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ANALYSIS OF ALTERNATE SYSTEMS FOR CANADIAN COMMERCIAL & MILITARY MOBILE SATELLITE SERVICES

VOL. I - MAIN REPORT

ANADIAN ASTRONAUTICS LIMITED

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SPACE PROGRAM

ANALYSIS OF ALTERNATE SYSTEMS FOR CANADIAN COMMERCIAL & MILITARY MOBILE SATELLITE SERVICES

VOL. I - MAIN REPORT

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LIST OF ABBREVIATIONS

ACS - Altitude Control Subsystem
ACSSB - Amplitude Companded Single Side Band
ADV RCA SATCOM - Advanced RCA Bus, 2770 lbs Communication Spacecraft
AI - Articulation Index
AKM - Apogee Kick Motor
ANT - Antenna
ATS-6 - Applications Technology Satellite - 6

BER - Bit Error Rate
BH - backhaul
BIPROP - bipropellant
BL - blocking rate
BOL - beginning of life
BW - bandwidth

CAP - capacity
CCS - Central Control Station
CH - channel
CMD - command
C/A - carrier-to-adjacent channel interference ratio
C/I - carrier-to-interference ratio
C/IM - carrier-to-intermodulation ratio
C/N - carrier-to-thermal noise ratio
C/No - carrier-to-thermal noise density ratio
C(No+I)- carrier-to-thermal noise density plus interference (noise density) ratio

D or d	downlink
DAMA	Demand-Assignment Multiple Access
DIA	diameter
DRP	Data Relax Package
D/L	downlink
EAHT	electrically augmented hydrogen thrusters
ECCM	Electronic-counter-counter-measures
EHF	Extremely High Frequency
EIRP	effective isotropic radiated power
EOC	edge of coverage
EOL	end of life
EPC	Electric Power Conditioning
EPIRB	Emergency Position - Indicating Radio Beacon
ERL/U	erlangs/user
Eb/No	energy per bit-to-thermal noise density ratio
fs	signalling rate in bit/sec
FSK	Frequency Shift Keying
FWD	forward
f/D	focal length-to-reflector diameter ratio
g	ground
G.E.	General Electric
GFEC	graphite fibre epoxy compound
G/T	antenna gain to receiver noise temperature ratio; figure of merit

HPA - High Power Amplifier
HSKP - housekeeping
Hz - Hertz, cycles/sec

IF - intermediate frequency
IM - intermodulation
ISL - Intersatellite link
IUS - Inertial Upper Stage
I-V - Intelsat V

JCS - Joint Chiefs of Staff

K - Boltzmans Constant = -228.6 dB/°K/Hz
Kb/S,KBPS - kilo bits per second
KU - one thousand users

Ld - downlink path loss
Lu - uplink path loss
LAM - Liquid Apogee Motor
LHC - left hand circular (polarization)
LV - launch vehicle

Md - downlink fade margin
M_E - mass of a Electric Power Conditioning circuit
M_H - mass of a High Power Amplifier
M_T - total mass
M_U - uplink fade margin
MRS - Mobile Radio Service
MSAT - Mobile Communications Satellite
MSK - minimum shift keying
MTS - Mobile Telephony Service
MUSAT - Multipurpose UHF Satellite

N - total number of channels
N_A - total number of simultaneously active channels in a transponder
N_B - number of beams
N_{CB} - number of channels/beam
N-S - north-south
NBFM - narrowband F.M.
NiCd - nickel-cadmium
NiH2 - nickel hydrogen
NSSK - north-south stationkeeping
NVA - no voice activation

PT - total power
PAM - Payload Assist Module
PIM - passive intermodulation
PRIM - primary
PWR - power
P/L - payload
PE/LPC - pitch excited/linear predictive coding

Rx - receive
RCS - Reaction Control Subsystem
RF - radio frequency
RHC - right hand circular (polarization)
ROM - rough order of magnitude
RMS - root mean square
RTN - return
RE/LPC - residual excited/linear predictive coding

SAT	- satellite
SCPC	- Single Channel per carrier
SHF	- super high frequency
STKP	- stationkeeping
STS	- Space Transportation System
SSUS	- Spinning solid upper stage
T_A	- antenna noise temperature
T_F	- antenna feed noise temperature
T_R	- receiver, LNA noise temperature
T_S	- satellite system receive noise temperature
Tx	- transmit
TLM	- telemetry
TRAC	- Truss Rib Antenna Configuration
T&C	- Telemetry and Command
TT&C	- Tracking, Telemetry and Command
TWTA	- travelling wave tube amplifier
U, U/L	- uplink
U/C	- upconverter
UHF	- ultra high frequency
V.A.	- voice activation
XPR	- transponder
WGN	- White Gaussian Noise
Θc	- beam cross-over angle
η	- efficiency

1.0 INTRODUCTION

1.1 SCOPE

At the present time, several extensions of communication satellite service are under investigation by the Department of Communications. Specifically, Canadian military communications requirements and mobile radio telephony service are not adequately served by Canadian spacecraft at the present time. This study addresses the question of whether existing designs of communication spacecraft can be modified to support either or both of the military and mobile requirements.

1.2 METHODOLOGY OF THE STUDY

The study has been performed in the manner outlined in Figure 1-1. First, the performance requirements of each of the missions were reviewed. Next, a number of existing spacecraft were evaluated for their compatibility with the mission requirements. Parametric sensitivity analyses were performed, and compromised but realizable performance defined. Conceptual designs were then sketched for each of the missions. This enabled critical new technology areas to be identified and spacecraft layouts produced. Finally, the development schedule and program cost estimates were deduced.

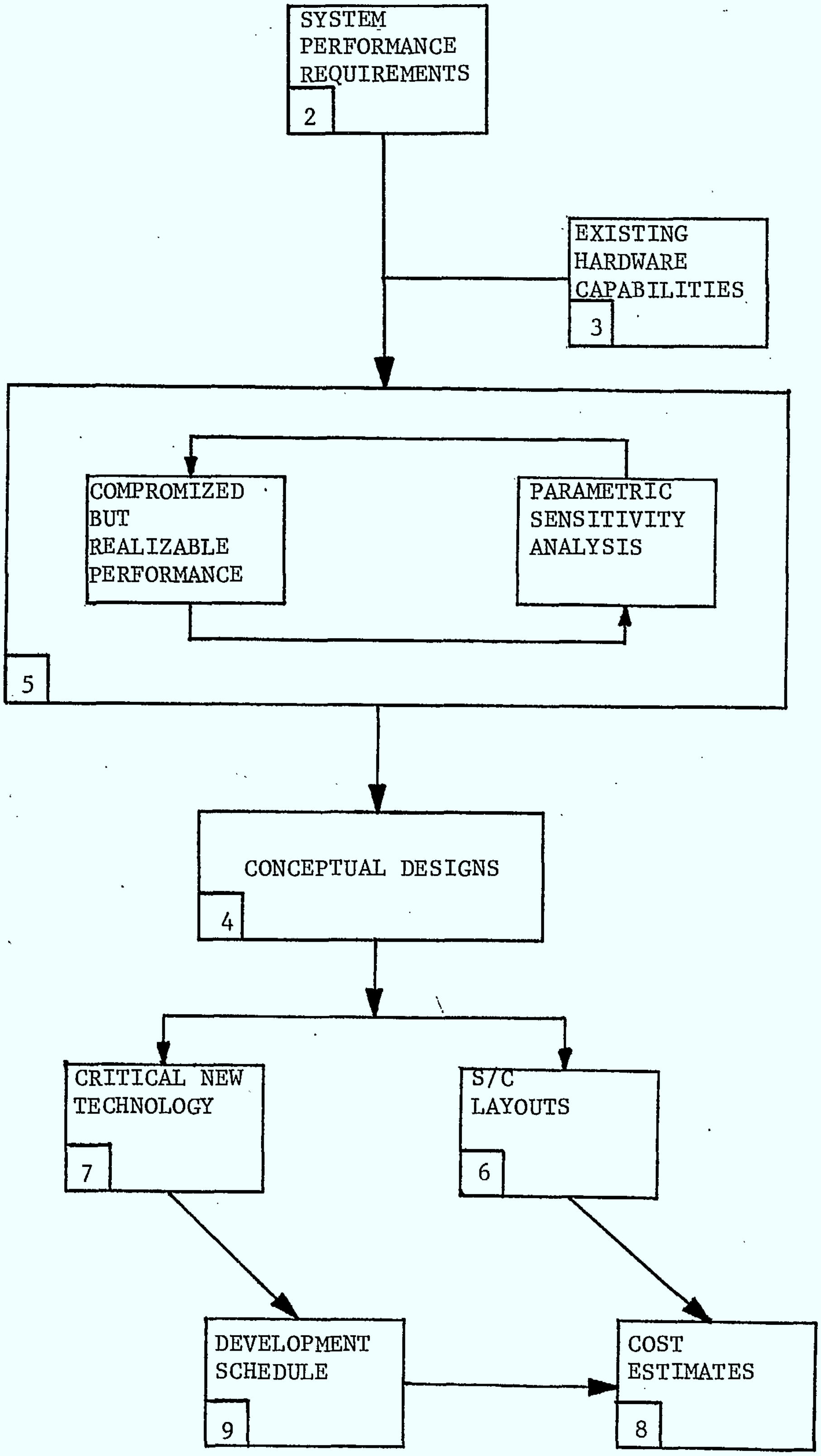


Figure 1-1 Study Flow Chart

2.0 DEFINITION OF THE MISSION REQUIREMENTS

In this section, the performance requirements for each of the three missions will be defined. These missions have been termed the military, the mobile, and the combined service.

2.1 THE MILITARY SYSTEM PERFORMANCE REQUIREMENTS

The system performance requirements for the military system have been under study for some years. Reference 1 defines the current set of performance requirements which have been used as the baseline for this study.

As a consequence of coverage requirements of the SHF Arctic Service to the far northern reaches of Canada, North-South stationkeeping becomes an essential requirement for this mission. However, if this service is not required, then NSSK would not be mandatory.

It should be noted that two additional government but non-military requirements have been included in this payload ensemble. These may be considered as desirable options, but not necessary to include in the baseline. They are marked by an asterisk in Table 2-1, which defines the required services by frequency and coverage requirements. Table 2-2 defines the frequency and polarization allocation for these services.

The antenna and payload requirements resulting from these services are listed in Table 2-3 for UHF and Table 2-4 for EHF services. This study did not consider any detailed trade-offs in these antenna payload designs, except the UHF payload. Further study of the antenna payload designs will be required in the next phase.

Furthermore, if the L-Band service is not required, and since it is not a military payload; it is suggested that the next phase study should address the upgrading of the military payload to provide additional capability.

Table 2-1 Military System Performance Requirements: Operating Frequencies And Coverage Requirements

SERVICE	Frequency			Coverage
	Uplink	Downlink	Backhaul	
1 Military Mobile	400 MHz	300 MHz	7/8 GHz	11 deg. circle centred at 55°N lat. and zero relative longitude.
* 2 Data Relay Package (DRP)	400 MHz	-	7 GHz	All Canada plus 200 nautical miles of coastal waters
3 EPIRB	400 MHz	-	7 GHz	All Canada plus 200 nautical miles of coastal waters
4 Mobile to Mobile ECCM	400 MHz	300 GHz	--	11 deg. circle centred at 55° N
* 5 Maritime Mobile	1.6 GHz	1.5 GHz	7/8 GHz	10 deg. circle centred at 55°N lat. and zero relative longitude
6 EHF Secure Communications	44 GHz	20 GHz	--	Steerable spot beam global coverage. Single beam, 4 x 10 deg. Canada
7 Intersatellite Link	59 GHz	60 GHz	--	No ground coverage.
8 Fixed ECCM	8 GHz	7 GHz	--	8 deg. circle centred at 40°N lat. and zero relative longitude.
9 Arctic service	8 GHz	7 GHz	--	8 deg. circle centred at 40°N lat. and zero relative longitude.
10 DAMA	8 GHz	7 GHz	--	8 deg. circle centred at 40°N lat. and zero relative longitude.
11 SHF Global	8 GHz	7 GHz	--	Global coverage.

*This service is not part of the military payload, and its mass and power requirements are not to be considered part of the military payload.

Table 2-2 Frequency and Polarization Allocations

Service	Frequency	Polarization	Bandwidth per Beam
1 Military Mobile	387.4-389.4 and		
Uplink	397.4-399.4	RHC	2 MHz
Downlink	275.5-277 and	RHC	2 MHz
	285-287 MHz		
2 DRP Uplink	401-403 MHz	RHC	2 MHz
* 3 EPIRB Uplink	406-406.1 MHz	RHC	0.1 MHz
4 Mobile to Mobile ECCM			
Uplink	335.4-399.9 MHz		64.5 MHz
Downlink	275-275.5 MHz		0.5 MHz
* 5 Maritime Mobile			
Uplink	1636.5-1644.0 MHz	RHC	2 MHz
Downlink	1535-1542.5 MHz	RHC	2 MHz
6 EHF			
Uplink	43.5354-43.5999	RHC	64.5 MHz
Downlink	20.2000-20.20425	RHC	0.5 MHz
7 Intersatellite			
Forward	59.7145-59.715 GHz	RHC	0.5 MHz
Return	63.2850-63.2855 GHz	RHC	0.5 MHz
8 Fixed ECCM			
Uplink	8145-8230 MHz	RHC	85 MHz
Downlink	7420-7505 MHz	LHC	85 MHz
9 Arctic service			
Uplink	8255-8315 MHz	RHC	60 MHz
Downlink	7530-7590 MHz	LHC	60 MHz
10 SHF DAMA			
Uplink	8060-8120 MHz	RHC	60 MHz
Downlink	7335-7395 MHz	LHC	60 MHz
11 SHF Global			
Uplink	7975-8035 MHz	RHC	60 MHz
Downlink	7250-7310 MHz	LHC	60 MHz
12 Low UHF and			
L-Band backhaul	8360-8392.0 MHz	RHC	32.0 MHz
Uplink	7635-7669.0 MHz	LHC	34.0 MHz
Downlink			

*This service is not part of the military payload, and its mass and power requirements are not to be considered part of the military payload.

Table 2-3 MILITARY PAYLOAD REQUIREMENT SPECIFICATIONS

ANTENNA	CONFIGURATION	FREQ. MHz	POL (C.P)	PEAK	GAIN		3 db BEAMWIDTH BW_3	BORESIGHT	LINK MARGIN (db)
					±5.5° 15.5°	±9° EARTH			
UHF TRANSMIT	DUAL HELICES 154" L x 15" Dia. 67"between centres	275-285	RHC	–	16.0 dBi	–	–	55°N 108°W	5
UHF RECEIVE	SINGLE HELIX 113" L x 10.4" Dia.	370-406	RHC	–	14.0 dBi	–	–	55°N 108°W	5
* L-BAND Tx-Rx	QUAD HELIXES 26" L x 2.6" Dia. 18.1" between centres	1537-1644	RHC	–	18.0 dBi	–	≥10°	55°N 108°W	TBD
SHF(Prim) Tx-Rx	Parabolic Reflector 15" Dia.	7250-8250	Tx-LHC Rx-RHC	27.0 dBi	–	–	8°	40°N 108°W	3
SHF-(Earth) Tx-Rx	Corrugated Conical Horn	7250-8250	Tx-LHC Rx-RHC	–	–	17.0 dBi	18°	0°N 108°W	TBD

*This service is not part of the military payload.

ITEM NO.	ANTENNA	CONFIGURATION	QUANTITY	DIAMETER	UP DOWN LINK	FREQUENCY	CIRC. POLAR-IZATION	GAIN	3dB Beamwidth	BORESIGHT	MARGIN	C/N
					U/D	GHz	R/L	dBi	deg.	deg.	db	db
a	Spot Beams (A&B)	Centre fed Parabola single feed	1	TBD	U D	43.5-43.6 20.200-20.205	R L	45	TBD TBD	E-W ± 9° Centre 55°N All direct ±10° centre 55°N E-W over 105° for L.S.L.	TBD	TBD TBD
b	Flat Reflectors	Circular Flat	1	TBD	U D	43.5-43.6 20.200-20.205	R L			Steerable		
c	Drive Mechanism	For Flat Reflectors	1									
d	Electr-onics	Steering Reflectors	1									
e	Feed Horn	Rx Pyramidal	1		U	43.5-43.6		30.4 27.4 EOC	4 x 10	55°N 109°W	6	51.7 48.6 EOC
f	Feed Horn	Tx Pyramidal	1		D	20.200-20.205		30.4 27.4 EOC	4 x 10	55°N 109°W	6	46.7 43.7 EOC

Table 2.4 EHF 40/20 GHz Antenna Requirements

2.2 THE MOBILE SYSTEM PERFORMANCE REQUIREMENTS

2.2.1 SYSTEM DEFINITION

This system is based on the parameters defined in Reference 2. It is intended to cover Canada and its coastal waters to:

- demonstrate and provide market development of mobile telephony source (MTS) to vehicles, ships, aircraft and field portable terminals providing duplex switched telephone interconnection
- demonstrate and provide market development of vehicle radio source (MRS) to the above mobile users, providing half duplex voice or data
- provide limited service to remote mobile users. A satellite central channel station (CCS) will also act as a central channel assignment controller and a gateway station.

From the gateway or base station, a FORWARD LINK establishes an S, X, or K_u band backhaul uplink to the satellite, to be converted to an 866-870 MHz downlink to the mobile users.

The RETURN LINK establishes an 821 - 825 MHz uplink to the satellite, to be converted to an S, X, or K_u band backhaul downlink to the gateway or base station.

Thus a connection between a mobile and a fixed station is completed via a single forward or return link hop, Mobile-to-Mobile connection is completed via a double hop, i.e. a forward and a return link. Figure 2-1 shows a sketch of typical services provided by the system.

A user's survey was conducted by Woods-Gordon (Reference 3), and indicates that the M-SAT share of the market is expected to reach about 25,000 users by 1993, and 140,000 users by the year 2001. They are expected to be distributed as follows:

- Vehicular: MTS = 14.3% of total
  - MRS = 60.0% of total
- Portable: Personal (MRS) = 22.9% of total
  - Field = 1.4% of total
- Ships = 0.7% of total
- Aircraft = 0.7% of total

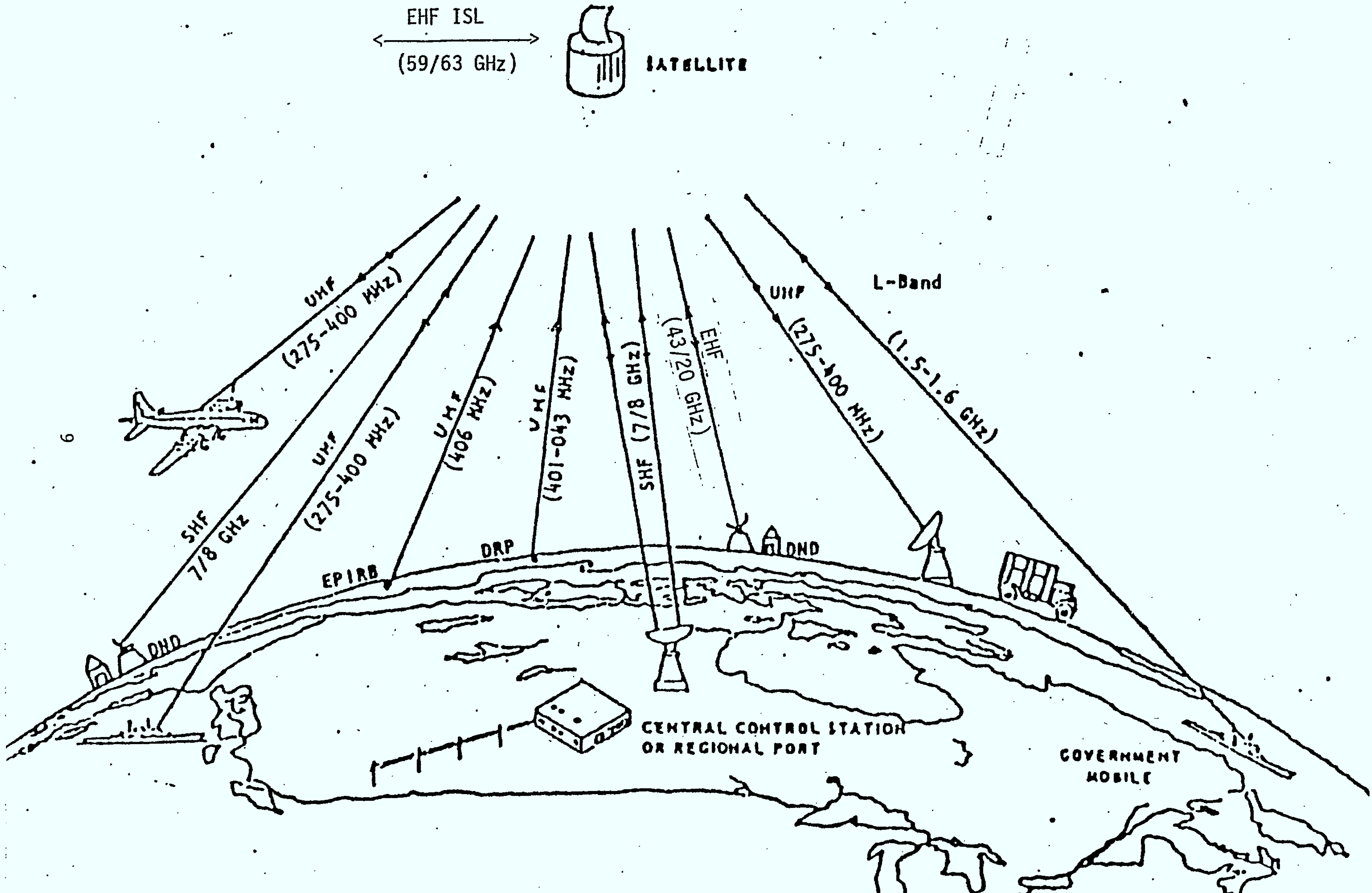


FIGURE 2-1 GOVERNMENT SERVICE LINKS

2.2.2 BASELINE REQUIREMENTS

The Baseline performance requirements considered are:

a) Traffic intensity of 0.012 Erlang per terminal, with 10% blocked call Erlang B statistics.

b) Four possible modulation schemes:
  - PE/LPC/MSK: PITCH EXCITED LINEAR PREDICTIVE CODING at 2.4 Kb/s.
  - RE/LPC/MSK: RESIDUAL EXCITED LINEAR PREDICTIVE CODING at 4.8 Kb/s.
  - NB FM: NARROWBAND FM
  - ACSSB: AMPLITUDE COMPANDED SINGLE SIDE BAND (NOT REQUIRED IN THIS STUDY)

c) The respective TOTAL LINK $C/(N_o+I)$ are:
42, 45 and 53 dB-Hz.

d) The corresponding 800 MHz EIRP/channel is:
28.7, 31.7 and 39.7 dBW.

e) Most mobile users are expected to have antenna Tx or Rx gains varying between +4 and +5 dBi. The fade margins are expected to be:
5 dB for the 800 MHz downlink
13 dB for the 800 MHz uplink
4 dB for the uplink and downlink backhaul at 7/8 GHz.

f) 4 MHz RF Bandwidth is available for the 821-825 MHz and 866-870 MHz uplink and downlink respectively.

g) Ships and aircraft aeronautical L-Band is suggested as 1636 - 1644 MHz and 1535 - 1542 MHz for the uplink and downlink respectively.

h) Satellite UHF Tx HPA (High Power Amplifier) and EPC (Electric Power Conditioning) efficiencies are 30% and 90% respectively, i.e. an overall efficiency of 27%.

i) Voice activation is the baseline.

j) Backhaul at 7/8 GHz or 12/14 GHz.

k) Eclipse serviceability: 25% for 800 MHz service and 100% for Military service.

2.2.3 PARAMETRIC REQUIREMENTS OF THE SYSTEM STUDY

This will be discussed in detail in Section 4. Certain parameters have not been defined in order to study their interdependence, and to thereby produce some parametric trade-of analyses.

For example, some of these parameters are the number and size of beams, type of traffic intensity and blockage, HPA efficiency, satellite and ground antenna gain, eclipse operation, and modulation type.

2.3 THE COMBINED SYSTEM PERFORMANCE REQUIREMENTS

This system, as the name suggests, is formed by the addition of the mobile system requirements to those of the military system. It is, as a baseline, intended that both services be operated simultaneously on the single spacecraft.

In this case, one 7/8 GHz band will be used for both the Mobile and the Military backhaul, therefore eliminating the need for the Ku-Band backhaul suggested for the Mobile-only mission. It should be noted that backhauls for the non-military payloads, such as the L-Band and DRP are provided at this frequency as a convenience to eliminate other separate backhaul transponders.

3.0 SURVEY OF EXISTING HOST SPACECRAFT

For this study a number of candidate spacecraft were considered as the host for the three missions. Data on each of these spacecraft was gathered from existing literature and from contacts with the manufacturers.

Appendix A to this report contains the TRIP/VISIT reports from contacts with selected manufacturers.

The spacecraft designs considered were:

- ANIK D (Hughes)
- ANIK B, SATCOM, ADVANCED SATCOM (RCA)
- Leasat (Hughes)
- FLTSATCOM (TRW)
- DSCS III (GE)
- Intelsat V (Ford)
- L-SAT (BAE)
- TDRSS (TRW)
- Insat, ARABSAT (Ford)

Appendix B lists some of the key features of each of these candidate spacecraft.

3.1 EVALUATION OF THE CANDIDATE SPACECRAFT

Two evaluation methods were used to establish the best choice of host spacecraft for each of the three missions defined in Section 2. The first method, which is described in the next section, is based on a detailed analysis of the performance characteristics of the candidate spacecraft in conjunction with the performance requirements of the missions. The second method consists of a consensus of subjective assessments by several experienced aerospace engineers who evaluated the candidate spacecraft in the light of the requirements and tempered by their experiences with the various contractors.

3.1.1 DETAILED EVALUATION OF CANDIDATE HOST SPACECRAFT

The detailed evaluation of the candidate spacecraft was performed in the following manner. First, the evaluation criteria were chosen and arranged into a weighted listing based on the Design Authority priorities. Second, the mission requirements were combined with the spacecraft capability listing. The logic for this evaluation is shown in Figure 3-1.

The next step in the evaluation was to combine the weighted evaluation criteria and the spacecraft relative capability ranking in order to arrive at a relative ranking of the spacecraft capable of fulfilling the mission requirements. The details of this analysis are contained in Appendix D. The results of this evaluation is given in Table 3-2 at the end of Section 3.2.

3.1.2 SUBJECTIVE EVALUATION OF SPACECRAFT

The subjective evaluation of candidate spacecraft was performed in parallel with the detailed analysis. It is difficult to describe the logical processes behind the choices except to state that the selections were arrived at by consensus among several experienced aerospace engineers. A summary of the capabilities of each of the candidate spacecraft is given in Volume II of this study, Appendix B.

Initially, certain candidate spacecraft were given only limited consideration (e.g. TDRSS) or removed from further consideration for the following reasons:

<u>ANIK D</u> - Was felt to be too close to design limits for dissipation, power and mounting area for any of the missions.

<u>BSE</u> - GE did not encourage consideration of this option. It does not have a large payload capability nor a good reliability record.

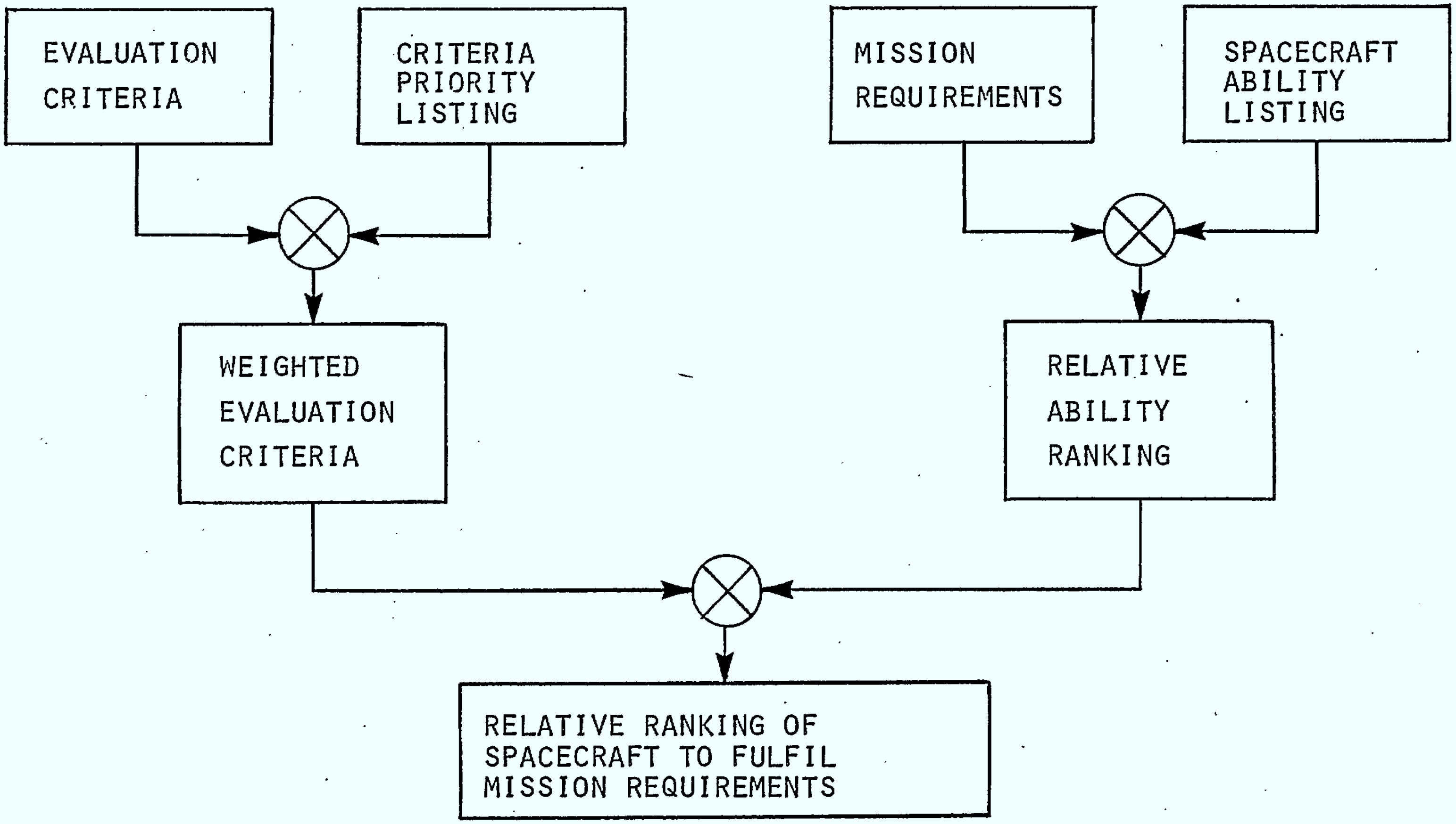


FIGURE 3-1 LOGIC FLOW DIAGRAM FOR DETAILED EVAULATION OF CANDIDATE SPACECRAFT

DSCS III -This spacecraft is designed for a dual launch on a TITAN III booster, or a dual launch with the IUS. It is not expected that a dual launch for a DSCS follow-on would be available. Any changes to the basic design (in order to accommodate a different launch vehicle) would be relatively costly. Furthermore, G. E. did not seem willing to even discuss the possibility of this bus forming the basis for any Canadian payload.

TDRSS - The TDRSS spacecraft is sufficiently large that it is only capable of launch from the shuttle. It is felt that the large payload capacity would not be fully utilized by our military-only or mobile-only missions and that smaller, cheaper spacecraft should be considered in preference to this design.

The remainder of the candidate spacecraft were considered in the light of the specific mission requirements.

MILITARY Mission

As a guideline, Delta-class vehicles were chosen as the prime candidates for the Military payload mission. Host spacecraft with excess capability were considered poorer candidates, as it was felt that the higher costs would not be warranted.

With this consideration, the RCA SATCOM and INSAT were considered the best choices. As the SATCOM is the more mature design of the two, it was felt it should be the first choice.

The other remaining candidates are LEASAT and FLTSATCOM, both of which have minimal N-S stationkeeping capability. LEASAT is a shuttle-optimized design and is a spinner. It has not yet been flown. FLTSATCOM is launched with an Atlas-Centaur and could presumably also be launched with the shuttle.

MOBILE Mission

The same guideline of a Delta-class preference was established for the Mobile-only mission, and the same candidate host spacecraft as for the Military mission were identified. The requirement for N-S stationkeeping was questioned for this mission and it was decided to baseline no N-S stationkeeping requirement for this mission.

Combined Mission

The three larger capacity spacecraft, LSAT, Intelsat V, and TDRSS are all candidates for the combined mission.

Table 3-1 outlines the list of candidate spacecraft and the relative rankings arrived at by the consensus of the assessors.

3.2 RELATIVE RANKING OF HOST SPACECRAFT

Table 3-2 summarizes the results of the evaluation task. For both the single purpose missions, it can be seen that a Delta-class spacecraft has been chosen as the first choice. It is interesting to note that the second choice by the experienced engineers is also a Delta-class vehicle, even though the detailed evaluation arrived at a new generation shuttle-optimized spinner as the next best choice. Thus the advanced version of the RCA SATCOM has been selected for the detailed configuration work for both the Military and the Mobile missions.

For the Combined mission, the newly designed L-SAT bus appears to be the best choice. This is primarily because of the significant growth potential for DC power that is inherently designed into the array. Under direction of the design authority, it has been decided to consider a conceptual design for the Combined mission based on the Intelsat V design of Ford Aerospace. This decision avoids duplication of effort as the Combined mission payload on L-SAT is being considered under separate contract. Also, for 1986 launch, the use of the Intelsat V bus may represent a lower risk program than L-SAT.

SPACECRAFT	MILITARY	MOBILE	COMBINATION
SATCOM ANIK B G-STAR	1 - possible	1 - possible	X - power, weight limited
ANIK D	X - little margin previous SPAR study	X - small equipment mounting area, especially for large antenna	X - power, weight, volume limited
BSE	X - little margin - not recommended by GE engineers	X - not recommended by GE engineers	X - power, weight limited
DSCS III	X - TITAN III launch vehicle not available	X - TITAN III launch vehicle not available	X - major cost for change to single launch
FLTSATCOM	4 - no N-S station-keeping	3 - possible	X - power weight limiting - no N-S station-keeping
INSAT ARABSAT	2 - possible (use north array like ARABSAT)	2 - possible	X - weight limited
INTELSAT V	X - too large	A - larger capacity than minimum	2 - Centaur - Ariane launch - Shuttle
LSAT	X - too large	B - larger capacity than minimum	1 - Ariane - Shuttle
LEASAT	3 - shuttle only	4 - shuttle only	X - power limited
TDRSS	X - too large - shuttle only	C - larger capacity than minimum - shuttle only	3 - shuttle only

'X' IN SMALL BOX DENOTES DISQUALIFICATION OF SPACECRAFT

'A','B','C' Denotes Acceptance Host But Larger Capacity Than Required

Table 3-1 Relative Rankings of Candidate Spacecraft

ALTERNATIVE M-SAT STUDY

REVIEW OF SPACECRAFT HARDWARE

RESULTS OF EVALUATION TASK

MILITARY	1	2	3	4
DETAILED	ADVANCED SATCOM	LEASAT	FLTSATCOM	INTELSAT V
CONSENSUS	ADVANCED SATCOM	ARABSAT	LEASAT	FLTSATCOM

MOBILE (MINIMUM)	1	2	3	4
DETAILED	ADVANCED SATCOM	LEASAT	INSAT	INTELSAT V
CONSENSUS	ADVANCED SATCOM	INSAT	FLTSATCOM	LEASAT

COMBINED	1	2	3	4
DETAILED	L-SAT	INTELSAT V	TDRSS	
CONSENSUS	L-SAT	INTELSAT V	TDRSS	

Table 3-2

4.0 PARAMETRIC ANALYSES

Analyses are required in order to establish the sensitivity of the baseline characteristics of the military, mobile and combined missions to variations of performance and technical characteristics.

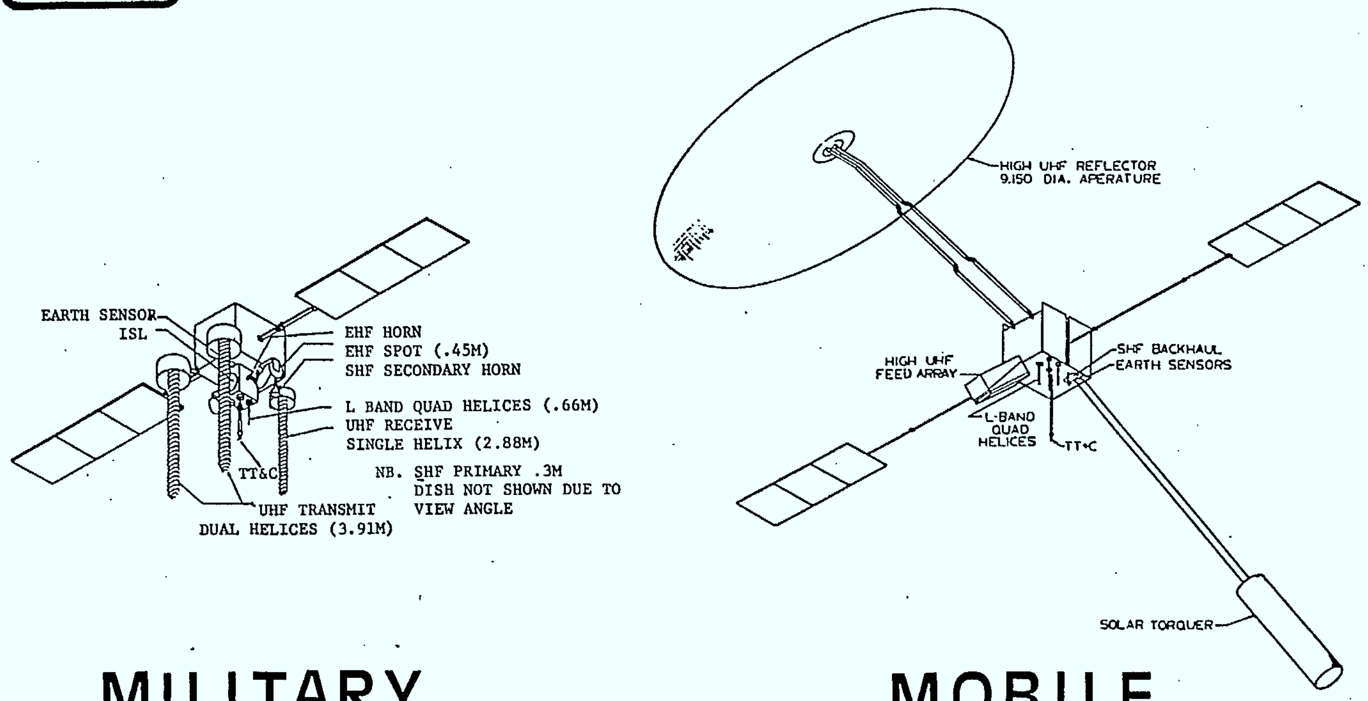
For the purposes of this study, the concept for the Military payload was taken essentially as fixed by the concept documents with some minor tradeoffs in antenna designs. Consequently, the parametric analyses were conducted to determine the optimum 800 MHz Mobile capability for purely Mobile, as well as the combined payloads.

The military mission has been defined to the extent that the principal parameters unique to that mission concern the UHF transmit and receive antennas, the L-band antenna, and the EHF/ISL antenna. The analyses are in Section 4.1. The need for parametric analysis for the mobile mission is considerable, and a number of studies and the results are contained in Sections 4.2 and 4.3. The impact of combining the missions is described in Section 4.4, while the sensitivity to parameter change is analysed in Section 4.5.

During the study, a number of specific problems relating to intermodulation products, MSK modulation, Solar torque, and array shadowing were examined and reported in Section 4.5 through 4.9.

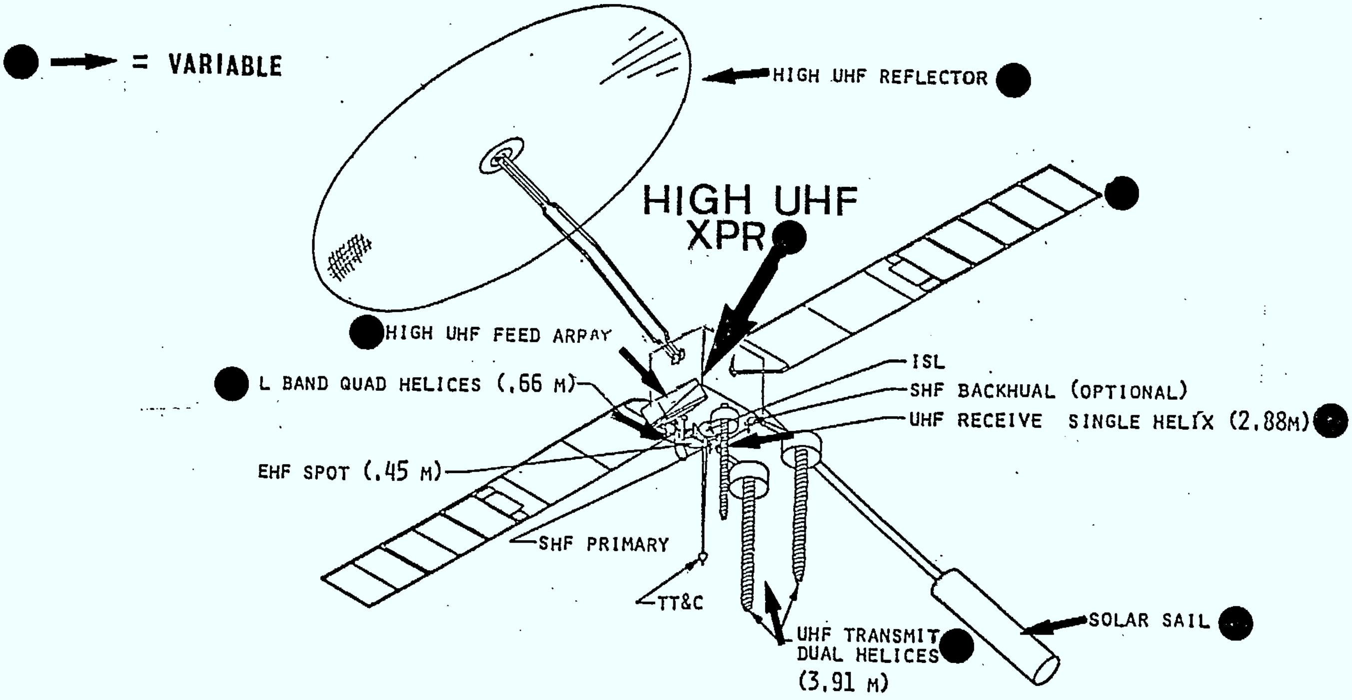
For convenience, Figure 4-1 illustrates the spacecraft configurations for the three missions; the development of these configurations is covered in Chapter 5.

On page 39, the methodology for the parametric analysis is described, while on page 40, the parameters of the three missions are tabulated.



MILITARY

MOBILE



COMBINED

FIG. 4.-1 INDICATION OF PARAMETERS TO BE VARIED, FOR TYPICAL MILITARY, MOBILE AND COMBINED MISSION SPACECRAFT

OBJECTIVES

A - Analyse, by detailed computations, the effects of all realistic payload parameters, within range of available buses.

B - Compare results with payload capabilities of available buses, in order to optimize simultaneously mass and power for best bus utilization, i.e. neither under, nor over, utilization of mass or power. Here, reference is made to system optimization, but not hardware design optimization.

C - For any given payload requirement, come up with a choice of several solutions to be decided upon later when combined with other bus trade-offs.

D - Supply major data/curves for DOC/DND for later use, for other buses and/or to suit variable payload requirements and options. This is not a statement of work requirement.

TASKS

A - Compute, analyse each payload variable separately,

B - Manage and organize large number parameters,

C - Compare variable payload mass and power to existing bus capabilities.

APPROACH

A - Need for simple solutions,

B - Explore graphical methods

PAYLOAD PARAMETRIC ANALYSIS & OPTIMIZATION FOR A GIVEN BUS

MILITARY

FIXED*
SHF XPR
EHF
ISL

VARIABLE	POSSIBLE SOLUTIONS
UHF TX ANT	DISH, HELIX OR HELICAL ARRAYS
UHF RX ANT	DISH, HELIX OR HELICAL ARRAYS
L-BAND ANT	DISH, HELIX OR HELICAL ARRAYS

MOBILE

FIXED
SHF ANT

	VARIABLE	RANGE
1	MODULATION SCHEME	PE,RE,FM
2	CHANNEL BANDWIDTH	3,6 -- 27 KHz
3	FREQUENCY REUSE	YES OR NO
4	NUMBER OF BEAMS, DOWNLINK	2 -- 8
5	UNIFORM TRAFFIC INTENSITY:ERLANG/USER	.008 -- .016 ERL/USER
6	BLOCKING RATE	1% -- 10%
7	PROJECTED 7 YEAR EOL # OF USERS	UP TO 25000
8	ECLIPSE CAPABILITY	25 -- 100%
9	NUMBER OF CHANNELS	200 -- 400 CH.
10	VOICE ACTIVATION	YES OR NO
11	TX NET EFFICIENCY	18 -- 36%
12	SAT.ANT.POINTING ACCURACY	0.30 DEGREES MAX.
13	SAT.ANT. NET GAIN	20 -- 33 dB
14	SAT.RF TX POWER/CH.	.3W - 30.W
15	GROUND MOBILE TX ANT.GAIN	1 - 7 dB
16	GROUND MOBILE TX RF POWER	0.5W - 120.W
17	SPACECRAFT N-S STATIONKEEPING	YES OR NO
18	SPACECRAFT LIFETIME	5 -- 10 YEARS
19	SHF BH XPR MASS & POWER	FOR 200 -- 400 CH.
20	TYPE OF DEPLOYABLE REFLECTOR	LOCKHEED (HARRIS)

COMBINED = **MILITARY + MOBILE**

*Operating characteristics are firm and were not varied for parametrics, except for obvious advantages in antenna design. In the case of the combined mission, military requirements were considered fixed while the mobile requirements were varied to optimize the utilization of the buses.

4.1 PARAMETRICS FOR MILITARY MISSION ANTENNAS

A trade-off analysis for the antenna sizes for the military spacecraft requirement was performed in order to determine the optimum mechanical configuration acceptable for the mission. The four antenna requirements addressed were the UHF transmit, UHF receive, L-band service and EHF including the inter-satellite link.

4.1.1 UHF TRANSMIT

The most difficult requirement would seem to be the UHF transmit antenna. The performance requirements have been determined as:

Frequency	275 to 287 MHz, λ = 1.07 m
Gain	17.5 dBi at 5.5° off boresight
Polarization	RHCP

It is assumed that the antenna nominal gain required to meet the EIRP requirement for the link is as defined in reference 1. It should be realized that a 5 dB margin is included, even though 2 dB was stated as adequate in most cases. Furthermore, the calculations were based on a nominal 50 watt HPA. Since it is important to reduce the size of the antenna to simplify its deployment and stowage, it has been assumed that the HPA power may be increased to offset any reduced antenna gain.

Helical antennas have been assumed as baseline for this application, and a pitch angle of 12.8° was used to be consistent with the data in reference 8 and 9. For end-fire helices, it is important to keep the circumference of the helix less than or equal 1.1λ. However, as the gain is proportional to diameter, it is important to use as large a diameter as possible. Thus a value of 1.1λ for the helix circumference was used for the analysis.

From reference 8, the boresight gain has been calculated as a function of number of turns or helix length. The resulting gain at the 5.5° edge of the coverage area has been deduced.

Finally, the ± 5.5° gains of the twin, triple and quad helices were estimated. The resulting gains are given in Table 4.1-1 and plotted in Figure 4.1-1. It is significant to realize that for helical antennas, unlike parabolic reflectors, the maximum usable gain value for practical considerations is 18 dB because helices become excessively long and the gain unpredictable. It is equally important to note that hardware experience with practical helices that have flown in spacecraft is relatively scarce. In many cases, measured values for gain have differed by as much as 1 dB from theoretical values, due to the lack of available adequate theoretical treatment of the subject. For example, the gain expression given by reference 8, equation (1) which itself is empirical, does not take into account the effect on gain values of tapering the last few turns of the helix, for matching purposes.

The original specification value for gain of 18 dB (later respecified as 17.5 dB) is plotted as well as levels 1, 2 and 3 dB below the specified level. If the nominal gain is based on 50 watts of HPA power, then the other levels correspond to 63, 80 and 100 watts of HPA power respectively.

The result is that there are 14 options for antenna design and amplifier performance which meet the required EIRP. These are summarized in Table 4.1-2.

Layout consideration would seem to favour a dual helix design for Delta-class vehicles, as stowage constraints prohibit consideration of quad helices. For the initial layout, a dual helix antenna was assumed with each helix about 0.38 m (15") in diameter and 3.91 m (154") long. This length of about 15 turns, corresponds to the -2 dB level and is adequate to include matching turns at the base of the helix. Spacing between the helix centres was 1.70 m (67") and the ground plane cups were 0.84 m (33") in diameter and 0.41 m (16") deep. The two helices are best aligned in a north-south direction because this will result in a pattern better optimized for Canadian land mass and coastal waters coverage.

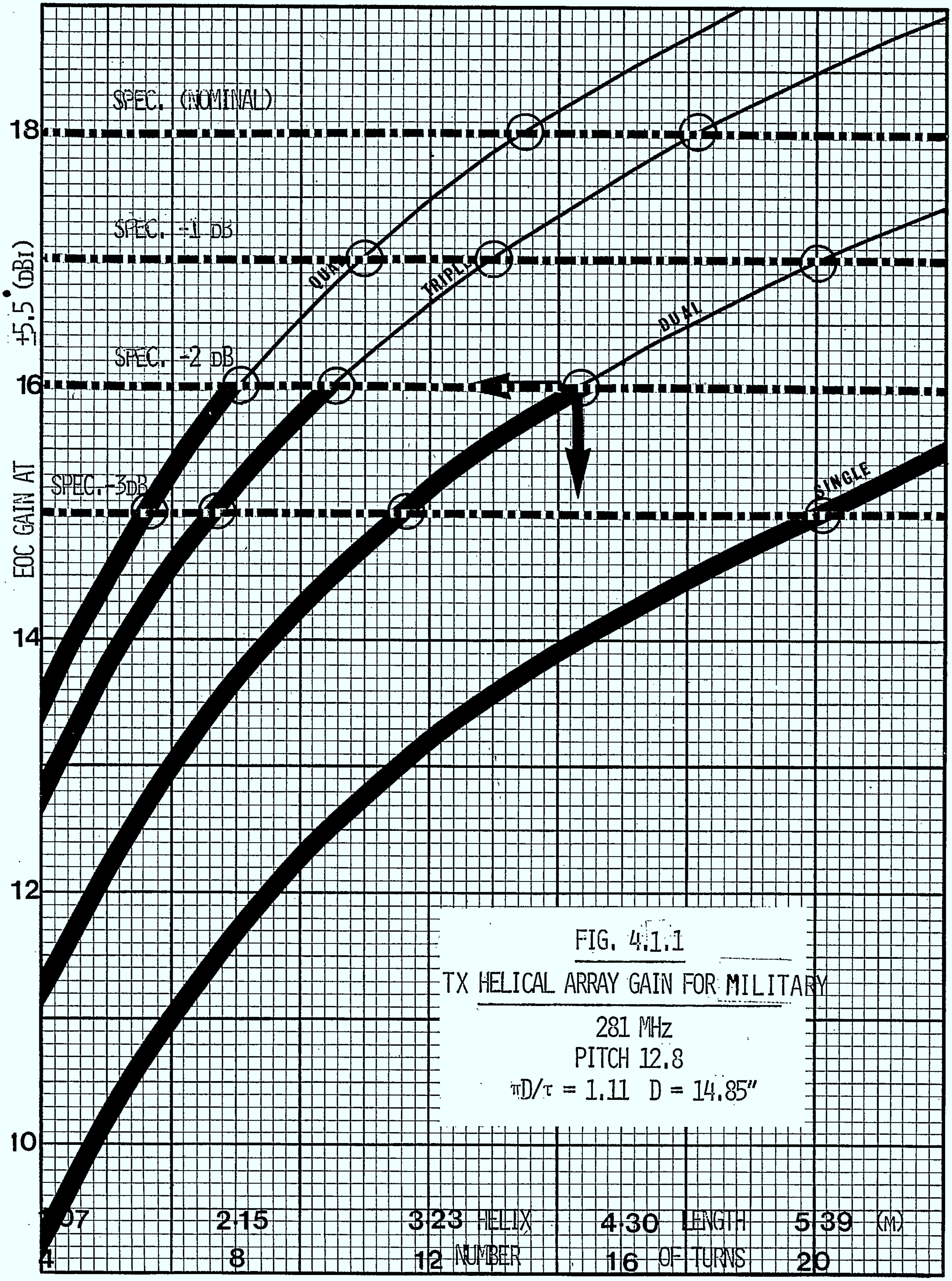


FIG. 4.1.1

TX HELICAL ARRAY GAIN FOR MILITARY

281 MHz

PITCH 12.8

$\pi D/\tau = 1.11$ D = 14.85″

Table 4.1-1 Transmit Antenna Gains in dB

No. of Turns Length (meters)	4 1.07	8 2.15	12 3.23	16 4.30	20 5.39
On Axis Gain	9.72	12.4	14.0	15.2	16.1
Gain at 5.5° off axis	9.2	11.7	13.2	14.2	15.0
Gain of Twin Helices	11.2	13.7	15.2	16.2	17.0
Gain of Triple Helices	12.7	15.2	16.7	17.7	18.5
Gain of Quad Helices	13.5	16.0	17.5	18.5	19.5

Table 4.1-2 Transmit Antenna Lengths in meters

		Length (Meters)		
	Single	Dual	Triple	Quad
Nominal Power 50 watts	---	6.12	4.05	3.23
+ 1 dB = 63 watts	---	4.74	3.05	2.47
+ 2 dB = 80 watts	6.46	3.55	2.37	1.93
+ 3 dB = 100 watts	4.72	2.68	1.83	1.48

4.1.2 UHF RECEIVE

A similar analysis has been performed for the receive antenna requirement of:

Frequency	397 - 406 MHz, λ = 0.75 m
Gain	14.0 dBi at 5.5° off boresight 9 dBi at 14.5° off boresight
Polarization	LHCP

Figure 4.1.2 shows the solutions for single, dual, three and quad helices. The length for each of the solutions is:

	Single	Double	Triple	Quad
Length (meters)	2.88	1.64	1.10	.88

A convenient solution is a 2.88 m (113") helix with a 0.26 m (10¼") diameter, using a 0.625 m (24.6") ground plane cup with 0.3 m (11¾") high sides.

