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Communications Platform Payload Definition Study

Technical Report

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Prepared for:
NASA Lewis Research Center
Cleveland, Ohio 44135

Prepared by:
RCA Astro-Electronics Division
Princeton, NJ 08540

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16. Abstract

Large geostationary communications platforms have been investigated in a number of studies since 1974 as a possible means to more effectively utilize the geostationary orbital arc and electromagnetic spectrum and to reduce overall satellite communications system costs. This NASA Lewis sponsored study addresses the commercial feasibility of various communications platform payload concepts circa 1998. It defines promising payload concepts, estimates recurring costs and identifies critical technologies needed to enable eventual commercialization.

Ten communications service aggregation scenarios describing potential groupings of services were developed for a range of conditions. Payload concepts were defined for four of these scenarios:

(1) Land Mobile Satellite Service (LMSS), meet 100% of CONUS plus Canada demand with a single platform;
(2) Fixed Satellite Service (FSS) (Trunking + Customer Premises Service(CPS), meet 20% of CONUS demand;
(3) FSS (Trunking + CPS + video distribution), 10 to 13% of CONUS demand; and
(4) FSS (20% of demand) + Inter Satellite Links (ISL) + TDRSS/TDAS Data Distribution.

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PREFACE

This study was conducted by RCA Astro-Electronics Division under NASA Contract NAS 3-24236 and the findings presented in their Report No. CR174986. A summary of the findings is presented prior to the seven sections and one appendix that make up this report; each describes in detail the findings.

Following this preface is a table of acronyms for ready reference.

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ACRONYMS

BBP	Baseband Processor
BOL	Beginning of Life
CER	Cost Estimating Ratio
CONUS	Contiguous United States
CPS	Customer Premises Service
DBS	Direct Broadcast Service
EOL	End of Life
EVA	Extra-Vehicular
FCC	Federal Communications Commission
FSS	Fixed Satellite Service
GEO	Geosynchronous Earth Orbit
IF	Intermediate Frequency
ISL	Intersatellite Links
IVA	Intro-Ventricular Activity
LEO	Low Earth Orbit
LMSS	Land Mobile Satellite Service
MSS	Mobile Satellite Service
NASA	National Aeronautics and Space Administration
OMV	Orbital Maneuvering Vehicle
ORU	Orbital Replacement Unit
OTV	Orbital Transfer Vehicle
RMA	Remote Manipulation Arm
RO	Receive Only
SMSA	Standard Metropolitan Statistical Area
SOW	Statement of Work
TDAS	Tracking and Data Acquisition System
TDMA	Time Divison of Multiple Access
TDRS	Tracking and Data Relay Satellite
TDRSS	Tracking and Data Relay Satellite System
WARC	World Administrative Radio Conference

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SUMMARY

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Ten communications service aggregation scenarios describing potential groupings of services circa 1998 were developed for a range of conditions. Payload concepts were defined for four of these scenarios:

(1) Land Mobile Satellite Service (LMSS), meet 100% of CONUS plus Canada demand with a single platform;

(2) Fixed Satellite Service (FSS) (Trunking + Customer Premises Service (CPS), meet 20% of CONUS demand;

(3) FSS (Trunking + CPS + video distribution), 10 to 13% of CONUS demand;

(4) FSS (20% of demand) + Inter Satellite Links (ISL) + TDRSS/TDAS Data Distribution.

The conceptual LMSS payload provides voice radio telephone service to 220,000 users via an 8-MHz frequency allocation. This is accomplished by employing 40 0.8° spot beams formed by a single 30-meter antenna. Digital data services (paging, dispatch) are provided to 1,200,000 units at L-band with a pair of 6-MHz allocations. Frequency reuse is provided by 52 0.7° spot beams formed by a 20-meter antenna aperture of the dual frequency L-band antenna. Coverage of the 50 to 100 gateway terminals is provided by a single Ku-horn. The LMSS payload mass is estimated to be 1172 kg and requires 8.1-kW end-of-life (EOL) dc power.

The second platform payload concept meets 20% of the projected year 1998 FSS demand for trunking and CPS (voice, data, and teleconference). Video distribution would be accomplished via a separate satellite. The platform could provide a total capacity of 511 36-MHz equivalent channels as follows: 109 C-band channels dedicated to trunking, 76 Ku-band channels dedicated to CPS, and 326 Ka-band channels for trunking and CPS. Cand Ku-band coverages are each provided by 23 0.5° fixed spot beams and a CONUS beam. Ka-band coverage is provided by 6 scanning beams and 17 fixed-spot beams with 0.25° beamwidth. The payload mass is 2144 kg and requires 15.6-kW power.

The third platform payload concept meets 13% of the year 1998 FSS demand for trunking and CPS and 10% of the demand for broadcast video distribution with 373 36-MHz equivalent transponder channels. Twenty-four channels of CONUS coverage are provided at C-band for video broadcast and trunking. Forty-one Ku-band channels are provided by the 1/4 CONUS coverage beams for CPS. Ka-band coverage is similar to the second platform payload concept except that 25 fixed-spot beams with 308 channels are provided for trunking and CPS. The 1508-kg payload requires 12.3-kW dc power.

The fourth payload concept aggregates three communications services on one platform: FSS, ISL, and data distribution. The FSS capability is the same as the second platform payload concept (capacity 20% of demand). The ISL capability provides links to Europe/Africa and Far East/Pacific FSS satellites. The ISL could operate as an optical link or at W-band (60 GHz). The ISL links meet 100% of the projected trunking/CPS traffic demand which is 15 36-MHz equivalent channels to the Pacific/Far East and 51 36-MHz equivalent channels

to Europe/Africa. The data distribution capability meets the requirements of the Tracking and Data Acquisition System (TDAS) which may replace the Tracking and Data Relay Satellite (TDRS) in the 1990's. The TDAS will accept single wideband links from user spacecraft as well as other TDAS spacecraft and will provide forward links to users and TDAS. The aggregated payload mass is 3155 kg and requires 19.0-kW dc power.

Critical technologies needed to enable the four payload concepts have been identified. Antenna technologies include a 30-meter unfurlable UHF/L-band reflector with microstrip feed, a Ka-band antenna with reduced surface tolerance, improved pointing accuracy (±0.025°) and reduced scan loss, and a W-band antenna with pointing accuracy of 0.010°. Reductions in size and weight are needed for multiplexer filters. The second payload concept (capacity 20% demand) requires 25 X 25 i.f. TDMA switching matrices and a baseband processor capable of switching 200 36-MHz equivalent channels.

Non-recurring costs (1984 dollars) were estimated for the four payload concepts. The cost per FSS platform transponder channel was about 10.9 to 35% less than the cost for current state of the art satellite transponder channels. Associated ground segment costs were estimated on a quantitative differential basis to enable comparison with non-aggregated concepts. Concepts 2, 3, and 4 reduce the number of earth station antennas that would be required to provide interconnectivity between satellites in a multiple satellite system. The ISLs provided by concept 4 eliminate the need for international gateway earth stations by interconnecting traffic directly to existing domestic trunking stations.

SECTION 1.0
INTRODUCTION

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INTRODUCTION

1.1 NASA'S GEOSTATIONARY COMMUNICATIONS PLATFORM PROGRAM

The first commercial communications satellite, INTELSAT I-I, was launched in 1965. Domestic satellite communications began in the U.S. in 1974 with the launch of WESTAR-1. Since then, the U.S. commercial satellite communications industry has grown rapidly, from 24 36-MHz equivalent transponders in orbit in 1974, to 168 transponders in 1980, to 480 36-Mhz equivalent transponders in orbit at the end of 1984. While it is likely that this growth rate will diminish, demand will continue to increase. According to NASA forecasts (Reference 1) potential demand might exceed the available capacity of Cand Ku-band satellites by the early 1990's (2° orbital spacing, 24 transponders per satellite, and improved transponder throughput assumed). NASA has responded to this projected shortfall in capacity by establishing a Geostationary Communications Platform Program with the overall goal to "enable the effective aggregation of space communications payloads to enhance the arc/spectrum resource."

The Geostationary Communications Platform Program was initiated with operational communications platform systems definition studies to:

- Establish the validity of payload aggregation for the 1995-2000 time frame.
- Identify critical technologies
- Identify and scope U.S. industry/NASA's role in developing the required technology

Two sets of parallel studies are being conducted. The first set, which includes the study documented in this report, defines viable aggregated commercial communications payloads that make sense from a communications service point of view. The second set addresses the requirements for future spacecraft buses, space transportation systems, and space operations capabilities necessary to enable GEO communications platforms. The payload and bus studies were coordinated by means of interface meetings and exchange of data on critical parameters and constraints. The bus contractors were responsible for integration of the payload and bus concepts into feasible communications platform designs.

1.2 STUDY OBJECTIVES AND TASKS

The following potential advantages of geostationary communications platforms have been suggested in past studies (References 2 through 10):

- Enable higher capacity per orbital slot
- Enable lower costs per unit of capacity
- Promote improved communications networks.

A number of fundamental institutional, operational, and technical issues have also been identified during a NASA-sponsored industry briefing and workshop (Reference 11). These include:

- Questions on economy of scale benefits
- Practical limitations on frequency reuse through multibeams
- Feasibility of large-scale aggregation of services
- Overall cost effectiveness

The objectives of this study are to:

- Determine the types of communications payloads that would be appropriate for a large geostationary facility initially operational in the late 1990's.
- Provide conceptual designs and descriptions of, and comparisons between, such payloads when implemented on a single spacecraft
- Provide indications as to the enabling and supporting of high risk technology development efforts required for their implementation.
- In meeting these objectives, this study verifies the advantages suggested in the earlier studies, addresses the issues of past critiques, and determines the viability of a communications platform as a commerially operational system.

The seven technical tasks defined in the Statement of Work (SOW) for this study are as follows:

- Task 1. Initialization/Database Development
- Task 2. Communications Service Aggregation Scenario Development
- Task 3. Payload Concept Development
- Task 4. Payload Definition
- Task 5. Costing
- Task 6. Critical Technology
- Task 7. System Comparisons

Task 1 develops the database required for successful completion of the remaining six technical tasks and includes development of:

- Study and task constraints
- Traffic forecasts for 1998
- Plant-in-place forecasts for 1998
- Forecasts of 1998 technology
- Development of costing methodologies

Task 2 develops a minimum of six communications service aggregation scenarios describing potential groupings of voice, video, and data services for 1998. Task 3 develops payload concept descriptions and systems architectures for four of these communications service aggregations. Task 4 defines payload system configurations and corresponding technical characteristics for the four concepts developed in Task 3. Task 5 provides costing information for the four payload concepts. Recurring costs are estimated for individual payload components and the assembled payload. Differential costs are provided for the associated ground segments to enable comparison of platform-related ground segment costs to ground segment costs in the absence of platforms. Task 6 identifies both enabling and supporting technologies critical to implementation and operation of each payload concept and describes the technology development scenarios required to enable implementation of the payload concepts operationally in 1998. Task 7 compares the platform payloads and describes the advantages and disadvantages of each relative to an environment without platforms present.

Section 2.0 of this technical report presents the scenario descriptions that result from Task 2. Section 3.0 provides details of the four payload concepts and descriptions developed in Tasks 3 and 4. Section 4.0 describes the costing approach and results from Task 5. Section 5.0 documents the Task 6 critical technology results, while Section 6.0 provides system comparisons (Task 7).

SECTION 2.0
COMMUNICATIONS SERVICE AGGREGATION SCENARIOS

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COMMUNICATIONS SERVICE AGGREGATION SCENARIOS

The study SOW calls for development and ranking of a minimum of six communications service aggregation scenarios describing potential groupings of voice, video, and data services and selection of four of these for payload concept development. This section presents a summary of ten candidate scenarios that were initially considered and discusses the details of the four scenarios selected for further development. The advantages and disadvantages of each scenario and corresponding payload design are presented in Section 6.0, System Comparisons.

2.1 CANDIDATE SCENARIOS

2.1.1 SCENARIO GUIDELINES AND CONSTRAINTS

The study SOW provided the following general guidelines and constraints:

- Utilization of 1998 operational technology
- No in-orbit payload assembly
- Minimum System lifetime of 10 years
- Conformance to anticipated regulatory requirements

The study SOW also provided a set of baseline conditions and a set of variations to be considered for scenario development. At least two scenarios were to be developed from each set of conditions. The baseline requirements are:

- Up to contiguous U.S. (CONUS) coverage
- Domestic Fixed Satellite Service (FSS) and Direct Broadcast Service (DBS). FSS includes trunking, customer premises service (CPS) and video distribution.
- C, Ku and, Ka frequency bands.

The scenario requirement variations are:

- Service coverage area up to entire Western Hemisphere
- Additional services: mobile (MSS for land, sea, air), data collection, others
- C, Ku and, Ka and other frequency bands
- Intersatellite link (ISL) capability to international satellites or other non-U.S. satellites or platforms.

The SOW also provided two launch concepts as constraints on the payload definition task (Task 4). These launch constraints were taken into consideration in the scenario development task to assure all concepts would be feasible. The two launch concepts permit spacecraft weight at geosynchronous transfer orbit of up to 12,000 pounds (single Shuttle launch) and 65,000 pounds (multiple Shuttle launches). Payload weight, power, volume, and lifetime envelopes imposed by various spacecraft/transportation system space operations capabilities were developed in the platform bus studies and provided by NASA early in this study. These envelopes, developed as constraints on Task 4, were also considered in scenario development.

2.1.2 SCENARIO SELECTION CRITERIA

The synthesis of candidate scenarios and their subsequent ranking and selection was driven by a set of scenario selection criteria developed in Task 1. The criteria were developed to assure that the scenarios make sense and that the payload concepts are likely to be commercially acceptable. The criteria address a number of issues that are likely to be raised by the commercial satellite communications industry. The scenario selection criteria and likely issues are:

- Platform capacity consistent with realistic forecast demand per orbital slot ("How big?")
- Clear advantage over non-aggregated satellites ("why aggregate?")
  - Satellite capacity inadequate
  - Potential platform system (space and ground segment) cost savings
  - Improved connectivity
- Acceptable level of risk ("can it be done?")
  - Institutional
  - Technological
- Minimal impact on ground segment plant-in-place ("What about the sizeable investments already made/committed?")
- Platform scenarios sufficiently different to lead to alternative payload designs

2.1.3 CANDIDATE SCENARIO SUMMARY

The ten candidate scenarios (five baseline and five variations) summarized in Table 2.1-1 represent various aggregations of services and coverage areas. FSS includes trunking, CPS, and broadcast video distribution. CPS provides connectivity directly to an antenna located at the customer's premise. Trunking and CPS can provide voice, data, and videoconference communications. DBS is a new service that will be available in the near future providing television service directly to the home. LMSS is another new service that will be available in the late 1980's to provide communications links between land mobile users and fixed site users via terrestrial gateways. ISL provides connectivity between

TABLE 2.1-1. COMMUNICATIONS SERVICE AGGREGATION SCENARIO SELECTION SUMMARY

Rank Order	Service	Area	Capacity(1)	Frequency Band
1	FSS (Trunking + CPS)	CONUS	20%	C, Ku, Ka
2	FSS (Trunking + CPS)	CONUS	13%	C, Ku, Ka
3	FSS (Trunking + CPS + Video Dist.)	CONUS	13%TR/CPS 10% TV	C, Ku, Ka
4	LMSS	CONUS + Canada	100%(2)	UHF, L
5	FSS + ISL + Data Dist.	CONUS E/W Global	20%	C, Ku, Ka, W (or optical), S
6	FSS + LMSS	CONUS	20% FSS 100% LMSS	C, Ku, Ka, UHF, L
7	DBS, Video Dist.	CONUS	50%	C, Ku
8	FSS, ISL	Western Hemisphere	20% US 100% Non	C, Ku, Ka, W (or optical)
9	DBS	CONUS	50%	Ku
10	DBS, Video Dist.	Western Hemisphere	25% US 50% Non	C, Ku

NOTES:

(1) Platform Capacity relative to total satellite addressable demand (Year 1998)
(2) LMSS capacity sized to end-of-life demand.

users in CONUS and users in Europe or Asia via links to international satellites. Data collection and distribution is currently provided by TDRSS to establish connectivity between user satellites and ground station(s) in CONUS.

2.1.3.1 FSS Scenarios

Scenarios 1, 2, and 3 provide FSS only, to CONUS. The FSS/CONUS scenarios are ranked higher than the other scenarios, because the provision of FSS to CONUS is and will remain the "bread and butter" of the satellite communications industry. It is also the most vulnerable of all the services to competition from terrestrial alternatives such as fiber optics cables. FSS includes point-to-point communications (Trunking, CPS) and point-to-multipoint communications (broadcast video distribution). Today's satellites provide both types of communications by means of CONUS antenna beams. Point-to-point communications satellite capacity can be increased by utilizing narrow spot beams to provide increased frequency reuse. Point-to-multipoint communications however requires wide beams (e.g., CONUS or 1/2-CONUS).

Thus, as spacecraft capacity requirements increase, beam requirements diverge for the two types of communications. Scenarios 1 and 2 recognize this divergence by placing point-to-point and point-to-multipoint communications on separate spacecraft. Scenario 3 takes the traditional approach of providing point-to-point and point-to-multipoint communications from the same platform. Scenario 2 differs from scenario 1 in terms of the platform capacity requirement.

2.1.3.2 LMSS Scenarios

LMSS can operate from, at most, two or three orbital slots without producing severe co-channel interference problems because of the mobile terminal antenna characteristics. Operation from a single slot offers a potential advantage over a multiple satellite system by reducing the mobile terminal antenna requirements from a steerable antenna to a fixed antenna. The LMSS scenarios assume the end-of-life (EOL) demand (year 2008) is met by a single platform, a second-generation LMSS spacecraft. The first-generation LMSS, yet to be approved by the FCC, will be replaced circa 1998. Scenario 4 describes a dedicated LMSS platform, while Scenario 6 aggregates the LMSS payload with the 20% capacity FSS payload from Scenario 1. The LMSS platform provides links between the spacecraft and mobile user, and the spacecraft and a gateway. The gateway is linked to the public switched telephone network. Scenario 6 eliminates the LMSS gateways required in Scenario 4. Connectivity would instead be by links to trunking stations and CPS terminals. The FSS and LMSS have different transponder bandwidth requirements: 36 MHz for FSS vs. 1 MHz or less for LMSS. Operationally, the FSS and MSS payloads may have different lifetime requirements. There has been a trend in satellite communications towards longer satellite lifetimes: from 3 to 5 years in the 1960's to 7 years in the 1970's to 10 years in the 1980's. Even longer lifetimes should be achievable by 1998. LMSS operates from one orbital slot and its capacity must be sized to the expected EOL demand. Because forecasting uncertainties increase rapidly as the planning horizon is extended, the platform operator may prefer to limit his risk by designing to a lifetime requirement (e.g. 7 years) far less than can be technically achieved.

2.1.3.3 ISL and Data Distribution Scenario

Scenario 5 aggregates the Scenario 1 20% capacity FSS payload with an ISL payload and a data distribution payload. The ISL payload provides connectivity to users in Europe/Africa and in the Pacific/Far East regions via links to international satellites. Connectivity is completed to CONUS users via the FSS payload, eliminating the need for the eastern and western gateways currently used for U.S. to international traffic. The data distribution payload is based on the TDAS requirements (reference 12). TDAS is a proposed replacement satellite for the current TDRSS satellite.

2.1.3.4 DBS Scenarios

A DBS payload is combined with an FSS video distribution payload, forming a point-to-multipoint video distribution platform for CONUS (Scenario 7) and the Western Hemisphere (Scenario 10). The Scenario 7 platform would service 50% of the CONUS market with 32 DBS transponders and 48 FSS TV distribution transponders (transponders are 36-MHz equivalent). FSS distribution would operate at C-and Ku-bands. DBS would operate at Ku-band using the 500 MHz allocated to Broadcast Satellite Service. The video distribution scenarios did not appear to offer any clear advantages over separate DBS and FSS video distribution satellites and were not developed as a payload concept. The aggregated platform payloads could share the Ku-band antenna and a common bus. However, the two payloads have little in common:

- Different end customers
  - FSS distribution to cableheads and motels/apartments (SMATV)
  - DBS directly to homes
- Different assignment of the frequency spectrum
- No connectivity improvement by aggregating

2.1.3.5 Western Hemisphere Scenarios

Two scenarios were developed that provided Western Hemisphere coverage. Scenario 10 aggregated DBS and TV distribution and is discussed in Section 2.1.3.4. Scenario 8 aggregated the FSS and ISL payloads from Scenario 5 with an FSS payload providing additional coverage to Canada, Central America, and South America. Non-U.S. Domestic traffic in the Americas is forecast to be 355 36-MHz equivalent transponders in 1998. International traffic within the Americas is forecast to be 55 transponders. The "Western Platform" would meet 100% of this demand in addition to 20% of the U.S. domestic traffic and 100% of the ISL traffic. The Western scenarios were ranked lower in preference than the CONUS coverage scenarios, because:

- Orbital slot conflicts

- Institutional/Political issues of international operation

- Satellites (e.g., Pan Am Sat) could meet the Western Hemisphere traffic demands (U.S. domestic excluded)

- At least Canada and Mexico (and possibly Brazil) are expected to meet domestic demand with their own satellites.

All U.S. domestic communications satellites in orbit or authorized are located between 62° and 146° west longitude. South America is centered at approximately 60° west longitude. Thus a satellite positioned for ideal coverage of South America is at a less than ideal location for coverage of the Western U.S., particularly at Ka-band.

A "Western Platform" concept faces increasing competition from a number of sources. Pan Am Sat has selected 57° west longitude for its Western Hemisphere Satellite System, and would capture some of the demand intended for the Western Platform. Canada, which makes up over half of the non-U.S. domestic traffic, has its own domestic satellite communications system. Mexico has plans for its own national system, and it is likely that by 1998 Brazil will also have its own system. These three countries together comprise 84% of the forecast non-U.S. domestic traffic demand.

2.1.3.6 Scenario Selection

The SOW calls for selection of two baseline scenarios and two "variations" scenarios for concept development and definition. FSS Scenarios 1 and 3 are selected for development. Scenario 2 was not selected because it is likely to produce a design very similar to Scenario 1. "Variation" Scenarios 4 and 5 are also selected for development. In subsequent sections of this report, the LMSS scenario will be referred to as "Concept 1", the 20% capacity scenario as "Concept 2", the 13% capacity scenario as "Concept 3", and the FSS/ISL/TDAS scenario as "Concept 4", as indicated by Table 2.1-2.

2.2 MOBILESAT SCENARIO

Investigation of the database for land mobile communications traffic forecasted for the 1998 time frame and developed under Task 1 suggested a scenario where a single platform would be dedicated to the land mobile communications satellite service. The FCC's January 1985 "notice of proposed rule making" proposes allocation of a pair of 4-MHz bands at uhf (821 to 825 MHz and 866 to 870 MHz) and use of L-band (1.5 GHz) for mobile satellite services that cannot be accommodated at uhf. The study assumes a pair of 6-MHz bands will be allocated at L-band in addition to the 4-MHz pair at uhf.

A first-generation mobile satellite may be operational by the end of this decade. At present there are 12 mobile satellite applications under review and evaluation by the FCC. The FCC will grant only one mobile license. The first-generation Mobilesat will be replaced in the mid to late 1990's. Several studies have been performed to explore options for a second generation system. A JPL-sponsored "Mobile Satellite Configuration Design Study" was conducted by RCA (reference 13), and a "Satellite System Design Study" was performed by TRW for NASA LeRC (reference 14).

The LMSS platform described by this scenario represents a third-generation design, with capacity sized to 1998 demand.

2.2.1 LAND MOBILE SATELLITE (LMSS) DESCRIPTION

The first-generation mobile satellite will provide introductory service over CONUS. The configuration will consist of a restricted number of beams and

TABLE 2.1-2. SCENARIO SELECTION

Development Concept #	Scenario Ranking	Service	Capacity
1	4	LMSS	100%
2	1	FSS (trunking & CPS)	20%
3	3	FSS (trunking & CPS & TV)	13%
4	5	FSS & ISL & TDAS	-

consequently only a limited frequency-reuse scheme. The land mobile traffic will saturate this configuration as demand increases into the 1998 time frame.

Single satellite and multiple satellite configurations are being proposed for the second-generation land mobile satellite service. The single satellite configuration increases the number of beams and consequently the frequency-reuse scheme on a single satellite for CONUS coverage. The number of beams is increased by decreasing beamwidth through use of a larger diameter antenna and a more complex feed network. This configuration was designed under contract to JPL by RCA using currently available bus technology and launched from the Space Shuttle using Shuttle Compatible Orbit Transfer Subsystem (SCOTS), an RCA-developed solid fuel apogee kick motor.

The offset antenna diameter drives the spacecraft design in the deployed and stowed configurations. As the antenna diameter is increased, the length of the supporting boom and mast structures increases. The physical size of the deployed structure imposes new requirements on the attitude control system to orient the dish toward the CONUS reference point (Kansas City). The weight, cube, and deployment characteristics of the stowed configuration limit the antenna which can be deployed from the Space Shuttle using available RCA bus and apogee kick motor designs. For this design approach, the second-generation LMSS beamwidth is limited, frequency reuse of the allocated band is limited, and the projected 1998 traffic cannot be accommodated.

Another design approach to increase the frequency reuse of the allocated bandwidth uses two spacecraft for CONUS coverage. The burden of discriminating between the two spacecraft falls on the mobile antenna, which must detect, discriminate, and steer to signals from either of the two spacecraft. These steerage requirements imposed on the mobile antenna increase the cost per mobile unit and substantially increases the cost of the overall system. It is not likely the average mobile user will purchase service if the cost per unit increases much above that for cellular radio. Thus, for economic reasons, it is desirable to impose as much complexity as required on the spacecraft to relieve the mobile user of costly technical refinements.

For these reasons, one of the platform concepts selected is dedicated to the land mobile user and provides adequate frequency reuse for the mobile traffic anticipated in the 1998-to-2008 period. The payload is sized to cover CONUS and Canada; coverage to Hawaii and Alaska is not provided. The antenna diameter selected is adequate to provide beamwidth and corresponding frequency reuse sufficient to meet the requirements for the 1998-to-2008 mobile traffic forecast.

The traffic forecast for 1998 includes a requirement to provide paging and dispatch services using digital data packets. Digital data services are provided at L-Band and design constraints similar to those at uhf apply. The Mobilesat Platform provides a deployable UHF reflector which can serve a dual function as a reflector at L-Band.

Table 2.2-1 summarizes the land mobile traffic forecast for the year 2008 EOL demand for the 1998 platform) that was provided by NASA LeRC. The year 2008 forecast was obtained by extrapolating the year 2000 forecasts at a 4% annual growth rate. The voice channels are spaced at 7 kHz with a 3-kHz i.f. bandwidth. The digital data services (paging, dispatch) have a 10-kHz channel spacing. Information rates are approximately 3 kbps and the average message length is 500 characters. A digital data service system reduces the channel requirements by a significant amount. An unpublished NASA LeRC study (Reference 15) indicates a comparable voice paging and dispatch service would require over 10,000 channels.

TABLE 2.2-1. LAND MOBILE TRAFFIC FORECAST - YEAR 2008

	Service			
	Mobile Radio Telephone (Voice)		Digital Data Services	
Coverage	Users	Channels	Users	Channels
CONUS	180,000	3780*	1,000,000	556
Canada	20,000	728	100,000	90
TOTAL	200,000	4508	1,100,000	646

*Supports 180,000 users with 20% blockage probability during peak busy hour.

The 180,000 CONUS users will be supported by 3780 voice channels with a 20% blockage probability during the peak busy hour; 4680 channels would be required to support the same users with a 2% blockage probability. Support for 20,000 Canada users is provided by 728 voice channels with a 2% blockage.

The Mobilesat concept, shown in Figure 2.2.-1, requires gateway stations to interconnect mobile users with the standard telephone network, and with other mobile users. A mobile user wishing to connect to the telephone network or another mobile user will access an available channel in the uhf beam covering his geographic area. The signal will be upconverted to Ku-band by the platform and relayed to the gateway stations. The gateway station assigned to the beam will access the telephone network for a standard station or retransmit in the Ku-band to the platform identifying the uhf beam and mobile user dialed. A telephone in the standard network will access a mobile user by connecting to the platform through the most convenient gateway station in a similar manner.

The L-band digital data service will operate in a similar manner sharing the Ku-band and gateway switching facilities with the uhf band. The voice mobile service will request a channel in the uhf band using a dedicated orderwire channel to and from the gateway stations. The Network Management Center will

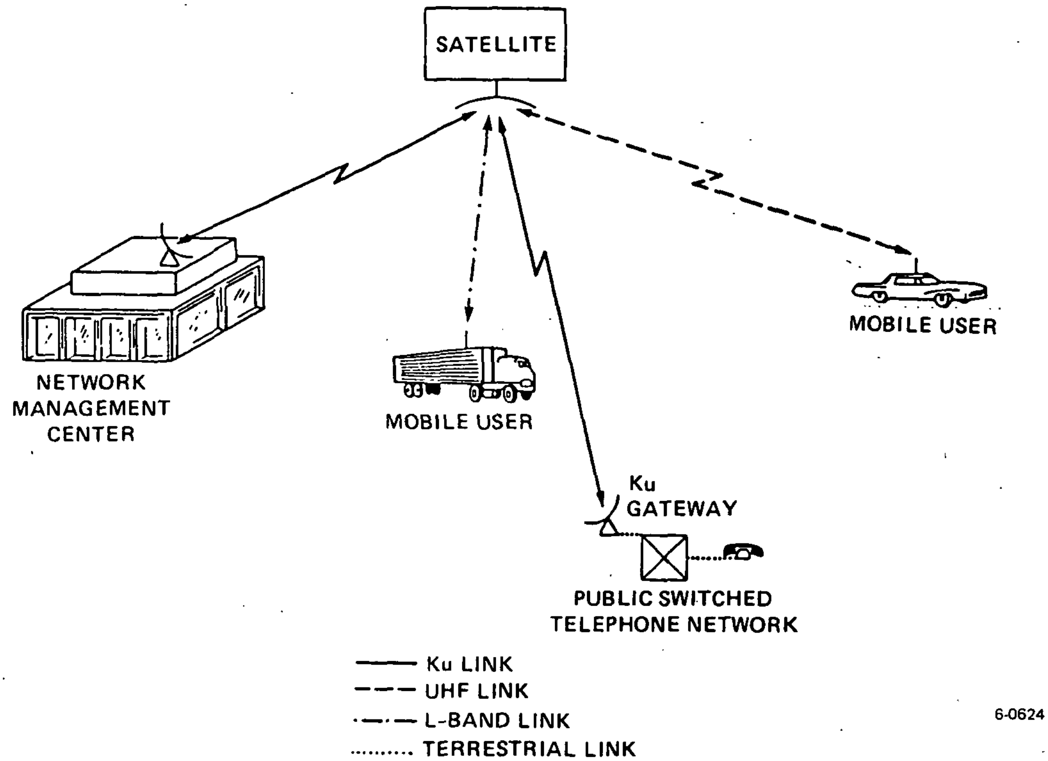


Figure 2.2-1. LMSS Network Configuration

control and allocate the available channels to the mobile users. At L-band, the paging and dispatch data services will be transmitted in packets, and a modified form of demand access will allocate channels under control of the Network Management Center.

2.3 FSS (20% CAPACITY) SCENARIO

This section provides the rationale behind the selection of an FSS platform that can accommodate 20% of the 1998 U.S. domestic demand for trunking and CPS services. The introduction of an FSS platform circa 1998 is seen as an evolutionary process driven by the inability of a conventional satellite to accommodate the increased demand that is forecast. The evolution of FSS platforms is described in Section 2.3.1. The allocation of the available frequency bands to trunking and CPS is discussed in Section 2.3.2. The platform capacity requirement is derived in Section 2.3.3.

2.3.1 FSS PLATFORM EVOLUTION

A major change in the way growth in satellite communications capacity is achieved will occur by 1998. Growth in satellite communications system capacity today is achieved by launching conventional spacecraft with 24 C-band and/or 24 Ku-band transponders (36-MHz equivalent) into unused orbital slots. There were 16 C-band, 4 Ku-band, and 2 hybrid C-band/Ku-band satellites in orbit at the end of 1984. Present authorizations by the FCC will more than double the U.S. domestic satellite capacity. The FCC orbital assignment plan released in July 1985 authorizes 24 C-band, 21 Ku-band, and 9 hybrid C-band/Ku-band satellites. Several more slots are assigned to Canada and Mexico and not available to the U.S. The inventory of unassigned slots is being rapidly depleted; only 3 C-band and 1 Ku-band slots remain unassigned. By 1998, growth in satellite communications capacity will be achieved by utilization of Ka-band and by greater frequency reuse at C-band and Ku-band. The growth will be implemented by replacing spacecraft with platforms of increased capacity since unused orbital slots will no longer be available. Platform capacity will grow at the same rate as demand.

The evolutionary transition from satellites to platforms is shown in Figure 2.3-1. It is assumed that the market leader has captured 50% of the satellite addressable communications market and has FCC authorization for six orbital slots. He uses two of these slots to provide video distribution services by conventional satellite. The four remaining slots are used to provide trunking and CPS capacity. The trunking/CPS spacecraft have a 10-year lifetime and are launched every 2-1/2 years. The year 1998 platform replaces a satellite launched in 1988 and has a capacity equivalent to 20% of the total 1998 satellite addressable demand. The year 2000 platform is larger, with a capacity equal to 20% of the year 2000 demand.

This scenario assumes platforms of increasing capacity are launched at uniform intervals. An alternative scenario was examined in which a generation of four platforms of equal capacity are developed and launched to replace satellites at decreasing time intervals between 1998 and 2008. The alternative scenario reduces nonrecurring development and design cost per platform, but requires a platform capacity equal to 14% of the year 2008 demand which is approximately 25% of 1998 demand. The uniform launch interval scenario was selected to provide a more conservative capacity requirement.

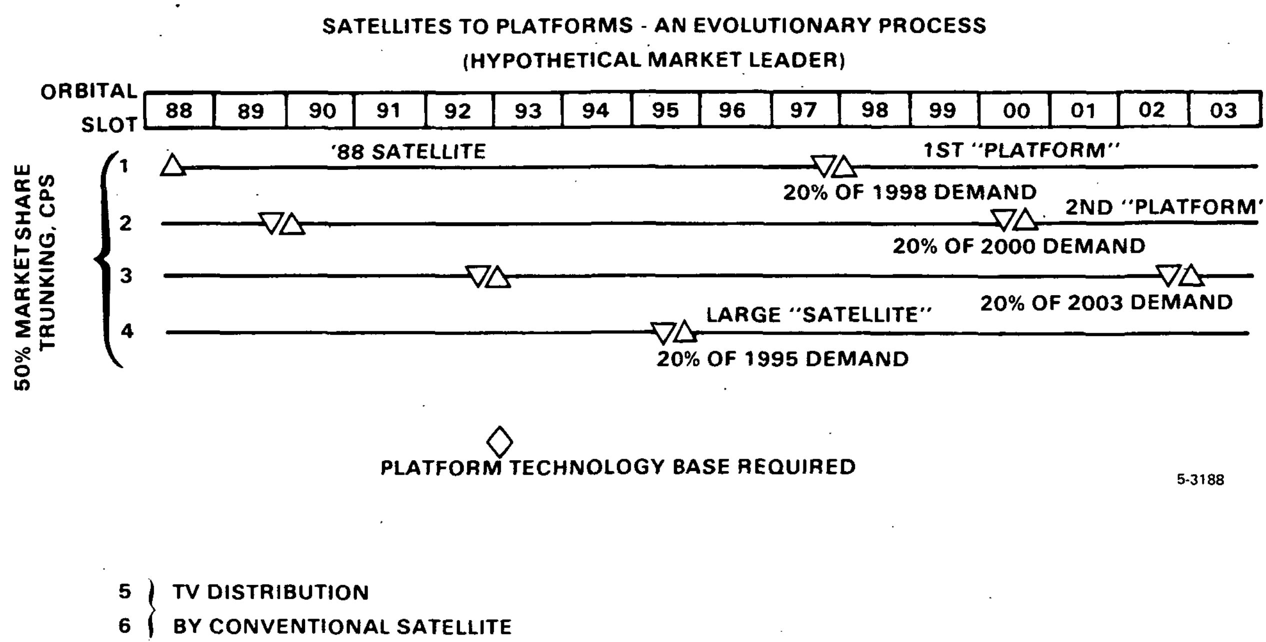


Figure 2.3-1. FSS Platform Evolution

2.3.2 FREQUENCY BAND ALLOCATION TO SERVICES

Three frequency bands are available for FSS, as shown on Table 2.3-1.

TABLE 2.3-1. BANDWIDTH AVAILABILITY FOR FSS IN U.S.

Band	Bandwidth (MHz)	Platform Scenario Allocation
C	500	Trunking
Ku	500	CPS
Ka	2,500	Trunking, CPS

C-band is used extensively today, and meets 85% of the current demand (4Q 1984) for transponders. The remaining demand is met by Ku-band transponders. Most traffic today is trunking and TV distribution. In the platform scenario, C-band is allocated to trunking and Ku-band is allocated to CPS. Ka-band is allocated to trunking and CPS to meet demand that exceeds the available capacity in C- or Ku-bands. Crosstrapping is required between C-, Ku-, and Ka-bands to provide full connectivity.

There has been a considerable investment to date in C-band earth-station trunking equipment. C-band was allocated to trunking in the FSS platform scenarios to minimize the impact on terrestrial plant-in-place. CPS is a relatively new service and there is therefore greater flexibility in selecting an appropriate band. Ku-band was selected over C-band because of smaller antenna requirements, the relative ease is siting earth stations, and the higher EIRP permitted. The FCC places greater constraints on C-band satellite communications to reduce problems of interference with terrestrial C-band microwave transmission. Ku-band is not used for terrestrial communications. Ku-band was selected over Ka-band as a first choice for CPS because rain attenuation is much less severe, and techniques such as site diversity are not required.

2.3.3 PLATFORM CAPACITY REQUIREMENT

The required platform capacity is affected by:

- Addressable market size
- Platform operator's market share
- Degree to which spacecraft capacity will be utilized (fill factor)
- Demand growth rate
- Platform life
- Number of orbital slots operator dedicates to trunking/CPS

The platform capacity requirement is derived from the market leader's total system capacity requirement for 1998 which is given by:

$$\text{Leader's Capacity} = \frac{(\text{Market Share}) \times (\text{1998 Addressable Market}) \times (\text{Demand Growth Factor})}{(\text{Fill Factor})}$$

The leader must have enough capacity in 1998 to meet the demand expected in 2000, when the next platform will be launched. The demand growth factor adjusts for this growth and is given by:

$$\text{Demand Growth Factor} = (1. + g)^{L/N}$$

Where:
- g = The annual demand growth rate in 1998
- L = Platform life (10 years assumed)
- N = Number of spacecraft (4).

Given the following assumptions,

Market Share = 50%
Demand Growth Rate[1] = 6%
Maximum Fill Factor = 90%

the leader's total 1998 capacity requirement is:

$$\text{Leader's System Capacity} = \frac{(0.5) \times (1.0) \times (1.06)^{2.5}}{(0.9)}$$

$$\boxed{\text{Leaders System Capacity} = 64\% \text{ of the 1998 addressable market}}$$

[1]Year 2000 addressable demand growth rate in transponders (reference 16)

The 1998 platform capacity requirement is given by:

$$\text{Platform Capacity} = \frac{(1+g)^{\frac{N-1}{N} L}}{\sum_{m=1}^{N} (1+g)^{\frac{m-1}{m} L}} \times (\text{System Capacity})$$

$$= 0.31 \times \text{System Capacity}$$

$$\boxed{\text{Platform Capacity} = 20\% \text{ of 1998 addressable market}}$$

The relative capacities of the leader's four spacecraft in 1998 are given in Table 2.3-2.

TABLE 2.3-2. SPACECRAFT RELATIVE CAPACITIES

Spacecraft No.	Launch Year	Relative Capacity (6% Growth Rate)
1	1990 + 1/2	0.198
2	1993	0.229
3	1995 + 1/2	0.265
4 (Platform)	1998	0.307
Leader's Total System	-	1.00

2.3.3.1 U.S. Domestic Traffic Forecast

The U.S. domestic satellite addressable traffic forecast for the year 2000 was provided by NASA (reference 16) and is summarized in Table 2.3-3. Satellite addressable traffic represents that portion of the total telecommunications traffic that can be competitively carried by satellite. This study assumes all satellite addressable traffic will be captured by satellite system operators. It includes the FSS services (trunking, CPS, and broadcast video distribution) and DBS. The forecast assumes the demand for FSS transponders grows at an average rate of 9% between 1980 and 2000. The growth rate gradually slows to 6% at the turn of the century. The traffic growth rate measured in terms of voice, data, and video channels is higher than for transponders because it is assumed technological improvements will improve the bandwidth efficiency. The NASA study assumes voice traffic grows at a 10% rate, while data traffic grows at a 15% rate in the 1980 to 2000 period.

TABLE 2.3-3. U.S. DOMESTIC SATELLITE ADDRESSABLE TRAFFIC FORECAST SUMMARY - YEAR 2000

Service	Traffic	Bandwidths Efficiency	Transponders (36 MHz)
Trunking			
• Voice	6816×10^3 Channels	120 Channels/MHz	1578
• Data	3348 Mbps	2.25 Mbits/MHz	41
• Videoconf	7814 Channels	1.1 Channels/MHz	203
CPS			
• Voice	35×10^3 Channels	60 Channels/MHz	16
• Data	25038 Mbps	1.5 Mbits/MHz	477
• Videoconf	411 Channels	0.68 Channel/MHz	17
Total Trunking & CPS			2332
Broadcast Video Distribution	233 Channels	0.069 Channels/MHz	92
Total FSS			2424
DBS	50 Channels	0.028 Channels/MHz	50
TOTAL DOMESTIC			2474

The domestic traffic demand is not uniformly distributed over the U.S., but is concentrated at the population centers. The demand distribution between the 28 largest Standard Metropolitan Statistical Areas (SMSA) is summarized in Table 2.3-4, normalized to 100,000 channels. Fourteen and one-half percent of the traffic is with New York and 30% of the traffic is with the Boston-Washington corridor; thus, the traffic demand distribution is heavily skewed towards the Northeast.

The 20% FSS scenario requires a platform capacity equal to 20% of the 1998 trunking plus CPS demand or 466 transponders (2000 demand forecast used). The

TABLE 2.3-4. U.S. DOMESTIC TRAFFIC DISTRIBUTION MATRIX (1 of 3)

US DOMESTIC VOICE TRAFFIC

TRAFFIC MATRIX
EARTH STATION TO EARTH STATION

TOTAL TRAFFIC FOR US IN 2000 IS 100024 CHANNELS.

ES. NAME	NO.	NEW_YORK 1	LOS_ANGL 2	CHICAGO 3	SAN_FRAN 4	BOSTON 5	DETROIT 6	WASHINGT 7	CINCINNA 8	PHILADEL 9	CLEVELND 10
NEW_YORK	1	0	1342	1209	948	930	875	857	839	785	749
LOS_ANGL	2	1342	0	575	451	442	416	407	399	373	356
CHICAGO	3	1209	575	0	406	398	375	367	359	336	321
SAN_FRAN	4	948	451	406	0	312	294	288	282	263	251
BOSTON	5	930	442	398	312	0	288	282	276	258	247
DETROIT	6	875	416	375	294	288	0	265	260	243	232
WASHINGT	7	857	407	367	288	282	265	0	254	238	227
CINCINNA	8	839	399	359	282	276	260	254	0	233	222
PHILADEL	9	785	373	336	263	258	243	238	233	0	208
CLEVELND	10	749	356	321	251	247	232	227	222	208	0
DALLAS	11	625	297	268	210	206	194	190	186	174	166
ANAHEIM	12	555	264	238	186	183	172	168	165	154	147
ATLANTA	13	503	239	215	169	166	156	153	149	140	133
HOUSTON	14	451	215	193	151	148	140	137	134	125	120
SYRACUSE	15	417	198	178	140	137	129	126	124	116	110
MIAMI	16	400	190	171	134	131	124	121	119	111	106
ST_LOUIS	17	383	182	164	128	126	118	116	114	106	101
RALEIGH	18	366	174	156	123	120	113	111	108	101	97
TAMPA	19	332	158	142	111	109	103	100	98	92	88
MINNEAPL	20	315	150	135	105	103	97	95	93	87	83
SEATTLE	21	298	142	127	100	98	92	90	88	83	79
KANSAS_C	22	281	133	120	94	92	87	85	83	78	74
DENVER	23	264	126	113	88	87	82	80	78	73	70
MILWAUKE	24	197	94	84	66	65	61	60	58	55	52
SAN_ANTO	25	181	86	77	60	59	56	55	53	50	48
PHOENIX	26	164	78	70	55	54	51	50	48	45	43
NEW_ORLE	27	147	70	63	49	48	45	44	43	41	39
SALT_LAK	28	131	62	56	44	43	40	39	39	36	34
TOTAL		14544	7619	6916	5508	5408	5108	5005	4904	4604	4403

TABLE 2.3-4. U.S. DOMESTIC TRAFFIC DISTRIBUTION MATRIX (2 of 3)

US DOMESTIC VOICE TRAFFIC

TRAFFIC MATRIX
EARTH STATION TO EARTH STATION

TOTAL TRAFFIC FOR US IN 2000 IS 100024 CHANNELS.

ES. NAME	NO.	DALLAS 11	ANAHEIM 12	ATLANTA 13	HOUSTON 14	SYRACUSE 15	MIAMI 16	ST_LOUIS 17	RALEIGH 18	TAMPA 19	MINNEAPL 20
NEW_YORK	1	625	555	503	451	417	400	383	366	332	315
LOS_ANGL	2	297	264	239	215	198	190	182	174	158	150
CHICAGO	3	268	238	215	193	178	171	164	156	142	135
SAN_FRAN	4	210	186	169	151	140	134	128	123	111	105
BOSTON	5	206	183	166	148	137	131	126	120	109	103
DETROIT	6	194	172	156	140	129	124	118	113	103	97
WASHINGT	7	190	168	153	137	126	121	116	111	100	95
CINCINNA	8	186	165	149	134	124	119	114	108	98	93
PHILADEL	9	174	154	140	125	116	111	106	101	92	87
CLEVELND	10	166	147	133	120	110	106	101	97	88	83
DALLAS	11	0	123	111	100	92	88	85	81	73	69
ANAHEIM	12	123	0	99	88	82	78	75	72	65	62
ATLANTA	13	111	99	0	80	74	71	68	65	59	56
HOUSTON	14	100	88	80	0	66	64	61	58	53	50
SYRACUSE	15	92	82	74	66	0	59	56	54	49	46
MIAMI	16	88	78	71	64	59	0	54	51	47	44
ST_LOUIS	17	85	75	68	61	56	54	0	49	45	42
RALEIGH	18	81	72	65	58	54	51	49	0	43	40
TAMPA	19	73	65	59	53	49	47	45	43	0	37
MINNEAPL	20	69	62	56	50	46	44	42	40	37	0
SEATTLE	21	66	58	53	47	44	42	40	38	35	33
KANSAS_C	22	62	55	50	45	41	39	38	36	33	31
DENVER	23	58	52	47	42	39	37	35	34	31	29
MILWAUKE	24	43	38	35	31	29	28	26	25	23	22
SAN_ANTO	25	40	35	32	29	26	25	24	23	21	20
PHOENIX	26	36	32	29	26	24	23	22	21	19	18
NEW_ORLE	27	32	29	26	23	21	20	20	19	17	16
SALT_LAK	28	29	25	23	21	19	18	17	17	15	14
TOTAL		3704	3300	3001	2698	2496	2395	2295	2195	1998	1892

TABLE 2.3-4. U.S. DOMESTIC TRAFFIC DISTRIBUTION MATRIX (3 of 3)

US DOMESTIC VOICE TRAFFIC

TRAFFIC MATRIX
EARTH STATION TO EARTH STATION

TOTAL TRAFFIC FOR US IN 2000 IS 100024 CHANNELS.

ES. NAME	NO.	SEATTLE 21	KANSAS_C 22	DENVER 23	MILWAUKE 24	SAN_ANTO 25	PHOENIX 26	NEW_ORLE 27	SALT_LAK 28
NEW_YORK	1	298	281	264	197	181	164	147	131
LOS_ANGL	2	142	133	126	94	86	78	70	62
CHICAGO	3	127	120	113	84	77	70	63	56
SAN_FRAN	4	100	94	88	66	60	55	49	44
BOSTON	5	98	92	87	65	59	54	48	43
DETROIT	6	92	87	82	61	56	51	45	40
WASHINGT	7	90	85	80	60	55	50	44	39
CINCINNA	8	88	83	78	58	53	48	43	39
PHILADEL	9	83	78	73	55	50	45	41	36
CLEVELND	10	79	74	70	52	48	43	39	34
DALLAS	11	66	62	58	43	40	36	32	29
ANAHEIM	12	58	55	52	38	35	32	29	25
ATLANTA	13	53	50	47	35	32	29	26	23
HOUSTON	14	47	45	42	31	29	26	23	21
SYRACUSE	15	44	41	39	29	26	24	21	19
MIAMI	16	42	39	37	28	25	23	20	18
ST_LOUIS	17	40	38	35	26	24	22	20	17
RALEIGH	18	38	36	34	25	23	21	19	17
TAMPA	19	35	33	31	23	21	19	17	15
MINNEAPL	20	33	31	29	22	20	18	16	14
SEATTLE	21	0	29	28	20	19	17	15	13
KANSAS_C	22	29	0	26	19	18	16	14	13
DENVER	23	28	26	0	18	16	15	13	12
MILWAUKE	24	20	19	18	0	12	11	10	9
SAN_ANTO	25	19	18	16	12	0	10	9	8
PHOENIX	26	17	16	15	11	10	0	8	7
NEW_ORLE	27	15	14	13	10	9	8	0	6
SALT_LAK	28	13	13	12	9	8	7	6	0
TOTAL		1794	1692	1593	1191	1092	992	887	790

PRINT TRAFFIC SORT2 $

transponder requirement by SMSA as shown in Table 2.3-5 for the (20% capacity) FSS scenario. It is assumed that 75% of the demand for trunking and CPS is from the 28 largest SMSAs, and 25% of the total demand is from other areas within CONUS.

TABLE 2.3-5. FSS (20%) SCENARIO TRAFFIC REQUIREMENTS

City	Total Trunking Requirements	Total CPS Requirements
New York	40	11
Los Angeles	21	6
Chicago	19	5
San Francisco	15	4
Boston	15	4
Detriot	14	4
Washington	14	4
Cincinnati	14	4
Philadelphia	13	4
Cleveland	12	3
Dallas	10	3
Anaheim	9	3
Atlanta	8	2
Houston	7	2
Syracuse	7	2
Miami	7	2
St. Louis	6	2
Raleigh	6	2
Tampa	5	2
Minneapolis	5	1
Seattle	5	1
Kansas City	5	1
Denver	4	1
Milwaukee	3	1
San Antonio	3	1
Phoenix	3	1
New Orleans	3	1
Salt Lake City	2	1
Others	89	24
Totals	364	102

2.3.3.2 Market Share and Fill Factor

Transponder activity for the fourth quarter of 1984 is summarized in Table 2.3-6, based on the FCC's "Quarterly Transponder Loading Report." Transponder loading is defined as occupancy or usage at the time of observation, usually between 8:00am EST and 10:00pm EST. An "inactive recheck" is done on those transponders observed to be inactive during the original quarterly "spot check", and is usually performed later that same day.

TABLE 2.3-6. TRANSPONDER ACTIVITY STATUS - Q4, 1984

Company	# Satellites			Transponders(1)				Fill(2) Factor (%)		Market Share (%)
				Total		Active				
	C	Ku	C/Ku	C	Ku	C	Ku	C	Ku	
RCA Americom	5	-	-	120	-	88	-	73	-	33
Western Union	4	-	-	72	-	54	-	75	-	20
AT&T/COMSAT	4	-	-	96	-	44	-	46	-	17
Hughes Com.	3	-	-	72	-	33	-	46	-	13
GTE Spacenet	-	-	2	48	24	14	8	29	33	8
SBS	-	4	-	-	48	-	25	-	52	9
Subtotal	16	4	2	408	72	233	33	57	46	100
Grand Total		22		480		266		55		100

Notes:

(1) 36-MHz Equivalent

(2) Ratio of Active to Total

The 22 satellites include 4 launched since the FCC's third-quarter report (1 each for ATT/COMSAT, Hughes, GTE, and SBS). The launches appear to have little impact on the companies' fill factor which changed only slightly from the previous quarter. The fill factor is the ratio of transponders in use to transponders available. The industry's average fill factor for C-band has remained at 57 ± 1% for the past 8 quarters. RCA and Western Union together capture 53% of the market, and each operates at a fill factor of about 75%. The other four operators each have a smaller market share and have fill factors less than 50%. The satellite communications industry is relatively young, growing rapidly, and experiencing excess capacity. The industry will mature by 1998, growth will slow, and fill factors are likely to be higher. The FSS platform scenario assumes the market leader's fill factor will be 90% just before launch of a replacement platform. The capacity added at launch reduces the fill factor to 78%. The leader's average fill factor over several years will therefore be about 84%.

The satellite communications market leader today has a one-third market share. Typically the market leader increases his market share as a market matures. This has been true for the automobile, computer, etc. markets. It is likely to be true for the satellite communications market as well. It is assumed the market leader will have a 50% market share by 1998.

2.3.3.3 Orbital Slot Requirements

RCA currently occupies five orbital slots. The FCC has authorized an additional expansion location in C-band and three locations for Ku-band satellites (two of which will be collocated with C-band satellites). Assuming a future reassignment to collocate the third Ku-band satellite, RCA will be authorized six orbital slots. With only three C-band orbital slots remaining unassigned, and ten operators authorized to date and many more applicants expected to file, it is unlikely that RCA will be able to expand beyond six slots. It appears that none of the other operators are likely to be authorized beyond six slots; therefore, the FSS scenarios assume the market leader operates from six slots.

2.3.3.4 Terrestrial System Plant-In-Place

The FSS scenarios assume an evolutionary transition from satellites to platforms with little or no impact on the terrestrial plant-in-place. This section summarizes the projected 1998 terrestrial system plant-in-place that is associated with the total satellite addressable market. Table 2.3-7 summarizes the transmit/receive earth stations. Table 2.3-8 provides the characteristics of the receive only (RO) earth stations.

TABLE 2.3-7. DOMESTIC FSS TRANSMIT/RECEIVE EARTH STATIONS (1998)

Category	Frequency Band	Size (meter)	Quantity
Shared Use			
• Common Carrier	C/Ku/Ka	7 - 15	275
• Voice/Data Resellers	C/Ku	5 - 11	200
• Video Resellers	C/Ku	9 - 11	150
Total Shared Use			625
Dedicated Use			
• Carrier Owned	C	7 - 15	65,000
	Ku/Ka	2 - 5	150,000
• Reseller Owned	Ku/Ka	2 - 5	500
• Privately Owned	C	7 - 15	300
	Ku/Ka	2 - 5	5,000
Total Dedicated Use			220,800
TOTAL TRANSMIT/RECEIVE			221,425

The terrestrial plant-in-place forecasting methodology utilized the existing installed earth station base where appropriate, and considered market demand and growth potential by market segment. The impact of technology development was taken into consideration. Data sources included:

- Existing installed base
- FCC license applications
- Industry journal publications/directories
- FCC applications for new satellites/slots
- Market research studies

TABLE 2.3-8. DOMESTIC FSS RECEIVE ONLY EARTH STATIONS (1998)

Category	Frequency Band	Size (meter)	Quantity
Commercial TVRO			
• Broadcast TV	C Ku	8 - 10 5 - 7	1,800
• Cable TV	C Ku	3 - 5 2 - 4	11,000
• SMATV	C Ku	3 - 5 2 - 4	2,500
• MDS	C Ku	3 - 5 2 - 4	50
• LPTV	C Ku	3 - 5 2 - 4	4,000
• STV	C Ku	3 - 5 2 - 4	50
• Videoconferencing	Ku	2	3,500
Total Commercial TVRO			22,900
Audio	C/Ku	2 - 5	8,000
Backyard			
• Commercial	C/Ku	2 - 5	100,000
• Private	C	1 - 3	600,000
Total Backyard			700,000
TOTAL RECEIVE ONLY			730,900

2.4 FSS (13% CAPACITY)

The conditions and assumptions for Scenario 3, designated as FSS (13% capacity), are the same as for the 20% capacity platform scenarios described in Section 2.3 except that the platform provides video distribution as well as trunking and CPS communications. The market leader uses all six of his spacecraft for these services instead of dedicating two locations to video distribution and the remaining four to trunking and CPS. This reduces his trunking/CPS platform capacity requirements (Table 2.4-1) from 466 transponders to 303 transponders. The platform also provides 10 CONUS transponders for video distribution. Each of the market leader's other 5 spacecraft also provide 10

TABLE 2.4-1. FSS (13% capacity) SCENARIO TRAFFIC REQUIREMENTS

City	Total Trunking Requirements	Total CPS Requirements
New York	26.1	7.3
Los Angeles	13.7	3.9
Chicago	12.4	3.5
San Francisco	9.9	2.7
Boston	9.6	2.6
Detriot	9.0	2.5
Washington	9.0	2.5
Cincinnati	8.8	2.5
Philadelphia	8.2	2.3
Cleveland	7.9	2.2
Dallas	6.5	1.8
Anaheim	5.9	1.7
Atlanta	5.3	1.4
Houston	4.7	1.4
Syracuse	4.4	1.3
Miami	4.3	1.2
St. Louis	4.0	1.0
Raleigh	3.8	1.0
Tampa	3.5	1.0
Minneapolis	3.3	0.9
Seattle	3.3	0.9
Kansas City	2.9	0.8
Denver	2.8	0.8
Milwaukee	2.0	0.7
San Antonio	1.9	0.5
Phoenix	1.7	0.5
New Orleans	1.7	0.5
Salt Lake City	1.2	0.3
Others	59.3	16.6
Totals	237.1	66.3

transponders for video distribution, for a total distribution capacity of 60 transponders to service 50% of the market demand (92 transponders). The excess system capacity of 14 transponders provides spares for protection against catastrophic loss. The platform video distribution is via C-band. It did not appear practical to split the 10-transponder capacity over C- and Ku-bands. Some system capacity could be provided at Ku-band on the other spacecraft if required. In the fourth quarter of 1984, there were 115 C-band and 5 Ku-band transponders providing TV communications. Since video distribution today is predominantly C-band, C-band rather than Ku-band was selected for video distribution on the platform.

2.5 FSS/ISL/TDAS SCENARIO

The FSS/ISL/TDAS scenario combines the FSS (20% capacity) payload with an Intersatellite Link (ISL) payload and a Trunking and Data Acquisition System

(TDAS) payload. The ISL payload provides connectivity between the platform and international satellites serving Europe/Africa and the Far East/Pacific regions. Additional transponders on the FSS payload provide connectivity between CONUS and the platform for the international traffic. The TDAS payload is independent of the FSS and ISL payloads, but shares the FSS Ka-band and Ku-band antenna reflectors.

2.5.1 ISL PAYLOAD

The year 2000 traffic forecast for America to Europe/Africa and the Far East/ Pacific is summarized in Table 2.5-1. The platform would carry 100% of the point-to-point communications traffic which totals 66 36-MHz equivalent transponder channels. Half the number of channels are for transmission via ISL to CONUS, and half are for transmission from CONUS via ISL. Thus the ISL payload has a cross-link capacity of 33 36-MHz equivalent channels and the FSS payload capacity is increased by 33 36-MHz equivalent channels. It is assumed that the ISL traffic is distributed among the various cities and "other" destinations in proportion to the requirements established in the FSS traffic model. It is also assumed that the ISL IBS traffic is distributed as CPS traffic in CONUS. The ISL can operate as an optical link or at W-band (60 GHz).

2.5.2 TDAS PAYLOAD

The TDAS scenario is shown in Figure 2.5-1 and is based on Stanford Telecommunications TDAS architectural study (reference 12). TDAS provides connectivity between user spacecraft and five user sites in CONUS. The link to White Sands is via Ku-band and is compatible with the current Tracking and Data Relay Satellite System (TDRSS). The four remaining sites represent an expanded user capability provided by TDAS and are linked to the platform with Ka-band. Weather conditions at the Houston site will probably require site diversity to counter rain fade. Links to the user satellites are via S-, Ku-, or W-band. The FSS/ISL/ TDAS platform would be located over CONUS. Global coverage is provided by a second TDAS satellite over the Eastern Hemisphere. The TDAS architectural study specifies orbital locations of 96°E and 100°W. The TDAS-TDAS crosslinks are via optical or W-band.

The link bandwidth allocations and typical data rates are summarized in Table 2.5-2. The TDAS payload provides multiple and single access services as summarized in Table 2.5-3.

TABLE 2.5-1 TRAFFIC FORECAST SUMMARY - YEAR 2000-AMERICA TO EUROPE/AFRICA AND THE FAR EAST/PACIFIC

Service	BW Efficiency	To Europe/Africa		To Far East	
		Traffic	Transponders (36-MHz)	Traffic	Transponders (36-MHz)
Trucking • Voice • Data	 120 Channels/MHz 2.25 Mbits/MHz	 158 x 10^3 Channels 84 Mbps	 37 1	 40 x 10^3 Channels 22 Mbps	 10 1
IBS* • Voice • Data • Videoconf	0.5 Mbits/MHz	219 Mbps	13	62 Mbps	4
Total Point-to-Point			51		15
Broadcast Video Distribution	0.069 Channel/MHz	18 Channels	8	30 Channels	12
TOTAL			59		27

*Intelsat Business Services

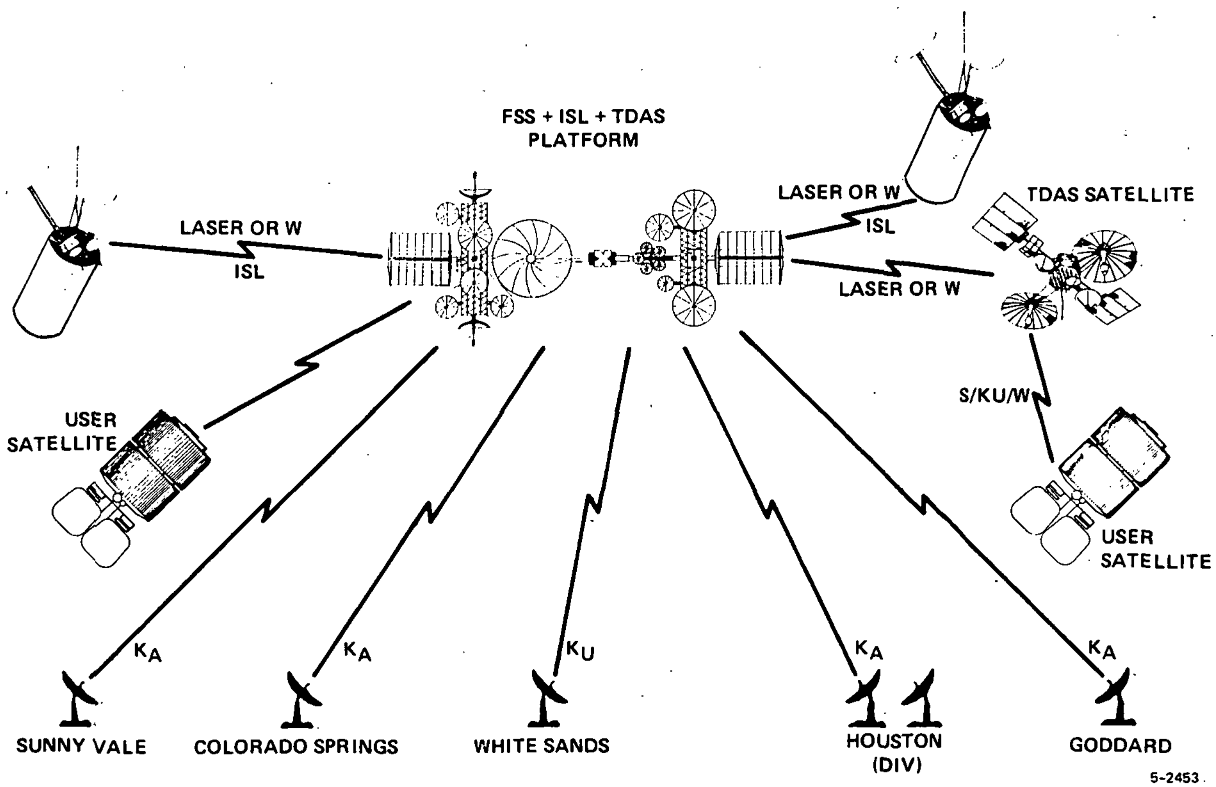


Figure 2.5-1. FSS (20% capacity)/ISL/TDAS Architecture

TABLE 2.5-2. TDAS LINK BANDWIDTH ALLOCATION AND TYPICAL DATA RATES

Link	Access	Band	Frequency Span (GHz)	Bandwidth (MHz)	Data Rates
TDAS To User (Forward)	MA	S	2.104 - 2.109	5	≤ 50 kbps
	SA	S S Ku W	2.020 - 2.104 2.109 - 2.120 13.75 - 13.80 54.25 - 58.20	84 11 50 3950	≤ 300 kbps ≤ 300 kbps ≥ 300 kbps ≤ 1 Gbps
User To TDAS (Return	MA	S	2.285 - 2.290	5	≤ 50 kbps
	SA	S S Ku W	2.200 - 2.285 2.29 - 2.30 14.89 - 15.11 54.25 - 58.20	85 10 220 3950	≤ 300 kbps ≤ 300 kbps ≥ 300 kbps ≤ 1 Gbps
TDAS To GT (Return)	White Sands	Ku Ku	13.40 - 13.73 13.82 - 14.05	330 230	> 300 kbps > 300 kbps
	Other GT	Ka	17.7 - 21.2	3500	< 50 Mbps
GT To TDAS (Forward)	White Sands	Ku Ku	14.5 - 14.83 15.15 - 15.23	330 80	> 300 kbps > 300 kbps
	Other GT	Ka	27.5 - 31.0	3500	< 50 Mbps
TDAS To TDAS (Forward)	NA	W	59.64	5000	25 Mbps
TDAS To TDAS (Return)	NA	W	59.64	5000	1.8 Gbps

MA - Multiple Access
S - Single Access

TABLE 2.5-3. TDAS MULTIPLE ACCESS (MA) AND SINGLE ACCESS (SA) SERVICES

- TDAS/TDRSS Compatibility Assumed

- Multiple Access - Forward
  - One user at a time, time shared
  - Discrimination - PN Code
    - Phased Array Pointing

- Multiple Access - Return
  - 10 users accepted simultaneously
    Discrimination - PN code
    - Phased Array Pointing

<u>Single Access - Forward</u>

- <u>Links</u>
  - 1 Link at S or Ku Band
  - 5 Links at W Band
  - 1 Laser Link

- <u>S-Band (Multi-Users)</u>
  - Users at different frequencies and time shared
  - Discrimination at user terminal by frequency, polarization, PN Codes, TDAS Antenna Beam Pointing

- <u>Ku-Band (Multi-Users)</u>
  - Users in same band and time shared
  - GT discrimination by TDAS polarization, PN Codes and TDAS Antenna Beam Pointing

- <u>W Band And Lasers (5 Users)</u>
  - Same approach as Ku-Band above

<u>Single Access - Return</u>

- <u>Links</u>
  - 1 at S or Ku per each 4.0 Meter Antenna
  - 5 at W Band with 1 Meter Dish
  - 1 Laser Link

- <u>S-Band</u>
  - Time shared basis for users
  - TDAS Discrimination by frequency, TDAS beam pointing and polarization
  - GT discrimination by user PN codes

- <u>Ku-Band</u>
  - Same frequency band, served on time-shared basis
  - TDAS discrimination by TDAS beam pointing and polarization
  - GT discrimination by user PN codes

- <u>W Band and Laser</u>
  - Presumably handled as per Ku band above

SECTION 3.0
PAYLOAD CONCEPTS AND DEFINITIONS

SECTION 3.0
PAYLOAD CONCEPTS AND DEFINITIONS

Payload concepts were defined for the following four selected scenarios and described in this Section:

- Land Mobile Satellite Service
- Fixed Satellite Service (capacity 20% of demand)
- Fixed Satellite Service (capacity 13% of demand)
- Fixed Satellite Service (capacity 20% of demand) + Intersatellite Links + TDRSS/TDAS

Payload concept definition was accomplished over two tasks: Task 3 Payload Concept Development and Task 4 Payload Definition. Task 3 resulted in concepts defined to the subsystem block diagram level along with communications architecture descriptions and terrestrial system characteristics required for each payload concept. Payload system configurations and corresponding technical characteristics were developed in Task 4 to the component block diagram level. Payload requirements on the spacecraft were also defined. Task 3 and Task 4 guidelines and constraints provided by NASA are described in Section 2.0, Communications Service Aggregation Scenarios, since they were considered from the very start of the study. The relative advantages and disadvantages of each concept are presented in Section 6.0, System Comparisons.

3.1 CONCEPT 1 - LAND MOBILE SAELLITE SERVICE (LMSS)

3.1.1 LMSS PAYLOAD REQUIREMENTS

The LMSS Payload requirements were derived by iterating concepts developed in the initial phases of the study. The LMSS Platform payload was designed to comply with the final system requirements as defined by NASA/LeRC, and which are described below.

3.1.1.1 Frequency Allocations

The voice mobile LMSS payload design assumes that the FCC will allocate a pair of 4-MHz bands, one for the uplink and one for the downlink in the UHF spectrum currently dedicated to cellular radio. Both of these frequency bands are assumed to be available for CONUS and Canadian coverage. The digital paging and dispatch payload assumes a pair of 6-MHz bands, one for the downlink and one for the uplink, in the L-band spectrum allocated for digital services. Similarly, both of these frequency bands are assumed to be available for CONUS and Canadian coverage.

A pair of 50-MHz Ku-bands will be provided for the backhaul uplink and downlink to the Gateways. The 50-MHz bandwidth provides a 27-MHz band for mobile CONUS, a 5.1-MHz band for mobile Canada, a 5.6-MHz band for digital data CONUS, and a 1-MHz band for digital data Canada. Additional bandwidth is provided for guard bands and frequency reuse.

The details of the assumed frequency allocations are given in Table 3.1-1.

It should be noted that the FCC has not made any land mobile frequency allocations to date. The 4-MHz pair of bands at uhf are currently allocated as "reserve" bands. The 6-MHz pair of L-bands are currently part of the spectrum set aside for Aeronautical Mobile by the 1979 World Administrative Radar Conference (WARC).

3.1.1.2 Capacity Requirement

The LMSS platform capacity is designed to meet 100% of the projected year 2008 demand which is expected at the platform EOL.

3.1.1.3 Single Platform Coverage

The voice mobile radio telephone market defined in Section 2.1 can be covered by a 4-frequency-reuse scheme which covers CONUS with 27 uhf beams and Canada with 13 uhf beams of 0.8° beamwidth, each spanning 1 MHz of the 4-MHz uhf band. The paging and dispatch digital data service market can be covered by a 4-frequency-reuse scheme which covers CONUS with 35 L-band beams and Canada with 17 L-band beams of 0.7° beamwidth, each spanning 1.5 MHz of the 6-MHz L-band.

At uhf frequencies, the 0.8° beamwidth can be achieved using a 30-meter diameter antenna, and at L-band frequencies the 0.7° beamwidth can be achieved using a 20-meter diameter antenna. The 20-meter and 30-meter antenna diameter requirements can be satisfied using one dish with a 20-meter L-band reflective screen superimposed on a 30-meter uhf reflective screen.

The backhaul link to the gateway terminals is satisfied using one Ku-band horn for CONUS and Canadian coverage.

TABLE 3.1-1. LMSS FREQUENCY ALLOCATION

Service	Band	Bandwidth (MHz)	Center Frequency (MHz)	
			Uplink	Downlink
Voice	UHF	4	823	868
Digital	L	6	1556	1657
Gateway (Total)	Ku	50	13200	11650
• CONUS Voice		27		
• Canada Voice		5.1		
• CONUS Digital		5.6		
• Canada Digital		1		
• Guard Bands		11.3		

3.1.1.4 Modulation Schemes

The standard FSK modulation implemented in cellular radio requires 30-kHz bandwidth channels. More efficient use of the 4-MHz band allocated to LMSS by the FCC is required to satisfy the projected traffic demand.

