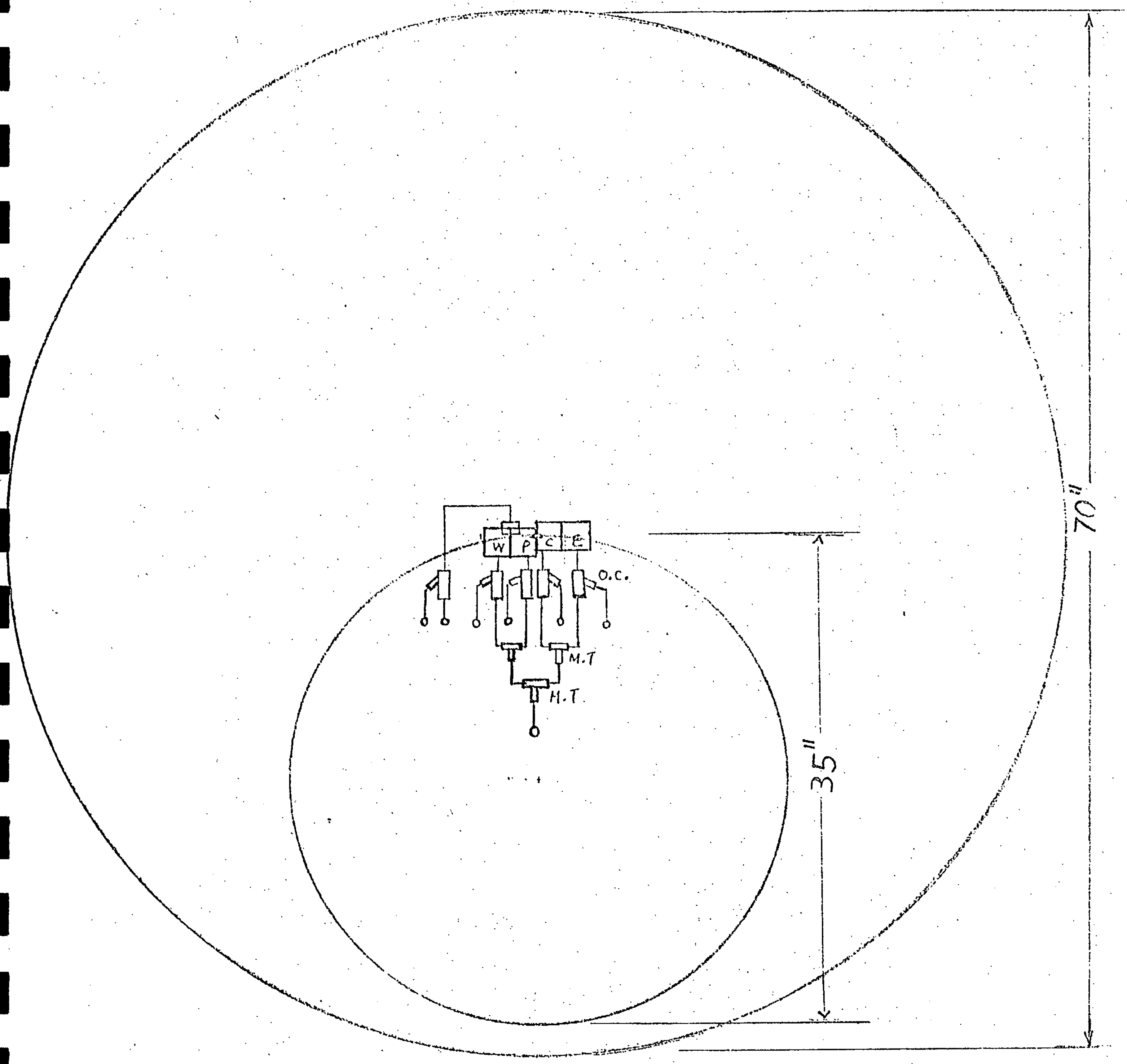


Fig. II-8 Antenna layout for Configuration A.

TABLE II-1

EFFICIENCY AND GAIN CHARACTERISTICS OF COMMUNICATION ANTENNA FOR THE PUBLIC OPERATION OF CONFIGURATION A

Frequency GHz	12	14
Reflector (in.) Diameter (λ)	35 35.56	35 41.49
Horn dimension	2.20" × 2.16" Off set fed or 90° rotated	2.20" × 2.16" Off set fed or 90° rotated
Pattern shape	Circular	Double dog-bone
Component beamwidth (deg.)	2.0	1.80
η_A (dB)	.51	0.83
η_S (dB)	1.00	0.66
η_X (dB)	.15	.18
η_p (dB)	.15	.18
η_r (dB)	.10	.10
η_Δ (dB) (for Δ = .02 in., rms)	.28	.40
η_L (dB)	.25	.35
η_{scan} (dB)	.10	.15
η_{block} (dB)	.10	.10
η (dB)	2.64	2.95
G_O (dB)	40.96	42.30
G_M (dB)	38.32	33.35
G_e (dB)	35.32 (-3 dB)	29.25 (-4.1 dB)

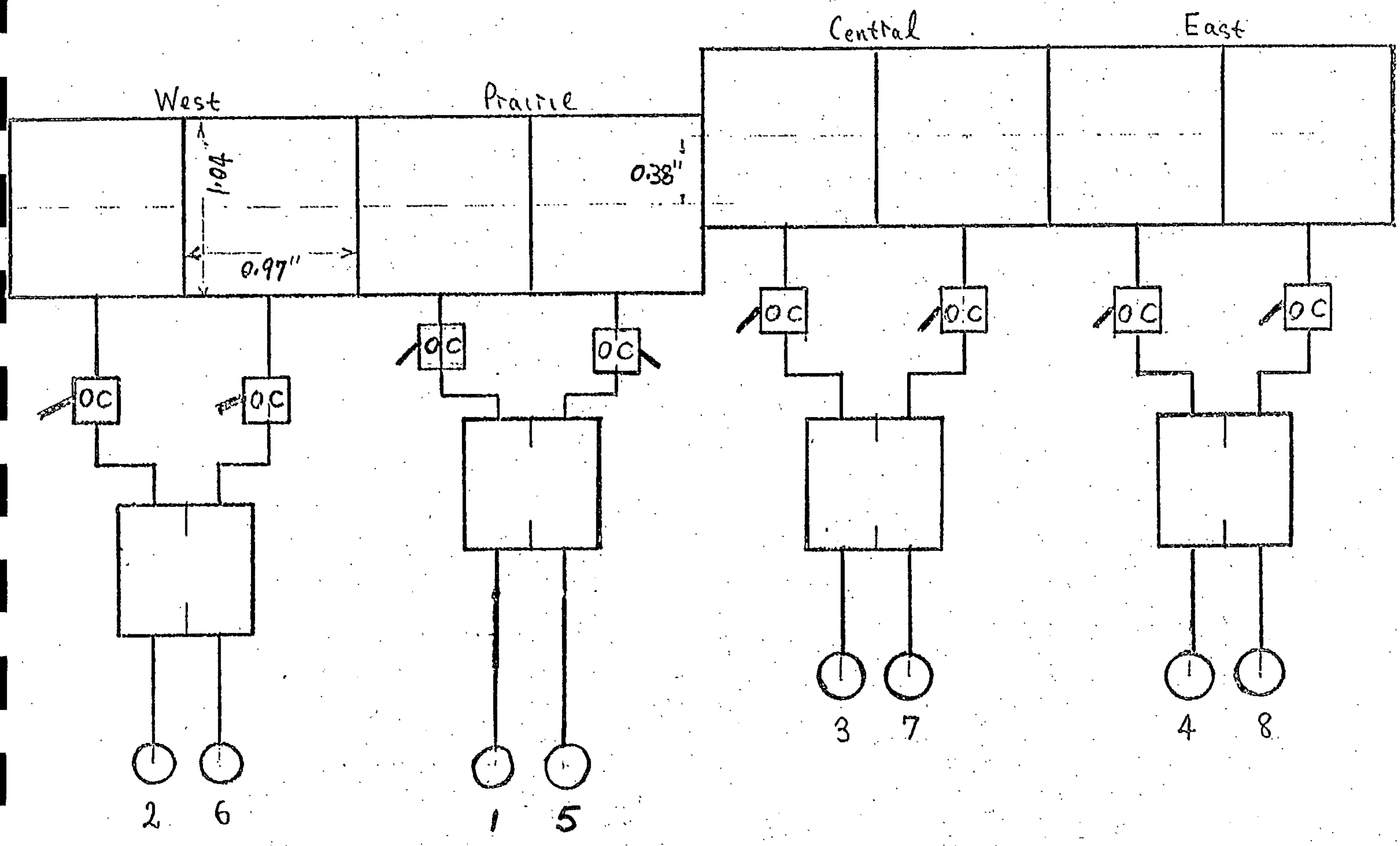


Fig. II-9 Circuit layout for Configuration B.