4.1.3 L-BAND SERVICE

Using the same analysis, the sizing of the MARISAT L-band quad helix antenna was duplicated. This antenna has an on-axis gain of 18 dBi. The 20 dBi specification can be met by lengthening the four helixes from 0.66 m to 1.13 m each. However, it is recommended to relax the specification to be the same as the MARISAT requirement so that the L-band Maritime service antenna designed for Intelsat V could be used without modifications. The size of this antenna was calculated to be four helices each 0.066 m (2.6") diameter by 0.66 m (26") long, on a centre to centre spacing of 0.30 m (11.9") with ground cups 0.157 m (6.2") in diameter and 0.076 m (3") high.

If there is any interest in removing the L-Band payload and then replacing the dual helices with either triple or quad helices, further work will be required.

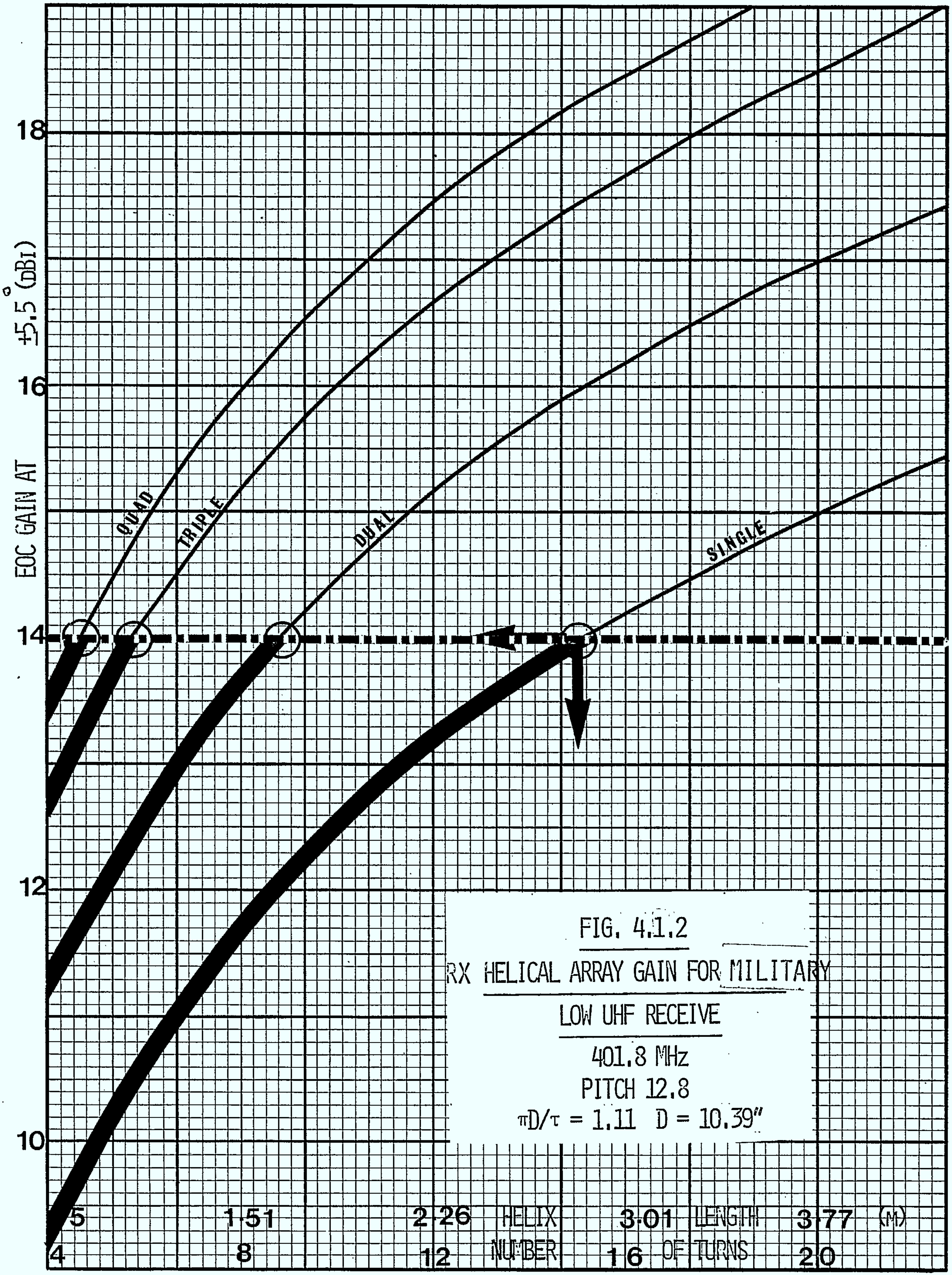


FIG. 4.1.2

RX HELICAL ARRAY GAIN FOR MILITARY

LOW UHF RECEIVE

401.8 MHz

PITCH 12.8

πD/τ = 1.11 D = 10.39″

4.1.4 EHF AND ISL ANTENNAS

It is feasible to consider an EHF system with a 0.2 m transmit dish (steerable plate) along with a 0.7 m receive antenna. The larger receive antenna would increase the jamming margin on the uplink because of the smaller beam size. Unfortunately, because of mounting constraints on the forward deck, no larger than 0.45 m diameter reflectors can be accommodated.

The ISL link can be implemented with a 0.5 m reflector as required by the baseline document.

4.2 PARAMETRIC ANALYSES FOR MOBILE MISSION PAYLOAD

INTRODUCTION

Typical configurations for Military, Mobile and Combined mission spacecraft are shown in Figure 4-1. For the purpose of completeness all payload parameters, identified by arrows, are considered for the parametric analysis, although the statement of work specifies six parameters only. These are:

1 - Spacecraft lifetime
2 - UHF antenna
3 - UHF Tx efficiency
4 - Eclipse
5 - Mobile gain antenna
6 - Voice activation and duplex

Some assumptions have been made. For instance, useful payload power and mass values to be considered from this study are only those that do not require, for available buses, any major redesign of bus parameters, such as D.C. Power (Solar array and battery), dynamic, thermal, structural or mechanical redesign. Typical useful ranges for payload power and mass are 700 W to 1500 W and 100 Kg to 300 Kg, as indicated in the survey of candidate spacecraft.

4.2.1 MOBILE BANDWIDTH AND (C/N) CONSIDERATIONS

Two major considerations are vital in the efficient design of a mobile satellite system:

- channel bandwidth, due to the limited available bandwidth
- RF and hence dc power per channel bandwidth on the transponder, since the mobile user has a low gain antenna and serious blockage.

Reference 2 addresses various modulation schemes, namely Narrow Band Frequency Modulation (NBFM) and Digital Modulation. The objective was to adopt a modulation scheme that reduces both channel bandwidth and power, and yet conserves an acceptable intelligibility. An "Articulation Index" (AI), Reference 10, is a Figure of Merit or a weighted fraction representing, for a given speech channel and noise condition, the effective proportion of the normal speech channel which is available to the listener for conveying intelligibility. CCIR, Reference 11, reports the results of some subjective assessments of the speech quality of NBFM.

The baseline requirements for total link C/N were given as 42 dB.Hz, 45 dB.Hz and 53 dB.Hz for the Pitch Excited/Linear Predictive Coding (PE/LPC), Residual Excited/Linear Predictive Coding (RE/LPC) and NBFM respectively. The corresponding satellite 800 MHz EIRP per channel are given as 28.7, 31.7 and 39.7 dBW/channel.

The channel spacing was given as:

- 30 kHz for NBFM, the bandwidth being 27 kHz, and
- 5 kHz for PE/LPC and RE/LPC

Granemyer and McBride, Reference 5, have determined, via computer simulation of band-limited double-hop links, the "performance degradation" with respect to ideal detection (infinite bandwidth) versus channel noise bandwidth. Performance degradation is defined as the ratio of the total link E_b/N_o required on the simulated link to achieve the desired BER to the E_b/No required on an infinite bandwidth, White Gaussian Noise (WGN) channel to achieve the same BER. For example, a channel bandwidth of 1.1 f_s (f_s is the signalling rate in bit/sec) gives a degradation of ≈0.6 and ≈0.8 dB for BER of 10^{-4} and 10^{-7} respectively.

In addition, they have calculated the C/A (carrier to adjacent channel interference ratio) for a range of filter bandwidths and channel spacings. Using their results, for a C/A = 25 dB, a 1.1 f_s channel spacing gives a 0.75 dB performance degradation and requires a 1.05 f_s bandwidth.

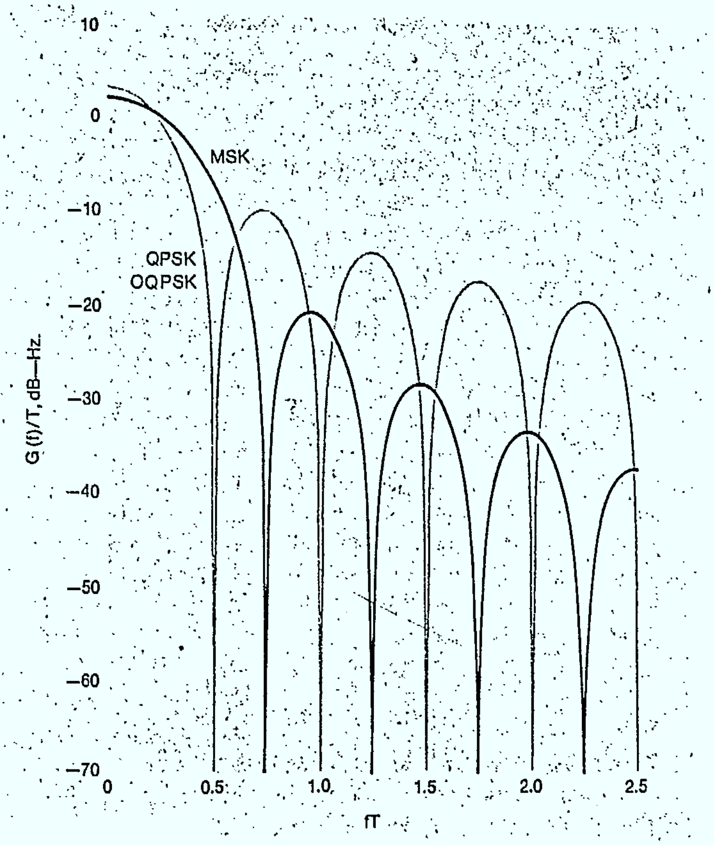
Although narrower bandwidths could be used without significant degradation, if delay equalization is used, then the 1.1 f_s bandwidth point represents a knee in the theoretical degradation vs channel bandwidth curve (Figure 9 in Reference 5) below which the degradation increases significantly. The permissible channel spacing is determined by the C/A specification as well as the allowable BER or available power to maintain a certain BER.

However, due to some discrepancy between experimental and theoretical results (Reference 4), a value of 1.5 f_s for channel bandwidth was adopted to ensure in principle, a BER of 10^{-7}, and an E_b/N_0 degradation of 0.2 dB theoretical and 1.4 dB experimental due to equipment degradation.

The MSK can be viewed either as an OQPSK signal with sinusoidal pulse weighting or as a continuous phase FSK signal with a frequency separation equal to half the bit rate. (Reference 12).

The spectral density G(f) for MSK is given by:

$$\frac{G(f)}{T} = \frac{16}{\pi^2}\left[\frac{\cos(2\pi f T)}{1-16 f^2 T^2}\right]^2 \quad \text{[shifted to baseband]}$$



Spectral Density of QPSK, OQPSK, and MSK

Bandwidth (BW) is usually considered to be the main lobe width. For,

MSK/PE/LPC: channel spacing specification from document (Reference 2) is 5 kHz.

LPC coding at 2.4 KBPS → $T = 1/2400$ Hz

$$\therefore BW = \frac{1.5}{T} = 3.6 \text{ kHz}$$

So the 5 kHz channel spacing ensures some adjacent channel isolation of 1.4 kHz.

MSK/RE/LPC: LPC coding at 4.8 kbps

BW = 1.5 x 4800 Hz = 7.2 kHz;

if 1.4 kHz channel isolation is used for LPC

Ch. spac. = 7.2 + 1.4 = 8.6 kHz

Since it is mentioned in the document, an 8.6 kHz channel spacing is recommended as an adequate spacing for RE/LPC. It should be noted that the channel spacing will depend upon the modulation scheme used. For example, a multiple phase modulation scheme requires less bandwidth. Also note that the above analysis does not account for spectrum dispersion caused by multipath and Doppler normally encountered in a mobile environment.

4.2.2 NUMBER OF MOBILE CHANNELS FROM BANDWIDTH AND TRAFFIC STATISTICS

4.2.2.1 Bandwidth Considerations

This is an important consideration that may lead to a decision for frequency reuse with three or more beams across Canada.

The available RF bandwidth for the 800 MHz Mobile Service is only 4 MHz. For the purpose of this study, the available RF bandwidth for the 800 MHz Mobile Service is assumed to be 4 MHz for both uplink and downlink, although more may be available pending appropriate negotiations. Therefore, assuming that PE/LPC, RE/LPC and NBFM require 5 kHz, 8.6 kHz and 30 kHz per channel respectively, then it is clear that the maximum number of RF channels possible with no frequency reuse would be:

- 800 for PE/LPC
- 465 for RE/LPC
- 133 for NBFM

4.2.2.2 Voice Activation

This has the effect of reducing the required satellite transmitted power. For a large number of available channels per beam, e.g. 100 or more, the equivalent number of simultaneously active channels requiring power at any one time is greatly reduced, e.g. by a factor of 2.5 to 1. However, for smaller number of channels per beam, e.g. 30, only 18 channels are considered simultaneously active. Figure 4.2-1, Reference 16, indicates the effect on the required number of channels of voice activation. Should negotiations for frequency spectrum for Canadian Mobile Communications result in a 10 MHz bandwidth in each the uplink and downlink, the maximum number of physical channel circuits that the link can handle becomes:

2000 channels for PE/LPC
1163 channels for RE/LPC
333 channels for NBFM

This implies that for a 10 MHz bandwidth, frequency reuse is not needed if the total number of channels does not exceed those above. Figure 4.2-2 displays the results.

Assuming that large numbers of channels per beam are used, the payload power requirements for a full 4 MHz and 10 MHz bandwidth would be reduced by a factor of 2.5, i.e. equivalent to:

4 MHz BW		10 MHz BW
320 channels		800 channels
186 channels	and	465 channels respectively
53 channels		133 channels

This represents a considerable reduction to the payload power requirements.

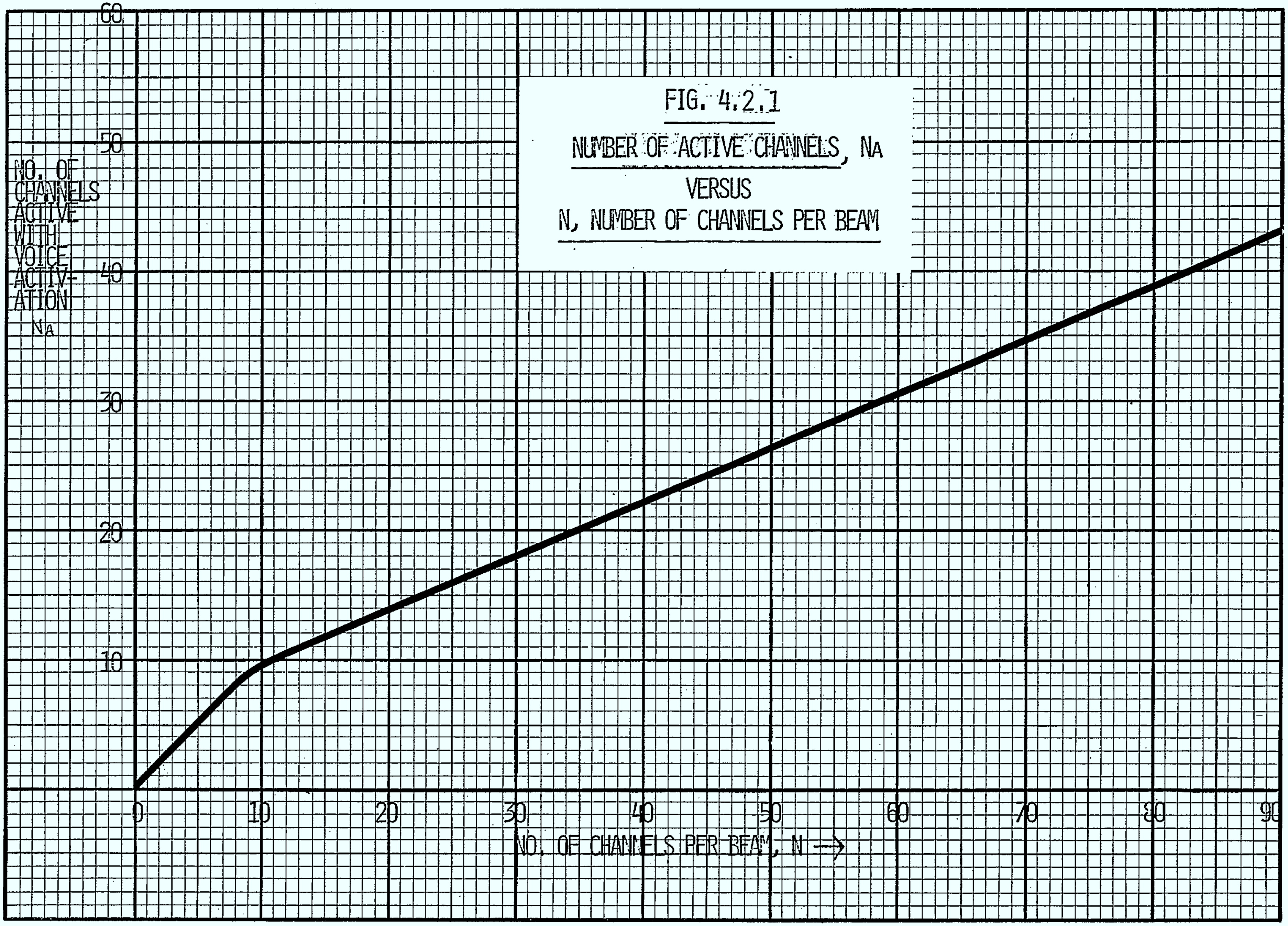


FIG. 4.2.1

NUMBER OF ACTIVE CHANNELS, N_A

VERSUS

N, NUMBER OF CHANNELS PER BEAM

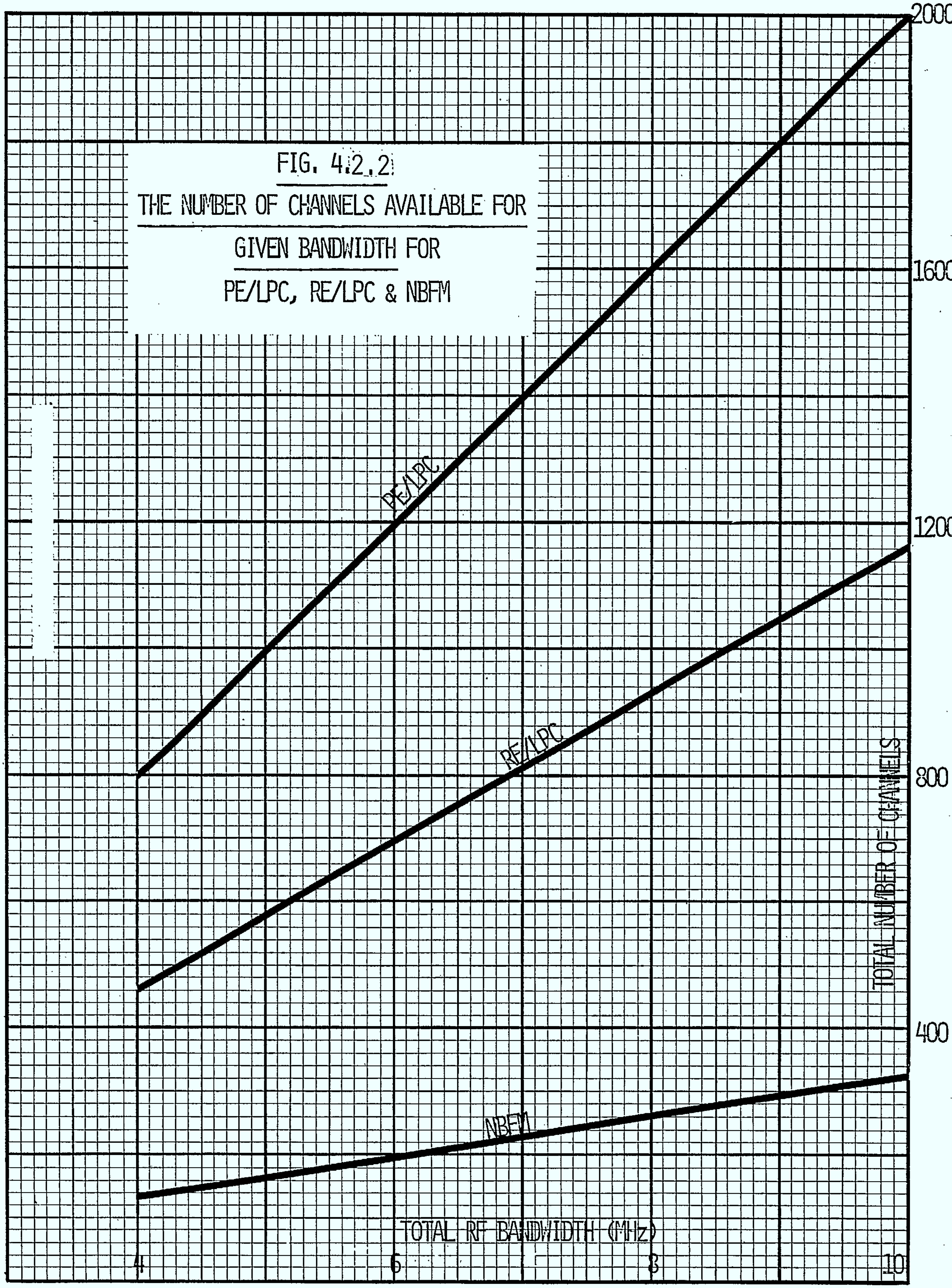


FIG. 4.2.2
THE NUMBER OF CHANNELS AVAILABLE FOR
GIVEN BANDWIDTH FOR
PE/LPC, RE/LPC & NBFM

4.2.2.3 Number of Users From Market Study

During the progress of our study, the results of a market evaluation were made available (Reference 3). This indicates that by year 1993, corresponding to 7 years into the mission, the service would be used by approximately 25,000 mobile users.

This market projection found that about 0.012 Erlang per user would be the traffic intensity at the busiest hour of the day. Table 4.2-1 and Figure 4.2-3 displays the distribution of users, by type and year.

Table 4.2-1 M-SAT Projected Number of Mobiles*

	IN THOUSANDS OF USERS BY YEAR 1987	1991	1996	2001	% OF TOTAL
In Vehicle					
MRS	0.4	6.6	35	84	60.0
MTS	0.1	1.2	7	20	14.3
Personal Portable	0.1	2.1	12	32	22.9
Field Portable	0.0	0.1	1	2	1.4
Transportable	0.0	0.1	1	2	1.4
TOTAL	0.6	10.1	56	140	100.0%

*Reference 3.

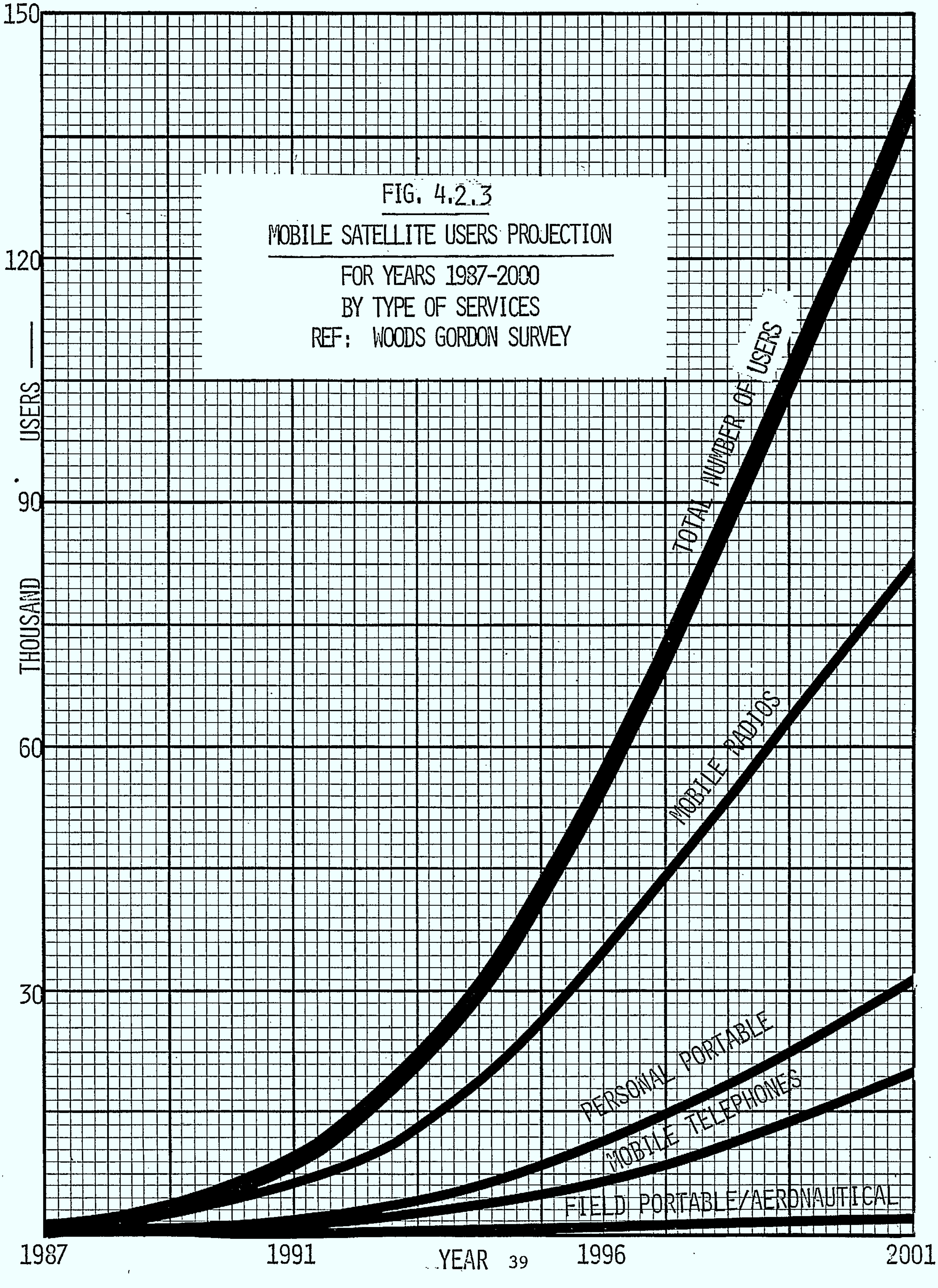


FIG. 4.2.3

MOBILE SATELLITE USERS PROJECTION

FOR YEARS 1987-2000
BY TYPE OF SERVICES
REF: WOODS GORDON SURVEY

4.2.2.4 Number of Channels Per Beam From Traffic Statistics

One of the objectives of the parametric study is to evaluate the effect of varying the number of beams and hence the resulting channels per beam, according to different assumptions of traffic intensity and blockage rate.

The baseline requirement specifies a maximum capacity based on 25,000 users with a 0.012 Erlang per user. Note that these conditions exist only at the end of life of the mission.

It is worth looking into the required number of channels per beam for:

- Traffic intensity of 0.008, 0.012 and 0.016 Erl/user.
- Blocking rates of 10%, 3% and 1%, i.e. 1 call in 10, 33 or 100 calls is lost during the busiest hour (an indication of the Grade of Service).

Erlang B loss probability functions will be assumed here. This model assumes that calls, not immediately satisfied at the first attempt, are cleared from the system and are not delayed or held.

25,000 users require: 25,000 x (0.008 or 0.012 or 0.016 Erl/user) or a total of 200, 300 or 400 Erlangs.

This traffic is assumed to be shared equally amongst N_B Beams and not demographically. Therefore, for N_B varying from 2 to 8, the traffic intensity per beam varies between 25 and 200 Erl/beam. The corresponding number of "circuits" required to carry this traffic, N_{CB}, at three grades of service, are taken from Erlang B statistics. The results applicable to 25,000 users are shown in Table 4.2-2 and are plotted in Appendix H. However, Figure 4.2-4 shows typical case for voice activiation and .012 Erl/user.

In addition, the total number N_A of simultaneously active channels in a transponder was deduced, using the voice activation chart of N_{CB}, Figure 4.2-1.

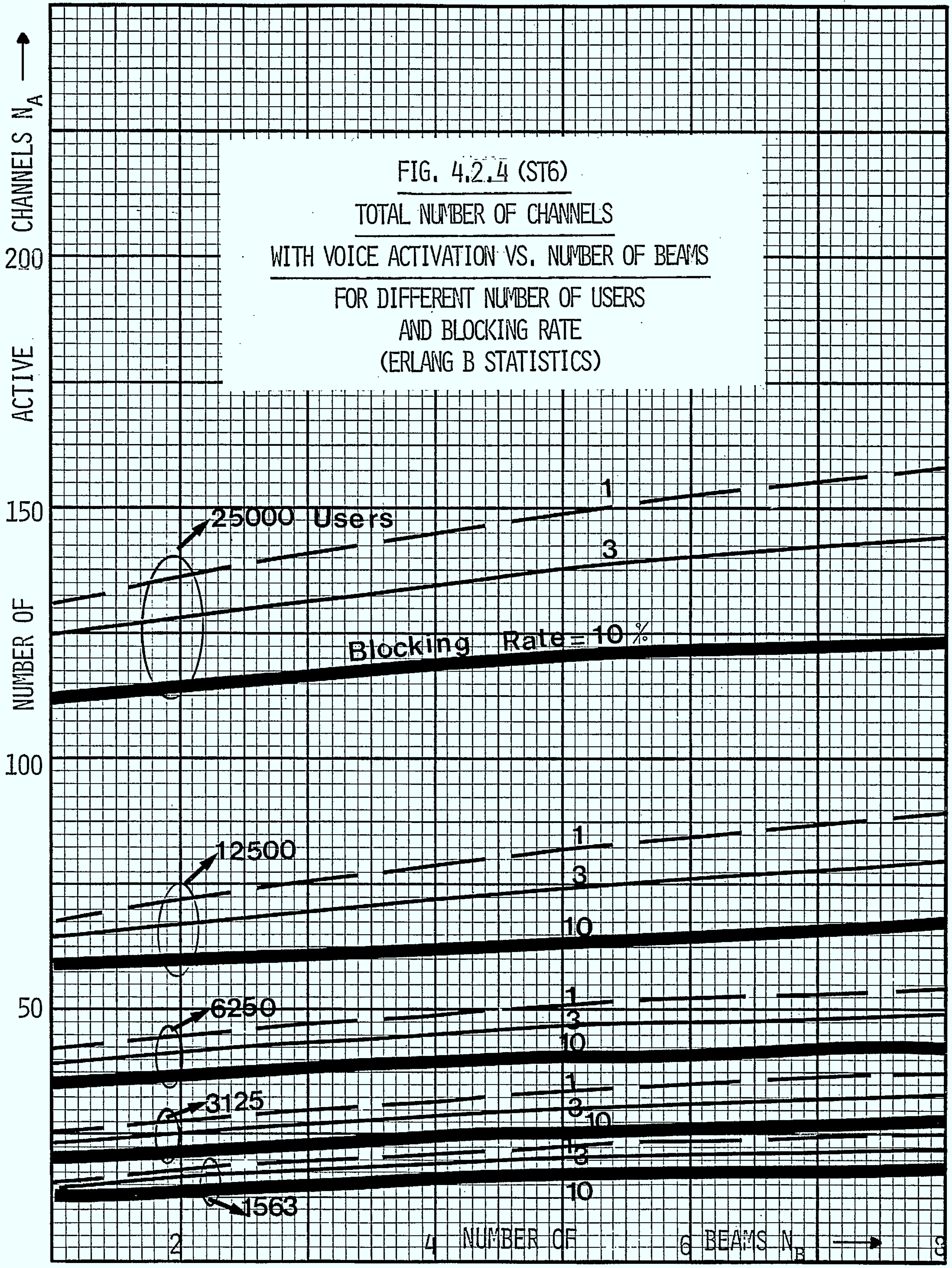


FIG. 4.2.4 (ST6)

TOTAL NUMBER OF CHANNELS

WITH VOICE ACTIVATION VS. NUMBER OF BEAMS

FOR DIFFERENT NUMBER OF USERS

AND BLOCKING RATE

(ERLANG B STATISTICS)

From the transponder payload utilization point of view, the use of the smallest number of beams possible would be more efficient.

The grade of service, from 10% to 1% blocking rate has a first order effect on the number of channels N or Na required.

For eclipse requirements, we may use the number of channels corresponding to 25% of total users, i.e. 6250 users for the corresponding Erl/channel and blocking rate.

TABLE 4.2-2

NUMBER CHANNELS/BEAMS N_{CB}, TOTAL NUMBER OF CHANNELS N, AND NUMBER OF ACTIVE CHANNELS N_A FROM ERLANG "B" FUNCTION STATISTICS

			.008 ERL/USER				.012 ERL/USER				.016 ERL/USER			
			No. of BEAMS				No. of BEAMS				No. of BEAMS			
No. of USERS	BLOCK. RATE %	No. CHAN.	2	4	6	8	2	4	6	8	2	4	6	8
25000 (100%)	10%	N_{CB}	97	50	35	27	142	73	51	39	188	96	66	51
		N	194	201	210	216	284	293	303	310	376	384	395	404
		N_A	78	80	84	87	114	117	121	124	151	153	158	162
	3%	N_{CB}	110	59	41	32	160	84	59	45	210	110	71	59
		N	220	234	246	257	320	336	350	363	420	440	453	467
		N_A	88	93	99	103	128	134	140	145	168	176	181	187
	1%	N_{CB}	117	63	45	36	170	91	64	50	222	117	82	63
		N	234	253	269	283	340	361	380	396	444	468	488	506
		N_A	94	101	108	113	136	144	152	158	178	188	195	203
12500 (50%)	10%	N_{CB}	51	27	19	15	74	39	27	21	97	51	35	27
		N	101	108	115	120	147	155	162	169	194	202	210	216
		N_A	46	48	50	52	60	62	65	68	78	81	84	87
	3%	N_{CB}	59	32	23	18	84	45	32	25	110	59	41	32
		N	117	128	138	147	168	181	192	202	220	234	246	257
		N_A	51	54	57	60	67	72	77	81	88	93	99	103
	1%	N_{CB}	63	35	26	21	91	50	36	28	117	68	45	36
		N	127	142	154	165	181	198	212	225	234	284	269	283
		N_A	54	58	63	66	72	79	85	90	94	101	108	113

TABLE 4.2-2 (continued)

No. of USERS	BLOCK. RATE %	No. CHAN.	.008 ERL/USER				.012 ERL/USER				.016 ERL/USER			
			No. of BEAMS				No. of BEAMS				No. of BEAMS			
			2	4	6	8	2	4	6	8	2	4	6	8
6250 (25%)	10%	N_{CB}	27	15	11	9	39	21	15	12	51	27	19	15
		N	54	60	65	69	78	84	90	95	101	108	114	120
		N_A	28	30	32	34	38	40	42	49	46	48	50	52
	3%	N_{CB}	32	18	13	11	45	25	18	15	59	32	23	18
		N	64	73	81	87	91	101	110	117	117	128	138	146
		N_A	32	36	38	41	42	46	48	51	51	54	57	60
	1%	N_{CB}	36	21	15	13	50	28	21	17	63	36	26	21
		N	71	82	92	100	99	113	124	133	127	142	154	165
		N_A	35	39	43	46	45	49	53	56	54	58	63	66
3125 (12%)	10%	N_{CB}	15	9	6	5	21	12	9	7	27	15	11	9
		N	30	35	39	42	42	48	52	56	54	60	65	70
		N_A	18	20	21	23	23	25	28	28	28	30	32	34
	3%	N_{CB}	18	11	8	7	25	15	11	9	32	18	13	11
		N	37	44	49	55	51	59	65	71	64	73	81	87
		N_A	21	24	25	28	26	30	32	35	32	36	38	41
	1%	N_{CB}	21	13	10	8	28	17	13	10	36	21	15	13
		N	41	50	57	64	56	67	75	83	71	82	92	100
		N_A	22	26	29	32	29	33	36	39	35	39	42	46
1562 (6%)	10%	N_{CB}	9	5	4	3	12	7	5	4	15	9	6	5
		N	17	21	24	27	24	28	32	35	30	35	39	42
		N_A	13	14	15	16	15	17	19	20	18	20	21	23
	3%	N_{CB}	11	7	5	4	15	9	7	6	18	11	8	7
		N	22	27	32	36	29	36	41	45	37	44	49	55
		N_A	14	17	19	20	18	20	22	24	21	24	26	28
	1%	N_{CB}	13	8	6	5	17	10	8	7	21	13	10	8
		N	25	32	38	43	33	41	48	54	41	50	57	64
		N_A	15	19	21	23	19	22	25	28	22	26	29	32

4.2.3 MOBILE MISSION LINK ANALYSIS

4.2.3.1 Assumptions

A) From reference 2 and further discussions with DOC, it has been concluded that for the 800 MHz LINK, i.e. either FORWARD or RETURN, the one way total average Carrier-to-Noise Density and Interference ratio $(C/N_o+I)_t$ is assumed to be:

$(C/N_o+I)_t$ =

a) 42 dB.Hz for PE/LPC for acceptable, but below Toll quality,
b) 45 dB.Hz for RE/LPC for acceptable, but below Toll quality,
c) 53 dB.Hz for NBFM for Toll quality.

where, for convenience, Interference is treated as noise. It should be noted that within the constraints, the digital modulation schemes cannot achieve Toll quality by virtue of their coding distortion and not necessarily the noise density. The effect of using a $(C/(N_o+I))$ value of 47 dBHz for PE/LPC, instead of 42 dBHz, is investigated in Volume IV of this report.

B) The satellite (EIRP)s is assumed to be:

(EIRP)s = 28.7 dBw/channel for PE/LPC
31.7 dBw/channel for RE/LPC
39.7 dBw/channel for NBFM

C) In general, for one way link, e.g. Forward i.e. from Base to Mobile:

$$(C/N_o+I)_t = \text{sum contributions } \left[(C/N_o)_u+(C/N_o)_d+(C/IM)_{shf}+(C/IM)_{uhf}+(C/I)_{ib}\right].$$

The suffixes u, d, and ib refer to uplink, downlink, and interbeam.

$(C/N_o)_u$ = uplink, here SHF backhaul, Carrier-to-Thermal Noise Density Ratio

$(C/N_o)_d$ = downlink, here Mobile 800 MHz, Carrier-to-Thermal Noise Density Ratio

$(C/IM)_{shf}$ = SHF backhaul, here uplink, Amplifier Carrier-to-Intermodulation Ratio

$(C/IM)_{uhf}$ = UHF 800 Mobile, here downlink, Amplifier Carrier-to-Intermodulation Ratio

$(C/I)_{ib}$ = Interbeam, only in case of frequency reuse, Carrier-to-Interference Ratio, due to finite sidelobe levels.

In any one link, it is assumed arbitrarily that 70% of total average noise and interference assigned is due in this case to the UHF path Thermal Noise or 1.5 dB below total noise, while the other 30% is due to the backhaul path, or 5.23 dB below total noise.

Therefore, for the Forward link, the 800 MHz $(C/N_o)_d$ is:

$(C/N_o)_d$ = 43.5 dB.Hz for PE/LPC
46.5 dB.Hz for RE/LPC
54.5 dB.Hz for NBFM

The remaining 30% of the total average noise, intermodulation and interference power are budgeted for the rest of the link, i.e. for, in this case:

$(C/N)_u + (C/IM)_{shf} + (C/IM)_{uhf} + (C/I)_{ib}$ = 47.2 dB.Hz for PE/LPC
50.2 dB.Hz for RE/LPC
58.2 dB.Hz for NBFM

D) Minimum allowable $(C/I)_{ib}$, in the cases where three or more beams with frequency reuse are considered, as $(C/I)_{ib}$ = 18 dB in 27 kHz for NBFM.

Although this ratio could be less for the PE and RE/LPC modulation, it is assumed to be the same as for the NBFM, for the purpose of this study.

$(CI)_{ib}$ = 53.6 dB.Hz for PE/LPC, 3.6 kHz wide channel

56.6 dB.Hz for RE/LPC, 7.2 kHz wide channel

62.3 dB.Hz for NBFM, 27 kHz wide channel

E) The minimum permissible intermodulation ratios are:

$(C/IM)_{uhf}$ = 20 dB

$(C/IM)_{shf}$ = 25 dB

$(C/IM)_{uhf}$ = 55.6 dB.Hz for PE/LPC, 3.6 kHz wide channel

58.6 dB.Hz for RE/LPC, 7.2 kHz wide channel

64.3 dB.Hz for NBFM, 27 kHz wide channel

$(C/IM)_{shf}$ = 60.6 dB.Hz for PE/LPC, 3.6 kHz wide channel

63.6 dB.Hz for RE/LPC, 7.2 kHz wide channel

69.3 dB.Hz for NBFM, 27 kHz wide channel

4.2.3.2 Forward Link (Figure 4.2.5(A))

4.2.3.2.1 7/8 GHz SHF Backhaul Uplink

Since the 7/8 SHF GHz will be used as backhaul link, in both Military and combined missions, it will be considered at this point. Further frequency scaling could be used for the 12/14 GHz band suggested as the backhaul for the mobile only mission.

$$C/(N_0+I)_t = \text{sum contributions } \left[(C/N_0)_u+(C/IM)_{shf}+(C/IM)_{uhf}+(C/I)_{ib}\right]$$

i.e. $$(C/N_0)_u = \text{sum contributions } \left[C/(N_0+I)_t\right] - \left[(C/IM)_{shf}+(C/IM)_{uhf}+(C/I)_{ib}\right]$$

$$(C/N_0)_u = 49.8 \text{ dB.Hz for PE/LPC}$$
$$52.8 \text{ dB.Hz for RE/LPC} \quad (3)$$
$$60.1 \text{ dB.Hz for NBFM}$$

The Carrier-to-Thermal noise density ratio or C/KT ratio is given by:

$$(C/N_0)_u = (EIRP)_g - Lu - Mu + (G/T)_s - 10 \log K \quad (4)$$

where $(EIRP)_g$ = ground EIRP

Lu = uplink SHF Backhaul mean free space loss

Mu = uplink SHF Backhaul Fade Margin

$(G/T)_s$ = Satellite SHF Backhaul gain over system noise

K = Boltzman's Constant = 1.38×10^{-23} J/K =−228.6 dB/°K/Hz

Mu for the 8 GHz uplink is assumed equal to 4 dB. (It will be higher if 14 GHz is adopted.)

Lu = 202.5 dB at 7931 MHz

An SHF parabolic dish of 0.45 m is assumed, together with one uplink SHF beam of 8.7 degrees across the continent of Canada and 200 miles beyond the Eastern and Western shores. This would give an EOC gain of 29-7 = 22 dBi. However, it is unlikely the CCS will be located at sea, or even at the extreme Eastern and Western land tips spanning some 6.8 degrees across continental Canada.

The land EOC gain would be: 29-4 = 25 dBi. Assuming an RF circuit loss of 2 dB, the next minimum EOC gain is 23 dB. In fact, the net EOC gain for a 0.45 m backhaul dish, lies between 27 and 23 dB.

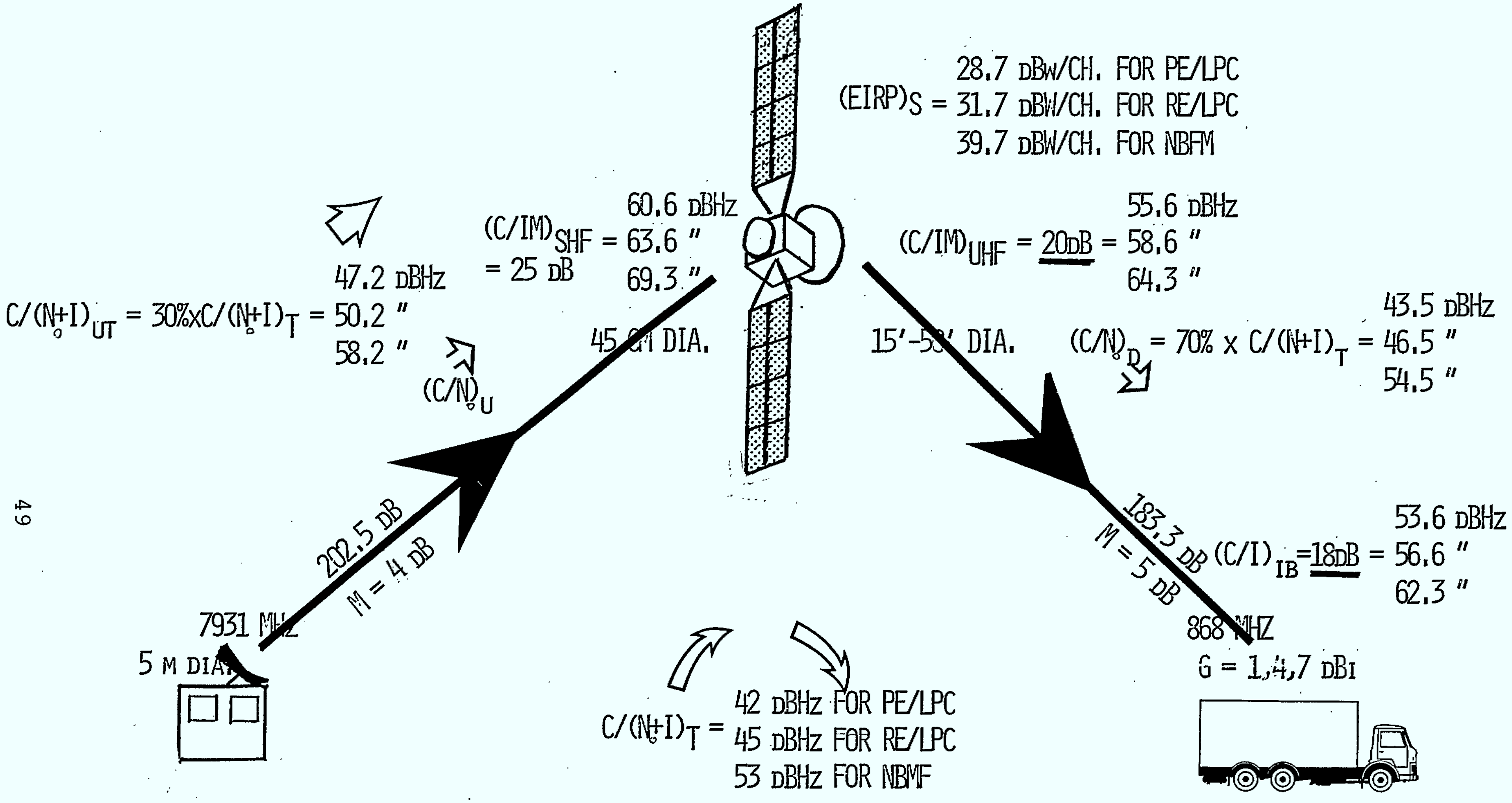


FIG. 4.2.5 (A) FORWARD LINK PARAMETERS

If an SHF Satellite Antenna System Temperature of 1000°K or 30 dB is assumed, then the worst value of $(G/T)_s$ is :

$$(G/T)_s = 23 - 30 = -7 \text{ dB/°K}$$

Replacing in equation (4)

$$\boxed{(EIRP)_g} = \boxed{(C/N_0)_u - 15.1} \qquad (5)$$

$$(EIRP)_g = +34.7 \text{ dBW/ch for PE/LPC}$$

$$+37.7 \text{ dBW/ch for RE/LPC}$$

$$+45.0 \text{ dBW/ch for NBFM}$$

For a 5 m dish, the boresight gain is: 49.8 - 2 = +47.8 dBi

Modulation	$(C/N_0)_u$	$(EIRP)_g$	SHF 8 GHz ground Transmit Power	
	dB.Hz	dB W/ch	dbW/ch	mW/ch
PE/LPC	49.8	34.7	-13.1	49.
RE/LPC	52.8	37.7	-10.1	98.
NBFM	60.1	45.0	- 2.8	525.

For FM, nearly half a watt per band RF power is required. This value will significantly increase at 14 GHz, where a higher uplink margin is required.

4.2.3.2.2 800 MH Downlink

Applying equation (4) for the downlink:

$$(C/N_o)_d = (EIRP)_s - L_d - M_d + (G/T)_g - 10 \log K$$

where:

L_d = downlink path loss, at 868 MHz

M_d = downlink fade margin (assumed 5 dB), much lower than the 13 dB that will be assumed for the UHF uplink, since it is assumed that mobile listeners (in the forward link) are less critical to toll quality degradation than Switched Telephone Network listeners (in the return link).

$10 \log K = -228.6$ dB/°K/Hz

Thus:

$$(C/N)_d = (EIRP)_s - 183.3 - 5 + (G/T)_g + 228.6$$

$$\text{or } (G/T)_g = \begin{array}{ll} 3.2 - (EIRP)_s & \text{for PE/LPC} \\ 6.2 - (EIRP)_s & \text{for RE/LPC} \\ 14.2 - (EIRP)_s & \text{for NBFM} \end{array}$$

The satellite (EIRP)s per channel has been baselined as 28.7, 31.7 and 39.7 dBW/channel respectively.

Thus $(G/T)_g$ = −25.5 dB/°K is the minimum value for all 3 types of modulations.

However, for practical cases, the following ground receive parameters can be considered as a guideline:

USERS		UHF GROUND RX				UHF FADE MARGIN AVAILABLE
TYPES	PERCENTAGE OF TOTAL	ANTENNA GAIN	ANTENNA LOSS	T	$(G/T)_g$	
		dBi	dB	°K	dB/°K	dB
Vehicular	MTS = 14.3% MRS = 60.0%	4	0	900	-25.5	5
Portable	Personal MRS = 22.9% Field = 1.4%	10	0.8	460	-17.4	13.1
Ship	0.7%	15	TBD	(500)	-12	18.5
Aircraft	0.7%	4	TBD	(400)	-22	8.5

The results of the forward link analysis are summarized in Table 4.2-3.

