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Report

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Communications Platform Payload Definition Study

Executive Summary

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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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**SECTION 1.0
INTRODUCTION**

SECTION 1.0

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 C- and Ku-band satellites by the early 1990s (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." This Communications Platform Payload Definition Study was conducted as the first phase of a multi-phase program.

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 commercially 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 description and systems architectures for four of these communications service aggregations. Task 4 defines payload system configurations and corresponding technical characteristics 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 enabling and supporting technologies critical to implementation and operation for 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.

This Executive Summary summarizes the key results of these tasks, identifies the critical system issues and discusses study conclusions.

1.3 STUDY GUIDELINES AND CONSTRAINTS

The study Statement of Work (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 variation requirements 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). 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).

SECTION 2.0
COMMUNICATIONS PLATFORM CONCEPTS

SECTION 2.0

COMMUNICATIONS PLATFORM CONCEPTS

Several communications service aggregation scenarios describing potential groupings of voice, video, and data services circa 1998 were synthesized and four were selected for payload concept development.

The synthesis of candidate scenarios and their subsequent ranking and selection was driven by a set of scenario selection criteria 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 ("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
 - Technical
- 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

The four selected payload concepts are summarized in Table 2-1.

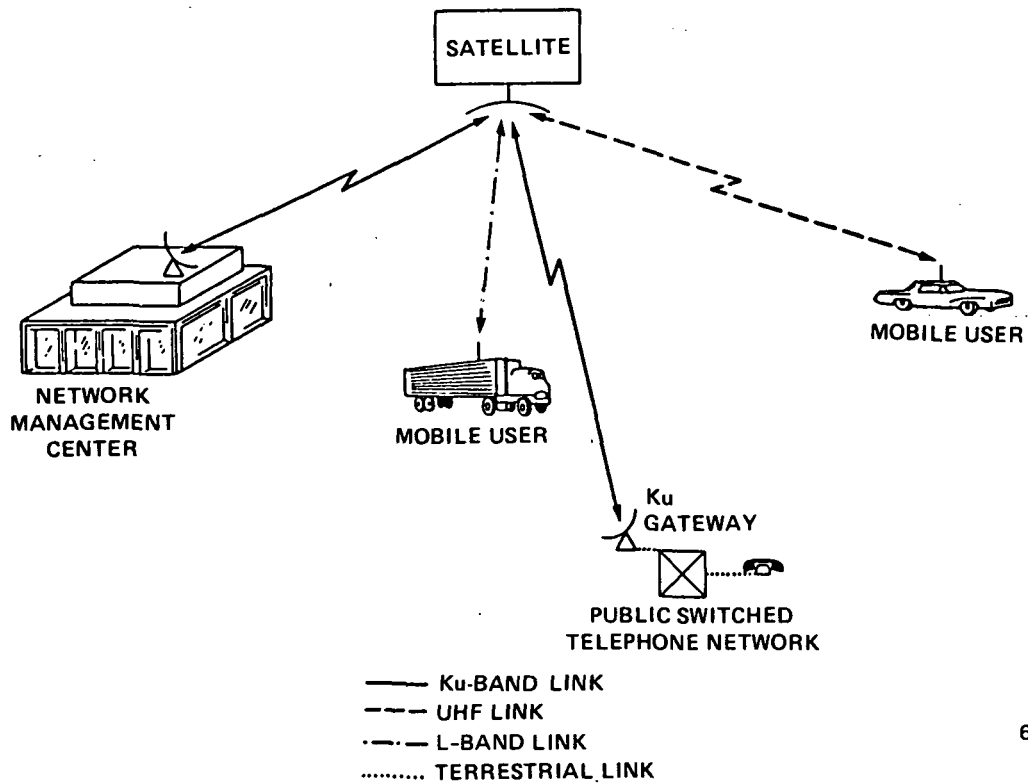
2.1 CONCEPT 1: LAND MOBILE SATELLITE SERVICE (LMSS)

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 MSS scenario assumes the end-of-life 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. The LMSS platform provides links between the spacecraft and mobile user, and the spacecraft and a gateway as shown in Figure 2-1. The gateway is linked to the public switched telephone network.

TABLE 2-1. COMMUNICATIONS PLATFORM PAYLOAD CONCEPTS SUMMARY

SERVICE	AREA	FREQUENCY	PLATFORM CAPACITY*	PAYLOAD WEIGHT (Kg)	POWER (Kw)
1. LMSS	CONUS + CANADA	UHF, L	100%	1172	8.1
2. FSS - TRUNKING - CPS	CONUS	C, Ku, Ka	20%	2144	15.5
3. FSS - TRUNKING - CPS - TV DIST	CONUS	C, Ku, Ka	13% (10% TV)	1508	12.3
4. FSS+ ISL+ TDAS	CONUS E/W GLOBAL		20% 100% 100%	3155	18.9