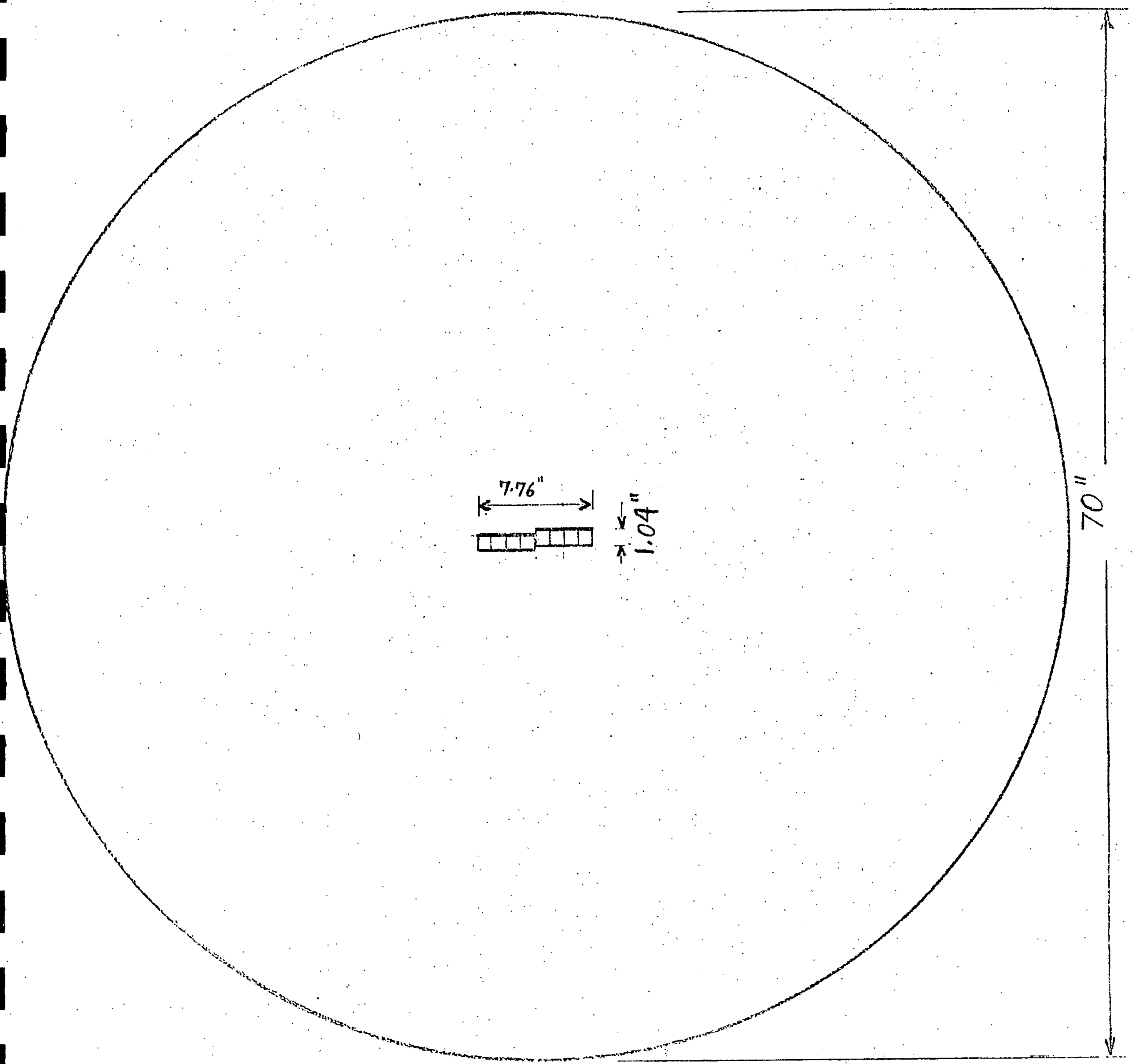


Fig. II-10 Antenna layout for Configuration B.

TABLE II-2

EFFICIENCY AND GAIN CHARACTERISTICS OF COMMUNICATION ANTENNA FOR THE PUBLIC OPERATION OF CONFIGURATION B

Frequency (GHz)	12 2.5 cm = .9842 in.	14 2.143 = .8436 in.
Reflector diameter (in.) (λ)	70 71.123	70 82.98
Horn dimensions	1.02" × 1.09" (↑ arrow in box); Center fed or 90° rotated	1.02" × 1.09" (→ arrow in box); Center fed or 90° rotated
Pattern shape	Dog-bone	Quadruple dog-bone
Component beamwidth (deg.)	1 x 1	1 x 0.9
η_A (dB)	.51	.85
η_S (dB)	.95	.70
η_X (dB)	.15	.18
η_P (dB)	.15	.18
η_r (dB)	.10	.10
η_Δ (dB) (for Δ = .022 in., rms)	.34	.49
η_L (dB)	.35	.35
η_{scan} (dB)	.20	.20
η_{block} (dB)	.18	.18
η (dB)	2.93	3.23
G_O (dB)	46.96	48.30
G_M (dB)	41.03	36.07
G_e (dB)	38.03 (- 3 dB)	32.00 (-4.1 dB)

II-4.3 14 GHz Band Public Operation - Continued

Configuration A

The feed circuit for this mode of operation consists of 4 horns which are combined in phase by three magic Tee types of hybrids (Figure II-8). The polarization is orthogonal to the 12 GHz band.

Since the component beams from the individual horns are about 10% narrower than at 12 GHz, the problem of crossover levels between component beams again occurs as in the 4/6 GHz band systems. However, since in the SHF band, the relative frequency ratio between band centers is much smaller, adequate coverage gain uniformity can be achieved without the use of the wire grating technology.

The performance characteristics for this case are shown in Table II-1.

Configuration B

The feed circuit in this mode of operation consists of 8 horns which are combined by an 8-way power divider network as shown in Figure II-11. The performance of this configuration is given in Table II-2.

II-4.4 12/14 GHz Band Spot Beam Operation

The basic requirement for this mode is to provide a high gain - low sidelobe level transmit-receive spot beam toward the Calgary region.

This can be achieved by a separate horn for Configuration A while an already existing horn can be used for Configuration B. This results in a 5-horn or 8-horn system for the complete antenna system.

Configuration A

The location and relative size of the spot beam horn is shown in Figure II-7. This horn illuminates the complete 70 in. diameter reflector, thus, its dimensions will be the same as shown in Table II-2. This horn has a diagonal transformer at its input in order to fit the horn better into the cluster of the already present four horns. Furthermore, it has its own orthocoupler to separate the transmit and receive frequency bands. The peak gain of the beam associated with this horn will be 44.03 dB at 12 GHz and 45.07 dB at 14 GHz. However, its boresight will be .5° shifted to the south relative to the center of the 2° wide communication beams. That means that in the Calgary region, the edge gain will be only ~ 41 dB and ~ 41.5 dB in the 12 GHz and 14 GHz bands respectively.

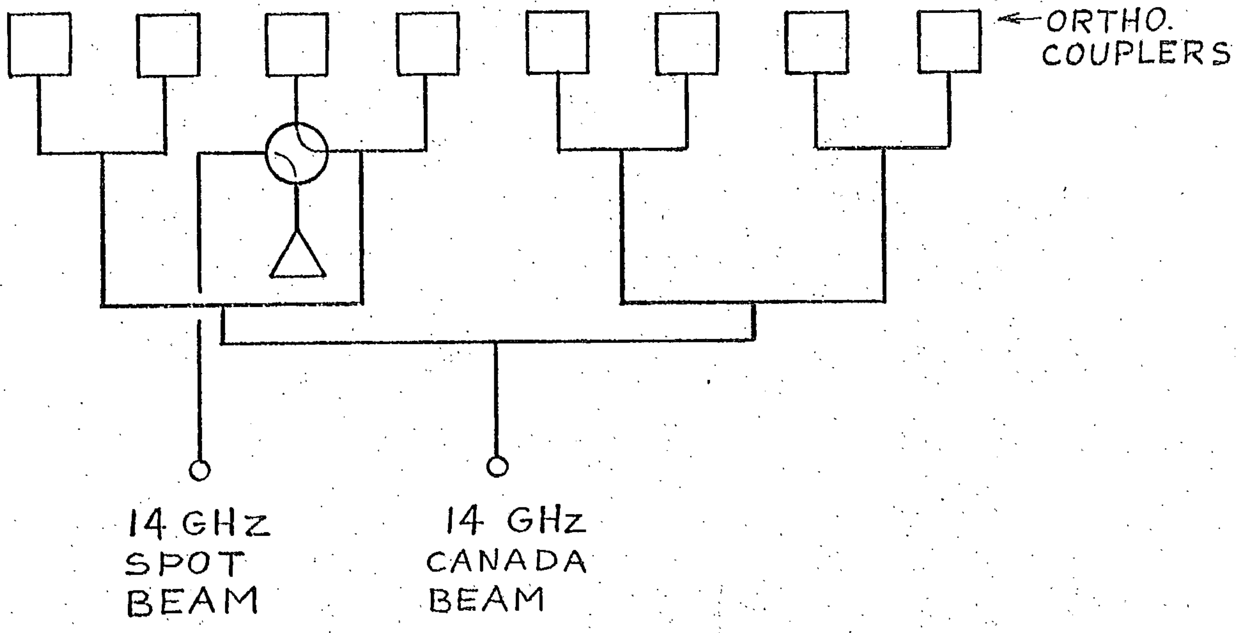


Fig. II-11 Circuit layout for 14 GHz, Canada and spot beam operation.

II-4.4 12/14 GHz Band Spot Beam Operation - Continued

Configuration B

According to Figure II-11, no new horn is required for this case, but a switch has to be inserted at the output of the prairie beam for receive operation.

II-4.5 UHF Band Antenna

As a first approximation, the UHF band antenna configuration is the same, whether 4/6 GHz or 12/14 GHz is selected for the public and spot beam communications. A minor change occurs when the "communication" dish is only 70 in. in diameter for the 12/14 GHz operation instead of the 84 in. diameter for the 4/6 GHz operation. This causes a second order reduction in the weight of the overall reflector system.

The main characteristics of the UHF antenna system remain the same as has been discussed in Section I-5.0.

II-4.6 Overall Configuration and Weight

Table II-3 summarizes the weight estimate of the antenna for Configuration A and B. It can be seen that within the accuracy of the present estimate Configuration A is about 9 lbs. lighter. The weight of the UHF subsystem in each case is 21 lbs. With 10% contingency, the resulting antenna weight is ~ 67 lbs. and ~ 76 lbs. for Configuration A and B respectively.

TABLE II-3

PRELIMINARY WEIGHT BUDGET FOR THE UHF AND 12/14 GHz ANTENNA SYSTEM

CONFIGURATION A

Component	No. of Unit	Unit Weight (lb.)	Total Weight (lb.)
Horn	4 + 1	.20 and .13	.93
Orthocoupler	5	.25	1.25
Magic Tee	3	.28	.84
Waveguide Run (5 ft. per run, .17 lb./ft.)	9	.85	7.65
Reflector (.56 lb./ft.^{2})	1	15	15.00
Support Tower	1	10	10.00
Thermal Hardware	1	3	3
Total SHF Antenna			38.67
TTC Antenna	1	1.5	1.50
UHF Antenna	1		21.00
Contingency			6.00
TOTAL			67.17

Table II-3 - Continued

CONFIGURATION B

Component	No. of Unit	Unit Weight (lb.)	Total Weight (lb.)
Horn	8	.13	
Hybrid	15	.10	1.50
Orthocoupler	8	.25	2.00
Phase Shifter	3	.05	.15
Filter	4	.15	.60
Waveguide Runs	16	.85	13.60
Switch	2	.25	.50
Reflector	1	15.00	15.00
Support Tower	1	10.00	10.00
Thermal Hardware	1	3.00	3.00
Total SHF Antenna			47.39
TTC Antenna			1.50
UHF Antenna			21.00
Contingency			6.00
TOTAL, switching in both bands			75.89
TOTAL, switching in 14 GHz band only			74.74

II-5.0 WEIGHT AND POWER BUDGET

The weight and power estimates for the Configuration A transponder are presented in Table II-4. As much as possible these are based on CTS technology. Also presented in Table II-4 are the UHF weight estimates. These are identical to the UHF components list presented in Table I-10 except that the 4 GHz driver amplifiers (CDA 1 and 2) have been changed to UHF amplifiers (UDA 5 and 6) and placed before the upconverters (UMX 3 and 4). This eases the design of the amplifier somewhat but makes the design of the upconverter more difficult. The final decision on the location of the amplifier will depend on a more detailed trade-off study but there will be very little impact on the weight and power budget.

