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30/20 GHZ FLIGHT EXPERIMENT SYSTEM PHASE II FINAL REPORT

by L. Bronstein, Y. Kawamoto, J. J. Ribarich, J. R. Swope, B. J. Forman, S. G. Bergman, S. Reisenfeld

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16. Abstract

Volume 1 contains summary information on the communication system design, communication payload, space vehicle, and a development plan.

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1. INTRODUCTION AND SUMMARY

The object of this study was to provide the information which NASA requires to select a concept for a 30/20 GHz flight experiment and to procure the major system elements of the 30/20 GHz communications system. The study, which began in April 1980, first examined a baseline concept provided by NASA; then several alternate concepts suggested by the contractor and approved by NASA. Evaluations were made of the cost, schedule, risk and technology development requirements associated with these concepts. A final concept was defined by NASA in March 1981. This report is devoted entirely to that final concept. The analyses of the previous concepts were presented to NASA as they were developed and were documented in task completion reports.

The design for the communication subsystem components is presented in Section 3. Although NASA is funding technology development studies, which will result in proof of concept models for most of these components, the design presented in this report is a Hughes design. This approach is taken for two reasons. First, the technology studies were still in an early stage at the time the design was made; and second, Hughes considers that it will be more competent to reach correct make or buy decisions and to effectively procure components if it has been through the preliminary design process. At this time no decisions have been made regarding the source of any of the communication components. Make or buy decisions will be made early in the system definition phase (Phase B).

The final concept was selected by NASA because it was considered to provide as comprehensive an experiment as could be performed within realistic funding constraints. The communication concept is described in the next section. It consists of trucking service (TS) and customer premise service (CPS) experiments. The trucking system serves four spot beams which are interconnected in a satellite switched time division multiple access (SS-TDMA) mode by an IF switch matrix. The CPS system covers two large areas in the eastern half of the United States with a pair of scanning beams. The individual spots which comprise these CPS areas are interconnected through a baseband processor (BBP) onboard the satellite. Both trunk and CPS systems use an antenna with a 3 meter main reflector. The downlink data rate of 256 Mbps (for both trunk and CPS) are supported by 40 watt TWTAs being developed for NASA by Hughes Electron Dynamics Division. Since the trunk and the CPS services are not simultaneous, the trunk TWTAs are also used for the CPS. The CPS total uplink data rate is broken into 32 Mbps uplink channels so that low cost earth stations can be employed.

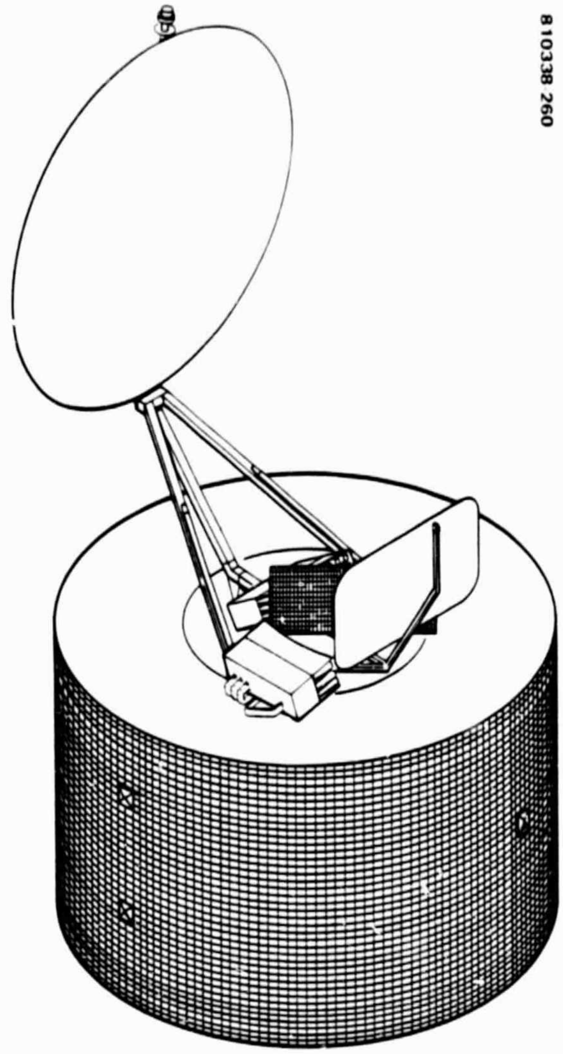

FIGURE 1-1. SPACECRAFT ISOMETRIC

The NASA 30/20 GHz flight experiment has a 2 year duration, however, the satellite is to be designed for a 4 year lifetime so that additional use of the satellite can be made by industry if there is a need. The spacecraft propulsion system must have fuel for 4 years of stationkeeping in inclination, longitude, and spacecraft attitude.

It is a NASA requirement that the communication payload be installed on an existing spacecraft bus. A 4 year lifetime is required. The bus employed by Hughes is the LEASAT spacecraft. Figure 1-1 shows the 30/20 GHz flight experiment installed on the LEASAT bus. The antenna employs a Cassegrain configuration. The planar surface is a frequency selective screen which separates the transmit and receive signals. The trunk feeds are part of the scanning beam feed arrays which are shown. The 20 GHz beacon antenna is also visible. The beacon signal is available on propagation measurements anywhere in the contiguous United States (CONUS). It also carries the telemetry and ranging data.

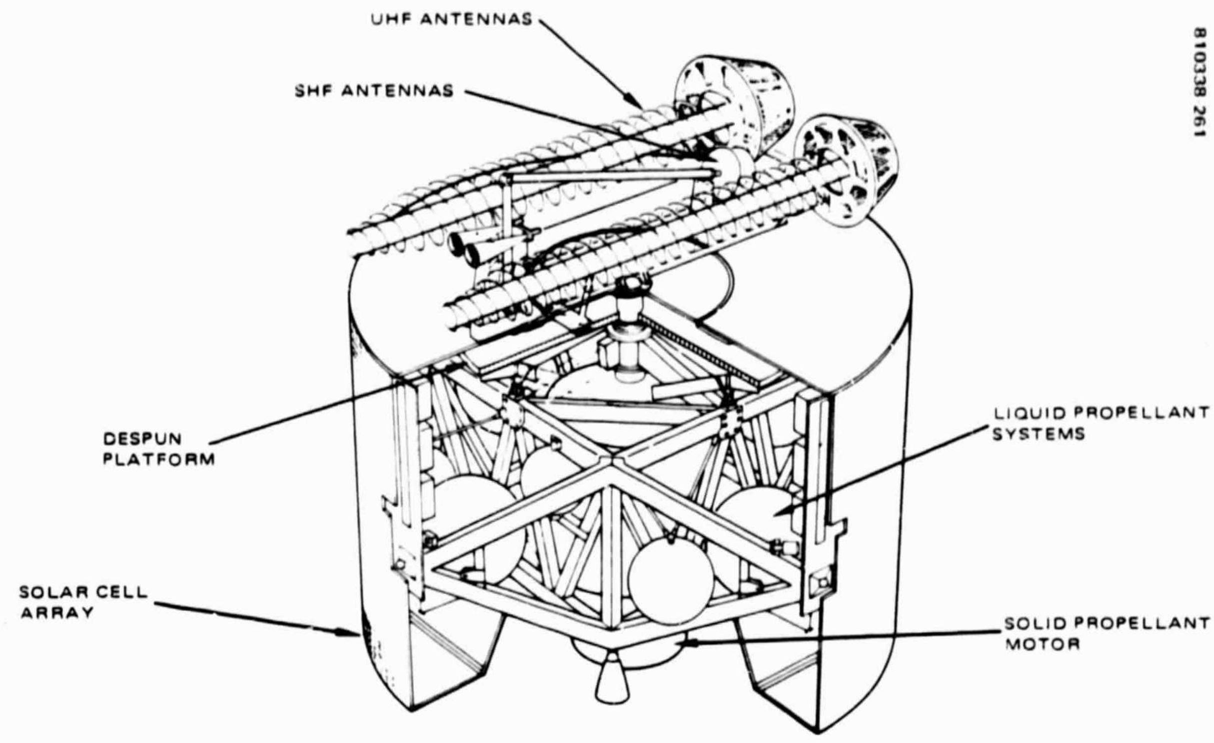

FIGURE 1-2. LEASAT SPACECRAFT STOWED CONFIGURATION

The LEASAT spacecraft configuration is shown in Figure 1-2. It is the first communication satellite designed to be launched only by the Space Shuttle and to take full advantage of the Shuttle's considerable launch cost savings. In its launch configuration, LEASAT is 422 cm in diameter and 430 cm in height. The spacecraft is a dual spin configuration, with a rate of 30 rpm on station. The spinning section contains the propulsion, attitude control, and power subsystems. The despun section contains the telemetry, command, and communication subsystems and the spacecraft's earth pointing antennas. The antennas and the equipment on the despun platform are replaced by the 30/20 GHz payload. The spinning section is virtually unchanged.

The LEASAT propulsion system incorporates the perigee and apogee stages needed to lift the spacecraft from low Shuttle orbit into synchronous orbit. A liquid propellant system will be used for perigee augmentation and the complete apogee impulse. Four years of on-orbit station keeping and attitude control will be provided by a standard monopropellant hydrazine system.

The 30/20 GHz flight experiment vehicle will weigh 17,071 pounds in the Shuttle bay and 3,095 pounds when it reaches synchronous orbit. Its weight at the end of 4 years will be 2,750 pounds. A weight summary is given in Table 1-1. The total spacecraft weight margin provided by excess propulsion capability is 156 pounds. A 10 percent payload weight margin of 42 pounds was allocated to the payload leaving 114 pounds as rotor weight margin. The ultimate limit in payload weight is the stability requirement that the spin to

TABLE 1-1. SPACECRAFT WEIGHT SUMMARY

Item	Payload Weight, lb	
Payload		465
Antenna	189	
Microwave	123	
Digital	111	
Margin (10%)	42	
Bus		2,285
TT&C	123	
Controls	75	
Power	541	
Propulsion	323	
Structure	1,100	
Margin (rotor)	114	
Spacecraft (dry)		2,750
Propellant (BOL)		345
RCS (4^+ yr)	324	
LAM residual	21	
Spacecraft (BOL)		3,095
Transfer orbit expendables		12,191
Shuttle deployment		15,286
Cradle and ASE		1,785
Shuttle payload		17,071

transverse inertia (I_s/I_t) ratio be greater than 1.05. As much as half of the 114 pound rotor margin could be reallocated to the payload if the remainder of the rotor margin were positioned near the perimeter of the rotor. The actual fraction of the 114 pounds which is available for the payload depends on whether the payload weight growth was above the despun platform (e.g., antenna) or in the despun platform which is near the center of gravity. If the first of two options which were studied at NASA's direction were implemented, the payload weight would be reduced by 49 pounds by eliminating one of the scanning beams and reducing the BBP throughput. The additional margin provided by option 1 does not appear necessary. The second option, which added an FDMA capability to the payload, added 16 pounds to the payload. Adoption of option 2 would appear to leave adequate margin. Also, option 2 could be removed if necessary without any significant effect on the remainder of the payload.

Table 1-2 is a power summary of the 30/20 GHZ spacecraft. The major portion of the trunking service payload power is for the four 40 watt TWTAs. In the CPS mode, only two of the TWTAs are used but the BBP, which is used primarily for the CPS mode, replaces these TWTAs as a power user. The effect in power demand of the two options is insignificant compared to the very large power margin.

TABLE 1-2. POWER SUMMARY (WATTS)

Item	Baseline	
	TS	CPS
Payload		
Antenna	1.8	9.8
Microwave	515.6	285.6
Digital	41	223.2
Bus	228	228
TT&C (48)		
Controls (37)		
Power (92)		
Thermal (51)		
Spacecraft	786.4	746.6
Capability (4 yr)	1,090	1,090
Margin	303.6	343.3

The 30/20 GHz flight experiment spacecraft will be carried in the Space Shuttle as shown in Figures 1-3 and 1-4. It will be held in the Shuttle bay by a reusable cradle, which attaches to the mainframe of the Shuttle at five points. While the Shuttle is orbiting at an altitude of 160 n. mi., the spacecraft will be ejected by two springs which supply a separation of 160 n. mi., the spacecraft will be ejected by two springs which supply a separation velocity of 40 cm/sec and a rotational speed of 1.8 rpm. Spinup rockets will increase the satellite's rate to 30 rpm approximately 300 seconds after release. The solid propellant perigee motor will be fired 45 minutes after release. The empty motor case and its supporting structure will then be dropped. The liquid propellant motors will supply the additional velocity needed to put the spacecraft in elliptic transfer orbit. On reaching synchronous orbit, the communications antenna will be deployed and operational service will begin.

A summary estimate of the reliability of the space segment is given in Table 1-3. The reliability of the launch and orbit insertion is included in the estimates. The estimate uses an existing reliability estimate for the LEASAT bus and the number and type of parts used in the payload. The assumptions and model used are described in 4.3, Space Vehicle Reliability.

The reliability shown is quite adequate to meet mission objectives, particularly since the partial failures of case 4 will not seriously interfere with these objectives. The scanning beams each have a total of 16 spots in the uplink and 10 spots in the downlink so the loss of one spot from each of the two areas can be tolerated. The reason for the lower reliability of the CPS relative to the trunking service is the complexity of the beam forming networks of the scanning beams.

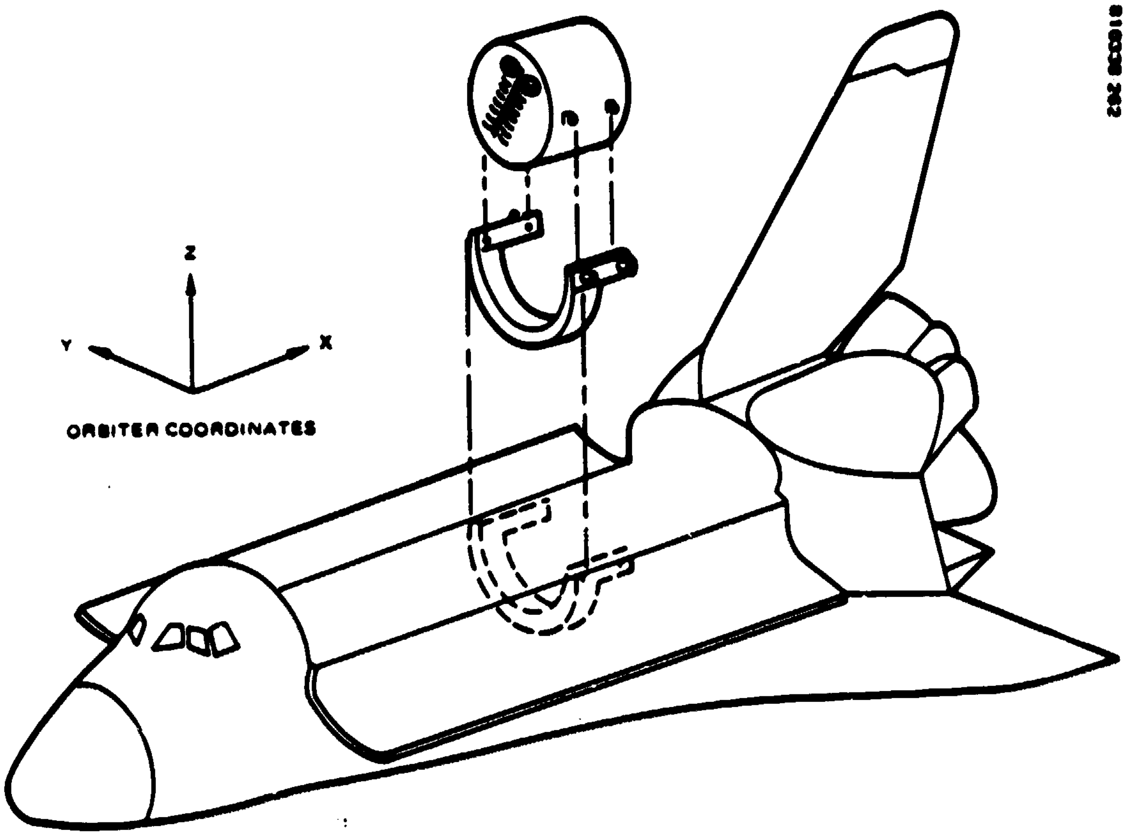

FIGURE 1-3. LAUNCH CONFIGURATION

TABLE 1-3. SPACE SEGMENT RELIABILITY

Item	2 years	4 years
1) Complete communication capability	0.80	0.62
2) Complete trunk capability	0.94	0.81
3) Complete CPS capability	0.81	0.66
4) Loss of no more than 1 of 4 trunk beams and no more than 1 spot from each scanning beam	0.92	0.79

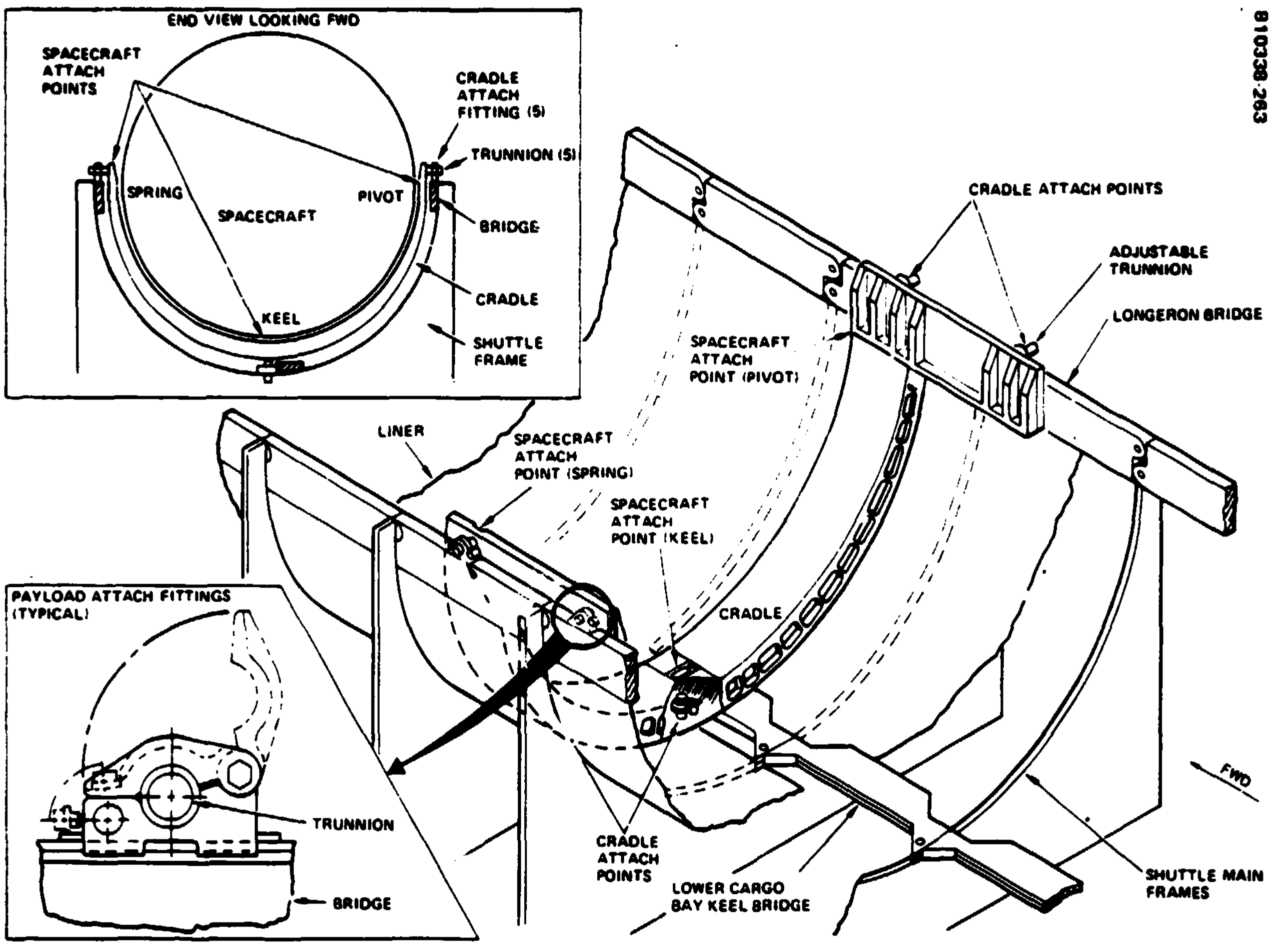

FIGURE 1-4. TYPICAL CRADLE SHUTTLE BAY INSTALLATION

The terrestrial segment of the 30/20 GHz flight experiment consists of trunk terminals, CPS terminals, and a master control terminal (MCT). The trunk terminals have 5 meter antennas and employ site diversity to improve propagation reliability. The CPS stations are of two types: 1) small stations which transmit at a 32 Mbps burst rate and use a 3 meter antenna, and 2) large stations which transmit at 128 Mbps and use 5 meter antennas. All terminals receive at 256 Mbps. The MCT consists of a trunk terminal and a central control station which controls both the communication network and the spacecraft operation. NASA will procure the MCT and a small CPS terminal; experimenters will procure other terminals.

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2. COMMUNICATION SYSTEM DESIGN

The design of the 30/20 GHz flight experiment communication system has the following three aspects:

1) Design of the communication links which satisfy the specified service requirements

2) Design of the communications operations system which controls the communication links and enables the multiplicity of users to access the system in an orderly and efficient manner

3) Design of the experiments which make use of the communication system

2.1 COMMUNICATIONS

2.1.1 Requirements

The flight experiment must address the service capabilities of an operational system of the 1990's and the technologies required to provide these capabilities. This flight experiment, as defined by NASA, is illustrated in Figure 2-1. The experiment has two parts: a trunk service (TS) and a customer premise service (CPS). The TS provides high data rate bulk communications to a limited number of nodes. In an operational system as many as 20 or more nodes might be served. The flight experiment is specified to comprise a six node network with four nodes active simultaneously. The six nodes are shown in Figure 2-2. Los Angeles and Cleveland are always part of the network. Tampa and Houston are alternates to New York and Washington, respectively. The specified access method is satellite switched time division multiple access (SS-TDMA). Each node transmits sequential bursts of data to the other nodes. Each station transmits at least one burst per frame to each node with which it communicates. The bursts are in synchronism with a switch matrix onboard the satellite. This switch matrix, which operates at IF, connects each uplink beam at any instant in time with the downlink beam for which its data is intended. The means by which the use of the SS-TDMA is controlled and synchronized is discussed in 2.2. The earth terminals for the TS are specified to have

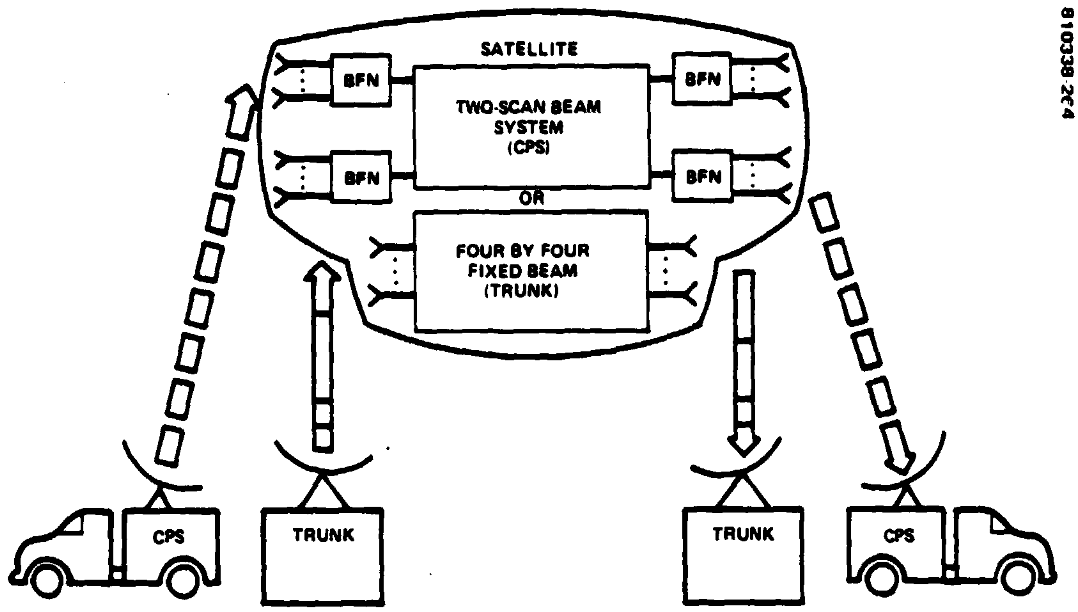


FIGURE 2-1. 30/20 GHZ FLIGHT EXPERIMENT SYSTEM

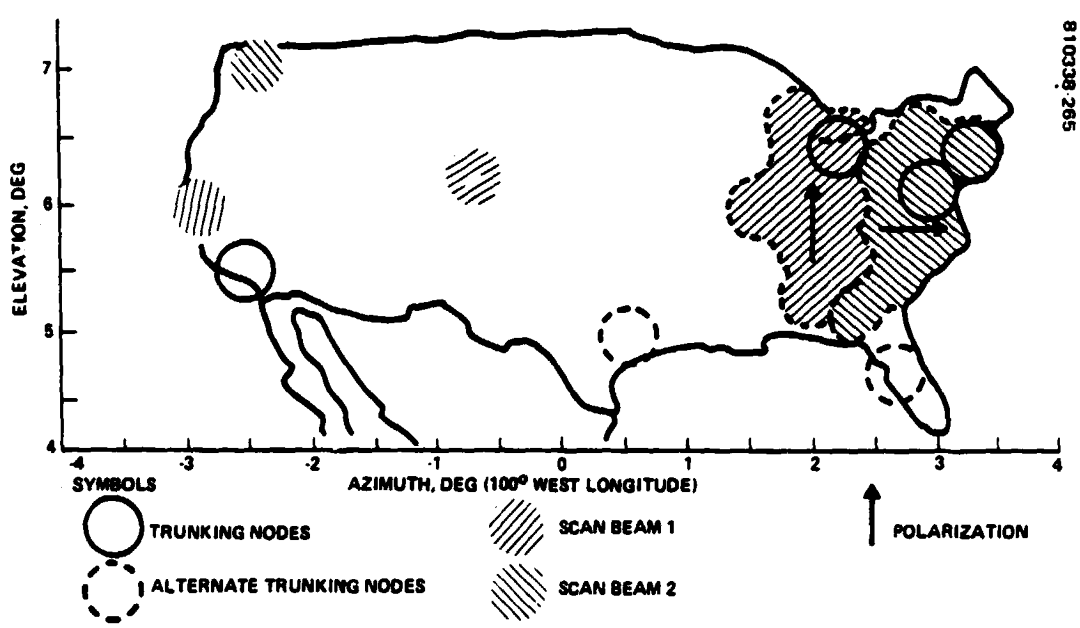


FIGURE 2-2. TYPICAL ANTENNA COVERAGE

5 meter antenna diameters and to employ site diversity to minimize the effect of rain attenuation. The burst rate is specified to be 256 Mbps. The average data rate will be somewhat less because of the overhead resulting from guard time and preambles. The bit error rate (BER) requirement is 10^{-6}. The required rain margins are 18 dB on the uplink and 8 dB on the downlink. The resulting propagation reliability is discussed later in this section.

An operational CPS serves many small and medium users scattered about the country. The CPS requires two scanning beams. The required coverage of these beams is illustrated in Figure 2-2. Each beam covers a contiguous area in the eastern United States plus one or two isolated beams in the west. The scanning beam covers its area by moving a spot beam about the area. This antenna configuration imposes SS-TDMA operation because users in different spots have access to the satellite at different times. The fraction of the satellite capacity assigned to each spot is adjusted to match the traffic requirements by varying the fraction of the TDMA frame spent by the beam at each spot. A baseband processor (BBP) is required to store data received from each uplink spot until a downlink beam is pointed at the spot for which the uplink data is intended. Without this store and forward capability the up and downlink beams would be constrained to point simultaneously at each pair of spots which had a traffic interconnection. This would require a very large number of antenna steps. The time consumed by these stepping operations would reduce the system efficiency to an inadequate level. The store and forward capability allows each beam to address each spot in its area once per frame. During this dwell it would receive and transmit all data associated with the spot. The requirement to provide forward error correction capability also imposes a need for a BBP to demodulate and decode uplink coded data and encode data for attenuated downlinks.

Two types of CPS terminals are required. Terminals which transmit a 32 Mbps burst rate require 3 meter antennas and terminals which transmit 128 Mbps require 5 meter antennas. All CPS terminals receive at 256 Mbps. The CPS is required to maintain performance in the presence of 15 dB of uplink attenuation and 6 dB of downlink attenuation. As mentioned above, forward error correction (FEC) is specified as an aid to meeting this requirement.

Simultaneous operation of the TS and CPS systems is not required.

One of the objectives of the flight experiment is to improve frequency reuse by means of the multispot beam antenna. Figure 2-3 and 2-4 show the NASA frequency plan. This plan requires all trunk modes to reuse the same frequency band except for Washington which can be frequency isolated from New York. Likewise, the two scanning beams occupy the same channel but are polarization isolated. The total uplink burst rate is 128 Mbps. This can be composed of either four 32 Mbps channels or a single 128 Mbps channel. A single downlink channel at 256 Mbps is required on each beam. Because the uplink throughput on this experiment is only half the downlink throughput, at most one-half of the uplink frame is occupied.

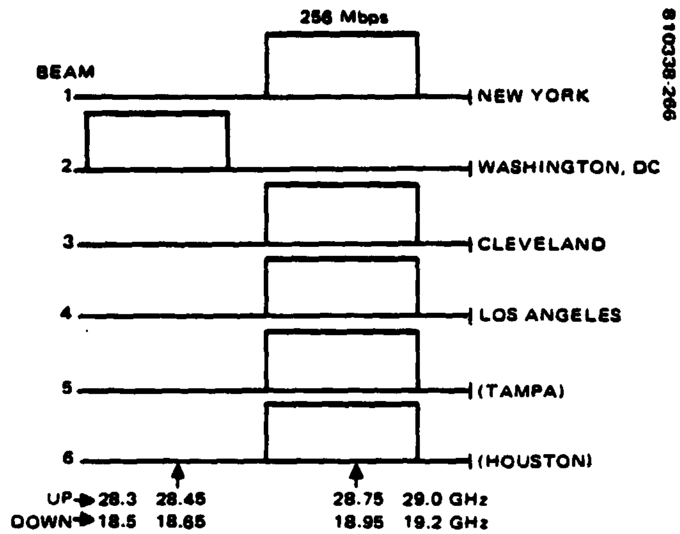


FIGURE 2-3. TRUNKING SERVICE FREQUENCY PLAN

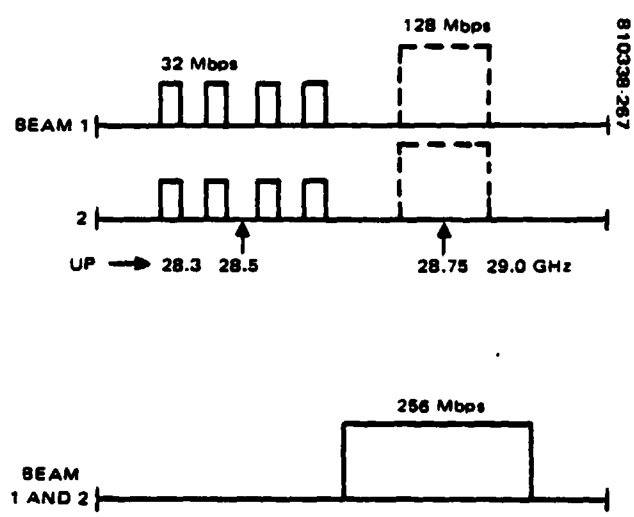


FIGURE 2-4. CPS FREQUENCY PLAN

The service requirements discussed above are summarized in Table 2-1.

In addition to the service requirements NASA has specified a number of technology requirements which are required by potential operational systems of the 1990's but which are not needed to satisfy the service requirements of this flight experiment. These technology requirements are summarized in Table 2-2. NASA required that the receive antenna beamwidth equal the transmit beamwidth to minimize the number of receive feeds; however, although the use of a single reflector for both transmit and receive doubles the number of receive feeds required to cover the assigned area, this approach has two important advantages for both the satellite and earth terminals. The earth terminal transmitter power can be reduced by over 3 dB because of the increased satellite receive gain. The satellite benefits in two ways. First, the weight of a second reflector (2 meters diameter), its support structure, and deployment mechanism is eliminated. Second, the transmit antenna can be pointed more accurately since it includes the uplink beacon tracking feeds. A single reflector for both frequencies is made possible by the use of a planar frequency selective surface (FSS) which creates separate focal regions for transmit and receive feeds. Thus no diplexers are required and receive and transmit feeds can be independently optimized. This FSS technology is considered by Hughes to be important for multispot beam antennas because it provides two antennas without requiring a second reflector. Consequently, with NASA's permission, Hughes has designed the satellite antenna with a 3 meter aperture for both transmit and receive.

2.1.2 Spacecraft Payload Block Diagram

The spacecraft payload shown in Figure 2-5 implements the requirements described previously. The upper portion of the diagram represents the trunk service components and the lower half the CPS components. The switches are shown in the TS mode configuration. Low noise amplifiers (LNA) are installed at the feeds in order to establish the spacecraft noise figure before the losses imposed by the beam forming network of the CPS scanning beam antenna are incurred. At the time this configuration was developed the beam forming networks (BFN) loss was estimated to be over 3 dB. Recent data from Electromagnetic Sciences indicates that the loss will be less than 1 dB. Consequently, the use of LNA at the feeds will be reevaluated in the next phase of this program. The use of an LNA at each feed imposes a significant weight penalty especially when redundancy is provided. The weight penalty for using distributed LNAs is about 6 pounds. If the CPS LNAs were redundant the weight penalty (including the redundancy switches) for distributed LNAs would be about 15 pounds. The trunk feeds are also provided LNAs because several of them are also used for the scanning beams. Also, at 30 GHz, the losses in waveguide runs are appreciable. The TS LNAs are 3 for 2 redundant because of the importance of each of the small number of beams. CPS LNAs are single string to avoid the weight penalty associated with providing additional LNAs and the associated switching for the large number of receive scan beam feeds. There are 29 feeds for the receive

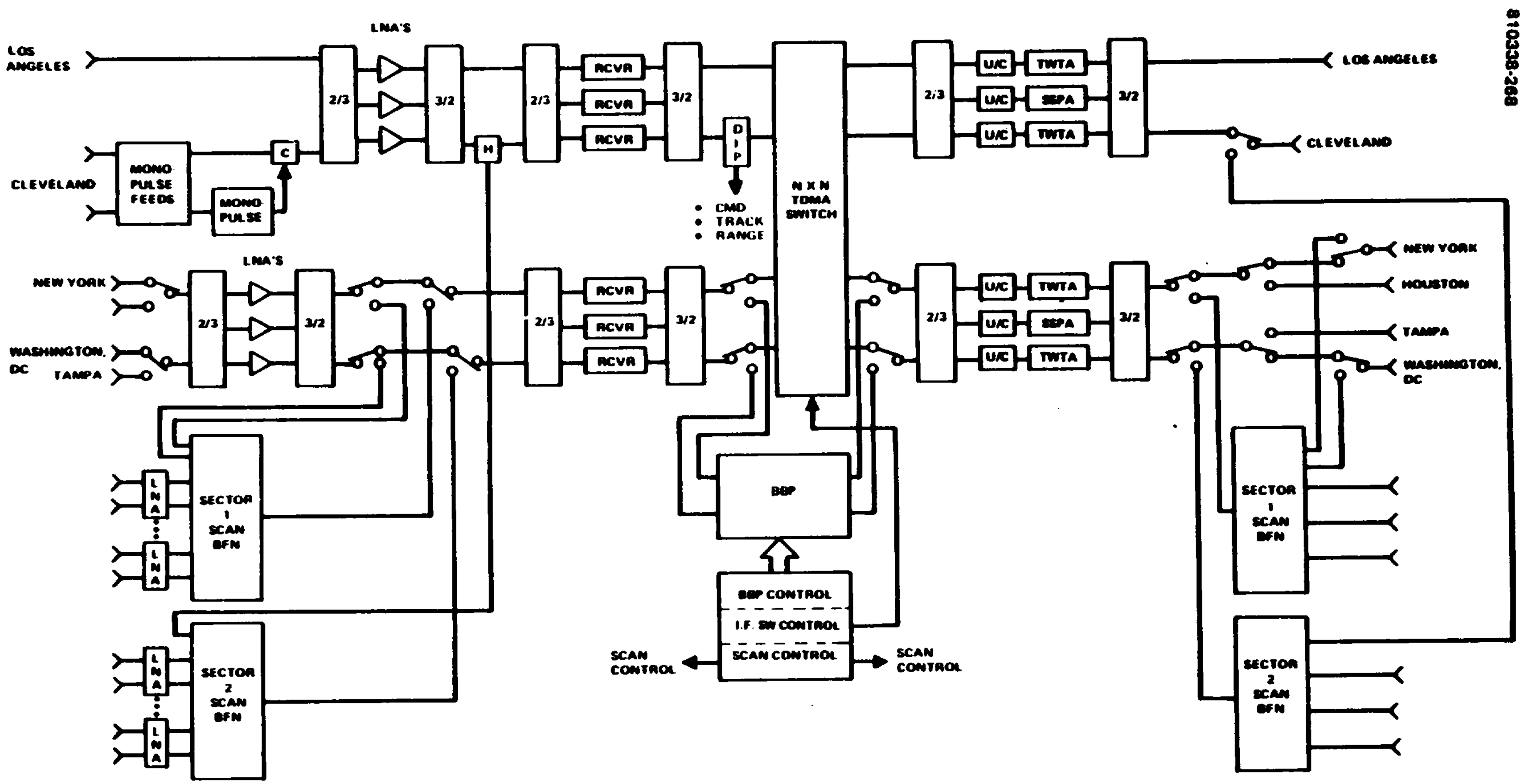


FIGURE 2-5. SPACECRAFT FUNCTIONAL BLOCK DIAGRAM

TABLE 2-1. SERVICE REQUIREMENTS SUMMARY

Service / Requirements	Trunk Service	Customer Premise Service
Coverage	Four-by-four with two alternate nodes (Los Angeles, Cleveland, New York, Washington, Tampa, Houston)	Two adjacent sectors in the earth, United States plus isolated spots in western United States
Burst data rates	256 Mbps, nominal	Uplink: H - 32 Mbps or 1 - 128 Mbps, nominal Downlink: 1 - 256 Mbps
Interconnectivity	Four-by-four SS-TDMA	Baseband processor and beam forming network
Ground station antenna size	5 m (site diversity)	5 m for 128 Mbps 3 m for 32 Mbps
Rain margin (uplink/downlink)	18/8 dB (power)	15/6 dB (power + FEC)

TABLE 2-2. TECHNOLOGY REQUIREMENTS

Satellite transmit antenna	Diameter = 3 m Peak gain > 51 dB (3° from boresight)
Satellite receive antenna	Halfpower beamwidth equal to transmit HPBW
Baseband processor	Scalable to throughputs of 480 Mbps/beam and 4 Gbps total
Satellite high power amplifier	Primary HPAs: 40 W TWTA with efficiency greater than 40% Backup HPAs: solid state
IF switch matrix	Scalable to 20 beams interconnect

scan beams. Individual receivers with 3 for 2 redundancy are provided for the four active trunk beams because all trunk modes except Washington use the same frequency. The receivers downconvert the signals to 6 GHz which has been selected as the operating frequency of the IF switch matrix. The switch matrix interconnects the four active uplinks with four active downlinks to provide SS-TDMA. A 6 by 4 matrix is used to provide redundancy. A 1 ms frame is divided into subframes. During each subframe, each uplink is connected to a single downlink. Over the course of the frame each uplink is connected to each of the downlinks.

The four trunk transmitters use 40 watt TWTAs as high power amplifiers as required by NASA. The redundant transmitters are required to be solid state. Hughes has chosen GaAs FET HPAs over IMPATTs because of the greater potential of the GaAs FET. This trade is discussed in 3.2. A saturated output power of 7.5 watts is anticipated to be available with these backup transmitters. The impact of this low power is discussed in 2.1.5.

