Spacecraft (Mobile Satellite) Configuration Design Study

Final Report

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INTRODUCTION AND SUMMARY

1.1 INTRODUCTION

RCA Astro-Electronics undertook a system configuration study for the Jet Propulsion Laboratory of California in the fall of 1984. The ultimate goal of this study was to determine the relative costs to procure and operate a two-satellite Mobile Satellite System designed to operate either in the UHF band or the L Band, and with several antenna diameter options in each frequency band. As configured, the study limited the size of the spacecraft to the current RCA Series 4000 Geosynchronous Communications Spacecraft bus, which spans the range from 4000 to 5800 pounds in the transfer orbit. The Series 4000 bus forms the basis around which the Mobile Satellite transponder and associated antennas were appended. Although the resultant configuration has little outward resemblance to the present Series 4000 microwave communications spacecraft, the structure, attitude control, thermal, power, and command and control subsystems of the Series 4000 spacecraft are all adapted to support the Mobile Satellite mission.

1.2 SUMMARY AND CONCLUSIONS

At the start of the study, JPL specified a frequency and channelization plan which took advantage of frequency reuse through spatial diversity provided by a multiple spot beam spacecraft antenna. The plan placed an upper-bound on the number of RF channels that the system could support due to the assumed availability of spectrum. Table 1-1 summarizes these channel limitations for both UHF and L-Band configurations.

TABLE 1. BANDWIDTH LIMITED CHANNELS ACCOMMODATED

Reflector diameter (meters)	20	15	10	5
UHF/Ku Alternative	6840	3420	2280	
L/Ku Alternative		13965	6840	2280

During the course of the study, it was found that the capacity of the spacecraft, under some configurations, could significantly exceed these channel limitations. In order to preserve the clarity of the hardware tradeoff study results, it was decided to maintain the number of beams defined by the specified frequency plan but to allow the consumed spectrum to increase without bound with the notion that either more spectrum may eventually become available or that a more efficient use of the available spectrum could be accomplished through some means of frequency plan modification. The study results therefore demonstrate the impact of antenna size and frequency of operation on spacecraft capacity without the restrictions imposed by a specific frequency plan.

The results are summarized as follows. The cost per channel is optimized for a 5800-pound UHF-band spacecraft configuration using a 15-meter aperture antenna reflector. This configuration supports 5675 5-kHz full time channels with 12 beams during spacecraft daylight and half that many channels during spacecraft eclipse. The yearly cost per channel is 9140 dollars. This configuration requires approximately the median dollar outlay for the UHF systems studied, requiring 363 million dollars for the 7-year mission, including all development, launch, and operating expenses on a self-insured basis. Production and development costs of the mobile terminals are not included.

Results at L Band favored the use of the largest aperture antenna configuration studied, that of 15 meters. The Series 4000 spacecraft will support 3915 daylight channels with a 50% eclipse capability. These channels are distributed into 49 beams, taking advantage of a real frequency reuse factor of 1.96. The yearly cost per channel for this L-Band configuration is 14,850 dollars.

It is interesting to note that the UHF 15-meter case has greater capacity than that supported by the assumed frequency play and therefore requires a different frequency plan aproach. The L-Band 15-meter configuration, however, does not use up the available spectrum. The 15-meter UHF case studied has a bandwidth limitation of 3420 channels, but the hardware configuration can support 5675 channels. Similarly, the 15-meter L-Band case has a bandwidth capacity of 13965 channels and a utilization of only 3925 channels.

The use of a 15-meter antenna at L-Band shows promise for a system which supports conservation of the spectrum through frequency reuse. Implementations at UHF frequencies do not allow such a conservation unless very large antennas (approaching 50 meters) are employed.

1.3 STUDY ASSUMPTIONS

As with all studies of this nature, many assumptions were made at the outset, mainly to bound the extent of the study investigations. A list of major assumptions follows:

- Number of beams vs. aperture given by JPL.
- Transponder capacity limited to 285 channels per beam.
- Equal channel distribution to all geographic areas.
- All channels operated at 100% duty factor.
- Amplifier efficiency was the best estimated 1990 technology.
- No North/South stationkeeping employed.
- Use SCOTS subsystem when applicable.
- Cost estimate based on non-government commercial practice.
- Single gateway station assumed.

An explanation of each assumption is given. The order of presentation does not imply relative importance.

1.3.1 ANTENNA BEAMS VS. ANTENNA APERTURE

The total number of beams for each of the antenna options studied was determined by JPL prior to the study. The number of beams, the beam crossover level, and the carrier to interference (C/I) ratio of second adjacent beams are intertwined in the frequency plan given by JPL and followed by RCA.

1.3.2 TRANSPONDER FREQUENCY PLAN

The transponder frequency plan was offered by JPL and agreed to by RCA as a reasonable plan which was compatible with the frequency reuse algorithm specified by JPL and also appropriate for all configurations studied. No further effort was expended in refining this plan nor in assessing its practicality from a business standpoint. Strict use of the plan will limit the system channel capacity, but since any plan invented will do so, it was adopted prima facie. As a result, the 10- and 15-meter UHF cases are exceptions because the frequency plan limit is exceeded by the capacity of the 5800-pound spacecraft.

1.3.3 CONSTANT CHANNEL DENSITY

The total coverage footprint, including all of CONUS, Alaska, and Canada, was covered by a constant channel density with no regard to population distribution or other items reflecting communication capacity needs. Since the beam occupancy typically is not bandwidth limited, the impact of this assumption is minimal.

1.3.4 ALL CHANNELS OPERATED AT 100% DUTY FACTOR

For purposes of the study, an unrealistic situation was made whereby all downlinks were busy 100% of the time. The impact of this assumption is that of an ultra-conservative design, where the power system is sized to support the worst case traffic load. A more realistic duty factor estimate would be 25 to 30% for the "push-to-talk" mode of communication. For digital communications, a higher duty factor may occur. Therefore, the study results should be judged accordingly (i.e., a published 1000 channel capacity at a 25% duty factor could support 4000 communication channels).

1.3.5 POWER AMPLIFIER EFFICIENCY

The configuration of the RF power amplifier assumed in the study is that of a reasonably efficient solid-state power amplifier using bipolar technology with predistortion linearizers incorporated into the amplifier drivers. Use of the linearizers allows operation of the amplifiers at an average backoff of 4.2 dB. This places the anticipated signal peaks at the saturation point of the linearizer/amplifier combination. Without the linearizers, a 7-dB backoff would be necessary. The efficiency used varied as amplifier power varied, but was approximately 31% as an average.

The impact of a decrease in efficiency of the power amplifier was estimated for the case of the UHF frequency and the 20-meter antenna. A 5% reduction in efficiency amounted to 17% reduction in channel capacity for this configuration.

1.3.6 NORTH/SOUTH STATIONKEEPING

A baseline assumption in the study was that no North/South stationkeeping would be required for any configuration under study. Should such stationkeeping be required, a weight penalty of approximately 60 pounds per year for fuel and 50 pounds for reaction control system hardware must be imposed for a 5800-pound geosynchronous transfer orbit (GTO) weight spacecraft.

1.3.7 SCOTS STAGE USED WHERE APPLICABLE

Use was made of the RCA developed Shuttle Compatible Orbit Transfer Subsystem (SCOTS) for all configurations which were in the 4000 to 6000-pound GTO weights. For configurations beyond that weight limit, no effort was expended to identify the source of the stage required. An assumption was made that a stage of the performance required was available and that the development and qualification costs were covered under the auspices of another program. In all instances, the horizontal configuration in the Shuttle was assumed.

1.3.8 COSTING ASSUMPTIONS

Cost estimates were based on present commercial practices with no government involvement. Departure from this assumption will invalidate the cost estimates.

1.3.9 GATEWAY STATION CONFIGURATION

For purposes of the study, a single gateway station was assumed which was collocated with the TT&C and SOC installation. Gateway station costs are related to channels handled simultaneously, as was assumed during this study, and provide all channels at 100% duty factor.

The technical impact of the assumption should be highlighted due to potential impacts on system performance when multiple gateway stations are implemented. This problem is the requirement to provide a means to control all downlink power levels.

The study assumed that all channels were operated at 100% duty factor and from a single gateway station. Under these assumptions, an automatic level controller (ALC) in the spacecraft transponder could easily provide a constant and proper drive level to all power amplifiers regardless of fading conditions existing on the Ku-band uplink.

When either multiple gateway stations are implemented or less than 100% channel duty factor is used, then the practicality of an ALC on the spacecraft disappears due to the downlink power variations which would occur because of differential fading of the different Ku-band uplink beams and the variations in drive level caused by altering the number of simultaneous carriers present at the ALC detector. The transponder must therefore be operated in a fixed gain mode with an external means provided to accomplish uplink power control, thereby providing downlink power control.

Since the modifications to the spacecraft configuration necessary to accomplish this control are very minor, no attempt was made to alter the transponder study configuration which was agreed to at the start of the study.

1.4 TECHNICAL AREAS NOT ADDRESSED IN STUDY

Several technical areas were not addressed during the study due to the scope of the contracted work. These areas are discussed below.

1.4.1 ANTENNA POINTING

A detailed assessment of the Series 4000 attitude control system to maintain antenna pointing within a moderate tolerance was not made during the study. An overall assessment of the ability to remain stable was accomplished; however, the detailed flexbody analysis required to assess the impact of antenna boom and reflector flexure on antenna pointing was not accomplished. Since the inclusion of a simple RF sensor in the multibeam antenna subsystem would provide the data necessary to maintain pointing to the fractional degree region, a detailed analysis was not performed.

1.4.2 FEASIBILITY OF LARGE L-BAND LIMIT CASES NOT ADDRESSED

In the study, limit cases of spacecraft performance were determined. This study only looked at the weight of flight hardware required to accomplish such a configuration, not whether such a spacecraft configuration was technically feasible. For example, the 5-meter aperture L-Band configuration supporting the maximum bandwidth limited capacity at 2280 channels is questionable, requiring close to 15 kW of solar array power. From a strict scaling sense, such an array would consist of 36 panels, 18 per side, and the viability or practicality of such a configuration is in doubt. Nonetheless, weight scaling was done on these configurations to provide relative differences among the various configurations.

1.4.3 UPLINK POWER CONTROL

The requirements for this study did not include the study of methods available to control uplink power. The problem here is that the variations in attenuation due to atmospherics occurring at Ku-Band will cause, barring an extensive active control loop, dissimilar drive levels to the power amplifiers fed from gateway stations in various parts of the country. This is of particular importance when a multi-gateway system is envisioned, with signals originating from gateway stations at random places within the footprint. The frequency reuse algorithm specified by JPL relies on a reasonably fixed downlink power from each carrier in the single channel per carrier (SCPC) environment, thereby requiring a control of some sort on the Ku-Band uplink to ensure an equitable distribution of power in the UHF and C-Band downlinks.

A relatively simple solution to this problem exists if the echo of the Ku-Band uplink is retransmitted by the spacecraft for all gateways to monitor. This would allow each gateway to adjust its uplink power to provide the required control of downlink power distribution. As this solution is at hand, no further investigation into its implementation was accomplished in the study.

SECTION 2.0
RCA APPROACH TO THE STUDY

2.1 SPACE SEGMENT

RCA accomplished the configuration portion of the study by first selecting the RCA Series 4000 spacecraft bus as a baseline, and then modifying that configuration to accommodate the Lockheed wrap-rib unfurlable antenna. This task was accomplished in detail for the largest (and hence, worst case configuration) antenna aperture of 20 meters. Mass properties scaling was then accomplished for the remaining antenna apertures studied, together with the various transponder configurations appropriate to the antenna aperture under study. Then, the resultant spacecraft configurations were subjected to a costing analysis to determine their respective spacecraft, launch, and ground system operation costs.

2.1.1 SERIES 4000 SPACECRAFT BUS

The RCA Series 4000 spacecraft bus was originally designed for microwave communications satellites placed in a geosynchronous orbit whose transfer orbit weight spanned the range from 4000 to 6000 pounds. The Series 4000 bus has a nominal 5800-pound upper weight limit imposed by the performance limits of the Shuttle Compatible Orbit Transfer Subsystem (SCOTS), also developed by RCA specifically for Shuttle launches of this spacecraft series.

The Series 4000 baseline structure is used in this study, as are the Telemetry and Command Subsystem, Attitude Control Subsystem, Power Subsystem, and Thermal Subsystem. Each of these subsystems are tailored to the Mobile Satellite requirements, but the extent of modifications is small enough to maintain the configuration of the baseline Series 4000 spacecraft.

The baseline Series 4000 spacecraft utilizes a solid propellant AKM of the Star 37 series, with sufficient propellant to circularize at geosynchronous attitude from a 27.5-degree inclination transfer orbit which is nominal from Shuttle.

To decrease fuel requirements, the baseline bus employs electrothermal hydrazine thrusters (EHT) for North/South stationkeeping. Since there is no North/South requirement in the spacecraft configuration of this study, no EHT's are installed.

The in-orbit configuration does not resemble the Series 4000 box-like shape due to the size of the reflector and the supporting truss assemblies. Nonetheless, it is a Series 4000 bus.

2.1.2 ANTENNA REFLECTOR

The reflector selected for the study was the Lockheed wrap-rib configuration described in the Lockheed "Interim Report for Study of Wrap Rib Antenna Design," under JPL Contract 955345, which supported a previous JPL study program. Although other antenna configurations could have been employed (such as those from Harris Corporation or General Dynamics), only the Lockheed reflector was used in order to reduce the scope of the study. The selection of the Lockheed design is not meant as an endorsement of its design over that of competitors.

In the Lockheed report, a single mast was used for reflector deployment from a position in the vicinity of the antenna feed assembly. Our study resulted in a configuration which used two separate mast assemblies, one deploying the reflector and the other deploying the feed and transponder assembly. The vicinity of the deployment is equivalent to the near right angle bend of the mast in the Lockheed report.

In the study, the major configuration effort was devoted to the 20-meter UHF case, as this was assumed to be the worst case from both the structural standpoint and the attitude control standpoint due to environmental torques. Once this configuration was agreed upon, it was adopted for all reflector diameters studied.

2.1.3 SCALING FACTORS

A series of mass scale factors was developed through which a computer could be employed to determine, automatically, the total mass impact on the spacecraft due to changes in antenna diameter, frequency of operation, number of RF channels supported, and percent of payload operation during eclipse. The items which were subject to mass scaling are listed in Table 2-1. Included in the table is the identification of whether the item is primarily scaled due to antenna aperture selection or due to the number of channels supported.

TABLE 2-1. ITEMS SUBJECTED TO MASS SCALING

Item	Due to Aperture Selected	Due to No. of Channels	Spacecraft GTO Weight
Antenna Support Structure	X		
Reflector	X		
Reflector Mast	X		
Feed Assembly Mast	X		
Solar Array Masts	X		
Transponder	X		
Power Subsystem		X	
Thermal Subsystem		X	
Fuel Budgets			X

The major mass scaling which takes place for aperture changes is due to the mass of the reflector, masts, and support structure. In the transponder, the mass scaling is due to the number of beams which the antenna can support and to the number of RF channels supported. In the Power Subsystem, as in the Thermal Subsystem, the scaling is related to the power demand which pertains to the number of RF watts required, frequency, antenna aperture, and number of channels supported.

The mass of the support structure, masts, and reflector is given in Table 2-2. The transponder, Power Subsystem, and Thermal Subsystem weights depend on the number of channels supported; their weight and power summaries are given in Section 4.3.

TABLE 2-2. SCALED WEIGHTS VS. ANTENNA DIAMETER

Item	Weight (pounds) per Antenna Diameter of			
	5 Meters	10 Meters	15 Meters	20 Meters
Antenna Support Structure	90	100	120	150
Reflector	32.7	78.4	137.1	208.8
Reflector Mast	23.9	41.3	58.6	75.9
Feed Assembly Mast	47.9	82.5	117.2	151.8
Solar Array Masts	13.5	27	40.5	54

The spacecraft fuel budgets change only if the GTO weight of the spacecraft changes. This occurs in the limit cases described in Section 2.1.5. Similarly, the weight of AKM fuel is also scaled in cases where the GTO weight is other than 5800 pounds.

2.1.4 MASS SCALING ANALYSIS

Once the mass scaling algorithms and the computer program were established, the number of RF channels which could be supported by a 5800-pound GTO weight spacecraft was solved for. In this solution, the weight margin was intended to remain at 200 pounds; however, the spacecraft scaling program used discrete steps for items such as battery capacity available, number of batteries used, and solar array panels required. As a result of these discrete steps in mass, the weight margin could not always be kept at 200 pounds; therefore, the reported margins vary slightly from that target.

In the instances of the UHF configuration for both 10 and 15 meter antenna apertures, the bandwidth limited case (as defined by the JPL-supplied guidelines) was satisfied by a spacecraft of less than 5800 pounds GTO weight. These cases are reported upon in Section 4.3. A further solution was requested in which the restrictions of the JPL guidelines defining the number of RF channels per beam were disregarded and the number of RF channels was solved using the full 5800-pound capability. These solutions are also included in Section 4.3. They represent a transponder with the same number of beams as defined in the JPL guidelines, but with more channels supported by each beam through some undefined frequency plan or method.

2.1.5 LIMIT CASES

One of the analyses required in the study was to determine the capacity of a spacecraft of both one half the size and twice the size of the 5800-pound spacecraft configuration. During the study, RCA determined that a more useful study would be to solve for the lower limit of spacecraft GTO weight required to support a zero RF channel capacity and also, the GTO weight to satisfy the upper bound of the RF bandwidth limit as given by the JPL guidelines. These results are included in Section 4.3. In cases where the GTO weight departs from 5800 pounds, mass scaling is accomplished for the structure and fuels. No perigee stage was identified for weights above 5800 pounds, but one was assumed to exist in essentially the same form as the SCOTS stage with a suitable propellant growth and spacecraft mass support capability.

2.1.6 COST ANALYSIS

Selected configurations were costed to determine development cost, production cost, launch cost, and operating costs (refer to Section 5.0). All costs were based upon current commercial programs at RCA, with the exception of the antenna. Lockheed provided cost estimates to RCA for the range of antenna sizes selected for study.

2.2 GROUND SEGMENT

The Satellite Control Network (SCN) was patterned after the RCA Astro-Electronics Satellite Operations Center currently used by RCA for spacecraft control. Deleted from this design, however, was the transfer orbit control capability. Instead, RCA employs their own Guam and Carpentersville, New Jersey stations during transfer orbit, handing over to the Mobile Satellite SCN only after each spacecraft is in its final orbital position. This approach allows for a reduction in the nonrecurring cost of the SCN. The manpower to support stations of the type required was derived from manning recommendations developed for existing fixed service spacecraft.

The gateway station was collocated with the Satellite Operations Center (SOC) and the Telemetry, Tracking, and Command (TT&C) station to reduce manpower costs and allow some economies of equipment commonality, such as antennas and test equipment, to be realized. The cost driver for the gateway station will be the single-channel-per-carrier (SCPS) equipment. A baseline cost of 4000 dollars per channel unit has been used by RCA.

The baseband switching in the gateway will be accomplished using commercially available PBX switches. Requirements unique to spacecraft operation will be incorporated into existing designs rather than generate a bottom-up design.

Because the system feasibility is based on user capacity, the total costs are reduced to a cost-per-channel value assuming a 100% duty factor and a single gateway. Multiple gateways or statistical duty factors for digital or push-to-talk type operation will reduce this duty factor, and the cost per channel would need to be modified accordingly.

SECTION 3.0
SYSTEM DESCRIPTION

3.1 TRAFFIC FLOW

For the purpose of this study, the flow of communications traffic was assumed to always be via the SHF link to and from a gateway station, thereby causing all communications between two mobiles to be of double hop complexity. This assumption was made to simplify the configuration of the spacecraft at the cost of imposing a double hop-time delay on mobile-to-mobile communications. The inclusion of an IF matrix switch in the spacecraft transponder, which would allow single hop mobile-to-mobile communication, would not cause a large enough weight penalty to significantly change the spacecraft related study conclusions. Control of direct mobile-to-mobile communications would be a factor however in the design of the overall system; this factor was not addressed in this study.

Another issue regarding traffic flow that was not addressed during this study was the use of multiple gateway stations. This issue has many system ramifications, some of which are: (1) the impact on communications of rain fades on the SHF uplinks, (2) inter-gateway communications links implementation, and (3) management of channel assignments and system utilization.

A rather simple hardware implementation in the spacecraft could help alleviate many of the problems associated with this issue. That implementation is the inclusion of an echo link which repeats all SHF uplink traffic in a separate SHF downlink channel. Reception by the gateway stations of this echo of the uplink traffic can be used for uplink power control as well as the use of edge-of-band frequencies for inter-gateway voice and data communications. An enhancement of the use of this link for uplink power control is the insertion at the spacecraft of a fixed and known level of a signal for a reference power level around which all uplink power is controlled.

This echo link was not included in this study but should be investigated due to its possible multiple uses.

3.2 SYSTEM CONTROL AND OPERATION

System control and operation was treated in the study in the following manner. Satellite operations and control was accomplished by a single TT&C station which was redundant in configuration and collocated with a Satellite Operations Center (SOC). SHF communications equipment would be used for this purpose, using the fixed service frequency band. Spacecraft control during transfer orbit would be accomplished via RCA owned and operated facilities which would be used until the spacecraft orbit location was attained and spacecraft checkout was completed.

Also collocated at the SOC would be the single gateway station assumed to exist for the purposes of the study. Since a single gateway was assumed, no inter-gateway communications or control computer was assumed. A single communications computer was assumed to exist at the gateway, and the complexity of this computer was that of a telephone switching computer of the same capacity as that on an individual spacecraft.

Expansion of the systems concepts to allow multiple gateway stations and the use of multiple spacecraft would require adjustments to the cost-per-channel-per-year numbers provided.

3.3 OPERATIONAL CONFIGURATIONS

3.3.1 TRANSPONDER FREQUENCIES

The scope of this study encompassed evaluation of six candidate second-generation type Mobile Satellite configurations designated by JPL; three employing Ku- and UHF-Band frequencies, and three employing Ku- and L-Band frequencies. In both cases, the Ku Band is used for satellite reception at 13.2 GHz from a gateway station (shown in Figure 3-1) and transmission from the satellite to the gateway at 11.65 GHz. The channels received at the 13.2-GHz frequency are translated through several mixer conversion steps to the 866 to 870 MHz and 890 to 896 MHz UHF bands for downlink transmission to the mobile terminals shown in Figure 3-1 for the Ku-Band/UHF-Band candidates. For the Ku-Band/L-Band option, the downlink frequencies employed would lie in the band of 1549 to 1559 MHz. Responses from the mobile users are received by the satellite in the 821 to 825 MHz and 845 to 851 MHz bands for the Ku-Band/UHF-Band candidates or 1650 to 1660 MHz for the Ku-Band/L-Band option candidates. Additional details regarding the subdivision of channels among these UHF and L-Band bandwidths (that total 10 MHz in each case) are provided in Section 3.3.4 following the explanation of antenna aperture sizes, number of spot beams, and frequency reuse for each of the six candidates.

3.3.2 ANTENNA APERTURE

The differences among the six candidates are three different spacecraft UHF and L-Band antenna apertures and accompanying numbers of spot beams for CONUS coverage for the two basic Ku-Band/UHF-Band and Ku-Band/L-Band configurations. These six candidate configurations are evaluated as follows:

Candidate	Configuration Designation	Antenna Aperture (meters) UHF	Antenna Aperture (meters) L-Band	Number of Spot Beams
1	KU-1	20	-	24
2	KU-2	15	-	12
3	KU-3	10	-	8
4	KL-1	-	15	49
5	KL-2	-	10	24
6	KL-3	-	5	8

3.3.3 FREQUENCY REUSE

Using configuration candidate KU-1 as an example, Figure 3-2 shows the Ku-Band uplink from a gateway station. This transmission at 13.2 GHz occupies 50 MHz of bandwidth derived as 24 beams of 285 channels/beam and 5 kHz per channel

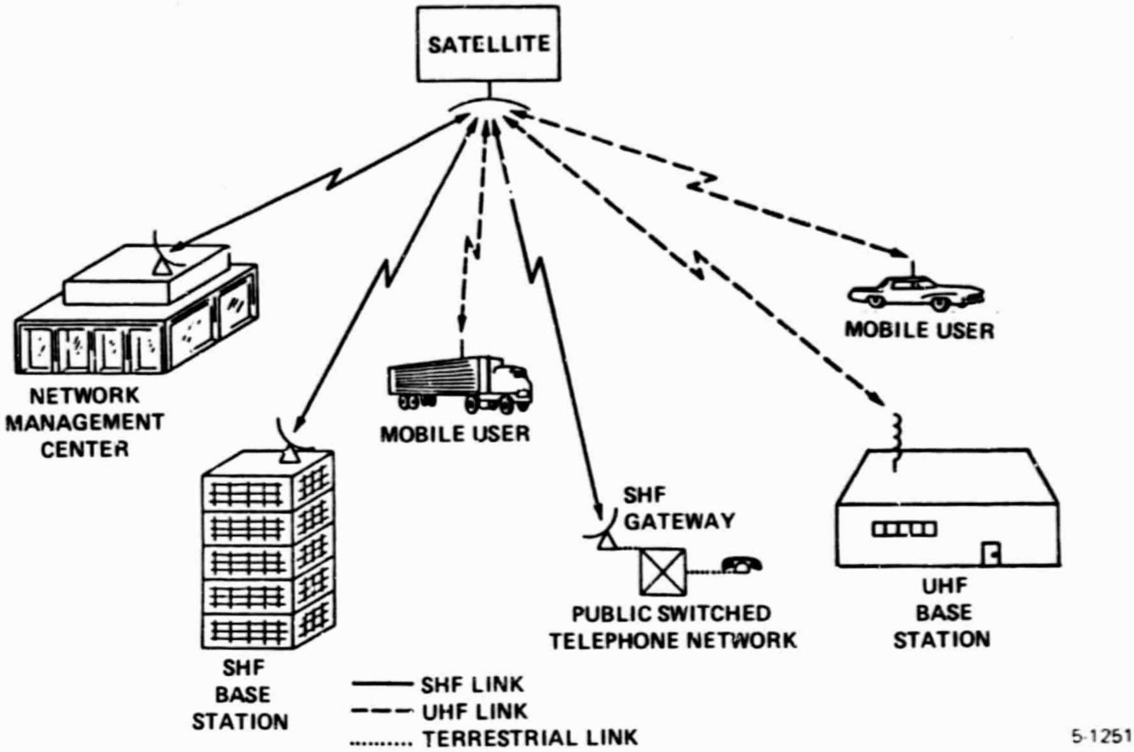

Figure 3-1. Mobile Satellite Network

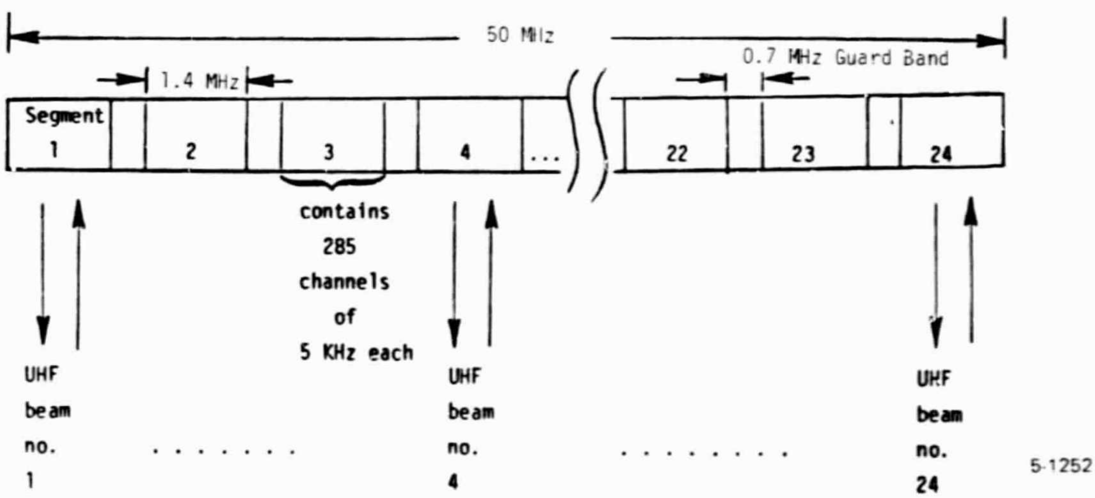

Figure 3-2. Ku-Band Frequency Plan and Ku/UHF Relationship

(34.2 MHz) plus 23 guard bands of 0.7 MHz each. As defined in Section 3.3.1, only 10 MHz bandwidth is available for the UHF band (or L-Band for Ku-Band/L-Band candidates) for communications between the satellite and mobile users. Accordingly, a frequency reuse factor of 34.2/10 (or 3.42) must be achieved for the UHF band for the KU-1 candidate to be feasible. Such frequency reuse is obtained by spatial diversity, polarization diversity, or some combination of each. Studies by JPL* led to the selection of spatial diversity (only) for the UHF spot beams using seven different frequency sub-bands, each of 1.425 MHz (285 channels at 5 kHz each).

Figure 3-3 shows the division of the 10-MHz UHF bandwidth into seven sub-bands of 1.425 MHz. However, because of the tentative allocation of the 10 MHz as 4 MHz (821 to 825 MHz) plus 6 MHz (845 to 851 Mhz), Figure 3-3 shows that sub-band 3 would consist of 1.15 MHz (823.85 to 825 MHz) plus 0.275 MHz (845 to 845.275 MHz). Reuse of the seven sub-bands in a spatial diversity plan is shown in the antenna spot beam coverage layout of Figure 3-4 for the KU-1 example candidate. The beams are numbered 1 through 24 with small numbers, and the larger sized numbers refer to the seven reused frequency sub-bands. The number of times each sub-band is used is tabulated on the figure. Figure 3-4 also shows that the coverage encompasses the contiguous United States (CONUS) and the southern areas of Canada. Other information provided shows the spot beam crossover beamwidth to be 1.4 degrees at crossover gain of 37.5 dB (4 dB below the 41.5-dB peak boresight gain expected for each beam). The coverage map of Figure 3-4 pertains to a geostationary orbit position of 90°W longitude.

3.3.4 PAYLOAD SPECIFICATIONS

The major specification relevant to the three Ku-Band/UHF-Band and three Ku-Band/L-Band communications payload candidates are summarized in Table 3-1. This table summarizes the JPL requirements* (or RCA parameters derived from these JPL requirements) provided to RCA as the basis for this study contract. The following comments are provided for specifications that have not been explained in preceding paragraphs of this report or that are not considered self-explanatory:

(1) Parameters 2 (antenna gain), 4 (EIRP), 5 (transmitter RF power), 10 (received signal strength), 12 (receive system temperature), and 14 (receiver noise figure) were obtained from the "Design Control Table" link analyses**.

(2) Parameter 6 (number of channels accommodated) was derived as a bandwidth limited number based on the product of channels per beam (285) times the number of beams for each candidate (Parameter 3). One of the major study tasks was to determine whether this bandwidth limited number of channels could be accommodated or whether the associated dc power and spacecraft weight constraints would limit the number of channels to fewer than the bandwidth limit. The results of these evaluations are given in Section 4.3 of this report.

(3) The total transmitter RF power to be provided for UHF or L-Band (Parameter 8) or Ku-Band (Parameter 9) transmission was calculated as the product of per-channel values (Parameter 5) times channels per beam (285) times the number of beams (Parameter 3). These are also bandwidth limited results, modification of which (where dc power/spacecraft weight constraints prevail) are provided in Section 4.3

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*Refer to References 1, 2, and 3 in Appendix A.
**Refer to Reference 2 in Appendix A.

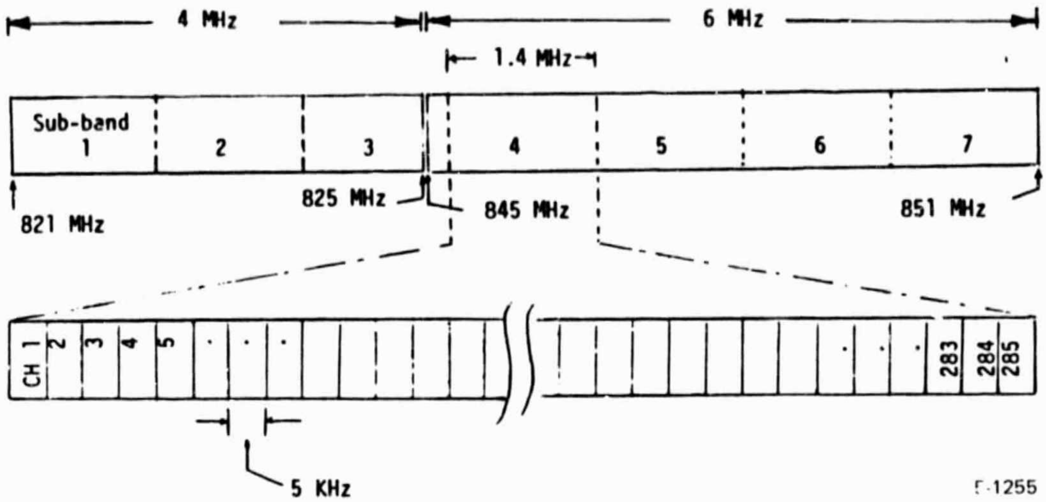
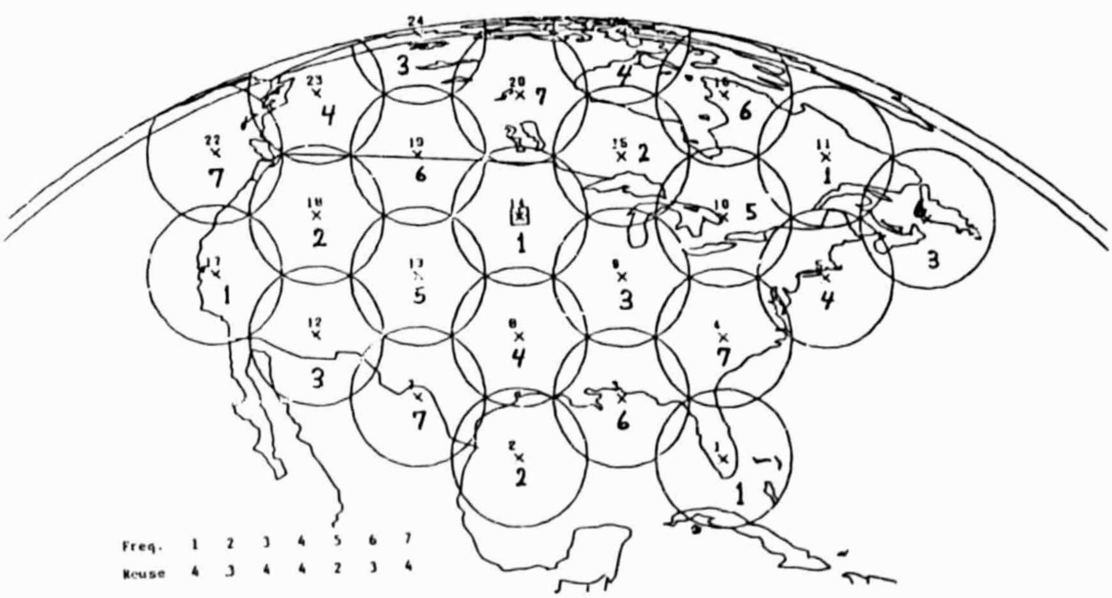


Figure 3-3. UHF Uplink Frequency Plan



ANTENNA DIAMETER: 20 m; CROSSOVER BEAMWIDTH: 1.4°; CROSSOVER GAIN: 37.5 dB
SATELLITE POSITION: 90°W LONGITUDE GEOSTATIONARY ORBIT

5-1256

Figure 3-4. MSAT-2 Satellite Antenna Beam Layout

(4) Parameter 11 (total transponder gain) is the difference between Parameters 10 and 5, minus the losses** from the transmitter output to the transmit antenna.