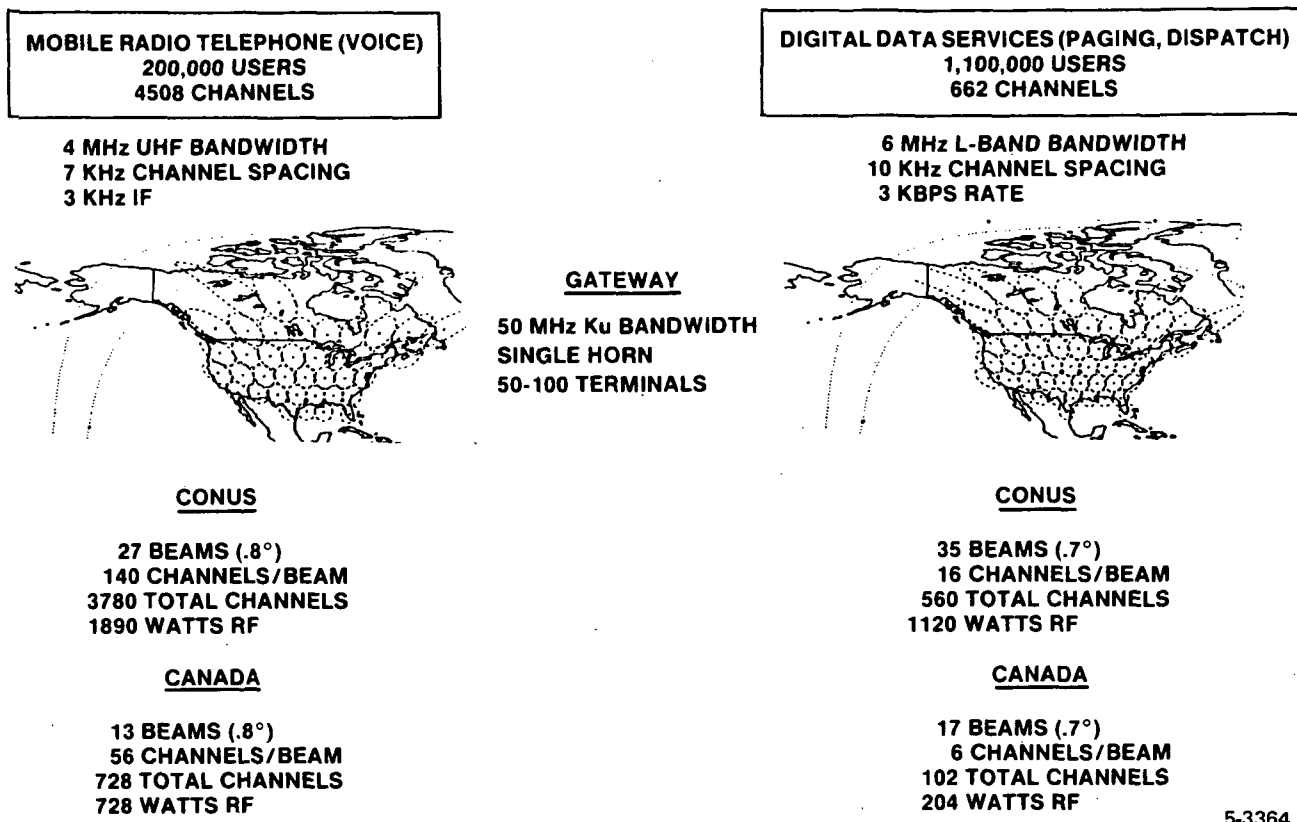
* % OF TOTAL YEAR 1998 SATELLITE ADDRESSABLE DEMAND



6-0624

Figure 2-1. LMSS Network Configuration

The LMSS scenario is summarized in Figure 2-2. LMSS provides voice and digital data (paging, dispatch) services to users in CONUS and Canada. Table 2-2 summarizes the land mobile traffic demand forecast for the year 2008.



5-3364

Figure 2-2. Concept 1 - LMSS Scenario Summary

TABLE 2-2. LAND MOBILE TRAFFIC FORECAST - YEAR 2008

Coverage	Service			
	Mobile Radio Telephone (Voice)		Digital Data Services	
	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

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. A comparable voice paging and dispatch service would require over 10,000 channels.

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 can not 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.

The voice mobile radio telephone market, defined in Table 2-2, is 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 is 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 is achieved using a 30-meter diameter antenna, and at L-band frequencies the 0.7° beamwidth is achieved using a 20-meter diameter antenna. The 20-meter and 30-meter antenna diameter requirements can be satisfied using a single 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 a single Ku-band horn for CONUS and Canadian coverage.

Details of the LMSS payload definition are summarized in Figure 2-3. The LMSS configuration is shown in Figure 2-4.