The receive beam forming networks scan the antenna beams over the coverage area by switching the receiver input from feed to feed. Switching is also provided to allow the New York and Washington receivers to be used for the CPS when the system is in the CPS mode. The baseband processor receives the 6 GHz output of the receivers. Each of these signals contains either four 32 Mbps frequency multiplexed QPSK signals or a single 128 Mbps signal. The signals are demodulated and the data stored until a downlink scanning beam is pointed at the spot for which the data is intended, at which time it is read out to the appropriate transmitter at a rate of 256 Mbps.

2.1.3 Satellite Antenna Pointing

A requirement to point the satellite antenna to within ±0.05 degrees (3σ) of the designated target has been imposed to limit pointing loss to less than 0.5 dB on the uplink. Because the spacecraft attitude cannot be maintained to this accuracy the antenna points independently of the spacecraft attitude by tracking an earth based beacon. The antenna has two degrees of freedom. Elevation tracking is provided by a mechanical drive which is also used to rotate the reflector from its launch position stowed against the top of the spacecraft cylinder to its deployed position. Azimuth tracking is provided by the spacecraft despin system which despins the entire payload equipment platform to point the antenna at its azimuth position. The error signal for both the elevation and despin control systems is derived from a two axis monopulse tracker. This monopulse tracker uses four auxiliary feeds surrounding the Cleveland feed to measure the elevation and azimuth errors relative to the beacon transmitted from the MCT at Cleveland. This beacon could be located at a location less susceptible to rain attenuation with the tracking feeds suitably relocated; however, the beacon which is modulated by the command signal is narrowband and has a large rain margin. Earth sensors, which are required for spacecraft attitude control as well as for despin during transfer orbit operations, provide a less accurate backup pointing capability in case of beacon outage.

2.1.4 Antenna Configuration Trades

Figure 2-6 illustrates the effect of scan loss on the gain of large antennas operating at high frequencies. The curves apply to a beam which is directed to Boston, 3 degrees from the antenna boresight. Because the beam defocussing increases with the number of beamwidths by which the beam is displaced from boresight, the off axis scan loss is particularly severe at 30 GHz. This defocussing can be reduced by increasing the ratio of focal length to antenna diameter (F/D).

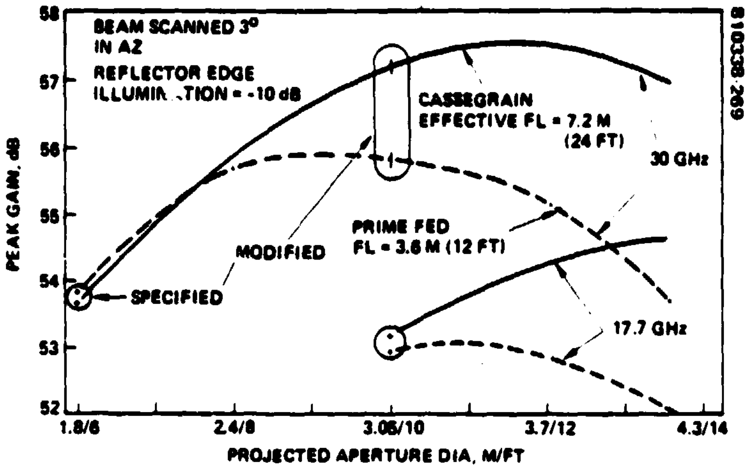


FIGURE 2-6. ANTENNA CONFIGURATION SELECTION

The practical focal length of a prime fed antenna is limited by the satellite dimensions to about 12 feet. A Cassegrain configuration allows this limit to be overcome. The focal length which can be obtained with a Cassegrain configuration depends on the eccentricity of the hyperloidal subreflector. An eccentricity of 3 provides a 24 foot focal length. The diameter of the parent parabolic antenna is also 24 feet. (The 10 foot antenna is an offset section of the parent parabola.) The Cassegrain antenna then has an F/D = 1 compared to 0.5 for the prime fed configuration.

The original specification was for a 10 foot (3 meter) diameter for the transmit antenna and a receive beamwidth equal to the transmit beamwidth. At 20 GHz, a 6 foot (1.8 meter) diameter provides the required beamwidth. It can be seen that at the specified diameters, there is little advantage to the Cassegrain configuration; however, for Shuttle diameter antennas which NASA considers appropriate to operational systems, the improvement provided by the Cassegrain configuration is significant. Consequently, the Cassegrain configuration was selected. Also, since a 10 foot receive diameter has been adapted, as discussed in 2.1.1 the Cassegrain configuration, in conjunction with this increase in diameter provides a substantial increase in receive gain.

2.1.5 Terrestrial Segment

The terrestrial segment of the 30/20 GHz Flight Experiment system, Figure 2-7, consists of the master control terminal (MCT) and a CPS station provided by NASA and trunk and CPS stations provided by experimenters. The NASA CPS station will be mobile.

The MCT shown in Figure 2-8 located in Cleveland is a trunk station with the central control station (CCS) attached. The trunk station is composed of a trunk terminal and two antenna sites. The antenna sites include the burst modems and all of the RF equipment. The trunk terminal includes the equipment which interfaces with the user, buffers continuous user data

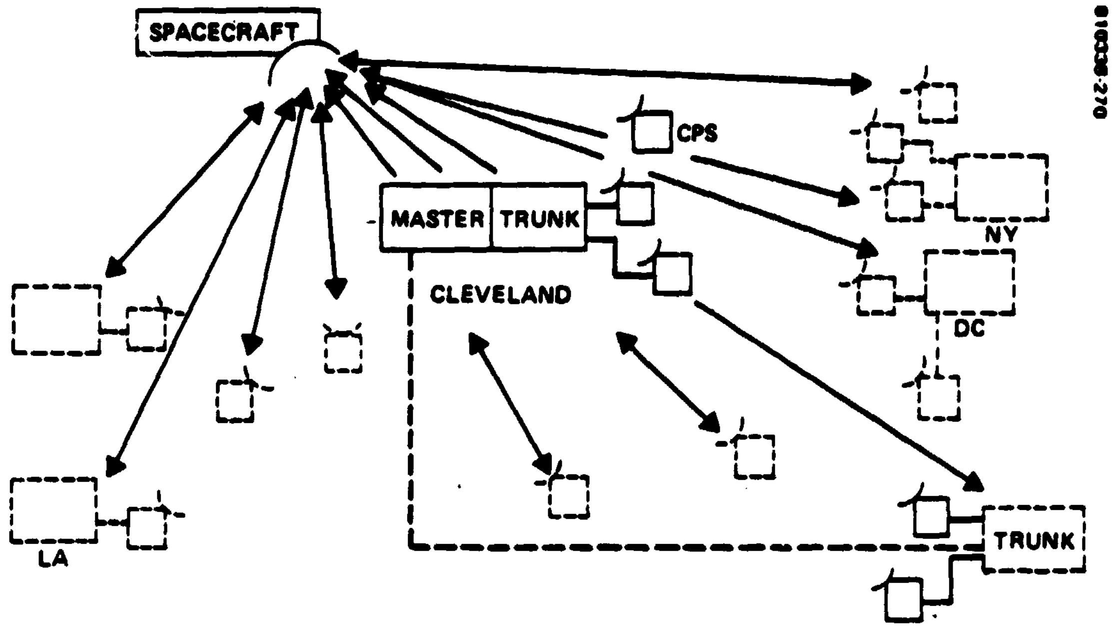


FIGURE 2-7. TERRESTRIAL SYSTEM

to convert this data to TDMA burst data and synchronizes the transmission of the data bursts. The diversity switch connects the trunk terminal with one or the other 5 meter antenna sites depending on the severity of rain attenuation at each site. At the MCT one of the antenna sites is colocated with the trunk terminal and the other is connected by a microwave link. The MCT has, in addition to its trunk capability, a CPS capability with a 128 Mbps uplink. This capability eliminates the need for a NASA CPS terminal with a 5 meter antenna in addition to the 3 meter CPS terminal.

The CCS controls the mission operations, the communication operations, and the experiment operations. The mission operations which included the operation of the spacecraft during launch and transfer orbit and the maintenance of the spacecraft bus attitude, orbit and health throughout the mission are supported by the mission operations computer. The communication operations include the activities which coordinate earth terminals and payload. These activities which include TDMA burst synchronization, demand assignment, link control and payload control are supported by the network control computer.

A typical TDMA trunk station shown in Figure 2-9 is identical to the trunk service portions of the MCT. It includes the TIM, microprocessor controlled TDMA terminal, and diversity switch. One of the two antenna sites is collocated with the station and the remote antenna site is connected by a microwave link.

There are two types of CPS stations considered for this system (Figure 2-10). One is a 5 meter antenna station which handles the 128 Mbps

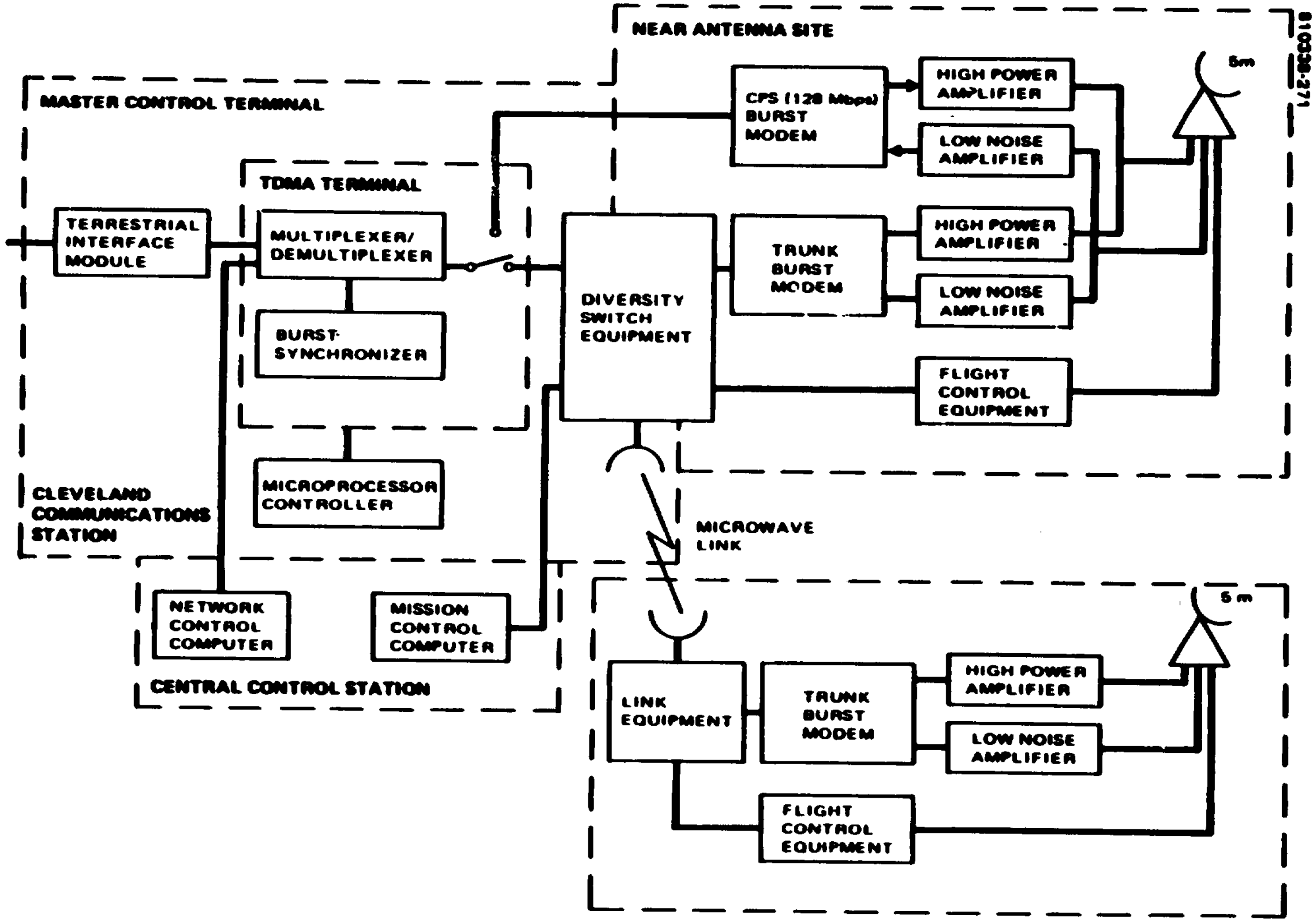


FIGURE 2-8. MASTER CONTROL TERMINAL

uplink burst rate and the other is a 3 meter antenna station with a 32 Mbps uplink to burst rate. The downlink burst rate is 256 Mbps for both stations. TDMA synchronization is accomplished with burst synchronizer and formatting, and decommutation is handled by microprocessor.

The RF parameters of the earth terminals are given in the next section.

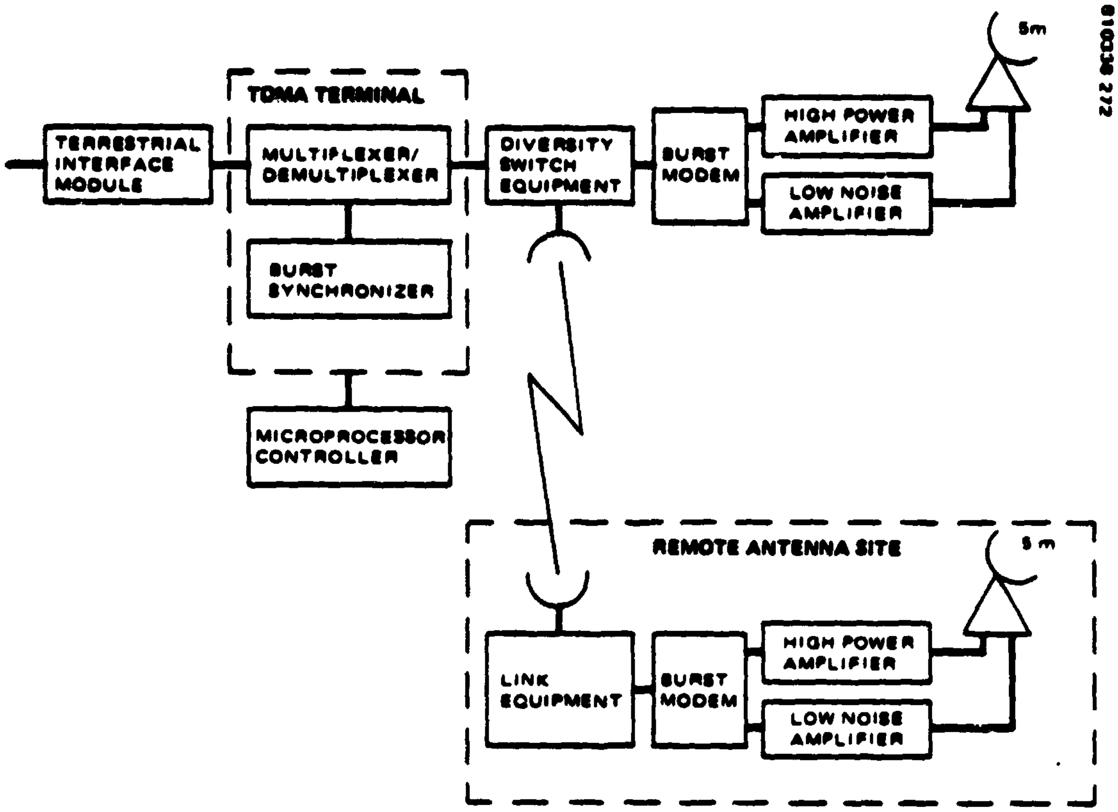


FIGURE 2-9. TDMA TRUNK STATION

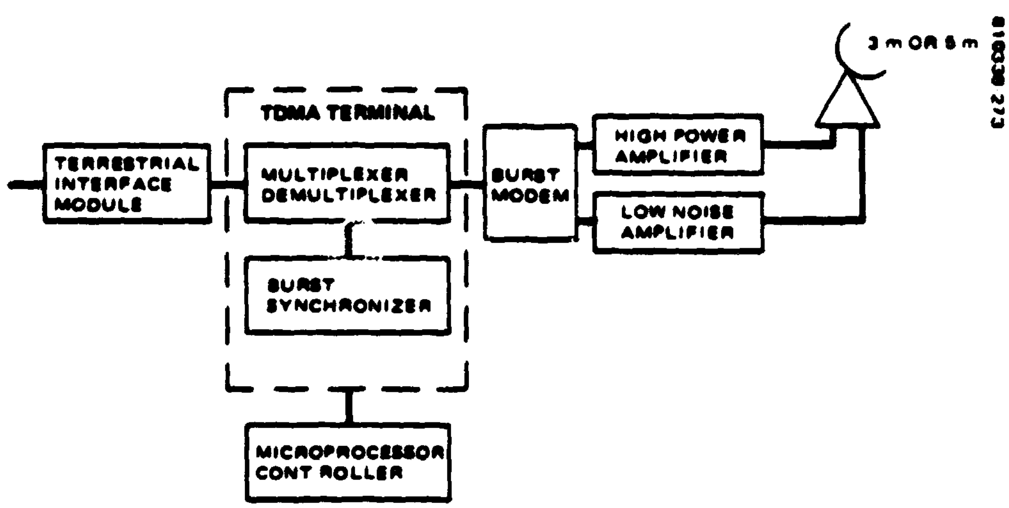


FIGURE 2-10. TDMA CPS STATION

2.1.6 Communication Link Performance

2.1.6.1 Spacecraft RF Performance

The spacecraft RF performance is summarized in Table 2-3. The antenna performance is for a beam pointed at the vicinity of New York. This beam is approximately 3 degrees from the antenna boresight. Consequently, it suffers a loss of 1.6 dB on receive and 1 dB on transmit due to off axis defocussing. The contour level loss suffered by the antenna in the CPS mode results from the requirement for contiguous coverage. The stated loss is for a feed system in which each spot beam is associated with a single feed. This loss can be reduced by more complex feed structures; however, except for an experiment involving two feeds, the performance of the simpler arrangement was accepted. Also, a higher gain is available over most of the coverage area. As shown in Figures 2-11(a) and (b) the loss can be reduced from 8 dB in transmit to about 4 dB by giving up 14 percent of the area and to 3 dB by sacrificing 35 percent of the area.

The transmit circuit loss for both TS and CPS includes 0.15 dB for the circular switches used to select the power amplifier, 0.3 dB for five feet of WR51 waveguide from the output circuits to the antenna feed.

TABLE 2-3. SPACECRAFT RF PERFORMANCE

	19.0 GHz		28.8 GHz	
Antenna	Trunk	CPS	Trunk	CPS
Diameter, m	3	3	3	3
Peak gain (3° from boresight), dB	53.1	53.1	56.1	56.1
Contour level, dB	-	8.1	-	7.1
Feed loss, dB	1.6	1.9	0.9	0.9
Net gain, dB	51.5	43	55.2	48.1
	TWTA		SSPA	
Transmit (19 GHz)	Trunk	CPS	Trunk	CPS
Power out, dBW	16 (40 W)	16 (40 W)	8.5 (7 W)	8.5 (7 W)
Circuit loss, dB	-0.45	-0.45	-0.45	-0.45
Power to antenna (dBW)	15.5 (36 W)	15.5 (36 W)	8 (6.4 W)	8 (6.4 W)
EIRP, dBW	67	58.5	59.5	51
Receive (28.8 GHz)	CPS		Trunk	
Antenna temperature, °K	290		290	
Receiver noise figure, dB	5 (627°K)		5 (627°K)	
Circuit loss, dB	-0.4		-0.7	
System noise temperature, dB-°K	30		30.3	
G/T, dB	18.1		24.9	

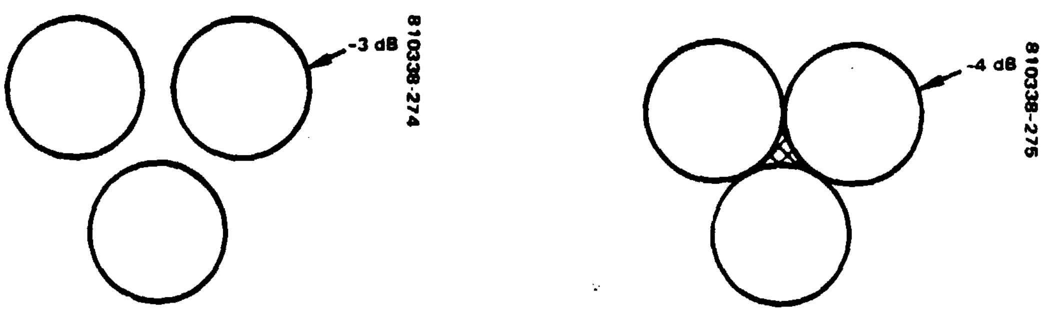
The satellite receiver noise figure is for a four stage GaAs FET amplifier with a 4.9 dB noise figure and about 30 dB of gain followed by a receiver with a 7.5 dB noise figure. The circuit loss is made small by the placement of the LNAs near the feeds. The trunk loss is slightly higher because of the associated redundancy and configuration switches.

2.1.6.2 Earth Terminal Performance

The performance of the earth station RF is shown in Table 2-4. The antenna diameter was specified by NASA. The 5 meter CPS stations are capable of a 128 Mbps uplink. The 3 meter stations are limited to 32 Mbps. The antenna efficiency is 60 percent before accounting for surface tolerance losses of 2.0 dB at 30 GHz and 1.0 dB at 20 GHz. These losses are based on a tolerance of 0.64 mm rms and an F/D of 0.5. The maximum transmitter

TABLE 2-4. TERRESTRIAL RF PERFORMANCE

	Trunk	CPS	
Antenna Diameter, m	5	5	3
28.8 GHz			
Transmit gain, dB	59.7	59.7	55.3
Transmit loss, dB	-1.3	-1.3	-1.3
Transmitter power, dBW	21 (125 W)	13 (20 W)	13 (20 W)
EIRP, dBW	79.4	71.4	67
19 GHz			
Receive gain, dB	57.2	57.2	52.7
Receive loss, dB	-0.5	-0.5	-0.5
Sky noise temperature, °K	260	260	260
Receiver noise figure, dB	1.9	1.9	1.9
System noise temperature, dB °K	26.8 (479°K)	26.8	26.8
G/T	30.4	30.4	25.9



a) 35 PERCENT TOTAL COVERAGE AREA LOSS

b) 14 PERCENT TOTAL COVERAGE AREA LOSS

FIGURE 2-11. REDUCED AREA COVERAGE

power for the trunk service is 125 watts. In clear weather the transmitter is backed off by 18 dB. The power is continuously adjusted to match the rain attenuation. The 5 meter CPS terminal transmitter has a saturated output of 20 watts for the 128 Mbps signal. The 3 meter CPS terminal uses the same transmitter for the 32 Mbps signal.

The sky noise temperature in clear weather is only 60°K but a sky temperature of 260°K is used to compute the system temperature because of the increase in sky temperature when rain attenuation is present. This high sky temperature reduces the benefit obtained by cooling the low noise amplifier. A GaAs FET noise figure of 1.9 dB is expected to be achievable at room temperature for this mission. Cooling would improve G/T less than 1 dB.

2.1.6.3 Trunk Link Budget

The trunk link budget is shown in Table 2-5. The basis for the EIRP and G/T were given in the previous sections.

The earth station antenna pointing error includes ±0.02° for spacecraft orbital motion and ±0.03° due to antenna setup errors and environmentally induced errors. This error could be reduced to a negligible value by autotracking or, perhaps, steptracking and might be reducible by more elaborate setup procedures and a more expensive structure. The potential

TABLE 2-5. TRUNK LINK BUDGET (dB)

Component	Uplink, 28.8 GHz	Downlink TWTA, 19 GHz	Downlink SSPA, 19 GHz
EIRP, dBW	79.3	67	59.5
Pointing loss (transmit)	1.5	0.2	0.2
Path loss	213.1	209.5	209.5
Rain attenuation	18	8	0.5
Atmospheric loss	0.7	1	1
Pointing loss (receive)	0.6	0.7	0.7
G/T (dB/°K)	24.9	30.4	30.4
Boltzmann's Constant, dBW/°K	-228.6	-228.6	-228.6
C/N_o	98.9	106.6	106.6
C/N_o, end-to-end		98.2	98.2
Data rate (256 Kbps)		84.1	84.1
E_b/N_o		14.1	14.1
E_b/N_o, required		14.1	14.1

reduction of the downlink pointing loss of 0.7 dB does not justify the additional expense and, although the uplink loss of 1.5 dB is considerable it appears less costly to compensate with increased transmitter power. Improvements in antenna technology could alter this conclusion. The polarization loss due to depolarization by rain is considered part of the rain attenuation.

The link requirement that E_b/N_o = 14.1 dB includes 3.5 dB for implementation, interference, and nonlinearity degradations and 10.6 dB to achieve a 10^{-6} BER.

The 40 watt TWTA, required by NASA for reasons of technology development, allows the trunk link requirement to be satisfied with a 120 watt earth terminal transmitter. When the 7 watt SSPA is used the link requirements can only be met with a 0.5 dB downlink rain margin rather than the required 8 dB. The 8 dB margin could be restored by increasing the earth terminal transmitter output to 550 watts.

2.1.6.4 CPS Link Budgets

The CPS uplink budget is shown in Table 2-6. The downlink budget is shown in Table 2-7. Because of the regeneration of the digital signals by the BBP the up and downlinks are independent and each is allocated one-half

TABLE 2-6. CPS UPLINK BUDGET

Component	5 m (128 Mbps)	3 m (32 Mbps)
EIRP, dBW	71.4	67.0
Pointing loss	1.5	1.5
Atmospheric loss	0.7	0.7
Path loss	213.1	213.1
Rain attenuation prior to use of FEC	7.6	7.6
G/T	18.1	18.1
Boltzmann's Constant (dBW/°K)	-228.6	-228.6
C/N_o	95.2	90.8
Data rate	81.1	75.1
E_b/N_o	14.1	15.7
Rate change gain	3	3
Coding gain	4.4	4.4
Additional rain attenuation when FEC applied	7.4	7.4
Equivalent E_b/N_o at maximum attenuation	14.1	15.7
Required E_b/N_o	14.1	14.1
Margin	0	1.6

TABLE 2-7. CPS DOWNLINK BUDGET (256 Mbps)

Component	5 m		3 m	
	TWTA	SSPA	TWTA	SSPA
EIRP, dBW	58.5	51.	58.5	51.
Path loss	209.5	209.5	209.5	209.5
Rain attenuation prior to FEC	2.	1.1	2.	0
Atmospheric loss	1.	1.	1.	1.
Pointing loss	0.7	0.7	0.7	0.7
G/T	30.4	30.4	25.9	25.9
Boltzmann's Constant (dBW/°K)	-228.6	-228.6	-228.6	-228.6
C/N_o	104.3	98.2	99.8	94.3
Data rate	84.1	84.1	84.1	84.1
E_b/N_o	20.2	14.1	15.7	10.2
Rate change gain	3	3	3	3
Coding gain	4.4	4.4	4.4	4.4
Additional rain attenuation when FEC applied	7.4	7.4	7.4	3.5
Equivalent E_b/N_o at max. rain attenuation	20.2	14.1	15.7	14.1
Required E_b/N_o	14.1	14.1	14.1	14.1
Total rain margin	15.5	8.5	11	3.5*

*If FEC used on all channels

of the 10^{-6} bit error rates. The theoretical requirement for a BER = 0.5 x 10^{-6} is E_b/N_o = 11.1. Three dB is added for impairments and interference for a total of 14.1 dB.

The uplink losses are the same as for the trunk link discussed above. The rain attenuation, however, is handled differently because of the use of FEC. The total uplink rain margin is required to be 15 dB. FEC provides a gain of 7.4 dB of which 3 dB is due to a 2 to 1 reduction of the bit rate when the rate 1/2 coding, is applied and the burst rate is unchanged. Thus, a 7.6 dB power margin is required to complete the 15 dB rain margin. All rain attenuation up to 7.6 dB is accommodated by boosting the terminal transmitter power. The FEC is only applied when the attenuation exceeds 7.6 dB because a coded channel requires twice as much of the TDMA frame as an uncoded channel. The received E_b/N_o remains at the clear weather values of 14.1 dB and 15.7 dB for the 5 and 3 meter stations respectively until the attenuation exceeds 7.6 dB at which time FEC is applied and E_b/N_o increases. As the attenuation increases to 15 dB the effective E_b/N_o drops to the clear weather value. Note that the ratio of symbol energy to noise density, E_b/N_o, never drops below 9.6 dB so the coding gain does not fall below 4.4 dB.

The downlink data rate is 256 Mbps for all cases. The normal mode is to use the TWTA. A 2 dB power rain margin is provided so that FEC will not be required for low rain rates which occur frequently. When the attenuation exceeds the power margin, the FEC is applied. Again the 40 watt TWTA is oversized so that a high E_b/N_o is obtained when 6 dB of rain attenuation is experienced. Thus, a total rain margin of 16 dB is available for the 5 meter earth terminal. Another way of presenting the link budget would allot a 8.6 dB power margin so that FEC would only be required when the attenuation exceeded that value. The total rain margin is still 16 dB. A similar situation obtains for the 3 meter earth terminal with a total margin of 12.2 dB. Of course if the downlink rain attenuation reached these values the uplink would not be available because the attenuation at 30 GHz would exceed the available margin.

When the SSPA is used with the 5 meter terminal the rain margin still exceeds the required 6 dB; however, the combination of SSPA with 3 meter terminal requires FEC even in clear weather. Thus, if a TWTA failed and were replaced by an SSPA only coded signals could be successfully transmitted to the 3 meter terminals.

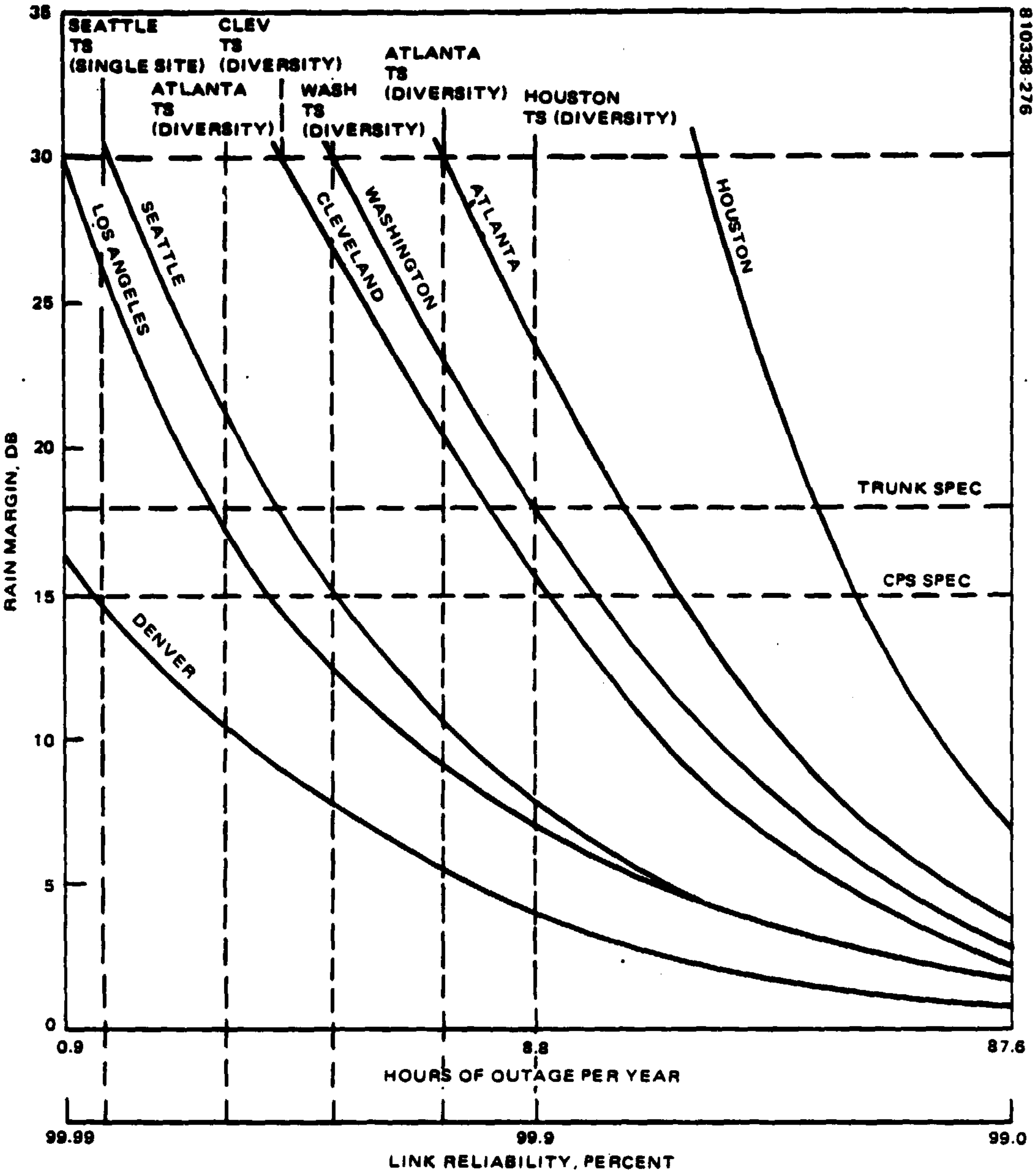
2.1.7 Propagation Reliability

The performance of the communication system and the resulting rain margins were discussed in the previous section. An estimate of the propagation reliability associated with these margins is given in this section.

The relation between rain margin and the percentage of the time that links are out of service because of rain is not generally established. Experimental data exists for a very limited number of locations in the United States and for very limited periods (1 or 2 years). Because of the great variations in rain rate characteristics between even areas in the same rain zone and from year to year it is difficult to extrapolate this data to predict rain outage in a particular location for any year or to predict rain outage averaged over a long period of time (e.g., 10 years). Another approach to estimating rain outage is to use one of the models which has been developed for this purpose. The model divides the world into rain zones. Each zone is associated with a frequency distribution of rain rate. The model combines this data with the physics of rain attenuation and a model of rain height to determine the frequency distribution of rain outage.

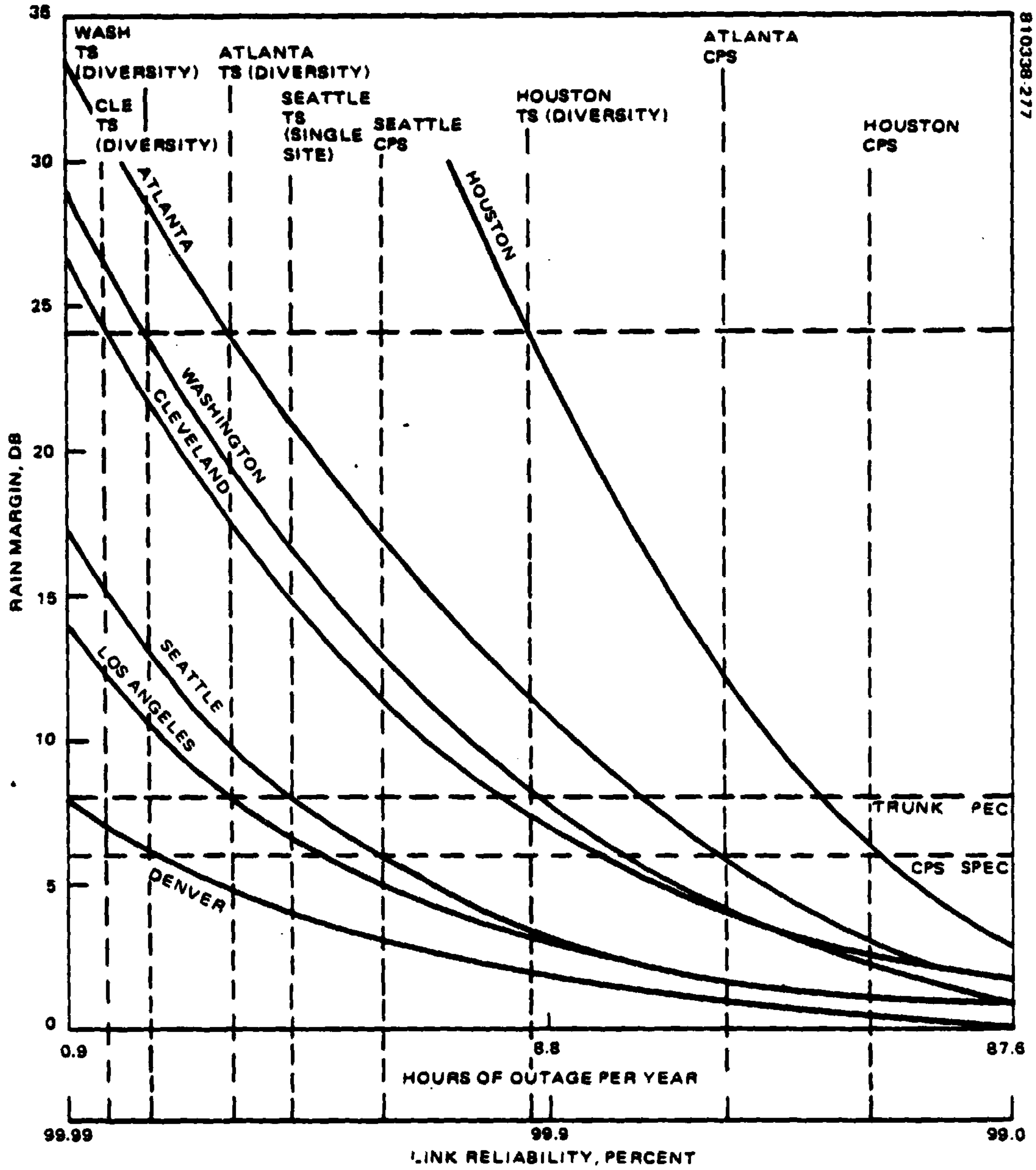
The modified Global Prediction Model (Cruse and Blood, 1979) presented in the NASA Communications Division Publication "A Propagation Effects Handbook for Satellite Systems Design" pages 6-18 to 6-26 was used to develop the propagation reliability estimates presented below.

For each selected location ground station latitude, longitude and altitude, and satellite elevation angle are entered into the model. Results are shown in Figure 2-12(a) for the 20 GHz downlink and in Figure 2-12(b) for the 30 GHz uplink. Results are given in terms of the propagation



a) 30 GHZ UPLINK

FIGURE 2-12. LINK RELIABILITY



b) 20 GHZ DOWNLINK

FIGURE 2-12 (CONTINUED). LINK RELIABILITY

reliability or hours per year of outage as a function of the rain margin provided. The specified rain margins are shown. For the 20 GHz downlink the specified rain margins are 8 dB for the trunk and 6 dB for the CPS. The lowest propagation reliability in the system is, as expected, the Houston CPS link which has a reliability of 99.5 percent. This reliability is also achieved on the 30 GHz uplink indicating a good balance of rain margins. The single site trunk reliability is only slightly better; however, site diversity is available for trunk sites. The diversity improvement was estimated using the technique of Goldhirsch and Rohrsik. For a 14 km site separation, a single site attenuation of 24 dB at 20 GHz is associated with a diversity gain of 16 dB. Thus, when an 8 dB rain margin is provided at each of two reundant sites the resulting propagation reliability is the same as would be achieved by providing a 24 dB rain margin at a single site. The resulting reliabilities are shown for several downlinks. Similar results are obtained at 30 GHz.

For a link to be useful in most applications it is necessary that the link be available in both directions. The propagation reliability of some duplex trunk circuits is given in Figure 2-13 and for CPS links in Figure 2-14. The use of diversity saves about 24 hours per year on the Houston-Washington circuit and about 11 hours on the LA-Washington circuit. Almost all of the gain on the LA-Washington circuit is due to the diversity of Washington. In general, it does not appear cost effective to apply diversity to terminals in the arid West since the single site reliability of these stations is higher than the reliability with diversity in the rainy areas of the country. The reliability of the CPS circuits which terminate at an Eastern city run between 99.5 percent and 99.9 percent for the specified rain margins.

2.1.8 Telemetry Tracking and Command

The telemetry tracking and command (TT&C) system will operate on two frequency bands. During transfer orbit, the TT&C system will operate at S band in conjunction with the NASA STDN network. Once the satellite is at its orbital station, the TT&C function will operate through the 30/20 GHz payload as discussed below. If the 30/20 GHz TT&C link should become unavailable because of an anomaly or severe rain attenuation the on-station TT&C function can return to the S band mode. The S band TT&C links operate through the NASA standard near earth transponder (NASA/SNET).