The total weight for Configuration A of the communications payload including antenna is 178.1 lbs. exclusive of the redundant UHF power amplifier. The prime power requirements, also excluding the UHF power amplifier is estimated at 426 watts. The UHF power amplifier is subject to trade-off and its weight and power requirements are presented in Section II-6.0 as a function eclipse requirement and HPA efficiency.

For Configuration B the main difference is in the reduction of the number of TWTAs from 8 to 6 and a reduction in the number that are simultaneously powered from 7 to 5. This saves 11 lbs. of weight and 112 watts of power. The array weight to supply 112 watts is .135 x 112 = 15.1 lbs. giving a total weight of 26.1 lbs. equivalent to 21 channels at 35% efficiency and 50% eclipse. Referring to Figure II-13 for Configuration A and 5 out of 7 12 GHz channels operating during eclipse, the number of UHF channels at 50% eclipse and 35% efficiency is 67. For Configuration B this becomes 88 channels with 5 out of 5 12 GHz channels operating during eclipse.

TABLE II-4

CONFIGURATION A WEIGHT AND POWER BUDGET

SHF COMPONENTS

Item	Number	Weight (oz.) Per Unit	Total	Power (watts)
12 GHz TWTA (20W)	8	88	704	390 (7)
12 GHz Input MUX (3 filter)	1	8	8	
12 GHz Input MUX (4 filter)	1	10	10	
12 GHz Output MUX (3 filter)	4	10	40	
12 GHz Hybrid	5	3	15	
Switchable Phase Shifters	4	3	12	
Adjustable Phase Shifters	8	2	16	
Telemetry Filter	1	3	3	
12 GHz Isolators	7	1	7	
12 GHz FET Amplifier	2	10	20	2
Mixer & L.O.	2	10	20	2
14 GHz Switch	1	4	4	
Command Suck-Out Filter	1	3	3	
Input Filter	1	3	3	
Channel 8 Input Filter	1	4	4	
14 GHz Switch	1	6	6	
14 GHz Circulator SW	1	6	6	
Output Filter	5	3	15	
12 GHz Switch	2	4	8	
12 Ghz Coupler	1	2	2	
12 GHz Termination	1	.25	.25	
12/14 GHz Attenuators	2	.25	.05	
2 Way Power Dividers	3	.25	.75	
Coax & Plumbing	1	10	10	
Wiring Harness	1	12	12	
PT&C Unit	1	50	50	2
Brackets and Hardware	1	32	32	
RFI Enclosure & Hardware	2	14	28	
			1044.5 oz. = 65.3 lbs.	396 watts

Table II-4 - Continued

UHF COMPONENTS

Unit	Number	Weight (oz.) Per Unit	Weight (oz.) Total	Power (watts)
UDUPI-UHF Duplexer	1	36	36	
USWI, 4-UHF Switch	2	8	16	
ULNAI, 2-UHF LNA				
UMX5,6-UHF/UHF Mixer	2	30	60	11
UL02,4-UHF/UHF L.O.				
UDA2,4-UHF Driver Amplifier				
UDA1,3-UHF Driver Amplifier	2	8	16	10
UCPR2 to 7-UHF 3 dB Hybrid	6	2	12	
UFL1 to 4-UHF Filter	4	18	72	
UCR2 to 10-UHF Isolator	9	2.5	20	
USW2,3-UHF Fer Switch	2	2.5	5	
UPN1 to 4-UHF Pin Diode Att.	4	8	32	2
UALC1 to 4-UHF Pin Level Ctl.				
UCPR1,8-UHF Coupler	2	4	8	
UPA1,2-UHF Power Amplifier	2	Subject to Trade-off		
UCR1-UHF Output Isolator/Term.	1	25.6	25.6	
UATTI-UHF Attenuator	1	.25	.25	
UMX 1 to 4-UHF/SHF Mixer	4	8	32	
UL01-UHF/SHF L.O. (redundant)	1	38	38	3
UR2 to 12-UHF Termination	11	.25	2.75	
PT&C Unit	1	80	80	3
Coax Plumbing	1	48	48	
Wiring Harness	1	6	6	
Brackets and Hardware	1	24	24	
RFI Enclosure and Hardware	2	14	28	
UDA 5,6 UHF Driver Amplifier	2	4	8	1
			569.60 oz.	30
			= 35.6 lbs.	
SHF Transponder			65.3	396
Total Transponder (excluding HPA)			100.9	426
Margin (10%)			10.0	
			110.9	
Antenna			67.2	
Total (excluding HPA)			178.1 lbs.	426 watts

II-6.0 TRADE-OFF CALCULATIONS

The trade-off calculations for the 12/14 GHz transponder have been carried out using the same weight coefficients as presented in Section I-8.1 along with the weight and power budget for the 12/14 GHz transponder Configuration A presented in Table II-4.

To provide the required minimum UHF channel capacity, in number of channels, with the standard EIRP of 18 dBW, the 12/14 GHz service has been reduced during eclipse. The trade-off calculations have been carried out for the cases where the UHF backhaul channel plus 2, 3, and 4 channels of commercial traffic are carried through eclipse at 12/14 GHz. These are presented in Figures II-12, II-13, and II-14. For one specific eclipse capability namely four channels out of seven plus 50% at UHF, the sensitivity to weight and to UHF antenna gain has been calculated and is presented in Figure II-15. Also, for this specific case, namely 4 out of 7 channels operating during eclipse the weight of the HPA, as well as the weights of the battery and array to power the complete communications payload, plus the prime power of the HPA and the total prime power have been calculated and are presented in Figures II-16 and II-17, II-18, II-19.

It should be noted that the prime power requirements for the total communications payload shown in Figure II-18 exceeds 600 watts in all cases. For payload power exceeding about 600 watts it would be necessary to change the array from a two panel configuration to some other arrangement such as a three panel array. This change would require redesign of the deployment mechanism and may impact on the weight budget.

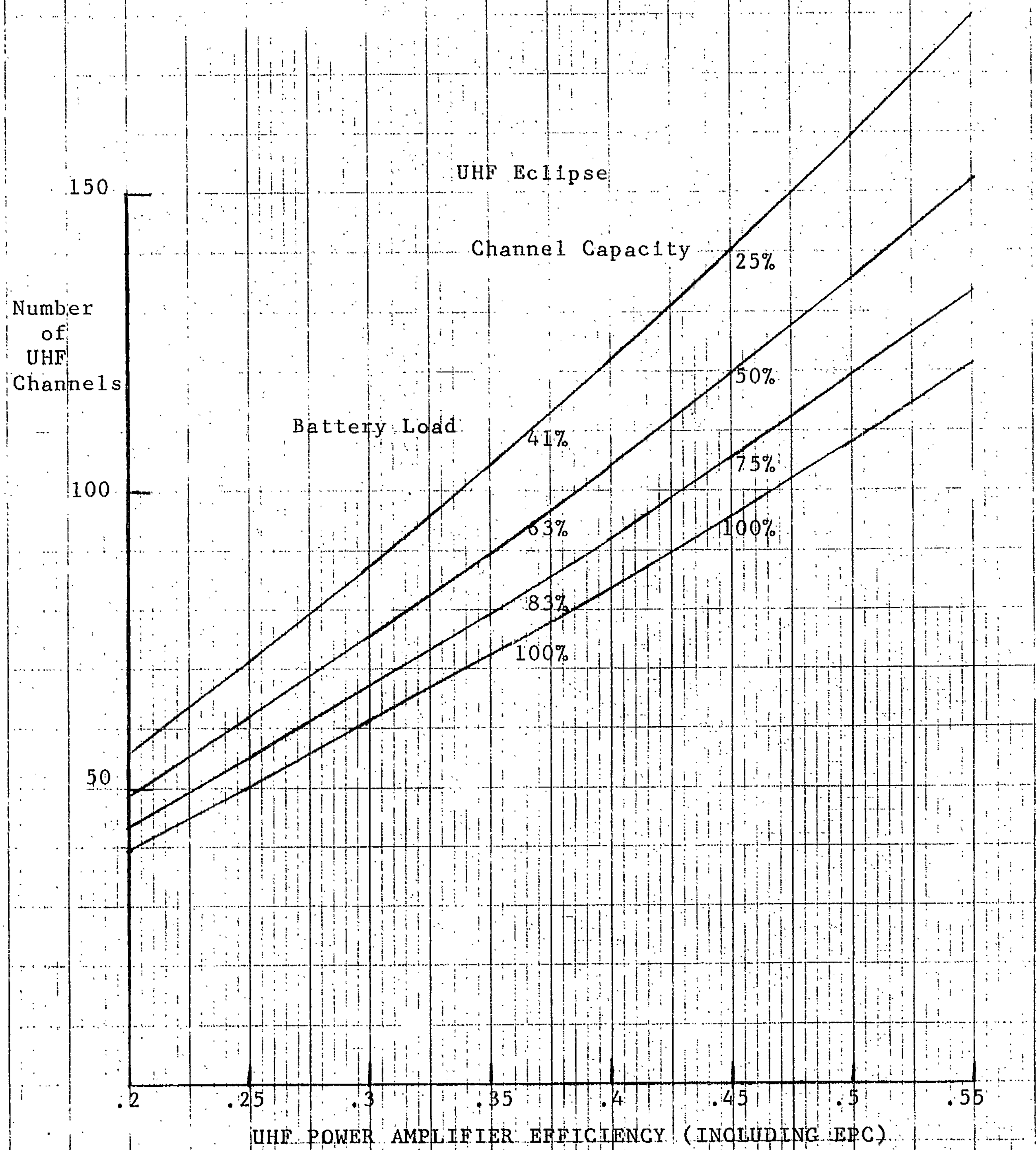


Figure II-12 Number of UHF channels for the case where 3 out of 7 12 GHz channels are operating during eclipse