4.2.3.3 Return Link (Figure 4.2-5 (B))

4.2.3.3.1 800 MHz, Uplink

The same assumption holds i.e. 70% of the total link noise, Intermodulation and interference is allocated to the 800 MHz uplink.

$$(C/N_o)_u = 43.5 \text{ dB.Hz for PE/LPC}$$

$$46.5 \text{ dB.Hz for RE/LPC}$$

$$54.5 \text{ dB.Hz for NBFM}$$

Also, equation (4) applied to the 823 MHz uplink is:

$$(C/N_o)_u = (EIRP)_g - Lu - Mu + (G/T)_s - 10 \log K$$

However, the uplink margin Mu can be assumed as a variable, the worst value being 13 dB, due to diffuse multipath reflection from ground and shadowing by trees, i.e. constraints of the ground mobile transmitter antenna and its location. Taking,

$$(C/N_o)_u = (EIRP)_g - 182.8 - 13 + (G/T)_s + 228.6$$

$$\boxed{(EIRP)_g} = \boxed{\begin{matrix} 10.7 - (G/T)_s \text{ for PE/LPC} \\ 13.7 - (G/T)_s \text{ for RE/LPC} \\ 21.7 - (G/T)_s \text{ for NBFM} \end{matrix}} \qquad (6)$$

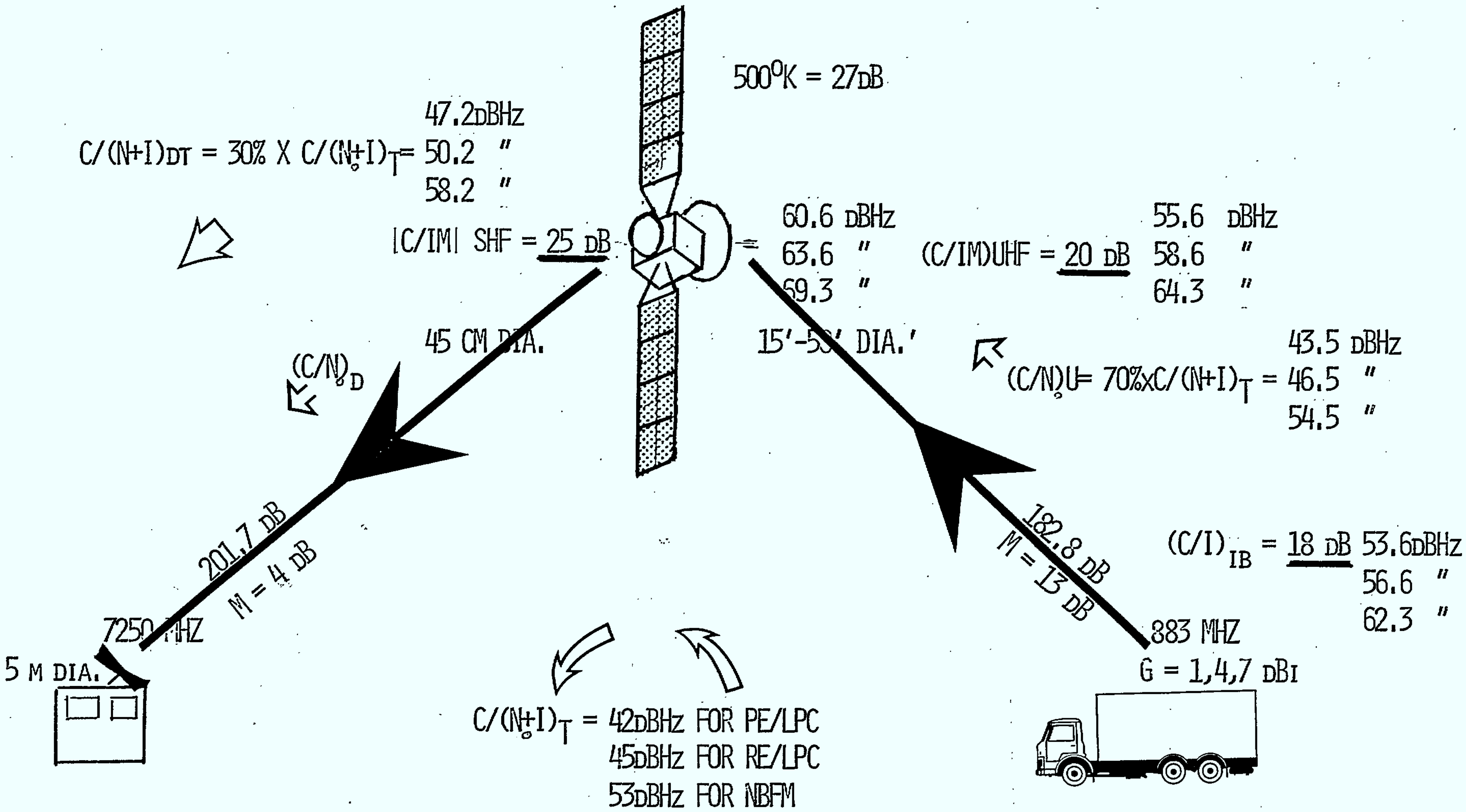


FIG. 4.2.5(B) RETURN LINK PARAMETERS

Therefore to determine the exact required ground mobile terminal transmit power, careful calculation of uplink satellite $(G/T)_s$ must be studied. The satellite receive system temperature T_s °K, is given by:

$$T_s = aT_A + (1-a)\, T_F + T_R \tag{7}$$

T_A, T_F and T_R refer to the temperature of the antenna, the feed and the receiver LNA referred to its input, respectively. They are assumed as:

$$T_A = 300°K \quad T_F = 290°K \quad \text{and} \quad T_R = 600°K$$

The antenna feed, has a loss L_R of 2 dB where, $a = 10^{-0.1L_R}$ $\therefore$ $a = 0.631$

$$T_S = 0.631 \times 300 + 0.369 \times 290 + 600 = 896°K \text{ or } 29.5 \text{ dB}$$

To finally calculate $(EIRP)_g$, we need to specify G in equation (6). However, it will be shown later that the satellite antenna gain, depends on several parameters, mainly the reflector diameter, the number and shape of beams, (assumed the same for TX or RX), the angular diameter of each beam configuration, which itself depends on the pointing accuracy assumed.

The results of these gain considerations are dealt with in Section 4.2.4, and will be used in Section 4.2.3.4 to arrive at the value of ground mobile transmitter power versus its antenna net gain.

4.2.3.3.2 7/8 GHz SHF Backhaul Downlink

Similarly, it is assumed that 30% of $C(N_o+I)_t$ contribution relates to the link less the 800 MHz uplink thermal noise. Thus applying equation (6) to the rest of the link:

$(C/N_o)_d$ = 49.8 dB.Hz for PE/LPC

52.8 dB.Hz for RE/LPC

60.1 dB.Hz for NBFM

and,

$$(C/N_o)_d = (EIRP)_d - L_d - M_d + (G/T)_g - 10 \log K \qquad (8)$$

Assume a 5m ground backhaul antenna of 49.0-2 = 47 dBi net gain at 7250 MHz, and a RX system temperature of 1000°K or 30 dB.

$\therefore (G/T)_g = 47 - 30 = 17$ dB/°K

Assume at 8 GHz, fade margin of 4 dB = M_d

$(C/N_o)_d = (EIRP)_d - 201.7 - 4 + 17 + 228.6$

$\therefore$ $(EIRP)_d$ = 9.9 dBW/ch for PE/LPC

12.9 dBW/ch for RE/LPC

20.2 dBW/ch for NBFM

The SHF backhaul downlink TX dish has a 0.45 m radius and a net boresight gain of 28.2 - 2 = 26.2 dBi at 7250 MHz.

Using the same discussion as in Section 4.2.3.2.1, the minimum net continental EOC SHF backhaul antenna gain is: 26.2 - 4 = 22.2 dB.

The SHF 7250 MHz Tx Power is:

$$P_d = (EIRP)_d - 22.2 \text{ dB}$$

MODULATION	$(C/N_o)_d$	$(EIRP)_g$	At 7250 MHz	
			For 0.45 m BH* Sat. Ant. and Net EOC gain of 22.2 dB	
			SAT BH* TX POWER	
	dBHz	dBW/ch	dBW/ch.	mW/ch.
PE/LPC	49.8	+ 9.9	-12.3	59
RE/LPC	52.8	+12.9	- 9.3	117
NBFM	63.1	+20.2	- 2.0	631

*BH = backhaul

4.2.3.4 Parametrics for 800 MHz Mobile Transmitter Gain & Power

It will be shown in Section 4.2.4 how the satellite antenna edge of coverage gain is dependant on its diameter, the number and shape of beams, as well as the angular diameter of each beam, as increased by the pointing inaccuracy.

The pointing error was assumed to be ±0.3°. If it is less than this value, further work would be required to treat pointing accuracy as another parametric variable.

Obviously, since there is, in general, more than one choice of number of beams associated with each satellite antenna diameter, the following "possibly limiting" cases have been adopted, namely:

- 3 to 4 beams for 15 foot antenna
- 3 to 6 beams for 24 foot antenna
- 4 to 8 beams for 30 foot antenna

The net EOC gains, after taking into account the circuit losses, are:

- 27.0 dB for 15 foot antenna with 4 beams
- 30.0 dB for 24 foot antenna with 6 beams
- 31.2 dB for 30 foot antenna with 8 beams

It was shown earlier in Section 4.2.3.3.1 that the 800 MHz satellite system temperature T_S was about 900°K or +29.5 dB. Combined with the above satellite net gain,

$(G/T)_s$ = -2.5 dB/K for 15 foot antenna chosen
+0.5 dB/K for 24 foot antenna chosen
+1.7 dB/K for 30 foot antenna chosen

With equation (6), we get:

		SATELLITE ANTENNA		
		15'	24'	30'
		4 beams	6 beams	8 beams
G/T (dB/°K)		-2.5	+0.5	+1.7
$(EIRP)_g$ for PE/LPC dBW/ch		13.2	10.2	9.0
$(EIRP)_g$ for RE/LPC dBW/ch		16.2	13.2	12.0
$(EIRP)_g$ for NBFM DBW/ch		24.2	21.2	20.0
MOBILE ANTENNA GAIN	MOD.	GROUND MOBILE 823 MHz TRANSMIT POWER/USER (in WATTS)		
+1 dBi	PE/LPC	16.5	8.4	6.2
	RE/LPC	33.3	16.6	12.4
	NBFM	210.0	105.0	80.0
+4 dBi	PE/LPC	8.4	4.2	3.1
	RE/LPC	16.5	8.4	6.2
	NBFM	105.0	52.6	40.0
+7 dBi	PE/LPC	4.2	2.1	1.6
	RE/LPC	8.4	4.2	3.1
	NBFM	52.6	26.3	20.0

These parametric results, for only special cases of satellite antenna diameter, number of beams and pointing accuracy are plotted in Figure 4.6-6. It is not expected that the mobile antenna gain will exceed 4 dBi nor be less than 1 dBi; NBFM requires a mobile Tx RF power of some 120 W to 22W, while the PE/LPC digital modulation, with just below toll quality requires only some 9 W to 2 W. This factor should be taken into account, when the satellite communication payload parameters are selected.

The results of the return link analysis are summarized in Table 4.2-4.

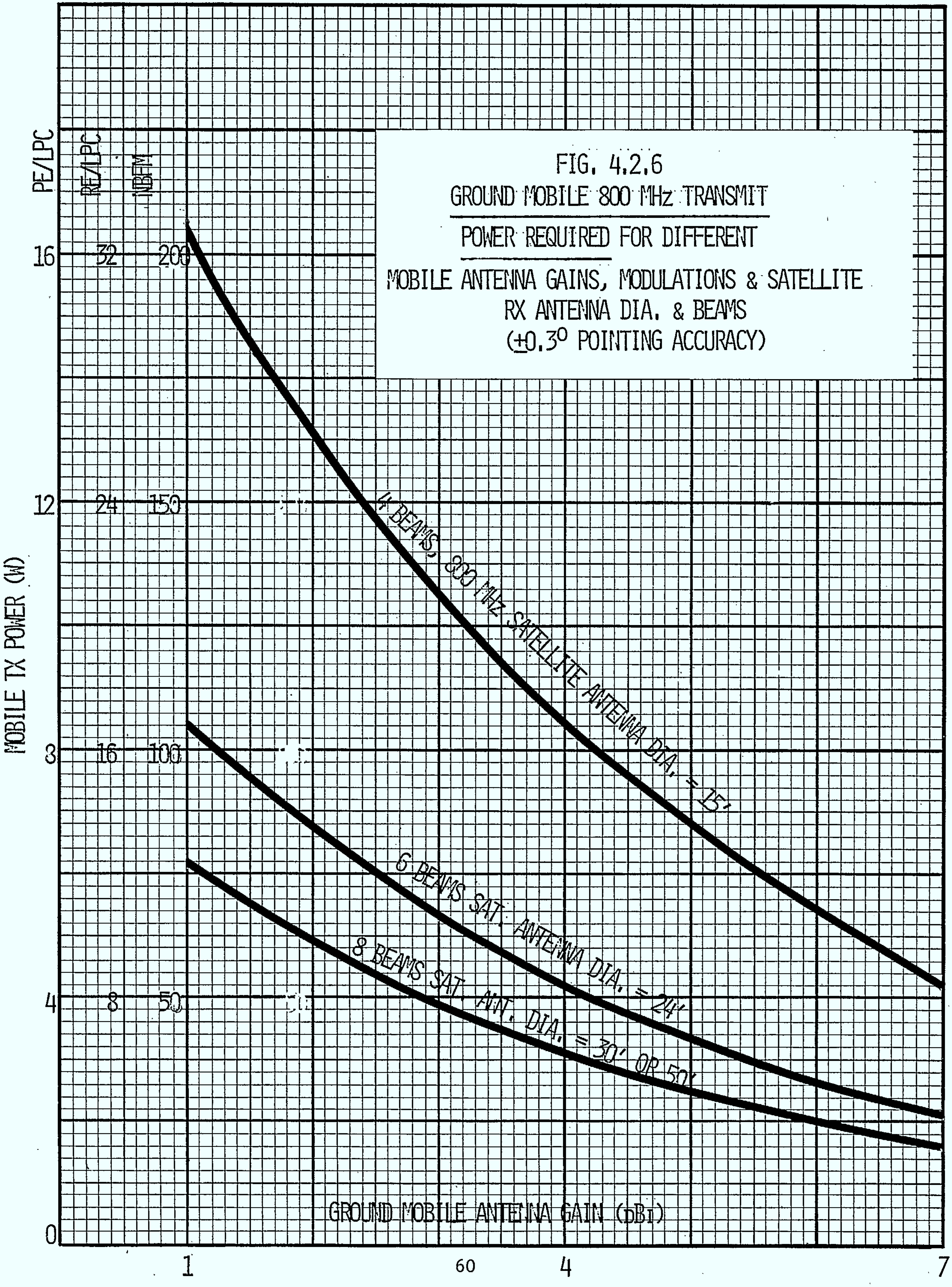


FIG. 4.2.6
GROUND MOBILE 800 MHz TRANSMIT
POWER REQUIRED FOR DIFFERENT
MOBILE ANTENNA GAINS, MODULATIONS & SATELLITE
RX ANTENNA DIA. & BEAMS
(±0.3° POINTING ACCURACY)

Table 4.2-3 Forward Link Analysis

FORWARD LINK i.e. TO MOBILE

	PARAMETERS	UNITS	MODULATION				NOTES
				PE/LPC	RE/LPC	NBFM	
1	$C/(N_o+I)_t$ for total link	dBHz		42	45	53	Basic assumption
2	Channel bandwidth	kHz		3.6	7.2	27	
3	$(C/IM)_{shf}$	dBHz		60.6	63.6	69.3	SHF 25 dB Internal
4	$(C/IM)_{uhf}$	dBHz		55.6	58.6	64.3	20 dB 868 MHz Internal
5	$(C/I)_{ib}$	dBHz		53.6	56.6	62.3	18 dB interbeam, if frequency reuse
6	$(C/N_o)_d$	kHz		43.5	46.5	54.5	868 MHz Thermal
7	$(C/IM)_u$ SHF Backhaul (Thermal)	dBHz		49.8	52.8	60.1	
8	Path Loss SHF Uplink	dB	202.5				7931 MHz
9	Uplink Margin	dB	+4				7931 MHz
10	G/T Satellite *	dB/K	-7				.45 m dish, 8.7° EOC
11	SHF BH $(EIRP)_g$/ch	dBW/ch		+34.7	+37.7	+45.0	at 7931 MHz
12	SHF Ground TX Power/Channel	W		0.049	0.098	0.525	.45 m dish
13	(C/N_0)d 868 MHz (Thermal)	dBHz		43.5	46.5	54.5	assumed 70% of TOTAL LINK
14	Margin downlink	dB	+5				
15	Path loss 863 kHz	dB	183.3				
16	UHF EIRP/Ch	dBW		28.7	31.7	39.7	Basic assumption
17	G/T Mobile RX	dB/K		-25.5	-25.5	-25.5	
18	(UHF) downlink satellite TX Power/ch	W W W		1.48 0.871 0.871	2.96 1.74 1.74	22.9 17.4 17.8	for 15' Sat Ant for 24' Sat Ant for 30' Sat Ant All above for a 4-beam Sat Ant and ±0.3° pointing accuracy

*The (G/T)s is calculated at the continental EOC; however, the CCS would likely be located well within the beam giving a $(G/T)_s$ between -3 and -7 dB/K.

Table 4.2-4 Return Link Analysis

RETURN LINK i.e. FROM MOBILE

	PARAMETERS	UNITS	MODULATION				NOTES
				PE	RE	FM	
1	$C/(N_0+I)$ for total link	dBHz		42	45	53	Basic Assumption
2	$(C/N_0)_u$ (Thermal)	dBHz		43.5	46.5	54.5	assumed 70% of total link
3	UHF Margin (Mu) (uplink)	dB	+13				for vehicular only, other users need less due to higher gain antennas
4	Path loss	dB	182.8				at 823 MHz
5	G/T Satellite	dB/K dB/K dB/K	-2.5 +0.5 +1.7				for 15' Sat Ant for 24' Sat Ant for 30' Sat Ant
6	Mobile TX EIRP	dBW dBW dBW		13.2 16.2 24.2	10.2 13.2 21.2	9.0 12.0 20.0	for 15' Sat Ant for 24' Sat Ant for 30' Sat Ant
7	Mobile TX Power for a Mobile Antenna gain of +4 dBi	W W W	4 Beams 6 Beams 8 Beams	8.4 4.2 3.1	16.6 8.4 6.2	105.0 52.6 40.0	for 15' Sat Ant for 24' Sat Ant for 30' Sat Ant
8	Channel Bandwidth	kHz		3.6	7.2	27	
9	$(C/IM)_{uhf}$	dBHz		55.6	58.6	64.3	20 dB 823 MHz Internal
10	$(C/IM)_{shf}$	dBHz		60.6	63.6	69.3	SHF 25 dB Internal
11	$(C/I)_{ib}$	dBHz		53.6	56.6	62.3	18 dB Interbeam, if frequency reuse
12	$(C/N_0)_d$ SHF Backhaul (Thermal)	dBHz		49.8	52.8	60.1	SHF downlink
13	Path loss	dB	201.7				at 7250 MHz
14	Downlink Margin	dB	+4				7250 MHz
15	Ground G/T	dB/K	+17				5 m dish, net gain of 47 dB
16	SHF BH EIRP/Ch.	dBW		+9.9	+12.9	+20.2	0.45 m dish
17	Sat. SHF TX Power/Ch.	W		0.059	0.117	0.631	

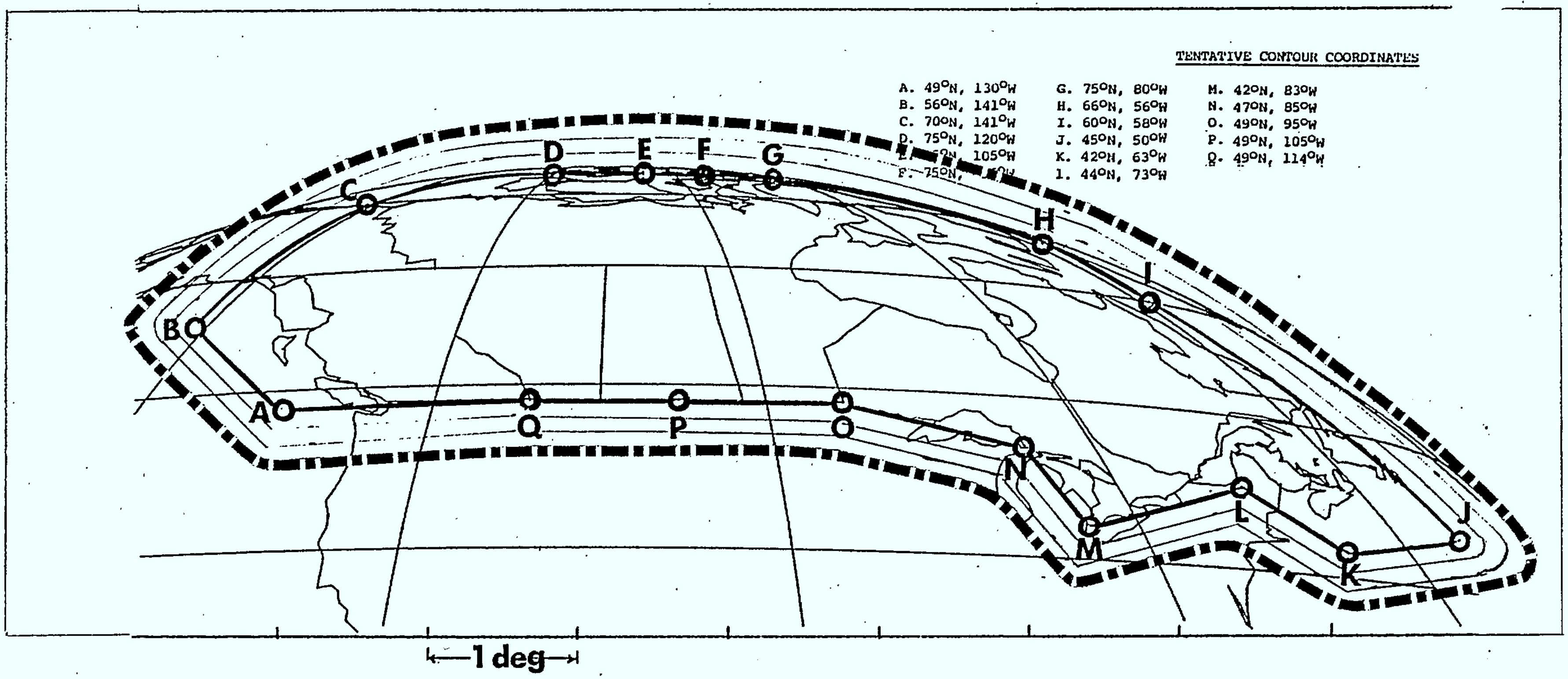
4.2.4 SATELLITE UHF ANTENNA CONSIDERATIONS FOR MOBILE MISSION

4.2.4.1 Basic Coverage

The service area to be covered by the mobile satellite antenna is the continental Canada plus 200 miles of coast. This is defined by the points and coordinates indicated in Figure 4.2-7. It represents the satellite antenna azimuth and elevation contours to be covered by a spacecraft positioned at 109° W longitude. This is a "nominal" rectangle of about 1.5° x 8.3° size.

The antenna to cover the required service area can be designed in a number of ways. It is not the purpose of this study, nor its scope, to design the mobile high UHF antenna. However, it is essential to refer to the effect of varying the parameters of a realistic antenna on the NET GAIN and TOTAL ANTENNA MASS. These parameters include the offset parabola diameter, f/D, number and shape of beams, and hence the feed parameters (number of horns, their sizes and shapes), the type of IF or RF BEAM FORMING NETWORK, the side-lobe levels and, as will be demonstrated further on, the spacecraft pointing accuracy.

It is essential to realize that what is most relevant to the effect of the antenna on the Mobile payload design, is not its BORESIGHT or 3 dB GAIN, but the EDGE OF COVERAGE (EOC) gains, under different conditions and assumptions. Only the MINIMUM GAIN across the coverage area is considered. Here it is worth mentioning that there is, in practice, no such luxury as 100% service area completely covered (see CAL DBS Reconfigurable Antenna Study, Ref 13). It is inevitable that a small percentage of relatively less vital area to be covered, may fall out-side the EOC. This, coupled with the fact that slightly different gain values and distribution can be arrived at by design, for a given diameter, indicates that all absolute gain values for "shaped beams" should be considered to have a 1 dB tolerance, or more, depending on diameter, etc. However, their relative values, which are important for a payload parametric study, have in general a tighter tolerance.



TENTATIVE CONTOUR COORDINATES

A. 49°N, 130°W	G. 75°N, 80°W	M. 42°N, 83°W
B. 56°N, 141°W	H. 66°N, 56°W	N. 47°N, 85°W
C. 70°N, 141°W	I. 60°N, 58°W	O. 49°N, 95°W
D. 75°N, 120°W	J. 45°N, 50°W	P. 49°N, 105°W
E. [illegible]N, 105°W	K. 42°N, 63°W	Q. 49°N, 114°W
F. 75°N, [illegible]	1. 44°N, 73°W	

FIGURE 4.2.7 CANADIAN SERVICE AREA AT 109°W WITH EFFECT OF ±0.1°, ±0.2° & ±0.3° POINTING ERROR ON CONTOUR

Assume, for the purpose of illustration, that only one beam is required to cover Canada (an inadvisable design, since it would require only one active HPA, highly inefficient in RF performance and in DC heat dissipation). The EOC gain is that value that corresponds to ±8.3°/2, i.e. ± half the angle of the beam spanning the service area, at its widest position.

In the case of MULTIPLE BEAMS,as illustrated in Figure 4.2-8, this angle corresponds to the INTERSECTION of TWO ADJACENT BEAMS, optimally positioned to "completely" cover that allocated part of the service area. For example, one third of this area would be covered for the case of 3 beams, if all were designed to be identical, which may not necessarily be the case. Also, throughout this study, the concept of using four square horns for each beam is used, "square" for circular polarization, and "four" to maintain symmetry and power sharing by adjacent horns, to achieve the beam cross-over levels at the EOC.

Different beam configurations and numbers have been studied. The case of a 50 foot reflector is illustrated. Figure 4.2-9 shows its radiation pattern with 4 horns, each having a 0.66 λ side, and an $f/D = 0.625$. For the same antenna, the EOC GAIN VALUES CAN ONLY BE DETERMINED AFTER SPECIFYING THE NUMBER OF BEAMS AND SEVERAL DETAILED SUPERPOSITIONS OF THE INDIVIDUAL BEAMS ONTO THE COVERAGE AREA, to contain the highest possible gain. Even then, for the entire country, the worst or "lowest" values of the best possible gain should be adopted, in a system design, as the average fit EOC gain, less the array circuit losses.

This approach is different to a previously used simplified approach where single gain values for a given diameter were provided, without introducing the effect of number of beams on the gain values.

From radiation patterns and geometrical consideration, the beam CROSS-OVER ANGLE θ_c that corresponds to the worst fit, in a multiple beam layout, should be considered. For the case of a 4 beam configuration across Canada, and no pointing error, $\theta_c = 2.4°/2$. This means worst cross-over between beams occurs at ± 1.2° of the beam "basic" pattern, assuming they are all equal. If unequal, then the worst θ_c can still be considered; this corresponds to the critical θ_c where the lowest EOC gain is available. In Figure 4.2-9, this intersection at $\theta_c = 1.2°$ is indicated as point C, where the EOC is 32.3 dB.

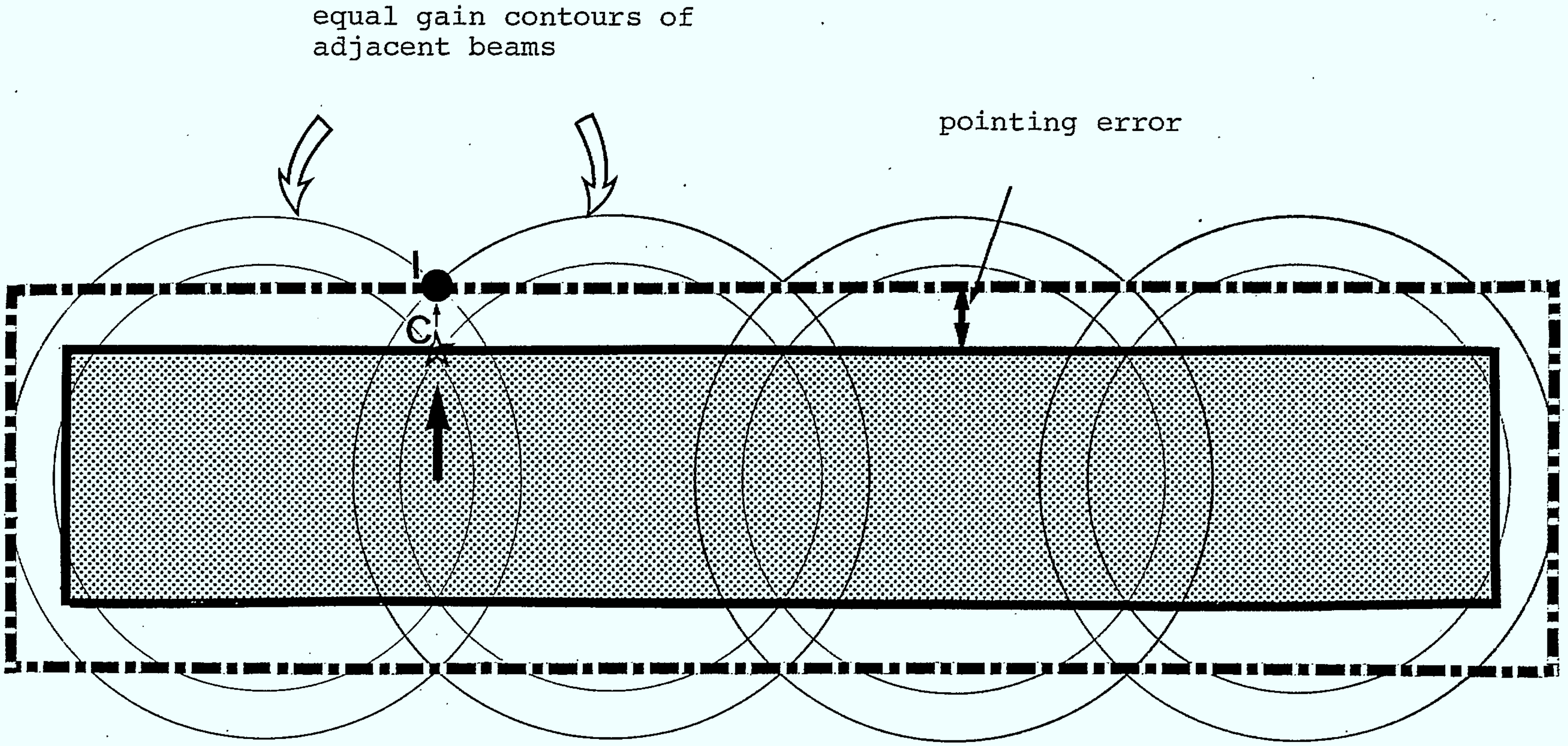


FIGURE 4.2.8 ILLUSTRATION OF THE PRINCIPLE OF CROSS-OVER POINT BETWEEN TWO BEAMS AND THE DISPLACEMENT OF THIS POINT DUE TO SPACECRAFT POINTING ACCURACY WHERE GAIN SLOPE IS CRITICAL TO THE USEFULNESS OF GAIN

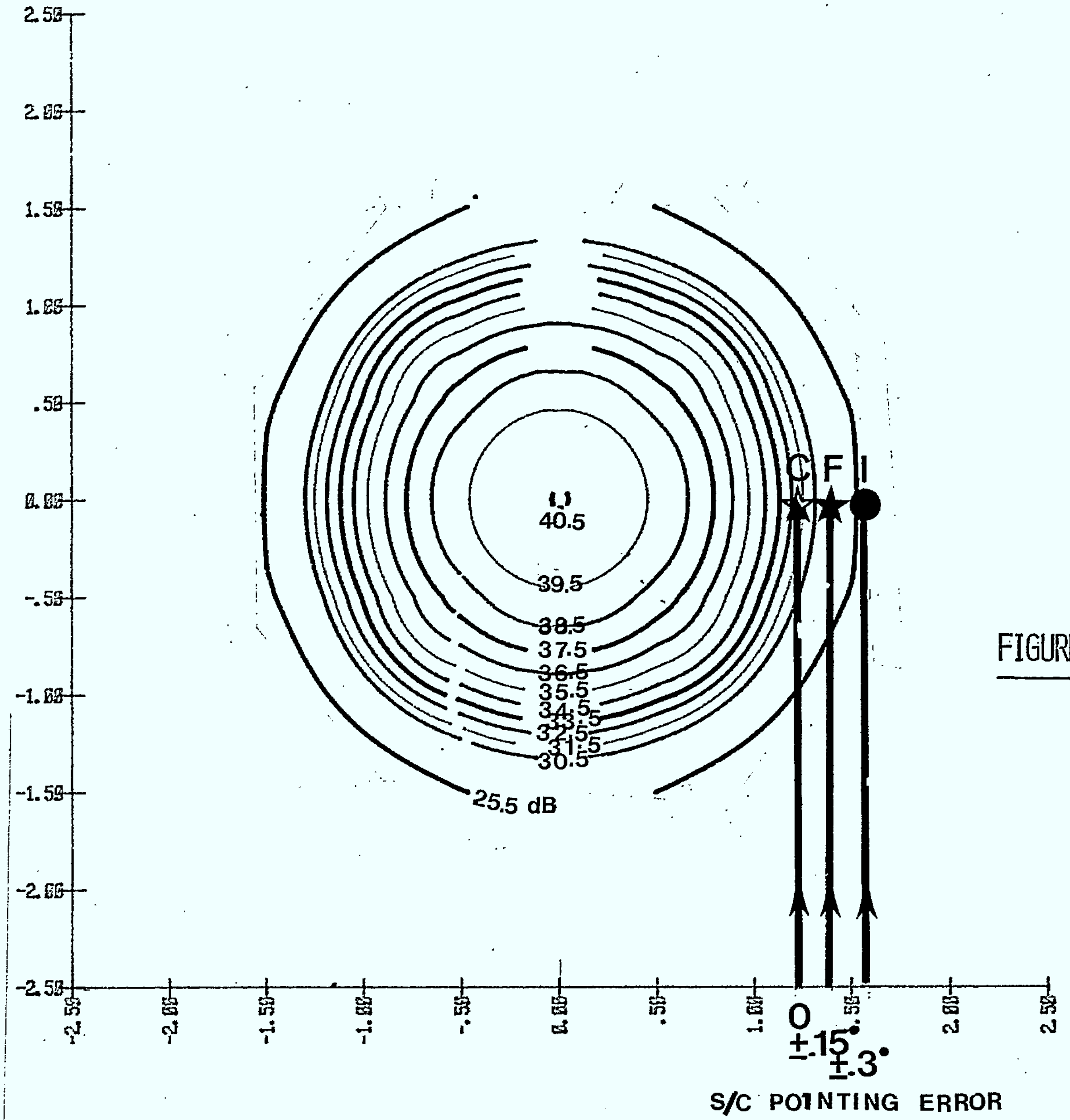


FIGURE 4.2.9 GAIN CONTOURS FOR 50 FT. REFLECTOR FED BY HORNS (EQUAL AMPLITUDE AND PHASE). C, F, & I ARE BEAM CROSS-OVER POINTS FOR A 4 BEAM LAYOUT AT 0°, ±0.15° AND ±0.3° POINTING ACCURACY

. 80 28 35 16 393.

The radiation patterns for three different diameters are plotted in Figure 4.2.10. For the case of 4 beams, the EOC gains correspond to points A, B and C for diameters of 15, 30 and 50 foot, respectively, with no pointing error.

It is clear that, θ_c has different values for different numbers of beams. The larger number of beams, the smaller is the cross-over angle θ_c, and hence the higher is the EOC gain. Obviously, for a given reflector diameter, there is a limit to the maximum or minimum number of beams possible. Feeds occupy an angular span. Scan loss, coma lobes and high spill-over loss, feed mass, etc., are affected by considerations f/D, horn aperture, reflector diameter, etc. It is possible to consider the number of beams of 4, 6 and 8 for antenna diameters of 15, 24 and above 30 foot respectively. For practical reasons, no antenna diameter beyond 50 foot is considered.

In light of the above discussion and later results, it is doubtful if even a 50 foot antenna serves any useful net benefit.

4.2.4.2 Effect of Pointing Error on Net Gain

The same analysis holds when there is, as always, a pointing inaccuracy. The only difference is now the service area has increased by a certain contour, as shown in Figure 4.2-7 for 3 cases of ±0.1°, ±0.2 and ±0.3° pointing errors. The EOC cross-over points for ±0.15° and ±0.3° pointing errors, for a 50 foot antenna are indicated as points F and I on Figures 4.2.9 and 4.2.10.

It becomes clear, that, particularly as the antenna diameter increases, i.e. gain slopes significantly increase, that the EOC gain values degrade, with larger pointing errors. The baseline pointing accuracy was given as ±0.3°.

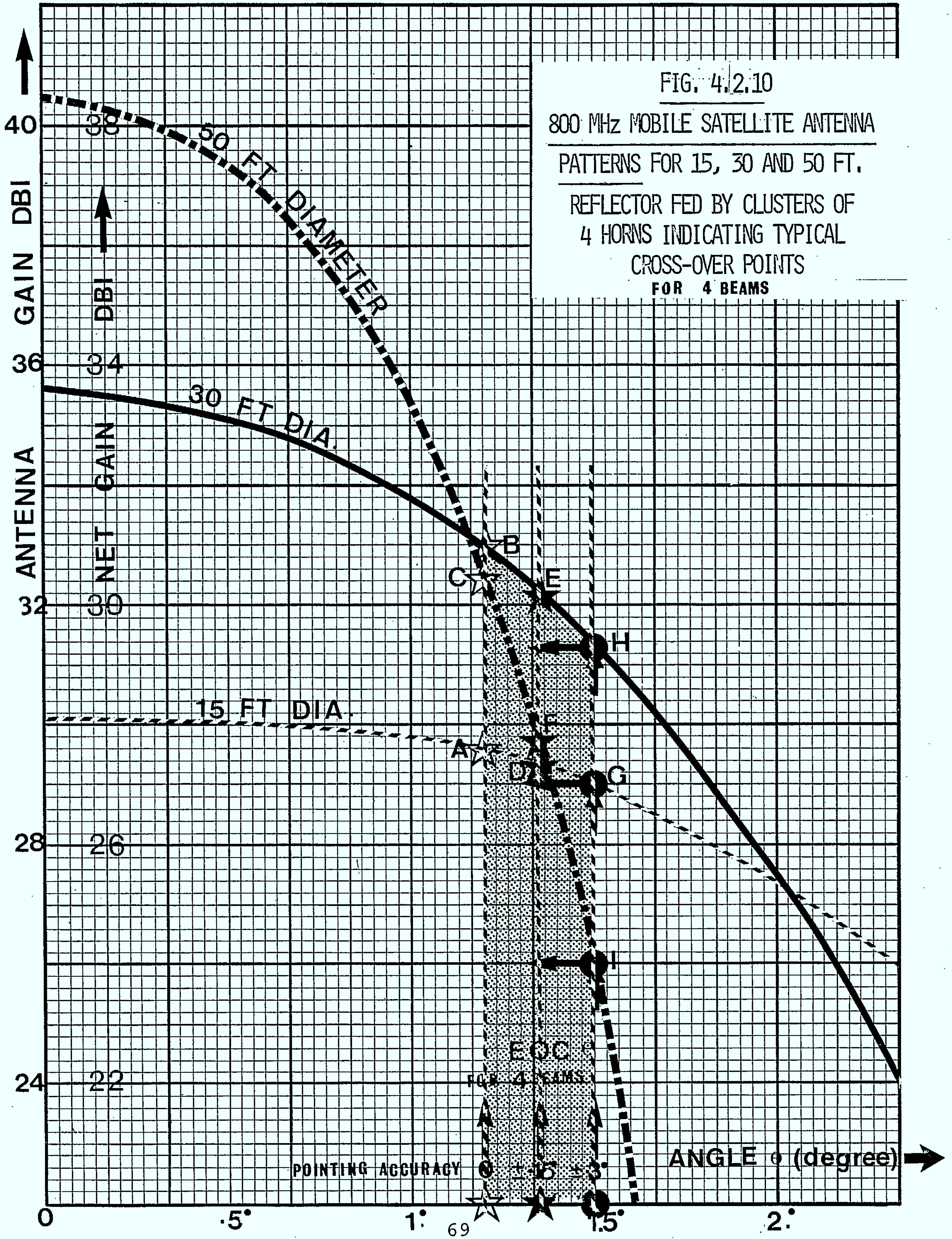


FIG. 4.2.10

800 MHz MOBILE SATELLITE ANTENNA

PATTERNS FOR 15, 30 AND 50 FT.

REFLECTOR FED BY CLUSTERS OF
4 HORNS INDICATING TYPICAL
CROSS-OVER POINTS
FOR 4 BEAMS

All values of gain mentioned so far should be reduced by a total RF circuit loss, assumed to be 2.0 dB, to give what will be referred to, from now on, and from Figure 4.2-10 onwards, as the "NET" EOC gain value. The circuit power inbalance between various amplifier circuits, and the phase drift in the circuits accounts for 0.7 dB. while 1.3 dB is the output circuit loss.

Figure 4.2-11 is very important. It displays the NET EOC GAIN for antennas of DIFFERENT DIAMETERS and particularly for DIFFERENT NUMBERS OF BEAMS, all for a ±0.3° pointing accuracy. The dotted regions of the curves are recommended limits of use, e.g. for a 50 foot reflector, 3 beams are by no means an optimum choice.

There is no way, within the scope of this parametric study to "optimally design" large numbers of antennas, corresponding to all possible combinations of diameters and number of beams, and hence gain and mass values. One single baseline approach was considered, namely an f/D of .625 and single beam basic patterns of a cluster of four square horns of nine inch sides. The value of f/D chosen is a a compromise between mechanical and dynamic constraints favoring a low f/D and radiation requirements of a large f/D.

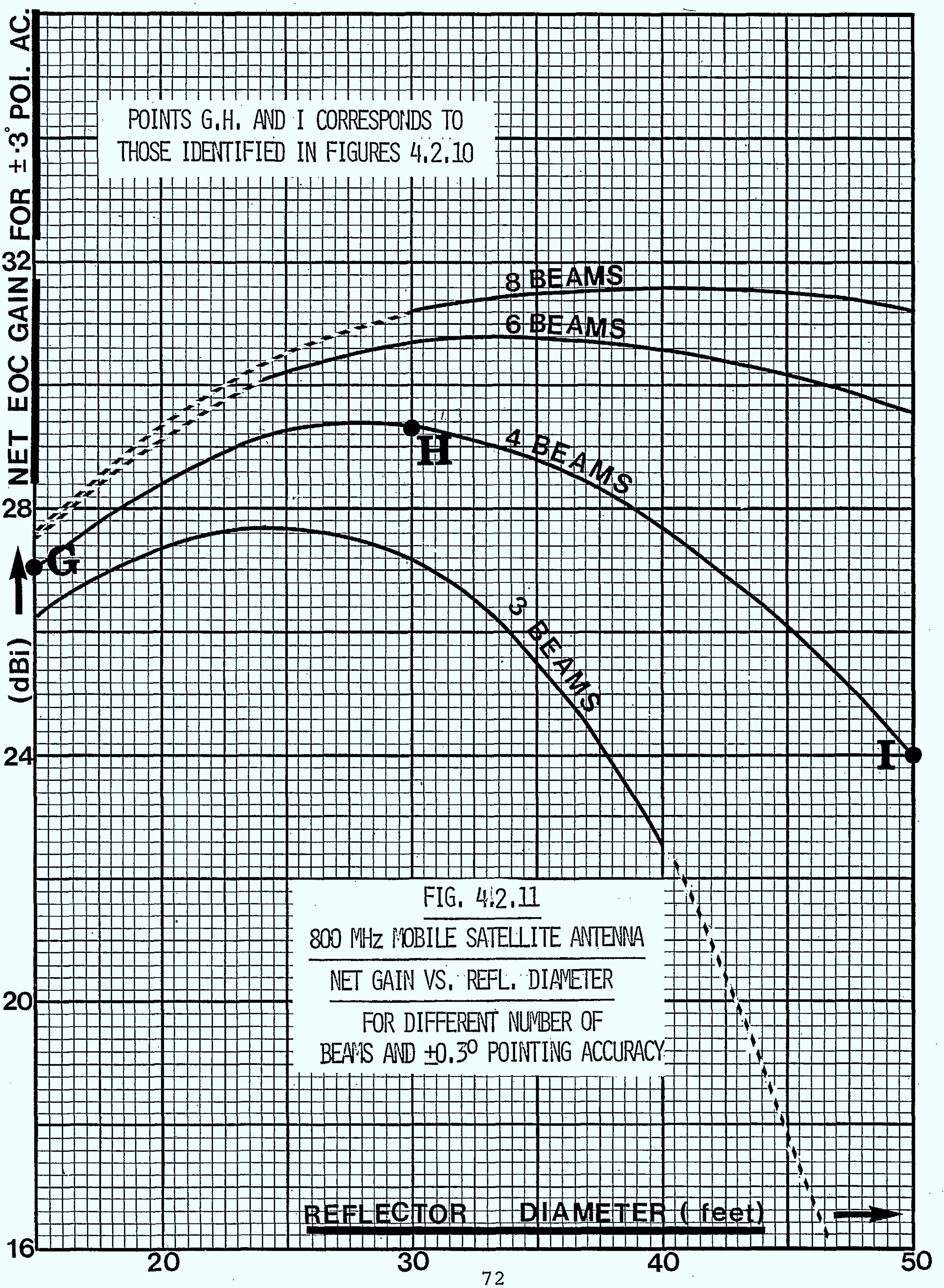
However, in actual practice, many variables ar changed, in order to control the "fanning out i.e. spreading out" or "excessive overlapping" of beams. Such variables can be: the size of the horns, their positions, the signals relative phase and magnitude, f/D and D of course.

Figure 4.2.11(A) is a design example, for a 30 foot reflector and four beams, formed by five clusters of four horns, of 11 inch sides, and an f/D of 0.625, covering Canada with a ± 0.30 pointing accuracy.

Other examples were considered. For instance, for a 24 foot diameter, and an f/D fixed at 0.625, then a 31 dB beam cross-over point can be achieved for 3,4,5 and 6 beams, by reducing the basic size of the horns from 10 inches down to 5.6 inches.

The effect of all these possible variables is to read the values for gains in Figure 4.2.10 and 4.2.11 as being mean values with some spread, depending on the region of operation. But for system approach, it is important to consider the trend. The effect of number of beams on gain could not be ignored.

Equally important here, is the fact that gain slope at EOC were not assumed. The effect of ±0.3° pointing accuracy were derived "directly" from the basic beam patterns of Figure 4.2.10.



POINTS G.H. AND I CORRESPONDS TO THOSE IDENTIFIED IN FIGURES 4.2.10

FIG. 4.2.11

800 MHz MOBILE SATELLITE ANTENNA

NET GAIN VS. REFL. DIAMETER

FOR DIFFERENT NUMBER OF BEAMS AND ±0.3° POINTING ACCURACY

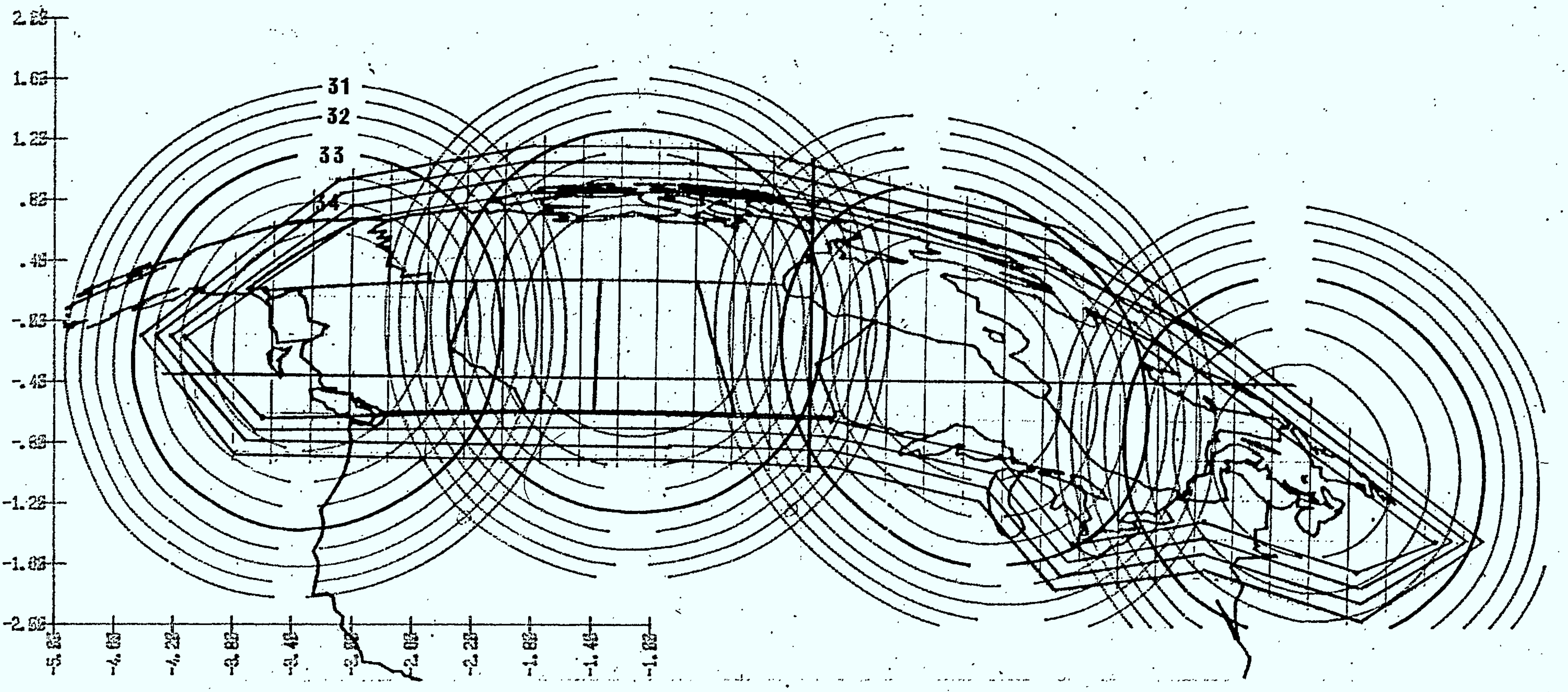


FIGURE 4.2.11(A) EXAMPLE OF A 30 FT. DIA., WITH 4 BEAMS, AND BASIC SQUARE HORNS OF 0.8λ APERTURE

(HORNS POSITION NOT FINALIZED)

. 63 45 .42 17 912

4.2.5 MOBILE TRANSPONDER HPA AND EPC POWER AND MASS

For the operating conditions of the 800 MHz mobile Forward or Return link, the most significant dc power and mass contributions are those of the 800 MHz downlink High Power Amplifier and Electric Power Conditioning circuits (HPA + EPC). (HPA + EPC) power algorithms supplied by CRC, as well as empirical mass algorithms used for the main M-SAT study will be used for the (HPA + EPC).

4.2.5.1 (HPA + EPC) POWER

Based on their work on 300 MHz amplifiers, operating at different ratings, CRC arrived at the value P_{DC} for the total dc power used by an amplifier, rated at "(P_{RF}) rated" and actively operating at (P_{RF}).

$$P_{DC} = 0.59\ (P_{RF})\ \text{rated} + 2.2\ P_{RF} \qquad (1)$$

Since this is applicable to an amplifier with a total RF to DC efficiency η of 36%, then at any other efficiency η

$$P_{DC} = \frac{.36}{\eta} \left[\ 0.59\ (P_{RF})\ \text{rated} + 2.2\ P_{RF}\ \right] \quad \text{or}$$

$$P_{DC} = \frac{1}{\eta} \left[\ 0.212\ (P_{RF})\ \text{rated} + 0.792\ P_{RF}\right] \qquad (2)$$

4.2.5.2 (HPA + EPC) MASS

The following empirical algorithms have been used, for the HPA mass M_H and the EPC mass M_E:

$$M_H = 0.35 + 0.0048\ (P_{DC})_H \qquad \text{kg} \qquad (3)$$

$$M_E = 0.25 + 0.12\ (P_{DC})_{E+H} \qquad \text{kg} \qquad (4)$$

$(P_{DC})_H$ = DC power consumed by the HPA

$(P_{DC})_{E+H}$ = DC power consumed by the HPA + EPC

Expressions (1) to (4) are used for the (HPA + EPC) power and mass evaluation, for the 800 MHz Mobile mission.

4.2.6 TOTAL PAYLOAD PARAMETRIC ANALYSIS AND SOME RESULTS FOR MOBILE MISSION

4.2.6.1 Total Payload Mass & Power

Table 4.2-5 sums up the TOTAL MOBILE MISSION COMMUNICATION PAYLOAD.

TABLE 4.2-5 TOTAL MOBILE PAYLOAD

ANTENNA		TRANSPONDER	
UNIT	VALUE	UNIT	VALUE
MASS		MASS	
AM1-High UHF reflector and feed	variable	TM1-High UHF	variable
AM2-SHF Backhaul	2.7 Kg	TM2-SHF Backhaul	variable
AM3-L-Band helices	2.5 Kg	TM3-L-Band	5.9 Kg
AM4-TT&C Bicone	1.8 Kg		
AM5-Solar Sail	8.2 Kg		
		POWER	
		TP1-High UHF	variable
		TP2-SHF Backhaul	variable
		TP3-L-Band	80 W

The constant values of mass and power above have been derived as shown in the scrolls contained in Appendix G.

AM1 is the total high UHF M-SAT antenna mass, i.e. the sum of the reflector and feed. The two most commonly available deployable reflectors are considered, namely the Lockheed wrap-rib and the Harris TRAC reflectors. The mass of the feed depends on the number of beams N_B. Each beam is formed by a cluster of 4 horns. For N_B beams, 2 (N_B+1) horns are required. The basic horn considered in this study is square, with 9 inch sides and 24 inches long.