The satellite TT&C configuration is shown in Figure 2-15. When the satellite is in its normal on-station mode it receives the 30 GHz carrier containing the command and ranging information on the Cleveland beam of the multibeam antenna. As shown previously in the payload block diagram, the uplink TT&C signals are always continuously available whether the Cleveland beam is being used as a fixed beam in the trunk mode or as a scanning beam in the CPS mode. The TT&C signal is separated from the communication uplink by a frequency diplexer and downconverted to the NASA/SNET frequency.

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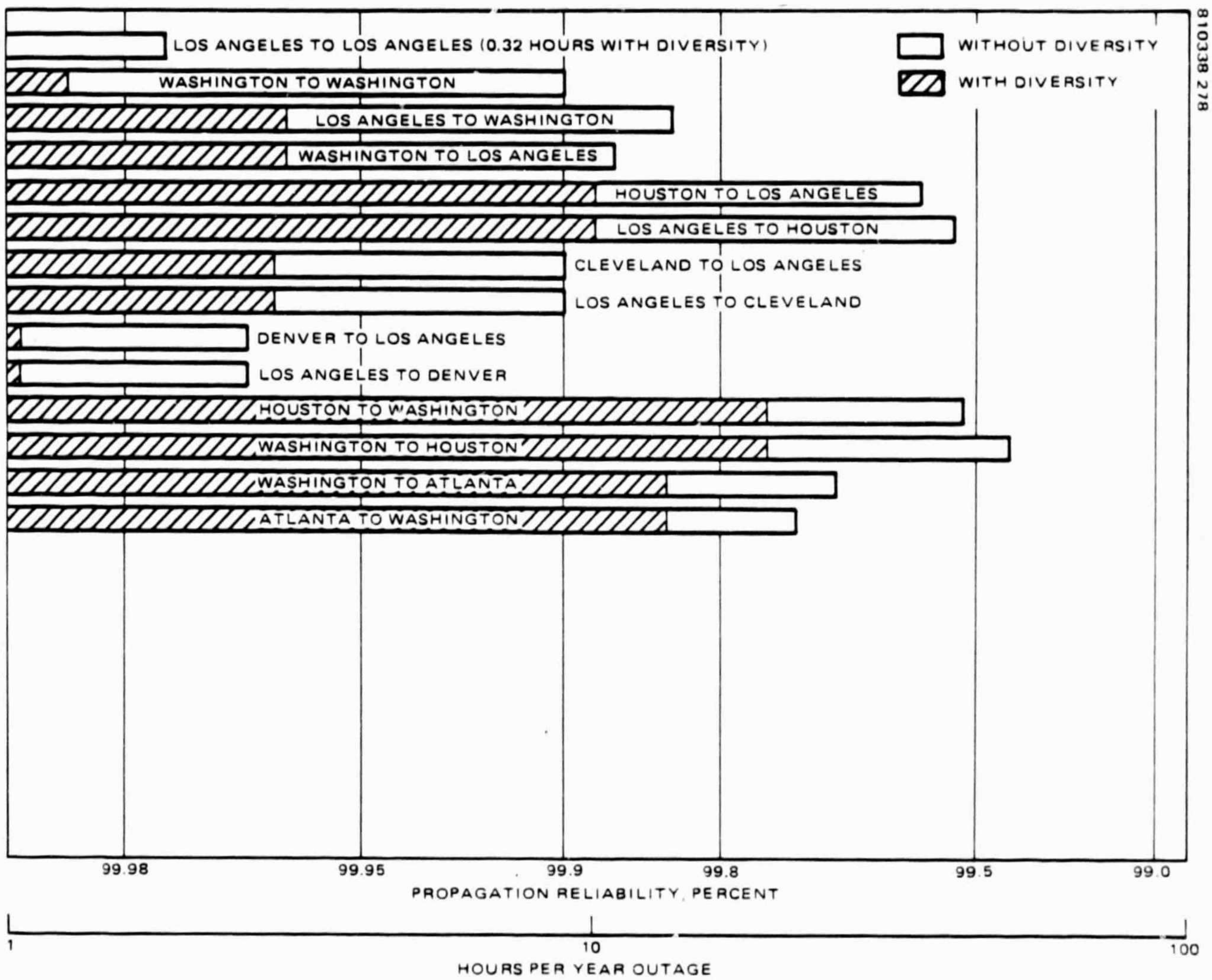

FIGURE 2-13. DIVERSITY RECEPTION AND TRANSMISSION EFFECT ON TRUNK LINE RAIN OUTAGE

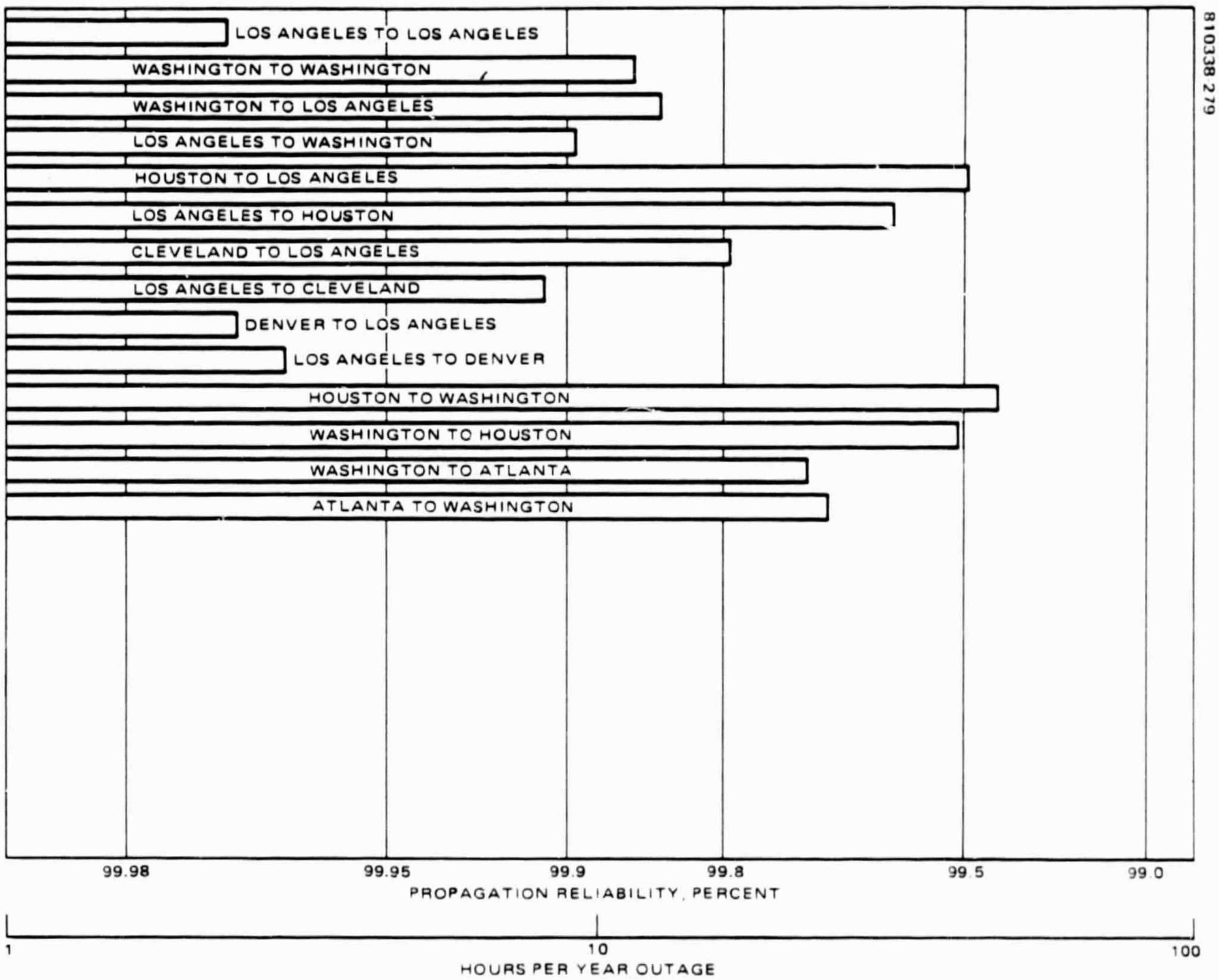

FIGURE 2-14. CPS LINKS EXPECTED RAIN OUTAGE

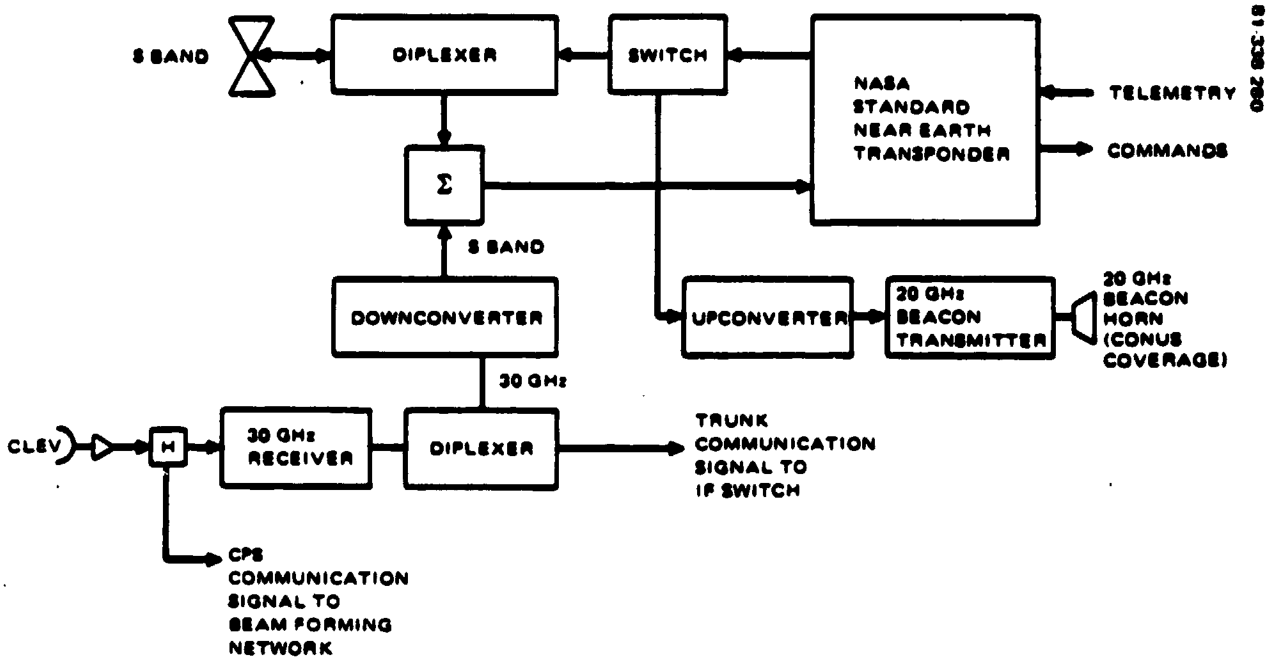

FIGURE 2-15. SATELLITE TT&C CONFIGURATION

The input signal to the NASA/SNET is identical to that received on the STDN uplink. The S band telemetry and ranging signal generated by the NASA/SNET can be switched between the S band antenna and the 20 GHz upconverter. The upconverted signal is transmitted over the 20 GHz beacon which also serves the experiment plan discussed in the next section. The beacon transmitter is an 0.5 watt GaAs FET amplifier. The beacon antenna is a horn with half power beamwidth of approximately 3 by 6 degrees which covers all of the contiguous United States.

2.1.9 Payload Weight and Power

Table 2-8(a) summarizes the weight of the spacecraft payload. This weight is well within the capability of the LEASAT bus. Table 2-8(b) gives the prime power requirement imposed by the payload. In the trunk mode, which sizes the solar panels, the largest user is the transmitter whose 4 TWTAs consume 460 watts. When a 7 watt SSPA replaces a 40 watt TWTA, the power requirement drops by 43 watts. In the CPS mode only two transmitters are used. This power savings offsets the requirement of the BBP.

Another power related spacecraft problem is that of dissipating heat generated on the payload platform. Table 2-8(c) summarizes this dissipation. Again, the power dissipated by the BBP in the CPS mode is offset by the reduction of TWTA dissipation.

TABLE 2-8(a). SPACECRAFT PAYLOAD WEIGHT

Item	Weight, lb
Antenna	189
Microwave	127.4
Baseband processor	111.2
Total	427.6

TABLE 2-8(b). SPACECRAFT PAYLOAD POWER REQUIREMENT

Item	Trunk Mode, W	CPS Mode, W
Antenna	2	10
Microwave	521	268
Baseband processor	41	225
Total	564	503

TABLE 2-8(c). PAYLOAD POWER DISSIPATION

Item	Trunk		CPS	
	4 TWTAs	2 TWTAs/2 SSPA	2 TWTAs	1 TWTA/1 SSPA
Antenna	31	17	20	12
Equipment platform				
Microwave	377	346	196	181
BBP	41	41	225	225
Equipment platform Total	418	387	421	406
Payload total	449	404	441	418

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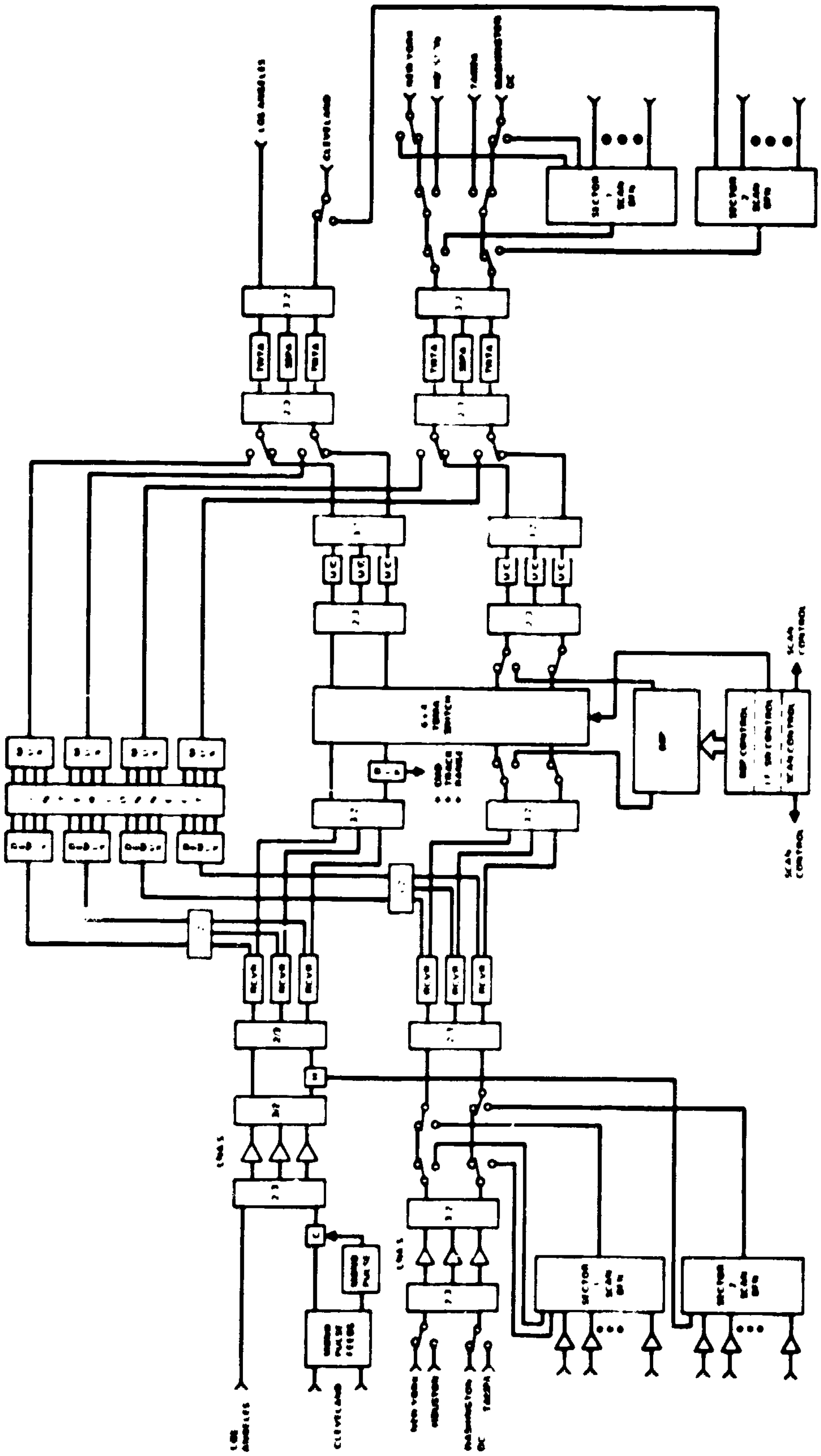


FIGURE 2-16. OPTION 2 SPACECRAFT FUNCTIONAL BLOCK DIAGRAM

2.1.10 Options

Two options, specified by NASA, were examined to determine their impact on spacecraft weight, power, and cost. Option 1 is to eliminate one of the two CPS scanning beams and to reduce the throughput of the remaining beams from four 32 Mbps and one 128 Mbps uplink channels to a pair of 32 Mbps channels. The downlink burst rate is reduced from 256 Mbps to 128 Mbps.

The purpose of considering Option 1 was to reduce payload weight and cost and increase the spacecraft weight margin. The weight saving in the antenna is only 16 pounds because the reflector system, antenna support structure, and telemetry are unaffected. The BBP weight reduction of 33 pounds is more significant. The BBP power requirement in the CPS mode is reduced from 225 watts to 89 watts but the solar power requirements are driven by the trunk mode. In any case, neither weight nor power differences impact the choice of spacecraft bus.

Option 2 adds a four beam by four beam FDMA routing experiment to the baseline communication system as shown in Figure 2-16. The nodes selected for the FDMA experiments are the same as the fixed trunk beams in the baseline. Full interconnectivity is provided by the waveguide connections.

Option 2 does not significantly affect power and only increases payload weight by 16 pounds. Since payload weight margin is more than adequate it appears that this experiment would be accommodated.

2.2 COMMUNICATION SYSTEM CONTROL

The design and performance of the communication links have been summarized in Section 2.1. This section describes the functions of the system which controls the operation of these links. Several aspects of the communications system and its use must be controlled.

1) Channel access. In an operational system with many users whose traffic requirements vary over time and location it is necessary for efficient operation to assign time and frequency channels to users as they are needed and in a way that avoids interference between users. The problem of controlling channel access is discussed in 2.2.1.

2) System synchronization. In order to implement the control of channel access it is necessary to synchronize earth station transmissions with each other and with the spacecraft switching functions. The method for doing this is described in 2.2.2.

3) Link control. Rain margins for a 30/20 GHz system will be considerably larger than those provided at C and Ku Band. In order to maintain uplink carrier to interference ratio it is necessary to control earth station transmitter power so that the carrier power density of all signals received at the spacecraft are approximately equal. This requires that the transmitter power vary with rain attenuation. This problem is discussed in 2.2.3.

4) Payload control. The spacecraft payload has an IF switch matrix for trunk service, a baseband switch for customer premise service and a scanning beam antenna which uses a beam switching arrangement. Another set of switches controls the flow of coded signals to the baseband processor decoders. Subsection 2.2.4 describes the method of controlling the format and sequence of these switching operations.

5) Station control. The operation of the stations is monitored and controlled (in part for manned stations) by the central control station. This task is discussed in 2.2.5.

2.2.1 Channel Access

In the 30/20 GHz flight experiment channel access is primarily a CPS problem. In the trunk system the spacecraft routing between uplink and downlink beams is preassigned. The user facility has the responsibility of multiplexing data from its individual sources into sets of data. Each set is composed of data for a particular downlink beam. The user facility informs the earth terminal of the composition of the data stream. The earth terminal has the responsibility of transmitting each of these sets of data at a time such that the spacecraft IF switch routes it to the proper downlink.

CPS data is not preassigned. Unlike the trunk service, the CPS portion of the satellite communication system sets up a TDMA channel for each message. The routing in the BBP is revised for each message initiation or termination. The satellite antenna scanning format, however, is preassigned. When an individual source initiates a call the earth terminal will forward the channel request to the master control terminal (MCT) which will assign a time slot for the data and notify the BBP when in the frame the signal will be received and where it is to be routed.

2.2.2 System Synchronization

Each earth station transmission in this SS TDMA system must be synchronized so that the burst reaches the satellite coincident with the satellite window for that burst. In the trunk system the window is established by the IF switch matrix which sets up a connection to route the burst to the intended downlink. In the CPS system the window is established by the BBP which assigns a destination to each received burst according to the time it is received. If CPS terminals are synchronized with their BBP windows they will automatically avoid interference with uplinks from other terminals in the same beam. Trunk terminals do not share beams in this system; however, if there was more than one trunk station in a beam the same principle would apply.

The NASA specification requires closed loop synchronization for both trunk and CPS systems. Hughes has conceived closed loop synchronization schemes which make use of the spacecraft switching to minimize the earth terminal hardware requirements and the dependence of earth terminals on the MCT. These schemes are described in the following sections.

2.2.2.1 Trunk Synchronization

Trunk synchronization involves timing the uplink burst transmissions so that they arrive at the spacecraft when the IF switch is in the proper state to route the signals to the desired destination. In order to allow trunk stations to synchronize these transmissions with the IF switch matrix, a loopback subframe is provided in the TDMA frame. During this subframe the uplink signals are routed back to the transmitting terminal. By measuring the truncation of a metric code by the beginning or end of the IF switch loopback subframe the terminal can determine whether its burst is early, late, or on time. An initial estimate of the burst time is derived from orbit data by the MCT. Burst times are measured from a downlink frame synchronization burst received by the terminal from the MCT via the satellite communication link.

2.2.2.2 CPS Synchronization

CPS sychronization is similar to trunk synchronization except that the BBP measures the position in the frame of the metric code received from the terminal relative to the assigned location and reports the error back to the transmitting terminal. By synchronizing with the BBP the terminal automatically synchronizes its burst with the scanning beam and with other terminals in the same spot.

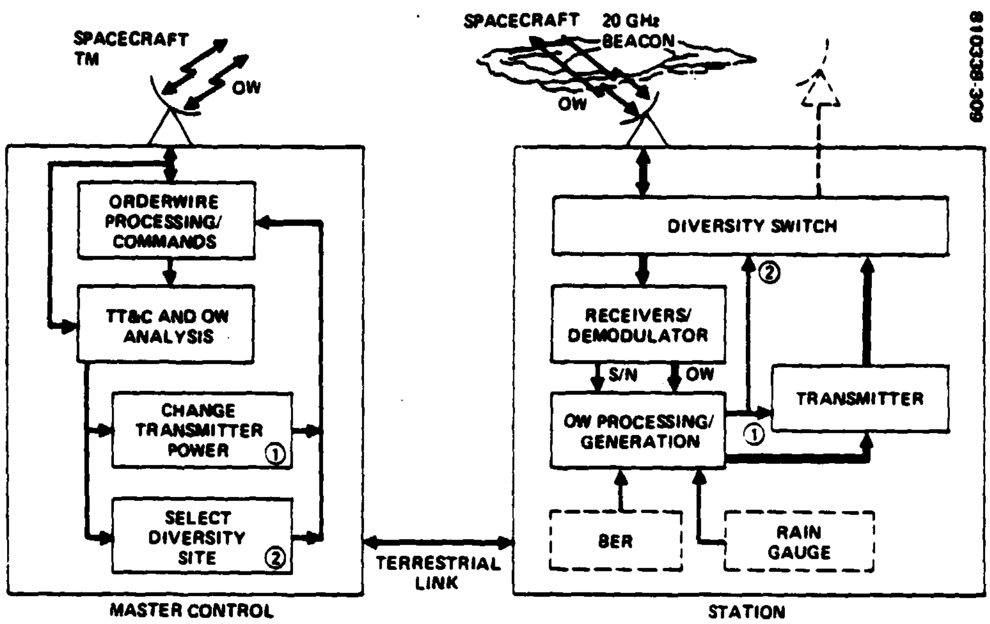


FIGURE 2-17. TRUNKING SITE LINK CONTROL

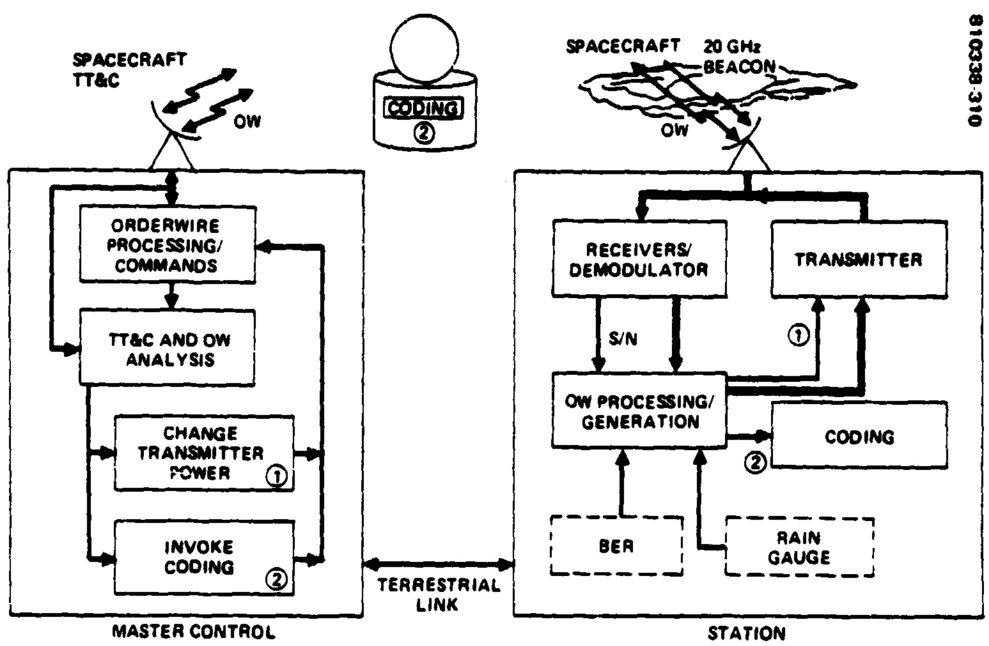


FIGURE 2-18. CPS LINK CONTROL

2.2.3 Link Control

An important characteristic of any operational system at 30/20 GHz is its approach to maintaining high propagation reliability despite the severe degradation associated with realistic rain rates. Because of the uncertainties in the statistics of this degradation and the novelty of the techniques which are appropriate to this band, the demonstration of these techniques is an important objective of the 30/20 GHz experiment program. The techniques applied in the experiment programs are uplink power control at both the trunk and CPS stations, site diversity at the trunk stations, and forward error correction coding in the CPS subsystem.

2.2.3.1 Trunk Station Link Control

Control of the trunk station link margin is illustrated in Figure 17. The trunk station measures the signal to noise ratio of the 20 GHz spacecraft beacon signal. These measurements are either relayed to the CCS for analysis or processed by the local microprocessor computer. As the S/N decreases due to rain, the station begins to increase its transmitter power (1). When the transmitter power limit is reached, the CCS or trunk station initiates diversity switching (2). In addition to the beacon signal, the CCS receives rain gauge, BER, and spacecraft received signal strength measurements which can be used for link margin control decisions. The implementation of site diversity is discussed in the Terrestrial Segment, Trunk Station Section.

2.2.3.2 CPS Station Link Control

Control of the CPS station link margin is illustrated in Figure 18. The CPS station measures the signal to noise ratio of the 20 GHz spacecraft beacon signal. These measurements are either passed to the CCS for analysis or processed in the local microprocessor computer. The uplink transmitted power is adjusted to match rain attenuation. When the transmitter power limit is reached, coding is invoked by the CCS. Bit error rate, rain gauge data and satellite received signal strength measurements are also available for link control decisions.

2.2.4 Payload Control

The most flexible satellite processor design concept is to use programmable random access memory (RAM) sequence controllers for each of the multiple access switching modes: trunking IF switch, CPS store and forward processor, and scanning beam controller. A circuit assignment change is made by the central control station reloading the appropriate RAMs via the command or data channel. For instantaneous frame changeover, a ping-pong set of RAMs is used, updating a memory at a slow control channel rate. The master station accumulates assignment changes and implements total system frame changeover at pre-established sync times. The payload control requirements were developed for this design concept implementation.

2.2.5 Station Control

All remote trunk and CPS stations are under control of the CCS. The remote stations send station status and configuration messages to the CCS via the orderwire or a terrestrial link. The CCS in turn sends experiment

TABLE 2-9. SERVICE EXPERIMENTS

Experiment as Designated in NASA LeRC "Experiments Planning Document," June 1980		
ID No.	Title	Experiments in This Plan
PS-1	30/20 GHz Propagation Measurements	5.2, 6.5
PS-2	Prop Constraints on Digital Systems	6.3, 8.2
PS-3	Prop Constraints on Scanning MBA Systems	8.2
PS-4	Above 40 GHz Propagation	Equipment not available in baseline system
PS-5		
PS-6		
PS-7		
PS-8	Demon of Voice, Video and Data Services	Carrier experiment
PS-9	FDMA/TDMA Operational Comparison	Carrier experiment, Option 2
PS-10	Bit Stability During Switching	6.2
PS-11	Customer Premise Station	
PS-12	Demand Assignment Control for CPS	7.2
PS-13	Narrowband FDMA System	Carrier experiment
PS-14	System Synchronization Evaluation	4.3, 6.4, 7.1, 8.2
PS-15	Heavy Route Trunking Applications	Carrier experiment; see PS-8
PS-16	Long Haul Spacecraft Compatibility Experiment	Carrier experiment
PS-17	Long Haul Space Diversity Experiment	Carrier experiment
PS-18	Service Demand Experiments - Non-Diversity	Carrier experiment
PS-19	Service Demand Experiments - Diversity	Carrier experiment
PS-20	Dynamic Traffic Model - Trunking	Carrier experiment
PS-21	Dynamic Traffic Model - CPS	Carrier experiment
PS-22	Dynamic Traffic Model - Combined	Carrier experiment
PS-23	C-Band and Ku-Band Experiments	Equipment not available in baseline system
PS-24	Synchronization Parameterization	4.3, 7.1
PS-25	Diversity Operation	6.2
PS-26	Link Power Control	6.1
PS-27	Propagation Availability	5.2, 5.3, 6.3, 6.5, 8.2
PS-28	Market Development Experiment	Carrier experiment; see PS-8
PS-29	Propagation Experiment	5.2, 5.3, 6.2, 6.3, 6.5
PS-30	User Acceptance	Carrier experiment
PS-31	30/20 GHz Propagation Phenomena	5.2, 5.3, 6.3, 6.5, 8.2
PS-32	Systems Impact of 30/20 GHz Propagation	3.1, 5.1, 6.1, 6.2
PS-33	30/20 GHz Propagation Experiment	5.2, 5.3, 6.3, 6.5, 8.2
PS-34	Test Market Experiment	Carrier experiment

directives, and reconfiguration commands to the remote stations. These messages are in addition to the normal exchange of channel assignments, link control, and synchronization messages required for normal operation.

2.3 EXPERIMENTS

Experiments are the primary objective of the 30/20 GHz flight experiment system. In this section, a detailed experiment plan is described and then the experiment operations are discussed.

2.3.1 Experiment Plan

2.3.1.1 Experiments Summary

The overall experiment plan has two primary objectives: 1) to evaluate and demonstrate the quality of communication service to be achieved in an operational system in the 30/20 GHz frequency band, and 2) to evaluate newly developed technologies whose performance is critical to successful operation in this band. Although the actual experiments to be conducted during the mission will be determined from the responses to the announcement of opportunities to experiment this plan is based on the NSAS LeRC "Experiment Planning Document," June 1980.

Experiments are broken into three categories: 1) service experiments (Table 2-9), 2) service and technology experiments (Table 2-10), and 3) technology experiments (Table 2-11). The ID numbers in the tables' left columns are the codes used in NASA's document; the right columns indicate the corresponding experiments in this plan with the first numbers indicating the segments and the category of experiments. Of 68 experiments in the Experiment Planning Document 58 are accommodated by the Hughes design.

TABLE 2-10. SERVICE AND TECHNOLOGY EXPERIMENTS

Experiment as Designated in NASA LeRC "Experiments Planning Document," June 1980		
ID No.	Title	Experiments in This Plan
PSAT-1	Air-to-Ground Communications	CPS user experiment
PSAT-2	Spread Spectrum Feasibility	Emergency service user experiment
PSAT-3	Multilevel TWT Control	Equipment not available
PSAT-4	Cophasing Parameterization	Equipment not available in baseline system
PSAT-5	Cophasing Stability Measurements	Equipment not available in baseline system
PSAT-6	Low Bit Rate FDMA/TDM	Carrier experiment; see PS-13
PSAT-7	Variable Bit Rate SS-TDMA	8.1
PSAT-8	Trunking and CPS Experiments	4.3, 6.1, 6.4, 7.1, 8.1, 8.2
PSAT-9	Space Diversity Experiment	6.2
PSAT-10	Adaptive Fade Compensation	6.1, 6.2, 8.1
PSAT-11	Adaptive Polarization	3.1, 5.1, 5.2, 6.5

TABLE 2-11. TECHNOLOGY EXPERIMENTS

Experiment as Designated in NASA LeRC "Experiments Planning Document," June 1980		
ID No.	Title	Experiments in This Plan
PT-1	Transponder Performance Evaluation	3.2, 4.1
PT-2	20 GHz TWT Transmitter Experiments	3.2.3, 4.1
PT-3	Multiple Spot and Scanning Beam Antenna Evaluation	3.1, 4.2, 7.2
PT-4A	Impatt Solid-State Transmitter	Equipment not available
PT-4B	GaAs FET Solid-State Transmitter	3.2.2, 4.1
PT-5		
PT-6	Intersatellite Relay	Equipment not available in baseline system
PT-7	IF Switch Matrix Performance Test	3.2.4, 4.1
PT-8		
PT-9	Baseband Processor Evaluation	3.2.5, 4.1
PT-10		
PT-11	Channel Interference Experiment	3.2.3, 4.1, 4.4
PT-12	Baseband Processor Error Detection and Correction	8.1
PT-13	Small Earth Station Dual Feed Experiment	Carrier experiment
PT-14	Intersatellite Link	Equipment not available in baseline system
PT-15	30/20 GHz Multiple Scanning Spot Beam Antenna	Equipment not available in baseline system
PT-16	Synchronization	4.3, 7.1
PT-17	Intersatellite Link Capability	Equipment not available in baseline system
PT-18	Fade Control Techniques	6.1, 6.2, 8.1
PT-19	Ground Terminal Technology	7.2
PT-20	Antenna Pointing Accuracy	4.2, 7.2
PT-21	Interference Assessment	4.4
PT-22	Intersatellite Link	Equipment not available in baseline system
PT-23	Network Link System Monitoring	6.1, 6.2, 8.1
PT-24	Multiple Carriers Per Amplifier	3.2.3, 4.1
PT-25	Beam Acquisition and Tracking	2.1, 3.3
PT-26	Prelaunch Simulation and Tests	1.1, 1.2
PT-27	Fundamental Flight System Tests	2.1
PT-28	Technology Experiments	3.2, 4.1, 7.2

3. COMMUNICATION PAYLOAD

The design for the communication subsystem components is presented in Section 3. Although NASA is funding technology development studies, which will result in proof of concept models for most of these components, the design presented in this report is a Hughes design. This approach is taken for two reasons. First, the technology studies were still in an early stage at the time the design was made; and second, Hughes considers that it will be more competent to reach correct make or buy decisions and to effectively procure components if it has been through the preliminary design process. At this time no decisions have been made regarding the source of any of the communication components. Make or buy decisions will be made early in the system definition phase (Phase B).

3.1 SATELLITE ANTENNA

3.1.1 Requirements

The performance requirements were discussed in Section 2.1 and are summarized in Table 3.1-1.

3.1.2 Antenna Design

As discussed in Section 2.1 a Cassegrain configuration has been selected to achieve an adequate F/D ratio. Other critical design issues are the selection of a technique to scan the CPS beams and the integration of the several antenna functions into a single physical antenna.

There are two methods of scanning independent multiple CPS beams using a dual reflector (Cassegrain) configuration with a spherical wave source. One method uses a small linear phased array which is imaged onto a large main reflector by a suitably designed pillbox feed system. This technique, which would distribute the high power amplification among the feed elements, is in too early a stage of development to consider for this flight experiment. Also, a single 40 watt power source for each beam has been specified. The other method uses an array of fixed feeds. A switching beam forming network routes receive and transmit power to or from a particular feed element or small group of feed elements. The beam is scanned by varying the switch connections in time. The latter technique has been adapted

TABLE 3.1-1. PERFORMANCE REQUIREMENTS FOR MULTIPLE BEAM ANTENNA

Service	Link	Trunking Fixed Beam	Customer Premise Scanning Beam
Half power beamwidth, deg	Up Down	0.27 recommended 0.4 specified	0.27 recommended 0.4 specified
Operational frequency range, GHz	Up Down	27.5 to 30.0 17.7 to 20.2	27.5 to 30.0 17.7 to 20.2
Bandwidth, GHz	Up Down	2.5 2.5	2.5 2.5
Number of beams	Up	4 simultaneously active (6 nodes)	2 simultaneously active
	Down	4 simultaneously active (6 nodes)	2 simultaneously active
Minimum peak gain 3 deg off boresight, dB	Down	51	51
Isolation between beams, dB	Up Down	≥26 ≥26	≥26 ≥26
Power handling capability, W	Down	40	40
Pointing accuracy, deg		0.04 (3σ)	0.04
Polarization	Both	Linear	Linear

for the flight experiment. The problems associated with successful use of this technique are discussed later in this section.

The number of separate functions performed by the antenna is illustrated in Table 3.1-2. In addition to transmit and receive functions for both CPS and TS it should be noted that for each CPS function there are two beams. It is desirable, in order to minimize antenna cost and spacecraft weight and complexity, to reduce the number of physical antennas in operational systems as well as for the flight experiment system. As shown below, Hughes has configured the antenna system with only one main reflector. This configuration provides separate transmit and receive feed systems.

Because of the use of fixed feeds as the basis of the scanning beam, those scanning beam feeds which point at trunk terminals can be used as the trunk feeds. Thus the trunk and CPS feed arrays can be combined. The two CPS beam feed arrays are essentially a single large feed array with separate switching networks. Thus they readily share the same antenna. The only problem, then, in satisfying all the antenna requirements with a single reflector is to separate transmit and receive feeds. It is undesirable to use common feeds for transmit and receive because it is difficult if not impossible to achieve adequate performance in a close packed feed array for both bands. Also, waveguide diplexers are lossy. Consequently, a means was sought to provide separate feed regions for transmit and receive.

TABLE 3.1-2. ANTENNA REQUIREMENTS FOR BASELINE SYSTEM

Four Antenna Functions	
1) Transmit TS signals	Six fixed spot beams ~0.4° HPBW
2) Receive TS signals	Six fixed spot beams ~0.3° HPBW
3) Transmit CPS signals	Two scanning spot beams two sectors ~0.4° HPBW
4) Receive CPS signals	Two scanning spot beams two sectors ~0.3° HPBW

The method selected is depicted in Figure 3.1-1. Two focal regions are created with a common aperture by utilizing a planar FSS. In this example, the common aperture is a subreflector of a dual reflector antenna system. The FSS spatially isolates the receive feed from the transmit feed with the receive feed located about the secondary focus of the subreflector and the transmit feed located about the mirror image of that focus. A two-layer FSS structure designed as a two-section transverse electromagnetic wave filter with the transmission characteristic depicted performs this desirable function. This approach was selected for use in the dual reflector configuration shown in Figure 3.1-2.

The selected antenna subsystem configuration is shown in side and front views in Figure 3.1-2. Three antennas comprise the subsystem: 1) communications; 2) tracking and command (T&C); and 3) beacon.

The communications antenna is an offset Cassegrain with a reflector diameter of 3 meters (10 feet) and a prime focal length of 3.66 meters (12 feet). Offset, subreflector aperture, and focal length dimensions are adjusted to allow use of a planar FSS between the subreflector and the secondary focus at which the receive feed is located. The FSS is inclined approximately 45° to the boresight symmetry plane of the reflector and designed for low transmission loss at receive frequencies and low reflection loss at transmit frequencies. The transmit feed is positioned at the mirror image of the secondary focus which is at the side of the FSS in the front view. This configuration spatially isolates the transmit and receive feeds and allows independent design optimization.