A number of modulation techniques that use the allocated spectrum more efficiently have been proposed in the literature. A number of modulation techniques requiring less than 30-kHz bandwidth have been proposed, each of which will in some degree be incompatible with cellular radio. The first generation Mobilesat design has been constrained to be compatible with cellular radio or to require a conversion kit to adapt the LMSS modulation to the cellular format. The third-generation LMSS Platform is not so constrained and uses amplitude commanded single sideband (ACSSB) with 7-kHz channel spacing and 3-kHz i.f. bandwidth.

The digital data paging and dispatch service will use FSK modulation with 10-kHz channel spacing. A 4.8-kbps coding rate using (32, 21) error correction coding will be used resulting in an information rate of approximately 3 kbps. This coding scheme will yield a 10^{-4} bit error rate for 10-dB Rician fading. The LMSS modulation schemes are summarized as follows:

- Voice Service (Mobile Radio Telephone at uhf)

  ACSSB with 7-kHz channel spacing and 3-kHz i.f. bandwidth

- Digital Data Service (at L-band)

  FSK with 10-kHz channel spacing

  - 4.8 kbps (32, 21) Coding
  - 10^{-4} BER for 10-dB Rician Fading
  - Noncoherent Detection
  - Information Rate Approximately 3 kbps

3.1.1.5 Link Parameters

A number of detailed link analyses have been calculated for the first- and second-generation Mobilesat. The third-generation analyses relax the link requirements on the mobile units and increase the requirements on the Platform payload as summarized in Table 3.1-2. The voice mobile unit antenna is assumed to provide 9 dBic and the mobile receiver will operate with a noise temperature of 575°K and a G/T of -20 dB/°K. The digital data unit antenna is assumed to provide 4 dBic and the receiver will operate with a noise temperature of 1000°K and a G/T of -26 dB/°K.

The requirements on the communications link are an EIRP per channel of 37 dBW for mobile voice units at uhf. For digital data units and EIRP per channel of 38.6 dBW will cover 50% of the users 50% of the time and an EIRP per channel of 46.3 dBW will cover 90% of the users 90% of the time.

TABLE 3.1-2. LINK PARAMETERS

Link Parameters	Requirements
Mobile Units	
• UHF Antenna	• 9 dBic/T approximately 575°K • G/T approximately -20 dB/K°
• L-Band Antenna	• 4 dBic/T approximately 1000°K • G/T approximately -26 dB/K°
Communications	
• Voice at UHF	• EIRP/Channel approximately 37 dBW
• Digital Data at L-Band	• EIRP/Channel approximately 38.6 dBW (50/50 coverage), approximately 46.3 dBW (90/90 coverage)

3.1.1.6 Digital Data Transponder Requirements

The digital data transponder requirements are summarized in Table 3.1-3. The traffic requirement for CONUS of 1 x 10^6 users having an average message length of 500 characters can be supported with 556 channels. This requirement can be supported by a coverage pattern of 35 beams with 16 channels per beam. The power requirement of 2 watts per channel results in a requirement of 32 watts per beam for the transponders and a 1,120-watt requirement on the payload for CONUS coverage.

The traffic requirement for Canadian coverage of 100,000 users having an average message length of 500 characters can be supported with 90 channels. This requirement can be supported by a coverage pattern of 17 beams with 6 channels per beam. The power requirement of 2 watts per channel results in a requirement of 12 watts per beam for the transponder and a 204-watt requirement on the payload for Canadian coverage.

3.1.1.7 Mobile Radio Telephone Transponder Requirements

The uhf voice transponder requirements are summarized in Table 3.1-4. The voice channel bandwidth of 7-kHz provides 140 channels per 1-MHz beam, each of which uses 1 frequency subset out of the 4 available within the allocated 4-MHz uhf band. The 27 beams will support the CONUS traffic requirement of 180,000 users at 0.026 erlangs per user for a 20% blockage probability during the peak busy hour. The power requirement of 0.5 watt per channel results in a requirement of 70 watts per beam for the transponder and a 1900-watt requirement on the payload for CONUS coverage.

Canadian coverage requires only 56 channels per beam to support the traffic requirement of 20,000 users at 0.026 erlang per user for a 2% blockage probability. The Canadian power requirement of 1.0 watt per channel results in a requirement of 56 watts per beam for the transponder and a 728-watt requirement on the payload.

TABLE 3.1-3. DIGITAL DATA (L-BAND) TRANSPONDER REQUIREMENTS

Parameter	Requirements
<u>CONUS</u>	
• CONUS Coverage	• 16 channels/beam • 556 total channels support 1 x 10^6 users having an average message length of 500 characters
• CONUS RF Power	• RF/beam = 32 watts • Total RF power = 1,120 watts
<u>Canadian</u>	
• Canadian Coverage	• 6 Channels/beam • 90 Total Channels Supports 1 x 10^5 users having an average message length of 500 characters
• Canadian RF Power	• RF/beam = 12 watts • Total RF power = 204 watts

TABLE 3.1-4. LMSS MOBILE RADIO TELEPHONE (UHF) TRANSPONDER REQUIREMENTS

Parameter	Requirements
<u>CONUS</u>	
• CONUS Coverage	• 140 channels/Beam • 0.026 erlangs per user • Supports 180,000 users allowing blockage probability to expand to 20 percent during peak busy hour
• CONUS RF Power	• RF power/beam = 70 watts • Total RF power = 1900 watts
<u>Canadian</u>	
• Canadian Coverage	• 56 channels/beam • 0.026 erlangs per user • Supports 20,000 users to probability of blockage of 2 percent
• Canadian RF Power	• RF power/beam = 56 watts • Total RF power = 728 watts
Note: 4 Frequency subsets within the 4-MHz UHF band	

3.1.2 PAYLOAD DESIGN

The LMSS payload concept was designed based on the traffic model and transponder requirements developed in the initial phase of the study. A conceptual design for the LMSS service was developed by JPL for NASA and was adapted for the second-generation Mobilesat by RCA under contract to NASA. These studies formed the basis for the conceptual block diagram and design sketches described below.

A receiver/frequency translator channel is provided for each uhf and L-band beam. The uhf receiver channels are combined and fed to one Ku-band upconverter, and the L-band receiver channels are combined and fed to the other Ku-band upconverter. The voice and digital data are received from the gateway at assigned subbands in the 50-MHz Ku-band.

The voice and digital data subbands are demultiplexed, the voice subband feeds the uhf transmit stages and the digital data subband feeds the L-band transmit stages. The uhf transmit stages are fed from one input which is routed to the addressed transmit beam by the uhf power divider. CONUS coverage is provided by 27 of the uhf channels and Canadian coverage is provided by 13 of the uhf channels. Similarly, the L-band transmit stages are fed from one input which is routed to the addressed transmit beam by the L-band power driver. CONUS coverage is provided by 35 of the L-band channels and Canadian coverage is provided by 17 of the L-band channels.

3.1.2.1 Payload Block Diagram

The LMSS concept block diagram shown in Figure 3.1-1 consists of transponder sections at K-band, L-band and uhf frequencies. Each section consists of transmit and receive stages isolated by diplexers. In each case the transmitter and receiver use the same antenna.

The Ku-band stage consists of one high-power output stage and one low-noise amplifier input stage isolated by a Ku-band diplexer. The Ku-band high-power stage is fed by two multiplexed low-power stages, one upconverted from the output of the uhf receiver stage and one upconverted from the output of the L-band receiver stage.

Each of the 40 input uhf voice channels is fed into a uhf beam forming network (BFN) which routes the signal to four uhf feed arrays. The signal is apportioned in phase among the four feed arrays to form a beam directed at the coverage area with suppressed sidelobe levels optimized at the crossover points between adjacent beams. The feed arrays are shared among adjacent beams and the total number of feed arrays is 61, which is greater than the number of beams and corresponding input channels. The preamplifiers and high-power amplifiers are between the BFN and the feed arrays to minimize the power dissipated due to losses in the BFN.

Similarly, each of the 52 input L-band digital data channels is fed into an L-band BFN which routes the signal to four L-band feed arrays. Again, the signal is apportioned among shared L-band feed arrays to form noninterferring beams using 77 preamplifiers, high-power amplifiers, and feed arrays.

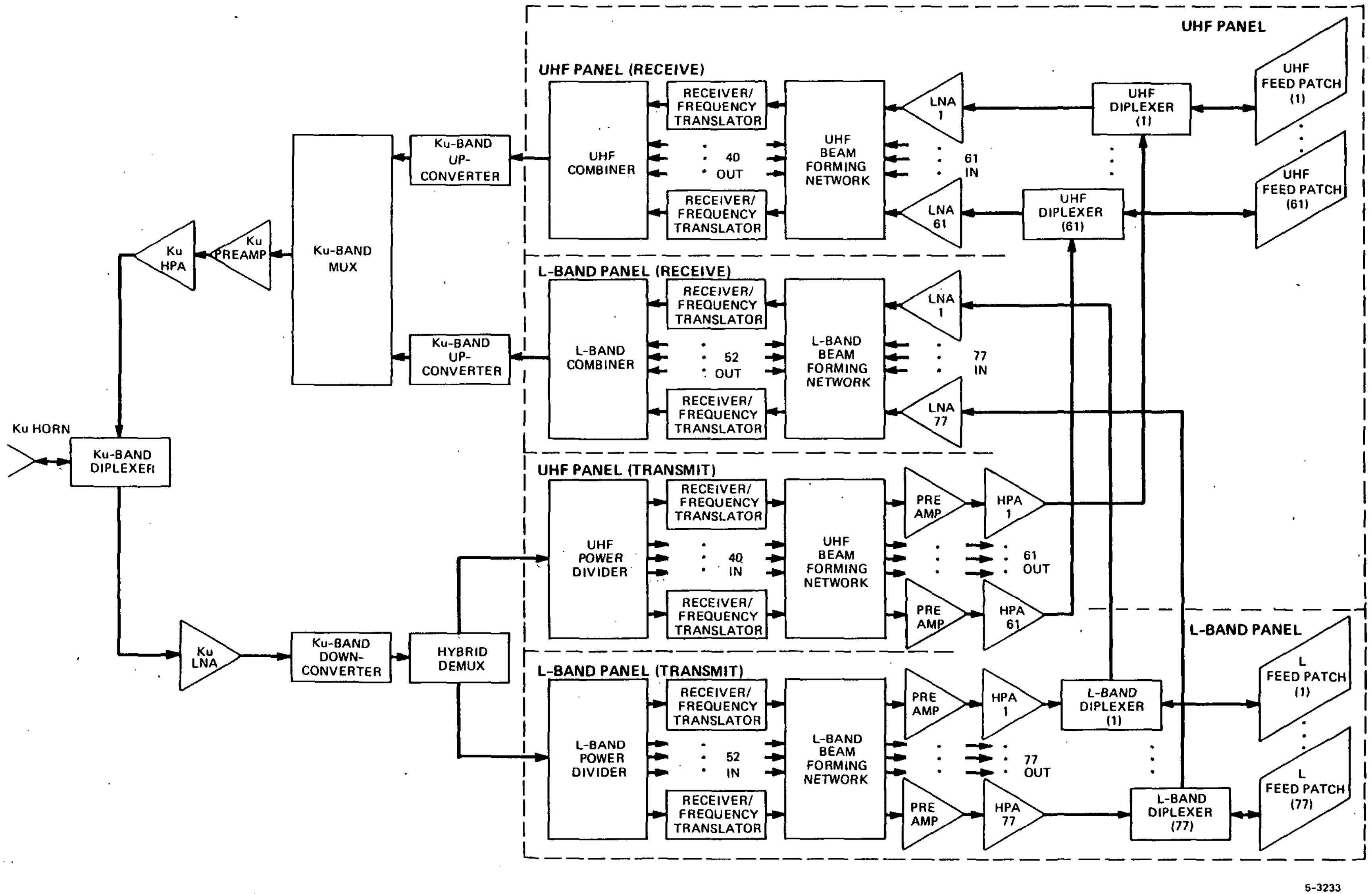


Figure 3.1-1. LMSS Concept Block Diagram

The uhf and L-band receive channels follow paths similar to the transmit channels which are isolated by diplexers at the feed arrays. Each of the 61 uhf feed arrays is amplified and connected to the uhf beam forming network. The 61 uhf input channels are combined by the BFN to form 40 uhf receive antenna beams corresponding to the 40 uhf transmit antenna beams.

Similarly, each of the 77 L-band feed arrays is amplified and connected to the L-band BFN. The 77 L-band input channels are combined by the BFN to form 52 L-band receive antenna beams corresponding to the 40 L-band transmit antenna beams.

The uhf receive and transmit channel components are mounted within the uhf feed panel structure. The L-band receive and transmit channel components are similarly mounted within a separate L-band feed panel structure. As shown in Figure 3.1-1, the uhf and L-band components within the dashed line are to be mounted within the uhf and L-band feed panels, respectively. The feed panels are mounted on the antenna boom remotely from the Platform bus. The Ku-band components are mounted on the Platform bus. This design minimizes the number of connections between the bus and feed panels and minimizes the power dissipation loss by interconnecting the signals at low-power i.f.

3.1.2.2 Payload Configuration

RCA has developed a spacecraft configuration for the second-generation Mobilesat as shown in Figure 3.1-2. The concepts were applied to the third-generation Mobilesat Platform to indicate the requirements and design considerations which the payload concept imposes on the Platform bus.

3.1.2.2.1 Deployed Payload

The deployed platform consists of the offset antenna, supporting mast, feed panels, boom, frequency selective screen, platform bus, and attached solar panels. The antenna dish, feed panels, and supporting structures dominate the platform design because of the large dimensions required to generate the beam pattern at uhf and L-band frequencies.

Solar torque and gravity gradient forces can deflect the platform and distort the CONUS and Canadian beam-coverage patterns. These forces are at a maximum if the platform bus is located at the base of the antenna dish or at the feed panel. These forces are minimized if the platform bus is located at the junction of the antenna mast and feed panel boom. Other locations along the mast or boom may prove to be desirable for ease of deployment and possess acceptable solar and gravity gradient torques.

3.1.2.2.2 Stowed Payload

The conceptual configuration of the stowed platform consists of the apogee kick motor, a mounting cradle for the Space Shuttle, the bus, collapsed solar panels, the furled wrap rib antenna hub, stowed feed panels, canisters containing the boom and mast segments, and support structures. The concept shown in Figure 3.1-3, which is for the second-generation Mobilesat, is designed for dynamic balance, for thrust load strength and dimensional conformance with the Space Shuttle envelope.

The feed panels for the third-generation Mobilesat are too large to fit within the Space Shuttle envelope without folding. Also, the addition of the second feed panel and frequency selective screen requires the boom to be divided into sections. The additional number of canisters from which the platform boom and mast are deployed and the large folded feed panels and frequency selective screen require careful dimensional and balancing analysis.

3.1.2.2.3 Payload Servicing Considerations

The deployment of the Mobilesat Platform will be a complex process because of the large physical sizes of the structural components imposed by the uhf and L-band frequencies. Further, the complexity of the deployment may result in misalignment of the antenna feed or more catastrophic structural failures. The use of large deployable antennas is a new technology which has not as yet been put to commercial use. Failure of the antenna to deploy properly could result in degradation of performance or loss of the Mobilesat mission.

Deployment of the Platform at low earth orbit (LEO) was investigated as a servicing concept to reduce deployment risk, to simplify support structures, and to ease design compatibility with the Space Shuttle envelope. The concept utilizes EVA or automation and robotics or both to assist LEO deployment. Following deployment in LEO, measurements will verify antenna radiation patterns and payload performance.

Deployment at LEO requires a number of design modifications and prerequisites as summarized below:

- Availability of low-thrust booster
- Strengthening of platform structure to withstanding low-thrust (0.1g) Acceleration
- Redesign to direct line of thrust through deployed Platform c.g.
- Augmented attitude control subsystem to prevent tumbling during boost
- Use of automation and robotics to assist LEO deployment
- Equipment checkout at LEO

The availability of a low-thrust orbital transfer vehicle is required to transport the deployed platform from low earth orbit to geostationary orbit. The concept of LEO to GEO transport requires strengthening of platform structures to withstand low thrust (0.1 g) acceleration and redesign of the platform configuration to direct the line of thrust through the deployed c.g. instead of through the stowed c.g. An augmented attitude control system is required to prevent the deployed platform from tumbling during the low thrust boost. The usual method of stabilizing the spacecraft by spinning is not appropriate to the deployed configuration.

The design of the antenna dish and supporting boom and mast structures provides for automatic deployment. Elaborate mechanisms for automatically extending and locking collapsed structural members are implicit in the design. The wrap rib

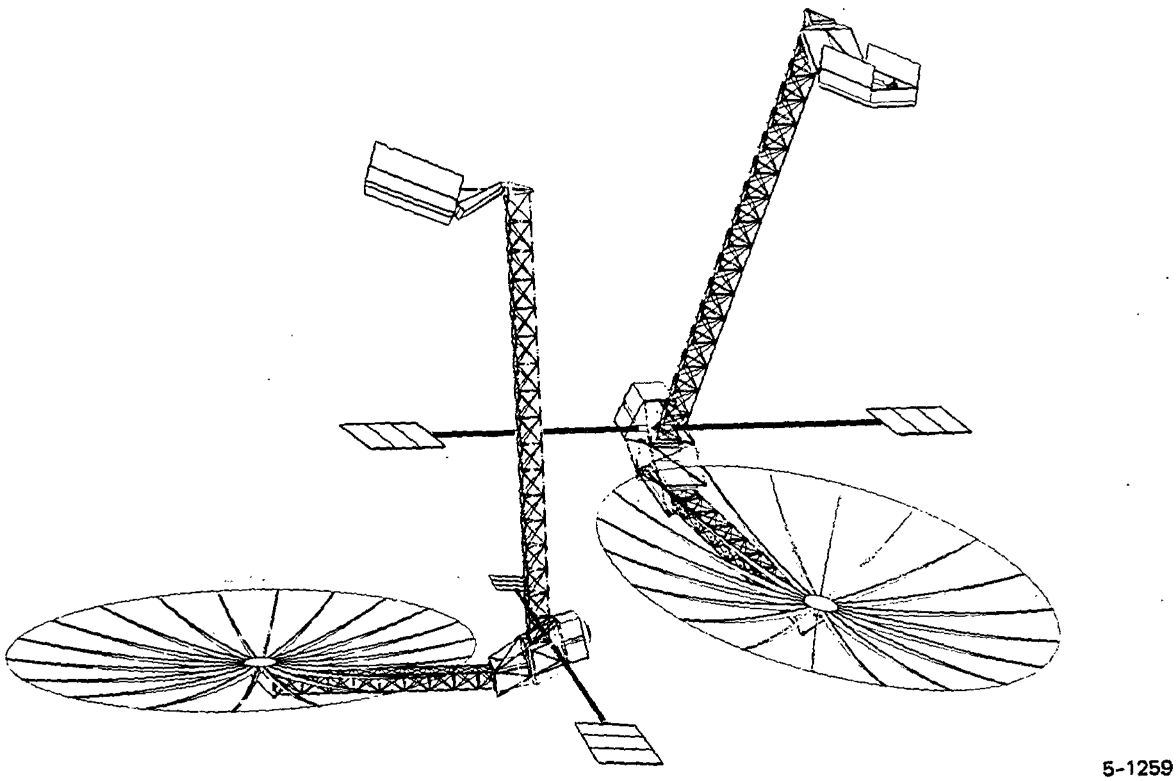


Figure 3.1-2. Second-Generation LMSS Mission Configuration

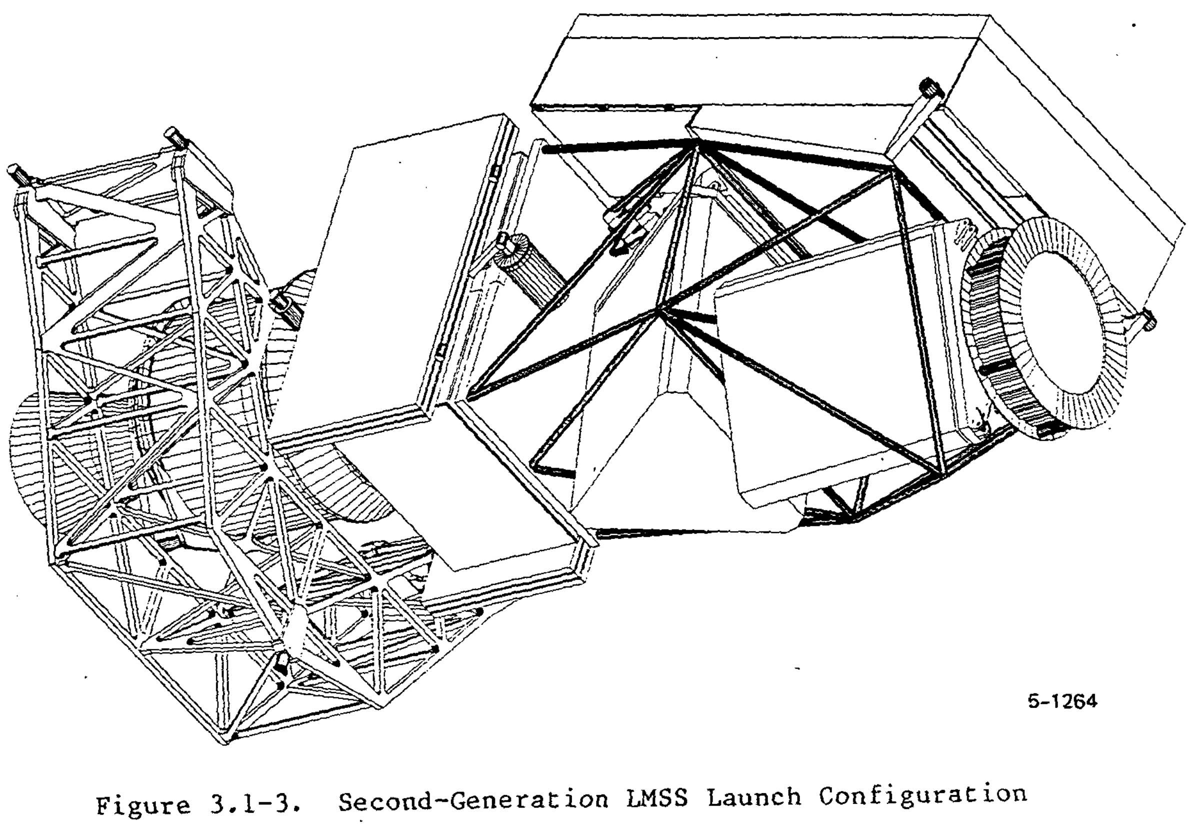


Figure 3.1-3. Second-Generation LMSS Launch Configuration

antenna is deployed by rotating a circular hub around which individual members are wrapped. The design and reliability of these structures may be simplified if EVA assistance is provided for their deployment.

Servicing concepts are being studied and are under development to extend the life of spacecraft. In general, these concepts require modular design of the spacecraft, servicer vehicles to transport modules, and automation and robotics mechanisms to assist in assembly and replacement. These servicing concepts are extendible to assist in deployment of the LMSS payload at LEO or GEO.

As designs for large aggregated platforms mature, the complexity of equipment suggests that assigned deployment may be necessary not only to simplify design, but also to checkout test and verify equipment operation. The servicing concept provides for modular replacement of components which fail in infancy as well as replacement of components at EOL.

Currently, spacecraft are designed with a unitized payload and bus structure as indicated below:

- Single-Unit Design

  - Requirement to fit within Space Shuttle envelope
  - Requirement to withstanding OTV thrust structurally, and to direct line of thrust through spacecraft c.g.

- Multiple-Unit Design

  - Separate packages, each of which must fit within Space Shuttle envelope
  - Possible EVA for assembly (snap-fit) of units at LEO
  - Possible use of automation and robotics for assembly of units at LEO

Components are permanently mounted to the structure, and ease of replacement is not a design constraint. The unitized spacecraft is designed to structurally withstand orbital transfer thrust and to direct the line of thrust through the spacecraft c.g. in a stowed configuration. The entire stowed configuration of payload, bus, and orbital transfer motor is required to fit within the Space Shuttle envelope.

The servicing concepts which are based on modular design relax these constraints. Since the platform would be designed with modular packaging of components, the modules can be stowed as separate packages within the Space Shuttle envelope. The same servicer mechanism used to replace failed modules would be equally useful for assembling modules on the platform bus. Modules may be designed for EVA assembly using techniques such as snap-fit which would not require dexterity manipulation or methodologies not available in an EVA environment.

3.1.2.2.4 Deployed Configuration Trade-off

A number of candidate configurations were analyzed for the second-generation Mobilesat study to optimize the deployed spacecraft. The experience gained and the optimization criteria used in the second-generation study are directly applicable to the Mobilesat Platform.

The payload deployed design considerations are as follows:

- Structural integrity of deployed antenna, boom, mast, feed array panels, and FSS
- Controlled gravity-gradient and solar torques
- Thermal control of payload
- Solar power panel optimization
- Attitude Control of Platform
- Alignment of parabola, feed panels, and frequency selective screen

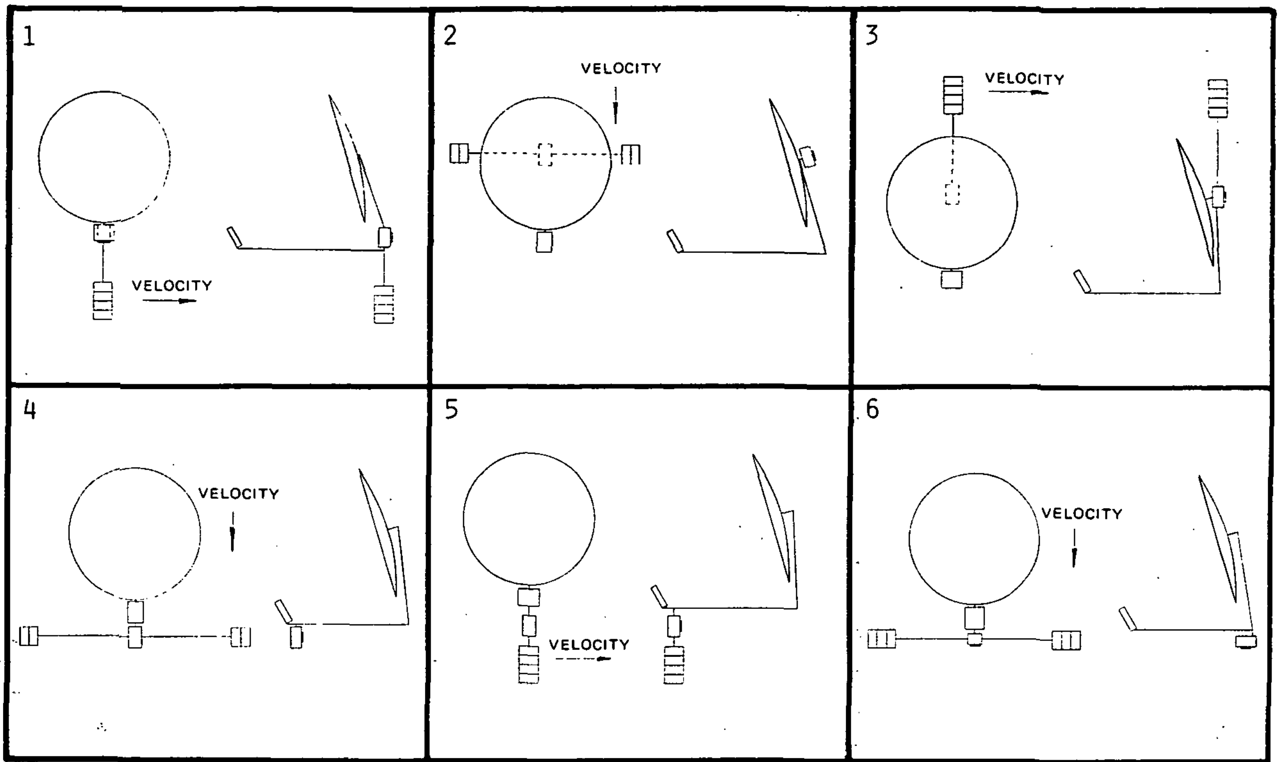
The mechanical design was first based on a requirement to ensure the structural integrity of the deployed antenna, boom, mast, feed array panels, and frequency selective screen.. The platform design must be physically realizable, using existing materials and techniques; the development techniques were based on existing technologies or development technology documented in the literature.

Locating the platform bus on the boom or mast creates gravity-gradient torques which impact the attitude control system of the platform. Platform configurations in which the gravity-gradient torques are at a maximum are undesirable. Since the solar power panels are deployed from the spacecraft bus, the orientation of the solar panels contributes to the total gravity-gradient torque along with the spacecraft bus. Locating the platform bus on the antenna mast in line with the feed panels, with the solar panel balancing the antenna dish, minimizes the total gravity-gradient torque.

Deploying a single solar panel from the spacecraft bus creates a geometry where solar pressure produces a torque, disturbing the orientation of the platform. Deploying two symmetrical panels, with the center line normal to the antenna beam axis and as close as possible to the platform c.g. minimizes the solar torque. The solar panel booms must be extended far enough to prevent shadowing of the panels by the large antenna dish and supporting structures.

The Mobilesat Platform requires a standard bus attitude control subsystem to stationkeep at geostationary orbit and orient the platform toward the boresight city (Kansas City) with the required pointing accuracy. The large antenna, feed panels, frequency selective screen, and supporting structures must be aligned to precise tolerances to ensure that correct beam patterns are formed, noninterfering and directed toward the required locations. Further investigation is indicated to define the alignment precision of these structures when deployed. An accurate laser calibration system is suggested to measure the alignment of the feed panels and frequency selective screen with the antenna dish. A separate alignment reaction control system is indicated which would be mounted on the antenna hub to position the antenna dish with respect to the feed panels.

The second-generation Land Mobile Service Study considered six configurations which differed in the location of the bus and solar panels; see Figure 3.1-4 and Table 3.1-5. One configuration (No. 6) was tentatively selected for the LMSS platform as satisfying the design requirements (Figure 3.1-5). The transponder and feed panel are designed as an integral unit to eliminate long



(SOURCE: REFERENCE 13)

5-1257

Figure 3.1-4. Second-Generation LMSS Candidate Concepts

RF coax or waveguide runs from the panels to the bus. The platform bus is located to provide controllable gravity-gradient torque and separates the boom and mast for ease of deployment and stowage in the Space Shuttle. The LMSS design requires two feed panels and a frequency selective screen on the mast implying a separate mast segment between the feed panels. A symmetrical solar array with two long array booms provides a low solar torque design, which also prevents shadowing by the large antenna dish. Designing the feed panels as an integral unit with embedded transponders reduces the thermal load on the platform bus, but requires an independent thermal control mechanism on each feed panel to dissipate heat generated by the transponders.

3.1.2.2.5 Launch Configuration

A stowed configuration for Space Shuttle launch of the second-generation Mobilesat was designed using the SCOTS orbital transfer system (Figure 3.1-6). The third generation LMSS platform is larger, heavier, and requires a higher thrust vehicle, but the same stowage constraints apply. The components to be balanced in a stable configuration are the platform bus, the solar panels, the feed panels, the antenna hub assembly, and the containers for the collapsed boom and mast segments. The second-generation design is based on the Series 4000 spacecraft bus and a SCOTS vehicle mounted in the Space Shuttle with a horizontal launch cradle. The feed panel and canisters are mounted to the spacecraft with a support structure and arranged in an overlapping configuration which is within the Space Shuttle envelope. The feed panel occupies the most space in the launch configuration, and the third-generation platform feed panels are too large to fit within the Space Shuttle envelope without folding.

TABLE 3.1-5. SECOND-GENERATION LMSS CANDIDATE TRADE

Payload Elements	Trade-offs LMSS Candidates					
	1	2	3	4	5	6
Transponder	• On Mast with Feed • Short W/G or Gain • Easy Thermal Control	• On Mast with Feed • Short W/G or Gain • Easy Thermal Control	• On Mast with Feed • Short W/G or Gain • Easy Thermal Control	• At Spacecraft • Short W/G or Coax	• At Spacecraft • Short W/G or Coax	• On Mast with Feed • Short W/G or Coax • Easy Thermal Control
Feed	• On Mast with Transponder	• On Mast with Transponder	• On Mast with Transponder	• At Spacecraft • Deployed to Focus	• At Spacecraft • Deployed to Focus	• On Mast with Transponder
Reflector	• Separate Mast	• On Spacecraft	• On Spacecraft	• On Mast	• On Mast	• Separate Mast
Solar Array	• Single Sided • Boom length to reduce solar pressure torque	• Symmetrical	• Single Sided	• Symmetrical	• Single Sided	• Symmetrical
LMSS System	• Reflector & Feed Separately Deployed • Two Masts for System • Single Array Boom • High Diurnal Cylic Solar Torque	• Single Mast for System • Two Long Array Booms • Thruster Plume Impingement on Reflector • High Gravity-Gradient Torque	• Single Mast for System • Single Array Booms • Thruster Plume Impingement on Reflector • High Gravity-Gradient Torque • High Diurnal Cylic Solar Torque	• Single Mast for System • Two Long Array Booms to Prevent Shadowing • High Gravity-Gradient Torque	• Single Mast for System • Single Short Array Boom Adequate to Prevent Shadowing • High Diurnal Cylic Solar Torque • High Gravity-Gradient Torque	• Reflector & Feed Separately Deployed • Two Masts for System • Two Long Array Booms to Prevent Shadowing • Controllable Gravity-Gradient Torque • Low Solar Torque

	6
TRANSPONDER	• ON MAST WITH FEED • SHORT W/G OR COAX • EASY THERMAL CONTROL
FEED	• ON MAST WITH TRANSPONDER
REFLECTOR	• SEPARATE MAST
SOLAR ARRAY	• SYMMETRICAL
SYSTEM	• REFLECTOR & FEED SEPARATELY DEPLOYED • THREE MASTS FOR COM. SYSTEM • TWO LONG ARRAY BOOMS TO PREVENT SHADOWING • CONTROLLABLE GRAVITY GRADIENT TORQUE • LOW SOLAR TORQUE
FREQUENCY SELECTIVE SCREEN	• ON MAST WITH TRANSPONDER

PLATFORM STUDY CONCEPT

DEPLOYED CONFIGURATION

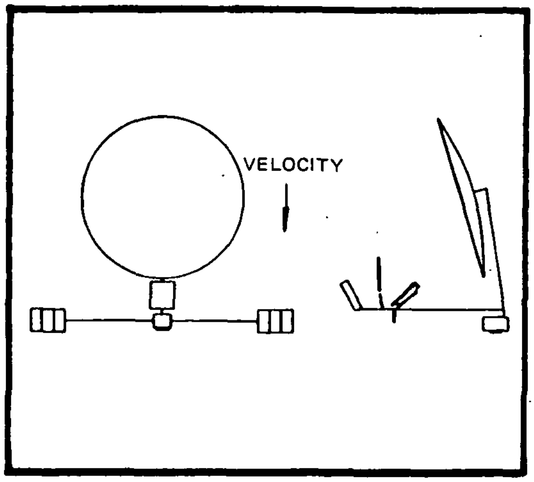


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Figure 3.1-5. Second-Generation LMSS Concept

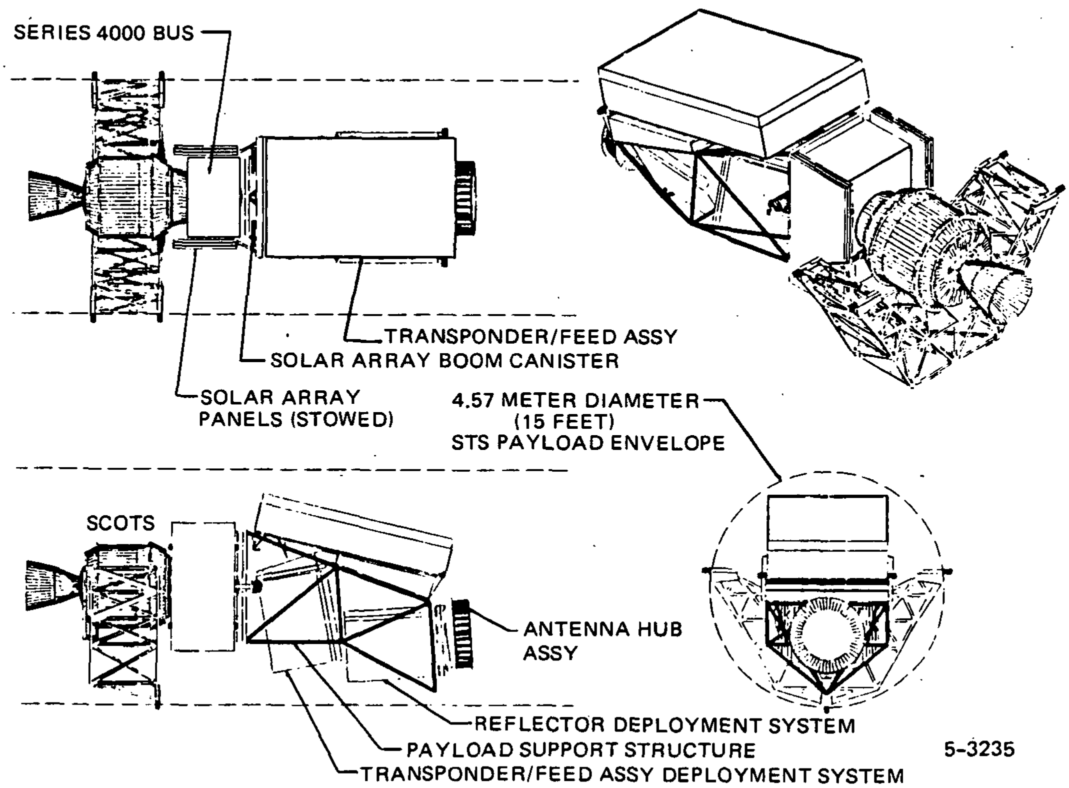

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Figure 3.1-6. Second-Generation LMSS Launch Configuration

3.1.3 LMSS PAYLOAD TECHNICAL CHARACTERISTICS

The service requirements for the LMSS Platform guided the development of the tentative specifications for the payload. A detailed block diagram compliant with the specifications was generated. Characteristics of each component on the block diagram were investigated to obtain electrical properties, power requirements, component weight, and component dimensions. An analysis of the antenna properties resulted in a feed array and offset antenna design which radiated the desired beam pattern. The type of antenna, design geometry, antenna gain, sidelobe level at beam crossover, and antenna dish and structure weights were calculated. The technical characteristics which resulted from these design studies are discussed below.

3.1.3.1 Bus Requirements

The communications payload design imposes the requirements on the platform bus which are listed in Table 3.1-6. The large deployable offset antenna dominates the platform design. It will consist of a 30-meter offset dish fed by a multi-beam panel for the uhf voice mobile service. The antenna will also serve L-band digital data traffic by providing a mesh, reflective at L-band, over 20-meters of the dish diameter fed by a multibeam panel. The backhaul link to the gateways will be provided by a single beam Ku-band horn. The tight uhf and L-band beam patterns impose an overall pointing requirement of 0.1° on the bus.

The uhf voice mobile service requires 40 beams formed from 61 feed elements. The L-band digital mobile service requires 52 beams formed from 77 feed elements. One Ku horn is required for the backhaul link to/from the gateways. The total payload weight including antenna dish, structure, and feed panels is 1172 kg. The dc power required for the payload at end of life (EOL) is 8.1 kW. The payload is designed for an operating temperature range of 0° to -50°C and the platform is projected to have a minimum lifetime of 10 years.

The mobile service traffic model projects peak service to occur during daylight hours. Traffic is projected to be at a minimum during eclipse. Therefore, the bus is specified to provide an eclipse capability equivalent to 25% of EOL power.

3.1.3.2 Transmitter Specification

The average required power per beam was used to calculate the effective power per transmitter for the uhf and L-band payload. The power per transmitter was then multiplied by the number of transmitters to obtain the power impact on the platform bus. The design approach suggested by NASA and pursued by RCA provides 3780 voice channels to support 180,000 CONUS users with 20% blockage probability during the peak busy hour. To provide a 2% blockage probability, 4680 channels would be required. The transmitter power requirements were conservatively estimated to provide enough power to meet a 2% blockage probability figure. Thus, the average power per transmitter is increased by the "traffic ratio" of 4680:3780. The 27 required beams are generated by 41 feed elements each powered by a transmitter, and the average power should be reduced by the beam/feed element ratio of 27:41. The voice mobile system design assumes 40% "on time" voice statistics with VOX implementation, and the average rf power should be reduced to 40%. The state-of-the-art for solid-state power amplifiers projects to a 40% efficiency level by 1998. Electrical power conditioning is projected to remain at 85% efficiency in 1998.

TABLE 3.1-6. LMSS BUS STUDY DATA REQUIREMENTS

Parameter	Requirements
Antennas • UHF • L-Band • Ku-Band	 30-meter Multibeam 20-meter Multibeam Horn, Single Beam
Pointing	0.1°
Temperature	0-50°C
Lifetime (minimum)	10 years
Service	• UHF to/from Voice Mobiles • L-Band to/from Digital Data Mobiles • Ku-Band to/from Gateways
Beam Coverage	• 40 Beams, 61 Feed Beams UHF • 52 Beams, 77 Feed Beams L-Band • 1 Ku-Band Backhaul
Mass	1172 kg
DC Power Required (EOL)	8.1 kW
Eclipse Capability	25%

The equation for effective rf output power per transmitter for the voice mobile payload at uhf becomes:

Effective RF Power = Beam Power x Traffic Ratio x Beam/Feed Element Ratio x VOX

The effective dc power per transmitter is related to the effective rf power by the equation:

$$\text{Effective DC Power} = \frac{\text{Effective RF Power}}{\text{SSPA Efficiency} \times \text{EPC Efficiency}}$$

Application of these equations for CONUS traffic using the values in Table 3.1-7 results in an effective dc input power of 68 watts per transmitter with an effective rf output power of 23 watts and a dissipated power of 45 watts per transmitter.

TABLE 3.1-7. VOICE MOBILE (CONUS)

Parameter	Values
RF Beam Power	70 watts
Traffic Ratio	4680:3780
Beam/Feed Element Ratio	27:41
VOX Reduction	0.40
SSPA Efficiency	0.40
EPC Efficiency	0.85
DC Effective Feed Element Power	68 watts
RF Effective Output Power Per Transmitter	23 watts
Dissipated Power Per Transmitter	45 watts

Similarly, application of these equations for Canadian traffic using the values in Table 3.1-8 results in an effective dc input power of 31 watts per transmitter with an effective rf output power of 10.5 watts and a dissipated power of 20.5 watts.

TABLE 3.1-8. VOICE MOBILE (CANADIAN)

Parameter	Values
RF Beam Power	56.0 watts
Traffic Ratio	520:728
Beam/Feed Element Ratio	13:20
VOX Reduction	0.40
SSPA Efficiency	0.40
ECP Efficiency	0.85
DC Effective Feed Element Power	31.0 watts
RF Effective Output Power	10.5 watts
Dissipated Power	20.5 watts

In the case of the L-band mobile digital data, the channel capacities are in excess of the demand and the effective rf power equation simplifies to:

Effective RF Power = Beam Power x Beam/Feed Element Ratio

Application of the power equation for digital mobile traffic for CONUS coverage using the values in Table 3.1-9 results in an effective dc input power of 63 watts with an effective rf output power of 21.5 watts and a dissipated power of 41.5 watts.

TABLE 3.1-9. DIGITAL DATA (CONUS)

Parameter	Values
RF Beam Power	32.0 watts
Beam/Feed Element Ratio	35:52
SSPA Efficiency	0.40
EPC Efficiency	0.85
DC Effective Feed Element Power	63.0 watts
RF Effective Output Power	21.5 watts
Dissipated Power	41.5 watts

Application of these equations for Canadian digital mobile traffic using the values in Table 3.1-10 results in an effective dc input power of 24 watts per transmitter with an effective RF output power of 8 watts and a dissipated power of 16 watts.

TABLE 3.1-10. LMSS TRANSMITTER POWER REQUIREMENT FOR DIGITAL DATA (CANADIAN SERVICE)

Parameter	Values
RF Beam Power	12.0 watts
Beam/Feed Element Ratio	17:25
SSPA Efficiency	0.40
EPC Efficiency	0.85
DC Effective Feed Element Power	24.0 watts
RF Effective Output Power Per Transmitter	8.0 watts
Dissipated Power Per Transmitter	16.0 watts

The Ku-band backhaul link to the gateway stations carries all of the voice mobile and digital data traffic for CONUS and Canadian coverage for a total requirement of 5170 channels as given in Table 3.1-11. The available Ku-bandwidth of 50 MHz will accommodate the 5170 channels. Assuming an rf power of 0.003 watt per 10 kHz, which is the same as that used in the second-generation Mobilesat study, the total Ku-band rf beam power required is 15 watts.

TABLE 3.1-11. Ku-BAND BACKHAUL LINK

Parameter	Requirement
Voice Mobile Channels (CONUS)	3780 channels
Voice Mobile Channels (Canadian)	728 channels
Digital Data Channels (CONUS)	560 channels
Digital Data Channels (Canadian)	102 channels
Total Ku-band Channel Requirement	5170 channels
Total Available Bandwidth	50 MHz
RF Power per 10 kHz	0.003 watt
RF Beam Power	15.0 watts
SSPA Efficiency	0.35
EPC Efficiency	0.85
Dissipated Power (SSPA + EPC)	35.0 watts
Diplexer Power Loss	30.0 watts
Total DC Input Power	53.0 watts

At Ku-band, the SSPA efficiency projected for 1995 is 0.35 which results in a dc input power of 50 watts and a dissipated power of 35 watts. Adding in 3 watts for the diplexer power loss results in an input power requirement of 53 watts.

Each component on the equipment block diagram was sized in cube and weight for the transmitter power per channel for uhf and L-band channels; results are summarized in Table 3.1-12. Power dissipation in passive components including diplexers, signal splitters, combiners, multiplexers, and switches was derived based on the power per channel. The weight and cube for active L-band, uhf and Ku-band transmitter elements which include preamplifiers, high-power amplifiers, electrical power conditioners, and upconverters were computed based on dc input power. The weight and cube for active uhf, L-band, and Ku-band receiver elements which include low noise amplifiers, frequency translators, and downconverters were computed from the received signal power, noise temperature, and gain.

The weight, cube, and power for the master oscillator was also calculated. The results were tabulated and the total weight, average dc input and power dissipated were computed for the payload as shown in Table 3.1-12.

The results are based on RCA-developed state-of-the-art designs for communications satellites projected into the 1998 time frame. They represent realizable design configurations developed by RCA Engineering. The results are summarized in Table 3.1-13 which gives the derived dc power for the uhf, L-band, and Ku-band transponder elements and the mass for the transponder elements, antenna reflectors, uhf feed panel, and L-band feed panel.

The uhf and L-band feed array panels are to be constructed of a unitized microstrip design with the transponder elements embedded in the structure. The bus temperature control subsystem must dissipate the heat generated by the transmitter elements, receivers, frequency translators, upconverter, diplexer, and switches. The total power dissipated in the uhf panel is given in Table 3.1-14, and the total power dissipated by the L-band panel is given in Table 3.1-15.

3.1.3.3 Payload Redundancies

Spacecraft design practice provides redundant transmitter and receiver paths for active elements, but no redundancy for diplexers and passive devices. Active elements are grouped to provide a maximum of redundancy with a minimum of switching. The design goal is to provide two redundant paths for each group with the group size dependent on the reliability history of group elements.

Table 3.1-16 provides the redundancy grouping for active uhf and L-band transmitter and receiver elements. In all but one case, the groupings provide dual redundancy path, but the redundancy ratio is the same as for CONUS.

In the case of the Ku-band, Table 3.1-17, all uhf and L-band traffic is combined into a single transponder channel. Loss of the Ku channel will result in total loss of the voice mobile and digital data mission. Therefore, a three-to-one redundancy ratio is provided for all active components of the Ku transponder. Since the master oscillator is also a single point of failure, a three-to-one redundancy is provided as well.

3.1.3.4 Power Conditioning

The LMSS payload is designed to interface with a specific bus power distribution system. The design specifics unregulated power with high- and low-voltage limits to be distributed by the spacecraft power system. Each of the bus and payload subsystems will condition the unregulated power as required. Four power distribution buses are specified; transponder, essential, electrothermal hydrazine thruster and pyrotechnic. The transponder bus provides power to the active payload components enumerated in Section 3.1.3. The voltage range permitted under normal load and under eclipse conditions for the four buses is given in Table 3.1-18.

3.1.4 ANTENNA DESIGN

The LMSS platform requires one large offset reflective parabolic antenna fed by two arrays of feed element, one for the uhf band and one for the L-band. A mesh reflective over the uhf band will cover the 30-meter diameter, and a mesh reflective over the L-band will cover the 20-meter diameter. A frequency selective dichroic screen reflects the energy radiated from the uhf feed panel into the antenna dish and transmits the energy from the L-band feed panel into the antenna dish.

3.1.4.1 Offset-Fed Single Reflector

The offset-fed reflector geometry in Figure 3.1-7 defines the parameters given in Table 3.1-19 which are required by the design. The specified diameter of

TABLE 3.1-12. PAYLOAD UNIT AND PHYSICAL CHARACTERISTICS

Payload Unit		Characteristics/Unit						Totals				
		Weight	Size (inches)			Power (Watts) Ave. DC		Number of Units on	Number of Units Powered	Weight	Power (Watts) Ave. DC	
No.	Name	(lb)	L	W	H	Input	Dissip.	Satellite	Simult.	(lb)	Input	Dissip.
1	Ku-Band Diplexer	1.0	8	7	2	NA	3.1	1	NA	1.0	NA	3.1
2	Ku-Band Receiver (LMA + Down Converter)	1.1	5	3	4	5.8	5.8	3	1	3.3	5.8	5.8
3	Hybrid (3 dB)	0.5				NA	NEGL	1	NA	0.5	NA	NEGL
4	Signal Splitter	0.4	5" Dia.		2	NA	NEGL	2	NA	0.8	NA	NEGL
5	UHF Downlink Receiver/ Freq. Translator											
5A	• CONUS	0.3	5	3	1	1.2	1.2	52	41	15.6	Incl. in Item 21	49.2
5B	• Canada	0.3	5	3	1	1.2	1.2	25	20	7.5		24
6	UHF Transmitter (Preamp & HPA + EPC)											
6A	• CONUS	5.7	15	5	5	68	45	52	41	296	2788	1845
6B	• Canada	5.5	15	5	5	31	20.5	25	20	138	620	410
7	UHF Diplexer CONUS	2.0	15	3	3	NA	4.6	41	NA	82	NA	189
	Canada	2.0	15	3	3	NA	2.2	20	NA	40	NA	44
8	L-Band Downlink Receiver Freq. Translators											
8A	• CONUS	0.3	5	3	1	1.2	1.2	70	52	21	Incl. in Item 21	62.4
8B	• Canada	0.3	5	3	1	1.2	1.2	35	25	10.5		30
9	L-Band Transmitter (Preamp + HPA + EPC)											
9A	• CONUS	5.0	13	5	4	63	41.5	70	52	350	3276	2158
9B	• Canada	3.8	13	5	4	24	16	35	25	133	600	400
10	L-Band Diplexer CONUS	2.0	15	3	3	NA	4.4	52	NA	104	NA	229
	Canada	2.0	15	3	3	NA	1.7	25	NA	50	NA	43

TABLE 3.1-12. PAYLOAD UNIT AND PHYSICAL CHARACTERISTICS (Continued)

Payload Unit		Characteristics/Unit								Totals		
		Weight	Size (inches)			Power (Watts) Ave. DC		Number of Units on	Number of Units Powered	Weight	Power (Watts) Ave. DC	
No.	Name	(lb)	L	W	H	Input	Dissip.	Satellite	Simult.	(lb)	Input	Dissip.
11	UHF Receiver (LMA + Freq. Translator	0.7	5	2	3	3.25	3.25	81	61	56.7	Incl. in Item 21	198
12	L-Band Receiver	0.7	5	2	3	3.25	3.25	99	77	69.3		250
13	UHF Combiner	0.65	5" Dia		2	NA	NEGL	1	NA	0.65	NA	NEGL
14	L-Band Combiner	0.65	5" Dia		2	NA	NEGL	1	NA	0.65	NA	NEGL
15	UHF/Ku Up Converter	1.15	3	3	4	5.6	5.6	3	1	3.5	5.6	5.6
16	L-Band/Ku Up Converter	1.15	3	3	4	5.6	5.6	3	1	3.5	5.6	5.6
17	Ku-Band Multiplexer	TBD				NA	NEGL	1	NA	<10	NA	NEGL
18	Ku-Band Preamplifier	1.0	7.5	4.5	1.5	0.6	0.4	3	1	3.0	5.6	0.4
19	Ku-Band HPA (SSPA)	1.1	8	8	1		30	3	1	3.3		30
20	EPC for Up-Downlink	2.5	10	3	4	53	8	3	1	7.5	53	8
21	EPC for Up-Downlink Freq. Translators	5.3	8.8	7.9	4.6	772	108	3	1	15.9	722	108
22	Master Oscillator	2.0	4	3.5	2.5	4.2	4.2	3	1	6.0	4.2	4.2
23	Redundancy W/G Switches	0.3	4	2	2	NA	0.7 for one switch only	20	NA	6.0	NA	0.7
24	Redundancy Coax Switches	0.2	2.6	2.2	1.5	NA	Ave of 0.44 for each of 138 switches	632	NA	126.	NA	62
25	Miscellaneous Plus Coax and Waveguide Run (not on feed panel)											
	• Coax	12	NA	NA	NA		NEGL	1 set	NA	12	NA	NEGL
	• W/G						NEGL	1 set	NA		NA	NEGL
	TOTALS									1576	8081	6165

TABLE 3.1-13. PAYLOAD MASS AND POWER SUMMARY

Parameter	Mass [lb (kg)]	End-of-Life DC Power (watts)
Transponder Elements • UHF-Transmitters/Receiver • L-Band Transmitters/Receivers • Ku-Band Transmitters/Receivers • Diplexers (Ku, UHF, L-Band) • Singlan Splitters/Combiners • Frequency Translators • Power Supplies • Master Oscillators • HG and Coax Switches • Coax and Waveguide not on Feed Panel	1576 (714.4)	8081
Antenna Reflectors • 30/20-meter (UHF/L-Band) • Frequency Selective Screen	391.1 (177.8) 50.0 (22.7)	- -
Ku-Band Horn (CONUS)	Negligible	-
UHF Feed Array Panel excluding UHF transmitters, receivers, diplexers, and thermal control elements (such as heat pipes, etc.), but including all interconnecting cabling	284 (128.8)	
Same but for L-Band	283 (128.6)	
Total	2583 (1172)	8081

TABLE 3.1-14. UHF DISSIPATED POWER

Parameter	Power (watts)
UHF Downlink Receiver/Frequency Translator	73.2
UHF Transmitter (Preamp + HPA + EPC)	2255.0
UHF Diplexer	233.0
UHF Receiver (LNA + Frequency Translator)	1198.0
UHF/Ku Upconverter	5.6
UHF Coax Switches	26.8
UHF Panel	3792.0

TABLE 3.1-15. L-BAND DISSIPATED POWER

Parameter	Power (watts)
L-Band Downlink Receiver/Frequency Translator	92.4
L-Band Transmitter (Preamp + HPA + EPC)	2558.0
L-Band Diplexer	272.0
L-Band Receiver (LNA + Frequency Translator)	250.0
L-Band/Ku Upconverter	5.6
L-Band Coax Switches	33.9
L-Band Panel	3212.0

TABLE 3.1-16. UHF REDUNDANCIES L-BAND REDUNDANCIES

Item	Configuration	Redundancy Ratio
UHF HPAs for CONUS	5 groups, 10 for 8 1 group, 2 for 1	52 for 41
UHF HPAs for Canada	5 groups, 5 for 4	25 for 20
UHF Receivers	9 groups, 8 for 6 1 group, 9 for 7	81 for 61
L-Band HPAs for CONUS	8 groups, 8 for 6 1 group, 6 for 4	70 for 52
L-Band HPAs for Canada	5 groups, 7 for 5	35 for 25
L-Band Receivers	11 groups, 9 for 7	99 for 77
Note: There are no redundancies for all diplexers and passive devices.		

TABLE 3.1-17. Ku-BAND REDUNDANCIES

Item	Redundancy Ratio
Ku-Band Receiver	3 for 1
Ku-Band Preamp Ku-Band HPA	3 for 1
Ku-Band HPA EPC	1 per HPA
UHF/Ku-Band Upconverters	3 for 1
L-band/Ku-Band Upconverters	3 for 1
EPC for Up/Down Line Translators	3 for 1
Master Oscillator	3 for 1

TABLE 3.1-18. POWER CONDITIONING

Parameter	Requirements
• Spacecraft Power System	• Unregulated Power • Four Power Distribution Buses
• Power Distribution Buses	(1) Transponder (2) Essential (3) Electrothermal Hydrazine Thruster (EHT) (4) Pyrotechnic
• Transponder Essential	Normal +23.5 Vdc to +35.5 Vdc
• EHT Pyrotechnic	Normal +21.5 Vdc to +35.5 Vdc
• Transponder (Eclipse)	+23.5 Vdc to +35.5 Vdc
• Essential (Eclipse or High Load)	+23.5 Vdc to +34.0 Vdc
• EHT (Eclipse)	+21.5 Vdc to 32.0 Vdc
• Pyrotechnic (Eclipse)	+21.5 Vdc to +32.0 Vdc
• Harness Voltage Drop	0.5V to 23.0 Vdc at TPA

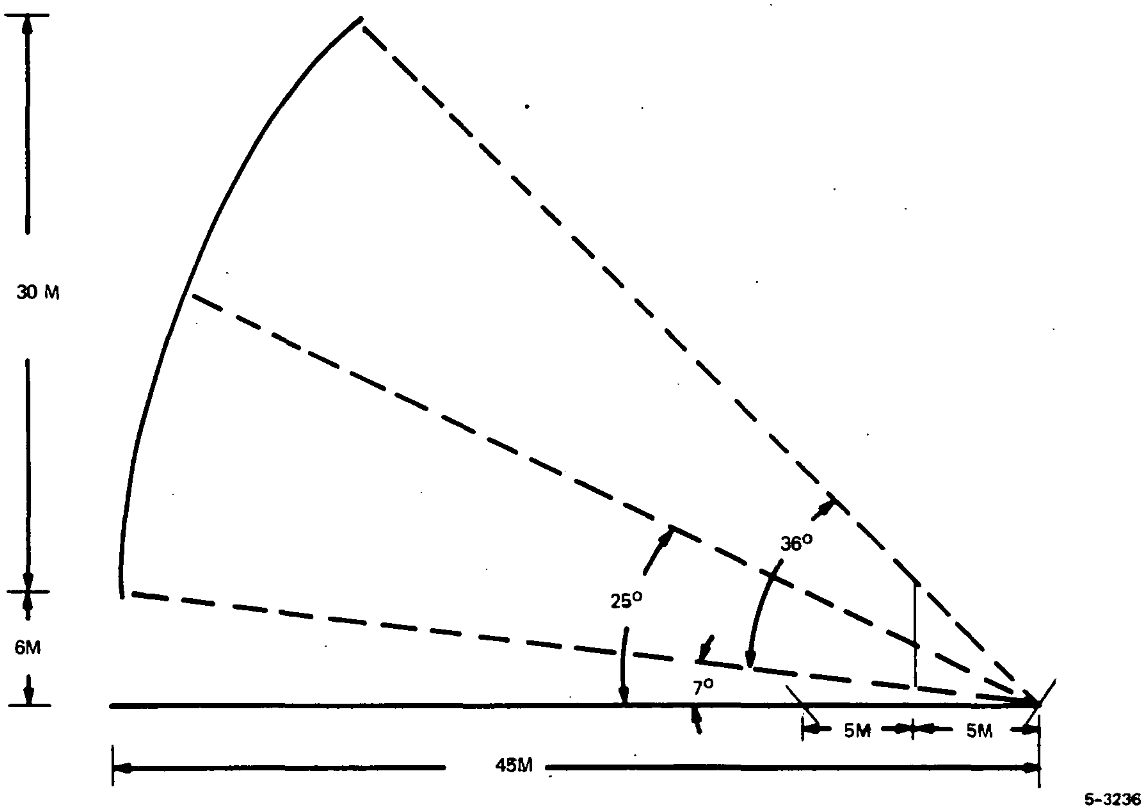


Figure 3.1-7. UHF/L-Band Dimensions

30 meters at 868 MHz requires a focal length of 45 meters to radiate 0.80° beams. The CONUS and Canadian coverage requirements can be satisfied by radiating 40 beams. The offset distance is assumed to be 6 meters.

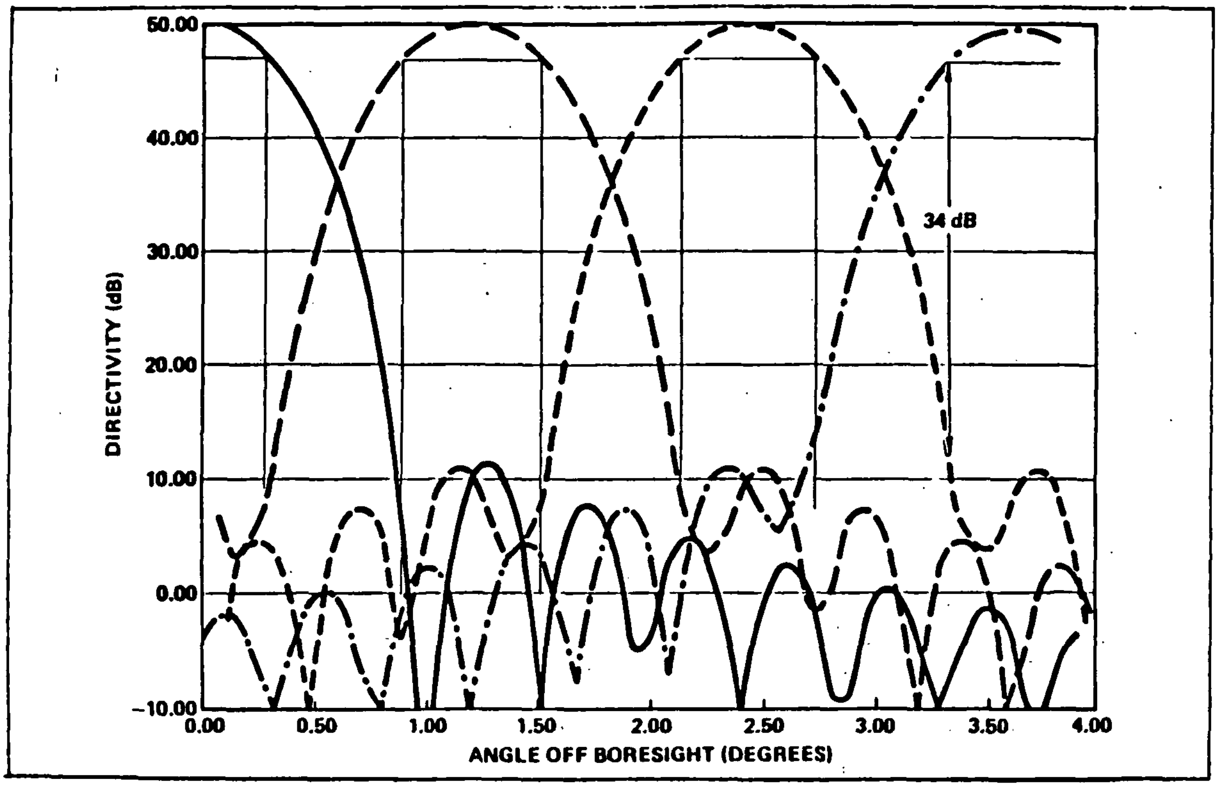
The diameter of 20 meters at 1556 MHz requires a focal length of 45 meters to radiate 0.70° beams. The CONUS and Canadian coverage requirements can be satisfied by radiating 52 beams. The offset distance is assumed to be 6 meters.

The allocated 4-MHz uhf band is divided into four 1-MHz subbands, and the 1-MHz subbands are allocated to beams. Since there are 40 beams, this scheme results in a 10-fold reuse of the available bandwidth. Beams are arranged in a triangular pattern such that each beam is touched by three pairs of beams on opposite sides of the center beam. Each of the three pairs of opposite beams is assigned one of the 4 subbands and the central beam, the remaining 1-MHz subband. This scheme separates all beams of the same frequency by one beamwidth.

Beam patterns have been calculated for center-fed and offset-fed parabolic antennas as a function of angle off boresight (see Figures 3.1-8 and 3.1-9) (reference 17). The results show that the first sidelobe levels for the center-fed antenna beams are unacceptably high and interfere with the main beams of adjacent co-channel beams. The offset feed design controls the sidelobe levels, but interference between the main beams at the cross-over point occurs. The cross-over point interference is controlled by shaping the main beam using a 4-set feed cluster. Each beam is formed by superimposing the radiation pat- terns from a cluster of four adjacent feed elements. Other

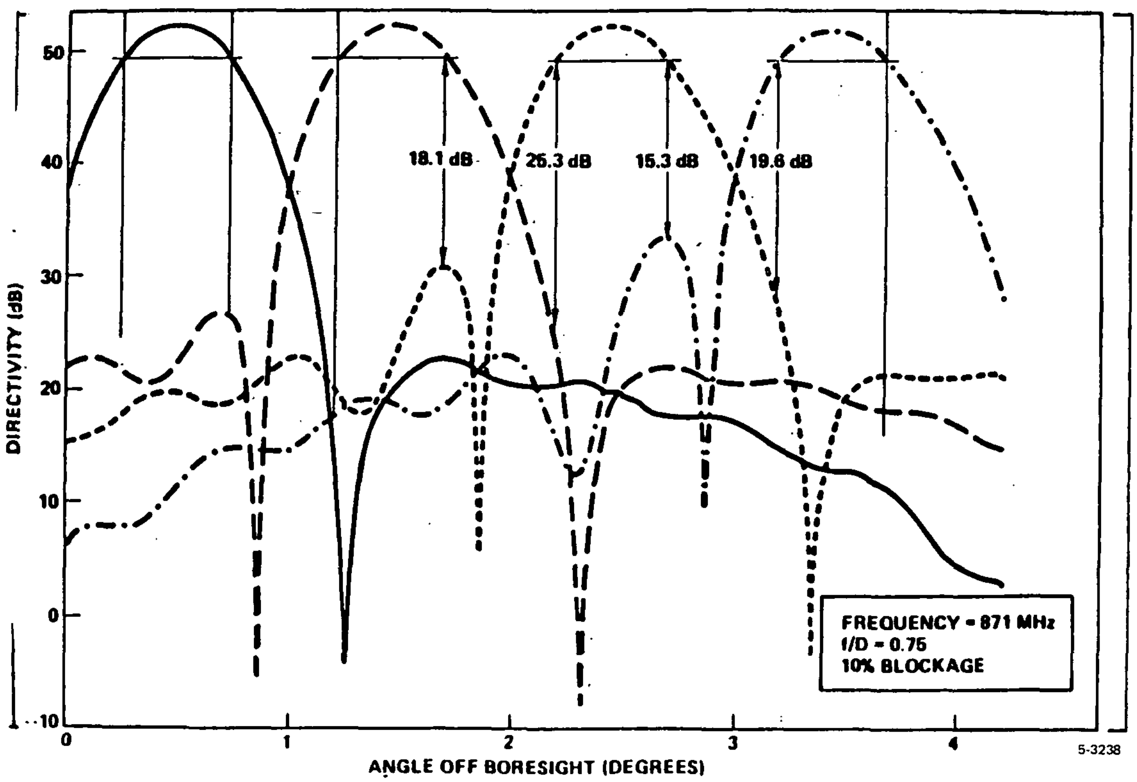
TABLE 3.1-19. LMSS 30/20-METER REFLECTOR ANTENNA

Parameter	Values	
	UHF	L-Band
Frequency (MHz)	868	1556
Wavelength (meter)	0.35	0.19
F of reflector (meter)	45.00	45.00
D of reflector (meter)	30.00	20.00
Aperture Gain (dB)	48.71	50.26
Misc. losses (dB)	4.01	4.01
loss due to FSS (dB)	0.50	0.50
Focal Beam Gain (dB)	44.20	45.75
Scan Loss (dB)	0.40	0.40
Edge Beam Gain (dB)	43.80	45.35
Assumed Offset (meter)	6.00	6.00
F/D	1.50	2.25
Subtended Scan (deg)	35.88	24.08
Azimuth Scan (meters/deg)	0.83	0.83
Elevation Scan (meters/deg)	0.83	0.83
Crossover Bandwidth (deg)	0.80	0.70
Feed Aperture (meter x meter)	0.66 x 0.57	0.58 x 0.50
Feed Spacing, Triangular (wavelength)	1.89 x 1.65	3.01 x 2.60
Total No. of Beams	40	52
No. of Elements per beam	4	4
No. of Elements required estimated	61	77
Max. dimensions (meter)	7.9 x 5.2	8.0 x 4.9
Area of feed (sq. meter)	23.00	21.50



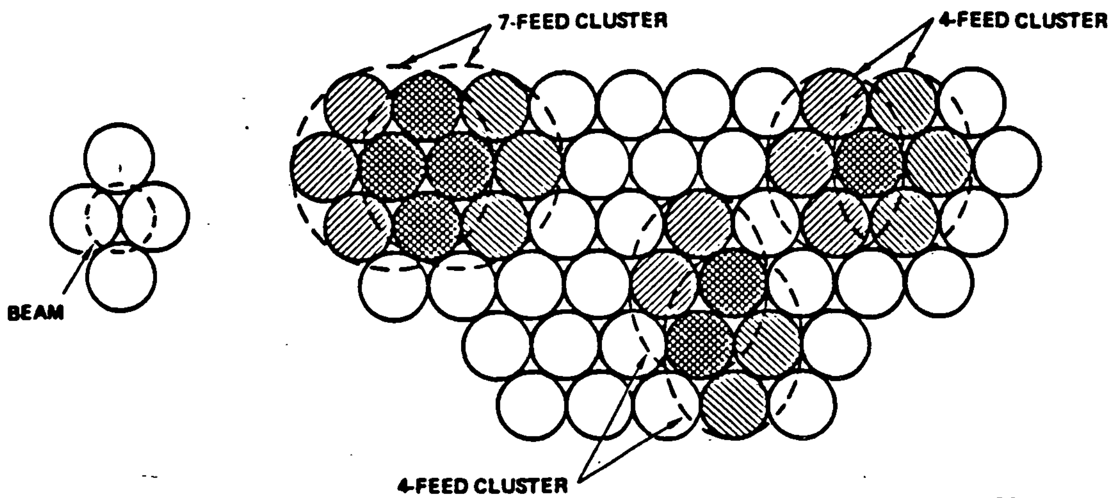
(SOURCE: TRW REFERENCE 17) 5-3237

Figure 3.1-8. Co-Channel-Beam Gain Patterns for Offset-Fed Antenna with 4-Frequency Sets



(SOURCE: TRW REFERENCE 17)

Figure 3.1-9. Co-Channel Beam Gain Patterns for Center-Fed Antenna with 4-Frequency Sets patterns including 7-element feed clusters have been suggested in the literature (see Figure 3.1-10) (reference 17). The 4-cluster approach in a triangular array yields acceptable results as shown in Figure 3.1-8 and 3.1-9.



(SOURCE: TRW REFERENCE 17)

Figure 3.1-10. Feed-Cluster Approach to Beam Formation

Each of the 40 uhf beams is formed from the feed elements of a cluster of four adjacent beams. Beams located at the periphery of the CONUS and Canadian coverage area cannot be formed from the existing 40 feed elements. Therefore, additional feed elements must be included to form the beam patterns at the periphery of the coverage area. An additional 21 uhf feed elements are required for a total of 61 feed elements to form 40 uhf beams.

The principles applied to the uhf offset-fed parabolic antenna are applicable to the L-band antenna design. The 20-meter offset-parabola has a focal length of 45 meters and radiates a 0.70° wide beam. The 6-MHz bandwidth is divided into four 1.5-MHz subbands divided among the 52 L-band beams for a frequency reuse factor of 13. A four-feed element cluster is used requiring 77 feed elements to form the 52 beams.