2.2 CONCEPT 2: FIXED SATELLITE SERVICE (20% CAPACITY)

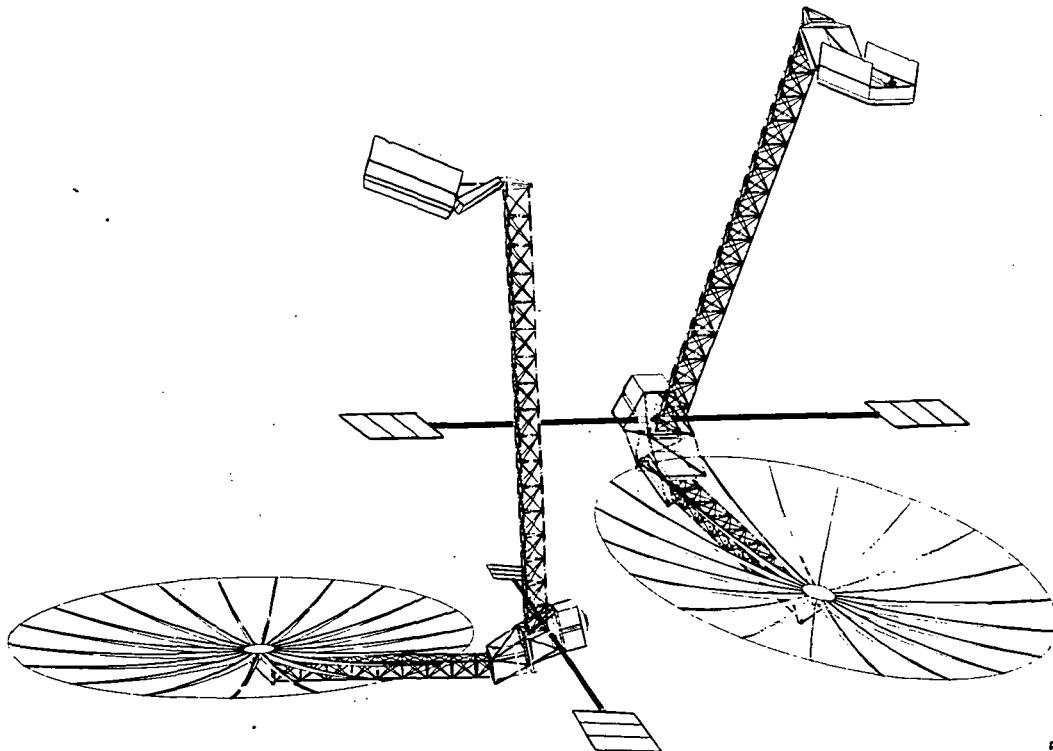
2.2.1 FSS (20% CAPACITY) SCENARIO

Concept 2 provides FSS only, to CONUS. The FSS/CONUS scenario was developed 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. Concept 2 recognizes this divergence by placing point-to-point and point-to-multipoint communications on separate spacecraft. Concept 3 (discussed in Section 2.3) takes the traditional approach of providing point-to-point and point-to-multipoint communications from the same platform. Concept 2 scenario is summarized in Figure 2-5.

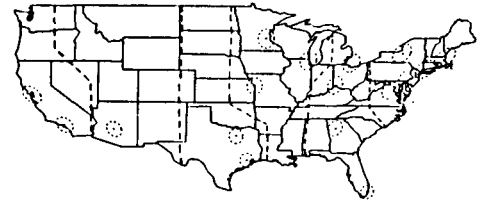
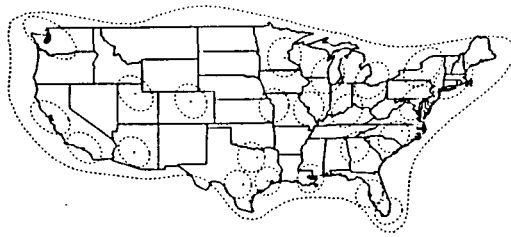
UHF - MOBILE RADIO TELEPHONE	L-BAND - DIGITAL DATA SERVICES
<ul style="list-style-type: none"> • 7.9X FREQUENCY REUSE (40 BEAMS) • 30M ANTENNA (DUAL FREQUENCY) • TRANSPONDERS (1 MHz BANDWIDTH, CONUS) <ul style="list-style-type: none"> — 81 RECEIVERS (61 ACTIVE) — 77 TRANSMITTERS (61 ACTIVE) • SWITCHING/PROCESSING - NONE REQUIRED • ACSSB MODULATION • ACCESS METHOD - DAMA 	<ul style="list-style-type: none"> • 1.1X FREQUENCY REUSE (52 BEAMS) • 20M APERTURE • TRANSPONDERS (160 KHz BANDWIDTH, CONUS) <ul style="list-style-type: none"> — 99 RECEIVERS (77 ACTIVE) — 105 TRANSMITTERS (77 ACTIVE) • SWITCHING/PROCESSING - NONE REQUIRED • FSK MODULATION • ACCESS METHOD - ORDER WIRE
KU-BAND BACKHAUL	
<ul style="list-style-type: none"> • SINGLE HORN ANTENNA • 3 RECEIVERS (1 ACTIVE) • 3 TRANSMITTERS (1 ACTIVE) 	
LMSS PAYLOAD	
<ul style="list-style-type: none"> • PAYLOAD MASS 1172 Kg <ul style="list-style-type: none"> — ANTENNA 200 Kg — TRANSPONDERS 972 Kg • DC POWER (EOL) 8.1 Kw 	

Figure 2-3. LMSS Payload Definition Summary



5-1259

Figure 2-4. LMSS Mission Configuration

**C-BAND**

- 23 0.5° SPOT + CONUS
- 109 CHANNELS (36 MHz)
- 60 MBPS/CHANNEL
- POWER:
 - 1 W/CHANNEL (SPOT)
 - 10 W/CHANNEL (CONUS)

Ku-BAND

- 23 0.5° SPOT + CONUS
- 76 CHANNELS (36 MHz)
- 60 MBPS/CHANNEL
- POWER:
 - 5 W/CHANNEL (SPOT)
 - 60 W/CHANNEL (CONUS)

Ka-BAND

- 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

5-3365

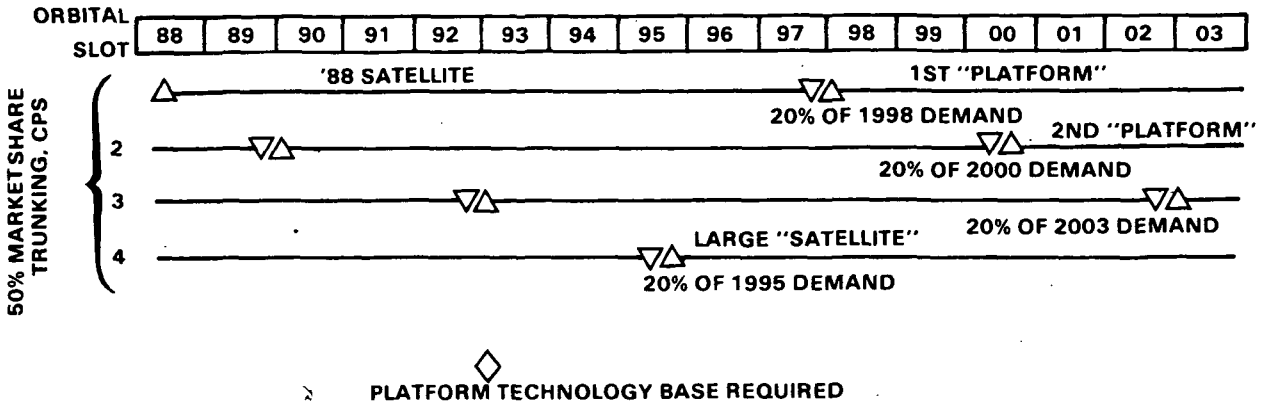
Figure 2-5. Concept 2: FSS (Capacity 20% of Demand) Scenario Summary

2.2.1.1 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 illustrated in Figure 2-6. 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 life-time and are launched every 2-1/2 years. The 1998 platform replaces a satellite launched in 1988 and has a capacity equivalent to 20% of the total 1998 satellite addressable demand. The 2000 platform is larger, with a capacity equal to 20% of the year 2000 demand.