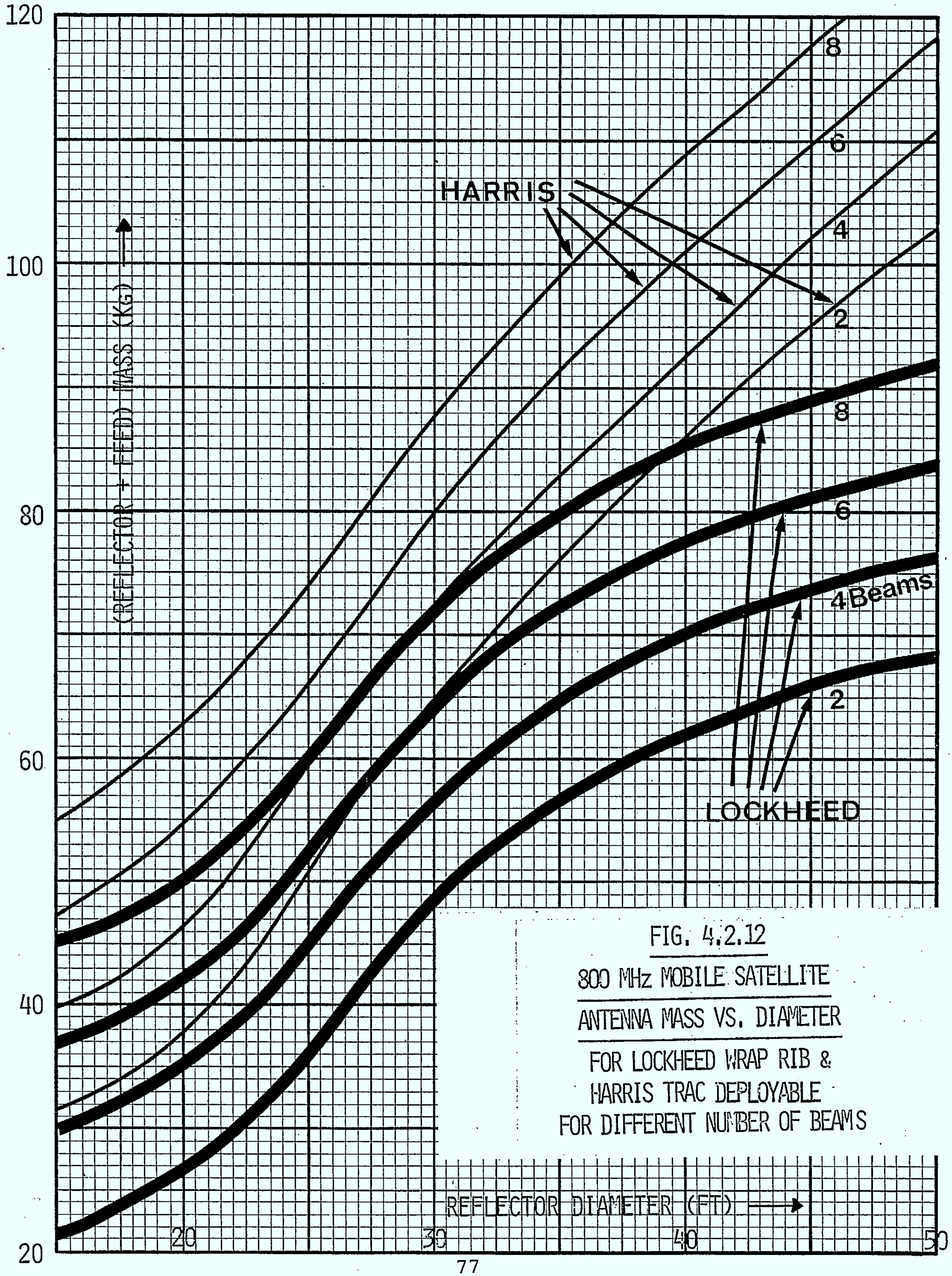


FIG. 4.2.12

800 MHz MOBILE SATELLITE

ANTENNA MASS VS. DIAMETER

FOR LOCKHEED WRAP RIB &
HARRIS TRAC DEPLOYABLE
FOR DIFFERENT NUMBER OF BEAMS

The total 800 MHz Antenna mass AM1 is plotted in Figure 4.2-12, with the number of beams and type of reflector as parameters. However, in the computed results, only Lockheed reflectors were choosen, obviously because of their lighter weight and convenient mechanical layout. Figure 4.2-12 provides the data that enables the consideration of Harris reflectors if needed.

The total mass and power TM1+2 and TP1+2, for the 800 MHz and Backhaul transponder are:

TM1+2 = TM1 + TM2
TP1+2 = TP1 + TP2

4.2.6.2 Some Results of Total Mobile Payload (800 MHz)

This section is meant to illustrate payload performance for 'typical' cases intentionally chosen to vary around the baseline requirements. These cases are applied for pitch-excited LPC modulation with voice activation, and 27% transmitter efficiency, for 0.012 Erl/user and 10% blocking rate, using Lockheed reflectors.

a) Variation of power and mass with antenna diameter.

Figure 4.2.13 displays such variations for the case of four beams across Canada. As the diameter increases from 15 feet, the payload power required for 25,000 users (nominal 300 channels) decreases from 1142 watts down to 758 watts around 27 feet. It then rises much more sharply to 2068 watts at 50 feet. This performance can best be understood by referring to Figure 4.2-11 where the net gain rises slowly to a maximum value at 27 feet and decreases sharply at 50 feet.

Note that a limiting factor in this case is the number of beams. As the diameter increases, it becomes necessary to provide EOC further down on the sides of the beam pattern.

The corresponding payload mass behaves somewhat in a similar manner. It decreases slowly from 178 kg to a minimum of 170 kg at 24 feet, to rise sharply to a value of 276 kg at 50 ft.

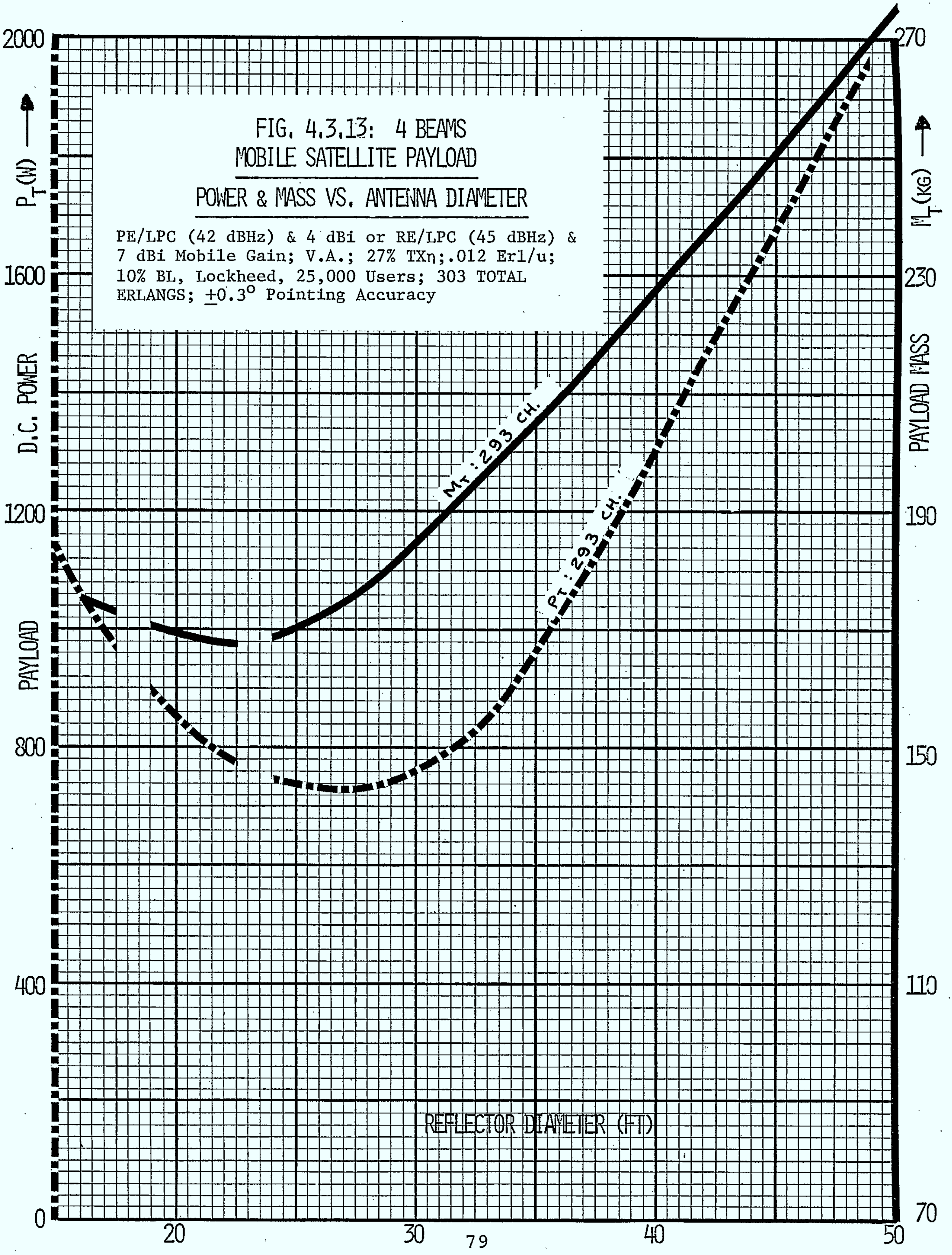


FIG. 4.3.13: 4 BEAMS
MOBILE SATELLITE PAYLOAD
POWER & MASS VS. ANTENNA DIAMETER

PE/LPC (42 dBHz) & 4 dBi or RE/LPC (45 dBHz) & 7 dBi Mobile Gain; V.A.; 27% TXη;.012 Erl/u; 10% BL, Lockheed, 25,000 Users; 303 TOTAL ERLANGS; ±0.3° Pointing Accuracy

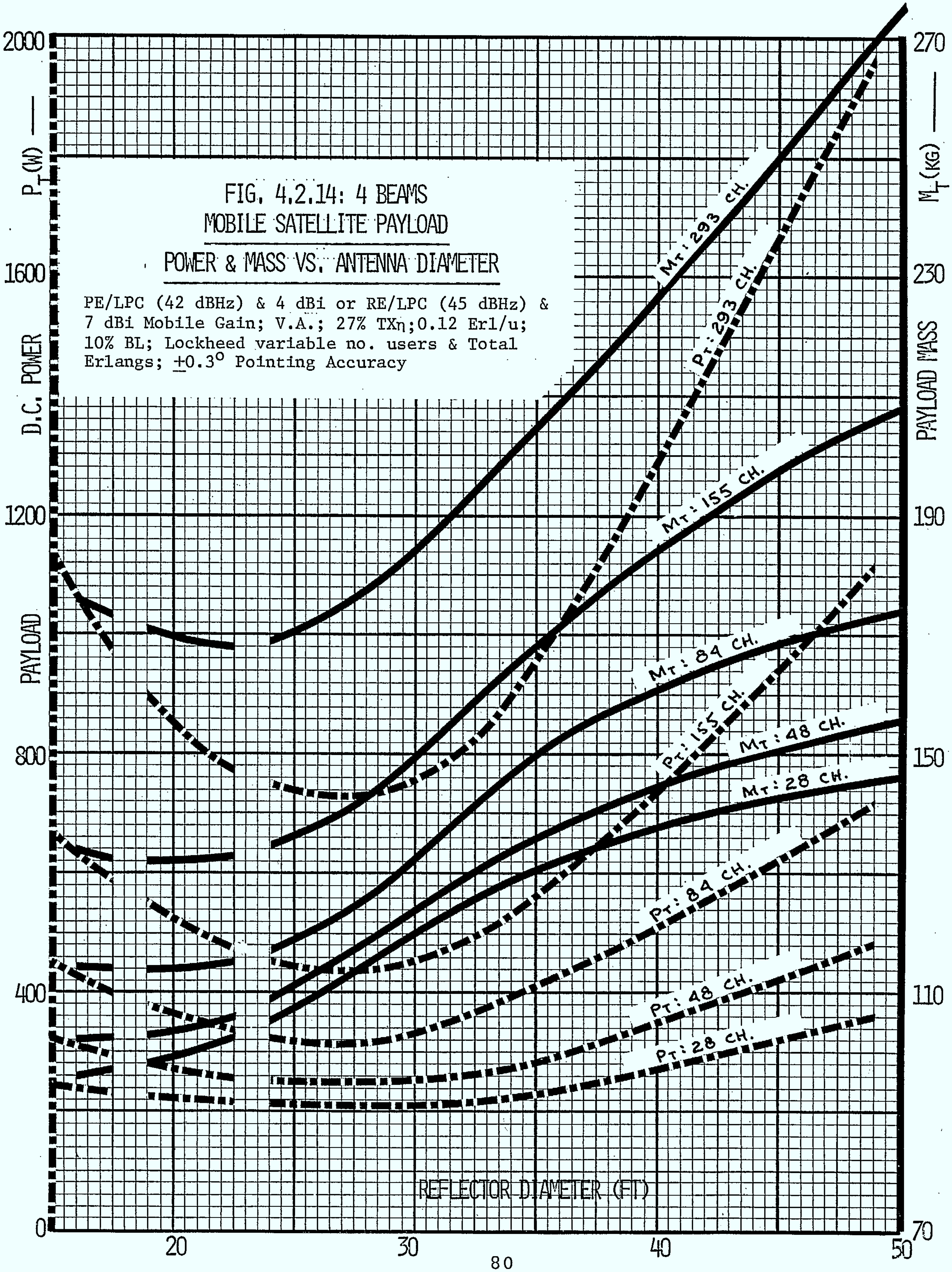


FIG. 4.2.14: 4 BEAMS MOBILE SATELLITE PAYLOAD

POWER & MASS VS. ANTENNA DIAMETER

PE/LPC (42 dBHz) & 4 dBi or RE/LPC (45 dBHz) & 7 dBi Mobile Gain; V.A.; 27% TXη;0.12 Erl/u; 10% BL; Lockheed variable no. users & Total Erlangs; ±0.3° Pointing Accuracy

To understand this performance it is worth noting that the payload mass is dependent in this respect on two parameters: the RF power per channel and the mass of the antenna and feed. The first slowly decreasing portion of this curve is closely related to the slow rising gain. The second sharply increasing payload mass curve is due to the combined effect of fast gain decrease and simultaneous antenna mass increase.

Similar performance is shown in Figure 4.2-14 for different numbers of channels, from 293 to 28, corresponding to 25,000 to 1562 users across Canada (refer to Table 4.2-2, i.e. 0.012, Erl/User, 4 beams, 10% blocking rate).

b) <u>Variation of power and mass with number of channels.</u>

Figures 4.2-15 and 4.2-16 display the variations. For large numbers of channels, the mass and power increase linearly with the number of channels. This is not so for the power required for smaller numbers of channels. This corresponds to the non-linear knee of Figure 4.2-1 (number of channels with voice activation).

c) <u>Variation of power versus mass.</u>

All spacecraft payload capabilities are specified in terms of a range of mass and power versus reflector diameters and the number of voice activated channels. Therefore, Figures 4.2-13 through 4.2-16 are not the most effective way of displaying the results.

The same information is more strikingly displayed as power versus mass as shown in Figures 4.2-17 and 4.2-18. The following information can be graphically illustrated on the same curve: constant number of channels (users), constant diameters, ranges of power and mass for a given number of channels or for a given diameter.

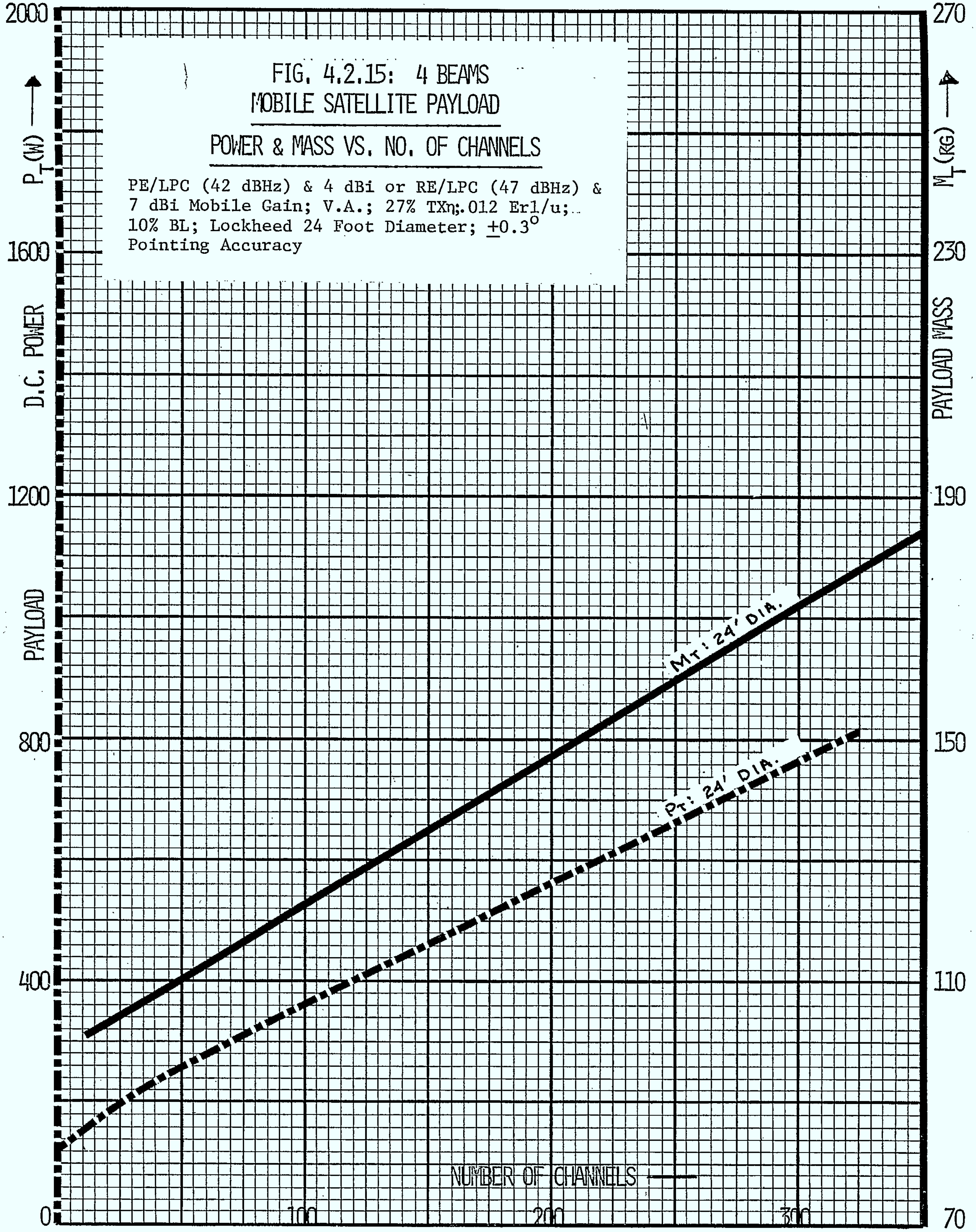


FIG. 4.2.15: 4 BEAMS
MOBILE SATELLITE PAYLOAD
POWER & MASS VS. NO. OF CHANNELS

PE/LPC (42 dBHz) & 4 dBi or RE/LPC (47 dBHz) & 7 dBi Mobile Gain; V.A.; 27% TXη;.012 Erl/u; 10% BL; Lockheed 24 Foot Diameter; ±0.3° Pointing Accuracy

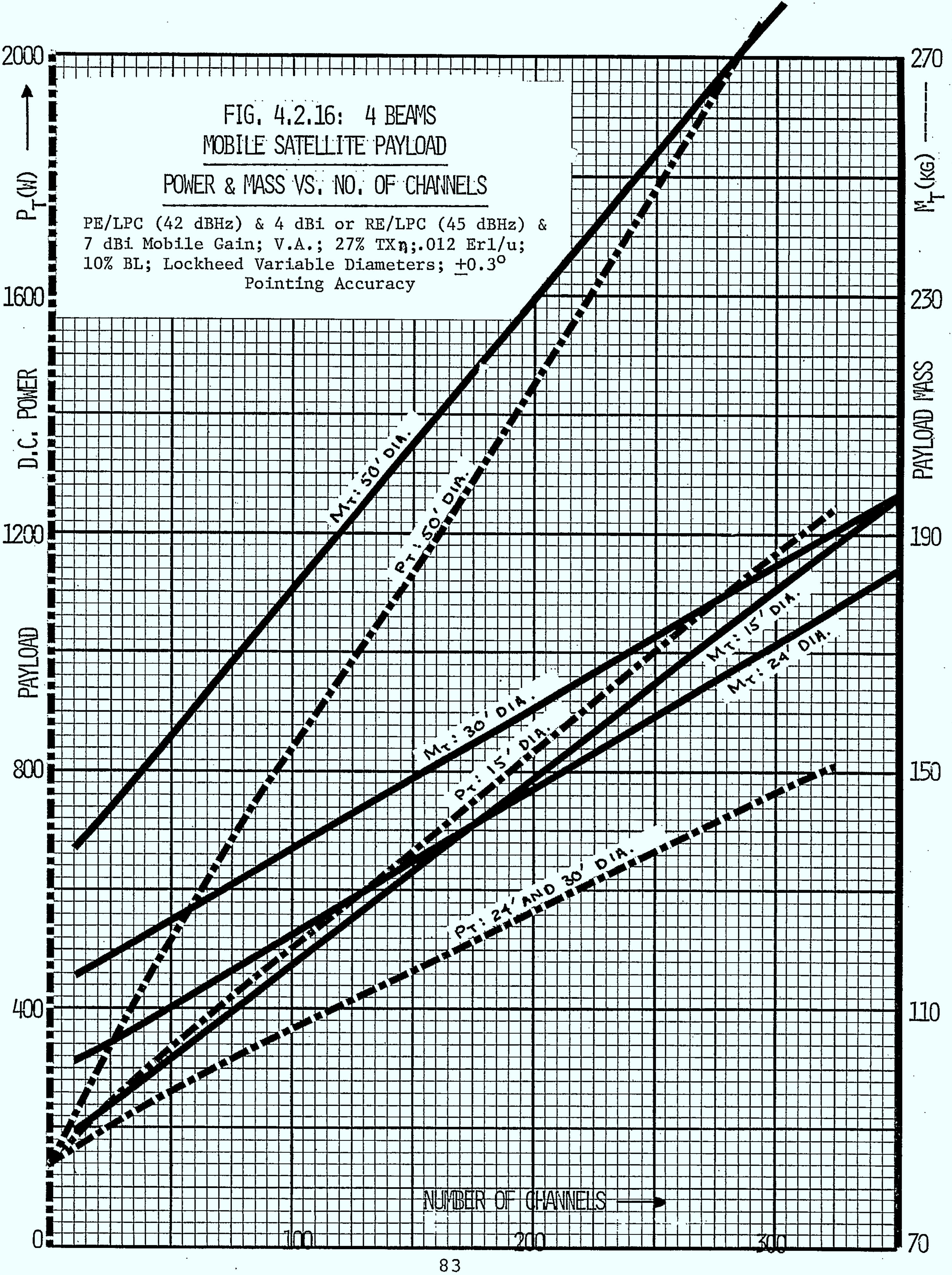


FIG. 4.2.16: 4 BEAMS
MOBILE SATELLITE PAYLOAD
POWER & MASS VS. NO. OF CHANNELS

PE/LPC (42 dBHz) & 4 dBi or RE/LPC (45 dBHz) & 7 dBi Mobile Gain; V.A.; 27% TXη;.012 Erl/u; 10% BL; Lockheed Variable Diameters; ±0.3° Pointing Accuracy

Using Figure 4.2-11 for ±0.3° pointing accuracy the payload mass versus power has been computed and displayed in Figures 4.2-19 through 4.2-21 for 3, 6 and 8 beams. It is important to realize the range of usefulness of these curves. Although it is possible for a 50 foot diameter to choose any number of beams up to 8, this is not so for a 15 foot diameter. In this latter case, up to 4 beams may be feasible.

In these curves and in subsequent ones, most data show parametrics for 3 to 8 beams. This shows the trends of the curves and their continuity. However, for practical purposes, the following limitations should be considered in reading any of these curves:

- for 15 ft diameter consider with 3 - 4 beams
- for 24 ft diameter consider with 3 - 6 beams
- for 30 and 50 ft diameter consider with 4 - 8 beams

Even those limiting numbers of beams can be debated within one beam.

Complete parametric sets of curves are shown in Appendices I, J, K. For the PE/LPC modulation, all parametrics are shown for 18%, 27% and 36% Tx efficiency as well as for 10%, 3% and 1% traffic blocking rate, all these with voice activation. In addition, one set for no-voice activation is presented. Baseline curves for RE/LPC and NBFM are also given.

In all these parametrics it is essential to realize that, since there is a 3 dB difference in Satellite EIRP between the PE/LPC and RE/LPC modulations, curves for PE/LPC and 4 dBi ground antenna gain correspond to RE/LPC and 7 dBi gain respectively. Conversely, PE/LPC and 1 dBi curves correspond to RE/LPC and 4 dBi.

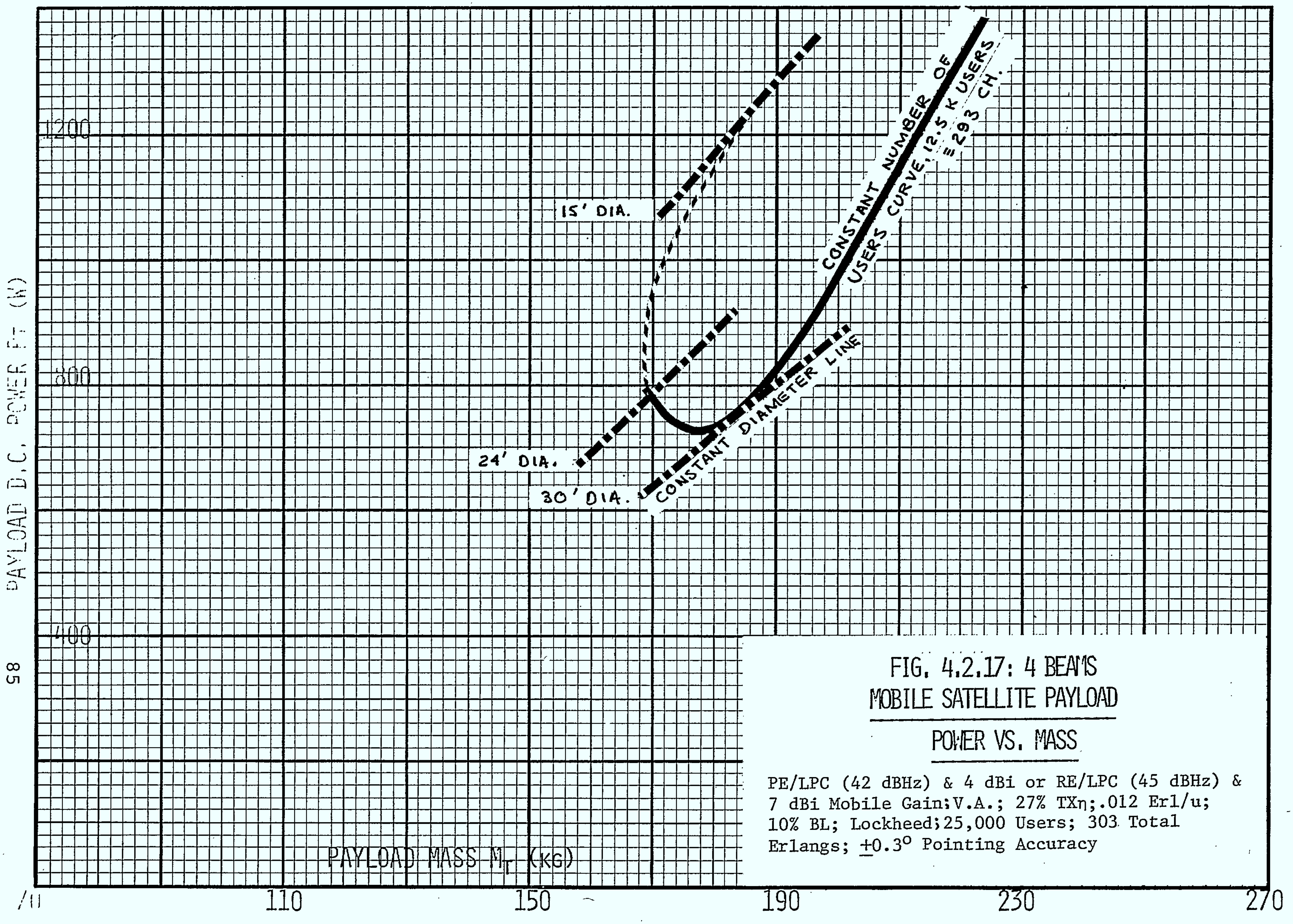


FIG. 4.2.17: 4 BEAMS
MOBILE SATELLITE PAYLOAD

POWER VS. MASS

PE/LPC (42 dBHz) & 4 dBi or RE/LPC (45 dBHz) & 7 dBi Mobile Gain; V.A.; 27% TXη; .012 Erl/u; 10% BL; Lockheed; 25,000 Users; 303 Total Erlangs; ±0.3° Pointing Accuracy

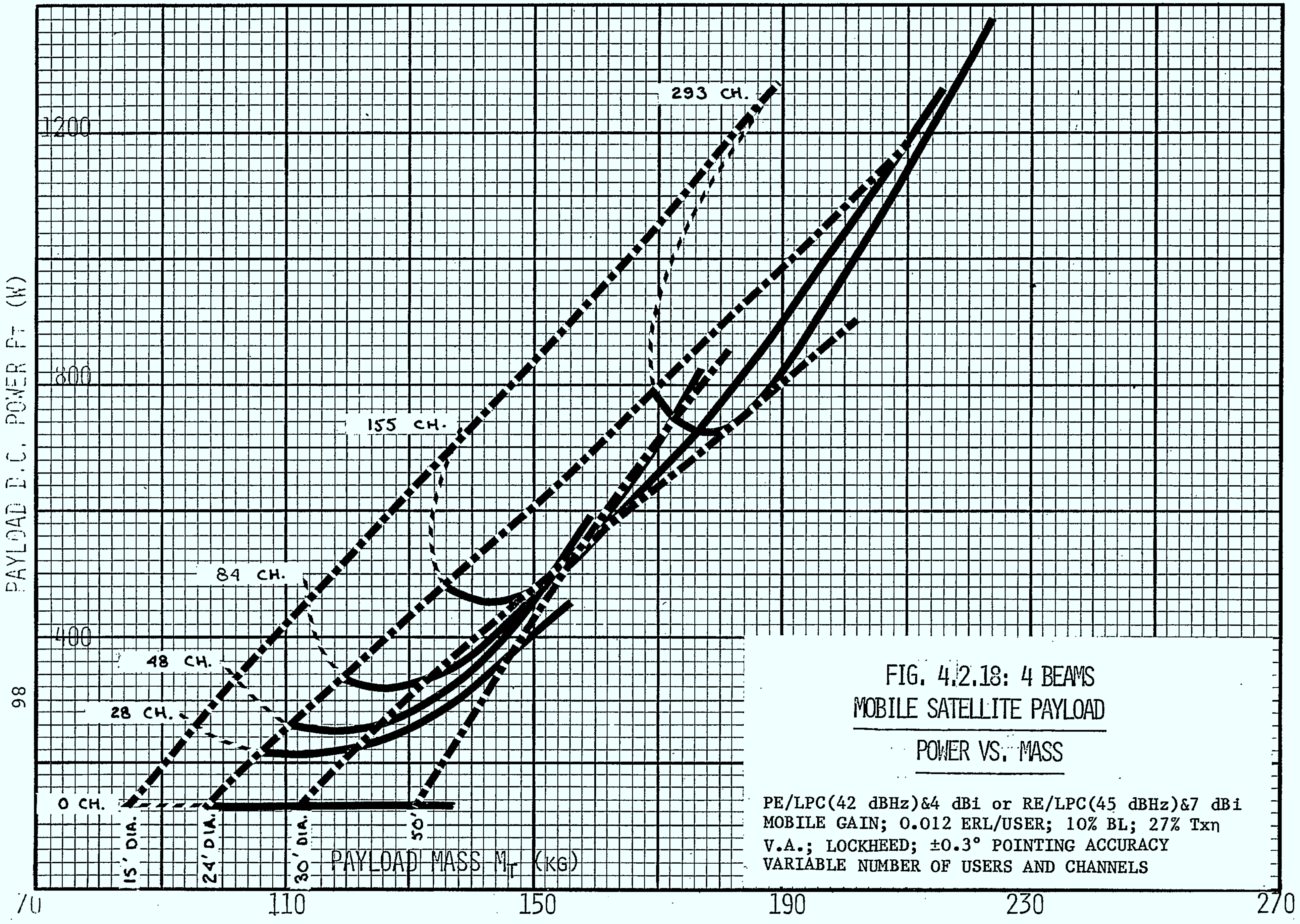


FIG. 4.2.18: 4 BEAMS
MOBILE SATELLITE PAYLOAD

POWER VS. MASS

PE/LPC(42 dBHz)&4 dBi or RE/LPC(45 dBHz)&7 dBi
MOBILE GAIN; 0.012 ERL/USER; 10% BL; 27% Txn
V.A.; LOCKHEED; ±0.3° POINTING ACCURACY
VARIABLE NUMBER OF USERS AND CHANNELS

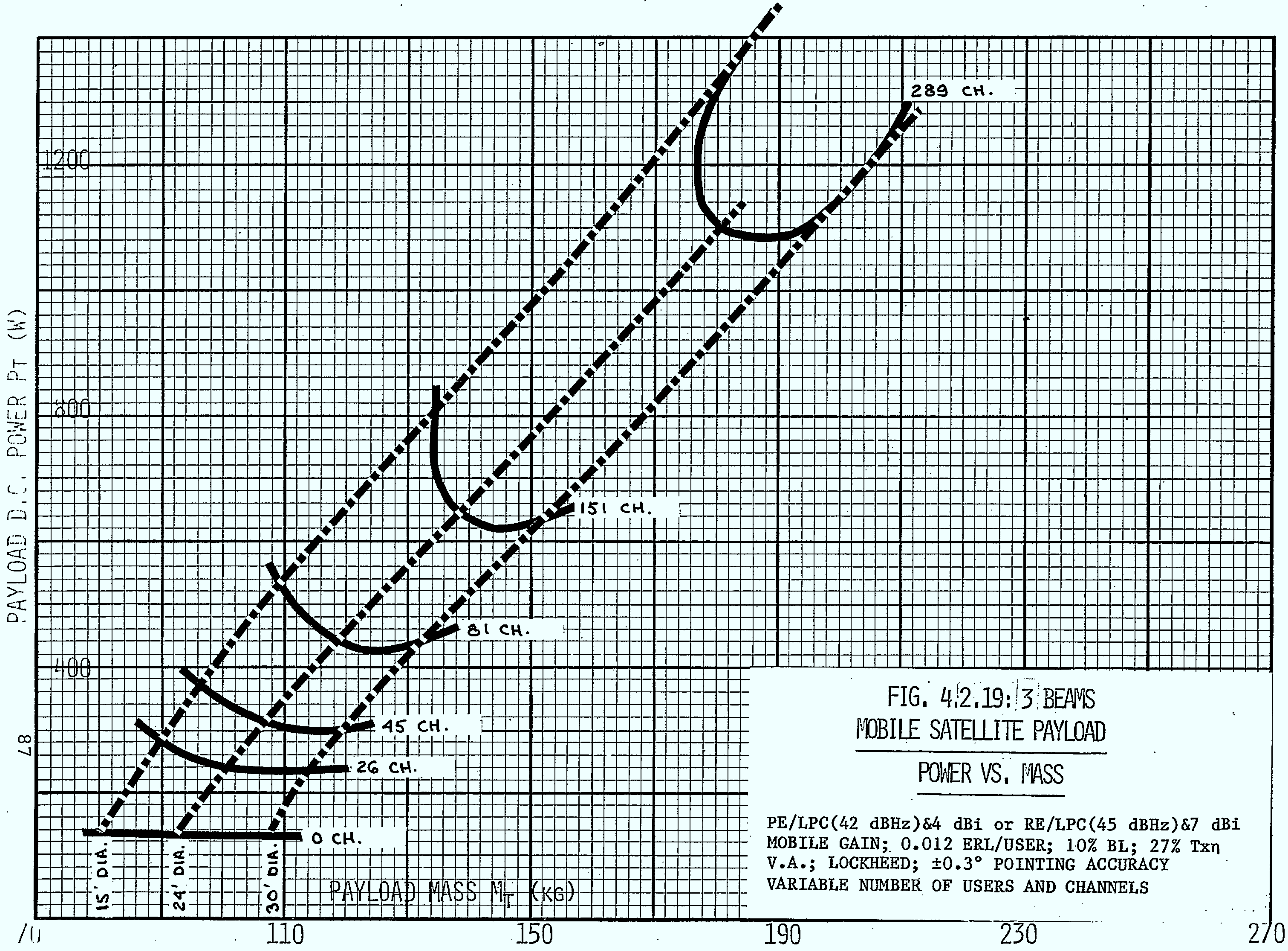


FIG. 4.2.19: 3 BEAMS MOBILE SATELLITE PAYLOAD

POWER VS. MASS

PE/LPC(42 dBHz)&4 dBi or RE/LPC(45 dBHz)&7 dBi MOBILE GAIN; 0.012 ERL/USER; 10% BL; 27% Txη V.A.; LOCKHEED; ±0.3° POINTING ACCURACY VARIABLE NUMBER OF USERS AND CHANNELS

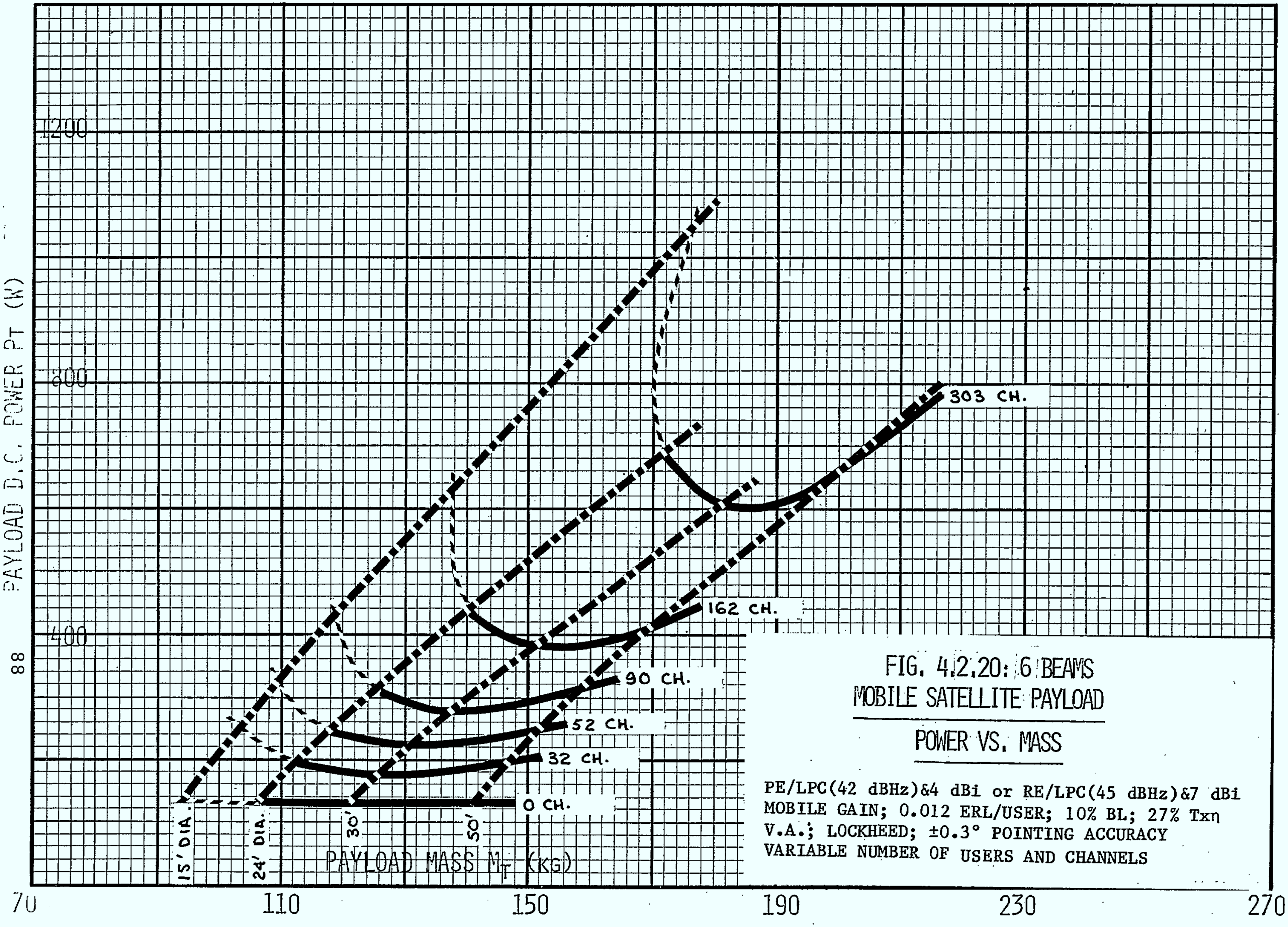


FIG. 4.2.20: 6 BEAMS MOBILE SATELLITE PAYLOAD

POWER VS. MASS

PE/LPC(42 dBHz)&4 dBi or RE/LPC(45 dBHz)&7 dBi MOBILE GAIN; 0.012 ERL/USER; 10% BL; 27% Txn V.A.; LOCKHEED; ±0.3° POINTING ACCURACY VARIABLE NUMBER OF USERS AND CHANNELS

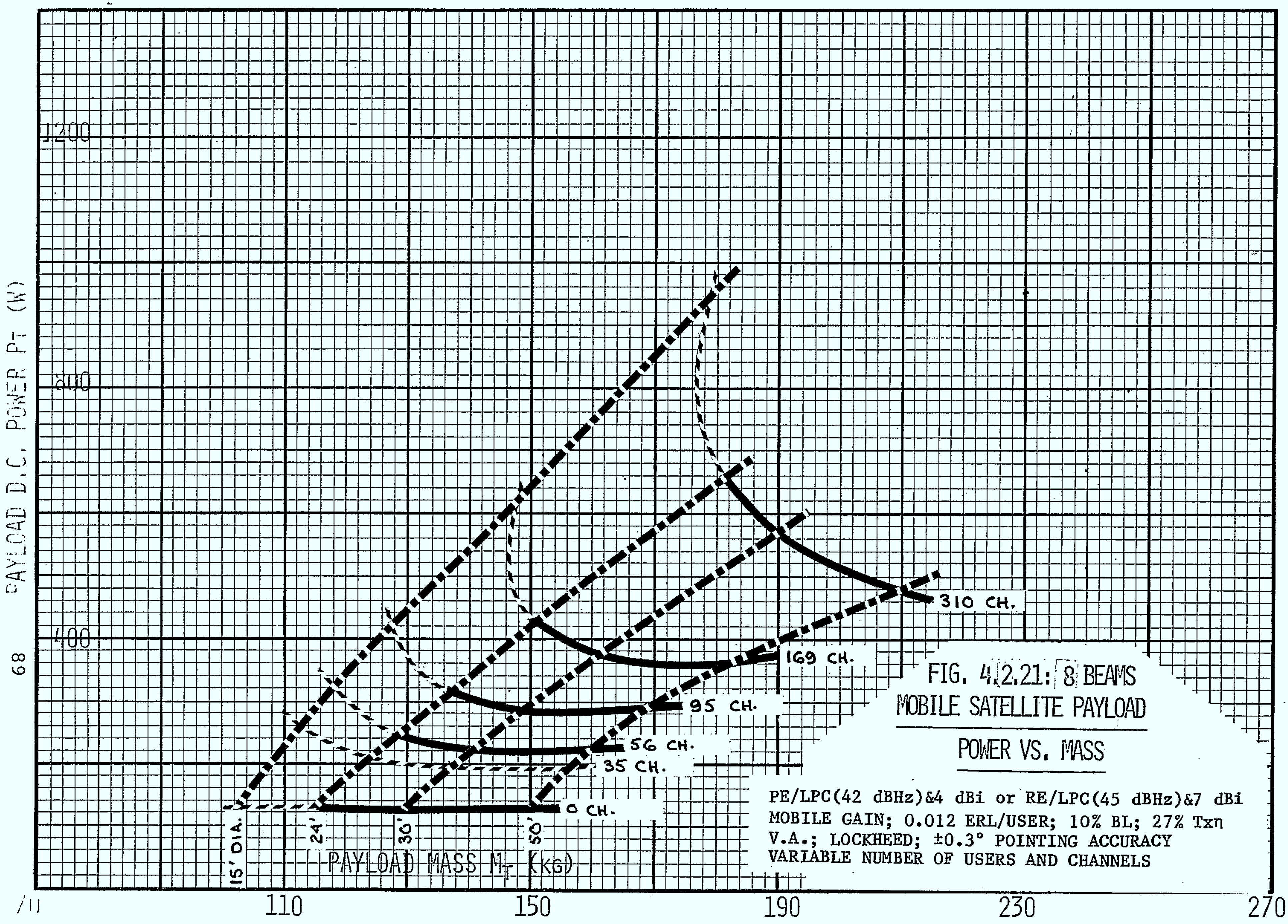


FIG. 4.2.21: 8 BEAMS MOBILE SATELLITE PAYLOAD

POWER VS. MASS

PE/LPC(42 dBHz)&4 dBi or RE/LPC(45 dBHz)&7 dBi MOBILE GAIN; 0.012 ERL/USER; 10% BL; 27% Txη V.A.; LOCKHEED; ±0.3° POINTING ACCURACY VARIABLE NUMBER OF USERS AND CHANNELS

4.3 SIMPLE GRAPHICAL SOLUTIONS TO PAYLOAD OPTIMIZATION

4.3.1 OBJECTIVES

It is obvious from the parametric analyses of Section 4.6, that the Mobile Mission payload characteristics depend on a large number of parameters.

On the other hand, the purpose of any parametric study is to make full use of the results by relatively simple and fast methods, in order to optimize the payload system design. It is clear from the results of mass and power versus antenna diameter or the number of channels, in Section 4.2.6, that their presentation is not easily visible to interpret.

It would be desirable to be able to display the results simultaneously in as many "dimensions" as possible, and at the same time, superimpose on the display, any desired bus capabilities. This could help in a direct and immediate evaluation of the "over utilization" or "under utilization" of the bus, and by what margins of mass and power.

So far, the payload results have been plotted, as values of power along the vertical axis, versus mass along the horizontal axis. It is evident the whole families of curves of payload power and mass will emerge for any constant number of users, antenna diameters, number of beams, Erlang per user, Blocking rate, (HPA and EPC) efficiency, etc....

4.3.2 BUS PAYLOAD ENVELOPES

The evaluation of various candidate spacecraft in Section 3.0 led to the conclusion that, for a 1986 launch, and without major bus redesign or modification, three buses are promising: R.C.A. Advanced SATCOM, Intelsat V and L-SAT. The latter is considered in another study.

4.3.2.1 R.C.A. Advanced SATCOM Bus

It has a nominal payload power of 1065 W and 136 Kg for 9.5 year lifetime with N-S stationkeeping.

However, the manufacturers, RCA, confirmed that this nominal bus can be upgraded as follows:

a) with N-S stationkeeping, 25 lbs for each year of reduced NSSK from 9.5 years, can be added to the payload capability. This is due mainly to the reduction of the size of the solar array and power regulator.

b) without N-S stationkeeping, 20 lbs per year, from year one of mission start, can be saved for each year of reduced NSSK from 9.5 years. This is due to the savings in propellant required per year.

Figure 4.3-1 displays the full useful range of capabilities of the Advanced RCA SATCOM bus.

4.3.2.2 INTELSAT V Bus

Similar discussions with Ford Aerospace led to the upgrading of INTELSAT V bus, from an existing 768 W and 233 kg for 7 years with N-S stationkeeping (283 kg without NSSK), to 1012 W and 213 kg for 7 years and NSSK (263 kg without NSSK).

Further upgrading of the payload capabilities would be feasible, with a design of a wider body and wider solar sails. 1493 W and 186 kg are expected for a 7 year NSSK (or 236 kg without NSSK). This is illustrated in Figure 4.3-2.

> THE BUS PAYLOAD ENVELOPE SHOULD BE USED AS FOLLOWS: ANY PAYLOAD POINT THAT IS BELOW THE ENVELOPE, OR TO THE LEFT OF IT, IS A USABLE PAYLOAD THAT THE BUS IS CAPABLE OF HANDLING WITH A POSITIVE MARGIN.
>
> Those limits have been identified in Figure 4.3-3. Here, the limits of the useful area are clearly marked by vertical and horizontal boundaries: In addition, this Figure 4.3-3 combines the RCA and I-V data.