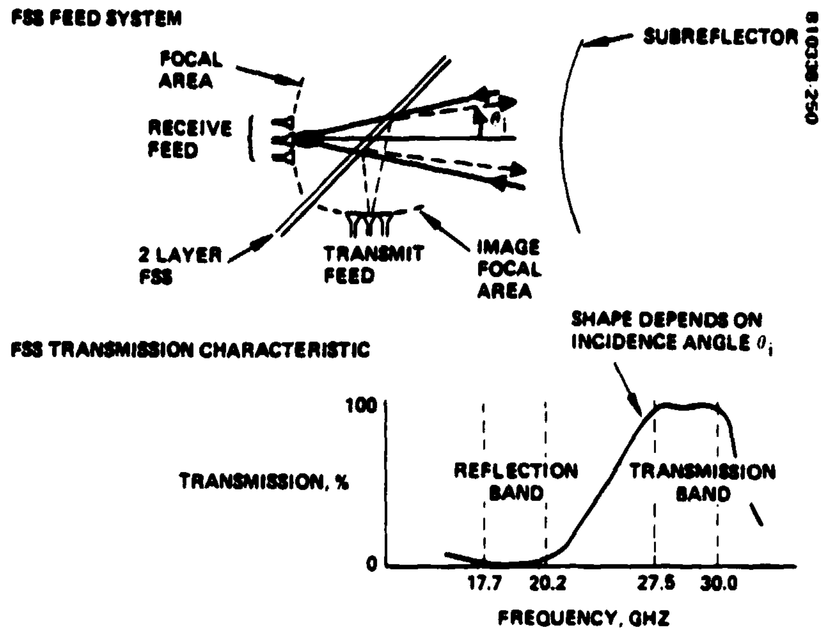


FIGURE 3.1-1. FREQUENCY SELECTIVE SURFACE CREATES TWO FOCAL AREAS FOR TWO SEPARATE FREQUENCY BANDS

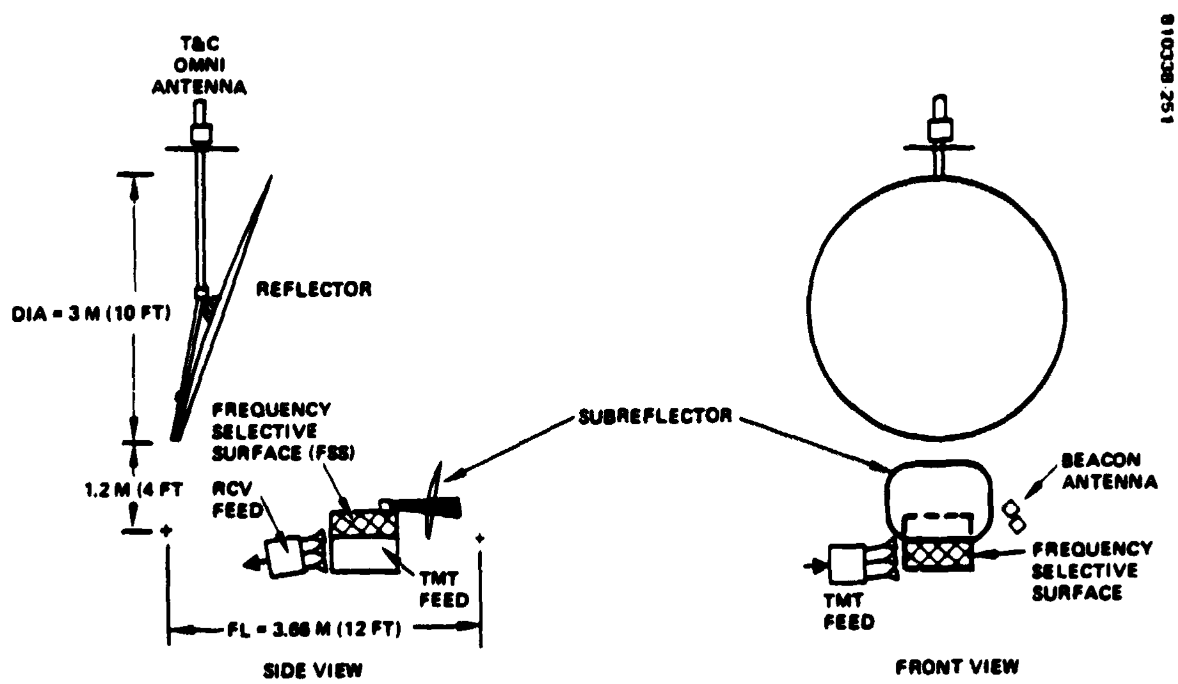


FIGURE 3.1-2. ANTENNA SUBSYSTEM CONFIGURATION

The T&C omni antenna uses a support structure similar to that of the SBS omni antenna. Antenna stowage and deployment will be similar to that of the SBS satellite.

The beacon antenna is an array of two pyramidal horns and is identical to the beacon antenna used on COMSTAR except for its structural support brackets.

The communications antenna performs a number of functions as described previously and the basic circuit block diagram that is used to describe how they are accomplished is given in Figure 3.1-3. There are a total of 29 receive feed horns and 15 transmit feed horns associated with the same diameter reflector and geographical coverage areas. The allocation of these feeds for accomplishing the four basic functional requirements for trunk and CPS signal routing internal and external to the subsystem is explained in the subsequent paragraphs. Low noise amplifiers (LNA) are provided at the feeds to improve system noise temperature.

The trunking portion of the antenna has six feeds on both transmit and receive. Only one feed horn is used to generate a beam at a trunk node. Four of the six beams can be used at any time. Low speed latching switches connect either New York or Houston and either Washington, D.C. or Tampa to the transponder. Three LNAs are provided for each pair of feeds to help ensure that all trunk beams are usable with three for two redundancy.

There are two scanning beams for transmit and two for receive. Because the receive beamwidth is two-thirds that of transmit about nine-fourths as many receive horns are needed as for transmit to scan a beam over the same sector. On receive, one scanning beam serves the east coast sector with 13 spots plus an additional spot for Seattle. Two of the beam 1 spots are generated for New York and Washington, D.C. by sharing trunk feeds as shown. Low speed latching switches switch these feeds from the trunk waveguide to the CPS beam forming network. The other 11 spots have dedicated feeds. A total of fourteen horns is used therefore in the sector 1 receive beam forming network (BFN). The second scanning spot beam serves sector 2, adjacent to sector 1, also with 13 spots. One of the beam 2 spots is created by a shared Cleveland trunk feed and the remaining spots by 12 dedicated feeds. Two additional feeds for covering Denver and San Francisco are connected to the sector 2 receive BFN giving it a total of 15 feeds. The LNAs for the CPS feeds are nonredundant except for spots using trunk feeds.

Each transmit scanning beam serves six spots per sector. The sector 1 BFN shares two trunk feeds for New York and Washington, D.C. and uses four dedicated feeds for the rest of the sector. Seven feeds in all are needed since an additional feed is dedicated to Seattle. The sector 2 BFN has a total of eight feeds with one trunk feed shared for Cleveland, five dedicated feeds for the rest of the sector and two dedicated feeds for Denver and San Francisco.

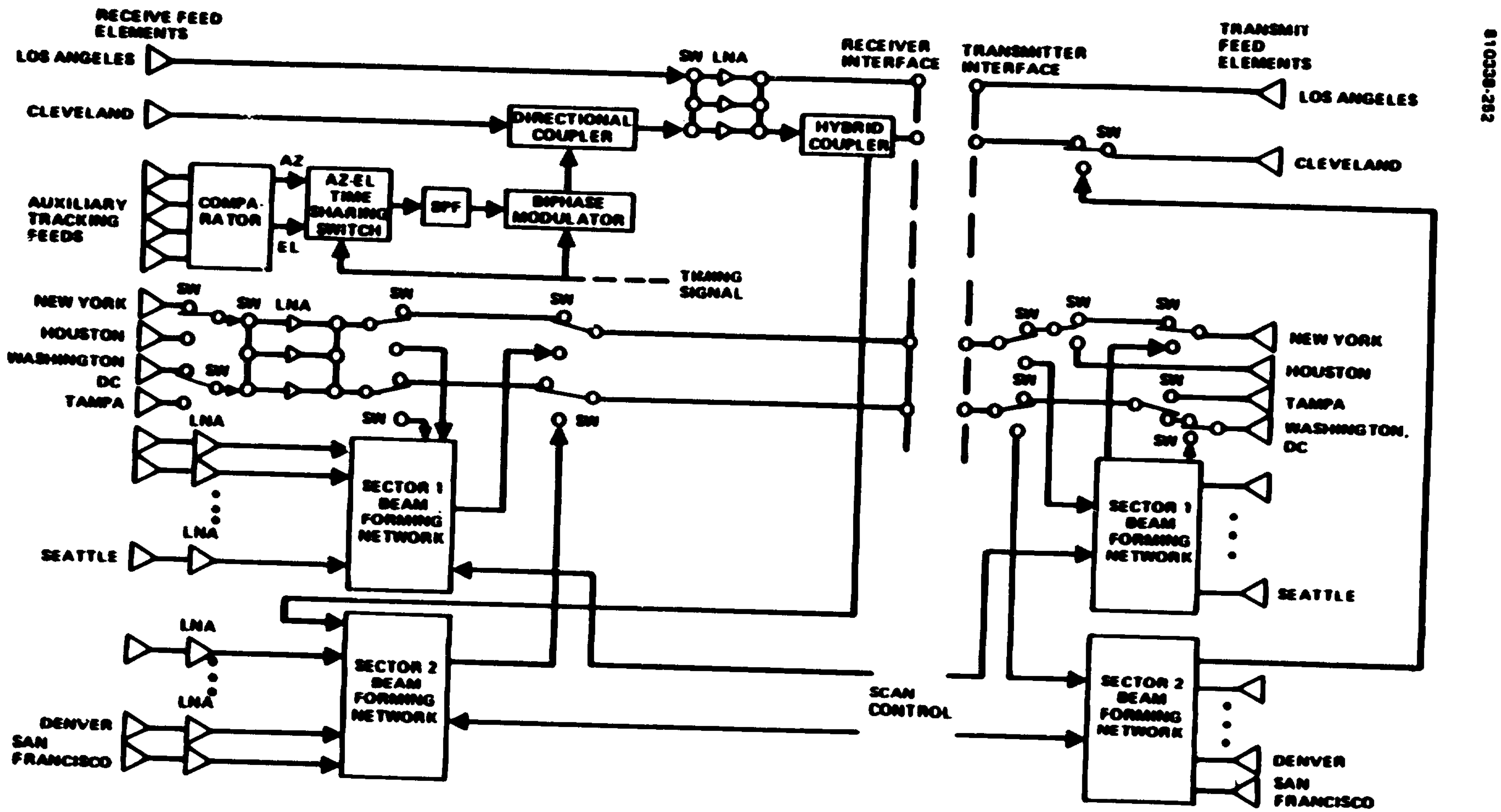


FIGURE 3.1-3. BASELINE COMMUNICATIONS ANTENNA BLOCK DIAGRAM

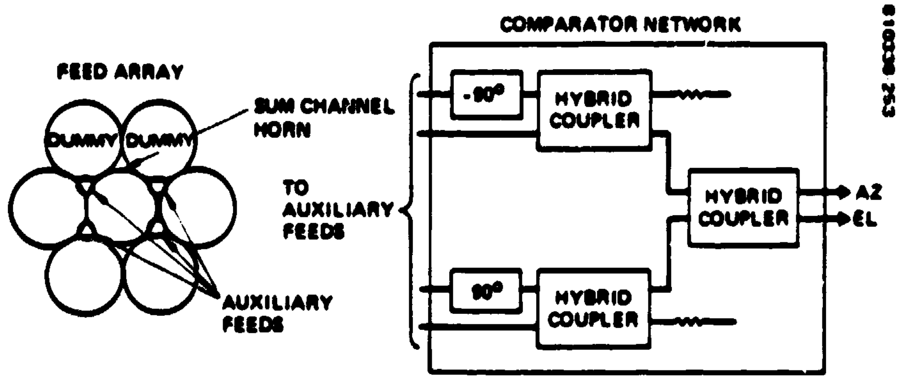


FIGURE 3.1-4. TRACKING FEED ARRAY AND COMPARATOR

Four auxiliary tracking feeds are included in the receive feed clustered about the Cleveland horn to provide signals for the monopulse tracking system. As shown in Figure 3.1-4, the tracking feed array includes a sum channel horn and four auxiliary feeds which surround the sum horn. Other horns identical to the sum horn are added where necessary to ensure a uniform mutual coupling environment to all four auxiliary tracking feeds. These additional like horns can be those used for communications if the beacon is completely within one of the scanning beam contiguous areas. If the beacon is in an isolated beam, the dummy horns are not required. The three hybrid coupler comparator network with two 90° fixed phase shifters produces two signal pair differences, i.e., azimuth and elevation signal outputs and connects the four horn array to the remainder of the receive tracking network shown in Figure 3.1-3. This technique is being implemented in the Space Shuttle Ku band radar communications antenna system.

Figures 3.1-5 and 3.1-6 illustrate the method of scanning a beam using a beam forming network (BFN). In the receive network the feeds are connected to the receiver through a switching network which, under control of the scan controller, connects one feed at a time to the receiver. The switches are high speed ferrite circulators with semiconductor driver circuits. The transmit BFN operates the same way to sequence the high power amplifier output to each of the transmit feeds. Coverage of the east coast sector by this technique is shown in Figure 3.1-7. The limitations of this approach are illustrated in Figure 3.1-8. Because of the finite size of the feeds (approximately two wavelengths in diameter) the coverage overlap is limited as shown. A terminal at the intersection of three spots would experience an uplink gain which is almost 7 dB below peak gain and a downlink gain over 8 dB below peak gain. If the coverage shown in Figure 3.1-9(a) can be accepted the gain loss reduces to about 4 dB and about 14 percent of the total coverage area is lost. If the coverage loss is limited to 3 dB, as shown in Figure 3.1-9(b), then 65 percent of the area is covered.

The BFN design described above provides adequate performance for the flight experiment because the links can be closed using the specified 40 watt satellite HPA and modest earth terminal transmitters. The required link margins are achieved even with the area losses of 7 and 8 dB; however, for operational systems better performance over an area covered by spot beams is desirable. One means of improving this performance is by sharing

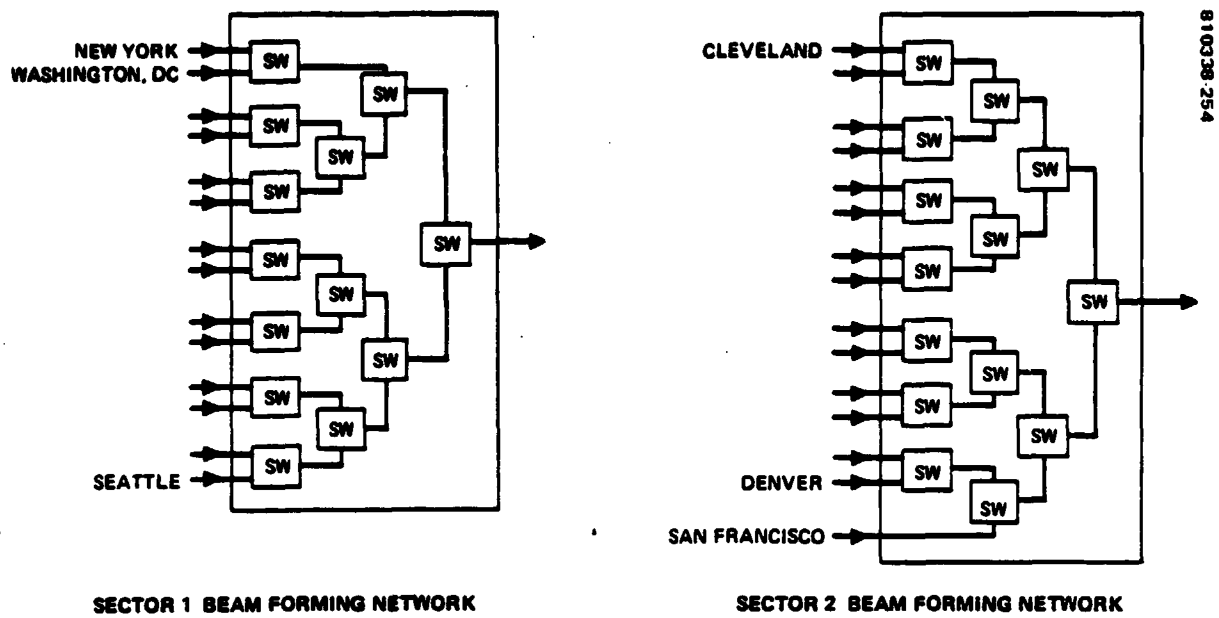


FIGURE 3.1-5. RECEIVE SCANNING FEED NETWORKS BASELINE

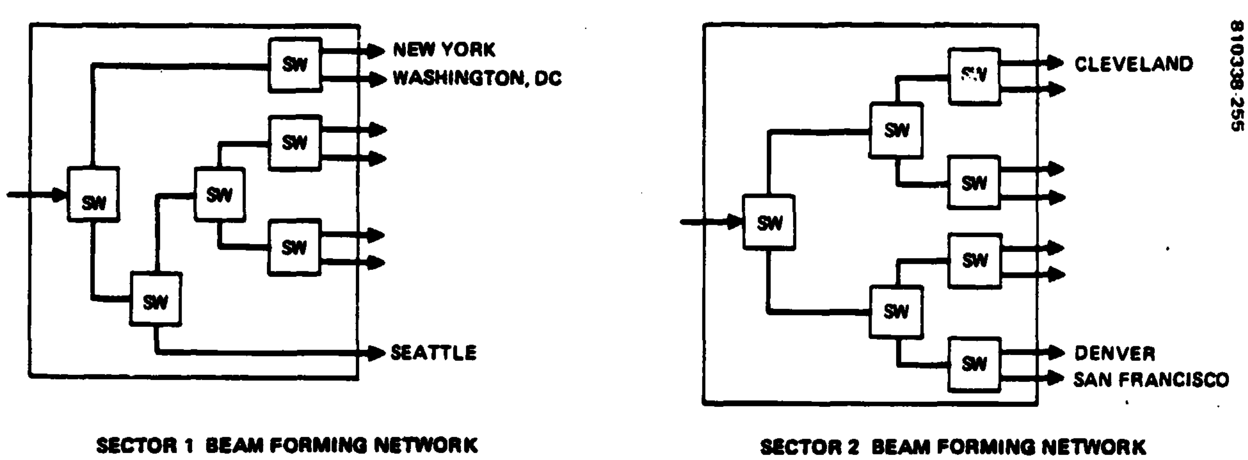


FIGURE 3.1-6. TRANSMIT SCANNING FEED NETWORKS BASELINE

power between contiguous feed elements to form doublets. In order to generate these doublets it is necessary to replace the switches of Figure 3. 1-5 and Figure 3. 1-6 by variable power dividers. The capability of generating a doublet has been implemented in the area between New York and Washington. Thus the switch in Figure 3. 1-6 and Figure 3. 1-7 which switches between the New York and Washington feeds is replaced by a variable power divider which can apply all power to either the New York or Washington feeds or share the power equally between these feeds to create the doublet shown in Figure 3. 1-8. The doublet provides a 2 dB improvement for terminals at the intersection of the beams.

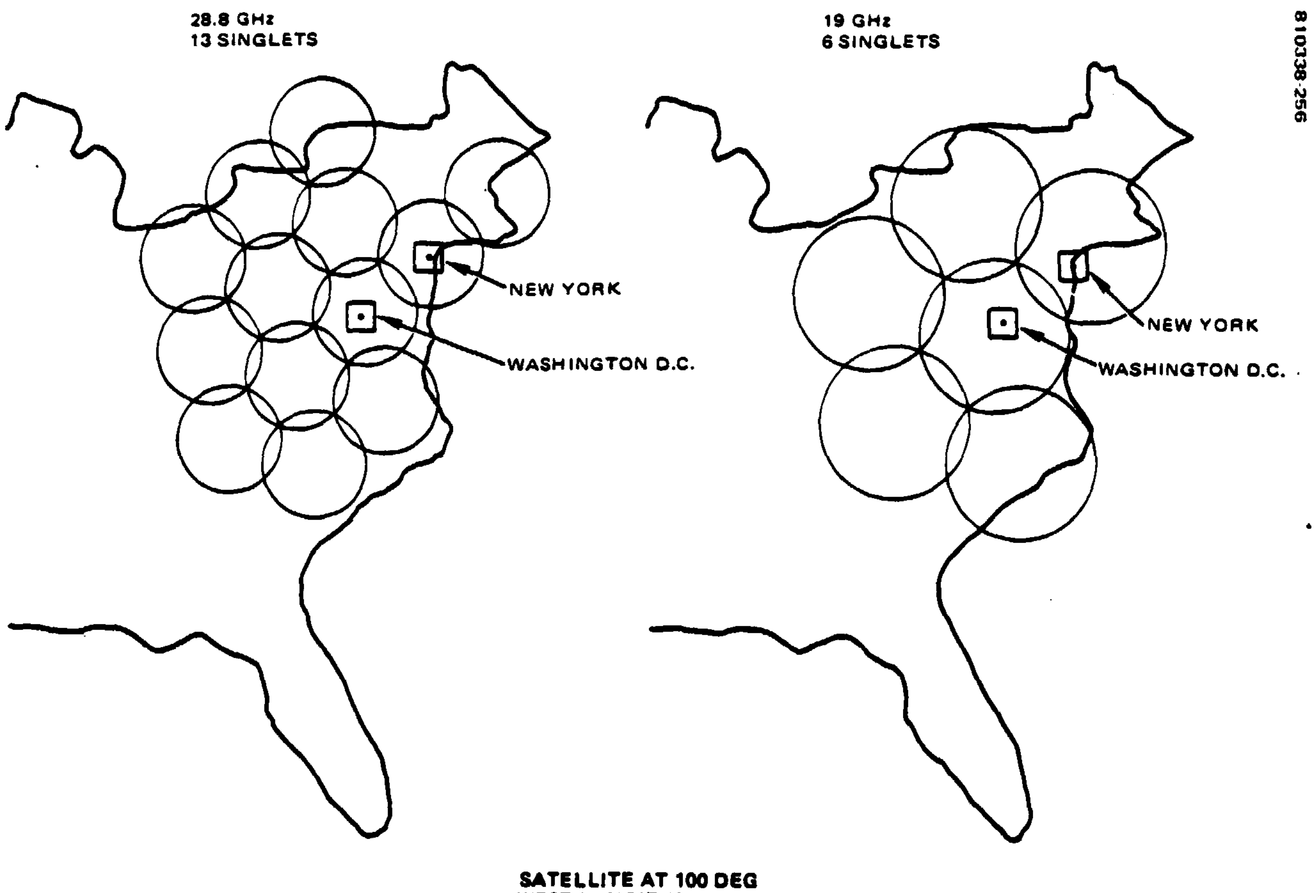


FIGURE 3.1-7. SECTOR 1 TRUNK/CPS COVERAGE

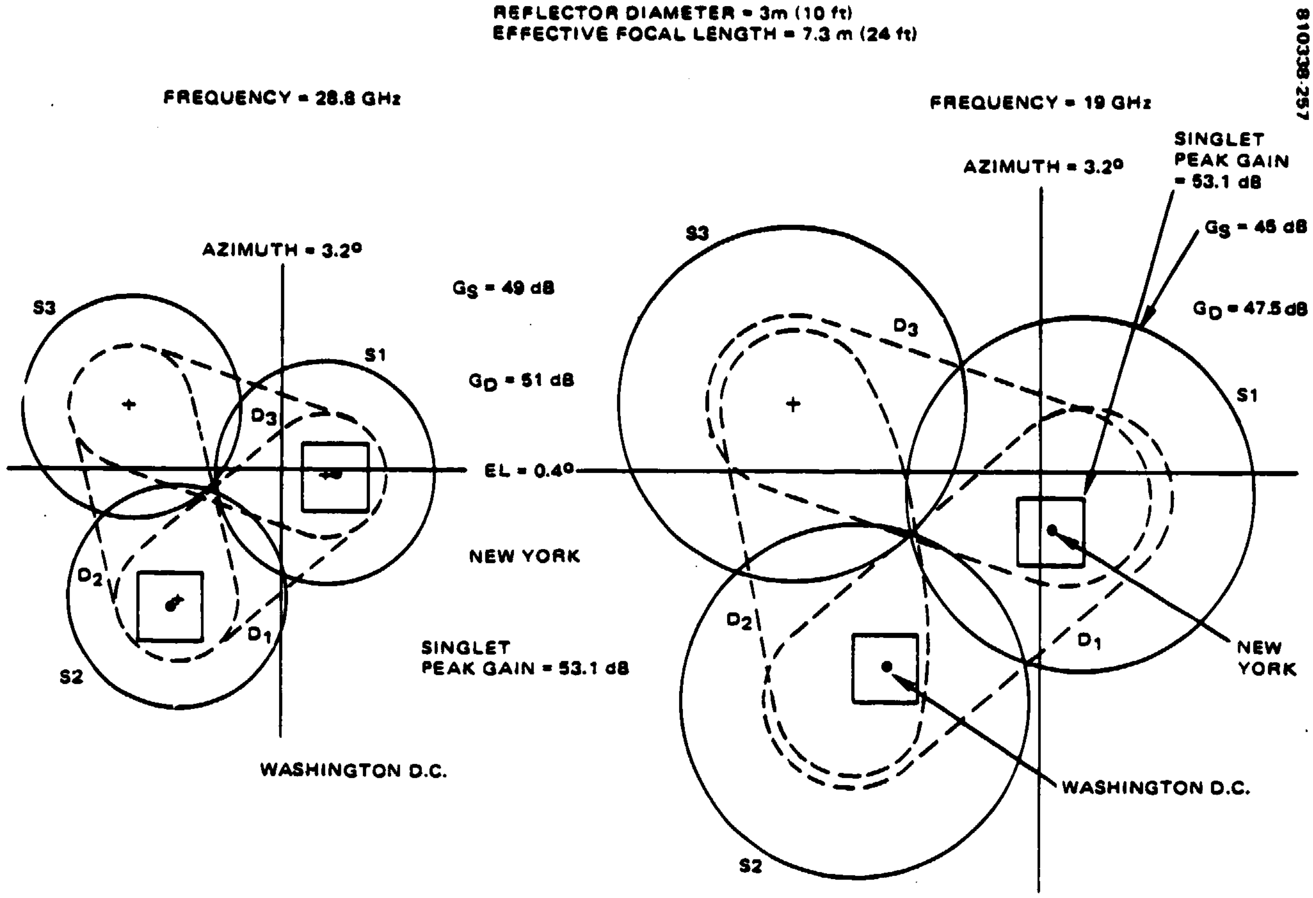
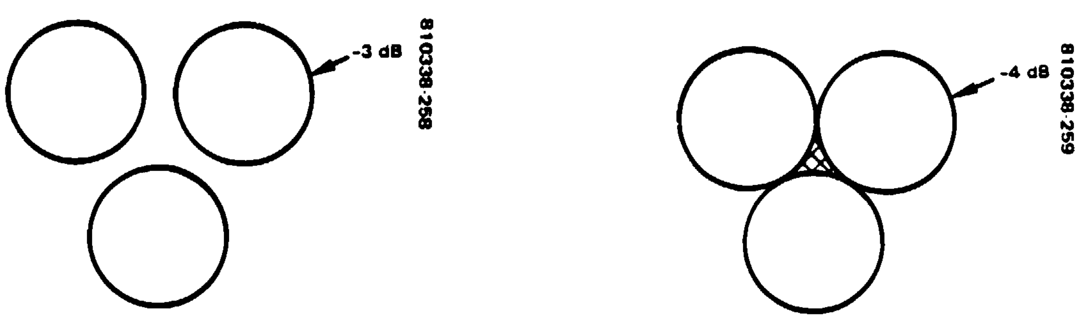


FIGURE 3.1-8. OFFSET CASSEGRAIN DIRECTIVE GAIN CONTOURS



a) 35 PERCENT TOTAL COVERAGE AREA LOSS

b) 14 PERCENT TOTAL COVERAGE AREA LOSS

FIGURE 3.1-9. REDUCED AREA COVERAGE

3.1.3 Electrical Performance

The electrical performance of the antenna is given in Table 3.1-3. The net gain in the bottom line is the gain used in the link budgets. The 8.1 dB and 7.1 dB losses for area coverage apply to CPS terminals located equidistant between three beam peaks.

3.1.4 Technology Status

Key component technology status is summarized in Table 3.1-4. New technologies are in the reflector with its large surface area and small surface tolerance, the 30 GHz LNA with a desired 5 dB noise figure and the integration of all components with a steadfast accurate alignment after reflector deployment. The reflector will be made with graphite structure that must be mechanically and temperature stable. The subreflector will also be made of graphite. For the subreflector size envisioned, experience with the Ku band Shuttle center fed reflector should extend to the hyperboloidal design without difficulty.

LNA technology status is discussed with the microwave subsystem. The integration and alignment of an offset Cassegrain antenna system with two reflectors, an FSS plate for separating transmit/receive feeds, a 30 GHz tracking feed and high speed beam forming networks using 30/20 GHz

TABLE 3.1-3. BASELINE CPS/TS ANTENNA PERFORMANCE ESTIMATES

Cassegrain Configuration Main Reflector Dia: 3 M (10 ft)

Parameter	Service			
	Trunking		Customer Premise	
Frequency, GHz	19	28.8	19	28.8
Half power beamwidth, deg	0.4	0.27	0.4	0.27
Directive gain of singlet on boresight, 100% aperture efficiency, dB	55.7	59.3	55.7	59.3
Losses due to illumination taper spillover and scan	2.6	3.2	2.6	3.2
Directive gain of singlet scanned 3.2° Az and 0.4° El, dB	53.1 peak	56.1 peak	53.1 peak	56.1 peak
Area gain loss due to operation off beam peak	Negligible	Negligible	8.1	7.1
Polarization loss, dB	0.1	0.1	0.1	0.1
Feed losses, dB				
Frequency selective surface (FSS)	0.5	0.5	0.5	0.5
Switching circulator, high speed	–	–	0.6	–
Switching circulator, low speed	0.5	0.2	0.3	0.2
Waveguide and horn	0.5	0.1	0.5	0.1
Net loss	1.5	0.8	1.9	0.8
Net gain, dB	51.5	55.1	43.0	48.1

TABLE 3.1-4. ANTENNA TECHNOLOGY ASSESSMENT

Component/Activity	Technology Status
Reflector, paraboloidal	New technology (graphite) large accurate surface
Subreflector, hyperboloidal	Ku band shuttle (graphite paraboloid)
30/20 GHz FSS	Design technique exists
Feed horn	Designs scaled from lower RF
LNA	Device expected to achieve 5.0 dB NF
High speed switch	Designs exist at other frequencies
VPD and driver	Receive: Scaled version of transmit Transmit: Existing technology
Tracking feed	Several approaches related to existing technology, e.g., Ku band shuttle radar/communications antenna
T&C omni-antenna	GOES/GMS design
20 GHz beacon antenna	Existing technology
Integration	New technology

circulator switches represents a new satellite subsystem technology. The use of 30/20 GHz frequency components will place emphasis on their accurate alignment by specifying fine tolerances throughout the subsystem that significantly exceed those encountered at lower satellite communication bands.

3.1.5 Weight and Power

Weight and power estimates for antenna subsystem components are given in Table 3.1-5. Major weight contributions are from the reflector and support structures. The baseline transmit and receive feed weights, including the tracking circuit, total 48 pounds or 25 percent of the total subsystem weight. For option 1 the total feed weight is 34 pounds, or 19.6 percent of the subsystem weight. Feed horns are conical and of aluminum construction. T&C omni antenna and beacon antenna weights are known quantities, since existing designs are assumed.

Also, included in Table 3.1-5 are estimates of total power consumption for the switches and VPDs in the baseline and optional subsystems for a typical uplink/downlink interconnectivity plan for which a TDMA frame time of 1 ms is divided into as many subframes as there are CPS feeds. The baseline CPS feed power consumption is nearly halved in relation to the option 1 CPS feeds. This is due to the reduction of scanning beams from two to one, which thereby reduces the number of control switches from 26 to 14 in the option 1 receive CPS feed, and from 12 to 8 in the option 1 transmit CPS feed. LNA power consumption is based on all LNAs being active except for the two redundant LNAs (baseline and option 1).

TABLE 3.1-5. ANTENNA SUBSYSTEM WEIGHT AND POWER

Component	Quantity		Total Weight, lb		Total Power, W			
					Baseline		Option 1	
	Baseline	Option 1	Baseline	Option 1	CPS	Trunk	CPS	Trunk
Reflector	1	1	50	50				
Subreflector	1	1	6	6				
30/20 GHz FSS	1	1	5	5				
Receive feed								
Horn	32	19	12.8	7.6				
LNA	32	19	6.4	3.8	5.2	0.8	3.2	0.8
Low speed circulator switch	18	17	1.6	1.5	Nil	Nil	Nil	Nil
High speed circulator switch	27	15	2.4	1.4	2.4		1.4	
Transmit feed								
Horn	18	13	12.6	9.1				
Low speed circulator switch	7	6	0.7	0.6	Nil	Nil	Nil	Nil
High speed circulator switch	13	9	1.3	0.9	1.2		0.7	
Waveguide interconnection, TX and RX	1 set	1 set	6	5				
Receive tracking circuit	1	1	4	4	1	1	1	1
T&C omni antenna	1 assembly	1 assembly	0.6	0.6				
Telemetry beacon antenna	1 assembly	1 assembly	7.8	7.8				
Support structures	1 set	1 set	61.8	60				
Miscellaneous			10	10				
Totals			189	173	9.8	1.8	6.3	1.8

*As of 25 June 1981.

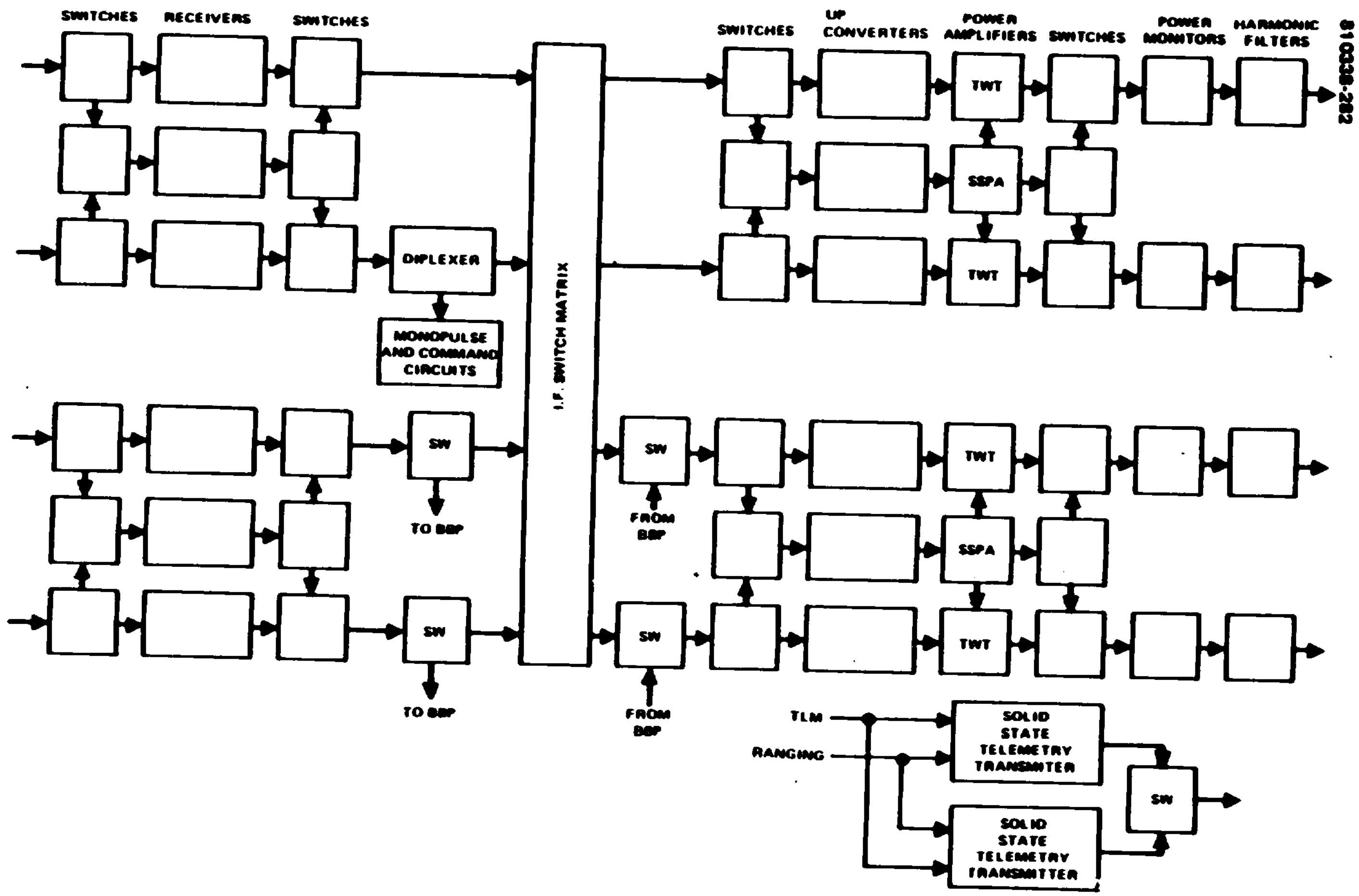


FIGURE 3.2-1. BASELINE MICROWAVE SUBSYSTEM BLOCK DIAGRAM

3.2 MICROWAVE SUBSYSTEM

3.2.1 Subsystem Design

The composition of the microwave subsystem is illustrated in Figure 3.2-1. The frequency conversion plan is shown in Figure 3.2-2. The microwave subsystem frequency plan selection is based upon the considerations listed below:

1) Compatibility with the entire available frequency band

2) Spurious responses

3) Simplicity of local oscillator design

4) Compatibility with IF TDMA switch matrix

5) Avoidance of spectral inversion

The frequency plan chosen should meet the criteria listed in items 2 through 5 over the entire band available for use, i.e., 27.5 to 30 GHz for the uplink and 17.7 to 20.2 GHz for the downlink. The requirements to use a SS TDMA switch dictates that a dual conversion frequency plan be used since implementation of this switch at the output frequency range is very difficult and costly. Ease of local oscillator implementation and the desire to avoid spectral inversion leads to the use of low side downconversion and upconversion to avoid the generation of very high local oscillator frequencies.

Figures 3.2-3 and 3.2-4 show the gain distribution and signal levels for the CPS and trunk service links. The level associated with each stage is the level at the input of the stage above the level number given in each block. The signal level at the antenna output is calculated from the system noise density, data rate, and uplink E_b/N_o data as given in the link budgets of section 2.1 of this report.

The solid state power amplifiers are not shown in Figure 3.2-3 and 3.2-4, however the SSPA gain is approximately 7.5 dB less than the TWT and is consistent with the SSPA power output of 7 watts. Automatic gain control (AGC) is implemented in the IF amplifier section of the upconverter. The AGC is placed in this unit so that it can compensate for gain variations of all components prior to the upconverter. The AGC dynamic range requirement is determined by the minimum input level for the CPS application and the maximum upconverter input level associated with the higher data rate trunk service. This level range is 15.3 dB; the actual design requirement of 20 dB includes margin for gain drift of all components preceding the upconverter.