**SATELLITES TO PLATFORMS - AN EVOLUTIONARY PROCESS
(HYPOTHETICAL MARKET LEADER)**



- 5 } TV DISTRIBUTION
- 6 } BY CONVENTIONAL SATELLITE

5-3188

Figure 2-6. FSS Platform Evolution

2.2.1.2 Frequency Band Allocation to Services

Three frequency bands are available for FSS, as shown on Table 2-3.

TABLE 2-3. 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 (forth quarter 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. Cross-strapping 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.

2.2.1.3 Platform Capacity Requirement

The platform has a capacity equivalent to 20% of the total 1998 satellite addressable demand. The factors used to calculate the required platform capacity and their assumed values are:

The required platform capacity is affected by:

- Addressable market size
- Platform operator's market share (50%)
- Degree to which spacecraft capacity will be utilized (fill factor - 90% maximum)
- Demand growth rate in transponders (6%)
- Platform Life (10 years)
- Number of orbital slots operator dedicates to trunking/CPS (4)

A detailed description of the capacity requirement calculation is presented in Section 2.3 of Volume 2, Technical Report.

2.2.1.4 U.S. Domestic Traffic Forecast

The U.S. domestic FSS traffic forecast for the year 2000 was provided by NASA (reference 12) and is summarized in Table 2-4. 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 domestic traffic demand is not uniformly distributed over the U.S., but is concentrated at the population centers and 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).

2.2.1.5 Coverage

Coverage is provided by a combination of fixed spot beams for the largest standard metropolitan statistical areas and CONUS or scanning spot beams for the less populated areas. C- and Ku-band coverages are similar, consisting of 23 0.5° 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 0.25° spot beams are used and CONUS coverage is provided by six scanning spot beams. The Ka-band power level may be increased from 4 to 40 watts per channel to counter rain fades.

TABLE 2-4. U.S. DOMESTIC SATELLITE ADDRESSABLE TRAFFIC
FORECAST SUMMARY - YEAR 2000

Service	Traffic	Bandwidths Efficiency	Transponders (36 MHz)
Trunking			
• Voice	6816 x 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 x 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

2.2.2 PAYLOAD DEFINITION

The Concept 2 FSS (capacity 20% of demand) payload definition is summarized in Figure 2-7. The concept is characterized by extensive frequency reuse at all three FSS bands. The C-band spot-beam coverage is obtained using a Cassegrain type of antenna having an unfurlable 10.5-meter main reflector.

Payload interconnectivity allows maximum flexibility in establishing earth station characteristics and 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 i.f. traffic matrix switching.

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.

Where sufficient traffic exists between certain beam (city) pairs, dedicated wideband channels are established which bypass the switching matrix. 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.

- **FREQUENCY REUSE**
 - C-BAND 9.1X
 - Ku-BAND 6.3X
 - Ka-BAND 5.4X
- **UNFURLABLE ANTENNA (10.5M) REQUIRED FOR C-BAND SPOT BEAM**
- **SWITCHING/PROCESSING PROVIDES FULL CONNECTIVITY**
 - BASEBAND PROCESSOR (200-60 MBPS CHANNELS)
 - IF TDMA SWITCHES
 - 7 - 25 x 25 MATRICES
 - 6 - 12 x 12 MATRICES
- **PAYLOAD MASS** 2144 Kg
 - ANTENNAS 332 Kg
 - TRANSPONDERS 1812 Kg
- **DC POWER (EOL)** 15.6 Kw

Figure 2-7. Concept 2: FSS (Capacity 20% of Demand) Payload Definition Summary

The baseband processor provides 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 means for demodulation/modulation, buffer storage, and baseband matrix switching required to realize the appropriate input-output interconnections.

2.3 CONCEPT 3: FIXED SATELLITE SERVICE (13% CAPACITY)

The conditions and assumptions for the Concept 3 scenario, designated as FSS (13% capacity), are the same as for the 20% capacity platform scenario described in Section 2.2 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 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 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 both 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. The Concept 3 scenario is summarized in Figure 2-8. Figure 2-9 summarizes the Concept 3 payload definition.