3.1.4.2 Beam Forming Network

The clusters of four feed elements are laid out on microstrip panels which have the dimensions and weight shown in Figure 3.1-11. The UHF and L-band feed panels are greater in length and width than the 15-foot diameter of the Space Shuttle cargo bay. As a result, each of the feed panels must be separated into three parts with a folding mechanism to permit stowage in the Shuttle.

The power dissipated per unit area of the panel was calculated from the transponder components embedded in the panel and the area of the panel. The calculated values of 1125 watts/ft^2 for the uhf panel and 13.86 watts/ft^2 for the L-band panel indicate a need for a separate heat control mechanism for each panel.

Each of the uhf and L-band clusters will be fed by four microstrip squares which radiate circularly polarized waves. The dimensions of the squares and

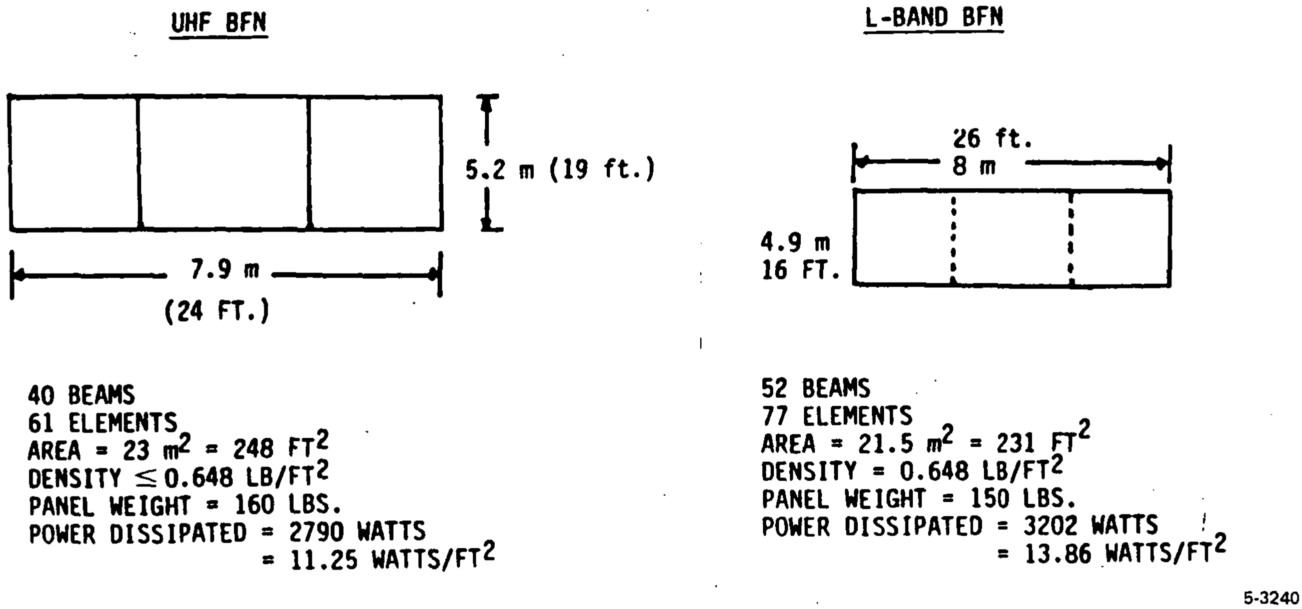


Figure 3.1-11. Beam Forming Network (BFN) Maximum Dimensions

their orientation in four-element patch clusters are given in Figure 3.1-12. Each of the four squares is fed in phase from a central feed point. Each square is fed from two orthogonal sides with a 90° phase difference to radiate right-hand circularly polarized waves.

The construction of a uhf microstrip feed panel has been investigated by JPL for a beam forming network of seven feed clusters as shown in Figure 3.1-13 (Reference 18). The construction consists of several layers which include the feed-element layer, ground planes, beam-port power divider layer, transmission-line layer, and honeycomb spacer panels. Embedded in the layer are power dividers, combiners, amplifiers, and diplexers. The supporting structure and heat control mechanisms are also diagrammed. The design requires further investigation to include mechanical folding and electrical and thermal coupling mechanisms for compatibility with the Space Shuttle.

The estimate of panel weight given in Table 3.1-20 was based on the estimate of feed panel components listed in Table 3.1-12.

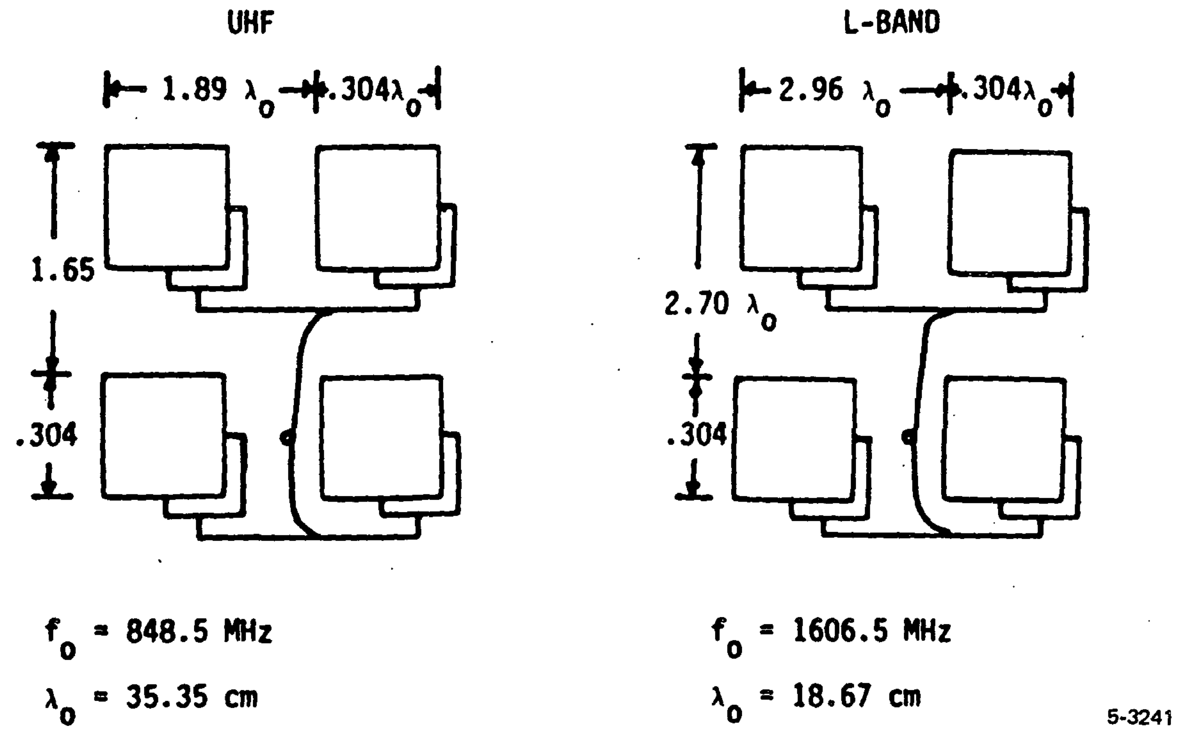
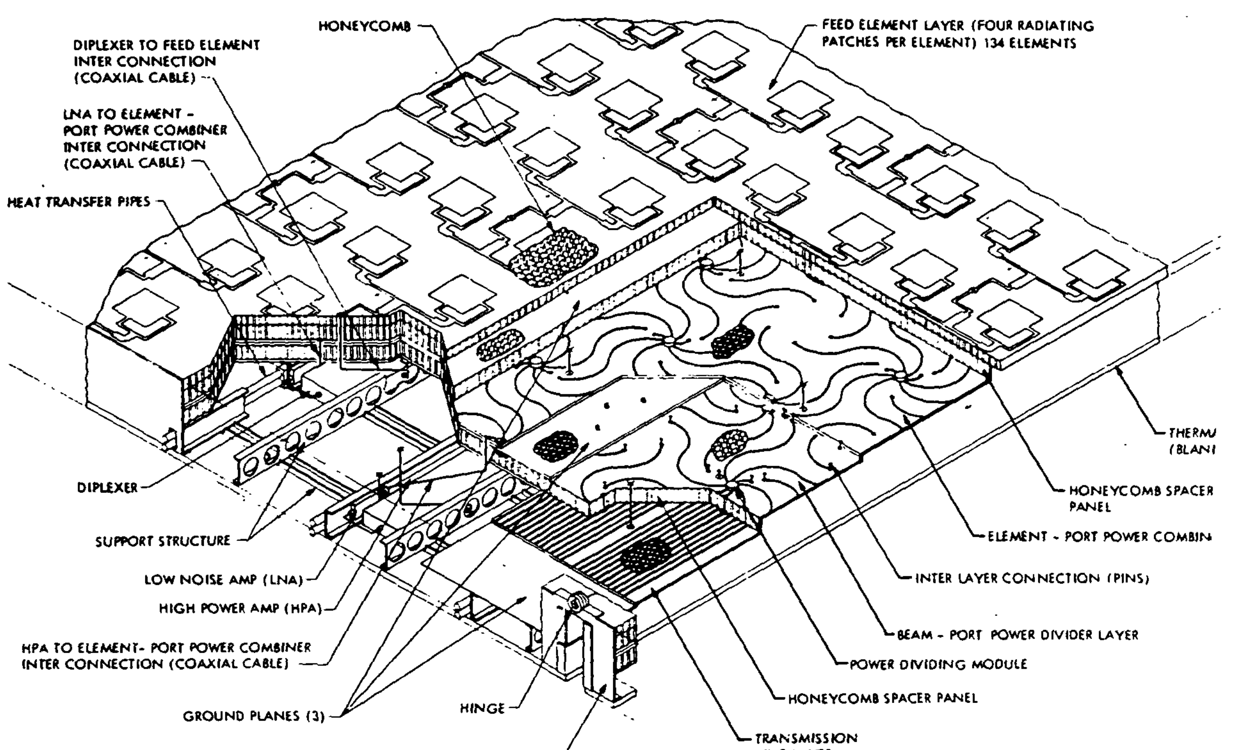


Figure 3.1-12. Patch Design



(SOURCE: NASA-JPL REFERENCE 18)

Figure 3.1-13. LMSS UHF Feed Array Assembly

TABLE 3.1-20. BEAM FORMING NETWORK PANEL WEIGHT ESTIMATE

Element	Weight (lb)	
	UHF	L-BAND
Panel Weight	160	150
Connectors	4	5
Feed	3.2	4
Transmission Line Adaptors	4	5
Hinges	48	41
Power Dividers	7	7
Subtotal	226.2	212
Cables	44.3	56
Connectors	13.1	15
Subtotal	57.4	71
TOTAL	284	283

3.1.4.3 Coverage

The uhf and L-band radiated beams corresponding to the centroid of the groups of four clusters of 4 patch elements were plotted in the focal plane of the parabolic antenna. Existing computer routines were modified to superimpose the locations of the radiated beams over a plot of the spherical earth sector corresponding to the North American continent as it would appear at the focal plane of the platform. Using these plots, the locations of the beams were iterated until optimum CONUS and Canadian coverage was obtained using an 0.8° beamwidth for UHF and a 0.7° beamwidth for L-band. The computer routines were adapted to plot the North American continent using a standard map projection, and the beams located in the focal plane were plotted on this map. Also plotted on the map are the horizon of the platform or 0° satellite elevation and the contour of 10° platform elevation as viewed from a mobile terminal.

The coverage pattern of the Mobilesat platform is better represented by a plot of overlapping beams diagramming the triple crossover point. The triple crossover point occurs at the location where three adjacent beams converge in a triangular pattern. The triple crossover point is the location where the signal power from the main beam is at a minimum. For the uhf voice mobile design, the triple crossover point occurs at 0.92° beamwidth, and for the L-band digital data design, the triple crossover point occurs at 0.81° beamwidth.

The location in X, Y coordinates (in inches) of the centroid of the beams was calculated for the uhf and L-band coverage and is given in Table 3.1-21. The coordinates calculated are for the centroid of the four beam clusters forming the pattern. These beams are the radiated beams of interest in calculated geographic coverage. Each beam is formed from a symmetrical array of four radiating microstrip patches. The design coordinates of the feed panels can be directly derived from the beam coordinates and the relative coordinates of the feed patch elements forming each beam in the four-beam cluster.

TABLE 3.1-21. CLUSTER CENTROID FEED PANEL COORDINATES

UHF (inches)			L-band (inches)		
Horn No.	Phase Center DXI	Phase Center DYI	Horn No.	Phase Center DXI	Phase Center DYI
1	77.9469	74.3033	1	82.3423	79.6742
2	39.0001	70.8300	2	-9.6577	79.6743
3	13.0001	70.8300	3	70.8423	59.7556
4	-12.9999	70.8301	4	47.8423	59.7557
5	78.0000	48.3133	5	24.8423	59.7557
6	52.0000	48.3133	6	1.8423	59.7557
7	26.0000	48.3133	7	21.1577	59.7557
8	0.0001	48.3134	8	-44.1577	59.7558
9	-25.9999	48.3134	9	-67.1577	59.7558
10	-51.9999	48.3134	10	82.3423	39.8370
11	-77.9999	48.3135	11	59.3423	39.8370
12	91.0000	25.7966	12	36.3423	39.8371
13	65.0000	25.7966	13	13.3423	39.8371
14	39.0000	25.7967	14	-9.6577	39.8372
15	13.0000	25.7967	15	-32.6577	39.8372
16	-13.0000	25.7968	16	-55.6577	39.8372
17	-39.0000	25.7968	17	-78.6577	39.8372
18	-65.0000	25.7968	18	101.6577	39.8373
19	-91.0000	25.7968	19	93.8422	19.9184
20	130.0000	3.2799	20	70.38422	19.9185
21	104.0000	3.2800	21	47.8422	19.9185
22	78.0000	3.2800	22	24.8422	19.9185
23	52.0000	3.2800	23	1.8422	19.9186
24	26.0000	3.2801	24	-21.1577	19.9186
25	0.0	3.2801	25	-44.1577	19.9186
26	-26.0000	3.2801	26	-67.1577	19.9186
27	-52.0000	3.2802	27	-90.1577	19.9187
28	-78.0000	3.2802	28	128.3422	-0.0002
29	143.0000	-19.2367	29	105.3422	-0.0001
30	117.0000	19.2367	30	82.3422	-0.0001
31	91.0000	-19.2366	31	59.3422	0.0001
32	65.0000	-19.2366	32	13.3422	0.0
33	39.0000	-19.2366	33	13.3422	0.0
34	13.0000	19.2365	34	-9.6578	0.0
35	-13.0000	19.2365	35	-32.6578	0.0
36	-39.0000	19.2365	36	-55.6578	0.0
37	-65.0000	19.2364	37	-78.6578	0.0001
38	77.8936	-41.7532	38	139.8422	-19.9188
39	0.1062	41.7532	39	116.8422	-19.9187
40	-25.8938	41.7532	40	93.8422	-19.9187
			41	70.8422	-19.9187
			42	47.8422	-19.9186
			43	24.8422	-19.9186
			44	1.8422	-19.9186
			45	-21.1578	-19.9186
			46	-44.1578	-19.9185
			47	-67.1578	-19.9185
			48	82.3421	-39.8373
			49	13.3422	-39.8372
			50	-9.6578	-39.8372
			51	-32.6578	-39.8371
			52	-55.6578	-39.8371

3.1.4.3.1 UHF Voice Mobile

The plot of radiated beams as seen from the focal plane of the antenna is shown in Figure 3.1-14. The Mobilesat platform is located in a geostationary orbit at a longitude of 90° West. The optimum boresight of the platform antenna is toward a geographic location of 98.8° West longitude and 44.8° North latitude. The beams are plotted in a spherical coordinate system with the azimuth and elevation angles from boresight given as axis. The boresight angle itself is located at +1.05° azimuth and -6.80° elevation from nadir at the platform.

The plot of the UHF 0.8° beams on CONUS and Canada is shown in Figure 3.1-15 as a function of latitude and longitude. The coverage is adequate across CONUS and the populated strip of Canada adjacent to the CONUS border. Additional beams cover north central Canada, but northwest Canada, Alaska, and Hawaii are not covered. The Platform is below the horizon for the northwest part of Alaska and coverage can not be obtained from the selected orbital slot by the addition of spot beams.

The plot of 0.92° overlapping beams as seen from the local plane of the antenna is shown in Figure 3.1-16. The plot of the 0.92° overlapping beams on CONUS and Canada as a function of latitude and longitude is shown in Figure 3.1-17.

3.1.4.3.2 L-Band Digital Data

The plot of spherical coordinates of the L-band radiated beams is shown in Figure 3.1-18. The coordinates of the antenna geometry are the same as in the UHF case because the L-band antenna is 20 meters of the 30-meter UHF antenna diameter.

The plot of the 0.7° digital data beams on CONUS and Canada is shown in Figure 3.1-19 as a function of latitude and longitude. The coverage is adequate across CONUS and most of Canada. Only the northern part of Canada, Alaska, and Hawaii are not covered.

The plot of 0.81° overlapping beams as seen from the focal plane of the antenna is shown in Figure 3.1-20. The plot of the 0.81° overlapping beams on CONUS and Canada as a function of latitude and longitude is shown in Figure 3.1-21.

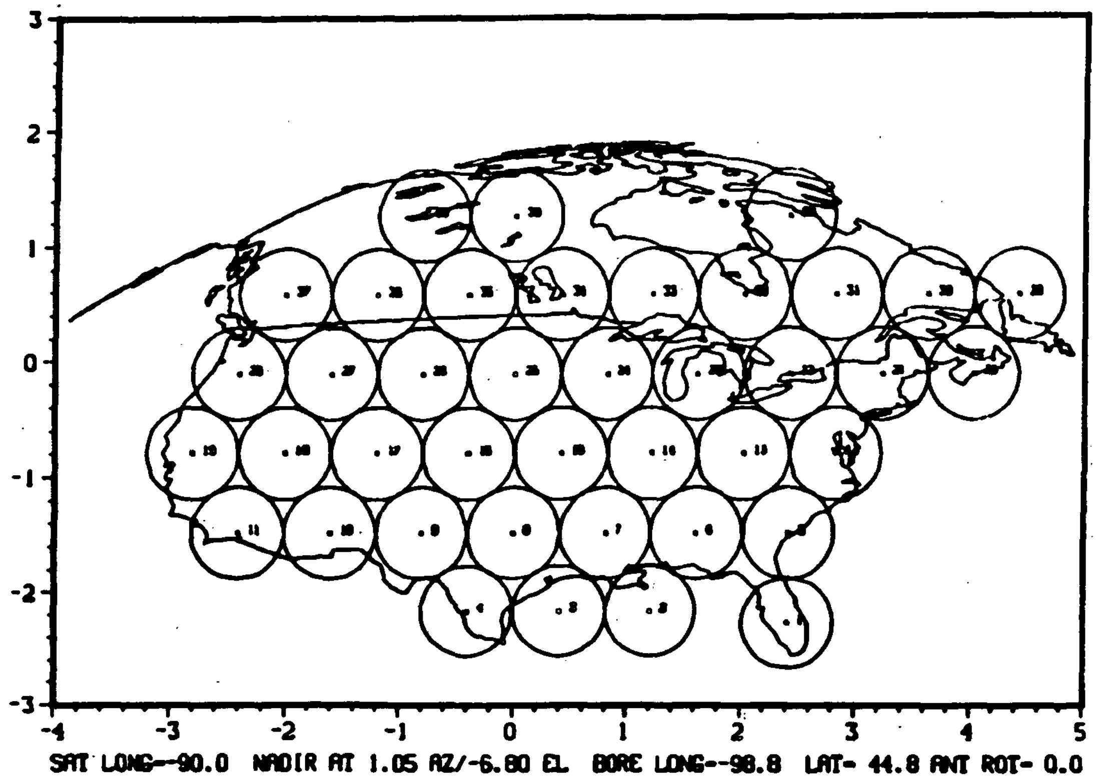


Figure 3.1-14. LMSS UHF Antenna Spot Beams Beamwidth: 0.80° by 0.80° Focal Plane Coordinates

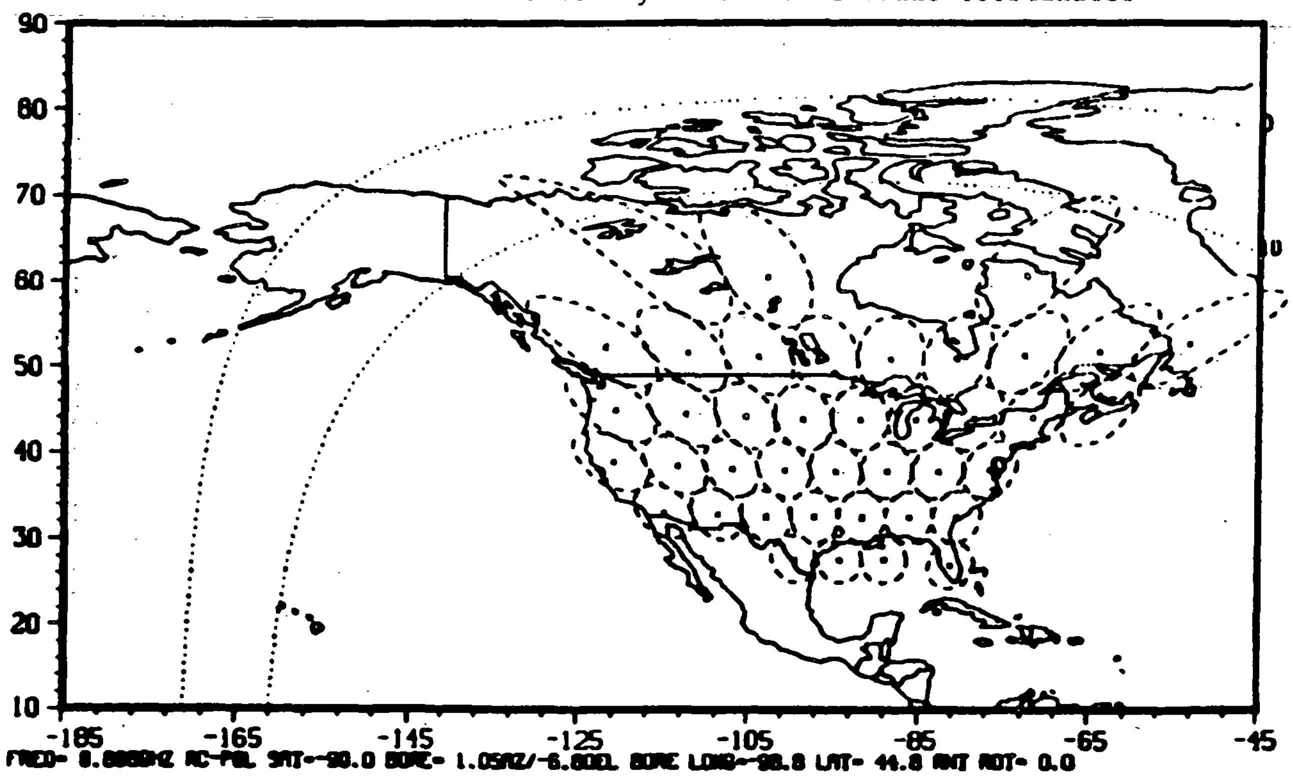


Figure 3.1-15. LMSS UHF Antenna Spot Beams Beamwidth: 0.80° by 0.80° Geographic Coordinates

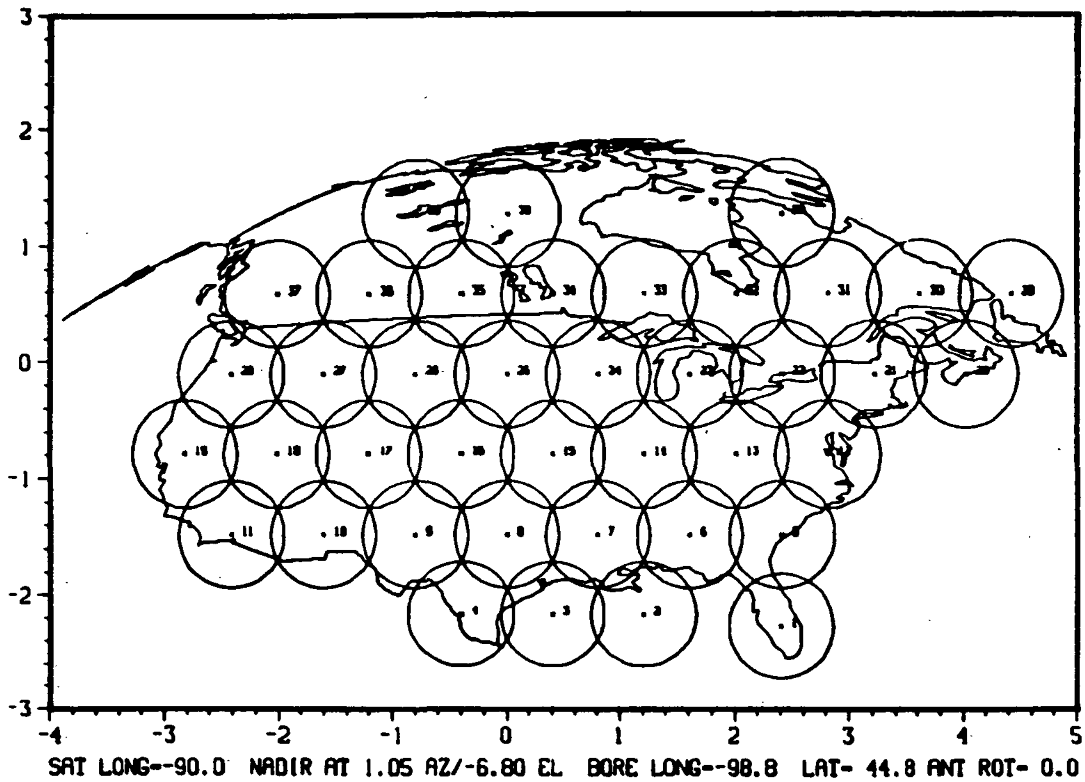


Figure 3.1-16. LMSS UHF Antenna Spot Beams Beamwidth: 0.92° by 0.92° Focal Plane Coordinates

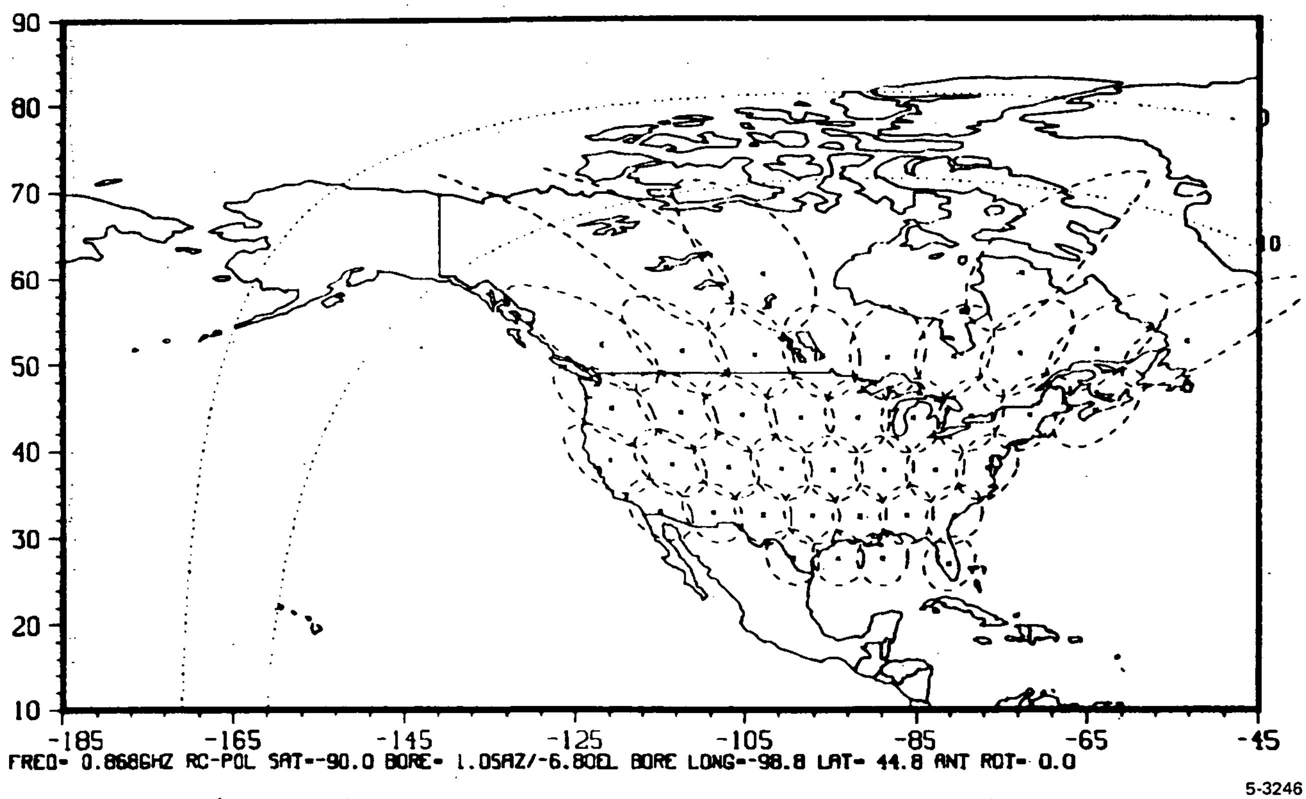


Figure 3.1-17. LMSS UHF Antenna Spot Beams Beamwidth: 0.92° by 0.92° Geographic Coordinates

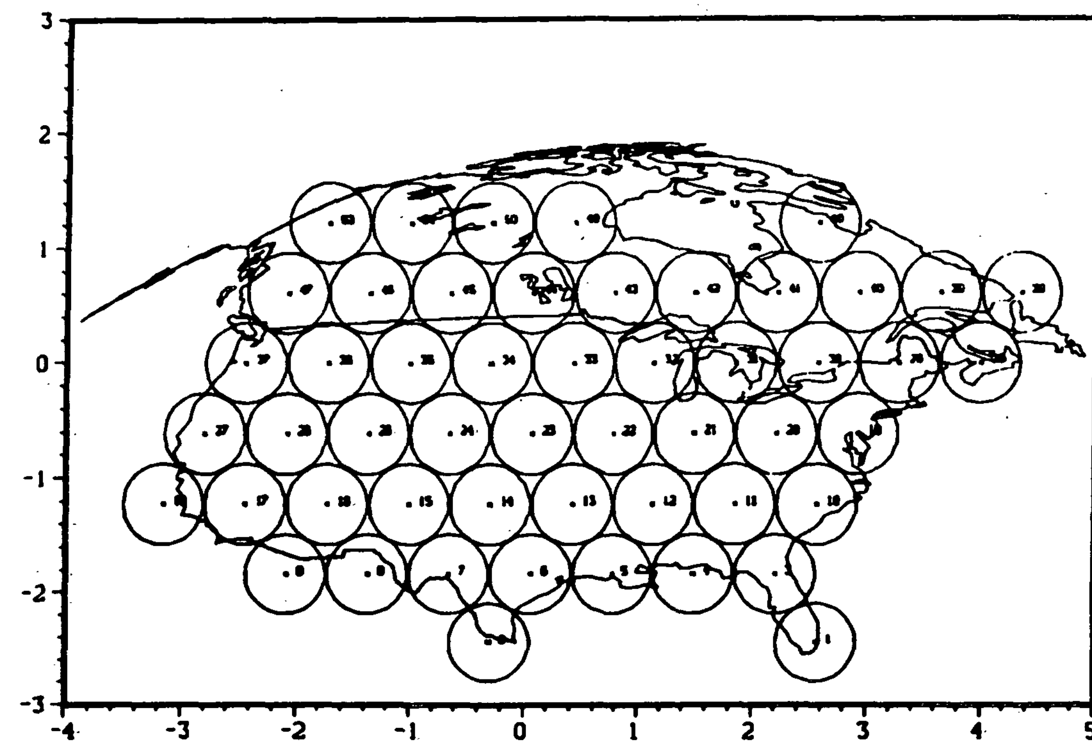


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Figure 3..1-18. LMSS L-Band Antenna Spot Beams Beamwidth: 0.70° by 0.70° Focal Plane Coordinates

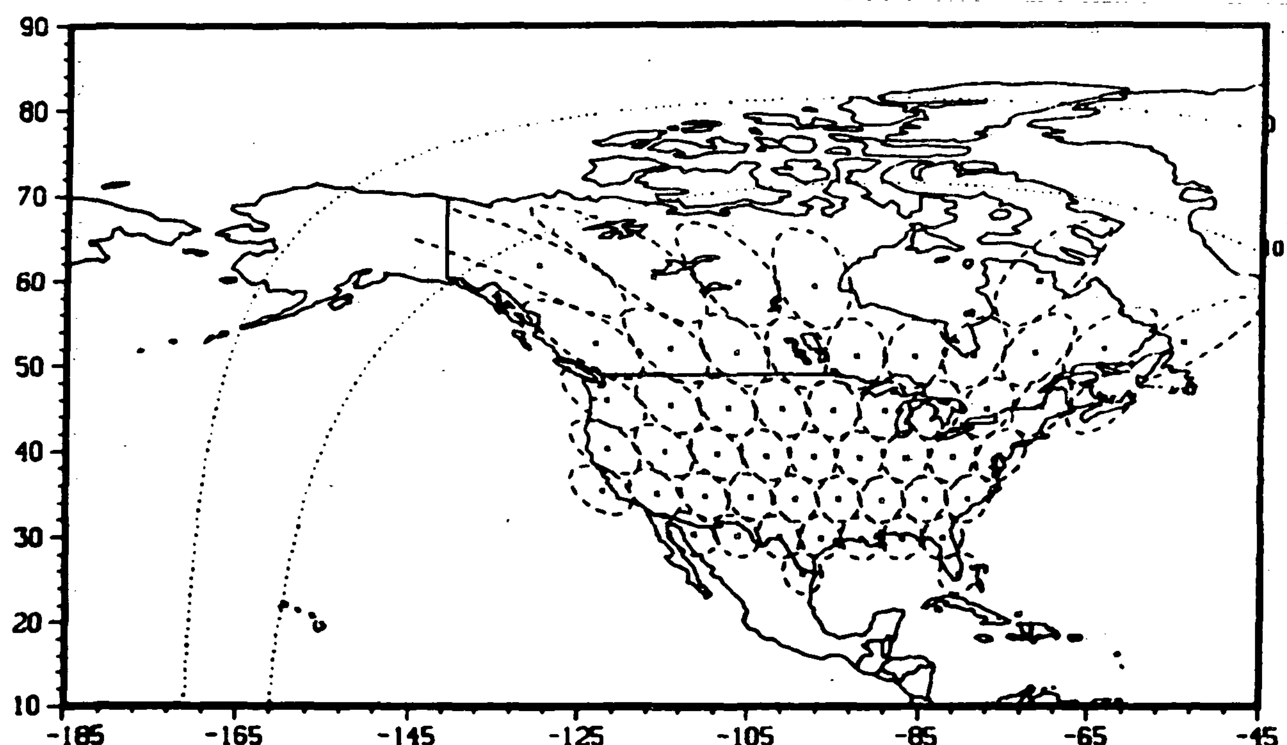

Figure 3.1-19. LMSS L-Band Antenna Spot Beams Beamwidth: 0.70° by 0.70° Geographic Coordinates

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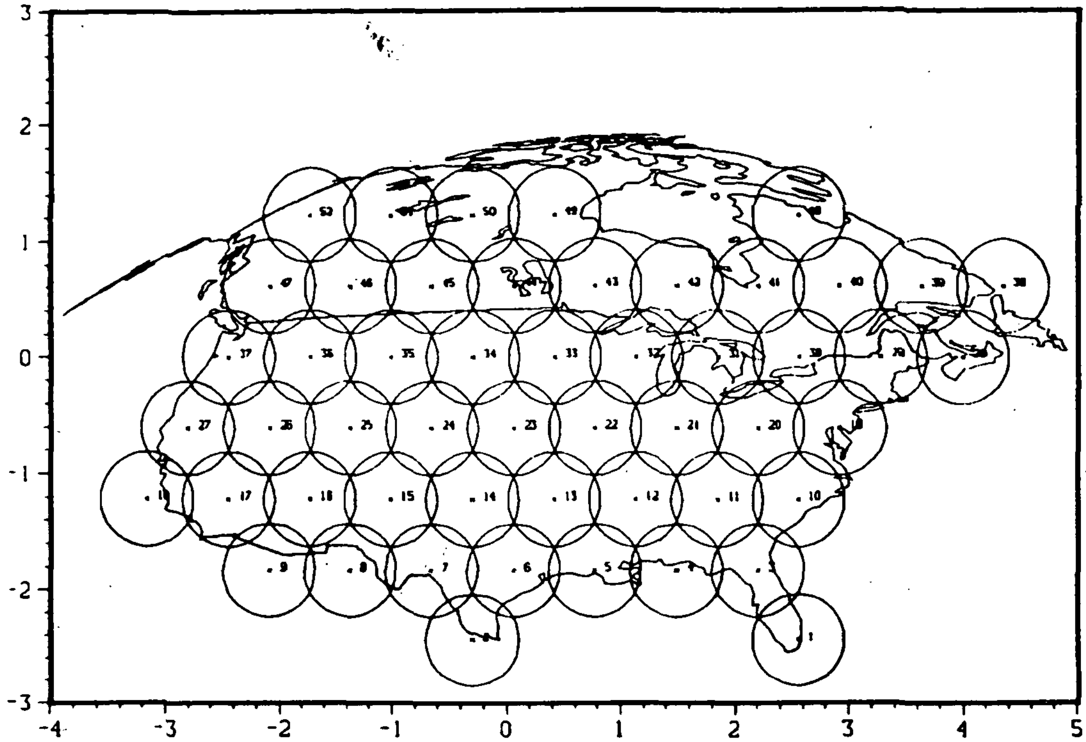

Figure 3.1-20. LMSS L-Band Antenna Spot Beams Beamwidth: 0.81° by 0.81° Focal Plane Coordinates

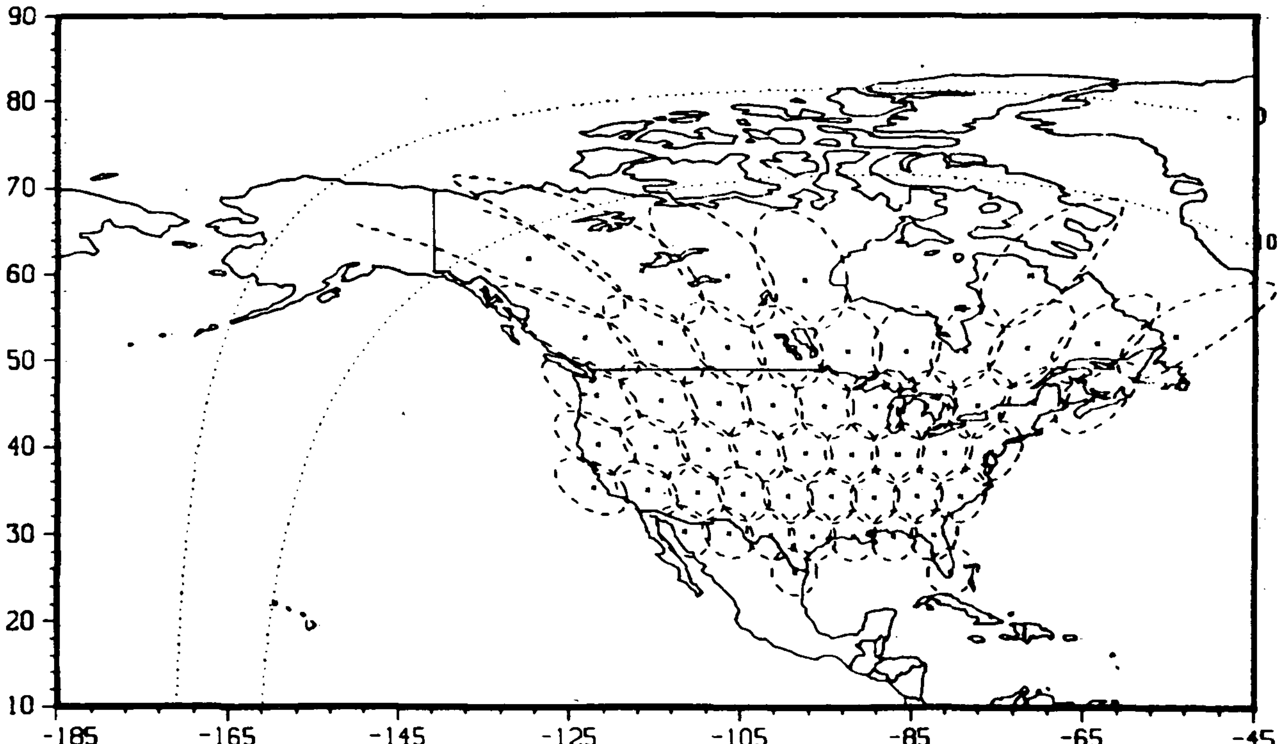

Figure 3.1-21. LMSS L-Band Antenna Spot Beams Beamwidth: 0.81° by 0.81° Geographic Coordintes

3.2 CONCEPT 2 - FIXED SATELLITE SERVICE - 20% MARKET SHARE

3.2.1 SYSTEM DESCRIPTION

3.2.1.1 Block Diagram and Summary Description

A summary of Concept 2 is provided in Table 3.2-1. This platform concept provides sufficient communications capacity to permit transmission of 20 percent of fixed satellite service (FSS) traffic for its 1998 time of utilization. Such traffic consists of the trunking and customer premises services (CPS) described earlier in this report. All three frequency bands, (C, Ku and Ka) are used for these transmissions operating within the following limits:

Band	Receive (GHz)	Transmit (GHz)	Available Bandwidth (MHz)
C	5.945-6.425	3.7-4.2	500
Ku	14.0-14.5	11.7-12.2	500
Ka	27.5-30.0	17.7-20.2	2500

A primary objective in the development of this concept is that of maximum utilization of C- and Ku-band to maintain maximum compatibility with existing ground terminal equipment, which will be in place in 1998, as well as to take advantage of the more favorable transmission conditions in these bands. The total traffic requirement requires considerable dependence on the substantial capacity available in Ka-band, but it is felt that use of the three bands should be as balanced as is reasonably possible.

Consistent with such an approach and to allow maximum flexibility in establishing earth station characteristics, payload interconnectivity permits links between C-, Ku-, and Ka-band earth stations. To obtain such interconnectivity without extensive use of onboard baseband processing, a 36-MHz channel bandwidth has been chosen as the system standard and interconnectivity is achieved largely by IF traffic matrix switching. Some exceptions to the 36 MHz standard are made for dedicated high rate links as described in Section 3.2.4.

The payload is thus of channelized design. Appropriate configuration of the onboard traffic matrix switches permits handling a large variety of traffic types within each channel. These range from narrowband FM SCPC to wideband TDMA. Taking advantage of spot and CONUS coverage beams, traffic may be received or distributed in a number of different transmission modes such as point-to-point, point-to-multipoint, point-to-CONUS, and vice versa.

A block diagram of the communication subsystem is shown in Figure 3.2-1. C-, Ku-, and Ka-band inputs interface with the i.f. TDMA/Circuit switching matrix after appropriate down conversion to provide inputs in the 3.7- to 4.2-GHz range. The receiver/downconverters are followed by input multiplexers which define the various 36-MHz channels which interface with the i.f. TDMA/Circuit switching matrix. As indicated on the block diagram, the switching matrix is actually implemented using 25 x 25 and 12 x 12 matrices. Matrix outputs are upconverted (except C-band) to their appropriate transmit frequencies on a channel-by-channel basis, and are amplified and combined in the output multiplexers. Each output multiplexer corresponds to a downlink beam which may be formed by a single feedhorn or by a beam forming network (BFN) feeding a group of horns, depending on the spatial separation between adjacent beams.

TABLE 3.2-1. CONCEPT 2 SUMMARY

C-Band	Ku-Band	Ka-Band
• 23 0.5° Spot + CONUS • 109 Channels (36 MHz) • 60 Mbps/Channel • Power: - 0.35 W/Channel (Spot) - 10 W/Channel (CONUS)	• 23 0.5° Spot + CONUS • 76 Channels (36 MHz) • 60 Mbps/Channel • Power: • - 5 W/Channel (Spot) • - 60 W/Channel (CONUS)	• 17 0.25° Fixed Spot • 6 0.25° Scan Spot • 326 Channels (36 MHz) • Power: • - 4 W/Channel (Clear) • - 40 W/Channel (Rain)
System Capacity 30.7 Gbps		
NOTES: (1) Trunking is via C and Ka (2) Customer Premises Service is Via Ku and Ka		

Where sufficient traffic exists between certain beam (city) pairs, dedicated channels are established which bypass the switching matrix as mentioned above. Such links are reserved for Ka-band since cities having high enough traffic to justify dedicated links already require Ka-band terminals. This band lends itself more readily to wideband operation.

Six Ka-band scanning beams are shown in the block diagram (Figure 3.2-1). They cover with alternating polarization the six traffic zones into which CONUS has been divided as shown in Figure 3.2-2. The input from each scanning beam is downconverted and channelized in an input multiplexer. Each multiplexer output is fed to the baseband processor where it is demodulated, stored in a buffer memory and switched via baseband matrix to an appropriate output modulator. Up-conversion to the desired transmit frequency is provided and is followed by high-power amplification, then channel filtering and combining in the output multiplexers. Beam switching networks (BSN) direct the outputs of each of the six output multiplexers to each of the six scanning downlink beams.

Coverage provided is considered in detail in Section 3.2.2. Briefly, C- and Ku-band coverages are similar, consisting of 23 fixed spot beams of one linear polarization and a single fixed CONUS beam of orthogonal polarization. Ka-band coverage also consists of spot beam and CONUS coverage. However, in this case, 17 spot beams are used and CONUS coverage is provided by the six scanning spot beams mentioned above.

3.2.1.2 C-Band Subsystem

The C-band subsystem is reserved for trunking traffic, partly because a good deal of C-band ground terminal equipment would already be in use and also because Ku-band is better suited to CPS use due to the smaller antenna used. This allocation is flexible, however, and nothing in the design of the platform precludes the use of Ku-band for trunking or C-band for CPS since interconnection between the different transmission bands is provided. The assumption of C-band trunking has been made for traffic allocation purposes which are described in Section 3.2.3.

The C-band portion shown in Figure 3.2-3 is a dual linearly-polarized system providing single beam CONUS coverage on one polarization (vertical in the

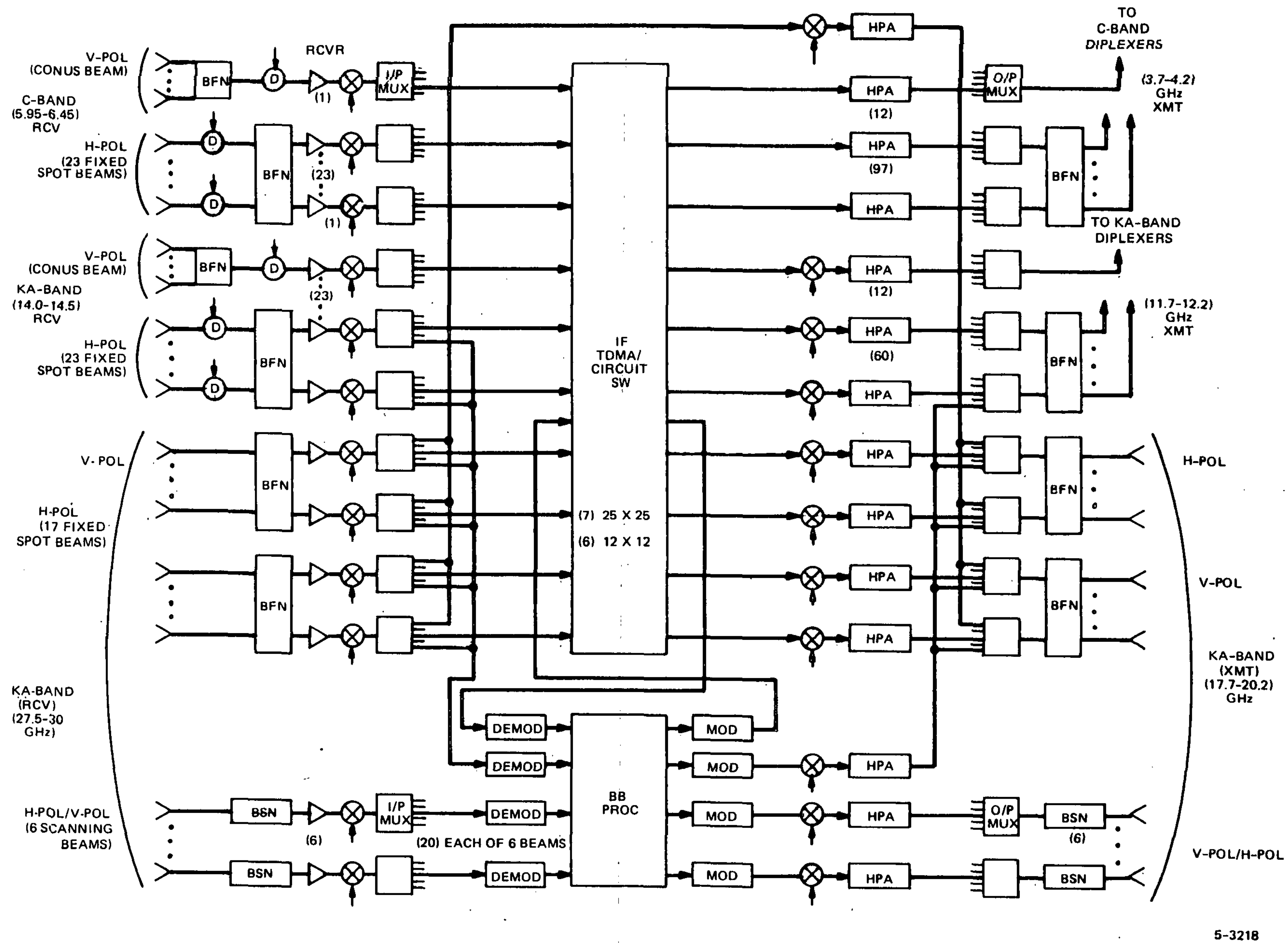

Figure 3.2-1. Block Diagram for 20% FSS Payload - Concept 2

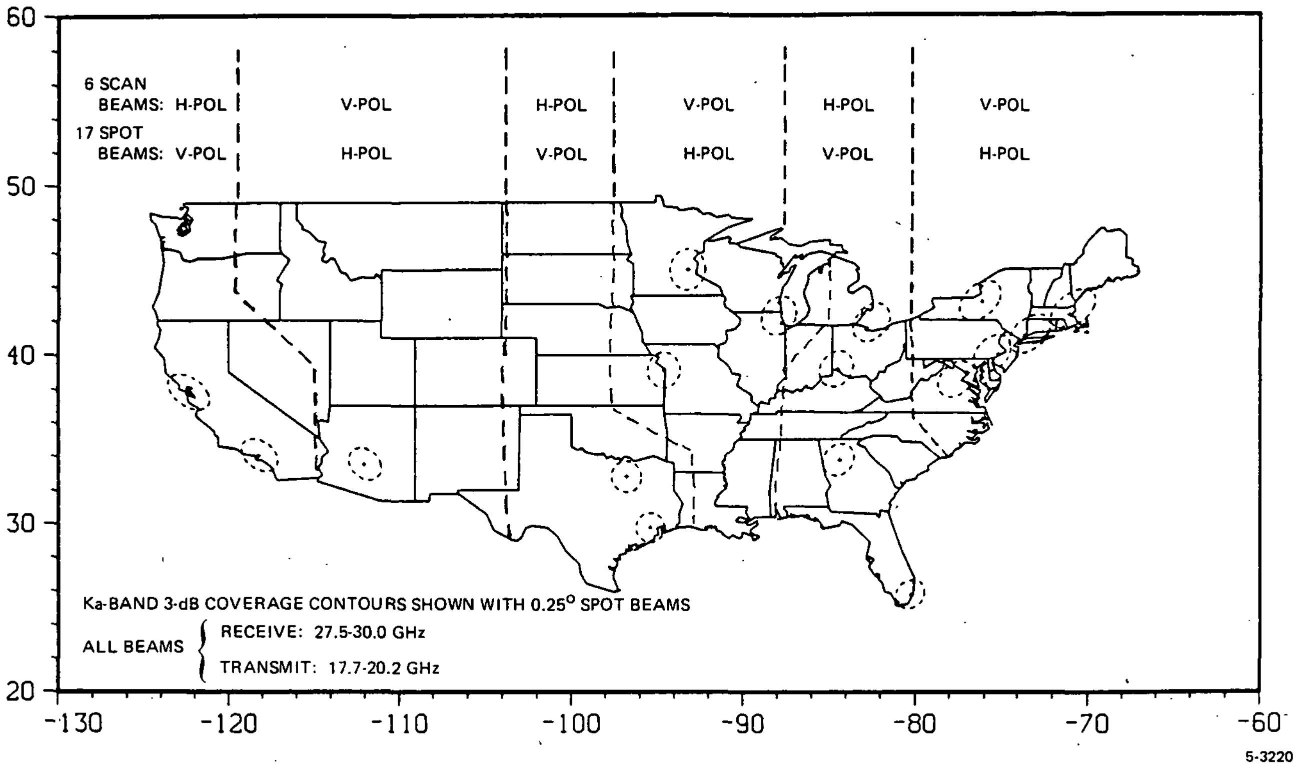

Figure 3.2-2. Concept 2: Ka-Band 3-dB Coverage Contours

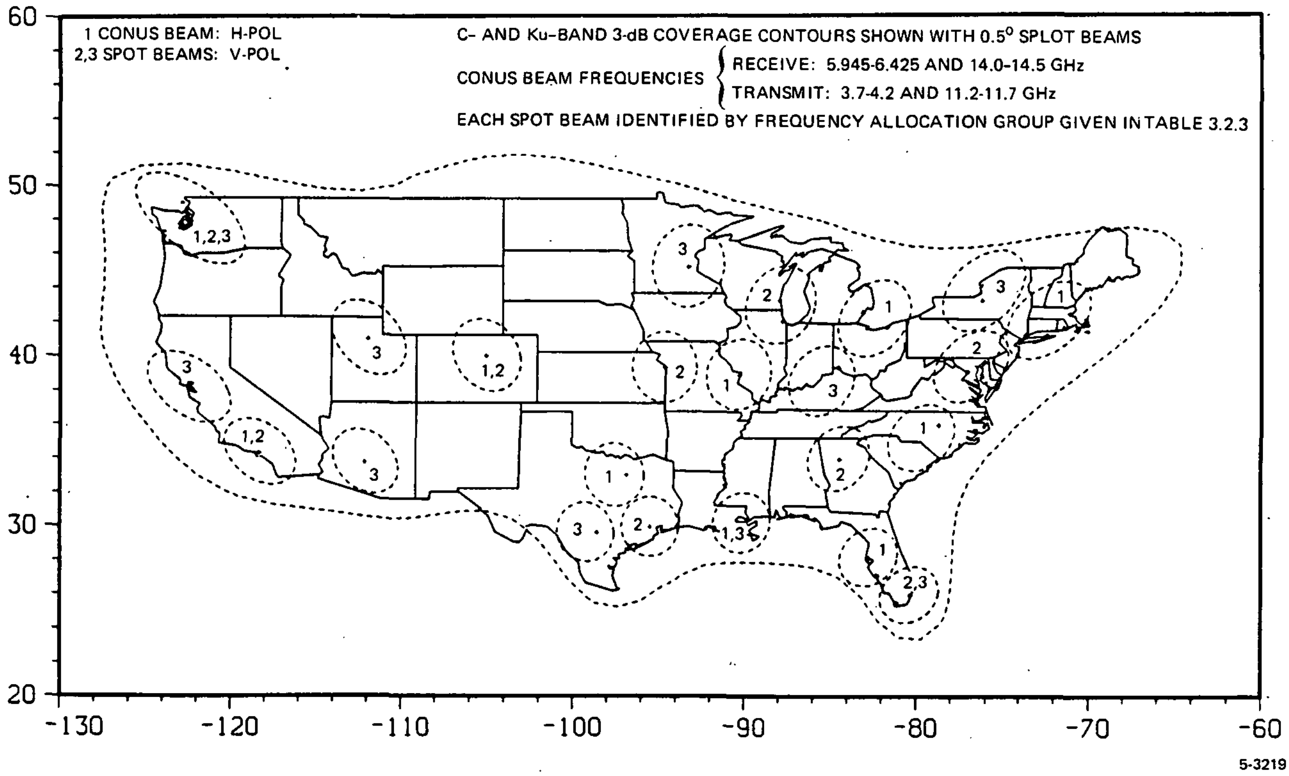

Figure 3.2-3. Concept 2: C- and Ku-Band 3-dB Coverage Contours

figure) and 23 fixed spot beams to high-traffic centers on the orthogonal polarization. A separate antenna is proposed for each polarization with each antenna supporting transmit and receive functions. The CONUS beam is formed using a 2-meter, solid deployable dish in combination with a feed array having 6 to 12 horns which would assure an efficient coverage pattern. This antenna would provide very good polarization performance so the extent of cross-polarization interference in orthogonally polarized spot beams can be expected to be well below 30 dB. This antenna design is comparable to those in current use and would involve a minimum risk.

The fixed spot beam coverage of 23 traffic centers is obtained using a Cassegrain type of antenna having an unfurlable 10.5-meter main reflector which provides 0.5° beams. Polarization selectivity is provided by the subreflector, which assures good cross-polarization isolation for the receivers. Some cross-polarization degradation in transmit can be expected for energy reflected from the unfurlable antenna surface toward the earth. It is expected that such degradation can be held to limits such that side lobe levels do not affect CONUS coverage receivers of orthogonal polarization. Transmit degradation within the main lobe is of no consequence since no ground reception of opposite polarization would be carried out in the main lobe.

As shown in the block diagram, CONUS inputs in the 5.95- to 6.45-GHz band enter a single active receiver via a wideband beam forming network (BFN) and diplexer, and are downconverted to the usual 3.7- to 4.2-GHz transmit band before entering the 36-MHz filters in the 12-channel input multiplexer. Outputs are fed to the i.f. TDMA/Circuit Switch Assembly which consists of seven switching matrices having 25 x 25 operating channels and six matrices having 12 x 12 operating channels. The switching matrix assembly is described in Section 3.2.4.

Similarly, inputs from the 23 spot beams are downconverted to the 3.7- to 4.2-GHz band and are fed to the switching matrix assembly via input multiplexers having 36-MHz channels. Each spot beam is provided with a separate receiver/downconverter and 12-channel input multiplexer.

The switching matrix will typically operate in TDMA fashion, providing rapid switching among inputs and outputs so as to establish the desired transmissions typically at 60 Mb/s. In cases where continuous transmissions between various transmit and receive sites should be desired, the matrix switches can be set up in a long term configuration which would also permit channel sharing for narrowband signals.

Outputs of the switching matrix assembly are connected to solid state power amplifiers having output levels of approximately 10 watts for CONUS channels and 0.35 watt for spot beam channels. Fourteen 10-watt amplifiers are required to assure operation of 12 active CONUS channels and 109 0.35-watt units assure the operation of 97 active spot beam channels. The power amplifiers feed contiguous output multiplexers having up to 12 channels of 36-MHz bandwidth.

3.2.1.3 Ku-Band Subsystem

It is planned that Ku-band capacity would be used largely for CPS traffic due to the reduced antenna size (relative to C-band) required to assure satisfactory link performance. As mentioned previously, this does not exclude its use for trunking traffic if it appears desirable.

The general configuration of the Ku-band system is much like that of the C-band system in the sense that CONUS coverage by a single beam is provided in one polarization while 0.5° spot beams are provided on the opposite polarization to 23 cities. CONUS coverage is assured by a 1.5-meter dish which would be located under a larger 3.5-meter spot beam reflector. The two reflectors form a single deployable assembly. They are illuminated by two horn arrays in direct feed configurations. Cross-polarization isolation is assured by appropriate gridding of the reflectors which should provide isolation in excess of 30 dB.

As shown in the block diagram, inputs from each beam are downconverted from the 14.0- to 14.5-GHz receive band to the 3.7- to 4.2-GHz band used for the i.f. switching matrices. As in the C-band case, downconverted signals from each of the 24 receivers are fed into 12-channel input multiplexers having 36-MHz channels. Most multiplexer outputs are connected to appropriate switching matrix inputs. However, some outputs are connected directly to demodulator inputs in the baseband processor which is associated principally with the Ka-band subsystem. Such connections permit direct transmissions from high-traffic locations to receiving sites that are outside metropolitan areas and which are serviced by the Ka-band scanning beam described in Section 3.2.1.4.

Outputs from the switching matrices are upconverted on a per channel basis and fed to the solid-state power amplifiers which provide 60-watt output levels for channels in the CONUS beam and 5-watt outputs in spot beam channels. There are 14 (12 active) of the former and 76 (64 active) of the latter. Power amplifier outputs are fed into the contiguous output multiplexers which feed up to 12 36-MHz channels to each of the beams of the antenna subsystems. Diplexers permit use of the same reflector for receive and transmit functions.

3.2.1.4 Ka-Band Subsystem

The Ka-band subsystem handles trunking and CPS traffic that cannot be handled by C- and Ku-bands. Its use tends to be concentrated at high-traffic centers while other cities having lower traffic loads do not require Ka-band links. The interconnection between C- and Ku-band links on the one hand and Ka-band links on the other is handled easily on board by fixed connections between inputs and outputs of the various antenna subsystems and those of the i.f. switching matrices. Traffic requirements for the Ka-band system are considered in greater detail in Section 3.2.3.

The Ka-band portion of the payload which is shown in the block diagram (Figure 3.2-1) is a dual linearly polarized system which provides fixed spot beam and scanning beam coverage in a fashion which is a logical extension of concepts and technology to be demonstrated on the NASA/ACTS program. The Ka-band subsystem uses separate dual polarized antennas for the receive and transmit functions. Seventeen fixed spot beams are provided. This number is somewhat smaller than the number of C- and Ku-band spot beams because the available capacity in those bands is sufficient to satisfy traffic requirements for a number of cities, as noted above. The spot beams are approximately 0.25° in diameter and require solid deployable main reflectors 4.5 and 3 meters in diameter for the transmit and receive functions respectively. Each main reflector is associated with a subreflector illuminated by vertically and horizontally polarized feed horn arrays having outputs or inputs combined in a polarization selective surface located at a point intermediate between the feed horn array and the subreflector.

Coverage of CONUS locations, outside those illuminated by the seventeen fixed spot beams is assured by six separate and independent scanning spot beams using the same reflector fed by scan beam horn arrays and beam switching networks as shown in Figure 3.2-4. Each scanning beam is assigned to its own geographical zone. The zones are sized on the basis of equal traffic. The six zones are defined by dividing lines running roughly north and south with beam polarizations alternating between horizontal and vertical from one zone to the next. Fixed spot beams within any zone are of polarization which is orthogonal to that of the scan beam which covers that zone.

As shown in the block diagram, inputs from the fixed spot beams are handled in much the same way as are those for the C- and Ku-band subsystems. The input for each beam enters its receiver in the 27.5- to 30-GHz band and is down converted to the frequency band used for i.f. switching. For Ka-band channels which must interface with C- or Ku-band channels, down conversion is to the 3.7- to 4.2-GHz band. Where Ka-band input channels will feed Ka-band output channels, down conversion can be to frequencies outside the 3.7- to 4.2-GHz band. It appears that multiple frequency down conversion for any given beam input can thus be avoided. This applies to dedicated channels which can be seen to bypass the i.f. switch matrix by two paths. Starting from the output of the input multiplexers it can be seen that one path consists of those channels which are simply upconverted, amplified to high-power levels, and then fed directly to the appropriate inputs of the output multiplexers. The second path consists of multiplexer outputs which are fed directly to input demodulators associated with the baseband processor.

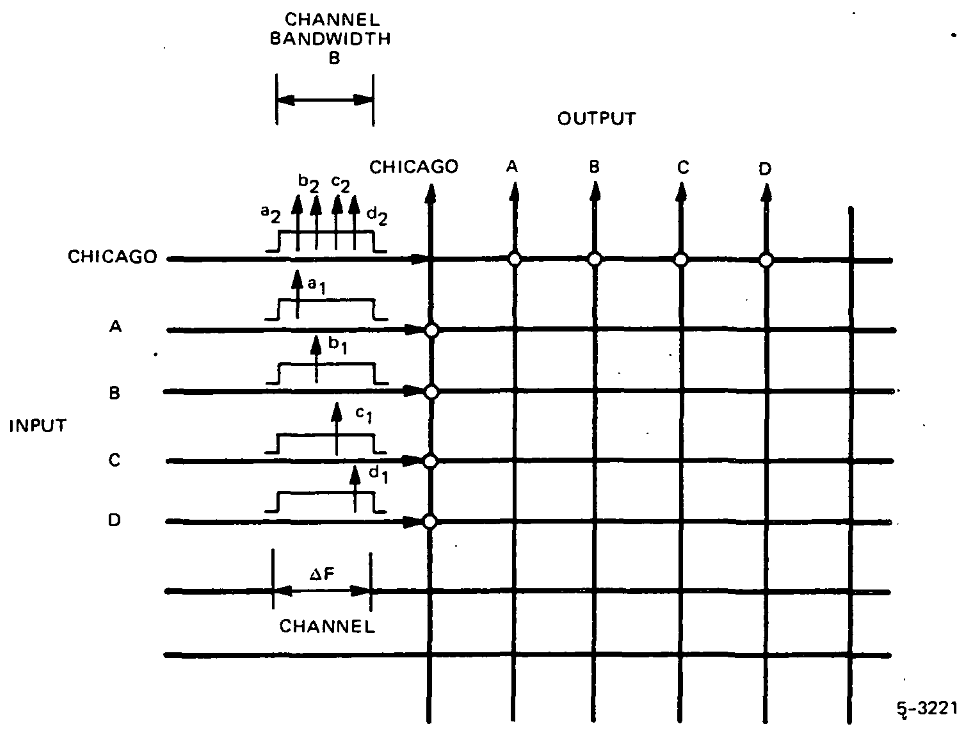

Figure 3.2-4. Long Term Multicarrier Matrix Connection

Signal bandwidths for all channels passing through the i.f. switch must be 36-MHz to assure compatibility with the Cand Ku-band channels with which the Ka-band subsystem interfaces. However, dedicated channels are of wider bandwidth, depending on the traffic load to be handled on any particular link.

Inputs from the six scanning beams are downconverted to an i.f. frequency suitable for input multiplexer filtering. For the present, 36-MHz channel bandwidths have been assumed. This appears to provide best compatibility with the frequency plan for the fixed spot beams. But the fact that scan beam uplinks interface only with the onboard demodulators would allow some freedom to modify that value if it were advantageous. Each spot beam carries 20 channels of traffic each of which interfaces with a demodulator. Each input channel carries a 60 Mb/s data stream in TDMA format using a QPSK type of modulation. There are thus 120 demodulators of this type required to interface with the six scanning beams. Additional demodulators are required to interface with dedicated Ka-band uplinks as well as i.f. switched channels from fixed spot beams, carrying traffic destined for CONUS points which are accessible only via the scanning beam. A total of approximately 200 demodulators provide inputs to the buffer memory and baseband matrix switching portions of the baseband processor. Outputs of these sections are then fed to a corresponding number of modulator channels and are upconverted in the output multiplexers, then sent to the appropriate antenna for transmission. Outputs so generated may appear at inputs to the scan or fixed beam Ka-band antenna feeds as well as at inputs to the C- or Ku-band antenna feeds. In the latter case, modulator outputs in the 3.7- to 4.2-GHz range are fed into the i.f. TDMA switch where they are integrated into the TDMA transmission format in the appropriate downlink channel.

3.2.2 COVERAGE

Typical antenna coverage diagrams for the C- and Ku-band subsystems are shown in Figure 3.2-3 and those for Ka-band are given in Figure 3.2-2. These correspond to satellite orbital positions in the range of 90 to 100° west longitude. City locations corresponding to spot beams are given in Section 3.2.3. Spot beam patterns correspond to 3 dB beamwidths. It is assumed that spatial isolation is sufficient to permit frequency reuse when the center-to-center spacing between any two beams is equal to two beamwidths or more. This results in a requirement for spectrum sharing between beams having closer spacing. It is particularly pertinent in the C- and Ku-band cases with their larger 0.5° beams. For the Ka-band case there are fewer such cases and these are concentrated in the Boston-Washington D.C. corridor.

The Ka-band case also shows the six scanning beam zones of equal traffic into which the CONUS area is divided. The boundaries shown are initial estimates which follow a rule of generally north-south scanning boundaries. The boundaries deviate from this rule to provide a one-beamwidth spacing between fixed spot beams and the scanning zone boundaries. This assures acceptable spatial isolation between spot beams in one zone and the scanning beam in an adjacent zone, both of which are of like polarization.

Whenever possible the frequency plan will be designed to avoid interference in such cases, but that will not always be possible, especially in regions having heavy traffic.

3.2.3 TRAFFIC DISTRIBUTION

Trunking and CPS traffic requirements, expressed in 36-MHz transponder channels, are summarized in Table 3.2-2. It shows 28 cities which account for 75% of the total with the remaining 25% of trunking and CPS traffic attributed to the rest (Other) of the CONUS area. The traffic shown is assigned first to C- and Ku-bands for trunking and CPS, respectively. Remaining traffic needs are then assigned to the Ka-band. This is shown in Table 3.2-3 where the original city list has been shortened from 28 to 23 entries because some of the 0.5° spot beams adopted for C- and Ku-bands include pairs of cities (e.g., New York/Boston, Los Angeles/Anaheim). This corresponds to the number of beams shown in Figure 3.2-1. Due to the closeness of many of the beams, frequency reuse is somewhat limited and the 12 channels available have been divided into the three frequency groups in the proportions shown at the bottom of Table 3.2-3. The three groups are then assigned to the listed cities or city pairs as shown. In translating traffic requirements to assignments in C-, Ku-, and Ka-bands, the number of 36-MHz channels involved has been rounded up to the nearest half channel. It can be seen that C-band satisfies trunking requirements for eight city pairs while Ku-band satisfies CPS requirements for 17 of them, each relative to a total of 23. The overflow from these assignments which represents Ka-band requirements (trunking, CPS and total needs) is shown in the last three columns of the table. The extent to which the use of Ka-band is necessary for satisfaction of requirements of the high-traffic centers can be seen in the table. The major portion of the traffic load is carried in Ka-band.

Table 3.2-3 shows C- and Ku-band traffic allocations since it is based on a city list using 0.5° spot beams as shown in Figure 3.2-3. It also shows the cities to which Ka-band service must be provided and which serves as a basis for establishment of the Ka-band coverage diagram given in Figure 3.2-2. To better define Ka-band traffic allocations, it is necessary to further modify the city list to accommodate coverage provided by the 0.25° beams. The Ka-band city list is given in Table 3.2-4 where city pairs have been separated when individual cities fall in separate beams as shown in Figure 3.2-2. Traffic allocation in those cases is proportional to the city traffic originally presented in Table 3.2-2. Assuming 40-MHz spacing with 36-MHz channels, there are 62 channels potentially available in the 2.5 GHz of usable Ka-band frequency space. It can be seen from Table 3.2-4 and the beam coverage pattern of Figure 3.2-2 that the Boston-Washington, D.C. corridor presents the most stringent requirement insofar as bandwidth use is concerned. A total of 57 channels are required for the adjacent Boston-New York beams and 55 are required for the New York-Philadelphia pair, leaving a minimum margin of five channels of the same polarization. The question of frequency planning is considered in greater detail in Section 3.2.6 where several alternatives, depending on multiplexer capabilities, are presented.