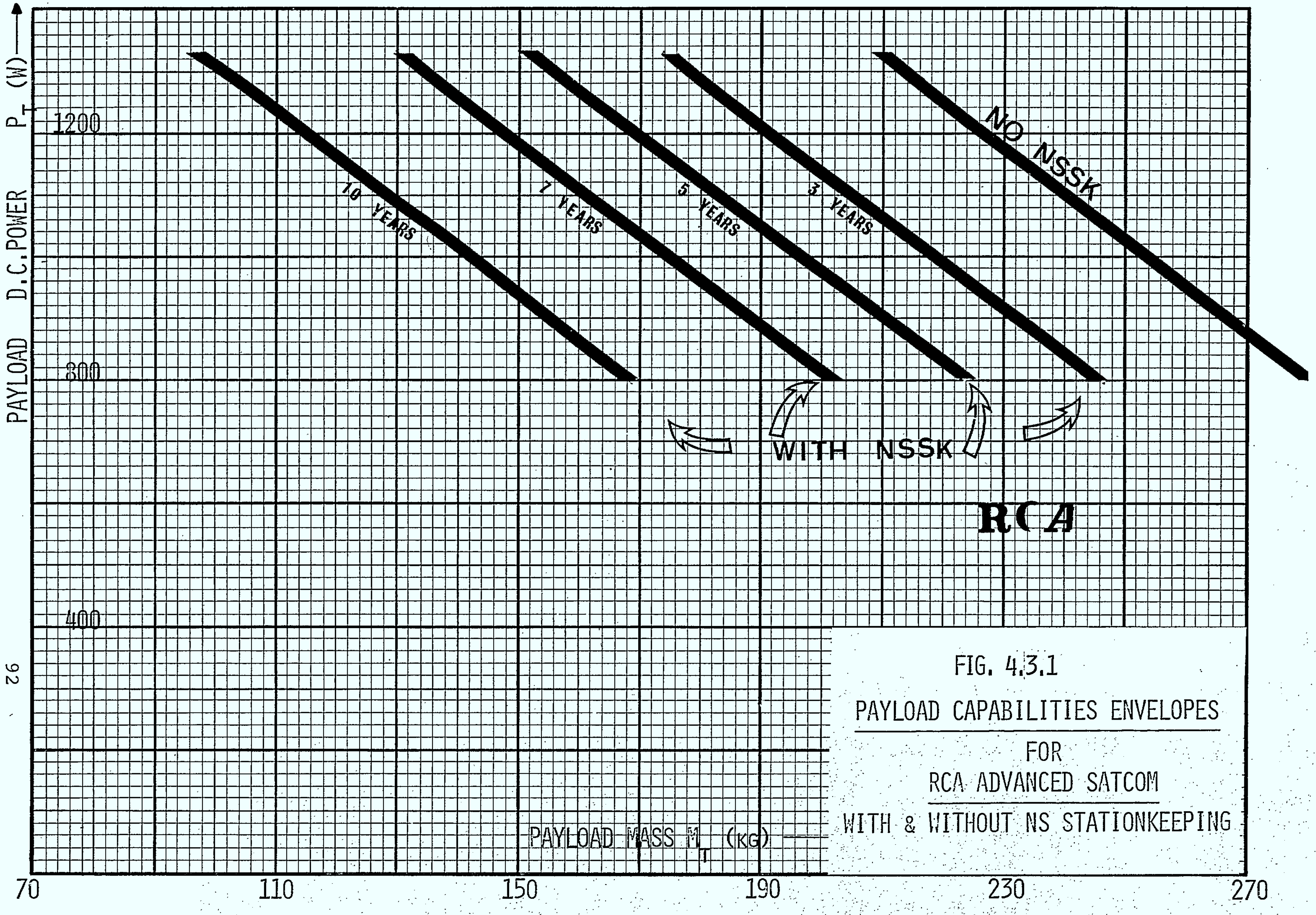


FIG. 4.3.1

PAYLOAD CAPABILITIES ENVELOPES

FOR

RCA ADVANCED SATCOM

WITH & WITHOUT NS STATIONKEEPING

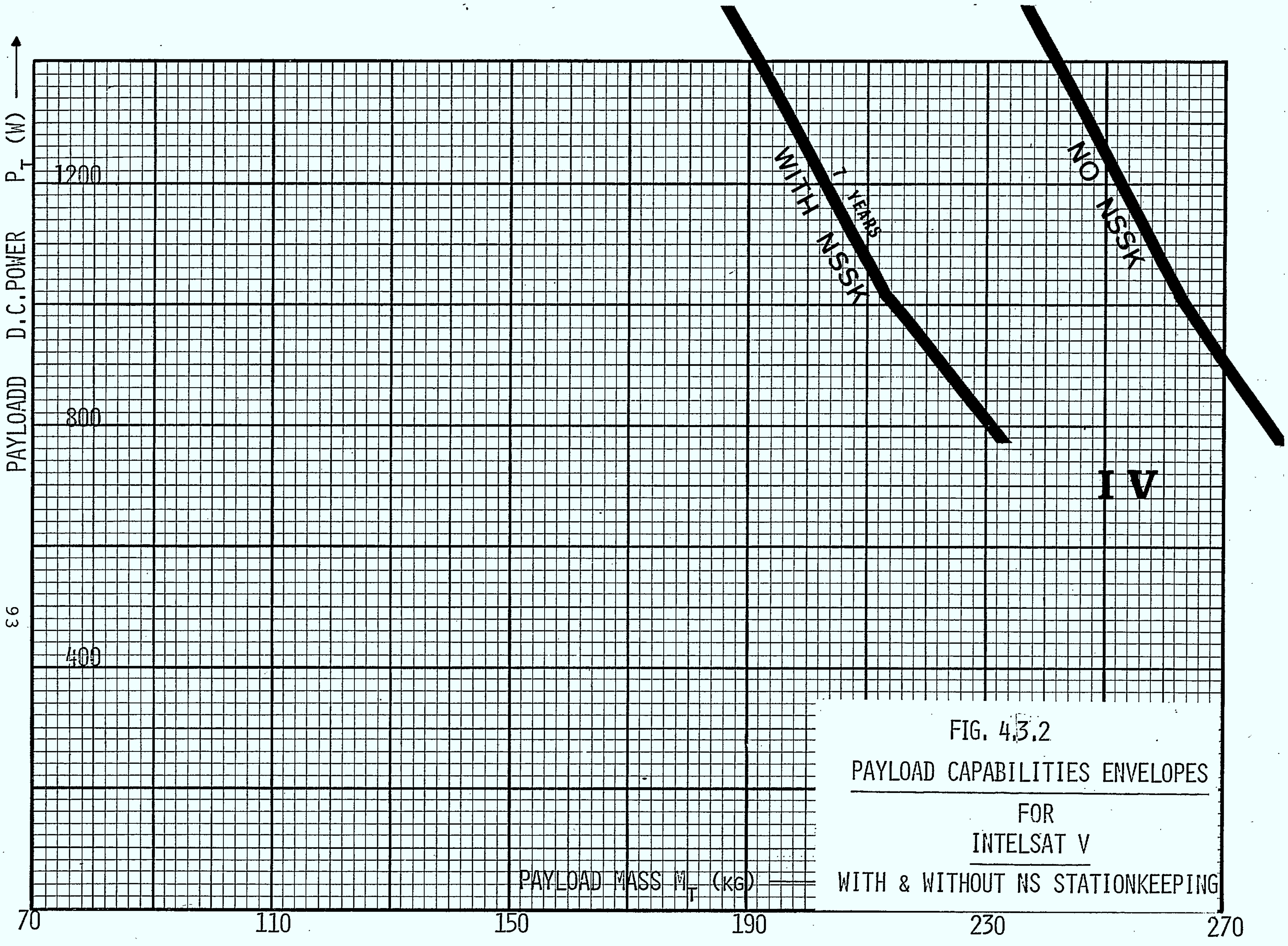


FIG. 4.3.2

PAYLOAD CAPABILITIES ENVELOPES

FOR

INTELSAT V

WITH & WITHOUT NS STATIONKEEPING

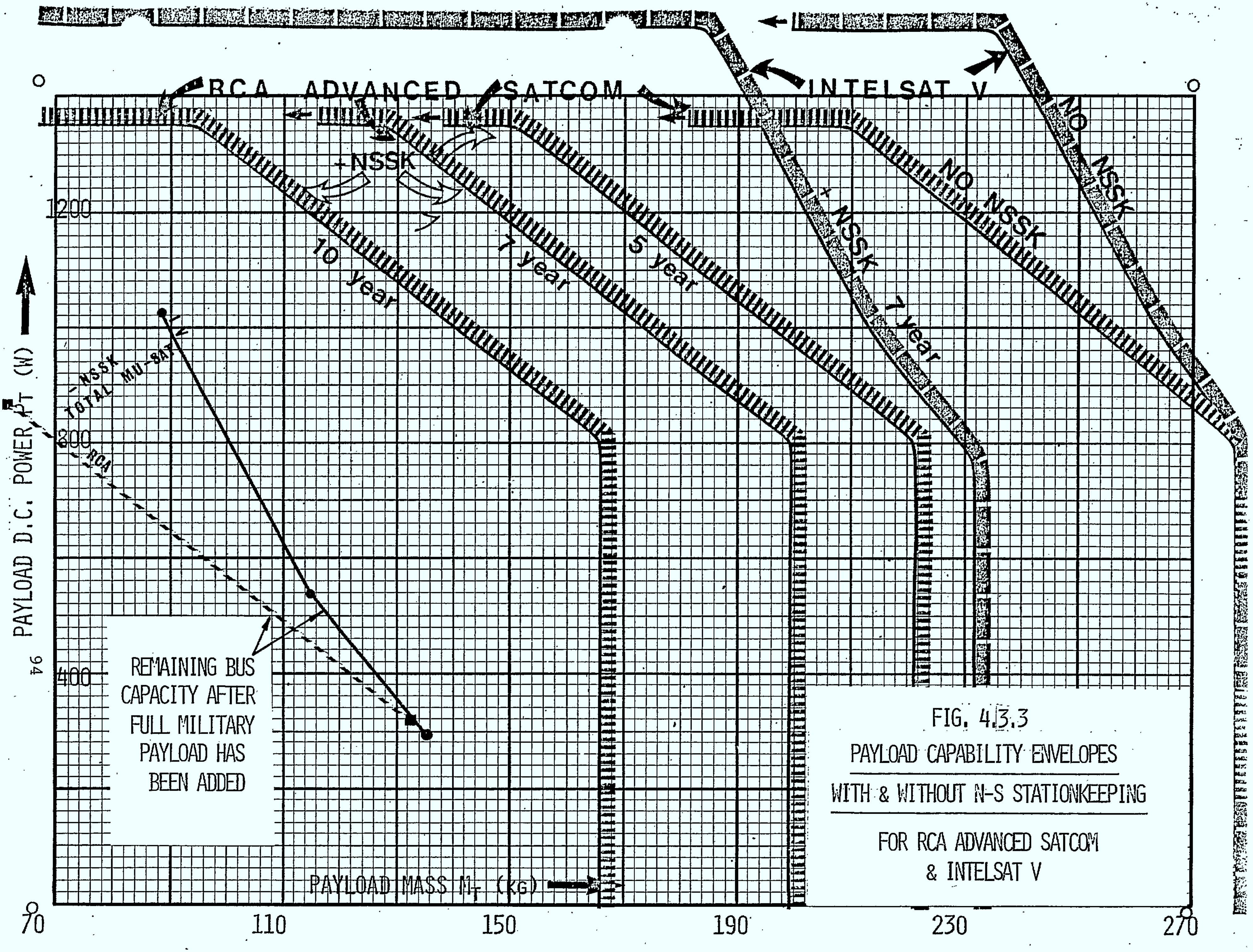


FIG. 4.3.3

PAYLOAD CAPABILITY ENVELOPES WITH & WITHOUT N-S STATIONKEEPING

FOR RCA ADVANCED SATCOM & INTELSAT V

4.3.3 SUPERPOSITION OF BUS ENVELOPES ON PAYLOAD PARAMETRICS

It is possible to superimpose the bus envelopes of Figure 4.3-3 or that of any other bus, on any of the power versus mass payload curves of Figures 4.2-18 through 4.2-21, provided both sets are plotted to the same scale.

In fact, this is demonstrated in Figure 4.3-4 where 4.3-18 is superimposed on 4.3-3.

It becomes apparent that such a graphical optimization is simple, fast and efficient.

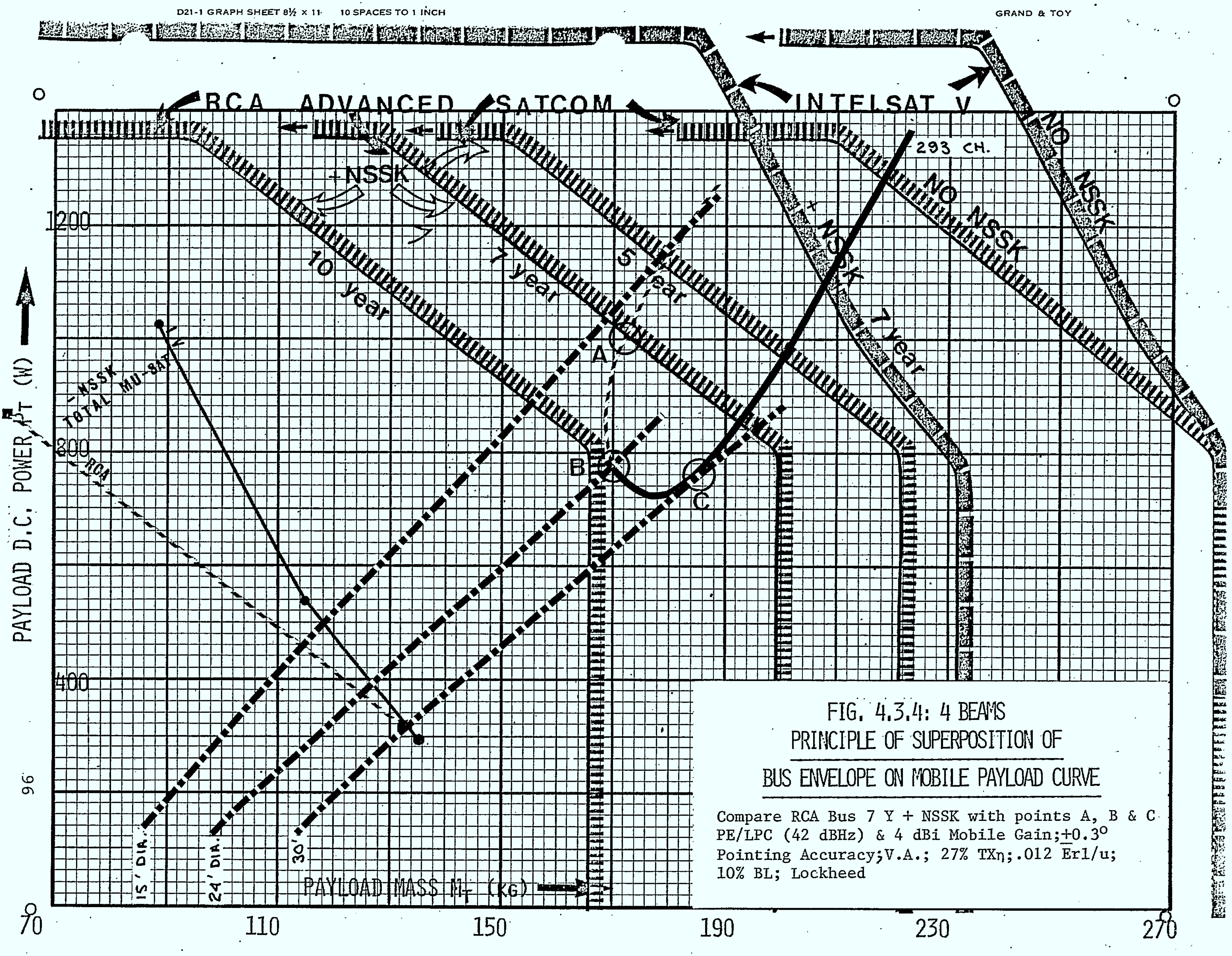


FIG. 4.3.4: 4 BEAMS PRINCIPLE OF SUPERPOSITION OF BUS ENVELOPE ON MOBILE PAYLOAD CURVE

Compare RCA Bus 7 Y + NSSK with points A, B & C
PE/LPC (42 dBHz) & 4 dBi Mobile Gain; ±0.3°
Pointing Accuracy; V.A.; 27% TXη; .012 Erl/u;
10% BL; Lockheed

For example, consider a seven-year Mobile-only mission with NSSK, on an RCA SATCOM in Figure 4.3-4. Some possible solutions, although not necessarily the optimum, could correspond to 4 beams across Canada and to the following points A, B, & C. They all apply for PE/LPC, 25,000 users, 293 channels, at 0.012 Erl/User and 10% blocking rate, 27% TX efficiency, using Lockheed deployable reflectors. However, each of these points, A, B, & C, applies to the following antenna diameters: 17, 24, & 30 feet, respectively, 1000 W, 758 W and 758 W respectively, 172 kg, 170 kg and 185 kg respectively, all points being at or below the 7 year, NSSK, RCA payload envelope. It is clear that in this case there is very little difference in the payload margins between choosing 24 or 30 foot reflectors. However, for the case of a 50 foot reflector, computations show that the payload requirements are 2068 W and 276 kg. At first sight, this is an unexpected result. Only after deeper analysis does this result emerge.

The implications of such a finding can be significant in the ultimate system design of the spacecraft. In this particular case, since either a 24 foot or a 50 foot reflector can equally satisfy the requirements, the 24-foot reflector would be the more obvious choice. The 50 foot antenna, apart from additional cost, may have a major impact (stability, dynamics, shadowing, etc) on the design of the bus, according to Ford and RCA. This conclusion is only valid for this particular case, and may not apply generally. For example, if more than 4 beams are considered. Section 4.5 will discuss the sensitivity analysis of the parametric results.

Typical positive margins for point B would be 120 watts and 14 kg. By the graphical method used in this report, it is possible to see at a glance, the effect of so many parameters on the use of a spacecraft.

THERE ARE TWO POSSIBLE WAYS OF MAKING USE OF THIS GRAPHICAL METHOD:

A) IF PAYLOAD REQUIREMENTS ARE KNOWN, THEN IT CAN BE SEEN WHETHER A CHOSEN BUS IS LIKELY TO BE UNDER OR OVER UTILIZED. THEREFORE, "FLOATING" PARAMETERS CAN BE CHANGED FOR FULL UTILIZATION.

B) IF PAYLOAD REQUIREMENTS ARE NOT DEFINED, BUT A SPECIFIC BUS IS AVAILABLE, THEN THIS METHOD REVEALS THE MAXIMUM NUMBER OF CHANNELS, AND HENCE USERS, THAT CAN BE SERVED BY THAT BUS.

Appendices I, J and K use this graphical representation throughout.

4.4 COMBINED MISSION PAYLOAD PARAMETRIC ANAYSIS

4.4.1 MILITARY PAYLOAD

Apart from the low UHF and L-Band helices which were made parametrically variable, and later optimized and hence fixed, the whole military payload becomes one constant for power and mass.

Therefore, the same graphical approach for the bus optimum utilization can be used as for the Mobile Mission in Section 4.3.4.

Table 4.4-1 sums up the MILITARY payload.

TABLE 4.4-1 TOTAL MILITARY PAYLOAD

ANTENNA		TRANSPONDER	
UNIT	VALUE	UNIT	VALUE
Mass		Mass	
AM3 L-Band Helices	2.5 kg	TM3 L-Band	5.9 kg
AM4 TT&C Bicone	1.8 kg	TM5 Low UHF	31.0 kg
AM6 UHF TX helices	19.1 kg	TM6 SHF Backhaul	26.4 kg
AM7 UHF RX helices	6.8 kg	TM7 EHF	20.7 kg
AM8 SHF Primary	2.7 kg	TM8 ISL	12.7 kg
AM9 SHF global	1.8 kg	TM9 misc.	23.6 kg
AM10 EHF	6.0 kg	Power	
AM11 ISL	4.9 kg	TP3 L-Band	80 W
		TP5 low UHF	217 W
		TP6 L-Band	102 W
		TP7 EHF	56 W
		TP8 ISL	84 W
		TP9 Misc.	23 W
Total Mass = 166 kg		Power = 562 W	

An alternative solution to the combined mission would be to replace, both low UHF TX and RX helices, by one TX-RX 22 foot dish weighing 23.5 kg, saving (19.1 + 6.8) - 23.5 = 2.4 kg. The main reason for this is that no solar sail would be required to balance the solar pressure on an unsymmetrical satellite; hence, a simplification and an additional saving of 8.2 kg. Thus total saving is 10.6 kg.

4.4.2 COMBINED PAYLOAD

For a combined mission, where the total of both MOBILE and MILITARY payloads is required, then both payloads in Tables 4.2-5 and 4.4-1 can be added. However, care must be taken not to duplicate some items, namely:

- L-Band antenna and transponder
- TT&C Bicone antenna
- SHF Backhaul antenna and transponder

Of course, depending on the requirements for NSSK, and some given priorities, the combined mission may be required to serve a percentage of the mobile users, and part of the Military payload. In fact this is the subject of a second study, which follows immediately after this main study, in a separate report.

Only as an illustration of the superposition of payload and bus envelopes, the whole envelope for say RCA Advanced Satcom or I-V is translated to the left, by taking out of the bus envelopes, the value of power and mass corresponding to the total or partial Military payload. This is shown in Figure 4.3-3, on the lower left corner.

The useful area that determines what payload capabilities are left for the Mobile mission, in a combined case, is the region to the left and below those translated envelopes, to wherever they happen to shift.

As an illustration, consider the curves of Figure PB4 as on page I-3 in Appendix I. The full Military payload envelopes for RCA Advanced SATCOM and I-V, without NSSK, are shown on the lower left hand corner. They clearly show, that, an RCA bus, for example, can satisfy the whole MILITARY payload plus the following Mobile payload: PE/LPC, 27% efficiency, 10% Blockage, 4 beams, either 84 channels (6250 users) with an antenna diameter of 24 feet with margins of 30 watts and 5 kg, or, in principle without margins, 84 channels for equally a 15 foot or a 30 foot antenna.

This is not to suggest that these actual values should be considered for a design, without adequate margins. The main issue here, is the ease with which these parametric curves can be used to optimize graphically the solution required.

4.5 SENSITIVITY ANALYSIS OF PARAMETRIC RESULTS AND CONCLUSIONS

4.5.1 SENSITIVITY RESULTS

Due to the large number of results, only representative cases will be discussed. The case of six beams was adopted. All the parametric changes should behave as expected, e.g. antenna gain requires more payload power, etc. However, what is to be learned in this sensitivity analysis is the range within which these changes occur.

4.5.1.1 TX Efficiency

The result of Figure 4.5-1 shows a larger increase in power for a decrease in efficiency from 27% to 18%, than from 36% to 27%.

4.5.1.2 Traffic Intensity

The limited range of 0.008 to 0.016 ErL/User shows on Figure 4.5-2, a significant change in both power and mass. This parameter has to be carefully determined from the onset of the mobile project. However, as will be shown in Figure 4.5-5, traffic intensity becomes important only towards the end of the spacecraft lifetime.

4.5.1.3 Blocking Rate

Variations in rates of 10%, 3%, and 1% show, on Figure 4.5-3, relatively smaller effects than variations in the traffic intensity. It is worth noting that for both cases the increase in payload is a direct result of the increase in the effective number of channels.

4.5.1.4 Voice Activation

As expected, voice activation offers a considerable reduction in the effective number of channels, and hence in the payload power. All curves shift vertically, as shown in Figure 4.5-4.

4.5.1.5 Spacecraft Usage With Years

Traffic forecast predicts that three, five, seven and ten years from the 1986 launch, the number of users will be 5,000, 12,000, 25,000 and 50,000, respectively. The impact on the payload usage is shown in Figure 4.5-5. It becomes clear that a larger traffic intensity can be used in the earlier years than 0.012 Erl/User. In addition, it is concluded that either an RCA Advanced SATCOM or an Intelsat V bus, without NSSK, has enough payload capability for a 10 year mobile-only mission, using about 600 channels.

4.5.1.6 Antenna Pointing Accuracy

Two payload points were selected on Figure 4.5-6, one for 30 feet, the other for a 50 foot reflector, for three cases: 0°, ±0.15° and ±0.3° pointing accuracy. It is clear from the result, that the 50 foot antenna, with sharper beam width, suffers greater loss of gain than a 30 foot antenna. This leads to a significant increase in the power requirements. It is felt that further, detailed work on the antenna system design is required, together with a complete trade-off study of the effect of pointing inaccuracy.

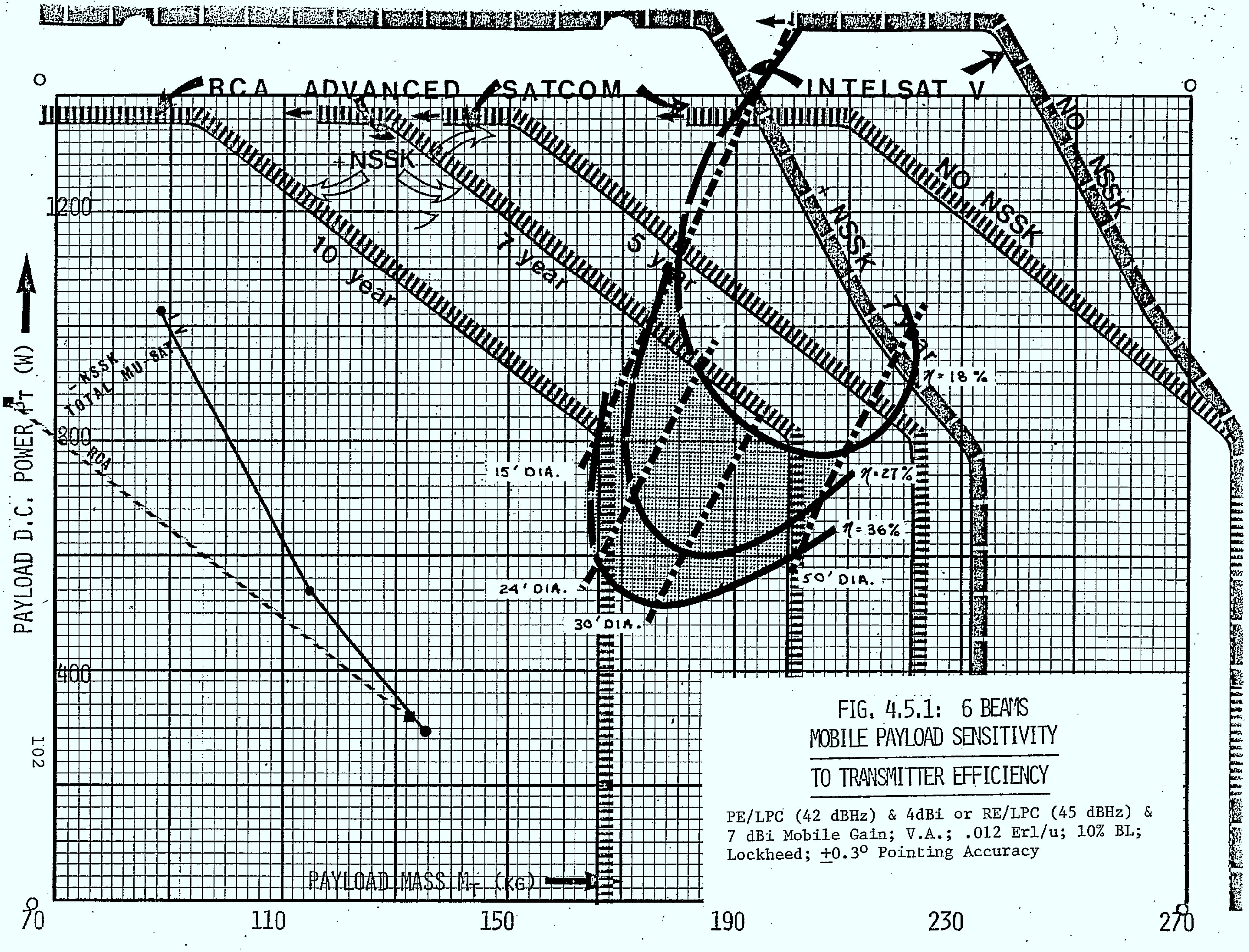


FIG. 4.5.1: 6 BEAMS MOBILE PAYLOAD SENSITIVITY TO TRANSMITTER EFFICIENCY

PE/LPC (42 dBHz) & 4dBi or RE/LPC (45 dBHz) & 7 dBi Mobile Gain; V.A.; .012 Erl/u; 10% BL; Lockheed; ±0.3° Pointing Accuracy

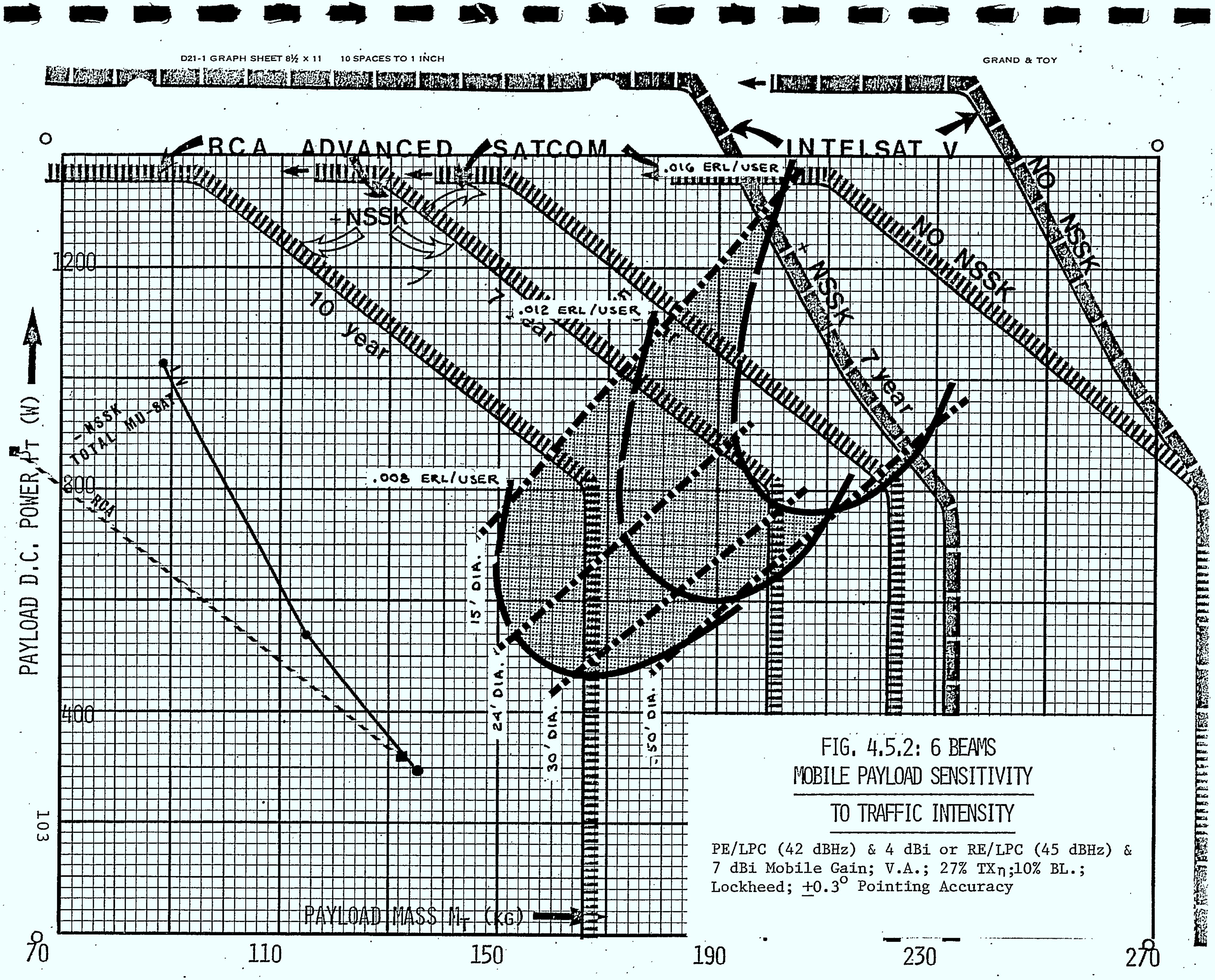


FIG. 4.5.2: 6 BEAMS MOBILE PAYLOAD SENSITIVITY TO TRAFFIC INTENSITY

PE/LPC (42 dBHz) & 4 dBi or RE/LPC (45 dBHz) & 7 dBi Mobile Gain; V.A.; 27% TX$_\eta$;10% BL.; Lockheed; ±0.3° Pointing Accuracy

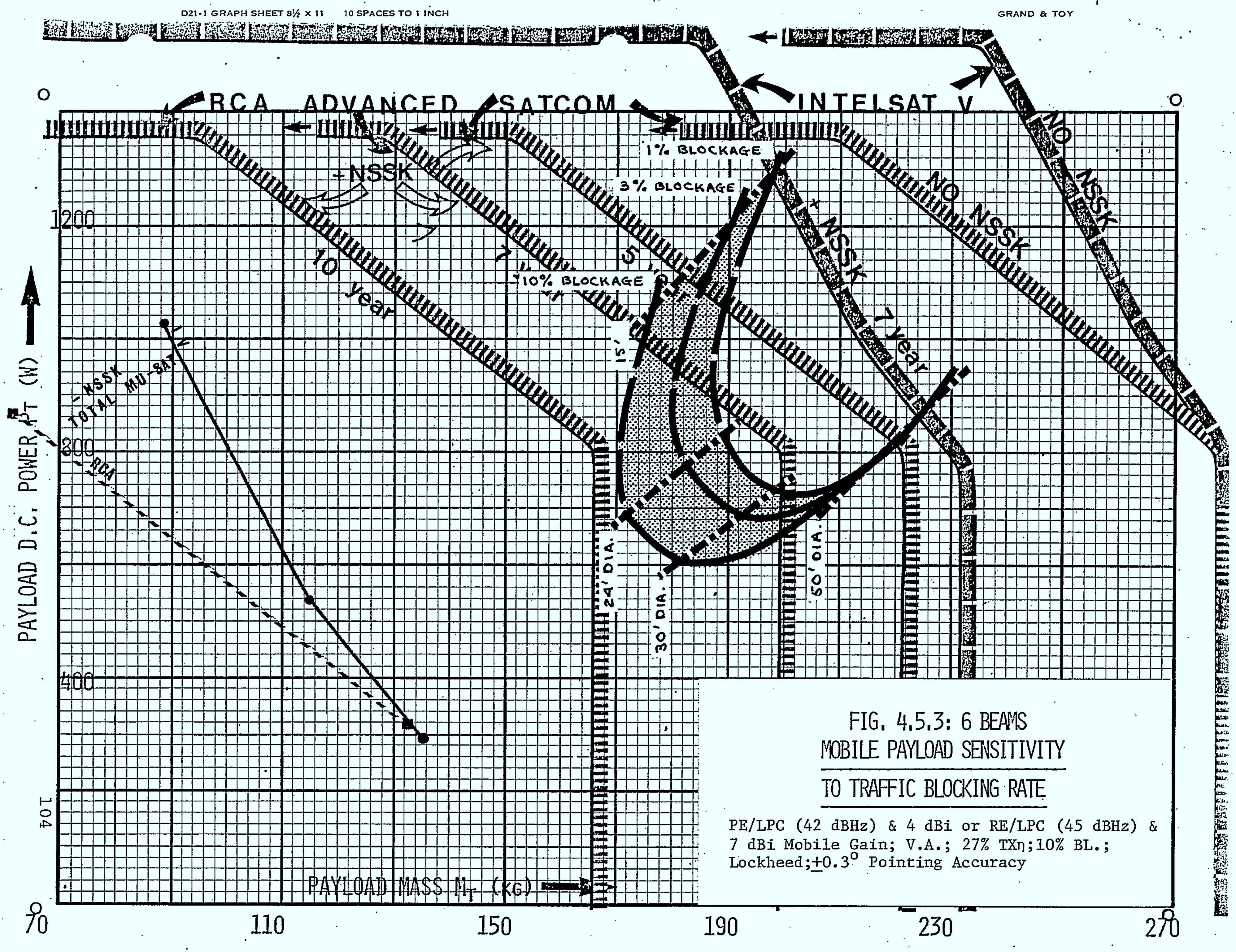


FIG. 4.5.3: 6 BEAMS MOBILE PAYLOAD SENSITIVITY TO TRAFFIC BLOCKING RATE

PE/LPC (42 dBHz) & 4 dBi or RE/LPC (45 dBHz) & 7 dBi Mobile Gain; V.A.; 27% TXη;10% BL.; Lockheed;±0.3° Pointing Accuracy

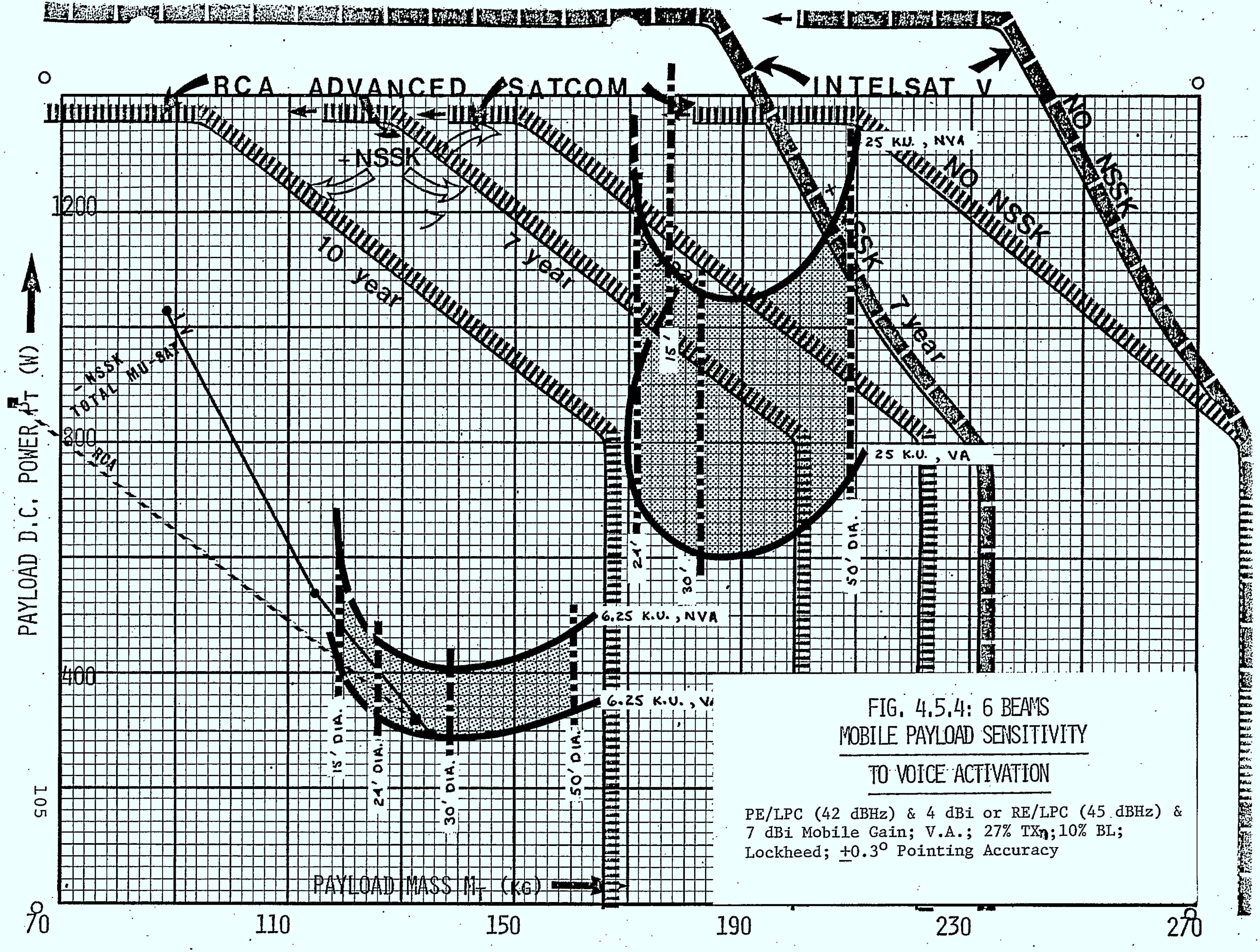


FIG. 4.5.4: 6 BEAMS MOBILE PAYLOAD SENSITIVITY TO VOICE ACTIVATION

PE/LPC (42 dBHz) & 4 dBi or RE/LPC (45 dBHz) & 7 dBi Mobile Gain; V.A.; 27% TXη; 10% BL; Lockheed; ±0.3° Pointing Accuracy

4.5.1.7 Number of Channels

The results are shown in Figure 4.5-7. They demonstrate a near-linear increase in power and mass with the number of channels.

4.5.1.8 Number of Beams

This was believed to be relevant only to the frequency reuse, if any. However, the result of the effect of different numbers of beams, coupled with different antenna diameters, has a direct impact on the payload requirements, as shown in Figure 4.5-8 through 4.5-10.

It was also found useful to consider the loci of the payload minima. These are the lower envelopes, shown in Figure 4.5-11. They represent the minimum payload requirements for any combination of number of beams and antenna diameters. Again, previous reservations about the usage of a limited number of beams for small antennas, should apply.

It is felt that the loci shown in Figure 4.5-11 are very important in making decisions on the trade-off between number of beams and the antenna diameter.

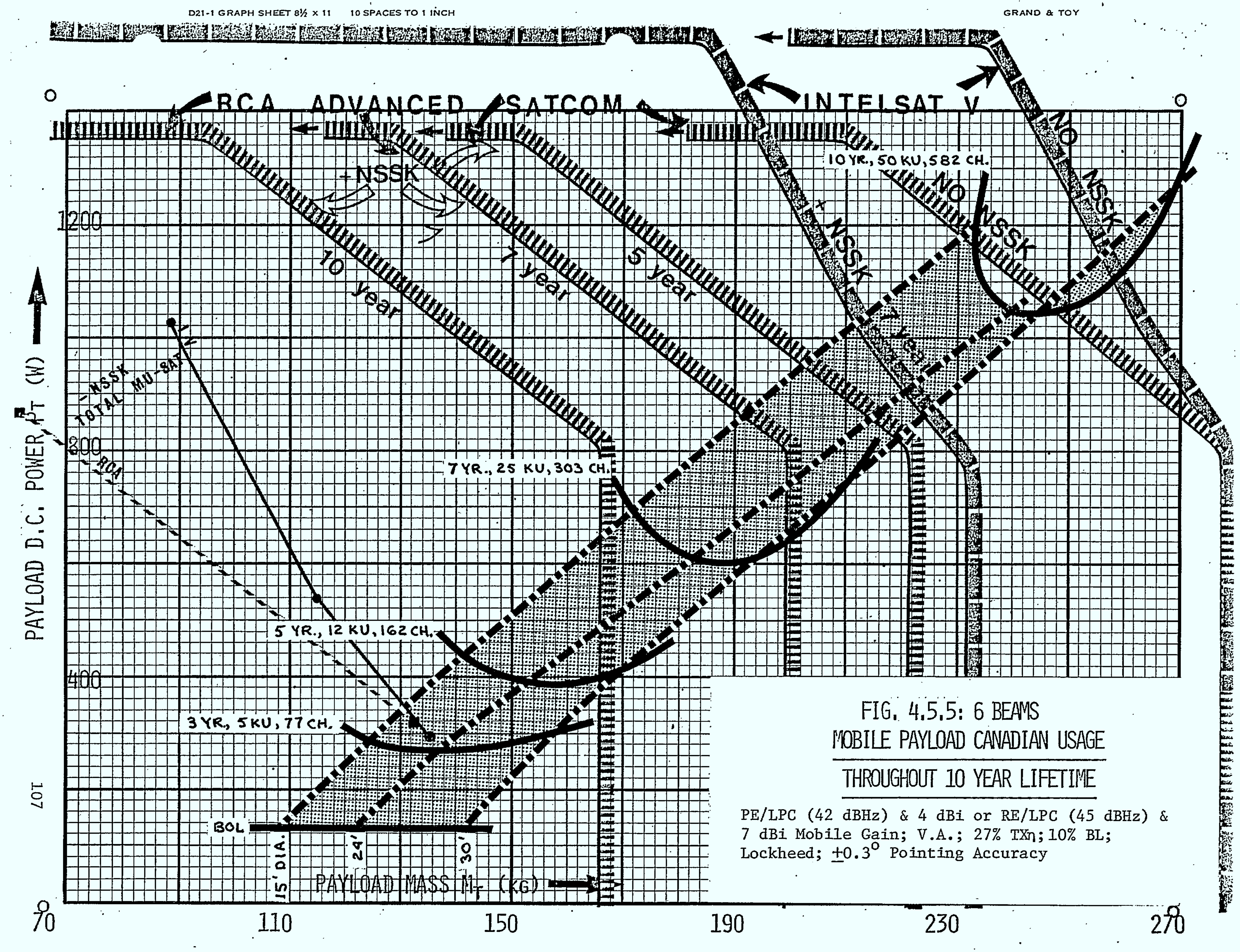


FIG. 4.5.5: 6 BEAMS MOBILE PAYLOAD CANADIAN USAGE THROUGHOUT 10 YEAR LIFETIME

PE/LPC (42 dBHz) & 4 dBi or RE/LPC (45 dBHz) & 7 dBi Mobile Gain; V.A.; 27% TXη; 10% BL; Lockheed; $\pm 0.3^{\circ}$ Pointing Accuracy

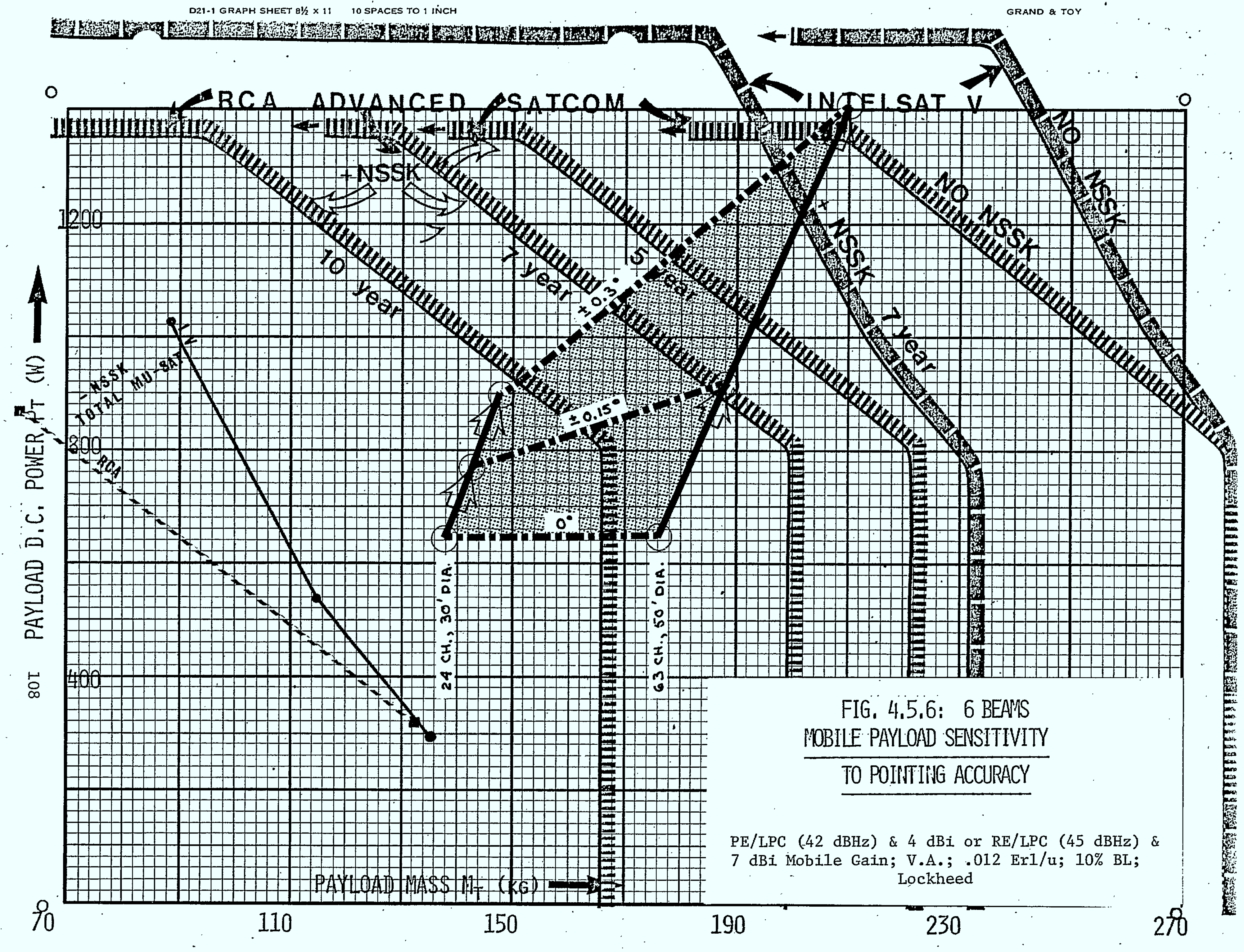


FIG. 4.5.6: 6 BEAMS MOBILE PAYLOAD SENSITIVITY TO POINTING ACCURACY

PE/LPC (42 dBHz) & 4 dBi or RE/LPC (45 dBHz) & 7 dBi Mobile Gain; V.A.; .012 Erl/u; 10% BL; Lockheed

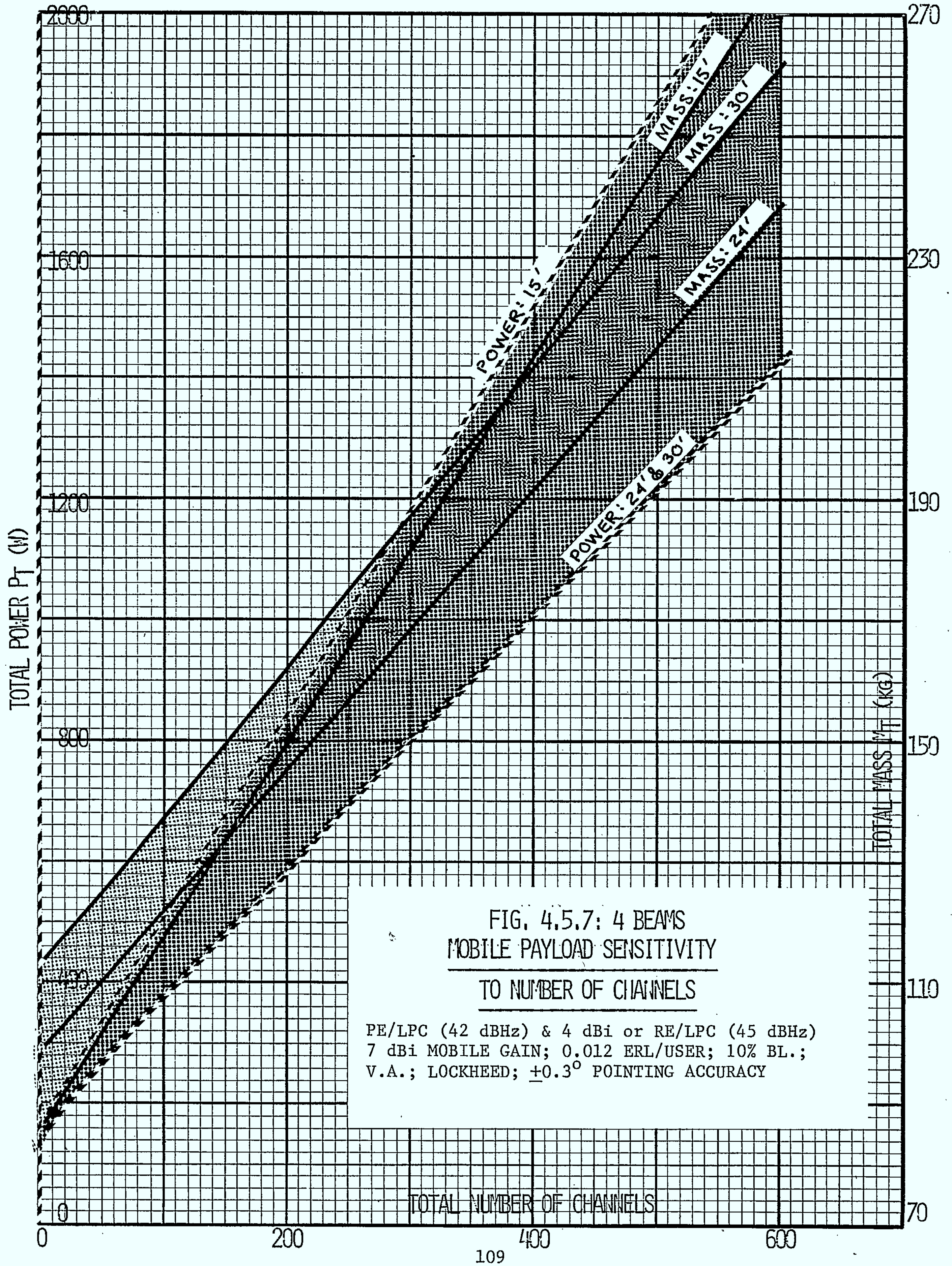


FIG. 4.5.7: 4 BEAMS
MOBILE PAYLOAD SENSITIVITY
TO NUMBER OF CHANNELS

PE/LPC (42 dBHz) & 4 dBi or RE/LPC (45 dBHz)
7 dBi MOBILE GAIN; 0.012 ERL/USER; 10% BL.;
V.A.; LOCKHEED; ±0.3° POINTING ACCURACY

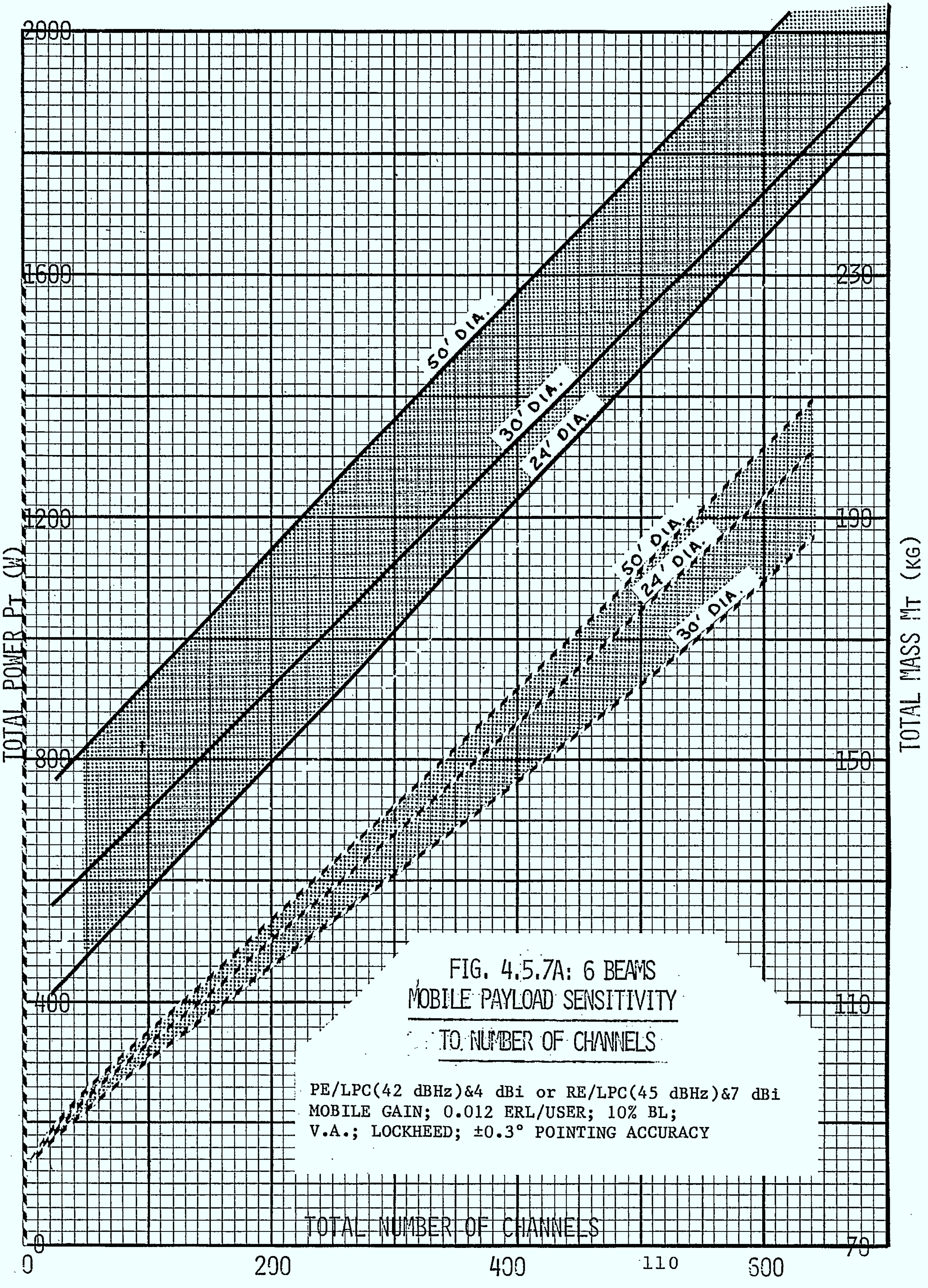


FIG. 4.5.7A: 6 BEAMS
MOBILE PAYLOAD SENSITIVITY
TO NUMBER OF CHANNELS

PE/LPC(42 dBHz)&4 dBi or RE/LPC(45 dBHz)&7 dBi
MOBILE GAIN; 0.012 ERL/USER; 10% BL;
V.A.; LOCKHEED; ±0.3° POINTING ACCURACY