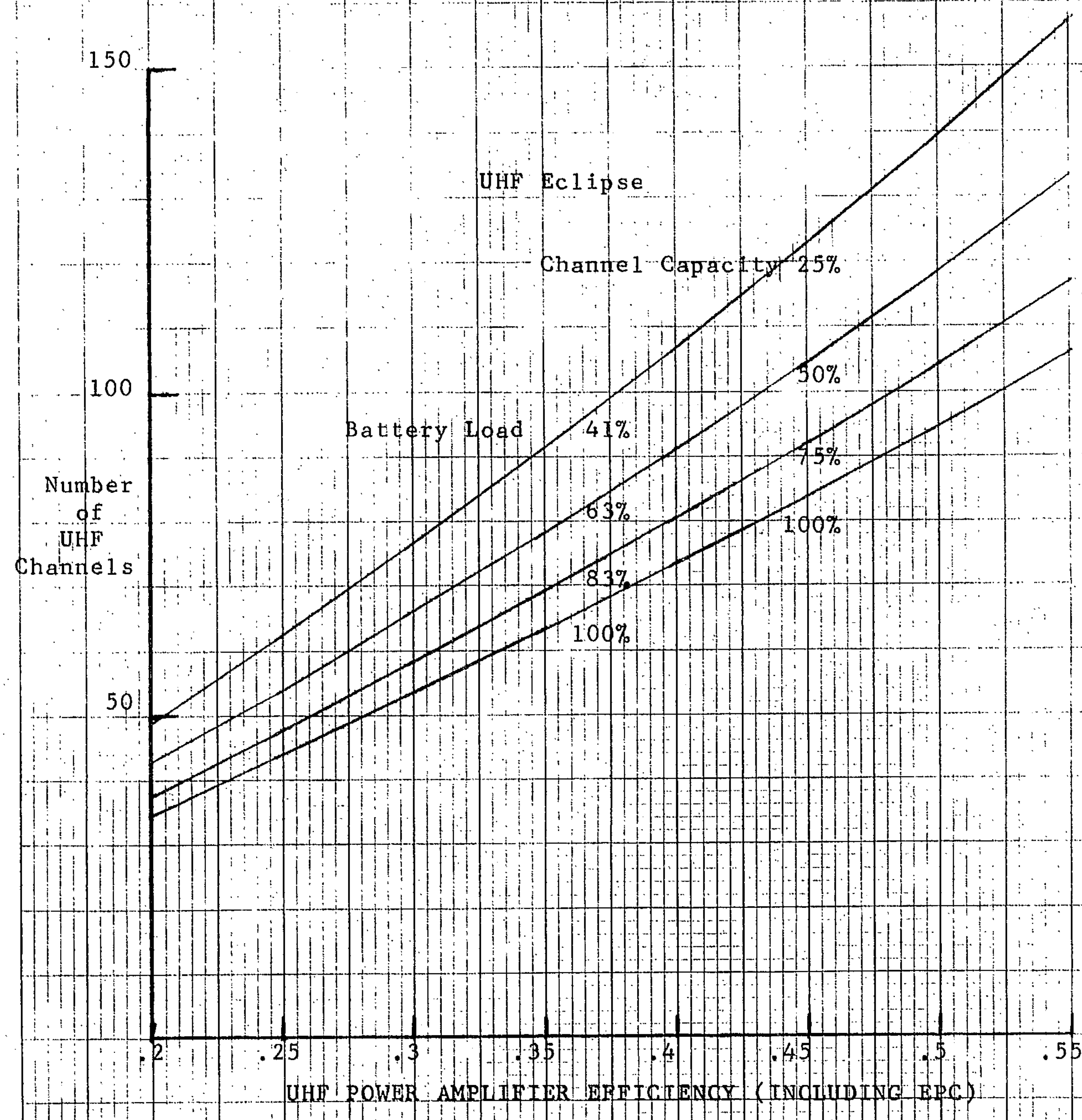


Figure II-13 Number of UHF channels for the case where 4 out of 7 12 GHz channels are operating during eclipse

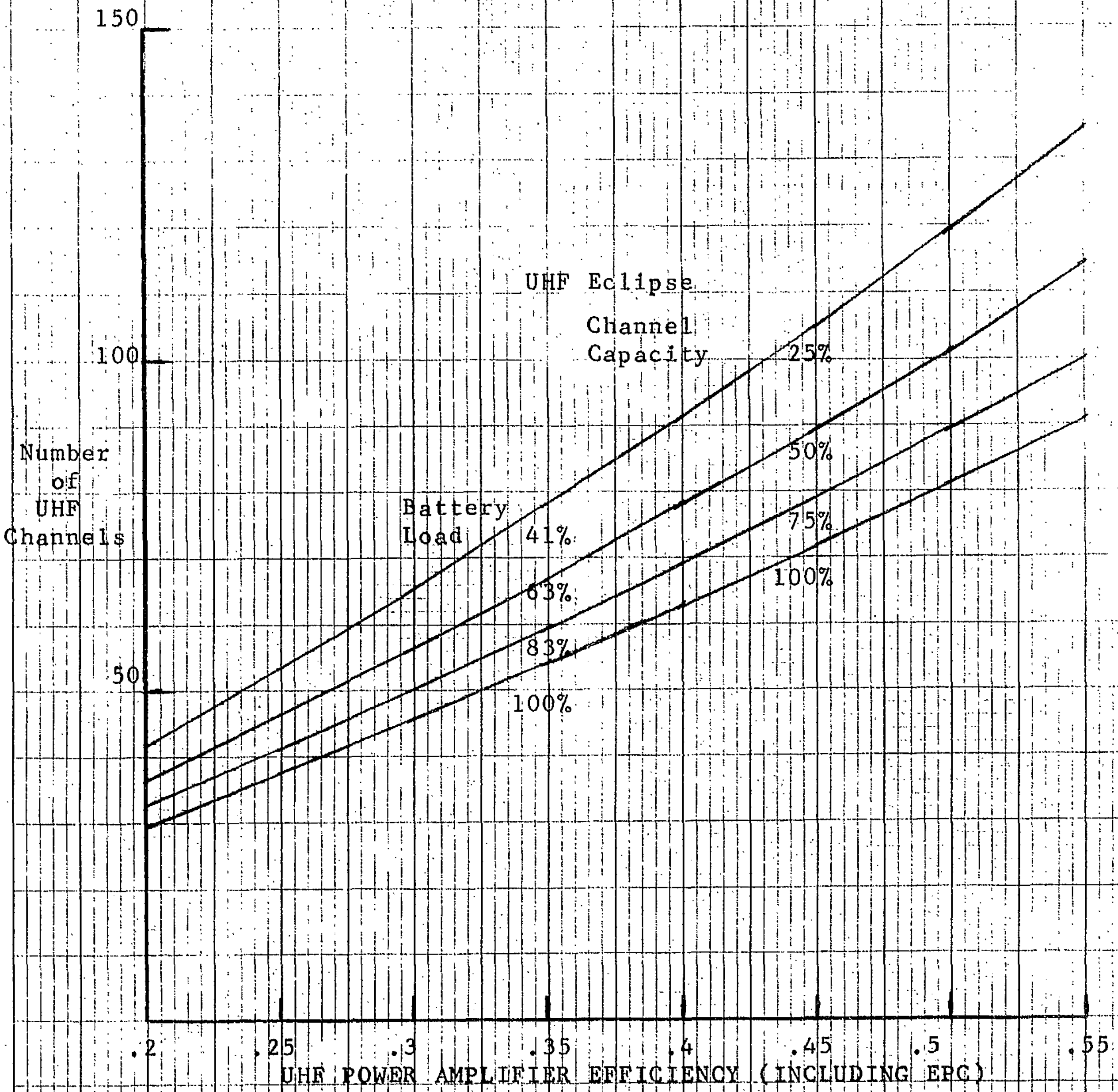


Figure II-14 Number UHF channels for the case where 5 out of 7 of the 12 GHz channels are operating during eclipse

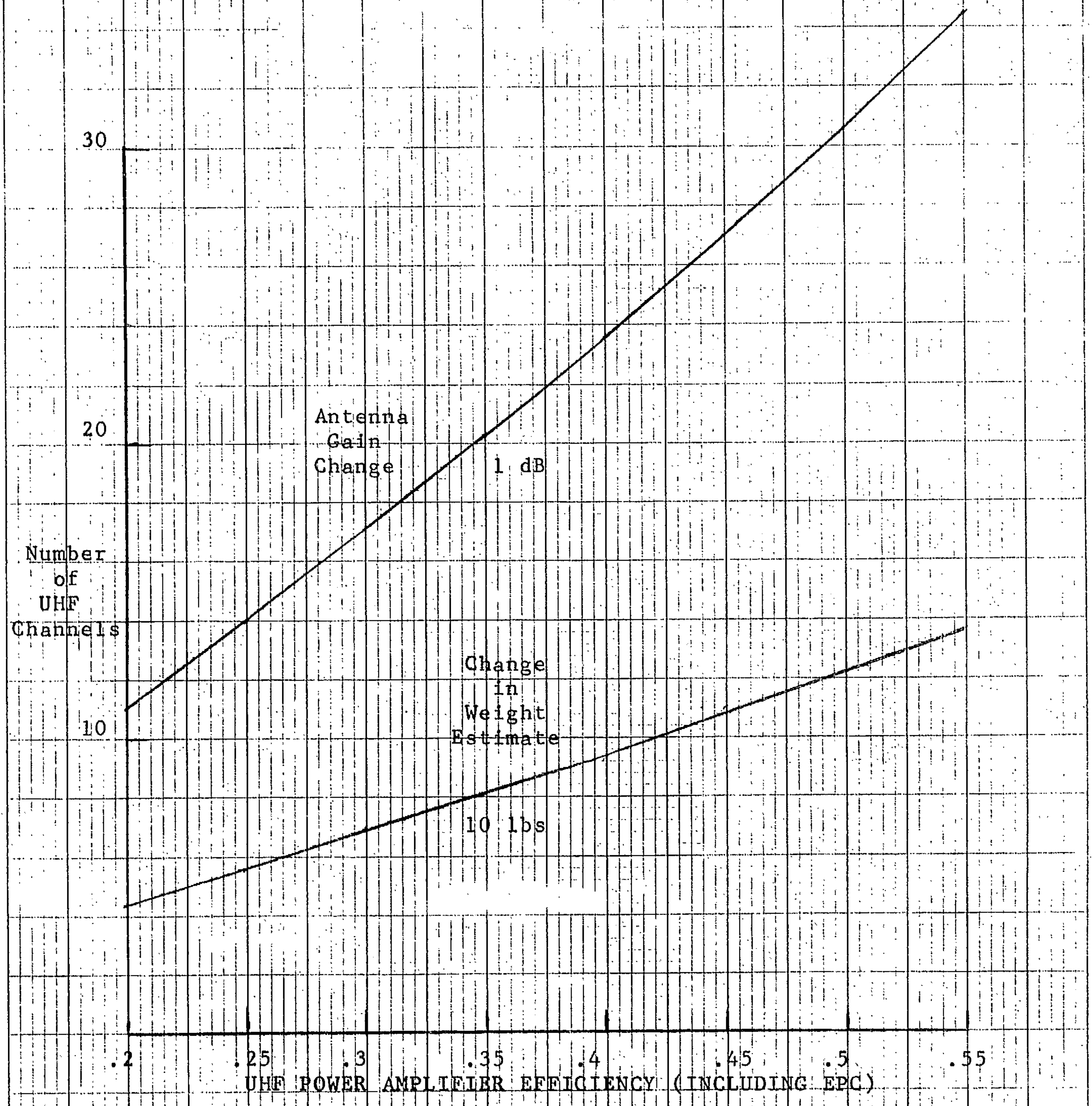


Figure II-15 Increase in number of UHF channels for 1 dB increase in antenna gain or 10 lb decrease in payload weight estimate (4 out of 7 12 GHz channels operating and 50% UHF eclipse)