3.2.4 TRAFFIC MATRICES

3.2.4.1 Allocation of Dedicated Channels

Using the city list given in Table 3.2-4, approximate traffic matrices for trunking and CPS have been established as shown in Tables 3.2-5 and 3.2-6. These matrices are established on the assumption that traffic between any two city pairs is symmetrical and proportional to the total trafffic for the city, without regard to geographic proximity. Time and column totals for each city

TABLE 3.2-2. BASIC TRAFFIC REQUIREMENTS FOR 20% MARKET CAPTURE EXPRESSED IN 36-MHz CHANNELS (CONCEPT 2)

City	Total Requirements	
	Trunking	CPS
New York	40.2	11.2
Los Angeles	21.0	6.0
Chicago	19.1	5.4
San Francisco	15.3	4.2
Boston	14.9	4.0
Detroit	13.8	3.8
Washington	13.8	3.9
Cincinnati	13.5	3.8
Philadelphia	12.6	3.6
Cleveland	12.2	3.4
Dallas	10.1	2.8
Anaheim	9.0	2.6
Atlanta	8.1	1.4
Houston	7.2	2.2
Syracuse	6.8	2.0
Miami	6.6	1.8
St. Louis	6.1	1.6
Raleigh	5.8	1.6
Tampa	5.4	1.6
Minneapolis	5.1	1.4
Seattle	5.1	1.4
Kansas City	4.5	1.2
Denver	4.4	1.2
Milwaukee	3.1	1.0
San Antonio	2.8	0.8
Phoenix	2.6	0.8
New Orleans	2.6	0.8
Salt Lake City	1.8	0.4
Totals - Fixed Spots	273.5	76.6
Others	91.1	25.5
Totals - All	364.6	102.1

in the matrices approximate values given in Table 3.2-2 with a precision that is more than sufficient for purposes of traffic allocation. Total traffic to be handled includes all bands (C, Ku, Ka) and so the matrices must satisfy total traffic given in Table 3.2-2 on a city-by-city basis. Traffic is simply combined for the city pairs Los Angeles/Anaheim, Chicago/ Milwaukee, and Detroit/Cleveland. Values in the tables are given in terms of equivalent 36-MHz channels of traffic. These matrices provide the basis for the sizing of the i.f. TDMA matrix switches. Each intersection on a traffic matrix shows the number of 36-MHz channels to be established between the corresponding city pairs.

TABLE 3.2-3. TRAFFIC ASSIGNMENT TO C- AND Ku-BANDS SHOWING OVERFLOW TO Ka-BAND (CONCEPT 2)

City	Freq. Group (1)	Total Requirements			C-Band Trunking Channels	Ku-Band CPS	Overflow to Ka-Band		
		Trunking	CPS	Avail. C/Ku			Trunking	CPS	Total
NY/Boston	1	55.1	15.2	7	7.0	7.0	48.5	8.5	57.0
LA Anaheim	1,2	30.0	8.6	10	10.0	9.0	20.0	0	20.0
Wash/Phila	2	26.4	7.4	3	3.0	3.0	23.5	4.5	28.0
Detroit/ Cleveland	1	26.0	7.2	7	7.0	7.0	19.0	0.5	19.5
Chicago/ Milwaukee	2	22.2	6.4	3	3.0	3.0	19.5	3.5	23.0
San Francisco	3	15.3	4.2	2	2.0	2.0	13.5	2.5	16.0
Cincinnati	3	13.5	3.8	2	2.0	2.0	11.5	2.0	13.5
Dallas	1	10.1	2.8	7	7.0	3.0	3.5	0	3.5
Atlanta	2	8.1	2.2	3	3.0	2.5	5.5	0	3.5
Houston	2	7.2	2.2	3	3.0	2.5	4.5	0	4.5
Syracuse	3	6.8	2.0	2	2.0	2.0	5.0	0	5.0
Miami	2,3	6.6	1.8	5	5.0	2.0	2.0	0	2.0
St. Louis	1	6.1	1.6	7	6.5	2.0	0	0	0
Raleigh	1	5.8	1.6	7	6.0	2.0	0	0	0
Tampa	1	5.4	1.6	7	5.5	1.5	0	0	0
Minneapolis	3	5.1	1.4	2	2.0	1.5	3.5	0	3.5
Seattle	1,2,3	5.1	1.4	12	5.5	1.5	0	0	0
Kansas City	2	4.5	1.2	3	3.0	1.5	1.5	0	1.5
Denver	1,2	4.4	1.2	10	4.5	1.5	0	0	0
San Antonio	3	2.8	0.8	3	3.0	1.0	0	0	0
New Orleans	1,3	2.6	0.8	9	3.0	1.0	0	0	0
Phoenix	3	2.6	0.8	2	2.0	1.0	1.0	0	1.0
Salt Lake City	3	1.8	0.4	2	2.0	0.5	0	0	0
Total Fixed Spot Beams		273.5	76.6	118	97.0	60.0	182.0	21.5	203.5
Other		91.1	25.5	12	12.0(2)	12.0(2)	79.0(3)	13.5(3)	92.5
Totals		364.6	102.1	130	109.0	72.0	261.0	35.0	296.0

(1) Freq. Group Ch Allocation/12

Freq. Group	Ch Allocation/12
1	7
2	3
3	2

(2) CONUS Coverage
(3) Scanning Beams

TABLE 3.2-4. TRAFFIC ASSIGNMENT FOR Ka-BAND BY CITY (CONCEPT 2)

City	Ka-Band Channels		
	Trunking	CPS	Total
New York	35.4	6.3	41.7
Los Angeles/Anaheim	20.0	0	20.0
Chicago/Milwaukee	19.5	3.5	23.0
San Francisco	13.5	2.5	16.0
Boston	13.1	2.2	15.3
Detroit/Cleveland	19.0	0.5	19.5
Washington	12.3	2.3	14.6
Cincinnati	11.5	2.0	13.5
Philadelphia	11.2	2.2	13.4
Dallas	3.5	0	3.5
Atlanta	5.5	0	5.5
Houston	4.5	0	4.5
Syracuse	5.0	0	5.0
Miami	2.0	0	2.0
St. Louis	0	0	0
Raleigh	0	0	0
Tampa	0	0	0
Minneapolis	3.5	0	3.5
Seattle	0	0	0
Kansas City	1.5	0	1.5
Denver	0	0	0
San Antonio	0	0	0
Phoenix	1.0	0	1.0
New Orleans	0	0	0
Salt Lake City	0	0	0
Totals - Fixed Spots	182.0	21.5	203.5
Others	79.0	13.5	92.5
Totals - All	261.0	35.0	296.0

It can be seen in the traffic matrices that a certain number of values exceed unity; e.g., New York-San Francisco where 2.03 channels of trunking traffic are predicted. Not all such intercity traffic need pass through the switching matrices but may be accommodated by dedicated connections established on board the platform. Thus two hard-wired connections would exist between New York receive channels and San Francisco transmit channels, as shown in the block diagram of Figure 3.2-1, and the remaining 0.03 channel of traffic between the two cities would be handled by the IF matrix switch. Comparison of Table 3.2-4 with the two traffic matrices shows that all city pairs having one channel or more of mutual traffic are provided with Ka-band facilities. It has been decided then to assign all dedicated channels to Ka-band rather than C- or Ku-bands to maximize flexibility in allocation of city traffic through the latter.

TABLE 3.2-5. MATRIX OF TOTAL TRUNKING TRAFFIC - CONCEPT 2

	New York	Los Angeles/Anaheim	Chicago/Milwaukee	San Francisco	Boston	Detroit/Cleveland	Washington	Cincinnati	Philadelphia	Dallas	Atlanta	Houston	Syracuse	Miami	St. Louis	Raleigh	Tampa	Minneapolis	Seattle	Kansas City	Denver	San Antonio	Phoenix	New Orleans	Salt Lake City	Others
New York	0.00	3.88	2.87	1.98	1.93	3.36	1.78	1.75	1.63	1.31	1.05	0.93	0.88	0.85	0.79	0.75	0.70	0.66	0.66	0.58	0.57	0.36	0.34	0.34	0.23	10.04
Los Angeles/Anaheim	3.88	0.00	2.03	1.40	1.37	2.38	1.26	1.24	1.15	0.93	0.74	0.66	0.62	0.60	0.56	0.53	0.49	0.47	0.47	0.41	0.40	0.26	0.24	0.24	0.16	7.49
Chicago/Milwaukee	2.87	2.03	0.00	0.99	0.97	1.69	0.90	0.88	0.82	0.66	0.53	0.47	0.44	0.43	0.40	0.38	0.35	0.33	0.33	0.29	0.29	0.18	0.17	0.17	0.12	5.55
San Francisco	1.98	1.40	0.99	0.00	0.64	1.11	0.59	0.58	0.54	0.43	0.35	0.31	0.29	0.28	0.26	0.25	0.23	0.22	0.22	0.19	0.19	0.12	0.11	0.11	0.08	3.82
Boston	1.93	1.37	0.97	0.64	0.00	1.08	0.57	0.56	0.52	0.42	0.34	0.30	0.28	0.27	0.25	0.24	0.22	0.21	0.21	0.19	0.18	0.12	0.11	0.11	0.07	3.72
Detroit/Cleveland	3.36	2.38	1.69	1.11	1.08	0.00	1.09	1.07	1.00	0.80	0.64	0.57	0.54	0.52	0.48	0.46	0.43	0.40	0.40	0.36	0.35	0.22	0.21	0.21	0.14	6.50
Washington	1.78	1.26	0.90	0.59	0.57	1.09	0.00	0.50	0.47	0.38	0.30	0.27	0.25	0.25	0.23	0.22	0.20	0.19	0.19	0.17	0.16	0.10	0.10	0.10	0.07	3.45
Cincinnati	1.75	1.24	0.88	0.58	0.56	1.07	0.50	0.00	0.46	0.37	0.30	0.26	0.25	0.24	0.22	0.21	0.20	0.19	0.19	0.16	0.16	0.10	0.09	0.09	0.07	3.37
Philadelphia	1.63	1.15	0.82	0.54	0.52	1.00	0.47	0.46	0.00	0.34	0.27	0.24	0.23	0.22	0.21	0.20	0.18	0.17	0.17	0.15	0.15	0.09	0.09	0.09	0.06	3.15
Dallas	1.31	0.93	0.66	0.43	0.42	0.80	0.38	0.37	0.34	0.00	0.21	0.19	0.18	0.17	0.16	0.15	0.14	0.13	0.13	0.12	0.11	0.07	0.07	0.07	0.05	2.52
Atlanta	1.05	0.74	0.53	0.35	0.34	0.64	0.30	0.30	0.27	0.21	0.00	0.15	0.14	0.13	0.12	0.12	0.11	0.10	0.10	0.09	0.09	0.06	0.05	0.05	0.04	2.02
Houston	0.93	0.66	0.47	0.31	0.30	0.57	0.27	0.26	0.24	0.19	0.15	0.00	0.12	0.12	0.11	0.10	0.10	0.09	0.09	0.08	0.08	0.05	0.05	0.05	0.03	1.80
Syracuse	0.88	0.62	0.44	0.29	0.28	0.54	0.25	0.25	0.23	0.18	0.14	0.12	0.00	0.11	0.10	0.10	0.09	0.08	0.08	0.07	0.07	0.05	0.04	0.04	0.03	1.70
Miami	0.85	0.60	0.43	0.28	0.27	0.52	0.25	0.24	0.22	0.17	0.13	0.12	0.11	0.00	0.10	0.09	0.09	0.08	0.08	0.07	0.07	0.05	0.04	0.04	0.03	1.65
St. Louis	0.79	0.56	0.40	0.26	0.25	0.48	0.23	0.22	0.21	0.16	0.12	0.11	0.10	0.10	0.00	0.09	0.08	0.07	0.07	0.07	0.06	0.04	0.04	0.04	0.03	1.52
Raleigh	0.75	0.53	0.38	0.25	0.24	0.46	0.22	0.21	0.20	0.15	0.12	0.10	0.10	0.09	0.09	0.00	0.07	0.07	0.07	0.06	0.06	0.04	0.04	0.04	0.02	1.45
Tampa	0.70	0.49	0.35	0.23	0.22	0.43	0.20	0.20	0.18	0.14	0.11	0.10	0.09	0.09	0.08	0.07	0.00	0.06	0.06	0.06	0.06	0.04	0.03	0.03	0.02	1.35
Minneapolis	0.66	0.47	0.33	0.22	0.21	0.40	0.19	0.19	0.17	0.13	0.10	0.09	0.08	0.08	0.07	0.07	0.06	0.00	0.06	0.05	0.05	0.03	0.03	0.03	0.02	1.27
Seattle	0.66	0.47	0.33	0.22	0.21	0.40	0.19	0.19	0.17	0.13	0.10	0.09	0.08	0.08	0.07	0.07	0.06	0.06	0.00	0.05	0.05	0.03	0.03	0.03	0.02	1.27
Kansas City	0.58	0.41	0.29	0.19	0.19	0.36	0.17	0.16	0.15	0.12	0.09	0.08	0.07	0.07	0.07	0.06	0.06	0.05	0.05	0.00	0.04	0.03	0.03	0.03	0.02	1.12
Denver	0.57	0.40	0.29	0.19	0.18	0.35	0.16	0.16	0.15	0.11	0.09	0.08	0.07	0.07	0.06	0.06	0.06	0.05	0.05	0.04	0.00	0.03	0.03	0.03	0.02	1.10
San Antonio	0.36	0.26	0.18	0.12	0.12	0.22	0.10	0.10	0.09	0.07	0.06	0.05	0.05	0.05	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.00	0.01	0.01	0.01	0.70
Phoenix	0.34	0.24	0.17	0.11	0.11	0.21	0.10	0.09	0.09	0.07	0.05	0.05	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.01	0.00	0.01	0.01	0.65
New Orleans	0.34	0.24	0.17	0.11	0.11	0.21	0.10	0.09	0.09	0.07	0.05	0.05	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.01	0.01	0.00	0.01	0.65
Salt Lake City	0.23	0.16	0.12	0.08	0.07	0.14	0.07	0.07	0.06	0.05	0.04	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.00	0.45
Others	10.04	7.49	5.55	3.82	3.72	6.50	3.45	3.37	3.15	2.52	2.02	1.80	1.70	1.65	1.52	1.45	1.35	1.27	1.27	1.12	1.10	0.70	0.65	0.65	0.45	22.78

TABLE 3.2-6. MATRIX OF TOTAL CPS TRAFFIC

	New York	Los Angeles/Anaheim	Chicago/Milwaukee	San Francisco	Boston	Detroit/Cleveland	Washington	Cincinnati	Philadelphia	Dallas	Atlanta	Houston	Syracuse	Miami	St. Louis	Raleigh	Tampa	Minneapolis	Seattle	Kansas City	Denver	San Antonio	Phoenix	New Orleans	Salt Lake City	Others
New York	0.00	1.10	0.82	0.54	0.51	0.92	0.50	0.49	0.46	0.36	0.28	0.28	0.26	0.23	0.21	0.21	0.21	0.18	0.18	0.15	0.15	0.10	0.10	0.10	0.05	2.59
Los Angeles/Anaheim	1.10	0.00	0.60	0.40	0.38	0.68	0.37	0.36	0.34	0.26	0.21	0.21	0.19	0.17	0.15	0.15	0.15	0.13	0.13	0.11	0.11	0.08	0.08	0.08	0.04	2.14
Chicago/Milwaukee	0.82	0.60	0.00	0.28	0.27	0.48	0.26	0.25	0.24	0.19	0.15	0.15	0.13	0.12	0.11	0.11	0.11	0.09	0.09	0.08	0.08	0.05	0.05	0.05	0.03	1.60
San Francisco	0.54	0.40	0.28	0.00	0.17	0.30	0.16	0.16	0.15	0.12	0.09	0.09	0.08	0.08	0.07	0.07	0.07	0.06	0.06	0.05	0.05	0.03	0.03	0.03	0.02	1.05
Boston	0.51	0.38	0.27	0.17	0.00	0.29	0.15	0.15	0.14	0.11	0.09	0.09	0.08	0.07	0.06	0.06	0.06	0.06	0.06	0.05	0.05	0.03	0.03	0.03	0.02	1.00
Detroit/Cleveland	0.92	0.68	0.48	0.30	0.29	0.00	0.30	0.30	0.28	0.22	0.17	0.17	0.16	0.14	0.12	0.12	0.12	0.11	0.11	0.09	0.09	0.06	0.06	0.06	0.03	1.80
Washington	0.50	0.37	0.26	0.16	0.15	0.30	0.00	0.14	0.14	0.11	0.08	0.08	0.08	0.07	0.06	0.06	0.06	0.05	0.05	0.05	0.05	0.03	0.03	0.03	0.02	0.97
Cincinnati	0.49	0.36	0.25	0.16	0.15	0.30	0.14	0.00	0.13	0.10	0.08	0.08	0.07	0.07	0.06	0.06	0.6	0.05	0.05	0.04	0.04	0.03	0.03	0.03	0.01	0.95
Philadelphia	0.46	0.34	0.24	0.15	0.14	0.28	0.14	0.13	0.00	0.10	0.08	0.08	0.07	0.06	0.06	0.06	0.06	0.05	0.05	0.04	0.04	0.03	0.03	0.03	0.01	0.90
Dallas	0.36	0.26	0.19	0.12	0.11	0.22	0.11	0.10	0.10	0.00	0.06	0.06	0.05	0.05	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.02	0.02	0.02	0.01	0.70
Atlanta	0.28	0.21	0.15	0.09	0.09	0.17	0.08	0.08	0.08	0.06	0.00	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.01	0.55
Houston	0.28	0.21	0.15	0.09	0.09	0.17	0.08	0.08	0.08	0.06	0.04	0.00	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.01	0.55
Syracuse	0.26	0.19	0.13	0.08	0.08	0.16	0.08	0.07	0.07	0.05	0.04	0.04	0.00	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.50
Miami	0.23	0.17	0.12	0.08	0.07	0.14	0.07	0.07	0.06	0.05	0.04	0.04	0.03	0.00	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.45
St. Louis	0.21	0.15	0.11	0.07	0.06	0.12	0.06	0.06	0.06	0.04	0.03	0.03	0.03	0.02	0.00	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.40
Raleigh	0.21	0.15	0.11	0.07	0.06	0.12	0.06	0.06	0.06	0.04	0.03	0.03	0.03	0.02	0.02	0.00	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.40
Tampa	0.21	0.15	0.11	0.07	0.06	0.12	0.06	0.06	0.06	0.04	0.03	0.03	0.03	0.02	0.02	0.02	0.00	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.40
Minneapolis	0.18	0.13	0.09	0.06	0.06	0.11	0.05	0.05	0.05	0.04	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.00	0.02	0.01	0.01	0.01	0.01	0.01	0.00	0.35
Seattle	0.18	0.13	0.09	0.06	0.06	0.11	0.05	0.05	0.05	0.04	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.35
Kansas City	0.15	0.11	0.08	0.05	0.05	0.09	0.05	0.04	0.04	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.00	0.30
Denver	0.15	0.11	0.08	0.05	0.05	0.09	0.05	0.04	0.04	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.00	0.30
San Antonio	0.10	0.08	0.05	0.03	0.03	0.06	0.03	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.20
Phoenix	0.10	0.08	0.05	0.03	0.03	0.06	0.03	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.20
New Orleans	0.10	0.08	0.05	0.03	0.03	0.06	0.03	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.20
Salt Lake City	0.05	0.04	0.03	0.02	0.02	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10
Others	2.79	2.14	1.60	1.05	1.00	1.80	0.97	0.95	0.90	0.70	0.55	0.55	0.50	0.45	0.40	0.40	0.40	0.35	0.35	0.30	0.30	0.20	0.20	0.20	0.10	6.38

By allocating as dedicated channels all those matrix intersections in excess of unity, it is possible to establish trunking and CPS matrices of dedicated channels, which are given in Tables 3.2-7 and 3.2-8 respectively. All entries in these tables are such that when subtracted from corresponding intersections in the total traffic matrices, the resulting values at each intersection are less than unity.

It is obvious that dedicated channels permit a considerable simplification in the transmission system on board the platform. To take advantage of this simplification we will use such channels when traffic between city pairs exceeds the following values:

- 0.9 channel when New York is one city of the pair
- 0.7 channel for all other city pairs.

This is somewhat wasteful of bandwidth, but in view of the inherent uncertainties in traffic predictions it is felt that the possible underutilization of available bandwidth is more than offset by the gain in simplification. Due to the very high traffic requirement for New York, we have set a higher utilization factor.

The higher value has been chosen for New York because available bandwidth is critical there. These values have been chosen on an arbitrary basis. A final choice would depend on the results of a trade-off between a reduction in platform complexity and a somewhat simpler system operation, on the one hand, and, on the other hand, the increased number of channels to be provided on board and in the ground equipment. The channel numbers given in the dedicated matrix tables reflect the above values. As shown in the tables, the total number of dedicated 36-MHz channels is as follows:

- 218 channels of a total requirement for 364.6 trunk channels.
- 32 channels of a total requirement for 102.1 CPS channels.

Approximately 50% of all traffic through the platform is carried by dedicated circuits which do not pass through the i.f. TDMA switching matrix. Of these dedicated circuits, 90 or roughly 20% carry spot beam communications in which case on board connections are established directly between input and output channels, as indicated in the above example of New York-San Francisco traffic. The remaining circuits are connected directly from input channels to demodulators in the baseband processor and from modulators to output channels ("other" traffic in the matrices). A preliminary examination of the effect of channel bandwidth shows that doubling the basic system bandwidth from 36-MHz to 72 MHz would reduce the proportion of dedicated spot beam traffic from 20% to less than 9%.

3.2.4.2 <u>Wideband Channels</u>

The Dedicated Trunking Matrix (Table 3.2-7) shows a number of cases in which several 36-MHz channels may be combined to form single wideband channels. The value shown at each of the matrix intersections corresponds to the number of channels combined. An example would be the San Francisco-New York link which requires two 36-MHz channels in each direction. These can be combined into one 72-MHz channel for each. Fixed spot beam traffic, for intercity wideband channels may be identified, as follows, where a QPSK modulation is assumed for estimation of bit rate.

TABLE 3.2-7. DEDICATED TRUNKING MATRIX - CONCEPT 2

	New York	Los Angeles/Anaheim	Detroit/Cleveland	Chicago/Milwaukee	San Francisco	Boston	Washington	Cincinnati	Philadelphia	Dallas	Atlanta	Houston	Syracuse	Miami	St. Louis	Raleigh	Tampa	Minneapolis	Seattle	Kansas City	Denver	San Antonio	Phoenix	New Orleans	Salt Lake City	Others
New York		4	3	3	2	2	1	1	1	1	1	1	1													10
Los Angeles/Anaheim	4		2	2	1	1	1	1	1	1	1	1														7
Chicago/Milwaukee	3	2	2		1	1	1	1	1	1																5
San Francisco	2	1	1	1																						4
Boston	2	1	1	1																						4
Detroit/Cleveland	3	2		2	1	1	1	1	1	1																6
Washington	1	1	1	1																						3
Cincinnati	1	1	1	1																						3
Philadelphia	1	1	1	1																						3
Dallas	1	1	1																							2
Atlanta	1	1																								2
Houston	1	1																								2
Syracuse	1																									2
Miami																										1
St. Louis																										1
Raleigh																										1
Tampa																										1
Minneapolis																										1
Seattle																										1
Kansas City																										1
Denver																										1
San Antonio																										1
Phoenix																										
New Orleans																										
Salt Lake City																										
Others	10	7	6	5	4	4	3	3	3	2	2	2	2	1	1	1	1	1	1	1	1	1				
Total	31	23	19	9	9	18	7	7	7	6	4	4	3	1	1	1	1	1	1	1	1	1				62

218 Total

TABLE 3.2-8. DEDICATED CPS MATRIX - CONCEPT 2

	New York	Los Angeles/Anaheim	Detroit/Cleveland	Chicago/Milwaukee	San Francisco	Boston	Washington	Cincinnati	Philadelphia	Dallas	Atlanta	Houston	Syracuse	Miami	St. Louis	Raleigh	Tampa	Minneapolis	Seattle	Kansas City	Denver	San Antonio	Phoenix	New Orleans	Salt Lake City	Others
New York		1	1																							2
Los Angeles/Anaheim	1		1																							2
Chicago/Milwaukee																										1
San Francisco																										1
Boston																										1
Detroit/Cleveland	1	1																								2
Washington																										1
Cincinnati																										1
Philadelphia																										1
Dallas																										1
Atlanta																										
Houston																										
Syracuse																										
Miami																										
St. Louis																										
Raleigh																										
Tampa																										
Minneapolis																										
Seattle																										
Kansas City																										
Denver																										
San Antonio																										
Phoenix																										
New Orleans																										
Salt Lake City																										
Others	2	2	2	1	1	1	1	1	1	1																
Total	4	4	4	1	1	1	1	1	1	1																13

32 Total

No. of 36-MHz Channels	No. of Cases	Wideband Channels Number	BW (MHz)	Reduction in No. of Channels
4	2	2	144	6
3	4	4	108	8
2	8	8	72	8

Use of these wideband channels would result in a reduction of 22 channels as compared to an all-36-MHz channel configuration.

In a similar fashion, a number of links between listed cities and "other" sources of traffic served by the CONUS or the scanning beams may be combined in wideband links. It can be seen, for example, that 10 channels of traffic are transmitted between New York and "other" places. Assuming that a maximum channel bandwidth of 144 MHz is adopted, all "other" traffic can be assigned to combinations of channels having bandwidths as tabulated above. In this case, an additional reduction of 74 channels can be obtained.

In the interest of standardizing bit rates and demodulator design, this modification has not been exploited in sizing of the baseband processor. However, it offers the possibility of reduced complexity in further refinement of the present platform design.

3.2.4.3 Traffic Through IF TDMA Switching Matrices

Subtracting the values shown in the dedicated traffic matrices (Tables 3.2-7 and 3.2-8) from those given for total traffic (Tables 3.2-5 and 3.2-6) allows one to determine the matrices representing traffic to be handled by the i.f. TDMA switching matrices. These are given in Tables 3.2-9 and 3.2-10 for trunking and CPS traffic respectively. It can be seen that in addition to the expected diagonal zeros, a number of zero values appear in the matrices as a result of the definition of dedicated channels. While these zero values are used in estimating total traffic to be handled by the switching matrices, they do not signify the elimination of the corresponding city as an input or output from the switch. Traffic estimations are statistical in nature and it is to be expected that capacity reserved in dedicated channels will be exceeded at times. Such overflow would be handled via the i.f. switch.

3.2.4.4 TDMA Switching Matrix Size and Number

In an ideal sense each traffic matrix could be implemented with matrix switches having the same number of inputs and outputs as are shown on the traffic matrix.

Examination of the column totals of the traffic matrices shows that capacity requirements would be satisfied by an assortment of matrices as follows, expressed as number of matrices x size:

- Trunking Traffic:

  2 x 26 + 1 x 25 + 1 x 22 + 1 x 19 + 1 x 12 + 1 x 8 + 1 x 4 + 2 x 1

- CPS Traffic:

  1 x 26 + 1 x 22 + 1 x 13 + 1 x 7 + 1 x 4 + 1 x 3 + 1 x 2 + 1 x 1

TABLE 3.2-9. IF TDMA SWITCH TRUNKING MATRIX - CONCEPT 2

	New York	Los Angeles/Anaheim	Chicago/Milwaukee	San Francisco	Boston	Detroit/Cleveland	Washington	Cincinnati	Philadelphia	Dallas	Atlanta	Houston	Syracuse	Miami	St. Louis	Raleigh	Tampa	Minneapolis	Seattle	Kansas City	Denver	San Antonio	Phoenix	New Orleans	Salt Lake City	Others
New York	0.00	0.00	0.00	0.00	0.00	0.36	0.78	0.75	0.63	0.31	0.05	0.00	0.00	0.85	0.79	0.75	0.70	0.66	0.66	0.58	0.57	0.36	0.34	0.34	0.23	0.04
Los Angeles/Anaheim	0.00	0.00	0.03	0.40	0.37	0.38	0.26	0.24	0.15	0.00	0.00	0.00	0.62	0.60	0.56	0.53	0.49	0.47	0.47	0.41	0.40	0.26	0.24	0.24	0.16	0.49
Chicago/Milwaukee	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.53	0.47	0.44	0.43	0.40	0.38	0.35	0.33	0.33	0.29	0.29	0.18	0.17	0.17	0.12	0.55
San Francisco	0.00	0.40	0.00	0.00	0.64	0.11	0.59	0.58	0.54	0.43	0.35	0.31	0.29	0.28	0.26	0.25	0.23	0.22	0.22	0.19	0.19	0.12	0.11	0.11	0.08	0.00
Boston	0.00	0.37	0.00	0.64	0.00	0.08	0.57	0.56	0.52	0.42	0.34	0.30	0.28	0.27	0.25	0.24	0.22	0.21	0.21	0.19	0.18	0.12	0.11	0.11	0.07	0.00
Detroit/Cleveland	0.36	0.38	0.00	0.11	0.08	0.00	0.09	0.07	0.00	0.00	0.64	0.57	0.54	0.52	0.48	0.46	0.43	0.40	0.40	0.36	0.35	0.22	0.21	0.21	0.14	0.50
Washington	0.78	0.26	0.08	0.59	0.57	0.09	0.00	0.50	0.47	0.38	0.30	0.27	0.25	0.25	0.23	0.22	0.20	0.19	0.19	0.17	0.16	0.10	0.10	0.10	0.07	0.45
Cincinnati	0.75	0.24	0.00	0.58	0.56	0.07	0.50	0.00	0.46	0.37	0.30	0.26	0.25	0.24	0.22	0.21	0.20	0.19	0.19	0.16	0.16	0.10	0.09	0.09	0.07	0.37
Philadelphia	0.63	0.15	0.00	0.54	0.52	0.00	0.47	0.46	0.00	0.34	0.27	0.24	0.23	0.22	0.21	0.20	0.18	0.17	0.17	0.15	0.15	0.09	0.09	0.09	0.06	0.15
Dallas	0.31	0.00	0.00	0.43	0.42	0.00	0.38	0.37	0.34	0.00	0.21	0.19	0.18	0.17	0.16	0.15	0.14	0.13	0.13	0.12	0.11	0.07	0.07	0.07	0.05	0.52
Atlanta	0.05	0.00	0.53	0.35	0.34	0.64	0.30	0.30	0.27	0.21	0.00	0.15	0.14	0.13	0.12	0.12	0.11	0.10	0.10	0.09	0.09	0.06	0.05	0.05	0.04	0.02
Houston	0.00	0.00	0.47	0.31	0.30	0.57	0.27	0.26	0.24	0.19	0.15	0.00	0.12	0.12	0.11	0.10	0.10	0.09	0.09	0.08	0.08	0.05	0.05	0.05	0.03	0.00
Syracuse	0.00	0.62	0.44	0.29	0.28	0.54	0.25	0.25	0.23	0.18	0.14	0.12	0.00	0.11	0.10	0.10	0.09	0.08	0.08	0.07	0.07	0.05	0.04	0.04	0.03	0.00
Miami	0.85	0.60	0.43	0.28	0.27	0.52	0.25	0.24	0.22	0.17	0.13	0.12	0.11	0.00	0.10	0.09	0.09	0.08	0.08	0.07	0.07	0.05	0.04	0.04	0.03	0.65
St. Louis	0.79	0.56	0.40	0.26	0.25	0.48	0.23	0.22	0.21	0.16	0.12	0.11	0.10	0.10	0.00	0.09	0.08	0.07	0.07	0.07	0.06	0.04	0.04	0.04	0.03	0.52
Raleigh	0.75	0.53	0.38	0.25	0.24	0.46	0.22	0.21	0.20	0.15	0.12	0.10	0.10	0.09	0.09	0.00	0.07	0.07	0.07	0.06	0.06	0.04	0.04	0.04	0.02	0.45
Tampa	0.70	0.49	0.35	0.23	0.22	0.43	0.20	0.20	0.18	0.14	0.11	0.10	0.09	0.09	0.08	0.07	0.00	0.06	0.06	0.06	0.06	0.04	0.03	0.03	0.02	0.35
Minneapolis	0.66	0.47	0.33	0.22	0.21	0.40	0.19	0.19	0.17	0.13	0.10	0.09	0.08	0.08	0.07	0.07	0.06	0.00	0.06	0.05	0.05	0.03	0.03	0.03	0.02	0.27
Seattle	0.66	0.47	0.33	0.22	0.21	0.40	0.19	0.19	0.17	0.13	0.10	0.09	0.08	0.08	0.07	0.07	0.06	0.06	0.00	0.05	0.05	0.03	0.03	0.03	0.02	0.27
Kansas City	0.58	0.41	0.29	0.19	0.19	0.36	0.17	0.16	0.15	0.12	0.09	0.08	0.07	0.07	0.07	0.06	0.06	0.05	0.05	0.00	0.04	0.03	0.03	0.03	0.02	0.12
Denver	0.57	0.40	0.29	0.19	0.18	0.35	0.16	0.16	0.15	0.11	0.09	0.08	0.07	0.07	0.06	0.06	0.06	0.05	0.05	0.04	0.00	0.03	0.03	0.03	0.02	0.10
San Antonio	0.36	0.26	0.18	0.12	0.12	0.22	0.10	0.10	0.09	0.07	0.06	0.05	0.05	0.05	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.00	0.01	0.01	0.01	0.00
Phoenix	0.34	0.24	0.17	0.11	0.11	0.21	0.10	0.09	0.09	0.07	0.05	0.05	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.01	0.00	0.01	0.01	0.65
New Orleans	0.34	0.24	0.17	0.11	0.11	0.21	0.10	0.09	0.09	0.07	0.05	0.05	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.01	0.01	0.00	0.01	0.65
Salt Lake City	0.23	0.16	0.12	0.08	0.07	0.14	0.07	0.07	0.06	0.05	0.04	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.00	0.45
Others	0.04	0.49	0.55	0.00	0.00	0.50	0.45	0.37	0.15	0.52	0.02	0.00	0.00	0.65	0.52	0.45	0.35	0.27	0.27	0.12	0.10	0.00	0.65	0.65	0.45	22.78

TABLE 3.2-10. IF TDMA SWITCH CPS MATRIX - CONCEPT 2

	New York	Los Angeles/Anaheim	Chicago/Milwaukee	San Francisco	Boston	Detroit/Cleveland	Washington	Cincinnati	Philadelphia	Dallas	Atlanta	Houston	Syracuse	Miami	St. Louis	Raleigh	Tampa	Minneapolis	Seattle	Kansas City	Denver	San Antonio	Phoenix	New Orleans	Salt Lake City	Others
New York	0.00	0.10	0.82	0.54	0.51	0.00	0.50	0.49	0.46	0.36	0.28	0.28	0.26	0.23	0.21	0.21	0.21	0.18	0.18	0.15	0.15	0.10	0.10	0.10	0.05	0.79
Los Angeles/Anaheim	0.10	0.00	0.60	0.40	0.38	0.00	0.37	0.36	0.34	0.26	0.21	0.21	0.19	0.17	0.15	0.15	0.15	0.13	0.13	0.11	0.11	0.08	0.08	0.08	0.04	0.14
Chicago/Milwaukee	0.82	0.60	0.00	0.28	0.27	0.48	0.26	0.25	0.24	0.19	0.15	0.15	0.13	0.12	0.11	0.11	0.11	0.09	0.09	0.08	0.08	0.05	0.05	0.05	0.03	0.60
San Francisco	0.54	0.40	0.28	0.00	0.17	0.30	0.16	0.16	0.15	0.12	0.09	0.09	0.08	0.08	0.07	0.07	0.07	0.06	0.06	0.05	0.05	0.03	0.03	0.03	0.02	0.05
Boston	0.51	0.38	0.27	0.17	0.00	0.29	0.15	0.15	0.14	0.11	0.09	0.09	0.08	0.07	0.06	0.06	0.06	0.06	0.06	0.05	0.05	0.03	0.03	0.03	0.02	0.00
Detroit/Cleveland	0.00	0.00	0.48	0.30	0.29	0.00	0.30	0.30	0.28	0.22	0.17	0.17	0.16	0.14	0.12	0.12	0.12	0.11	0.11	0.09	0.09	0.06	0.06	0.06	0.03	0.00
Washington	0.50	0.37	0.26	0.16	0.15	0.30	0.00	0.14	0.14	0.11	0.08	0.08	0.08	0.07	0.06	0.06	0.06	0.05	0.05	0.05	0.05	0.03	0.03	0.03	0.02	0.00
Cincinnati	0.49	0.36	0.25	0.16	0.15	0.30	0.14	0.00	0.13	0.10	0.08	0.08	0.07	0.07	0.06	0.06	0.06	0.05	0.05	0.04	0.04	0.03	0.03	0.03	0.01	0.00
Philadelphia	0.46	0.34	0.24	0.15	0.14	0.28	0.14	0.13	0.00	0.10	0.08	0.08	0.07	0.06	0.06	0.06	0.06	0.05	0.05	0.04	0.04	0.03	0.03	0.03	0.01	0.00
Dallas	0.36	0.26	0.19	0.12	0.11	0.22	0.11	0.10	0.10	0.00	0.06	0.06	0.05	0.05	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.02	0.02	0.02	0.10	0.00
Atlanta	0.28	0.21	0.15	0.09	0.09	0.17	0.08	0.08	0.08	0.06	0.00	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.01	0.55
Houston	0.28	0.21	0.15	0.09	0.09	0.17	0.08	0.08	0.08	0.06	0.04	0.00	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.01	0.55
Syracuse	0.26	0.19	0.13	0.08	0.08	0.16	0.08	0.07	0.07	0.05	0.04	0.04	0.00	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.50
Miami	0.23	0.17	0.12	0.08	0.07	0.14	0.07	0.07	0.06	0.05	0.04	0.04	0.03	0.00	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.45
St. Louis	0.21	0.15	0.11	0.07	0.06	0.12	0.06	0.06	0.06	0.04	0.03	0.03	0.03	0.02	0.00	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.40
Raleigh	0.21	0.15	0.11	0.07	0.06	0.12	0.06	0.06	0.04	0.03	0.03	0.03	0.02	0.02	0.00	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.40
Tampa	0.21	0.15	0.11	0.07	0.06	0.12	0.06	0.06	0.06	0.04	0.03	0.03	0.03	0.02	0.02	0.02	0.00	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.40
Minneapolis	0.18	0.13	0.09	0.06	0.06	0.11	0.05	0.05	0.05	0.04	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.00	0.02	0.01	0.01	0.01	0.01	0.01	0.00	0.35
Seattle	0.18	0.13	0.09	0.06	0.06	0.11	0.05	0.05	0.05	0.04	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.35
Kansas City	0.15	0.11	0.08	0.05	0.05	0.09	0.05	0.04	0.04	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.00	0.30
Denver	0.15	0.11	0.08	0.05	0.05	0.09	0.05	0.04	0.04	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.00	0.30
San Antonio	0.10	0.08	0.05	0.03	0.03	0.06	0.03	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.20
Phoenix	0.10	0.08	0.05	0.03	0.03	0.06	0.03	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.20
New Orleans	0.10	0.08	0.05	0.03	0.03	0.06	0.03	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.20
Salt Lake City	0.05	0.04	0.03	0.02	0.02	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10
Others	0.79	0.14	0.60	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.55	0.55	0.50	0.45	0.40	0.40	0.40	0.35	0.35	0.30	0.30	0.20	0.20	0.20	0.10	6.38

Use of a matrix having 25 inputs and outputs provides an efficient solution which appears to be technologically realistic for the time frame involved. Exclusive use of smaller matrices is also possible but requires extensive use of power division and combining circuits to achieve the required interconnectivity. Use of smaller 12 input/output matrices has been specified for a reduced number of input and output beams having higher traffic requirements. The number of each type of matrix switch may be calculated as follows using the relationships:

$$\Sigma \text{ (No. of matrices x No. of channels/matrix)} = N \times M$$

with M = Matrix Size
N = Number of M x M matrices

- For M = 25:

  Trunking:
  $2 \times 26 + 1 \times 25 + 1 \times 22 + 1 \times 19 = N \times 25$
  N = 4.7

  CPS:
  $1 \times 26 + 1 \times 22 = N \times 25$
  N = 1.9
  Total N = 6.6 ⟶ 7 matrices

- For M = 12:

  Trunking:
  $1 \times 12 + 1 \times 8 + 1 \times 4 = N \times 12$
  N = 2.0

  CPS:
  $1 \times 13 + 1 \times 7 + 1 \times 4 + 1 \times 3 + 1 \times 2 = N \times 12$
  N = 2.4
  Total N = 4.5 ⟶ 6 matrices

An additional margin is allowed in this case because the smaller matrices are largely devoted to cities having high traffic levels and corresponding higher uncertainty.

In the calculation for M = 12 the 2 x 1 term is omitted since it implies the need for two 1 x 1 matrices, which would be implemented with a dedicated connection which would bypass the switching matrices. A more detailed explanation of the above matrix selecltion procedure is given in Appendix A.

3.2.4.5 Non-TDMA Traffic

Each input to a switching matrix corresponds nominally to the traffic in a 36-MHz channel corresponding to a 60 Mb/s rate for a QPSK type modulation. Possibly other modulation formats may be used and these could all be interspersed provided that the bandwidth limitation is respected and that suitable signaling protocols and adaptable ground receiving equipment would permit reception of successive bursts having different modulation codes.

In any case, the matrix switch would operate typically in TDMA fashion, directing incoming traffic bursts from the various city uplinks to appropriate outputs for downlinking via city beams which are connected physically to each matrix output port. The switching matrix would be commanded by a matrix controller operating in a dynamic fashion, establishing connections for the duration of a TDMA burst and reconfiguring the switch as required from burst to burst.

If it is desired to transmit traffic continuously between two cities in a given channel, the appropriate matrix connection can be established on a long-term basis. This would provide for the transmission of multiple carriers or FDM signals between the two coverage points. Such transmissions can be established between any two points served by fixed beams but plainly cannot be used where a link is completed via one of the Ka-band scanning beams.

In some cases it may prove desirable to establish continuous links from several city beams to one city on a shared-channel basis as shown in Figure 3.2-4. In this case we suppose it is desired that the channel bandwidth B is to be shared by carriers a1, b1, c1, and d1 originating from cities A, B, C, and D. These carriers are to be transmitted to Chicago, for example, and the matrix connection is established in the Chicago column as shown where it is intersected by city rows A, B, C, and D. All four carriers, each occupying its assigned portion of the channel bandwidth, appear on the Chicago output of the matrix. In a similar fashion, four carriers a2, b2, c2, and d2 for transmission from Chicago to cities A, B, C, and D are received in the channel bandwidth and switched to the four cities via the circled connections shown in the Chicago row. Each city receives all four carriers, extracting only the one of interest.

3.2.5 Baseband Processor

The role of the baseband processor is that of providing an interface with the Ka-band scanning beams. This interface involves not only traffic moving from one scanning beam uplink to another scanning beam downlink, but also fixed-beam traffic that originates or has its destination in a scanning-beam location. The fixed-beam channels which interface with the scan beams may be of C-, Ku-, or Ka-band type. Functionally speaking, the baseband demodulator provides for demodulation/modulation, buffer storage, and baseband matrix switching required to realize the appropriate input-output interconnections. These functions are discussed in the paragraphs below. A digital controller commanded from the system ground control center assures internal coordination and switching for the baseband processor as well as beam switching commands for the scanning beams. Error correction decoding, most probably based on soft-decision decoding of a rate 1/2 convolutional code using the Viterbi algorithm, will be provided on a selectable basis as will rate 1/2 convolutional coding for downlinks. Other coding/decoding methods may appear in the time period preceding initiations of a platform construction program, but this appears unlikely. In any case, any improvement to be obtained in this area is not critical to the success of the program. The data rates involved, 30 Mb/s, are not so high as to make construction of decoding and encoding equipments a critical technological path provided that present design and development activities undertaken on the ACTS program are continued.

In a general sense, the basic concept and operation of the on-board processor is based largely on concepts presently being developed on the NASA/ACTS program as described in Reference (19), for example.

3.2.5.1 Demodulation/Modulation

The baseline design assumes that all demodulation/modulation is carried out on 60-Mb/s bit streams using a QPSK-type of modulation which occupies a 36-MHz channel. An estimation of the number of demod/mod channels is based on the traffic given in Table 3.2-3 where it can be seen that the total fixed spot beam load including trunking and CPS contributions is 350.1 channels while the total traffic from "other" sources is 116.6 channels. Rounding these values off and neglecting the relatively small capacity offered by the C- and Ku-band fixed beams, the traffic transfer diagram is shown in Figure 3.2-5(a) where traffic at the input nodes is shown as 360 channels from fixed spot beams and 120 channels from the scanning beams. It is assumed that the total number of outputs to the fixed spot and scanning beam nodes is the same as the number of inputs and that the fractional portion of traffic transferred from an input node to an output node is the same as the traffic ratio.

To better visualize the requirements placed on the demodulators and modulators, the transfer diagram has been redrawn in Figure 3.2-5(b) which shows the relationship of the baseband processor in the traffic transfer process. It can be seen that all inputs from the scan beams must be demodulated even if three-quarters of these inputs are destined for fixed spot beams. In addition, all fixed spot beam inputs destined for scan beams must also be demodulated. Consequently, the total number of demodulators is found to be

$$120 + 1/4\ (360) = 210 \text{ demodulators.}$$

For estimation purposes, this number has been rounded off to 200 in view of the approximations noted above. The number of modulators is likewise taken to be 200.

As noted above, these demodulators/modulators would all handle 60 Mb/s QPSK streams. These are relatively modest values that should facilitate on-board demodulator fabrication and which should be readily achievable in small CPS

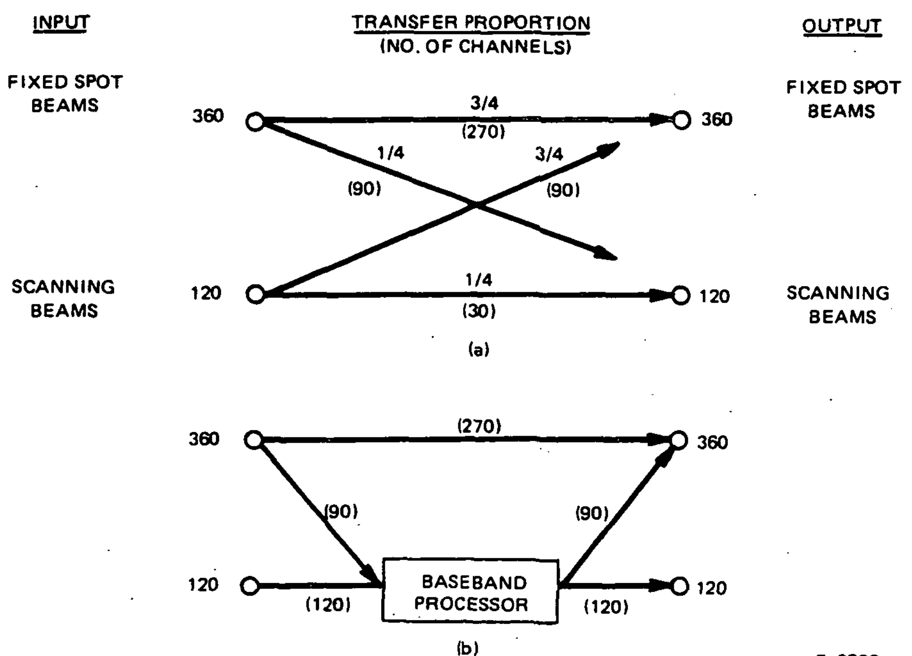

Figure 3.2-5. Traffic Transfer Diagram

terminals. It is assumed that uplinking at a given scan beam position would be done in TDMA fashion with sequential time-spaced bursts from each of the active terminals in the 0.25° beam area. Downlinking would be achieved in a continuous TDM data stream which would require carrier and symbol sync acquisition only once during the dwell time of the scanning spot beam.

3.2.5.2 Buffer Storage

The buffer memory consists of input and output sections. The former is required to store all demodulator outputs during a 1 msec time frame, preliminary to their passage through the baseband switching matrix. Matrix outputs would be stored in the output section for an additional frame period for transfer to the BBP modulator units.

Assuming that the memory interfaces with 200 demodulators/ modulators, each carrying a 60-Mb/sec bit stream, it can be seen that total on-board storage capacity, C, will be:

$$C = N\,R\,n\,T_f$$
$$= 24 \text{ Mbits}$$

where N = No. of demodulators = 200
R = Bit rate (Mb/s) = 60
n = No. of frames stored = 2
T_f = Frame length (sec) = 0.001.

Since the data streams are obtained and transmitted in QPSK form, it is assumed that each 60-Mb/s channel may be handled as a pair of 30-Mb/s data stream if desired. This would assure that low-power technology could be used for the various logic functions associated with the on-board memories.

Inputs to the input section of the buffer memory would be serial and bursty in nature, corresponding to the TDMA bursts received by the demodulator from each uplink terminal. Outputs of the output section of the memory would be continuous during each scan beam dwell time in keeping with the downlink TDM format. Transfers between the two memory sections via the baseband matrix switch would require random access capabilities.

3.2.5.3 Baseband Matrix Switch

The baseband matrix switch functions so as to provide connectivity between any of 200 input channels to any of 200 output channels of the BBP. Speed and duration of the connections will be comparable to those of the TDMA i.f. switching matrix. To achieve the full connectivity, smaller matrices may be used as shown in Figure 3.2-6 where 50 x 50 units are shown. This type of configuration requires simply that the 200 inputs be divided into four groups. Each individual input in any of the input groups is split into four separate paths so as simultaneously feed four 50 x 50 matrices in the same row. Individual outputs of four 50 x 50 matrices are combined by column in each of the four columns to complete system interconnectivity. The configuration shown is based on a straightforward, single-level, crossbar switching concept (i.e. one switching point for each input/output connection). Such an arrangement requires N^2 switching points to handle a matrix having N inputs and outputs. In 1953, Clos described (Reference 20) a more sophisticated arrangement in which several smaller switching matrices can be arranged in a tandem fashion

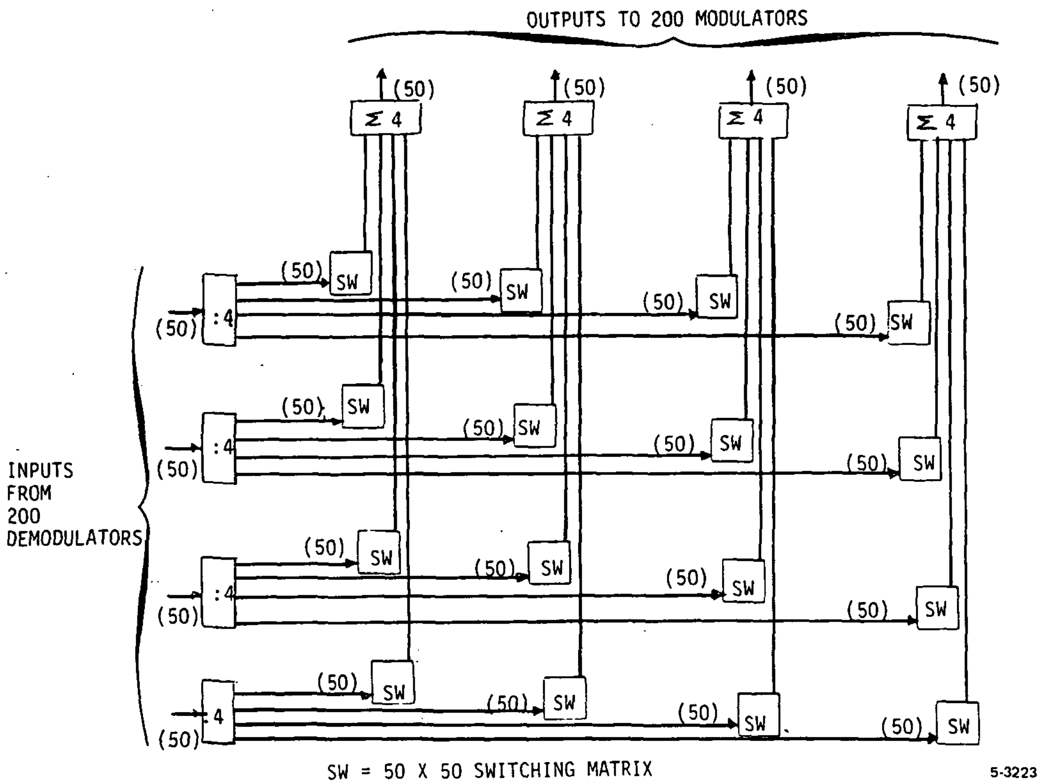

Figure 3.2-6. 200 x 200 Baseband Switching Matrix Assembly

so as to obtain the same connectivity, but at a smaller cost in terms of total switching points. In this case, several switching points must be traversed between any given input and output channel. While fewer switching points are needed, command logic and interconnection between matrices are more complex. Motorola (Reference 21) and Ford Aerospace (Reference 22) consider the possibility of such multiple level switching. While potentially attractive, it is not now clear that this approach would be finally adopted; so it is felt that the present approach is a prudent one.

3.2.5.4 Reduction in Baseband Processing Requirements

The baseline system described assumes the use of uniform 60-MHz QPSK demodulators as well as the need to provide buffer storage on links between scanning beam and fixed spot beam locations. In the following paragraphs, the possibilities of alternate approaches are considered.

- Wideband Links
  The use of wideband channels for dedicated channels not passing through the TDMA i.f. switch was considered in Section 3.2.4.2. Tables 3.2-7 and 3.2-8 include the number of dedicated channels between fixed city spot beams as well as those between fixed spot and scanning beams ("other" column and row). The following tabulation of the various channel requirements shows the possible reduction in the number of channels interfacing with the scan beams via the BBP by the use of wider channel bandwidths. In assigning wider channels to replace the standard 36-MHz channels, it is assumed that the wider band channels are chosen from a set having bandwidths of 72, 108, and 144 MHz as developed in Section 3.2.4.2. These channels are distributed as follows:

No. of 36-MHz Channels	No. of Cases	Wideband Channels Number	Wideband Channels BW (MHz)	Reduction in No. of Channels
10	2	4	144	
		2	72	14
7	2	2	144	
		2	108	10
6	2	4	108	8
5	2	2	108	
		2	72	6
4	4	4	144	12
3	6	6	108	12
2	12	12	72	12

The total reduction possible amounts to 74 channels, found by summing values given in the last column. The total number of demodulators/modulators required in the BBP would decrease from 200 to approximately 125. The resulting mixture of different data rates would require reduction to some common subsystem rate while maintaining the integrity of bursts from different terminals uplinking from the same coverage area.

- Scanning/Fixed Beam Interface

  The architecture of the present system supposes that all transmissions between scanning and fixed beams must pass through the BBP. In the fixed-to-scanning sense, for example, it was felt that timing uncertainty as to the delivery of a given burst on the scan beam down-link made it necessary that uplink bursts from fixed beam locations be stored in the buffer memory awaiting insertion in the downlink transmission format. Since traffic patterns probably vary slowly in comparison with the duration of any given message, it would appear possibly to establish a direct TDMA link between a fixed beam and a scanning beam without use of the on-board buffer memory. Such transmissions would then move through the TDMA i.f. switching matrix and would make no demands on the BBP. It would be necessary to provide some method for integrating scanning beam inputs/outputs passing via the i.f. switch and those passing through the BBP. Possibly this might be done by simple assignment of channels. It should be noted that downlinks from the BBP would be continuous TDM during the dwell time of the scanning beam while downlink transmissions via the TDMA i.f. switch would have the same bursty characteristic as the uplinks.

3.2.6 Scanning Beam/TDMA Operation

The scanning beams will carry 120 channels of traffic as indicated in Section 3.2.5.1. For six scanning beams, this results in a requirement of 20 36-MHz channels per beam. To establish characteristics of the TDMA transmissions, it is necessary to determine the number of spot locations to be serviced by each of the scanning beams. This is determined first by the total number of beams required to cover the CONUS area. Assuming that it is desired to cover an area approximately 3< x 7°, it can be seen from Figure 3.2-7 that this is assured by a total of 480 spot beams. The 0.25< beams overlap to assure that total coverage is obtained in the 3-dB beamwidth matrix. Each of the six scanning beams is thus assigned a maximum of 80 spots. It appears reasonable to assume that 20 of the 80 spots would contain active terminals at a given

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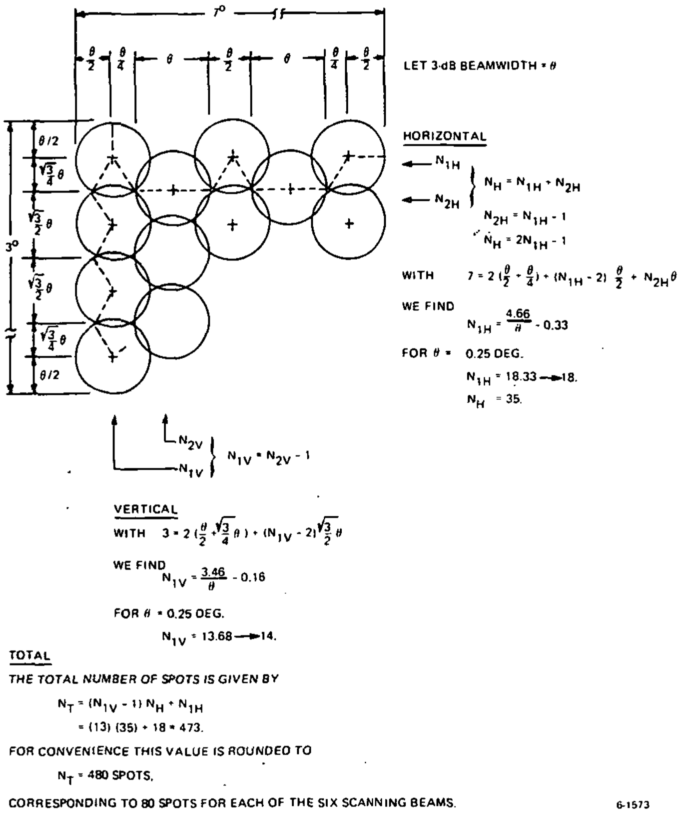


Figure 3.2-7. Scanning Beam Geometry

time. Assuming 100 active terminals in each of the 20 spots to be serviced by the scan beam, the average burst length from each terminal is:

$$N_b = \frac{R_c T_f}{N_s} \cdot \frac{N_c}{N_{term}}$$

where R_c = Channel bit rate = 60 Mb/s

T_f = Frame duration (time for beam to scan all active spots) = 1 msec

N_s = No. of active spots = 20

N_{term} = No. of active terminals/spot = 100

N_c = No. of channels = 20

which yields

$$N_b = 600 \text{ bits/burst.}$$

This is an average value. Some bursts could be shorter in length if, for example, 56-kb/s transmissions are involved. Short transmissions lead to large overhead requirements, so it is better if the participating terminals do not transmit during each frame but buffer their transmissions for a certain number of frame intervals.

It has been assumed that beam switching requires approximately 0.5 μsec. Assuming 20 operations during one frame period, corresponding to the number of active spots, leads to a switching overhead of:

$$\frac{T_s N_s}{T_f} = 1.0\%$$

with T_s = Beam switching time.

This appears to be a reasonable value.

3.2.7 Frequency Plan

The frequency plans for C- and Ku-bands are fairly straightforward. The CONUS beams simply provide 12 36-MHz channels in each of the two bands. If desired, these channels could be held in reserve for use in cases where precipitation causes loss of Ka-band capacity. Both bands also provide spot beam coverage. In that case, it is not possible to allocate the full 12 channels of capacity to each spot due to the proximity of adjacent beams. This leads to division of the channel capacity as indicated in Section 3.2.3 and shown in Table 3.2-3. Ka-band is used to fill channel capacity requirements which exceed C- and Ku-band capabilities. Generally, available Ka-band capacity easily meets these needs. However, frequency planning for the Boston-Washington, D.C. corridor does present a problem. Solutions are very much related to the eventual configuration adopted for the output multiplexer, and several alternates are considered for different multiplexer configurations. Table 3.2-4 and the following (rounded) list show the total channel requirements for cities in the corridor:

Boston	15
New York	42
Philadelphia	13
Washington, D.C.	15

Assuming that frequency reuse is possible between alternate cities on the above list (see Figure 3.2-2), it can be seen that a maximum of 57 channels are required for the Boston-New York combination. This leaves a margin of five unused channels, considering that there are 62 channels of capacity available on a single polarization. It is assumed that the scanning beam does not cover areas served by the fixed spot beams, but it does provide coverage adjacent to them. This is not an inconvenience since transmission rates are the same in both types of beams except for a limited number of special wideband channels. For scanned locations close to the New York and Boston beams, rain depolarization could present a problem. The five unused channels would be assigned to those locations. It remains to be seen how the output multiplexer problem is to be handled insofar as providing 42 channels of capacity to New York. Using the above considerations as a starting point, the following possibilities present themselves:

(a) <u>Forty-two 36-MHz channels on a contiguous multiplexer</u>

Too many channels to be feasible.

(b) <u>Pair of twenty-one 36-MHz channel non-contiguous multiplexers</u>

Requires a dual-mode antenna feed (does not appear feasible for spot beam) or dual antennas (too complex).

(c) Use of wideband channels

Table 3.2-7 shows that New York is connected to a number of 36-MHz dedicated channels (NE) which may be converted to wideband channels as follows:

Source	No. of NB Channels	No. of WB Channels	
Los Angeles	4	1	
Chicago	3	1	
San Francisco	2	1	
Boston	2	1	
Detroit	3	1	
Other	10	3	2 @ 144 MHz 1 @ 72 MHz
Totals	24	8	

Use of such channels would reduce the total need from 42 to 26 channels. This would require an output multiplexer having 26 contiguous channels of which 18 would be narrowband (36 MHz) while 8 would be wideband (72 to 144 MHz).

(d) Use of higher order modulation

Using Table 3.2-7 permits an estimation of the number of channels required for New York if a higher order modulation such as 8 PSK were adopted instead of QPSK. The following estimate may be made:

Source	No. of NB Channels	No. of 8 PSK Ch.	Remaining NB Ch.
Los Angeles	4	2	
Chicago	3	1	1
San Francisco	2	1	
Boston	2	1	
Detroit	3	1	1
Other	10	5	
Total	24	11	2

Twenty-four 36-MHz channels carrying QPSK modulation may be replaced by 13 36-MHz channels, 11 of which would carry 8 PSK with QPSK in the two others. The total number of channels required drops by 11, from 42 to 31. This has the advantage of reducing bandwidth requirements by a corresponding amount. It eases the possible rain induced polarization problem in the adjacent scanning beam as mentioned above. Two SSPAs could be operated in parallel in high-power mode in the channel, but a theoretical performance penalty of 2.3 dB would be incurred in any case.

Several multiplexer options may be envisaged in this case:

(1) <u>31 Non-contiguous Channels</u>

Channel bandwidth: 36-MHz
Channel spacing: 80-MHz

This multiplexer would cover the entire 2.5-GHz band available at Ka-band in one polarization. Alternate channels of the same polarization would be assigned to adjacent cities. Good filter band edge performance would not be required since some spatial isolation would be obtained in the adjacent beams. The scan beams would use opposite polarization.

(2) <u>31 Contiguous Channels</u>

Channel bandwidth: 72-MHz
Channel spacing: 80-MHz

This case is shown in Figure 3.2-8. The multiplexer would also cover the entire 2.5-GHz band on one polarization. The channel bandwidth is relatively wide, which should facilitate realization of a low-loss filter. Since the useful signal occupies only the central half of the filter bandwidth, it would not be necessary that it provide good performance over the outer portions. The filters would provide no attenuation of residual power outside the nominal 36-MHz signal bandwidth. Such out-of-band power as remained beyond 18 MHz from channel center, and would interfere with the next adjacent channel, would be reduced by the cross-polarization isolation.

As shown in the figure, New York would occupy the entire bandwidth on one polarization (31 channels). Boston would occupy 15 alternate channels on the opposite polarization. This leaves 16 channels on that same polarization for the scanning beam. This shortfall from the 20 channels normally required per sector could be made up for either by declaring a 16-channel sector or by limiting channel capacity at scanning spots adjacent to the Boston spot beam. This would complicate somewhat the task of the system controller, but there would not appear to be any intrinsic reason why some such non-uniformities in the design of

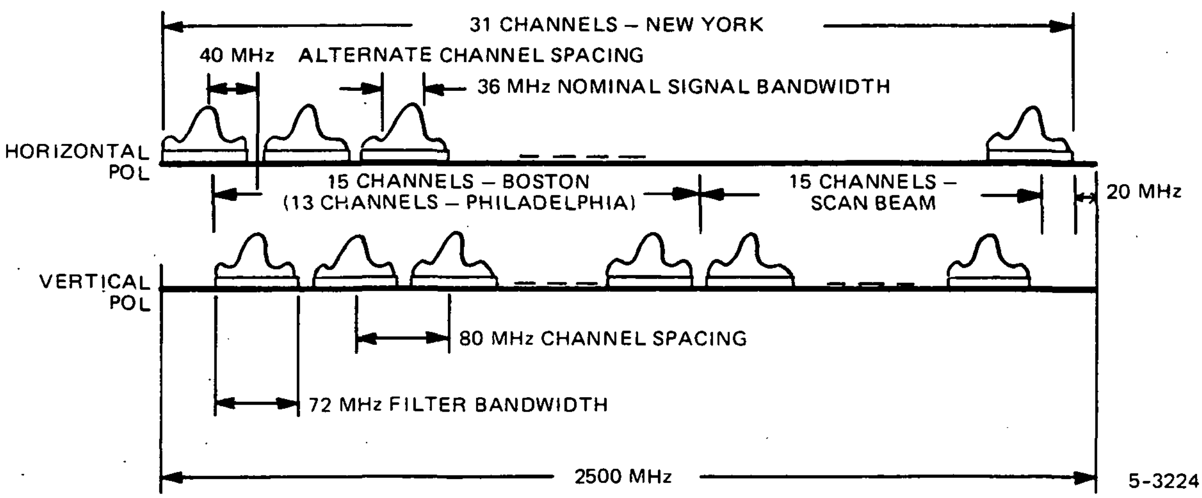


Figure 3.2-8. Frequency Plan, 31 Contiguous Channels to New York

the scanning beam system cannot exist provided that appropriate compensations are made to maintain overall performance.

(3) <u>Alternating 15/16 Non-contiguous Channels on Two Multiplexers</u>

Channel bandwidth: 36-MHz
Channel spacing: 80-MHz

This case is shown in Figure 3.2-9. New York coverage is obtained with 16 channels on one polarization and 15 channels on the other. The remaining channels on each polarization are divided between Boston and the scanning beam. There is a requirement for good sidelobe performance in horizontally polarized channels as shown in the figure, since frequency reuse is assumed in New York/Washington and Boston/Philadelphia beam pairs. However, for vertically polarized channels, where New York and scanning beams are fed separately, sidelobe performance is not a primary requirement in the vicinity of New York since frequency assignments there are mutually exclusive. In a general sense it should be noted that Ka-band frequency assignments are such as to not require frequency reuse to a given point based on polarization isolation.

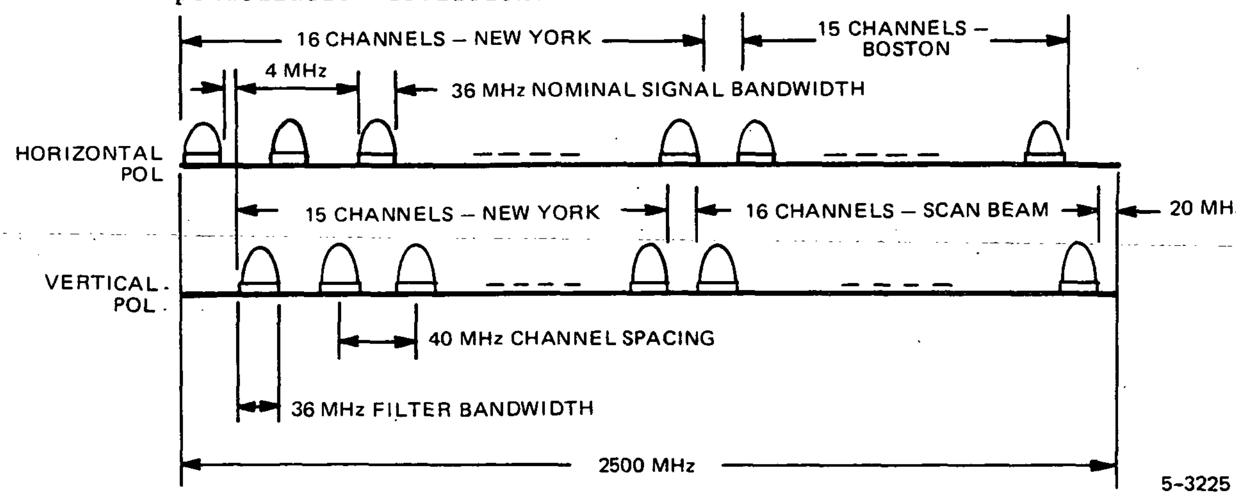


Figure 3.2-9. Frequency Plan, 16/15 Noncontiguous Channels to New York

As shown in the figure, scan-beam channel capacity is limited to 16 channels in spots adjacent to the New York beam. Considerations advanced in the previous paragraph also apply in this case.

If this approach is used, the most demanding multiplexer requirement becomes that of the scan beam where 20 non-contiguous 36-MHz channels are required. In adjacent scanning sectors, beam polarizations are orthogonal and channel frequency assignments are interlaced. This avoids possible interference along sector boundaries due to rain induced cross-polarization isolation degradation.

This multiplexer solution is to be preferred from the point of view of technical risk. It does require multiplexer channels of relatively narrow (36-MHz) bandwidth. However, it should be noted that 24-MHz bandwidth channels are current in Ku-band (12-GHz). A projection of 36 MHz at 18 GHz would not then seem unreasonable.

3.2.8 Link Budgets

Tables 3.2-11 to 3.2-16 provide typical link budgets for all three transmission bands. C- and Ku-band budgets are fairly straightforward and are self-explanatory. They show sufficient margins for the typical system parameters which have been chosen. In all cases, a 60-Mb/s link was assumed. For Ka-band computations 60- and 240-Mb/sec links were assumed for CPS and trunking cases. The latter corresponds to the dedicated links having the widest bandwidth (144 MHz) as shown in Section 3.2.4.2. CPS terminals may be serviced by fixed spot or scanning spot beams. In the former case, the transmit power level may be increased from 4 to 40 watts to counter rain fades; in the latter case, power level switching is more speculative and has not been included. The link budgets assume QPSK modulation. If 8-PSK modulation is used, as discussed in Section 3.2.7(4), an overall link penalty of 2.3-dB should also appear in the analysis. This would be offset by a 3-dB gain since the 8-PSK data rate is 120 Mb/sec, one-half the value used for the wideband link analysis shown.

CPS uplink budget appears marginal insofar as rain margin at 30 GHz is concerned. Especially true where transmission via the i.f. TDMA switch is used. In cities subject to deep rain fades it would be desirable to upgrade the CPS ground terminal as follows:

Improvement	Link Gain (dB)
Increase reflector size from 2 to 4m	6.0
Increase transmit power from 50 to 100W	3.0
Total Link Gain	9.0

TABLE 3.2-11. C-BAND UPLINK BUDGET

Contributor	Trunk Terminal		Comments
	CONUS	Spot Beam	
Transmit Power (dBW)	14.8	10.0	30W/10W
Transmit Ant. Gain (dB)	53.3	47.3	10m/5m Reflector
Transmitter Loss (dB)	-3.0		
EIRP (dBW)	65.1	54.3	
Path Loss (dB)	-199.7		6.0 GHz
Receive Ant. Gain (dB)	30.0	53.5	
Received Power, C (dBW)	-104.6	-91.9	
Receive System Noise Temp. (dBk)	28.9		
Boltzman Const.	-228.6		
Noise Power Density, N_o	-199.7		
C/N_o	95.1	107.8	
Data Rate	77.8		60 Mb/s
E_b/N_o (dB)	17.3	30.0	

TABLE 3.2-12. C-BAND DOWNLINK BUDGET

Contributor	Trunk Terminal		Comments
	CONUS	Spot Beam	
Transmit Power (dBW)	10.0	-4.5	10W/0.35W
Transmit Ant. Gain (dB)	30.0	48.7	
Transmitter Loss (dB)	-3.0	-5.0	(1)
EIRP (dBW)	37.0	39.2	
Path Loss (dB)	-196.2		4.0 GHz
Receive Ant. Gain (dB)	49.7	43.7	10m/5m Reflector
Received Power, C (dBW)	-109.5	-113.3	
Receive System Noise Temp. (dBk)	24.1		
Boltzman Const.	-228.6		
Noise Power Density, N_o	-204.5		
C/N_o	95.0	91.2	
Data Rate	77.8		60 Mb/s
E_b/N_o (dB)	17.2	13.4	
E_b/N_o Net (dB)	14.2	12.8	Including Uplink for IF Switched Traffic
(1) Modest output power requirement allows physical location of spot beam power amplifiers at a point convenient to platform mechanical conception, thus higher transmitter loss.			