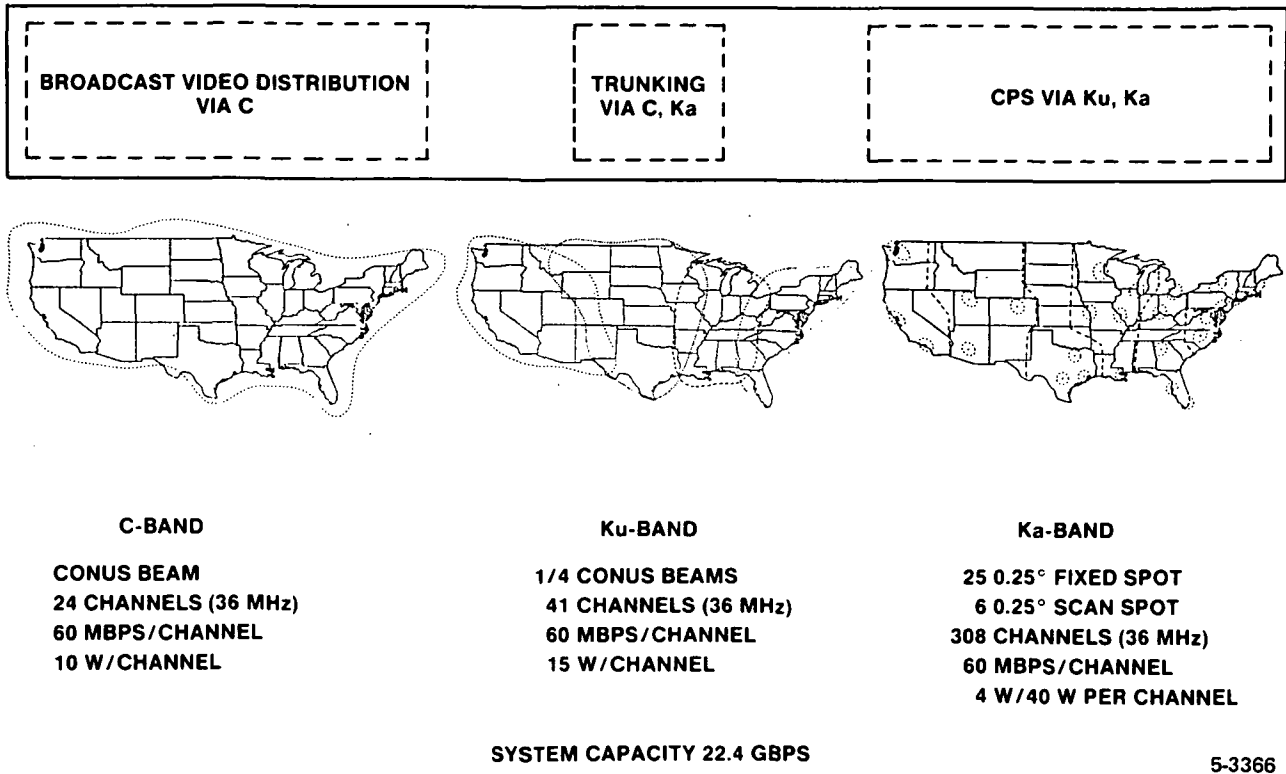


Figure 2-8. Concept 3: FSS (Capacity 13% of Demand) Scenario Summary

Many of the objectives set forth in the development of the 20% FSS concept have also been applied to Concept 3: 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 residue of each to Ka-band.

● FREQUENCY REUSE	
— C-BAND 2.0X	
— Ku-BAND 3.4X	
— Ka-BAND 5.1X	
● SWITCHING/PROCESSING PROVIDES FULL CONNECTIVITY	
— BASEBAND PROCESSOR (133-60 MBPS CHANNELS)	
— IF TDMA SWITCHES	
6 - 25 x 25 MATRICES	
4 - 12 x 12 MATRICES	
● PAYLOAD MASS	1508 Kg
— ANTENNAS	208 Kg
— TRANSPONDERS	1300 Kg
● DC POWER (EOL)	12.3 Kw

Figure 2-9. Concept 3: FSS (Capacity 13% of Demand) Payload Definition Summary

The Ka-band subsystem is quite similar to that adopted for the 20% FSS with six scanning beams and 0.25° 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 IF TDMA switches and the baseband processor are reduced.

2.4 CONCEPT 4: FSS/ISL/TDAS

The FSS/ISL/TDAS concept combines the FSS (20% capacity) payload with an Inter-satellite Link (ISL) payload and a Tracking 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. ISL capacity for broadcast video is not provided on the platform because in Concept 2, broadcast video distribution is provided by conventional satellite. The Concept 4 scenario is summarized in Figure 2-10, and its payload definition is summarized in Figure 2-11.

2.4.1 ISL PAYLOAD

The year 2000 traffic forecast for America to Europe/Africa and the Far East/Pacific is summarized in Table 2-5. The forecast is based on an extrapolation of Intelsat traffic projections developed in 1984. The platform would carry 100% of the point-to-point communications traffic which totals 66 36-MHz