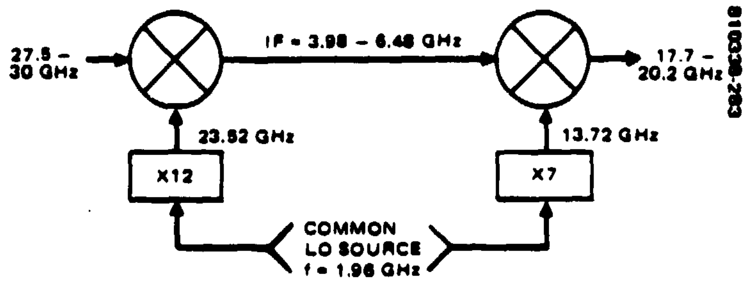
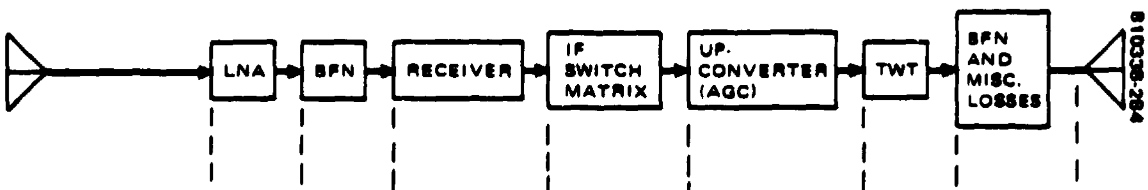
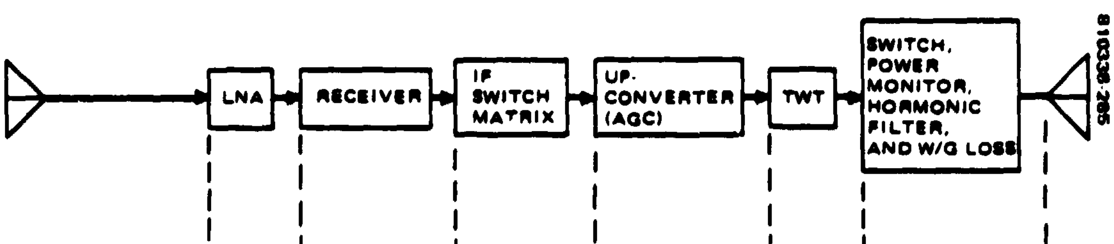


FIGURE 3.2-2. FREQUENCY CONVERSION PLAN



GAIN, dB	20	-2	46	-18	19370.9	55 dB	1.8	
MAXIMUM LEVEL, dBm (INPUT)	-73.3	-53.3	-55.3	-10.3	-28.3	-9	46	44.2
MINIMUM LEVEL, dBm (INPUT	-79.9	-59.9	-61.9	-17.9	-35.9			

FIGURE 3.2-3. CPS GAIN DISTRIBUTION AND LEVELS



GAIN, dB	20	46	-18	11.6	55	1.0	
LEVEL, dBm	-67.6	-47.6	-2.6	-20.6	-9	46	45

FIGURE 3.2-4. TRUNK GAIN DISTRIBUTION AND LEVELS

3.2.2 Transponder Components

3.2.2.1 Receiver Design

As discussed in Section 2.1 the satellite payload has been configured with LNAs at the antenna receive feeds. The total receiver function is then divided between the LNAs and the receiver.

3.2.2.1.1 Low Noise Amplifier Design

The LNA provides low noise amplification with sufficient gain to establish the communications repeater noise figure. A low noise amplifier based upon GaAs FET devices has been chosen for its combination of low noise figure and its weight and power. A four or five stage GaAs FET low noise amplifier will weigh less than 0.25 lb, require approximately 0.2 watts of regulated power and enable a system design based upon a 5 dB uplink receiving subsystem noise figure. If a 0.1 dB post-LNA contribution is allowed which is consistent with an LNA gain of 20 dB and a receiver noise figure of 7.5 dB then the LNA noise figure should be 4.9 dB and the gain should be at least 20 dB. To achieve the desired system noise figure it is apparent a device noise figure of about 3.5 dB with an associated low noise gain of 4.5 to 5.0 dB is required.

The low noise amplifier using such a device is a four stage amplifier consisting of a waveguide circulator at the input and two waveguide mounted microwave integrated circuit (MIC) amplifiers each having two GaAs FET low noise devices. An additional waveguide circulator is used between the two sections of the amplifier. Figure 3.2-5 shows the configuration of a two stage waveguide mounted amplifier.

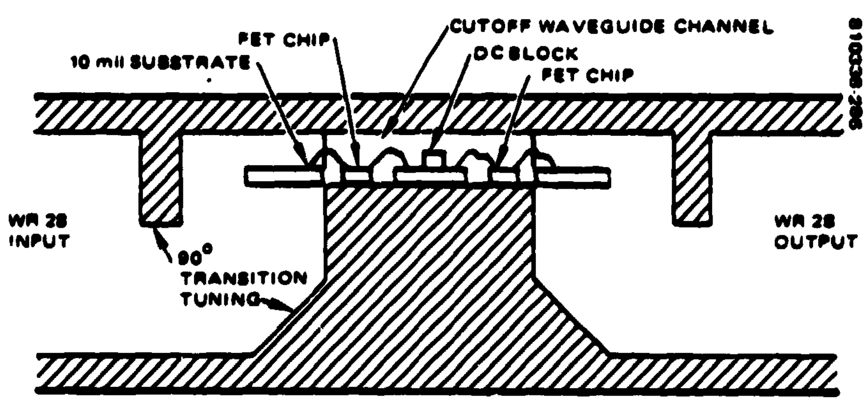


FIGURE 3.2-5. TWO STAGE AMPLIFIER CONFIGURATION

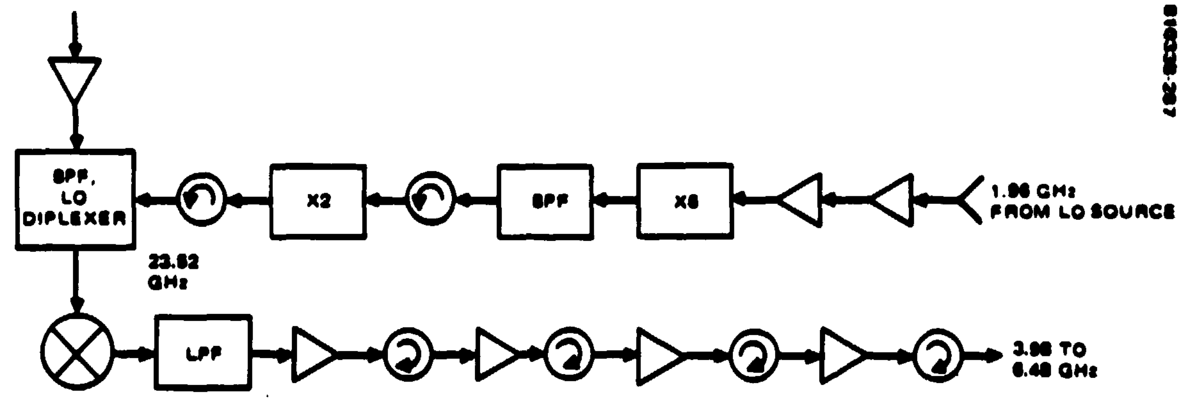


FIGURE 3.2-6. BASELINE RECEIVER

3.2.2.1.2 Receiver

Figure 3.2-6 is a block diagram of the system receiver. The receiver includes one low noise RF amplification stage, a single ended waveguide first mixer, the first local oscillator times 12 frequency multiplier, and a four stage IF amplifier. The low noise RF stage is used to reduce overall receiver noise figure to permit the use of a simple first mixer rather than resorting to an image enhancement mixer. The first local oscillator and the input signal are summed in a common junction diplexer consisting of a bandpass filter centered at the signal frequency and a bandpass filter centered at the local oscillator frequency. A low pass filter which has a cutoff frequency of approximately 7 GHz is used following the mixer to reject signal and local oscillator frequencies. The four stage IF amplifier uses high gain (12 dB per stage), low noise GaAs FET amplifiers. Construction of the receiver is in MICs except for the first mixer and the final times two frequency multiplier of the local oscillator chain.

3.2.2.2 IF Switch Matrix

The order of the IF switch for the flight experiment is 4 by 4, however, the technology employed is required to be applicable to a 20 by 20 matrix. A coupled crossbar design has been determined to be optimum because it can be easily packaged, made internally redundant, used in a broadcast mode, and is smaller in size and weight especially in a high order matrix switch.

Another tradeoff has led to the selection of GaAs FET switching devices because of lower power consumption and higher switching speed. A passive FET switch has tentatively been selected for the flight experiment because it is somewhat more reliable and is easily implemented in monolithic MIC; however, because of the greater loss of the passive switch, which may lead to unacceptable total loss in the switch matrix for a 20 by 20 matrix, an active switch will be considered in the next phase of the program. This will especially be the case if the proof of concept developments being funded at GE and FACC are successful with their active switch approach.

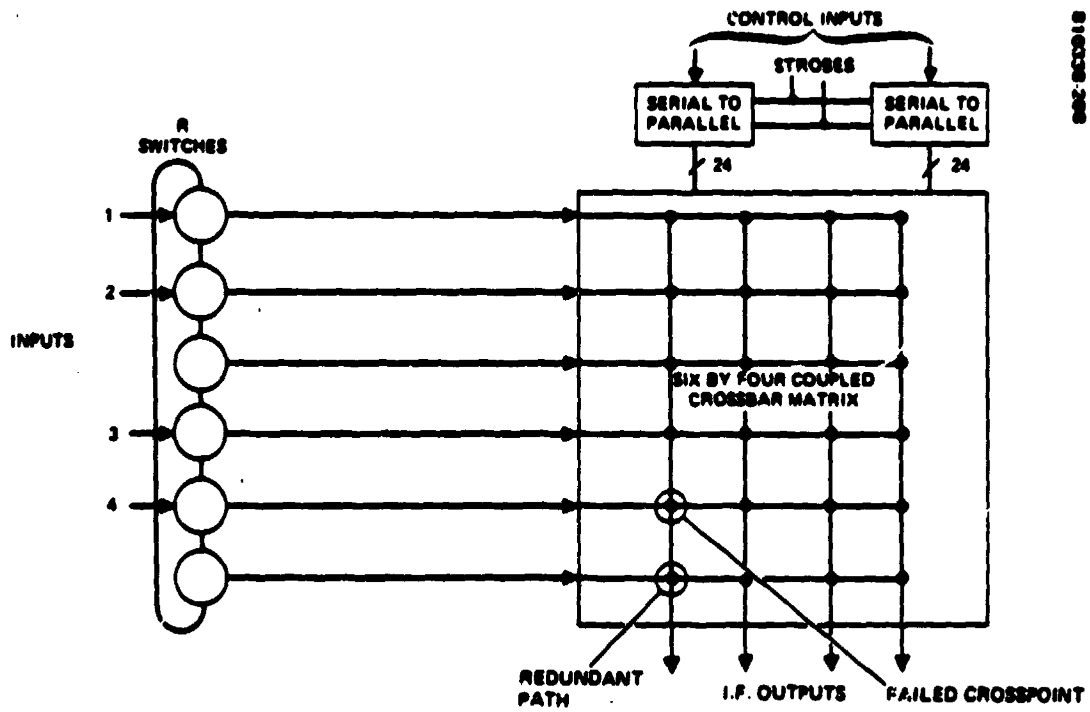


FIGURE 3.2-7. IF SWITCH MATRIX CONCEPT

The third design trade concerns the method of implementing redundancy. Again previous in-house trade studies clearly favor the use of the wraparound internal redundancy technique over other possible approaches.

The basic concept of the IF switch matrix is shown in Figure 3.2-7. Redundant serial to parallel converters are used to convert the serial command data from the switch matrix digital control unit to parallel on/off signals routed to each crosspoint of the coupled crossbar switch matrix. The redundant on/off crosspoint control signals are combined in a diode "or" circuit contained in the switch driver circuit used with each crosspoint.

The six "R" switches at the inputs are used to select redundant paths by routing the appropriate input signal to a redundant path. This is accomplished by changing the digital control unit program memory when a failure is detected.

3.2.2.3 Upconverter Design

Figure 3.2-8 is a block diagram of the upconverter. A three stage IF amplifier amplifies the signal prior to upconversion. The output of the third stage is sampled, detected, amplified, filtered, and used to control a current controlled diode AGC attenuator to maintain a constant signal level at the input to the upconverter mixer. The mixer is a balanced two diode MIC mixer since conversion loss is not critical. The bandpass filter following the mixer is a three pole, 0.1 dB ripple. Chebyshev filter constructed in waveguide. This filter has an equal ripple bandwidth of 2 GHz. Net gain

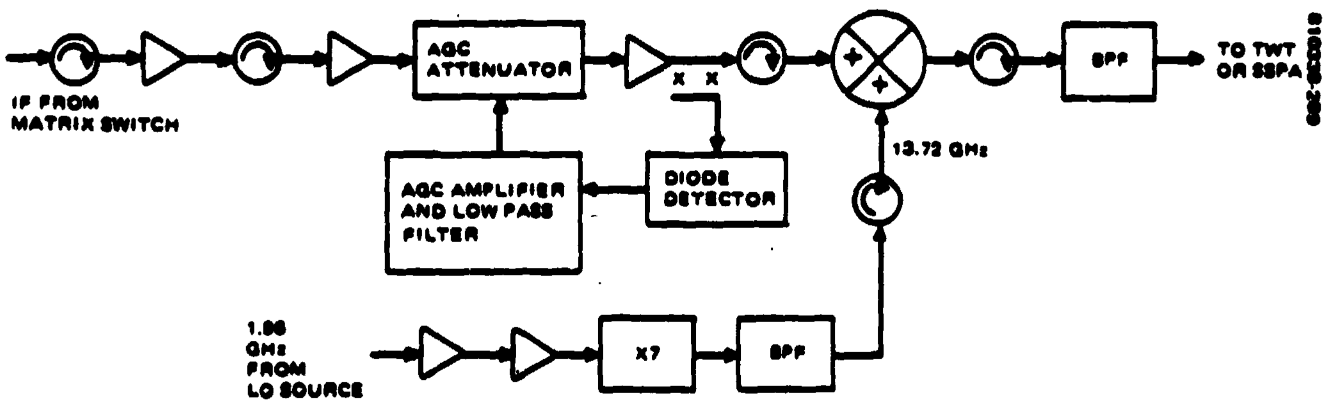


FIGURE 3.2-8. UPCONVERTER DESIGN

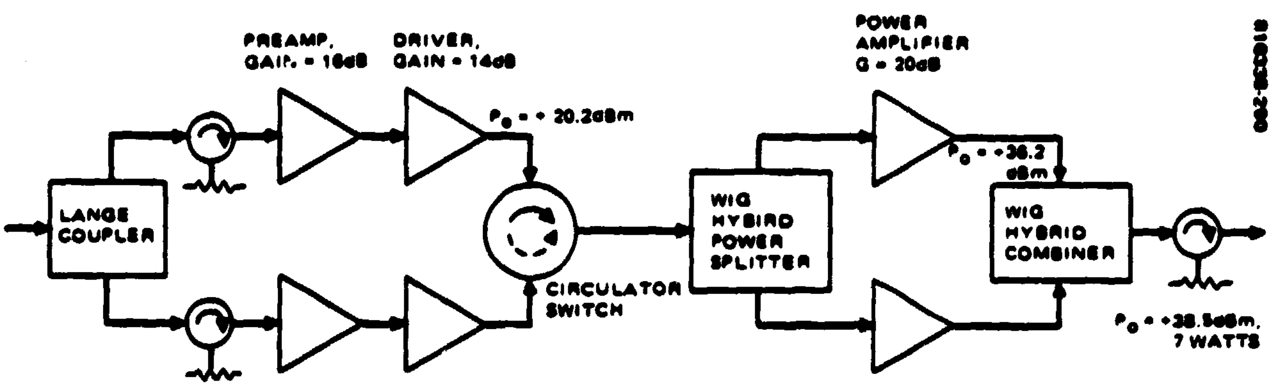


FIGURE 3.2-9. 7 WATT GaAs FET SSPA

of the upconverter from IF input to RF output is 30 dB when the AGC attenuation is minimum. AGC control range is 20 dB. All circuits except the output bandpass filter are constructed in MIC.

3.2.2.4 TWT Characteristics

Table 3.2-1 gives the TWT and the TWT power supply characteristics. These characteristics are based upon a recent proposal made by Hughes Electron Dynamics Division for a 36 watt TWT at the same frequency.

3.2.2.5 Solid State High Power Amplifier Design

Table 3.2-2 is a comparison of the two design approaches considered for the SSPA. At this point in time IMPATT is capable of higher device power capability and higher efficiency; however, the GaAs FET power

TABLE 3.2-1. TWTA CHARACTERISTICS

• Helix type	
• Three collectors for high efficiency	
• Frequency range	17.7 to 30.2 GHz
• Saturated gain	55 dB
• Saturated power output	40 W
• Efficiency	40% TWT 90% high voltage supply* 36% overall
• Weight, lb	
TWT	3
Power supply	7

*Constant current linear regulator, efficiency at min or EOL bus voltage = 90%.

TABLE 3.2-2. SSPA COMPARISON

Parameter	GaAs FET Design	Impatt Design
Efficiency, % (including power supply)	10	15
RF power output, W	7	7
Total number of GaAs FET preamp devices	12	18
Total number of high power devices	36	6 (2 watt), 3 (4.5 to 5 watt diodes)
Bandwidth	>1 GHz easily achievable	Gain/bandwidth tradeoff
Stability	Unconditionally stable	Negative resistance device
Effects on modulated signal fidelity	Negligible	Potential problem area for injection locked design
Power device junction, temperature, °C	≤100	200 to 250
Supply voltages, volt	8 to 15	70 to 80; tight regulation required
Growth capability	Greater potential	Mature technology

technology is rapidly changing. The comparison in one year could change in favor of the GaAs FET as device power capability and efficiency can be expected to improve and the GaAs FET approach has significant advantages in several other respects.

A block diagram of the SSPA is shown in Figure 3.2-9. Overall transmitter gain is 48 dB.

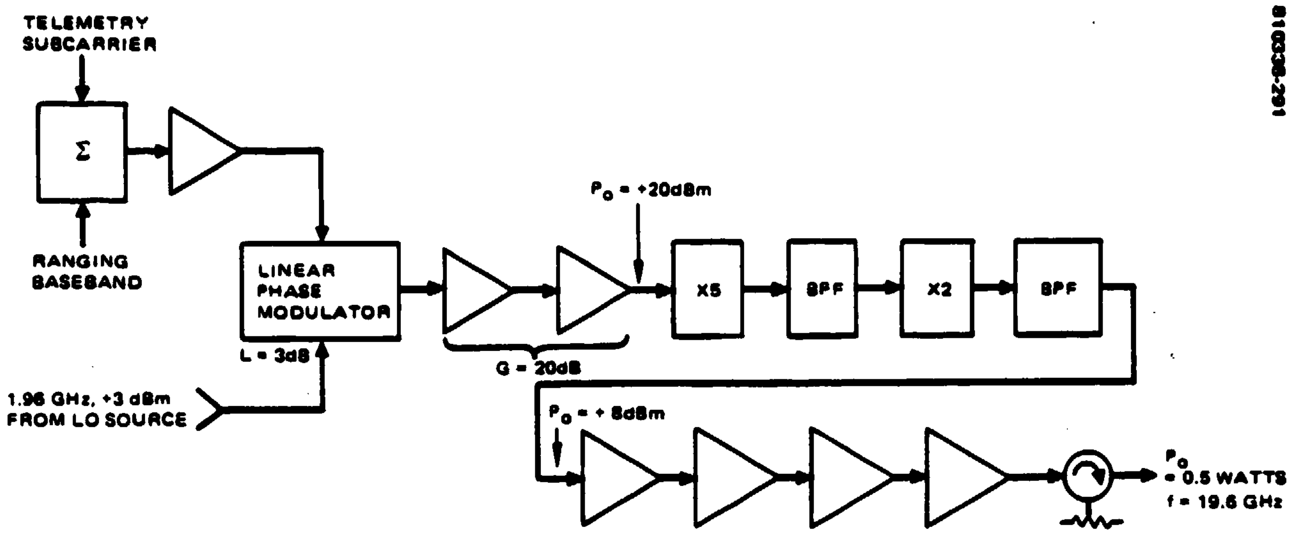


FIGURE 3.2-10. TELEMETRY TRANSMITTER

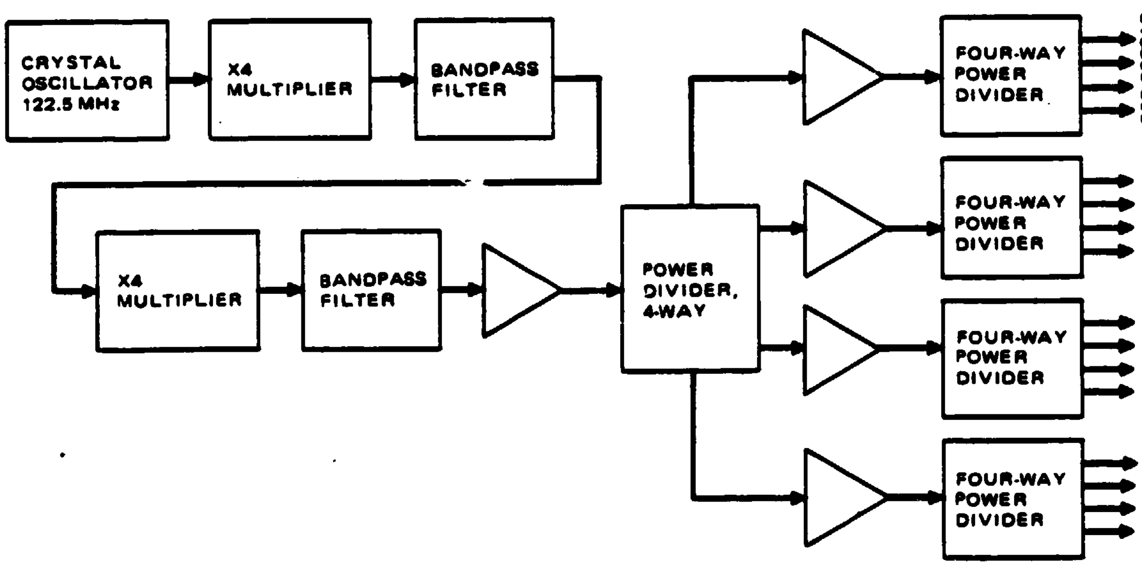


FIGURE 3.2-11. LOCAL OSCILLATOR SOURCE DESIGN

3.2.2.6 Telemetry Transmitter

The telemetry transmitter block diagram is shown in Figure 3.2-10. The telemetry subcarrier and the ranging baseband from the uplink command receiver circuits are combined and used to linearly phase modulate a 1.96 GHz carrier from the local oscillator source. A times ten frequency multiplier multiplies the 1.96 GHz carrier to 19.6 GHz. A four stage GaAs FET power amplifier provides a one-half watt power output. This transmitter was used as a beacon on the COMSTAR satellites.

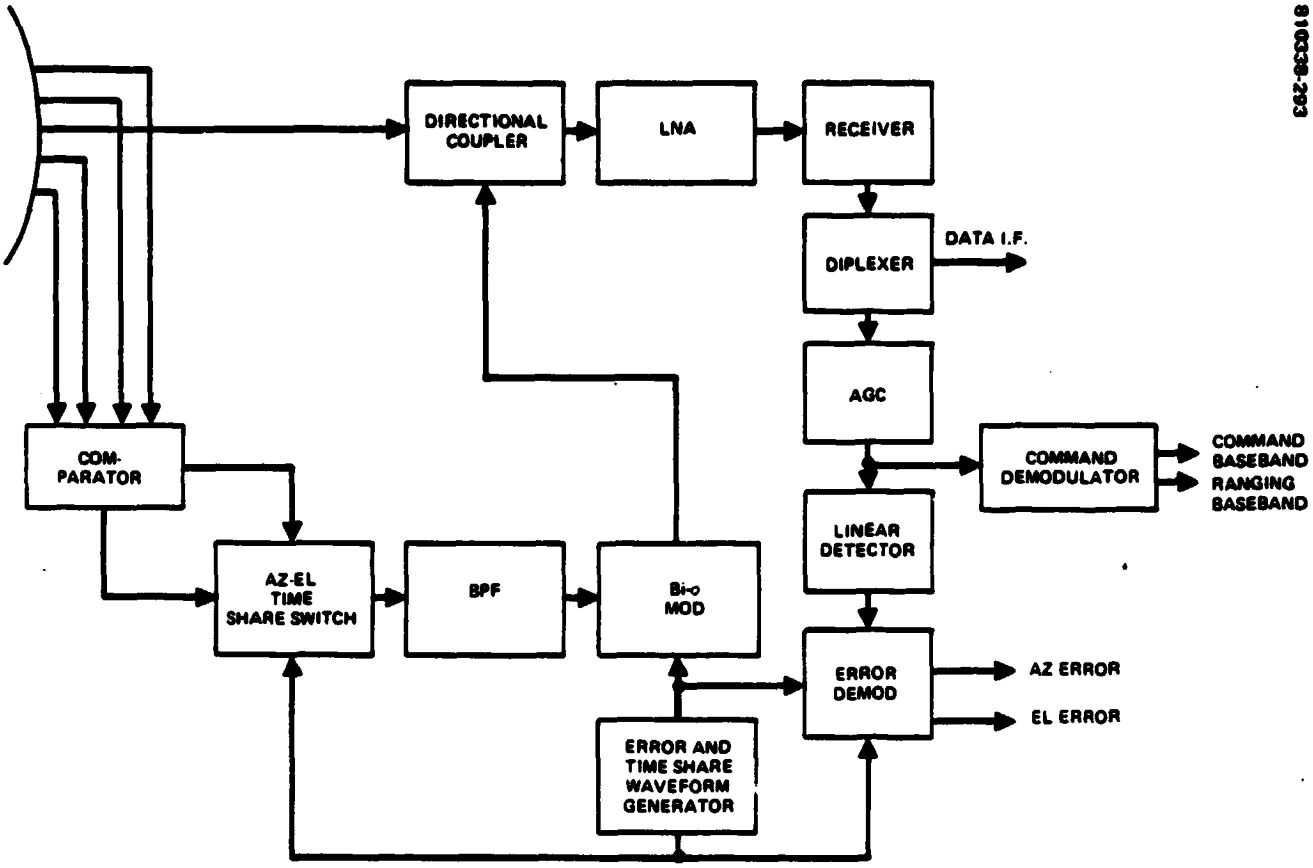


FIGURE 3.2-12. MONOPULSE TRACKING MICROWAVE CIRCUITS

3.2.2.7 Local Oscillator Source Design

Figure 3.2-11 is a block diagram of the local oscillator source. The crystal oscillator frequency is set relatively high to reduce the frequency multiplication ratio. This also reduces the phase noise generated in the local oscillator frequency multiplier chain. The crystal oscillator is housed in a temperature controlled enclosure to ensure good frequency stability.

Two identical local oscillator sources are used in the microwave subsystem and both have power on so that individual outputs can be selected in the event of a failure.

3.2.2.8 Monopulse Tracking Microwave Circuits

The implementation of the antenna monopulse angle tracking function is shown in Figure 3.2-12. A single channel monopulse technique used successfully in previous space programs provides angle tracking. T[illegible] antenna uses four different feeds symmetrically spaced about the sum channel feed horn and a comparator network of three waveguide magic tees to generate azimuth and elevation error signals. These error signals are time-shared by a circulator switch which alternately selects one or the other. The time-shared signal then goes through a bandpass filter which passes the command carrier but rejects data carriers. The error signal is processed in a line length modulator with two circulator switches. The resulting biphase-modulated error signal is summed in a directional coupler with the sum signal and the relative phase adjusted to produce amplitude modulation of the received uplink command carrier. The combined signal is then amplified and converted to IF by the LNA and the receiver. The diplexer following the receiver separates the receiver IF output into data and command carrier outputs. The command carrier, amplitude modulated with error signal information, is then passed through an AGC circuit to ensure that the antenna/receiver error transfer function remains nearly constant and independent of command signal level variation. The AGC circuit output is then detected, synchronously demodulated, and separated into dc error signals whose amplitude is a function of angle error magnitude and whose polarity is a function of error direction. A separate command and ranging demodulator is used to demodulate the frequency modulated command and ranging signals.

The time-sharing signal and error modulation are generated by digital circuits and are low rate (≤200 Hz) for compatibility with the low speed circulator switch in the antenna subsystem. The time-sharing signal period is both synchronous with and twice that of the error signal.

3.2.3 Weight and Power

The component weights and power are listed in Table 3.2-3. The upper portion of the chart lists components for the baseline system. The lower portion lists additional components required for option 2. The option 2 receiver weight is increased by 0.5 pounds and power is increased by 0.5 watt because of the addition of an upconverter, additional local oscillator, multiplier, and RF output amplifier stages. The weight and power of the LNAs is accounted for in the antenna subsystem.

3.2.4 Performance

3.2.4.1 Output Circuit Losses and Power Delivered to Antenna

Table 3.2-4 gives the circuit losses, amplifier power, and the power delivered to the antenna feed for the four possible cases. The circuit losses given in the table include 0.15 dB for the circulator switches used to select the power amplifier and 0.3 dB for the power monitor and harmonic filter. The loss of 0.55 dB for five feet of WR 51 waveguide from the output circuits to the antenna feed is accounted for in the antenna gain budget as is the loss in the high speed beam forming network switches and the low speed antenna configuration switches.

3.2.4.2 Channel Bandpass Characteristics

The channel bandpass characteristics of primary interest are gain flatness and phase linearity over the data bandwidth. The two principal contributors to these parameters are the bandpass filter in the upconverter

TABLE 3.2-3. MICROWAVE SUBSYSTEM WEIGHT AND POWER

Component	Quantity*	Weight, lb	Power, W Trunk Mode	Power, W CPS Mode
Receiver	4 + 2	18	30	15
IF diplexer	1	0.3		
IF switch matrix	1	4	3	
30 GHz circulator switches	6	1.8		
Upconverters and IF amplifiers	4 + 2	9	9	4.5
TWTA	4	40	460	230.0
Solid state power amplifier (SSPA)	2	14	**	**
20 GHz circulator switches	7	2.1		
Monopulse and command electronics	1 + 1	6	3	3
IF coaxial switches	30	9		
LO source	2	8	8	8
Telemetry transmitter	1 + 1	4	6	6
Output power monitor	4	2	1.6	1.6
Output harmonic filters	4	1.2		
Interconnections		8		
Totals (baseline)		127.4	520.6	268.1
20 GHz circulator switches	22	6.6		
Additional for receiver	4 + 2	3	3	3
Demultiplexer	4	4.8		
Summer	4	1.6		
Additional for option 2		16.0	3	3

*Operating plus redundant.
**SSPA is used in place of a TWTA.

TABLE 3.2-4. CIRCUIT LOSSES AND POWER DELIVERED TO ANTENNA FEED

Power Amplifier Type and Power Output	Service	Circuit Losses	Power Delivered to Antenna Feed
TWT-40	Trunk	0.45 dB	36.1
TWT-40	CPS	0.45 dB	36.1
SSPA-7	Trunk	0.45 dB	6.3
SSPA-7	CPS	0.45 dB	6.3

and the bandpass filter preceding the downconverter mixer in the receiver. The upconverter filter is deliberately made very wide in bandwidth so that its contribution is small. The receiver bandpass filter must be more narrow in bandwidth since it precedes the AGC circuit of the upconverter in the case of the trunk service and it is desirable to minimize transmitter noise power sharing due to uplink receiver noise. Other contributors to gain flatness and phase linearity performance are the receiver active cir-

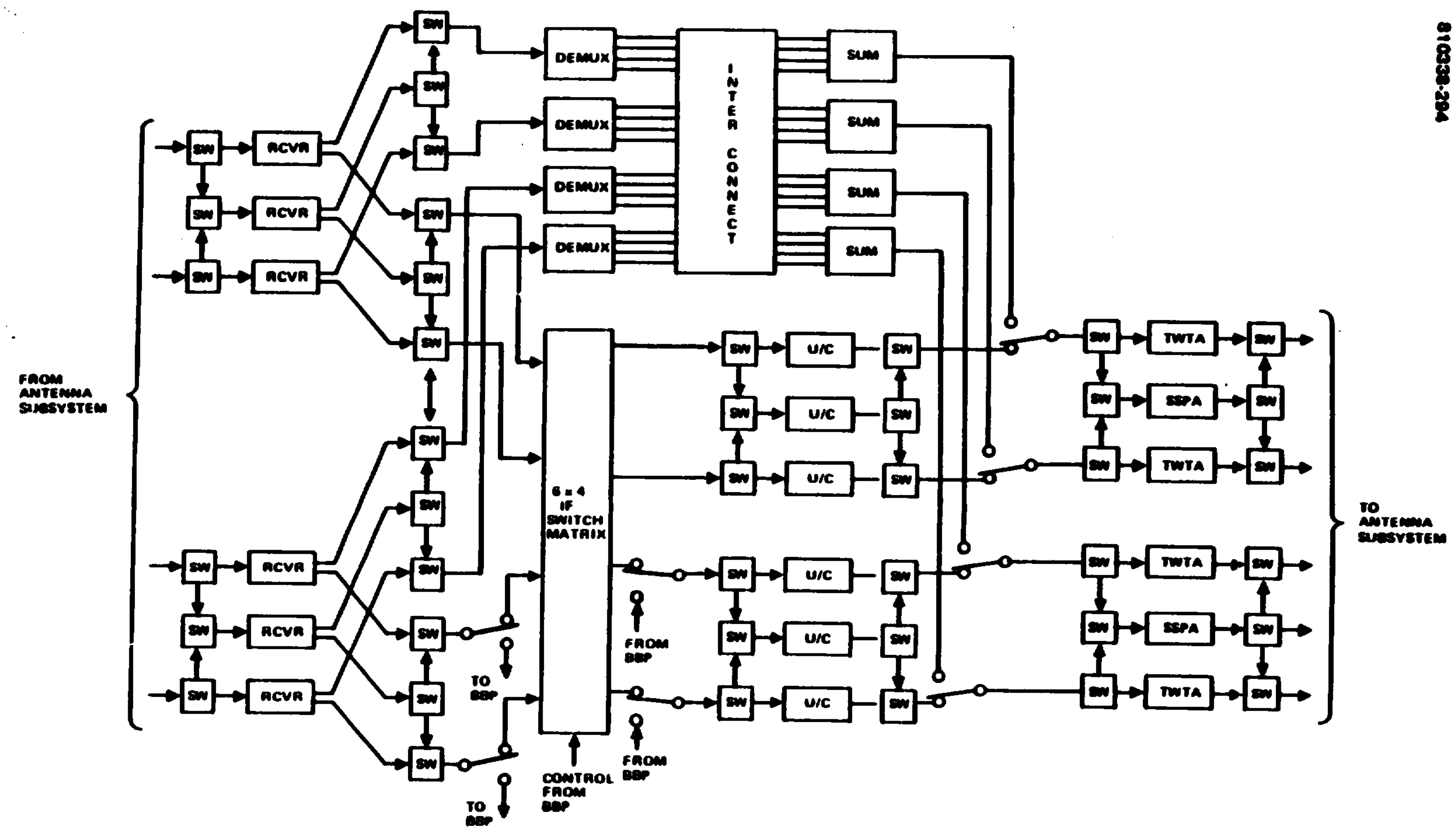


FIGURE 3.2-13. OPTION 2 MICROWAVE SUBSYSTEM BLOCK DIAGRAM

TABLE 3.2-5. MICROWAVE SUBSYSTEM GAIN FLATNESS AND PHASE LINEARITY

Mode	BPF Phase Variation, deg	BPF Filter Gain Variation, dB	Component Phase Ripple, deg	Component Gain Ripple, dB	Total Phase Variation, deg	Total Gain Variation, dB
CPS	±0.02	±0.05	±5	±0.4	±5	±0.45
Trunk	±1.91	±0.05	±7	±0.55	±8.9	±0.6

cuits, the switch matrix, the upconverter circuit, and the power amplifier. These circuits contribute primarily phase and gain ripple due to intercomponent impedance mismatches.

Table 3.2-5 gives phase linearity and gain flatness estimates for the microwave subsystem for both trunk service and CPS service. The filter data of Table 3.2-5 are based upon theoretical filter response characteristics. The component phase ripple and amplitude ripple data are estimated based upon similar subsystems.

3.2.5 Options

3.2.5.1 Option 2 Modifications to Microwave Subsystem

Figure 3.2-13 shows the configuration of the microwave subsystem for option 2 which provides the capability of either SS TDMA or FDMA operation for the trunk service.

The configuration has several additions to the baseline system. The receivers provide an RF output for FDMA operation of the trunk service. Additional redundancy switches are required to select the receiver RF outputs. Four 4 channel demultiplexing filters, interconnections, and four 4 way summers are added to provide the FDMA capability. Additional mode switches are required to select FDMA or TDMA inputs to the power amplifiers.

3.2.6 Technology Assessment

The technology required for the microwave subsystem is considered to be within the state of the art with the exception of the low noise amplifier used in the antenna subsystem. The noise figure and associated low noise gain required to meet the system noise figure goal of 5 dB requires a modest improvement in GaAs low noise device performance at the uplink frequency.

The Hughes Electron Dynamics Division has a contract from the NASA Goddard Space Flight Center to develop a low noise receiver consisting of a five stage preamplifier, mixer, and local oscillator with an overall noise figure design goal of 4 dB. Results to date indicate that 5 dB should be achievable within the next year. Device noise figures as low as 3.6 dB with an associated low noise gain of 4 dB have been measured on devices having a gate length of 0.5 microns. Work is being done to improve device manufacturing processes to permit reduction of device gate length in order to obtain improved noise figure and associated gain.

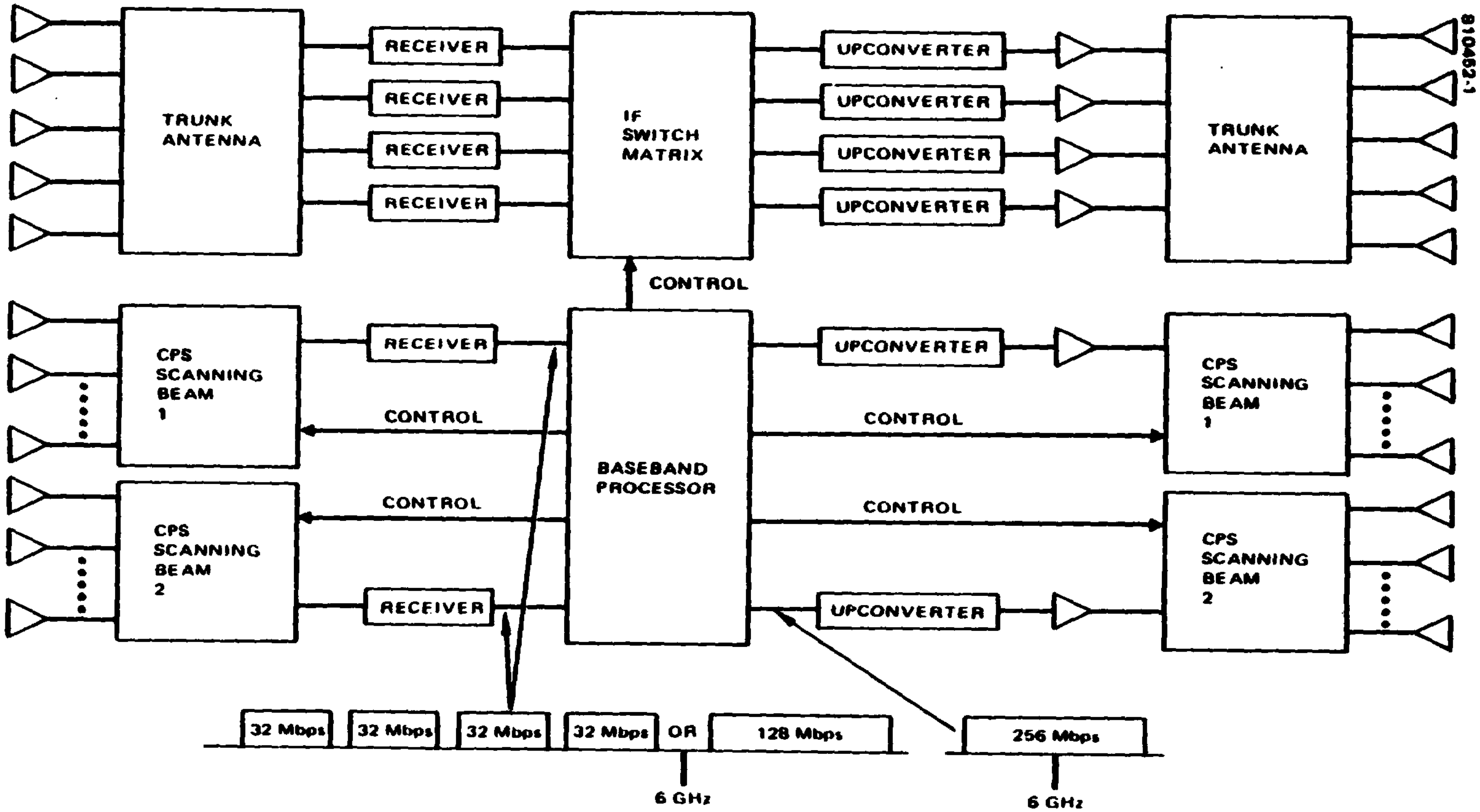


FIGURE 3.3-1. BASEBAND PROCESSOR FUNCTIONS

3.3 BASEBAND PROCESSOR

3.3.1 Introduction

The baseband processor (BBP) design is presented in this section. Although NASA is funding a technology development study which will result in a proof of concept model for the BBP, the design presented in this report is a Hughes design. This approach is taken for two reasons. First, the technology studies were still in an early stage at the time the design was made; and second, Hughes considers that it will be more competent to reach correct make or buy decisions and to effectively procure components if it has been through the preliminary design process. At this time no decisions have been made regarding the source of any of the communication components. Make or buy decisions will be made early in the system definition phase (Phase B).