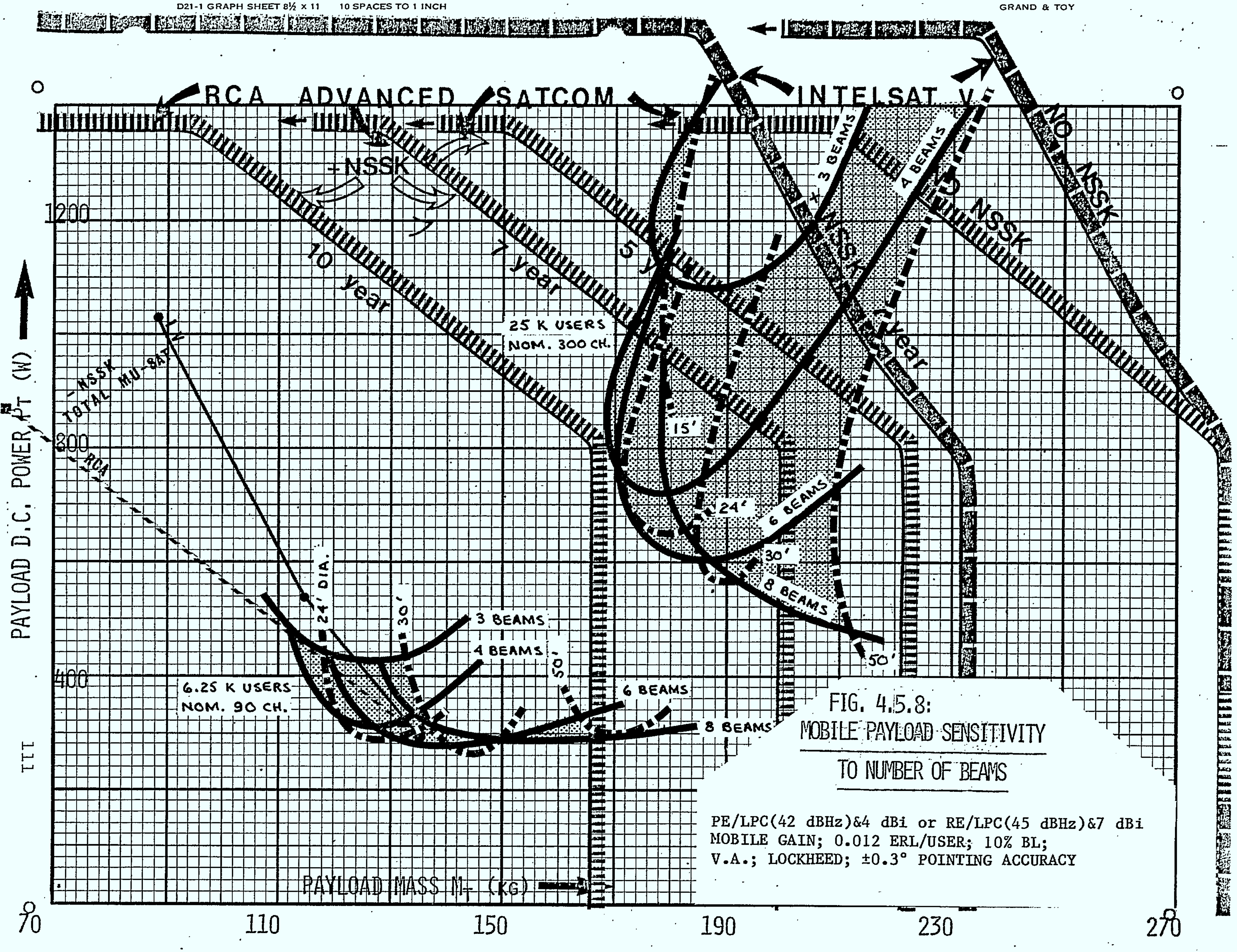


FIG. 4.5.8: MOBILE PAYLOAD SENSITIVITY TO NUMBER OF BEAMS

PE/LPC(42 dBHz)&4 dBi or RE/LPC(45 dBHz)&7 dBi MOBILE GAIN; 0.012 ERL/USER; 10% BL; V.A.; LOCKHEED; ±0.3° POINTING ACCURACY

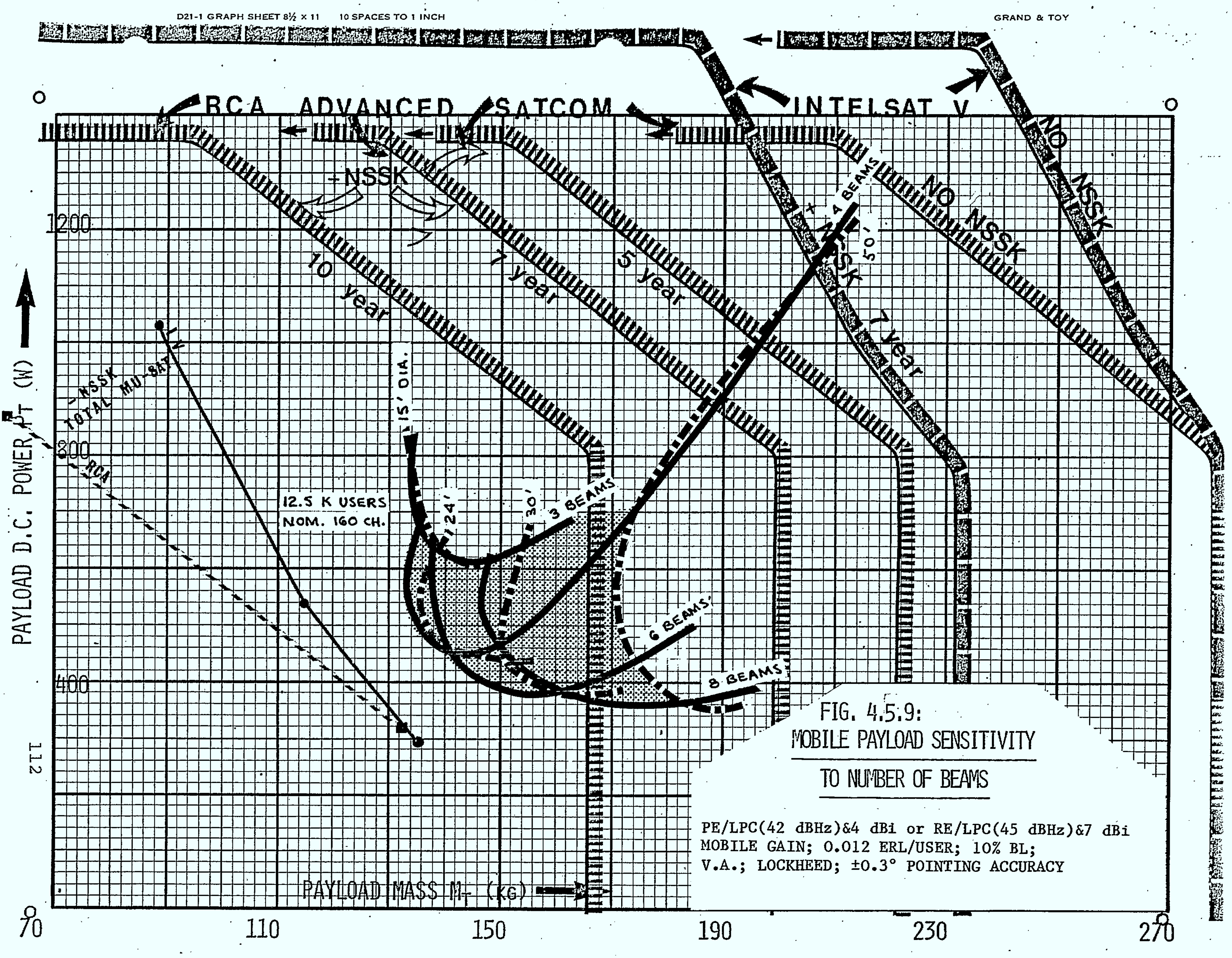


FIG. 4.5.9: MOBILE PAYLOAD SENSITIVITY TO NUMBER OF BEAMS

PE/LPC(42 dBHz)&4 dBi or RE/LPC(45 dBHz)&7 dBi MOBILE GAIN; 0.012 ERL/USER; 10% BL; V.A.; LOCKHEED; ±0.3° POINTING ACCURACY

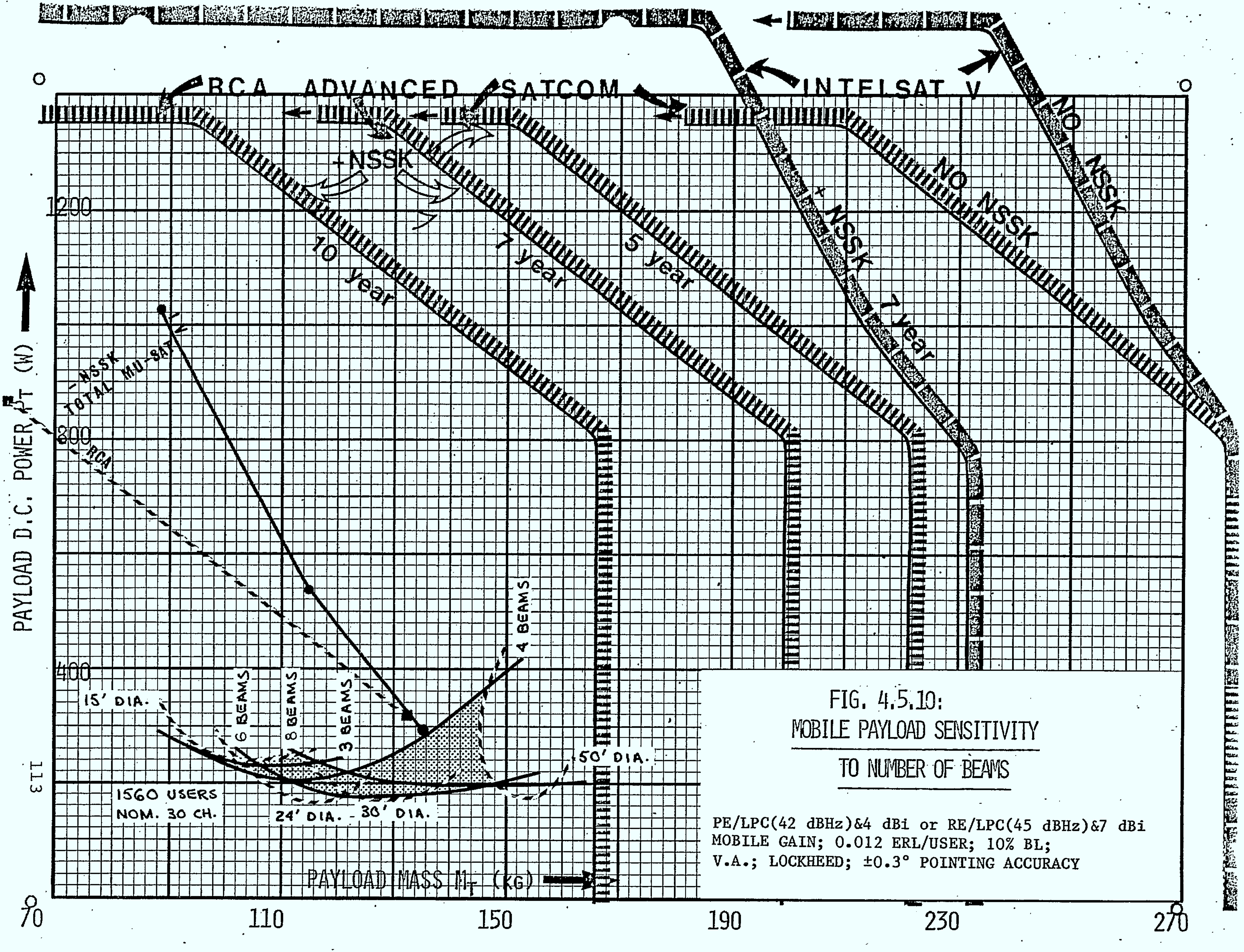


FIG. 4.5.10: MOBILE PAYLOAD SENSITIVITY TO NUMBER OF BEAMS

PE/LPC(42 dBHz)&4 dBi or RE/LPC(45 dBHz)&7 dBi MOBILE GAIN; 0.012 ERL/USER; 10% BL; V.A.; LOCKHEED; ±0.3° POINTING ACCURACY

D21-1 GRAPH SHEET 8½ x 11   10 SPACES TO 1 INCH   GRAND & TOY

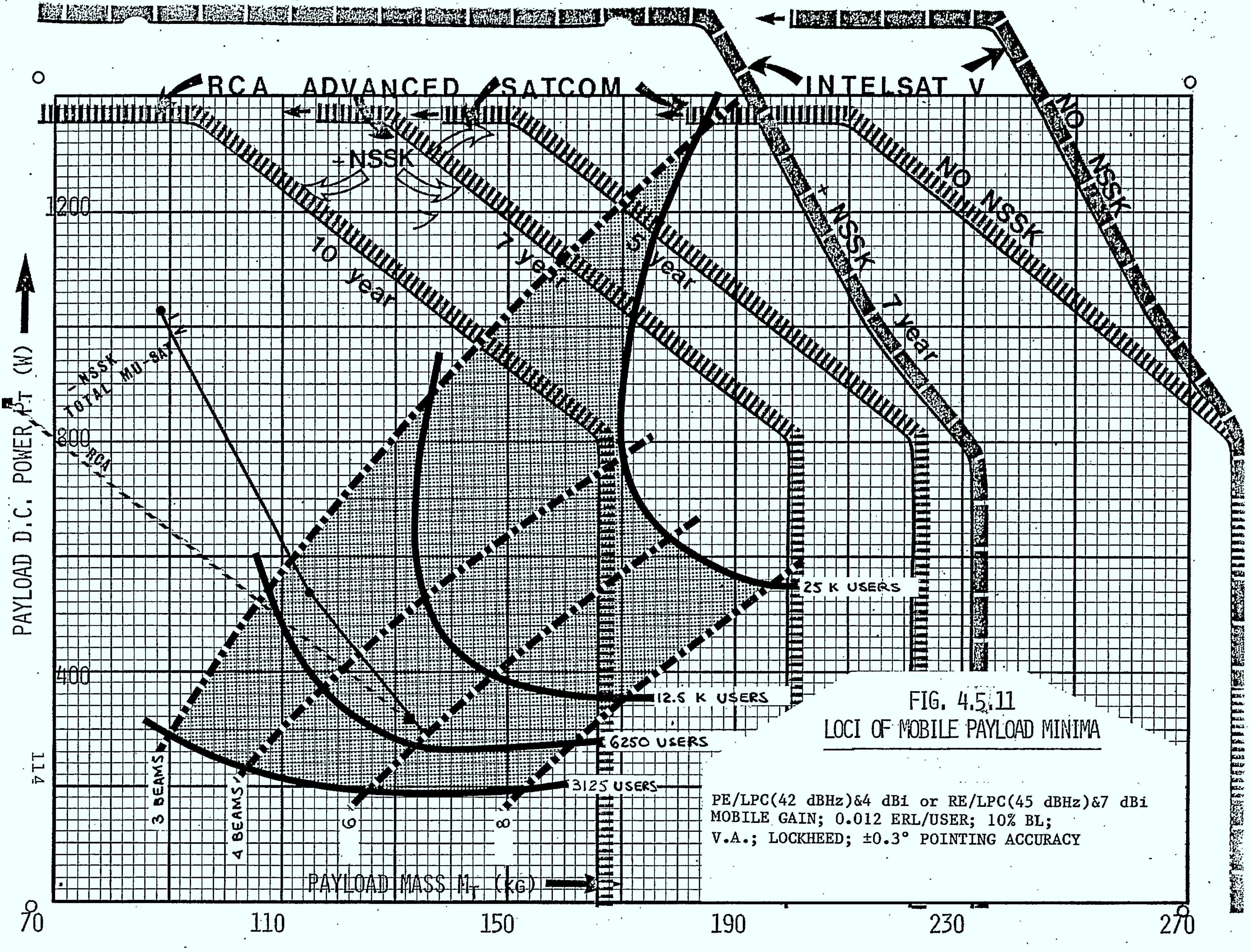


FIG. 4.5.11

LOCI OF MOBILE PAYLOAD MINIMA

PE/LPC(42 dBHz)&4 dBi or RE/LPC(45 dBHz)&7 dBi
MOBILE GAIN; 0.012 ERL/USER; 10% BL;
V.A.; LOCKHEED; ±0.3° POINTING ACCURACY

4.5.1.9 Comparison of PE/LPC with RE/LPC and NBFM

Since NBFM is highly inefficient in terms of power requirements, only a limited number of channels can be considered, e.g. 26 and 18 channels for a 3 beam case. The results for 3, 4, 6 and 8 beams are shown in Figures 4.5-12 through 4.5-15. They show payload power requirements are significantly reduced for PE/LPC compared to NBFM, particularly so for small numbers of beams.

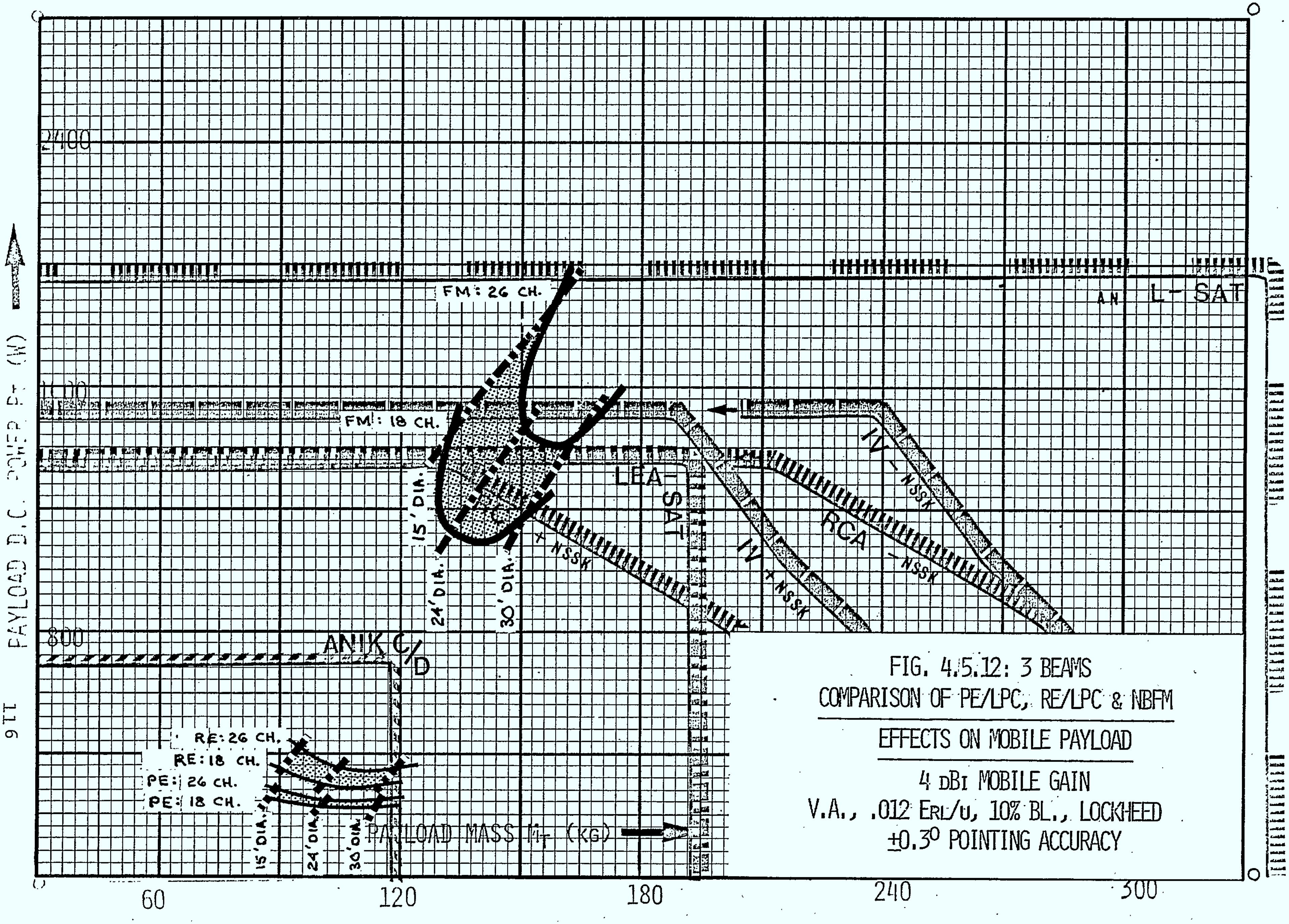


FIG. 4.5.12: 3 BEAMS

COMPARISON OF PE/LPC, RE/LPC & NBFM

EFFECTS ON MOBILE PAYLOAD

4 dBi MOBILE GAIN

V.A., .012 Erl/u, 10% BL., LOCKHEED

±0.3° POINTING ACCURACY

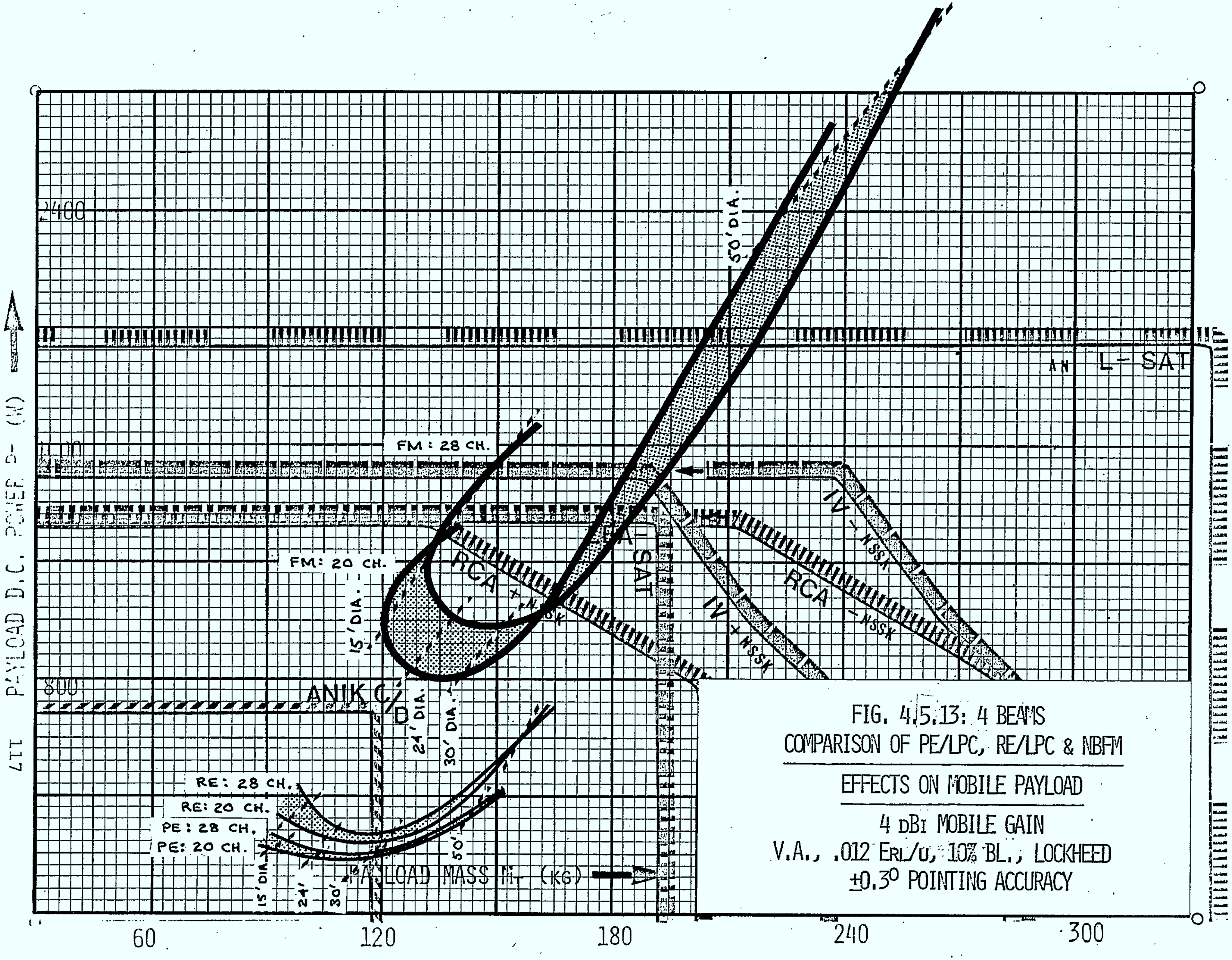


FIG. 4.5.13: 4 BEAMS
COMPARISON OF PE/LPC, RE/LPC & NBFM
EFFECTS ON MOBILE PAYLOAD
4 dBi MOBILE GAIN
V.A., .012 Erl/u, 10% BL., LOCKHEED
±0.3° POINTING ACCURACY

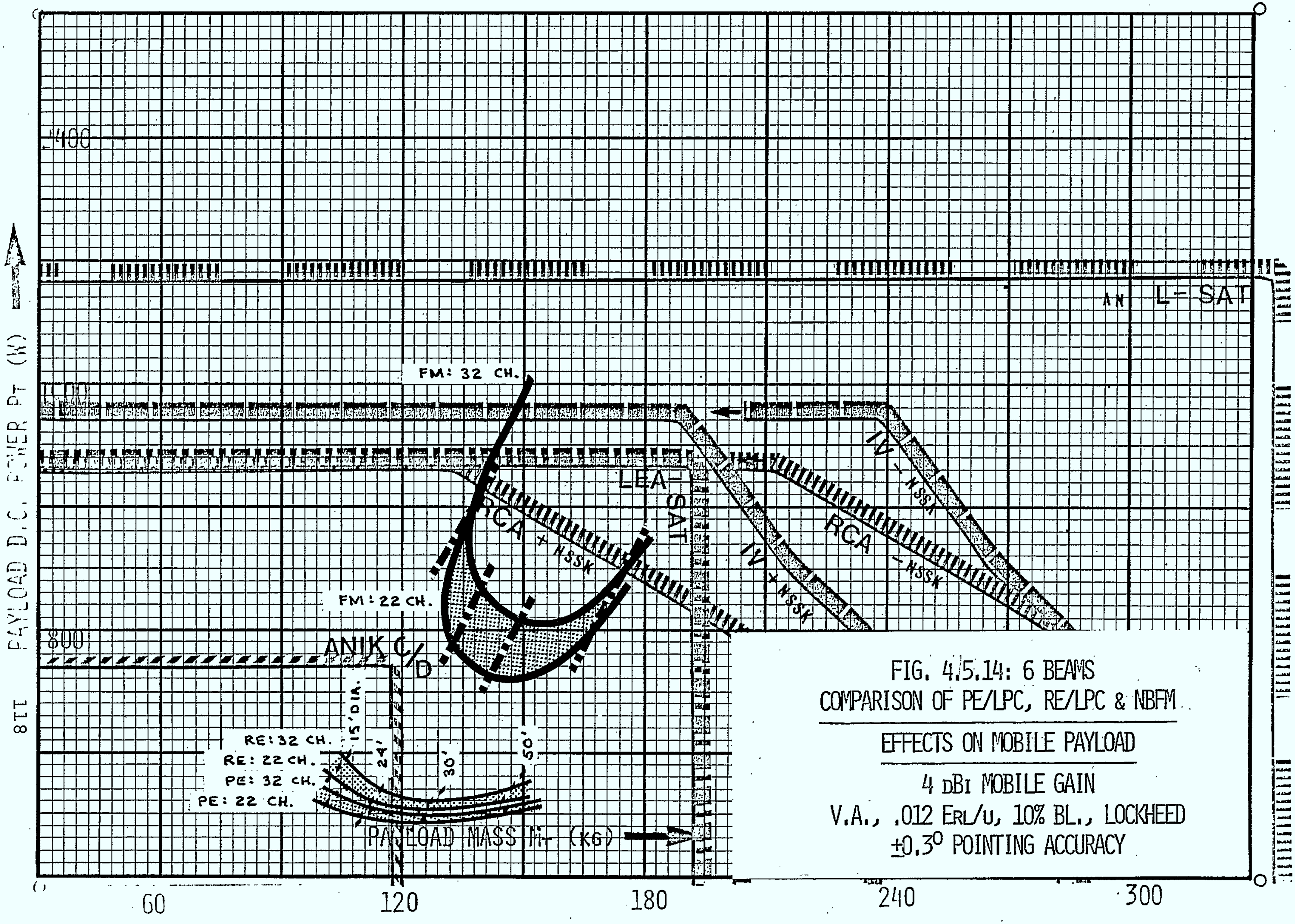


FIG. 4.5.14: 6 BEAMS
COMPARISON OF PE/LPC, RE/LPC & NBFM

EFFECTS ON MOBILE PAYLOAD

4 dBi MOBILE GAIN
V.A., .012 Erl/u, 10% BL., LOCKHEED
±0.3° POINTING ACCURACY

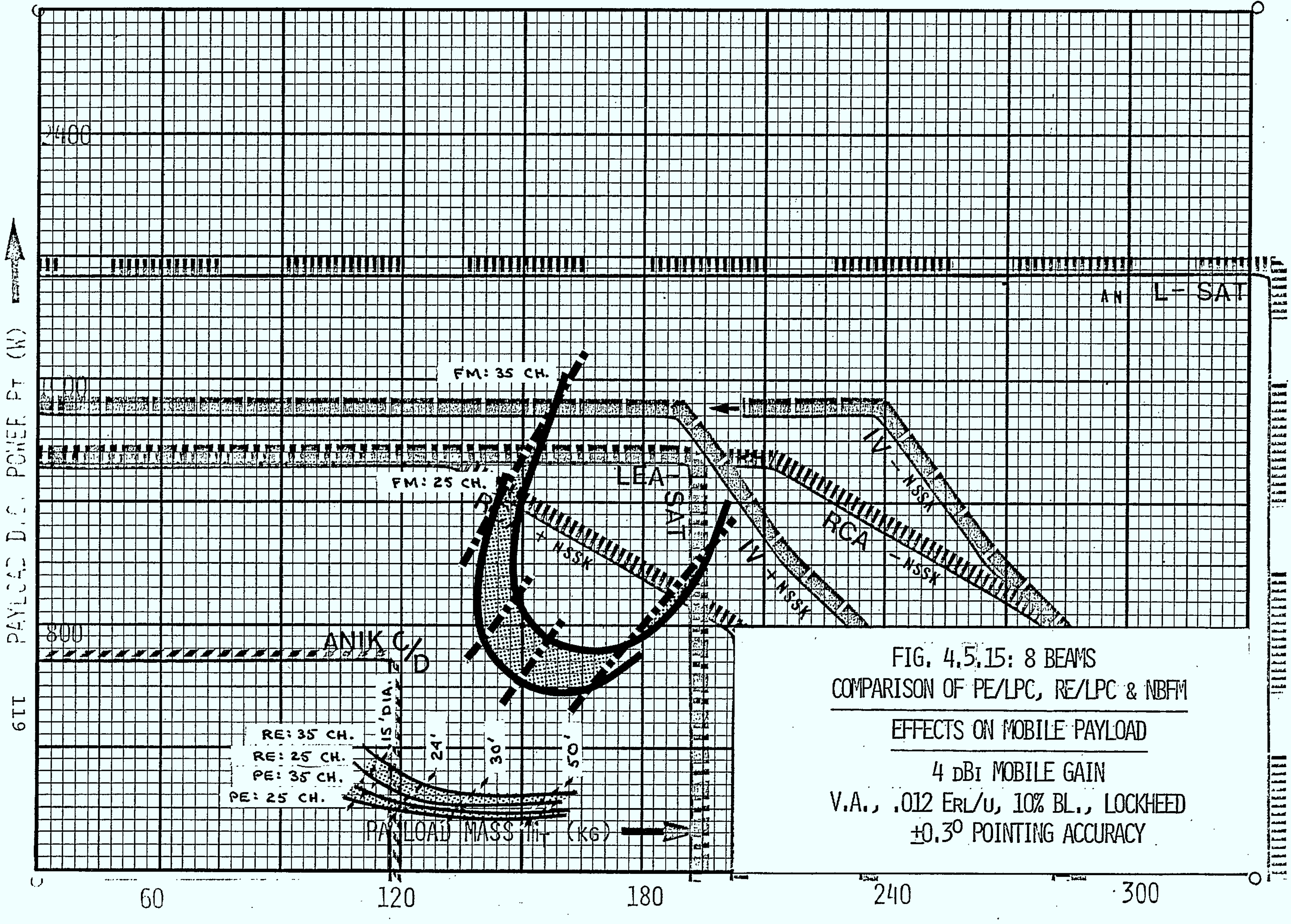


FIG. 4.5.15: 8 BEAMS
COMPARISON OF PE/LPC, RE/LPC & NBFM

EFFECTS ON MOBILE PAYLOAD

4 dBi MOBILE GAIN
V.A., .012 Erl/u, 10% BL., LOCKHEED
±0.3° POINTING ACCURACY

4.5.2 CONCLUSION OF PARAMETRIC SENSITIVITY

The Statement of Work stipulates that the following is a MINIMUM list of parameters:

1) Spacecraft lifetime
2) UHF Antenna System
3) UHF TX efficiency
4) Eclipse
5) Mobile antenna gain
6) Voice activation and duplex operation

However, several other parameters, mostly independent of one another, were found to have a DIRECT IMPACT on the payload power and mass, and therefore on the ACTUAL SPACECRAFT DESIGN.

Rearranging some of the parameters mentioned earlier, in Section 4.2, these additional parameters are:

7) Modulation scheme
8) Channel Bandwidth and hence frequency reuse
9) Number of beams
10) Traffic intensity
11) Blocking rate
12) Number of users at E.O.L.
13) Satellite antenna pointing accuracy
14) Ground mobile TX antenna gain
15) Ground mobile TX RF power
16) Type of deployable reflector.

The objectives of this parametric study are as follows:

We start with a given number of users, to be served by an 800 MHz Mobile spacecraft. The real issue is to find to what extent will a change in any of the parameter values above, affect the total payload requirements, and hence the spacecraft system design.

If this results in a change in payload of more than a few percent, for example above 10%, then this parameter cannot be ignored, particularly since the cumulative effect of changes in the independant parameters can be significant.

That cumulative effect is clearly visible when we plot the results of reasonable changes in all parameters on the same payload graph, as illustrated in Figure 4.5-16. This demonstrates that the resulting payload mass and power requirements can vary over a very wide range.

The evaluation of the effect of all these parameters, complex as it is, has to be performed, particularly:

a) if the effect of some parameter changes is negligible under one set of conditions, but particularly significant under others, e.g. the pointing accuracy of 0.1° to 0.3° has little effect on the spacecraft design for a satellite antenna of 15 feet, but a serious effect for an antenna of 50 feet.

b) if,obviously, the parametric effect is itself significant, e.g. assuming different traffic intensities: changing from 0.008 to 0.016 Erl/user. It is worth noting that the Canadian baseline assumes 0.012 Erl/user, while the U.S.A. varies between 0.006 (NASA) and 0.026 (JPL) Erl/user, all showing significant divergences.

c) if it is known that any parametric change will lead to a change in the payload Mass and Power requirements. However, what is often not clear is whether a decrease in power, "normally" coupled with an increase in mass, is better than the reverse, i.e. an increase in power coupled with a decrease in mass.

Therefore, the guideline proposed in this study was to carry out the parametric changes, and yet, at the same time, to "monitor" whether we remain within or go beyond the limits of the bus payload envelope.

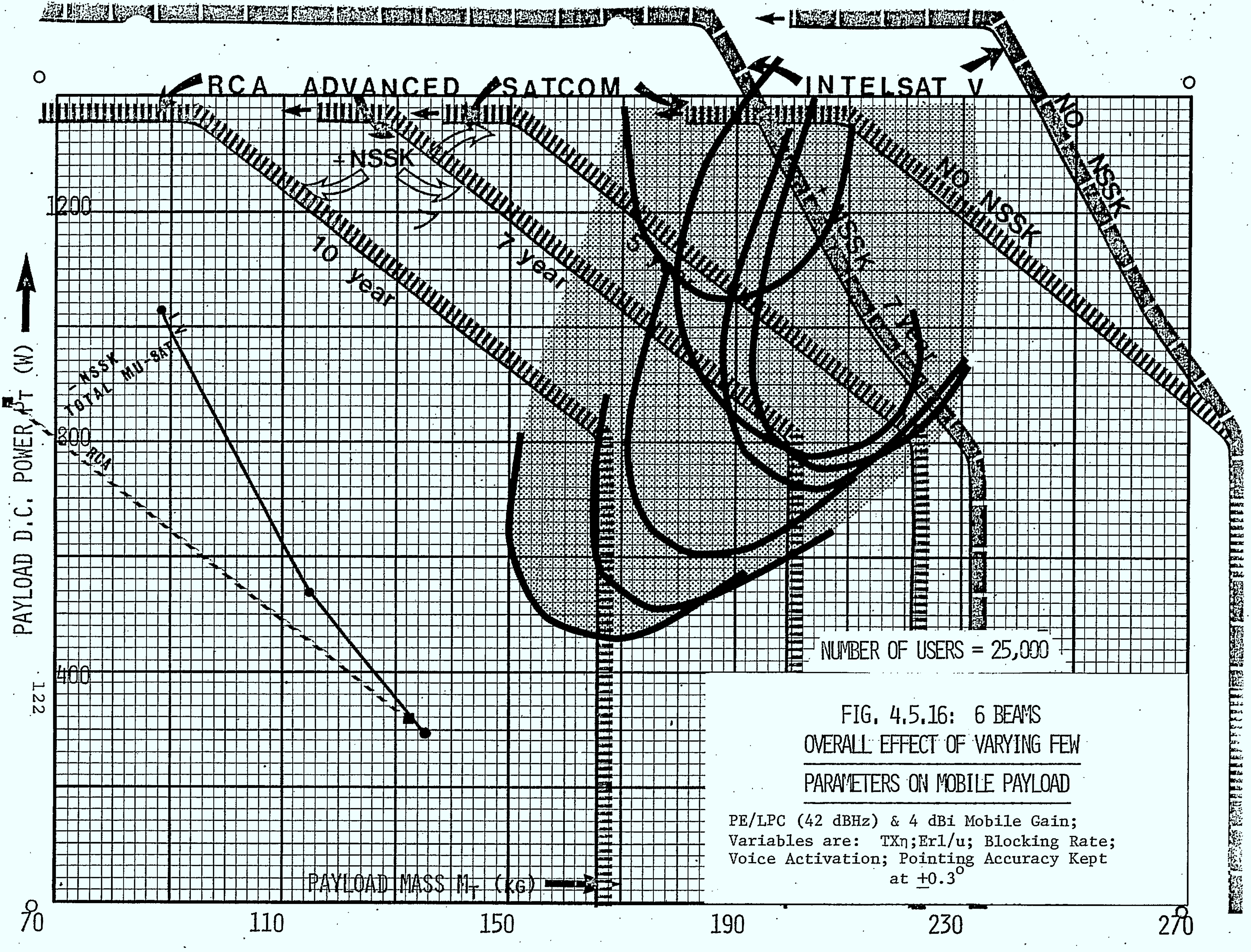


FIG. 4.5.16: 6 BEAMS OVERALL EFFECT OF VARYING FEW PARAMETERS ON MOBILE PAYLOAD

PE/LPC (42 dBHz) & 4 dBi Mobile Gain; Variables are: TXη;Erl/u; Blocking Rate; Voice Activation; Pointing Accuracy Kept at ±0.3°

For example, a large increase in power, undesirable as it may appear, is more welcome than a decrease in power, if it leads to bringing the payload requirement point within the bus payload envelope, rather than outside it.

Therefore, this parametric study, far from being academic, should prove to be of direct, practical relevance to the actual planning of a mobile or combined mission. Once the original method of analysis treated in this study has been understood, it provides a simple and effective guide to the choice of an optimum mobile satellite system.

It paves the way, to apply novel ideas, by simple graphical methods, for combining Mobile and Military payloads, sharing one or more spacecraft, redistributing by load sharing, varying the number of years or usage, and possibly using NSSK for fractions of the lifetime.

4.6 INTERMODULATION PRODUCT ANALYSIS

Passive Intermodulation (PIM) phenomena was a severe problem on the FLTSATCOM spacecraft. This was caused by a frequency plan that permitted low order intermodulation products from the transmit band to fall in the receive band. At UHF frequencies in particular, it appears that non-linearities in passive components, such as filters and reflectors, can generate significant intermodulation products. The solution on FLTSATCOM was to physically separate the transmit and receive antennas.

The frequency plan for the UHF Combined mission was analysed to determine whether low order intermodulation products fall in any of the receive bands. The UHF channels are FDMA for the most part, and the intermodulation (IM) products of pairs of carriers produced by a P-th order non-linear characteristic may be computed. A computer program was written to perform this task, which requires as input the receive and transmit channel spacing and the order of the non-linearity. The program identifies receive band components and lists the total number of IM product occurrences for all combinations of input carrier frequency pairs. Individual IM product occurrences (within the receive bands) may be optionally listed. The analysis was performed for all UHF band services in the combined system.

4.6.1 COMBINED UHF FREQUENCY PLAN

The following is a list of UHF services that were examined.

a) Mobile 800 MHz mobile satellite service uplink at (821, 831) MHz - 30 kHz FM channel spacing

b) Mobile 800 MHz mobile satellite service downlink at (866, 876) MHz - 30 kHz FM channel spacing

c) MILITARY: UHF-ECCM uplink at (335.4, 399.9) MHz
- spread spectrum

d) MILITARY: UHF-ECCM downlink at (275, 275.5) MHz
- spread spectrum

e) MILITARY: UHF-SCPC (FDMA) uplink at (397.4, 399.4) MHz
- 25 kHz channel spacing (MSK)

f) MILITARY: UHF-Earth Exploration Service uplink at (401, 403) MHz

g) MILITARY: UHF-Emergency Beacon Monitoring Service uplink at (406, 406.1) MHz

h) MILITARY: UHF-SCPC (FMDA) downlink at (285, 287) MHz
-25 kHz channel spacing (MSK)

4.6.2 INTERMODULATION COMPUTATION RESULTS

13th order non-linearities were arbitrarily assumed, that is

$$V_{out} = a_0 + a_1 v_{ln} + a_2 v_{ln}^2 + a_3 v_{ln}^3 + \dots + a_{13} v_{ln}^{13}$$

Where $V_{ln} = b_1 \cos\theta_1 + b_2 \cos\theta_2$, $\theta_i = W_i t$

a) Interference Identified: 800 MHz mobile system downlink on uplink
(866, 876) MHz $\xrightarrow{\hspace{4em}}$ (821, 831) MHz

- \# of input (transmit) channels: 333 at 30 KHz spacing
- total # of combinations investigated = 55278

IM - 9th order: 689 combinations (1.25%) detected
11th order: 3691 combinations (6.68%) detected
13th order: 5277 combinations (9.55%) detected

Carrier pairs that produce receive band IM components are at least 5 MHz apart.

b) Interference Search: 800 MHz mobile system downlink on MILITARY-SCPC (FDMA) uplink

(866, 876) MHz ⟶ (397.4, 399.4) MHz

- no IM components detected

c) Interference Search: 800 MHz mobile system downlink on MILITARY-ECCM uplink

(866, 876) MHz ⟶ (335.4, 399.9) MHz

- no IM components detected

d) Interference Search: 800 MHz mobile system downlink on earth exploration service uplink

(866, 876) MHz ⟶ (401, 403) MHz

- no IM components detected

e) Interference Search: 800 MHz mobile system downlink on beacon monitoring service uplink

(866, 876) MHz ⟶ (406, 406.1) MHz

- no IM components detected

f) Interference Search: MILITARY-SCPC downlink on 800 MHz mobile service uplink

(285, 287) MHz ⟶ (821, 831) MHz

- Δf_c = 25 KHz; total # of combinations investigated: $3160 = \binom{80}{2}$

- no IM components detected

g) Interference Search: MILITARY-SCPC downlink on MILITARY-ECCM uplink

(285, 287) MHz ⟶ (335.4, 399.9) MHz

- no IM components detected

h) Interference Search: MILITARY-SCPC downlink on beacon monitoring service uplink

(285, 287) MHz ⟶ (406, 406.1) MHz

- no IM components detected

i) Interference Search: MILITARY-SCPC downlink on MILITARY-SCPC (FDMA) uplink

(285, 287) MHz ⟶ (397.4, 399.4) MHz

- no IM components detected

j) Interference Search: MILITARY-SCPC downlink on earth exploration service uplink

(285, 287) MHz ⟶ (401, 403) MHz

- no IM components detected

NOTE: Interference effect of MILITARY-ECCM downlink (275, 275.5) MHz on other receive bands was not examined due to the usage of spread spectrum techniques on ECCM channels. Even if the ECCM service spectrum was composed of predominant carriers which could be combined, it may be inferred from the above results that any combination of ECCM carriers would have no effect on other services.

4.7 IMPACT OF MSK MODULATION ON NBFM TRANSPONDER DESIGN

The baseline for the mobile satellite high UHF service initially postulated single-channel-per-carrier Narrow Band Frequency Modulated (NBFM) transmissions. Analysis has shown that the bandwidth available and the power required per channel are both insufficient to support the user community projected for the mobile satellite service. It is anticipated therefore, that more sophisticated, efficient modulation schemes will be used for the system. This section contains a brief discussion of the implication that minimum-shift-keyed (MSK) modulation would impose on transponders designed for NBFM.

An MSK system will suffer from performance degradation because of high power amplifier or TWTA amplitude limiting and band pass filter bandwidth and group delay characteristics. These are discussed in turn.

4.7.1 FILTER BANDWIDTH

The MSAT high-UHF service uses FDMA and thus the transponder design is quite different from the INTELSAT V TDMA systems modelled in the literature (4,5,6). Most of the important filtering in an MSK-FDMA environment is done at the mobile modem where transmitter filtering of the MSK infinite spectrum ensures efficient data packing in a restricted bandwidth while the receive filter eliminates out-of-band noise. The effect of transmitted bandwidth on performance degradation is typically depicted in Figure 4.7-1. The filtering performed in the transponder is essentially implemented before upconversion or after downconversion and beam-forming, and so this type of filtering should have no detrimental effect on the modulated signal.

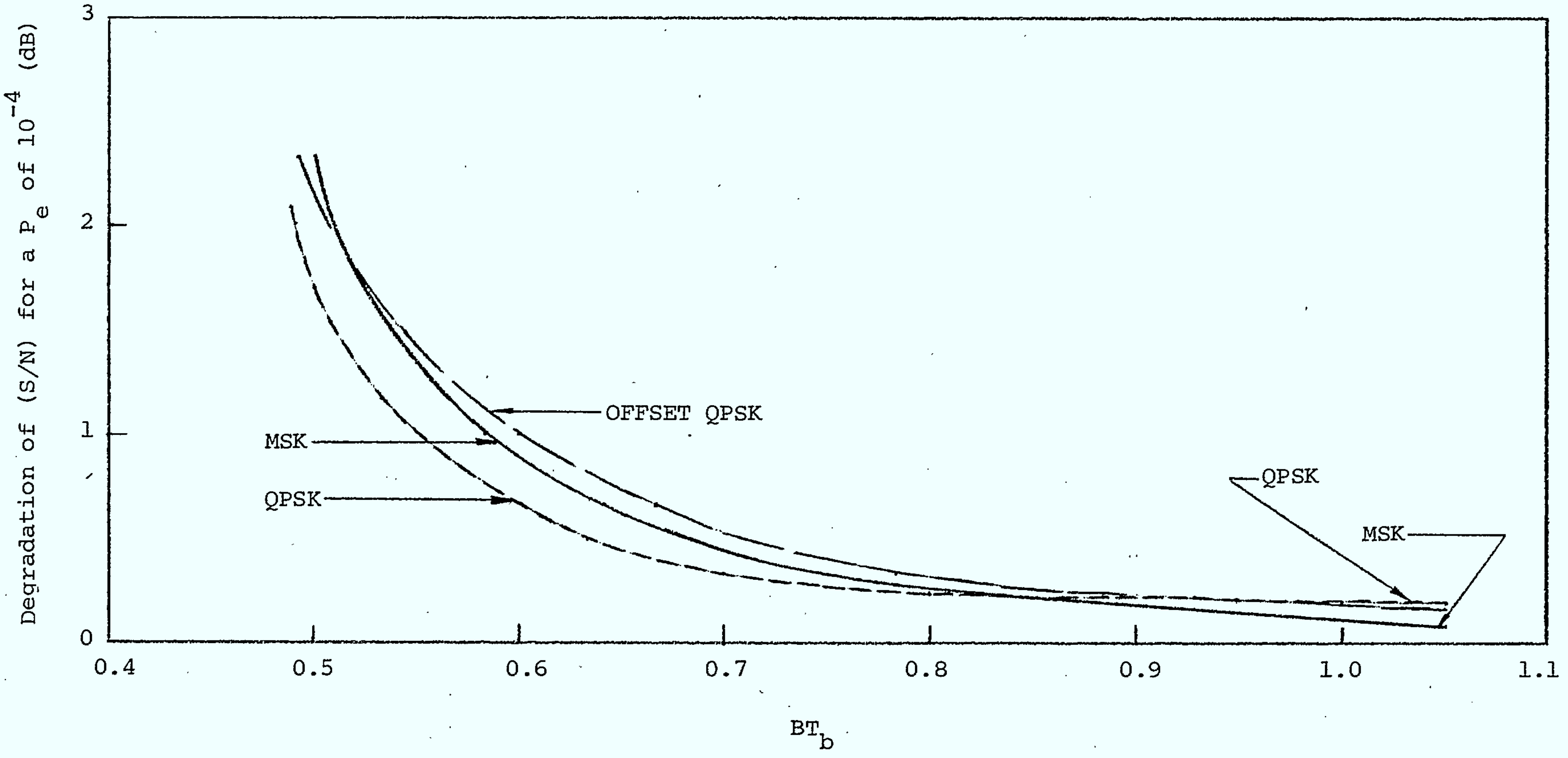


Figure 4.7-1 Degradation, due to filtering, then limiting, of $(S/N_b)_{\text{rcvr.input}}$ versus normalized prelimited filter bandwidth.

4.7.2 FILTER DELAY

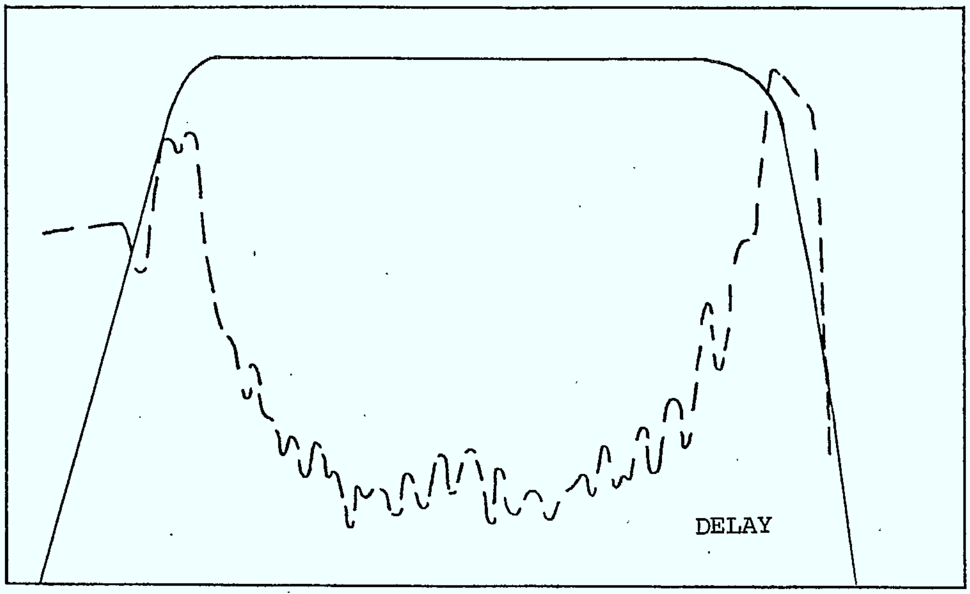
Figure 4.7-2 (ref. 7) shows the MSK spectrum along with a typical channel filter amplitude and delay response. Much of the MSK signal is contained in the channel passband, but the additional energy is located near the filter skirts where it arrives delayed and degrades rather than aids in detection. The transponder channels would only be affected at the extremities of the IF filters, thus delay is not a limiting factor. A mobile receiver with an adaptive channel equalizer would take advantage of the energy near the band edge, and thus could improve performance.

4.7.3 AMPLIFIER NON-LINEARITIES

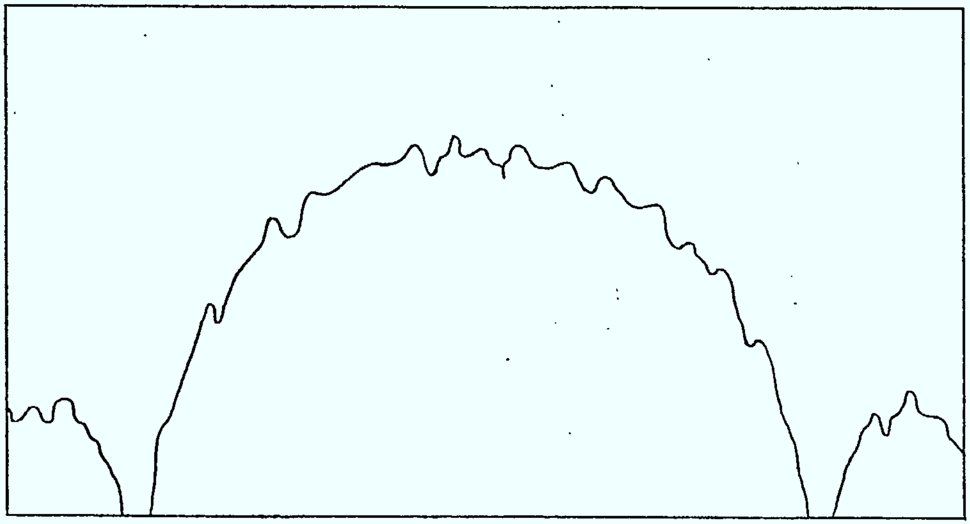
Communications systems containing nonlinear elements prefer to employ constant envelope modulation to minimize AM-PM impairments. This is so because a memoryless nonlinearity produces extraneous sidebands when passing a signal with amplitude fluctuations. Such sidebands introduce out-of-band interference to other adjacent channels. An example of a signal with AM is a bandlimited QPSK signal. The MSK signal possesses a constant envelope even after bandlimiting (due to its smooth phase changes) and thus is less affected by amplitude limiting devices, such as TWTA's and HPA's operating near power saturation.