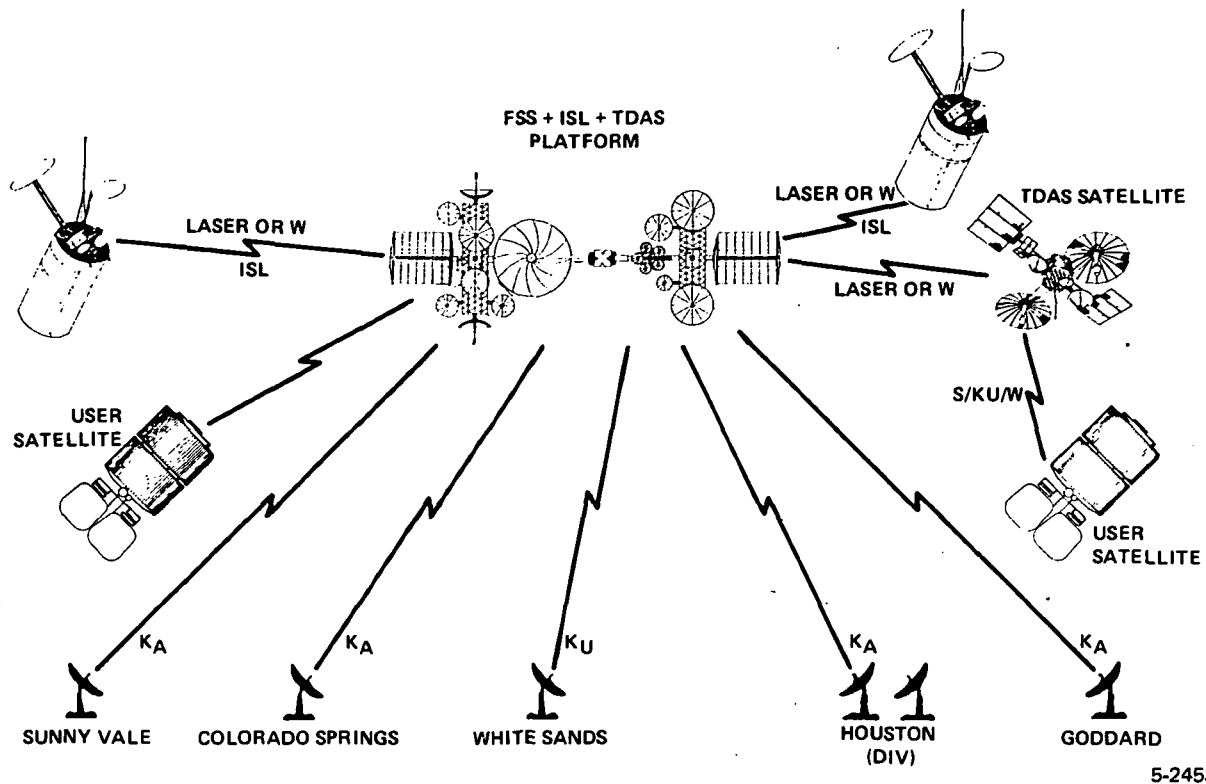


Figure 2-10. Concept 4: FSS/ISL/TDAS Scenario Summary

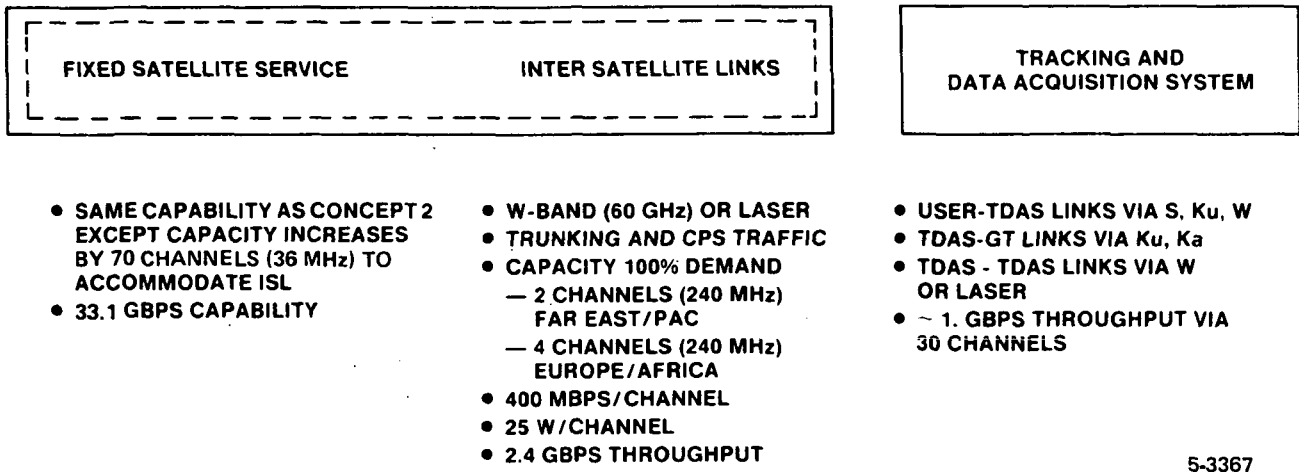


Figure 2-11. Concept 4: FSS/ISL/TDAS Payload Definition Summary

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).

TABLE 2-5. 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)
Trunking ● 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					

2.4.2 TDAS PAYLOAD

The TDAS scenario is illustrated in Figure 2-10 and is based on Stanford Telecommunications TDAS architectural study (Reference 13). 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.

**SECTION 3.0
COST ANALYSIS**

SECTION 3.0 COST ANALYSIS

3.1 COSTING METHODOLOGY

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.

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 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.

Payload costs 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. Relevant ground segment costs are summarized in Section 5.0, System Comparisons and Conclusions.

3.2 COST ESTIMATES

3.2.1 PAYLOAD COSTS

A summary of the recurring communications platform payload cost in 1984 dollars for each concept is given in Table 3-1. The indicated cost represents the average of the results obtained from the two modeling approaches. The results of the two approaches were within 15% of the concept average for all four concepts. Payload cost estimates are also shown for current RCA C-band and Ku-band satellites; these cost estimates are based on the SAMSO model only, because RCA actual costs are proprietary.

The cost per unit of transponder mass has historically been constant. While this relationship may not necessarily apply to future satellites because of technology and design architecture changes, it does provide a "sanity check" for platform payload costs. The FSS platform transponder costs per unit of mass are in agreement with 1984 satellite cost per unit mass.

TABLE 3-1. COMMUNICATIONS PLATFORM PAYLOAD RECURRING COST COMPARISONS (\$1984)

Concept	Mass (kg)	Cost (\$M)	Cost/Mass (\$k/kg)	Active Transponder Channels*	Mass (kg/Ch*)	Cost (\$k/Ch*)
1. LMSS						
Antenna	200	24	120			174
Transponder	972	96	99			696
Total	1172	120	102	138	8.5	870
2. FSS (20%)						
Antenna	332	14	38			27
Transponder	1812	216	119			423
Total	2144	230	107	511	4.2	450
3. FSS (13%)						
Antenna	208	8	36			21
Transponder	1300	158	121			424
Total	1508	166	109	373	4.0	445
4. FSS/ISL/TDAS						
Antenna	567	25	42			43
Transponder	2588	296	115			510
Total	3155	321	102	580	5.4	553
1984 Satellites:						
C Antenna	42	1.4	33			58
C Transponder	88	10.4	118			434
C Total	130	11.8	91	24	5.4	492
Ku Antenna	32	1.2	38			50
Ku Transponder	131	15.4	118			642
Ku Total	163	16.6	102	24	6.8	692
*Transponder channels: LMSS Bandwidth 60 kHz to 1 MHz, FSS Bandwidth 36 MHz, ISL Bandwidth 240 MHz						

The cost per active transponder channel is more important to the spacecraft operator than the cost per unit mass. The cost per FSS platform transponder channel is about 10% less than the cost for a current-generation C-band satellite transponder channel and about 35% less than the cost for a Ku-band transponder channel. However, the difference may not be significant if cost-estimation uncertainties are considered. Use of TWTAs rather than SSPAs accounts for much of the higher cost associated with the current Ku-band satellites. The SAMSO-5 model indicates economies of scale are likely, when the total spacecraft is costed. However, spacecraft costing is beyond the contract scope of work and was not performed. The FSS payload cost drivers are presented in Table 3-2. The LMSS major cost elements are: antenna (24%), receiver (23%), SSPA (17%), and EPC (17%).