The functional requirements on the baseband processor are illustrated by Figure 3.3-1. The BBP performs complex baseband data routing functions in the CPS mode. The single trunk function is that of sequencing the IF switch matrix. This switch sequence is reprogrammable in the BBP via the command link.

The primary function of the BBP is the routing of CPS data which is gathered by the scanning beams and downconverted to a 6 GHz IF by the receiver. At any time the receiver output contains either four 32 Mbps quadrature phase shift keying (QPSK) channels or a single 128 Mbps channel. The BBP must demultiplex and demodulate these signals and store the data until one of the downlink scanning beams is pointed at the terminal for which each message is intended, at which time it reads out that data to the transmitter serving that scanning beam. The output data is a single channel for each beam at 256 Mbps QPSK. The routing format can be modified via the orderwire in response to changes in the CPS traffic pattern. Because the output rate on each beam is twice the total input rate, the downlink outputs will be active for at most half the TDMA frame.

As much as 25 percent of the received CPS data can be FEC encoded. The BBP must separate this data from the uncoded data and decode it before processing it through the store and forward operation described above. Similarly, the BBP can FEC encode up to 25 percent of the transmitted CPS data.

In addition to the store and forward and FEC functions, the BBP controls the operation of the scanning beam antenna as well as the IF switch matrix, takes part in the system synchronization and orderwire functions, and provides the master clock for the system.

The baseband processor is divided into four sections as shown in Figure 3.3-2.

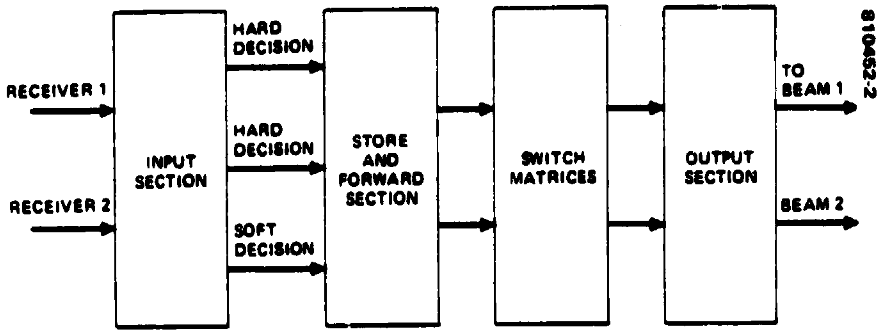


FIGURE 3.3-2. BASEBAND PROCESSOR SIMPLIFIED FUNCTIONAL BLOCK DIAGRAM

3.3.2 Input Section (Figure 3.3-3)

The demultiplexer downconverts the received signal to an 800 MHz band centered at 575 MHz and demultiplexes the four 32 Mbps channels and the 128 Mbps channel. This data is then downconverted to a common 20 MHz center frequency for the 32 Mbps data and a 125 MHz center frequency for the 128 Mbps data. FEC encoded data is routed to the soft decision demodulators.

The demodulators have carrier and clock acquisition circuits which are specially designed for burst mode operation. The incoming signal is passed through an X^4 nonlinearity to produce an unmodulated signal at four times the carrier frequency from which a carrier is extracted. This approach allows much more rapid carrier acquisition than can be achieved with a Costas loop. The hard decision demodulators reproduce the modulating bit stream while the soft decision demodulators encode each bit as a 3 bit word for the FEC decoder. The demodulator also supplies a measurement of the signal strength at a rate which allows the signal strength measurement unit to estimate the strength of individual uplink bursts for transmission to the MCT.

The unique word detector provides the sync interface unit with a measure of the timing error of the uplink burst. This error is relayed to the transmitting earth station so that uplink burst timing can be corrected.

3.3.3 Store and Forward Section (Figure 3.3-4)

The demodulated data is stored in double buffered CMOS input memories. Each half stores one frame (1 msec) of data. The output of the input memories are dynamically cross-connected to the output memories by the baseband switch. The orderwire interface unit extracts uplink orderwire data from the MCT uplink data stream and interleaves BBP originated orderwire data on the MCT downlink.

The routing sequence may be modified under master control station command. A new control sequence may be sent to the spacecraft either on the orderwire channel or on the command link. A changeover in time slot

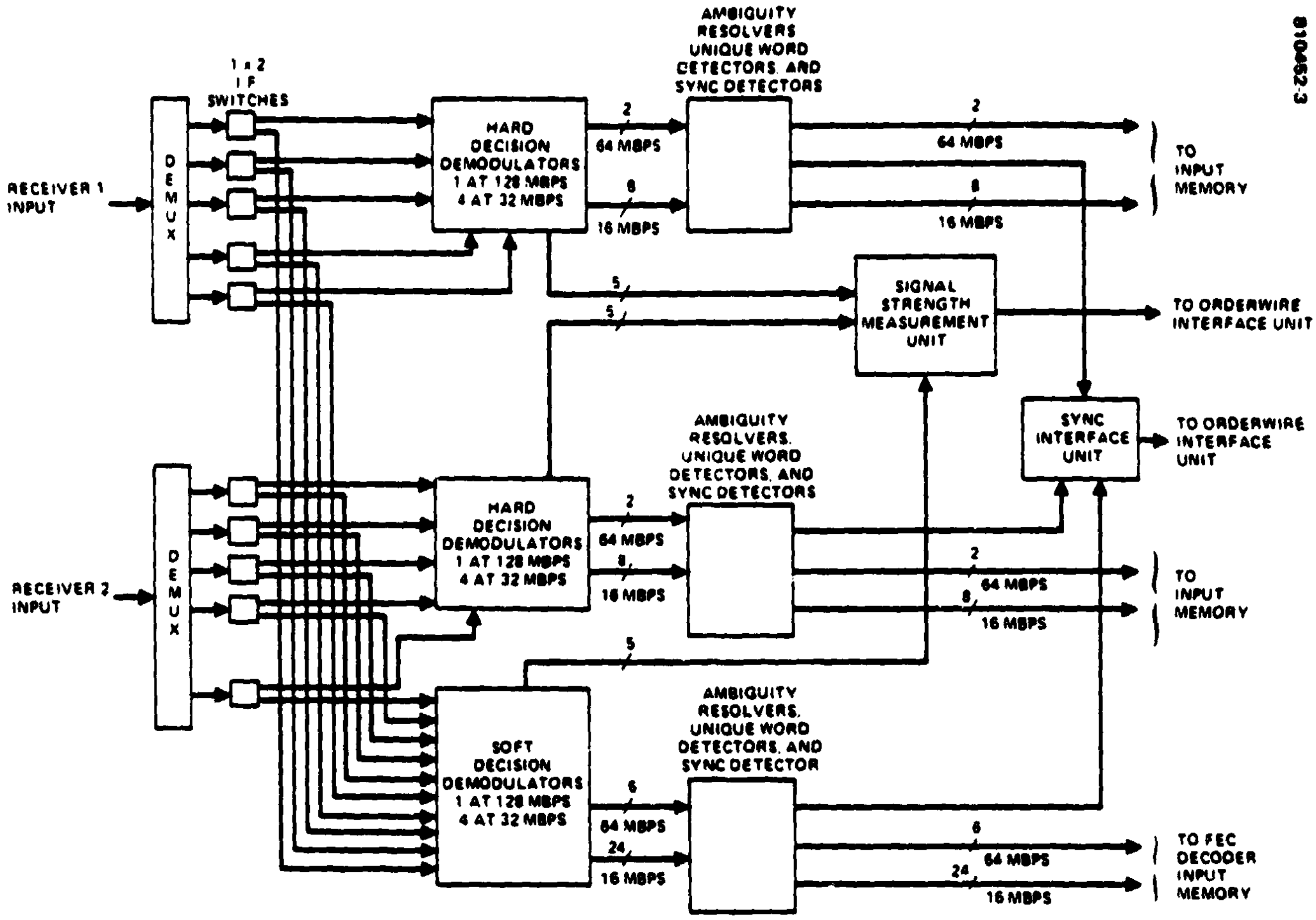


FIGURE 3.3-3. BASEBAND PROCESSOR BLOCK DIAGRAM, INPUT SECTION

assignment and store and forward timing and control may be made in a single frame without interruption of service or loss of data. The routing sequence in spacecraft memory may be monitored either on the downlink orderwire channel or on the telemetry link.

The convolutional decoders are used on rain attenuated encoded bursts. The coding gain makes up for link loss due to rain attenuation. Rate 1/2, constraint length 5, 3 bit soft decision convolutional decoders are used. The decoders implement the Viterbi Algorithm. The coding gain is 4.4 dB. Since the burst rate is fixed, a rate 1/2 encoding of the data implies that twice as much energy per information bit will be used in transmission. The result is a rate gain of 3 dB. The overall improvement due to decoding is the sum of the coding gain and the rate gain which is 7.4 dB.

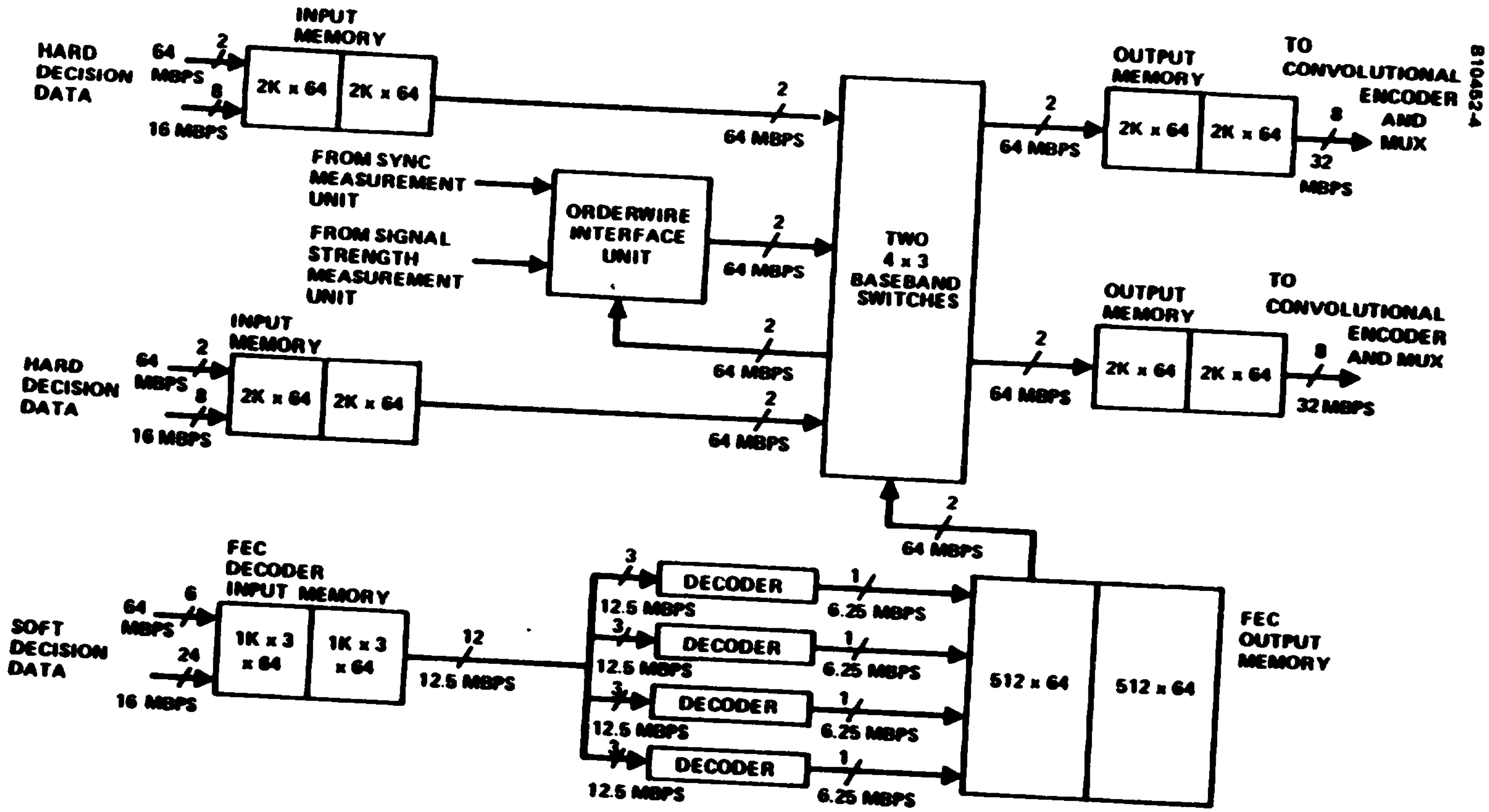


FIGURE 3.3-4. BASEBAND PROCESSOR BLOCK DIAGRAM, STORE AND FORWARD SECTION

3.3.4 Output Section (Figure 3.3-5)

The output of each of the two output memories goes to a convolutional encoder and a mux. For data which will not be convolutionally encoded, all eight lines contain 32 Mbps serial bit stream data. For data which will be convolutionally encoded only four of the eight 32 Mbps lines contain data because the encoder will double the data rate. The convolutional encoder outputs are eight lines at 32 Mbps. The convolutional encoders are Fairchild Isoplanar ECL gate array LSI devices. The nonencoded or encoded eight lines at 32 Mbps are multiplexed together and converted into two 128 Mbps serial bit streams for each of two multiplexers, on the same gate array as the encoder. The two 128 Mbps bit streams are input into each of two 256 Mbps QPSK modulators. The modulators use ECL digital circuits, thin film RF amplifiers, and RF hybrids. The two modulator outputs are upconverted to 6 GHz and are output to the two upconverters which correspond to the two scanning beam downlink antennas.

3.3.5 Control Functions

In addition to the functions shown in the previous block diagrams there are a large number of control functions required for operation of the BBP as well as for control of the IF switch matrix and the scanning beam.

As shown in Figure 3.3-6, the baseband processor contains an onboard oscillator which is the master oscillator for the TDMA system. This oscillator may be frequency corrected from the ground either by the command link or through the uplink orderwire channel. The baseband processor contains a beam forming network controller which controls the scanning sequences of the uplink and downlink scanning beam antennas. The digital routing controller controls the data memory write and read sequences, the analog routing switch sequences, the baseband switch sequences, the decoder timing, the encoder timing, and the Mux timing to implement the store and forward, decode, and encode functions. New data routing sequences may be loaded into the controller memory via the uplink orderwire channel or via the command link. For trunk operation, which cannot occur simultaneously with CPS operation, the IF switch controller controls the IF switch sequence.

New IF switch sequences may be entered via the command link. The contents of the IF switch controller sequence memory may be monitored via the telemetry link. The contents of the BFN controller sequence memory or the digital routing controller sequence memory may be monitored either on the downlink orderwire channel or on telemetry.

3.3.6 Weight and Power Estimates for the Baseband Processor

The weight and power for the baseband processor is shown in Table 3.3-1. The weight includes redundancy. Option 1 eliminates one of the scanning beams and reduces the throughput of the remaining beam to a single 128 Mbps signal on the downlink and two 32 Mbps signals in the uplink.

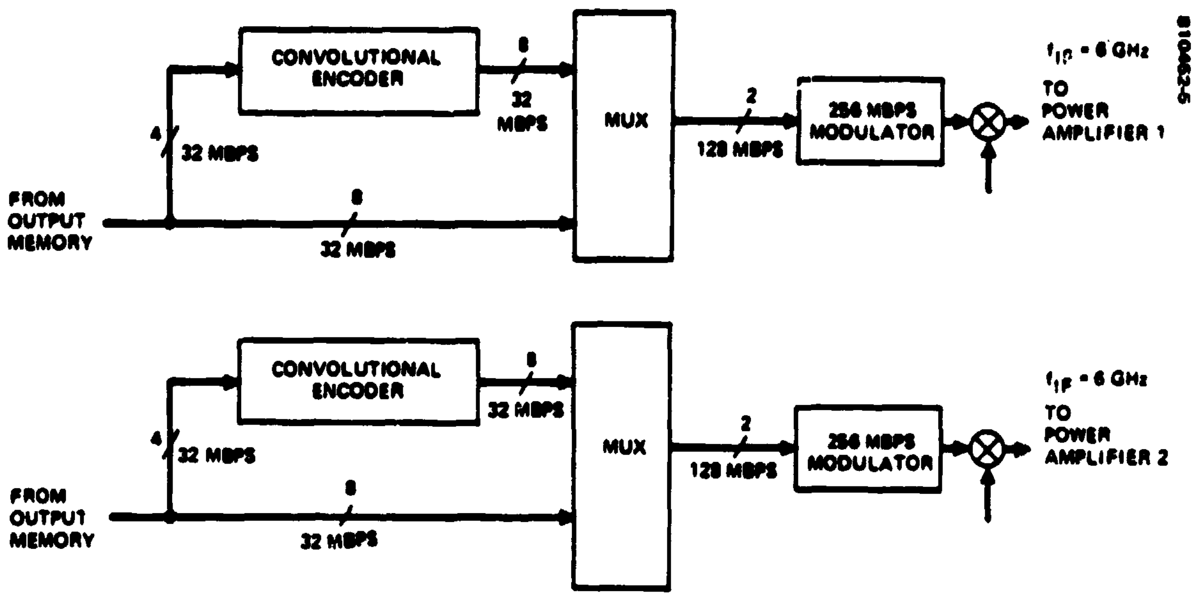


FIGURE 3.3-5. BASEBAND PROCESSOR BLOCK DIAGRAM, OUTPUT SECTION

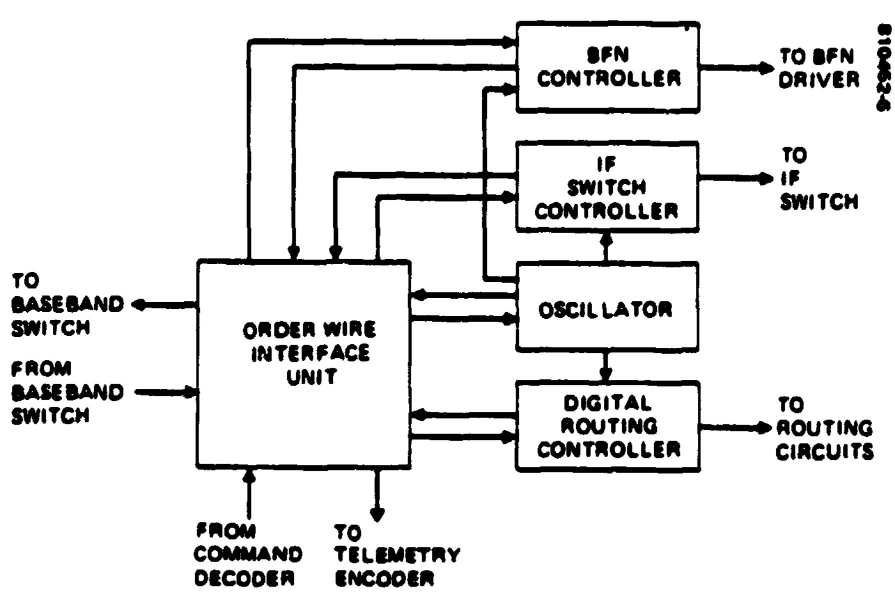


FIGURE 3.3-6. BASEBAND PROCESSOR TIMING

TABLE 3.3-1. BASEBAND PROCESSOR POWER AND WEIGHT SUMMARY

Component	Full Capacity Processor			Reduced Capacity (Option 1) Processor		
	CPS Mode Power, W	Trunk Mode Power, W	Weight, lb	CPS Mode Power, W	Trunk Mode Power, W	Weight, lb
Analog electronics	56.3	0	37.0	13.8	0	15.5
Digital electronics	168.2	41	74.2	75	41	63.1
Total	224.5	41	111.2	88.8	41	78.6

3.3.7 Technology Assessment

All of the technologies utilized in the baseband processor design will be available in 1982. The required LSI devices will be developed using gate array technology. Gate array devices have significant advantages over custom LSI devices:

1) Design time and cost of gate array development is far lower than full custom development.

2) Gate array device characteristics are better known than the characteristic of a newly developed custom LSI device.

Several device technologies are used for the gate array device types used in the design. The use of technology that meets the clock rate requirements of the logic design, and does not wastefully exceed the requirements, minimizes the overall power dissipation is the baseband processor.

In the serial data transfer between memories which occur at a 64 Mbps clock rate, Fairchild FAST logic was chosen because of its speed capability at a low power dissipation level. While ECL is faster than FAST, it is considerably more power consuming and is on a poorer delay power product contour.

The gate array devices and technologies used in the baseband processor are listed in Table 3.3-2. The numbers of devices and gate array technologies used in the digital electronics in the baseband processor design are listed in Table 3.3-3 and the analog electronics technologies are listed in Table 3.3-4. The physical design of the analog and digital electronics in the baseband processor is shown in Table 3.3-5.

TABLE 3.3-2. GATE ARRAY DEVICES USED IN THE BASEBAND PROCESSOR DESIGN

Function	Gate Array Technology
Convolutional decoder	Fairchild 9480 I^3L
32 bit serial to parallel converter	Fairchild FAST
32 bit parallel to serial converter	Fairchild FAST
Ambiguity resolver	Fairchild FAST
Sync detector	Fairchild FAST
32 bit serial to parallel converter	Hughes 5 uM SOS-CMOS
32 bit parallel to serial converter	Hughes 5 uM SOS-CMOS
Convolutional encoder	Fairchild isoplanar ECL
High speed ambiguity resolver	Fairchild ECL
High speed sync interface	Fairchild ECL

TABLE 3.3-3. BASEBAND PROCESSOR DIGITAL ELECTRONICS COMPLEXITY ESTIMATE

					Gate Array Devices				
Subunit	Disc	SSI	MSI	LSI	SOS CMOS	Large I^2L	Small I^2L	ECL	Fast
Input memory			64		6				4
Output memory			64						8
FEC input memory			192		42				6
FEC output memory			32		8				2
FEC decoder			14			4			
Memory control		4	18						
Convolutional encoder		2						1	
128 Mbps ambiguity resolver		2						1	
32 Mbps ambiguity resolver		2					1		
128 Mbps sync interface		2						1	
32 Mbps sync interface		2					1		
Signal strength interface		1		1					
OW interface			32		8				2
Scan beam controller		12	38						
IF switch controller		10	30						
Digital routing controller			10	3					
Power supply	400	10							

TABLE 3.3-4. ANALOG ELECTRONICS TECHNOLOGY

Component	Technology/Packaging
IF downconverter and routing switch	• Thin film RF amplifier chips, RF hybrid packages and GaAs FET solid state switches integrated into complex hybrid package
	• Discrete component filters
128 Mbps demodulator	• Thin film RF amplifiers and RF hybrids
	• ECL digital circuits
	• Discrete component filters
	• Quenchable BPFs are helical resonators
32 Mbps demodulators	• Thin film RF amplifiers and RF hybrids
	• Schotky TTL and ECL digital circuits
	• Discrete component filters

TABLE 3.^-5. BASELINE PHYSICAL DESIGN APPROACH

Component Packaging	
RF analog	1 x 2 in. hybrids
	Multilayer PWBs
Digital	Multilayer PWBs
Power supply	3-D soldered/welded modules
Construction	
RF analog	PWBs bonded to honeycomb panel mounted in RFI partitioned chassis
Digital	Multilayer PWBs bonded to honeycomb panel mounted in machined chassis
Power supply	Machined aluminum subassembly
Chassis	Milled out aluminum
	60 mil lids

4. SPACE VEHICLE

4.1 SPACECRAFT BUS

The LEASAT bus has been chosen for the 30/20 GHz payload because it has ample payload capacity (>500 pounds, >850 watts) and requires minimum modification but is inexpensive to launch. The LEASAT with the 30/20 GHz payload installed will require just over one-fourth of the payload bay length. Thus, the weight and length fractions of the shuttle payload will be nearly equal. This balance minimizes the shuttle launch cost and maximizes the opportunities for ride sharing. Also, the bus incorporates its own perigee stage so that a costly PAM is not needed. Other Hughes spacecraft were eliminated because either they had lower payload capability (SBS) or were more costly (HS 350). The LEASAT spacecraft will be flown and flight proven before the 30/20 GHz launch.

A description of the present LEASAT design will be presented first and then followed with a discussion of the modifications required for the 30/20 GHz program.

4.1.1 Spacecraft Design

4.1.1.1 Baseline Design

The LEASAT spacecraft is a dual spin configuration. The vehicle is spin stabilized and the communications payload is despun. It is inherently stable in all phases of the mission. The dual spin spacecraft is a well established, conservative design approach which has been used, and is now being used, for many satellites. Figure 4-1 provides an overview of the spacecraft system.

The cylindrical, spinning section of the LEASAT spacecraft contains the solar cell arrays, power electronics, batteries, propulsion, and attitude control equipment. The despin section consists of an electronic equipment platform on which the communications and the telemetry, tracking, and command subsystem (including their antennas) are mounted. The despin function is accomplished through a bearing and power transfer assembly (BAPTA).

4.1.1.2 Spinning Section

The external boundary of the spinning portion of the spacecraft illustrated by Figure 4-2 is the solar cell array cylinder. The cylinder, which is made up of four quarter cylinder sections, is supported by a truss structure at each of the four mating joints. The panels are removable to allow access to the spacecraft internal components. The four-sided truss structure is the primary load-carrying structure of the spacecraft. It supports the solar panel, all of the propulsion subsystem equipment, and eight platforms onto which are mounted the power control, attitude control, and TT&C spun electronics (see Figure 4-3). At its forward end, the truss also supports the BAPTA which, in turn, supports the despun section. The batteries are mounted on panels immediately adjacent to the solar panel mating joints.

The propulsion subsystems occupy most of the spinning section's volume. The solid propellant subsystem (SPS) is housed in the central cavity of the truss structure. The tanks of the liquid bipropellant subsystem (LBS) and the reaction control subsystem (RCS) are nestled between the members of the truss. These tanks include four 33 inch diameter propellant tanks and two helium tanks for the LBS, and four hydrazine tanks for the RCS. The SPS case is jettisoned from the spacecraft after its propellant has been expended.

4.1.1.3 Despun Section

The LEASAT satellite has all of the communications subsystem equipments, including the antennas, and most of the TT&C subsystem equipments in the despun section. Accordingly, no RF rotary joint is required and all RF signals travel unbroken paths between the multiplexers and the antennas, thereby eliminating a potential source of IM products and RF losses. The despun platform is located within the forward end of the spinning solar panel. High power transmitter equipments are mounted on the forward (antenna) side of the platform, and low signal level receiver and digital equipments are mounted to the aft side.

4.1.1.4 Design and Performance Characteristics

Large spacecraft bus performance margins support the prime mission objective of providing the specified communications service with a high probability of service continuity. This objective is achieved with an uncomplicated bus design incorporating key subsystem components which have been proven through wide use in long life synchronous orbit communications applications. Large margins are also provided for the communications subsystem performance.

A weight summary is shown in Table 4-1.

SPACECRAFT SUBSYSTEMS

- **STRUCTURE**
  - **STS Cost-Geometry Optimized**
  - **Conservatively Oversized**
  - **In Current Flight Implementation**
  - **Truss**
    - **GRP Composite**
  - **Solar Panel Substrates**
    - **Kevlar Construction from Current Flight Programs**
    - **166" D x 108" L**
  - Motor Adapter
    - Permits Alternate Growth Motor

- **THERMAL**
  - Predictable, Standard Spinner Design
  - Benign (40° F to 71° F, 20° F Eclipse Min) Equipment Environment
  - Spin Averaged Solar Load, Passive Design
  - Simple Heater Augmentation on Propulsion, Batteries

- **POWER**
  - Large Margins; Redundant
  - Array Performance Backed by Over 80 Orbit Years Instrumented Flight Data
  - Solar Cells, Power Control Electronics from Current Programs; Batteries, Discharge Regulator Scaled from Existing Designs
  - 1216 w. 5 year Equinox, Solar Flare Plus Trapped Radiation, 15% Array Margin
  - Three 28.9 Ahr Batteries Including Redundancy; 42% DOD
  - Constant Power, Current-Shared Battery Discharge
  - Standard Passive Charge Control via Current-Limited Solar Cells; Continuous Trickle, Commandable High Rate

- **ATTITUDE CONTROL**
  - Common Stable Spinner, Passive Nutation Damping, 50 RPM
  - Motor/Bearing/Slipring Assembly: Intelsat IV/IVA, Comstar Design (over 50 orbit years on specific type)
  - Existing Earth Sensors (14 flights), Sun Sensors (standard on all spinning Spacecraft)
  - Earth Center Finding Despin Control – Simplification of Similar Flight Designs

- **PROPULSION SUBSYSTEMS**
  - Proven Components
  - System Proof Underway
  - Provides 11% Mass Margin
  - Solid Propellant Subsystem: Existing Minuteman Motor, over 600 Built; 7308 lb. Propellant, Fiberglas Case, CTPB 88% Solids
  - Liquid Bipropulsion Subsystem: Regulated Bipropellant; Redundant Existing Design 100 lb. Thrusters (Apollo) with 100:1 Nozzles; 3088 lb. Capacity, 4 Titanium Tanks, 2 Helium Bottles, Welded Construction
  - Reaction Control Subsystem: Flight Proven Tanks, Thrusters (Intelsat, Comstar, Others); Welded System, 352 lb. Capacity Accommodates 7 Years; 4 Lateral, 2 Axial 5 lb. Thrusters, Over 100 Flown

COMMUNICATION SUBSYSTEM

- **ANTENNAS**

  UHF
  - Design Based on Flight Experience/Test
    - MARISAT, SDS, TACSAT
    - Range Data On Modeled Spacecraft
  - Intermodulation (IM) Product Control
    - Separate Transmit and Receive Antennas
    - Deployed Position Eliminates Spacecraft Coupling
    - Low-IM Construction
  - Simple, Reliable Deployment
  - Transmit and Receive
    - Type: Bifilar Helix — Axial Ratio: 0.8 dB
    - Polarization: RHCP — Gain: 13.9 Tx/14.1 Rec at ± 9.

  X-BAND HORNS
  - Intelsat IVA Derived
  - Earth Coverage, RHCP Transmit, LHCP Receive
  - Gain 17.0 dB at ± 9.0°
  - Axial Ratio ≤ 1.5 dB

- **REPEATER**
  - Hardware Based on over 15 Orbit Years UHF Experience
    - MARISAT, SDS, TACSAT
  - Extraordinarily High Reliability (0.937, 5 years)
    - Low Level Crosstrapping in Receiver
    - Ample Power and Mass Capability of Bus Used for Conservative Re
  - I/M Control
    - Low-I/M Components in Transmit Line
    - No Common Transmit/Receive Path

CHANNEL	QTY	BW	G/T, dB/°K	E
FB				
SHF Rcv		30 MHz	16.9	–
SHF Tx		50 MHx	–	1
UHF		25 KHz	–	2
25 KHz	6	25 KHz	13.9	2
500 KHz	1	500 KHz	13.9	2
5 KHz	5	5 KHz	13.9	1

- **COMMAND SUBSYSTEM**
  - Reliable – Separate, Redundant Systems
  - Clean Interface – Fully Compatible with Navy Equipment
  - Capacity:
    - Despun: 256 Pulsed, 8 Serial
    - Spun: 128 Pulsed, 4 Serial

PARAMETER	FBP	OMNI
Link Margin	50 dB	19 dB
Coverage	Earth	40° Toroid
Frequency		7980 MHz
Modulation	FSK	FM/FSK
Rate	2/sec	≈ 1/sec

- **TELEMETRY SUBSYSTEM**
  - Flexible Formatting, Reliable – Hughes Standardized Modular T/M
  - Clean Interface – Fully Compatible with Navy Equipment
  - Solid State Amplifier

  Characteristics

Frequency, MHz:	7245, 7275
EIRP, dBm:	28.3 over 40° Toroid in Transfer Orbit 37.4 over 13.4° Coverage On Orbit
Data Rate:	**1000 bps**
Modulation:	**PCM/Biphase; 1.4 Rad max. Mod Index**
Despun Channels:	**256**
Spun Channels:	**128**
Dwell Mode:	**1-7 CH.**
Submultiplexing:	**Battery Cell Voltages (96) Temperatures**

FIGURE 4-1. SPACECRAFT SYSTEM OVERVIEW

FOLDOUT FRAME

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OF POOR QUALITY

810338-295

UBSYSTEM

Flight Experience/Test
DS, TACSAT
n Modeled Spacecraft
(IM) Product Control
smit and Receive Antennas
ition Eliminates Spacecraft Coupling
truction
Deployment
ceive
Helix Axial Ratio: 0.8 dB
RHCP Gain: 13.9 Tx/14.1 Rec at ± 9.3°

rived
RHCP Transmit, LHCP Receive
± 9.0°
5 dB

on over 15 Orbit Years UHF Experience
DS, TACSAT
High Reliability (0.937, 5 years)
osstrapping in Receiver
and Mass Capability of Bus Used for Conservative Repeater Design

ponents in Transmit Line
Transmit/Receive Path

QTY	BW	G/T, dB/°K	EIRP, dBw
	30 MHz	16.9	–
	50 MHx	–	14.7
	25 KHz	–	27.5
6	25 KHz	13.9	27.5/CH
1	500 KHz	13.9	29.5
5	5 KHz	13.9	18.0/CH

TEM

e, Redundant Systems
Fully Compatible with Navy Equipment

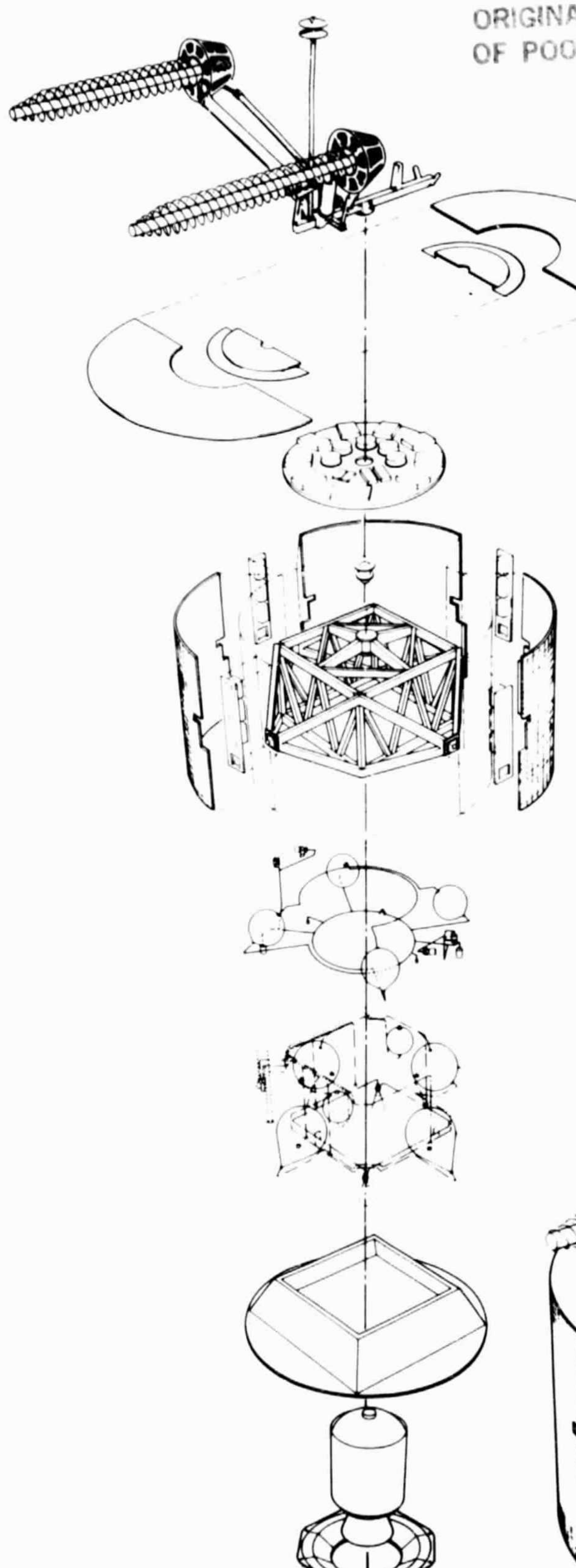
lsed, 8 Serial
lsed, 4 Serial

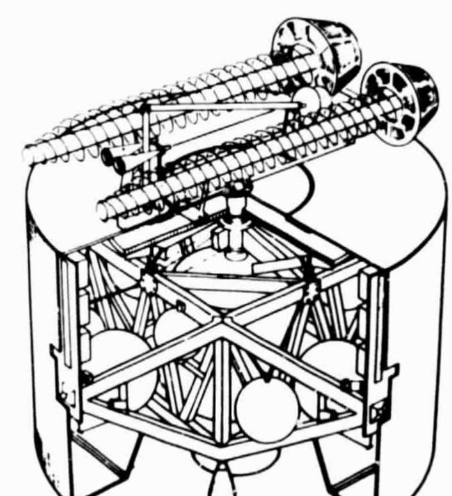
	FBP	OMNI
	50 dB	19 dB
	Earth	40° Toroid
		7980 MHz
	FSK	FM/FSK
	2/sec	≈1/sec

YSTEM

ng, Reliable – Hughes Standardized Modular T/M
Fully Compatible with Navy Equipment
fier

z: 7245, 7275
28.3 over 40° Toroid in Transfer Orbit
37.4 over 13.4° Coverage On Orbit
1000 bps
PCM/Biphase; 1.4 Rad max. Mod. Index
s: 256
128
1-7 CH.
: Battery Cell Voltages (96)
Temperatures





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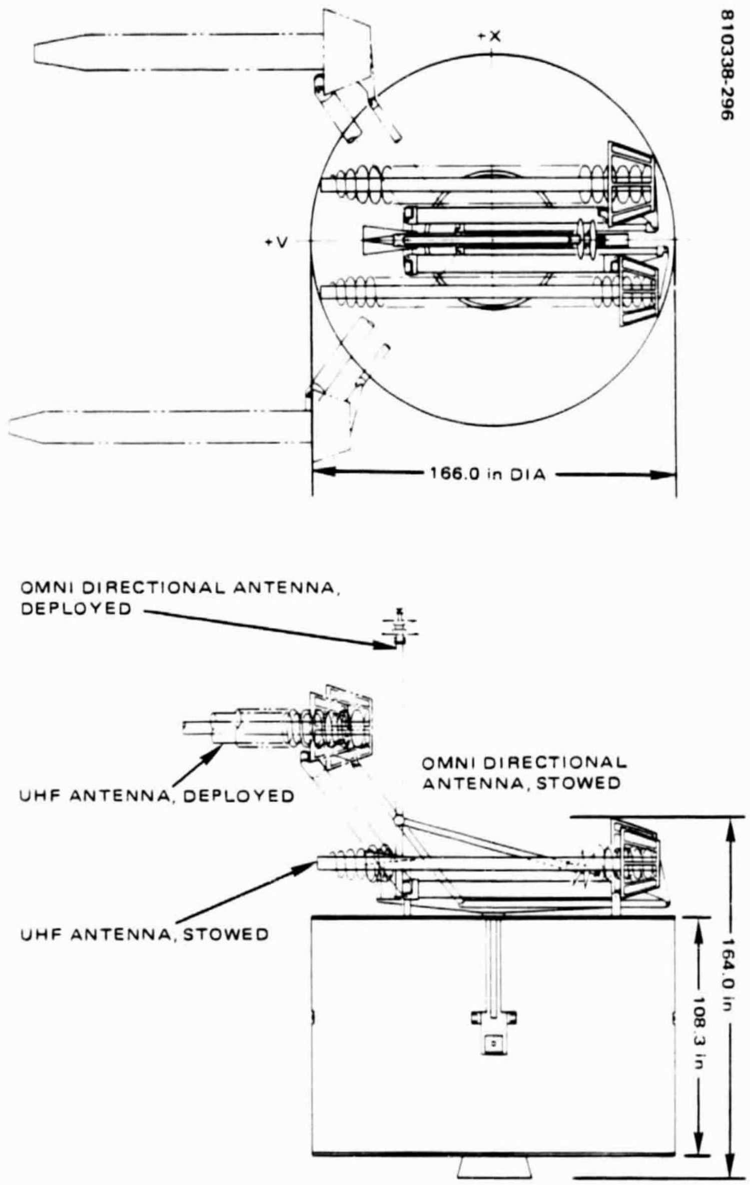


FIGURE 4-2. LEASAT EXTERNAL CONFIGURATION

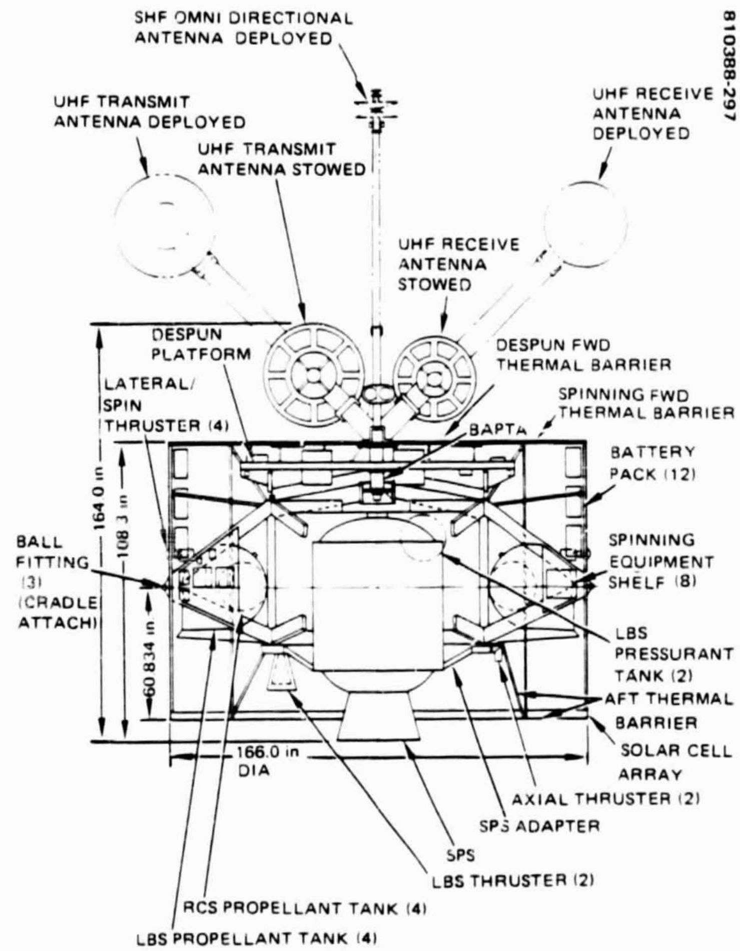


FIGURE 4-3. LEASAT INTERNAL CONFIGURATION

TABLE 4-1. WEIGHT SUMMARY

Item	Weight, lb
Communications	481
Telemetry and command	174
Attitude control	68
Reaction control (dry)	37
Electrical power	540
Thermal control	143
Structure	842
Wire harness	104
Liquid bipropellant subsystem (dry)	285
Balance weight	11
Margin	22
Spacecraft weight, end of 7 yr	2,729
Hydrazine used on station, 7 yr	137
Orbit acquisition hydrazine	122
Weight following apogee burn	2,989
Apogee burn	2,628
Preburn hydrazine	36
Attitude/orbit trim hydrazine	37
Weight following perigee burn	5,690
Perigee augmentation	1,381
SPS jettisoned mass	705
SPS expendables	7,387
Spinup hydrazine	20
Spacecraft at separation	15,181

The basic LEASAT spacecraft structure sizing has been based on a conservative 1.5 safety factor. Further, recent coupled loads analysis has shown that additional margin exists relative to current load levels. Owing to the large equipment shelf area which can be made available within the 166 inch diameter spacecraft body, ample installation volume exists for growth or the addition of experiments.