4.7.4 IMPACT ON TRANSPONDER DESIGN

The use of MSK does not consequently constrain the transponder design and shows promise at being a robust modulation method in an environment corrupted by intermodulation interference.



Channel Amplitude and Group Delay Response



MSK Transmitted Power Spectrum

Figure 4.7-2

4.8 SOLAR TORQUE PRODUCED ON A LARGE REFLECTOR

4.8.1 NATURE OF SOLAR TORQUES

A spacecraft is constantly bombarded by photons originating from the sun when it is in orbit. The force resulting from the momentum transfer during the collision between the intercepting surface and the photons is quite small. However, in the case of a large reflector, whose center of pressure is far from the center of mass of the spacecraft, the resulting solar torque becomes appreciable.

For the purpose of analysis, conceptual design Configuration #2 (mobile mission) of Section 5.2 was used. The solar torque was calculated for a 30 ft. diameter aperture Lockheed wraprib reflector for two different mesh materials; copper-plated dacron and gold-plated molybdenum. The solar torque was broken down into a pitch component and a roll/yaw component. The following table lists the maximum torques for each of the mesh types.

MESH	TORQUE	
	PITCH	ROLL/YAW
COPPER-PLATED DACRON	1123.63×10^{-6} Nm	82.88×10^{-6} Nm
GOLD-PLATED MOLYBDENUM	823.50×10^{-6} Nm	59.09×10^{-6} Nm

A complete description of the method of analysis, assumptions made, and the results in tabular and graphical form can be found in Appendix E.

4.8.2 IMPLICATIONS ON SATCOM DESIGN

In a brief discussion with engineers of RCA, it was felt that despite the solar torque components being larger than normal, the ACS on the advanced RCA SATCOM should be able to accomodate them. This might require the use of a larger momentum wheel and some other minor modifications. The use of solar sails to move the center of pressure closer to the center of mass of the spacecraft would also solve the problem.

During the course of the analysis, the center of mass was found to have moved towards the reflector hub. This displacement has profound implications on the stability of the spacecraft. It may be necessary to use two identical reflectors on opposite sides of the spacecraft or to reposition other payload components to adjust from the centre of mass shift.

In conclusion, the solar torque should not create any major problems; however, it is important to note the center of mass problem as a critical technology area.

4.9 ARRAY SHADOWING BY 30 FT. REFLECTOR

4.9.1 THE PROBLEM OF SHADOWING

There are various problems which arise from mounting a 9.144 m (30 ft.) diameter aperture reflector on a spacecraft. This section will discuss the results of a detailed analysis addressing the potential problems of a large reflector shadowing the solar array. A complete description of this analysis is given in Appendix F of this report.

For analysis purposes, the Mobile mission (conceptual design Configuration #2) was used.

A Fortran program was written to generate and plot the location of the shadow in meters from the center of the satellite for an east face mounted reflector. Figure 4.9-1 shows the shadow, at half hour intervals, as it moves across the plane of the array. It should be realized that the satellite is drawn to correspond to 6:00 a.m. satellite local time, and that the satellite's body (but not the array) should be rotated as time progresses.

The plot shows that the duration of the eclipse period, in the worst case (at time of a solstice), is 4 hours, starting at 6:00 a.m. to 10:00 a.m. satellite local time. The shadow, at 6:00 a.m., is an ellipse with a major axis about twice the length of the minor axis. The ellipse gradually changes to become almost circular at the end of the eclipse period.

Once the duration of the shadowing was determined and by studying a modified daily airtime usage pattern derived from the Woods-Gordon Report (reference 3), the demand during the interruption periods was calculated. The conclusion is that the airtime demand during the morning is slightly lower than that of the evening, i.e. 23.05% of the daily total versus 23.49% for the latter. From this, it is recommended that the reflector be mounted on the east face of the spacecraft.

4.9.2 USE OF BATTERIES DURING SHADOWING

The Fortran program also calculated and plotted the area of the solar array being shadowed with respect to local satellite time. The power loss is characterized by a set of skewed bell-curves shown in Figure 4.9-2. The curves were calculated for increments of 10° of the earth's orbit between a solstice and an equinox.

SHADOW OF 30 ft. REFLECTOR ON PLANE OF SOLAR ARRAY

TIME FROM 6:00-10:00 A.M.

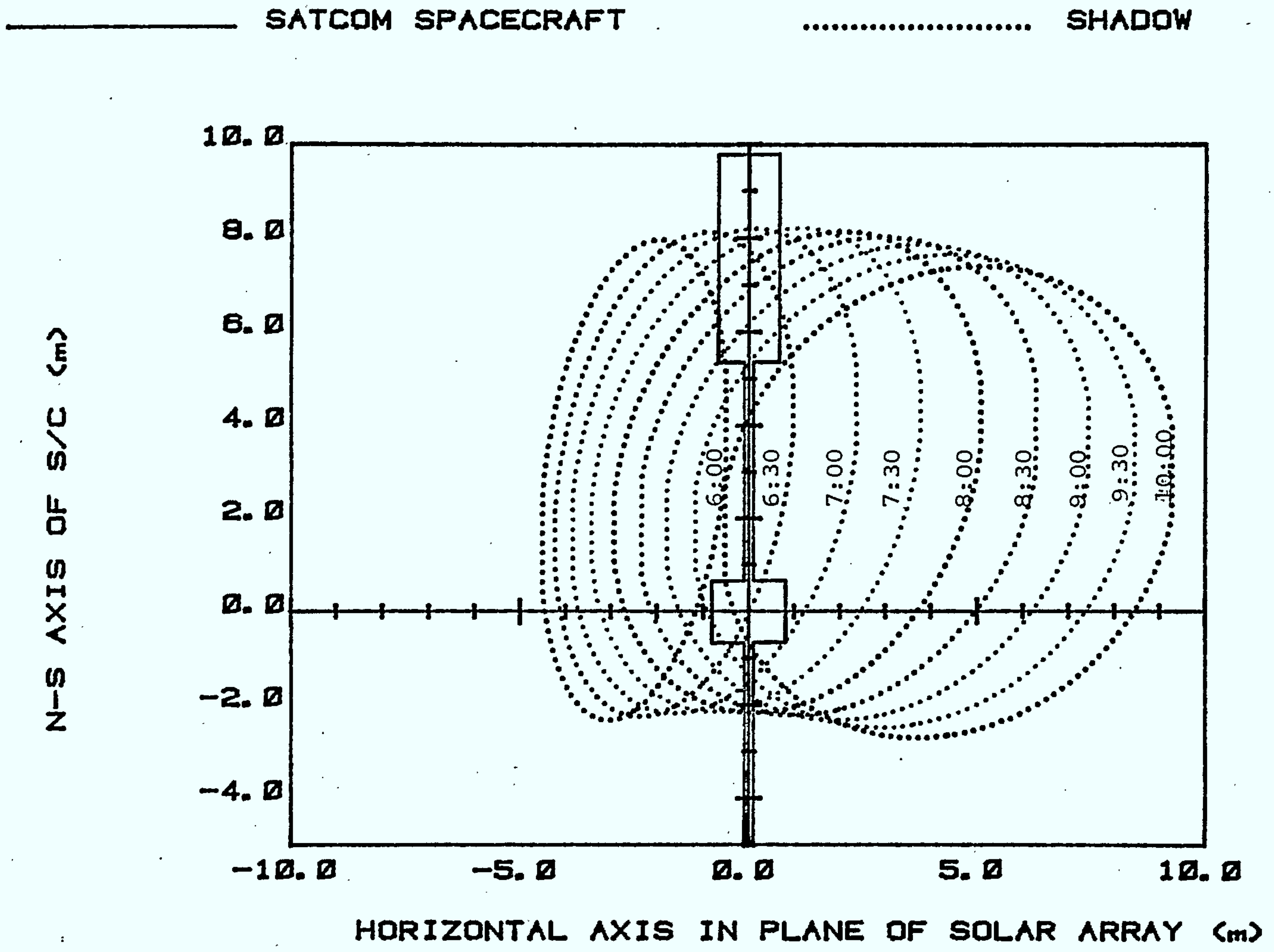
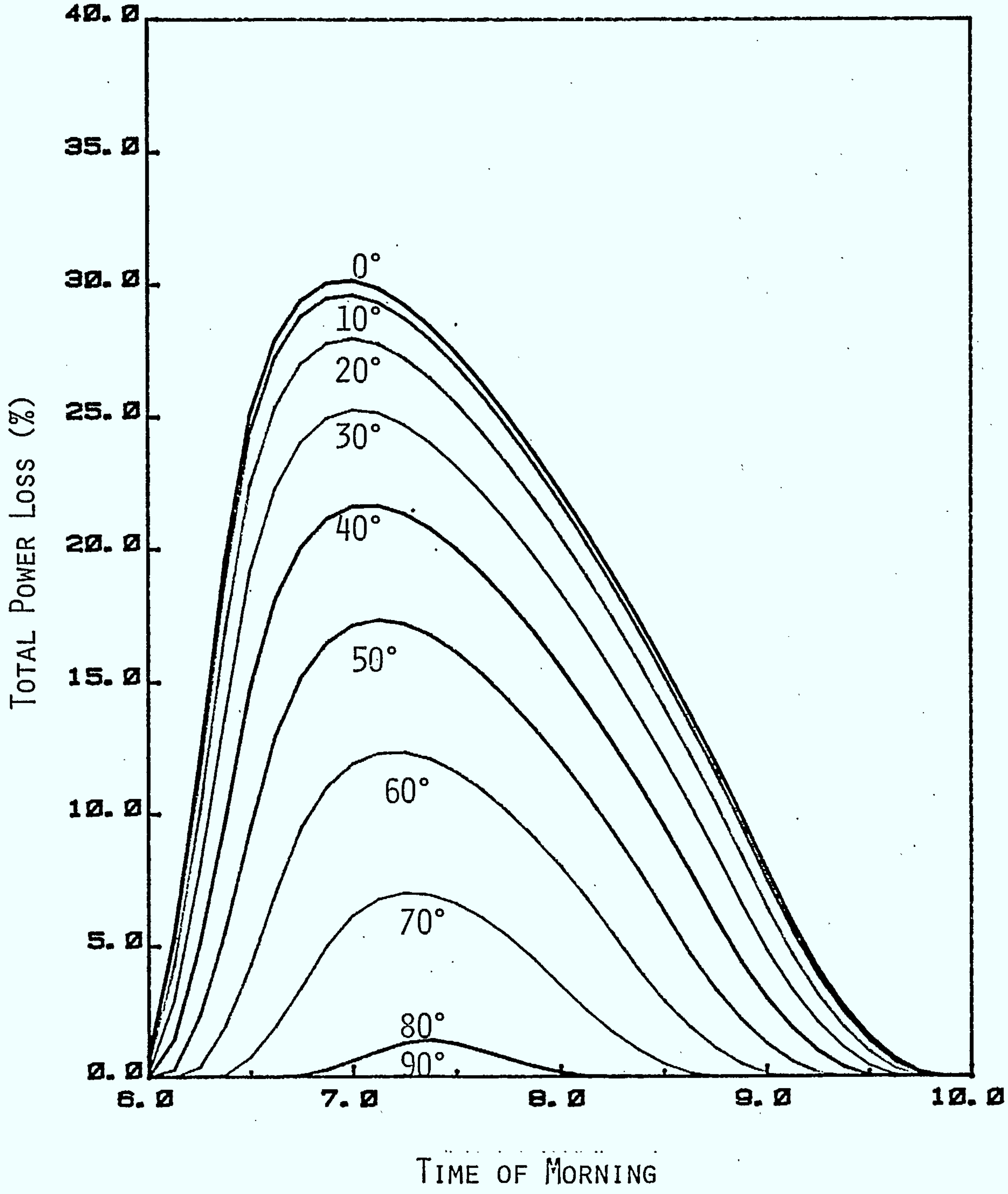


FIGURE 4.9-1

FIGURE 4.9-2

TOTAL ARRAY POWER LOSS BETWEEN 6:00-10:00 A.M. AS EARTH MOVES FROM SOLSTICE TO EQUINOX



SOLSTICE= 0° EQUINOX=90°

The use of the batteries to supplement the power loss was also considered. Assuming the batteries can supply full payload power for 72 minutes, they should be capable of supplying, on average, 30% of full payload power for 4 hours. The worst case power loss due to reflector shadowing is an average of 16.35% over 4 hours, with a peak loss of 30%. Thus, the batteries of the advanced SATCOM spacecraft are capable of maintaining full payload power throughout the year.

The above analysis is applicable if the solar arrays are extended sufficiently far from the satellite's body so that no shadowing occurs during times of equinox. This way, eclipse of the arrays by the earth's shadow occurs at equinox, while shadowing due to the reflector reaches its peak at the solstices. Thus, the two eclipses can be considered as independent events.

For the specific geometry chosen, one can see from Figure 4.9-2, that the two events are not totally independent. As an approximation, 1° of the earth's orbit about the sun is equal to 1 earth day. Eclipse of the satellite by the earth lasts a total of 46 days, centered about the equinox. From Figure 4.9-2, at the start of the eclipse by the earth, the peak blockage due to the reflector is 8%. To alleviate this problem, the solar arrays in Configuration 2 should be extended out by another meter.

4.9.3 IMPACT OF SHADOWING ON SATCOM DESIGN

It should be realized that the reflector is not totally opaque and its shadow intensity is similar to the penumbra, as opposed to the umbra, of a shadow. It is likely that the blockage is lower than was calculated, and some major design work on the connections of the solar cell strings could reduce the effect to even lower levels.

Even in the worst case, the existing batteries should be capable of compensating the power loss. However, further analysis should be done to determine the impact on the life of the batteries due to the additional charges and discharges. The time available for the charge cycle must also be considered in greater detail.

In conclusion, the problems created by the shadow of a large reflector should prove challenging but not critical.

5.0 CONCEPTUAL DESIGN

The following section describes the implementation of the military and mobile payloads on the RCA Advanced SATCOM, and the combined payload on the Intelsat V spacecraft. The decisions for using these spacecraft were previously discussed in Section 3.

The objectives in this design phase were to:

i) ensure that all the antennas could be mounted on the body of the spacecraft, keeping the possibility of radio interference in mind

ii) ensure that all the antennas can be stowed within the payload envelope of the desired launch vehicle

iii) ensure that the payload does not exceed the capabilities of the spacecraft in terms of mass, power, payload mounting area and thermal dissipation.

5.1 MILITARY PAYLOAD

The basic services to be provided by this payload are:

A) LOW UHF
   - i) UHF mobile service at 240-328.6 and 335.4-339.9 MHz
   - ii) UHF earth exploration at 401-403 MHz
   - iii) EPIRB at 406-406.1 MHz

B) L-BAND

Maritime mobile service at 1535-1542.5 MHz

C) SHF FIXED

Satellite service at 7250-7750 and 7900-8400 MHz providing Canada and Arctic coverage with ECCM and DAMA capabilities.

D) EHF MOBILE

Satellite service at 20.2-21.2 and 43.5-47.0 GHz

E) INTERSATELLITE LINK (ISL)

Satellite to satellite at 60 GHz.

F) T & C

Primarily for Telemetry, Ranging and Command of spacecraft primarily during Transfer Orbit.

Detailed transponder diagrams for these services are shown in Appendix G. The payload complement for these services is given in Table 5-2.

5.1.1 GENERAL CONFIGURATION

The baseline host spacecraft for the military payload is the Advanced RCA SATCOM. The capabilities of this spacecraft is summarized in Table 5-1.

A trade-off analysis (Section 4.1) on the choice of antennas to meet the military mission requirements was performed by CAL. The recommendations from this analysis are:

A) UHF TRANSMIT

Use a dual helix antenna having helices 0.381 m (15") in diameter and 3.91 m (154") long. The ground plane cups are 0.838 m (33") in diameter and 0.406 m (16") deep. The spacing between helix centers should be 1.702 m (67").

B) UHF RECEIVE

Use a single helix 0.26 m (10¼") diameter and 2.87 m (113") long. The ground cup used should be 0.625 m (24.6") in diameter and 0.298 m (11 3/4") deep.

Table 5-1 Capabilities of RCA Advanced SATCOM

DIMENSIONS: L = 162.6 cm (64")
W = 132.1 cm (52")
H = 124.5 cm (49")
The height on the north-south panels may be extended to 175.3 cm (69") to accommodate larger solar panels.

TRANSPONDER MASS: rated at 136.4 kg. (300 lbs.)

TRANSPONDER POWER: 1065 W

ARRAY POWER: 1250 W (EOL)
1900 W (BOL)

HOUSEKEEPING POWER: 185 W

PROPELLANT LIFETIME: 9.5 years (incl. NSSK) using Hydrazine

BATTERY: NiH_2 providing 90 A-hr.

LAUNCH VEHICLE: 3920 PAM, STS-SUSS D.

STABILIZATION: 3-axis using momentum wheels.

C) L-BAND

The best choice for this service is a quad helix antenna. The helices are 0.066 m (2.6") in diameter and 0.66 m (26") long. The ground cups used are 0.157 m (6.2") in diameter and 0.076 m (3") deep. The spacing between helix centers are set at 0.302 m (11.9").

D) SHF

The primary coverage for this service is provided by a 0.381 m (15") diameter reflector with a corrugated horn for secondary coverage.

E) EHF (FIXED EARTH)

One 0.45 m reflector was chosen for spot coverage while two horns provide secondary earth coverage.

F) ISL

One 0.5 m reflector-mirror combination.

G) T & C

One Omni-directional Bicone Antenna, for Transfer Orbit.

5.1.1.1 Deployed Configuration

The conceptual on-station configuration is illustrated in Figures 5-1, 5-2 and 5-3. Fully deployed, the satellite is 14.732 m along north-south (array) axis, 4.420 m along its east-west axis; and 5.550 m from front to back.

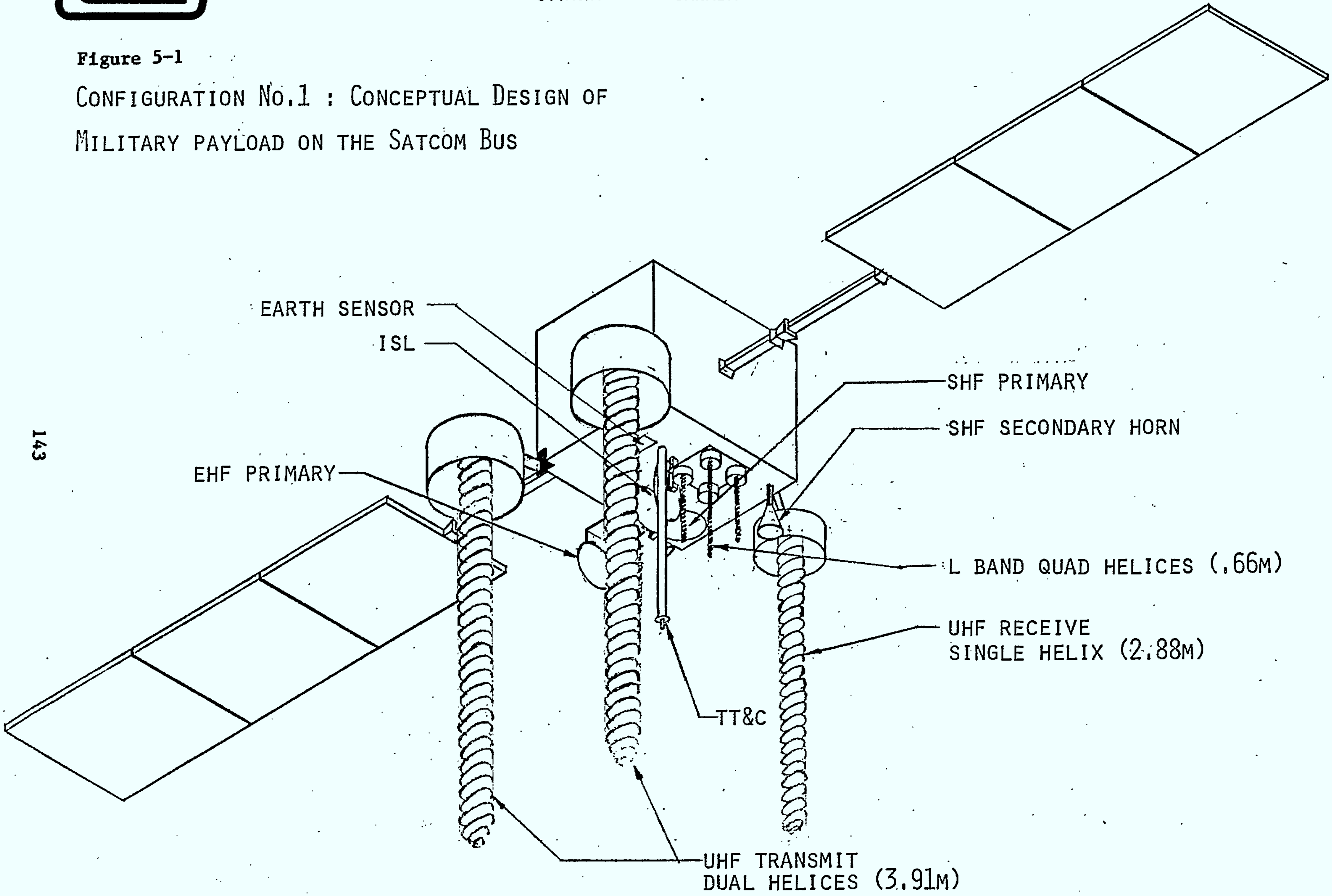
The dual UHF transmit helices are mounted on the east face while the single UHF receive helix is on the west face. On the earth facing panel, from north to south along the north-south axis, there is the L-band quad helices, the ISL, and the EHF (fixed earth) primary spot and secondary horns respectively. The SHF primary and secondary antennas are found on the south-west and north-west corners of the earth facing panel respectively. The TT&C antenna is mounted just east of the L-band quad helices.

5.1.1.2 Stowed Configuration

In order to stow the spacecraft within the Delta 3920-PAM-D shroud, the UHF transmit and receive helices are compressed along the axis of the helix. The deployment arms for the helices are hinged-mounted to the body of the spacecraft and assume a vertical alignment when inside the shroud. This is shown in Figure 5-4 and 5-5.

Figure 5-1

CONFIGURATION No.1 : CONCEPTUAL DESIGN OF MILITARY PAYLOAD ON THE SATCOM BUS



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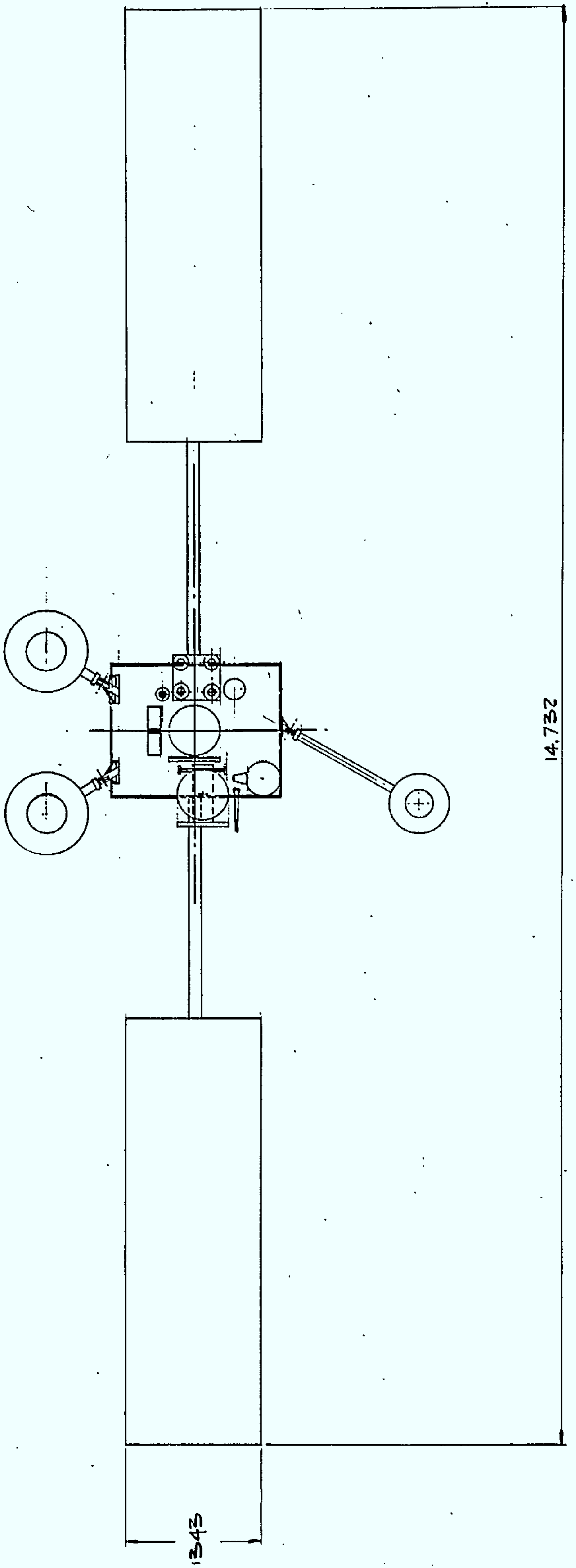

Figure 5-2 Military Payload on SATCOM Bus Deployed (Top View)

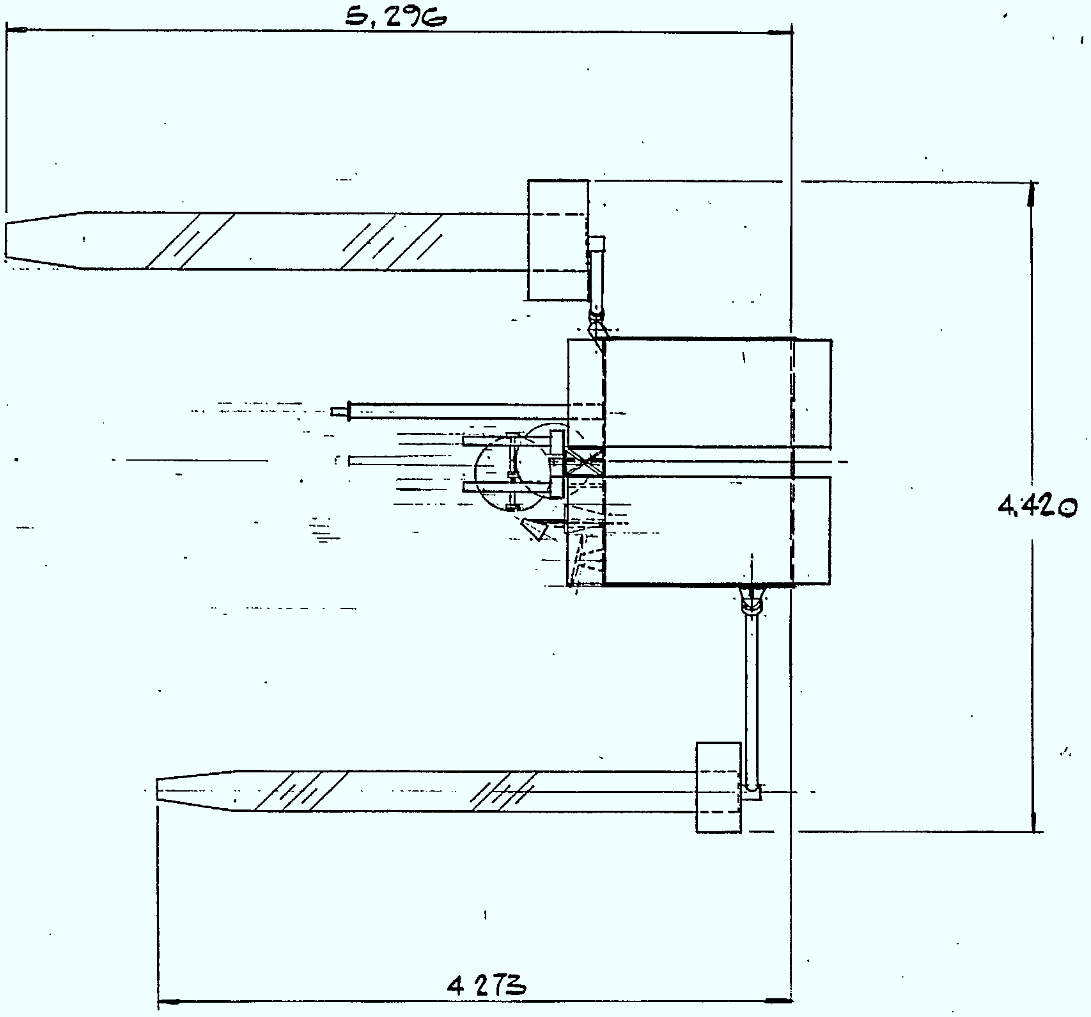

Figure 5-3 Military Payload on SATCOM Bus Deployed (Side View)

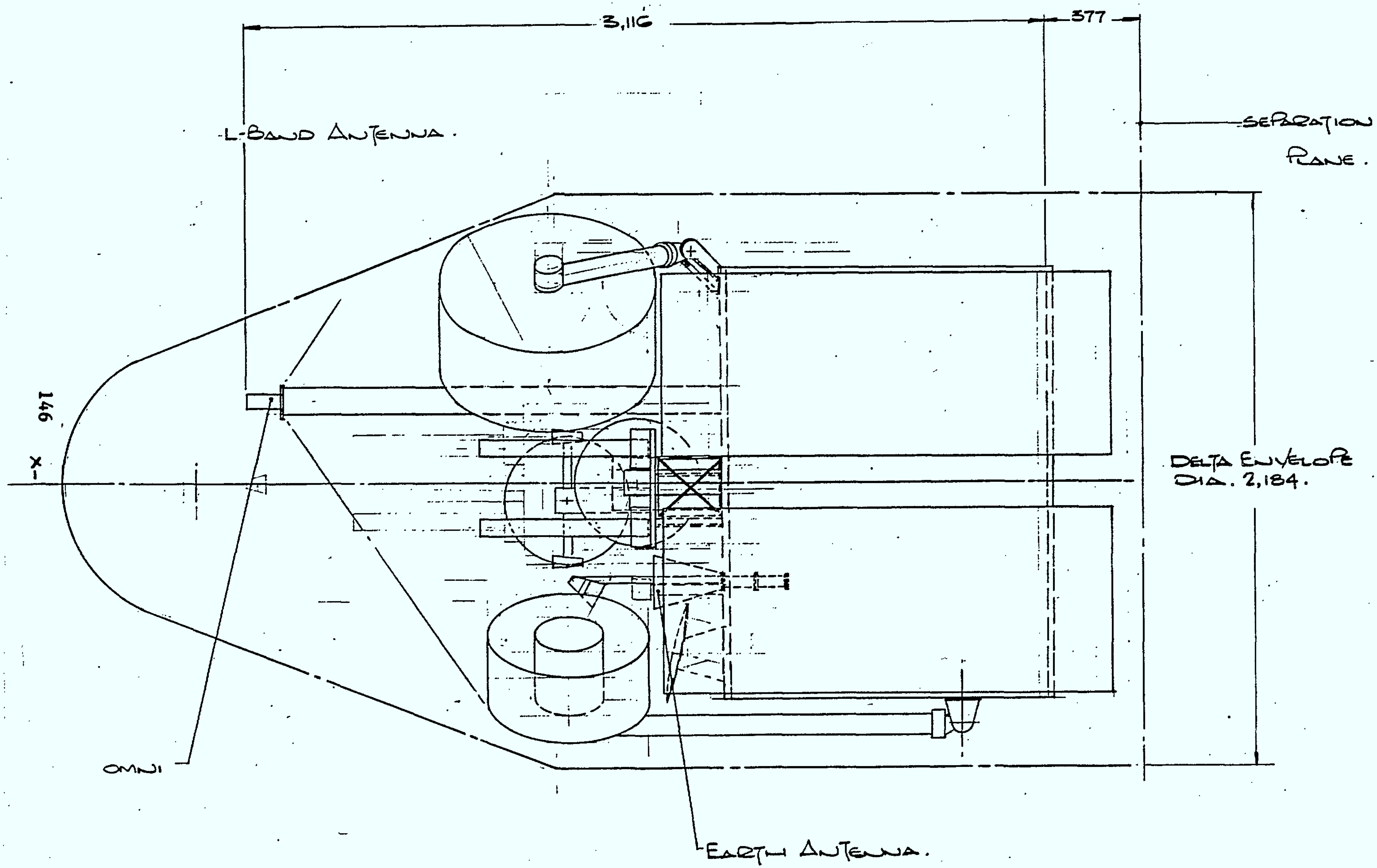

Figure 5-4 Military Payload on SATCOM Bus Stowed (Side View)

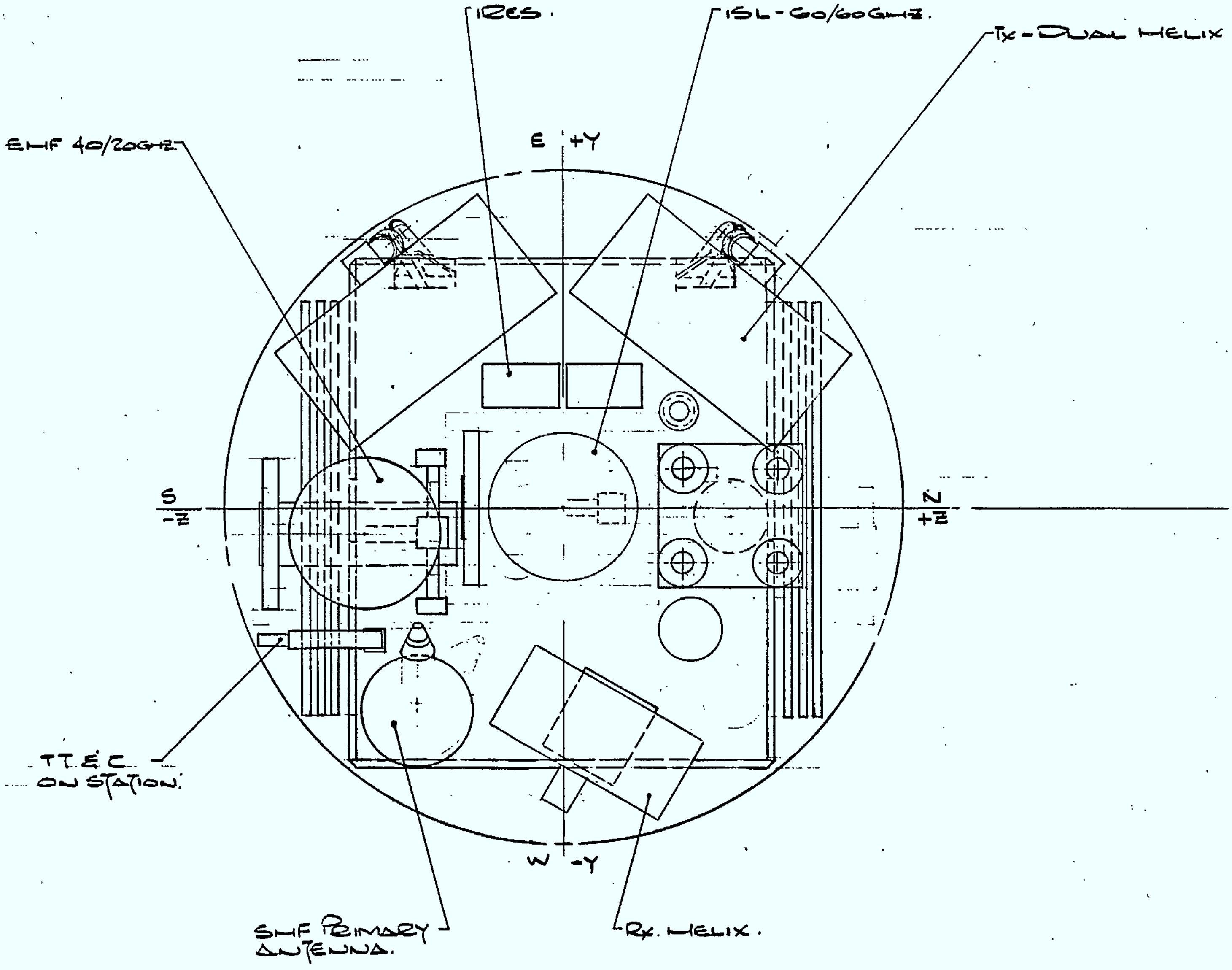

Figure 5-5 Military Payload on SATCOM Bus Stowed (Top View)

5.1.2 MASS BUDGET

5.1.2.1 Design Spacecraft Mass Requirements

The mass, power and interior mounting area budgets for the military payload are given in Table 5-2. The detailed breakdown of communication packages is given in the scroll in Appendix G.

The total payload mass of the transponder and the antennas is 165.9 kg. Adding a 10 percent contingency, the mass becomes 182.5 kg.

5.1.2.2 Advanced SATCOM Mass Capability

The rated payload mass capability for the Advanced SATCOM is 136.4 kg based on 9.5 years of propellant life. This would mean a negative margin of 29.5 kg.

From the tradeoff analysis on reducing propellant mass to increase the payload mass, it was found that for a seven-year life, the mass capability increases to 164.8 kg. This reduces the negative mass margin to 1.1 kg. Then using the tradeoff curve of mass as a function of DC power, the available capability becomes 201.0 kg, which results in a positive margin of 35.1 kg. The corresponding reduction to its power capability is from 1065 W to 800 W.

TABLE 5-2 - MILITARY PAYLOAD MASS, POWER AND MOUNTING AREA BUDGETS

COMMUNICATION SERVICE	MASS (kg)	POWER (W)	POWER DISSIPATION (W)	MOUNTING AREA (in^2)
1) LOW UHF:				
Repeater	31.00	217.6	177.1	1255.4
Antenna: Dual helices-transmit	19.1			
: Single helix-receive	6.8			
	56.9			
2) L-BAND:				
Repeater	5.9	80.2	68.3	418.0
Antenna: Quad helices	2.5			
	8.4			
3) SHF:				
Repeater	26.4	102.4	87.4	1376.0
Antenna: Primary	2.7			
Secondary	1.8			
	30.9			
4) EHF:				
Repeater	20.7	56.4	53.4	954
Antenna: Primary & Secondary	6.0			
	26.7			
5) ISL:				
Repeater	12.7	83.9	81.9	826
Antenna	4.9			
	17.6			
6) TT & C:				
Scrambler/Descrambler	10.0	10.0	10.0	164
Antenna	1.8			
7) MILITARY PAYLOAD MISC.:	13.6	13.0	13.0	162
TOTAL	165.9	563.5		5155.4
CAPABILITY AVAILABLE	201.0	800.0		5600.0
MARGIN	+35.1	+236.5		+444.6
	(+17.5%)	(+29.6%)		(+7.9%)

5.1.3 POWER BUDGET

5.1.3.1 Design Spacecraft Power Requirement

The total payload power required is 563.5 W and 619.9 W with a 10% contingency.

5.1.3.2 Advanced SATCOM Power Capability

The available payload power of advanced SATCOM is 1065 W. This value remains relatively constant when design life is backed off from 9.5 years to 7 years, since the major degradation of the solar array occurs during the first three years of operation.

This provides a positive margin of 502 W. This large power margin allows us to trade solar array mass for payload mass. The results of this tradeoff analysis shows one desirable configuration is to have 800 W of available power while increasing the payload mass capability to 201. kg.

The final margins for mass and power are:

AVAILABLE		REQUIRED	MARGIN
MASS	201. kg	165.9 kg	+ 35.1 kg (17.5%)
POWER	800 W	563.5 W	+236.5 W (29.6%)

5.1.4 PAYLOAD MOUNTING AREA

5.1.4.1 Design Spacecraft Mounting Area Requirement

It has been demonstrated that the Advanced SATCOM bus has the capability to accommodate the military payload; however, it is important to verify that the payload can be mounted according to thermal dissipation constraints. From the scroll the total payload mounting area required is 5155.4 sq. in.

5.1.4.2 Payload Mounting Area Available

All of the payload and most of the housekeeping equipment is mounted on the north and south panels. These panels may be extended an additional 10 inches at each side to accommodate more payload. The housekeeping equipment which is mounted on the north and south panels amount to 1900 sq. in. This includes 700 sq. in. required by the battery for full eclipse operation.

Thus the mounting area available is:

	(SQ. IN)
Total North/South Panel Mounting Area	5500
Housekeeping Equipment	-1900
Available Payload Mouning Area	3600
Maximum Mounting Area Gained by Extending Panels	2000
Maximum Payload Mounting Area Available	5600

Thus there should be no problems in accommodating the payload and the panels should not have to be extended. The margin on mounting area is 444.6 sq. in. (+7.9%).

5.2 MOBILE PAYLOAD

The basic services to be provided by this payload are:

a) HIGH UHF
  i) uplink 821-825 MHz
  ii) downlink 866-870 MHz

b) L-BAND
  Maritime mobile service at 1535-1542.5 MHz

c) BACKHAUL
  i) uplink: 14 GHz
  ii) downlink: 12 GHz

d) T&C

Primarily for telemetry, ranging and command of spacecraft during transfer orbit.

5.2.1 GENERAL CONFIGURATION

The advanced RCA SATCOM bus will carry the commercial mobile payload.

Although there is a great benefit in keeping open certain options, to make use of the results of the parametric analysis, it was decided to investigate the maximum use of the existing Advanced SATCOM bus, without any major redesign. Then it is possible to back-off to the optimum payload by matching certain assumed priorities to the results of the Parametric Analyses.

This configuration consists of:

a) UHF TRANSMIT AND RECEIVE

One 30 foot dia. aperture offset parabolic Lockheed Wraprib reflector is used. The feed array (for 4 beams across Canada) consists of ten 9-inch square aperture horns, each 24" deep.

b) L-BAND

The same optimum quad helix antenna as in the military payload is used.

c) BACKHAUL

A 0.254 m (10") x 0.457 m (18") elliptical reflector was chosen with horn and waveguide feed supported by a small 1.36 kg tower.

d) T&C

Deployable for the on-station mode.

5.2.1.1 Deployed Configuration

The conceptual on-station configuration is illustrated in Figures 5-6 to 5-8. Fully deployed, the satellite is 19.588 m along the N-S (solar array) axis, 20.557 m along its E-W axis and 9.785 m from front to back.

The 30 ft. Lockheed wraprib reflector deploys on the east side via a triply articulated boom that holds the dish from the inside. The reflector is balanced for solar torques, by a 0.914 m dia. 3.048 m long solar sail, deployed on the opposite (west) side and hinged to the west panel.

The solar panels extend along the N-S axis at a point 5.360 m away from the body centre, to reduce the shadowing effect of the 30 foot reflector. The earth facing panel contains, on the north-west central area, the L-band quad helix antenna, and on the north central area, the TT&C bicone and the SHF backhaul elliptical reflector.

5.2.1.2 Stowed Configuration

The Delta 3920 PAM D shroud constraints and the Advanced RCA SATCOM Bus design require that the solar panels be folded into a three layer stack, along the N and S panels. Also the triply articulated deployment boom for the 30 ft. reflector is designed to occupy one single layer of boom, stowed along the east panel. The Feed Array assembly is hinged on the earth facing side, to the southwest corner, to stow it within the Delta envelope. The spacecraft's configuration inside the shroud is shown in Figures 5-9 and 5-10.

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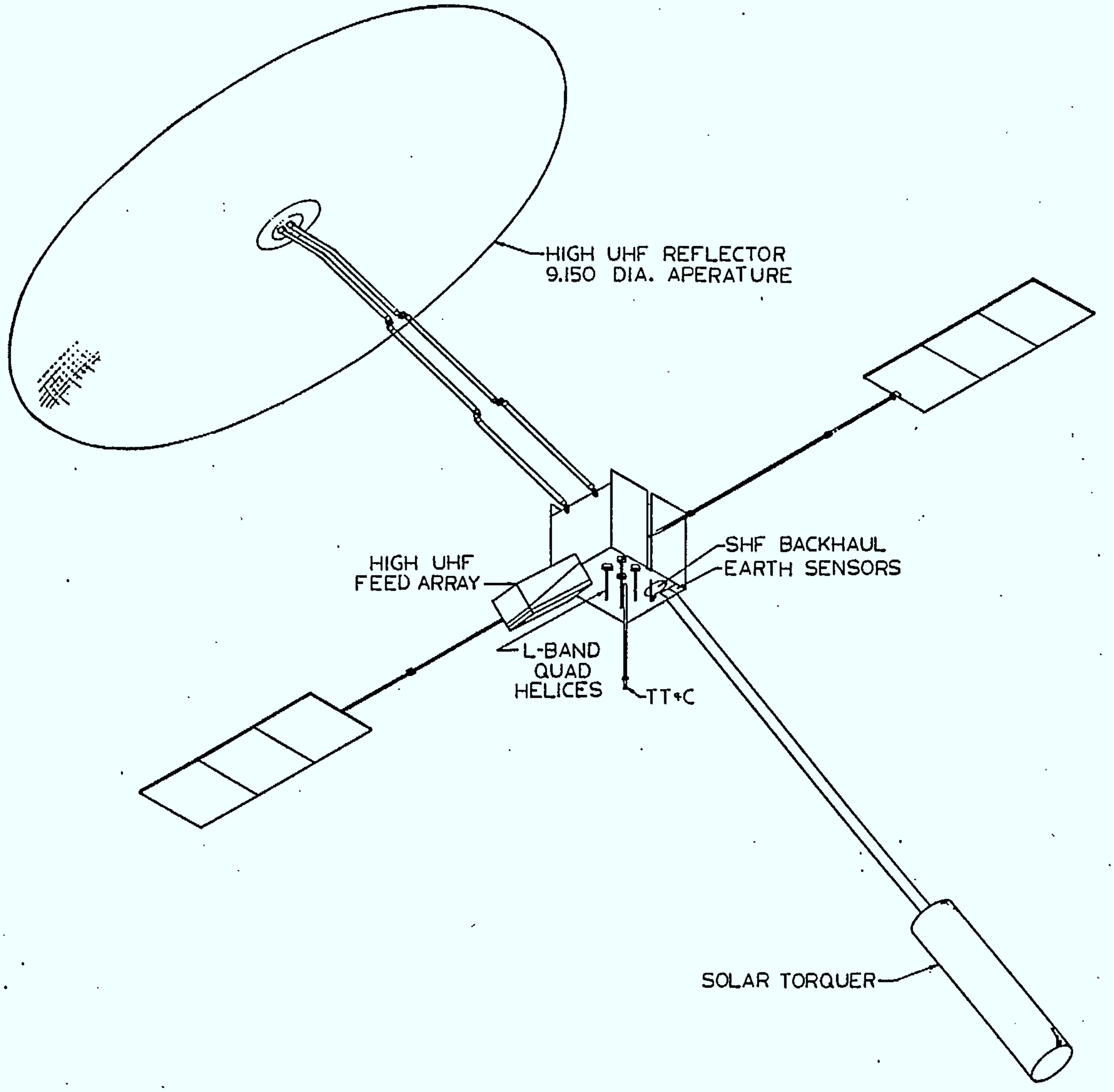


D. NG

CANADIAN ASTRONAUTICS LIMITED
OTTAWA CANADA

Figure 5-6 Conceptual Design of Mobile Payload on SATCOM Bus

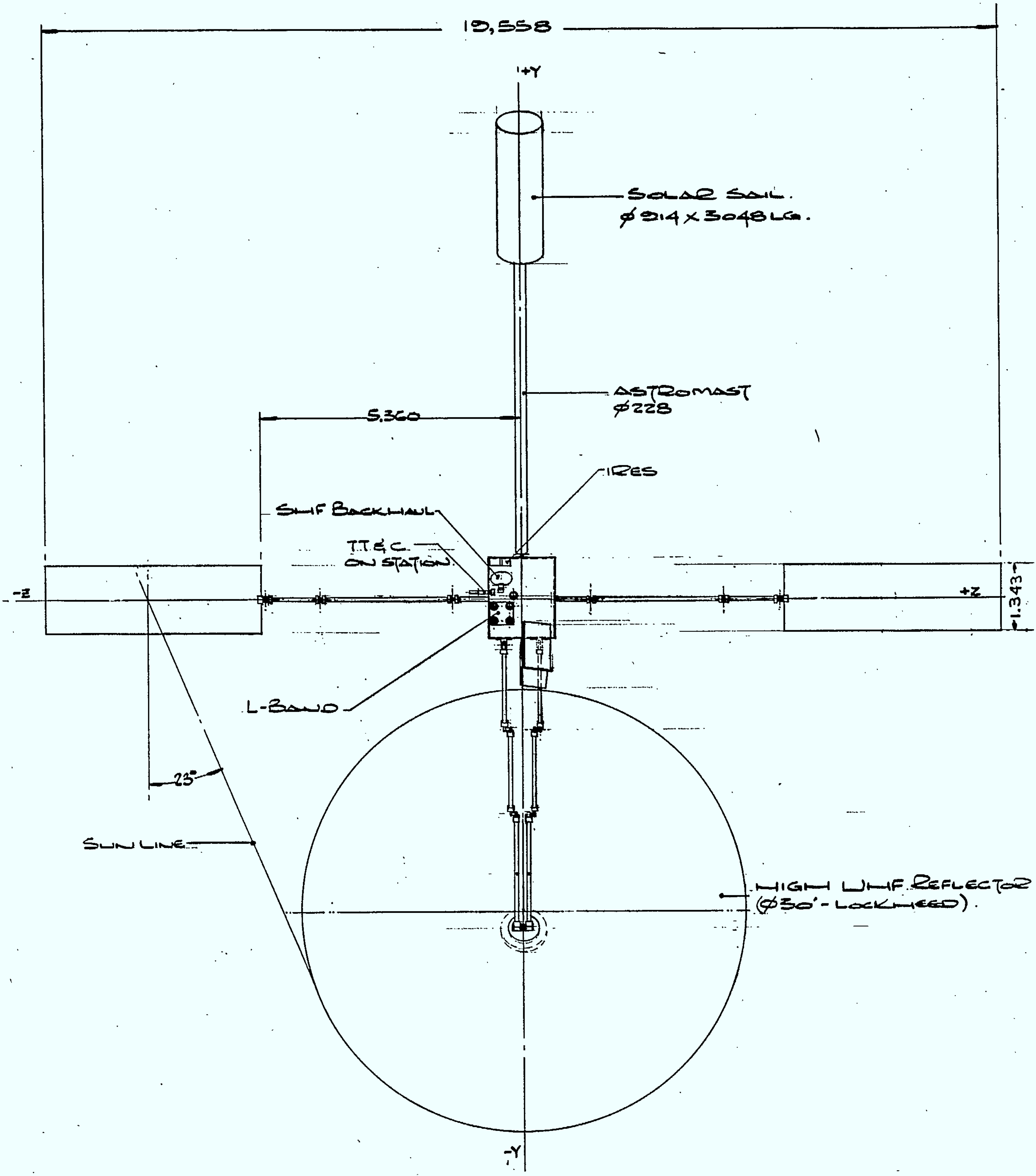


Figure 5-7 Mobile Payload on SATCOM Bus Deployed (Top View)

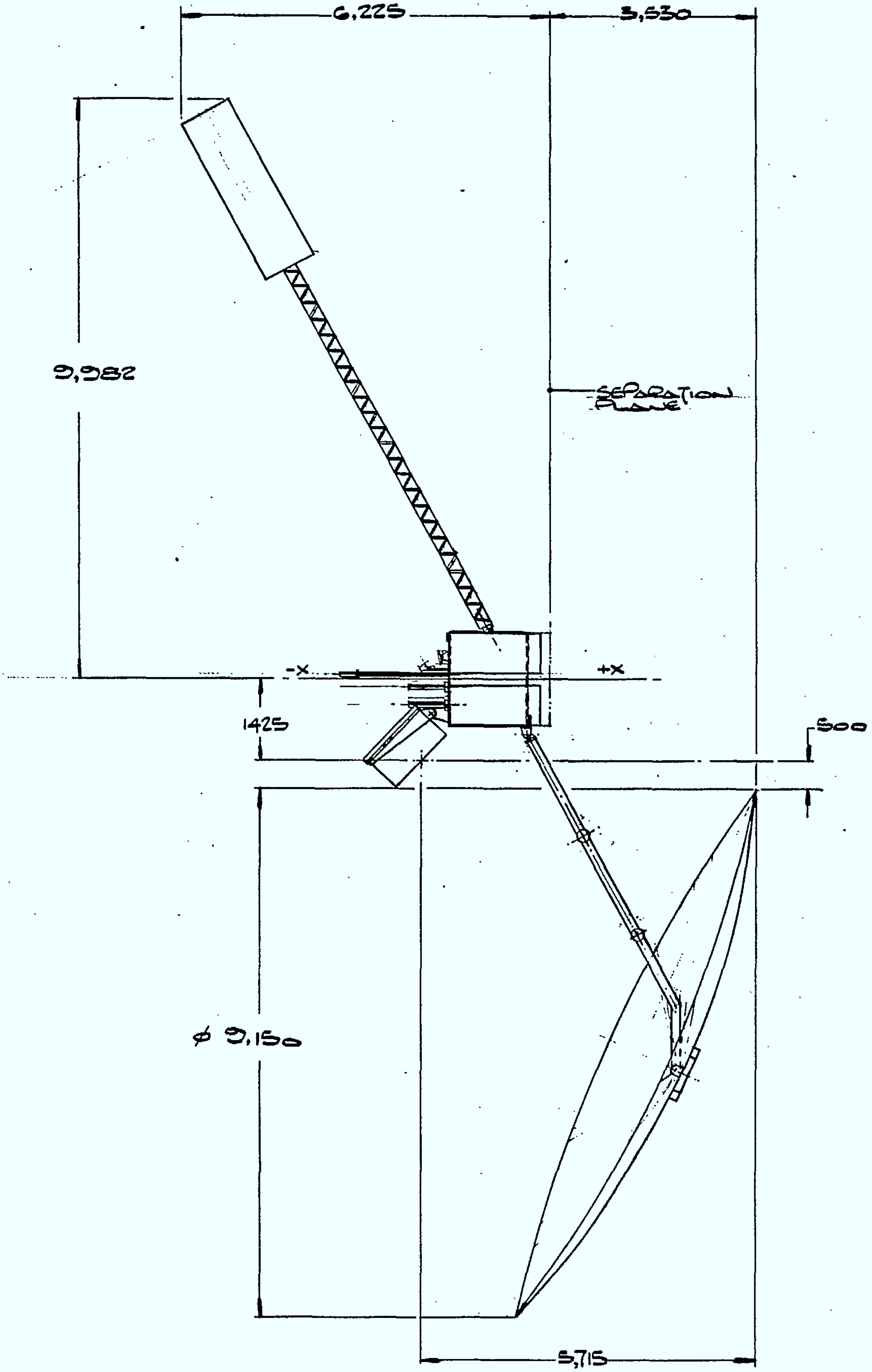


Figure 5-8 Mobile Payload on SATCOM Bus Deployed (Side View)