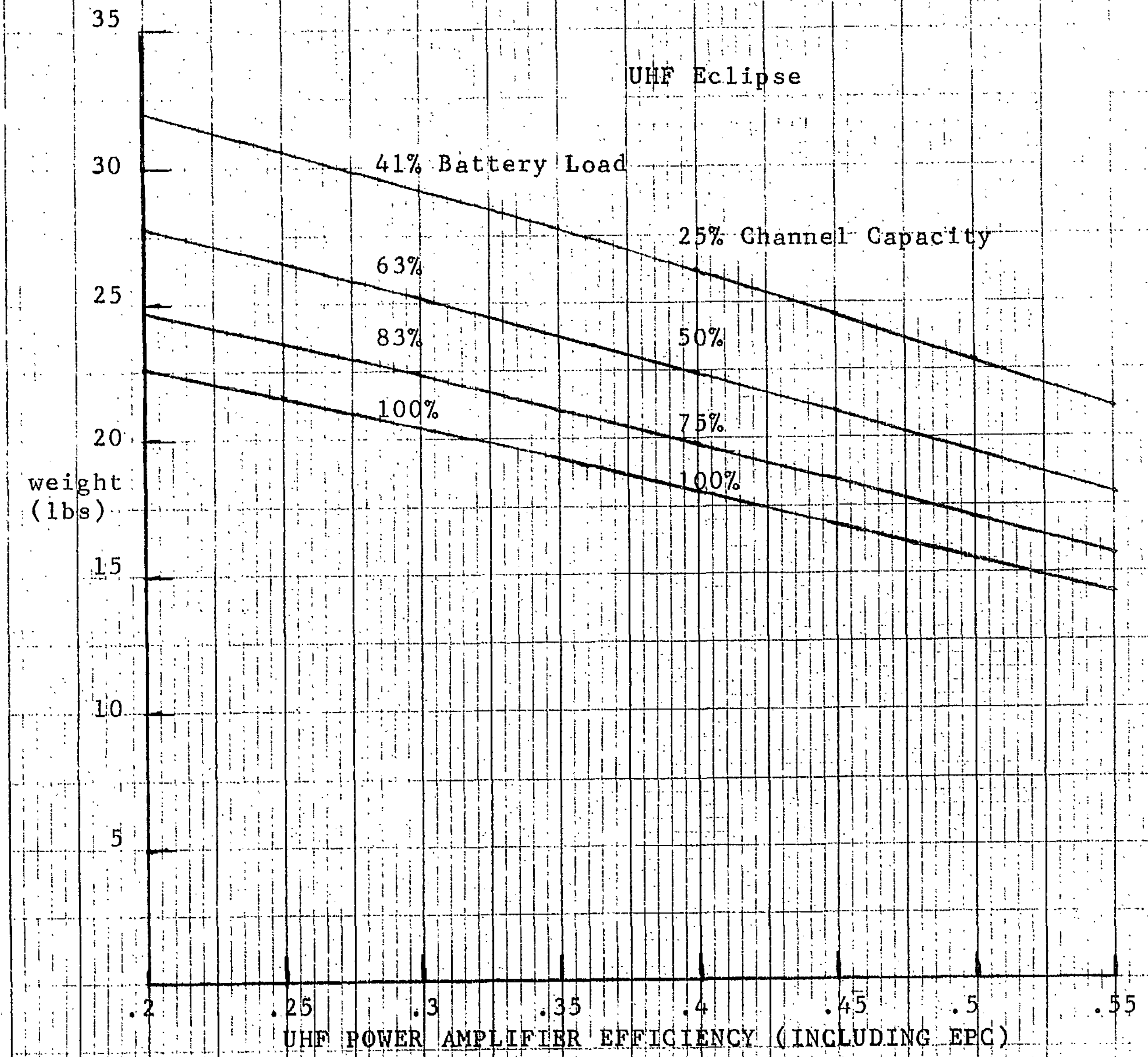


Figure II-16 Power amplifier weight with 4 out of 7 channels at 12 GHz operating during eclipse

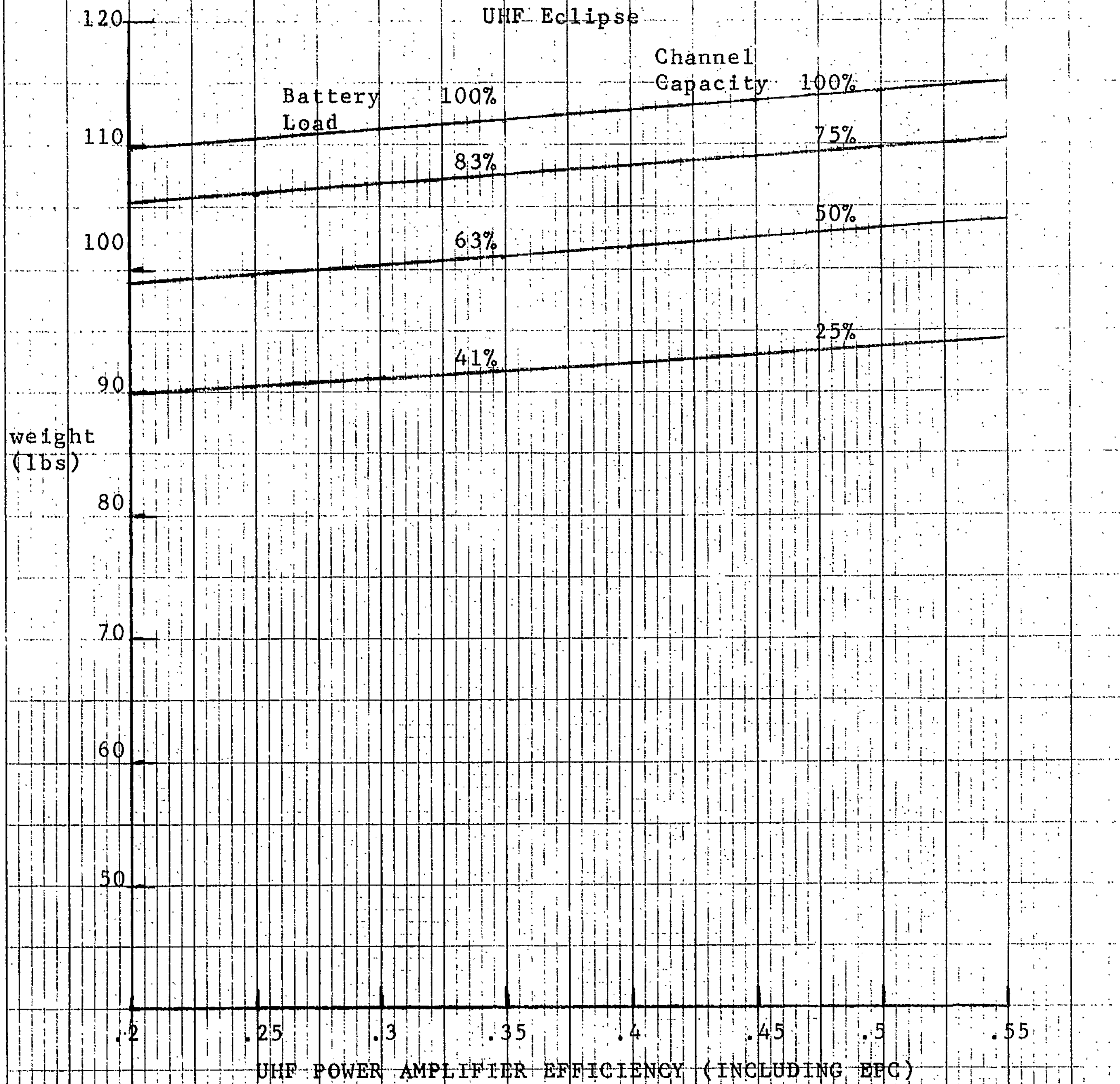


Figure II-17 Battery weight for total communications payload with 4 out of 7 channels at 12 GHz operating during eclipse

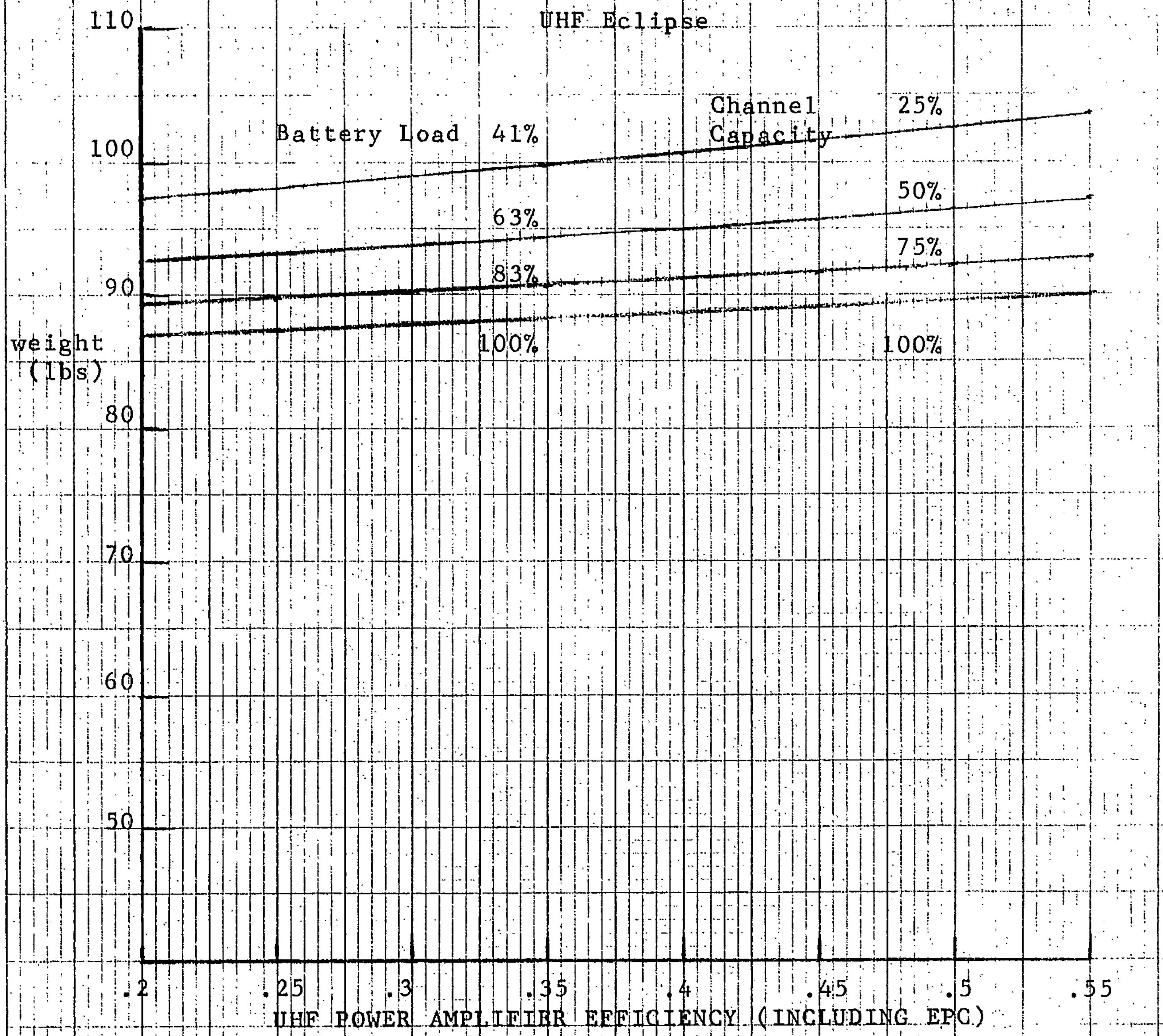


Figure II-18 Solar Array weight for total communications payload with 4 out of 7 channels at 12 GHz operating during eclipse