TABLE 3.2-13. Ku-BAND UPLINK BUDGET

Contributor	Trunk Terminal		Comments
	CONUS	Spot Beam	
Transmit Power (dBW)	20.0	10.0	100W/10W
Transmit Ant. Gain (dB)	57.7	46.8	7m/2m Reflector
Transmitter Loss (dB)	-3.0		
EIRP (dBW)	74.7	53.8	
Path Loss (dB)	-207.2		14.25 GHz
Receive Ant. Gain (dB)	30.0	51.7	
Received Power, C (dBW)	-102.5	-101.7	
Receive System Noise Temp. (dBk)	29.3		
Boltzman Const.	-228.6		
Noise Power Density, N_o	-199.3		
C/N_o	96.8	97.6	
Data Rate	77.8		60 Mb/s
E_b/N_o (dB)	19.0	19.8	

TABLE 3.2-14. Ku-BAND DOWNLINK BUDGET

Contributor	Trunk Terminal CONUS	Trunk Terminal Spot Beam	Comments
Transmit Power (dBW)	17.8	7.0	60W/5W
Transmit Ant. Gain (dB)	30.0	50.2	
Transmitter Loss (dB)	-3.0		
EIRP (dBW)	44.8	54.2	
Path Loss (dB)	-205.8		12.0 GHz
Receive Ant. Gain (dB)	56.2	45.4	7m/2m Reflector
Received Power, C (dBW)	-104.8	-106.2	
Receive System Noise Temp. (dBk)	26.6		
Boltzman Const.	-228.6		
Noise Power Density, N_o	-202.0		
C/N_o	97.2	95.8	
Data Rate	77.8		60 Mb/s
E_b/N_o (dB)	19.4	18.0	
E_b/N_o Net (dB)	16.2	15.8	Including Uplink for IF Switched Traffic

3.2.9 Weight and Power Estimate

Weight and power summaries are shown in Table 3.2-17. These are based on assumptions as to the types of advance technologies which will be space-qualified by the year 1993. Total numbers of active components (receivers, SSPAs) shown include an allowance for redundancy. The number of active units actually required to satisfy traffic needs is shown in parentheses. It can be seen that the use of SSPAs as the high-power amplifier has been assumed for all three frequency bands. In C- and Ku-bands, the two power levels shown correspond to spot and CONUS beam coverage.

Receiver weights given do not include local oscillators which are included in the down/up converter category. SSPA weights given are projections based on experience gained in building C-band units which are presently in use as well as on a mature program of 40-watt Ku-band amplifier development. All input multiplexer filters operate in C-band as do the output filters for transmission in that band. It is assumed that these would be of the dielectric cavity type to conserve size and weight. It is assumed that Ku-band transmit filters would also be of that type, though this is admittedly a higher risk assumption. Baseband processor (BBP) weight and power is based on the Motorola study (Reference 19) which assumed a processor throughput of 4 Gb/sec. Values found by Motorola have been scaled to the present requirement of 12-Gb/sec throughput. While Motorola estimates were based on near term technology, it is felt that this is compensated by the considerably larger number of demodulator/

TABLE 3.2-15. Ka-BAND UPLINK BUDGETS

Contributor	CPS Terminal	Trunk Terminal	Comments
Transmit Power (dBW)	17.0	20.0	50W/100W Respectively
Transmit Ant. Gain (dB)	52.8	67.0	Includes 0.5 dB/0.3 dB Pointing Loss with 2m/10m Antennas Respectively
Transmitter Loss (dB)	-3.0	-3.0	
EIRP (dBW)	66.8	84.0	
Path Loss (dB)	-213.7	-213.7	30.0 GHz
Receive Ant. Gain (dB)	53.8	56.4	Includes 3 dB Edge of Coverage Loss (CPS) and 0.4 dB Pointing Loss (Trunk)
Receive Power, C (dBW)	-93.1	-73.3	
Receive System Noise Temp. (dBk)	30.7	30.7	
Boltzman Const.	-228.6	-228.6	
Noise Power Density, N_o	-197.9	-197.9	
C/N_o	104.8	124.6	
Data Rate	77.8	83.8	60 Mb/s and 240 Mb/s Respectively
E_b/N_o (dB)	27.0	40.8	

modulators requires in the present design. Assuming the demodulators represent the single largest contribution to BBP weight, it can be seen that a demodulator weight of 1 kg would represent a total contribution of 200 kg out of the total of 480 kg given in the table. Weight for the i.f. TDMA switching matrix assumes the use of MMIC technology such as that described by Ford Aerospace (Reference 21) assuming predicted 1987 technology. The weight used represents a better than 2:1 gain over a more conventional hybrid approach (Reference 22) also described by Ford.

3.2.10 PHYSICAL CONFIGURATION

Figure 3.2-10 shows a general arrangement of the payload with the antennas in deployed and in stowed positions. The main emphasis in the layout is given to disposition of the various antennas. Transponder elements would be lodged in a central zone (Zone D) which would facilitate interconnection among the three frequency bands and which would minimize waveguide runs to the radiating horns. No attempt has been made to foresee the form of the spacecraft structure, rather the objective is to show deployed and stowed configurations relative to an envelope representing available shuttle volume. While they consume a substantial portion of the available shuttle crossectional area, it can be seen that the various antenna feed arrays can be lodged within the central core of the platform. It can be seen that the Ka-band transmit and receive antennas are deployed to opposite sides of the spacecraft along the north-south

TABLE 3.2-16. Ka-BAND DOWNLINK BUDGETS

Contributor	CPS Terminal	Trunk Terminal	Comments
Transmit Power (dBW)	6.0	6.0	4W
Transmit Ant. Gain (dB)	52.9	55.6	Includes 3 dB Edge of Coverage Loss (CPS) and 0.3 dB Pointing Loss (Trunk)
Transmit Feed Loss (dB)	-3.0	-3.0	
EIRP (dBW)	55.9	58.6	
Path Loss (dB)	-209.3	-209.3	18.0 GHz
Receive Ant. Gain (dB)	48.4	62.6	2m/10m Antennas with 0.4 dB/ 0.2 dB Pointing Losses Respectively
Receive Power (dBW)	-105.0	-88.1	
Receive System Noise Temp. (dBk)	28.4	27.6	
Boltzman Const.	-228.6	-228.6	
Noise Power Density, N_o	-200.2	-201.0	
C/N_o	95.2	112.9	
Data Rate	77.8	83.8	60 Mb/s and 240 Mb/s Respectively
E_b/N_o (dB)	17.4	29.1	
Implementation Loss	-3.0	-3.0	Demodulator
Effective E_b/N_o	14.4	26.1	
Required E_b/N_o	10.6	10.6	BER = 10^{-6}
Margin (dB)	3.8	15.5	
Improvements (dB):			
Increase Xmt Power	10.0	10.0	To 40W for Fixed Spot Beams
Coding Gain	5.0	5.0	Rate 1/2 (Convolutional/Viterbi
Bit Rate Reduction	3.0	3.0	Decode) 1/2 Transmission Rate
Max. Improvements	18.0	18.0	
Net Margin Including Improvements	21.8 11.8	33.5 NA	Fixed Spot Beams Scanning Beams

TABLE 3.2-17. WEIGHT AND POWER(1) - 20% TRAFFIC CAPTURE/0% VIDEO BROADCASTS

Payload Elements	Weight (kg)	Power (W)
Transponder Elements		
C-Band		
30 Receivers @ 0.5 kg (24 active @ 8W)	15.0	192.0
109 Input mux channels @ 0.25 kg/ch.	27.3	
Diplexers, down/up converters	12.5	
116 0.35W SSPAs @ 0.5 kg (97 active @ 1.4W)	58.0	136.0
14 10W SSPAs @ 0.7 kg (12 active @ 28W)	9.8	336.0
109 Output mux channels @ 0.25 kg/ch.	27.3	
Ku-Band		
30 Receivers @ 0.5 kg (24 active @ 8W)	15.0	192.0
76 Input mux channels @ 0.25 kg/ch.	19.0	
Diplexers, down/up converters	9.0	
76 - 5W SSPAs @ 1.2 kg (64 active @ 17W)	91.2	1088.0
14 - 60W SSPAs @ 1.4 kg (12 active @ 190W)	19.6	2280.0
76 Output mux channels @ 0.25 kg/ch.	19.0	
Ka-Band		
30 Receivers @ 0.5 kg (24 active @ 8W)	15.0	192.0
326 Input mux channels @ 0.25 kg/ch.	81.5	
Down/up converters	26.0	
350 - 40W SSPAs @ 1.6 kg (310 active/4W @ 18W)	560.0	5580.0
(16 active/40W @ 132W)		2112.0
326 Output mux channels @ 0.25 kg/ch.	81.5	
Baseband processor (200-60 Mb/s channels)	480.0	3000.0
IF TDMA/Circuit Switching		
7 - 25 x 25 matrices @ 6 kg/20W	42.0	140.0
6 - 12 x 12 matrices @ 1.5 kg/10W	9.0	60.0
Other including wideband input filters, coax, W/G, W/G and coax switches, LO freq. generation	194.3	
Total Transponder Elements	1812.0	15308.0
Antenna Subsystem		
C-Band		
Unfurlable 10.5m spot beam reflector	35.0	
10.5 meter boom	42.0	
Feed Array and BFN	40.0	
Deployable 2m CONUS reflector	12.0	
Feed Array and BFN	12.0	
Ku-Band		
Deployable 3.5m spot beam reflector	25.0	
Feed Array and BFN	25.0	
Deployable 1.5m CONUS reflector	11.0	
Feed Array and BFN	10.0	
Ka-Band		
Deployable 4.5m transmit dual-pol reflector	35.0	
Feed Arrays and BFNs	30.0	100.0
Deployable 3m receive dual-pol reflector	25.0	
Feed Arrays and BFNs	30.0	100.0
Total Antenna Subsystem	332.0	200.0
TOTAL PAYLOAD	2144.0	15508.0

(1) Based on 19983 space-qualified technology.

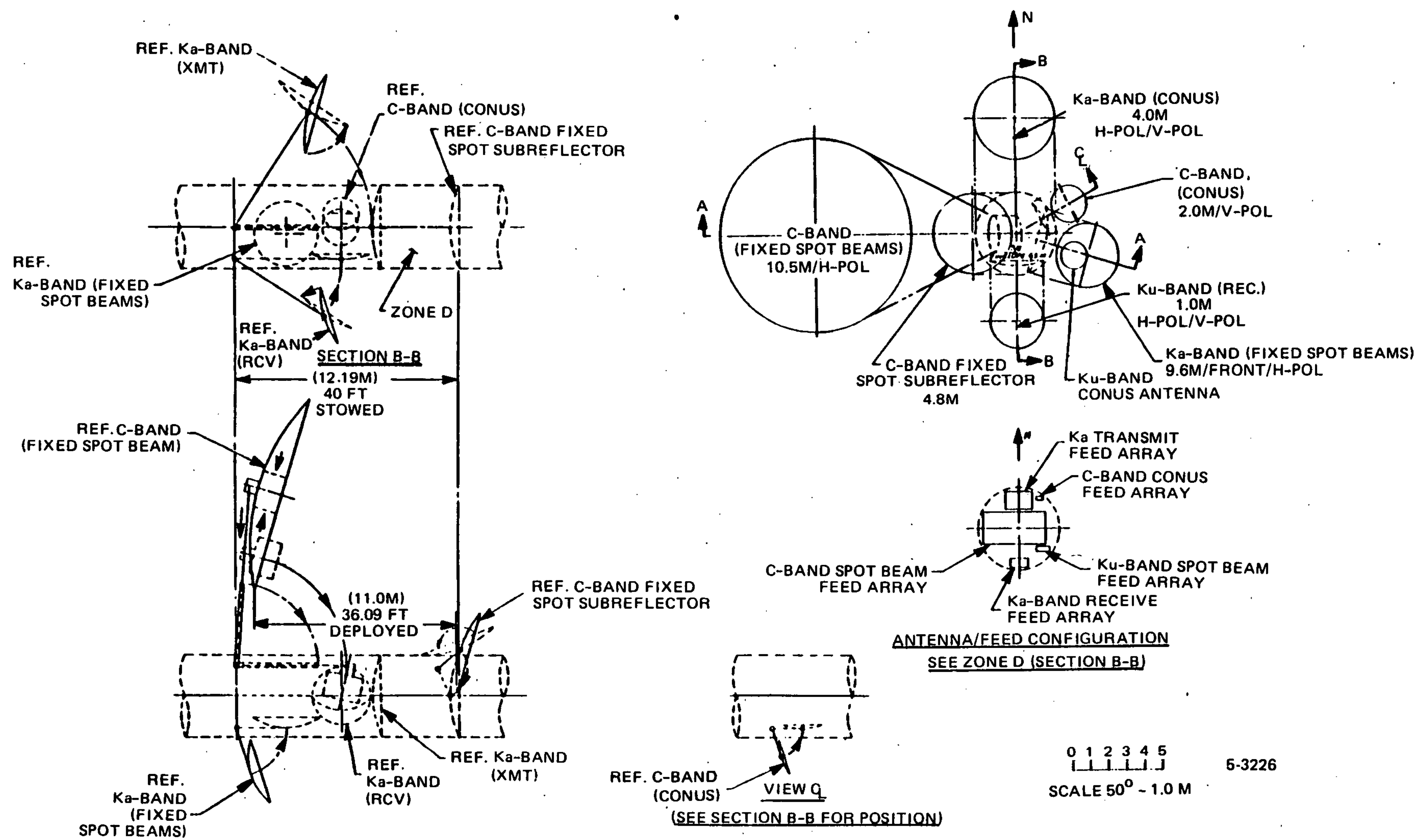


Figure 3.2-10. Platform Physical Configuration

axis. Solar arrays would be deployed along the same axis. It would be necessary that the arrays be located beyond the Ka-band antennas. It is felt that this Ka-band antenna deployment offers reasonable symmetry in terms of solar destabilization about the east-west axis.

The Ku-band antennas which provide spot and CONUS coverage on orthogonal polarizations are superimposed as shown somewhat below the east-west axis. They are deployed as one mechanical unit.

Two separate C-band antennas are shown. The small solid reflector which provides CONUS coverage is deployed to the same side as are the Ku-band reflectors. C-band spot beam coverage is assured by the unfurlable 10.5-meter reflector and its deployable solid subreflector. This deployment is along the east-west axis. While this antenna represents a large destabilizing force, its mesh construction will alleviate that problem to some extent.

Geometrical configurations of the principal antennas are shown in Figures 3.2-11 to 3.2-13. A summary of basic dimensions for all antennas is provided in Tables 3.2-18 through 3.2-20.

TABLE 3.2-18. C-BAND ANTENNA DIMENSIONS

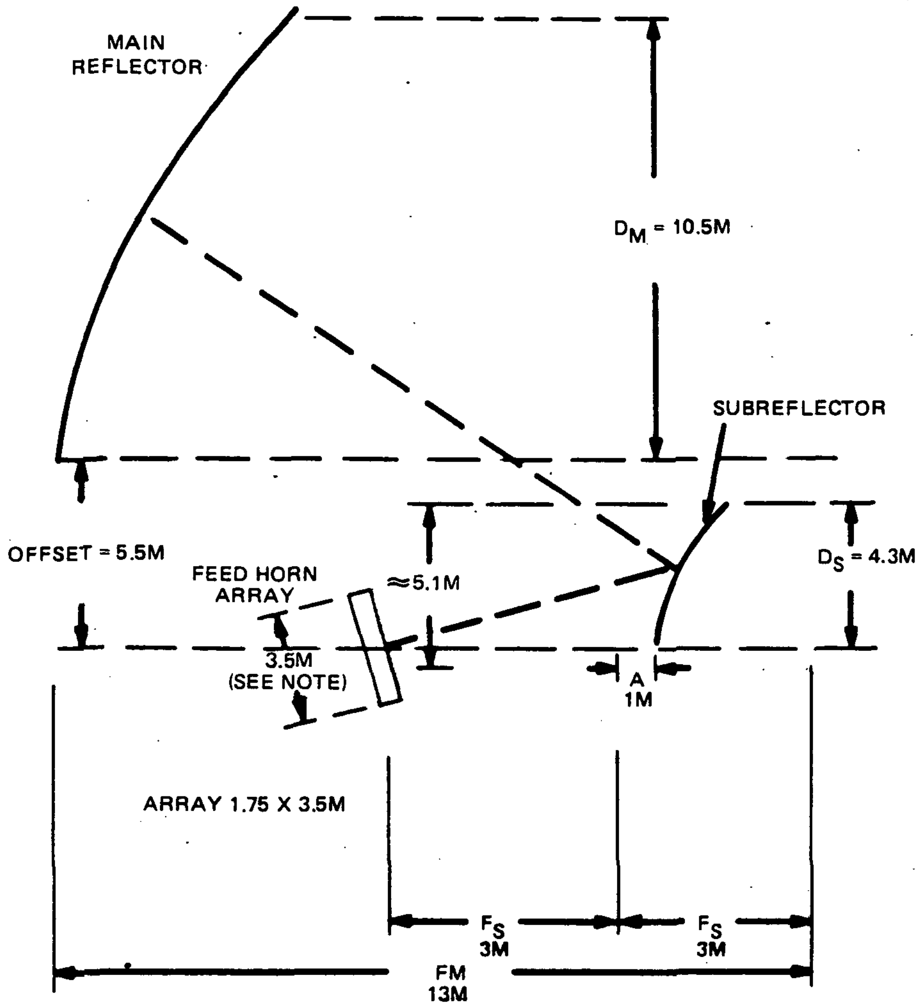
	Spot Beam	CONUS
Main Reflector		(Front Feed)[2]
D_M	10.5m	2.0m
F_M	13.0m	2.0m
Offset	5.5m	0.3m
Subreflector		
D_S	4.3m	
F_S	3.0m	NA
A	1.0m	
Feed Array[1]	350 cm x 175 cm (138" x 69")	20 cm x 40 cm (8" x 16")

NOTES:

(1) Long dimension of feed array in East-West direction in all cases.
(2) Front Feed geometry shown on Figure 3.2-12.

TABLE 3.2-19. Ku-BAND ANTENNA DIMENSIONS (BOTH FRONT FEED)

	Spot Beam	CONUS
Main Reflector		
D_M	3.5m	1.5m
F_M	4.3m	1.5m
Offset	1.8m	0.25m
Feed Array	70 cm x 35 cm (27" x 13.5")	10 cm x 22.5 cm (4" x 9")



NOTE:

DIMENSION GIVEN ASSUMES EAST-WEST ANTENNA DEPLOYMENT. FOR NORTH-SOUTH DEPLOYMENT, 3.5M AND 1.75M DIMENSIONS ARE INTERCHANGED SO THAT 3.5M DIMENSION IS EAST-WEST.

Figure 3.2-11. C-Band Spot Beam Antenna Geometry

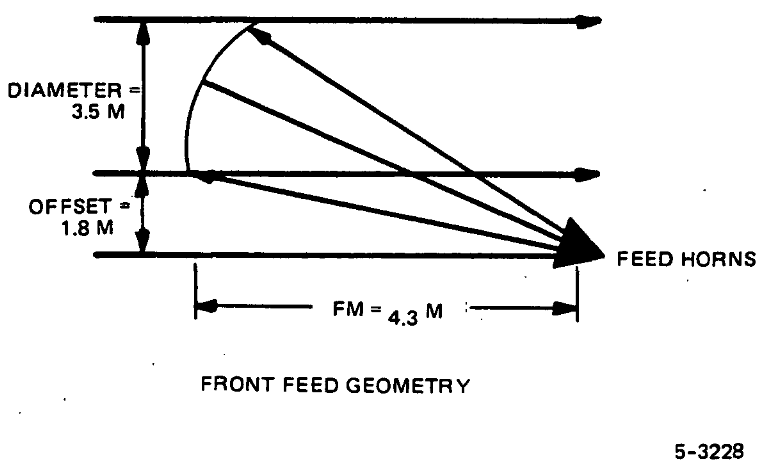
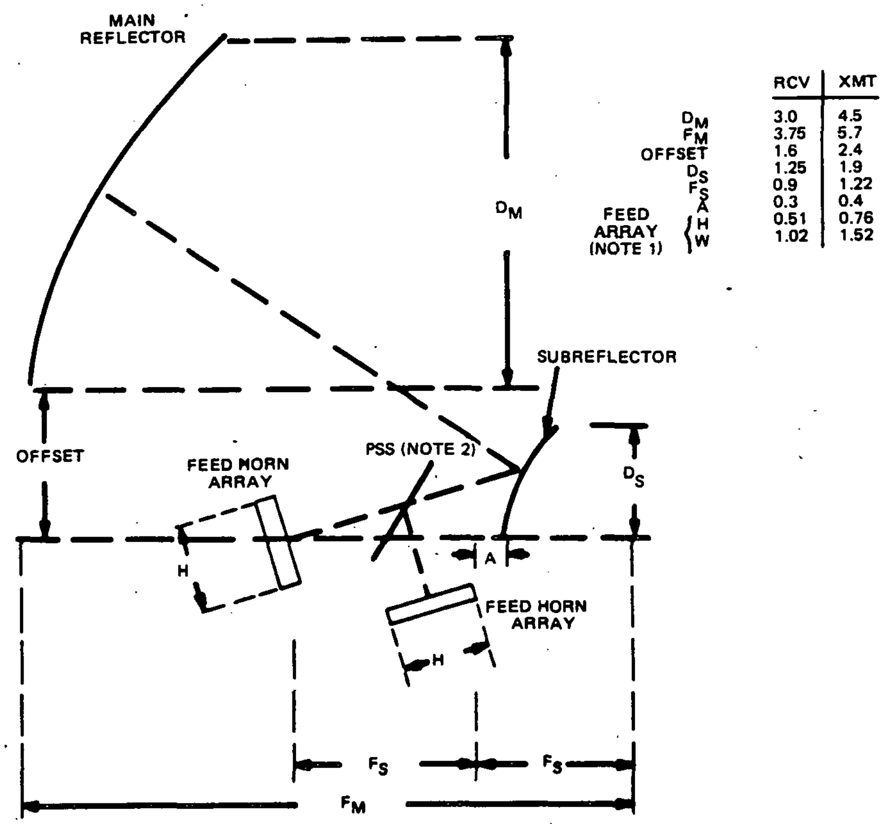


Figure 3.2-12. Ku-Band Spot Beam Antenna Geometry



NOTES:

1. DIMENSIONS GIVEN ASSUME NORTH-SOUTH ANTENNA DEPLOYMENT. FOR EAST-WEST DEPLOYMENT, H AND W VALUES ARE INTERCHANGED (LARGER DIMENSION ALWAYS EAST-WEST).

2. PSS = POLARIZATION SELECTIVE SURFACE

6-3229

Figure 3.2-13. Ka-Band Antenna Geometry

TABLE 3.2-20. Ka-BAND ANTENNA DIMENSIONS

	30 GHz	20 GHz
Main Reflector		
D_M	3.0m	4.6m
F_M	3.75m	5.7m
Offset	1.6m	2.4m
Subreflector		
D_S	1.25m	1.9m
F_S	0.9m	1.22m
A	0.3m	0.4m
Feed Array	102 cm x 51 cm (40" x 20")	152 cm x 76 cm (60" x 30")

3.3 CONCEPT 3 - FIXED SATELLITE SERVICE (13% MARKET SHARE) AND VIDEO DISTRIBUTION (10% MARKET SHARE)

3.3.1 SYSTEM DESCRIPTIONS

3.3.1.1 Block Diagram and Summary Descriptions

A summary chart of the basic characteristics of Concept 3 is shown in Table 3.3-1. The platform envisaged for this concept will carry 13% of the market share of fixed-satellite-service (FSS) traffic as well as 10% of the predicted video-distribution traffic. The latter represents a requirement for ten 36-MHz channels and involves a point-to-multipoint type of transmission similar to that currently used for cable TV distribution. Because receiving terminals may be located over a wide geographic area, CONUS coverage has been assumed for those channels. Transmission in C-band has been chosen because there is no strong requirement for a small antenna at the receiving terminal, which is a central installation from which local distribution would be effected rather than an individual user's receiver.

TABLE 3.3-1. CONCEPT 3 SUMMARY

CONUS Beam 24 Channels (36 MHz) 60 Mbps/Channel 10 W/Channel	1/4 CONUS Beams 41 Channels (36 MHz) 60 Mbps/Channel 15 W/Channel	25 0.25° Fixed Spot 6 0.25° Scan Spot 308 Channels (36 MHz) 60 Mbps/Channel 4 W/40 W per Channel
System Capacity 22.4 Gbps		
NOTES: (1) Broadcast Video Distribution via C-band (2) Trunking via C-, Ka-band (3) CPS via Ku-, Ka-band		

Many of the objectives set forth in the development of the 20% FSS concept have also been applied to this concept: channelized design using 36-MHz transponders permitting maximum interconnectivity among the C-, Ku-, and Ka-bands provided in this communications payload.

Since 10 C-band channels are devoted to CONUS coverage for video distribution, the remaining 14 channels are also provided with that coverage rather than using the spot beams as in the preceding concept. The complexity of a large antenna does not seem justified for the remaining channels. Furthermore, the total fixed-service traffic requirement is substantially lower in the present case, which reduces the need for maximum C-band use. This same factor entered into the decision to simplify Ku-band coverage relative to the previous concept. In the present case, quarter-CONUS beams are used with alternating polarization to permit a maximum four times frequency reuse. As in the previous concept, it has been assumed for traffic allocation purposes that trunking traffic is assigned to C-band, CPS to Ku-band, and the remainder of each to Ka-band.

The Ka-band subsystem is quite similar to that adopted for the 20% FSS with six scanning beams and 0.25-degree spot beams to traffic centers. In the present case, the number of fixed spot beams is increased from 17 to 25 due largely to the reduced C-band availability. Capacity requirements for the i.f. TDMA switches and the baseband processor are reduced.

The block diagram given in Figure 3.3-1 shows the relationship between the C-band, Ku-band, and Ka-band subsystems which are described in the following sections.

3.3.1.2 C-Band Subsystem

The dual linearly-polarized antenna consists of a pair of superimposed two-meter reflectors which deploy as one unit. It provides 12 input channels on each polarization. Inputs from each of the two horn arrays are combined in a

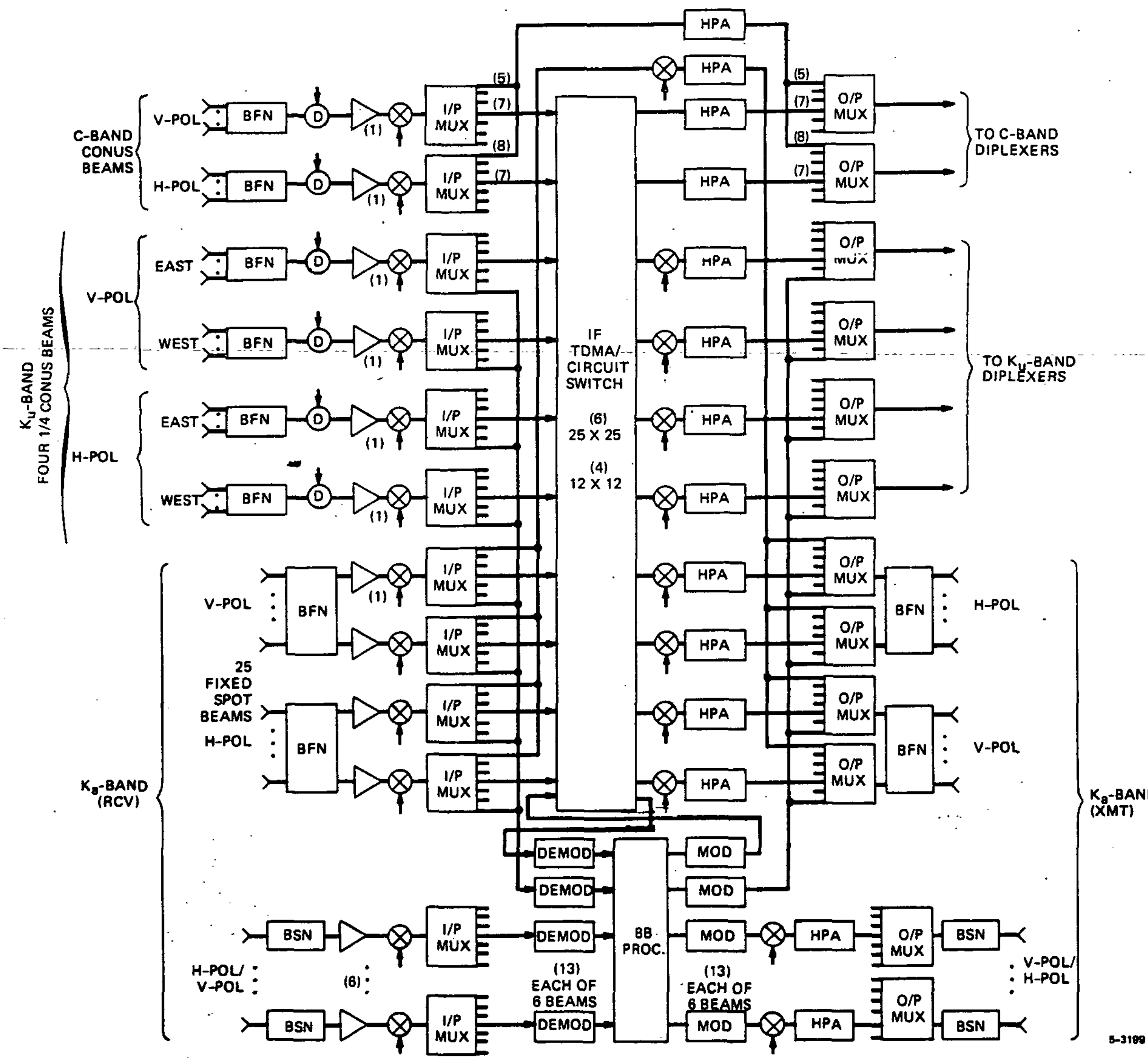


Figure 3.3-1. Block Diagram for 13% FSS/10% Video Broadcast

beam forming network (BFN) before entering the receiver/downconverter and are then channelized in the input multiplexer. Ten of the multiplexer outputs, the video broadcast channels, are connected directly to the 10-watt SSPA high power amplifiers and go to the wideband antenna diplexer after channel filtering and combining in the output multiplexer. The remaining 14 channels enter the i.f. TDMA switching matrices where they are switched to their appropriate destinations in the C-band, Ku-band, or Ka-band transmit channels. C-band outputs of the matrix switches are also amplified in 10-watt SSPAs and are recombined with the video broadcast channels in the two output multiplexers.

3.3.1.3 Ku-Band Subsystem

The two-meter Ku-band antennas form quarter-CONUS beams with alternate vertical and horizontal polarization. Beam isolation is sufficient to permit full frequency reuse in each beam, which corresponds to 12 channels of available capacity per beam. Inputs are downconverted, channelized in the input multiplexer, and connected to the i.f. switch matrices. Outputs of the matrices are TDMA switched to the appropriate C-, Ku-, and Ka-band channels. Ku-band outputs are amplified in 15-watt SSPAs, combined in the output multiplexers, and connected to the BFNs via wideband diplexers.

3.3.1.4 Ka-Band Subsystem

As indicated in Section 3.3.1.1, the Ka-band subsystem is conceptually the same as that described in Section 3.2.1.4. Twenty-five 0.25° spot beams are required, one for each city or city pair designated as a traffic center. Due to reduced FSS traffic requirements, a smaller number of i.f. switching matrices is required and the number of 36-MHz channels to be handled by the baseband processor is reduced from 200 to 133. Each scanning beam in this case will carry 13 36-MHz traffic channels.

3.3.2 COVERAGE

Typical antenna coverage diagrams for all three frequency bands are given in Figures 3.3-2 to 3.3-4. They correspond to a platform centrally located in the 90° to 100° west longitude range. City locations on the Ka-band diagram correspond to those given in the traffic requirements table in Section 3.3.3. As in the 20% FSS concept, the polarization of Ka-band scanning beams alternates from one sector to the next. The polarization of the spot beams is orthogonal to that of the scanning beam for the sector in which they are located.

3.3.3 TRAFFIC DISTRIBUTION

It has been shown that 10% of total video-distribution requirements can be satisfied using ten 36-MHz transponders; thus, 10 C-band channels with CONUS coverage have been allocated to satisfy this demand. FSS traffic is then distributed in the remaining channels using the Table 3.3-2 data on basic traffic requirements as a starting point. The distribution is shown in Table 3.3-3. The 14 remaining C-band channels have been assigned to trunking traffic attributed to "other" sources. This leaves 45.2 channels to be handled by the Ka-band scanning beams. The cities listed in Table 3.3-2 have been assigned to one of the four quarter-CONUS beams and noted as E (east), E-C (east-central), W-C (west-central) and W (west). CPS requirements for each

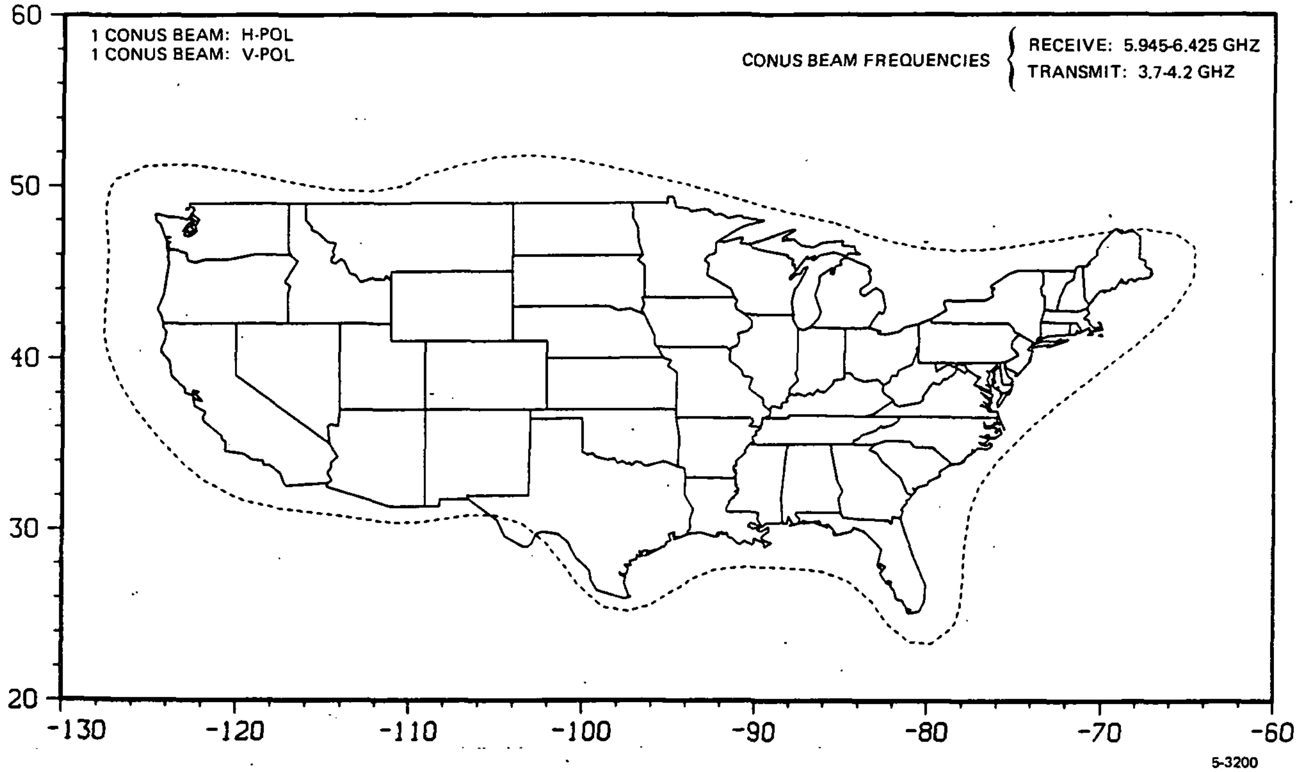


Figure 3.3-2. Concept 3: C-Band 3-dB Coverage Contours

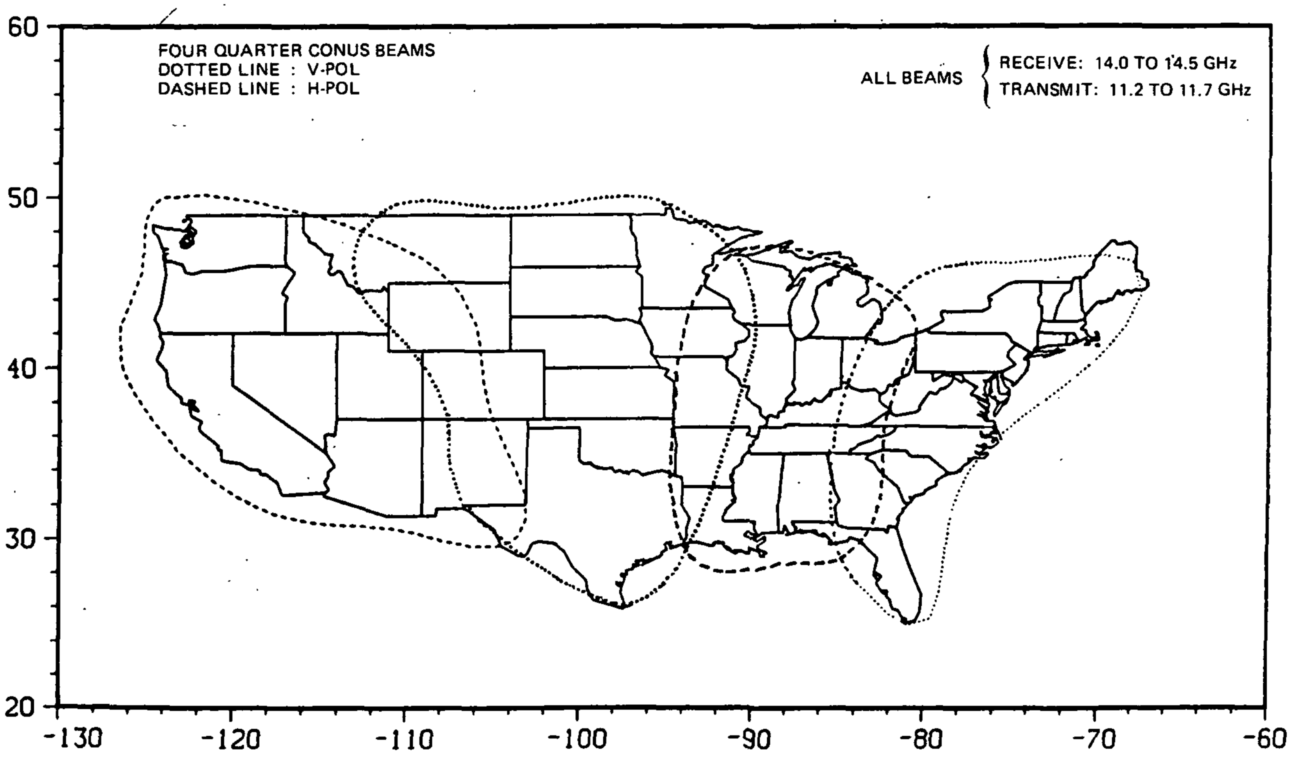


Figure 3.3-3. Concept 3: Ku-Band 3 dB Coverage Contours

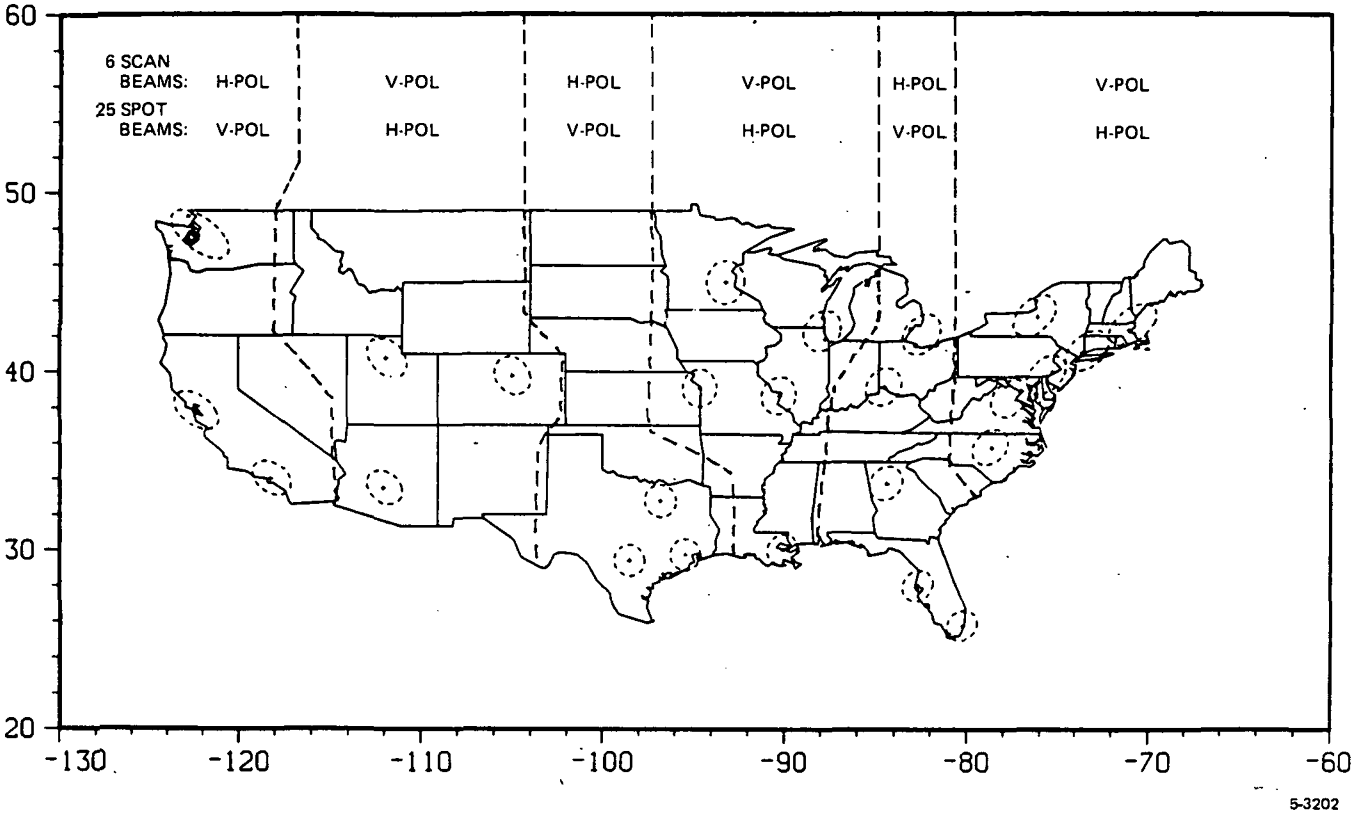


Figure 3.3-4. Concept 3: Ka-Band 3 dB Coverage Contours

city are summed and compared to available Ku-band capacity for each beam. Unsatisfied demand is then assigned to Ka-band. It can be seen that CPS requirements are met to a considerable degree by the quarter-CONUS Ku-band beams. Trunking requirements on a quarter-CONUS beam basis are included only for comparative reasons. City trunking needs are satisfied by the Ka-band spot beams. It can be seen that these needs far exceed CPS requirements in Ka-band.

It can be seen in Table 3.3-3 that Ku-band capacity is not completely utilized for west-central and west beams where 6.5 and 10 channels are utilized respectively for CPS traffic. Such theoretical underuse of capacity would allow wide options such as Ku-band trunking if that would be desired. This would reduce, but not eliminate Ka-band requirements.

3.3.4 TRAFFIC MATRICES

Using requirements given in Table 3.3-2 matrices for trunking and CPS traffic have been established and are shown in Tables 3.3-4 and 3.3-5. Proceeding in the fashion outlined in Section 3.2.4.1, matrices of dedicated trunking and CPS channels are drawn up as shown in Tables 3.3-6 and 3.3-7. TDMA switching matrix traffic is then established by taking the difference between Tables 3.3-4 and 3.3-6 for trunking traffic and Tables 3.3-5 and 3.3-7 for CPS traffic. The resulting matrices of TDMA switching traffic are given in Tables 3.3-8 and 3.3-9.

TABLE 3.3-2. BASIC TRAFFIC REQUIREMENTS FOR 13% FSS MARKET CAPTURE EXPRESSED IN 36-MHz CHANNELS (CONCEPT 3)

City	Total Requirements (in 36-MHz Channels)	
	Trunking	CPS
New York	26.1	7.3
Los Angeles, Anaheim	19.5	5.6
Detroit/Cleveland	16.9	4.7
Chicago/Milwaukee	14.4	4.2
San Francisco	9.9	2.7
Boston	9.6	2.6
Washington	9.0	2.5
Cincinnati	8.8	2.5
Philadephia	8.2	2.3
Dallas	6.5	1.8
Atlanta	5.3	1.4
Houston	4.7	1.4
Syracuse	4.4	1.3
Miami	4.3	1.2
St. Louis	4.0	1.0
Raleigh	3.8	1.0
Tampa	3.5	1.0
Minneapolis	3.3	0.9
Seattle	3.3	0.9
Kansas City	2.9	0.8
Denver	2.8	0.8
San Antonio	1.9	0.5
Phoenix	1.7	0.5
New Orleans	1.7	0.5
Salt Lake City	1.2	0.3
Total - Fixed Spots	177.8	49.7
Others	59.2	16.6
Totals - All	237.0	66.3

TABLE 3.3-3. TRAFFIC ASSIGNMENT TO C-, Ku-, AND Ka-BANDS (CONCEPT 3)

City	Beam	Total Requirements		Avail.	C-Band	Ku-Band	Ka-Band		
		Trunking	CPS	Ku-Band	Trunking	CPS	Trunking	CPS	Total
New York Boston Philadelphia Washington, DC Syracuse Raleigh Miami Tampa	E	68.9	19.2	12	0	12	68.9	7.2	76.1
Cleveland Detroit Milwaukee Chicago Cincinatti St. Louis New Orleans Atlanta	E-C	51.1	14.3	12	0	12	51.1	2.3	53.4
Minneapolis Kansas City Denver San Antonio Houston Dallas	W-C	22.2	6.2	12	0	6.5	22.2	0	22.2
Seattle San Francisco Los Angeles Anaheim Phoenix Salt Lake City	W	35.6	10.0	12	0	10	35.6	0	35.6
Subtotals		177.8	49.7			40.5	177.8	9.2	187.3
Other		59.2	16.6		14		45.2	16.6	61.8
Total		237.0	66.3						

TABLE 3.3-4. MATRIX OF TOTAL TRUNKING TRAFFIC

	New York	Los Angeles/Anaheim	Chicago/Milwaukee	San Francisco	Boston	Detroit/Cleveland	Washington	Cincinnati	Philadelphia	Dallas	Atlanta	Houston	Syracuse	Miami	St. Louis	Raleigh	Tampa	Minneapolis	Seattle	Kansas City	Denver	San Antonio	Phoenix	New Orleans	Salt Lake City	Others
New York	0.00	2.53	2.18	1.86	1.28	1.24	1.16	1.14	1.06	0.84	0.68	0.61	0.57	0.55	0.52	0.49	0.45	0.43	0.43	0.37	0.36	0.25	0.22	0.22	0.15	6.52
Los Angeles/Anaheim	2.53	0.00	1.56	1.33	0.91	0.80	0.83	0.81	0.76	0.60	0.49	0.43	0.41	0.40	0.37	0.35	0.32	0.30	0.30	0.27	0.26	0.18	0.16	0.16	0.11	4.90
Chicago/Milwaukee	2.18	1.56	0.00	1.12	0.77	0.74	0.70	0.68	0.64	0.50	0.41	0.36	0.34	0.33	0.31	0.29	0.27	0.26	0.26	0.23	0.22	0.15	0.13	0.13	0.09	4.22
San Francisco	1.86	1.33	1.12	0.00	0.64	0.62	0.58	0.57	0.53	0.42	0.34	0.30	0.28	0.28	0.26	0.24	0.23	0.21	0.21	0.19	0.18	0.12	0.11	0.11	0.08	3.60
Boston	1.28	0.91	0.77	0.64	0.00	0.40	0.38	0.37	0.35	0.27	0.22	0.20	0.19	0.18	0.17	0.16	0.15	0.14	0.14	0.12	0.12	0.08	0.07	0.07	0.05	2.47
Detroit/Cleveland	1.24	0.88	0.74	0.62	0.40	0.00	0.37	0.36	0.33	0.26	0.22	0.19	0.18	0.18	0.16	0.15	0.14	0.13	0.13	0.12	0.11	0.08	0.07	0.07	0.05	2.40
Washington	1.16	0.83	0.70	0.58	0.38	0.37	0.00	0.33	0.31	0.25	0.20	0.18	0.17	0.16	0.15	0.14	0.13	0.12	0.12	0.11	0.11	0.07	0.06	0.06	0.05	2.25
Cincinnati	1.14	0.81	0.68	0.57	0.37	0.36	0.33	0.00	0.30	0.24	0.20	0.17	0.16	0.16	0.15	0.14	0.13	0.12	0.12	0.11	0.10	0.07	0.06	0.06	0.04	2.20
Philadelphia	1.06	0.76	0.64	0.53	0.35	0.33	0.31	0.30	0.00	0.22	0.18	0.16	0.15	0.15	0.14	0.13	0.12	0.11	0.11	0.10	0.10	0.06	0.06	0.06	0.04	2.05
Dallas	0.84	0.60	0.50	0.42	0.27	0.26	0.25	0.24	0.22	0.00	0.14	0.12	0.11	0.11	0.10	0.10	0.09	0.09	0.09	0.08	0.07	0.05	0.04	0.04	0.03	1.62
Atlanta	0.68	0.49	0.41	0.34	0.22	0.22	0.20	0.20	0.18	0.14	0.00	0.10	0.09	0.09	0.08	0.08	0.07	0.07	0.07	0.06	0.06	0.04	0.04	0.04	0.02	1.32
Houston	0.61	0.43	0.36	0.30	0.20	0.19	0.18	0.17	0.16	0.12	0.10	0.00	0.08	0.08	0.07	0.07	0.06	0.06	0.06	0.05	0.05	0.03	0.03	0.03	0.02	1.17
Syracuse	0.57	0.41	0.34	0.28	0.19	0.18	0.17	0.16	0.15	0.11	0.09	0.08	0.00	0.07	0.07	0.06	0.06	0.06	0.06	0.05	0.05	0.03	0.03	0.03	0.02	1.10
Miami	0.55	0.40	0.33	0.28	0.18	0.18	0.16	0.16	0.15	0.11	0.09	0.08	0.07	0.00	0.07	0.06	0.06	0.05	0.05	0.05	0.05	0.03	0.03	0.03	0.03	1.07
St. Louis	0.52	0.37	0.31	0.26	0.17	0.16	0.15	0.15	0.14	0.10	0.08	0.07	0.07	0.07	0.00	0.06	0.05	0.05	0.05	0.04	0.04	0.03	0.03	0.03	0.02	1.00
Raleigh	0.49	0.35	0.29	0.24	0.16	0.15	0.14	0.14	0.13	0.10	0.08	0.07	0.06	0.06	0.06	0.00	0.05	0.05	0.05	0.04	0.04	0.03	0.02	0.02	0.02	0.95
Tampa	0.45	0.32	0.27	0.23	0.15	0.14	0.13	0.13	0.12	0.09	0.07	0.06	0.06	0.06	0.06	0.05	0.05	0.00	0.04	0.04	0.04	0.04	0.02	0.02	0.02	0.87
Minneapolis	0.43	0.30	0.26	0.21	0.14	0.13	0.12	0.12	0.11	0.09	0.07	0.06	0.06	0.05	0.05	0.05	0.04	0.00	0.04	0.03	0.03	0.02	0.02	0.02	0.01	0.82
Seattle	0.43	0.30	0.26	0.21	0.14	0.13	0.12	0.12	0.11	0.09	0.07	0.06	0.06	0.05	0.05	0.05	0.04	0.04	0.00	0.03	0.03	0.02	0.02	0.02	0.01	0.82
Kansas City	0.37	0.27	0.23	0.19	0.12	0.12	0.11	0.11	0.10	0.08	0.06	0.05	0.05	0.05	0.04	0.04	0.04	0.03	0.03	0.00	0.03	0.02	0.02	0.02	0.01	0.72
Denver	0.36	0.26	0.22	0.18	0.12	0.11	0.11	0.10	0.10	0.07	0.06	0.05	0.05	0.05	0.04	0.04	0.04	0.03	0.03	0.03	0.00	0.02	0.02	0.02	0.01	0.70
San Antonio	0.25	0.18	0.15	0.12	0.08	0.08	0.07	0.07	0.06	0.05	0.04	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.00	0.01	0.01	0.01	0.47
Phoenix	0.22	0.16	0.13	0.11	0.07	0.07	0.06	0.06	0.06	0.04	0.04	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.00	0.01	0.01	0.42
New Orleans	0.22	0.16	0.13	0.11	0.07	0.07	0.06	0.06	0.06	0.04	0.04	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.00	0.01	0.42
Salt Lake City	0.15	0.11	0.09	0.08	0.05	0.05	0.05	0.04	0.04	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.30
Others	6.52	4.90	4.22	3.60	2.47	2.40	2.25	2.20	2.05	1.62	1.32	1.17	1.10	1.07	1.00	0.95	0.87	0.82	0.82	0.72	0.70	0.47	0.42	0.42	0.30	14.81

TABLE 3.3-5. MATRIX OF TOTAL CPS TRAFFIC

	New York	Los Angeles/Anaheim	Chicago/Milwaukee	San Francisco	Boston	Detroit/Cleveland	Washington	Cincinnati	Philadelphia	Dallas	Atlanta	Houston	Syracuse	Miami	St. Louis	Raleigh	Tampa	Minneapolis	Seattle	Kansas City	Denver	San Antonio	Phoenix	New Orleans	Salt Lake City	Others
New York	0.00	0.72	0.61	0.54	0.35	0.34	0.32	0.32	0.30	0.23	0.18	0.18	0.17	0.15	0.13	0.13	0.13	0.12	0.12	0.10	0.10	0.06	0.06	0.06	0.04	1.83
Los Angeles/Anaheim	0.72	0.00	0.44	0.40	0.26	0.25	0.24	0.22	0.17	0.13	0.13	0.12	0.11	0.09	0.09	0.09	0.09	0.09	0.09	0.08	0.08	0.05	0.05	0.05	0.03	1.40
Chicago/Milwaukee	0.61	0.44	0.00	0.32	0.21	0.20	0.19	0.19	0.18	0.14	0.11	0.11	0.10	0.09	0.08	0.08	0.08	0.07	0.07	0.06	0.06	0.04	0.04	0.04	0.02	1.18
San Francisco	0.54	0.40	0.32	0.00	0.18	0.18	0.17	0.17	0.16	0.12	0.09	0.09	0.09	0.08	0.07	0.07	0.07	0.06	0.06	0.05	0.05	0.03	0.03	0.03	0.02	1.05
Boston	0.35	0.26	0.21	0.18	0.00	0.11	0.10	0.10	0.09	0.07	0.06	0.06	0.05	0.05	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.02	0.02	0.02	0.01	0.68
Detroit/Cleveland	0.34	0.25	0.20	0.18	0.11	0.00	0.10	0.10	0.09	0.07	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.02	0.02	0.02	0.01	0.65
Washington	0.32	0.24	0.19	0.17	0.10	0.10	0.00	0.09	0.09	0.07	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.01	0.63
Cincinnati	0.32	0.24	0.19	0.17	0.10	0.10	0.09	0.00	0.09	0.07	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.01	0.63
Philadelphia	0.30	0.22	0.18	0.16	0.09	0.09	0.09	0.09	0.00	0.06	0.05	0.05	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.01	0.58
Dallas	0.23	0.17	0.14	0.12	0.07	0.07	0.07	0.07	0.06	0.00	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.45
Atlanta	0.18	0.13	0.11	0.09	0.06	0.05	0.05	0.05	0.05	0.04	0.00	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.35
Houston	0.18	0.13	0.11	0.09	0.06	0.05	0.05	0.05	0.05	0.04	0.03	0.00	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.35
Syracuse	0.17	0.12	0.10	0.09	0.05	0.05	0.05	0.05	0.04	0.03	0.03	0.03	0.00	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.33
Miami	0.15	0.11	0.09	0.08	0.05	0.05	0.05	0.05	0.04	0.03	0.02	0.02	0.02	0.00	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.30
St. Louis	0.13	0.09	0.08	0.07	0.04	0.04	0.04	0.04	0.03	0.03	0.02	0.02	0.02	0.02	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.25
Raleigh	0.13	0.09	0.08	0.07	0.04	0.04	0.04	0.04	0.03	0.03	0.02	0.02	0.02	0.02	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.25
Tampa	0.13	0.09	0.08	0.07	0.04	0.04	0.04	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.25
Minneapolis	0.12	0.09	0.07	0.06	0.04	0.04	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.23
Seattle	0.12	0.09	0.07	0.06	0.04	0.04	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.23
Kansas City	0.10	0.08	0.06	0.05	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.20
Denver	0.10	0.08	0.06	0.05	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.20
San Antonio	0.06	0.05	0.04	0.03	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.13
Phoenix	0.06	0.05	0.04	0.03	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.13
New Orleans	0.06	0.05	0.04	0.03	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.13
Salt Lake City	0.04	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08
Others	1.83	1.40	1.18	1.05	0.68	0.65	0.63	0.63	0.58	0.45	0.35	0.35	0.33	0.30	0.25	0.25	0.25	0.23	0.23	0.20	0.20	0.13	0.13	0.13	0.08	4.14

TABLE 3.3-6. DEDICATED TRUNKING MATRIX

	New York	Los Angeles/Anaheim	Detroit/Cleveland	Chicago/Milwaukee	San Francisco	Boston	Washington	Cincinnati	Philadelphia	Dallas	Atlanta	Houston	Syracuse	Miami	St. Louis	Raleigh	Tampa	Minneapolis	Seattle	Kansas City	Denver	San Antonio	Phoenix	New Orleans	Salt Lake City	Others
New York		2	2	2	1	1	1	1	1	1	1															6
Los Angeles/Anaheim	2		1	1	1	1	1	1																		5
Chicago/Milwaukee	2	1	1																							3
San Francisco	1	1	1																							2
Boston	1	1	1																							2
Detroit/Cleveland	2	1		1	1	1	1	1																		4
Washington	1	1	1																							2
Cincinnati	1	1	1																							2
Philadelphia	1																									2
Dallas	1																									1
Atlanta	1																									1
Houston																										1
Syracuse																										1
Miami																										1
St. Louis																										1
Raleigh																										1
Tampa																										1
Minneapolis																										1
Seattle																										1
Kansas City																										1
Denver																										1
San Antonio																										
Phoenix																										
New Orleans																										
Salt Lake City																										
Others	6	5	4	3	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1						
Total	19	13	12	7	5	5	5	5	3	2	2	1	1	1	1	1	1	1	1	1						40

128 Total

TABLE 3.3-7. DEDICATED CPS MATRIX

	New York	Los Angeles/Anaheim	Detroit/Cleveland	Chicago/Milwaukee	San Francisco	Boston	Washington	Cincinnati	Philadelphia	Dallas	Atlanta	Houston	Syracuse	Miami	St. Louis	Raleigh	Tampa	Minneapolis	Seattle	Kansas City	Denver	San Antonio	Phoenix	New Orleans	Salt Lake City	Others	Total
New York		1																								2	
Los Angeles/Anaheim	1																									1	
Chicago/Milwaukee																										1	
San Francisco																										1	
Boston																											
Detroit/Cleveland																										1	
Washington																											
Cincinnati																											
Philadelphia																											
Dallas																											
Atlanta																											
Houston																											
Syracuse																											
Miami																											
St. Louis																											
Raleigh																											
Tampa																											
Minneapolis																											
Seattle																											
Kansas City																											
Denver																											
San Antonio																											
Phoenix																											
New Orleans																											
Salt Lake City																											
Others	2	1	1	1	1																						
Total	3	2	1	1	1																					6	14

TABLE 3.3-8. IF TDMA SWITCH TRUNKING MATRIX

	New York	Los Angeles/Anaheim	Chicago/Milwaukee	San Francisco	Boston	Detroit/Cleveland	Washington	Cincinnati	Philadelphia	Dallas	Atlanta	Houston	Syracuse	Miami	St. Louis	Raleigh	Tampa	Minneapolis	Seattle	Kansas City	Denver	San Antonio	Phoenix	New Orleans	Salt Lake City	Others
New York	0.00	0.53	0.18	0.00	0.28	0.24	0.16	0.14	0.06	0.00	0.00	0.61	0.57	0.55	0.52	0.49	0.45	0.43	0.43	0.37	0.36	0.25	0.22	0.22	0.15	0.52
Los Angeles/Anaheim	0.53	0.00	0.56	0.33	0.00	0.00	0.00	0.00	0.00	0.60	0.49	0.43	0.41	0.40	0.37	0.35	0.32	0.30	0.30	0.27	0.26	0.18	0.16	0.16	0.11	0.00
Chicago/Milwaukee	0.18	0.56	0.00	0.12	0.00	0.00	0.00	0.00	0.64	0.50	0.41	0.36	0.34	0.33	0.31	0.29	0.27	0.26	0.26	0.23	0.22	0.15	0.13	0.13	0.09	0.22
San Francisco	0.00	0.33	0.12	0.00	0.64	0.62	0.58	0.57	0.53	0.42	0.34	0.30	0.28	0.28	0.26	0.24	0.23	0.21	0.21	0.19	0.18	0.12	0.11	0.11	0.08	0.60
Boston	0.28	0.00	0.00	0.64	0.00	0.40	0.38	0.37	0.35	0.27	0.22	0.20	0.19	0.18	0.17	0.16	0.15	0.14	0.14	0.12	0.12	0.08	0.07	0.07	0.05	0.47
Detroit/Cleveland	0.24	0.00	0.00	0.62	0.40	0.00	0.37	0.36	0.33	0.26	0.22	0.19	0.18	0.18	0.16	0.15	0.14	0.13	0.13	0.12	0.11	0.08	0.07	0.07	0.05	0.40
Washington	0.16	0.00	0.00	0.58	0.38	0.37	0.00	0.33	0.31	0.25	0.20	0.18	0.17	0.16	0.15	0.14	0.13	0.12	0.12	0.11	0.11	0.07	0.06	0.06	0.05	0.25
Cincinnati	0.14	0.00	0.00	0.57	0.37	0.36	0.33	0.00	0.30	0.24	0.20	0.17	0.16	0.16	0.15	0.14	0.13	0.12	0.12	0.11	0.10	0.07	0.06	0.06	0.04	0.20
Philadelphia	0.06	0.00	0.64	0.53	0.35	0.33	0.31	0.30	0.00	0.22	0.18	0.16	0.15	0.15	0.14	0.13	0.12	0.11	0.11	0.10	0.10	0.06	0.06	0.06	0.04	0.05
Dallas	0.00	0.60	0.50	0.42	0.27	0.26	0.25	0.24	0.22	0.00	0.14	0.12	0.11	0.11	0.10	0.10	0.09	0.09	0.09	0.08	0.07	0.05	0.04	0.04	0.03	0.62
Atlanta	0.00	0.49	0.41	0.34	0.22	0.22	0.20	0.20	0.18	0.14	0.00	0.10	0.09	0.09	0.08	0.08	0.07	0.07	0.07	0.06	0.06	0.04	0.04	0.04	0.02	0.32
Houston	0.61	0.43	0.36	0.30	0.20	0.19	0.18	0.17	0.16	0.12	0.10	0.00	0.08	0.08	0.07	0.07	0.06	0.06	0.06	0.05	0.05	0.03	0.03	0.03	0.02	0.17
Syracuse	0.57	0.41	0.34	0.28	0.19	0.18	0.17	0.16	0.15	0.11	0.09	0.08	0.00	0.07	0.07	0.06	0.06	0.06	0.06	0.05	0.05	0.03	0.03	0.03	0.02	0.10
Miami	0.55	0.40	0.33	0.28	0.18	0.18	0.16	0.16	0.15	0.11	0.09	0.08	0.07	0.00	0.07	0.06	0.06	0.05	0.05	0.05	0.05	0.03	0.03	0.03	0.02	0.07
St. Louis	0.52	0.37	0.31	0.26	0.17	0.16	0.15	0.15	0.14	0.10	0.08	0.07	0.07	0.07	0.00	0.06	0.05	0.05	0.05	0.04	0.04	0.03	0.03	0.03	0.02	0.00
Raleigh	0.49	0.35	0.29	0.24	0.16	0.15	0.14	0.14	0.13	0.10	0.08	0.07	0.06	0.06	0.06	0.00	0.05	0.05	0.05	0.04	0.04	0.03	0.02	0.02	0.02	0.00
Tampa	0.45	0.32	0.27	0.23	0.15	0.14	0.13	0.13	0.12	0.09	0.07	0.06	0.06	0.06	0.05	0.05	0.00	0.04	0.04	0.04	0.04	0.02	0.02	0.02	0.02	0.00
Minneapolis	0.43	0.30	0.26	0.21	0.14	0.13	0.12	0.12	0.11	0.09	0.07	0.06	0.06	0.05	0.05	0.05	0.04	0.00	0.04	0.03	0.03	0.02	0.02	0.02	0.01	0.00
Seattle	0.43	0.30	0.26	0.21	0.14	0.13	0.12	0.12	0.11	0.09	0.07	0.06	0.06	0.05	0.05	0.05	0.04	0.04	0.00	0.03	0.03	0.02	0.02	0.02	0.01	0.00
Kansas City	0.37	0.27	0.23	0.19	0.12	0.12	0.11	0.11	0.10	0.08	0.06	0.05	0.05	0.05	0.04	0.04	0.04	0.03	0.03	0.00	0.03	0.02	0.02	0.02	0.01	0.00
Denver	0.36	0.26	0.22	0.18	0.12	0.11	0.11	0.10	0.10	0.07	0.06	0.05	0.05	0.05	0.04	0.04	0.04	0.03	0.03	0.03	0.00	0.02	0.02	0.01	0.01	0.00
San Antonio	0.25	0.18	0.15	0.12	0.08	0.08	0.07	0.07	0.06	0.05	0.04	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.00	0.01	0.01	0.01	0.47
Phoenix	0.22	0.16	0.13	0.11	0.07	0.07	0.06	0.06	0.06	0.04	0.04	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.00	0.01	0.01	0.42
New Orleans	0.22	0.16	0.13	0.11	0.07	0.07	0.06	0.06	0.06	0.04	0.04	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.00	0.01	0.42
Salt Lake City	0.15	0.11	0.09	0.08	0.05	0.05	0.05	0.04	0.04	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.30
Others	0.52	0.00	0.22	0.60	0.47	0.40	0.25	0.20	0.05	0.62	0.32	0.17	0.10	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.47	0.42	0.42	0.30	14.81

TABLE 3.3-9. IF TDMA SWITCH CPS MATRIX

	New York	Los Angeles/Anaheim	Chicago/Milwaukee	San Francisco	Boston	Detroit/Cleveland	Washington	Cincinnati	Philadelphia	Dallas	Atlanta	Houston	Syracuse	Miami	St. Louis	Raleigh	Tampa	Minneapolis	Seattle	Kansas City	Denver	San Antonio	Phoenix	New Orleans	Salt Lake City	Others
New York	0.00	0.00	0.61	0.54	0.35	0.34	0.32	0.32	0.30	0.23	0.18	0.18	0.17	0.15	0.13	0.13	0.13	0.12	0.12	0.10	0.10	0.06	0.06	0.06	0.04	0.00
Los Angeles/Anaheim	0.00	0.00	0.44	0.40	0.26	0.25	0.25	0.24	0.24	0.22	0.17	0.13	0.13	0.12	0.11	0.09	0.09	0.09	0.09	0.08	0.08	0.05	0.05	0.05	0.03	0.40
Chicago/Milwaukee	0.61	0.44	0.00	0.32	0.21	0.20	0.19	0.19	0.18	0.14	0.11	0.11	0.10	0.09	0.08	0.08	0.08	0.07	0.07	0.06	0.06	0.04	0.04	0.04	0.02	0.18
San Francisco	0.54	0.40	0.32	0.00	0.18	0.18	0.17	0.17	0.16	0.12	0.09	0.09	0.09	0.08	0.07	0.07	0.07	0.06	0.06	0.05	0.05	0.03	0.03	0.03	0.02	0.05
Boston	0.35	0.26	0.21	0.18	0.00	0.11	0.10	0.10	0.09	0.07	0.06	0.06	0.05	0.05	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.02	0.02	0.02	0.01	0.00
Detroit/Cleveland	0.34	0.25	0.20	0.18	0.11	0.00	0.10	0.10	0.09	0.07	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.02	0.02	0.02	0.01	0.65
Washington	0.32	0.24	0.19	0.17	0.10	0.10	0.00	0.09	0.09	0.07	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.01	0.63
Cincinnati	0.32	0.24	0.19	0.17	0.10	0.10	0.09	0.00	0.09	0.07	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.01	0.63
Philadelphia	0.30	0.22	0.18	0.16	0.09	0.09	0.09	0.00	0.06	0.05	0.05	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.0	0.01	0.58
Dallas	0.23	0.17	0.14	0.12	0.07	0.07	0.07	0.07	0.06	0.00	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.45
Atlanta	0.18	0.13	0.11	0.09	0.06	0.05	0.05	0.05	0.05	0.04	0.00	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.35
Houston	0.18	0.13	0.11	0.09	0.06	0.05	0.05	0.05	0.05	0.04	0.03	0.00	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.35
Syracuse	0.17	0.12	0.10	0.09	0.05	0.05	0.05	0.05	0.04	0.03	0.03	0.03	0.00	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.33
Miami	0.15	0.11	0.09	0.08	0.05	0.05	0.05	0.05	0.04	0.03	0.02	0.02	0.02	0.00	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.30
St. Louis	0.13	0.09	0.08	0.07	0.04	0.04	0.04	0.04	0.03	0.03	0.02	0.02	0.02	0.02	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.25
Raleigh	0.13	0.09	0.08	0.07	0.04	0.04	0.04	0.04	0.03	0.03	0.02	0.02	0.02	0.02	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.25
Tampa	0.13	0.09	0.08	0.07	0.04	0.04	0.04	0.04	0.03	0.03	0.02	0.02	0.02	0.02	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.25
Minneapolis	0.12	0.09	0.07	0.06	0.04	0.04	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.23
Seattle	0.12	0.09	0.07	0.06	0.04	0.04	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.23
Kansas City	0.10	0.08	0.06	0.05	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.20
Denver	0.10	0.08	0.06	0.05	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.20
San Antonio	0.06	0.05	0.04	0.03	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.13
Phoenix	0.06	0.05	0.04	0.03	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.13
New Orleans	0.06	0.05	0.04	0.03	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.13
Salt Lake City	0.04	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08
Others	0.00	0.40	0.18	0.05	0.04	0.65	0.63	0.63	0.58	0.45	0.35	0.35	0.33	0.30	0.25	0.25	0.25	0.23	0.23	0.20	0.20	0.13	0.13	0.13	0.08	4.14

Using column totals as in Section 3.2.4.3, the number of switching matrices may be estimated as follows:

- Trunking Traffic:

  $2 \times 26 + 1 \times 22 + 1 \times 16 + 1 \times 11 + 1 \times 6 + 1 \times 4 + 1 \times 2$

- CPS Traffic:

  $1 \times 26 + 1 \times 18 + 1 \times 10 + 1 \times 5 + 1 \times 2$

  Using 25 x 25 and 12 x 12 matrices, the number of each is given by

  <u>For M = 25</u>

  Trunking:

  $2 \times 26 + 1 \times 22 + 1 \times 16 = N \times 25$

  $N = 3.6$

  CPS:

  $1 \times 26 + 1 \times 18 = N \times 25$

  $N = 1.8$

  Total $N = 5.4 \longrightarrow 6$ matrices

  <u>For M = 12</u>

  Trunking:

  $1 \times 11 + 1 \times 6 + 1 \times 4 + 1 \times 2 = N \times 12$

  $N = 1.9$

  CPS:

  $1 \times 10 + 1 \times 5 + 1 \times 2 = N \times 12$

  $N = 1.4$

  Total $N = 3.3 \longrightarrow 4$ matrices

3.3.5 BASEBAND PROCESSOR

Processor considerations parallel those developed in Section 3.2.5, the principal difference being the traffic capacity required. Taking total trunking and CPS fixed beam traffic from Table 3.3-2 as one input and total "other" traffic from that table as the scanning beam input, a traffic transfer diagram may be constructed as shown in Figure 3.3-5. As can be seen from part (b) of

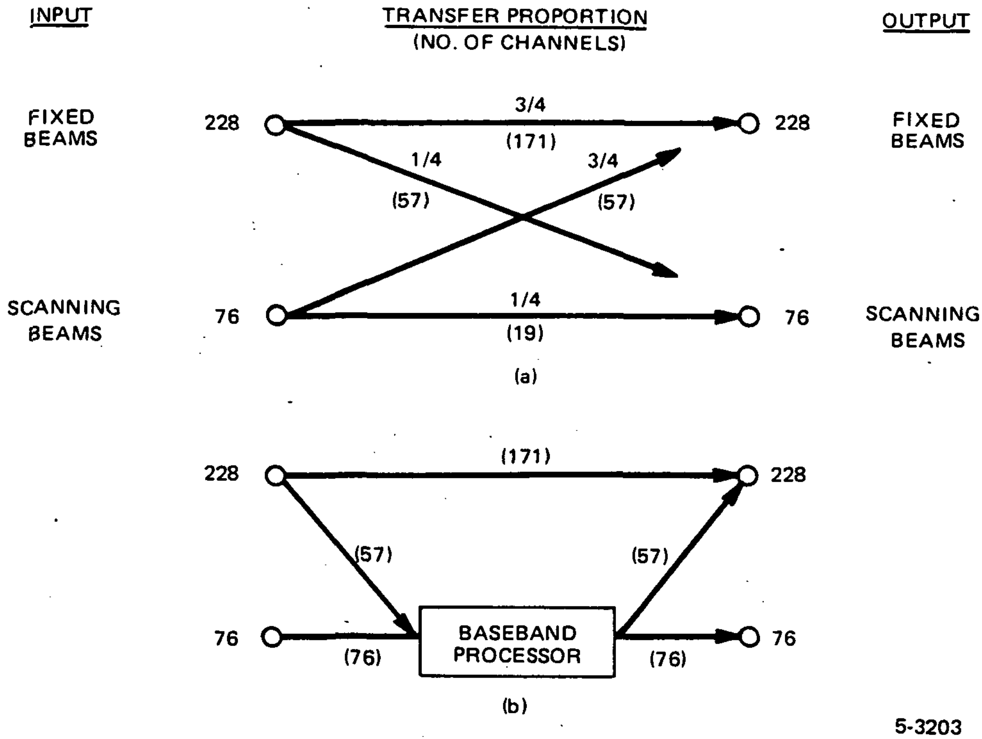


Figure 3.3-5. Traffic Transfer Diagram

Figure 3.3-5, the total number of BBP input/output channels is found as follows:

- 25% of Fixed Beam Traffic (57 channels)
- Total "other" Traffic (76 channels)
- Total Inputs/Outputs (133 channels)

All channels have a 36-MHz bandwidth and would carry 60-Mbps data streams. The buffer memory requirement is then

$$C = NR\, n\, T_f$$

where N = 133 demodulator/modulator channels

R = 60 Mbps

n = 1 frame

T_f = 1 msec

Using the nomenclature of Section 3.2.5.2, we find

$$C \cong 16 \text{ Mbits}$$

Baseband matrix switch requirements are two-thirds of those indicated in Section 3.2.5.3, requiring connectivity between 133 input and output channels. This would require a group of nine 50 x 50 switching matrices in a 3-by-3 configuration, using Figure 3.2-6 as a basis for comparison. Whether the actual matrix switch would consist of an arrangement of fewer or more switching matrices would depend on how rapidly this technology advances. In any case, it does not appear to require an unreasonable level of technological development.