Power sources are sized with large margins for support of loads throughout 7 years as shown in Table 4-2. Multiple redundant batteries are sized for very low stress — 43 percent depth of discharge for the longest eclipse and full system load. This figure is in contrast to other 7 year synchronous orbit systems which are frequently designed to a more highly stressed 50 percent DOD. Redundancy provided by the three batteries permits full load support with loss of one of the batteries, increasing DOD to only 49 percent. Voltage sizing of the batteries permits loss of at least two of the 32 series cells in each battery.

TABLE 4-2. POWER SOURCE SIZING

Allocation	Power at 28 V		
	Summer Solstice	Equinox	Eclipse
Communications	739	739	739
Telemetry and command	71	71	71
Attitude control	34	34	34
Thermal control	51	96	51
Power control and distribution	61	66	177
Total	956	1006	1072
Battery charge	31	96	–
Main bus	987	1102	1072 (1254 Whr. 1.17 hr eclipse)
Available	7 yr: 1063	1194	3387 Whr.
Array margin, %	7 yr: 8	8	–
Battery depth of discharge, %	–	–	43

The solar panel output of 1194 watts at equinox is sized for an initial design margin of 15 percent, including full 7 year conservative solar flare and trapped radiation exposures. Over 80 orbit years of accurately telemetered spinning solar array performance on Hughes synchronous spacecraft shows predictability of array output to within ±2 percent when the actual environment is taken into account. Thus, the excess panel allocation in the LEASAT design ensures that loads can be supported throughout the mission and that load increases for addition of experimental packages or for other purposes can be accommodated.

For assessment of communications payload and bus performance in orbit, a flexible telemetry subsystem has been provided. Table 4-3 lists the channel allocation to communications and bus subsystems. The total allocation includes 105 spare channel or 27 percent of the expected requirement. With the standardized modular telemetry system selected, increase or restructuring of this allocation is easily achieved. Commands are also summarized in the table. Sufficient capacity exists to support anticipated system needs, including specific payload requirements, serial digital commands for operations such as nonreal time thruster pulsing, and general purpose pulse commands. Spares include 66 pulse commands or 17 percent of the expected requirement, and 12 serial digital commands or 200 percent of the expected requirement.

TABLE 4-3. COMMAND AND TELEMETRY ALLOCATION

Subsystem	Command		Telemetry			
	Pulse	Serial	Analog	Bilevel	Conditioned	Serial-Digital
Communications	169	0	13	107	35	0
Attitude control	13	2	5	0	0	2
Power	79	0	14	7	22	0
Propulsion	20	0	0	9	31	0
TT&C	37	2	8	19	7	0
Total Required	318	4	40	142	95	2
Available	384	12	384 total channels			
Spares	66	8	105			

Thermal environments provided by the LEASAT dual spin bus design are a benign 40°F to 71°F for the payload over all seasonal conditions throughout the 7 year mission while in sun, and 20°F to 70°F including eclipses. These values are similar to or even more moderate than those for typical 7 year Hughes synchronous orbit spinning spacecraft, so that expected LEASAT electronic part performance can be predicted accurately by using established derating factors and on-orbit life history, thereby supporting LEASAT reliability computations.

Orbit control requirements are accommodated in the spacecraft design and fuel budgets. This provision includes fuel for the specified repositioning maneuvers and the inclination maneuver planned to maintain ≤3 degree latitude during the seventh year.

The system specification requires that the spacecraft parts and materials, including the solar array, meet performance requirements while taking into account the natural radiation exposures over the mission life. Because of the importance of geosynchronous orbit, the expected environment has been assessed over more than the past 10 years and the models upgraded continuously. The large number of geosynchronous spacecraft successfully operated have supported the adequacy of the environmental models and the suitability of the spacecraft designs. The LEASAT spacecraft achieves ample radiation hardening margins by use of circuits and components screened for environments in excess of those expected. Further, many components are hardened to the additional extremes of artificial exposures. Conservative trapped and solar flare environment models used for solar array sizing are those commonly used for Intelsat, COMSTAR, MARISAT, and others. Solar array flight data conclusively show the models are more severe than actual environments.

Proper LEASAT performance will be assured through electromagnetic control provisions based on existing Hughes spacecraft designs such as SDS. The LEASAT electromagnetic design will be implemented through a formal system level activity including design, analysis, and, as required, test.

Requirements specified or assumed for design purposes for control of electromagnetic effects are summarized in Table 4-4.

4.1.2 LEASAT Modifications for 30/20 GHz System

Using the previous LEASAT spacecraft description as a baseline, the following sections present the modifications of the LEASAT required to develop a 30/20 GHz spacecraft design. The telemetry, tracking, and command system is modified to provide TT&C service at 30/20 GHz and at an S band rather than at the X band and UHF frequencies associated with LEASAT's defense application. The attitude control system is modified to accept a radio beacon error signal for platform despin and the liquid apogee motor system is provided to improve off the shelf thrusters for better performance.

4.1.2.1 Telemetry, Tracking, and Command System

The telemetry tracking and command (TT&C) system will operate on two frequency bands. During transfer orbit, the TT&C system will operate at S band in conjunction with the NASA STDN network. Once the satellite is at its orbital station, the TT&C function will operate through the 30/20 GHz payload as discussed below. If the 30/20 GHz TT&C link should become unavailable because of any anomaly or severe rain attenuation the on-station TT&C function can return to the S band mode. The S band TT&C links operate through the NASA standard near earth transponder (NASA/SNET). Operating at S band the system will be completely compatible with planned modification of STDN to make it compatible with the deep space network (DSN). The use of K band TT&C requires no modification of the spacecraft bus since the payload will downconvert the 30 GHz TT&C signal to the NASA/SNET S band input frequency and upconvert the NASA/SNET S band output to the 20 GHz downlink frequency. The 30/20 GHz TT&C RF link is discussed in Section 2.1, Communications. A functional block diagram of this proposed system is shown in Figure 4-4. The diagram depicts appropriate cross-strapping between the S and K band portions of the system.

TABLE 4-4. ELECTROMAGNETIC EFFECTS CONTROL REQUIREMENTS

Category	Requirement	Specified	Assumed Design Goal
EMI	MIL-STD-461/ MIL-STD-1541		X
TEMPEST	NACSEM 5100		X
Electrostatic discharge	Hughes design criteria		X
Intermodulation product control	Any 120 Hz BW: -23 dB Total, 5 kHz channel: -14 dB Any channel, at receive input: -30 dB above noise power density	X	
GFE unit power regulation		X	

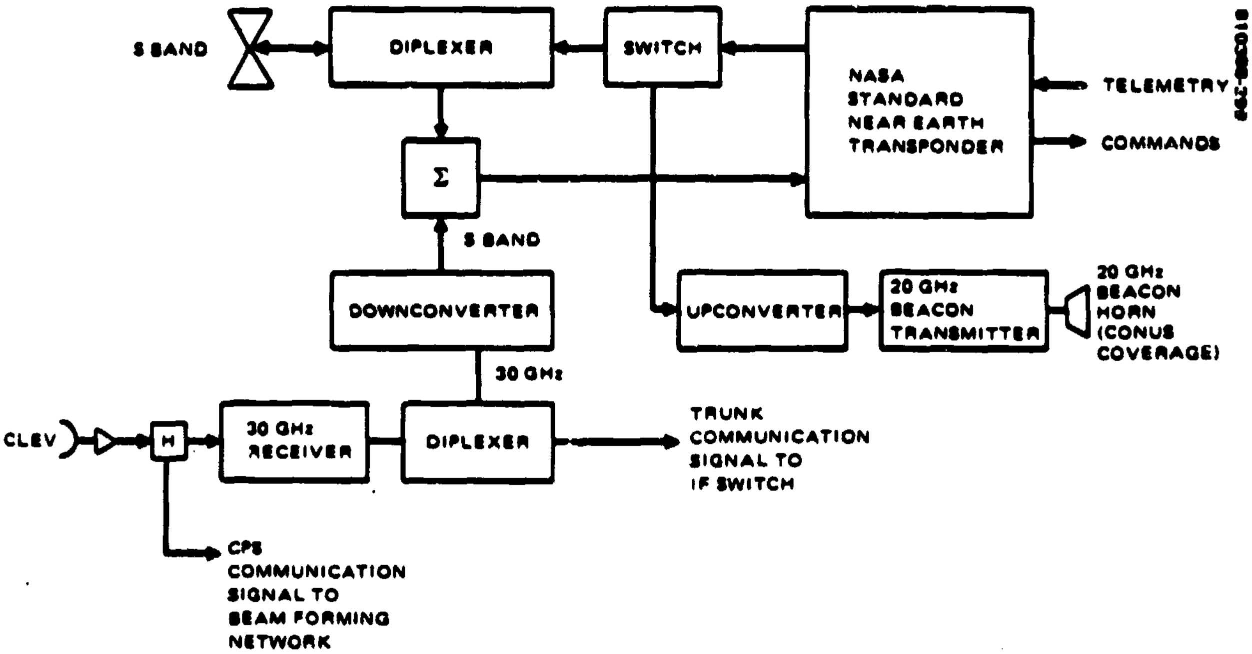


FIGURE 4-4. 30/20 GHz TT&C SUBSYSTEM

The NASA/SNET proposed for this mission is fabricated by Motorola and is currently under consideration by Hughes for the next series of GOES spacecraft under negotiation with NASA. The transponder has been developed and qualified to meet the needs of most NASA missions by providing factory installed options for some application variable parameters. The command unit in SNET interfaces with redundant spacecraft command decoders. It is programmable to operate at a selectable bit rate varying from 125 to 2000 bps. The data is in nonreturn to zero (NRZ) format. The transmitter functions as either a telemetry transmitter or in conjunction with the receiver as a coherent ranging transponder. The downlink modulation indices are selectable by command.

Table 4-5 contains the link budgets for commanding from the STDN 9 meter and 34 meter antenna subnets. The uplink signal will consist of a ranging and command signal; either or both may be present. The command signal is a 2 Kbs NRZ-L data stream ±90° PSK modulated on a 16 kHz subcarrier, which is phase modulated on the main carrier (f_c = 2034.2 MHz). The ranging signal is a 125 kHz square wave which phase modulates the main carrier directly. Phase modulation indices are assumed accurate to within ±10 percent, based on previous program experience, and adverse tolerances have been considered in compiling the budgets. The modulation loss values are given for both command only and simultaneous commanding and ranging. Losses are computed for nominal and worst case (due to +10 percent tolerance) values of the modulation indices.

The link budgets for telemetry from the spacecraft to the 9 meter and 34 meter DSN subnets are presented in Table 4-6. The telemetry signal is a 2 Kbs Bi-0L (Manchester encoded) data stream phase modulated directly on the downlink carrier (f_c = 2209.086 MHz). This carrier may also be simultaneously phase-modulated by the command subcarrier which is allowed to leak through the transponder, and ranging squarewave received on the uplink.

TABLE 4-5. SYSTEM COMMAND LINK (S BAND)

Item	Units	9 M Subnet				34 M Subnet			
Ground antenna size	m	9				34			
EIRP	dBm	113				128.3			
Polarization loss	dB	3				3			
Space loss*	dB	193.4				193.4			
Ground antenna track loss	dB	0.5				0.5			
Receive antenna gain	dB	-10.5				-10.5			
Losses between antenna and receiver	dB	5.7				5.7			
Received signal power	dBm	-100.1				-84.8			
Modulation indices									
Command	Radians	0.4	0.38	1.0	0.9	0.4	0.38	1.0	0.9
Ranging	Radians	0.4	0.44	-	-	0.4	0.44	-	-
Command signal mod loss	dB	-11.9	-12.9	-4.1	-4.8	-11.9	-12.9	-4.1	-4.8
Command threshold P_R	dBm	-111.1	-110.1	-118.9	-118.2	-111.1	-110.1	-118.9	-118.2
Margin	dB	11.1	10.1	18.8	18.1	26.3	25.3	34.1	33.4

*Space loss for D = 55,000 km and f = 2,034.2 MHz.

TABLE 4-6. SYSTEM TELEMETRY LINK (S BAND)

Item	Units	9 M Subnet				34 M Subnet			
S/C EIRP	dBm	20				20			
Polarization loss	dB	0.2				0.2			
Space loss*	dB	194.1				194.1			
Ground antenna track loss	dB	0.5				0.5			
G/T, ground station	dB/°K	24.1				34.2			
Received S/N_0	dB	47.9				58			
Mod indices									
Telemetry	Radians	1.0	0.9	1.4	1.26	1.0	0.9	1.4	1.26
Command	Radians	0.4	0.44	1.0	1.1	0.4	0.44	1.0	1.1
Ranging	Radians	0.4	0.44	-	-	0.4	0.44	-	-
Mod loss	dB	-2.6	-3.4	-2.4	-3.3	-2.6	-3.4	-2.4	-3.3
Available S/N_0	dB	45.3	44.5	45.5	44.6	55.4	54.6	55.6	54.7
Required E_b/N_0**	dB	9.6				9.6			
Implementation loss	dB	1.5				1.5			
Bit rate, Q	dB	33				33			
Margin	dB	1.2	0.4	1.5	0.5	11.3	10.5	11.5	10.6

*Space loss calculated for D = 55,000 km, f = 2,209.086 MHz.

**Theoretical required E_b/N_0 for 10^{-5} BER.

For the 9 meter subnet the margins are very small, only a 0.4 dB margin results for simultaneous telemetry, ranging, and commanding when worst case index values are used. Due to the increase in ground station G/T these margins improve by 10.1 dB when the 34 meter subnet is used.

4.1.2.2 Attitude Control

The 30/20 GHz system requires that the multibeam antenna be pointed to within an accuracy of less than 0.05° to satisfy communication link performance. The LEASAT antenna is pointed with an accuracy of 0.7° by controlling the attitude of the spin axis and the angular position of the despun platform in response to error signals from an earth sensor. The order of magnitude improvement required of the 30/20 GHz spacecraft is achieved by reorienting the antenna main reflector in elevation relative to the spacecraft body in response to an error signal from a 30 GHz earth based beacon. The azimuth orientation is still controlled by platform despin but also in response to a beacon error signal. The use of the elevation axis circumvents the problem of maintaining constant spin-axis attitude in the face of solar torques. This approach is identical to that used on the operational Hughes SBS design, wherein the received beacon signal is resolved into east-west and north-south components, and then processed by the antenna positioning electronics (APE) and attitude control electronics (ACE) to drive the north-south antenna positioning mechanism (APM) and east-west despin platform motor. Since the present LEASAT design does not include an APE or APM, they will be added and almost identical to those of the SBS design. Also the LEASAT ACE will receive minor modifications to accept the APE east-west signal as primary drive for the azimuth positioning of the antenna. The use of a spinning spacecraft with a despin platform results in a yaw gyroscopically stabilized vehicle requiring only a single beacon station and a single elevation control mechanism on the spacecraft antenna. The use of the earth sensors on the 30/20 GHz design will be relegated to transfer orbit and on-orbit attitude determination, initial on-orbit antenna despin and acquisition, and as a backup to the primary beacon mode.

Typical antenna pointing error budgets applicable to the 30/20 GHz system are listed in Tables 4-7 through 4-9. All results satisfy the 0.05° requirement.

Figure 4-5 shows the block diagram of the APE, APM, and command track receivers. The communications and track receivers are part of the microwave subsystem. Figure 4-6 and Table 4-10 give further details on the APE and APM.

4.1.2.3 Propulsion

The LAM subsystem will use the Ford qualified thrusters rather than the Marquart thrusters to obtain an increase in specific impulse (308 sec). This improvement plus targeting the orbit for 0° inclination results in additional RCS propellant (no pre-on-orbit burns) being made available to satisfy a 4 year stationkeeping requirement of ±0.02° in inclination.

C-2

TABLE 4-7. EAST-WEST BEAM POINTING ERROR BUDGET

Error Types and Sources	Error, deg (3σ)
Constant	
Tracking boresight calibration	0.0064
Omni antenna interference offset	0.0056
Command bias granularity	0.0016
Servo electronics null offset	0.0010
RSS subtotal	0.0089
Long term variations	
Track receiver	0.0104
Servo electronics	0.0010
RSS subtotal	0.0104
Diurnal variations	
Track receiver	0.0108
Track filter network	0.0058
BAPTA friction torque variation	0.0040
RSS subtotal	0.0129
Short term variations	
Track receiver noise	0.0013
Beacon signal random variation	0.0042
Dynamic coupling of wobble into E-W	0.0008
BAPTA friction torque disturbances	0.0050
Response to accelerometer noise	0.0003
RSS subtotal	0.0067
Total error in steady state operation	0.0389
Maneuver transient errors	
E-W velocity maneuver	0.0055
N-S velocity maneuver	0.0021
Attitude trim maneuver	0.0060
Worst case pointing error	
Sum of steady state and worst case maneuver transient errors	0.0449

TABLE 4-8. NORTH-SOUTH BEAM POINTING ERROR BUDGET

Error Types and Sources	Error, deg (3σ)
Constant	
Tracking boresight calibration	0.0052
Omni antenna interference offset	0.0056
Command bias granularity	0.0015
Servo electronics null offset	0.0010
RSS subtotal	0.0077
Long term variations	
Track receiver	0.0041
Servo electronics	0.0010
RSS subtotal	0.0042
Diurnal variations	
Track receiver	0.0040
Track filter network	0.0030
RSS subtotal	0.0050
Short term variations	
Beacon signal random variation	0.0028
Wobble and bearing runout	0.0025
Stepper servo deadband	0.0035
Nutation induced by antenna stepping	0.0002
Dynamic coupling of E-W jitter to N-S	0.0004
RSS subtotal	0.0052
Total error in steady state operation	0.0221
Maneuver transient errors	
E-W velocity maneuver	0.0029
N-S velocity maneuver	0.0035
Attitude trim maneuver	0.0100
Worst case pointing error	
Sum of steady state and worst case maneuver transient errors	0.0321

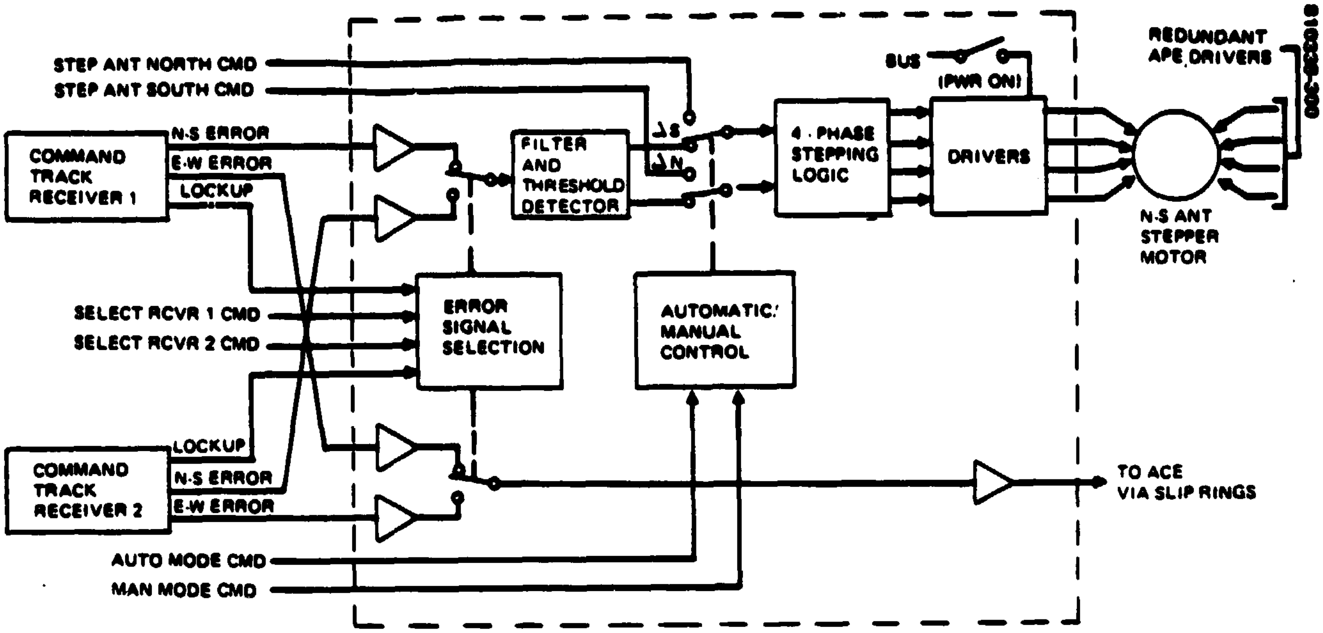
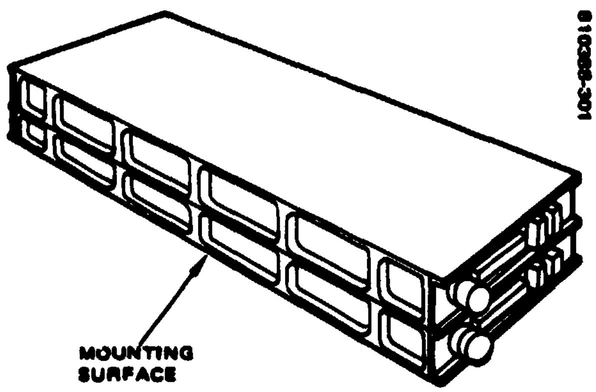


FIGURE 4-5. ANTENNA POSITIONER ELECTRONICS BLOCK DIAGRAM



PHYSICAL CHARACTERISTICS

SIZE = 45.5 x 15.0 x 7.1 cm

WEIGHT = 3.43 kg (7.55 lb)

POWER = 2.5 W

PARTS COUNT
124 I/C + 1036 DISCRETE

UNIT INTERNALLY REDUNDANT

FIGURE 4-6. ANTENNA POSITIONER ELECTRONICS

TABLE 4-9. BEAM ROTATION ERROR BUDGET

Error Types and Sources	Error, deg (3σ)
Constant	
Antenna rotation misalignment	0.0050
RSS subtotal	0.0050
Long term variations	
No identified errors	
Diurnal variations	
Spin axis attitude drift	0.1600
Attitude trim correction error	0.0620
Attitude measurement uncertainty	0.0200
RSS subtotal	0.1728
Short term variations	
Wobble and bearing runout	0.0025
Nutation induced by antenna stepping	0.0002
Dynamic coupling of E-W jitter to rotation	0.0004
RSS subtotal	0.0025
Total error in steady state operation	0.1803
Maneuver transient errors	
E-W velocity maneuver	0.0024
N-S velocity maneuver	0.0062
Attitude trim maneuver	0.0100
Worst case pointing error (rotation)	0.1903
Sum of steady state and worst case maneuver transient errors	
Equivalent pointing error	0.017

TABLE 4-10. ANTENNA POSITIONER MECHANISM CHARACTERISTICS

Drive system	Redundant
Motor	Size 15, PM, 45 deg stepper
Torque output	16 ft-lb
Output shaft stiffness	1025 ft-lb/deg
Positioning increment	0.0025 deg/step
Travel range	70 deg
Backlash	Zero
Potentiometer	42 kΩ, conductive plastic
Motor power	Approx 15 W (during step)
Weight	3.44 kg (7.57 lb)
Temperature range	-51° to 65.6°C (-60° to 150°F)

4.1.2.4 Configuration and Structural Modifications

The LEASAT despun shelf modifications necessary to accommodate the 30/20 GHz payload are illustrated in Figures 4-7 through 4-9. Figure 4-7 shows the forward and aft (dashed) layout of the payload, TT&C, and APE units on the despun shelf. The high power RF units are on the forward side and couple easily to the antenna. They are located radially outward to couple thermally to the forward spinning thermal barriers for heat removal. The low power RF units and digital units are shielded from high power units by locating them on the aft side of the shelf.

All units have been located with a concern for minimizing waveguide lengths, digital cable lengths, mass properties, and thermal control. Figure 4-8 shows a side view of the shelf with the associated despun and spinning thermal barriers. Both barriers will be modified LEASAT designs. The shelf dimensions and design are identical to those of the LEASAT, only the unit mounting bolt holes and attachment features need changes. The extensive shelf area leaves ample margin for repositioning and growth of the payload if required.

The antenna layout is shown in Figures 4-8 (side and top views) and 4-9 (reflector axis view). The main reflector and omni antennas are shown both stowed and deployed. All antenna elements, beacon antennas, waveguides that connect to the shelf units and structural support elements are shown.

A spacecraft isometric is shown in Figure 4-10.

4.1.2.5 Thermal and Structural Analyses

The results of thermal and structural analysis of the 30/20 GHz flight experiment spacecraft are reported in Volume 2. Both thermal and structural loads imposed by the 30/20 GHz payload are less severe than those due to the LEASAT payload.

4.1.3 Mass Properties

The spacecraft weight summary is presented in Table 4-11. The communication payloads are detailed in Section 3.

The on-orbit weight capability is somewhat less than that for the present LEASAT, but there is more RCS propellant available for stationkeeping in the 30/20 GHz design. This additional propellant is required to maintain the tight north-south orbital control (±0.025°) over a 4 year period. This requirement is driven by the desire to implement low cost nontracking ground station antenna systems.

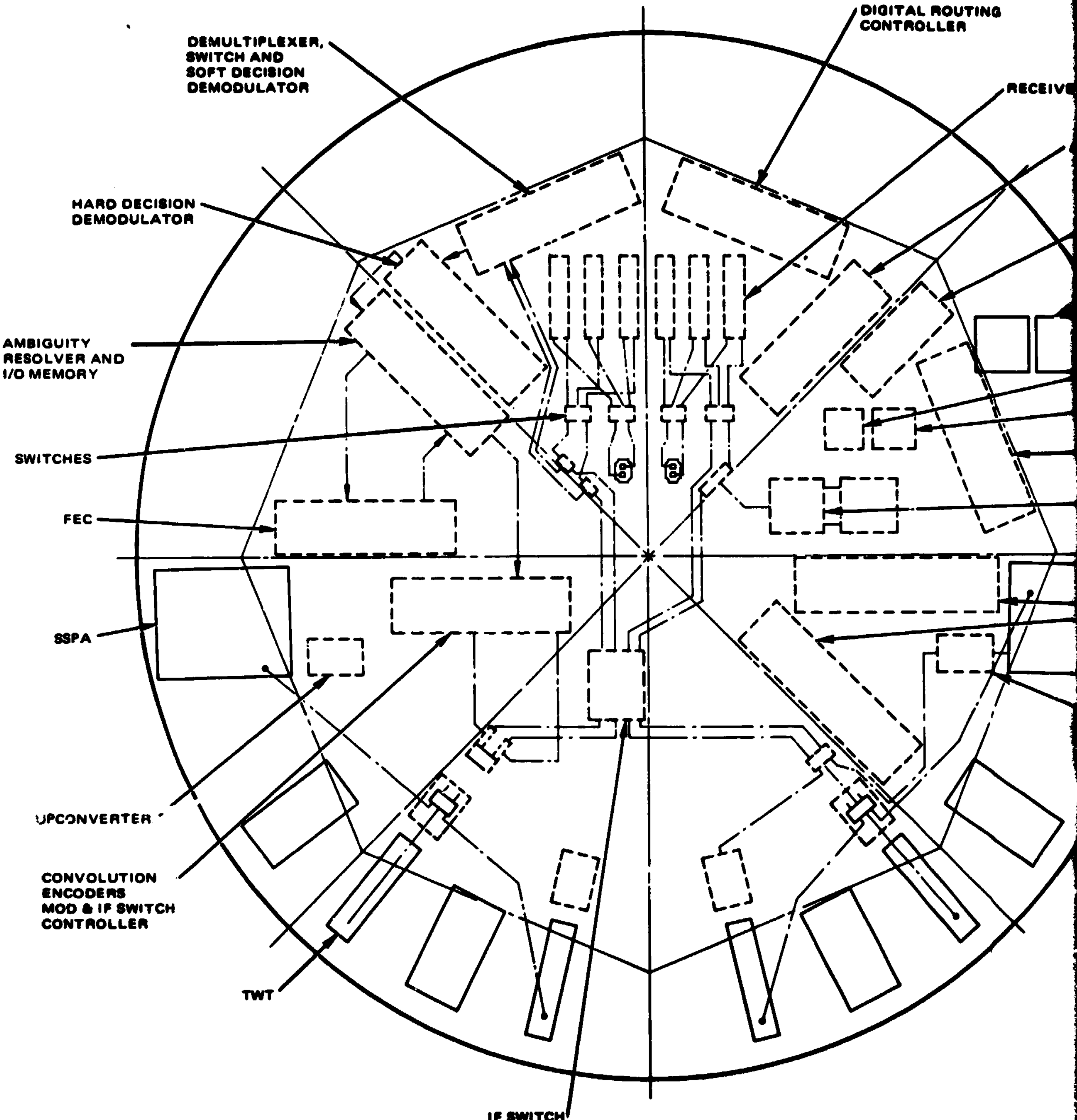


FIGURE 4-7. 30/20 GHz STUDY

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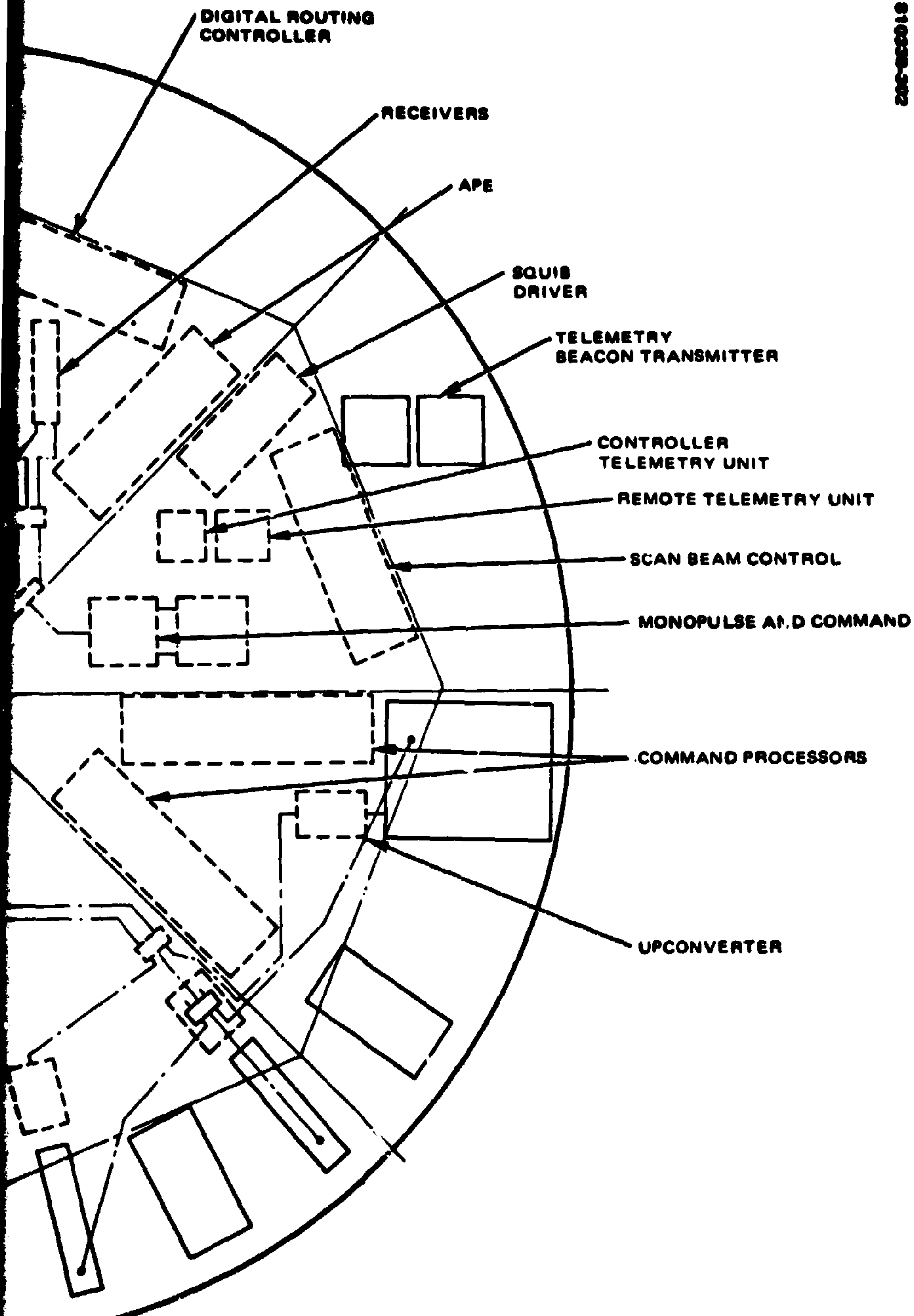

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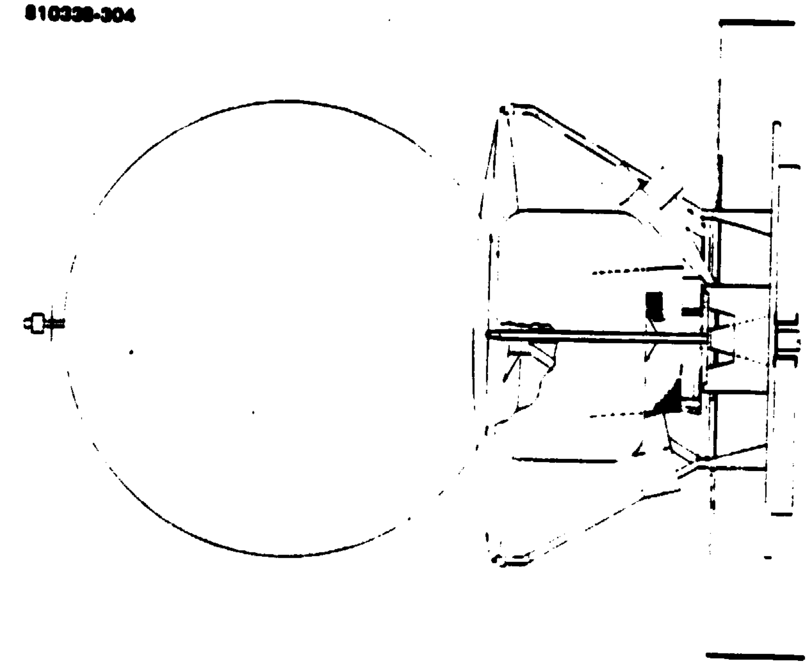

FIGURE 4-9. REFLECTOR AXIS VIEW OF SHELF

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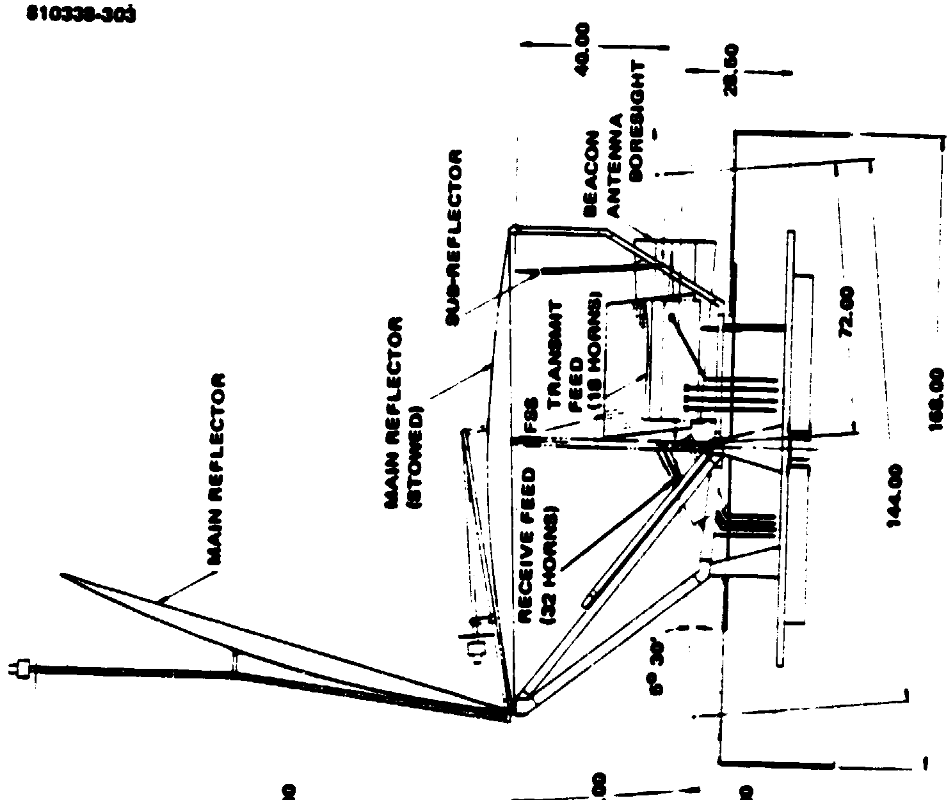


FIGURE 4-8. SIDE VIEW OF SHELF WITH ASSOCIATED DESPUN AND SPINNING THERMAL BARRIERS

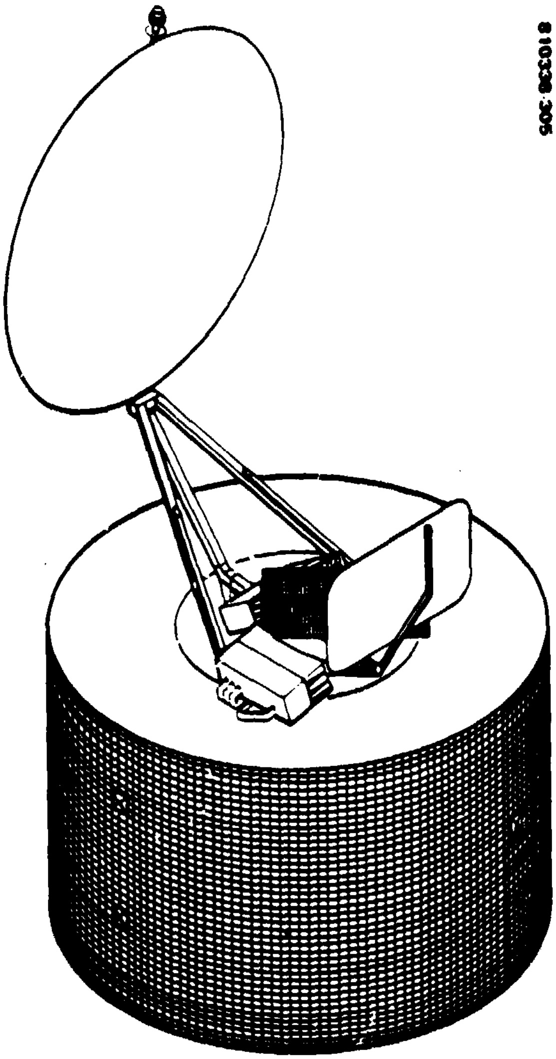


FIGURE 4-10. LEASAT SPACECRAFT ISOMETRIC

TABLE 4-11. SPACECRAFT WEIGHT SUMMARY

Item	Payload Weight, lb	
Payload		465
Antenna	189	
Microwave	123	
Digital	111	
Margin (10%)	42	
Bus		2,285
TT&C	123	
Controls	75	
Power	541	
Propulsion	323	
Structure	1,100	
Margin (rotor)	114	
Spacecraft (dry)		2,750
Propellant (BOL)		345
RCS (4^+ yr)	324	
LAM residual	21	
Spacecraft (BOL)		3,095
Transfer orbit expendables		12,191
Shuttle deployment		15,286
Cradle and ASE		1,785
Shuttle payload		17,071

The total spacecraft weight margin provided by excess propulsion capability is 156 pounds. A 10 percent payload weight margin of 42 pounds was allocated leaving 114 pounds as a rotor margin. Some of the 114 pounds rotor margin can be shared between rotor margin and payload margin. The ultimate limit on the payload weight is the requirement that the spin to transverse inertia ratio (I_s/I_t) be greater than 1.05 for spacecraft stability. If one-half of the 114 pounds rotor weight margin (or weight growth) is deployed at the perimeter of the satellite an I_s/I_t ratio of 1.064 results at the end of 4 years. Of the remaining 57 pounds, a large fraction could be added to the payload if the remainder was distributed at the rotor perimeter. The fraction would depend on whether the weight growth was above the despun platform (e.g., the antenna) or on the platform which is very near the center of gravity.