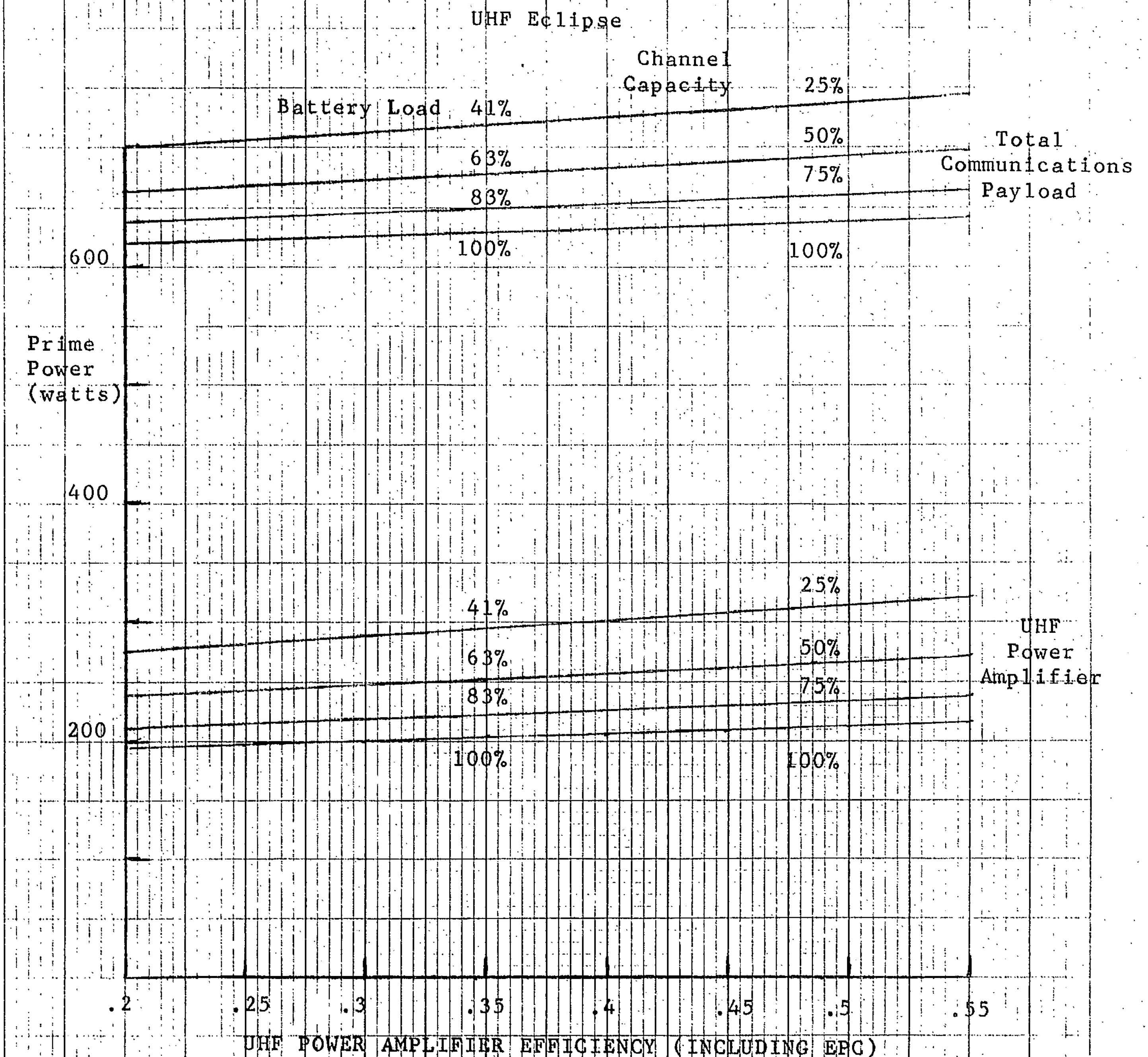


Figure II-19 Prime power requirements for the UHF power amplifier and the total communications payload with 4 out of 7 channels at 12 GHz operating during eclipse

APPENDIX A

UHF/4-6 GHz TRANSPONDER MODEL

A-1.0 GENERAL GUIDELINES

The general guidelines for the 4 - 6 GHz portion of the transponder are contained in attachment prepared by Telesat.

A-2.0 4-6 GHz POLARIZATION/FREQUENCY PLAN

Twelve channels at 4-6, similar polarization and frequency plan as for the present Anik system (see attachment).

A-3.0 UHF BACKHAUL

For the present time, one of the 12 xhannels will be used for the UHF backhaul to the central control station. Telesat made the suggestion that spectral space adjacent to the Fixed-Satellite service allocation be investigated for the UHF backhaul. This is being actioned by Telesat/DOC.

Various concepts for the backhaul redundancy were discussed, including (a) switch in of another 4-6 GHz channel for redundancy; (b) redundant TWT for backhaul channel; (c) both (a) and (b).

A-4.0 UHF FREQUENCY PLAN/BACKHAUL CROSS-STRAPPING

Assuming a 36 MHz backhaul channel for the UHF, the following is tentatively suggested as a frequency plan, subject to later revision:

- UHF uplink 372 - 406.1 MHz cross-strapped to 4 GHz downlink
- UHF downlink 300 - 328 MHz cross-strapped to 6 GHz uplink
- SHF/SHF: 2 MHz of bandwidth strapped directly from 6 GHz uplink to 4 GHz downlink (i.e., bottom 2 MHz of the 36 MHz backhaul channel)
- UHF/UHF: one meghertz of bandwidth (suggest 327-328 for downlink and 399-400 for uplink) for direct UHF/UHF cross-strap. Requirement for this mode of operation will have to be confirmed with the users. To implement it, an ALC circuit will be required for the UHF amplifier (approx. 2.5 lbs, one watt), a filter (1 lb) and a switch ($\frac{1}{2}$ lb).

A-5.0 **ECLIPSE CAPACITY**

Ten out of twelve channels at 4/6 GHz ± UHF backhaul. 50% and 100% capacity at UHF. (This means 100% power to all parts of the transponder except the UHF PA, which can be cut back to 50% DC power. This amounts to 50% reduction in UHF capacity if the RF power is assumed to be nearly linear with the DC power consumption).

A-6.0 **ANTENNA COVERAGE**

4/6 GHz: See Telesat attachment.

UHF: All land mass and ocean areas from 40°W to 140°W, and from 49° to northern limit of coverage

A-7.0 **UHF EIRP**

Nominal UHF channel is 18 dBW, although the concept of dynamic assignment of EIRP will probably allow EIRP to vary ± 10 – 5 dB from this nominal value. A target minimum of 40 – 18 dBW channels is suggested.

A-8.0 **SPOT BEAM REQUIREMENT**

It is expected that a spot beam ($1-2^\circ$ beamwidth) will be required for the 6 GHz uplink. It would also be desirable, but not essential for a spot beam on the 4 GHz downlink. RCA will look at the antenna hardware implications.

A-9.0 **TRADE-OFFS**

Weight and power budgets will be carried out parametrically to establish the range of available UHF capacity. As well, a specific weight/power budget will be carried out to establish the UHF capacity with presently qualified flight hardware for the UHF HPA (i.e., the TRW power amplifier).

GUIDLINES FOR DOC/RCA UHF STUDY

4/6 GHz

Basic Parameters

12 channels - one for UHF link (10 + 1 + 1 spare)
(eclipse 10 + UHF backhaul out of 12)

BW: 36 MHz nominal

EIRP: 34 dBW over centre 10 MHz, Canadian coverage (minimum) for all Canadian landmass

34.5 dBW at Dawson, St. John's)
) (Goals)
35 dBW over 90% of Canada)

G/T: - 6 dB/^{o}k over Canadian coverage (Typical of present ANIK)

SFD: - 80 dBW/m^2 minimum Canadian coverage (-82 as a goal)

LO stability: 10 in 10^6 maximum (long term) and eclipse
$\pm$ 1 in 10^6 per month (including eclipse

Communications performance: Per Anik 1 and 2

Consideration for Redundancy

1) Redundant TWT's for UHF link

2) Redundant channels for UHF link

3) Redundant TWT's and redundant channels for UHF link

UHF

1) Main Telesat question is, what is a realistic EIRP for aircraft-use with 0dB antenna gain? 28 dBW or 31 dBW?

Telesat favours the more conservative approach, viz: 31 dBW. How much fading can be tolerated? What about circular to linear polarization loss (for aircraft)?

2) Also Telesat would like to see more realistic values developed for RF power, efficiency, bandwidth and IM distortion using off-the shelf flight hardware, eg. TRW/FLTSATCOM class AB 40w amplifier.

3) Is it practicable to use same antenna for transmit and receive? What IM problems are we likely to run into as per experience on other programs (due to non-linearities in passive components eg. antenna mesh, duplexers, etc.)?

Communications Performence - 4/6 GHz

At this point in the UHF// 4/6 GHz study the communications performance is best defined by the attached transmission characteristics. The characteristics should be achievable using an input multiplexer with full-height waveguide filter with L. Keyes of RCA.

Output TWT

Telesat would probably use the 6.3W Telefunken TWT, unless the EIRP can be met with a 5W tube, eg. the Hughes Anik type.

Batteries

The required 4/6 GHz eclipse performance should be met with 66% depth of discharge with two out of three batteries operational, ie. assuming three batteries but one totally unservicable.

TT & C

The basic TT & C system used for the RCA Globcom domestic satellite should be adequate.