(5) Parameter 13 (G/T) was derived as the difference (in dB) between the antenna receive gains, G, (Parameter 2) and the temperature, T, (Parameter 12).

These specifications were modified as defined in Section 4.0, where necessary, based on the spacecraft dc power and/or weight, and were used as the basis for the payload component preliminary designs described in Section 4.1.2.

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TABLE 3-1. MAJOR SPECIFICATIONS FOR THE OVERALL COMMUNICATIONS PAYLOAD

Parameter	Ku/UHF Alternate			Ku/L-Band Alternate		
	UHF Antenna Dia. (meter) Candidates			L-Band Antenna Dia. (meter) Candidates		
	20	15	10	15	10	5
1. Carrier Frequency Ranges						
Ku-Uplink	13.2 GHz					
Ku-Downlink	11.65 GHz					
UHF or L-Band Uplink	UHF: 821-825, 845-851 MHz			L-Band: 1650-1660 MHz		
UHF or L-Band Downlink	UHF: 866-870, 890-896 MHz			L-Band: 1549-1559 MHz		
2. Antenna Gains (dB)						
Ku Receive (0.4 meter dia.)	32.3					
Ku Transmit (0.4 meter dia.)	31.2					
UHF or L-Band Receive	38.5	36.0	32.5	42.0	38.5	32.5
UHF or L-Band Transmit	41.5	39.0	35.5	45.0	41.5	35.5
3. Number of Spot Beams						
Ku Receive + Transmit	1 Common for Receive/Transmit					
UHF or L-Band Receive + Transmit	24	12	8	49	24	8
4. Transmit EIRP Values (dBw) - per channel						
Ku (to Gateway Terminal)	4.5					
UHF or L-Band (to Mobile Terminal)	28.6	28.6	28.6	34.7	34.7	34.7
5. Transmitter RF Power Per Channel						
Ku-Band (to Gateway Terminal) dBw	-25.2					
Ku-Band (to Gateway Terminal) watts	0.003					
UHF or L-Band (to Mobile Terminal) dBw	-10.5	- 8.0	- 4.5	- 7.9	- 4.4	+ 1.6
UHF or L-Band (to Mobile Terminal) watts	0.09	0.16	0.36	0.16	0.36	1.45
6. Number of Channels Accommodated						
• Bandwidth Limit	6840	3420	2280	13965	6840	2280
7. RF Power per Beam [UHF or L-Band Transmitter Output] - Watts						
• Bandwidth Limited Case (285 channels/beam)	25.65	45.6	102.6	45.6	102.6	413.25
8. Total RF Power [UHF or L-Band Transmitters Total] - Watts						
• Bandwidth Limited Case	615.6	547.2	820.8	2234.4	2462.4	3306
9. Total Ku-Band Transmitter Output RF Power (watts)						
• Bandwidth Limited Case	20.5	10.3	6.8	42	20.5	6.8
10. Received Signal Strength per 5 KHz Channel at Receive Antenna Output to Diplexer (minimum) - (dBw)						
Ku-Band (from Gateway)	-130					
UHF or L-Band (from Mobile)	-140.4	-142.9	-146.4	-142.9	-146.4	-152.4
11. Total Transponder Gain, Receive Antenna Output to Transmit Antenna Input (dB)						
• Ku-Band to UHF or L-Band	117.1	119.6	123.1	119.7	123.2	129.2
• UHF or L-Band to Ku-Band	113.7	116.2	119.7	116.2	119.7	125.7
12. Receive System Temp. at Satellite (dBK)						
• Ku-Band	29					
• UHF or L-Band	29	29	29	29	29	29
13. G/T at Satellite (dB/K)						
• Ku-Band	+3.18					
• UHF or L-Band	+9.38	+6.88	+3.38	+12.88	+9.38	+3.38
14. Receiver Noise Figure (dB)						
• Ku-Band	3.0					
• UHF or L-Band	1.5	1.5	1.5	1.5	1.5	1.5

3.4 SPACE SEGMENT

The requirement and candidates which were evaluated in deriving the Mobile Satellite Space Segment configuration are described in Paragraphs 3.4.1 and 3.4.2.

3.4.1 REQUIREMENTS

Although the Mobile Satellite design encompasses a wide range of performance parameters, a 20-meter aperture antenna was defined at the start of the study as the baseline for the pursuit of hardware and design issues. Smaller apertures were treated parametrically.

The RCA Series 4000 bus was defined as the baseline spacecraft which will be modified for the Mobile Satellite system. This bus is the latest in RCA's Satcom family of geosynchronous communications satellites, and it is currently in development for both the Satcom Ku-Band spacecraft and the USSB direct broadcast spacecraft. Its three-axis stabilized attitude is maintained on-orbit by a momentum bias system. Hydrazine thrusters allow its orbital station to be maintained within 0.1° of latitude and longitude (where mission requirements dictate). It is designed for GTO weights ranging from 4000 pounds to 5800 pounds, and its launch vehicle interface allows it to be launched by the Ariane or the Shuttle and with either the PAM-DII or the RCA SCOTS perigee stage.

The designated launch vehicle for the Mobile Satellite is the Shuttle. Early analysis showed that the PAM-DII perigee stage cannot inject sufficient payload from the Shuttle's orbit into a geosynchronous transfer orbit to meet the needs of the Mobile Satellite system nor would a vertical Shuttle configuration be adequate for a Mobile Satellite antenna configuration. Therefore, RCA's Shuttle Compatible Orbit Transfer System (SCOTS) was selected as the baseline perigree stage.

3.4.2 CANDIDATE CONCEPTS

Simplified representations of system configurations which were conceptually designed and evaluated for suitability in the Mobile Satellite mission are presented in Figure 3-5. Variations among the candidates include the following:

- Proximity of feed assembly and transponder.
- Proximity of feed assembly and bus.
- Proximity of transponder and bus.
- Proximity of reflector and bus.
- Number of antenna masts.
- Number of solar array booms.
- Potential for shadowing of the solar array by the antenna.

Less visible, but even more significant, are the differences in center of mass location and in moments and products inertia, properties which determine their susceptibilities to orbital disturbance torques.

**Refer to Reference 2 in Appendix A.

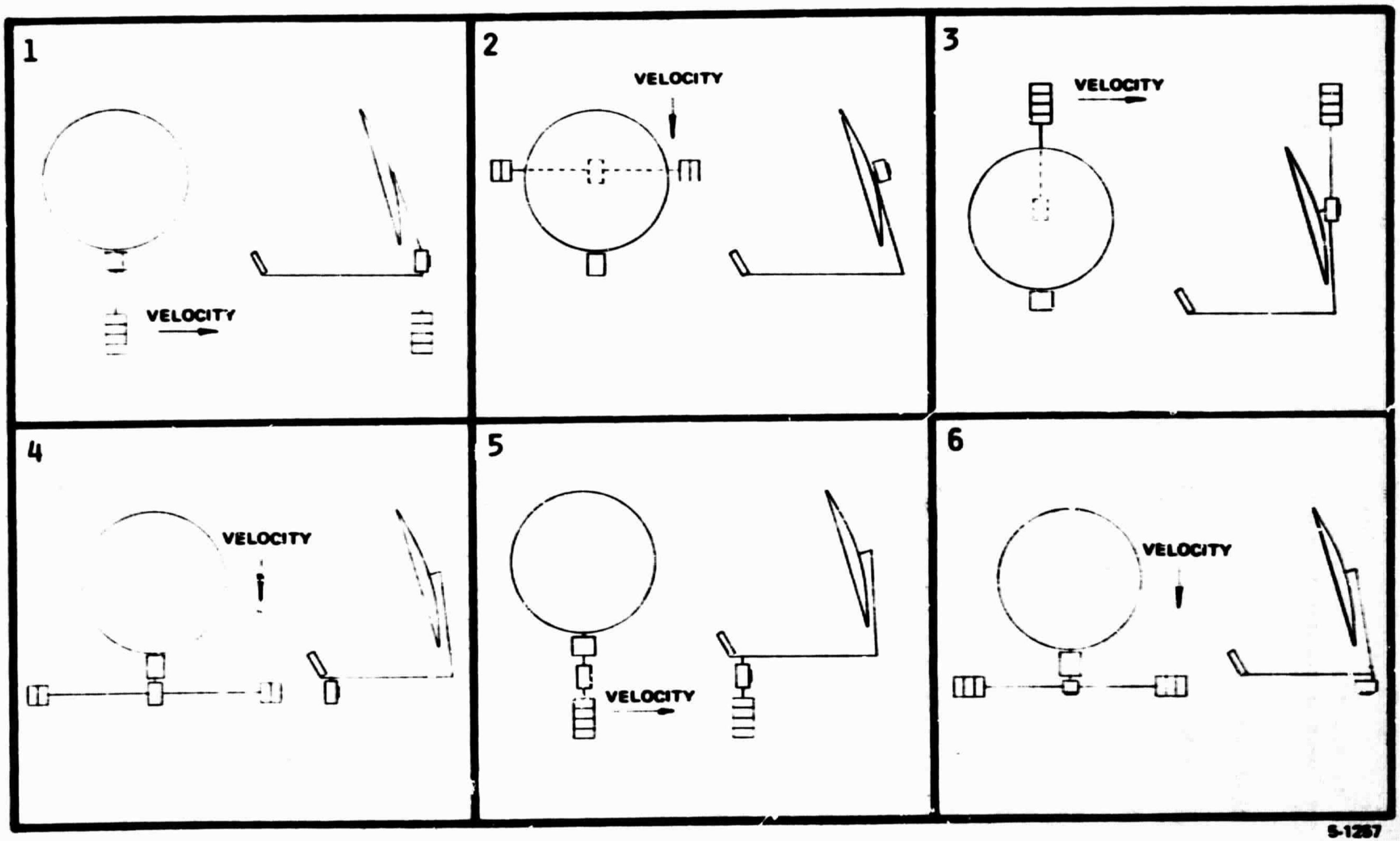

Figure 3-5. Mobile Satellite Candidate Concepts

These characteristics are summarized for the candidates in Table 3-2. Although differences exist in antenna and solar array characteristics, the overriding issue is susceptibility to disturbance torques. Much larger control capability could be provided for Candidates 1 through 5, but doing so would be a radical departure from the proven Satcom Attitude Control System. Hence, Candidate 6 was selected to be the most feasible configuration concept for further study.

3.5 GROUND SEGMENT

In conducting the study, RCA assumed that a single Satellite Control Network (SCN) site would be employed to provide the gateway facilities, the TT&C, and the Satellite Control Center (SCC). If additional gateway stations were added to the system, the SCN would function as the focal point for all network operations.

3.5.1 GATEWAY STATION

The gateway station will provide the equivalent of a telephone central office to the Mobile Satellite system; i.e., routing traffic via predetermined paths to final destinations and generating the signaling required to enable those paths.

The translation of RF carriers and baseband signals will be accomplished using commercially available single-channel-per-carrier (SCPC) communications hardware. Since only a single gateway station is assumed, the SCPC equipment is provided at a 100% duty factor loading. If additional gateways were added to the system, the duty factor would be reduced to prevent unnecessary cost escalations.

Once at baseband, the signal will be controlled in a manner similar to its control in current telephone networks. The communications channel switching will be accomplished using a commercially available switch. Any satellite unique control requirements will be incorporated into existing control software.

3.5.2 TELEMETRY, TRACKING, AND COMMAND STATION

The Telemetry, Tracking, and Command (TT&C) Station is comprised of the Command, Ranging, and Telemetry (CR&T) Subsystem and the RF system. This station will be collocated with the gateway station and will share the antennas with the gateway function.

This study has assumed that the transfer orbit operations and final positioning will be performed by other TT&C stations, such as the RCA tracking stations in New Jersey and Guam and the RCA Astro-Electronics Satellite Operations Center. This permits the use of limited motion antennas at the Mobile Satellite TT&C site, thus reducing nonrecurring costs.

The CR&T Subsystem performs the following major functions:

- Generate spacecraft commands under SOC and/or TT&C front-panel manual control.
- Perform both antenna and spacecraft command verification under computer or manual control.

TABLE 3-2. MOBILE SATELLITE CANDIDATE TRADES

ITEM	1	2	3	4	5	6
TRANSPONDER	• ON MAST WITH FEED • SHORT W/G OR COAX • EASY THERMAL CONTROL	→	→	• AT SPACECRAFT • SHORT W/G OR COAX	→	• ON MAST WITH FEED • SHORT W/G OR COAX • EASY THERMAL CONTROL
FEED	• ON MAST WITH TRANSPONDER	→	→	• AT SPACECRAFT • DEPLOYED TO FOCUS	→	• ON MAST WITH TRANSPONDER
REFLECTOR	• SEPARATE MAST	• ON SPACECRAFT	→	• ON MAST	→	• SEPARATE MAST
SOLAR ARRAY	• SINGLE SIDED • BOOM LENGTH TO REDUCE SOLAR PRESSURE TORQUE	• SYMMETRICAL	• SINGLE SIDED	• SYMMETRICAL	• SINGLE SIDED	• SYMMETRICAL
SYSTEM	• REFLECTOR & FEED SEPARATELY DEPLOYED • TWO MASTS FOR COM. SYSTEM • SINGLE ARRAY BOOM • HIGH DIURNAL CYLIC SOLAR TORQUE	• SINGLE MAST FOR COM. SYSTEM • TWO LONG ARRAY BOOMS • THRUSTER PLUME IMPINGEMENT ON REFLECTOR • HIGH GRAVITY GRADIENT TORQUE	• SINGLE MAST FOR COM. SYSTEM • SINGLE ARRAY BOOM • THRUSTER PLUME IMPINGEMENT ON REFLECTOR • HIGH GRAVITY GRADIENT TORQUE • HIGH DIURNAL CYCLIC SOLAR TORQUE	• SINGLE MAST FOR COM. SYSTEM • TWO LONG ARRAY BOOMS TO PREVENT SHADOWING • HIGH GRAVITY GRADIENT TORQUE	• SINGLE MAST FOR COM. SYSTEM • SINGLE SHORT ARRAY BOOM ADEQUATE TO PREVENT SHADOWING • HIGH DIURNAL CYCLIC SOLAR TORQUE • HIGH GRAVITY GRADIENT TORQUE	• REFLECTOR & FEED SEPARATELY DEPLOYED • TWO MASTS FOR COM. SYSTEM • TWO LONG ARRAY BOOMS TO PREVENT SHADOWING • CONTROLLABLE GRAVITY GRADIENT TORQUE • LOW SOLAR TORQUE

- Provide visual warning and enable/disable control over computer or manually generated hazardous commands.

- Provide alphanumeric and graphic displays on video terminals and print-out of telemetered data in engineering units.

- Provide spacecraft range and attitude data to the SOC.

- Perform (under computer or manual control) station baseband, IF, and RF signal routing; antenna pointing; RF polarization control; and HPA output level adjust.

- Provide determination of the signal routing, antenna pointing angle, polarization setting, high-power amplifier output level, status of essential station equipment, and feedback of that status to the SOC.

- Provide visual and audible alarms for selected out-of-limit conditions to the TT&C and SOC.

- Communicate with the SOC using a high level computer-to-computer communications protocol.

Redundant computers provide data processing in support of TT&C functions. The equipment configuration is designed to preclude single-point failures. The operator displays, keyboard controls, and data processing is similar to that found in the SOC. This design permits control and monitoring of satellites in the event of brief SOC equipment outages. Computer control of the TT&C equipment, selection of equipment connectivity, and monitoring of equipment status are performed using the multiprogrammer as the interface between the equipment and the computer. Local switching of all signal paths through the TT&C equipment and visual indication of the selected path are provided by a Station Control Panel located in the operator's console. Universal time code (UTC) time is received using a standard time receiver that is used to synchronize a time code generator. The time code generator provides a visual time readout to the operator and time signals to station equipment, including the computer.

The RF and antenna facilities include all equipment necessary to convert the CR&T uplinks and downlinks from a 70-MHz interface to Ku-Band. Major RF items related to the CR&T function include:

- Upconverters (70 MHz to Ku-Band).
- High-power amplifiers.
- Limited motion antennas.
- Low-noise amplifiers for telemetry reception.
- Telemetry/ranging downconverters (Ku-Band to 70 MHz).

All RF equipment, except antennas, would be configured redundantly, with cross-strapping between units to allow for additional flexibility.

3.5.3 SPACECRAFT OPERATIONS CENTER

The SOC has the capacity to process telemetry, ranging, and attitude data from two spacecraft simultaneously. As such, it initiates all commands necessary to control the spacecraft and processes all telemetry data to monitor spacecraft health.

The SOC includes redundant, identically configured real-time computers which were selected for their capabilities in providing real-time, operator intervention capabilities in the control of and accumulation of data from hardware peripherals. Normally, both computers operate all the time, providing an active backup should one computer fail. The real-time processing computers are menu driven, thus reducing the amount of procedural information operators must commit to memory. The menu displays permit the operator to construct command files, display telemetry data, observe messages, and perform other program requirements.

The SOC is the normal command center for the satellite in its mission orbit. Similarly, the redundant real-time equipment controls the telemetry processing at the SOC. The console operator can select, for display, telemetry data grouped by any criteria previously defined. Out-of-limit conditions detected by the computer are permanently recorded, appear on an out-of-limits display, and cause an audible alarm to be sounded to alert operators to the existence of an out-of-limits condition.

Computer-processed satellite tracking data consist of ranging data to the satellite merged with station antenna-angle data. These data, telemetry data, and other sensor data are provided to the mission computer (off-line computer) for further processing and analysis.

The mission analysis computer functions during orbit operations to provide ground antenna-pointing predictions, orbital maneuvering and stationkeeping planning data, propulsion management data, and telemetry long-term trend data analysis and display.

All of the equipment selected for the SOC is based on designs previously implemented by RCA and proven during years of spacecraft operations.

SECTION 4.0
SPACE SEGMENT DESCRIPTION

The Space Segment developed by RCA for the Mobile Satellite Mission is derived from and supports JPL's payload definition. The Space Segment employs the Space Shuttle and RCA-Developed SCOTS to provide large geosynchronous transfer orbit capabilities. The spacecraft was derived from the RCA Series 4000 design, modified to allow the use of extensible masts and large (20-meter diameter baseline) unfurlable reflectors.

4.1 SPACECRAFT CONFIGURATION

The Series 4000 Spacecraft was designed by RCA to fully exploit the enhanced performance of today's launch vehicles. The geosynchronous transfer orbit weight of this type of spacecraft approaches 6000 pounds. These spacecraft trace their heritage to the space-proven three-axis, body stabilized, RCA Satcoms and Series 3000 Spacecraft. The design of the Series 4000 Spacecraft has the flexibility to support a variety of payloads for both fixed satellite service (FSS) and direct broadcast satellite service (DBS). The common bus design affords the opportunity to reduce nonrecurring costs and thus provide a more economical Space Segment.

4.1.1 GENERAL CONFIGURATION

The selected Mobile Satellite mission configuration for the representative 20-meter antenna is presented in Figures 4-1 and 4-2. The communications payload and feed assembly are supported from a payload support structure which is cantilevered from a mast which extends from the side of the bus structure of the Series 4000 bus. Another mast, also extending from the bus structure, supports the wrap-rib reflector.

The payload support structure contains all elements of the the transponder and feed systems, the Ku-Band antenna system, earth sensor assemblies (ESA's), and some of the hydrazine thrusters and tanks necessary to the mission. Transponder components are mounted on the North and South surfaces of the compartment to maximize their heat rejection ability, and those surfaces are sized to meet the thermal control requirements of the transponder. If the North and South panels were sized to satisfy the thermal requirements, a compartment of extremely large dimensions would be necessary, causing its stowage during launch to be difficult. A volumetrically more efficient arrangement is achieved by using a compartment of relatively low stowed height, but having hinged thermal radiation covers which support part of the transponder. These covers are deployed to increase the active area of the thermal radiator.

Most spacecraft housekeeping functions are contained within the Series 4000 bus. For example, with the exception of the mission orbit earth sensors located in the transponder/feed compartment, the rest of the Attitude Control Subsystem is within the bus. In addition to the redundant momentum wheel assemblies, magnetic torquers, and attitude control electronics, the bus contains the horizon sensors and sun sensors which provide attitude reference data during the spinning portion of the transfer orbit.

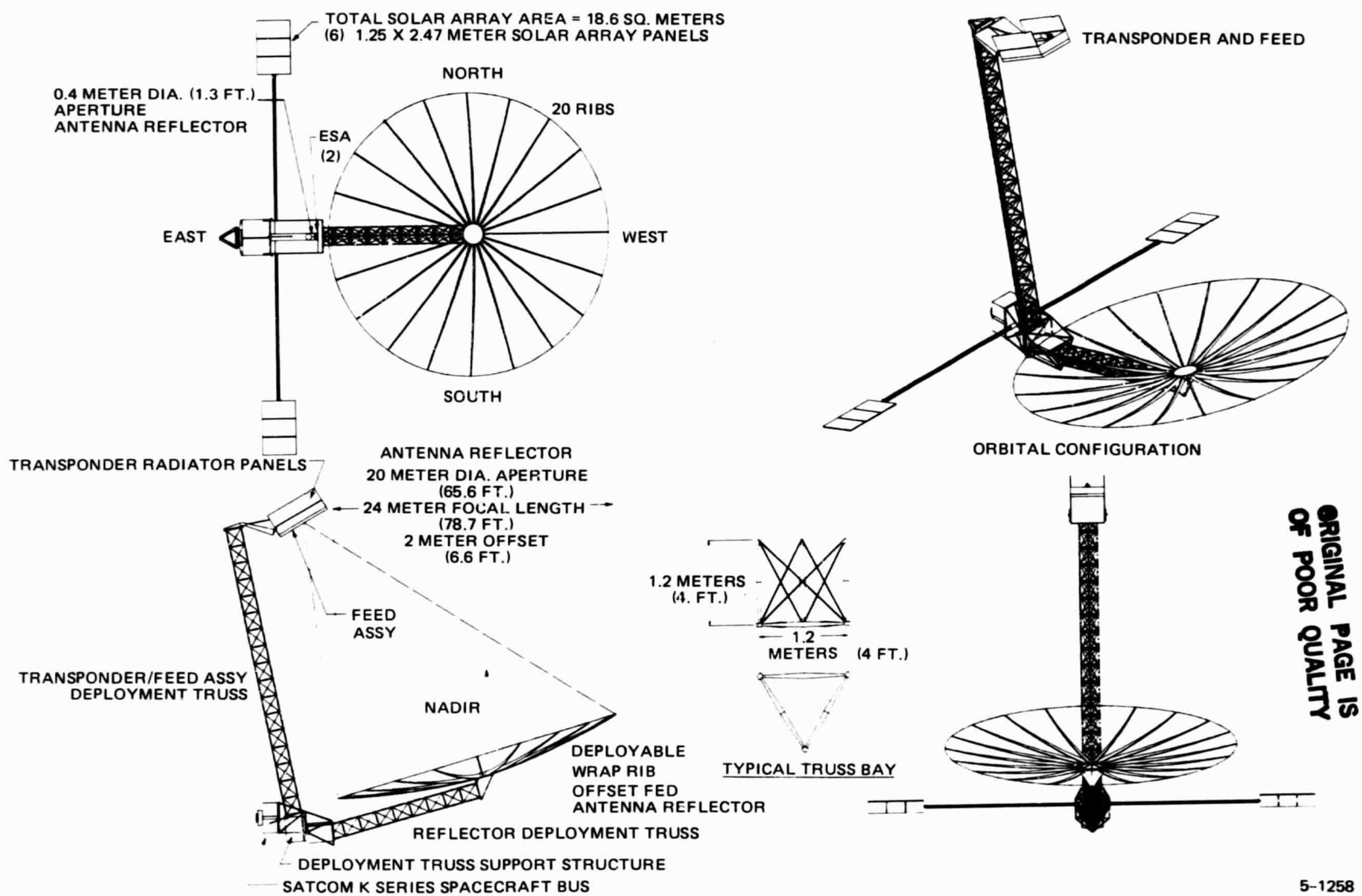

Figure 4-1. Mobile Satellite Mission Configuration

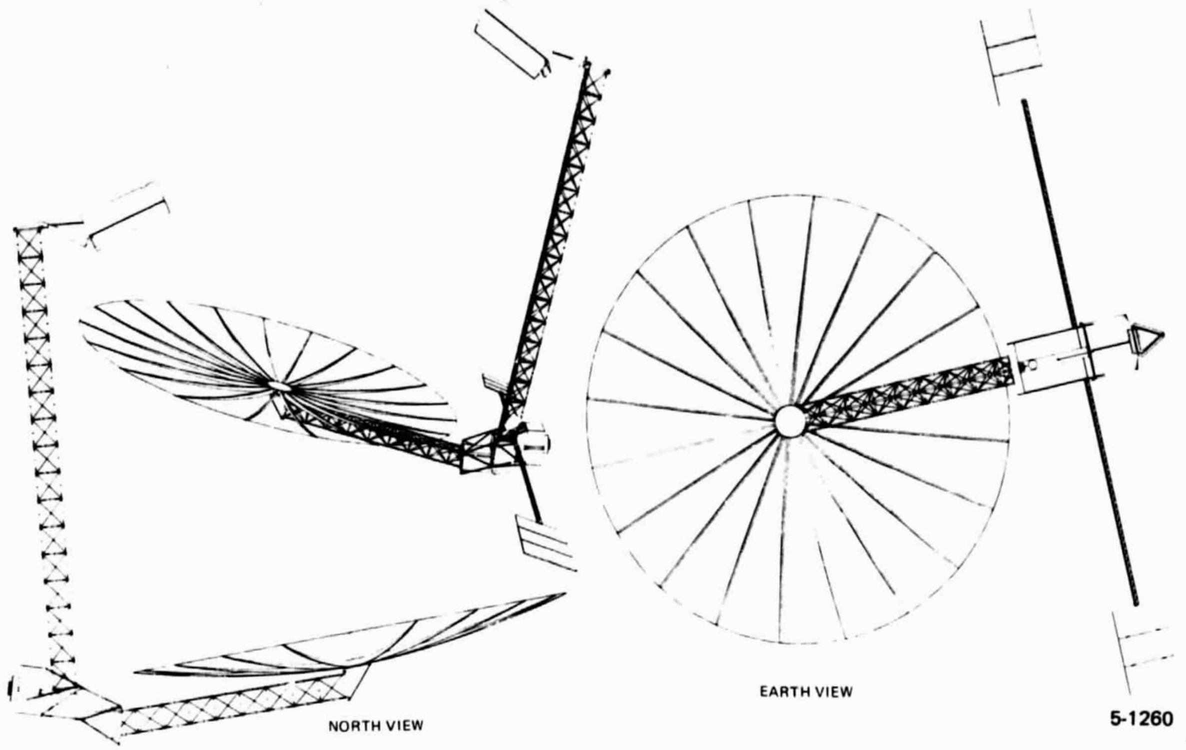

Figure 4-2. Alternate Views of Mobile Satellite Mission Configuration

The bus also contains the TT&C and Power Subsystem components and the remainder of the Propulsion Subsystem. Tanks and thrusters are located both in the bus and in the transponder/feed compartment. This distribution of thrusters is necessary to develop adequate torque capability and to surround the system mass center with thrusters when stationkeeping thrusting is performed. It then becomes advantageous to distribute the hydrazine propellant tanks in the same way to eliminate the difficulty of long collapsible propellant lines along the mast. The disposition of thrusters and their functions are presented schematically in Figure 4-3.

Power is supplied by a four-panel solar array which is stowed at launch in two stacks on the North and South surfaces of the bus. The panels sustain launch loads by means of nested conical shear fittings and by hold-down cables which maintain engagement of the cones. Pyrotechnic cable cutters release the solar panels for their spring-energized deployment. Rotary viscous dampers prevent the buildup of excess energy during deployment. To prevent shadowing of the deployed array by the communications antenna reflector, long booms are necessary to deploy the panels to a position determined by the worst solstice sun angles. The conventional folding booms are unsuited to such long dimensions and have been replaced by the Astromast type of collapsible boom. The canisters which contain these booms are located at the base end of the payload support structure, and arms fixed to the inboard solar panels join the panels to the booms. This location for the boom canisters and the solar array drives allows their relative large volume to be accommodated in the ample space of the open truss, thereby eliminating the necessity of major changes in the bus for their installation.

THRUSTER LEGEND

POND:
5 THROUGH 12

SCOTS SPIN-UP:
13 & 14

SPIN RATE CONTROL IN TRANSFER ORBIT:
7 & 10 or 5 & 12

SPIN AXIS PRECESSION:
6, 8, 9, 11

DESPIN AFTER AKM BURN:
5 & 12

DUAL SPIN TURN ACTIVE DAMPER:
5, 7, 10, 12

MOMENTUM CONTROL:
(19 or 20) or (6 & 9) (Positive)
(21 or 22) or (8 & 11) (Negative)

EAST-WEST:
(19 or 20) & (15 & 17) or (19 or 20) & (16 & 18) — EAST
(21 or 22) & (1 & 3) or (21 or 22) & (2 & 4) — WEST

ROLL TORQUE:
(5 & 12) or (7 & 10)

YAW TORQUE:
(3 & 15) or (4 & 16)
(1 & 17) or (2 & 18)

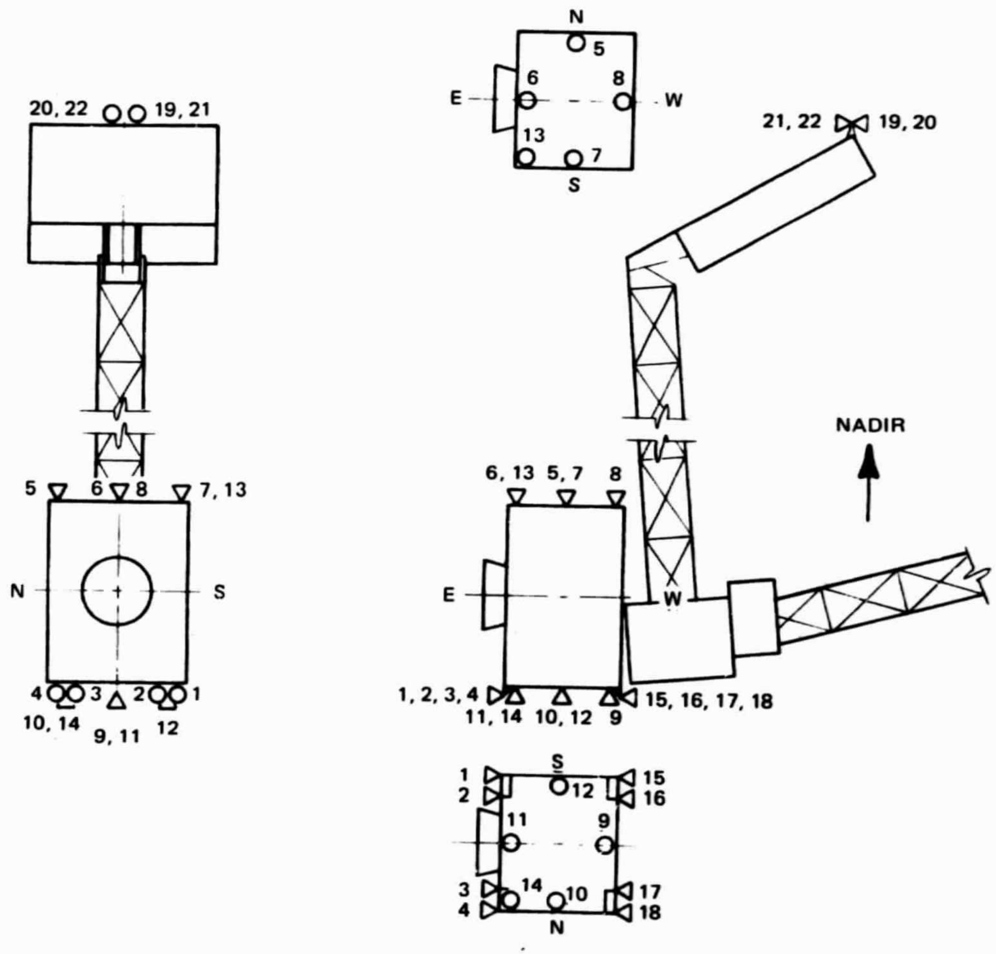

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Figure 4-3. Mobile Satellite Thruster Geometry

The communications antenna is the Lockheed wrap-rib, a type which was flown with a 10-meter aperture on ATS-F. In the Mobile Satellite 20-meter design, the reflector contains 20 radial ribs cantilevered from a central hub. The ribs have sufficient lateral flexibility to allow them, when hinged at their roots, to wrap elastically around the hub diameter. The reflecting surface is a mesh of 0.001-inch diameter gold-plated molybdenum wire which is supported by the radial ribs. The stored energy of the ribs in their wrapped configuration provides much of the deployment energy necessary to expand the reflector. Additional energy is provided in large aperture antennas by a hub-mounted mechanism. A pyrotechnically released restraining cable allows deployment to begin.