If option 1 was implemented the payload weight would decrease by 49 pounds. Option 1, which is described in 2.1, eliminates one of the scanning beams and reduces the BBP throughout. Option 2, also described in 2.1, adds a frequency division multiple access (FDMA) experiment which weighs 16 pounds. Although this cuts into the 42 pounds (10 percent) weight margin the additional payload weight available from the rotor weight margin could compensate. In any case, if weight growth required a reduction of the payload the entire FDMA experiment could be removed without impact to the basic system.

4.1.4 Power Summary

All spacecraft designs have ample power margins as shown in Table 4-12. During eclipse operation, the margin on batteries is reduced, but still ample as shown in Table 4-13 for the baseline TS design.

TABLE 4-12. POWER SUMMARY (WATTS)

Item	Baseline		Option 1		Option 2	
	TS	CPS	TS	CPS	TS	CPS
Payload						
Antenna	1.8	9.8	1.8	6.3	1.8	9.8
Microwave	515.6	285.6	515.6	285.6	518.6	285.6
Digital	41.0	223.2	41.0	88.8	41.0	223.2
Bus	228.0	228.0	228.0	228.0	228.0	228.0
TT&C (48)						
Controls (37)						
Power (92)						
Thermal (51)						
Spacecraft	786.4	746.6	786.4	608.7	789.4	746.6
Capability (4 yr)	1,090	1,090	1,090	1,090	1,090	1,090
Margin	303.6	343.3	303.6	481.3	300.6	343.4

TABLE 4-13. ECLIPSE POWER SUMMARY (WATTS)

Payload	
Antenna	1.8
Microwave	515.6
Digital	41.0
Bus	313.0
TT&C (48)	
Controls (37)	
Power (177)	
Thermal (51)	
Spacecraft	871.4
Capability (43% DOD)	1,072
Margin	200.6

4.1.5 Conclusion

The LEASAT spacecraft can be readily adapted to accommodate the 30/20 GHz program. The new 30/20 GHz spacecraft will satisfy all mission objectives, minimize shuttle launch costs, and provide ample payload weight and power margins for future growth.

4.2 LAUNCH VEHICLE SYSTEM

4.2.1 Introduction

The function of the launch vehicle system (LVS) is to provide an interface between the spacecraft and the shuttle while the spacecraft is in the shuttle; to perform the functions required to separate the spacecraft from the shuttle; and to change the spacecraft's orbit from the shuttle's low altitude orbit to the designated near synchronous drift orbit.

The approach chosen for the LEASAT and for the 30/20 GHz flight experiment system which uses the LEASAT bus is to integrate the LVS into the spacecraft. The spacecraft is injected into transfer orbit by the combination of a perigee kick motor (PKM), which is mounted within the spacecraft structure, and the first burn of a restartable liquid apogee motor (LAM). The spacecraft is then injected into the synchronous orbit by the LAM second burn and the spacecraft reaction control system (RCS). The use of a PKM mounted within the structure of the spacecraft rather than an externally mounted stage, such as the SSUS-A, reduces the length of the shuttle payload. The combination of an integrated PKM, LAM and a widebody satellite (422 cm/14 feet in diameter) results in a shuttle payload which occupies only 17 feet of the shuttle payload bay when the spacecraft antenna is stowed. This short length is a significant advantage because the cost of a shuttle launch and the ability to share a launch with other payloads depends on the ratio of payload length to shuttle bay length or the ratio of payload weight to the shuttle total payload weight capability, whichever is greater. This design approach results in nearly equal ratios for weight and length which is an optimum shuttle payload configuration.

4.2.2 Shuttle Bay Installation

The installation of the payload in the shuttle bay is illustrated in Figure 4-11 and Figure 4-12. The mechanical interface with the shuttle is provided by a reusable cradle, with five contact points between the spacecraft and the cradle, and five contact points between the cradle and the shuttle. The cradle provides mechanical support to the spacecraft during launch; avionics and electrical interfaces between the spacecraft and orbiter; and a means for ejecting the spacecraft from the orbiter.

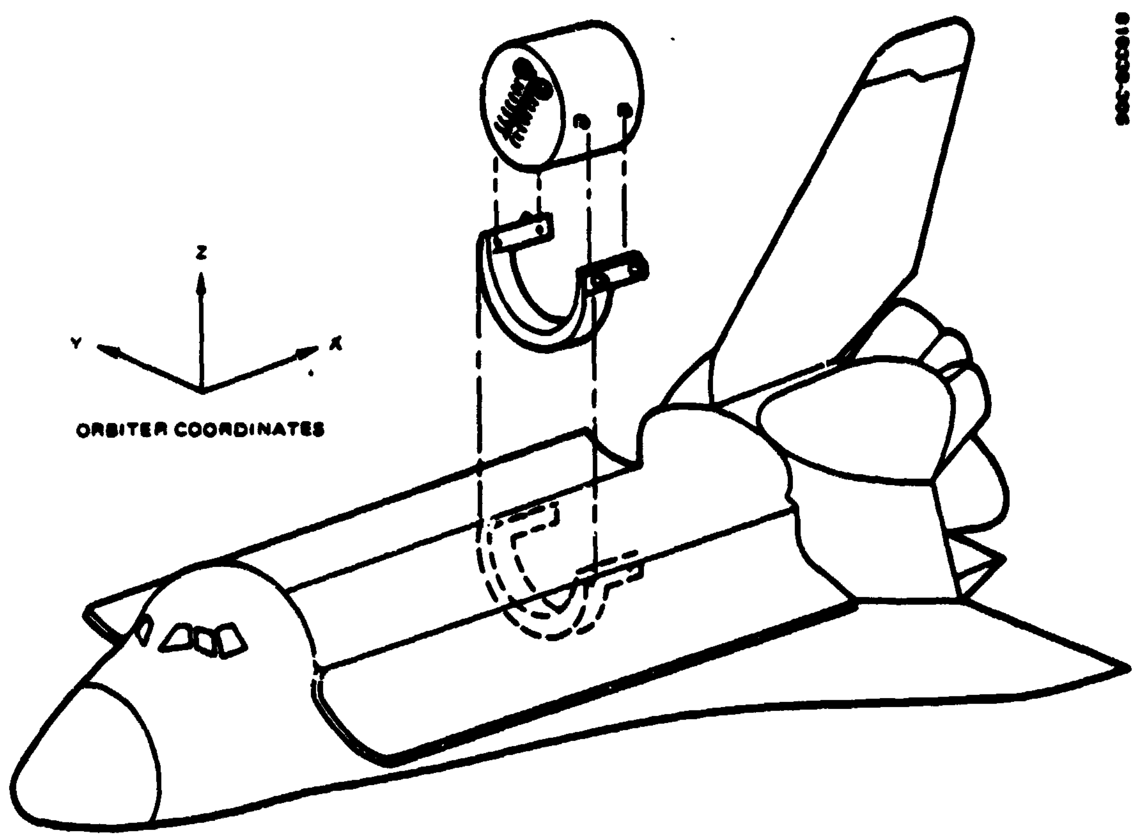


FIGURE 4-11. LAUNCH CONFIGURATION

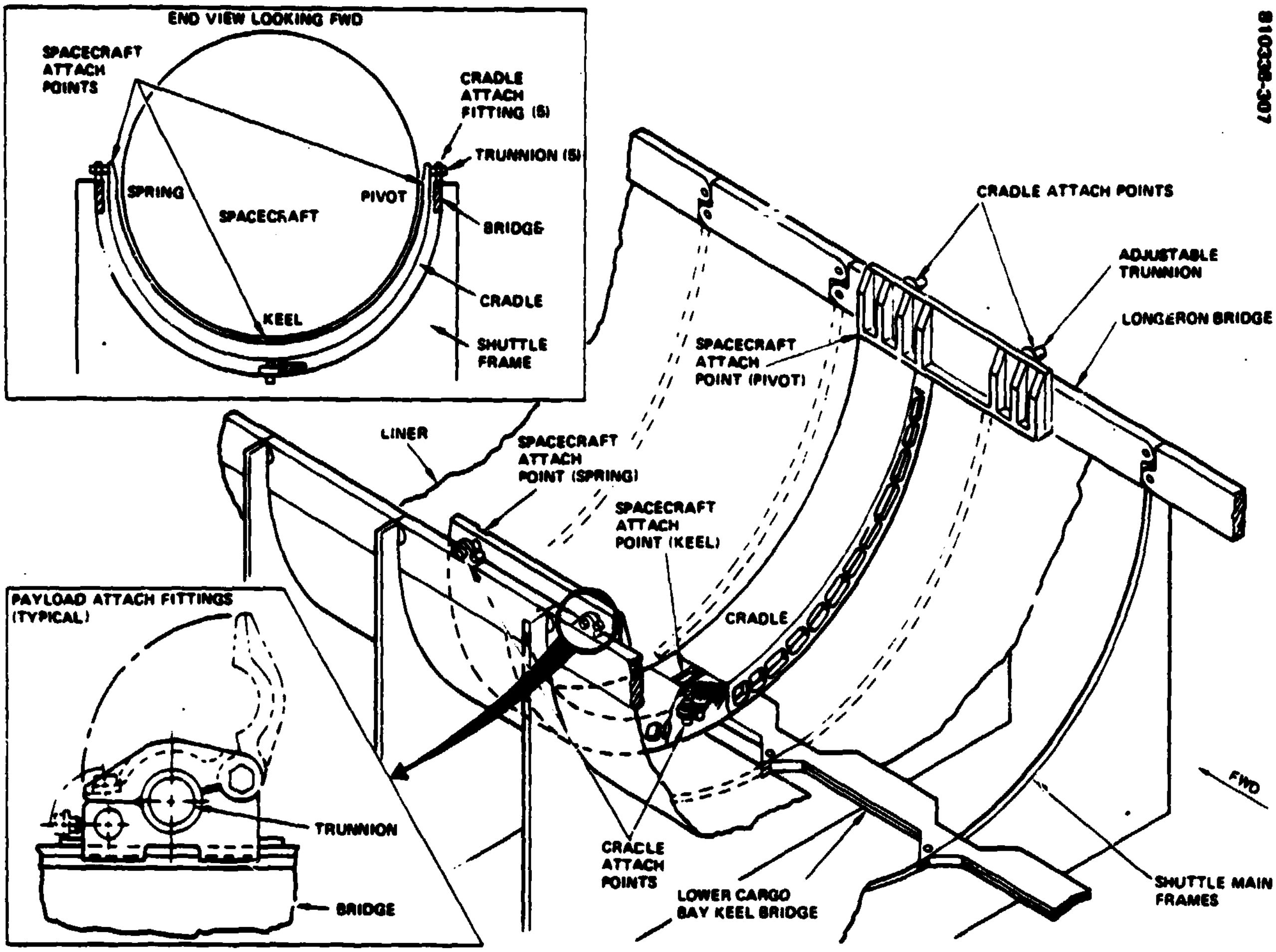


FIGURE 4-12. TYPICAL CRADLE SHUTTLE BAY INSTALLATION

4.2.3 Ascent Operations Overview

This section describes the activities/operations required of the shuttle (STS), the spacecraft, and the ground controllers in order to effect a successful ascent to synchronous orbit. The activities described begin at the time the payload bay doors of the STS are closed for the last time and end with a brief "on-orbit test" description, which is the last activity planned prior to starting service. (Figure 4-13)

The shuttle payload bay doors are closed at nominally L-20 hours. The spacecraft batteries are fully charged, and the spacecraft is completely checked out and reported "ready-for-launch" by this time. Once the payload bay doors are closed, the spacecraft is unpowered (except for special thermal control power later provided by the shuttle) and there will be neither a command nor a telemetry link.

The STS is launched into a 160 nautical mile, 90 minute parking orbit. The STS attitude is controlled such that the payload bay doors are earth

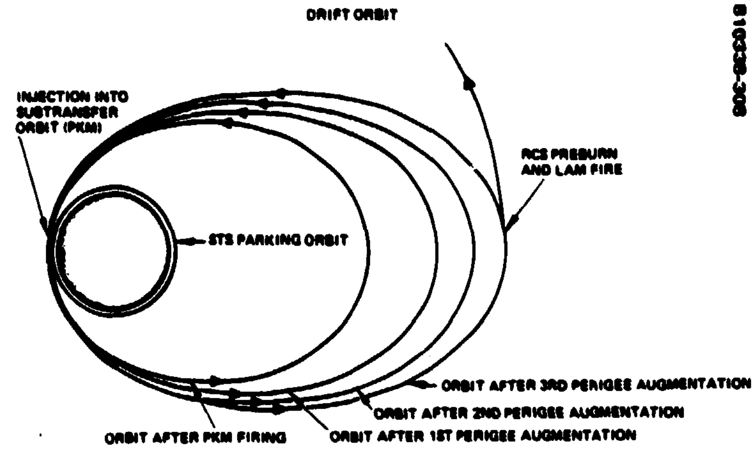


FIGURE 4-13. ASCENT OPERATIONS OVERVIEW

facing, and the doors are opened (nominally at L+2 hours). After bay door opening, the payload bay is earth facing, with maximum excursions of 30 minutes sun facing and 90 minutes deep space facing (thermal stabilization between excursions required). Life support systems for the STS are sized for a maximum of 7 days in orbit. The spacecraft will be manifested with at least two other payloads. NASA expects that the first payload will be ejected within 24 hours of launch, and subsequent payloads will be ejected at a rate of one per day.

Spacecraft ejection from the shuttle is nominally 1.5 fps and 2 rpm. The postejection sequencer (PES) starts and automatically turns on the spacecraft, deploys the TT&C antenna, spins up the spacecraft to 35 rpm, fires the perigee kick motor to place the spacecraft into the first elliptical subtransfer orbit, and turns on the required heaters, all at the proper time. In order to achieve the target apogee altitude for injection into synchronous orbit, three augmentations are required using the liquid apogee motor (LAM) bipropellant subsystem. These augmentations are ground controlled and timed to occur at perigee. Once reaching the target apogee, the LAM is used again to inject the spacecraft into synchronous orbit. Upon achieving synchronous orbit, the spacecraft is configured for earth pointing and a comprehensive on-orbit test is performed to verify spacecraft performance. Upon completion of the test, the spacecraft is placed into service.

4.3 SPACE SEGMENT RELIABILITY

Estimates of the reliability of the 30/20 GHz flight experiment's space segment are given in Tables 4-14 and 4-15. The reliability shown, which is calculated from the number and type of parts, is relatively high compared to that of current communication satellites. This is due to the shorter life (2 and 4 years compared with 7 to 10 years) and the smaller number of traveling wave tube amplifiers (TWTA) required for success. Of course, this analysis does not account for the immaturity of much of the technology involved and the lack of experience in designing, building, and operating such a system.

The estimate shows a very high probability (0.92) that at least partial experiments in both trunk and CPS modes can be carried on for a minimum of 2 years and a high probability (0.76) that this capability will be available for 4 years. This partial capability is quite adequate. Since there are 16 spots in the uplink and 10 spots in the downlink for each scan beam, the loss of a single spot in each beam is easily tolerated. The three trunk nodes remaining if one trunk transponder is lost are adequate to meet the objectives of trunk experiments.

TABLE 4-14. 30/20 GHz RELIABILITY FOR VARIOUS SUCCESS CRITERIA
MISSION DURATION: 2 YEARS

Items	Full Capacity	Full Trunk Capacity	Full CPS Capacity	Partial Capacity		
				Loss of ≤1 Trunk Beam <2 Scan Beam Spots	Loss of ≤1 Trunk Beam	Loss of <2 CPS Spots
Antenna subsystem	0.8494	0.9981	0.8499	0.9795	0.9882	0.9832
Microwave subsystem	0.9732	0.9732	0.9861	0.9851	0.9952	0.9861
BBP	0.9842	0.9999	0.9842	0.9842	0.9999	0.9842
Payload	0.8136	0.9713	0.8249	0.9503	0.9834	0.9543
Bus	0.9744	0.9744	0.9744	0.9744	0.9744	0.9744
Boost	0.991	0.991	0.991	0.991	0.991	0.991
System reliability	0.7857	0.9379	0.7965	0.9176	0.9496	0.9216

*This allows one spot failure in each beam.

TABLE 4-15. 30/20 GHz RELIABILITY FOR VARIOUS SUCCESS CRITERIA
MISSION DURATION: 4 YEARS

Items	Full Capacity	Full Trunk Capacity	Full CPS Capacity	Partial Capacity		
				Loss of ≤1 Trunk Beam <2 Scan Beam Spots	Loss of ≤1 Trunk Beam	Loss of <2 CPS Spots
Antenna subsystem	0.7537	0.9867	0.7398	0.9568	0.9872	0.9609
Microwave subsystem	0.9025	0.9025	0.9481	0.9462	0.9906	0.9481
BBP	0.9534	0.9999	0.9534	0.9534	0.9999	0.9534
Payload reliability	0.6485	0.8904	0.6814	0.8335	0.9778	0.86
Bus	0.9232	0.9232	0.9232	0.9232	0.9232	0.9232
Boost	0.991	0.991	0.991	0.991	0.991	0.991
System reliability	0.5933	0.8146	0.6228	0.7625	0.8946	0.7947

*This allows one spot failure in each beam.

The reason for the lower reliability of the CPS relative to the trunking service is the complexity of the beam forming networks which generate the scanning beams. Although the BBP is the most complex part of the payload, its reliability is high because of the extensive use of large scale integrated circuits.

The bus reliability shown is the result of detailed calculations made as part of the LEASAT program. The probability of successful boost and orbit insertion (0.991) is based on historical data. This reliability may be different for shuttle launch but the difference will have a negligible effect on overall reliability.

5. 30/20 GHz SYSTEM DEVELOPMENT PLAN

The 30/20 GHz system development plan is based heavily on experience with previous communication satellite systems produced by the Hughes Aircraft Company. Since the spacecraft bus is almost identical to that of the current LEASAT bus presently under development, its production and subsequent system integration and test will be rather routine. A bonus derived from the use of the LEASAT bus is the elimination of an intermediate upper stage and the attendant management, development, interface, and cost tasks. The LEASAT has an integrated built-in perigee boost capability that not only simplifies programmatic aspects, but optimizes launch cost-effectiveness and enhances shuttle sharing flexibility.

The flight system payload is based on technology that is presently in its embryonic stage. This implies that careful attention be given to these new technology items to ensure a minimum risk is imparted to the final experimental 30/20 GHz flight system. Towards this objective, the payload subsystem: antenna, digital, and microwave, although utilizing all possible results from the technology efforts currently in progress, will be developed beginning with breadboards, brassboards, and engineering models. In the case of the digital baseband processor, these additional tasks plus the need for a significant preprogram LSI development effort will result in a tight critical program schedule.

The terrestrial segment of the system presents no critical development or schedule problems because of the lengthy time period determined by the overall program schedule. Such key items as 30/20 GHz TWTAs and receivers, and high data rate modems can be engineered and developed within the allotted schedule. The complex total system architecture that primarily impacts the ground system software will be given special emphasis early in the program to ensure that all system elements interact and perform properly and in a cost-effective manner.

The guidelines that apply to the 30/20 GHz program are listed in Table 5-1.

The development plan is based on Hughes making all units and subsystems. This was done to understand the problems in detail and set the base for the make or buy decisions which will be made for each payload component prior to program go-ahead. All payload components will be subjected to make or buy tradeoffs during the system definition phase.

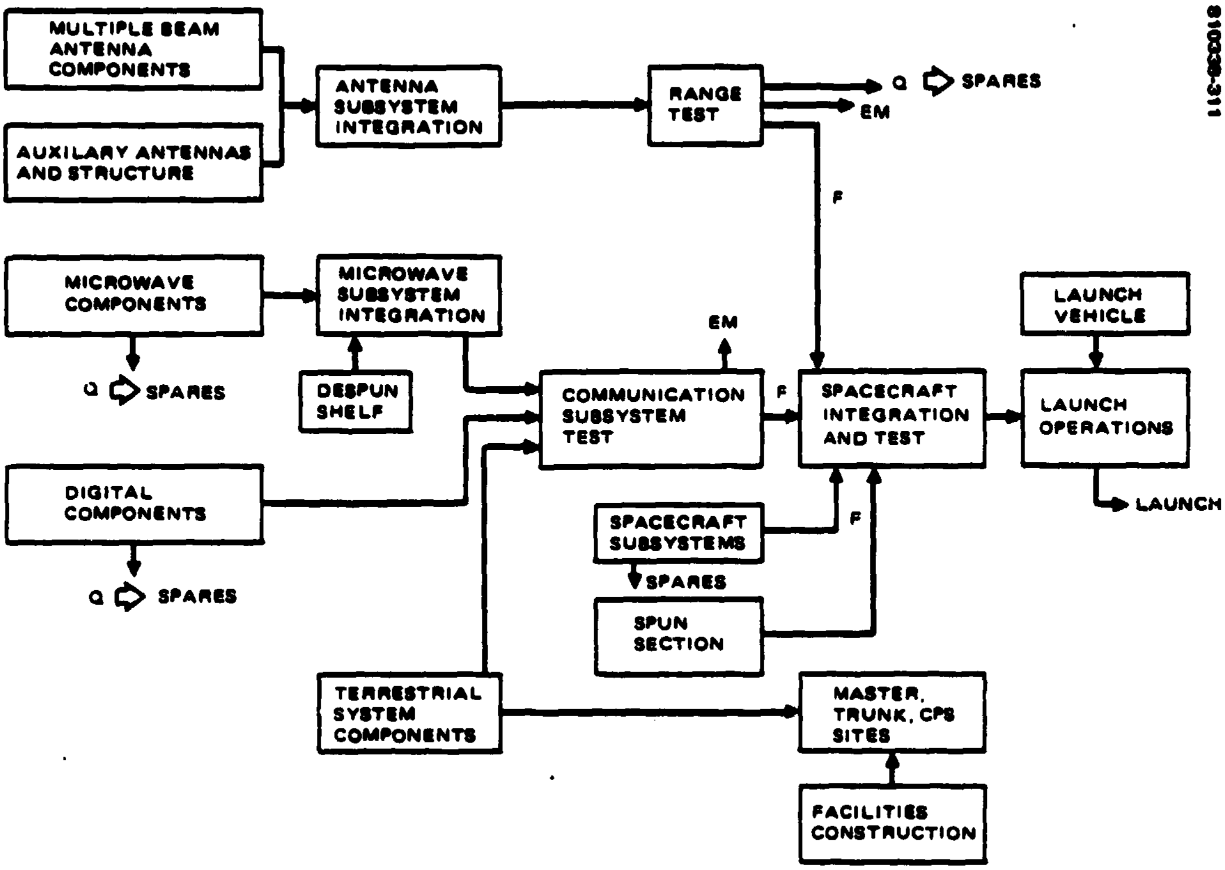


FIGURE 5-1. 30/20 GHz PROGRAM FLOW

TABLE 5-1. 30/20 GHz PROGRAM GUIDELINES

- Contact go-ahead, 1 August 1983
- Launch date, 1 October 1987
- Single flight system plus spare subsystems
- One trunking diversity terminal, Cleveland
- Master control station (MCS), Cleveland
- One customer premise service terminal, mobile
- 2 year mission/experiment operations support
- LEASAT bus
- Turnkey experimental system
- 1983 technology

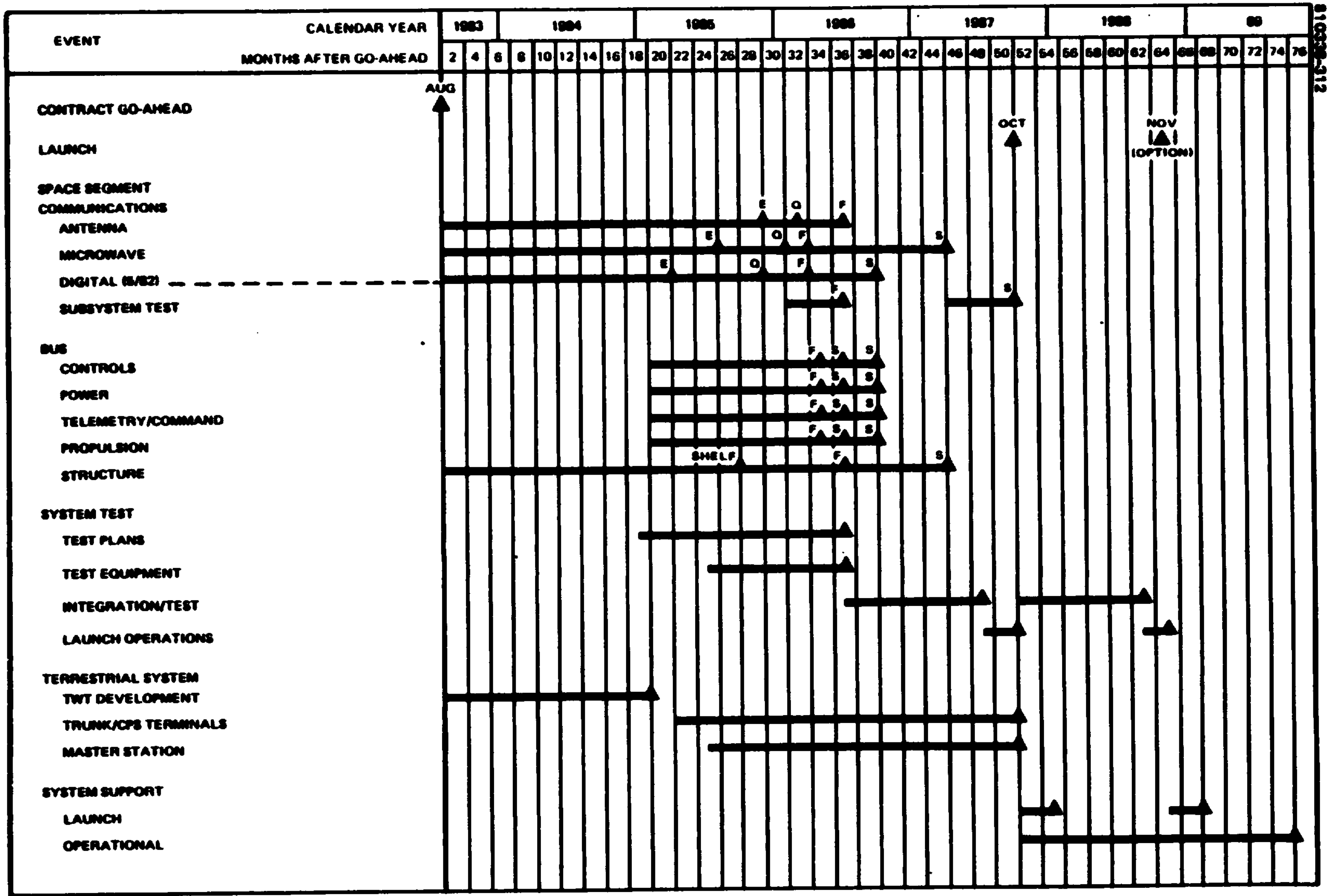
5.1 PROGRAM FLOW

The elements of the 30/20 GHz system along with their integration, test, and final verification are illustrated on the program flow chart (see Figure 5-1). The multibeam antenna components, auxiliary antennas, and structure are integrated and range tested. This is done for the engineering model, qualification model, and flight model. The qualification model is refurbished and becomes the optional spare. After completing range tests, the antenna subsystem is delivered to the spacecraft system integration and test area.

The microwave components are completed and integrated with the spacecraft despun shelf to produce the microwave subsystem. An engineering model, flight model, and optional spare subsystem will be developed. The microwave qualification units will be used as spares for the flight and optional programs.

Prior to delivery of the microwave subsystem to spacecraft system integration and test, it is integrated with the digital components for an all-up communications subsystem test. This key test also will include elements of the terrestrial system and be performed in an end-to-end configuration to ensure that all components of this complex subsystem perform together properly. The qualification model digital components will be used as spares for the flight and optional spare systems.

The remaining spacecraft bus subsystems; telemetry and command, controls, power, propulsion, and spinning structure and harness, are delivered along with the communications/antenna subsystems for all-up integration and test. The bus will include a flight and optional spare system plus a set of spare units. Spacecraft integration and testing will consist of a complete buildup of the spacecraft, and ambient and environmental tests. Emphasis during this phase is placed on end-to-end testing over the complete range of environmental conditions.



E - ENGINEERING MODEL
Q - QUALIFICATION MODEL
F - FLIGHT MODEL
S - SPARE (OPTION)

FIGURE 5-2. 30/20 GHz PROGRAM SCHEDULE

The final phase of the program flow consists of prelaunch checkout, integration with the Shuttle, and launch. During this final period, assembly and checkout of the terrestrial system will proceed in parallel and a final total systems readiness test will be performed to verify flight and ground segment integrity.

5.2 MASTER PROGRAM SCHEDULE

The 30/20 GHz Program Schedule, Figure 5-2, is bounded by a contract go-ahead date of August 1983 and a launch date of October 1987, or 50 months. The 15 months prior to launch are allocated for system integration, test and launch operations, leaving 35 months for design, fabrication, and test of all flight subsystems. Since the bus is a LEASAT derivative, it presents no schedule problems. The despun payload shelf will need modifications to relocate units, but there is ample time within the schedule.

The antenna and microwave subsystems can be developed within the schedule, but not without some concern and therefore risk. The antenna schedule could be slipped a few months because it is not needed immediately for system integration and test. The microwave (and digital) subsystem is needed for the overall communication subsystem test that already has been compressed, and therefore its schedule is firm.

The digital subsystem is known to present schedule risks. To meet the present schedule a preprogram effort must begin at least 15 months before formal program go-ahead, May 1982. This period is necessary to develop selected LSI components and define the baseband processor specifications. Even with an advanced effort, the technology and attendant problems result in the digital subsystem schedule being the high risk phase of the overall 30/20 GHz program schedule.

The terrestrial system schedule is comfortable for development of the terminals and master control station including a special phase needed to produce the new 30 GHz TWTs.

Following delivery of the flight system items, the spare subsystems for an optional system are produced. If the option is exercised by October 1987, the new system can be integrated and tested and be ready for a November 1988 launch.

Also shown on the schedule are 90 days of mission operations support for each flight, and 24 months of support for mission, communications and experiment operations following the October 1987 launch.

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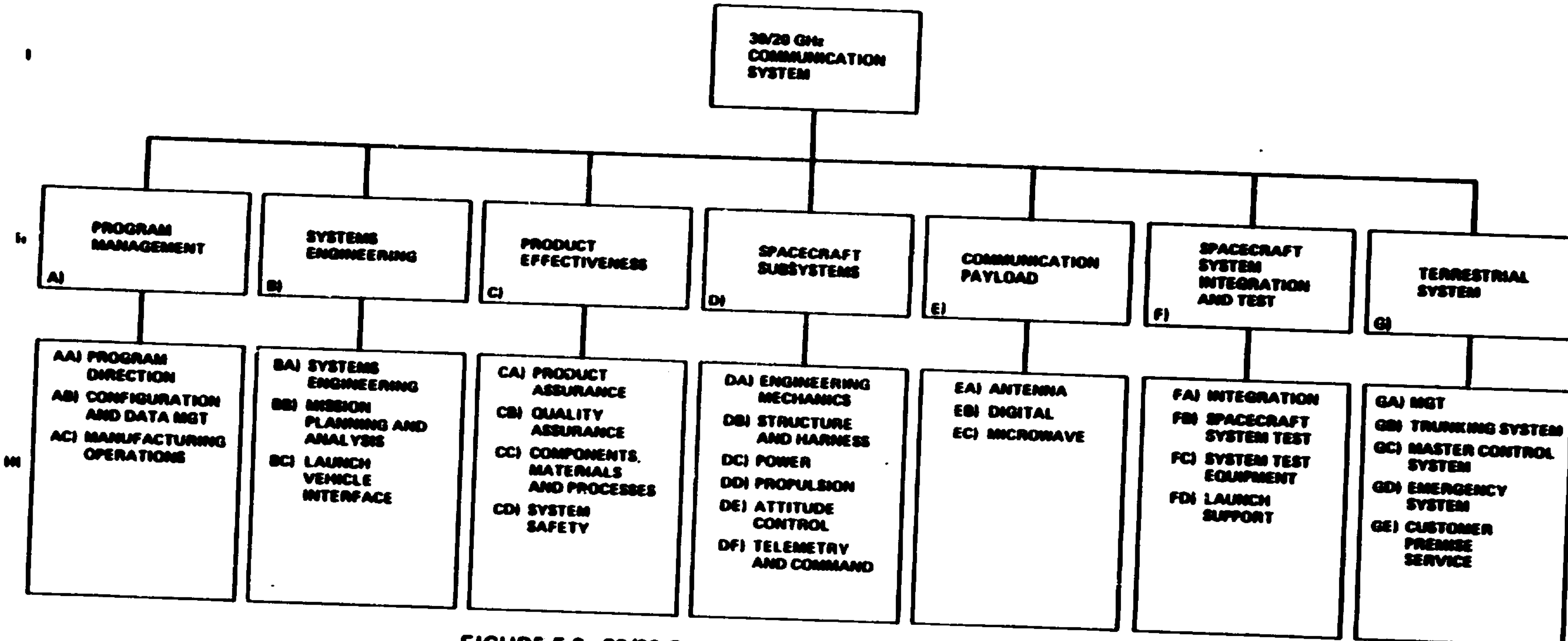

FIGURE 5-3. 30/20 GHz WORK BREAKDOWN STRUCTURE

5.3 WORK BREAKDOWN STRUCTURE

The 30/20 GHz Program work breakdown structure (WBS) to level III is shown on Figure 5-3. The first three items on level II relate to the overall program direction, control, performance, and system quality: program management, systems engineering, and product effectiveness. Program management and product effectiveness include not only the typical tasks as listed on Tables 5-2 and 5-3, but an additional program level technology consultant task under program management, and system safety (STS), radiation design, new technology, and enhanced subcontract monitoring under product effectiveness.

The system engineering tasks include the flight and ground system elements encompassing the spacecraft bus, payload, Shuttle interface, ground terminals, master control station, and total system architecture and design. The tasks have been selected to ensure that the system is approached from the "top-down" to generate a complete specification and a system that satisfies program key objectives. Table 5-4 lists the system engineering work breakdown structure (WBS).

TABLE 5-2. PROGRAM MANAGEMENT

- Managers
- Technology consultants
- Cost/schedule control
- Configuration management
- Data management
- Parts management
- Subcontracts
- Manufacturing

TABLE 5-3. PRODUCT EFFECTIVENESS TASKS

- PA* and reliability management
- Reliability analysis and engineering
- Quality assurance management
- Quality control
- Components and materials
- Component radiation characterization
- System safety

*Product Assurance

TABLE 5-4. SYSTEM ENGINEERING WBS

- Managers
- Communications system engineers
  - Manager
  - RF/link
  - Digital
  - Architecture/software
  - Antenna
  - Communications operations
- Spacecraft bus engineers
  - Manager
  - Telemetry
  - Controls
  - Power
  - Harness
  - EMC
- System engineers
  - System specification
  - Integrated test plan
  - Launch vehicle integration
  - Mission operations
  - Experiment operations
  - Orbital dynamics
  - Other
- Mission support

The remaining four level II items; spacecraft subsystems, communication payload, spacecraft system integration, and test and terrestrial system are subdivided in a conventional manner. The detailed level III, and below, WBS is presented in the following section.

5.4 ROM COST DATA

The 30/20 GHz program ROM costs (1981 $M) based on the previously presented development plan are summarized in Table 5-5. These costs are shown spread over the fiscal years and include G and A and fee. The subsystems cost for an optional spacecraft are included, but the system integration and tests costs are not included. Shuttle launch costs are not shown.

TABLE 5-5. COST SUMMARY, 1981 $M

	FY83	FY84	FY85	FY86	FY87	FY88	FY89	Total
Program management (8%)	0.5	3	3	3	3	–	–	12
Systems engineering	0.4	2.2	2.2	2.2	2.2	0.3	0.3	9.8
Product effectiveness (10%)	0.6	4.3	4	4.4	1.3	–	–	14.6
System integration and test*	–	–	2	8	5.7	–	–	15.7
Flight systems	6	42	37	25.7	2.4	–	–	113.1
Ground terminals	0.1	0.9	1	5.5	3.2	–	–	10.7
Master control station	–	–	0.4	5.1	1.6	–	–	7.1
Operations, maintenance and support	–	–	–	–	–	0.9	0.9	1.8
Subtotal	7.6	57.9	55.1	53.9	19.4	1.3	1.3	186
G&A (12%)	0.9	7	6.6	6.5	2.3	0.2	0.2	22.2
Fee (15%)	1.3	9.7	9.3	9.1	3.3	0.2	0.2	31.1
Total	9.8	69.6	66	69.5	25	1.7	1.7	238.3

*Integration and testing of major systems including master control station simulations, GSFC simulations and launch base support = $1.1M.