3.3.6 FREQUENCY PLAN

As indicated in Section 3.3.1, 10 channels of C-band capacity have been reserved for video broadcast transmission. The remaining 14 available 36-MHz channels are then assigned to trunking traffic originating from or received in "other" areas outside the major traffic centers. Possibly use of these channels could be divided between major traffic centers having high rainfall, the remaining channels being used for "other" terminals also in high rainfall areas. Thus 9 to 10 channels might be assigned to Miami, Tampa, and New Orleans, and 4 or 5 to "other" terminals in the Southeast.

Ku-band channels may be assigned in the same fashion. Of the 12 channels available in the eastern quarter-CONUS beam, preference could be given to cities and "other" terminals in the Southeast. Ka-band transmission would then be left to less vulnerable regions.

As a worst case, it may be assumed that all trunking and CPS traffic in the northeast corridor would be handled in Ka-band.

Traffic requirements for that band would then be the total trunk and CPS needs expressed in Table 3.3-2. New York-Boston combined demand is then 46 channels while New York-Philadelphia require 44 channels. This compares to basic requirements for 57 and 55 channels for the two respective cases as shown in Section 3.2.7 for 20% FSS. In spite of increased reliance on Ka-band for this concept, the smaller overall traffic requirement leads to a simpler Ka-band implementation. The use of higher order modulation formats such as 8 PSK would not be required in the present case. Adding the New York/Boston requirement for 46 channels to the 13 channels provided in the scanning beam gives a total channel requirement of 59 in and around the New York beam. Since 62 channels are available on a single polarization, needs can be satisfied without having to rely on crosspolarization isolation even on adjacent beams.

Insofar as output multiplexer design is concerned, a pair of noncontiguous units each having 17 36-MHz channels on opposite polarizations would feed the New York beam. The scanning beam would require a noncontiguous multiplexer having 13 36 MHz channels.

3.3.7 WEIGHT AND POWER ESTIMATES

Weight and power estimates are summarized in Table 3.3-10. Underlying assumptions are essentially the same as those stated in Section 3.2.9. It is of interest to note that except for the baseband processor, power and weight for the Ka-band subsystem are very nearly the same as those for the 20% FSS concept. In that concept, the additional traffic is carried largely in C-band

TABLE 3.3-10. WEIGHT AND POWER - 13% TRAFFIC CAPTURE/10% VIDEO BROADCAST

Payload Elements	Weight (kg)	Power (W)
Transponder Elements		
• C-Band		
4 Receivers @ 0.5 kg (2 active @ 8W)	2.0	16.0
24 Input mux channels @ 0.25 kg/channel	6.0	
28 10W SSPAs @ 0.7 kg (24 active @ 28W)	19.6	672.0
24 Output mux channels @ 0.25 kg/channel	6.0	
• Ku-Band		
6 Receivers @ 0.5 kg (4 active @ 8W)	3.0	32.0
41 Input mux channels @ 0.25 kg/channel	10.3	
48·15W SSPAs @ 1.2 kg (41 active @ 50W)	57.6	2050.0
41 output mux channels @ 0.25 kg/channel	10.3	
• Ka-Band		
30 Receivers @ 0.5 kg (24 active @ 8W)	15.0	192.0
308 Input mux channels @ 0.25 kg/channel	77.0	
Down/up converters	26.0	
330 40W SSPAs @ 1.6 kg (292 active/4W @ 18.W,		5256.0
16 active/40W @ 132W)	528.0	2112.0
308 Output mux channels @ 0.25 kg/channel	77.0	
Baseband processor (133 60-Mbps channels)	320.0	1600.0
• IF TDMA/Circuit Switching		
6 25 x 25 matrices @ 6 kg/20W	36.0	120.0
4 12 x 12 matrices @ 1.5 kg/10W	6.0	40.0
• Other, including wideband input filters, coax, W/G, W/G and coax switches, LO frequency generation, diplexers	100.0	
Total Transponder Elements	1300.0	12090.0
Antenna Subsystem		
• C-Band		
Deployable 2-m dual pol reflector	20.0	
Feed Arrays and BFMs	24.0	
• Ku-Band		
Deployable 2-m dual pol reflector	20.0	
Feed Arrays and BFNs	24.0	
• Ka-Band		
Deployable 4.5-m transmit dual pol reflector	35.0	
Feed Arrays and BFNs	30.0	100.0
Deployable 3-m receive dual pol reflector	25.0	
Feed Arrays and BFNs	30.0	100.0
Total Antenna Subsystem	208.0	200.0
Total Paylaod	1508.0	12290.0

and to some extent in Ku-band. Payload weights for both concepts are approximately proportional to total traffic. However, power consumption is relatively higher for the present concept. This is due to the fairly large number of high power amplifiers required for the Ku-band quarter-CONUS beams. The 20% FSS concept relies more heavily on narrow spot beams, a more efficient approach when there is sufficient traffic demand to justify its use.

3.4 CONCEPT 4 - FIXED SATELLITE SERVICE (20%) COMBINED WITH INTERSATELLITE LINKS AND TDAS CAPABILITY

3.4.1 SYSTEM DESCRIPTION

3.4.1.1 Block Diagram and Summary Description

A summary chart of concept 4 characteristics is given in Table 3.4-1 and the block diagram showing the concept is presented in Figure 3.4-1. The FSS portion is similar to that described in Section 3.2 and shown in Figure 3.2-1 with the exception of W-band inputs and outputs required for intersatellite links (ISL). (The intersatellite links result in increased TDMA switch and baseband processor capacity.) W-band ISLs could be replaced by laser links with no significant change in the system configuration shown in Figure 3.4-1. This consideration is discussed in the following section. An additional spot beam is provided in the Ku-band subsystem to permit TDAS transmissions to White Sands.

TABLE 3.4-1 CONCEPT 4 SUMMARY

FIXED SATELLITE SERVICE	INTER SATELLITE LINKS	TRUNKING AND DATA ACQUISITION SYSTEM
• Same Capability as Concept 2 Except Capacity Increases by 40 Channels (36 MHz) to Accommodate ISL • 33.1 GBPS Capability	• W-Band (60 GHz) or Laser • Trunking and CPS Traffic • Capacity 100% Demand --2 Channels (240 MHz) Far East/PAC --4 Channels (240 MHz) Europe/Africa • 400 MBPS/Channel • 25 W/Channel • 2.4 GBPS Throughput	• User-TDAS Links via S. Ku., W • TDAS-GT Links via Ku, Ka • TDAS - TDAS Links via W or Laser • 1.GBPS Throughput 30 Channels

In addition to the ISL links, which are integrated into the FSS portion of the payload, the block diagram shows the inclusion of TDAS functions. These include S-, Ka-, and W-band links to user spacecraft in low earthorbit as well as a link to a TDAS spacecraft at some other point on the geosynchronous arc from which data from other user spacecraft would be conveyed (See Figure 2.5-1). Data received from these various sources are relayed via Ku- and Ka-band links to ground terminals
at the locations shown. It can be seen that this function is easily integrated into the payload insofar as interfacing with space-to-ground terminal links is concerned. For up and down links in Ka-band, it is necessary only to add channels to input and output multiplexers for the beams to San Francisco, Houston, and Washington, D.C. In addition, it is necessary to simply add antenna feeds to Denver in Ka-band and White Sands in Ku-band. The inclusion of the TDAS function is thus advantageous in that the on-board antenna system required for the space-ground links is available at virtually no cost.

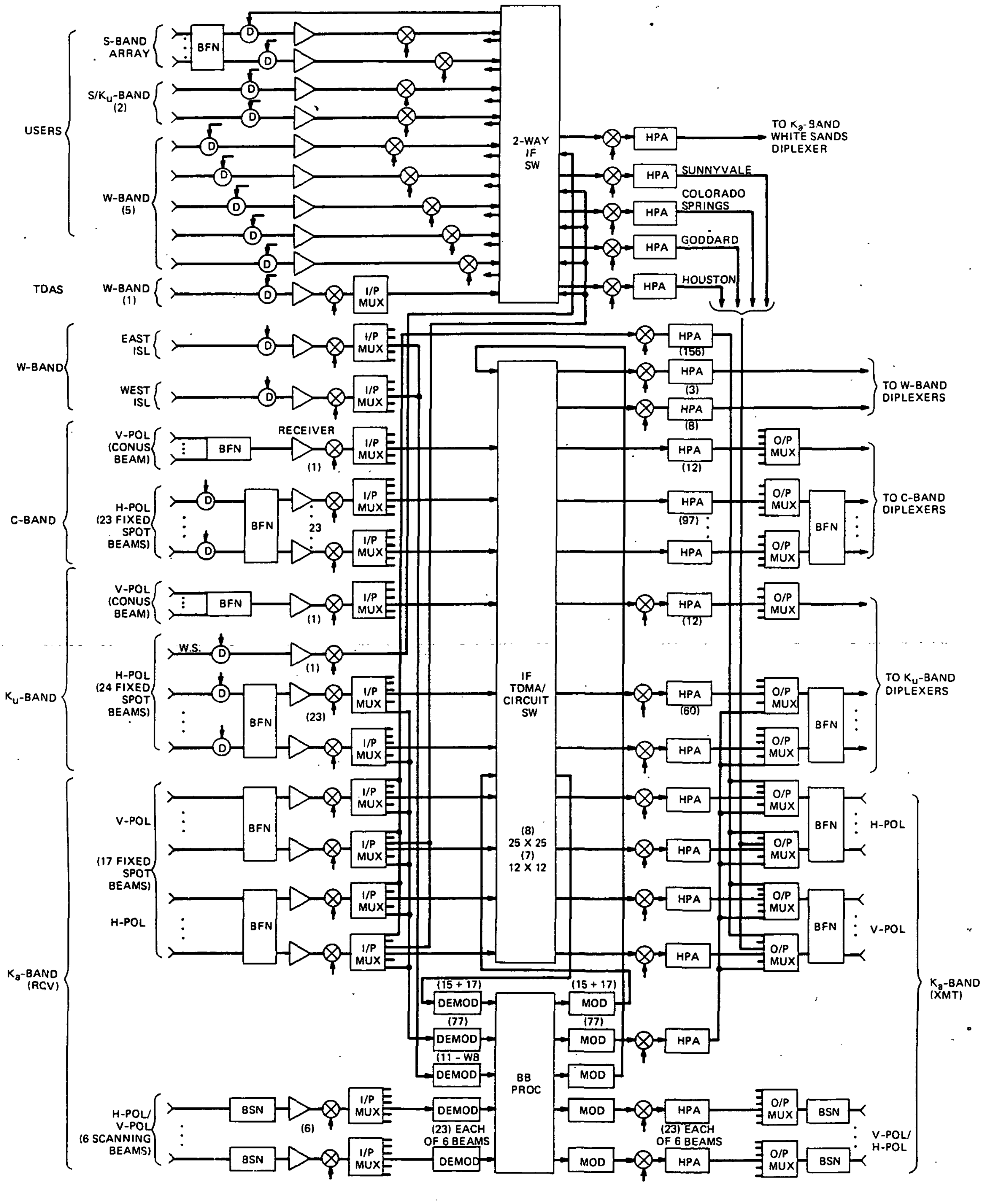


Figure 3.4-1. Block Diagram for 20% FSS/ISL/TDAS Payload - Concept 4

3.4.1.2 Intersatellite Links (ISL)

Intersatellite links are provided to other communications satellites at east and west locations relative to the platform. These would correspond to satellites serving Europe and the Asia-Pacific basin, including Australia and thus would provide an international service. At W-band or laser wavelengths, such links would be relatively wideband and would involve higher data rates than those possible using the 36-MHz channels as used in the FSS payload. It is necessary, therefore, that all incoming and outgoing ISL links pass through the BBP to make the appropriate bit rate conversions. In this manner, ISL traffic may be integrated into the bit streams intended for distribution to, and reception from CONUS cities and "other" locations.

For W-band links, it is assumed that 25-watt TWTA high-power amplifiers which feed three-meter antennas are used for outgoing links. In the likely event that laser links are adopted, transmit power of up to one watt would be required using GaA/As and/or in GaAsP lasers emitting in the 0.83-0.85 and 1.3-1.6 μm wavelength regions, respectively, with optical systems having 25-cm diameter. Special wideband demodulators interface with the incoming ISL links. Data rates would be 400 Mbps for W-band inputs or for laser inputs using quadruple wavelength multiplexing (0.83, 0.85, 1.3, 1.55 μ meters). If optical wavelength multiplexing is not used, a maximum input data rate of 1.6 Gbps would be received from the eastern communications satellite.

3.4.1.3 TDAS Links

The configuration shown in Figure 3.4-2 is based on results given in References 12 and 23. Links to user spacecraft are provided in a number of different forms. A 61-element, S-band array antenna having a diameter of 1.75 meters provides multiple access links to 10 spacecraft. In addition, single access links to five user spacecraft are provided by five independent W-band antennas of 1-meter diameter, each with its own receive and transmit subsystem. Assuming user spacecraft are equipped with 25-watt TWTAs and 1-meter antennas, such links could support data rates to 240 Mbps. Alternative use of laser links would permit higher data rates. The use of laser links would require on-board processing as part of the TDAS subsystem. This would permit remodulation of the received data stream on the Ku- and Ka-band downlinks to the ground terminals. The present concept is sized to provide the following downlinks:

Band	Number of Links	Max. Bit Rate per Link (Mbps)
Ku	1	50
Ka	4	300

Additional downlink capacity could be made available by simply adding the required power amplifiers and multiplexer channels. If a Ka-band link to White Sands is desired, the addition of a feed horn to the Ka-band antenna (along with the required receive/transmit circuits) is all that would be required.

Two single-access Ku-band user links are also provided. These links would be equipped with four meter dishes, and could be adapted to provide S-band service, if required. On the basis of available bandwidth, link capacities of 200 to 300 Mbps would be provided.

3.4.2 COVERAGE

Ku- and Ka-band coverage is shown in Figures 3.4-2 and 3.4-3. These are quite similar to those given in the 20% FSS concept except that the Ku-band diagram includes an additional spot beam for White Sands while the Ka-band figure shows an additional spot beam on Denver. C-band coverage is the same as that shown in Figure 3.2-3.

3.4.3 TRAFFIC DISTRIBUTION

The TDAS function has no noticeable impact on traffic distribution. As indicated in Section 3.4.1.1, additional channels are required to San Francisco, Houston, and Washington, D.C. These would be 300-Mbps channels with an equivalent bandwidth requirement being 240 MHz (equal to five standard 36-MHz channels). Compared to Ka-band requirements for these cities (which would be found by summing Table 3.2-4 requirements and the ISL increases shown in Table 3.4-2), it can be seen that five additional channels pose no capacity problem. This may be seen in the following summary of traffic requirements for these cities exposed in terms of 36-MHz channels:

City	Req'd for FSS/CPS (Table 3.2-4)	TDAS Rqm't	Total
San Francisco	16.0	5.0	21.0
Washington	14.6	5.0	19.6
Houston	4.5	5.0	9.5

The above totals are to be composed to the total of 62 channels of available Ka-band capacity. The above TDAS requirement is incorporated in the total traffic given in Table 3.4-2, which also includes the Denver and White Sands links mentioned above.

Transmissions to White Sands and Denver will require additional on-board equipment but will cause no capacity problems, as those cities had no previous requirements in their assigned bands.

Total traffic requirements are summarized in Table 3.4-2 which has been established using a city list corresponding tot Ka-band coverage, as was done in Table 3.2-4. This has been done because the relatively modest traffic increase due to ISL links has its greatest impact on New York region traffic which was shown to be near potential capacity limits for Concept 2. This basically effects Ka-band operations since C- and Ku-band allocations to New York are completely utilized as shown in Table 3.2-3. The ISL traffic also results in an increase in Ka-band scanning beam ("other) traffic.

In the case of New York traffic, a total increase of approximately four channels is shown. Section 3.2.7 shows that spectrum availability is critical and the various frequency plans shown in Figures 3.2-8 and 3.2-9 do not permit an increase in New York capacity without a corresponding decrease in Boston traffic. This may be largely solved by eliminating traffic requirements between New York and relatively close-by cities such as Boston and Philadelphia. The channels gained would then be assigned to ISL traffic. With regard to the scanning beams, a total increase of approximately eight channels is shown.

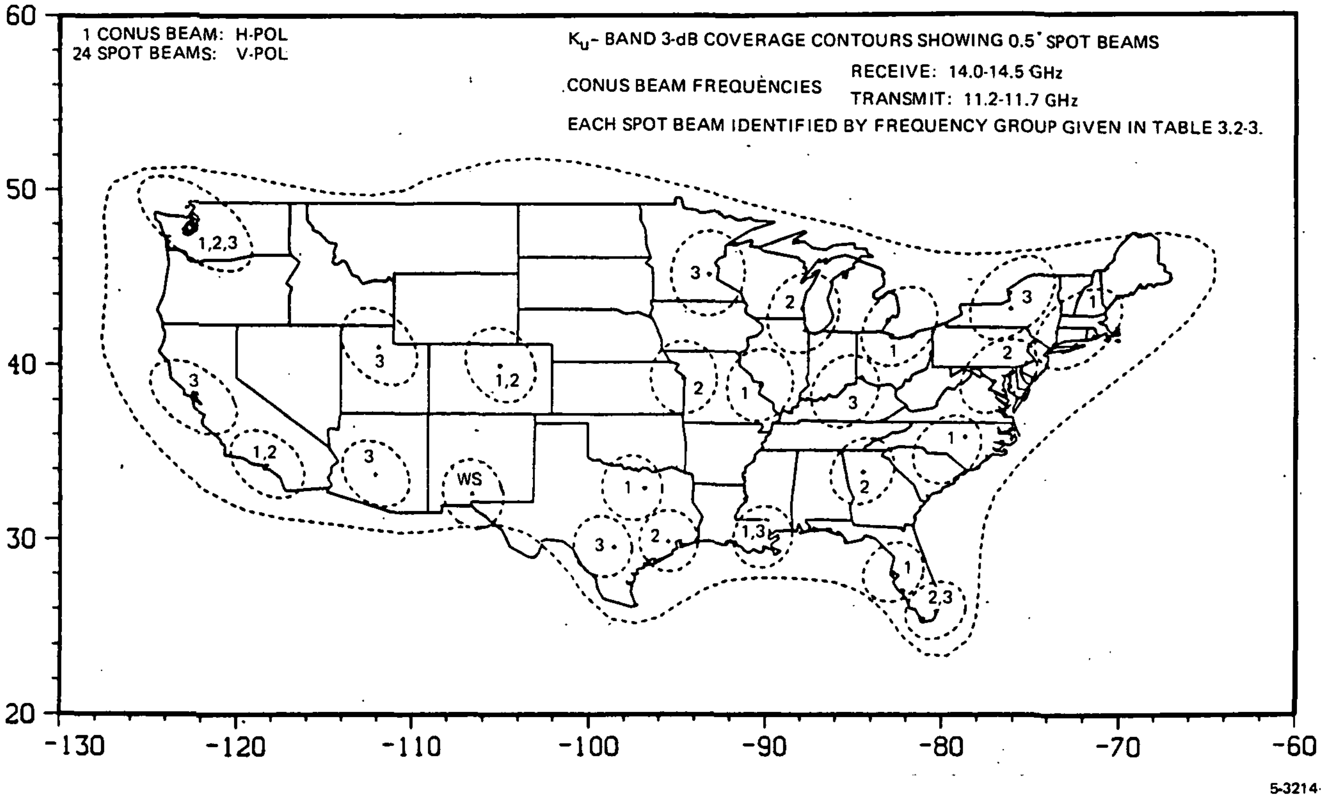


Figure 3.4-2. Concept 4: Ku-Band 3-dB Coverage Contours

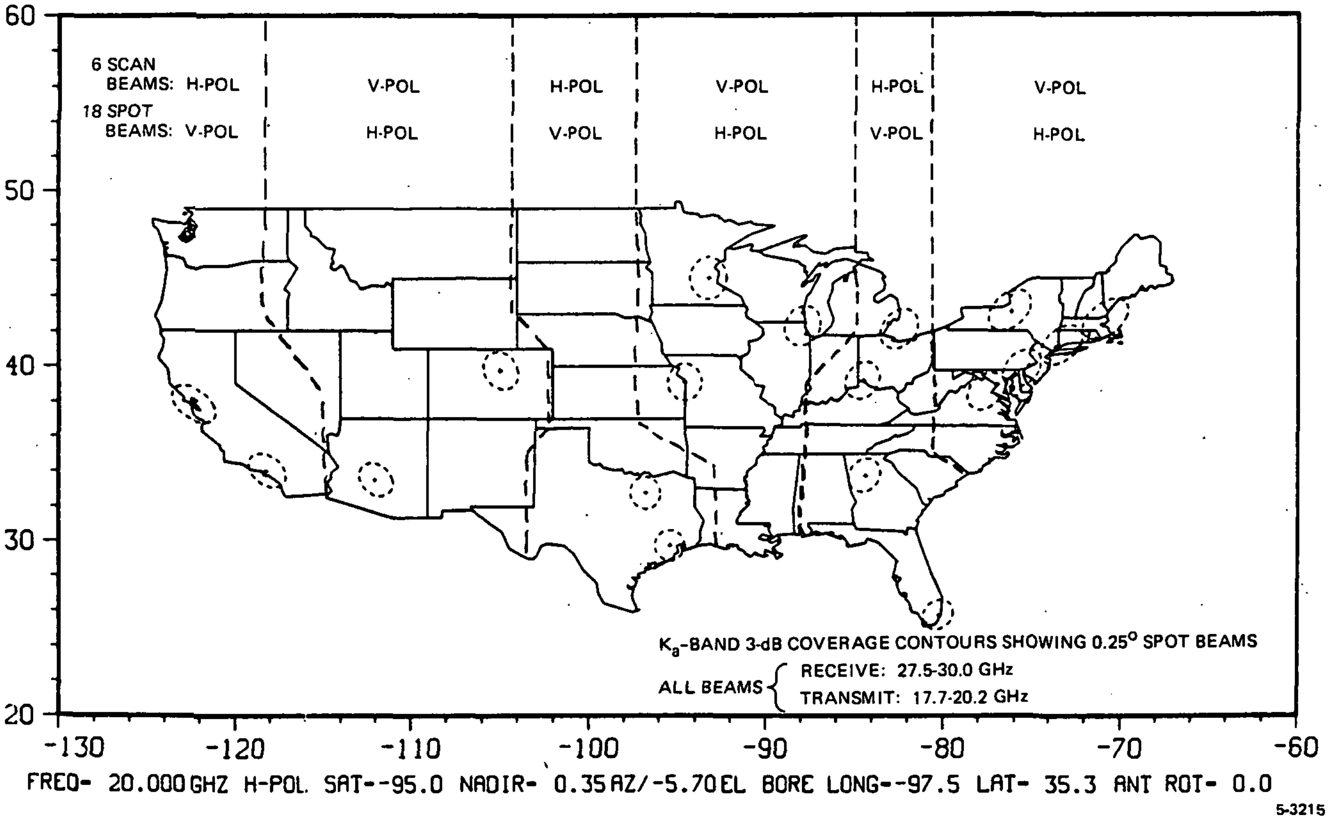


Figure 3.4-3. Concept 4: Ka-Band 3-dB Coverage Contours

TABLE 3.4-2. BASIC TRAFFIC REQUIREMENTS FOR TDAS-ISL-FSS (20%) EXPRESSED IN 36-MHz CHANNELS (CONCEPT 4)

City	20% FSS Trunking Reqmnts	20% FSS CPS Reqmnts	ISL-W Trunk Req	ISL-W CPS Req	ISL-E Trunk Req	ISL-E CPS Req	Total Trunking Reqmnts	Total CPS Reqmnts	Total TDAS	Total Overall
New York	40.2	11.2	2.20	.72	.60	.22	43.0	12.1	0	55.1
Los Angeles/Anaheim	30.	8.6	1.57	.55	.45	.17	32.0	9.3	0	41.3
Chicago/Milwaukee	22.25	6.4	1.16	.41	.34	.12	23.8	6.9	0	30.7
San Francisco	15.3	4.2	.80	.27	.23	.08	16.3	4.6	5.0	25.9
Boston	14.9	4.	.78	.25	.22	.08	32.2	4.3	0	36.5
Detroit/Cleveland	26.0	7.2	1.36	.46	.39	.14	27.8	7.8	0	35.6
Washington	13.8	3.8	.72	.24	.21	.08	14.7	4.1	5.0	23.8
Cincinnati	13.5	3.8	.70	.24	.20	.08	14.4	4.1	0	18.5
Philadelphia	12.6	3.6	.65	.23	.19	.07	13.4	3.9	0	17.3
Dallas	10.1	2.8	.52	.18	.15	.05	10.8	3.0	0	13.8
Atlanta	8.1	2.2	.42	.14	.12	.05	8.6	2.4	0	11.0
Houston	7.2	2.2	.38	.14	.11	.05	7.7	2.4	5.0	15.1
Syracuse	6.75	2.	.35	.13	.10	.04	7.2	2.2	0	9.4
Miami	6.6	1.8	.34	.12	.10	.04	7.0	2.0	0	9.0
St. Louis	6.15	1.6	.32	.10	.09	.03	6.6	1.7	0	8.3
Raleigh	5.85	1.6	.30	.10	.09	.03	6.2	1.7	0	7.9
Tampa	5.4	1.6	.28	.09	.09	.03	5.8	1.7	0	7.5
Minneapolis	5.1	1.4	.26	.09	.08	.03	5.4	1.5	0	6.9
Seattle	5.1	1.4	.26	.09	.08	.03	5.4	1.5	0	6.9
Kansas City	4.5	1.2	.24	.08	.07	.02	4.8	1.3	0	6.1
Denver	4.35	1.2	.22	.08	.07	.02	4.6	1.3	5.0	5.9
San Antonio	2.85	0.8	.15	.05	.05	.01	3.1	.9	0	4.0
Phoenix	2.55	0.8	.14	.05	.04	.01	2.7	.9	0	3.6
New Orleans	2.55	0.8	.14	.05	.04	.01	2.7	.9	0	3.6
Salt Lake City	1.8	0.4	.10	.02	.02	.01	1.9	.4	0	2.3
White Sands	0	0.5	0	0	0	0	0	0	5.0	5.0
Others	91.1	25.5	4.65	1.62	1.38	.50	97.1	27.5	0	124.6
Totals	364.6	102.1	19.	6.5	5.5	2.	389.1	110.6	25.0	524.7

This corresponds to an increase of one to two channels per scanning beam, which should pose no serious problem.

With regard to the additional ISL requirement to cities having low traffic requirements, it should be noted that this can in many cases be handled by C- or Ku-band links. Consider, for example, the case of New Orleans with a trunking requirement of 2.7 channels. Table 3.2-3 shows 9 available C-band channels so the small ISL increase can be accommodated with no need to provide additional Ka-band capacity.

3.4.4 FREQUENCY PLAN

3.4.4.1 FSS Requirements

These are essentially the same as those outlined in Section 3.2.7.

3.4.4.2 TDAS Requirements

As stated in Section 3.4.3, the space-ground links have some minor impact on FSS frequency planning. The added Ku-band link to White Sands, which is outside the FSS bands, lies within 13.4 to 13.73 or 13.82 to 14.05 GHz on the downlink, and within 14.5 to 14.83 or 15.15 to 15.23 GHz on the uplink. This poses no problem for the antenna system. The following bands would be available for user-platform links:

Link	Frequency Band (GHz)	Bandwidth (MHz)
TDAS to User		
• Multiple Access	(S) 2.104-2.109	5
• Single Access	(S) 2.020-2.104	84
	(S) 2.109-2.120	11
	(Ku) 13.75-13.80	50
User to TDAS		
• Multiple Access	(S) 2.285-2.290	5
	(S) 2.200-2.285	85
	(S) 2.20-2.30	10
	(Ku) 14.89-15.11	220

In addition, W-band capacity for User-TDAS and TDAS-TDAS (platform) links is available in the following frequency bands and bandwidths:

- 54.25-58.20 GHz 3950 MHz
- 59-64 GHz 5000 MHz

Each of five users having transmission requirements of 300 Mbps and an equivalent total transmission rate on a cross-link from another TDAS spacecraft can easily be handled in the available W-band. These capacities apply to return links; forward links are of substantially lower capacity requirements and do not materially affect this conclusion.

3.4.4.3 ISL Requirements

Traffic distribution given in Table 3.4-2 is based on the following prediction of total ISL traffic as given in the scenario development of Section 2. It is expressed in equivalent 36-MHz channels and in terms of whole 240-MHz channels proposed to accommodate the transmissions:

Direction	Trunking	CPS	Totals 36-MHz Ch.	Totals 240-MHz Ch.
East ISL	19	6.5	25.5	4
West ISL	5.5	2	7.5	2

The above requirements represent the number of channels needed in each direction, in receive and in transmit modes.

The use of 240-MHz channels at W-band appears reasonable since it would require filters having a ratio of:

$$\frac{\text{Bandwidth}}{\text{Center Frequency}} = \frac{0.24}{60} = 0.4\%$$

Output multiplexers on the east ISL would then have four non-contiguous 240-MHz channels as shown in Figure 3.4-4. Alternate channels would be used for transmissions to the west ISL.

The latter four ISL channels would support a transmission rate of 400 Mbps in each channel for a maximum total of 1.66 Mbps. The ISL links, as well as other W-band links, could be implemented using lasers operating at 0.8 to 1.6 μm wavelengths as has been indicated in Section 3.4.1.2.

3.4.5 BASEBAND PROCESSOR

The capacity of the BBP must be augmented to handle the added ISL traffic. The increased number of input demodulators must be capable of handling the total of six input wideband 400 Mbps links from east and west ISLs as discussed

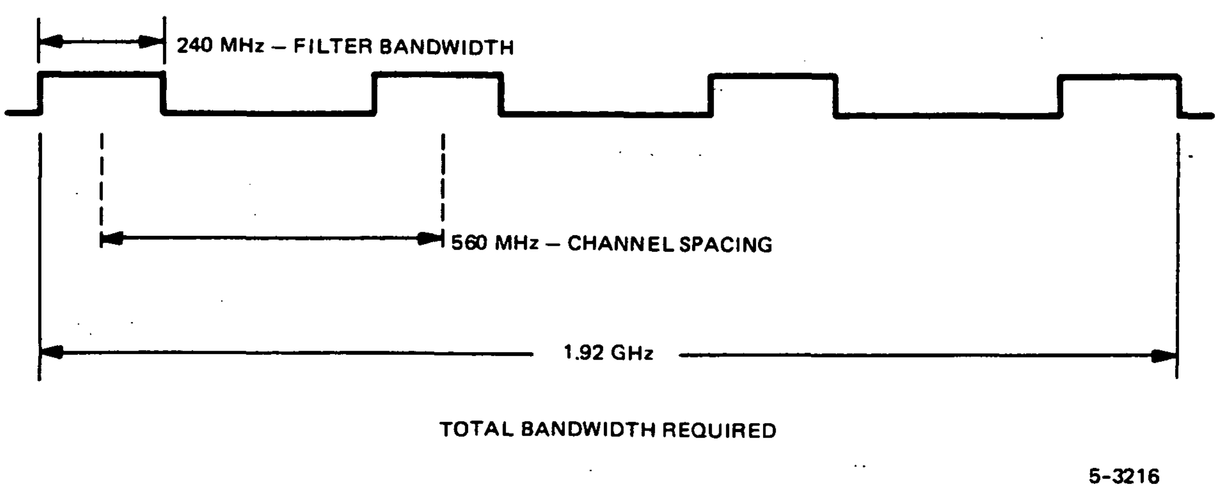


Figure 3.4-4. East ISL Multiplexer

in Section 3.4.4.3. In addition, an equivalent number of 60 Mbps demodulators must be provided to ensure the transmission of outgoing traffic from CONUS to the east and west ISLs.

Rounding off of the number of 36-MHz channels indicated in the same Section 3.4.4.3 results in a total of thirty-four 60-Mbps demodulators required. The resultant overall requirement is for a total of 40 additional demodulators and, similarly, an equal number of modulators. Total requirement is for 240 demodulators/modulators using the baseline development concept given in Section 3.2.5.1.

Buffer memory requirements also increase with the increased traffic flow. Since memory is required for incoming and outgoing channels, the total increase will be:

$$\Delta C = \Delta N \, R \, n \, T_f$$

$$= 8.16 \text{ Mbits}$$

where ΔN = Added number of equivalent 60-Mbps demodulators ($2 \times 34 = 68$)

and other parameters have the same definition and values as given in Section 3.2.5.2 where memory requirements for straightforward 20% FSS were found to be 24 Mbits. In the present case, the total buffer memory requirement is then;

$$C = 32.16 \text{ Mbits}$$

3.4.6 LINK BUDGETS

Representative link budgets for FSS traffic are given in Section 3.2.8. These analyses also apply to ISL traffic, which is integrated into the FSS operation and are also generally applicable for TDAS space-ground links. User-TDAS and W-band ISL links present the greatest uncertainty. Tables 3.4-3 and 3.4-4 provide analyses of typical links and show that satisfactory operation should be achievable for reasonable antenna sizes and transmit power levels. Antenna sizes for the links were determined partly on the basis of a trade-off between antenna gain and pointing error. This trade-off is summarized in the curves presented in Figure 3.4-5.

3.4.7 WEIGHT AND POWER ESTIMATE

Table 3.4-5 summarizes the weight and power estimate (including modifications to the basic FSS subsystem) required to accommodate the added traffic load from the ISLs.

TABLE 3.4-3. ISL (400 Mbps 60 GHz)

Parameter	Characteristic
Transmit Power (25W)	14.0 dBw
Output Loss	-2.0 dB
Transmit Antenna Gain (3m; 0.05° pointing error)	61.0 dB
Transmit EIRP	73.0 dBW
Path Loss (162° separation, synchronous)	-226.3 dB
Receive antenna gain (3m; 0.05° pointing error)	61.0 dB
Input Circuit Loss	-1.5 dB
Received Power	-93.8 dBW
Boltzmann Constant	-228.6 dBW/K
Receiver Temperature (1000°; FN - 6.5 dB)	+30.0 dBK
Bit rate bandwidth (400 Mbps)	+86.0 dB
Noise in Bit Rate Bandwidth	-112.6 dBW
E_b/N_o Available	18.8 dB
E_b/N_o Required	10.0 dB
Margin	8.8 dB
C/N (Carrier-to-Noise Ratio in 240 MHz channel)	19.8 dB

TABLE 3.4-4. USER RETURN LINK (240 Mbps 60 GHz)

Parameter	Characteristic
Transmitter Power (25W) (USER)	14.0 dBW
Output Loss	-2.0 dB
Transmit Antenna Gain (1m; 0.1° pointing error)	53.0 dB
Transmit EIRP (USER)	65.0 dBW
Path Loss (synchronous + 2 earth radii)	-221.8 dB
Receive antenna gain (1m; 0.1° pointing error)	53.0 dB
Input Circuit Loss	-1.5 dB
Received Power	-105.3 dBW
Boltzmann Constant	-228.6 dBW/K
Receiver Temperature (1000°; NF 6.5 dB)	30.0 dBK
Bit rate bandwidth (240 Mbps)	83.8 dB
Noise in Bit Rate Bandwidth	-114.8 dBW
E_b/N_o Available	9.5 dB
E_b/N_o Required (Rate 3/4 Code); Symbol rate: 320 Mbps	7.0 dB
Margin	2.5 dB

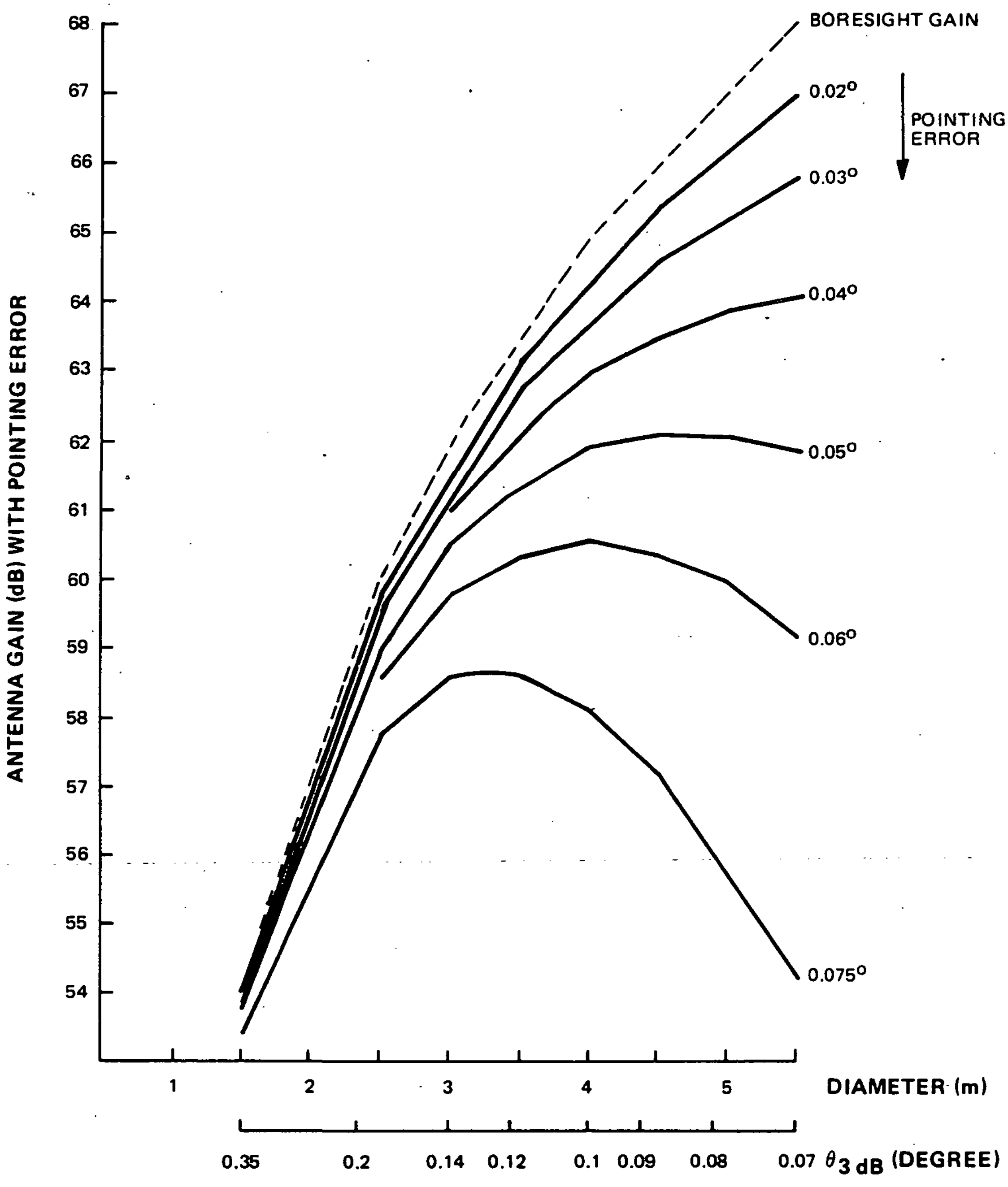


Figure 3.4-5. Antenna Gain at 60-GHz Gain-Pointing Error Trade-Off

TABLE 3.4-5. WEIGHT AND POWER ESTIMATE TDAS-ISL-FSS (20%)

Payload Elements	Weight (kg)	Power (W)
TDAS		
• S-band user antenna array, including transmit and receive subsystems	230.0	300
• 2 Ku-band user 4m antennas, each including transmit and receive subsystems	110.0	100
• 5 W-band user 1m antennas, each including transmit and receive subsystems	230.0	200
• 1 W-band TDAS crosslink 2m antenna, including transmit and receive subsystems	50.0	40
• 1 IF switch 36 x 9	3.0	20
• 2 60W Ka-band SSPAs (1 Active)	2.8	190
• 6 40W Ka-band SSPAs (3 Active)	9.6	600
• Added horn, W/G for Ku-band White Sands link	1	
• Upconverters, W/G	3	
Subtotals TDAS	639.4	1450
ISL		
• 2 W-band 3m antennas, including receive subsystems	110.0	40
• 1225W TWTAs (6 Active @ 6.5 kg/90W)	78.0	540
• Diplexers, Down/Up Converters, W/G	8.0	
Subtotals ISL	196.0	580
FSS (20% traffic - modified for ISL)	2320	16916
TOTAL PAYLOAD	3155	18946
Transponder Elements		
• C-Band		
30 Receiver @ 0.5 kg (24 Active @ 8W)	15.0	192
109 Input Mux Channels @ 0.25 kg/CH	27.3	
Diplexers, Down/Up Converters	12.5	
116 0.35W SSPAs @ 0.5 kg (97 Active @ 1.4W)	58.0	136
14 10W SSPAs @ 0.7 kg (12 Active @ 28W)	9.8	336
109 Output Mux Channels @ 0.25 kg/CH.	27.8	

TABLE 3.4-5. WEIGHT AND POWER ESTIMATE TDAS-ISL-FSS (20%) (Continued)

Payload Elements	Weight (kg)	Power (W)
• Ku-Band		
30 Receivers @ 0.5 kg (24 Active)	15.0	192
76 Input Mux Channels @ 0.25 kg/CH.	19.0	
Diplexers, Down/Up Converters	9.0	
76 - 5W SSPAs @ 1.2 kg (64 Active @ 17W)	91.2	1088
14 - 50W SSPAs @ 1.4 kg (12 Active @ 190W)	19.6	2280
76 - Output Mux Channels @ 0.25 kg/CH.	19.0	
• Ka-Band		
30 Receivers @ 0.5 kg	15.0	192
366 Input Mux Channels @ 0.25 kg/Ch	91.5	
Down/Up Converters	26.0	
392 - 40W SSPAs @ 1.6 kg (348 Active/4W @ 18W)	627.2	6264
(18 Active/40W @ 132W)		2376
366 Output Mux Channels @ 0.25 kg/Ch	91.5	
• Baseband Processor (240 Demodulators)	549	3430
• If TDMA/Circuit Switching		
8 - 25 x 25 Matrices @ 6 kg/20W	48	160
7 - 12 x 12 Matrices @ 1.5 kg/10W	10.5	70
• Other including wideband input filters, coax, W/G, W/G and coax switches, LO Frequency generation	207	
Total Transponder Elements	1988.4	16716
Antenna Subsystem		
• C-Band		
Unfurlable 10.5m spot beam reflector	35.0	
10.5-meter boom	42.0	
Feed Array and BFN	40.0	
Deployable 2m Conus Reflector	12.0	
Feed Array and BFN	12.0	
• Ku-Band		
Deployable 3.5m spot beam reflector	25.0	
Feed Array and BFN	25.0	
Deployable 1.5m Conus Reflector	11.0	
Feed Array and BFN	10.0	
• Ka-Band		
Deployable 4.5m Transmit Dual-Pol Reflector	35.0	
Feed Arrays and BFNs	30.0	100
Deployable 3m Receive Dual-Pol Reflector	30.0	
Feed Arrays and BFNs	30.0	100
Total Antenna Subsystem	332.0	200
TOTAL PAYLOAD	2320	16916

3.5 SERVICING

The study guidelines provided by NASA stated that the payloads were to be designed with the assumption that on-orbit payload assembly would not be available at deployment. The completed designs, however, were to be assessed (as part of Task 4 Payload Definition) with respect to the impact of in-orbit servicing technology on the payload characteristics and on the payload requirements imposed on the spacecraft, transportation, and space operations systems. The servicing assessment included a projection of the on-orbit servicing technology likely to be available in 1998 for low Earth orbit (LEO) and geosynchronous earth orbit (GEO) operations. The projection assumes the presence of a manned LEO Space Station and extra vehicular activity (EVA) capabilities.

This section 1) identifies candidate servicing functions that might be available in the 1998-2008 time frame, 2) describes two servicing concepts that could perform some or all of the servicing functions and that are likely to enhance the viability of geostationary platforms, 3) assesses the impact that servicing might have on the platform payload design process, and 4) assesses the impact of servicing on the four payload concepts defined in this study.

3.5.1 CANDIDATE PLATFORM SERVICING FUNCTIONS

A range of satellite servicing functions have been suggested in earlier studies (Referencess 24 and 25). The following is a summary of the candidate platform servicing functions at LEO and GEO that are considered to be technically feasible and potentially cost effective:

- Large Structure Assembly and Deployment
  - Manual assembly and deployment of large antennas and arrays
  - External mounting of transfer propulsion system

- Pretransfer Checkout and Assembly (LEO)
  - Antenna pattern measurements and adjustments
  - Removal of auxiliary launch support structure
  - Loading of liquid fuel
  - Removal of protective covers
  - Servicing of thermal blankets
  - Repair of pretransfer failures

- Remote Platform Servicing at (GEO)
  - Fueling/refueling
  - Module replacement
  - Payload modification/updates

A major challenge with platform development is to arrange the components and design the large structures to stow within the envelope of the Shuttle cargo bay. Much of the structural complexity is imposed by the mechanisms which deploy the large antenna reflector, booms, mast, and feed panel arrays. The platform design can be greatly simplified if manual-aided deployment and assembly are provided at the space station.

Due to the large mass of the platform designs, higher-thrust apogee kick motor designs are required. The higher-capacity booster designs require more fuel and more space within the cargo bay. Mounting and launch mechanisms for the platform and booster will also consume cargo bay space. Separate stowage of the platform and booster within the cargo bay might make more efficient use of the Shuttle cargo bay space. Following separation from the Shuttle, the transfer propulsion system could be externally mounted to the platform by EVA. Mass and volume requirements of very large platforms may require multiple shuttle launches with assembly at LEO.

Deployment of the platform can be simplified by manual removal of auxiliary launch-support structures. A weight reduction of the platform structure will result as well as a simplification of launch from the Shuttle.

Once assembled and deployed, the structures forming the antenna dish, mast, boom, and feed panels require checkout and calibration. The radiation pattern of the deployed antenna can be measured by a probe on an orbital servicer vehicle or by a fixed probe using the platform maneuvering capabilities. The risk of transfer or deployment failure could be reduced by a pretransfer checkout and subsequent repair of any failures.

One of the more promising servicing functions is refueling spacecraft on station. Spacecraft lifetime is limited by the stationkeeping capacity provided by the on-board fuel. Additional fuel limits payload mass for a given launch concept, and the ability to refuel can extend lifetime and permit increased payload mass. Loading of the platform stationkeeping fuel at LEO as part of the assembly process prior to GEO tranfer or performing initial fueling at GEO is also a servicing option. Additionally, protective covers can be removed at the time of pretransfer checkout and assembly, and damaged or displaced thermal blankets can be repaired.

3.5.2 SERVICING CONCEPTS

On-orbit servicing concepts have been evolving since the early 1970's. The early work led to a series of studies performed for NASA Marshall Space Flight Center and called Integrated Orbital Servicing Study (IOSS). The first study was completed by COMSAT in 1975. Martin Marietta has also participated in the IOSS and is currently developing an On-Orbit Servicer Concept (Reference 24) for NASA Marshall.

A range of servicing concepts and options were examined during this study to identify a baseline set of likely design requirements on the platform payload. The concepts that were studied will no doubt continue to evolve. However, the overall impact on the baseline set of payload design requirements due to these evolutions will probably be minor. The general servicing concept alternatives are:

- LEO
  - Intra-Vehicular Activity (IVA) using a Remote Manipulation Arm (RMA)
  - EVA

- GEO
  - Teleoperator Control (operator at Space Station or Ground Station)
  - Autonomous Control
  - Combination of man-in-the-loop and autonomous

EVA servicing at GEO does not appear feasible in the 1998-2008 time frame. Teleoperator control at GEO is analogous to IVA activity via an RMA approach at LEO. The GEO teleoperator approach however must contend with the inherent communications time delays that would be present in feedback loops. Autonomous control using robotics and artificial intelligence technology would eliminate the time lag problem. It is likely that some combination of teleoperator and artificial intelligence would be implemented in the 1998-2008 time frame.

3.5.2.1 RMA

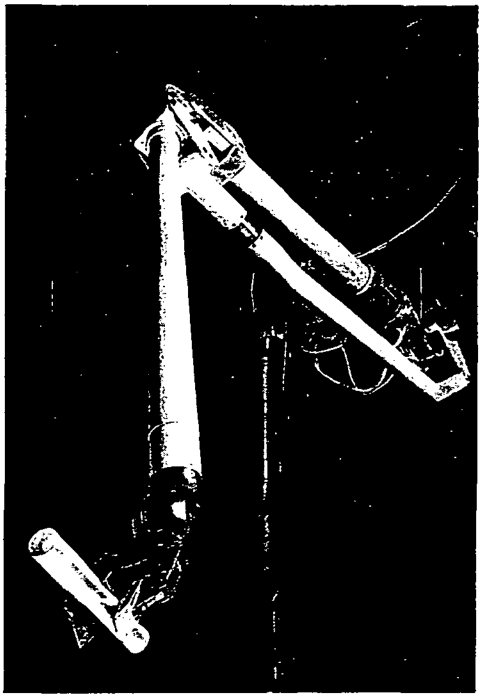
The RMA concept developed for space station construction is similar to the RMA developed for the space shuttle and has applicability to LEO and GEO servicing. In the Grumman developed space station concept, called a General Purpose Manipulation Arm, the RMA was permanently connected to the space station on a track (see Figure 3.5-1 and Reference 25). The RMA concept can be extended to a teleoperator controlled servicer unit (see Figure 3.5-2 and Reference 26) transferred to GEO by the Orbital Maneuvering Vehicle (OMV) and Orbital Transfer Vehicle (OTV). The OMV has a limited boost capability; the OTV is required for boost to GEO orbit.

3.5.2.2 On-Orbit Services

Martin Marietta has developed an on-orbit servicer concept and is developing a flight unit prototype servicer shown in Figure 3.5-3 (Reference 24). The on-orbit servicer module would be attached to the OMV and consist of:

- OMV or orbiter interface
- Docking mechanism/spacecraft interface
- Servicer mechanism with axial and near-radial module exchange capability
- Storage rack for storage of replacement modules and failed modules

The on-orbit servicer plus OMV/OTV would be able to transport replacement modules to GEO, exchange the failed modules with replacement modules, and return the failed modules to the space station. It could also transport fuel for refueling. Manual teleoperator control and monitoring of autonomous functions would be performed from a services control center that could be located at the space station, at a ground station, or in the shuttle.



(SOURCE: GRUMMAN, REFERENCE 25)

Figure 3.5-1. Remote Manipulator Arm

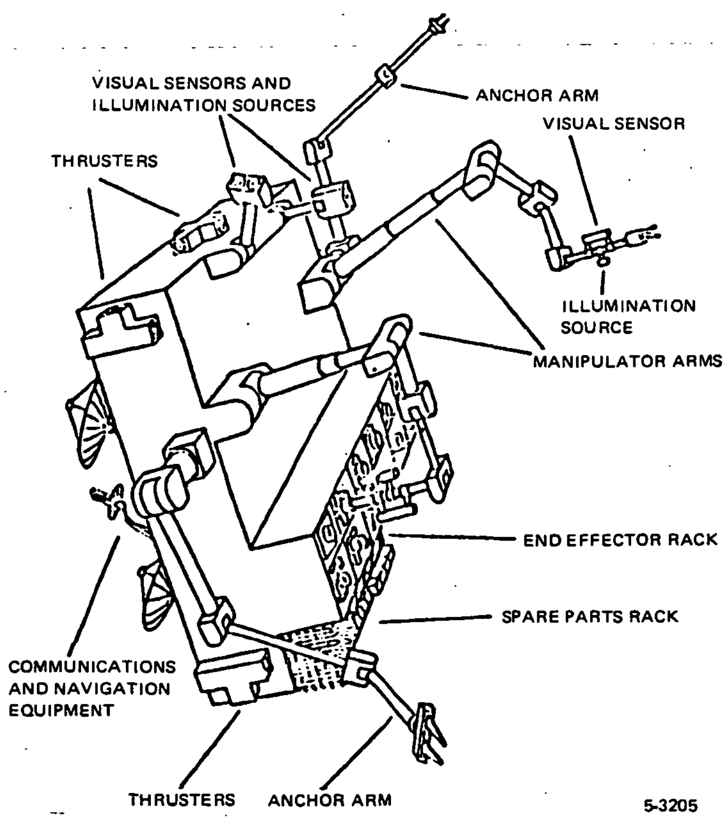
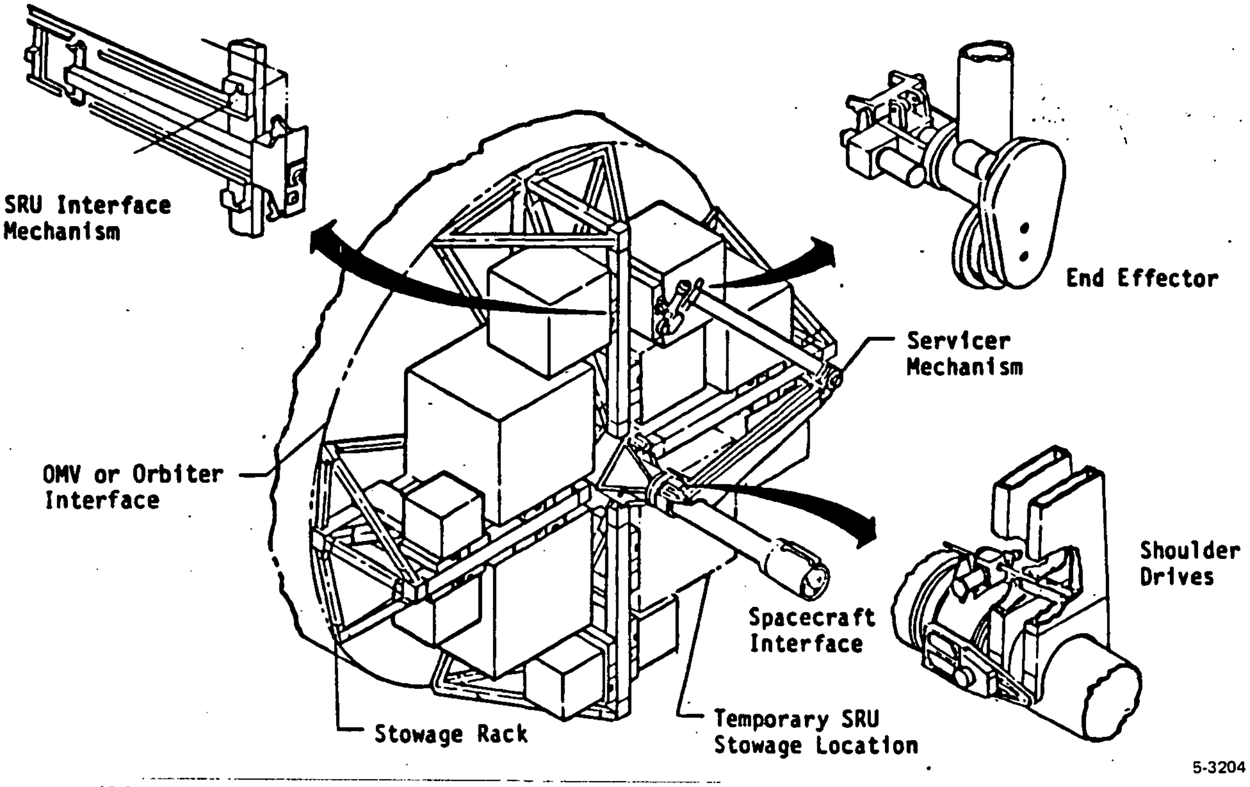


Figure 3.5-2. Conceptual Telepresence Servicer Unit



(SOURCE: MARTIN-MARIETTA, REFERENCE 24)

Figure 3.5-3. On-Orbit Servicer (Flight Unit Prototype)

3.5.3 Design Considerations

Today's geosynchronous communications satellites are not designed for serviceability. To take advantage of future servicing functions, spacecraft would have to be designed for serviceability and be compatible with the servicing concepts that are implemented. This section describes the impact of LEO and GEO servicing capabilities on spacecraft design.

3.5.3.1 Impact of LEO Servicing

Spacecraft must be redesigned to take advantage of the assembly, checkout and deployment functions that would be accomplished at LEO. Platform packages must be redesigned to be configured for stowage within the Space Shuttle cargo bay envelope and assembled into a platform at the space station. The assembly could be via EVA or application of a remote manipulation arm. Special assembly mechanisms such as positive locking mechanisms (snap-fit assembly) are needed that minimize the degree of manipulation required. Equipment checkout at LEO may require development or interfaces for test and calibration.

A large structure assembled at LEO will require a change from today's orbit transfer concepts. Satellites today are normally spin stabilized for transfer from LEO to GEO. The components and structure are designed to withstand the high thrust of the apogee kick motor while in a stowed mode and then deploy at GEO. A platform that is assembled in a deployed configuration at LEO can not be spin stabilized and will require an augmented attitude control subsystem to maintain platform orientation and prevent tumbling during boost to GEO. A low thrust booster and a deployed platform structure designed to withstand low thrust (0.1 g) acceleration will be required. The line of thrust must pass through the deployed platform e.g.

3.5.3.2 Impact of GEO Servicing

Payload servicing at GEO will require a number of payload design changes. The payload design considerations include:

- Built-in Test Equipment for fault detection and isolation to the module level prior to deployment of the servicer
- Safing capability to permit servicer docking and module access
- Module Replacement Compatibility requires design that conforms to a future servicer interface requirement, which will likely impact:
  - Module size
  - Module thermal and structural requirements
  - Payload configuration
  - Type of fastener
- Checkout/Test/Calibration capability prior to departure of servicer (function could be built in to payload or servicer.)

3.5.4 IMPACT ON COMMUNICATIONS PLATFORM PAYLOAD CHARACTERISTICS

3.5.4.1 Concept 1-LMSS Payload

The mobilesat Platform design can be effectively enhanced by incorporating a number of the servicing concepts under development for assembly and deployment as summarized below:

- Reduces mechanical complexity and deployment risk of 30/20-meter antenna and boom/mast
- LEO deployment requires structural stiffening (assumes low-thrust OTV available)
- Checkout and test
  - Antenna pattern measurement
  - Assembly adjustment
  - UHF/L-band transponder panels
- Servicing at GEO: Design sensitive to level of space replaceable unit (SRU)
  - Subsystem level: Replace 3 SRUs (UHF and L-band feed panels, K-band transponder module)
  - Further modularization requires complete redesign

Assembly and deployment of the Mobilesat antenna disk, boom, mast, and feed panels at LEO can be assisted by EVA or by the orbital-maneuvering-vehicle-concept. The impact of servicing of the Mobilesat Platform at GEO station is sensitive to the level of space replaceable unit desired.

3.5.4.1.1 Servicing of Mobilesat Platform at LEO

The large unfurlable wrap-rib 30/20-meter antenna represents a new development in size, and the deployment mechanisms and structural stability of the large antenna structures have yet to be verified. The mechanical complexity of the Mobilesat Platform can be reduced by assisting the deployment of the antenna and supporting structures at LEO. Furthermore, minor deployment malfunctions can be corrected in LEO reducing the risk of deploying the antenna remotely at GEO.

Deployment of the Mobilesat Platform at LEO requires a low-thrust orbital-transfer vehicle to boost the platform to GEO. It is expected to require up to 7 separate booster firings on different orbital passes at 0.1-g acceleration to transfer the platform to GEO station. The antenna structures being developed will not withstand even low-thrust transfer-orbit accelerations. Application of a low-thrust boost to the deployed Mobilesat Platform requires stiffening of existing structures, redesign of the wrap-rib dish and structures, or substitution of alternate design techniques.

Along with structural reinforcement, the balance of the platform must be redesigned to direct the line of low-thrust boost through the e.g. of the deployed platform. The attitude control system must be augmented to maintain proper orientation of the platform during boost.

The radiation pattern of the antenna will be measured and the assembly adjusted during the deployment process. The platform design must provide for alignment of the antenna and adjustment of the feed panels. Checkout and test of the high-power output of the L-Band and Ku-band transponder panels will be conducted at LEO along with the antenna tests.

3.5.4.1.2 Servicing of Mobilesat Platform at GEO

The feasibility of servicing the Mobilesat platform at GEO requires defining space replaceable modules. Due to the integral design of the L-Band feed panels, it was not thought possible to modularize components embedded in the panels. Three modules were identified which could be modified to be space replaceable: the feed panel, the L-band feed panel, and the K-band transponder module. Further modularization into individual transponder channels or beams requires a complete redesign of the feed panel and beamforming network.

3.5.4.2 Concepts 2, 3, and 4 - FSS Payloads

The FSS payloads have many characteristics in common, and so they will be treated in common. Some additional remarks with respect to Concept 4 payload are included in 3.5.4.2.3.

It is first necessary to recall that these applications are of a commercial nature, in a highly competitive environment. It is critical that the risk associated with the exploitation of a large platform be kept to a minimum, for a failure on the scale envisaged here would be catastrophic for those involved. Due to the complex nature of the payloads involved, it appears essential that appropriate servicing concepts be developed to reduce risk. The design of the platform payload should be such as to take full advantage of these servicing capabilities.

In addition to risk reduction, in-orbit servicing would permit significant extension to the useful life of the platform. Present communications satellites are designed for a 10-year life, with a trend toward 12 years. With so much capacity in a single orbit position, it would be reasonable, and indeed perhaps economically imperative, that design life should be 20 or perhaps 30 years.

The objectives of risk reduction and life extension may be achieved by servicing both at LEO and at GEO as discussed below.

3.5.4.2.1 Servicing at LEO

The highest risk factor would appear to involve the deployment and alignment of the various C-, Ku- and Ka-band reflectors. It is essential that the narrow spot beam from the separate antenna subsystem should be properly aligned with respect to one another. It will not be possible to correct some small pointing error in one antenna subsystem by some corrective tilting of the platform, since errors would then be introduced in the other antenna subsystem. Final verification of the alignments of these deployable antennas must be carried out at a space station facility, and the design of the antennas should permit the appropriate adjustments, if they are necessary, using relatively simple manipulations compatible with in-orbit capabilities.

It is anticipated that the deployments of the smaller antennas would be seem "automatic", requiring minimum intervention on the part of space station personnel. Deployment, or unfurling, of the large 10.5-meter C-band antenna presents another problem. Since the platform would be boosted from LEO to GEO in a fully deployed state, it is necessary that this antenna have mechanical characteristics permitting such a boost, be it a low-thrust operation. The types of large antennas designed for unassisted deployment at GEO would be unsuitable for this application because of their fragility. Indeed the type of robust structure required for boost to GEO in a deployed state would lend itself well to manually-assisted assembly techniques. It is anticipated, therefore, that the large C-band antenna could be conceived as a robust structure, using some mixture of manual and machine-assisted construction techniques. Design of this antenna would also permit alignment adjustment following some pattern radiation tests at LEO.

3.5.4.2.2 Servicing at GEO

This type of servicing primarily affects operating life of the platform. It is obvious that refueling for stationkeeping is such a capability. It is probable that the high-power amplifiers and their EPCs are the elements that pose the greatest limitations insofar as long life is concerned. Means should be provided for the replacement of both. A possible approach would be based on providing SSPA in groups of 13, for example, 12 of which would be active. The 13th unit would be switched in when an operating unit failed. The entire group would be replaced if it contained one failed unit. The redundant unit would permit spacing servicing calls to the platform over relatively long periods of time. The same doctrine would be adopted with regard to EPCs. The platform would be provided with a small number of large high-capacity EPCs since all SSPAs require the same low-voltage supplies. There would be arranged, for example, in say, a five-for-three redundant configuration. Failed units would be replaced when a service call was made.

It is clear that robotic replacement of power amplifiers requires the development of wave guide interfaces that lend themselves to this type of operation. It is felt that replacement of power amplifiers by blocks facilitates this since interfaces can be established by mechanically rigid groups. Certainly SSPAs lend themselves better to replacement since they may be replaced independent of their EPCs. To avoid possible effects of leakage from these remotely connectible wave guide interfaces, it would be desirable to locate the frequency conversion portion of the receivers with their subsequent amplification stages in positions well isolated from the high-power states. Since high-power stages are as close as possible to the antenna, this may mean locating portions of the receiver in a relatively distant place. To avoid degradation in receive noise temperative, it may be useful to provide some low-noise receive preamplification close to the antennas which would mask the wave guide losses incurred in a long run to the down conversion circuits.

It would also be possible to increase transmission capacity of the payload later in its life by replacing SSPAs with more powerful units. These could be accommodated by providing additional solar panels at a subsequent time and also by the inevitable evolution in SSPA capability that will take place between the initial build and the subsequent fabrication of replacement units over the 20 to 30 year life of the platform. Increased SSPA power would permit the use of higher-order modulation formats on the space links, with corresponding increase in communication capacity. It would be necessary, of course, that platform thermal design accommodate such an upgrade in capacity.

3.5.4.2.3 Concept 4 Considerations

Basically this consists of a Concept 2 FSS payload to which intersatellite link (ISL) and TDRSS capabilities have been added. It is likely that boost to LEO could not be achieved in a single launching, which would require some assembly activity there. A possible alternative to assembling the platform at LEO would be to design the ISL/TDRSS portion for remote union with the FSS payload at GEO. This would permit earlier launching of the FSS portion, providing Concept 2 capability, with subsequent growth at a later date to full Concept 4 operation.

SECTION 4.0
COST ANALYSIS

SECTION 4.0
COST ANALYSIS

A cost analysis of the four payload concepts was performed to estimate the recurring costs for the individual payload components and each assembled payload as a whole. Associated ground segment costs were also estimated to evaluate the relative economic merits of each payload concept. The cost drivers were identified and the cost sensitivity of critical performance variations in the drivers were estimated.

Payload costs in this report are defined as the first-unit, recurring cost-to-manufacture and exclude development cost, profit or fee, G&A, and launch costs. All costs are in 1984 dollars. Ground segment costs are estimated on a quantitative differential basis to enable comparison with non-aggregated scenarios. The earth-segment costs represent a sell price with installation included.

4.1 COSTING METHODOLOGY

Two cost modeling approaches are used independently in this study for estimating the cost of each communications platform payload. It was felt that this dual approach would bound the uncertainty inherent in the costing of advanced concepts and produce a more realistic set of cost data. One approach uses the RCA Heritage Model for estimating spacecraft payload cost and is based on index factors derived over the last 5 years of satellite design and manufacture at RCA Astro. These are then applied to each candidate payload through a knowledge of the mass of its components. The details of this model are provided in Subsection 4.1.1 of this report. The other cost estimating approach used in this study is based on the SAMSO-5 model. This model uses mass-dependent cost estimating relationships. These relationships were derived from an extensive data base of unmanned communications, experimental, military, and weather satellites. The details of this model are provided in Subsection 4.1.2 of this report.

4.1.1 RCA HERITAGE MODEL

The heritage model draws on a well-defined historical database that has been accumulated over the last five years of satellite design and manufacture at Astro.

This historical information was compiled by satellite type, normalized, and placed in a database file: The following items were entered:

- A labor-mix analysis which can be used with input pricing rates to generate labor rates that project historical labor mixes at input rates. (Labor and overhead cost can therefore be estimated in any time frame by altering the input rate deck).

- Actual engineering and manufacturing man-months expended.

- Actual material cost expended by task.

- Other cost expended.

The information is stored by task in a standard work breakdown structure. The tasks included in the work breakdown structure present the effort required to design, build, integrate, and launch spacecraft. The model is operated as follows:

- An engineering evaluation is made of the spacecraft being estimated. This evaluation, which considers weight, power, and other operational requirements, isolates a candidate spacecraft from the historical database.

- The database cost information for the candidate spacecraft is drawn from the file, reviewed by engineering, and accepted as representative of the spacecraft being estimated, or modified based on engineering judgement. The revised output becomes an input to a cost estimating model which uses this information along with input rate and historical mix data to estimate and present the information in a standard output format. A reviewed output set is also generated. The model can be cycled as often as necessary.

In configuration areas where the technology base differs significantly from the database of the heritage model, the output of this model is modified to compensate for cost impacts related to complexity and development uncertainties.

Adjustments of this nature are easily implemented by factoring specific subsystem outputs or totally replacing them with newly generated estimates from qualified sources. The adjusted output of the heritage model can be correlated to previous new-technology programs to give a high degree of confidence in the total program cost predicted.