The two masts which extend the reflector and the transponder/feed compartment from the spacecraft are expandable truss assemblies of triangular cross-section. This Lockheed design contains each stowed mast in a deployment cage. The deployment mechanism unfolds the longeron segments of the mast one bay at a time and preloads their bearings by the use of over-center latches. It was initially intended to use two different cross-sections for the Mobile Satellite masts because of the different masses and moments of inertia being supported. However, it was decided that significant volume and cost economies can be realized by using a common cross-section.

The Mobile Satellite stowed configuration is presented in Figures 4-4 through 4-6. The Series 4000 bus is cantilevered from SCOTS, and the communications payload is cantilevered from the forward end of the bus. The total length of the system is less than half the length of the Shuttle cargo bay (18.3 meters).

The SCOTS includes a cradle which provides a five-point interface with the Shuttle (four longeron fittings and a keel fitting). The perigee stage is supported in the cradle by a statically determinate system of three latches. (A more detailed description of SCOTS is presented in Section 4.2.2.) These interfaces, then, are the structural supports for the SCOTS/Series 4000 bus/communications payload as a combined system.

The payload itself is supported by the Payload Support Structure, an open truss whose geometry is tailored to the triangular cross-sections of the stowed antenna masts and to the existing hard points in the bus structure. The truss geometry also satisfies the large dimensions of the transponder/feed assembly.

All elements of the transponders and of the feed assembly are contained within the transformer/feed assembly compartment. The compartment includes heat pipes embedded in the sides and in the deployable covers so that thermal control of transponder components is a self-contained function. The dimensions of the compartment, when closed for launch, are 92 x 152 x 30 inches high. The large dimensions are determined principally by the area requirements of the feed elements, and the height is then limited by the envelope of the Shuttle. An interface platform attached to the end of the transponder/feed mast extends under the stowed compartment and supports the hinges and mechanism which accomplishes

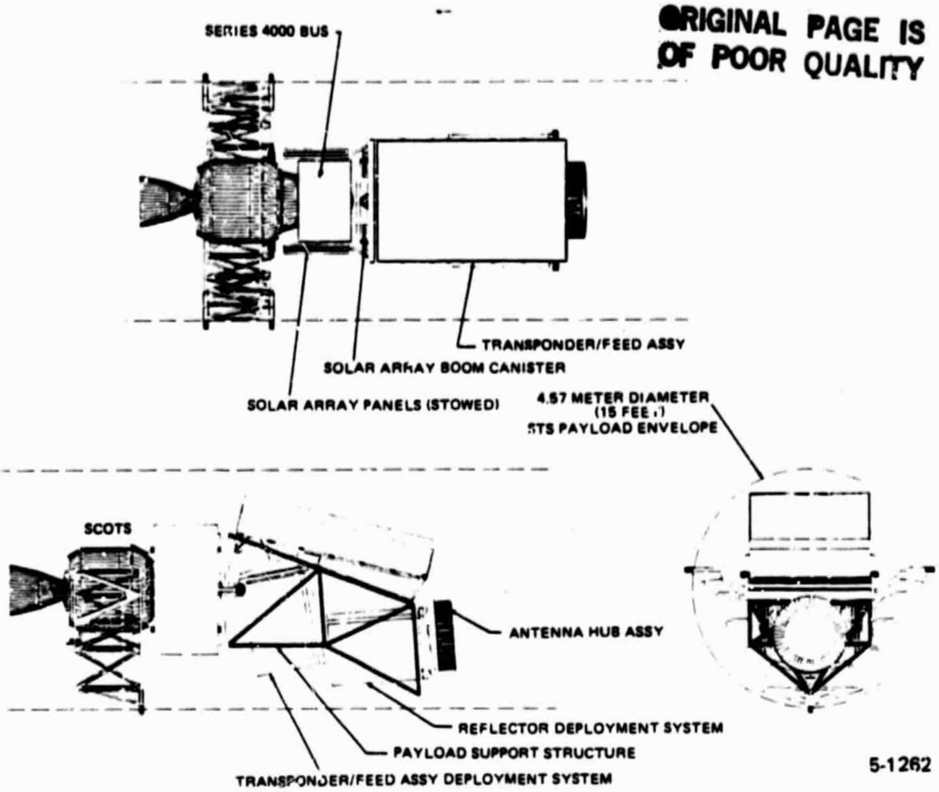

Figure 4-4. Mobile Satellite Launch Configuration

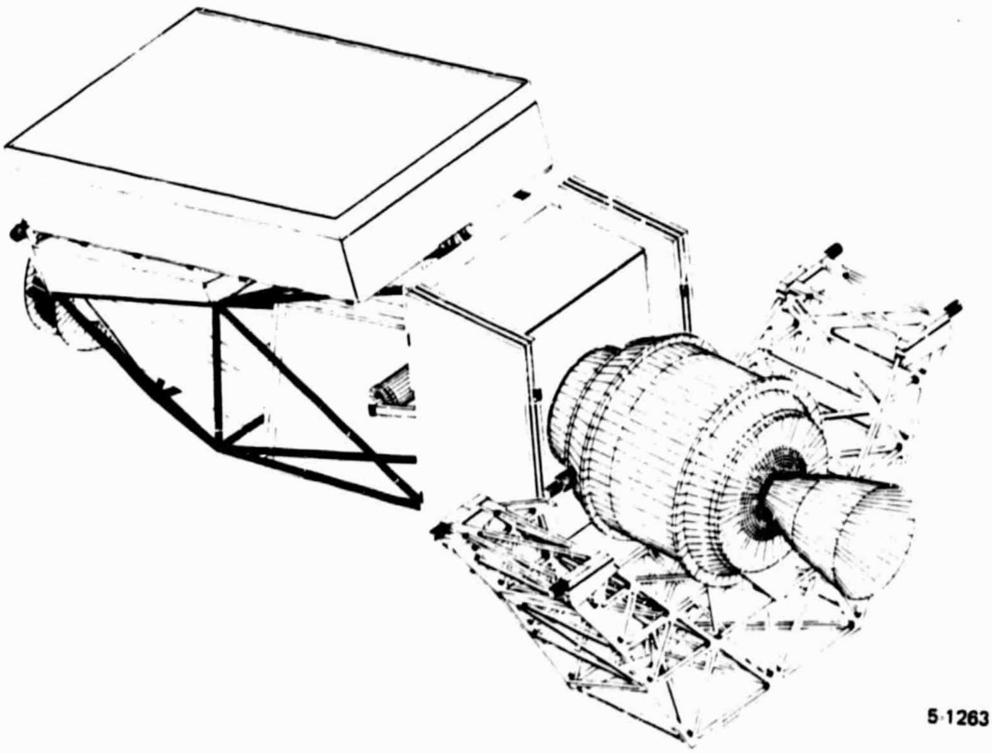

Figure 4-5. Mobile Satellite Launch Configuration, Isometric View

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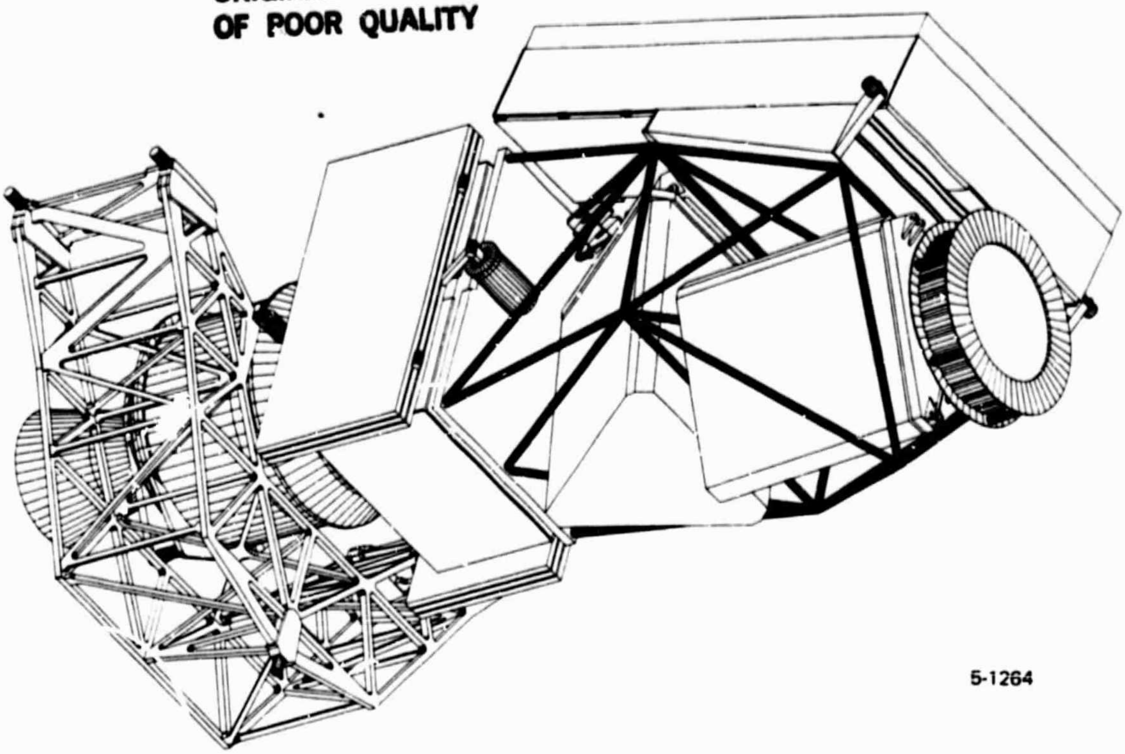


Figure 4-6. Mobile Satellite Launch Configuration, Isometric View 2

the final rotation and positioning of the compartment (feed) after the mast is fully extended. The electrical interface of the transponder with the main spacecraft body is provided by a harness that deploys with the truss.

Four points on the payload support structure support the transponder/feed compartment during launch. These points contain mating conical fittings to react in-plane shears and tension rods to sustain out-of-plane loads. Bolt cutters identical to those which release the bus from SCOTS will cut the tension rods and allow mast extension to begin. Rotation of the compartment to properly orient the feed is delayed by cables to the interface platform until the mast has been fully extended. Upon command, these cables are severed by cable cutter of the same type used to cut the solar array restraint cables.

This arrangement of the stowed payload system was selected after consideration of other candidates. It offers a compact assembly whose center of mass is as close as possible to the spacecraft bus. The compartment location will allow reasonable growth of both the feed plane and the thermal radiators.

4.1.2 TRANSPONDER

4.1.2.1 Configuration

The Mobile Satellite transponder was designed as a dual-band system, patterned after the payload definition proposed by JPL. The transponder is sufficiently flexible to support the inclusion of either a TWTA or SSPA design. The unit level designs have drawn heavily on microwave integrated circuit technologies evolved through spacecraft design programs at RCA.

A block diagram of the transponder for the Ku-Band/UHF-Band candidate, configuration KU-1, is given in Figure 4-7; the feed elements shown are part of the antenna subsystem. The Ku-Band power amplifier section is labeled HPA to allow the consideration of either a TWTA or SSPA design. RCA suggests that the HPA function and its RF power output be satisfied by an SSPA design. This suggestion is based on RCA's predictions of 1990 technology and its commitment to solid-state spacecraft technology development programs. The remaining three sections of the transponder are identified as the Ku-Band receiver, UHF receiver, and UHF transmitter.

4.1.2.2 Transponder Components

4.1.2.2.1 Ku-Band Receiver

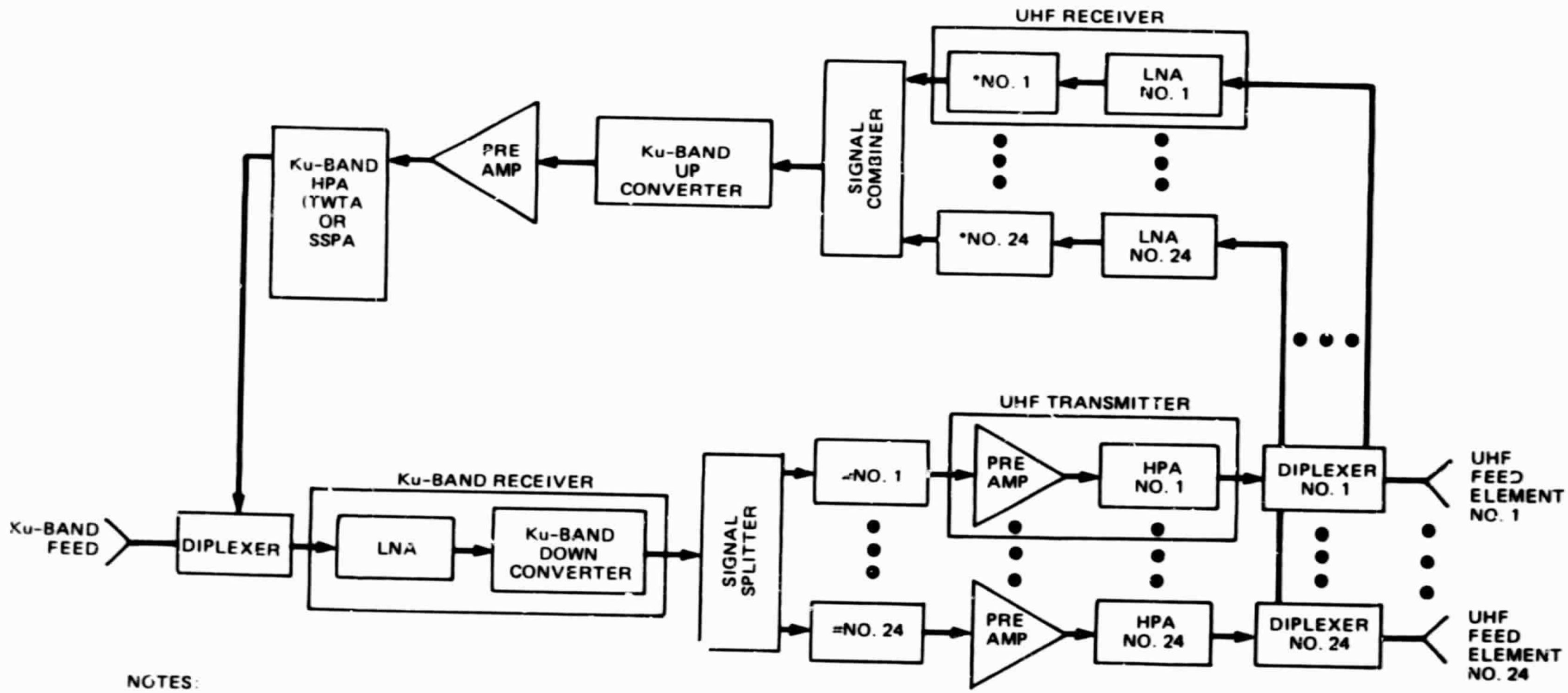
A block diagram showing the various receiver and translator type components in the transponder is illustrated in Figure 4-8. The configuration shown will be the same for the UHF and L-Band approaches.

The function of the Ku-Band receiver is to translate the uplink Ku-Band signal from the gateway station to an IF frequency; additional signal processing will take place at the IF in the downlink frequency translator. Specifications to be met by this unit are listed in Table 4-1. The uplink signal at 13.2 GHz is amplified in a four-stage low-noise GaAs FET amplifier. This signal is then mixed with a 13.0-GHz local oscillator signal in order to produce an IF frequency of 200 MHz. The output section of the receiver is an IF amplifier containing an automatic level control (ALC) loop which causes the gain of the stage to vary in order to compensate for variations in the level of the Ku-Band uplink signal. This ALC loop functions by monitoring the level of a pilot tone generated at the gateway station and assigned to a 5-kHz channel dedicated solely to level control purposes.

Also included in the Ku-Band receiver is a bandpass filter at 13.2 GHz which provides rejection at the 12.8-GHz image frequency as well as other undesired out-of-band input signals. This filter can be realized as a combline design using an evanescent waveguide structure or as a dielectrically loaded waveguide below cutoff structure.

A bandpass filter is also included to select the lower sideband of the mixing products. This filter can be implemented as a lumped component design or possibly as a surface acoustic wave (SAW) device.

The Ku-Band receiver is fabricated using microwave integrated circuit techniques for the 13.2-GHz amplifiers and uses hybrid circuits containing integrated circuits and chip components for the lower frequency circuits. The 3-dB noise figure is achievable using presently available semiconductor devices, and improved noise figure performance should be available by the 1990's.



NOTES:

- NON-OVERLAPPING FEEDS
- SINGLE Ku-BAND BACKHAUL BEAM
- UHF, 20-METER ANTENNA, 24 BEAMS
- UHF FEED ELEMENTS NO. 10 AND 13 REQUIRE TWO RECEIVER/TRANSLATORS ON THE UPLINK AND DOWNLINK DUE TO THE 4 MHz/6 MHz SPLIT IN THE UHF BAND.

* UPLINK UHF RECEIVER/FREQUENCY TRANSLATOR
= DOWNLINK RECEIVER/FREQUENCY TRANSLATOR

Figure 4-7. Transponder Block Diagram, Candidate KU-1

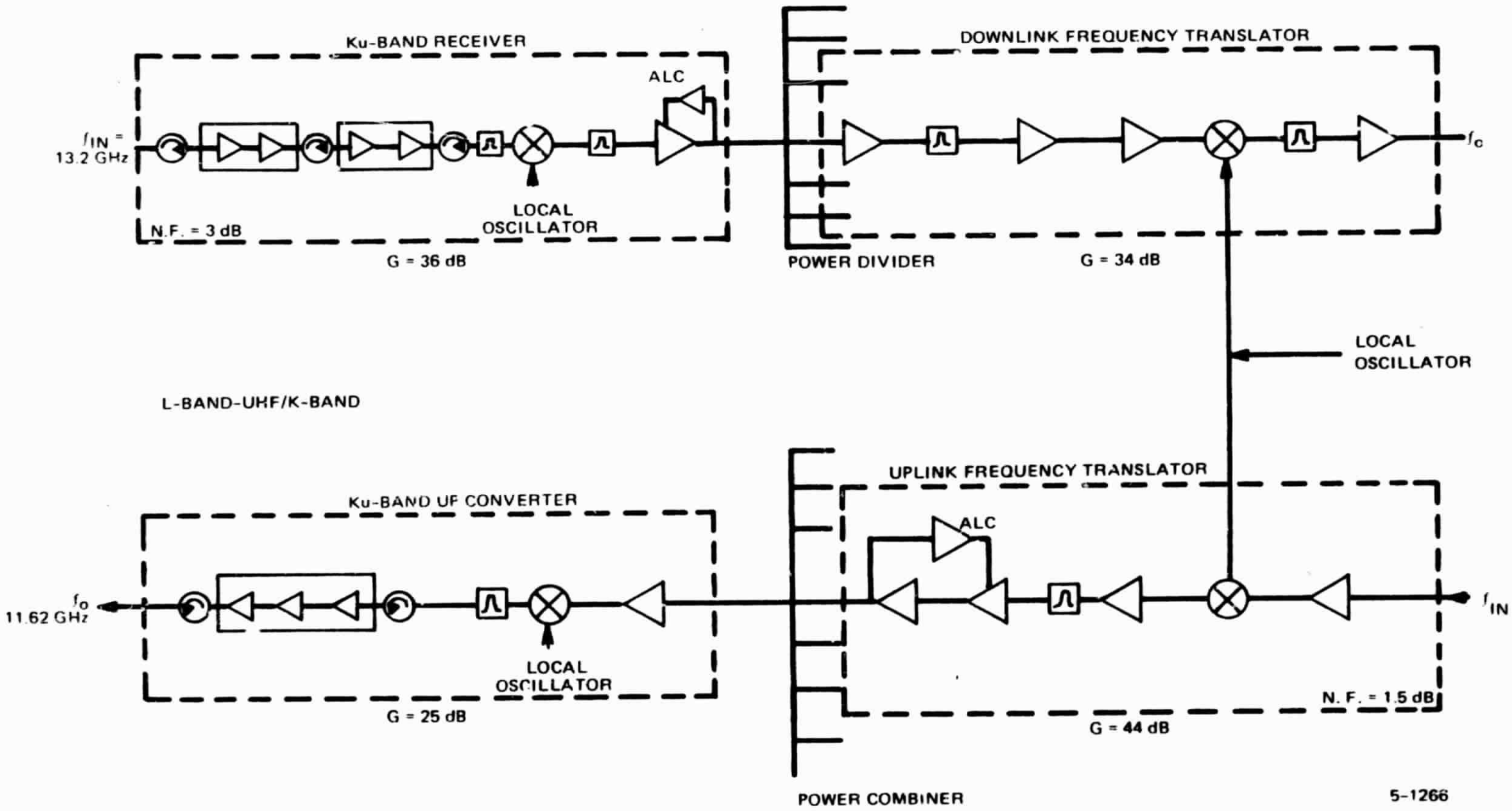


Figure 4-8. Receiver Block Diagram

TABLE 4-1. Ku-BAND RECEIVER SPECIFICATIONS

Parameter	Value
Receiver Frequency	13.2 GHz
RF Bandwidth	50 MHz max.
Noise Figure	3.0 dB max.
Received Signal Strength	-131.5 dBW/5 kHz
Intermodulation Performance	-45 dBc
Gain	36 dB
Isolation	
11.65 GHz	85 dB
866-896 MHz, 1549-1559 MHz	60 dB
Spurious Outputs	-45 dBc In Band -50 dBc Outside RF Band

Included in the Ku-Band receiver is a local oscillator section which contains all the circuits necessary to generate the local oscillator frequency, 13.0 GHz, as well as a dc/dc converter which provides all the operating voltages required for the various circuits.

The physical characteristics of the Ku-Band receiver are as follows:

Size:	5 x 3 x 4 inches
Weight:	1.1 pounds
DC Input:	5.8 watts

4.1.2.2.2 Ku-Band Upconverter

The Ku-Band upconverter converts the combined outputs of the uplink frequency translators from the intermediate frequency to Ku-Band, 11.62 GHz, by mixing with a local oscillator frequency. Included in the upconverter are an IF amplifier, mixer, Ku-Band amplifier, all circuits necessary to generate the local oscillator signal, and a dc/dc converter for supplying the necessary operating voltages. Included also is a waveguide filter to provide the required rejection of the local oscillator frequency and other spurious signals.

The upconverter will comply with the major performance specifications given in Table 4-2.

TABLE 4-2. Ku-BAND UPCONVERTER SPECIFICATIONS

Parameter	Value
Input Frequency	155 MHz
Gain	25 dB
Output Frequency	11.62 GHz
Intermodulation Performance	-45 dBc
RF Bandwidth	50 MHz Max.
Spurious Outputs	-45 dBc In-Band -50 dBc Outside RF Band

The physical characteristics of the Ku-Band upconverter are as follows:

Size:	5 x 3 x 4 inches
Weight:	1.15 pounds
DC Input Power:	5.6 watts

4.1.2.2.3 Downlink Frequency Translator

This unit selects one of the available 1.4-MHz beam signals and converts it to the assigned downlink UHF or L-Band Frequency by mixing with the appropriate local oscillator frequency. Since each of the beam signals is assigned one of seven downlink frequencies through a frequency reuse plan, a separate downlink frequency translator with a unique local oscillator frequency is required for each beam signal.

The output of the Ku-Band receiver is a signal containing all of the 1.4-MHz beam signals. This output signal is applied to the input of each frequency translator through a power divider network. The appropriate signal for a particular translator is selected by a unique filter having the correct center frequency, a bandwidth of 1.4-MHz, and rejection of adjacent beam signals by at least 45 dB. This signal is then amplified and mixed with a local oscillator signal selected to produce the required UHF or L-Band downlink frequency. Hybrid circuits using integrated circuits and chip components will be used for the downlink frequency translator. In both the UHF and L-Band configurations, the filter used after the mixer should be a combline structure to ensure that rejection requirements are satisfied. The 1.4-MHz filter can be implemented as a SAW device. All circuits required to generate the local oscillator frequency are included as part of the translator assembly.

The downlink frequency translator performance specifications are summarized in Table 4-3. The physical characteristics of the downlink frequency translator are as follows:

Size:	5 x 2 x 3 inches
Weight:	0.9 pound
DC Input:	3.25 watts

TABLE 4-3. DOWNLINK FREQUENCY TRANSLATOR SPECIFICATIONS

Parameter	Value
Input Frequency	200 MHz
Output Frequency	866-870 MHz, 890-896 MHz, 1549-1559 MHz
Gain	34 dB
Intermodulation Performance	-45 dBc
Bandwidth	1.42 MHz

4.1.2.2.4 Uplink Frequency Translator (UHF or L-Band Receiver)

Each uplink beam requires a separate frequency translator that will comply with the performance specified in Table 4-4. The uplink signal is amplified in a low-noise amplifier and is mixed with a local oscillator frequency to generate an IF signal which can be filtered sufficiently to reject adjacent beam signals and other spurious signals. The local oscillator frequency used is the same as the local oscillator frequency used in the downlink frequency translator for that beam signal. This approach minimizes the total number of local oscillator frequencies required and ensures that the proper frequency relationship is maintained among the beam signals when they are combined for downlink transmission at Ku-Band. An ALC loop is placed in the IF amplifier in order to prevent possible overloading of the transponder by one of the mobile users.

The output signals from all of the uplink frequency translators are combined in a power combining network for conversion to Ku-Band in the Ku-Band upconverter. Hybrid circuits using integrated circuits and chip components are used in the uplink frequency translator, with the 1.4-MHz filter implemented as a SAW device. Note that since the downlink and uplink frequency translators share the same local oscillator frequency, all three functions can be combined in a single assembly.

TABLE 4-4. UPLINK FREQUENCY TRANSLATOR SPECIFICATIONS

Parameter	Value
Receiver Frequency	821-825 MHz, 845-851 MHz 1650-1660 MHz
Bandwidth	1.42 MHz
Received Signal Strength	-150 dBW/5 kHz
Intermodulation Performance	-45 dBc
Noise Figure	1.5 dB Max.
Isolation	
866-870 MHz, 890-896 MHz 1549-1559 MHz 11.65 GHz	80 dB 85 dB 60 dB

The physical characteristics of the uplink frequency translator are as follows:

Size:	5 x 1 x 3 inches
Weight:	0.4 pound
DC Input Power:	1.2 watts

4.1.2.2.5 Local Oscillator Frequencies

Frequency stability requirements for receivers in a Mobile Satellite system necessitate the use of high quality oscillators as frequency sources in the generation of local oscillator frequencies. Crystal oscillators (5 MHz and 10 MHz) which exhibit a long-term drift rate of 2×10^{-8} per year are available at the present time. Such oscillators are somewhat large and heavy in a space-qualified configuration. Given the large number of local oscillator frequencies required (30 for the 20-meter UHF configuration), it would not be practical to use a separate high quality oscillator in each application. Instead, it is recommended that individual local oscillator frequency sources be phase locked to a high quality master oscillator, as illustrated in Figure 4-9. This would permit the use of smaller, lighter weight oscillators while maintaining the high stability of the master oscillator at each local oscillator frequency.

4.1.2.2.6 UHF and L-Band Transmitters

The major specifications for the UHF and L-Band transmitters are summarized in Table 4-5. There are six candidate antenna diameters; i.e., 20, 15, and 10 meters for the UHF frequencies and 15, 10, and 5 meters for the L-Band frequencies. The UHF frequencies are 866-870 MHz and 890-896 MHz, while the L-Band frequency band is 1549-1559 MHz.

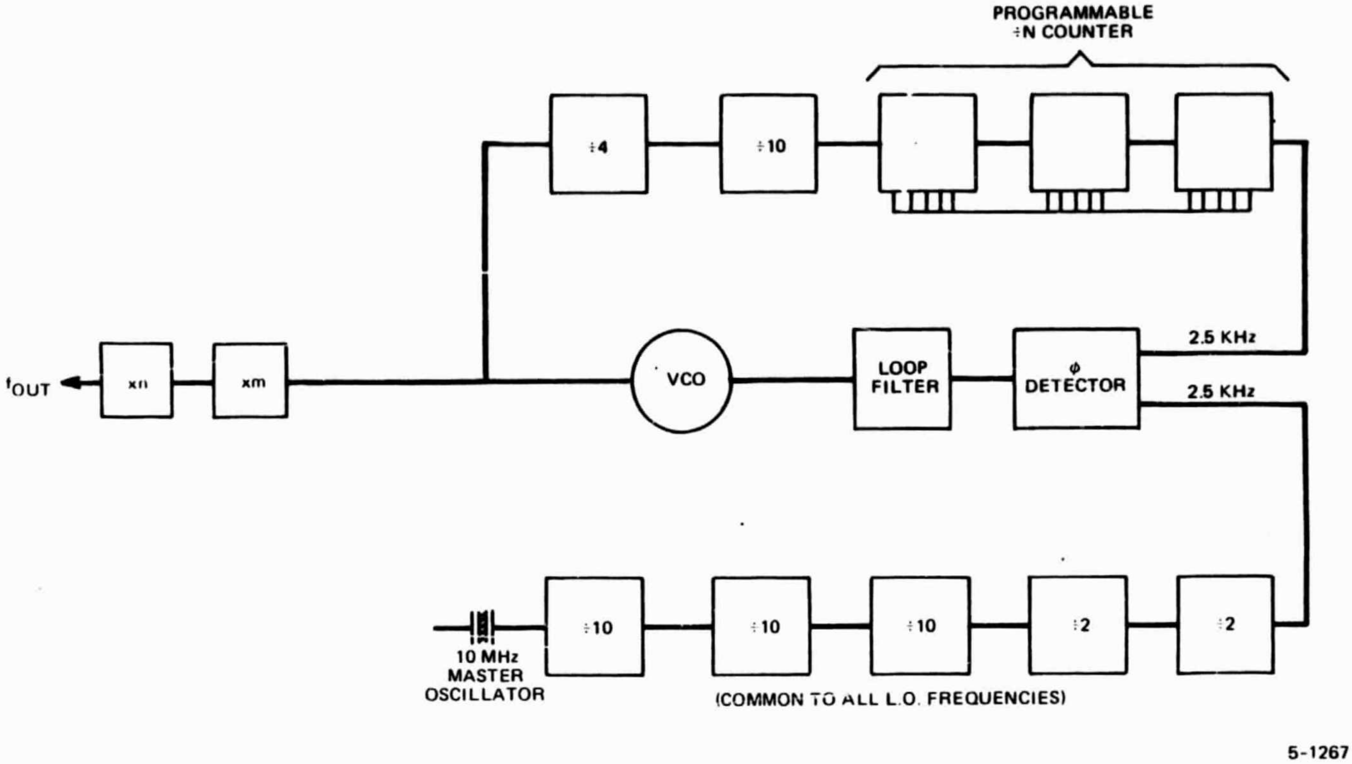


Figure 4-9. Block Diagram of Local Oscillator Frequency High Stability Phase-Locked Loop

The most stringent specification is that the maximum intermodulation (IM) power in any 5-kHz channel with all channels active (N-tone) shall be -26 dBc or less. To satisfy this stringent intermodulation noise specification, two techniques were considered. These two techniques are: (1) a reflective-diode linearizer (RDL) will be inserted in front of the SSPA to compensate for non-linearities generated in the solid-state power amplifier (SSPA), and (2) all transistor power amplifiers will be operated at 4.2-dB back-off from the saturation power level of the linearized RDL/power amplifier combination to provide the required IM power reduction when operated in a multi-carrier environment. The SSPA transponder configuration is described in Section 4.1.2.2.6.1, the operation of a reflective-diode linearizer is explained in Section 4.1.2.2.6.2, and the design of a typical silicon bipolar transistor high power amplifier is described in Section 4.1.2.2.6.3.

The physical characteristics for the UHF and L-Band transmitters are summarized for the six candidates in Table 4-6. Data for the electronic power conditioner (EPC) power supply are also provided in the table.

The RF output power per beam ranges from 14 watts for the 20-meter UHF configuration with 100% eclipse capability to 413 watts for the 5-meter L-Band configuration and the bandwidth limited case.