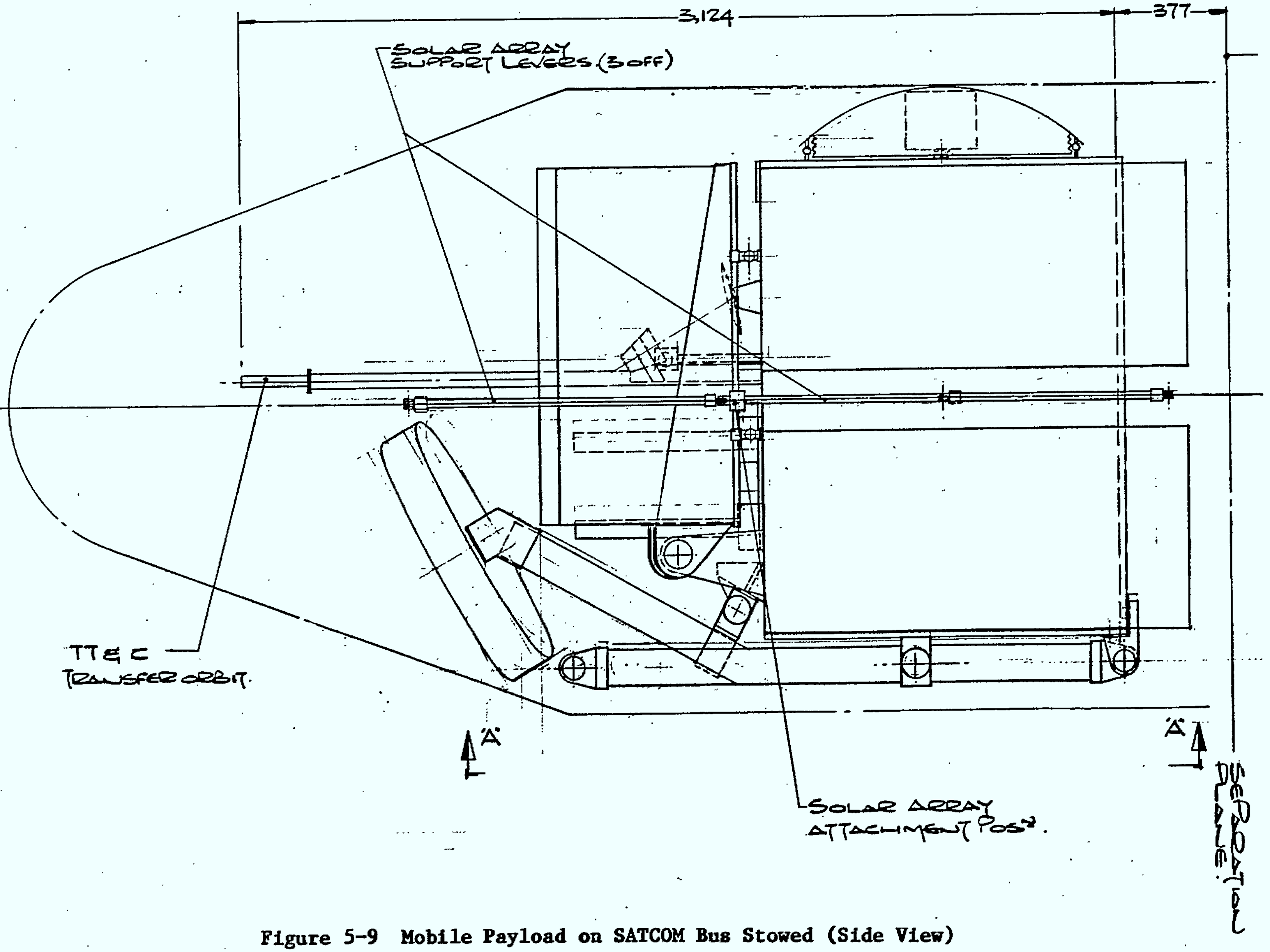


Figure 5-9 Mobile Payload on SATCOM Bus Stowed (Side View)

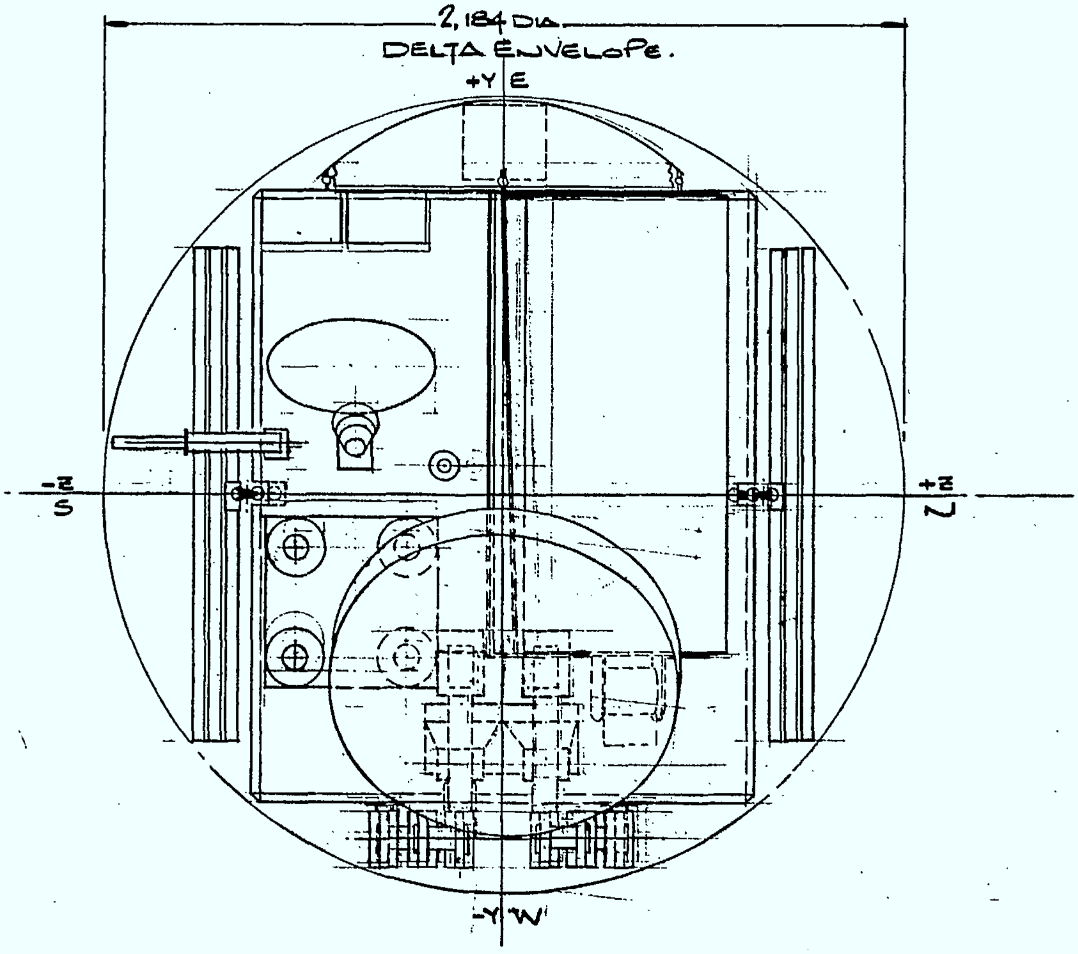


Figure 5-10 Mobile Payload on SATCOM Bus Stowed (Top View)

5.2.2 MASS BUDGET

5.2.2.1 Design Spacecraft Mass Requirements

The mass, power and interior mounting area budget for the mobile payload are given in Table 5-3. The detailed break down of communication packages is given in the scroll at the end of this section.

The total payload mass of the transponder and the antenna is 156.5 kg with a 10% contingency.

5.2.2.2 Advanced RCA SATCOM Mass Capability

The rated payload capability for the Advanced RCA SATCOM bus is 164.8 kg and 1065 W with 7 year life NSSK. However, if no NSSK is required then one possible payload capability is 195.5 kg and 1330 W.

The high UHF mass and power requirements of 63.1 kg and 703.7 W refers to a single point design of 5 channels per beam, for four beams, to give a total of 20 NBFM channels with voice activation. For that design, the total requirements are 166.9 kg and 886.3 W. This results in a negative margin for a mission with NSSK. Without NSSK, a positive margin of 28.6 kg (24.6%) exists.

5.2.3 POWER BUDGET

5.2.3.1 Design Spacecraft Power Requirements

The total payload power required for 20 channels NBFM is 886.3 W and 974.9 W with a 10% contingency.

Table 5-3 Mobile Payload Mass, Power and Mounting Area Budgets

COMMUNICATION SERVICE	MASS (kg)	POWER (W)	POWER DISSIPATION (W)	MOUNTING AREA (in^2)
1) HIGH UHF:				
Repeater	63.1	703.7	587.4	3403.4
Antenna	56.3			
2) L-BAND:				
Repeater	5.9	80.2	68.3	295
Antenna	2.5			
3) SHF BACKHAUL:				
Repeater	26.4	102.4	87.4	
Antenna	2.7			
4) TT&C:				
Antenna	1.8			
5) SOLAR SAIL:	8.2			
TOTAL	166.9	886.3		3698.4
CAPABILITY AVAILABLE	195.5	1330.0		5600.0
MARGIN	+28.6 (+14.6%)	+443.7 (+33.4%)		+1901.6 (+34.0%)

*Baseline is no NSSK.

5.2.3.2 Advanced RCA SATCOM Power Capability

As discussed above, if no NSSK is required, then 1330 W are available for the communication payload. The 20 channel design requires 886.3 W, hence a positive power margin of 443.7 W (33.4%).

5.2.4 PAYLOAD MOUNTING AREA BUDGET

5.2.4.1 Design Spacecraft Mounting Area Requirement

Table 5-3 indicates that 3698.4 sq. in. is required, without contingency.

5.2.4.2 Payload Mounting Area Available

As discussed in the military spacecraft, the maximum payload mounting area available after extending the N-S panels is 5600 sq. in. Therefore the net positive margin for the mounting area is 1901.6 sq. in. (34.0%).

5.2.5 PARAMETRIC DESIGN

So far, for a total of 20 NBFM Channels and the configuration proposed, the net margins with an advanced RCA SATCOM bus without NSSK are:

i) +14.6% for mass
ii) +33.4% for power
iii) +34.0% for mounting area

It is clear, that although excellent margins exist, a more efficient utilisation of the payload capabilities is possible, not only by increasing the number of channels beyond 20, but also by carrying out a detailed parametric analysis.

Whatever optimum combinations of parameters are to be chosen, it is not intended to go beyond a 30 foot reflector on the Advanced RCA SATCOM. Refer to Appendix A, Trip Report to RCA for discussion of RCA bus limitations.

5.3 COMBINED PAYLOAD

As the name suggests, the services provided by the combined payload, are the sum of the services of the Military and Mobile payloads. These services are summarized briefly below:

a) LOW UHF (MOBILE, ECCM)
b) LOW UHF DCP
c) LOW UHF EPIRB
d) L-BAND MARTIME MOBILE
e) SHF (LOW AND HIGH UHF MOBILE BACKHAUL, L-BAND BACKHAUL, ECCM, DAMA, GLOBAL, ARCTIC)
f) EHF MOBILE
g) INTERSATELLITE LINK (ISL)
h) HIGH UHF MOBILE
i) TT&C

To avoid repetition and excess mass, the high UHF backhaul at 14/12 GHz has been integrated into the low UHF backhaul at 8/7 GHz.

5.3.1 GENERAL CONFIGURATION

Ford Aerospace's Intelsat V will serve as the baseline host spacecraft for the combined payload. The capabilities of this spacecraft are summarized in Table 5-4.

Table 5-4 Capabilities of Ford Aerospace's Intelsat V

DIMENSIONS: L = 201 cm
W = 165 cm
H = 177 cm

TRANSPONDER MASS: rated at 272.5 kg (includes TT&C & GFEC tower)

TRANSPONDER POWER: 782.12 W

ARRAY POWER: 1354 W (EOL)
1780 W (BOL)

HOUSEKEEPING POWER: 322.9 W

PROPELLANT LIFETIME: 7 years (incl. NSSK) using Hydrazine

BATTERY: NiCd providing 68 A•hr
NiH2 for later versions

LAUNCH VEHICLE: ATLAS-CENTAUR, ARIANE 3, STS-SUSS A

STABILIZATION: 3 axis using momentum wheels

5.3.1.1 Deployed Configuration

A detailed description of the antennas can be found in Sections 5.1.1.1 and 5.2.1.1. The combined mission uses the same antennas as the Military and Mobile missions. These are listed below:

a) LOW UHF TRANSMIT - dual helices
b) LOW UHF RECEIVE - single helix
c) HIGH UHF - 9.144 m dia. aperture Lockheed Wraprib
d) L-BAND - quad helices
e) SHF - one spot and one horn
f) EHF - one spot and two horns
g) ISL - one reflector-mirror combination
h) TT&C - log conical spiral

The conceptual on-station configuration is illustrated in Figures 5-11, 5-12, and 5-13. Fully deployed, the satellite is 23.414 m along its north-south (array) axis; 22.058 m along its east-west axis.

The high UHF reflector is mounted on the east face. The low UHF dual transmit helices are located on the west face.

The remainder of the antennas are all mounted on the earth facing panel. The L-Band quad helices are placed in the south-east corner. Running north to south along the satellite's array axis are the EHF spot, the ISL and the low UHF receive single helix, respectively. The EHF earth coverage horn is located east and centre, while the SHF primary is placed on the south-west corner. An optional SHF backhaul (14/12 GHz), if it is used, would be situated on the north-west corner. The TT&C antenna is on a mast near the south-west corner. To balance the solar torque due to the 30 ft. reflector, a deployable solar sail is mounted on the west face of the satellite.

5.3.1.2 Stowed Configuration

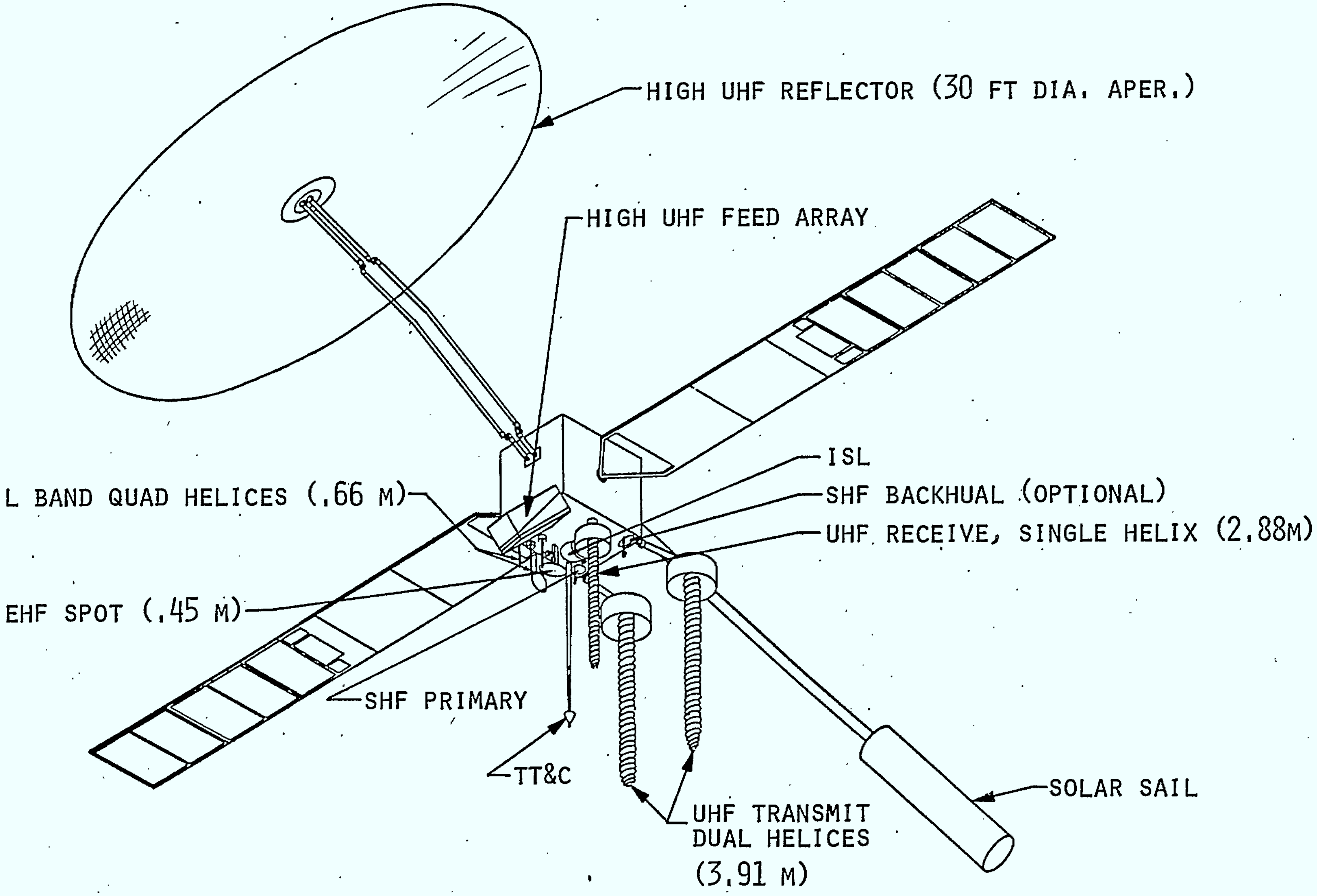
To stow the spacecraft within the shroud of the Atlas-Centaur or the Ariane 3, the low UHF transmit and receive helices are compressed along their longitudinal axes. The deployment arms for the UHF transmit helices are hinged and assume a vertical alignment when inside the shroud.

The high UHF reflector, being a Lockheed Wraprib, resembles a toroid when stowed and is held in the upper portion of the shroud by its deployment boom. The high UHF feed array is hinge-mounted to the earth facing panel and is locked in a vertical position when it is stowed.

The solar sail is collapsed into a small package on the west panel of the spacecraft. Figures 5-14 and 5-15 shows the spacecraft within the shroud.

Figure 5-11

CONFIGURATION NO.3 : CONCEPTUAL DESIGN OF THE COMBINED (MILITARY AND MOBILE) PAYLOAD ON THE INTELSAT V BUS



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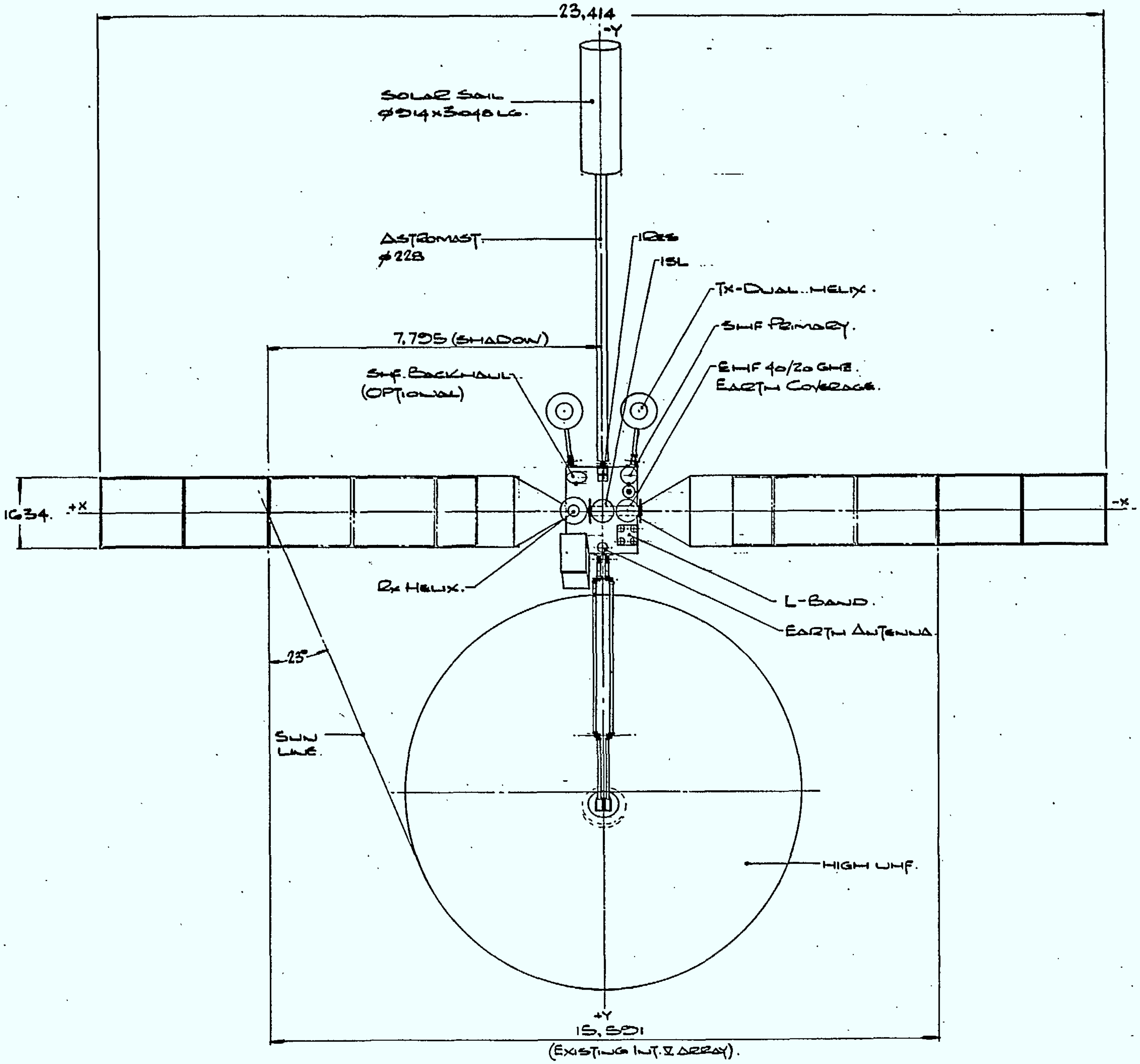

Figure 5-12 Combined Payload on Intelsat V Bus Deployed (Top View)

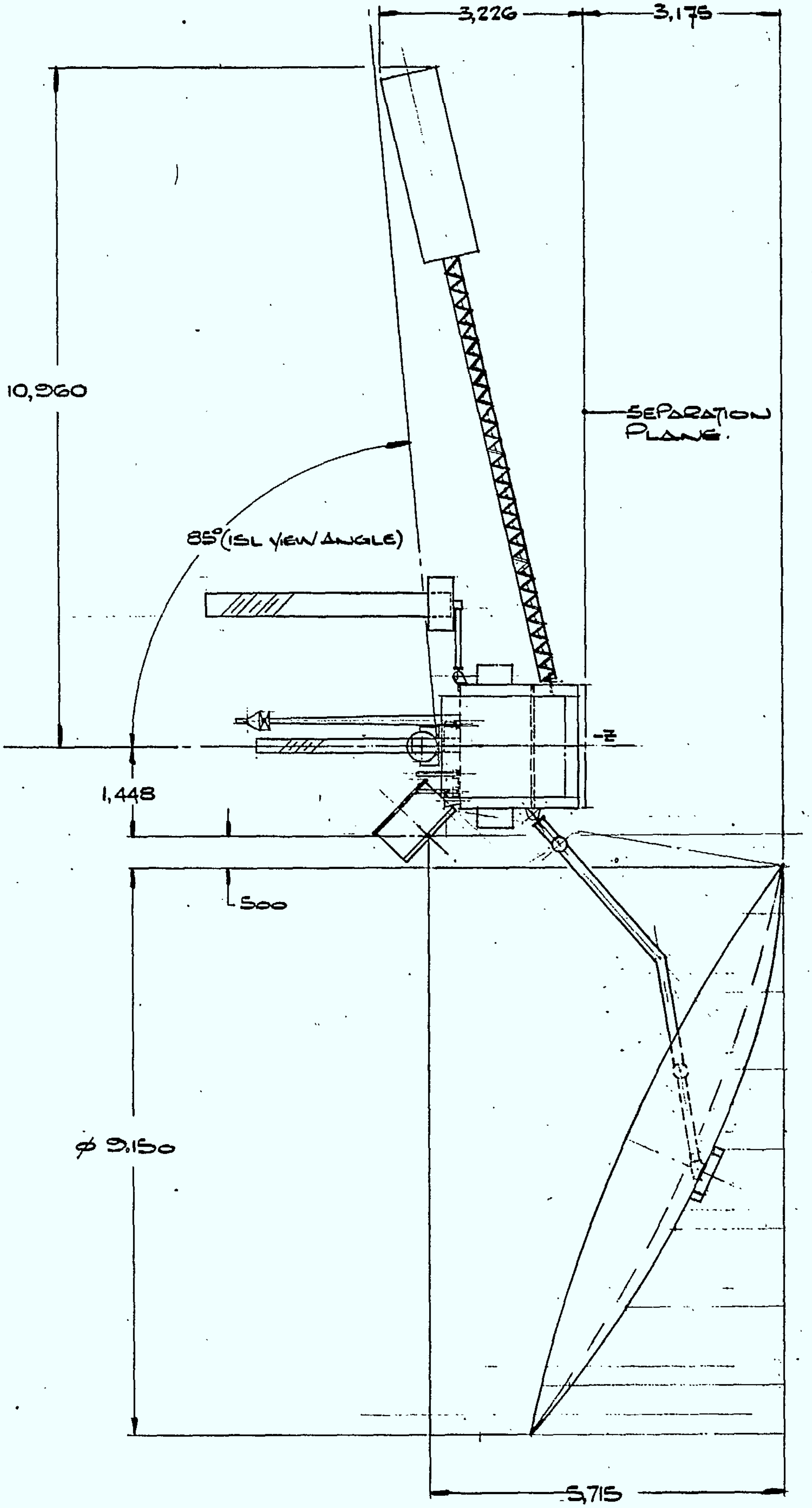

Figure 5-13 Combined Payload on Intelsat V Bus Deployed (Side View)

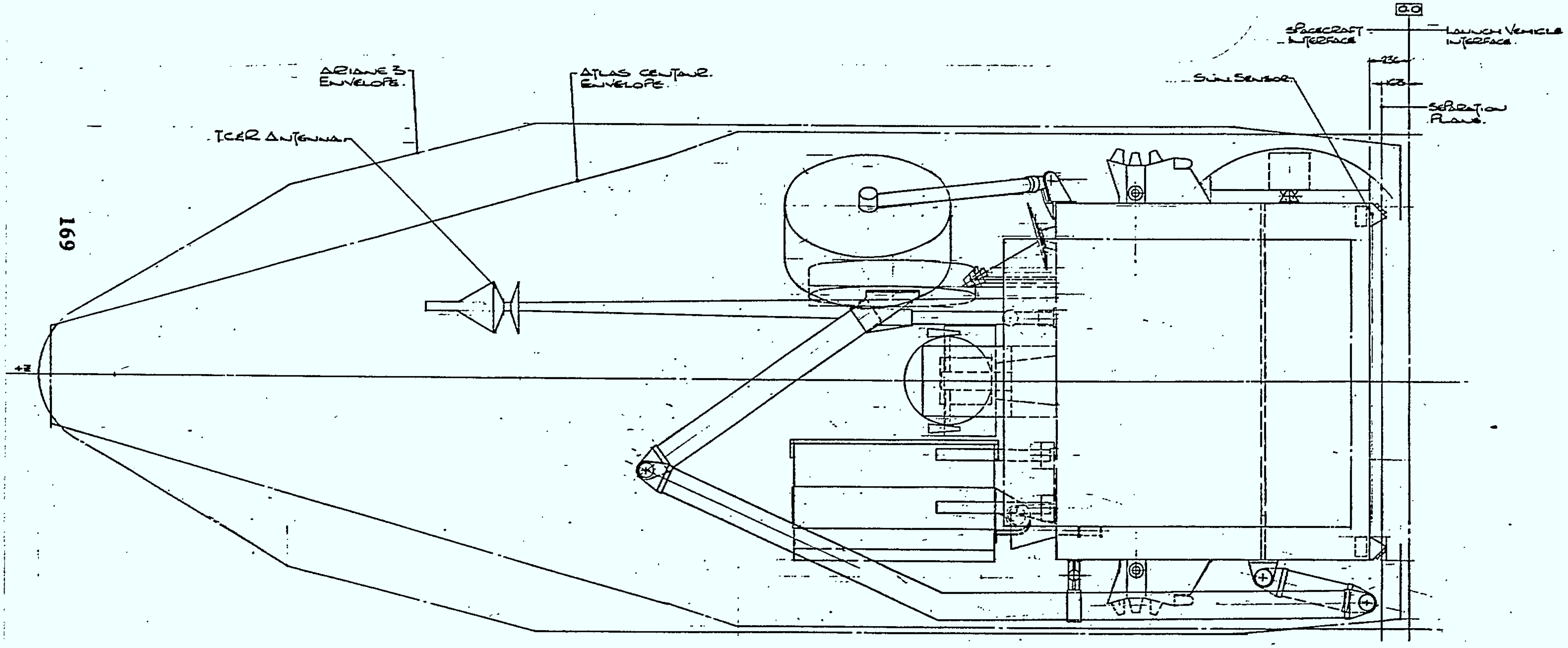

Figure 5-14 Combined Payload on Intelsat V Bus Stowed (Side View)

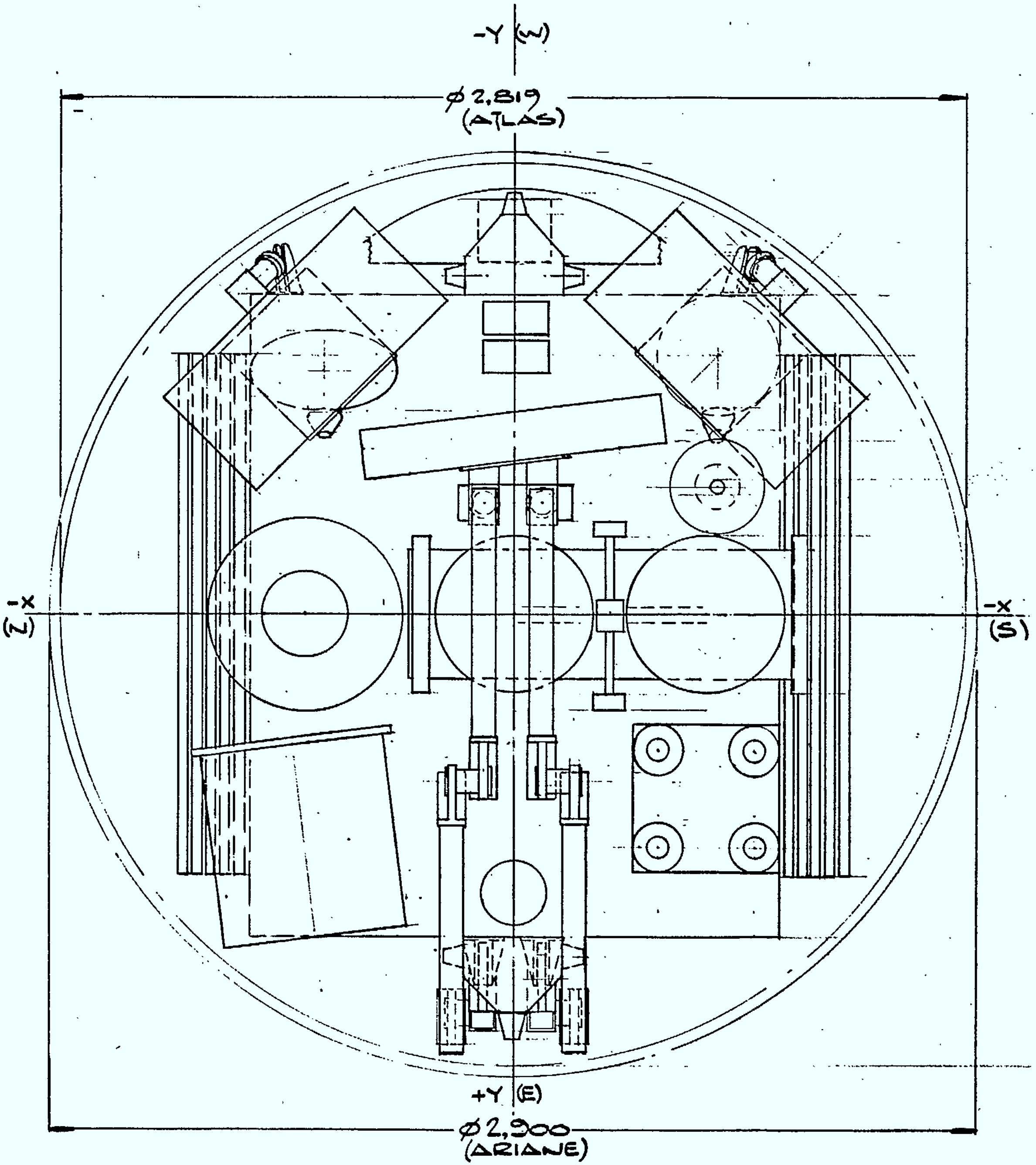

Figure 5-15 Combined Payload on Intelsat V Bus Stowed (Top View)

5.3.2 MASS BUDGET

5.3.2.1 Design Spacecraft Mass Requirements

The mass, power and interior mounting area budgets for the Combined payload are summarized in Table 5-5. The detailed breakdown of the communication packages is given in the scroll for Military and Mobile payload in Appendix G.

From Table 5-5, the total transponder and antenna mass is 293.5 kg.

5.3.2.2 Intelsat V Mass Capability

The rated payload mass capability is 233.5 kg. For configuration #3, the GFEC tower on the present Intelsat V will not be required. This adds another 39 kg to boost the maximum payload mass capability to 272.5 kg. Unfortunately, it falls short of the required 293.5 kg to give a negative margin of 21.01 kg (-7.7%).

5.3.3 POWER BUDGET

The power capability of the Intelsat V bus is 782 W. From Table 5-5, the required payload power is 1267.2 W. This results in a large negative margin of 485.2 W (-62%).

TABLE 5-5 - COMBINED PAYLOAD MASS, POWER AND MOUNTING AREA BUDGETS

COMMUNICATION SERVICE		MASS (kg)	POWER (W	POWER DISSIPATION (W)	MOUNTING AREA (m^2)
1) LOW UHF:					
Repeater		31.0	217.6	177.1	0.810
Antenna:	Dual helices-transmit	19.1			
:	Single helix-receive	6.8			
		56.9			
2) L-BAND:					
Repeater		5.9	80.2	68.3	0.270
Antenna:	Quad helices	2.5			
		8.4			
3) SHF:					
Repeater		26.4	102.4	87.4	0.888
Antenna:	Primary	2.7			
	Secondary	1.8			
		30.9			
4) EHF:					
Repeater		20.7	56.4	53.4	0.615
Antenna:	Primary & Secondary	6.0			
		26.7			
5) ISL:					
Repeater		12.7	83.9	81.9	0.533
Antenna		4.9			
		17.6			
6) HIGH UHF:					
Repeater		63.1	703.7	587.4	2.196
Antenna		56.3			
		119.4			
7) TT & C:					
Scrambler/Descrambler		10.0	10.0	10.0	0.106
Antenna		1.8			
8) MILITARY PAYLOAD MISC.:		13.6	13.0	13.0	0.105
9) SOLAR SAIL:		8.2			
TOTAL		293.5	1267.2		5.522
CAPABILITY AVAILABLE		272.5	782.0		3.200
MARGIN		-21.0 (-7.7%)	-485.2 (-62.0%)		-2.322 (-72.6%)

5.3.4 MOUNTING AREA BUDGET

The mounting area available on the Intelsat V bus is 3.2 m^2. Based on the assumption that the second surface mirrors can dissipate 350 W/m^2 and ½ inch clearance is required around each component for interface purposes, the mounting area required is 5.522 m^2. This results in a surprising negative margin of 2.322 m^2 (-72.6%).

5.3.5 CONCLUSIONS

It is obvious that the payload definition, as it exists, cannot be implemented on the Intelsat bus. For an Atlas-Centaur class spacecraft, the Intelsat V is surprisingly low on capabilities.

From Table 5-5, one critical item would be the high UHF transponder. Its power and mounting area requirements represents 55.5% and 39.8% of the total requirements respectively. From our parametric analysis on the high UHF transponders, CAL has shown that the payload requirements can be reduced while increasing the level of service. It is unlikely, though, that this optimization of the high UHF transponder will be able to lower the negative margin sufficiently.

The most critical item is the mounting area required by the power amplifier based on the thermal dissipation constraint. Since the constraint is not likely to be changed, the mounting area will continue to remain critical.

It is possible that a backed-off version of the Combined payload be implemented on the Intelsat V bus but facing such large negative margins, it would probably not be worthwhile.

In light of this analysis, it verifies that our first choice of using the L-SAT bus was correct. The L-SAT bus is a large bus and has more capabilities than the Intelsat V bus, and should accommodate the payload adequately.

6.0 CRITICAL TECHNOLOGY ITEMS

It is important to define areas of technology which are critical to the programs. To this end, specific items which are critical to the successful implementation of each service are discussed in this section. These items are not presented in any particular order as one is neither more or less important than another.

6.1 LARGE APERTURE REFLECTORS

For the mobile and combined missions, a thirty foot deployable reflector with an offset feed structure has been baselined. Offset fed parabolic reflectors are commonly used on current communications spacecraft and the design tools are well established for this type of antenna. The deployable reflector will require some development work but it does not represent a large change from the ATS-6 antenna which was flown successfully 7 years ago. The most significant difference would seem to be the additional tooling for the ribs to provide the asymmetric contour required for the offset design. The reflector surface tolerance is easily met because the highest wavelength for the mobile system is 1/10th of that used on ATS-6. The RMS surface tolerance of ATS-6 was $\lambda/30$ at 8.5 GHz. The relaxed contour tolerance means that fewer ribs are needed thus simplifying and lightening the reflector.

Thermal design for this structure is well in hand and no materials problems are foreseen.

In this study, a Lockheed wrap rib design similar to ATS-6 is proposed because the current manufacturer's data for reflectors of this diameter shows the Lockheed design to be lighter. In addition, it is easier to stow the wrap-rib design into the fairing constraints of the Delta class spacecraft. It should be noted, however, that Harris Corporation also have qualified deployable reflector structures up to sixteen feet in diameter (TDRSS) and have confidence that their newer Truss designs could also meet the performance requirements of our mission.

In summary, the problem of obtaining adequate deployable reflectors should result from a straight forward development program.

6.2 HIGH FREQUENCY COMPONENTS FOR THE MILITARY EHF PAYLOAD

The military payload requires experimental transponders to be flown using uplinks at 44 GHz and downlinks at 20 GHz. In addition, an intersatellite link is required which will use frequencies in the oxygen absorption band near 60 GHz. For the EHF service, the designs are derivative from hardware flown on LES 8 and LES 9, two spacecraft built by LINCOLN LABS for the U.S. Airforce. The components for these transponders are thus not commercially available in space qualified versions. Other experimental flight programs using microwave components in the 18 to 30 GHz range include the Italian SIRIO satellite, Japanese medium capacity Communication Satellite (CS) built by Ford Aerospace, and the 20/30 GHz millimeter wave experiments flown on ATS-6. It is anticipated that development work will be needed for receivers at 44 GHz and for the 60 GHz intersatellite link transponder components.

This development will take the form of redesign of laboratory and terrestrially-based commercial components so they can meet the rigours of the launch environment and operation in space. The reliability of semiconductor devices used at these frequencies will be an important feature to investigate. The method of manufacture of passive components, such as waveguide and antenna feeds must be considered. As well, the design and construction of filters, diplexers, isolators, power splitters and hybrids must be investigated. The mechanical tolerances required for antenna manufacture must be looked at.

It is anticipated that significant breadboard and brassboard work will be required for the development of the EHF and ISL transponders and antennas.

6.3 DEPLOYABLE HELICES

For the military UHF requirement, a single receive and dual transmit helices have been chosen. Because of the helix length necessary to achieve the required gain, these antennas must deploy on hinged arms, then extend axially. A similar design was developed by ASTRO as a backup design for FLTSATCOM, but it was not flown. For the military mission then, it is necessary to develop deployable helical antennas. This development will include the mechanical design and testing as well as antenna range tests. Vibration tests in the stowed configuration will be necessary. Thermal vacuum deployment tests shall be performed.

In the deployed state it will be necessary to measure the thermally induced bending and to ascertain the mechanical resonant frequencies. These frequencies must be factored into a flexible body dynamics analysis which will include interactions with the attitude and reaction control systems.

6.4 ARRAY SHADOWING - POWER SYSTEM INTERACTIONS

For the mobile service, the satellite will be equipped with a large aperture antenna. As the solar arrays must be oriented to rotate about the spacecraft pitch axis, the antenna reflector will cast a shadow on some inboard portion of the solar array at certain times of the day. To avoid this, the arrays must be positioned away from the spacecraft body. It is expected that the boom lengths required to completely avoid shadowing of the solar cells would result in mechanical configurations with natural frequencies falling into the pass band of the attitude control system response.

It is thus reasonable to investigate whether the power subsystem has the capability to provide power from the spacecraft battery during the periods when the array is shadowed. It should be noted that the greatest shadowing occurs about solstice, whereas the normal requirement for batteries occurs about the equinox eclipse season normally experienced by spacecraft in geosynchronous equatorial orbits.

Analysis must be made on the cycle life-time of the batteries, calculations of depth of discharge as a function of time into the mission and the optimum cell-string laydown pattern to minimize the number of strings simultaneously cut off. Blocking diodes must be included in the array electrical design.

Thermal analysis of the effects of local shadowing of the array will be necessary to insure that thermally-induced stresses do not cause cells or cover glasses to fracture or cell interconnects to break.

6.5 SOLAR TORQUE COMPENSATION

The asymmetrically positioned reflector surfaces required for the mobile service will cause a secularly varying torque about the spacecraft pitch axis. Detailed study must be made of the solar pressure on the large deployable structures taking into detailed account the surface properties and orientations of the component parts of the structure.

The resulting torques must be compensated in some manner. The two most obvious solutions are the use of an additional "solar sail" to counter balance the torque or an augmented momentum wheel incorporated into the attitude control system. Detailed dynamic simulation of the ACS must be performed in order to gain confidence that the required pointing accuracy can be maintained.

A problem also arises because the centre of mass of the spacecraft is shifted towards the outboard reflector. This asymmetry will require that the RCS thrusters be repointed to minimize unwanted torques when the thrusters fire. Significant analysis will be required if simple offset reflectors are used.

6.6 FLEXIBLE BODY DYNAMICS

All of the missions require antenna structures which are larger than those used at present for the 4-6 GHz and 12-14 GHz communication satellite services. These structures will be flexible and have mechanical resonant frequencies near the ACS control band. Although the pointing accuracy required of the spacecraft body may be relaxed, the flexible body dynamics of the system must be carefully examined.

In addition, for some mission requirements, the north-south station keeping requirement may be eliminated. If this is done, then the attitude control system will need a programmed pitch offset capability in order to maintain the antenna boresight at the proper location.

6.7 UHF TRANSPONDER COMPONENTS

The use of UHF transponder components is a new requirement for Canadian spacecraft. Hardware exists for the low UHF (military) requirements as this has been developed for FLTSATCOM (TRW), LEASAT (HUGHES) and DSCS III (GE). Many of the components should be available, however, it is necessary for Canadian industry to develop transponder design capability in this area. Also new developments in power FET technology may permit the design of simpler, more reliable and modular units for the output stages of the transponder.

The high UHF band, which is proposed for the mobile communications is not expected to have the same background of previous space programs from which to draw. Thus it will be necessary to proceed with development of qualified components for the 800 MHz band. This development will be able to draw on a large base of equipment designed for terrestrial use in both the military and civilian sectors.

6.8 UHF - MOBILE FEED DESIGN

As is the case for most reflector antennas, the design of the feed structure is a key element. This is the case for the 800 MHz mobile antenna. It will be necessary to breadboard and test the full-scale feed design including the beam forming network after a full numerical analysis and design trade off has been performed. This is important because many of the communications system parameters depend directly on the antenna performance.

7.0 CONCLUSIONS

The M-SAT Alternate system study, carried out by CAL, has achieved several objectives. It considered existing designs of communication satellites that can be modified with a minimum cost and risk, for a non-shuttle launch by 1987, to support either or both of the Military and Mobile missions. A detailed Mobile payload parametric analysis was carried out and optimum performance requirements for the Mobile spacecraft were established. These were reviewed, together with mainly well-defined Military performance requirements, to identify minimum cost spacecraft configurations which would satisfy varying degrees of communications payload and mission objectives, i.e. Mobile only, Military only and Combined missions. Finally, conceptual designs and potential programs to meet payload requirements were provided.

Candidate host spacecraft, (compatible with Delta launch), for each of the missions were chosen by two methods:

- Subjective evaluation after the spacecraft data was collected. The relative merits of each host spacecraft were being assessed against mission capacity requirements, cost, risk, schedule.

- Detailed relative ranking: after evaluation criteria and relative weighting percentages were established, host spacecraft were then ranked relatively for each weighted criterion, and scores summed up for each mission.

This resulted in the choice of the RCA 2770 lb. Advanced Satcom bus for both the Military and Mobile missions, and Intelsat V or L-SAT bus for the Combined mission. The Design Authority directed that Intelsat V should be considered here, while L-SAT was being studied under separate contract.

The need for a Military spacecraft to be hardened against the natural radiation environment, as well as a potential nuclear threat was considered. Natural radiation was treated by TRW and ESA. Hardening against nuclear threat has been dealt with by GE and TRW on DSCS II, III and FLTSATCOM. The cost of test programs can vary from 5% to 20% of total program.

Passive Intermodulation analysis on all low UHF and 800 MHz services revealed no significant products. The shadowing of the solar array by a large reflector was analyzed to determine the power loss for which the batteries would have to compensate. The power loss can be reduced by carefully increasing the array's boom length. Solar torque was calculated for an RCA Mobile mission. Two obvious solutions are suggested: the use of Solar sails or an augmented momentum wheel.

The 275-400 MHz Military operating characteristics, being firm, were not parametrically varied, except for the low UHF transmit and receive antenna designs, where for some candidate spacecraft, antenna mounting real estate difficulties were anticipated. This resulted in several possible antenna designs, of which a dual and a single helix were recommended for the Transmit and Receive antennas respectively, replacing the given quad and dual helilces.

For the 800 MHz Mobile payload requirements, a large number of parameters were analyzed, such as modulation schemes, voice activation, channel bandwidth, frequency reuse, type and size of antenna, number of downlink beams, traffic intensity, blockage rate, number of users and hence, the number of channels over varying spacecraft lifetimes, eclipse capabilities, transmit net efficiency, antenna pointing error and effect on net gain, N-S stationkeeping. Link analyses were carried out for the double hop configuration to determine such parameters as Mobile transmit RF power and antenna gain, backhaul requirements etc.

The parametric results can be efficiently compared with the capabilities of available buses. A novel and simple, but powerful, graphical solution was suggested for any Mobile or Military missions. It consists of plotting the payload required for any given case, as payload DC Power versus payload mass, and then superimposing on this plot the power versus mass payload "Envelope" capabilities of any available bus or buses.

It becomes apparent then, that not only any required payload falling "within the bus envelope" can be provided for by this bus, but also the maximum number of channels or payload services that can be achieve, lies "on the bus envelope". The interaction of all (variable) parameters mentioned above for the Mobile mission is simplified considerably by reducing the efforts to a graphical comparison.

The parametric analysis was conducted with the objective of achieving, on most existing candidate spacecraft, as many of the total number of channels as possible. If, over a lifetime of seven years, 25,000 Mobile users across Canada are expected, as suggested by a market survey study in another contract, then approximately 300 channels would be required. Therefore, the following results related to the possible number of channels were found, assuming at least 4 MHz RF bandwidth (possibly not more than 10 MHz) are available:

- NBFM is inefficient. It requires frequency reuse, voice activation, 10 MHz bandwidth, prohibitive ground antenna gain, Mobile DC power (as much as a few hundred watts) and large spacecraft antenna. In spite of these prohibitive demands on available bandwidths and technology, it can only provide a fraction of Canadian users coverage requirements.

- The only possible solution, for available technology and a 1987 launch, was found to be possible with voice activation and modulation schemes, such as Pitch Excited (42 dB•Hz) or Residually Excited (45 dB•Hz) with Linear Predictive Coding. In this case, there would be no need for frequency reuse. Table 6.1 (Volume III) indicates that, for an RCA Advanced Satcom, Intelsat V and L-SAT buses, 400, 565 and 900 PE/LPC Voice activated (42 dB•Hz) are possible, with only a 24 foot antenna, even with NSSK and ±0.3° pointing error and L-Band aeronautical service.

- The corresponding numbers for NBFM are 26, 39 and 64 channels.

- Pointing accuracy, antenna size and number of beams have a first degree effect on the net available gain, and hence the possible number of channels. The net gain decreases sharply at 50' for a ±0.3° pointing error. Therefore, a 50 foot diameter reflector is not recommended in this case, since EOC gain is provided further down the side of beam pattern, as antenna diameter and pointing error increase.

- The cumulative effect of changes in the independent parameters, even if small, was found to be surprisingly significant. This affects the total payload requirements and hence the spacecraft design.

Conceptual designs were given for three configurations, namely:

- Configuration 1: Military only (helices) on RCA Advanced Satcom
- Configuration 2: Mobile only (30' reflector) on RCA Advanced Satcom
- Conffiguration 3: Combined (helices and 30' reflector) on Intelsat V (FORD AEROSPACE)

The results of Table 6.1 indicate that for a Mobile only, including the aeronautical and Maritime L-Band service, and RCA bus can serve over 33,000 Canadian users using PE/LPC, i.e. an expected 8 year traffic, over 6 beams, without any frequency reuse. An Intelsat V bus does not offer much more capability. It is not worth considering NBFM on an IV Combined mission, since in practice, and insignificant number of channels would be available. On a Combined IV or equally RCA Satcom, depending on many parameters, between 80 to 100 PE/LPC Mobile channels are available, without NSSK.

In Volume III the effect of adding NSSK, an essential requirement for Arctic coverage by the Military, on an RCA Combined Mission, is analyzed in detail. The results, for a 24 foot reflector and 4 beams are summed up in Table 4.2 (Volume III). They suggest that for a 7 year mission:

- 108, 250 and 726 PE/LPC Mobile channels are available, if only low UHF service is combined on an RCA, IV and L-Sat respectively.
- zero, 125 and 608 PE/LPC Mobile channels are available, if low UHF and EHF services are combined.
- only L-SAT can provide any mobile channel (442) with a total Military payload.
- with an EHF experimental package, then 215, 297 and 640 Mobile channels are available.

Volume V deals with the cost and schedule for the program. For a 4 or 6 beam configuration, detailed antenna pattern computations, using CAL's existing software facilities, showed that, due to a ±0.3° pointing accuracy, the gain difference between 24 and 30 foot reflectors is only between 0.2 to 0.7 dB. A 30 foot reflector offers no significant improvement in gain, but is also regarded by RCA and FORD as a critical size, which should not to be exceeded, as it involves further dynamic and stability considerations. Therefore, for an RCA or IV bus, a maximum diameter of 24 feet is recommended for the Mobile transmit antenna.

Finally, the RCA Advanced SATCOM is recommended for a Mobile only mission. For a partially Combined mission, such as a preoperational spacecraft, both RCA Advanced Satcom and Intelsat V are recommended, without NSSK. NSSK is possible, at the expense of further reduction in the Military services and/or the spacecraft's lifetime. The use of the simple, graphical parametric approach paves the way to apply novel ideas of load sharing, dumping and of using several spacecraft with different lifetime and NSSK capabilities.

This study defines some critical technology items that have to be resolved for a successful implementation of the program. They do not represent completely new technology. They are related to the large aperture reflector, deployable helices, flexible body dynamics, Military EHF components, UHF Transponder components and Mobile Feed design, solar array shadowing power system interactions, and solar torque compensation.

Both RCA Advanced Satcom and Intelsat V have already flown many times. Both involve well-proven technology that should involve little risk, cost overrun or manufacturing delay for a 1987 launch.

ANALYSIS OF ALTERNATE SYSTEMS FOR
CANADIAN COMMERCIAL & MILITARY MOBILE
SATELLITE SERVICES: MAIN REPORT.