The RCA heritage model has been used as a cost analysis tool on many "in-house" communications satellite programs and was recently used to generate the cost analysis section of the JPL Mobilesat Study Report under JPL Contract 957002. It was previously used on the NASA ACTS Program Integration Study. The RCA heritage model is considered proprietary to RCA; its database and methodology are not offered as a part of this study.

4.1.2 SAMSO-5 COST MODEL

The SAMSO-5 cost model uses subsystem masses and the BOL power of the spacecraft to estimate the antenna subsystem, payload electronics, and other subsystem costs. The equations referred to as cost estimating relationships (CERs) were developed using regression analyses on cost data for many spacecraft programs consisting of military, NASA, and commercial programs. The CERs for each subsystem and cost item are shown in Table 4.1-1. Table 4.1-2 provides a definition of each subsystem. The CERs in Table 4.1-1 are expressed in fiscal year 1979 dollars. To express the estimate in 1984 dollars, a composite inflation factor of 1.44 is used. In this study, only the recurring costs for the payload are considered and therefore the cost estimating relationships are limited to those for the communications antennas and communications electronics.

TABLE 4.1-1. SAMSO-5 COST MODEL

Item	Cost Estimating Relationships		
	Nonrecurring (K$)	Recurring (K$)	Independent Variables
Structure, Thermal and Interstage M_1 = mass (kg)	$C_{N1} = 1203.97 + 190.29 (M_1)^{0.66}$	$C_{R1} = 39.52 (M_1)^{0.65}$	
TT&C	$C_{N2} = 892.08 + 90.79 (M_2)$	$C_{R21} = 42.43 + 74.95 M_2^{0.93}$	M_2 = mass (kg)
Communications Antennas *	$C_{N31} = 463.30 M_{31}^{0.59}$	$C_{R31} = 8.79 + 105.19 M_{31}^{0.59}$	M_{31} = mass (kg)
Communications Electronics *	$C_{N32} = 419.11 M_{32}^{0.70}$	$C_{R32} = 81.88 (M_{32})$	M_{32} = mass (kg)
Attitude Control M_4 = mass (kg)	$C_{N4} = 960.72 + 166.45 M_4$	$C_{R4} = 61.63 M_4^{0.95}$	
Power	$C_{N5} = 2419.43 + 0.04941 (M_pP)^{0.97}$	$C_{R5} = 83.56 (M_pP)^{0.29}$	M_p = mass (kg)
Apogee Kick I_t = total Motor	$C_{N6} = 223.37 + 0.002417 I_t$	$C_{R6} = 26.32 M_6^{0.72}$	impulse (10^{-3} N-s) M_6 = dry mass (kg)
Platform	$C_{NP} = C_{N1} + C_{N2} + C_{N31} + C_{N32} + C_{N4} + C_{N5} + C_{N6}$	$C_{RP} = C_{R1} + C_{R2} + C_{R32} + C_{R32} + C_{R4} + C_{R5} + C_{R6}$	
Launch Support		$C_{R7} = 27.44 + 0.6596 M_T$	M_T = mass (kg) in transfer orbit
Program	$P_N = 1.3568$		$P_R = 1.3291$
Ground Equipment	$G = 1.1131$		
Fees	$P_F = 1.13$		
Inflation * (79-82)	$X_I = 1.44$		
Total Cost	$C_N = C_{NP}P_NGP_FX_I (10^{-3})$	$C_R = (C_{RP}P_R + C_{R7}) P_FX_I (10^{-3})$	

* Used in this study

TABLE 4.1-2. SAMSO-5 SUBSYSTEM DEFINITIONS

Subsystem	Description
1. Structure, Thermal Control, and Interstage	Structure typically includes struts, substrates, antenna supports, experimental booms, solar panel supports, and mechanical despin equipment. Thermal includes paint, insulation, radiators, heaters, louver assemblies, temperature sensors, and heat pipes. Interstage refers to booster adapter or separation mechanism between the booster and spacecraft.
2. Telemetry, Tracking, and Command	Typical equipment includes analog/digital converters, coders, digital electronics (digital storage units, command distribution units, programmers) or computers, signal conditioners (filters, modulators, integraters), format control units, transmitters, antennas, receivers, decoders, switching relays, tape recorders, amplifiers, and clocks.
3.1. Communications Antenna*	Includes all antenna components except supports and braces.
3.2. Communications Electronics*	Includes all communications subsystem components, such as receivers, TWTAs or SSPAs, transmitters, switches, switch control units, and phased array control units.
4. Attitude Control	Includes sun sensors, horizon scanners or sensors, star sensors, control electronics (attitude computers, tachometers, pulse modulators), gyro electronics, solar array pointing mechanism and drive electronics, and reaction control nozzles, fuel lines, valves, fuel tanks, spacecraft spin-up system, spacecraft despin system, antenna despin system, nutation dampers, wobble dampers, momentum wheels, and gravity booms.
5. Electrical Power	Includes solar cells, regulators, converters, power distribution units, batteries, and wire harnesses.
6. Apogee Kick Motor	Typical equipment includes solid rocket motors, firing squibs, liquid engines, tanks, nozzles, and tubes.

*Used in this study.

The SAMSO-5 model is based on historical costs. Some adjustments are made in applying the SAMSO-5 model to the platform study to account for advanced technology not represented by the historical database. These include:

a. For Ka- and Ku-band antennas with solid reflectors, multipliers of 1.6 and 1.4, respectively, are applied to the SAMSO-5 antenna subsystem CER to account for the higher cost associated with a more stringent surface tolerance requirement. The rms surface tolerance is plotted against frequency in Figure 4.1-1 for a constant 0.1- and 0.4-dB loss due to surface error of the reflector. For equal diameter reflectors, the relative cost of the antenna is estimated and shown in Figure 4.1-2 as a function of surface tolerance (with the corresponding frequency bands marked).

b. For large, unfurlable-mesh reflectors of 10-m diameter or greater, the SAMSO-5 CER is not applicable; the cost of unfurlable antennas is related to the diameter, while the cost of conventional antennas is more closely relted to antenna mass. A separate CER is derived based on cost estimates received from manufacturers of unfurlable antennas. The cost estimating relation for this type of antenna is plotted in Figure 4.1-3.

c. On-board processors are treated as part of the transponder electronics in the cost estimates. This approach is based on observing that the estimate obtained by applying the SAMSO-5 CER for transponder electronics is within 10% of the actual contract cost for the NASA Advanced Communications Technology Satellite (ACTS) on-board processor. This comparison is shown in Table 4.1-3. The ACTS processor recurring cost was used as a data base even though the ACTS processor is a first-flight experimental model because there is only a limited database available for on-board processors.

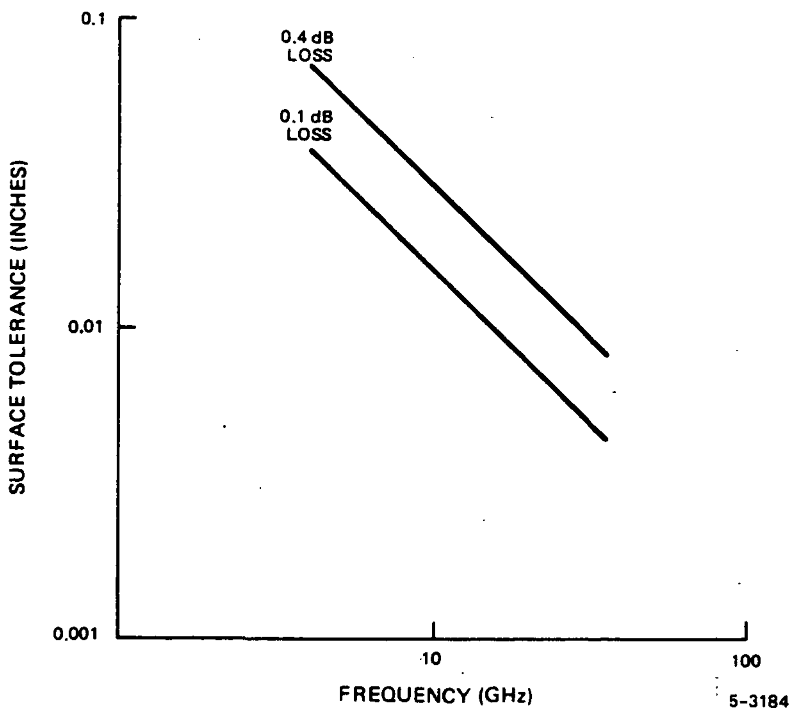


Figure 4.1-1. Surface Tolerance vs. Frequency

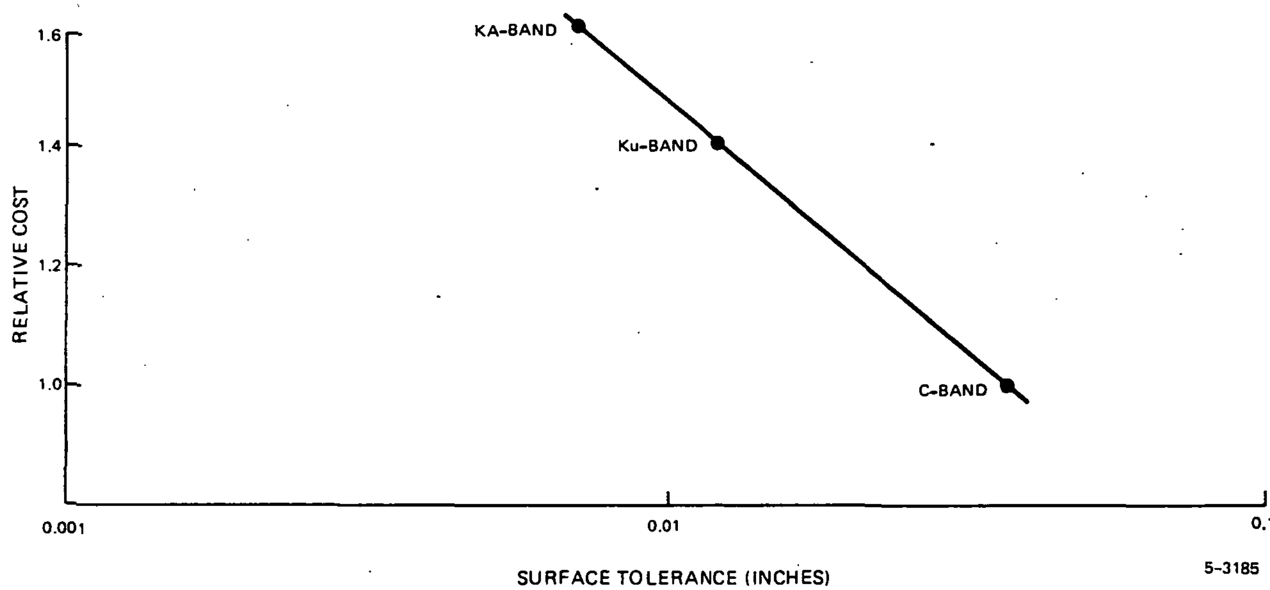


Figure 4.1-2. Relative Cost for Equal Diameter Antennas

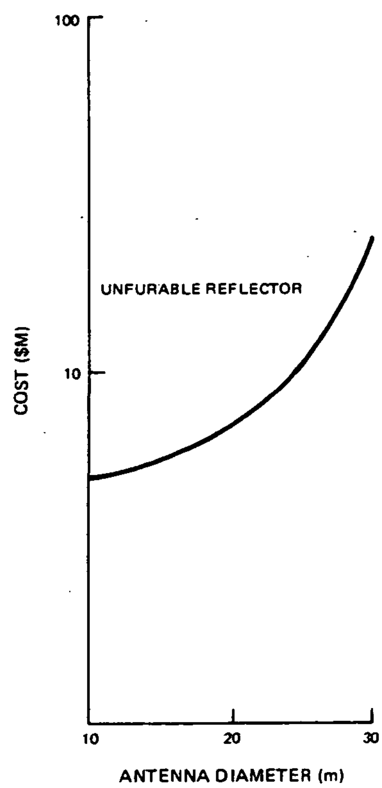


Figure 4.1-3. Recurring Antenna Cost Estimate (Reflector)

TABLE 4.1-3. ACTS ON-BOARD PROCESSOR

Mass	Recurring Cost	Predicted With CER	Δ
96.4 kg	$12.542M	$11.333M	$1.209M (9.64%)
Conclusion: Treat on-board processor as other spacecraft payload electronics.			

4.2 COST ESTIMATES

4.2.1 PAYLOAD COSTS

A summary of the communications platform payload costs for each concept is given in Table 4.2-1. A comparison of the results which are obtained using the heritage and SAMSO-5 cost models is provided and shows good agreement with each other. As shown for Concept 1 (the land mobile satellite system), the two methods gave results which are within ±15% of each other. For the other three concepts, the results compared to within a few percent of each other. In addition, the SAMSO model was used to estimate the payload costs of an RCA-Astro C-band and an RCA-Astro Ku-band satellite. The results of the SAMSO model are given and compare favorably with the actual RCA-Astro costs.* Based on these results, it was concluded that the SAMSO model could provide accurate estimates of the total payload costs and would be used in carrying out the cost comparisons involving the total payload. Where detailed component costing was required, it was decided to use the heritage cost model.

The detailed breakdown of the SAMSO cost estimates are given in Tables 4.2-2, 4.2-3, 4.2-4, and 4.2-5. To obtain the total payload costs, the costs of the individual antennas are added to the transponder electronics cost. The mass used in the computation is that which is provided in Section 3 of this report. It can be seen that the most costly and heaviest payload was that of Concept 4 at $333 million while the least expensive and lightest was that of Concept 1 at $138 million. Since the antenna cost is relatively small compared to the transponder cost, the cost of each payload is seen to vary nearly proportionally to the mass.

*Actual costs are RCA-Astro confidential.

TABLE 4.2-1. COMMUNICATIONS PLATFORM PAYLOAD COSTING SUMMARY ($1984)

Concept	Mass (kg)	Cost ($M)		
		Approach		Average
		1	2	
LMSS				
Antenna	200	24	24	24
Transponder	972	78	114	96
Total	1,172	102	138	120 ± 15%
FSS (20%)				
Antenna	332	13	16	14
Transponder	1,812	219	213	216
Total	2,144	232	229	230 ± 01%
FSS (13%)				
Antenna	208	8	9	8
Transponder	1,300	163	153	158
Total	1,508	171	162	166 ± 03%
TDAS-ISL-FSS				
Antenna	567	21	29	25
Transponder	2,588	289	304	296
Total	3,155	310	333	321 ± 03%
1984 Satellites				
C Antenna	42	---	1	
C Transponder	88	---	10	
C Total	130	---	11	
Ku Antenna	32	---	1	
Ku Transponder	131	---	15	
Ku Total	163	---	16	

Approach 1: Heritage

Approach 2: SAMSO-5

TABLE 4.2-2. CONCEPT 1: LAND MOBILE SERVICE

Platform Mass and Cost Estimates		
Subsystem	Mass (kg)	Cost ($M)
Antenna		
• 30-m UHF/L-Band (Reflector)	200	24
• Ku-Band Horn	–	–
ANTENNA TOTAL	200	24
TRANSPONDER	972	114
PAYLOAD TOTAL	1,172	138

TABLE 4.2-3. CONCEPT 2: FIXED SERVICE (20% CAPTURE)

Platform Mass and Cost Estimates		
Subsystem	Mass (kg)	Cost ($M)
Antenna		
• 10.5-m C-Band	117	6
• 2-m C-Band	24	1
• 3.5-m Ku-Band	50	2
• 1.5-m Ku-Band	21	1
• 4.5-m Ka-Band	65	3
• 3-m Ka-Band	55	3
ANTENNA TOTAL	332	16
TRANSPONDER	1,812	213
PAYLOAD TOTAL	2,144	229

TABLE 4.2-4. CONCEPT 3: FIXED SERVICE (13% CAPTURE, 10% VIDEO)

Platform Mass and Cost Estimates		
Subsystem	Mass (kg)	Cost ($M)
Antenna		
• 2-m C-Band	44	1
• 2-m Ku-Band	44	2
• 4.5-m Ka-Band	65	3
• 3-m Ka-Band	55	3
ANTENNA TOTAL	208	9
TRANSPONDER	1,300	153
PAYLOAD TOTAL	1,508	162

TABLE 4.2-5. CONCEPT 4: TDAS/ISL/FSS SERVICE

Platform Mass and Cost Estimates		
Subsystem	Mass (kg)	Cost ($M)
Antenna		
• S-Band Phased Array	75	2
• (2) 4-m Ku-Band	35	2
• (5) 1-m W-Band	75	6
• (1) 2-m W-Band	15	1
• (2) 3-m W-Band	35	2
FSS Antenna	332	16
ANTENNA TOTAL	567	29
Transponder		
• TDAS	439	51
• ISL	161	19
• FSS	1,988	234
TRANSPONDER TOTAL	2,588	304
PAYLOAD TOTAL	3,155	333

4.2.2 COMPONENT COSTS

In this subsection, the component costs of each payload are derived using the heritage cost model. Table 4.2-6 provides the results for the land mobile platform component costs and shows that the receivers, SSPAs, EPCs, and diplexers are the major contributors to the total transponder cost. The antennas represent 24% of the total payload cost.

The component costs for the FSS concepts, Concepts 2, 3, and 4, are summarized in Table 4.2-7. The major FSS cost drivers are presented in Table 4.2-8 showing that the input/output multiplexers are the major cost driver for all three of the FSS concepts which represent between 40 and 50 percent of the total payload cost. The baseband processor and SSPAs follow in importance to the overall payload cost.

TABLE 4.2-6. LMSS COMPONENT COSTS

Component	Cost ($M)	Percent
Receiver		
UHF	10.1	
L-band	12.4	
Ku-band	0.4	
Total	22.9	23
SSPA		
UHF	7.2	
L-band	9.9	
Ku-band	0.4	
Total	17.5	17
EPC		
UHF	7.2	
L-band	9.9	
Ku-band	0.4	
Total	17.5	17
Diplexer		
UHF	5.4	
L-band	4.0	
Ku-band	--	
Total	9.4	9
Other	10.2	10
Transponders	78.0	
Antenna	24.0	24
Total	102.0	100

TABLE 4.2-7. COMPONENT COST, FIXED SERVICE SATELLITES

Component	Cost/kg ($M)	20% Capacity Mass (kg)	20% Capacity ($M)	13% Capacity Mass (kg)	13% Capacity ($M)	20% Capacity + TDAS + ISL Mass (kg)	20% Capacity + TDAS + ISL ISL ($M)
Receivers	0.0930	45	4.2	20	1.9	175	16.3
I/O Mux	0.4444	256	105.3	186	82.8	273	121.1
TDMA/Circuit Sw	0.1494	51	7.6	42	6.2	59	8.7
Baseband Processor	0.1302	480	62.5	320	41.6	549	71.5
SSPAs	0.0440	739	32.5	615	27.1	1,172	54.4
TWTAs	0.1190	--	--	--	--	78	9.3
Other	---	241	7.1	117	3.7	260	7.9
Transponder		1,812	219.2	1,300	163.3	2,588	289.1
Antenna	0.0376	332	13.0	208	8.0	567	21.0
Total		2,144	232.2	1,508	171.3	3,155	310.1

TABLE 4.2-8. FSS COST DRIVERS

Component	Concept 2 (20% Capacity)	Concept 3 (13% Capacity)	Concept 4 FSS + ISL + TDAS
I/O Mux	45%	48%	39%
Baseband Processor	27%	24%	23%
SSPA	15%	16%	16%

4.3 COST COMPARISONS

The satellite payload recurring costs have been presented in Section 4.1 for each of the four payload concepts. Quantitative differential cost estimates were made for the associated ground segment of each concept to assess the economic merits relative to a non-platform approach. "Differential" refers to equipment that is different for platform and non-platform concepts. The cost estimates are based on the SAMSO-5 cost model. The system cost comparisons are based on the recurring costs of the payload and certain elements of the ground segment only. Total system costs including the bus and non-recurring costs are not included in this analysis because of the limited scope of the study's costing task.

4.3.1 CONCEPT 1 COMPARISONS

LMSS is an emerging service that is in a very dynamic state of development. There are currently 12 filings before the FCC offering a wide range of approaches; only one will be selected. Because of the current uncertainty, it is difficult to construct a meaningful baseline non-platform approach for comparison. Any comparison would be of limited value. NASA recognized the uniqueness of the LMSS platform concept and directed RCA not to make a comparison.

A major cost driver for the LMSS payload concept is the 30-m unfurlable antenna. A sensitivity analysis is provided in Table 4.3-1 which examines the cost per channel (7KHz voice and 10KHz data) as a function of antenna diameter. It can be seen that as the antenna diameter is reduced from 30 m, the capacity and payload cost decrease.

At 22 meters, the antenna cost decreases faster than the capacity (measured in number of voice and data channels), resulting in a lower cost per channel (i.e., $25,000/channel compared to $27,000/channel). At 14 m, the capacity is decreasing faster than the antenna cost, resulting in a higher cost per channel (i.e., $26,000/channel compared to the $25,000/ channel).

TABLE 4.3-1. CONCEPT 1: LMSS PAYLOAD COST DRIVER SENSITIVITY

LMSS - Antenna Dia. (m)	Total Capacity** (UHF + L-Band)	Antenna Cost ($M)	Electronics Cost ($M)	Total Payload Cost ($M)	Cost/Channel** ($K)
30	5,170	24	114	138	27
22*	2,585	8	57	65	25
14*	1,294	6	29	35	26

NOTE: *For these cases, bus power per channel must be increased.
**Capacity measured in terms of voice (7KHz spacing) and data (10KHz spacing) channels.

It should be noted that to maintain equivalent transmission performance for the reduced spacecraft antenna sizes, higher output power amplifiers are required. This cost differential is not considered significant. However, additional bus power would be required. This would even increase the cost advantage of the platform.

4.3.2 CONCEPT 2 COMPARISONS

The FSS concept 2 offers a high-capacity cross-strapped platform that provides a high degree of connectivity from one orbital slot. An alternative non-platform approach would require multiple satellites to provide the same capacity. The associated non-platform earth stations would require additional antennas to provide the same degree of connectivity as the platform concept. The costing effort included the impact of these additional ground station antennas.

A cost comparison of the FSS system of Concept 2 with a three-satellite non-aggregated system has been performed. The two systems are shown in Figure 4.3-1. Both systems provide the same total transponder capacity. Each satellite provides a capacity of 170 36-MHz equivalent transponders, equivalent to one-third the platform capacity. It is likely that the satellite would utilize antennas smaller than those of the platform. It is assumed that the satellite would include the following antennas:

- 2m C-Band providing CONUS coverage
- 2m Ku-Band providing 1/4 CONUS coverage
- 4.5m and 3m Ku-Band antennas providing coverage similar to platform concept.

Design of a satellite for comparison purposes is beyond the scope of the study and has not been performed.

The payload costs for the two options are shown in Table 4.3-2. It is assumed that the mass of the payload electronics is proportional to the capacity. Since electronic cost is proportional to mass, the total system electronic cost is the same for the two systems.

The payload costs for a three-satellite system are slightly greater ($8.6M) than that of the platform. The earth segment costs are provided in Table 4.3-3. These costs include only that equipment which is different for the two options. The differences in the earth segment are caused by the requirement for additional antennas to provide station-to-station interconnectivity in the three-satellite system. Each additional antenna will also require an additional low-noise amplifier (LNA). Since the total traffic carried by both systems is identical, common equipment (such as multiplexer, modulation, and frequency converters) is not considered since the analysis is based on cost differentials between the two systems.

The earth station characteristics for each service and frequency band are considered to be typical for the late 1990 time frame. The LNA noise figures, assumed for costing purposes, are 0.75 and 3 dB for C- and Ka-band trunking stations and 2 and 4 dB for Ku- and Ka-band CPS stations. The total earth

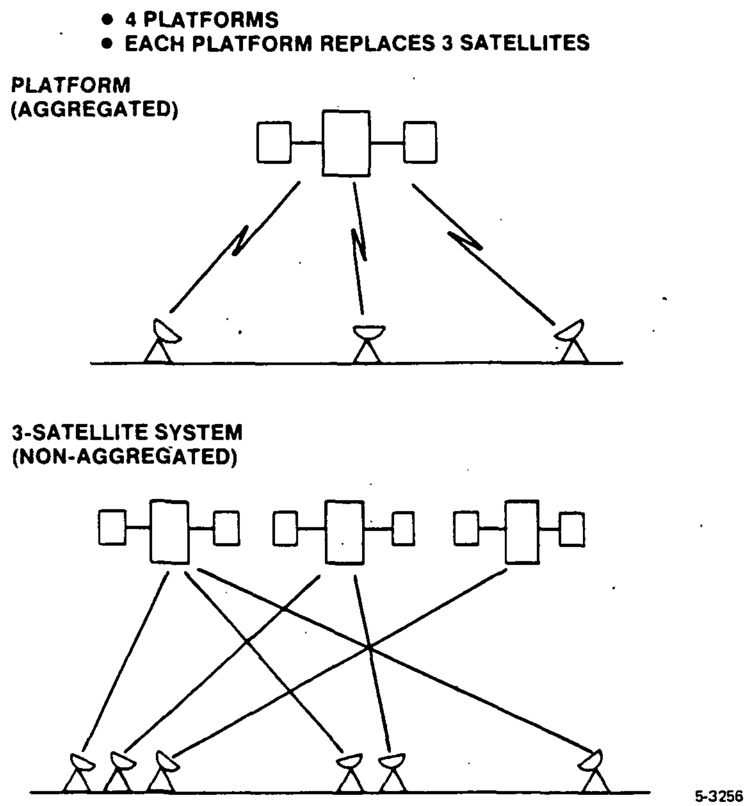


Figure 4.3-1. Fixed Service Option

segment cost for the platform is given in Table 4.3-4. The number of stations for each service is derived from the projections provided in Section 2.3. The number of stations is assumed to be 20% of the total since Concept 2 is based on a 20% traffic capture.

For the three-satellite option, the number of earth station antennas will increase to provide connectivity. It is clear that full connectivity can be provided if each station were to have three antennas. In this way, each station could access all three satellites. It is possible, however, to achieve full connectivity with stations having fewer than three antennas. For example, if we assume uniform traffic among the stations, it can be shown that on the average each station requires only 2.4 antennas.

TABLE 4.3-2. CONCEPT 2: FIXED SERVICE (20% CAPTURE)

Total Space Segment Cost Comparison (Payloads Only)									
Option	Antenna Cost ($M) Per Spacecraft			Number of Spacecraft	Total Antenna Cost ($M)			Total Electronic Cost ($M)	Total Cost Differential
	C-Band	Ku-Band	Ka-Band		C-Band	Ku-Band	Ka-Band		
Platform	7.5	3.4	5.4	1	7.5	3.1	5.4	213	0
3-Satellite System	1.0	1.8	5.4	3	3.0	5.4	16.2	213	8.6

TABLE 4.3-3. CONCEPT 2: FIXED SERVICE (20% CAPTURE)
EARTH STATION COST SUMMARY

Earth Station Costs					
Service	Frequency Band	Antenna Diameter (m)	Recurring Antenna ($K)	Recurring LNA Cost ($K)	Total Cost ($K)
Trunking	C	10	150	40	190
	Ka	10	350	40	390
CPS	Ku	2	1	15	16
	Ka	2	2	18	20

TABLE 4.3-4. CONCEPT 2: FIXED SERVICE (20% CAPTURE)
EARTH STATION COST PER PLATFORM

Total Earth Station Cost for Platform				
Service	Frequency Band	Antenna and LNA Recurring Cost ($K)	Number of Stations	Total Cost ($M)
Trunking	C	190	38	7.2
	Ka	390	87	33.9
CPS	Ku	16	21,000	346.5
	Ka	20	10,373	207.5
			Total	595.1

For nonuniform traffic distribution, this factor may even be less. For this analysis, we consider two cases in which the 2.4 factor is used. Case one provides complete interconnectivity between only the trunking stations, while in case two, complete interconnectivity is provided for both the trunking and CPS stations. Two cases were selected to estimate cost differences for systems of equal capability. Total interconnectivity represents an upper bound for cost estimating purposes and not a system requirement. Total interconnectivity, while desirable for trunking, may not be realistic for CPS. The results for these two cases are given in Table 4.3-5 and 4.3-6, respectively.

The total system costs for the space and earth segments are then compared in Table 4.3-7. It can be seen that the satellite system is $265 million more expensive than the platform system when complete trunking interconnectivity is required (total system of 4 platforms is compared to a total system of 12 satellites). If complete trunking plus CPS interconnectivity is required, the cost difference increases dramatically to over $3 billion. These results take into account that the system scenario described by Concept 2 defines a system using four such platforms to meet its total capacity requirement.

TABLE 4.3-5. CONCEPT 2: FIXED SERVICE (20% CAPTURE) (TRUNKING CONNECTIVITY)

Total Earth Station Cost for 3-Satellite Option (Complete Trunking Interconnectivity)				
Service	Frequency Band	Antenna and LNA Recurring Cost ($K)	Number of Antennas	Total Cost ($M)
Trunking	C	190	91	17.3
	Ka	390	209	81.5
CPS	Ku	16	21,000	346.5
	Ka	20	10,373	207.5
			Total	652.8

TABLE 4.3-6. CONCEPT 2: FIXED SERVICE (20% CAPTURE) (FULL CONNECTIVITY)

Total Earth Station Cost for 3-Satellite Option (Complete Trunking Plus CPS Interconnectivity)				
Service	Frequency Band	Antenna and LNA Recurring Cost ($K)	Number of Antennas and LNAs	Total Cost ($M)
Trunking	C	190	91	17.3
	Ka	390	209	81.5
CPS	Ku	16	50,400	831.6
	Ka	20	24,895	497.9
			Total	1,428.3

TABLE 4.3-7. CONCEPT 2: FIXED SERVICE (20% CAPTURE) SYSTEM COST SUMMARY

Recurring System Cost Summary (Bus Excluded)				
	Cost Differentials Per Platform			
Option	Space Segment ($M)	Earth Segment ($M)	Total ($M)	Total System Cost Differential* ($M)
Platform	0	0	0	0
3-Satellite System (Complete Trunking Interconnectivity)	8.6	57.7	66.3	265
3-Satellite System (Complete Trunking and CPS Interconnectivity)	8.6	832	840.6	3,362
*4 Platforms vs 12 Satellites				

4.3.3 CONCEPT 3 COMPARISONS

In this subsection, three systems are compared as shown in Figure 4.3-2: System 1, consisting of six Concept 3 platforms; system 2, consisting of four Concept 2 platforms with two satellites used for video distribution; and system 3, consisting of 14 satellites. All three systems can provide approximately the same total capacity and service.

The total payload cost for each system is given in Table 4.3-8. The costs per platform are those of either the Concept 2 or Concept 3 platforms and are taken from Subsection 4.2.1 of this report. The cost of the 48-transponder satellites used for the video distribution is assumed to be two times that of a 24-transponder satellite cost of $12 M that was provided in Subsection 4.2.1 of this report. It can be seen that the payload costs for any of the three system options are nearly identical.

The total cost of the earth segment (excluding common equipments as described in Subsection 4.3.2) is provided in Table 4.3-9 for Concept 3. The number of stations per platform is obtained by assuming 13 percent of the total number of earth stations projected for the late 1990s.

The projected number of earth stations is presented in Section 2.3. As in Concept 2, the split between C- and Ka-band for trunking and between Ku- and Ka-band for CPS traffic is identical to the division of traffic loading for the platform (see Section 3). The earth station costs are identical to those used in Concept 2. The earth station costs for video distribution are based on an antenna diameter of 5-m and LNA noise figure of 1.3 dB. The total system earth segment costs for each of the three systems is provided in Table 4.3-10. The results for system 3 are based on a complete interconnectivity capability for the trunking traffic. It can be seen that the earth segment costs for systems

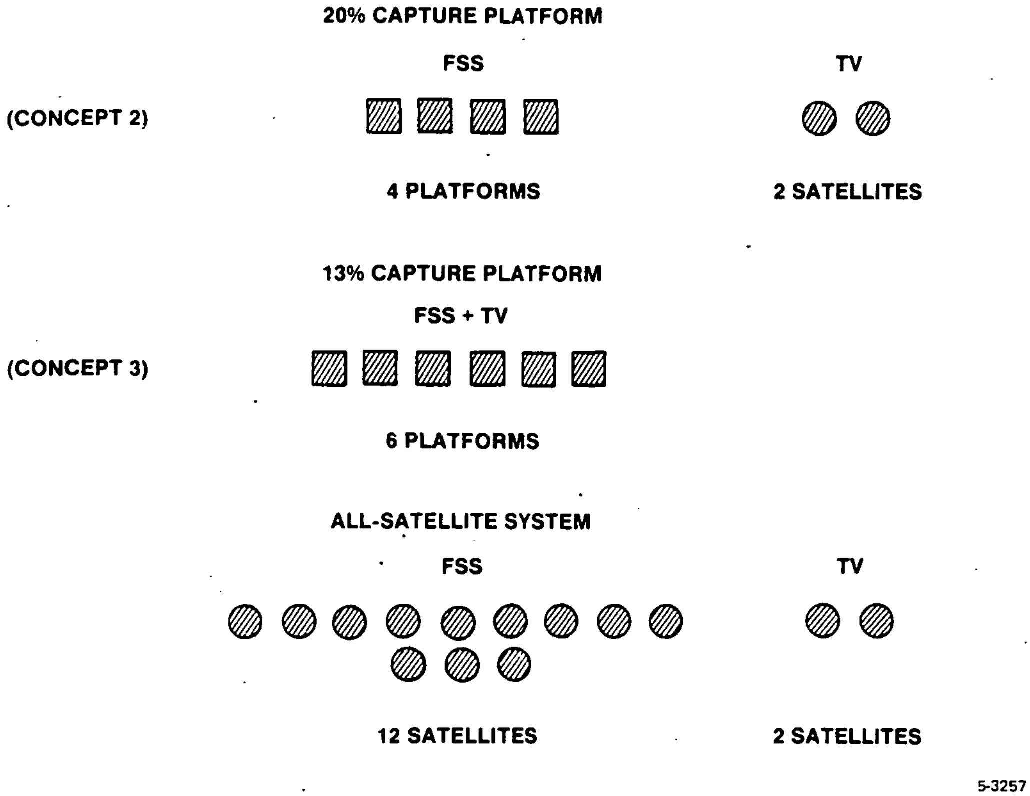


Figure 4.3-2. Fixed Service Options

TABLE 4.3-8. TOTAL PAYLOAD COST, CONCEPT & COMPARISON

	Cost Per Platform** ($M)	Number Of Platforms	Cost Per Satellite** ($M)	Number Of Satellites	Total Cost ($M)
System 1	162	6	-	0	972
System 2	229	4	24*	2	964
System 3	-	0	79	12	996
		0	24*	2	
*48-transponder satellite **Payload only					

TABLE 4.3-9. CONCEPT 3: FIXED SERVICE (13% CAPTURE), EARTH STATION COST PER PLATFORM

Service	Frequency Band	Number Of Stations/ Platform	Antenna and LNA Recurring Cost ($K)	Total Cost ($M)
Trunking	C Ka	5 76	190 390	0.9 29.6
CPS	Ku Ka	13,650 6,740	16 20	225.2 134.8
Video Distribution to Cable Head	C	1,100	8	8.8
Video Distribution (other)*	C	1,200	8	9.6
			Total	408.9

*Others include SMATV, LPTV, STV, Video conferencing.

TABLE 4.3-10. SYSTEM EARTH SEGMENT COST FOR CONCEPTS 2 AND 3 AND ALL-SATELLITE SYSTEMS

Concept	System Earth Segment Cost ($M)	Remarks
System 1	2,453	Six times earth segment cost for single 13-percent platform.
System 2	2,463	Four times earth segment cost for single 20-percent platform plus 75 percent of system 1 earth segment cost for video.
System 3	2,695	Four times earth segment costs of 3-satellite case plus 75 percent of system 1 earth segment cost for video (complete trunking inter connectivity).

1 and 2 are nearly the same and are lower than those of system 3 (fully deaggregated). The total system cost differentials are given in Table 4.3-11 and indicate that the total costs of systems 1 and 2 are nearly the same, but the cost of system 3 is almost $300 million higher. Only receiving costs are considered in this analysis. The space segment cost is for the payload only.

C-3

TABLE 4.3-11. CONCEPT 3: FIXED SERVICE (13% CAPTURE SYSTEM RECURRING COST SUMMARY (BUS EXCLUDED)

System	System Space Segment Cost* ($M)	System Earth Segment Cost (Antenna & LNA) ($M)	Total Cost ($M)	Cost Differential ($M)
System 1	972	2,453	3,425	0
System 2	964	2,463	3,427	2
System 3	996	2,695	3,691	266
*Payload only.				

4.3.4 CONCEPT 4 COMPARISONS

Concept 4 is an aggregation of Concept 2, the tracking, data acquisition satellite (TDAS) and intersatellite link (ISL) services. This concept provides for two ISLs which can directly link international traffic normally handled by the Atlantic and Pacific Gateway earth stations. The projected traffic to the Atlantic Gateway is 51 transponders and to the Pacific Gateway is 15 transponders. The ISLs can directly link this traffic to the end user by existing trunking stations and CPS terminals. This eliminates a significant portion of the terrestrial tails or possible second satellite hop as illustrated in Figure 4.3-3. This can result in a savings of over $300 million as compared to the double satellite hop alternative (see Table 4.3-12). A combination of terrestrial tails and satellite relay may reduce the cost savings of the ILS approach. However, comparison to a hybrid alternative was considered beyond the scope of the study.

Table 4.3-13 presents a derivation of the double-hop gateway differential cost. Gateway stations would be required on the east and west coasts. It is assumed tht existing facilities would be upgraded to handle the additional 66 transponders of traffic. Table 4.3-13 reflects the cost of the upgrade. Time delays associated with a double-hop system could result in a loss of synchronization in the TDMA network. One approach for achieving synchronization is to demodulate to baeband at the gateway to resynchronize. Table 4.3-13 includes the cost of demodulating to baseband.

TABLE 4.3-12. ISL SYSTEM RECURRING COST COMPARISON

Option	Payload ($M)	Earth Segment* ($M)	Total Cost ($M)	Cost Differential ($M)
ISL	41	-	41	-
Double-Hop	36	317	365	313
*Gateway Cost				

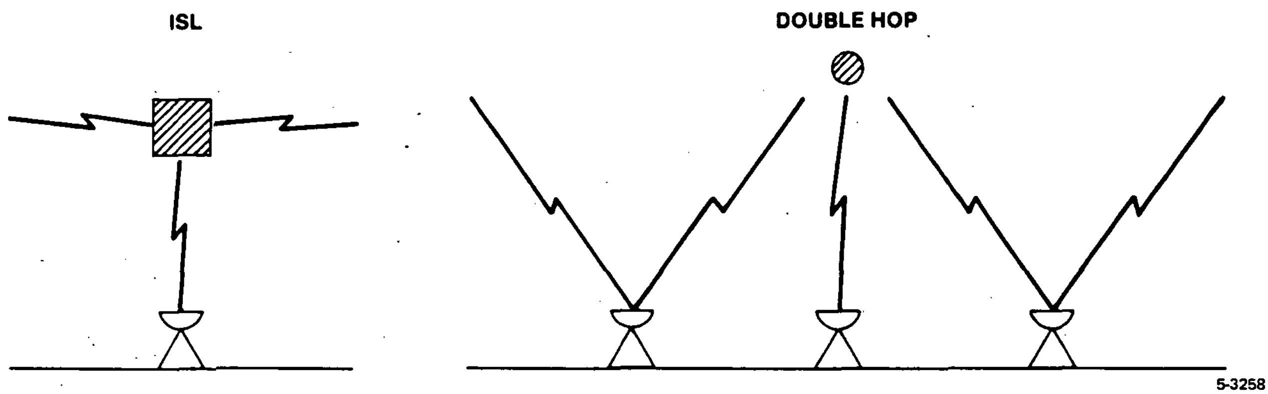


Figure 4.3-3. ISL System Recurring Cost Comparison Conus to East/West Options

TABLE 4.3-13. DOUBLE-HOP EARTH SEGMENT COST

Channels	
Voice 198,000	
Trunking Data (1.5 Mbps) 70	
IBS Data (56 Kbps) 7,000	
203,000 channels provided by 66 (36 MHz) transponders	
• 2 C-Band Standard A antennas @ $3M each	$ 6.0M
• 203,000 channel equipment @ $670 per channel $320 for MUX $250 for DSI $100 for LRE	136.0M
• 66 TDMA equipment @ $2M per transponder	132.0M
• 99 HPA (3kW klystron) 3 for 2 redundancy @ $40K each	4.0M
• LNA (70°K noise temperature) @ $35K per redundant pair	0.7M
• Power subsystem 2 standard A @ 4M each	8.0M
	$286.7M
Integration and Test (10%)	30.0M
Total Double-Hop Earth Segment Cost	$316.7M

SECTION 5.0
CRITICAL TECHNOLOGY

SECTION 5.0
CRITICAL TECHNOLOGY

The study tasking included a requirement to identify enabling and support technologies critical to the eventual implementation of each of the payload concepts. The identification includes technologies that have large economic uncertainity as well as technologies of great technical risks. The study tasking also required descriptions on the technology devèlopment scenarios required to reduce the technical and economic risks to the level of normal commerical risks and enable implementation of the payload concepts operationally in 1998.

A detailed review has been made of the technology required to implement each of the four payload concepts. Technology has been identified which is considered to be critical or which requires further development before it can confidently be used on a commercial satellite program. In this report, critical technology is defined as that technology which requires further development beyond its present level of technical maturity. Needless to say, much of the relevant technology, e.g., antenna, solid-state amplifier, etc., is in an evolutionary process of continual development and refinement. Certainly many technologies which are identified today as being critical may reach an adequate level of technical maturity by the time required for a late-1990 launch without an increase in present funding commitment. For this reason, a further distinction is made to classify the critical technologies in terms of those projected to require additional development beyond that being funded today.

A prioritized list of the critical technologies is given in Table 5.1-1. This list characterizes the technologies in terms of their technical risk and cost uncertainty as it exists today. The antennas, especially the 30-m UHF/L-band antenna of Concept 1, are rated as having the highest combined technical risk and associated cost uncertainty. The on-board processor required for Concepts 2, 3, and 4 is ranked second in this regard because of in-orbit lifetime, power requirements, and cost uncertainties associated with many of the processor components. Some of these uncertainties will be addressed by the NASA ACTS program. Three somewhat less critical technologies include the i.f. switch matrix (used in Concepts 2, 3, and 4), intersatellite links (used in Concept 4) and W- and Ka-band satellite high-power amplifiers (W-band used in Concept 4, Ka-band used in Concepts 2, 3, and 4). The multiplexer filters for Ka- and W-band are considered low technical risk and low cost uncertainty technology.

Each of the above mentioned technologies are described in more detail in the following subsections.

5.1 ANTENNAS

5.1.1 TECHNOLOGY REQUIREMENT

A review of the four platform concepts indicate a number of critical antenna technologies. Antennas requiring additional development beyond that which is available today are listed below:

- 30-m UHF/L-band antenna (Concept 1)
- 10.5-m C-band antenna (Concepts 2 and 4)
- 4.5-m Ka-band antenna (Concepts 2, 3, and 4)
- W-band antenna (Concept 4)

5.1.2 CRITICAL TECHNOLOGY ASSESSMENT

The critical areas associated with each antenna are identified in Table 5.1-2.

5.1.2.1 30-m UHF/L-Band Antenna (Concept 1)

The 30-m UHF/L-Band antenna for the LMSS concept is an unfurlable reflector with an active microstrip patch radiating feed. Preliminary work on such a feed, as shown in Figure 5.1-1, has been carried out and is described in JPL publication 82-19 (Reference 18). The feed array design must include, in addition to feed elements and the beam forming network, the power amplifiers, low-noise receivers, diplexers, and thermal control systems. It is envisaged that the feed assembly must be folded to be stowed. Special consideration must be given to ensure that performance is met over the expected in-orbit temperature range. The use of heat pipes will probably be required for thermal control.

TABLE 5.1-1. CRITICAL TECHNOLOGY SUMMARY

Technology	Priority	Technical Risk	Cost Uncertainty	Concept	Critical Areas
Antennas	1	High	High	All 4 (1 Highest)	30 M and 10 M Unfurlable Reflectors, Microstrip Feed Array
On-Board Processor	2	High	High	2,3,4	Demodulator Mass/Power/ Size/Reliability
IF Switch	3	Moderately High	Moderate	2,3,4	Cross-Talk Isolation, Wide Bandwidth, Switching Speed
Inter-satellite Links	4	Moderately High	Low	4	High-Power Ga Al As Transmitter, Pointing/ Tracking, W Reflector Surface Tolerance, Wide-band Modem
Satellite High Power Amplifier	5	Moderate	Low	2,3,4 (Ka-& W-Band)	Dual-Mode Power, Redundancy
Multi-plexer Filters	6	Low	Low	2,3,4 (Ka-& W-Band)	Ka or Higher I/O

A dichroic screen may be required to separate L-band and UHF frequencies if independent sets of feeds are employed. The development of a dual-band feed could eliminate the need for the dichroic screen.

Several methods of construction applicable to this type of unfurlable antenna have been or are currently being studied; these include: (1) the Lockheed wrap-rib reflector; (2) Harris rigid rib; (3) Harris deployable loop antenna; and (4) the General Dynamics GEO-TRUSS antenna (see Figures 5.1-2, 5.1-3, 5.1-4, and 5.1-5.

TABLE 5.1-2. ANTENNA CRITICAL TECHNOLOGY

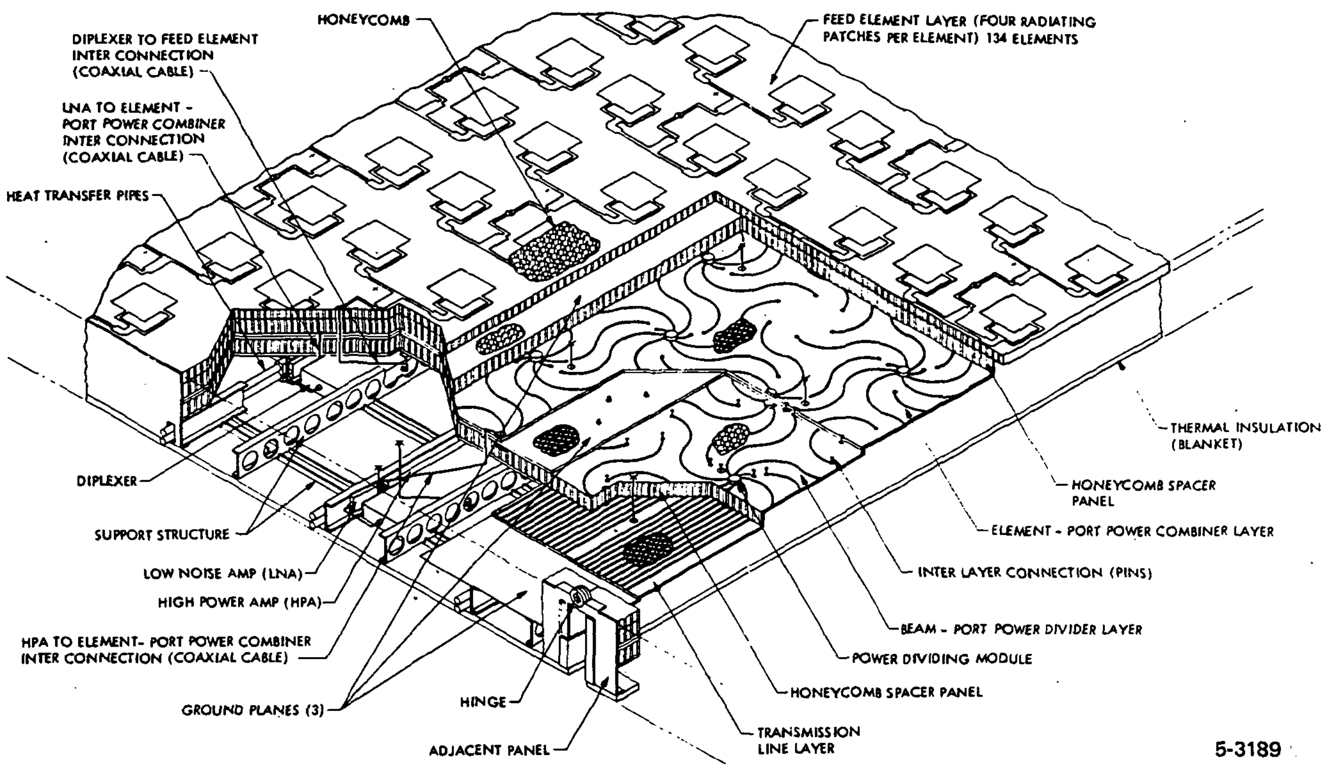
Antenna Type	Critical Area	Potential Problem
30-m UHF/L-Band unfurlable reflector with microstrip feed and dichroic screen	Microstrip feed Array Active microstrip feed array Dichroic screen Dual-band feed alternative which eliminates dichroic screen Unfurlable meshed reflector Large D/λ ∿90	New material and construction techniques to provide stable rf performance over temperature (feed) Requires improved heat extraction mechanism, studies required to determine optimum solution (feed) Unfurling technique for large reflectors; material and construction to reduce thermal effects on surface tolerance; passive intermod at mesh cross-connect points; test techniques need to be developed for large reflectors Sidelobe control critical to multibeam multifold frequency reuse High scan loss associated with large D/λ
Ka-Band	Antenna geometry Surface tolerance Pointing tolerance Large D/λ ∿470	Improved material and construction techniques to reduce RMS surface error due to thermal distortion Improved antenna pointing to achieve < 0.03° Antenna design to reduce scan loss Low sidelobe design required to reduce inter-beam interference High scan loss associated with large D/λ

TABLE 5.1-2. ANTENNA CRITICAL TECHNOLOGY (Continued)

Antenna Type	Critical Area	Potential Problem
W-Band (60 GHz)	Surface Tolerance Pointing Tolerance	RMS surface tolerance on the order of 0.005 inch required Effect of thermal distortion more critical Antenna pointing must be held to ∿0.01°
All	Antenna Arrangement	Interference between antennas by direct blocking or rf scattering Develop methods for modeling performance degradation due to scattering
10.5-m C-Band Unfurlable Reflector	Unfurlable Meshed Reflector Large D/λ ∿200	Surface tolerance required at C-band is significantly tighter than at UHF/L Material and construction to reduce thermal effects on surface error Sidelobe control critical to frequency reuse Passive intermods at mesh cross-connect points of mesh High scan loss associated with large D/λ

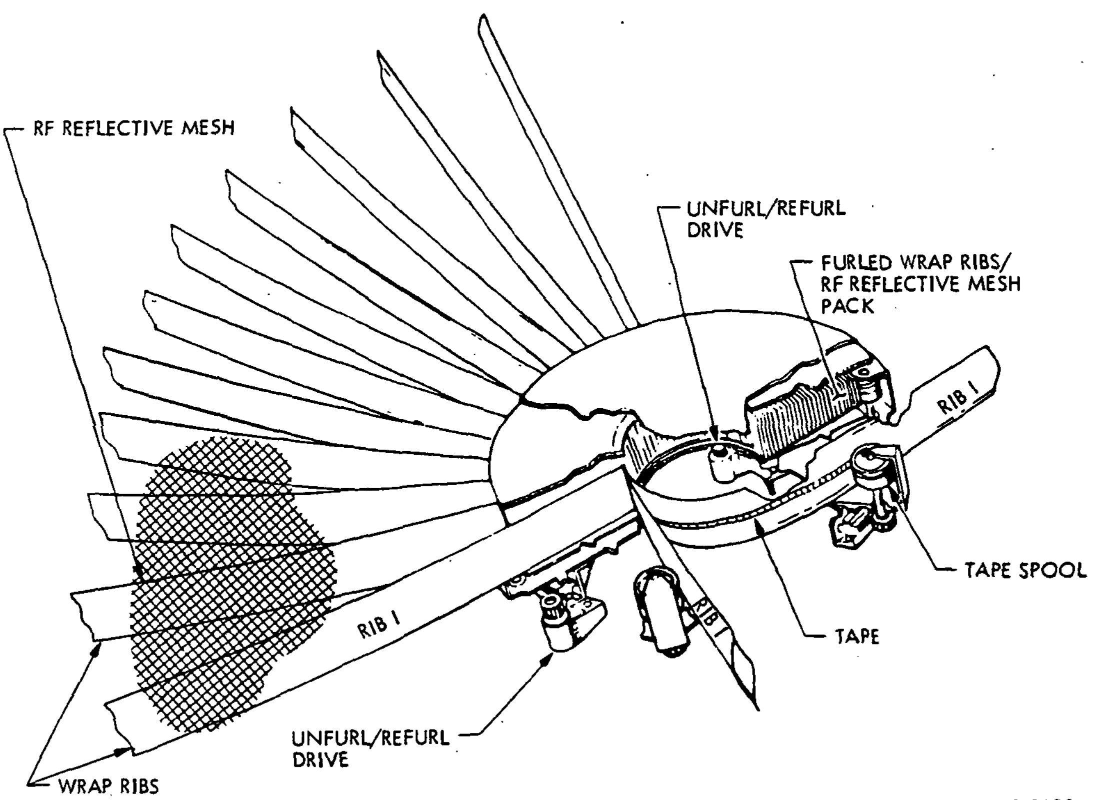
Special consideration must be given to the materials used in the construction of the antenna to reduce thermal distortion effects. Surface tolerance is a critical parameter in the antenna sidelobe performance. Passive intermods can also be a problem with mesh reflector surfaces. Methods for testing large reflectors in a zero-g environment must be developed.

Consideration must be given to the reflector and feed dynamics to ensure that deflections between the feed and reflector are controlled to an acceptable limit over the spacecraft lifetime and during maneuvers.



SOURCE: NASA-JPL (REFERENCE 18)

Figure 5.1-1. LMSS Feed Array Assembly



SOURCE: NASA-JPL (REFERENCE 18)

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Figure 5.1-2. Lockheed Wrap-Rib Reflector Deployment

RIGID RIB ANTENNAS

TRACKING AND DATA RELAY SATELLITE SYSTEM (TDRSS)

Space-qualified design

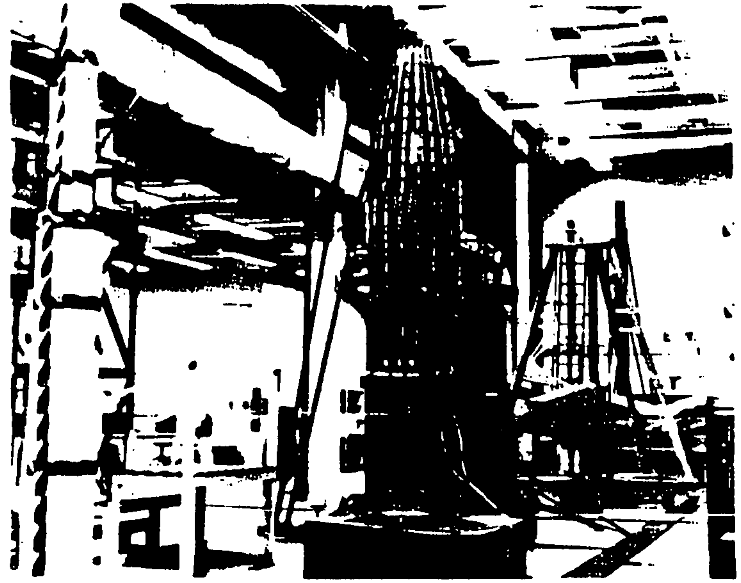
Shuttle compatible

4.8 meter diameter

52 lbs. including feed

S- and Ku-band frequencies

On-Orbit surface accuracy 0.020 in. RMS achieved by unique secondary drawing surface technique.



Stowed Antenna

DESIGN VERSATILITY

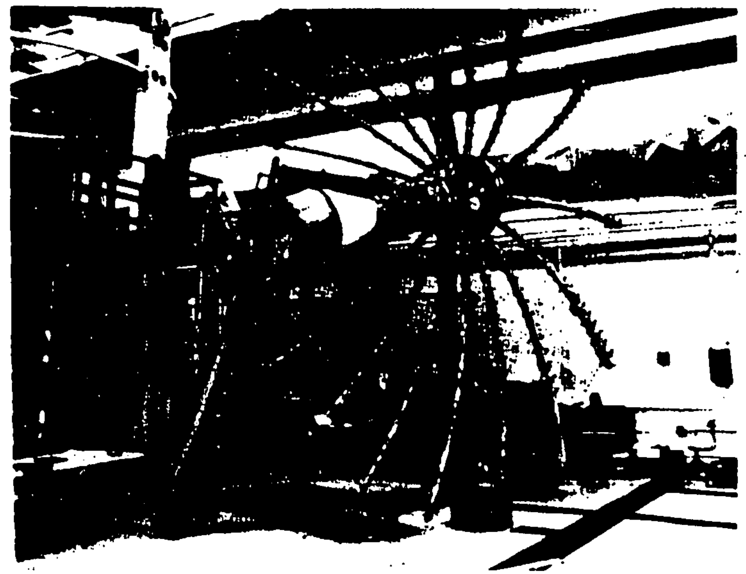
Adaptable to other space environments

Design adaptable to larger and smaller sizes

Controlled deployment and restow capability

Capable of millimeter wavelength operation

Current candidate for deep space communications antenna programs



Deployed Antenna

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SOURCE: HARRIS TECHNICAL BRIEF AS005 (REFERENCE 27)

Figure 5.1-3. Harris Deployable Rigid Rib Antenna

HOOP/COLUMN DEVELOPMENT

Design applicable to a wide range of aperture diameters (15 to 150 meters)

Stowed package size consistent with shuttle payload volume

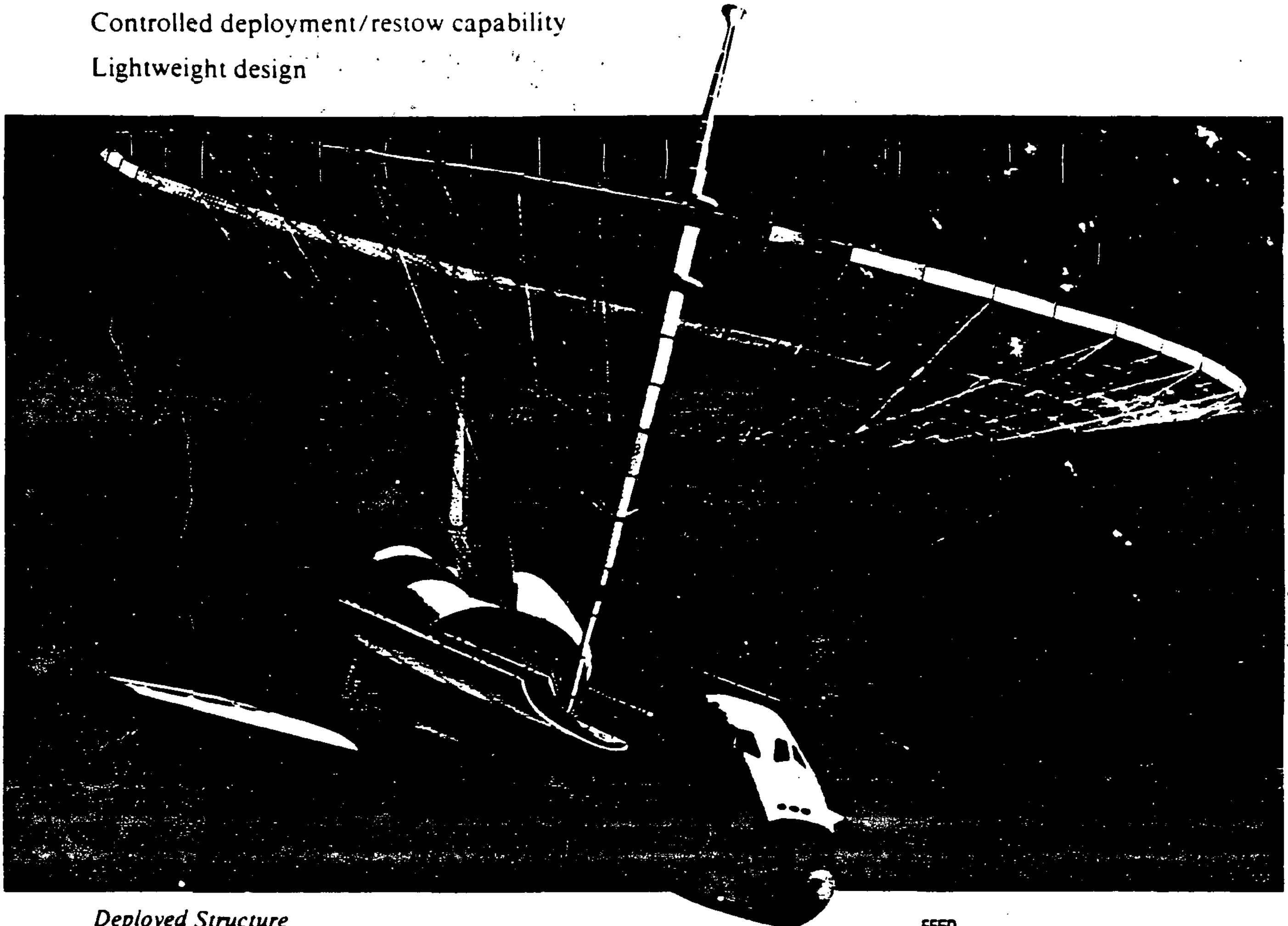
Controlled deployment/restow capability

Lightweight design

On-orbit active surface control capability

Applicable to various surface geometrics (parabolic, spherical, planar, etc.)

Adaptable to many missions, e.g., Communications, Radiometry, Astronomy, Radar



Deployed Structure

Rigid hoop construction

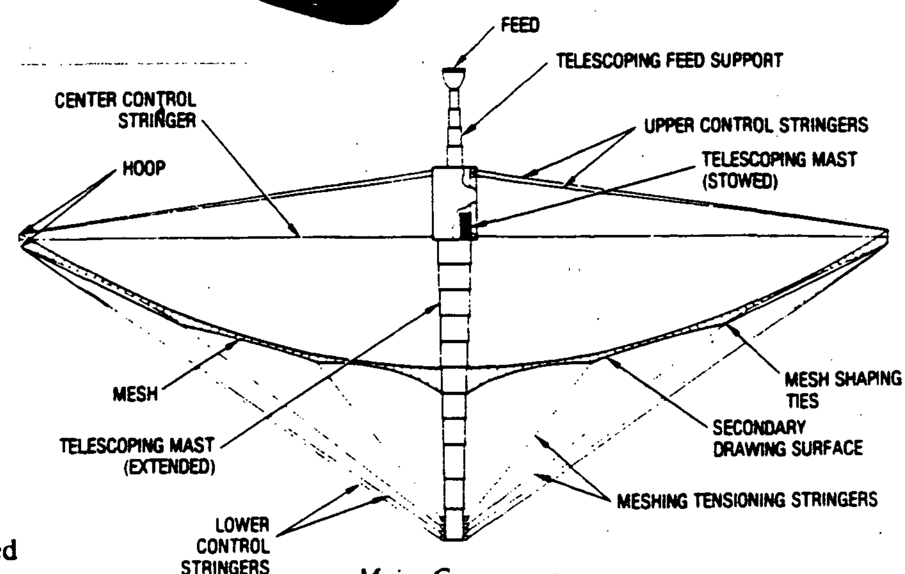
Extendable mast – contains microwave components and control mechanisms

Upper and lower control stringers position hoop

Control stringers control rate of deployment

Mesh tensioning stringers shape reflector contour

Existing secondary drawing surface technology incorporated



Major Components

SOURCE: HARRIS TECHNICAL BRIEF AS005 (REFERENCE 27)

Figure 5.1-4. Harris Deployable Hoop Antenna

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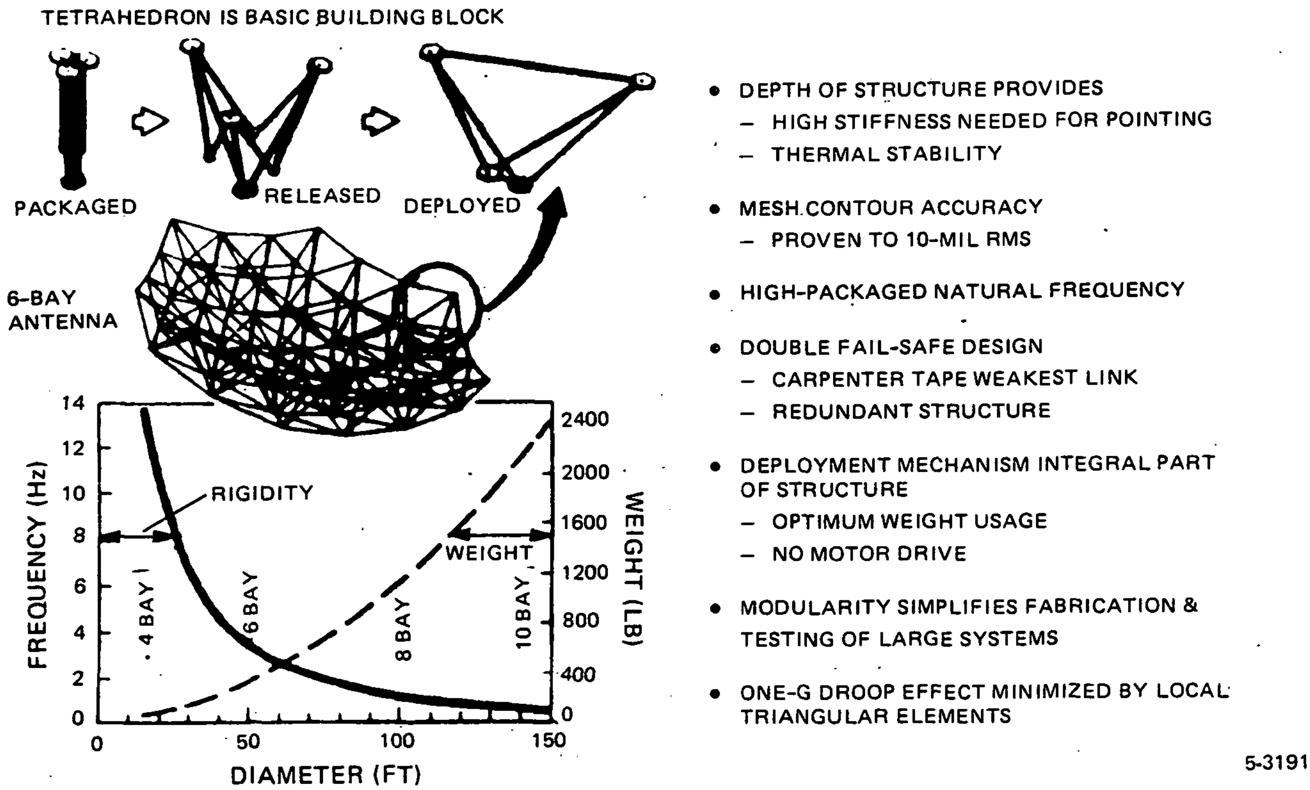


SOURCE: LARGE SPACE ANTENNA SYSTEMS TECHNOLOGY – 1982 (REFERENCE 28)

Figure 5.1-5. General Dynamics GEO-TRUSS

This antenna also will have a very large D/λ ∿90. It is known that as D/λ increases, the scan loss also increases as shown in Table 5.1-3.

5.1.2.2 <u>10.5-m C-Band Antenna (Concept 2 and 4)</u>

The 10.5-m C-band antenna will also be an unfurlable reflector as in the case of the 30-m antenna previously described. Although this antenna is substantially smaller, some of its performance requirements are more stringent since it must operate at a higher frequency band. For example, surface tolerance of the reflector will likely need to be more than five times as stringent. The scan loss can be significantly worse than for the 30-m antenna because it has even a higher D/λ ratio (200). The example shown in Table 5.1-3 indicates more than 6 dB of scan loss for a single offset parabola, showing why this geometry has been rejected. It can be seen that the Cassegrain configuration chosen should provide adequate performance.

5.1.2.3 <u>4.5-m Ka-Band Antenna (Concepts 2 and 4)</u>

This antenna will require a very good surface rms accuracy, probably better than 0.01 in. It represents a modest extension of performance to be anticipated on the ACTS program and considered feasible in NASA-sponsored 30/20-GHz studies (reference 29).

TABLE 5.1-3. SCAN LOSS COMPARISON (dB)

Type	D/λ						
	65	90	130	170	200	300	400
Single Paraboloid	1.25	1.9	2.6	4.9	6.3	10.5	12.0
Cassegrain	0.7	1.1	1.3	1.9	2.2	3.9	6.5
Near-Field Gregorian	0.9	1.2	1.3	1.45	1.65	2.6	3.7

NOTES:

- D/λ ∿90 for 30-m UHF Antenna
- D/λ ∿200 for 10-m C-Band Antenna
- D/λ ∿163 for 3.5-m Ku-Band Antenna
- D/λ ∿470 for 4.5-m Ka-Band Antenna
- Scan Angles = ±3.5°

5.1.2.4 W-Band Antenna (Concept 4)

At 60-GHz rms surface tolerance is extremely critical and will likely require an rms accuracy of better than 0.005 in. Antenna pointing would need to be held to about ∿0.01°.

5.1.3 DEVELOPMENT SCENARIOS

Based on the foregoing considerations, a development scenario for the antennas is presented in Table 5.1-4.

5.2 ON-BOARD PROCESSOR

5.2.1 TECHNOLOGY REQUIREMENTS

Requirements for the various elements of the on-board baseband processor are set forth for each concept in Sections 3.2.5, 3.3.5, and 3.4.5. These are summarized in Table 5.2-1 for the 20% FSS concept (Section 3.2) with modifications as required for the TDAS-ISL-20% FSS concept (Section 3.4) shown in Table 5.2-2. The 13% FSS concept Base Band processor requirements are similar to the 20% requirements but less stressing; therefore, they are not summarized in this section. Most noteworthy in the tables are the requirements for 8 PSK demodulators/modulators operating at 120 Mb/sec as discussed in Section 3.2.7(d) and for 400 Mb/sec demodulators/modulators required for ISL links as discussed in Section 3.4.