TABLE 4-5. MAJOR SPECIFICATIONS FOR UHF AND L-BAND TRANSMITTERS

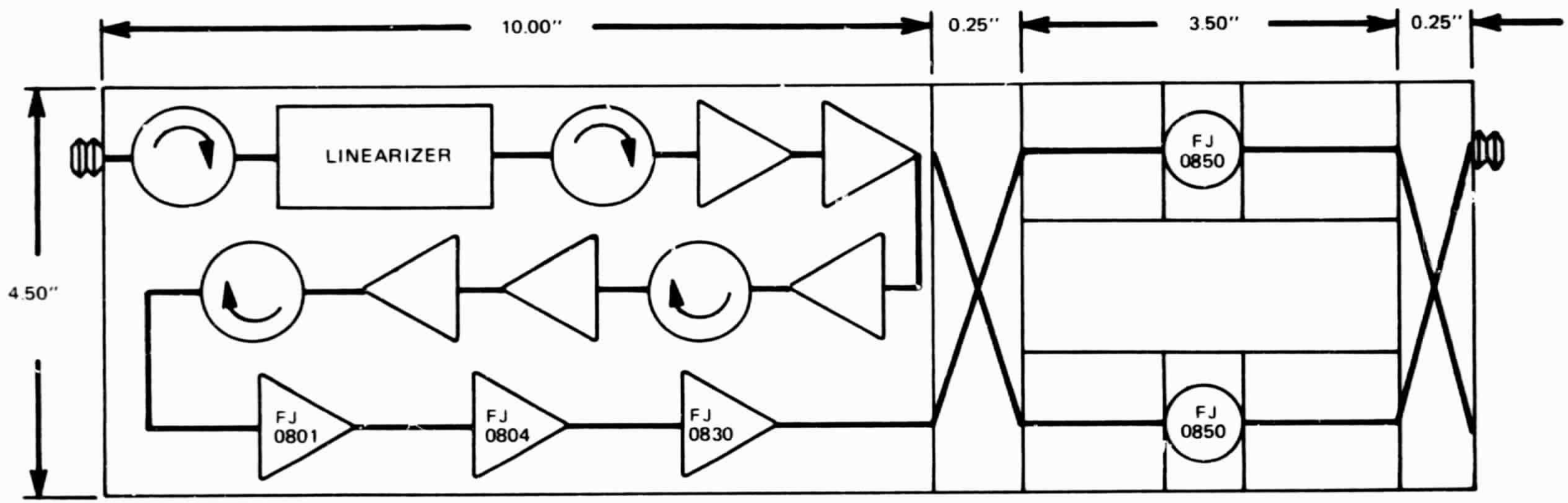
Parameter	Units	Values for Ku-Band/UHF Antenna Diameters of			Values for Ku-Band/L-Band Antenna Diameters of		
		20 m	15 m	10 m	15 m	10 m	5 m
• Frequency	MHz	866-870 and 890-870			1549-1559		
• Input Level	dBW	-50	-50	-50	-50	-50	-50
• Gain (Preamp + HPA)	dB	47	47	47	53	53	53
• Maximum IM in Any 5-kHz Channel with All Channels Active	dBc	-26	-26	-26	-26	-26	-26
• RF Bandwidth per Transmitter	MHz	1.4	1.4	1.4	1.4	1.4	1.4
• HPA Average Output Power							
• Per 5-kHz Channel	watts	0.09	0.16	0.36	0.16	0.36	1.45
• Per Beam	watts	25.65	45.6	102.6	45.6	102.6	413.25
(Bandwidth Limited Case)							
• HPA Instantaneous Peak Power to be Withstood Based on 4.2-dB Peak to Average Capability							
• Per 5-kHz Channel	watts	0.24	0.42	0.95	0.42	0.95	3.8
• Per Beam	watts	67	120	270	120	270	1086
(Bandwidth Limited Case)							
• Out-of-Band Maximum Levels to Avoid Interference with UHF, L-Band, and Ku-Band Receivers							
• 13.2 GHz	dBW/	-100	-100	-100	-100	-100	-100
• 821-825, 841-851 MHz	5-kHz	-120	-120	-120	NA	NA	NA
• 1650-1660 MHz	Chan.	NA	NA	NA	-120	-120	-120

TABLE 4-6. SIZES AND WEIGHTS OF MOBILE SATELLITE TRANSMITTERS FOR SIX ANTENNA PLANS AND BANDWIDTH LIMITED CAPABILITIES

Parameter	UHF			L-Band		
Antenna Diameter (meters)	20	15	10	15	10	5
RF Power/Beam (watts)	25.65	45.6	102.6	45.6	102.6	413.25
EPC Size (HWL in inches)	4x3.5x5	5x3.5x6	6x5x8	5x3.5x6	6x5x8	7x6x13
EPC Weight (pounds)	2.80	3.44	7.84	3.47	7.93	24.57
SSPA Size (HWL in inches)	1x14.5x 5.2	1x14.5x 5.2	1x12.5x 6.7	1x13.5x 5.2	1x11.5x 6.7	1x24.5x 9.2
SSPA Weight (pounds)	3.16	3.16	3.54	2.90	3.26	9.48
Total Weight (pounds)	5.96	6.6	11.38	6.372	11.19	34.05
DC Input Power Into SSPA (watts)	82.74	148.05	340.86	147.1	346.62	1519.3
Dissipated Power on SSPA (watts)	46.93	83.94	194.88	81.92	196.47	879.15
SSPA Efficiency (%)	31.00	30.8	30.1	31*	29.6*	27.2*
DC Efficiency (%)	85	86	86	86	86	86
DC Power from EPC (watts)	97.34	172.15	396.35	171.04	403.05	1766.6

*Assume common emitter bipolar transistor to be developed at 1.5 GHz with output power P=80W, gain=7 dB, and power-added efficiency η_{PA}=50%

4.1.2.2.6.1 SSPA Transponder. The layout of a typical solid-state power amplifier (SSPA) is presented in Figure 4-10. The plan shown is for the UHF 15-meter antenna case which requires 45.6 watts per beam. Two Fujitsu FJ-0850 common-emitter silicon bipolar transistors are combined by Lange-type 3-dB hybrids to generate the 45.6 watts output power. Since the saturated output power of the FJ-0850 is 65 watts each, the operating power level is 4.2 dB backed-off from its saturated output power. With this back-off, the SSPA can achieve better linearity characteristics while handling the large number of mobile radio channels involved.



ITEM \ PLAN	UHF (890-896 MHz) (866-870 MHz)			L-BAND (1549-1559 MHz)		
ANTENNA DIAMETER (Meters)	20	15	10	15	10	5
RF POWER/BEAM (Watts)	25.65	45.6	102.6	45.6	102.6	413.25
SSPA SIZE (HWL in inches)	1 X 14.5 X 5.2	1 X 14.5 X 6.7	1 X 12.5 X 6.7	1 X 13.5 X 5.2	1 X 11.5 X 6.7	1 X 24.5 X 9.2
SSPA WEIGHT (Pounds)	3.16	3.16	3.54	2.90	3.26	9.48
NUMBER OF POWER TRANSISTORS COMBINED	2	2	4	2	4	16
RF POWER/TRANSISTOR (Watts)	40	65	65	65	76.7	85.4

Figure 4-10. Typical Mobile Satellite SSPA Layout (Showing UHF 45.6-Watt Plan)

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The required power amplifier/device technology for the UHF and L-Band transmitters is summarized in Table 4-7. As shown in the table, the UHF band will use silicon bipolar transistors with 1.5-μm meshed emitters (existing technology), and the maximum output power per transistor can reach 80 watts with 7-dB gain and 60% collector efficiency. The power combiner will use coaxial-line 3-dB hybrids for handling high power.

TABLE 4-7. MOBILE SATELLITE POWER AMPLIFIER/DEVICE TECHNOLOGY (1990's)

Parameter	UHF	L-Band
Transistor	Silicon bipolar	Silicon bipolar
Critical Dimension	1.5 μm meshed-emitter	1 μm* meshed-emitter
Package	Internally matched	Internally matched*
Plated Heat Sink	N/A	N/A
Gain(1)	7 dB	7 dB
Efficiency(1)	60%	60%
Power/Transistor	80 W	80 W
Combiner Technology	Coaxial-line	Coaxial-line

*Technology to be developed by 1990.

(1) Gain and efficiency at referenced power level.

The L-Band SSPA will use silicon bipolar transistors with 1-μm meshed-emitter technology which will be developed by 1990. Maximum output power per transistor is expected to reach 80 watts with 7-dB gain and 60% collector efficiency. Advanced internally-matched packages have to be developed for these high-power devices. Again, coaxial-line 3-dB hybrids will be used for power combination.

4.1.2.2.6.2 RDL Linearizer. When the transponder is used to transmit multicarrier signals, the output power operating point of each UHF or L-Band power amplifier must be lowered (or backed off) to reduce intermodulation to an acceptable level. A linearizer can be used to generate a transfer characteristic which is opposite to that of the power amplifier and thus reduce the required output power back-off (OPBO) level.

Of the various linearizer approaches, a predistortion RDL type linearizer appears best suited to the Mobile Satellite application. It is small in size (1 x 2 inches), lightweight (less than 25 grams), relatively easy to tune, and requires only passive components. A schematic diagram of a basic RDL is shown in Figure 4-11.

A quadrature hybrid is used to split an incoming signal into two equal levels. One half of the input is applied to a variable reactance load (X) at port 2. All power arriving at X is reflected back to the hybrid. The phase angle of this reflected voltage is related to the incident voltage by the angle of the reflection coefficient of the reactance:

$$\phi = \mathrm{ARCTAN}\ [Z_o \cdot X/(X^2 - Z_o^2)] \qquad (1)$$

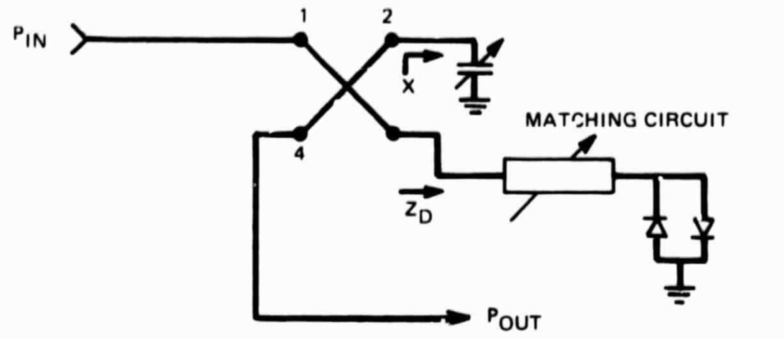

Figure 4-11. Basic Reflective Diode Linearizer

The other half of the input signal emerges from port 3 and is applied to anti-parallel diodes through a matching network. The majority of the power reaching these diodes is also reflected back to the hybrid. As these diodes are driven with greater power, the magnitude and phase angle of the voltage reflected from them will change; e.g., from $V_d \angle \theta_d$ to $V_d' \angle \theta_d'$ as illustrated in Figure 4-12. The relationship between the incident and reflected voltages from the diode port is:

$$V_d \angle \theta_d = V_i \, [(Z_d - Z_o)/(Z_d + Z_o)] \quad (2)$$

where Z_d is the impedance terminating port 3. Z_d varies as a function of the input power. The reflected voltage from ports 2 and 3 are vectorially combined by the hybrid and appear at port 4. The relation between the input power and the output power is:

$$P_{out} = P_{in} \, (1 \angle \theta_x - pd \angle \theta_d)^2/4 \quad (3)$$

where $1 \angle \theta_x$ is the reflection coefficient of reactance X and pd is the reflection coefficient of the diode branch. By proper choice of θ_d and Z_d characteristics, an expanding nonlinear transfer characteristic can be achieved whose variation from linear (as a function of P_{in}) is the opposite of that generated by a solid state amplifier in both magnitude and phase.

Numerous RDL linearizers have been constructed and tested at various frequencies and with several different types of amplifiers. One RDL was tested at 880 MHz with a multi-stage class A solid-state power amplifier having a gain of approximately 40 dB and a saturated power output of 10 watts. The magnitude and phase transfer characteristics of this unit are shown in Figures 4-13 and 4-14 when tuned for optimum two-tone carrier-to-total intermodulation (C/I) performance in the 3- to 8-dB OPBO range. (Total C/I is used as a measure of linearizer performance rather than carrier-to-third-order intermodulation (C/I3) since it is possible to tune a linearizer for excellent C/I3 and still have an unacceptable C/I ratio.) A comparison of the C/I performance achieved by the above SSPA alone to that of the RDL/SSPA combination is given in Figure 4-15. Although the RDL provides its greatest improvement in C/I ratio in the OPBO range from 3 to 8 dB where improvement is needed most, it does not degrade amplifier linearity at greater OPBO levels where uncorrected performance is satisfactory for system needs.

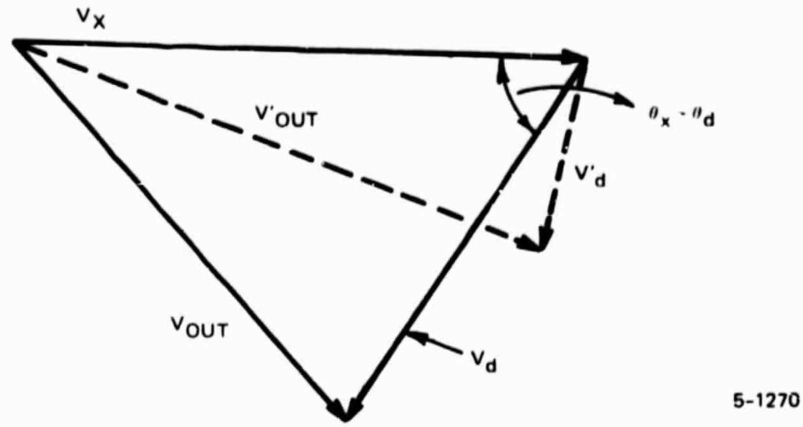

Figure 4-12. Vectorial Relation Between Input and Output RDL Signal Voltages

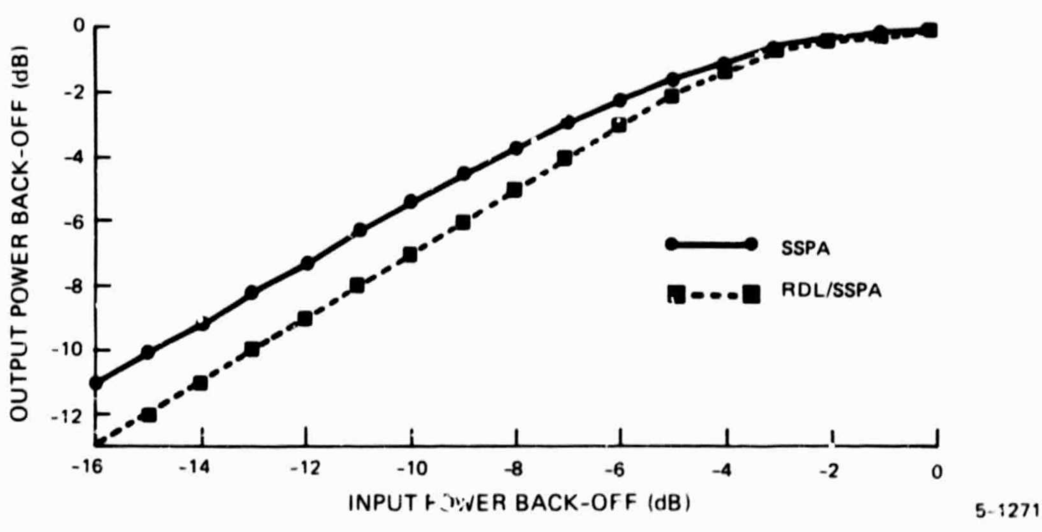

Figure 4-13. P_{in}-P_{out} Transfer Characteristics of RDL/SSPA

Performance of the RDL linearizers was also investigated for excitation by multi-tone signals. The measured improvement in C/I for two- and four-tone excitation as a function of OPBO shown in Figure 4-16 was obtained by adding and RDL to a TWTA at 12 GHz. The expected performance for the infinite carrier case was determined using computer modeling. The results of this calculation are also shown in Figure 4-16. It is believed that these results also apply to the SSPA case. These curves show that although the improvement provided by a linearizer is reduced as the number of tones is increased, and the point of optimum C/I improvement moves to a greater level of OPBO, a significant improvement in C/I can be achieved in the infinite carrier case. For the infinite carrier 26-dB C/I goal desired for the Mobile Satellite application, an OPBO reduction on the order of 4 to 5 dB should be possible.

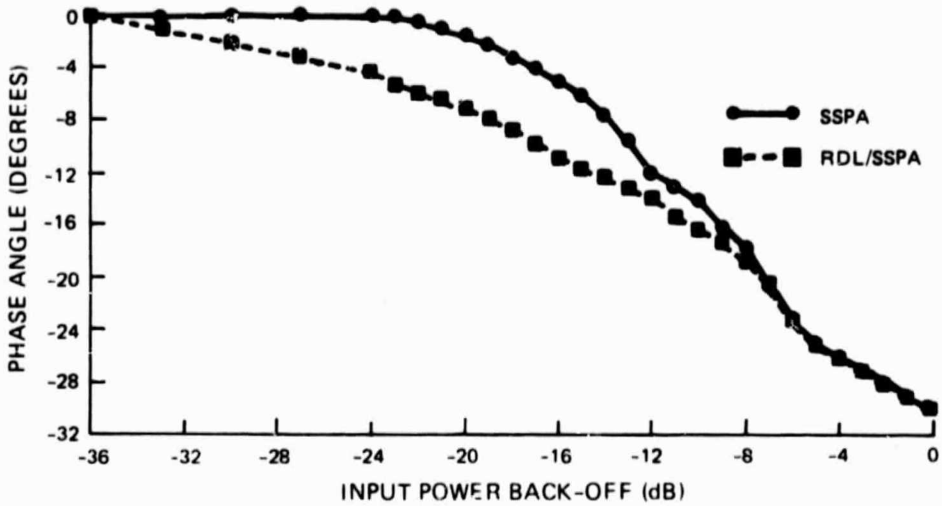

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Figure 4-14. Phase Transfer Characteristics of RDL/SSPA

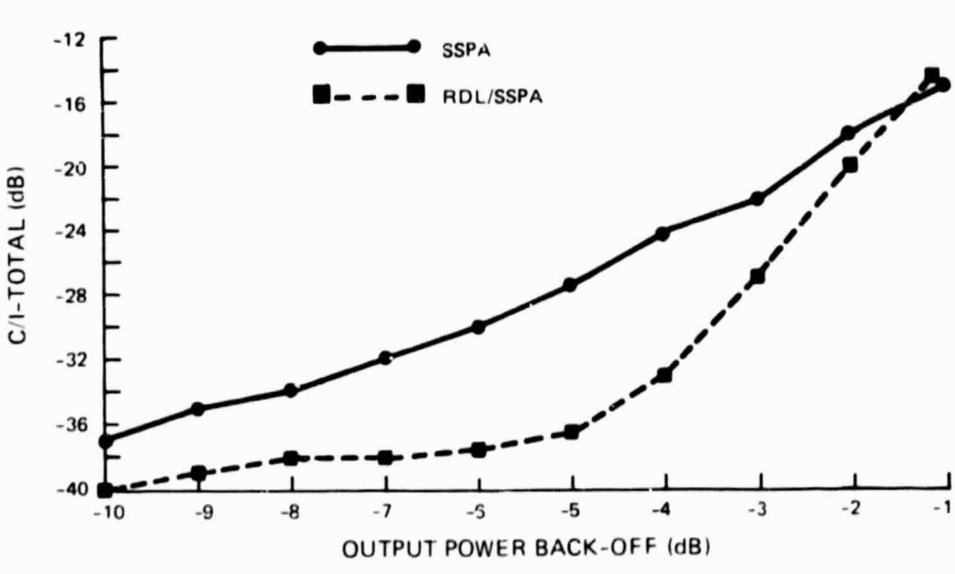

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Figure 4-15. C/I Performance of RDL/SSPA Compared to SSPA Alone

4.1.2.2.6.3 UHF High-Power Amplifier Development Model. In order to develop a state-of-the-art UHF solid-state power amplifier suitable for Mobile Satellite application, RCA acquired several FJ-0850 devices which are state-of-the-art high power silicon bipolar transistors developed by Fujitsu Semiconductor Inc. These transistors use the 1.5-μm meshed-emitter technology which can provide high power output with high gain.

A photograph of a high-power amplifier using FJ-0850 silicon bipolar transistors is shown in Figure 4-17. Special matching circuits with wide tuning capabilities are fabricated on G-10 substrates. The dc biasing circuits, consisting of lumped-element chokes and capacitors, are also shown in the figure. A

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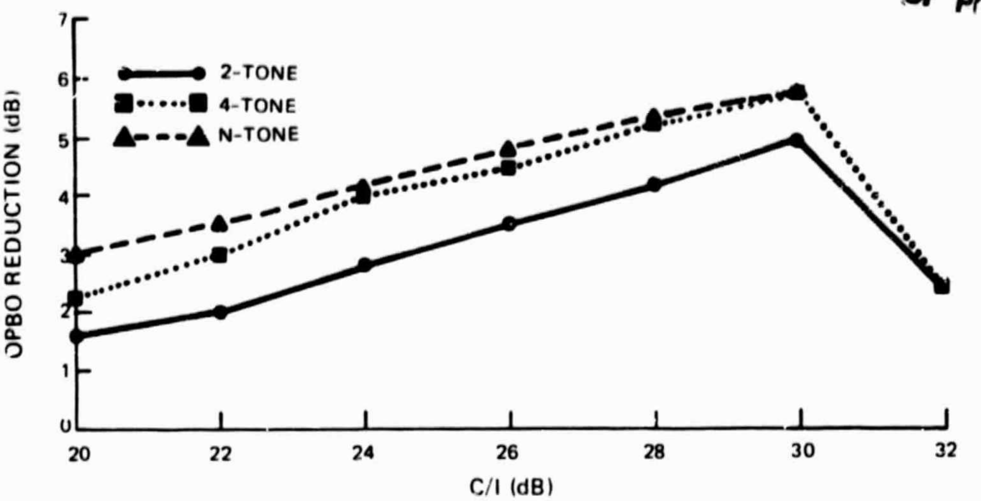


Figure 4-16. Improvement in C/I Provided by a Typical RDL for Two, Four, and Infinite Carrier Cases

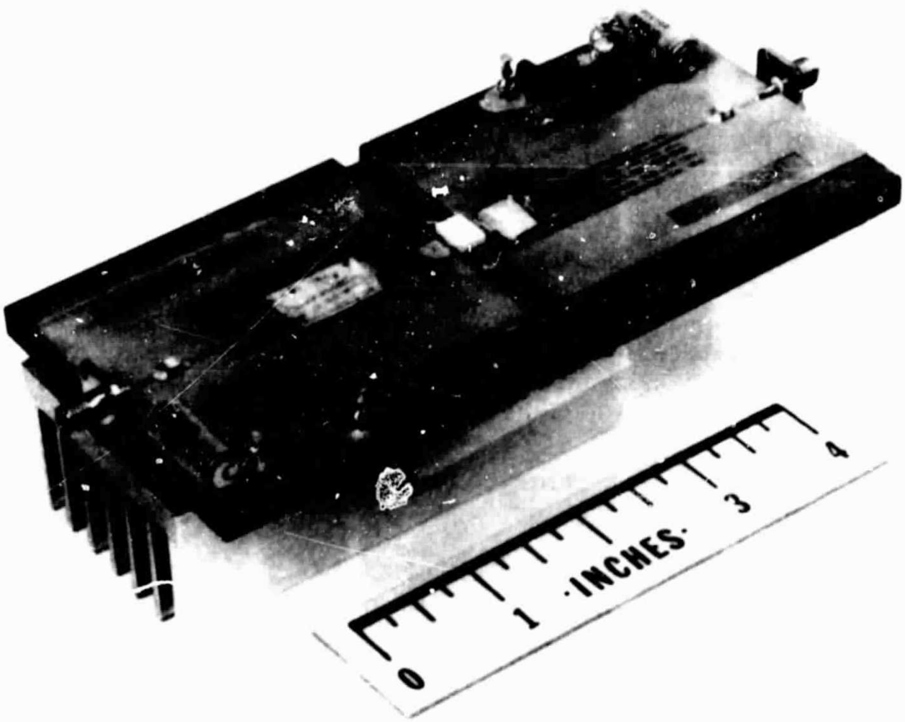


Figure 4-17. Mobile Satellite Power-Stage Bipolar Transistor Amplifier

large aluminum fin-type heat sink was mounted on the back of the amplifier to dissipate the 50-watt heat generated by the power transistor. The power amplifier size (6.5 x 3 x 1.5 inches) can be reduced by a factor of 2 in the final module by using alumina substrates.

The performance of the amplifier measured at 860 MHz, using FJ-0850 transistors, is given in Figure 4-18. Two sets of curves are presented in the figure. The curve marked "Fujitsu" is the supplied data from Fujitsu Semiconductors, while the curve marked "RCA" represents the new results obtained at RCA.

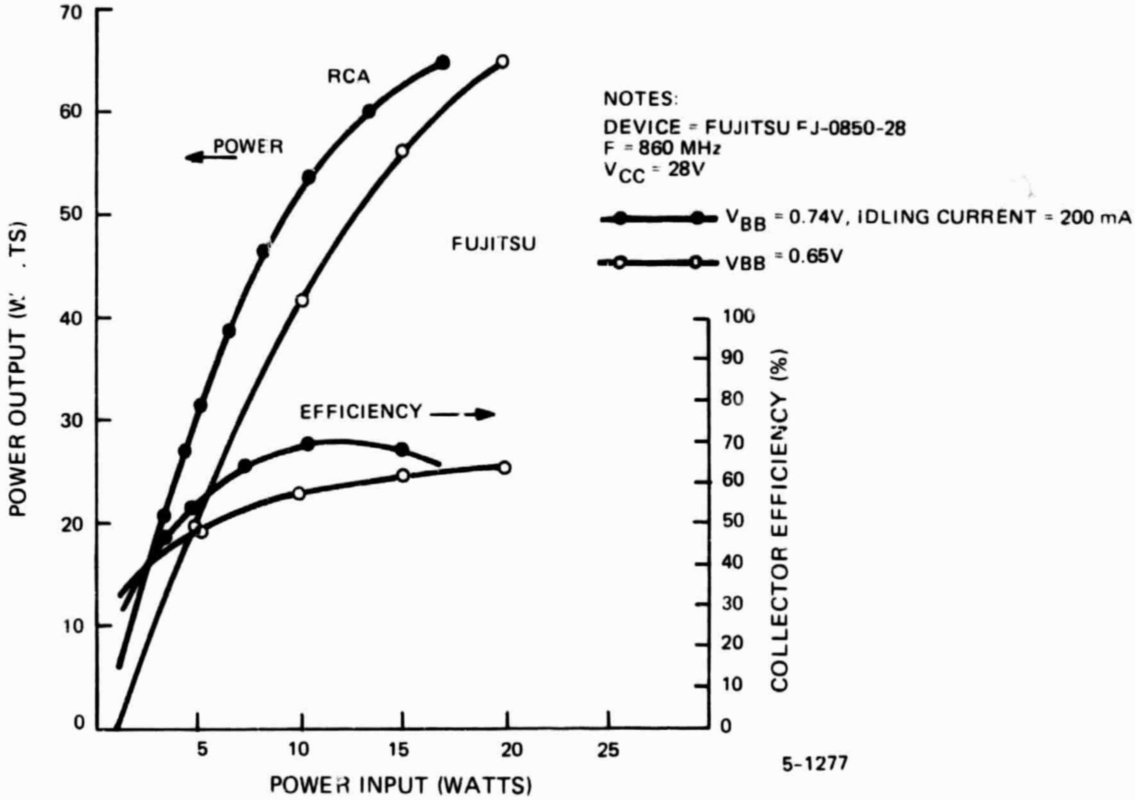


Figure 4-18. Performance of the FJ-0850 Amplifier at 860 MHz

The transistor collector is biased at V_{cc} = 28 volts, and the measured frequency is 860 MHz. The base of the transistor is biased (V_{bb}) at 0.74 volt with an idling current (I_{cc}) of 200 mA for the "RCA" curve, and the base biasing voltage (V_{bb}) for the "Fujitsu" curve is 0.65 volt. Since the idling current for the "RCA" curve is only 200 mA, the transistor is operating at Class B slightly toward Class AB. In this case, the dc collector current I_c is roughly proportional to the input driving signal level, but the amplifier maintains reasonable linearity.

As shown in Figure 4-18, both "RCA" and "Fujitsu" results indicate about the same saturated output power (P_{sat}) of 65 watts. However, the gain with the "RCA" approach is about 1-dB higher than that for the "Fujitsu" approach and the collector efficiency exhibited by the "RCA" data is about 10 percent better than that of the "Fujitsu" data. This improvement comes from the wide tuning capabilities of the matching circuits shown in Figure 4-17. These matching circuits are designed to match any device impedance in the range of 0.5 ohm to 2 ohms with any phase angle. It is this wide tuning capability that provides better overall gain and efficiency for the whole power amplifier.

Because the Mobile Communications Satellite has stringent intermodulation specifications (-26 dBc for N-tone), the power amplifier usually will not operate at the saturated output power level. In fact, it is designed to operate at 4.2 dB below (backed-off from) the saturated output power level to obtain better linearity.

Using Figure 4-19 as an example (which is the RCA curve shown in Figure 4-18), the saturated output power (P_{sat}) is 65 watts. The efficiency curve shown here is the power-added efficiency η_{pa} which is defined by

$$\eta_{pa} = \frac{P_{out} - P_{in}}{P_{DC}} \tag{4}$$

where P_{out} is the amplifier output power, P_{in} is the input power to the amplifier, and P_{DC} is the dc input power from the EPC.

Point A is the designed 4.2-dB back-off operating point at full traffic of the transponder. Point A' indicates that the power-stage amplifier efficiency (η_{pa}) is still as high as 42 percent. Point B is the 7-dB back-off point where the efficiency is 30 percent, and Point C is the 8-dB back-off point where the efficiency is only 28 percent.

In the case when the transponder traffic is light (few channels), the operating power level may be 10 dB below the saturation power output. Consequently, the efficiency may drop to only 21 percent. However, the transistor is biased Class AB, which means the dc input power is proportional to the input drive. At 10 dB below saturation, the required dc power to the amplifier also drops to 25 watts from its peak of 100 watts. Therefore, the efficiency is no longer as significant a factor as for the full traffic, high-power output level.

Since the Class AB biased silicon bipolar transistor amplifier can achieve both good efficiency and linearity, it is an ideal candidate for a solid-state power amplifier for Mobile Satellite communications applications.

4.1.2.2.7 Ku-Band Solid State Power Amplifier with a Preamplifier

The SSPA of the 1990's will provide peak power outputs between 20 watts and >100 watts depending upon the number of power GaAs FET devices combined in the last stage. The performance of 1985 technology, internally matched 7.2-mm and 10.6-mm GaAs FET chips in devices of 3 watts and 4 watts output power, respectively, will be enhanced by advances in control of the semiconductor expitaxial growth and geometry of the device architecture. Current power added efficiencies of 30% and 35% for the 4-watt and 3-watt devices will be improved well into the 40% range for devices manufactured to combine two FET chips inside single internally matched devices, providing a power output capability above 38 dBm per device for use in SSPA designs of the early 1990's.

Demonstration of low loss power combining for 16 GaAs FET devices using an integrated waveguide and microstrip transition structure has been made using 3-watt devices in the 11.7-GHz to 12.2-GHz band. Therefore, efficient and manufacturable SSPA designs are driven by the GaAs FET device technology.

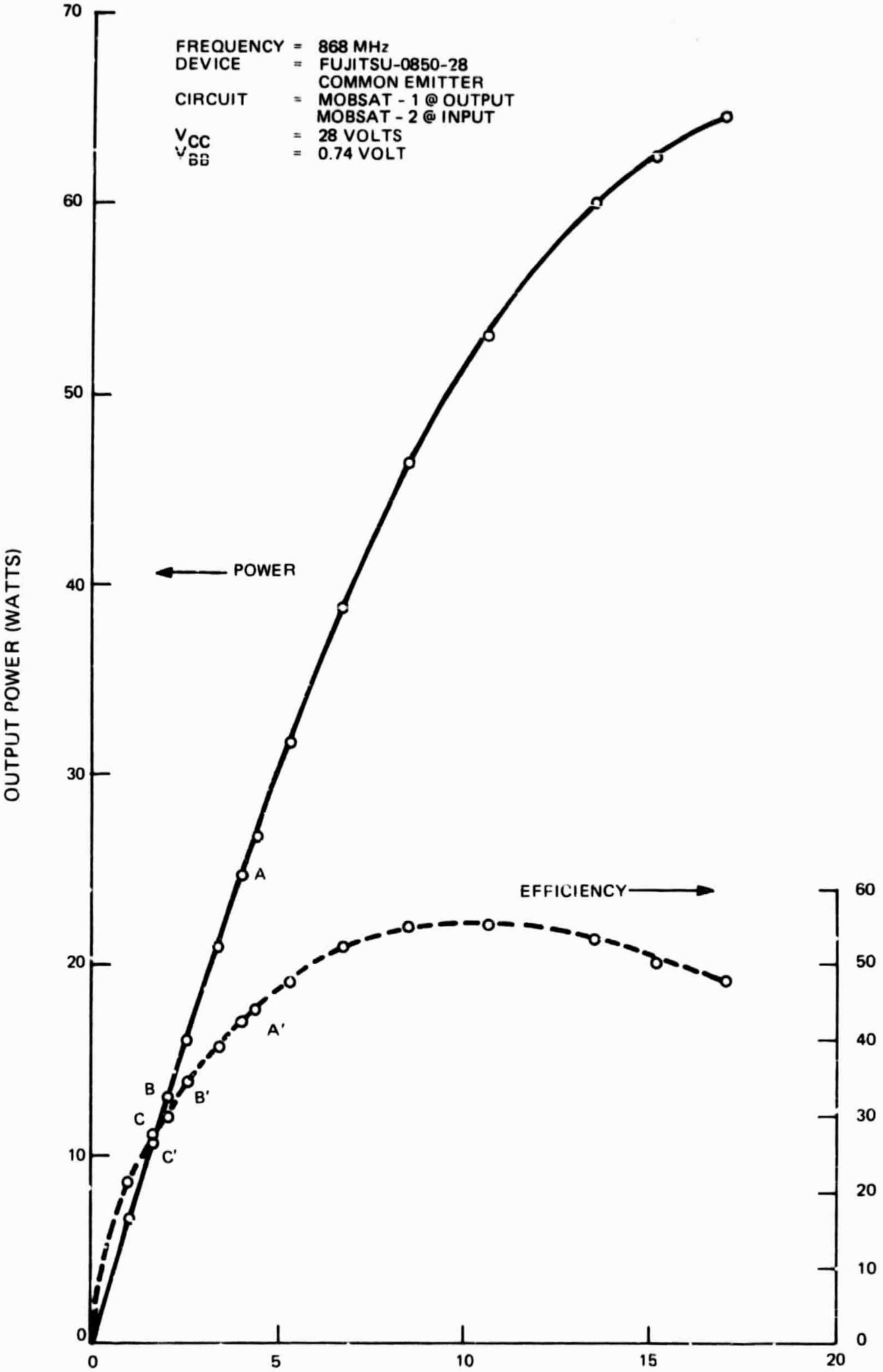


Figure 4-19. Performance of the FJ-0850 Amplifier at Various Back-Off Points

The SSPA block diagram shown in Figure 4-20 has exceeded the 35-watt power output level with greater than 24% dc-to-RF efficiency at Ku-Band. Power levels from 20 watts to >100 watts will be achieved using such a configuration, or a subset thereof, with devices having a power output between 6 and 7 watts and a gain of at least 6 dB. Typically, the overall gain for the SSPA is in the range of 55 dB to 65 dB. The configuration of a Mobile Satellite transponder will supplement the gain of the SSPA with a preamplifier of suitable design. Such a preamplifier will be designed using linear high gain device stages and probably will be electrically identical to the first two or three stages of the SSPA. For the purpose of efficient manufacture, the preamplifier will be packaged separately from the SSPA.