TABLE 3-2. 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%

**SECTION 4.0
CRITICAL TECHNOLOGY**

SECTION 4.0

CRITICAL TECHNOLOGY

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 4-1. 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 IF 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 to be only a low technical risk and low cost uncertainty technology.

TABLE 4-1. CRITICAL TECHNOLOGY SUMMARY

<u>TECHNOLOGY</u>	<u>PRIORITY</u>	<u>TECHNICAL RISK</u>	<u>COST UNCERTAINTY</u>	<u>CONCEPT</u>	<u>CRITICAL AREAS</u>
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 MATRIX	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 A1 As TRANSMITTER, POINTING/TRACKING, W REFLECTOR SURFACE TOLERANCE, WIDEBAND 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

SECTION 5.0
SYSTEM COMPARISONS AND CONCLUSIONS

SECTION 5.0

SYSTEM COMPARISONS AND CONCLUSIONS

5.1 IMPACT ON TERRESTRIAL PLANT-IN-PLACE

A comparison of the impact on the ground segment for each platform concept relative to satellites with smaller payloads is made in Table 5-1. 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.

TABLE 5-1. 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.

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.

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.

Concept 3 has a greater potential impact on the ground segment than Concept 2. TV distribution would be provided from six slots instead of the two slots in Concept 2, and would impose a greater antenna requirement at each of the cable TV heads, TVROs, etc. Concept 3 would also require a greater investment in Ka-band ground station equipment for the point-to-point communications, because TV distribution reduces the ability to reuse C-band (4% of Concept 3 capacity at C-band vs. 23% of Concept 2 capacity at C-band).

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.

5.2 FSS SYSTEM COMPARISONS

A cost comparison of the FSS system of Concept 2 with a 3-satellite nonaggregated system has been performed. The two systems are shown in Figure 5-1. Both systems provide the same total transponder capacity, i.e., each satellite has one-third the capacity of a platform. The payload costs for the two options are the same.

Two cases are considered for ground segment costing: complete interconnectivity between only the trunking stations and complete interconnectivity for the trunking and CPS stations.

The 3-satellite system is \$58 million more expensive than the platform system when complete trunking interconnectivity is required. If complete trunking plus CPS interconnectivity is required, the cost difference increases dramatically to \$833 million. The earth segment cost difference is caused by the need for additional antennas as indicated in Figure 5-1.

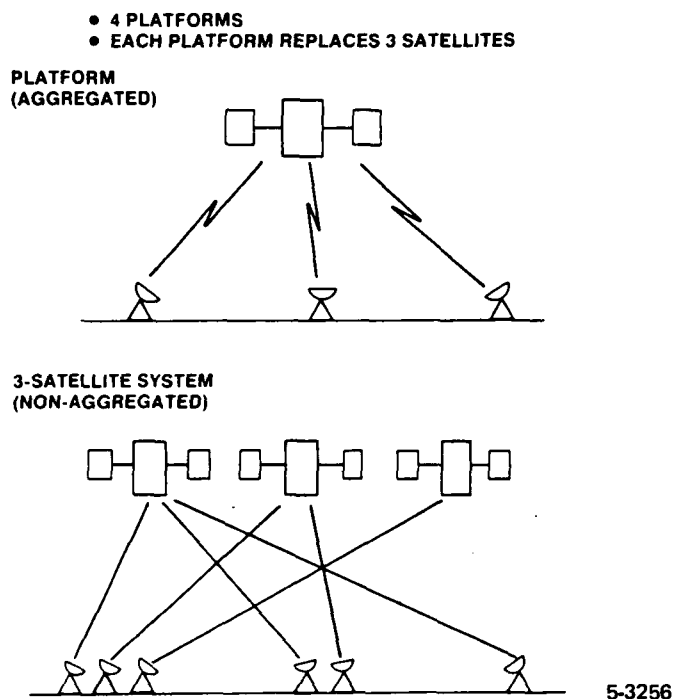
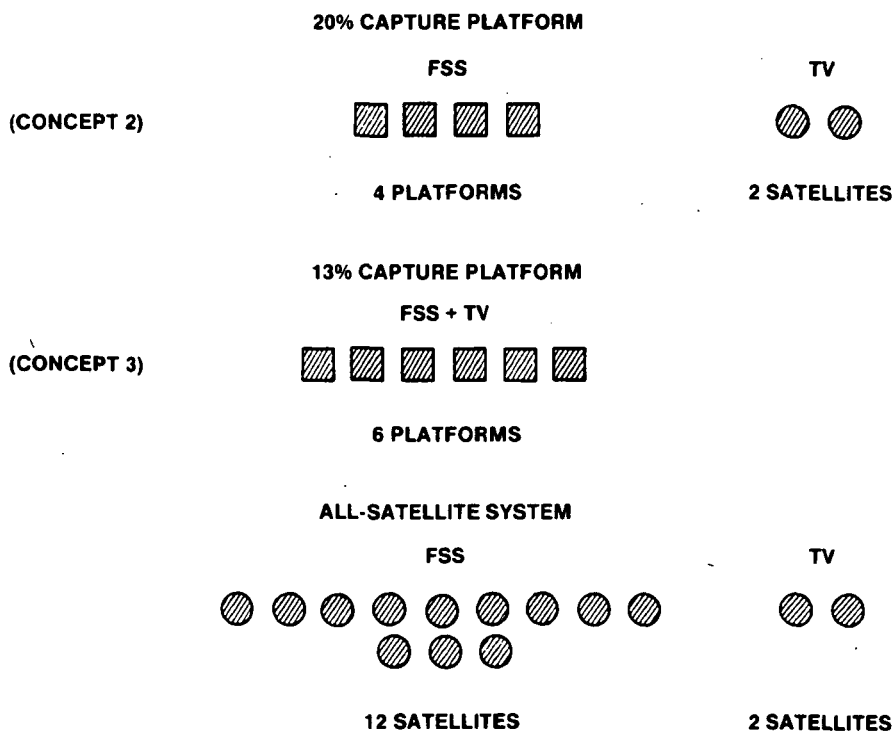