5.2.2 CRITICAL TECHNOLOGY ASSESSMENT

The on-board processor subsystem can be divided into the following separate functions:

- On-board regeneration
- Baseband switching
- On-board memory
- Beam switching

TABLE 5.1-4. ANTENNA DEVELOPMENT

Area	Objectives	Required Development Scenario	Time Frame
LMSS Microstrip Feed Array	To develop microstrip feed array suitable for space environment	Develop microstrip feed with adequate thermal control and temperature stability	1988-1900
	Examine feasibility of dual-band microstrip feed to eliminate dichroic screen	Feed must operate at UHF and L-band	
Reflectors	To demonstrate the feasibility of high-gain, narrow beamwidth and low sidelobe scanning beams over CONUS	Demonstrate that the gain, sidelobe, and scan loss requirements can be met for antennas with large D/λ (e.g., ≥90)	1987-1988
	To achieve performance with large D/λ offset geometrics desirable	Demonstrate that offset feed mesh antennas can meet the stringent gain sidelobe and scan loss requirements (e.g., LMSS and C-band antennas)	1988-1990
	At UHF, L- and C-band unfurlable mesh reflectors required	Techniques to adjust the phase and amplitude distribution in the feed array to compensate for phase aberration for scanned beams need to be developed	1987
	Eliminate passive intermods from mesh reflector over spacecraft lifetime	Study materials and techniques which will ensure passive intermods are held to acceptable level	1988-1990
	Develop testing methods for large unfurlable reflectors	Demonstrate test of large unfurlable antenna (e.g., farfield test with shuttle and rf source)	1990-1992
Reflector/Feed Dynamics	For LMSS antenna, reflector/feed dynamic interactions must be controlled	Demonstrate that reflector/feed deflections can be controlled to a tolerable limit over the spacecraft lifetime and during maneuvers	1990-1992
Antenna/Platform Structure	To determine the performance degradation of the antennas due to the mutual couplings between antennas and the scattering from the platform structure	Analysis of the mutual coupling effect and the scattering from the platform structures computer software to simulate the antenna and platform structure to predict the degradation in antenna patterns	1988

TABLE 5.2-1. BASEBAND PROCESSOR REQUIREMENTS

Function	Parameter/ Characteristic	Value	Comment
Demodulator/ Modulator	Number Modulator Format Data Rate Symbol Rate Performance Degradation	200 QPSK 60 Mb/s 30 Mb/s 3 dB	Also consider offset QPSK, MSK, and higher order modulation (8 PSK) for dedicated channels; 60-Mb/s data consists of two 30-Mb/s streams
Error Correction Decoder/Encoder	Number Type	10 Viterbi/ Half Rate Convolutional	5% of total channels, commandable for rain fading
Memory	Capacity Input/Output Capacity	24 Mb 200 Channels @ 60 Mb/s per channel	2 TDMA frames
Baseband Switching Matrix	Capacity	200 Channels Input/Output	Break down into smaller submatrices (discussed below)
	Switching Time	50 ns	Limited by controller. This speed does not appear to present a problem. System requirement not determined
	Matrix Size	100 x 100, 50 x 50 or 25 x 25	Operating channels not including redundancy. Use of 16 50 x 50 basic matrices shown in Figure 3.2-6 would require 4 100 x 100 or 64 25 x 25 matrices using same architecture
	Connectivity	Any Input to any Output	

TABLE 5.2-2. BASEBAND PROCESSOR REQUIREMENTS (ISL, TDAS CAPABILITIES)

Function	Parameter/ Characteristic	Value	Comment
Demodulator/ Modulator	Number	240	Includes 400 Mb/s demods and mods. Assuming quadruple wavelength multiplex on laser links (require 1.6 Gb/s units if no multiplex)
Memory	Capacity	32 Mb	2 TDMA frames for incoming and outgoing ISL traffic added
High Speed Interface	Data Rate	400 Mb/s to 30 Mb/s (1.6 Gb/s to 30 Mb/s)	Interface between demod output/modulator input for laser links and normal baseband processor logic

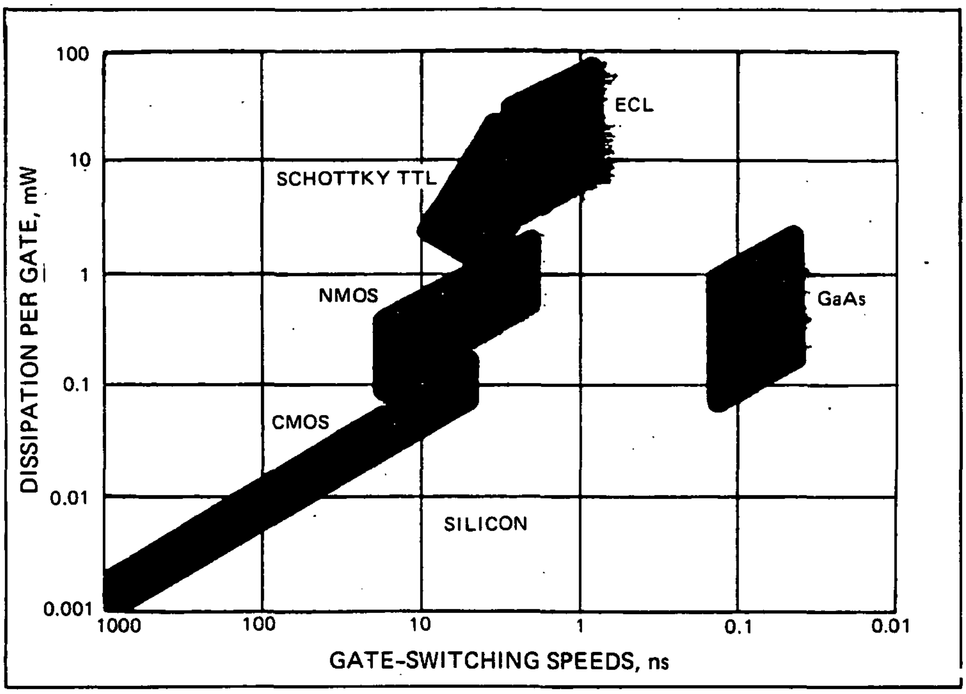
The on-board regeneration hardware comprises principally the 60-Mbit/s QPSK on-board demodulators and modulators. These numbers are between 133 for Concept 3 and 240 for Concept 4. Because of this, mass and power for each demodulator/modulator pair become an important consideration. The expected power consumption for each is expected to be about 1.5 W when conventional analog circuit implementation is employed. This leads to a total power requirement of 360 W for Concept 4 and about 200 W for Concept 3, for these functions alone.

A digitally implemented modem can provide significant increased operational flexibility by permitting changes in bit rates, filter characteristics, and even modulation method by reprogramming the on-board processor. In addition, a digitally implemented modem can eliminate problems which are commonly caused by analog circuit drift. Ultimately, such modems can lead to reductions in cost and mass with the use of custom LSI implementation. The major drawback of the digitally implemented modem is that it has a higher power dissipation in the range of 6 to 10 times as great as for the analog circuit implementation. With improved digital logic elements, e.g., high-speed CMOS and GaAs and with improved modem designs, this difference will be reduced significantly over the next 5 to 10 years. However, it is felt that these advances will not be significant enough to adopt this alternative for this time frame.

For Concept 2, the baseband switch is a 200 x 200 matrix. The 60-Mbit/s transmission bit rates can easily be handled with ECL logic. The power consumption for this matrix would be about 800 W. Other approaches would appear to be more appropriate in meeting requirements. High-speed CMOS or GaAs logic could be used in the future to reduce this requirement by at least a factor of 5 as shown by the data provided in Figure 5.2-1. In addition, the use of either nonblocking or a rearrangeable switch architecture can dramatically reduce the size, mass, and power consumption of the switch matrix described in Section 3.2.5.3 (see References 19 and 29). An example of this is shown in Figure 5.2-2 where a 128 x128 switch made up of a single stage architecture would require 16,384 switching elements. The non-blocking and rearrangeable implementations would require only 7,680 and 5,120 elements, respectively. Although the non-blocking switch would require more elements than the rearrangeable, less control data needs to be provided to the nonblocking switching elements. The routing through a rearrangeable switch for an on-going input/output connection may be changed to find a path for a separate input/output connection. Such rerouting is not required with a nonblocking switch.

Present NASA-sponsored studies relating to the conceptual design of a 100 x 100 switch matrix would lead to a satisfactory solution, possibly using a block diagram similar to that shown in Figure 3.2-6. It is of great importance that these studies be continued.

As shown in Section 3.2.5.2, the on-board memory required for storing the incoming traffic is equal to 12 Mbit with a similar memory likely at the output of the baseband switch. Using ECL logic, this memory would require more than 200 kW of power which is clearly out of the question. Parallel use of CMOS GaAs logic would reduce this requirement by at least a factor of 2000. The projected improvement in CMOS and GaAs technology is shown in Table 5.2-3. It can be seen that the projected power consumption for 1990 for CMOS and GaAs will be lower than that of today and it is expected that the level of integration will increase significantly for GaAs (by a factor of 16). The radiation



THE POWER DISSIPATION PER GATE OF GaAs ICs IS ABOUT THE SAME AS THAT OF SILICON NMOS, BUT ITS SWITCHING SPEEDS ARE 10 TIMES FASTER. SILICON EMITTER-COUPLED LOGIC IS THE FASTEST EXISTING COMMERCIAL IC TECHNOLOGY, BUT ITS POWER DISSIPATION RETRICTS PACKING DENSITY. ONLY CMOS HAS A SPEED-POWER PRODUCT COMPARABLE TO THAT OF GaAs.

(SOURCE: REFERENCE 30)

5-3194

Figure 5.2-1. Gate Power/Speed Characteristics

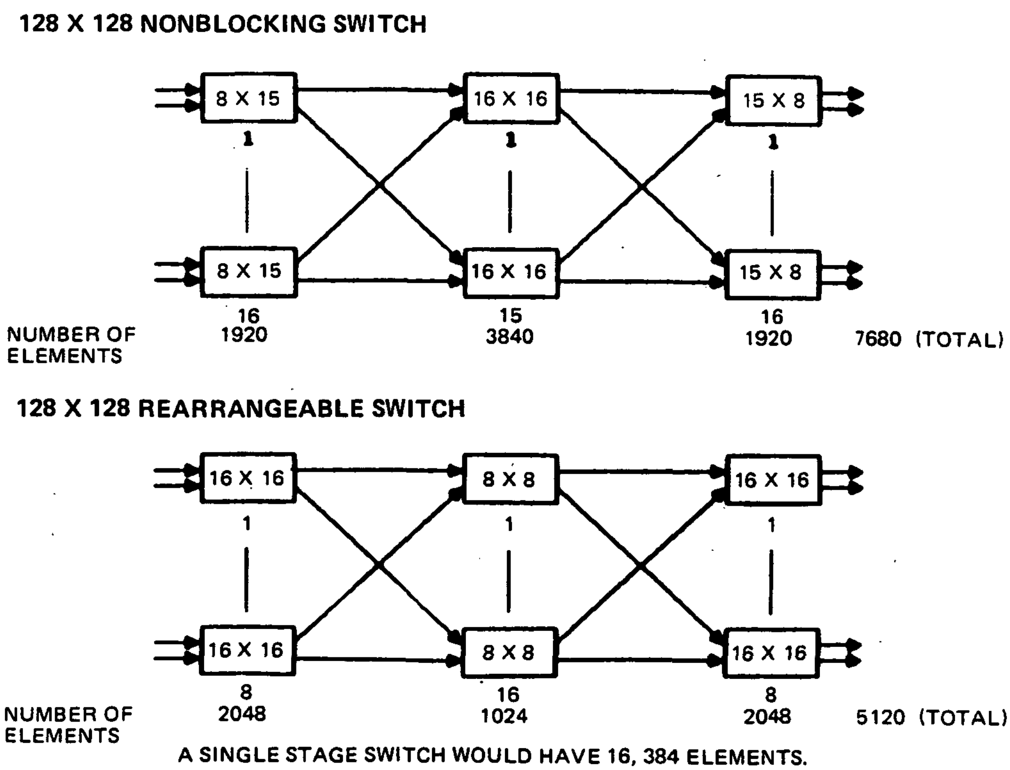


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Figure 5.2-2. Examples of Multistage Switch Matrices

TABLE 5.2-3. MEMORY TECHNOLOGIES

1984			1990			
	CMOS	GaAs		CMOS	GaAs	
Density	16K (4K x 4 bits)	1,024 (1,024 x 1 bit)	Density	64K (4K x 16 bits)	16K (16K x 1 bit)	(bits/chip)
Power/Bit	25 μW @ 15 MHz	66 μW @ 125 MHz	Power/Bit	15 μW @ 15 MHz	<50 μW @ 200 MHz	(μW/bit)
Radiation Hardness	10^4	10^7	Radiation Hardness	10^6	10^8	(rads Si or GaAs)
Data for silicon from References 31, 32.						
Data for GaAs from Reference 30. pp. 30-37.						

hardness of both technologies will likely be acceptable for spacecraft applications.

The beam switch network at the input and at the output of the processor is used to switch between the Ka-band uplink and downlink scanning beams. Each of six separate beams will be capable of scanning over approximately 45 geographic locations. This would require a 6-layer switching network ($2^6 = 64$ possible connections). The characteristics of two candidate switches for this network, the PIN-diode and the ferrite circulator switches, are shown in Table 5.2-4. Presently, the ferrite circulator switch is the better choice for this switching network because of its lower insertion loss (0.9 dB) compared to 2.1 dB for a 6-layer switching. The higher insertion loss of the PIN-diode would degrade the satellite noise temperature and satellite EIRP. Power rating of the PIN-diode would be a problem considering that 40 W is needed at the output of the network. The major advantage of the PIN-diode switch is its switching speed ($\sim <$ 500 ns as compared to $\sim$1 ωs). The impact of this on frame efficiency can be determined assuming that one frame's worth (1 ms) of traffic is stored on board and that each hopping beam scans 45 geographical locations. Then the percentage of the frame which would be lost is computed as

$$\frac{45 \times 10^{-6}}{1 \times 10^{-3}} = 4.5\%$$

of the frame for the ferrite circulator network and only

$$\frac{45 \times 50 \times 10^{-9}}{1 \times 10^{-3}} = 0.2\%$$

of the frame for the PIN-diode network. A summary of the various critical technology issues on the above discussion is presented in Table 5.2-5.

5.2.3 DEVELOPMENT SCENARIOS

Based on the foregoing considerations, a development scenario is shown in Table 5.2-6 for the on-board processor.

TABLE 5.2-4. BEAM-SWITCHING NETWORK - COMPETING TECHNOLOGIES

PIN-Diode Switch	Ferrite Circulator Switch
Compact	Bulky
Lightweight	Heavier
Short switching time ($\leq$50 ns)	Latching--dissipates only during switching
Power handling is a potential problem (40 W maximum/switch)	Longer switching time $\leq$ 1 μs)
Continuous dissipation	Can take higher power
Higher insertion loss ($\sim$0.35 dB/switch)	Smaller insertion loss ($\leq$ 0.15 dB/switch)
With six layers, the expected insertion loss is $\leq$2.1 dB	30-kg mass and 100 W dissipation appears to be reasonable in Ka-Band for the ferrite switch network
Riskier because of higher insertion loss and lower power handling capability	With six layers, the expected insertion loss $\leq$ 0.9 dB

TABLE 5.2-5. ON-BOARD PROCESSOR TECHNOLOGY ISSUES

Item	Critical Area	Potential Problem
Modulator/Demodulator	Mass, power, size, reliability	The total mass, power, and size requirements for a large number of modulators/demodulators can be very high
Digital modem implementation to increase flexibility	Power	Power consumption much higher than for analog approach
Baseband switch and memory	At high speed, power consumption is excessive if low power logic is not employed	CMOS or GaAs implementation and the use of nonblocking switching architectures minimize this problem
	Mass, power consumption, size, radiation hardness, and speed	
High-power switches	For ferrite implementation, improve speed, mass, and size of beam-scanning network	Mass and size may be a problem; low speed reduces throughput
	For PIN-diode implementation, improve insertion loss and power handling	High insertion loss and power handling capability may prohibit PIN-diode implementation

TABLE 5.2-6. ON-BOARD PROCESSOR DEVELOPMENT PLANNING

Area	Objectives	Required Development Scenario	Time Frame
Modulator/ Demodulator	Develop compact lightweight, low-power, space-qualified modem	Determine performance requirements of the modem	1986-1987
	Digital modem alternative to increase operational flexibility of processor	Design and construct prototype modem	1987-1990
Baseband Switch	Develop compact, low power, radiation-hardened baseband switch and memory	Continue development of 100 x 100 matrix switch	1985-1988
		Determine the switch architecture	1986-1987
		Design and construct laboratory prototype to test for radiation hardness	1987-1990
High-Power Switches	Develop beam switching network which achieves high speed with low mass	Specify requirements for speed and power handling capability	1986-1987
		Develop laboratory prototype for testing	1987-1989

5.3 IF SWITCH MATRIX

5.3.1 TECHNOLOGY REQUIREMENTS

Technology requirements are summarized in Table 5.3-1. As noted, matrix sizes do not include provisions for redundancy which is considered in Figure 5.3-1. Each output channel of the matrix is an input to a power amplifier. It is desirable that successive bursts from any one of up to 25 inputs should not cause too large a variation in power amplifier output since this will directly affect link performance. Since the output channel operates at saturation, the burst-to-burst level variation can be substantially larger than will be seen at the output. Assuming a permissible output variation of 0.3 dB, an insertion loss variation of 2 dB has been allocated to each matrix output channel. There is no requirement for gain matching between different output channels since they are connected independently to other power amplifiers. The performance value given is a goal, and some compromise between link performance and achievable gain variation will be adopted.

Critical performance requirements for the i.f. switch matrix are: (1) reliability, (2) isolation, (3) insertion loss, (4) switching time, and (5) size and weight. High reliability is generally achieved by providing redundant switching elements with the matrix; e.g., the INTELSAT i.f. switch matrix

TABLE 5.3-1. IF SWITCH MATRIX REQUIREMENTS

Parameter/Characteristic	Value	Comment
Size	25 x 25 12 x 12	Operating channels not including redundancy provisions (discussed below)
Operating Bandwidth	36 MHz	Corresponds to channel bandwidth
Usable Bandwidth	500 MHz	Assuming switch matrix may be assigned to any 36-MHz channel in frequency band 3.7-4.2 GHz
Switching Time	50 ns	Limited by controller. This speed does not appear to present a problem. System requirement not determined, requires study
Insertion Loss Variation (Peak-to-Peak)	2 dB	Nominal I.L. should be same for a given matrix output channel: Allowable variation leads to approximately 0.3-dB max. Variation in SSPA output power from burst-to-burst
Reconfiguration Time	1 μS	Applies to reconfiguration in case of failure. Requires system study of failure assessment and reconfiguration control
Channel Isolation	> 50 dB	24 adjacent channels add 13.8 dB to requirement for 35-dB/channel

is a 6 x 6 matrix employing four redundant rows (4 x 6 = 24 switches). In the event of a switch failure, a redundant row can be employed to replace the one which has failed. In addition, to ensure high reliability, special care must be taken that all devices in the switching matrix and on-board control circuitry and memories are radiation hardened to a level which presents radiation damage during the lifetime of the satellite (typically taken as 10^6 rads). Soft errors must also be considered since bit-flips occurring in on-board memories can cause system interruption. The severity of these occurrences can be reduced if on-board error correction is employed to periodically refresh the on-board memories.

5.3.2 CRITICAL TECHNOLOGY ASSESSMENT

Today, PIN-diodes or dual-gate FETs are used for the switching elements. Each has its own advantages and disadvantages. Both of the switching elements can provide over 50 dB of switch isolation, although for the case of the dual-gate FET, two devices connected in series are required. With a 25 x 25 matrix, the switch isolation will degrade by about 14 dB to 36 dB, which remains acceptable since the operating carrier-to-noise ratios will likely be more than 20 dB below this value. The switching time for the PIN-diode is less than 50 ns compared to less than 10 ns for the dual-gate FET. The insertion loss for the

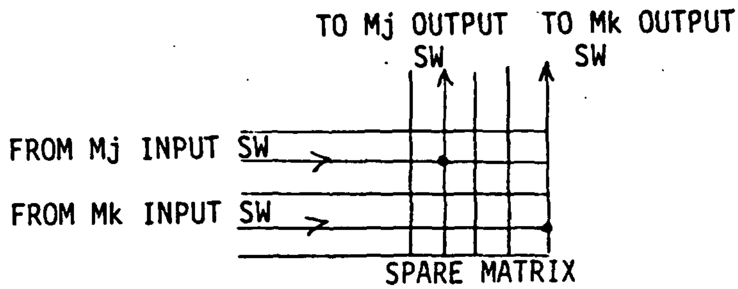
REDUNDANCY OPTIONS

SEVERAL DOCTRINES ARE POSSIBLE.

(1) PROVIDE SPARE MATRICES, SWITCH TO ALTERNATE MATRICES

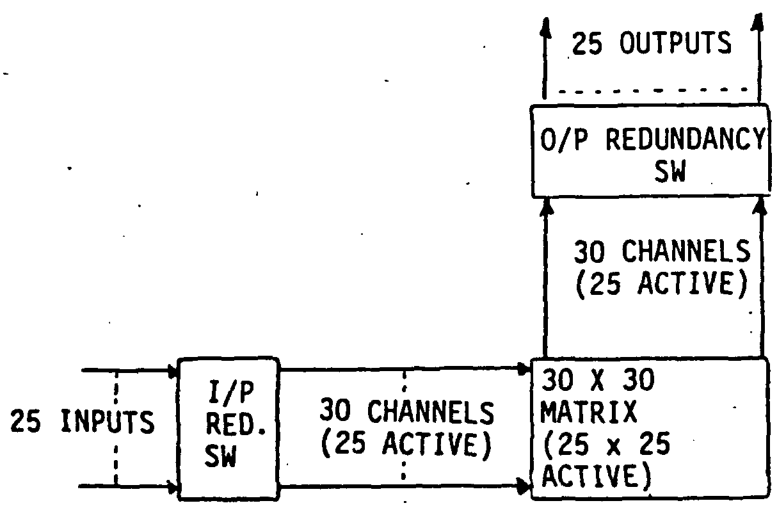
(A) REPLACE ENTIRE MATRIX WITH ALTERNATE AFTER FAILURE OF i CHANNELS.
MUST DETERMINE VALUE OF i.
REQUIRES EXTENSIVE INPUT/OUTPUT SWITCHING.

(B) SWITCH TO SPARE MATRIX ON CHANNEL-BY-CHANNEL BASIS.



SHOWS SINGLE CHANNEL FAILURES IN MATRICES Mj AND Mk.
PROVIDE SWITCHING AT INPUT AND OUTPUT OF MATRICES TO BE PROTECTED.

(2) PROVIDE SPARE CAPACITY IN EACH MATRIX WITH APPROPRIATE INPUT/OUTPUT SWITCHING.
E.G., PROVIDE 30-FOR-25 REDUNDANCY:



REQUIRES 30 X 30 MATRIX FOR 25 X 25 OPERATING CAPACITY

ENVISAGE 15 X 15 MATRIX FOR 12 X 12 OPERATING CAPACITY

SOME FORM OF THIS OPTION IS THE PREFERRED SOLUTION

5-3259

Figure 5.3-1. Matrix Redundancy Options

PIN-diode is ~30 dB as compared to 15 dB for the dual-gate FET. Because of this, an additional stage of amplification is usually required when PIN-diode switching is used. Work is currently in progress to reduce the mass of the switching matrix and control circuitry. This effort is concentrated in solid state integration of primary components. In view of these considerations, it would appear that the switching matrix for use in the 1998 time frame should be based on the use of FET devices. It would use Monolithic Microwave Integrated Circuit technology with a GaAs substrate material. Currently, a 2-inch wafer is used, which provides fifty 1 x 1 switch modules assuming a 50% yield. By 1998, 3-or-4-inch wafers will be more easily available and the size of the basic switch module can be increased to 2 x 2. For a 2 x 2 module having dimensions 1 cm x 1 cm, 50 such modules could be fabricated on a four-inch wafer.

5.3.3 DEVELOPMENT SCENARIO

A development scenario is shown in Table 5.3-2 for the i.f. switch matrix.

TABLE 5.3-2. IF SWITCHING MATRIX DEVELOPMENT PLANNING

Area	Objectives	Time Frame
GaAs Wafers	Develop 3 to 4 inch wafers. Grow active layer on wafer. Improve yield.	1986-1988
Switch Module	Increase size of module. Trade-off studies between yield and optimum module size (1 x 1, 2 x 2, or larger).	1986-1988
25 x 25 Matrix	Develop air bridge crossover for high isolation. Develop technology for assembly of basic switch modules to form matrix in planar form.	1986-1991

5.4 INTERSATELLITE LINKS

5.4.1 TECHNOLOGY REQUIREMENTS

Intersatellite links (ISLs) are employed in Concept 4 for two purposes: (1) inter-connecting traffic carried by Atlantic Ocean and Pacific Ocean international satellites directly into trunking stations, and (2) interconnecting the TDAS payload with other GEO and LEO payloads. The ISLs can be designed to operate at microwave frequencies, e.g., at 60 GHz or at optical frequencies. Today, optical links are less advanced than the microwave equivalent. For GEO-GEO and LEO-GEO links, optical ISLs appear to have a potential for lower payload mass and volume. Table 5.4-1 summarizes principal technological requirements for optical ISL links. Corresponding requirements for W-band links are included in Section 3.4.7, particularly in link budget allocations given in Tables 3.4-3 and 3.4-4.

TABLE 5.4-1. LASER ISL REQUIREMENTS

Transmitter Type	GaAs family
Transmit Power	0.5 to 1.0 W Requires development of power combining techniques
Modulation	PCM or PPM
Transmission Rate	1.6 Gb/s max. Total (400 Mb/s ea. of four wavelengths)
Reception	Direct or heterodyne detection - Direct - Simpler Heterodyne - 10-20 dB improvement over direct
Wavelength	0.8-1.6 μ
Multiplex	Use one or several wavelengths (preferred) Wavelength multiplexing permits lower power, lower transmission rate for each wavelength. Optical system more complex.
Optics Size	25 cm diameter
Pointing Accuracy	1 μrad.
Acquisition Time	Not critical for ISL. More critical to users. Consider rf-aided acquisition to minimize time required.

5.4.2 CRITICAL TECHNOLOGY ASSESSMENT

Development of GaAs systems in several phases from a single carrier, high data rate link, via wavelength division multiplexed multi-carrier links to heterodyne links is to be pursued. Data rates per carrier of 500 Mbits/s or more appear to be possible with antenna diameters of less than 50 cm.

The baseline concept described in Section 3.4 assumes on-board demodulation to baseband as the basic interface between the high rate ISL links and the 60 Mb/sec links to the ground. Two transmission modes that are considered possible candidates for ISL implementation are: (1) heterodyne repeater and (2) FM remodulation approaches. The heterodyne approach is a straightforward frequency conversion process. The ISL which uses fm remodulation can save on satellite power at the expense of bandwidth.

About a 3-dB power savings can be realized with an fm remodulation ISL over the heterodyne approach if the bandwidth is increased four-fold. Additional power savings may also be derived by the fm remodulation technique since the output amplifier can be operated close to saturation by virtue of the single carrier transmission mode. In contrast to this, the heterodyne ISL may translate several carriers together in a single ISL transponder and thus require the transmitter to be backed off from saturation for multicarrier transmission.

The potential problem areas for the ISL are summarized in Table 5.4-2 for the W-band (60 GHz) and optical approaches. At W-band, the greatest uncertainty is in the availability of the TWTAs. The W-band antenna and tracking system may also require some development as discussed in Subsection 5.1. To utilize fm remodulation, additional development work is required, especially in order to achieve good linearity with wide bandwidth (e.g., 240 MHz). Virtually all optical components, laser, tracking modem, multiplexer, and FEC would require further development before the optical ISL could be implemented for commercial use.

5.4.3 DEVELOPMENT SCENARIO

A development scenario for the ISL is given in Table 5.4-3.

5.5 SOLID-STATE HIGH-POWER AMPLIFIERS

5.5.1 TECHNOLOGY REQUIREMENTS

SSPAs have been selected to provide the high-power amplifier function in all three of the principal frequency bands (C, Ka, Ku). This choice is based, in part, on the fact that a bandwidth of 36 MHz has been chosen for the common channel which facilitates interconnection among the three frequency bands. There is, consequently, a lesser need for the high power levels required to assure satisfactory link performance when wideband channels are used, particularly at Ka-band.

C-band SSPAs in the 10-watt range are widely used at present and so they present no technical challenge except insofar as reliability may be improved, and the level of redundancy or life expectancy can be improved upon.

The 20% FSS (Concept 2) calls for 60-watt, Ku-band SSPAs. 40-watt Ku-band SSPAs have been designed, built, and tested in breadboard form as a result of an RCA Astro IR&D program. It would appear that the expectation of 60-watt performance for a 1998, or somewhat sooner, time frame entails a negligible technical risk.

The 40-watt Ka-band SSPA merits closer examination. A summary list of expected performance parameters is as follows:

- <u>20-GHz Operation at 300-MHz Bandwidth</u>

  Operation in a band wider than that to which the SSPA is assigned is necessary to permit redundancy switching in the event of failures of units in adjacent channels. A 300-MHz bandwidth seems adequate to satisfy such a requirement and is consistent with performance obtained at C- and Ku-bands.

- <u>Two Level Power Output</u>

  Each SSPA would be provided with low (4 watt) and high (40 watt) power sections. The high power section is switched on when rain fading is encountered.

TABLE 5.4-2. ISL TECHNOLOGY ISSUES

Item	Critical Technology	Potential Problems
Optical ISL	GaAlAs Transmitter	Reliable high-power (∿0.5W or more) transmitter with stable single mode and single frequency operation needs to be developed
	Tracking System	Fine tracking system with 300-nrad angular sensitivity
	Alignment	On-board alignment of multiple beams requires about 50 to 100 nrad accuracy
	Acquisition	Fast and reliable closed-loop acquisition system needs to be developed
	Modem/Multiplexer RF Demodulator	Development of high-speed/compact/low-power consumption pulse position modem, rf demodulator and multiplexers for high rate digital data is required
	FEC	Development of high-speed (∿400 Mbit/s), compact forward error correction coding is required to enhance link performance
3-m W-Band antenna	Reflector Fabrication	RMS surface tolerance
	Antenna Pointing/Tracking	To keep ISL aligned would require not only that the attitude control of each platform be held within tight tolerance, but may also require the two platforms to track each other
25-W TWTA (W-Band)	Coupled Cavity Design	Extension of present designs to 25 W-power level
	High Voltage Supply	
FM Modulator/ Demodulator	Wideband FM Modulator/ Demodulator for ISL	Wideband fm modulator/demodulator with good linearity over 240-MHz channel

TABLE 5.4-3. ISL DEVELOPMENT PLANNING

Area	Objectives	Required Development Scenario	Time Frame
TWTA	To ensure the availability of W-band TWTA suitable for ISL	Prepare a preliminary specification for a 25-W W-band TWT; extension of present low-power TWT development Release the RFP for prototype development	1991-1993
Antenna	To prepare for high precision 3-m W-band reflector required for ISL To study the effect of thermal distortion To determine the ISL link tracking requirement	Determine the surface tolerance requirement of 3-m W-band antenna design and construct a 3-m W-band antenna for the study of thermal effect, pointing requirement, and effect on attitude control	1987-1989
FM Modulator/ Demodulator	To determine feasibility of a wideband (240-MHz BW) FM modulator/demodulator	Prepare specifications, design, and construct wideband fm modulator/ demodulator	1986-1987
Optical ISL	To ensure the availability of reliable high-power GaAlAs transmitter	Prototype development	1986-1989
		Develop a computer model to simulate the tracking, alignment	1987-1990
	To determine the feasibility of high precision tracking/ alignment systems for the ISL	Fast and reliable closed-loop acquisition system needs to be developed Investigate possible use of combined rf system for faster acquisition	1986-1988
	To study the acquisition system To study RF requirement for the digital ISL link and to ensure the availability of digital equipment necessary for ISL	Develop system requirement in terms of performance required of FEC, modem, modulator, multiplex followed by hardware development	

- Competitive Efficiency in the 30% Range

  While power efficiency is not as great as can be expected from a TWTA, the weight and reliability advantages offset that. Furthermore, the use of SSPAs throughout would permit the adoption of a reduced number of common, redundant power conditioners.

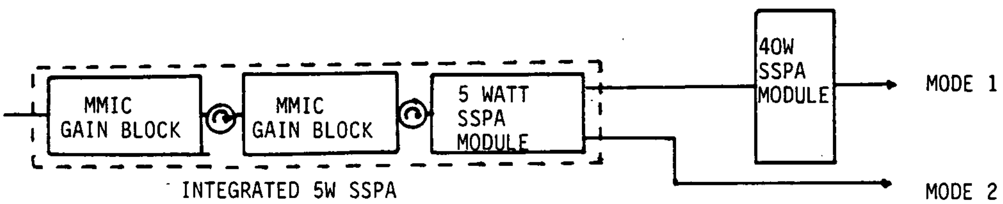
- Good Life Expectancy

  SSPA life expectancy should be such as to permit an in-orbit operation for periods approaching 15 years without the need to incorporate an elaborate redundancy system. SSPAs are more reliable than TWTAs and so lend themselves more readily to longer expected periods of operation.

5.5.2 TECHNOLOGY ASSESSMENT

A block diagram of the dual mode Ka-band SSPA is shown in Figure 5.5-1. Switching between the 40-watt mode 1 output and the normal 4-watt mode 2 operation would be achieved using low-loss ferrite switches of the type used in the beam forming network. The switch is incorporated in the 5-watt SSPA module.

The dual-mode SSPA is integrated using standard modules. The MMIC and 5-watt SSPA modules are packaged in a common assembly with the 40-watt SSPA module



GAIN (dB)	20		-.5	20	-.5	19	12		
MODE 1									
P_{RF} (dBm)	-23.5		-3.5		16		34.5	46.5	(45 WATTS)
P_{DC} (W)		1.0		1.0		14		116	132 WATTS
							EFFICIENCY 100% $\times \frac{45}{132}$ = 34%		
MODE 2									
P_{RF} (dBm)	-22		-2.0		18.5				37 dBm (5 WATTS)
P_{DC} (W)		1.0		1.0		16			18 WATTS
							EFFICIENCY 100% 5/18 = 28%		

5-3197

Figure 5.5-1. Platform Dual-Mode SSPA

attached via waveguide interface. Typical characteristics of the monolithic microwave integrated circuit (MMIC) gain block would be as follows:

P_{out} = 20 dBm (<1 dB gain compression)

Gain = 20 dB

BW = 1 GHz

P_{DC} = 1 W

The MMIC is implemented via a GaAs substrate and is hermetically packaged to be microstrip compatible.

The 5-watt SSPA is shown in Figure 5.5-2 and the 40-watt unit is shown in Figure 5.5-3. Characteristics of the GaAs FET power devices would be as follows:

P_{out} = 35 dBm

Gain = 6.5 dB

BW = 300 MHz

Power Added Efficiency = 40%

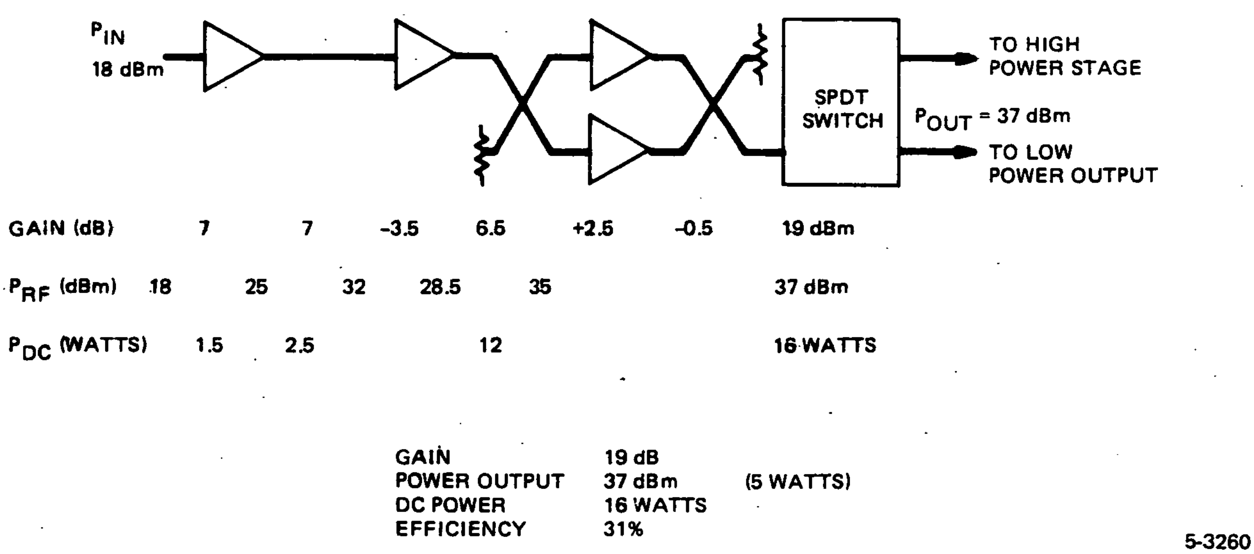


Figure 5.5-2. 5-Watt SSPA with Switched Output

The device is realized using a single FET chip mounted and matched on a carrier. The device is prematched over the 300-MHz band of interest at Ka-band.

5.5.3 DEVELOPMENT SCENARIO

Table 5.5-1 shows a development plan for the Ka-band SSPA. As well as points relating to the realization of 40-watt Ka-band SSPAs, the table includes other issues concerning their use on the platform. They include the development of redundancy networks for the SSPAs, which would take advantage of the large number of units to achieve a reduction in the number of spare units required to achieve a given system reliability level. Before undertaking such a development, preliminary studies should be made which would define more precisely the benefits occurring from this type of large-scale redundancy network.

Of related interest is the question of how system control should be exercised over the various redundancy structure that exist within large systems such as those envisaged for these communications platforms. Such control problems also apply to other operating procedures such as the two-level power control of the 4/40-watt Ka-band amplifier.

A second method of taking advantage of possible economics of scale involve the use of common shared EPCs rather than providing separate ones for each power amplifier. This is especially attractive in an all-SSPA platform since supplies are common to amplifiers operating in all three frequency bands.

TABLE 5.5-1. Ka-BAND SSPA DEVELOPMENT

Area	Activity	Time Frame
GaAs FET Power Devices	Ensure Device Availability	1986-1988
MMIC Gain Block	Develop Prototype Develop Flight Quality Model	1986-1990 1991-1994
5-W SSPA Module	Develop Prototype Develop Flight Quality Model	1986-1990 1991-1994
40-W SSPA Module	Develop Prototype Develop Flight Quality Model	1988-1991 1992-1996
Output Switch	Select Suitable Low Loss High Power Unit	1986-1990
EPC	Evaluate EPC Configuration Develop Protoflight, Flight Model	1986-1988 1989-1992
	Study, develop shared EPC concept	1986-1988
Redundancy Switching	Develop redundancy switching network which takes best advantage of large number of SSPAs used. Possibly extend network to permit common use of a reduced number of 40-W SSPA modules	1986-1990

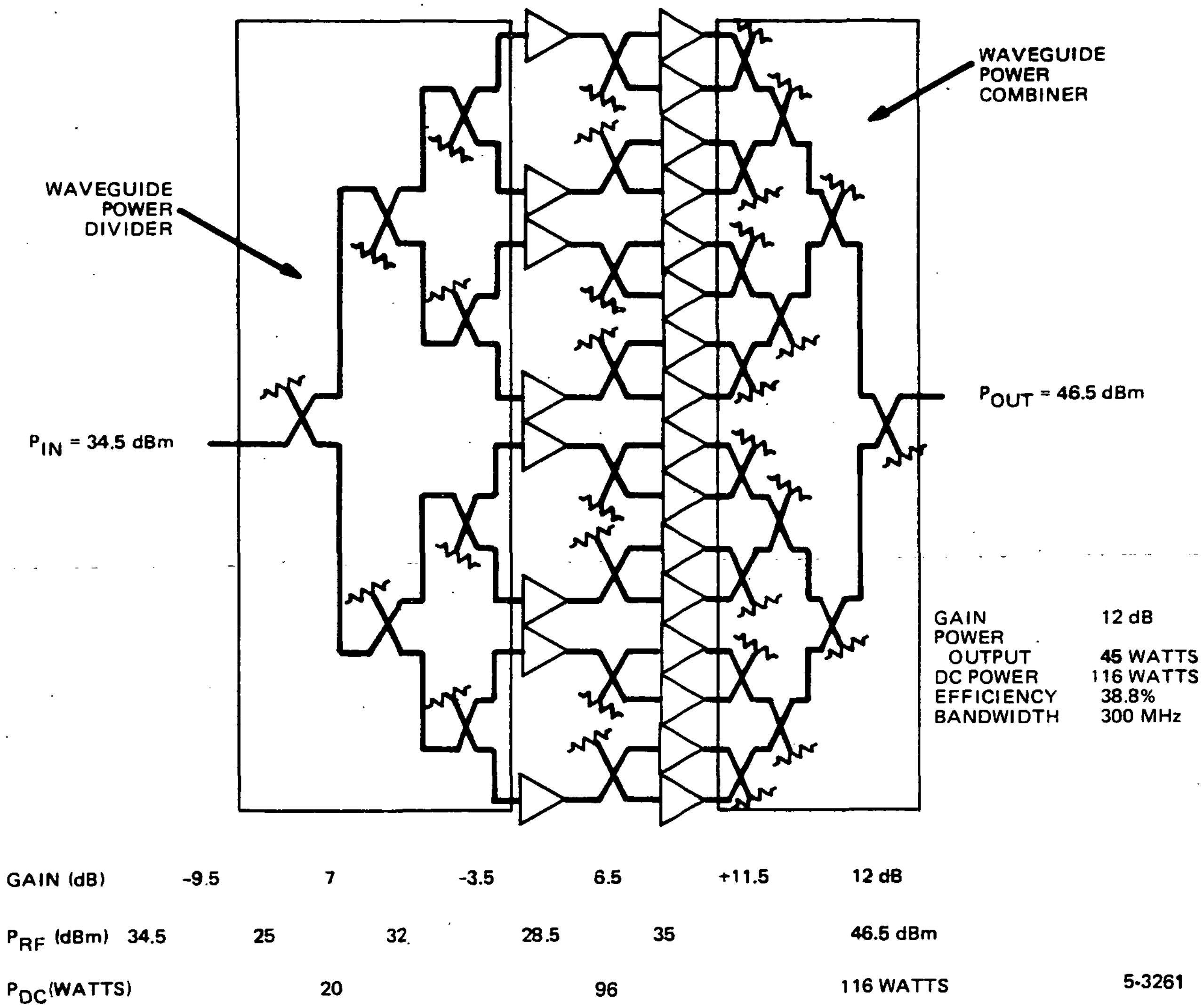


Figure 5.5-3. 20-GHz, 40-Watt SSPA Module

5.6 MULTIPLEXER FILTERS

5.6.1 TECHNOLOGY REQUIREMENTS

The various frequency plans discussed in Section 3.2.7 pose differing requirements insofar as multiplexer design is concerned. The option considered in that section appears to be the most reasonable one. It results in a requirement for 20-channel, noncontiguous output multiplexers at 18 GHz, and each channel having a bandwidth of 36 MHz. This is the most stringent requirement. All input multiplexer filters are in C-band while other output multiplexer filters are at C- and Ku-band where technology for these filters is well established. An exception to this involves possible use of W-band for ISL links. In such a case, there would be a requirement for 240-MHz filters disposed in a four-channel noncontiguous configuration as shown in Figure 3.4-4. The use of optical links would eliminate the need for such filters.

5.6.2 CRITICAL TECHNOLOGY ASSESSMENT

The multiplexer filters will likely be implemented in air cavity waveguides at K_u-, K_a-, and W-band wince these filters are relatively small and lightweight.

At UHF, L-band, C-band, and possibly at Ku-band, dielectric cavity filters would be used to reduce the size and mass of these filters. A reduction of about 50 percent in mass and about 90 percent in volume can be realized with dielectric cavity filters as compared to their air cavity filters. Potential problems exist, however, at K_a-band since the insertion loss increases inversely with the fractional bandwidth of the filter. At K_a-band, increased bandwiddths and/or higher order modes will be required to achieve acceptable insertion losses. Bandwidths of >150 MHz will enable the insertin loss to be reduced to an acceptable level ($\leq$1.0 dB). To achieve <0.5 dB insertion loss, higher order modes will be required. This will lead to a more complex multiplexer and limit the maximum bandwidth which can be utilized.

Care must also be given to the maximum number of output filters which can be placed on a single waveguide manifold. Today, it is possible to accommodate about 12 channels. With further development, possibly up to 30 filter could be accommodated. It might be necessary to place odd and even channels on separate manifolds. These can be combined by using separate antennas, separate senses of polarization, or dual-mode beam forming networks.

The use of the Ka- and W- bands also increase frequency drift due to temperature variations. For example, for an invar cavity filter, a ±25°C variation in temperature will cause about ±200-kHz frequency drift at C-band and about ±3-MHz frequency drift at W-band. The wider bandwidths, which are required to reduce the insertion loss, help to correct this situation by reducing variation when expressed in percent of the transponder bandwidth.

5.6.3 DEVELOPMENT SCENARIOS

Development scenarios are provided for the multiplexers in Table 5.6-1.

TABLE 5.6-1. MULTIPLEXER DEVELOPMENT PLANNING

Area	Objectives	Development Scenario	Time Frame
Ka-Band Output Filter	To determine the feasibility of output filters at Ka-band with given specifications to determine its performance, especially sensitivity to temperature variation	Determine a set of preliminary specifications and release a contract tothe industry for prototype development	1986-1987
UHF/L-Band Dielectric filter	To determine the performance of dielectric filters and the effects of temperature variations and vacuum environment	Determine a set of preliminary specifications and release contract to the industry for prototype development	1986-1987

SECTION 6.0
SYSTEM COMPARISONS AND CONCLUSIONS

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SYSTEM COMPARISONS AND CONCLUSIONS

This section provides comparisons between the payloads resulting from Tasks 3 and 4, payload concept development and definition, as well as the payload scenarios developed in Task 2, the payloads as compared in terms of capacity orbit utilization, impact on plant-in-place, cost (analyzed as part of Task 6), and technical risk. Only those platform scenarios that made sense based on commercial application (i.e., had a high probability of implementation) were selected for concept development. The payload capacity was sized to meet expected demand. The designs were based on projected technology expected to be available by about 1993.

6.1 OVERALL SYSTEM COMPARISONS

The four platform concepts are summarized in Table 6.1-1. Concept 1 provides land mobile satellite service with coverage to CONUS and Canada using the UHF and L-band frequencies. A single system owner is assumed to operate a system that would have 100 percent of the total LMSS market. The LMSS payload mass and power is 1172 kg and 8.1 kW, respectively.

Concept 2 provides FSS to CONUS using a combination of C-, Ku-, and Ka-bands. A single company is assumed to own and operate this system, which has 50 percent of the total market share. The platform occupies one of four slots dedicated to providing trunking and CPS services, and is designed to carry 20 percent of the total 1998 market demand. The mass and power of this platform payload are 2144 kg and 15.6 kW, respectively. The company provides video distribution service with two additional satellites.

Concept 3 also provides FSS to CONUS using a combination of C-, Ku-, and Ka-bands. A single company is also assumed to own and operate this system, which has 50 percent of the total market share. Each platform, however, is designed to carry only 13 percent of the total trunking and CPS capacity. In addition, 10 percent of the video distribution requirement is carried by this satellite. Six platforms are needed to provide 50 percent of the total capacity and provide adequate sparing. The payload mass and power are 1508 kg and 12.3 kW, respectively.

Concept 4 is an aggregation of several concepts: (1) FSS Concept 2; (2) Intersatellite Links that interconnect international traffic originating from Europe/Africa and the Far East; and (3) Tracking, Data, and Acquisition Satellite (TDAS) system. The payload mass and power are 3155 kg and 19.0 kW, respectively.

A summary of the four concepts in terms of orbit utilization is presented in Table 6.1-2. The results indicate a high spectrum utilization for LMSS UHF-band, and for FSS Concepts 2 and 4.

A comparison of the impact on the ground segment for each platform concept relative to satellites with smaller payloads is made in Table 6.1-3. The LMSS platform of Concept 1 reduces the complexity of the mobile antenna by eliminating the need for tracking or discriminating between multiple satellites. A multiple satellite LMS system would be an alternative means of meeting the total LMSS capacity requirements.

Concepts 2, 3, and 4 reduce the number of earth station antennas required to provide connectivity. Aggregation of capacity onto a single platform would likely require a conversion to a single TDMA transmission mode.

An alternative multi-satellite system would require additional earth station antennas to achieve the same level of connectivity by a high capacity platform.

TABLE 6.1-1. COMMUNICATIONS PAYLOAD CONCEPTS SUMMARY

Service	Area	Frequency Band	Ownership	Market Share (1998 %)	Number of Slots	Platform Capacity % of 1998 traffic	Payload Weight (kg)	Power (kW)
1. LMSS	CONUS + Canada	UHF, L	Single Company	100	1	100	1,172	8.1
2. FSS -Trunking -CPS	CONUS	C, Ku, Ka	Single Company	50	4	20	2,144	15.5
3. FSS -Trunking -CPS -TV Dist	CONUS	C, Ku, Ka	Single Company	50	6	13 (10% TV)	1,508	12.3
4. FSS +	CONUS	C, Ku, Ka	Single Company	50	1	20	3,155	18.9
ISL +	E/W			100	-	100		
Data Dist	Global	W, S, Laser		100	-	100		

TABLE 6.1-2. ORBIT UTILIZATION

Utilization Parameter	Concept			
	1. LMSS	2. FSS (20%)	3. FSS (13%)	4. FSS (20%) & TDAS & ISL
No. of Transponders				
UHF (1 MHz)	61	-	-	-
L (160 kHz)	77	-	-	-
C (36 Mhz)	-	109	24	109
Ku (36 MHz)	-	76	41	76
Ka (36 MHz)	-	326	308	366
TOTAL	138	511	373	551
Frequency Reuse				
UHF	7.9X	-	-	-
L	1.1X	-	-	-
C	-	9.1X	2.0X	9.1X
Ku	-	6.3X	3.4X	6.3X
Ka	-	5.4X	5.1X	6.1X

TABLE 6.1-3. IMPACT ON PLANT-IN-PLACE

Concept	Impact on Ground Segment
1. LMSS	Reduces complexity of mobile unit antennas by eliminating the need for tracking or discriminating between multiple satellites.
2. FSS (20% Capture)	Reduces number of earth station antennas required for connectivity. Cross-strapping between Frequencies eliminates requirement for Ka-band in most low traffic density areas.
3. FSS (13% Capture)	Requires conversion to a standardized TDMA transmission mode. Requires increased use of Ka-band in most high traffic density areas.
4. TDAS/ISL/FSS	Eliminates the need for double-hop satellite link or terrestrial links from international gateways. TDAS payload consistent with the TDAS requirements generated by Standford Telecommunications, Inc.

The FSS concepts (Concepts 2, 3, and 4) provide cross-strapping between frequencies which eliminates the requirement for the Ka-band in most low traffic density areas. A Ku-band CPS terminal in Arizona for example could communicate directly with a Ka-band CPS terminal in New York. High capacity platforms do require increased use of the Ka-band in high traffic density areas where the available bandwidth of C- and Ku-bands is inadequate to meet demand.

The ISLs provided by Concept 4 eliminate the need for international gateway earth stations by interconnecting traffic directly to existing trunking stations to provide domestic FSS service. This can also reduce the terrestrial link or double hop satellite link costs necessary to interconnect the gateways into the local area telephone networks.

A comparison is made in Table 6.1.4 between Concepts 2 and 3 in terms of the impact on plant-in-place equipment. The table shows how the trunking and CPS traffic is assigned to the frequency bands. It also shows that Concept 2 utilizes the C-band more extensively than Concept 3 (23 percent vs. 4 percent of its total traffic). For this reason, Concept 3 must rely more heavily on the Ka-band to satisfy its traffic requirement. Because of this, Concept 3 will have greater impact on plant-in-place equipment because systems will predominantly utilized the C- and Ku-bands during the late 1990s.

The platform payload recurring costs and cost drivers are summarized and compared in Table 6.1-5. Payload costs for the four platform concepts are based on an average of RCA Heritage and SAMSO-5 cost estimates. 1984 satellite costs are based on the SAMSO-5 model only. Cost driver analysis is based on the RCA Heritage model. LMSS comparative cost measures are included in the table. However, it is not appropriate to compare LMSS costs with FSS costs because of the differences in service requirements, transponder bandwidth, and technology utilized. Therefore, the LMSS is listed as a separate comparison category for which there is no other comparison data available (there are no existing systems and only one LMSS concept was developed). The comparisons narrative will therefore focus on FSS. Current generation C- and Ku-band satellites are listed for comparison. The Satcom C uses SSPA technology. The Satcom Ku is a higher power satellite based on TWTA technology.

The cost per unit mass off FSS payload is approximately the same on all three concepts and slightly higher than for 1989 satellites. This is not significant and results from the fact that antenna mass makes up a much smaller portion of the platform payload weight than the satellite payload weight, and antennas cost much less than transponders on a kilogram basis.

Spacecraft design is driven in part by weight considerations. Launch costs are proportional to weight, and launch concepts place a constraint on total spacecraft mass. Therefore, "kg/channel" is listed as a measure of performance in Table 6.1-5 to reflect the importance of weight in evaluating relative performance. It is seen that the FSS platform concepts offer an improvement over current satellite technology in terms of weight per transponder channel. The FSS platform payloads, considered heavy by satellite standards, are actually 25% lighter than today's C-band satellite payloads and 38% lighter than today's Ku-band satellite payloads on a per channel basis.

The economic benefit of a communications spacecraft may be measured in terms of its cost per transponder channel. Table 6.1-5 shows that the transponders in the FSS payload concepts cost about 8% less than the C-band satellite transponder and about 35% less than a Ku-band satellite transponder.

The 30-meter UHF/L-band antenna and receiver are the major cost drivers of the LMSS concept, comprising nearly 50% of the recurring payload cost. The FSS payload costs are dominated by the cost of the I/O multiplexers and the baseband processor.

TABLE 6.1-4. FSS (TRUNKING AND CPS) TRAFFIC DEMAND FREQUENCY BAND ASSIGNMENTS

Concept	Number of Transponders* (%)		
	C-Band	Ku-Band	Ka-Band
Concept 2--FSS (20% Capture)	109 (23)	72 (16)	294 (61)
Concept 3--FSS (13% Capture)	14 (4)	41 (14)	248 (82)

- Concept 2 makes moderate use of C- and Ku-band.
- Concept 3 relies heavily on Ka-band.
- Concept 3 will have greater impact on plant-in-place, which will continue to be predominantly C- and Ku-band even by late 1990s.

*Demand

TABLE 6.1-5. COMMUNICATIONS PLATFORM PAYLOAD RECURRING COST COMPARISONS ($1984)

Comparison Category	Concept	Mass (kg)	Cost ($M)	Cost/Mass ($k/kg)	Transponder Channels*	kg/Ch*	$k/Ch*	Cost Driver	
MSS	1. LMSS								
	Antenna	200	24	120				Antenna	24%
	Transponder	972	96	99				Receiver	23%
								SSPA	17%
	Total	1172	120	102	138	8.5	870	EPC	17%
FSS	2. FSS (20%)								
	Antenna	332	14	38				I/O Mux	45%
	Transponder	1812	216	119				BBP	27%
	Total	2144	230	107	511	4.2	450	SSPA	14%
	3. FSS (13%)								
	Antenna	208	8	36				I/O Mux	48%
	Transponder	1300	158	121				BBP	24%
	Total	1508	166	109	373	4.0	445	SSPA	16%
	4. TDAS/ILSS-FSS								
	Antenna	567	25	42				I/O Mux	39%
	Transponder	2588	296	115				BBP	23%
	Total	3155	321	102	580	5.4	553	SSPA	16%
	1984 Satellites:								
	C Antenna	42	1.4	33					
	C Transponder	88	10.4	118					
	C Total	130	11.8	91	24	5.4	492		
	Ku Antenna	32	1.2	38					
	Ku Transponder	131	15.4	118					
	Ku Total	163	16.6	102	24	6.8	692	TWTA	41%

* Transponder channel bandwidth: from 60kHz to 1 MHz for LMSS; 36 MHz for FSS

The cost benefits of a platform-based space communications system relative to an all-satellite system is shown in Table 6.1-6. The "20% Capacity" system consists of four platforms each with a capacity equivalent to 20% of the year 1998 demand that provides trunking and CPS services, and two 48-transponder satellites that provide video distribution. The "13 capacity" system consists of six platforms each with a capacity equal to 13% of the year 1998 demand and providing trunking, CPS, and video distribution services. The "satellite" system includes two 48-transponder video distribution satellites and 12 large satellites providing the same total capacity and services as the four "20% capacity" platforms. The cost comparison includes only the payload recurring costs and the earth segment antenna and LNA costs.

The "20%" and "13%" platform system costs are nearly identical and much less than an "all-satellite" system. Two cases are considered for the all-satellite system. The first provides the same trunking connectivity as the "20%" platform systems, but less CPS connectivity, and costs $265 million more than the platform system. The second "all-satellite" system case provides the same connectivity as the "20%" platform system for both trunking and CPS but costs over $3 billion more. User connectivity requirements have not been defined in this study. However, it is likely, in view of these cost considerations, that full connectivity for CPS would be too costly to implement for an "all-satellite" system.

A comparison of the ISL with a double-hop satellite system is given in Table 6.1-7. The traffic carried by the international gateway earth stations need to be interconnected to the end-user. This can be accomplished by terrestrial or satellite links. If a double-hop satellite link is used a system costing about $300 million more than an ISL payload is required. The ISL payload costs are about $40 million. The breakdown of the double hop earth segment cost estimate was presented in Section 4.0. The cost includes installation but excludes land and buildings.

TABLE 6.1-6. FSS SYSTEM RECURRING COST COMPARISON

FSS Concept	No. of Platforms	No. of Satellites	Payload ($M)	Earth Segment* ($)	Total Cost ** ($)	Cost Differential ($)
20% Capacity	4	2	964	2463	3427	0
13% Capacity	6	-	972	2453	3425	<2>
Satellite Connectivity:						
• Trunking Only	-	14	996	2695	3691	264
• Trunking and CPS	-	14	996	5726	6722	3295

*Antenna + LNA Only

**Bus, launch, non-recurring cost, etc. excluded.

TABLE 6.1-7. ISL SYSTEM COST COMPARISON

Option	Payload ($)	Earth Segment ($)	Total Cost ($)	Cost Differential ($)
ISL	41*	--	--	--
Double-Hop	36	317	353	312

*ISL Payload:

W Antenna	2.5
W Transponders	18.9
Ka Transponders	19.3
	40.7

The areas of concern related to the critical technologies for each concept are summarized in Table 6.1-8. For Concept 1, LMSS, the only area of technical risk is the 30-m UHF/L-band unfurable antenna with active microstrip feed array. For Concepts 2, 3, and 4, multiple spot beam antennas with large d/λ ratios are required. The large d/λ can significantly reduce scan performance. For Concepts 2 and 4, an unfurable 10-m antenna at C-band is required, which may have stringent surface tolerance and mechanical requirements. The on-board processor and i.f. switching matrices are also common area of concern for Concepts 2, 3, and 4. The dual-level 40 W/4W Ka-band SSPA also needs development. The Ka-band multiplexers pose some potential difficulties because of the small fractional bandwidths and higher temperature drifts associated with Ka-band. Intersatellite link development would be necessary for Concept 4 regardless if W-band or optical frequencies are chosen for implementation.

A number of institutional and regulatory issues have been considered in this study. They are summarized as follows:

- LMSS Concept:
  -Assumes single operator will have exclusive assignments of 10-MHz UHF/L-band
  -Design sensitive to bandwidth allocation and forecast demand
  --Frequency allocations currently do not exist
  --Demand uncertain (new service)
  -Uncertainty/politics of joint US-Canada venture

- FSS Concepts:
  -Scenario based on commercial realism
  -Single owner envisioned, but could be partnership
  -Growth in capacity seen as natural evolution
  -Commercial planning horizon is short (<< 1998)
  -Market Uncertainties
  --Softening Demand
  --Competition from fiber optics
  -Risk
  --Platform commercially acceptance if risk reduced
  --Space station services offer potential for risk reduction.

TABLE 6.1-8. TECHNICAL RISK COMPARISON

Concept	Areas of Concern
1. LMSS	30-m UHF/L-band unfurable reflector LMSS microstrip feed array
2. FSS (20% Capture)	10.5-m C-band unfurable reflector 4.5-m Ka-band reflector On-board processor 200 x 200 IF switching matrix 25 x 25 Ka-band SSPA Ka-band multiplexer filters
3. FSS (13% Capture)	4.5-m Ka-band reflector On-board processor 133 x 133 IF switching matrix 25 x 25 Ka-band SSPA Ka-band multiplexer filters
4. TDAS/ISL/FSS	W-band antenna 10-m C-band unfurable reflector 4.5-m Ka-band reflector On-board processor 200 x 200 IF switching matrix 25 x 25 Ka-band SSPA Ka- and W-band multiplexer filters Intersatellite links Lasers

6.2 STUDY CONCLUSIONS

The completion of the communications platform payload definition study has led to the following conclusions:

- Platform requirements driven by economic factors - Impact on "bottom line".
- Platforms will probably be needed circa 1998 to meet growing demand.
- Platforms appear to be cost-effective.
- Platforms offer improvements in connectivity.
- Platform era will evolve over 10-year period.
- Platform concepts are technically feasible.
- Key role for NASA: long-range planning and technology development.

The satellite communications industry is similar to other U.S. industries in one respect: it must provide an adequate return on the stockholders' investment. Additional business investments are made to remain competitive and (hopefully) increase profits. An additional investment is likely to be made if it:

- Lowers the cost of providing a product or service,
- Increases the quality of service, or
- Increases the size of the business while maintaining return-on-investment ratios..

This study has shown that platforms meet all three of these investment criteria. Platforms will be needed by 1998 to meet the growing demand that is projected through the year 2000. This demand can't be met by satellites because of limits on available spectrum and orbital slots. Continued growth of the satellite communications industry will require development of communications spacecraft of ever increasing capacity, reaching "platform size" around 1998 via a ten-year evolutionary process. This study indicates that the future capacity might be made available at a somewhat lower per transponder cost than is found today. A more detailed costing analysis that includes all costs (nonrecurring, bus/launch, insurance, operation, etc.) is needed to verify the cost advantage. Platforms offer an advantage over conventional satellites in the area of connectivity. The study included a platform payload concept with cross-strapping between the C-, Ku- and Ka-bands, and the intersatellite links to Europe and Asia.

The study design effort has demonstrated the technical feasibility of the concepts and identified technologies that need further development before a platform can be implemented. NASA can play a key role in this technology development process. The commercial satellite communications industry tends to focus on short-range planning, typically with a five-year planning horizon. Technology development for platforms will require a longer planning horizon. The appropriate technology must be available in 1993 if a platform is to be launched in 1998. Planning must be initiated now to make the technology available.

SECTION 7.0
REFERENCES

SECTION 7.0
REFERENCES

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APPENDIX A
IF SWITCHING MATRIX — SIZE AND NUMBER

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IF SWITCHING MATRIX — SIZE AND NUMBER

A.1 INTRODUCTION

Paragraph 3.2.4.4 describes development of the number and size of i.f. switching matrices to be incorporated in the concept 2 payload. A more detailed examination of this process is described in this appendix using the i.f. TDMA switch trunking matrix (Table A-1) as an example.

A.2 IDEAL NUMBER OF MATRICES

It can be seen that a 26 x 26 matrix has developed in this case. It is clear that one 26 x 26 matrix would handle up to one channel of traffic from all input and to all output destinations. Similarly, two matrices would handle up to two channels of traffic from all input and to all output destinations. Assume that we are furnished with two such matrices. Then we have provided sufficient capacity for all traffic in and out of Salt Lake City, which has an indicated requirement of 1.81 channels. It can be seen also that the cities of New Orleans, Phoenix, and San Antonio now have a residual need for 0.62, 0.62, and 0.10 channels, respectively. Since Salt Lake City has been taken care of, only a 25 x 25 matrix is required. Providing one matrix of such size satisfies traffic requirements to these three cities, 22 cities are left with unsatisfied traffic capacity requirements. Having provided these channels of capacity, the city of Denver now has a residual requirement of 0.40 channel, for example. Similarly Kansas City and Houston have residual requirements of 0.49 and 0.83 channel each. One 22 x 22 channel matrix fills those needs, leaving us now with the cities of Seattle, Minneapolis, Tampa, Raleigh, Syracuse, Atlanta, and Dallas which require further capacities of 0.06, 0.06, 0.39, 0.81, 0.20, 0.36, and 0.72 channels respectively. Since seven of the cities have been satisfied, a 19 x 19 matrix to be required provide service to the additional seven last-named cities. Such a matrix reduces the number of unsatisfied cities to 12, therefore a 12 x 12 matrix will be provided to supply the 0.10, 0.58, 0.78, and 0.46 channels of remaining capacity required by the cities of St. Louis, Miami, Philadelphia, and Chicago/Milwaukee, respectively. Eight cities now remain and an 8 x 8 matrix supplies the required residual capacity required by Cincinnati, Washington, Boston, and San Francisco, which are 0.63, 0.89, 0.26, 0.50 channels respectively. Four cities now remain, therefore a 4 x 4 matrix satisfies Detroit/Cleveland, Los Angeles/Anaheim and other beams in the amounts of 0.52, 0.77, and 0.57 channels, respectively.

Note that other traffic will be transmitted via the baseband processor while the cities named receive transmissions directly from the output of the i.f. switching matrix. Then New York remains with 1.75 channels of traffic, since a total of eight matrices of various sizes have been established. This would be handled by two 1 x 1 matrices, which translates into two direct links.

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TABLE A-I. IF TDMA SWITCH TRUNKING MATRIX - CONCEPT 2

	New York	Los Angeles/Anaheim	Chicago/Milwaukee	San Francisco	Boston	Detroit/Cleveland	Washington	Cincinnati	Philadelphia	Dallas	Atlanta	Houston	Syracuse	Miami	St. Louis	Raleigh	Tampa	Minneapolis	Seattle	Kansas City	Denver	San Antonio	Phoenix	New Orleans	Salt Lake City	Others
New York	0.00	0.00	0.00	0.00	0.00	0.36	0.78	0.75	0.63	0.31	0.05	0.00	0.00	0.85	0.79	0.75	0.70	0.66	0.66	0.58	0.57	0.36	0.34	0.34	0.23	0.04
Los Angeles/Anaheim	0.00	0.00	0.03	0.40	0.37	0.38	0.26	0.24	0.15	0.00	0.00	0.00	0.62	0.60	0.56	0.53	0.49	0.47	0.47	0.41	0.40	0.26	0.24	0.24	0.16	0.49
Chicago/Milwaukee	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.53	0.47	0.44	0.43	0.40	0.38	0.35	0.33	0.33	0.29	0.29	0.18	0.17	0.17	0.12	0.55
San Francisco	0.00	0.40	0.00	0.00	0.64	0.11	0.59	0.58	0.54	0.43	0.35	0.31	0.29	0.28	0.26	0.25	0.23	0.22	0.22	0.19	0.19	0.12	0.11	0.11	0.08	0.00
Boston	0.00	0.37	0.00	0.64	0.00	0.08	0.57	0.56	0.52	0.42	0.34	0.30	0.28	0.27	0.25	0.24	0.22	0.21	0.21	0.19	0.18	0.12	0.11	0.11	0.07	0.00
Detroit/Cleveland	0.36	0.38	0.00	0.11	0.08	0.00	0.09	0.07	0.00	0.00	0.64	0.57	0.54	0.52	0.48	0.46	0.43	0.40	0.40	0.36	0.35	0.22	0.21	0.21	0.14	0.50
Washington	0.78	0.26	0.08	0.59	0.57	0.09	0.00	0.50	0.47	0.38	0.30	0.27	0.25	0.25	0.23	0.22	0.20	0.19	0.19	0.17	0.16	0.10	0.10	0.10	0.07	0.45
Cincinnati	0.75	0.24	0.00	0.58	0.56	0.07	0.50	0.00	0.46	0.37	0.30	0.26	0.25	0.24	0.22	0.21	0.20	0.19	0.19	0.16	0.16	0.10	0.09	0.09	0.07	0.37
Philadelphia	0.63	0.15	0.00	0.54	0.52	0.00	0.47	0.46	0.00	0.34	0.27	0.24	0.23	0.22	0.21	0.20	0.18	0.17	0.17	0.15	0.15	0.09	0.09	0.09	0.06	0.15
Dallas	0.31	0.00	0.00	0.43	0.42	0.00	0.38	0.37	0.34	0.00	0.21	0.19	0.18	0.17	0.16	0.15	0.14	0.13	0.13	0.12	0.11	0.07	0.07	0.07	0.05	0.52
Atlanta	0.05	0.00	0.53	0.35	0.34	0.64	0.30	0.30	0.27	0.21	0.00	0.15	0.14	0.13	0.12	0.12	0.11	0.10	0.10	0.09	0.09	0.06	0.05	0.05	0.04	0.02
Houston	0.00	0.00	0.47	0.31	0.30	0.57	0.27	0.26	0.24	0.19	0.15	0.00	0.12	0.12	0.11	0.10	0.10	0.09	0.09	0.08	0.08	0.05	0.05	0.05	0.03	0.00
Syracuse	0.00	0.62	0.44	0.29	0.28	0.54	0.25	0.25	0.23	0.18	0.14	0.12	0.00	0.11	0.10	0.10	0.09	0.08	0.08	0.07	0.07	0.05	0.04	0.04	0.03	0.00
Miami	0.85	0.60	0.43	0.28	0.27	0.52	0.25	0.24	0.22	0.17	0.13	0.12	0.11	0.00	0.10	0.09	0.09	0.08	0.08	0.07	0.07	0.05	0.04	0.04	0.03	0.65
St. Louis	0.79	0.56	0.40	0.26	0.25	0.48	0.23	0.22	0.21	0.16	0.12	0.11	0.10	0.10	0.00	0.09	0.08	0.07	0.07	0.07	0.06	0.04	0.04	0.04	0.03	0.52
Raleigh	0.75	0.53	0.38	0.25	0.24	0.46	0.22	0.21	0.20	0.15	0.12	0.10	0.10	0.09	0.09	0.00	0.07	0.07	0.07	0.06	0.06	0.04	0.04	0.04	0.02	0.45
Tampa	0.70	0.49	0.35	0.23	0.22	0.43	0.20	0.20	0.18	0.14	0.11	0.10	0.09	0.09	0.08	0.07	0.00	0.06	0.06	0.06	0.06	0.04	0.03	0.03	0.02	0.35
Minneapolis	0.66	0.47	0.33	0.22	0.21	0.40	0.19	0.19	0.17	0.13	0.10	0.09	0.08	0.08	0.07	0.07	0.06	0.00	0.06	0.05	0.05	0.03	0.03	0.03	0.02	0.27
Seattle	0.66	0.47	0.33	0.22	0.21	0.40	0.19	0.19	0.17	0.13	0.10	0.09	0.08	0.08	0.07	0.07	0.06	0.06	0.00	0.05	0.05	0.03	0.03	0.03	0.02	0.27
Kansas City	0.58	0.41	0.29	0.19	0.19	0.36	0.17	0.16	0.15	0.12	0.09	0.08	0.07	0.07	0.07	0.06	0.06	0.05	0.05	0.00	0.04	0.03	0.03	0.03	0.02	0.12
Denver	0.57	0.40	0.29	0.19	0.18	0.35	0.16	0.16	0.15	0.11	0.09	0.08	0.07	0.07	0.06	0.06	0.06	0.05	0.05	0.04	0.00	0.03	0.03	0.03	0.02	0.10
San Antonio	0.36	0.26	0.18	0.12	0.12	0.22	0.10	0.10	0.09	0.07	0.06	0.05	0.05	0.05	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.00	0.01	0.01	0.01	0.00
Phoenix	0.34	0.24	0.17	0.11	0.11	0.21	0.10	0.09	0.09	0.07	0.05	0.05	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.01	0.00	0.01	0.01	0.65
New Orleans	0.34	0.24	0.17	0.11	0.11	0.21	0.10	0.09	0.09	0.07	0.05	0.05	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.01	0.01	0.00	0.01	0.65
Salt Lake City	0.23	0.16	0.12	0.08	0.07	0.14	0.07	0.07	0.06	0.05	0.04	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.00	0.45
Others	0.04	0.49	0.55	0.00	0.00	0.50	0.45	0.37	0.15	0.52	0.02	0.00	0.00	0.65	0.52	0.45	0.35	0.27	0.27	0.12	0.10	0.00	0.65	0.65	0.45	22.78

The above reasoning is summarized by the following sequence:

$$(2 \times 26) + (1 \times 25) + (1 \times 22) + (1 \times 19) + (1 \times 12) + (1 \times 8) + (1 \times 4) + (2 \times 1)$$

where each pair of numbers in the parentheses shows the number and the size of the matrices.

A.3 ACTUAL MATRIX SELECTION

It would not be practical to provide matrices of the various size indicated above. Use of nine full 26 x 26 matrices would provide adequate capacity but would clearly be wasteful. We will assume that two matrix sizes are to be used: 25 x 25 and 12 x 12. It is necessary that an equivalent number of channels be provided when using the two matrix types. This is assured by observing the following equality:

$$\Sigma \text{ (Number of matrices x Number of channels/matrix)} = N \times M$$

where IN = Standard matrix size (25 or 12)
N = Number of M x M matrices required

The left side of the above expression corresponds to the terms given in the sequence developed in paragraph A.2. Since two standard matrix sizes are involved, the sequence in paragraph A.2 must be partitioned. This is done as follows:

For $M = 25$:

$$(2 \times 26) + (1 \times 25) + (1 \times 22) + (1 \times 19) = N \times 25$$

From which

$$N = 4.7$$

For $M = 12$

$$(1 \times 12) + (1 \times 8) + (1 \times 4) = N \times 12$$

From which

$$N = 2.0$$