The SSPA of the 1990's will have a modular design. Devices will be assembled and tested in power stage modules. The power output level required of the SSPA will determine the number of such modules to be combined. The block diagram of Figure 4-20 shows a configuration that achieves the 100-watt level using four 25-watt modules in a balanced design. Packaged weight of this design approach will not exceed 3.2 pounds at the 100-watt output level and will be typically 2 to 2.5 pounds for intermediate power output levels of 20 to 50 watts.

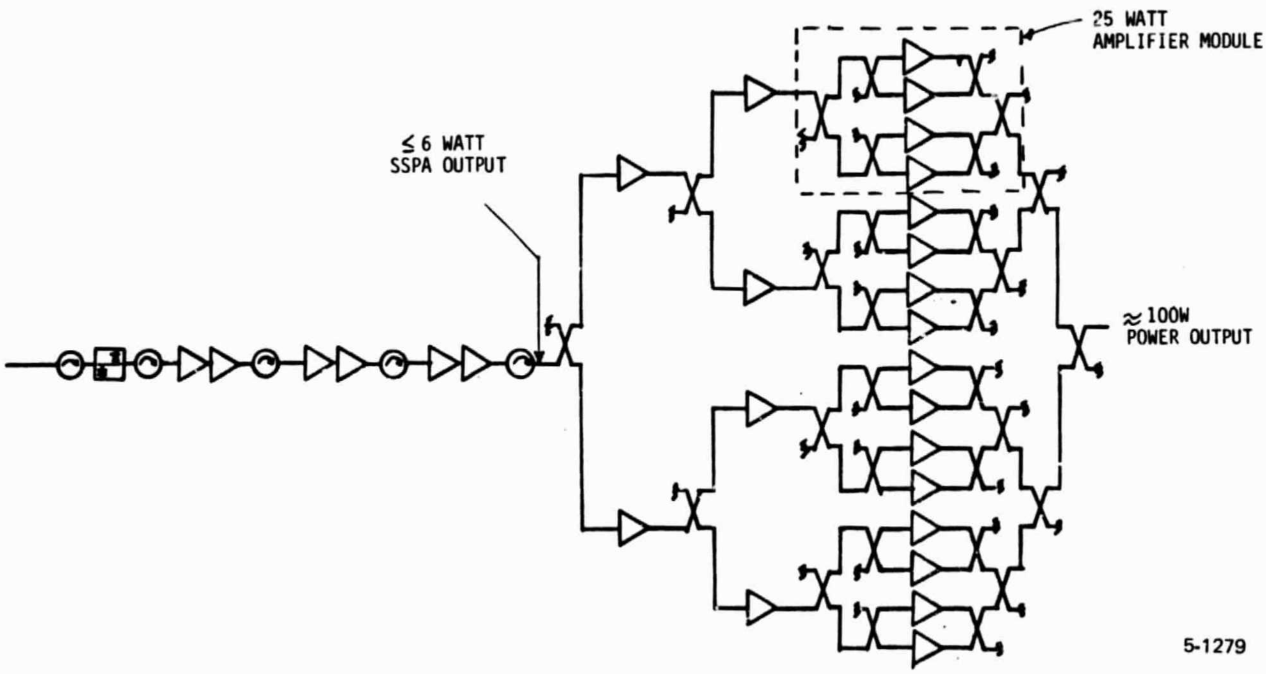


Figure 4-20. Mobile Satellite Ku-Band SSPA Using 6-Watt Devices (1990's Technology)

The major specifications to be met for the six candidate transponder and antenna configurations are given in Table 4-8. The high linearity of the GaAs FET at Ku-Band with associated large bandwidth makes the solid-state design approach highly attractive. The relatively narrowband requirement for Mobile Satellite channels provides a tradeoff which permits the design of a more efficient and higher linearity SSPA. The technique of automated load-pull varies the output impedance presented to a device under full drive, while plotting contours of impedance for maximum power output, efficiency, and linearity.

TABLE 4-8. MAJOR SPECIFICATIONS FOR Ku-BAND PREAMPLIFIER AND HPA (SSPA)

Parameter	Units	UHF/Ku-Band			L-Band/Ku-Band		
		20 m	15 m	10 m	15 m	10 m	5 m
Input Frequency	GHz	11.65	11.65	11.65	11.65	11.65	11.65
Input Level to Preamp	dBW	-97	-97	-97	-97	-97	-97
Gains - Preamp + HPA	dB	72	72	72	72	72	72
Max. IM Power in Any One 5-kHz Channel with All Channels Active	dBc	-26	-26	-26	-26	-26	-26
RF Bandwidth	MHz	50	25	16.3	102.2	50	16.3
SSPA RF Output Power/ Channel	watts	0.003	0.003	0.003	0.003	0.003	0.003
Total SSPA RF Output Power							
• Bandwidth Limited Case	watts	20.5	10.3	6.8	42	20.5	6.8
SSPA Peak (Instantaneous) RF Power Output Based on 4-dB Peak/ Average Capability to Meet -26 dB IM							
• Bandwidth Limited Case	watts	51	26	17	105	51	17
Out-of-Band Frequencies; Maximum Levels to Avoid Interference with Reception							
• 13.2 GHz	dBW/ 5-kHz Chan.	-120	-120	-120	-120	-120	-120
• 821-851 MHz		-100	-100	-100	NA	NA	NA
• 1650-1660 MHz		NA	NA	NA	-100	-100	-100

With this technique, it is possible to sacrifice wideband coverage for improvement in one or more of the plotted parameters. There is confidence that the 4-dB peak-to-average power output curve is conservative, and the actual design of these SSPA's will realize higher efficiency with the degree of linearity required to support the intended traffic.

Ku-Band SSPA's will incorporate high performance, internally matched GaAs FET devices above the 6-watt level by the early 1990's. Greater reliability and more linear high power performance are key advantages of SSPA's when compared to TWTA's of equivalent saturated output. The advantage of graceful degradation during long-life service is also a benefit accrued from the parallel combination of up to 16 GaAs FET devices in the SSPA output stage.

4.1.2.2.8 Diplexers

The diplexers described herein are referred to as units A, B, C, and D. Diplexers A and B are Ku-Band diplexers planned for use in either the Ku-Band/UHF-Band candidates (diplexer A) or Ku-Band/L-Band candidates (diplexer B). These diplexers are required to accommodate simultaneous reception from, and transmission to, a common Ku-Band single horn antenna. Diplexers C and D are UHF (C) or L-Band (D) units required to accommodate simultaneous reception from, and transmission to, single radiating elements of a multi-element array UHF antenna (for diplexer C) or L-Band antenna (for diplexer D).

4.1.2.2.8.1 Diplexers A and B. Interfaces for diplexers A and B and the worst case instantaneous peak power (represented by payload candidate KL-1) are shown in Figure 4-21. Preliminary specifications to be met by these diplexers are given in Table 4-9. Transmit power in the 11.65-GHz band must be suppressed by a combination of isolation provided by the Ku-Band diplexer and the Ku-Band receiver input filter. Com Dev Ltd. has indicated that 85 dB isolation can be achieved by the diplexer. This will result in a signal level of -110 dBW per channel at the receiver input and, with a receiver input filter isolation of 40 dB, a noise power of -150 dBW per channel. This should cause no perceptible degradation to reception at 13.2 GHz.

Out-of-band transmissions from the Ku-Band transmitter, in the 13.2-GHz receive band, should be at least 16 dB below the Ku-Band receiver noise power so as not to degrade the receiver noise power by more than 0.1 dB. The noise power (KTBF) at the receiver input will be -162.5 dBW per 5-kHz channel. Thus, noise from the Ku-Band transmitter in the 13.2-GHz band must be as low as -180 dBW per 5-kHz channel. This will be met with specifications of -120 dBW per 5-kHz at the transmitter output and 60 dB diplexer isolation.

Out-of-band transmissions from the Ku-Band transmitter in the bands of 866-896 MHz (UHF band) or 1549-1559 MHz (L-Band) must meet about the same -180 dBW per 5-kHz channel to prevent degradation of the UHF and L-Band noise powers. Thus, the same transmitter power output limitations and diplexer 60-dB isolation value derived for the 13.2-GHz receive band apply here. However, note that WR-75 waveguide would be used for the run from the Ku-Band transmitter to the diplexer. Since this waveguide has a cut-off frequency of 7.8 GHz, frequencies below 7.8 GHz will be suppressed far beyond the 60 dB specified. Additional protection exists, though not needed, because the potential interference from the Ku-Band transmitter in the UHF or L-Bands involves radiation via the Ku-Band horn (very lossy at UHF and L-Band frequencies) and a link propagation loss to the UHF or L-Band antenna.

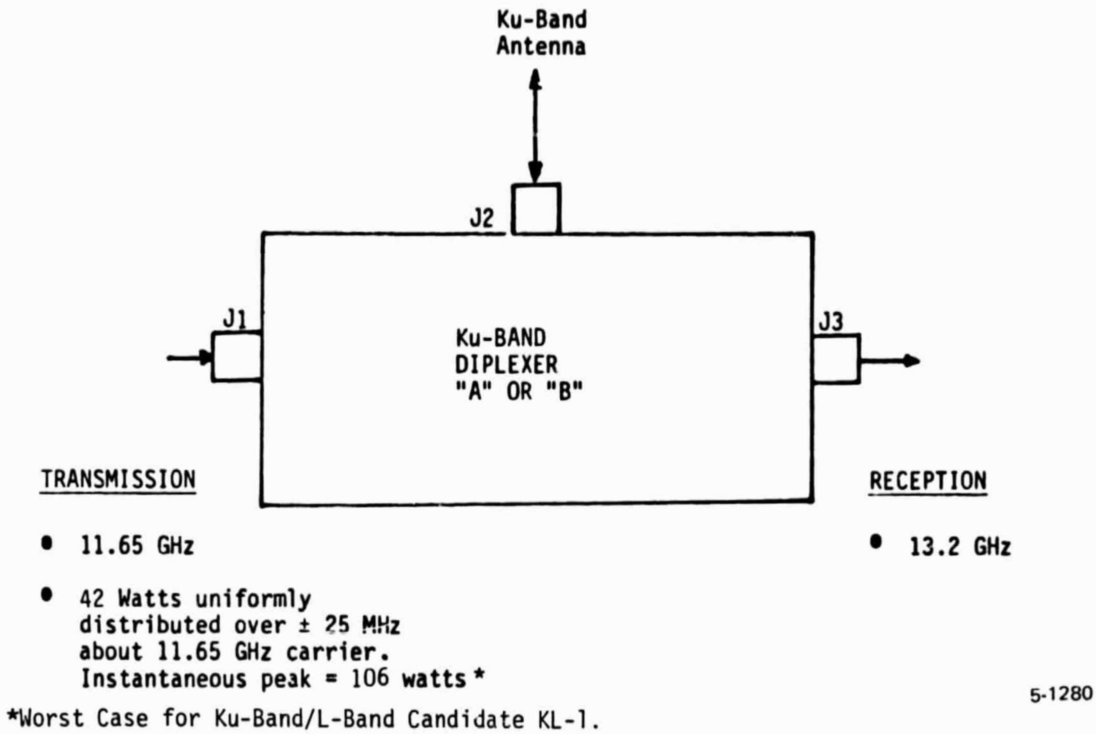


Figure 4-21. Diplexer Interfaces for Diplexers A and B

TABLE 4-9. PRELIMINARY SPECIFICATIONS FOR DIPLEXERS A AND B

MAXIMUM INSERTION LOSS	
Port Paths	Loss (dB)
J1 to J2 for transmission	1.0 dB (goal), 1.3 dB (max.)
J2 to J3 for reception	1.0 dB (goal), 1.3 dB (max.)

ISOLATION					
Ports	Frequency (MHz)	Diplexer Applicability "A"	Diplexer Applicability "B"	Isolation (dB)	J2 Termination
J1 to J3	11,650	x	x	85	50 ohm load
J2 to J3	866-896	x		60	50 ohm source
J2 to J3	1549-1559		x	60	50 ohm source
J1 to J2	821-851	x		60	50 ohm load
J1 to J2	1650-1660		x	60	50 ohm load

Overall construction for the Ku-Band diplexers would be aluminum for light weight. The bandpass filter would be a post type configuration in WR-75 waveguide, and the filter would be a 6-pole Chebyshev. The low-pass filter would employ single mode ridge waveguide for the distributed shunt capacitors and an evanescent mode ridge waveguide for the series inductors. The power handling capability is potentially much greater than that of traditional low-pass filters. The diplexer is similar to the one that Com Dev Ltd. supplied for the RCA Satcom Ku spacecraft. Each diplexer (A or B) will weigh 0.6 pound, and the size would be 7 x 8 x 2 inches.

Com Dev Ltd. has indicated that the insertion loss will meet the 1.0-dB goal for diplexers A and B.

4.1.2.2.8.2 Diplexers C and D. Interfaces for these UHF (C) and L-Band (D) diplexers are shown in Figures 4-22 and 4-23, respectively. The maximum average and peak transmit powers to be accommodated (shown on the figures) relate to the worst case payload configuration candidates KU-3 (for diplexer C) and KL-3 (for diplexer D) and the bandwidth limited levels. Neither multipaction nor generation of passive intermodulation (PIM) products are to occur at these power levels. (The same requirements apply for diplexers A and B.)

Preliminary specifications for insertion loss and isolations for these diplexers are given in Table 4-10. Com Dev Ltd. has indicated that these specifications can be met, including the 1.0-dB goal for insertion loss.

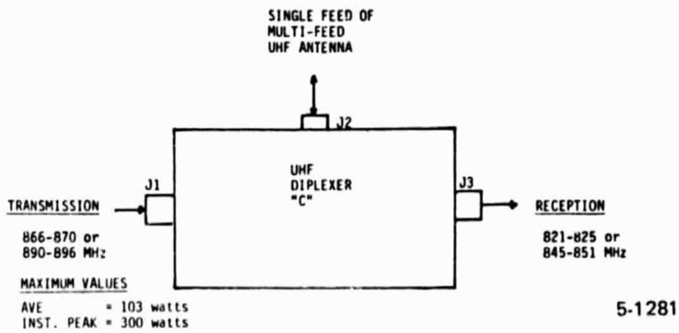


Figure 4-22. UHF Diplexer C Interfaces

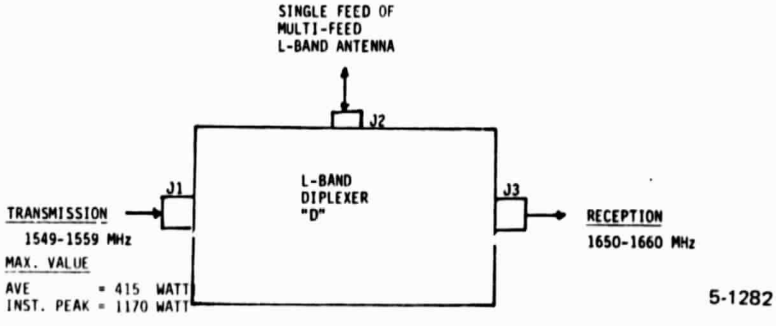


Figure 4-23. L-Band Diplexer D Interfaces

TABLE 4-10. PRELIMINARY SPECIFICATIONS FOR DIPLEXERS C AND D

MAXIMUM INSERTION LOSS	
Port Paths	Loss (dB)
J1 to J2 for transmission	1.0 dB (goal), 1.3 dB (max.)
J2 to J3 for reception	1.0 dB (goal), 1.3 dB (max.)

ISOLATION					
Ports	Frequency (MHz)	Diplexer Applicability		Isolation (dB)	J2 Termination
		"C"	"D"		
J1 to J3	866-896	x		80	50 ohm load
J1 to J3	1549-1559		x	80	50 ohm load
J1 to J3	821-851	x		60	50 ohm load
J1 to J2	13,200	x	x	60	50 ohm load
J2 to J3	11,650	x	x	60	50 ohm source
J1 to J3	1650-1660		x	60	50 ohm load

For diplexer C, transmit power in the bands of 866-870 MHz and 890-896 MHz (grouped as 866-896 MHz) must be suppressed by a combination of diplexer C and UHF receiver input filter isolations in this band. Com Dev Ltd. has indicated that 80 dB isolation can be provided for the diplexer using a 10-pole Chebyshev transmit port bandpass filter. This results in a signal power of -4.5 dBW (0.36 watt) -80 dB = -84.5 dBW per 5-kHz channel at the input to the receiver. Rejection of this band by the receive input filter should be at least 80 dB to provide a noise power of -164.5 dBW per channel at 866-896 MHz to guarantee no degradation to reception in the band of 821 to 851 MHz. This -164.5-dBW level is 18.5 dB lower than the normal -146 dBW per 5-kHz channel signal power in the 821 to 851 MHz receive band. The 80-dB isolation requirement for the receiver can be met with less difficulty than the same 80-dB isolation for the diplexer because filtering will be accomplished separately for each of 24 (KU-1 example candidate payload) receivers, each having a bandpass requirement of only 1.4 MHz for its respective beam (285 channels).

Out-of-band transmissions from the UHF transmitter in the receive band of 821-851 MHz must be suppressed to be at least 16 dB lower than the UHF receive thermal noise power so that the total noise power will not be increased by more than 0.1 dB. Since the thermal noise power is about -162.5 dBW per 5-kHz channel, noise from the transmitter in the 821-851 MHz receive band must be no stronger than -180 dBW per 5-kHz channel. This will be met by specifications of -120 dBW per 5-kHz channel from the UHF transmitter and 60-dB isolation for the diplexer.

Out-of-band transmissions from the UHF transmitter in the 13.2-GHz Ku-Band receiver band must also be at least 16 dB below the -162.5 dBW per 5-kHz channel noise power density so that the total noise power is not increased beyond 0.1 dB. This -180 dBW per 5-kHz channel resultant noise power density requirement is met by imposing specifications of -100 dBW per 5-kHz in the 13.2-GHz band at the UHF transmitter output and 60-dB isolation for diplexer C. Additional 20-dB minimum protection is provided by the link propagation loss between the UHF and Ku-Band antennas.

Isolation considerations for diplexer D are essentially the same as described above for diplexer C, but the L-Bands of 1549-1559 MHz and 1650-1660 MHz apply in this case instead of the UHF bands.

Proposed designs for diplexers C and D are similar to the L-Band diplexer supplied by Com Dev for the Maritime package on the Intelsat V satellites. These designs use quarter-wave coupled reentrant coaxial resonator structures to realize Chebyshev function filters. This configuration yields the best tradeoff between volume and practical unloaded Q's that can be realized in the UHF and L-Band frequencies. This proven design was also used for the L-Band diplexer supplied to European Space Agency and the UHF diplexer supplied to the Canadian Government for potential use on the Canadian Mobile Satellite program.

For diplexer C, 10-pole and 8-pole Chebyshev transfer function responses would be used to realize the transmit J1 port and receive J3 port requirements, respectively. A low-pass filter section would be used at the J2 port to meet the 60-dB isolation required for the 11.65-GHz and 13.2-GHz frequencies. This low-pass filter is required to suppress the Ku-Band signals while accommodating the UHF transmit peak power. To handle this power, the construction will consist of a stepped impedance filter. The outer diameter will be chosen such that the TE_{11} mode will be under cutoff. The stepped impedance section will suppress TEM mode propagation at the Ku-Band frequencies. A teflon sleeve would be used to enhance power handling capability. All interfaces would be met with TNC connectors due to the high power handling requirements.

The complete diplexer C weight would be 4.0 pounds. Its size would be 7 x 37 x 5 inches.

Diplexer D will have a quarter wave reentrant coaxial resonator cavity configuration similar to diplexer C. Specifications for the transmit and receive ports would be achieved using 4-pole Chebyshev transfer functions. A low-pass filter similar to that described for diplexer C would be used to meet the Ku-Band isolation specifications. To handle the high peak power, all potential breakdown points in the coaxial filter and low-pass filter would be insulated with dielectric material.

The complete diplexer D weight would be 2.0 pounds. Its size would be 3 x 15 x 3 inches.

4.1.2.2.9 Transponder Redundancy

A block diagram of the transponder configuration candidate KU-1 is given in Figure 4-7. The redundancy provisions, not shown in Figure 4-7, consist of the following:

Unit	Recommended Reliability (KU-1 Candidate)
• Ku-Band Receiver	3 for 1
• Ku-Band Upconverter	3 for 1
• Ku-Band Preamplifier	3 for 1
• Ku-Band High Power Amplifier	3 for 1
• UHF Transmitters	32 for 24 (4 groups of 8-for-6)
• UHF Receivers	32 for 24 (4 groups of 8-for-6)

The 3-for-1 redundancies apply for all six candidates (three Ku-Band/UHF-Band and three Ku-Band/L-Band), and redundancies for the UHF or L-Band transmitters and receivers were assumed as follows:

	Antenna Aperture (meters)		
Candidate	UHF	L-Band	Redundancy
KU-1	20	-	12 for 8
KU-2	15	-	18 for 12
KU-3	10	-	12 for 8
KL-1	-	15	56 for 49
KL-2	-	10	32 for 24
KL-3	-	5	12 for 8

4.1.2.2.10 Transponder Weight Summaries

A separate transponder configuration was made for each of the antenna apertures, for each frequency band, and for each of the various amounts of payload operation during eclipse. A total of 30 different payload configurations are summarized in tabular form in Section 4.3.1. Included in the table are the quantities of each device type for each antenna aperture as well as the device weight. Note that there are different weights for items such as the power amplifiers as the percentage of eclipse operation varies and as the number of 5-kHz channels varies. This is due to the mass scaling of the power amplifier as total RF output is varied.

4.1.3 COMMUNICATIONS ANTENNA

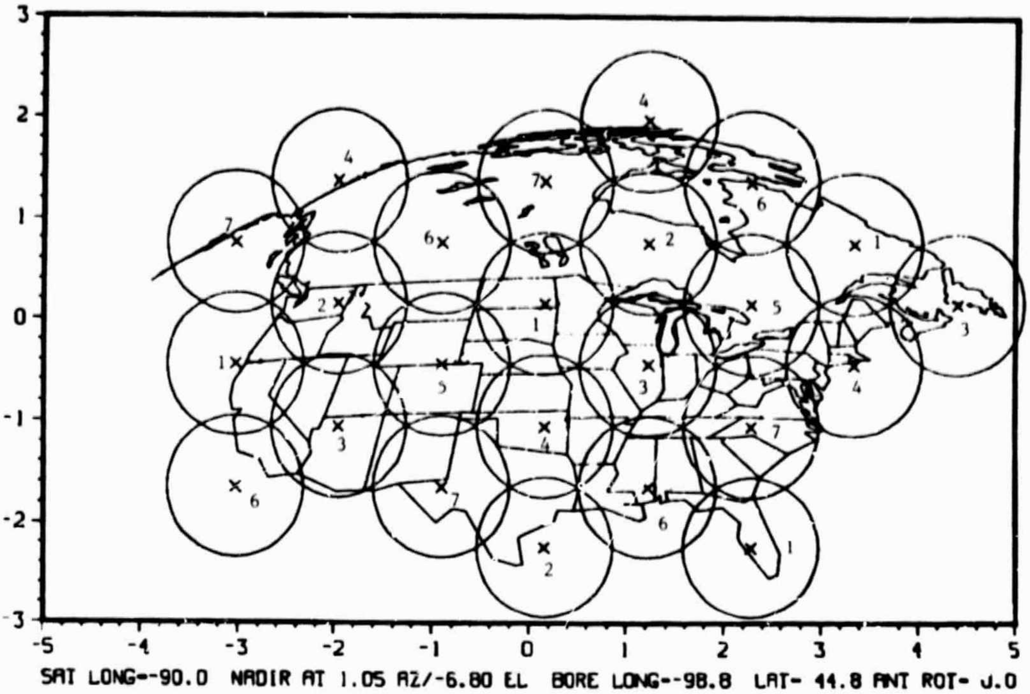
The antenna system selected by RCA for the Mobile Satellite program is a hybrid of two technologies. The antenna reflector, which, because of its size, must be stowed and collapsed during launch and transfer orbit, is an adaptation of the wrap-rib design developed by Lockheed. The antenna feed and beam-forming network will utilize a microstrip based patch antenna.

4.1.3.1 Antenna Reflector

The antenna reflector for the UHF band of operation will be selected from a 20-meter, 15-meter, or 10-meter diameter candidate; the corresponding candidates at L-Band are 15 meters, 10 meters, and 5 meters. The major specifications for the communications antenna are given in Table 4-11. A unity focal length to reflector diameter ratio was selected for all reflectors to reduce gain loss and side lobe deterioration for scanned beams. An offset configuration was chosen to remove possible blockage by the feed array. For an F/D equal to one, the span angle of the reflector is nearly 52 degrees and will remain constant for all of the reflector uses. Consequently, the following discussion is restricted to the 20-meter reflector for the UHF antenna. The same feed antenna can be used for the other UHF-band reflectors and scaled according to the frequency ratio at L-Band. The number of spot beams is reduced depending on the reflector size.

TABLE 4-11. MAJOR SPECIFICATIONS FOR COMMUNICATIONS ANTENNA

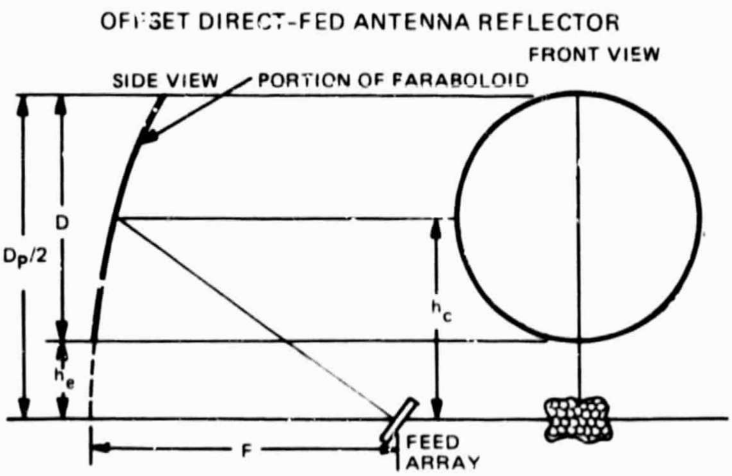
Parameter	Values for Ku-Band/UHF Antenna Diameters of			Values for Ku-Band/L-Band Antenna Diameters of		
	20 m	15 m	10 m	15 m	10 m	5 m
1. Carrier Frequency Ranges						
Ku-Band Uplink (GHz)	13.2	13.2	13.2	13.2	13.2	13.2
Ku-Band Downlink (GHz)	11.65	11.65	11.65	11.65	11.65	11.65
UHF or L-Band Uplink	UHF: 821-825, 845-851 MHz			L-Band: 1650-1660 MHz		
UHF or L-Band Downlink	UHF: 866-870, 890-896 MHz			L-Band: 1549-1559 MHz		
2. Antenna Gains (dB)						
Ku-Band Receive (0.4 m Diameter)	32.3	32.3	32.3	32.3	32.3	32.3
Ku-Band Transmit (0.4 m Diameter)	31.2	31.2	31.2	31.2	31.2	31.2
UHF or L-Band Receive	38.5	36.0	32.5	42.0	38.5	32.5
UHF or L-Band Transmit	41.5	39.0	35.5	45.0	41.5	35.5
3. Number of Spot Beams						
Ku-Band Receive + Transmit	1 Common for Receive/Transmit					
UHF or L-Band Receive + Transmit	24	12	8	49	24	8



FREQUENCY	1	2	3	4	5	6	7
REUSE	4	3	3	4	2	4	4

5-0933

Figure 4-24. Mobile Satellite Beam Coverage of CONUS, Alaska, and Canada Using a 20-Meter Antenna Reflector at 866 MHz



DEFINITION OF PARAMETERS:

- F — FOCAL LENGTH OF THE REFLECTOR
- D — REFLECTOR DIAMETER (DIAMETER OF THE CIRCULAR PROJECTED APERTURE)
- D_p — DIAMETER OF THE GENERATING (PARENT) PARABOLOID
- h_c — OFFSET DISPLACEMENT (HEIGHT) OF THE CENTER OF THE REFLECTOR APERTURE
- h_e — OFFSET DISPLACEMENT (HEIGHT) OF THE LOWER EDGE OF THE REFLECTOR

$D = 20$ m
$F = 20$ m, $F/D = 1$
$h_e = 2$ m
$h_c = 12$ m
$D_p = 44$ m, $F/D_p = 0.45$

5-0934

Figure 4-25. Geometry of 20-Meter Antenna Reflector

The 20-meter UHF Mobile Satellite antenna requires 24 spot beams for coverage of the United States and Canada. The UHF antenna operates in the 866-870 MHz, and 890-896 MHz bands for downlink transmission and in the 821-825 MHz and 845-851 MHz bands for uplink reception. The 24 beams used to give coverage of CONUS, Alaska, and Canada are shown in Figure 4-24 with the satellite in a geosynchronous orbit at 90°W longitude. The seven different frequencies used for the various beams are indicated. Each beam has a 3-dB beamwidth of about 1.1 degrees, and the antenna gain is in excess of 42 dB for all beams. The beam contours are approximately 37.5 dBi, and the crossover beamwidth is about 1.25 degrees, with a gain in excess of 37.5 dB at 866 MHz, corresponding to the lowest downlink channel frequency.

The geometry of the reflector is shown in Figure 4-25. The coverage contours for the boresight beam are shown in Figure 4-26, and the azimuth pattern is shown in Figure 4-27. The first sidelobe is about 20 dB below the main beam, and the antenna gain is 42.9 dBi.

The co-frequency (same frequency) beams, as shown in Figure 4-24, are separated by about 2.6 beamwidths, and the isolation is about 28 dB. The effect of surface irregularities of the reflector deteriorates the co-frequency isolation further. The surface roughness of 1/30th of a wavelength has been estimated to increase this isolation to 20 dB. For a 1/60th of a wavelength roughness, the isolation is estimated to be 25 dB and is used throughout the study. The antenna gain for the scanned beams range from 42.8 to 42.0 dB, and the first side lobes increase to about 18 dB for the furthermost beam. The gain contours and azimuth pattern of such a beam at the eastern edge of the coverage area are shown in Figures 4-28 and 4-29, respectively. The co-frequency isolation at about 2.6 beamwidths away is about 26 dB, and reflector surface roughness will decrease this isolation. The 37.5-dB contours (calculated) of some of the beams in the periphery of the coverage area are illustrated in Figure 4-30.

Improved sidelobe reduction and co-frequency isolation can be achieved by changing the illumination from the feed to the reflector. The maximum gain will be reduced as the edge illumination is decreased. Depending on the final systems criteria, the antenna design can be optimized. The coverage contours for the 15-meter and 10-meter reflectors for the on-focus beams are shown in Figures 4-31 and 4-32, respectively. The eight beams to cover CONUS, Alaska, and Canada for the 10-meter antenna are shown in Figure 4-33. The minimum gain of any of the contours is estimated to be 36.5 dB.

4.1.3.2 Antenna Feeds

The choice of 1.25 degrees for the beam separation restricts the spacing of the primary feed radiators to a square of about 18 inches for the 20-meter antenna reflector. Flat profile printed antennas are especially suited for this application, and the square aperture can accommodate a four-element array, with a primary beam illuminating the 20-meter reflector over a span angle of about 52 degrees. The array factor of the adjacent element spacing (about 0.7 wavelength) essentially determines the attenuation of the primary beam at the edges of the reflector.