TRANSPONDER "A"

(Canadian Coverage Beam)

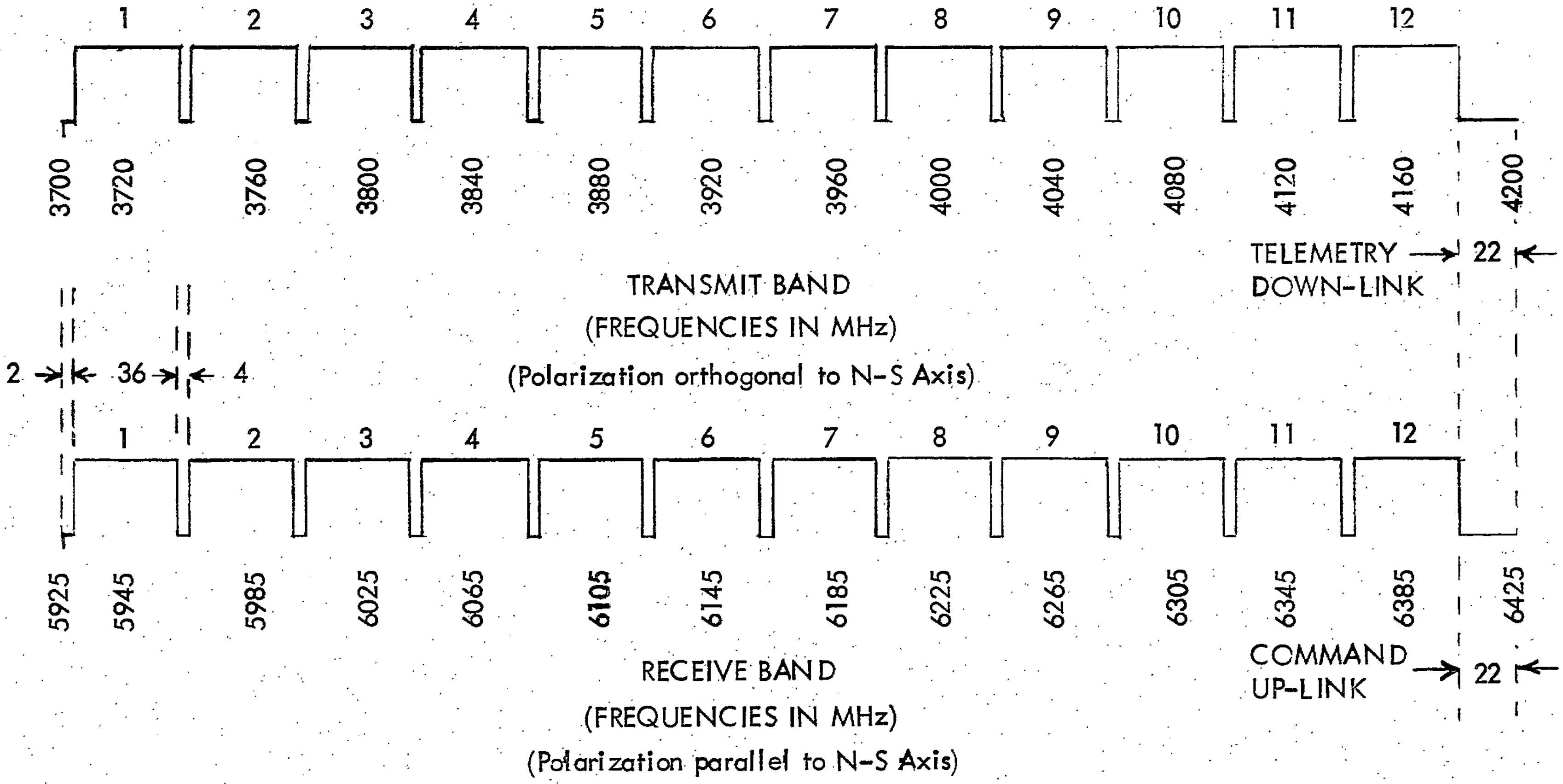


FIGURE 1.3.1 FREQUENCY AND POLARIZATION PLAN - TRANSPONDER "A"

APPENDIX B

INITIAL GUIDELINES FOR THE 12-14 GHz/UHF TRANSPONDER MODEL

B-1.0 SERVICE OBJECTIVES

UHF – to provide voice, data, and facsimile communications services to mobile and transportable UHF stations for government users. In addition, to receive data from data retransmission platforms and signals from emergency beacons.

SHF – to provide single channel per carrier (SCPC) and multi-channel per carrier (MCPC) services for public and commercial use.

B-2.0 TRANSPONDER PERFORMANCE

B-2.1 Transponder Functional Mode Diagram

Two functional transponder block diagrams are being considered. Configuration A, in Figure 1, is intended to meet all user service objectives. SCPC service is carried on channels 3 and 4, with the TWT power divided between adjacent spot beams. Multichannel Communications are carried on the remaining channels 1, 2, 5, 6 through the respective $2^{o} \times 2^{o}$ quarter-Canada beams. Channels 1 to 6 are received on a Canada coverage antenna. Channel 7, which is used for UHF backhaul, is normally received on the Canada-wide beam. This channel can be switched to a 1^{o} spot beam centered on the prairies. Channel 3 TWT provided redundancy for channels 1 and 5, and the channel 4 TWT provided redundancy for channels 2 and 6. The SCPC service can be carried on these two channels (3 and 4) until one of the TWT's for the other channels is lost. The SCPC and MCPC service must then be carried on the same TWT, with the generated power being split between adjacent quarter Canada beams.

Configuration B, in Fig. 2, is a simplified transponder and would be used if the SCPC services were dropped. In this case, the downlink spot beams would be $1^{o} \times 2^{o}$, with a Canada-wide ($1^{o} \times 8^{o}$) beam used for uplink. A TWT is allocated to each spot beam, with the transponder being channel cross-strapped so that adjacent TWT's can spare off for each other. The UHF backhaul channel normally transmits and receives on the Canada-wide beam, but can be switched to receive and transmit on the prairie beam.

B-2.2 Antenna Coverage

	UHF	Backhaul Channel	SHF
Configuration A	Land mass and ocean areas from 40°W to 140° W, from 49°N to limit of northern coverage; both uplink and downlink	Normal: Canada wide beam ($2 \times 8^\circ$) for both up and down links Special: 1° spot beam antenna on the prairies for both up and down-link	Uplink: Canada wide beam ($2 \times 8^\circ$) Downlink: four quarter Canada beam ($2^\circ \times 2^\circ$)
Configuration B	Same	Same	Uplink: Canada wide ($1^\circ \times 8^\circ$) Downlink: four $1^\circ \times 2^\circ$ spot beams

B-2.3 Polarization

	UHF	Backhaul Channel		SHF
Uplink	RHCP	Canada wide Spot	H H	H
Downlink	RHCP	Canada wide Spot	V V	V

B-2.4 FREQUENCY PLAN AND CHANNEL BANDWIDTHS

A tentative frequency plan for the configuration A transponder is given in figure 3. The arrangements of the UHF, UHF backhaul, cross-strapping modes and independent SHF channels are shown.

B-2.5 TYPICAL TRANSPONDER PARAMETERS

SHF

Antenna beam edge gain ($2^\circ \times 2^\circ$)	34 dB
EIRP (beam edge) saturated	46 dBw
Satellite G/T ($2^\circ \times 8^\circ$) dB-k	-8 dB
Saturating Flux density	-80 dBw/m^2

UHF

Same as previous UHF models

B-2.6 REQUIRED CAPACITY IN SUNLIGHT

The minimum required UHF capacity in sunlight is 80 channels each at a nominal 18 dBw EOC EIRP.

Normal sunlight operating mode for configuration A is all 6 SHF channels plus UHF backhaul channel operating.

B-2.7 Eclipse Operation

Reduced UHF capacity in eclipse is permissible, with an eclipse capacity range of 25 to 100% of the sunlight capacity being the range of interest. In the event that the minimum required UHF sunlight capacity of 80 channels cannot be met for full eclipse operation, of all 6 SHF channels, then eclipse capability of this portion of the transponder can be progressively reduced to a minimum of 2 operating channels (channels 3 & 4). The backhaul channel must be operational during eclipse.

B-2.8 Reliability Redundancy

The transponder block diagrams are to be configured so as to avoid single point failure of all active components. Redundant components must be provided to cover all first failure modes.

The batteries are to be in the form of three independent strings any two of which can meet the minimum required eclipse load defined above, with the depth of discharge not exceeding 66%.

B-3.0 TRADE OFF STUDIES

B-3.1 Antenna Concept Development

Alternative concept antenna configurations to meet the coverage requirements will be developed early in the transponder feasibility study, one of which will be selected as the baseline antenna. Preliminary electrical and mechanical characteristics of the antenna will be provided

B-3.2 Transponder Tradeoffs

A block diagram for baseline configuration A shall be developed from which weight and power budgets will be derived. Capacity tradeoffs will be carried out to determine if the required UHF and SHF sunlight capacity which can be provided. The available payload weight is that provided by a typical 2000 lb 3-axis bus with a 6 year fuel load.

B-3.3 Sensitivities to Payload changes

Although one configuration will be selected as the baseline, preliminary weight and power budgets for the alternate configuration will be provided based on weight/power information developed for the baseline configuration. In addition, electrical and mechanical changes necessary to convert the baseline 4-quarter Canada $2^{o} \times 2^{o}$ beam antenna to 4-$1^{o} \times 2^{o}$ beam antenna will be outlined. Detailed capacity tradeoffs for the alternate configuration will be carried out only if time and effort permits. At a minimum, approximate UHF capacity levels will be indicated for the alternate Transponder.