Figure 5-1. Fixed Service Option

Figure 5-2 illustrates the operational FSS system concepts defined by the FSS payload scenarios. Each operational system provides the same total capacity. The Concept 2 scenario requires four trunking/CPS platforms and two video-distribution satellites. The Concept 3 scenario requires six platforms, each providing trunking, CPS, and video-distribution services. The third operational concept, an "All-Satellite" system, replaces each of the Concept 2 platforms with three satellites and requires a total of 14 orbital slots. The cost benefits of the operational platform system concepts relative to the 14 spacecraft "All-Satellite" system is shown in Table 5-2.



5-3257

Figure 5-2. FSS Operational System Concepts

5.3 ISL SYSTEM COMPARISON

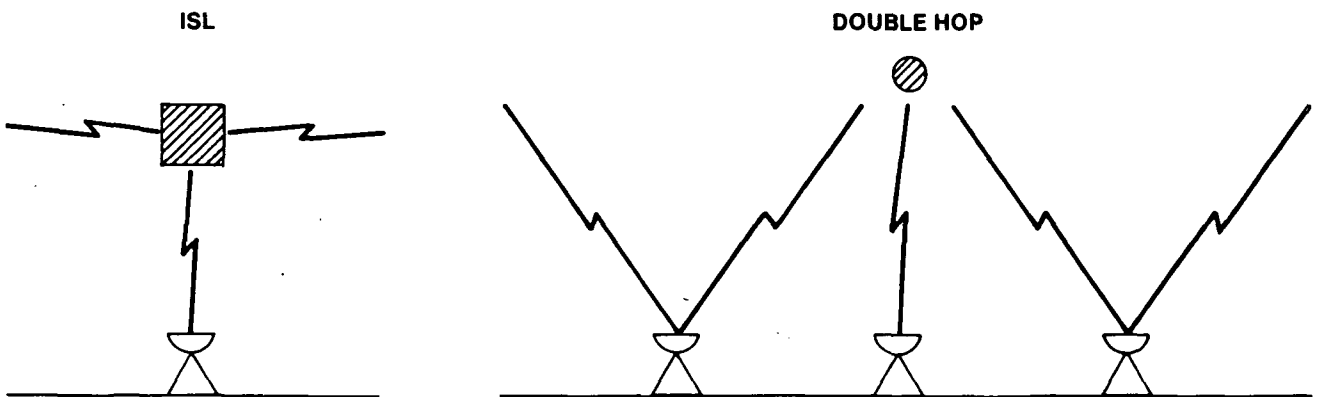
A comparison of the ISL with a double-hop satellite system is illustrated in Figure 5-3 and given in Table 5-3. The traffic carried by the international gateway earth stations need to be interconnected to the end-user. This can be accomplished by terrestrial and/or satellite links. If a double-hop satellite link is used a system costing about \$300 million more than an ISL system is required. The ISL payload costs are about \$40 million. The earth segment cost includes installation but excludes land and buildings.

TABLE 5-2. FSS SYSTEM RECURRING COST COMPARISON

FSS Concept	No. of Platforms	No. of Satellites	Payload (\$M)	Earth Segment* (\$M)	Total Cost (\$M)	Cost Differential (\$M)
20% Capacity	4	2	951	2463	3414	0
13% Capacity	6	-	975	2453**	3428**	14**
Satellite Connectivity:						
● Trunking Only	-	14	951	2695	3646	232
● Trunking and CPS	-	14	951	5796	6747	3333

*Antenna + LNA Only

**Impact of Terrestrial Plant-In-Place Due to High Reliance on Ka (308 of 373 Transponders) Not Assessed.



5-3258

Figure 5-3. ISL System Recurring Cost Comparison, CONUS to East/West Options

TABLE 5-3. ISL SYSTEM COST COMPARISON

Option	Payload (\$M)	Earth Segment (\$M)	Total Cost (\$M)	Cost Differential (\$M)
ISL	41*	--	--	--
Double-Hop	36	317	353	312

*ISL Payload:

W Antenna	2.5
W Transponders	18.9
Ka Transponders	19.3
	<u>40.7</u>

5.4 ISSUES AND CONCLUSIONS

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 acceptable if risk reduced
 - Space station services offer potential for risk reduction.

Candidate servicing functions and their impact on the platform payload designs were evaluated. The candidate services include:

- Large structure assembly and deployment
- Pre-transfer checkout and assembly
- Remote platform servicing at GEO.

The associated payload design issues are:

- Large structure snap-fit assembly
- Post-assembly adjustment
- Strength and center-of-gravity designed for low-thrust deployed platform transfer
- Removable modules (design sensitive to level of Space Removable Unit)

- Interface mechanisms (including rf)
- Post-replacement adjustment.

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 10-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 (non-recurring, 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 5-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 6.0
REFERENCES

SECTION 6.0 REFERENCES

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