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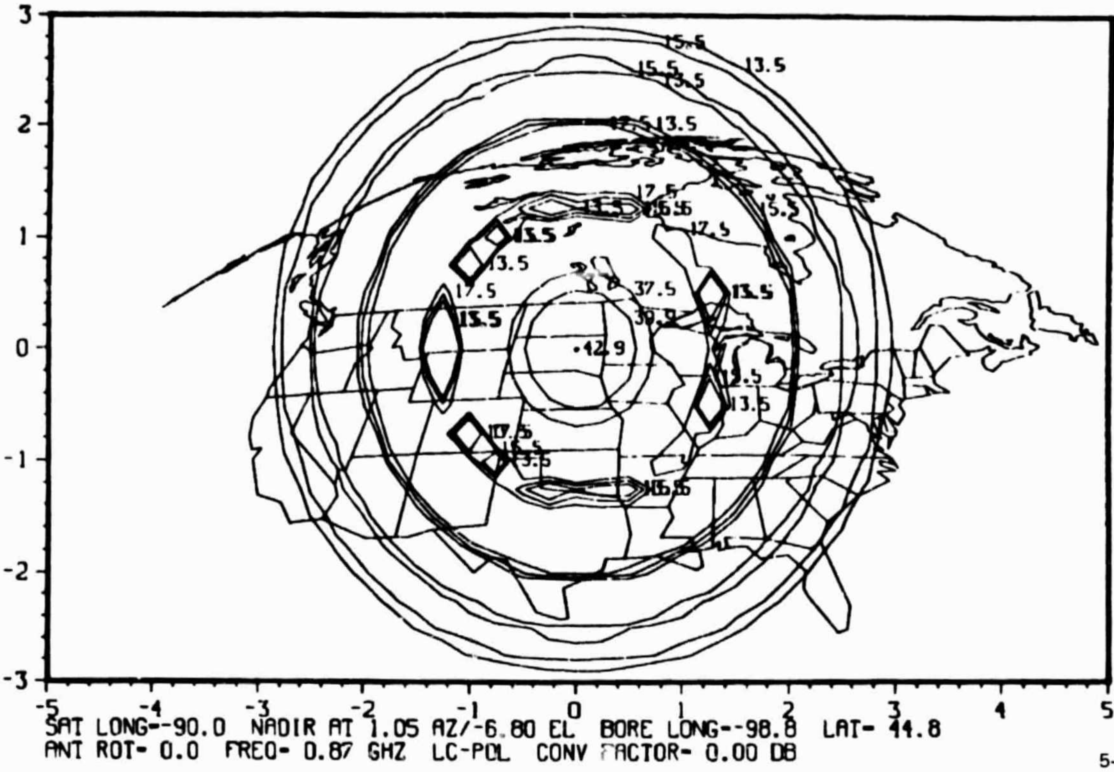

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Figure 4-26. Mobile Satellite Boresight Contours Using a 20-Meter Antenna Reflector at 866 MHz

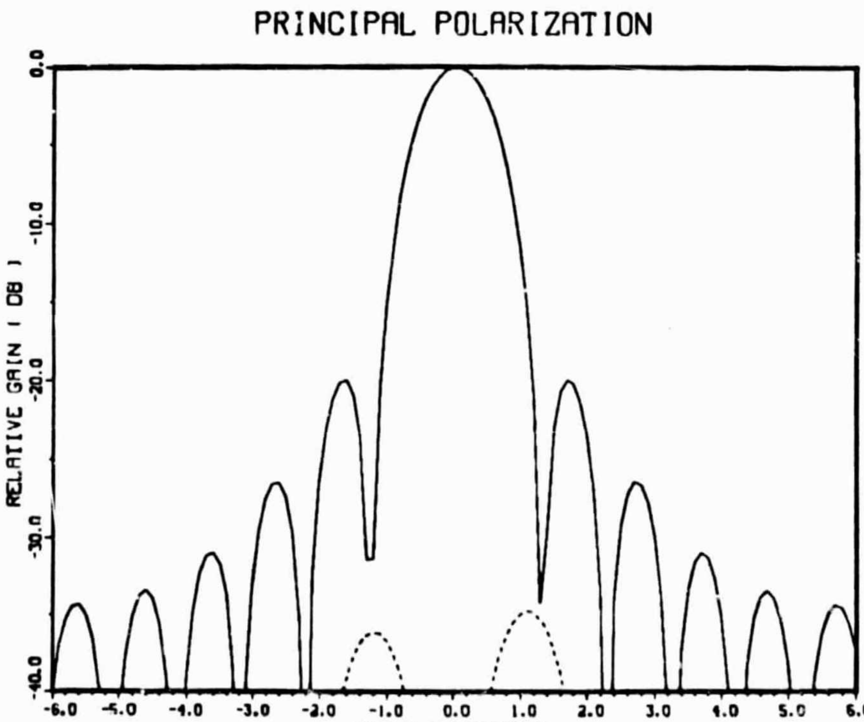

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Figure 4-27. Side-Lobe Contours for a 20-Meter Antenna Reflector

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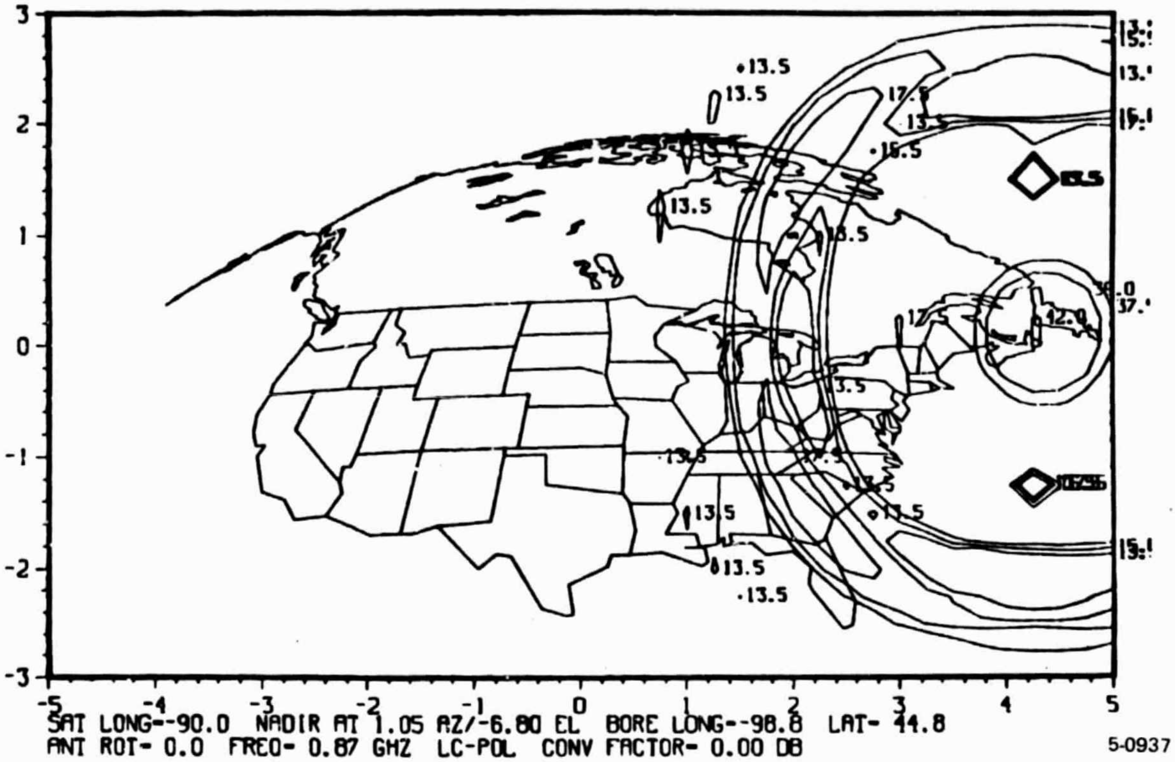

Figure 4-28. Gain Contours of Beam at Eastern Edge of Coverage Area

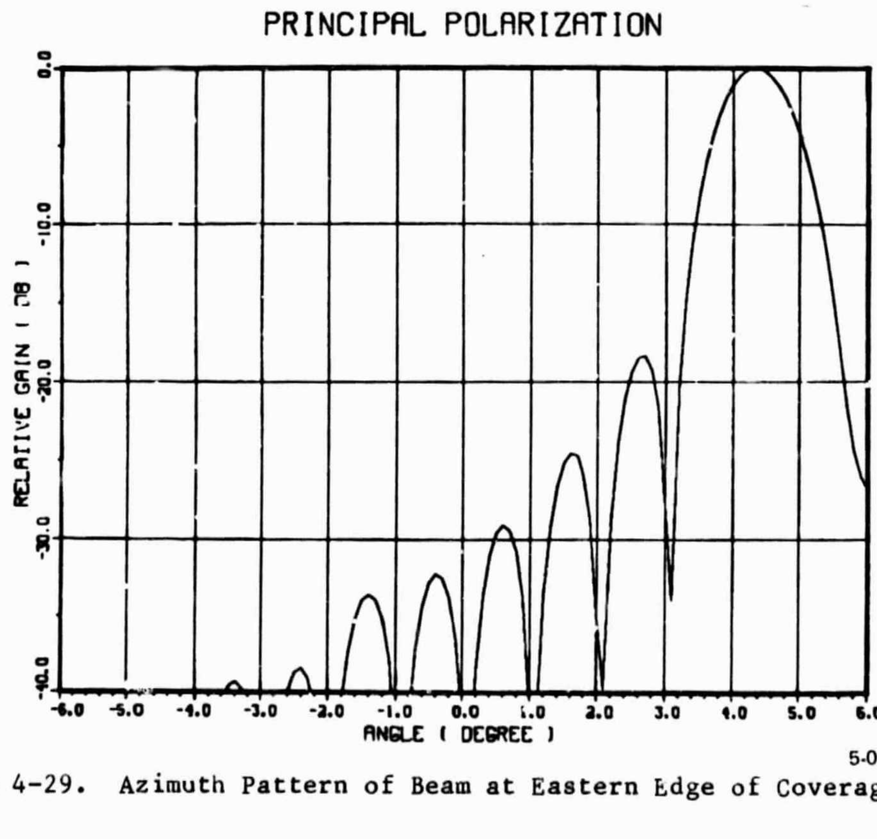

Figure 4-29. Azimuth Pattern of Beam at Eastern Edge of Coverage Area

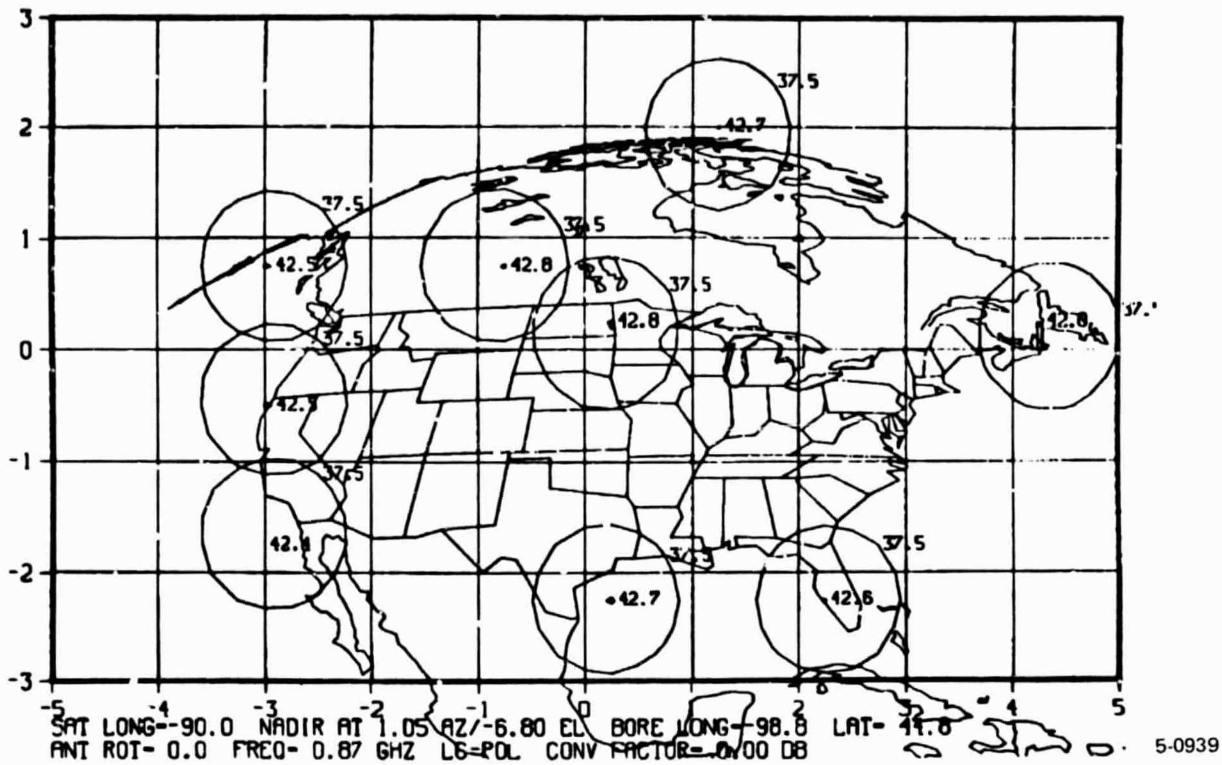

Figure 4-30. 37.5-dB Contours of Beams at Periphery of Coverage Area

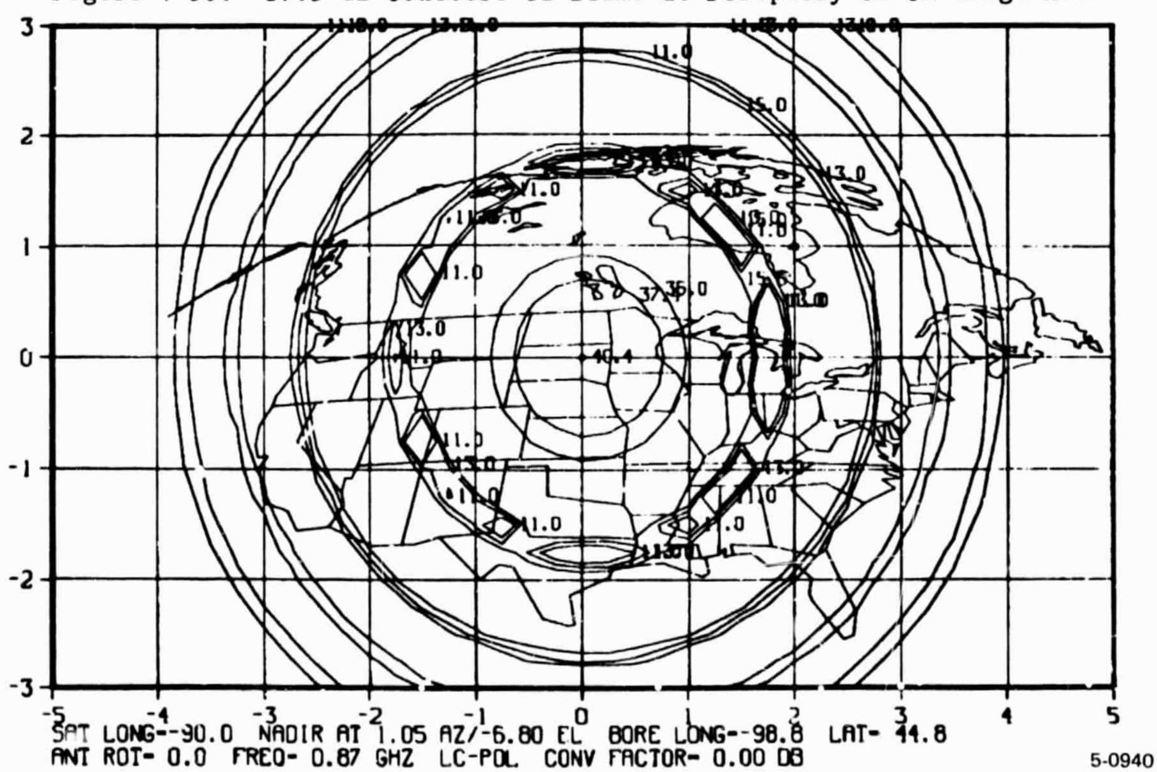

Figure 4-31. Coverage Contours for 15-Meter Antenna Reflector at 866 MHz

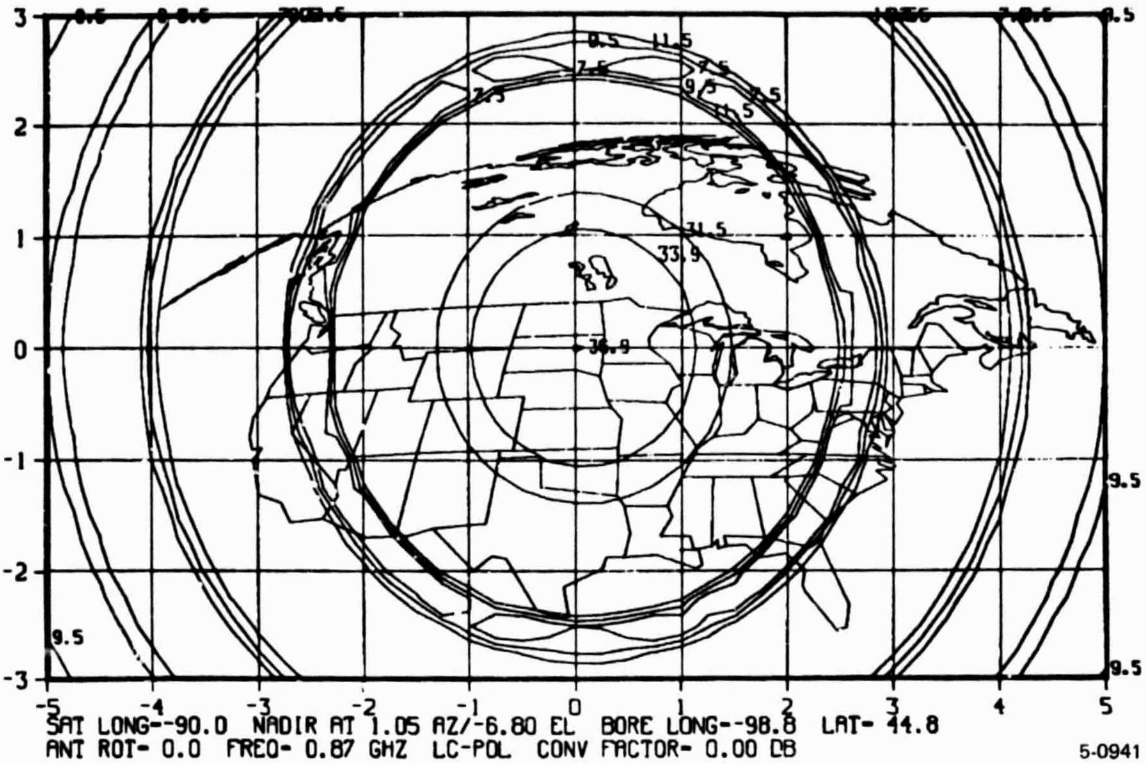

Figure 4-32. Coverage Contours for 10-Meter Antenna Reflector at 866 MHz

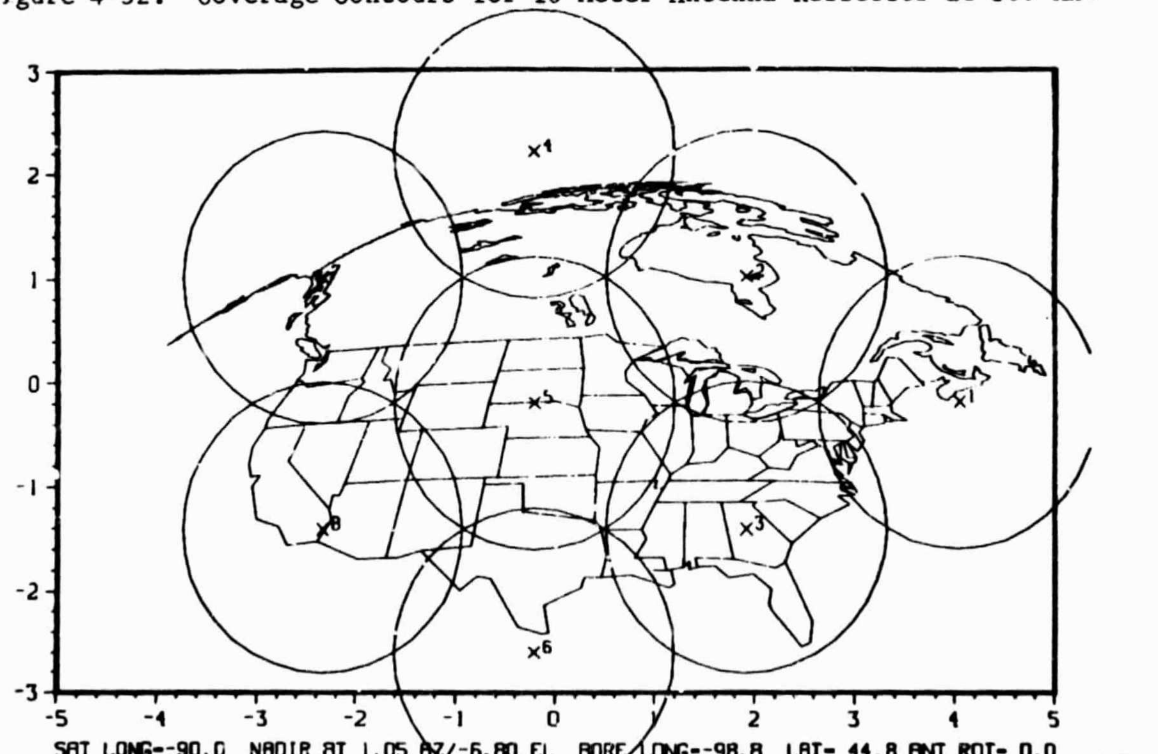

Figure 4-33. Mobile Satellite Beam Coverage of CONUS, Alaska, and Canada Using a 10-Meter Antenna Reflector at 866 MHz

Both the printed dipole antenna and the microstrip patch antenna have a thin profile and can be fabricated as a monolithic array. The printed dipole antenna has a broad bandwidth, in excess of the desired 6% for this application. However, it requires a complicated feed system utilizing baluns, and a pair of crossed dipoles (required for circular polarization) increases the complexity and design of the feedline runs. The microstrip patch antenna recommended by JPL has been selected for this application.

4.1.3.2.1 Microstrip Patch Antenna

The patch antenna has been in use since the 1970's, and its theory and performance has been reported widely. It is rugged, concise, and can be fed by microstrip line which can be etched on the same side as the patch or on the back to reduce interference. The antenna bandwidth can be extended to the 6% specified. The patch antenna can be designed for circular polarization by modifying the feed system.

The patch antenna in its simplest configuration is comprised of a radiating patch, usually square or circular in cross-section, and etched on one side of a dielectric (relative dielectric constant ranging from 1.15 to 3) with a ground plane coating on the other side. The width of the patch is approximately half a wavelength at the operating frequency. For linear polarization, the patch antenna is fed at the center of its side. Matching to a strip line feed is accomplished by making the radiating element slightly rectangular and/or moving the feed point towards the center of the patch. The patch antenna can be considered as a pair of radiating slots located half a wavelength apart at the edges of the patch. For achieving circular polarization, both orthogonal modes are excited in the patch by feeding adjacent sides in phase quadrature, as shown in Figure 4-34. A single probe at a corner simplifies the feed system, but a dual-probe feed reduces cross-polarization characteristics over a somewhat wider band.

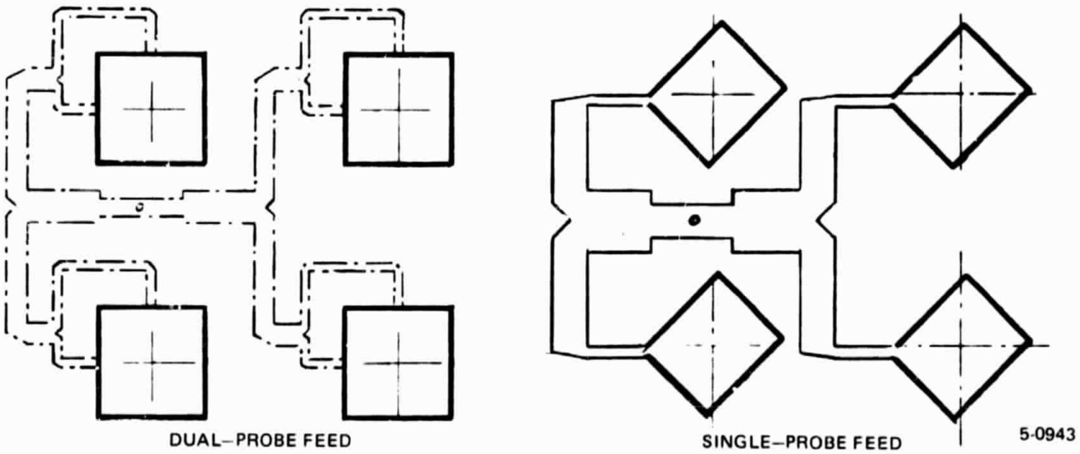

Figure 4-34. Patch Antenna Geometry

The patch antenna usually has a 1-2% bandwidth. Additional improvement in bandwidth is realized in the case of circularly polarized patch antennas. The bandwidth can be further extended to more than 6% by increasing the height of the dielectric between the patch and the ground plane to about 0.06 to 0.08 wavelength. For satellite applications, a honeycomb structure for the dielectric is selected for its light weight. The cell size is about 1/8 of an inch, which is about 1% of the wavelength. Thus, the entire structure appears to be a uniform dielectric surface.

4.1.3.2.2 Four-Element Patch Antenna Array

For this application, four patch antennas described in Section 4.1.3.2.1 are arranged in a monolithic square layer as shown in Figure 4-34. A branch network of microstrip lines feed each of the patch antennas at two points in phase quadrature. The antenna array is fed, in turn, by a quarter-inch coaxial line selected to handle the input power requirement of up to 100 watts per array. Feeding the patches by a single microstrip line from a corner is also shown in the figure. Orientation of the patch antennas with respect to the feed network is critical and minimizes the effects of spurious radiations. Such patch antenna arrays have been developed and successfully tested at the RCA Laboratories for the Ku-Band, and beamwidth in excess of 9% has been realized for a VSWR of 2:1. Axial ratio of better than 3 dB has also been measured over more than 5% of the band. The photograph of such an array is shown in Figure 4-35, and the significant results are shown in Figure 4-36.

Theoretical expressions were used to compute the patterns of a four-patch array. The principal plane patterns and the four-patch array patterns are shown in Figures 4-37 and 4-38 for L-Band and UHF frequencies, respectively. The JPL microstrip patch array design was scaled proportional to the frequency for the size and weight computations of the multiple beam feed.

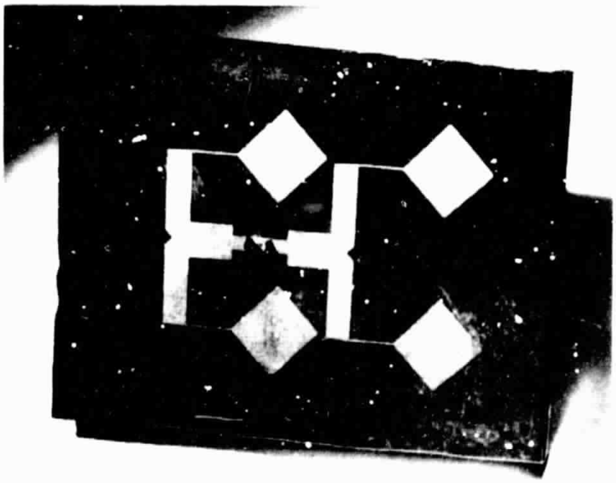

Figure 4-35. Patch Antenna Array

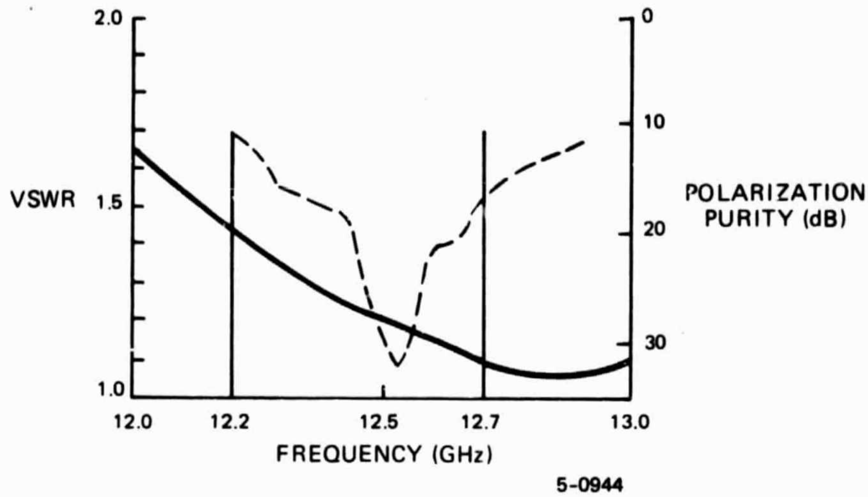

Figure 4-36. Patch Antenna Array Characteristics

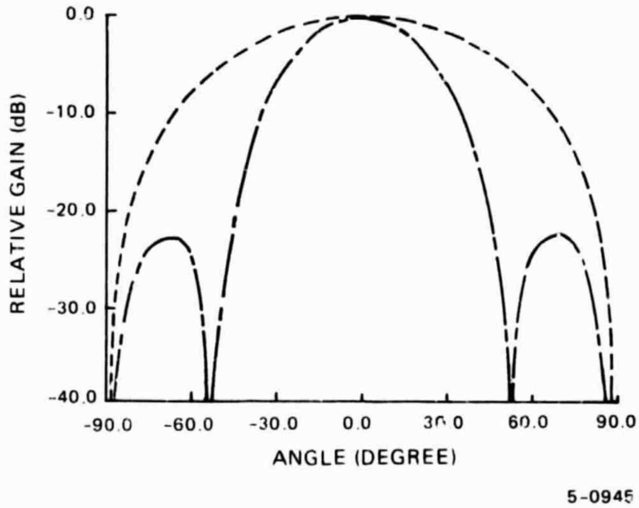

Figure 4-37. L-Band Four-Patch and Principal Plane Patterns

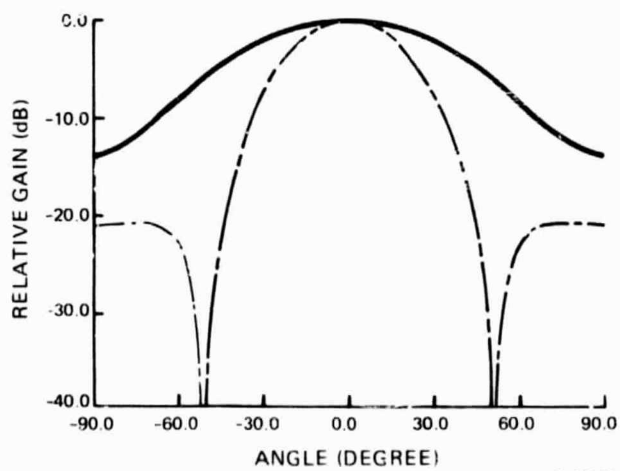

Figure 4-38. UHF Four-Patch and Principal Plane Patterns

4.1.3.2.3 Mechanical Design of Microstrip Antenna

The Mobile Satellite antenna array utilizes materials and construction techniques used on RCA satellites such as the Satcom Ku series. The sandwich construction shown in Figure 4-39 uses a resin bonded honeycomb. This lamination between the radiating substrate and the ground plane uses a low RF loss, high strength epoxy adhesive which has been employed successfully in the dual reflector fabrication of the Satcom Ku spacecraft. The laminated antenna panel is cured under pressure and heat, normally in an autoclave.

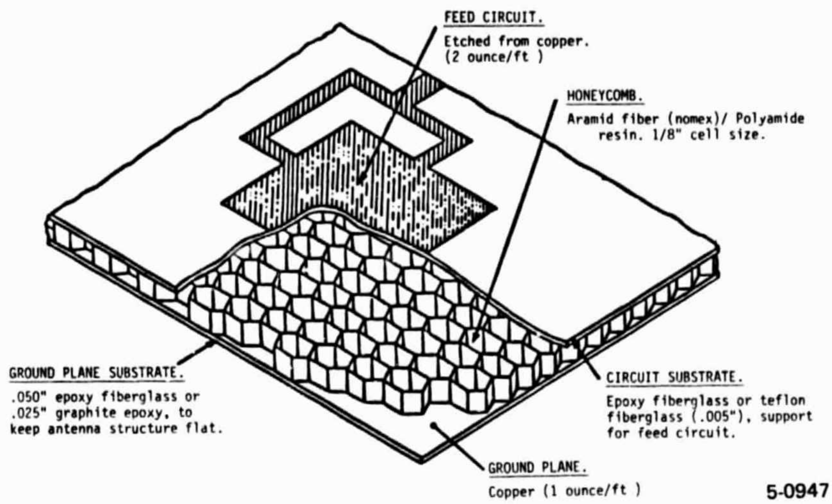

Figure 4-39. Mechanical Construction of Antenna Feed Array

The microstrip patch radiating elements are etched onto a 0.005-inch thick copper-clad teflon/fiberglass (Duroid), or epoxy/fiberglass, substrate. The etching process uses a two-exposure technique to ensure maximum accuracy. The substrate is then drilled for the RF feedthroughs from the connectors mounted on the rear of the ground plane panel. The 1-ounce copper ground plane is laminated onto 0.025-inch thick graphite/epoxy to ensure that the antenna has dimensional stability, is flat, and is ripple free. This thickness may be reduced depending on how such rigidity is added to the antenna panel by the deployment and supporting structures which will be bonded to it. It also will vary depending on the size of the antenna.

RF power to and from the radiating surface is achieved via an RF coaxial cable fed directly through the panel structure from a connector attached to the rear of the ground plane. The center conductor of the cable protrudes through the holes drilled in the radiating surface and is soldered directly onto the etched copper microstrip patch pattern on the front surface. The signal to and from the antenna is transmitted by 0.25-inch coaxial cable, all interface connections being made using standard type connectors.

The configuration and size of the feed array for producing 24 beams is shown in Figure 4-40. The weights of the feed array for different reflector sizes and the two bands of usage (UHF and L) are shown in Table 4-12.

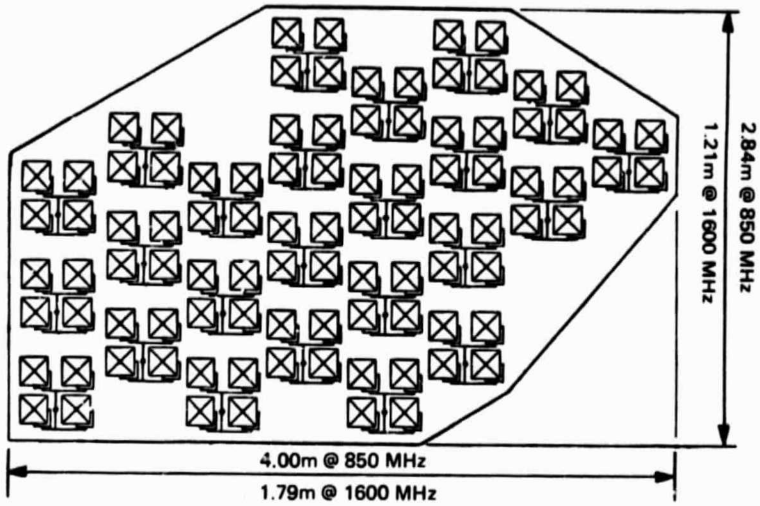

Figure 4-40. Configuration of a 24-Channel Microstrip Antenna Panel

TABLE 4-12. FEED ARRAY WEIGHTS FOR CANDIDATE UHF AND L-BAND REFLECTORS

Frequency (MHz)	Reflector Diameter (meters)	Number of Beams	Size X	Size Y	Antenna Weight (Kg)	Antenna Weight (lbs)	Connector Weight (Kg)	Connector Weight (lbs)	Cable Weight (Kg)	Cable Weight (lbs)	Total Weight (Kg)	Total Weight (lbs)
850	20	24	4.00	2.84	28.3	62.0	0.26	0.58	0.78	1.73	29.3	64.4
850	15	12	2.67	1.42	11.4	25.0	0.13	0.29	0.40	0.87	11.9	26.2
850	10	8	1.81	1.40	8.6	19.0	0.09	0.19	0.26	0.58	9.0	19.8
1600	15	49	3.06	1.67	15.0	32.9	0.54	1.18	1.61	3.53	17.1	37.6
1600	10	24	1.79	1.21	6.3	13.9	0.26	0.58	0.79	1.73	7.4	16.3
1600	5	8	0.95	0.74	2.0	4.53	0.10	0.20	0.26	0.58	2.4	5.3

4.1.4 STRUCTURE

The structure for the Mobile Satellite bus is taken directly from the Satcom Ku-Band spacecraft. It is the most advanced of those recently developed for the RCA Satcom family of communications satellites. Emphasis has been placed on ease of assembly and integration, alignment of components, and system test. Modularity and accessibility are major features. All Satcom spacecraft structures are based on the same form and type of construction, with improvements in size having been made as launch vehicle envelopes were enlarged, and in materials as more desirable properties became available.