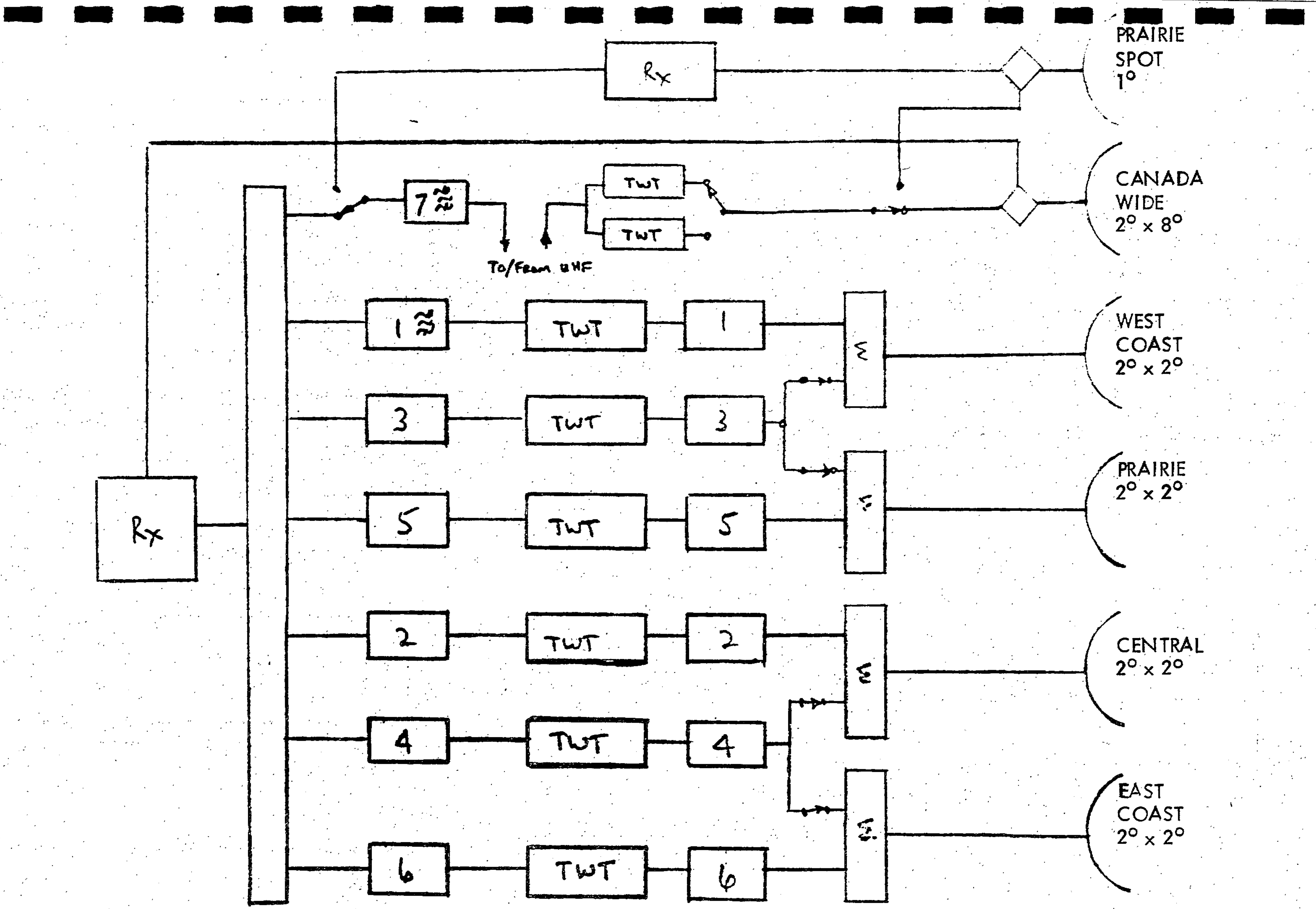


FIGURE 1 CONFIGURATION A 12-14 GHz/UHF TRANSPONDER FUNCTIONAL BLOCK DIAGRAM

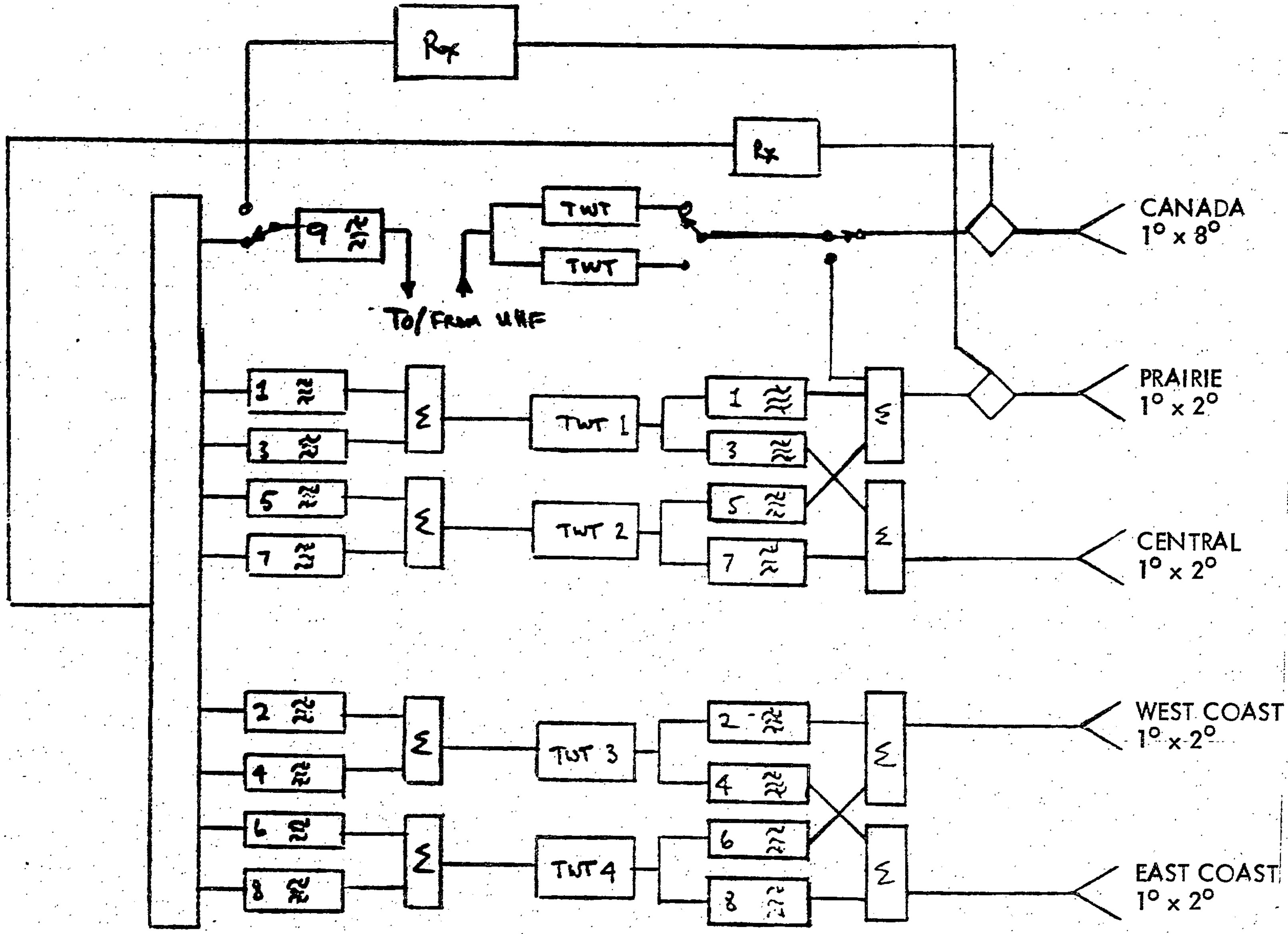
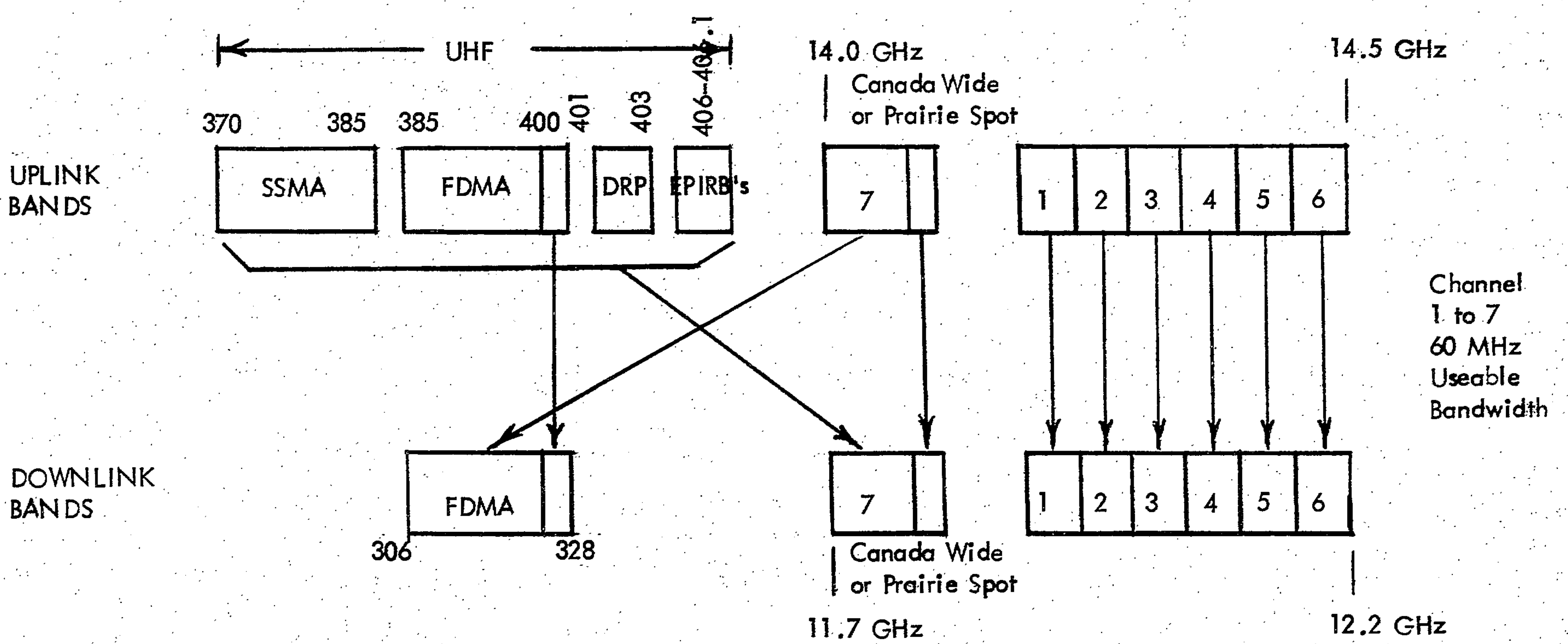


FIGURE 2 CONFIGURATION B 12-14 GHz/UHF TRANSPONDER FUNCTIONAL BLOCK DIAGRAM



Arrows indicate transponder cross connections

FIGURE 3 TENTATIVE FREQUENCY PLAN FOR CONFIGURATION A TRANSPONDER

ADDENDUM TO "GUIDELINES FOR THE 12-14 GHz/UHF TRANSPONDER MODEL" ISSUE 1 DATED MARCH 30, 1975

12-14 GHz Antenna Coverage

The required antenna coverage for the 12-14 GHz band is defined by the area bounded by the following locations: Victoria, Winnipeg, Toronto, Halifax, St. John's, Frobisher Bay, Resolute, Inuvik, Dawson, and Whitehorse. For the purpose of the feasibility study the following boresights may be assumed for the four $2^{\circ} \times 2^{\circ}$ spot beams in order to meet the above coverage requirement:

55 N, 120 W
55 N, 104 W
50 N, 85 W
50 N, 66 W

A boresight of 55 N, 110 W will be assumed for the 1° prairie spot beam.

11 April 1975