4.1.4.1 Functional Description

The principal functions of the structure are to serve as the physical interface between the spacecraft and the launch vehicle, to support all other spacecraft subsystems, to preserve the alignment of critical elements of the spacecraft system, and to facilitate access to internal components. In addition to the

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internal components that are accommodated, the structure supports external units such as the communications antenna, solar arrays, TT&C antennas, thrusters, and earth sensors. The Satcom Ku-Band structure is presented in Figures 4-41 and 4-42.

The North and South body panels are divided into halves separated by cavities in which the Satcom solar array booms are stowed. The Mobile Satellite array booms are Astromasts and are stowed in canisters on the payload support structure. The four North/South panels are designated as equipment panels that support the bulk of the electronic equipment. Their ease of removability permits these panels to be integrated separately with their components so that they can proceed in the production flow simultaneously on a noninterference basis.

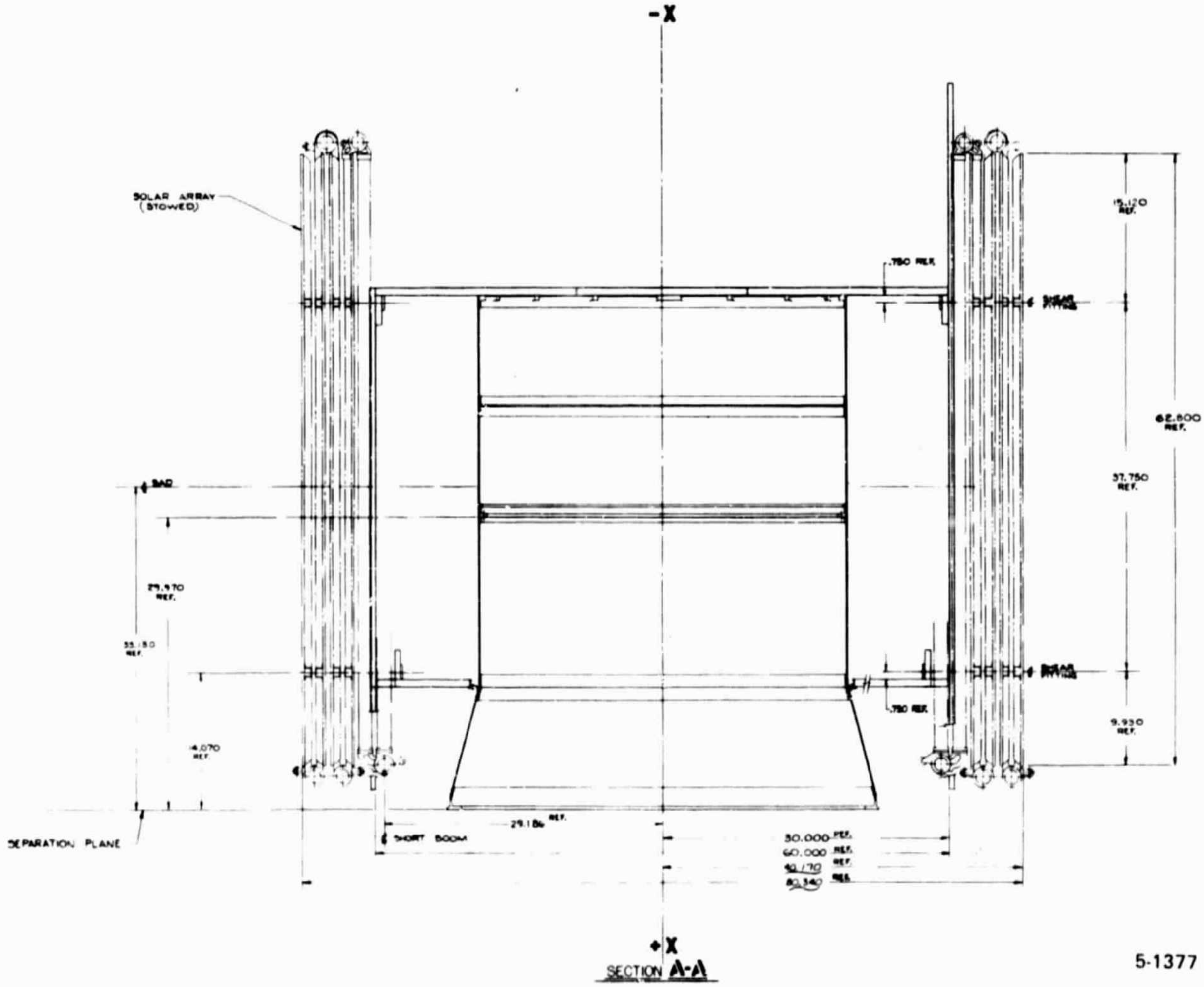

Figure 4-41. Satcom K Structure

The East and West panels are designed as structural shear panels that can be removed readily during all phases of integration and te t. Their removal will not disturb the propulsion tanks or propellant lines that are supported by the tank support structure and center structure assembly. Dowel pins and mating holes are precision machined and reamed in the panel edge members to ensure assembly integrity, alignment accuracy, and repeatability to within 0.01 degree through all integration operations.

The center structure assembly, extending from the forward panel (antenna panel) to the separation plane, is the primary load path of the spacecraft. It is a cylinder that is joined to the side panels by means of bulkheads. At the base panel, the center structure becomes conical and terminates in a separation ring that is the interface with the SCOTS. The center structure assembly directly supports the apogee motor (AKM). It also supports the Propulsion Subsystem components that are brazed into half-systems in a separate fixture and then joined to each other and to the center structure assembly. Struts extend from the cylinder and East/West bulkheads to the tanks to react lateral loads. Tank thrust loads are reacted by shear fittings in the bulkheads. The antenna panel and the base panel complete the box structure and transfer shear loads to the center structure.

Special precautions have been taken to ensure that electrical potential differences will not exist between different parts of the structure. Each component is grounded to the equipment panel skin by means of special inserts which cut and wedge into the panel at each mounting screw. Electrical resistance measurements are made from skin-to-skin in each honeycomb assembly and from panel-to-panel-to-bulkhead in the assembled spacecraft. Measured resistances on the Satcom series spacecraft are less than 0.1 ohm.

4.1.4.2 Center Structure Assembly

The center structure assembly is the primary load path of the spacecraft. It is a stiffened cylinder that is joined to the box panels by radial bulkheads. At the base panel, the center structure becomes conical and terminates in a separation ring that is the interface with the launch vehicle's payload attach fitting (PAF).

The cylinder/cone is a magnesium monocoque assembly. The selection of this design was the result of a tradeoff study that considered thermal requirements, strength, weight, and cost.

Four of the center-structure rings, made from magnesium alloy ZK60AT5, are located to interface with the antenna and base panels, the apogee motor, and tank support struts. The separation ring is aluminum alloy (7075-T73) because of the high loads at the launch vehicle interface. This temper is not susceptible to stress corrosion.

Six bulkheads are assembled into the center-structure assembly. On the North and South sides, two parallel bulkheads are riveted into the center cylinder to form a support for the solar array drives and to provide a flange that supports the inner edges of the two North and two South panels. The East and West bulkheads are conventional aluminum honeycomb sandwich, because their significantly greater depth demands a light weight method of achieving skin stability.

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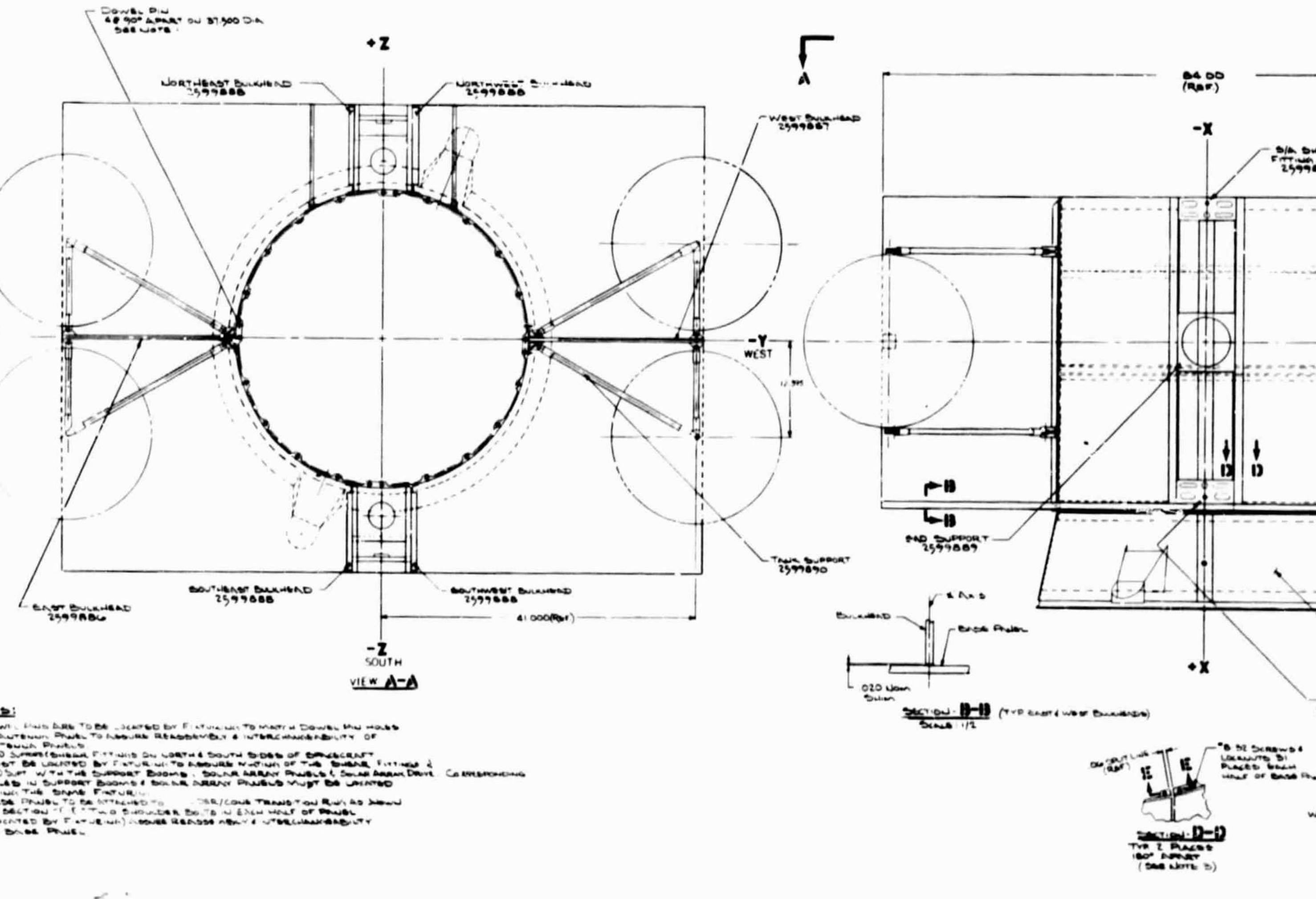

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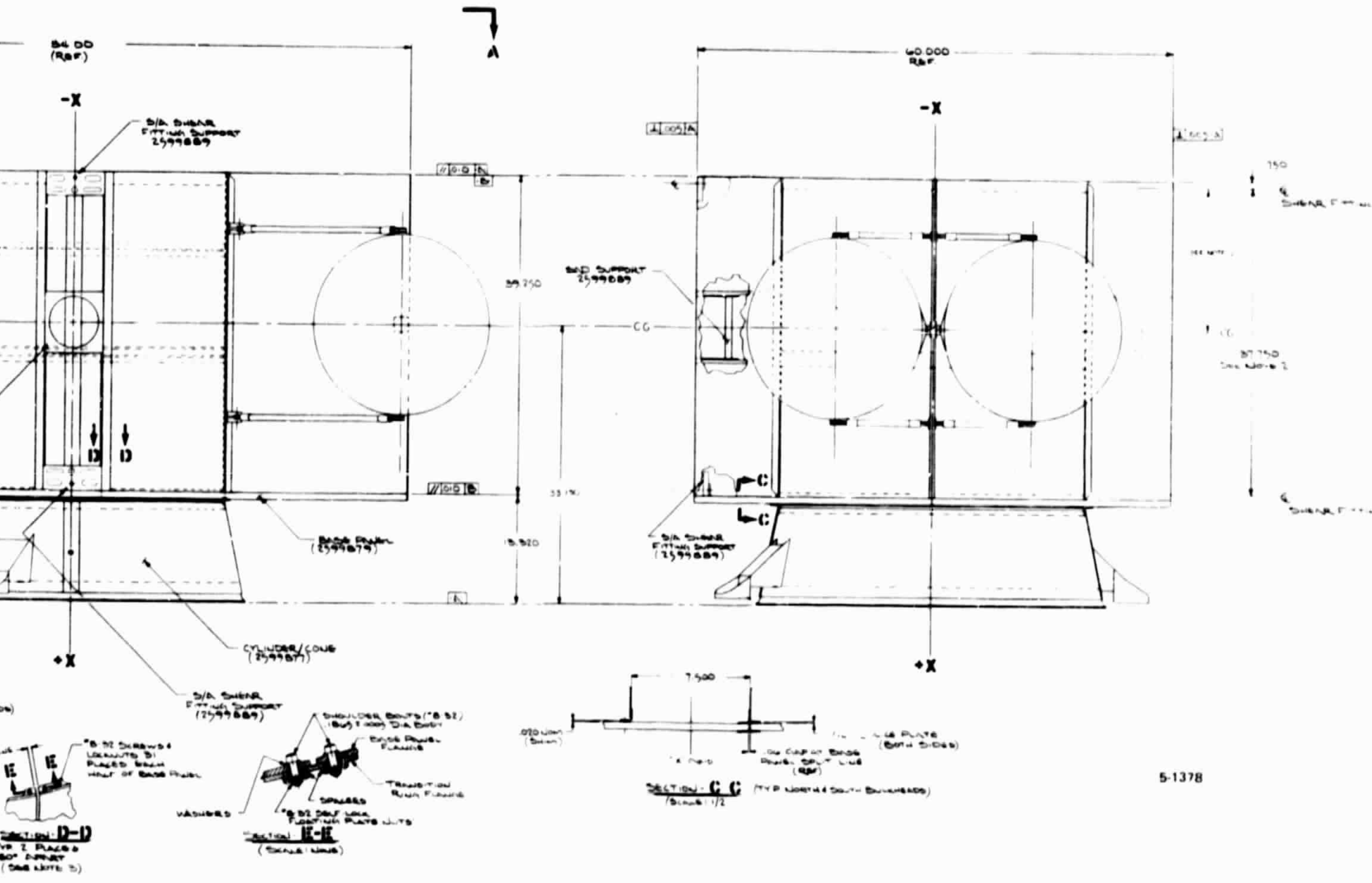

Figure 4-42. Satcom K Structural Core Interface

Thrust loads from the box structure are transmitted to the cylinder by the six bulkheads and then through the conical section to the launch vehicle's PAF. Apogee motor loads are transferred through the motor mounting ring to the cylinder and then through the cone to the PAF. Lateral loads are distributed to the cylinder by the antenna and base panels and carried in shear through the cone to the PAF.

4.1.4.3 Panel Construction

The six sides of the spacecraft and the five nonradiating sides of the transponder feed assembly are made of aluminum honeycomb panels. The four North and South equipment panels are of the same design, but each has certain special features. For example, the North panels contain holes that permit optical sighting of alignment mirrors on the two momentum wheel assemblies (MWA's). All equipment panels aid in spreading the heat dissipated by their individual components.

The higher local heat loads in the transponder areas of the transponder feed assembly are distributed by a system of heat pipes bonded into the honeycomb assembly. The uniformity of heat distribution is further enhanced by thicker panel skins. In the Mobile Satellite, no heat pipes are required in the main spacecraft body because the transponder is located in the transponder/feed compartment.

The upper and lower corners of the box support adjustable snubber fittings to react the forces from the solar array. Reinforcements for these solar-panel-induced loads are provided in the North and South panels by skin doublers. The base panel and the antenna panel are overlapped by the four side panels and receive additional support from the center-structure cylinder and bulkheads. They serve as shear panels in the box structure, and as normal supports for the equipment panels.

The East and West panels serve the two principal functions of shear panels in the spacecraft box structure and of in-plane support for the propellant-tank support trusses. The panels and tank support structure were designed to satisfy these functions and to allow the panels to be removed for access during integration without disturbing the tanks. As in the North and South panels, local skin doublers are bonded into the panels where the solar panel edges are supported.

4.1.4.4 Tank Support Structure

Two planar two-element trusses transmit all Y and Z loads to the cylinder, bulkhead, and East/West panel. The X loads are reacted by the bulkhead, and the resulting moments are reacted by the same trusses. A self-aligning bearing at the bulkhead support eliminates fixity and simplifies the installation. The structure is designed to permit removal of the East or West panel for access without disturbing the tanks.

4.1.4.5 Thermal Radiators

The volume of the transponder/feed compartment is determined by the area required by the feed elements on one surface and by the thermal radiator area required on the North and South sides to maintain the transponder components at the desired temperature. Heat rejection from any but the North and South surfaces is impractical typical transponder temperatures because all other surfaces will at some time experience normal incidence of sunlight and, in a geosynchronous orbit with body stabilization, close to a steady state thermal environment exists.

Radiator heat rejection capability as a function of transponder interface temperature is presented in Figure 4-43. Parameters upon which the curve is derived are based upon RCA's experience and practice with similar requirements. The absorptivity (α = 0.25) represents a value for optical surface reflectors which have been degraded to end-of-life values. The emissivity value is that of second surface mirrors with allowance for a temperature drop through the equipment panel. The angle of the sun from the radiator surface (θ = 25°) includes the maximum sun angle at solstice plus an allowance for offsetting the spacecraft about the roll axis. The radiator efficiency of 90% is typical for radiators employing heat spreading with heat pipes.

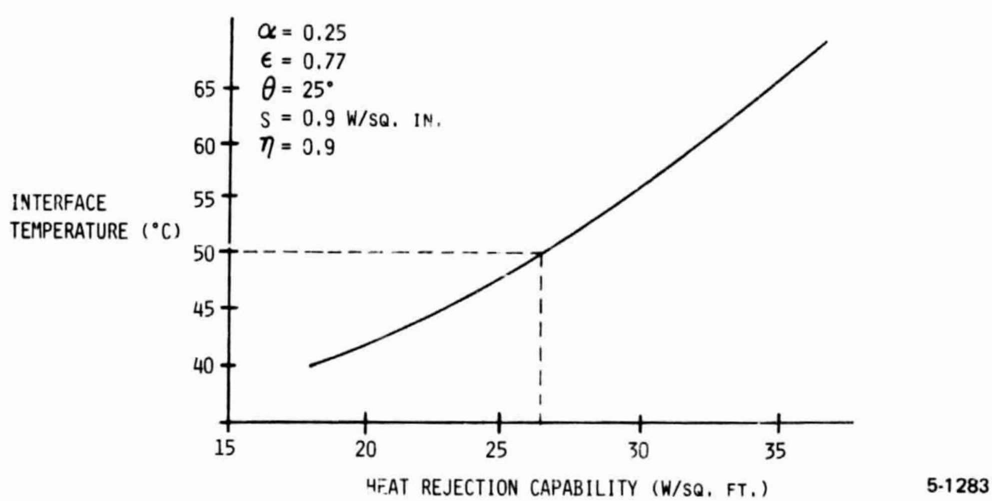

Figure 4-43. Transponder Thermal Radiator Performance

Figure 4-43 shows that, to operate the interface of the transponder at 50°C, the radiator can reject 26.4 watts per square foot; i.e., 5.45 square inches of radiator area are required for each watt to be rejected.

This relationship has been used in the design of the North and South panels of the compartment. Their combined areas for the reference design are 114 square feet. Rigid panels of such a size would demand a volume which is unacceptable, particularly in the launch mode. A more reasonable volume can be achieved if the thermal radiator panels are divided into fixed areas and hinged deployable areas. This concept is illustrated in Figure 4-44. The figure on the left shows the compact arrangement during launch. The fixed and deployable panels are thermally independent; i.e., each is sized for the heat load its components must reject. Similarly, each panel has a separate, self-contained arrangement of heat pipes to efficiently spread the heat over its radiator area. Thus, there is no need for heat pipe continuity across hinges. Sufficient redundancy exists in the heat pipe complement to ensure satisfactory performance, even with the failure of any heat pipe in a given panel. This same design concept has been implemented in RCA's STC/DBS and Satcom Ku-Band satellites. The cross-section through a heat pipe used in RCA's Satcom Ku-Band satellite is shown in Figure 4-45, and the assembly of the heat pipes prior to their being assembled into the honeycomb assemblies of spacecraft transponder panels is illustrated in Figure 4-46.

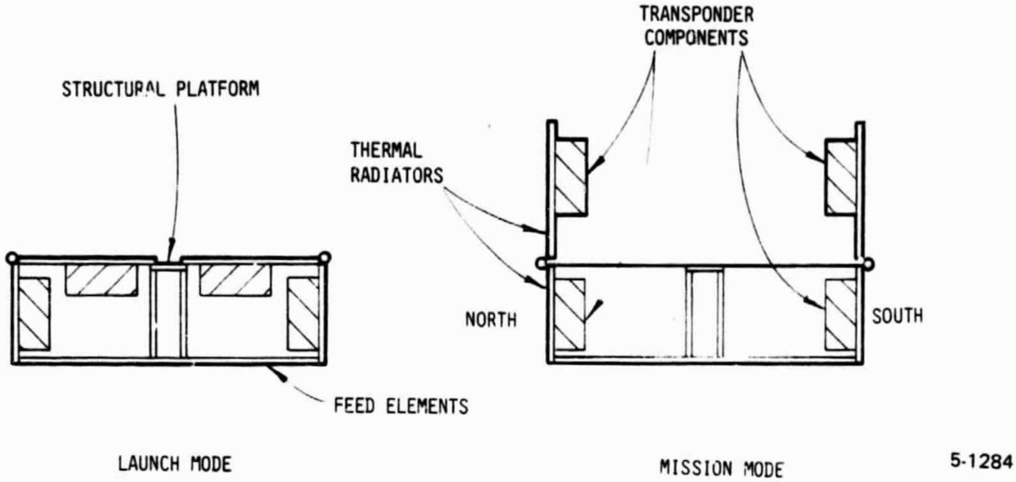

Figure 4-44. Transponder Thermal Control

- 3500 WATT-INCH IDEAL CAPABILITY.
- LESS IN REAL CASE WITH DISTRIBUTED HEAT SOURCES AND SINKS.

5-1285

Figure 4-45. Satcom Ku-Band Heat Pipe Cross-Section

4.1.5 COMMAND, RANGING, AND TELEMETRY

The Command, Ranging, and Telemetry (CR&T) Subsystem provides the capability to command each spacecraft individually from the ground, to measure accurately the distance of each spacecraft from the ground station, to collect spacecraft status/health data, and to transmit these data to the ground for analysis. The system will operate in Ku-Band for both ascent and on-orbit operations. CR&T facilities will be located in Guam and New Jersey for global coverage during the launch and ascent period.

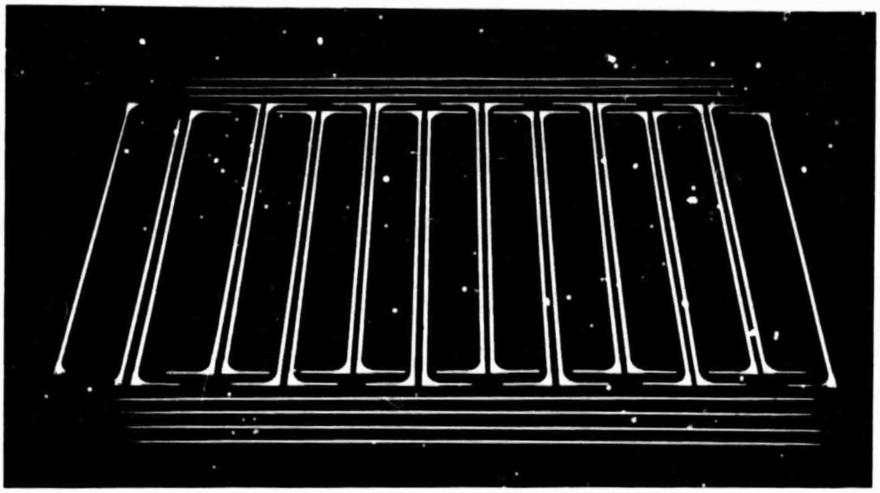

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Figure 4-46. Heat Pipe Elements

4.1.5.1 Command

A single frequency will be used to command all spacecraft. The command system will be fully redundant and will use an omnidirectional antenna during ascent, drift orbit, and in the event of loss of earth lock. During the mission mode, the Ku-Band directional antenna will be used to improve link margins. The antenna outputs will be combined passively to eliminate switching.

Ranging will be accomplished by using the command receiver and the telemetry transmitter as a transponder, returning the ranging signal received from the ground via the telemetry transmitter. The system will be calibrated so that the round trip propagation time of the signal will provide an accurate measure of the distance between the satellite and the ground station.

The command system provides reliable control of transfer orbit maneuvers, attitude operating modes, and orbital velocity of the satellite. Each spacecraft will have its own address, permitting commands to be addressed uniquely to a particular spacecraft even if more than one happens to be in the antenna beam at the time commands are being transmitted.

The standard FSK, three-tone Satcom command structure is adopted for the spacecraft. Unique command addresses, together with time-shared telemetry transmission, permit control of satellites with a single set of command/telemetry equipment at the ground stations. Security against false commanding is a standard feature of the system. The command tones are decoded and sent back to the ground for verification via beacons before sending an execute tone. Hazardous commands require special precautions at the ground station before transmission. Decode circuitry is powered only during commanding to minimize power and to increase reliability.

4.1.5.2 Telemetry

Like the command system, the telemetry system is fully redundant and employs both omnidirectional and high gain antennas. Unlike the command system, address separation cannot be used to distinguish the telemetry signals from different satellites. While the physical separation of the satellites is sufficient to separate telemetry signals once the satellites are in this mission mode, it may not be sufficient during ascent and drift-orbit operation. Therefore, different frequencies will be used to transmit telemetry from each of the satellites.

The telemetry system will collect and format health and status information from all satellite components. This information will be sufficient to assure proper operation of the satellite, to permit fault diagnosis, and to verify the operating configuration of the redundant components on the spacecraft.

Measurement of slant ranges from the TT&C site to the spacecraft are necessary for precise orbit determination. Multiple range-tone-modulated carriers from the site are received by the command receivers, demodulated, and retransmitted by the beacon transmitter. The beacon transmitter is phase modulated directly with the pulse code modulation (PCM) sampled telemetry signal.

The telemetry system monitors all satellite subsystems and transmits information to determine satellite attitude and subsystem performance. A telemetry commutate mode has all input signals digitized into a PCM biphase-L data stream at 1024 bps which phase modulates the beacon. A telemetry dwell mode with a 220-Hz bandwidth uses frequency modulation of an IRIG Channel 13 subcarrier that phase modulates the beacon with an analog signal, attitude monitor signal, command data verification, or a discrete digital signal.

The redundant telemetry module (RTM) collects data from points throughout the spacecraft and multiplexes it into the format appropriate for the respective mode of operation. All data necessary for controlling the spacecraft from the ground is telemetered. The RTM telemetry input channels provided include available spares. Telemetry transmitters provide RF carriers near 13 GHz for the transmission of telemetry data to earth. The telemetry units are designed for maximum compatibility with the applicable IRIG telemetry standards (Document 106-80).

4.1.6 ATTITUDE CONTROL SUBSYSTEM

The Attitude Control Subsystem selected for the Mobile Satellite is a mass expulsion augmented momentum bias system adapted directly from the RCA communications satellite programs.

A block diagram of the redundant subsystem is shown in Figure 4-47. The attitude processor electronics (APE) is a microprocessor-based controller which interfaces with all of the attitude control components and with the central logic processor (CLP); it is through the CLP that the APE interfaces with magnetic torqrod and thruster control. All of the control algorithms reside in the APE read-only memory (ROM); random access memory (RAM) is utilized for certain selectable gain and constant trimming and thruster pulsewidth firing time control.

On-orbit pitch control is accomplished by means of momentum transfer between the momentum wheel assembly (MWA) and the spacecraft body. The pitch attitude signal furnished by the earth sensor assembly (ESA) is conditioned in the APE and applied to the MWA, where momentum storage and transfer are accomplished to maintain the pitch attitude near zero error.

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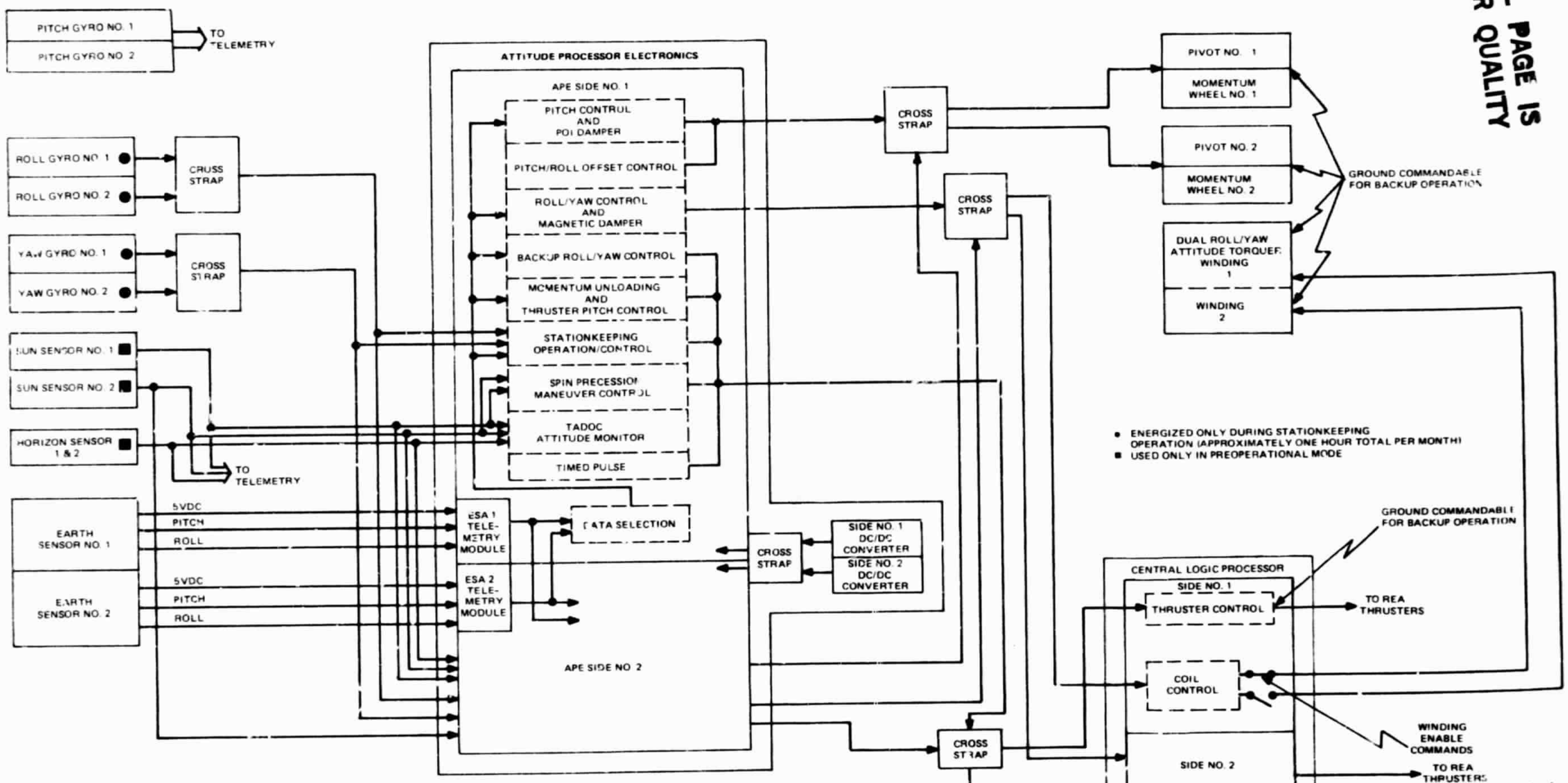

NOTE THIS DIAGRAM DEPICTS ONLY EQUIPMENT, INTERFACES AND THOSE FUNCTIONS OF THE APE WHICH ARE ACTIVE DURING THE TADOC AND OPERATIONAL CONTROL MODES.

Figure 4-47. Attitude Control Subsystem

For those periods where the MWA storage capability could be exceeded, the pitch control is augmented by means of autonomous short duration thruster firings. Provision is contained in the APE to provide a satellite pitch offset based on an uploaded command added to the ESA pitch signal over a range of $\pm 6°$.

On-orbit roll control is accomplished by means of torques generated by a magnetic dipole interacting with the Earth's magnetic field, supplemented by short duration thruster firings as required. The ESA roll attitude signal is filtered in the APE and applied to a double threshold circuit, the lower of which is used to actuate the magnetic torquer, and the higher the thruster control. As in the pitch control loop, roll offset may be accomplished by an upload command to the APE. The roll offset is accomplished by rotation of the MWA spin axis about the roll axis by means of a pivot assembly over a range of $\pm 2.3°$.

On-orbit yaw control is accomplished by means of the gyroscopic rigidity afforded by the MWA. By virtue of the orbital yaw/roll interchange inherent in a momentum bias system, overall roll/yaw correction is afforded by active roll control only.

During East/West stationkeeping, the integral of the rate gyro output will be used for attitude sensing, with thruster pulsing providing the control torques. The East/West velocity increment thrusters will be modulated with pulse widths consistent with the thruster location so as to minimize disturbance torques. The thruster timing and control logic reside in the APE.

Transfer orbit attitude maneuvers will be accomplished by open loop ground control, with the satellite spin stabilized about the AKM thrust axis. The sun sensor and horizon sensor outputs are used to determine the spin axis attitude. The sun sensor output is also used to time phase thruster firings via a commanded and stored time delay for spin axis precession maneuvers.

4.1.6.1 Attitude Control Technique Tradeoffs

The selection of the attitude control technique was driven by two considerations. The first factor concerned the disturbance torques which could develop as a result of both (a) the large spacecraft areas and center-of-pressure to center-of-mass distances which result in high solar torques, and (b) the large separation of the masses which leads to high gravity gradient torques. The second factor concerns the potentially large separation distance between the sensors and control actuators. In the presence of the flexible appendages, this condition presents substantial difficulty in the design of a stable high gain bandwidth control system.

Several spacecraft candidate concepts were evaluated based on minimizing the disturbance torques while still meeting the mission requirements. The six candidates are shown in Figure 3-5, with the sixth selected as the baseline. The selection was based on minimizing solar torque by use of a symmetrical solar array and minimizing gravity gradient torques by configuring the location of the payload and bus to reduce the inertia cross products. The characteristics of the six candidates are listed in Table 3-2.

The configuration selection criteria is common to any selected attitude control system since the intent is to minimize disturbance torques. An analysis was performed to determine the maximum disturbance torques for the selected configuration; the results are shown in Table 4-13. The estimated magnitude of the disturbances is based on a preliminary concept; however, final design values are not expected to change sufficiently to alter the conclusions.

TABLE 4-13. ENVIRONMENTAL TORQUE ESTIMATE

Disturbance Source	Torque (in-lb)	Momentum (in-lb-sec)
Gravity Gradient	4.1x10-4 (secular)	35/day buildup (about pitch axis)
Solar Torque		
Equinox	$\pm$0.033 (cyclic)	$\pm$360 peak-daily (pitch axis)
Solstice	$\pm$0.0038 (cyclic)	$\pm$50 peak-daily (roll/yaw axis)

A mass expulsion system augmentation is required regardless of whether a momentum bias system or a reaction wheel controlled zero momentum system is selected. To maintain reasonable weight, a momentum or reaction wheel implementation (500 in-lb-sec nominal momentum storage capability; e.g., the GSTAR MWA) is a good choice. With this capability, a zero momentum system would not require wheel desaturation by thrusters in the roll/yaw axis, but pitch axis desaturation would be required on a weekly basis.

For a momentum bias system, active thruster roll/yaw control will be required around solstice. The roll control would be straightforward, using the earth sensor. For yaw control, either a sun sensor or calibrated thruster firing sequence will be required. An on-board algorithm residing in the APE could be used to determine torquing requirements for yaw control based on thruster firings for roll control.

Considering the above, either a zero momentum reaction control system or a momentum bias system is satisfactory based on the present spacecraft baseline. The momentum bias system has been selected on a weight, cost, and performance basis because it uses two wheels instead of four, offers simple attitude acquisition, does not require three-axis gyros or derived rate, and may not require sun sensors.

4.1.6.2 Attitude Control Sensor Tradeoffs

The baseline subsystem utilizes an earth sensor assembly for sensing roll and pitch attitude. By definition, the control reference will thereby be at the ESA mounting point. Because of the large structure involved, including the reflector and deployment mechanisms, thermal effects may cause distortion sufficiently large to prevent accurate payload pointing. This effect requires careful attention during the spacecraft design phase and may require that a monopulse pointing or a bias calculation system be considered.

4.1.6.3 Performance Characteristics

Based on analyses and on-orbit performance capabilities of RCA Satcom and Spacenet communication satellites using the same baseline system, pointing accuracies of ±0.1 in roll and pitch and ±0.2 in yaw are attainable for the Mobile Satellite. This capability depends on the thermal/structural effects, deployment alignment accuracies, and calibration capability. As previously stated, the system via the APE has a pitch and roll offset capability both on a constant basis or programmable on a diurnal schedule. This technique of calibrating out known errors based on ground measurement is being incorporated on programs developed at RCA.

4.1.6.4 Subsystem Components

The components and heritage for the baseline momentum bias attitude control system are listed in Table 4-14. All components are flight proven with the exception of the centrifugal switch to be used for the SCOTS/STS launch. This component will be developed from flight-proven components.

4.1.7 ELECTRICAL POWER SUBSYSTEM

The Electrical Power Subsystem provides power to the spacecraft electrical loads for a minimum of 7 years in geosynchronous orbit. The Electrical Power Subsystem consists of north and south planar arrays of silicon solar cells, a secondary battery system, and the electronic circuitry required for the main spacecraft bus voltage control and battery charging.

A single bus voltage of 35 volts is employed for transponder operation, for providing power for spacecraft housekeeping loads, and for charging the spacecraft batteries. A partial shunt regulator maintains the loading on the array.

The spacecraft battery system consists of a number of series connected groups of storage cells charged and discharged in parallel, but with separate control circuits. Nickel-hydrogen storage cells is used due to their lighter weight and higher reliability. Battery sizing is available in 5-ampere-hour increments from 25 to 60 ampere hours. The batteries are sized to support the spacecraft housekeeping and payload loads during the maximum eclipse period at a 60% depth of discharge that will ensure reliable operation over the mission life.

The solar array is oriented by a single-axis, clock-rate system. Power from the rotating array is transferred through slip rings to the main bus. The array is sized to meet the power requirements over the 7-year life of the spacecraft with an appropriate margin. The array uses shallow junction, short-wavelength shifted, high-efficiency, n-on-p solar cells incorporating a back surface reflector.

TABLE -14. ATTITUDE CONTROL SUBSYSTEM COMPONENTS

Unit	Quantity per Spacecraft	Heritage
Earth Sensor Assembly	2	RCA Satcom, Anik-B, GSTAR, Spacenet, STC/DBS
Attitude Processor Electronics	1	GSTAR, Spacenet, STC/DBS, Satcom K (derived from RCA Satcom ALP)
Momentum Wheel Assembly	2	GSTAR, Spacenet, STC/DBS, Satcom K (derived from RCA Satcom)
Pivot Assembly	2	GSTAR, Spacenet, STC/DBS, Satcom K
Rate Measuring Assembly (Redundant)	3	RCA, Satcom, Anik-B, GSTAR, Spacenet, STC/DBS
Roll/Yaw Torquer (Redundant)	1	STC/DBS
Horizon Sensor Assembly (Dual)	1	RCA Satcom, Anik-B, GSTAR, Spacenet, STC/DBS
Sun Sensor Assembly (Redundant)	1	RCA Satcom, Anik-B, GSTAR, Spacenet, STC/DBS
Sensor Detector	2	RCA Satcom, Anik-B, GSTAR, Spacenet, STC/DBS
Electronics	1	
Accelerometer (Centrifugal Switch)	2	SM-T1, Condor, Poseidon Missiles

The cells are protected from radiation by fused silica platelets with anti-reflective coatings. The backs of the cells are protected by the solar array substrate. The panel sizes are fixed, with partial panel populations allowed.

The array drive consists of a brushless dc motor and resolver with gold-on-gold slip ring contacts, finely finished bearings, and special lubrication. The drive has a special bearing/diaphragm system capable of tolerating the thermal expansion rates and temperatures found in the spacecraft.

The power subsystem is fully redundant and contains fault-protection features which automatically respond to malfunctions. The power supply provides for changes in the power system operating modes, connects backup components in the event of a failure, and has override provisions for automatic functions in response to ground commands. Sufficient telemetry is provided to permit a comprehensive evaluation of in-flight performance and to derive complete equipment status.

4.1.8 THERMAL SUBSYSTEM

Thermal control of the payload and support subsystems is accomplished using conventional passive surface finish techniques augmented with heaters. The payload and housekeeping heat loads are dissipated through the North and South panels of the feed assemblies using conventional optical solar reflector radiators. Heat pipes are employed to increase the efficiency of the thermal radiator panels associated with the transponder feed assembly. Multi-layer insulation is provided as required to achieve overall thermal balance and maintain the payload and housekeeping components well within allowable operational temperature extremes. Battery temperatures will be maintained between 0°C and 15°C to ensure long life, and the other equipment will be controlled between 0°C and 45°C as necessary. Ground commandable and automatically actuated heaters augment the passive design where narrow temperature limits are required. These heaters provide low temperature protection for batteries and propellant. The basic thermal control elements and techniques are similar to those employed on RCA Satcom.

4.1.9 PROPULSION SUBSYSTEM

From transfer-orbit injection to stabilization in geosynchronous orbit, the Propulsion Subsystem provides propulsive forces in response to ground commands via the CR&T Subsystem. Timing of propulsive pulses in sequence is performed in the command logic processor of the CR&T Subsystem.

The baseline design is derived from the RCA Series 4000 spacecraft. Standard reaction engine thrusters are employed, fed by manifolds from surface tension tanks. The system is split into two parts, one associated with the main spacecraft body and the other associated with the feed assembly. The fuel budget for these is 2/3 to 1/3, respectively. Both systems are independent, but each is redundant within itself. A total of 22 thrusters are employed, with each thruster backed up by at least one thruster from the redundant side of its system.

4.1.10 AKM ASSEMBLY

The AKM for the Mobile Satellite program will be the Star 37XE, an expanded version developed by Thiokol from the successful Star 37 series of motors. To support the large payload, this unit will be stretched to increase its propellant capacity.

4.1.11 PROPELLANT

The hydrazine requirements for the L-Band and UHF spacecraft are approximately 140 pounds. Of this, 95 pounds are allocated for station acquisition activities. Once on-orbit, the remaining 45 pounds are required for East/West stationkeeping and attitude control.

4.2 BOOSTER CONFIGURATION

4.2.1 SHUTTLE

To place the spacecraft into geosynchronous orbit via the STS, the payload weight-lifting capability requires the use of the RCA design Shuttle Compatible Orbit Transfer Subsystem (SCOTS). SCOTS is specifically designed to place the communications spacecraft into geosynchronous transfer orbit (GTO) from the STS parking orbit. The GTO payload range of the stage is 3000 to 6000 pounds. At the upper weight limit, the total cargo element will typically require less than 30% of the STS Orbiter capability with a near optimum weight/length charge factor. For the Mobile Satellite configuration, the charge factor will be length determined and approach 50%.

4.2.2 SHUTTLE COMPATIBLE ORBIT TRANSFER SYSTEM

The development of SCOTS was initiated by RCA to extend the geostationary transfer orbit capability for Shuttle-launched payloads from the existing limit of about 4,000 pounds to approximately 6,000 pounds. Its first flight is planned for mid-1986.

SCOTS is designed as a spacecraft subsystem that has its power, command, timing, and telemetry functions provided either by the airborne support equipment in the Shuttle or by the spacecraft. The distribution of functions is illustrated in Figure 4-48. The system is further simplified by using the spacecraft Reaction Control Subsystem (RCS) to perform all injection sequence maneuvers.

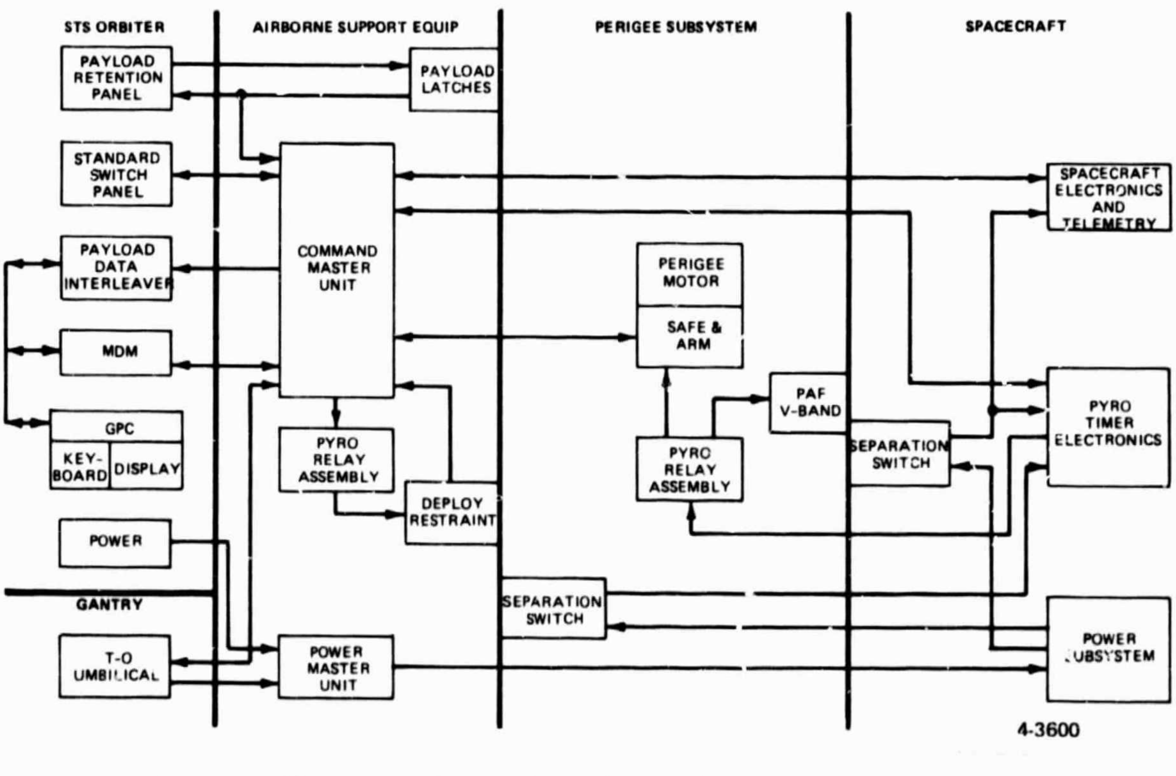

Figure 4-48. Function Allocation and Interfaces for SCOTS

4.2.2.1 SCOTS Configuration

The SCOTS provides the necessary injection velocity for satellite geosynchronous transfer from the low-altitude STS parking orbit as well as the mechanical and electrical interface between the satellite and Orbiter. The major elements of the SCOTS are the airborne support equipment (ASE), the perigee stage (PS), and the ground support equipment (GSE) used to accomplish integration, handling, and checkout testing.

The SCOTS weight is summarized in Table 4-15, and the mechanical configuration is shown in Figure 4-49. The satellite/SCOTS combination is mounted horizontally in the Orbiter bay, with the satellite cantilevered from the payload attach fitting (PAF) by means of a 47-inch diameter marmon-clamp interface. The spacecraft side of the interface is entirely forward of the cradle assembly, permitting use of the Orbiter's full 15-foot diameter for the satellite and its equipment. Spacecraft separation from the spent stage is accomplished by means of four spring on the PAF. The PAF is bolted to the forward skirt on the solid propellant motor and contains two trunnions that make up the forward support points for the three-point payload mount in the cradle assembly. The third support point is provided by a trunnion attached to the aft support assembly (ASA), which is bolted to the aft skirt of the solid motor. The motor selected for the injection maneuver is the Morton Thiokol, Inc. (MTI), 63E, a derivation of the proven 63-inch diameter MTI space motor family. The motor has a Kevlar fiber case, high-percentage-solid polymeric propellant, and a carbon-phenolic exit cone.

TABLE 4-15. SCOTS CARGO ELEMENT WEIGHT SUMMARY

Element	Weight (lb)
Transfer Orbit Payload (Baseline)	5,500
SCOTS Burnout Weight	1,100
PKM Expendables	8,600
Deployed Weight	15,200
Airborne Support Equipment	2,700
Cargo Element	17,900

The ASE consists of the cradle assembly (for the support and deployment of the perigee transfer stage), the avionics equipment that provides the necessary electrical interface to the Shuttle, and the prelaunch ground umbilical. The ASE is designed for multiple flight use without major refurbishment other than the replacement of the retention cable and pyrotechnic devices. Thermal control systems consist of local blanketing of the avionics, with no requirement for active elements, thermal shroud, or sun shields.

4.2.2.2 Deployment Sequence

The SCOTS payload deployment sequence is compatible with standard Orbiter services, minimizes astronaut involvement, and includes an internal payload-ready interlock in the sequence. The sequence of principal events is depicted in Figure 4-50. The basic deployment sequence starts approximately 2 hours

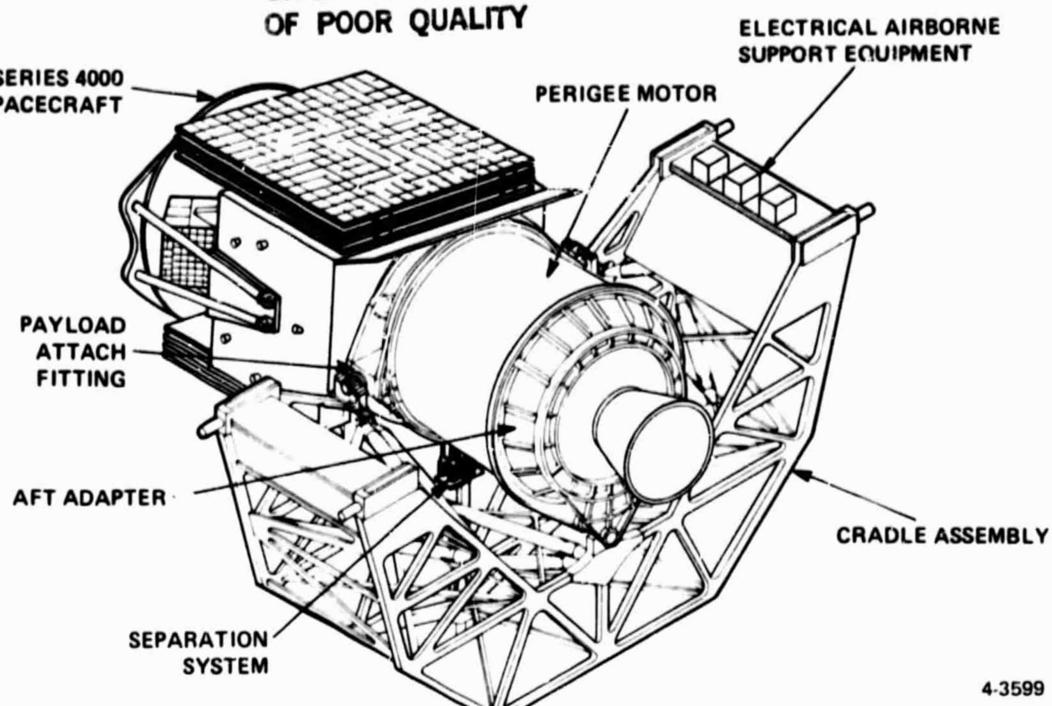

Figure 4-49. Integrated SCOTS/Spacecraft Mechanical Configuration

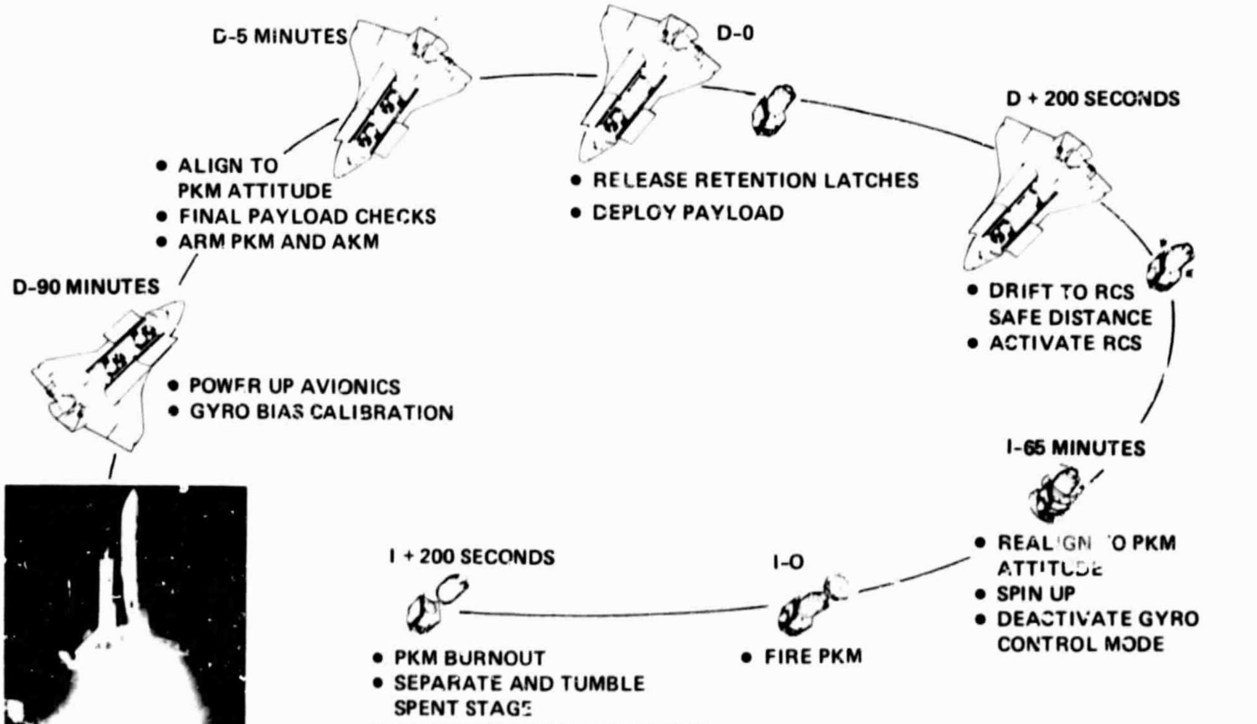

Figure 4-50. SCOTS Launch Sequence

prior to the planned deployment time. The sequence timer is initiated by an astronaut keyboard command to the SCOTS command master unit (CMU). The command sequence initiates power to the spacecraft control elements including the attitude system processor (ASP) and rate measurement assembly (RMA), a three-axis gyro package. Because the spacecraft equipment is used to control all perigee injection maneuvers, they are allowed to reach stable operating environments prior to initiating maneuvers. Approximately 1 hour prior to deployment, a gyro-bias drift test is performed on the RMA over a 30-minute interval. The drift rate is internally self-checked for reasonableness in the ASP and used for gyro calibration for subsequent events. If unsatisfactory results are obtained, the redundant equipment set is commanded on, and the procedure is repeated. Five minutes prior to deployment, the Orbiter is aligned to the PKM firing attitude. This spacecraft attitude reference is used to initialize the RMA output for the eventual PKM firing position. The terminal deployment sequence consists of arming the perigee and apogee solid motors, releasing the payload retention latches, and severing the retention cable, which allows spring ejection of the payload from the Shuttle bay.

The SCOTS is ejected in a free-float mode with no attempt to control the drift attitude. The attitude change from the initialization point is measured by the RMA during the drift period and accumulated in the ASP. When the SCOTS/spacecraft assembly has reached the required 200-foot clearance from the Orbiter, the spacecraft RCS is activated to initiate alignment and to spin up the spacecraft (nominal 35 rpm) for PKM firing. Spin-stabilized attitude control is utilized throughout the remainder of the transfer-orbit sequence. For the nominal SCOTS timeline, PKM ignition occurs 65 minutes after deployment. Active nutation damping using the spacecraft RCS is incorporated as required during all spinning phases. Following PKM burnout, the spent perigee stage is separated from the spacecraft to complete the SCOTS injection sequence.

Typical 3-sigma dispersion for the SCOTS injection into geosynchronous transfer orbit are given in Table 4-16. These errors include the contributions of the STS attitude error associated with the SCOTS deployment.

TABLE 4-16. TYPICAL SCOTS 3-SIGMA ORBIT DISPERSIONS

Parameter	Value
Apogee Altitude	± 500 nmi
Perigee Altitude	± 3.4 nmi
Inclination	± 0.6 deg
Argument of Perigee	± 1.3 deg

4.2.2.3 SCOTS Hardware

The SCOTS flight segment consists of two primary groups of equipment, the airborne support equipment and the expendable perigee stage. The ASE is comprised of those elements that remain in the Orbiter and are returned for reuse on subsequent missions; namely, the cradle assembly, the power master unit (PMU), the command master unit (CMU), and a pyrotechnic relay assembly (PRA).

The perigee stage is an integral subsystem of the spacecraft and contains the payload attach fitting, the solid motor assembly, the aft support assembly, and a PRA identical to that on the ASE.

4.2.2.3.1 Cradle Assembly

The cradle is the load-bearing structure which is the interface between the deployed payload and the Shuttle. It also provides the mounting structure for the CMU and PMU. The cradle is an open truss structure with a 5-point support to the Shuttle bay by means of standard attach fittings. Four trunnions mate to the Orbiter longeron fittings; the two forward points carry fore-and-aft loads and vertical loads, while the aft two carry only vertical loads. The fifth support mates to the Orbiter keel fitting and reacts the lateral loads. The cradle has been designed to support all loads associated with the launch and abort landing of the STS and to provide sufficient stiffness to maintain the cargo-element first-mode frequency above the STS requirement of 6.3 Hz for payloads of this weight class.

The cradle planar truss members are machined as single sections from aluminum plates. The planar sections are bolted together with high strength fasteners. Individual out-of-plane members are tubular struts with pin/clevis end fittings. The five titanium trunnions are secured to the cradle truss with high-strength bolts.

The SCOTS perigee stage is supported on the cradle by three motor-driven latch assemblies that pick up three trunnions on the stage. The retention latches are mounted to the cradle such that the centerline of the deployed stage and spacecraft coincide with the centerline of the Shuttle bay to maximize the spacecraft allowable envelope. The two forward supports react the fore-and-aft and vertical loads, while the aft support reacts vertical and lateral loads. The latches are standard NASA-qualified active payload-retention devices for Shuttle payloads.

Deployment of the stage is accomplished by a set of six springs located on the cradle and pushing against the PAF. The springs are arranged in two rows of three. Separation velocity is a minimum of 1 foot/second. Spring deployment until verification of latch opening is delayed by means of a retention cable with redundant pyrotechnic cutters.

4.2.2.3.2 Electrical ASE

The electrical ASE consists of three units; namely, the CMU, the PMU, and the PRA. These units are fully redundant and are mounted on the top starboard panel of the cradle assembly. Thermal control is provided by multilayer insulation blanketing over the units.

The main function of the PMU is to provide dc power to the spacecraft to charge batteries and maintain the spacecraft in a launch configuration. The PMU receives +28-volt primary power from the Orbiter and boosts it to 35.5 volts for spacecraft operation. As a backup, PMU primary power is also supplied by the GSE through the T-0 umbilical, should Orbiter power not be available.

The CMU provides command and telemetry interface compatibility between the Orbiter and spacecraft. The CMU also interfaces with the GSE via the T-0 umbilical for spacecraft testing and prelaunch checkout. The GSE provides the means to command the spacecraft and receive telemetry when the Orbiter is disabled. Commands are supplied to the CMU from the Orbiter via the standard switch panel (SSP) or the general-purpose computer keyboard via the multiplexer/demultiplexer (MDM). Spacecraft telemetry is conditioned in the CMU and distributed to the Orbiter payload data interleaver (PDI) for distribution to the ground and limited on-board status monitoring. Status telemetry is also sent to the Orbiter SSP and the MDM for display.

The PRA contains a redundant set of relays that are used to fire the redundant retention-cable cutters to effect deployment.

4.2.2.3.3 Solid Propellant Motor

The motor selected for the SCOTS perigee injection maneuver is the Morton Thiokol, Inc. 63E solid motor, an extended capability design of the IPSM-II and PAM-DII motors. The motor characteristics are summarized in Table 4-17, with an outline sketch presented in Figure 4-51. Due to the large thermal mass of the perigee stage and relatively short and benign orbital environment exposure, no active thermal control is required. Passive control is provided by multilayer insulation with a Beta-Sloth outer layer on the solid motor center section and fore-and-aft domes. The 63E motor utilizes the propellant formulation TF-H1202, a high-percentage-solid, hydroxyterminated polybutadiene (HTPB) with an HMX high-energy additive. The grain design is a head-end web to maximize the amount of propellant that can be loaded into the case. The propellant igniter is a wafer design bonded to the propellant surface. Ignition is controlled by a safe-and-arm device that is coupled to the wafer igniter by redundant explosive transfer assembly (ETA) lines. The safe-and-arm unit meets all STS safety requirements.

TABLE 4-17. SCOTS 63E PERIGEE MOTOR, TYPICAL PERFORMANCE CHARACTERISTICS

Parameter	Baseline Characteristics
Total Length	101 inches
Total Weight	9,200 pounds
Propellant Weight	8,400* pounds
Maximum Chamber Pressure	1,040 psia
Maximum Thrust	30,000 lb_f
Action Time	124 seconds
Expansion Ratio, AE/AT	80
Effective Specific Impulse	298 $lb_f\text{-sec}/lb_m$
Payload (ΔV = 8,000 ft/sec)	5,500 lb_m

*Maximum loaded propellant capability is 8,950 pounds.

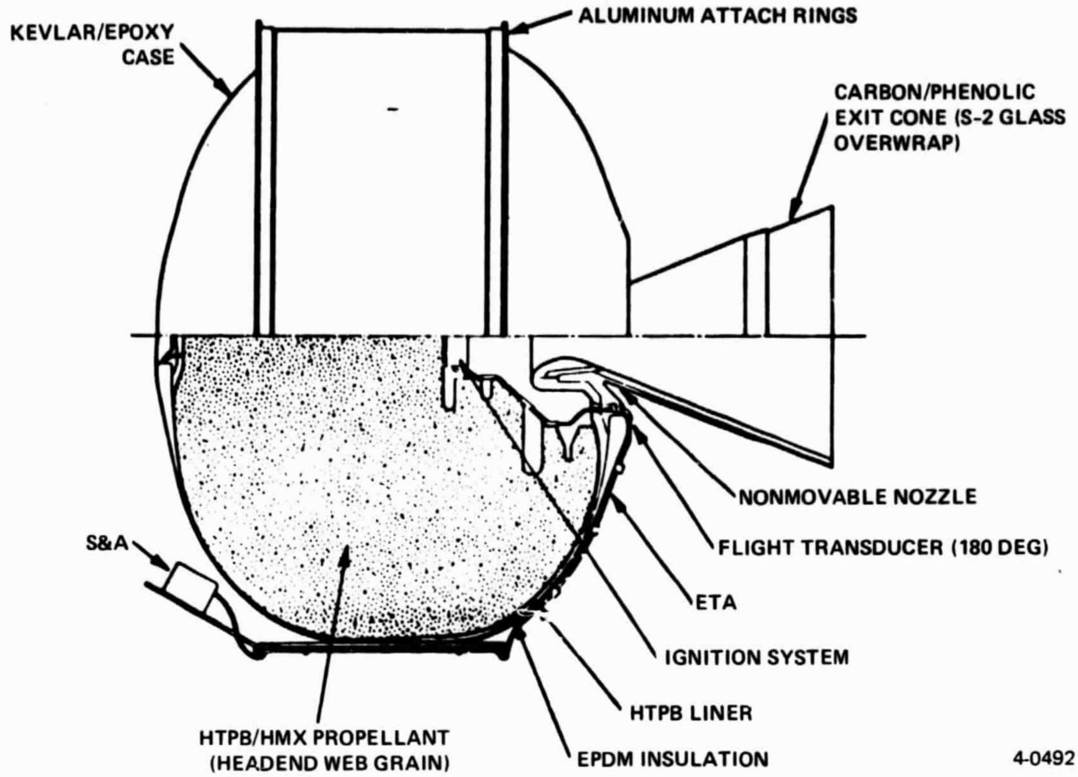

Figure 4-51. SCOTS MTI 63E Solid Rocket Motor

To maximize the propellant loading to the constraint of short length, the case is designed with relatively flat domes. The motor case is fabricated of Kevlar fiber in a low-density, semiflex epoxy-resin matrix. Aluminum polar bosses are used to seal the forward dome and provide the nozzle attachment flange on the aft end. Structural attachment is provided through integrally wound, fore-and-aft glass/epoxy skirts. Aluminum skirt-end attach rings provide a bolted interface with the SCOTS PAF and ASA. The nozzle assembly consists of a 3-D carbon/carbon integral throat and exit and a carbon-phenolic exit cone. The motor design elements are identical to the 63-inch diameter PAM-DII motor with a 9-inch stretched motor case and a longer exit cone.

4.2.2.3.4 Payload Attach Fitting

The payload attach fitting is a conical structure connecting the 63-inch forward mounting ring of the perigee motor (PKM) with the 47-inch aft ring of the spacecraft. The forward ring has a half-vee profile for attaching to the spacecraft with a marmon band. Two separable flight connectors are provided at the interface for spacecraft-to-SCOTS electrical harnessing.

The PAF is of aluminum sheet-metal construction, reinforced with longerons, and secured with high-strength shear fasteners. Machined fittings on the Y-axis support two trunnions that engage retention latches on the cradle. The PAF skin is aluminum-alloy sheet metal, and the forward ring is machined from a forging of aluminum alloy. Separation force between the spent perigee stage and the spacecraft is provided by four springs located on the PAF and pushing against the spacecraft structure. The minimum separation velocity is 3 feet per second.

4.2.2.3.5 Aft Support Assembly

The ASA is a conical structure that attaches to the 63-inch diameter aft ring of the PKM. It is constructed of aluminum forward and aft rings, connected by sheet metal reinforced with longerons, and secured with high-strength shear fasteners. Connected between the forward and aft rings is a trunnion, that, along with trunnions on the PAF, serves as the primary load path between the perigee stage and cradle. Mounted to the ASA are the PRA containing the PKM fire relays, the safe-and-arm device for the PKM, associated ETA lines, and balance weights.

4.2.2.3.6 SCOTS Electrical Equipment

The electrical equipment on the propulsion module is limited to separation switches and a PRA. The separation switches provide interlocks to satisfy STS safety requirements and separation signals for use by the spacecraft to establish the proper transfer-orbit operating mode. The switches are configured in quad redundancy to prevent a single switch failure from enabling the separation function. The PRA contains a set of primary and backup pyrotechnic fire relays for the propulsion-stage solid motor ignition. Both the PRA and separation switches are mounted on the aft support assembly.

4.3 WEIGHT AND POWER SUMMARIES BY SUBSYSTEM

The weight and power budgets for each of the transponder configurations are summarized in this section. All cases are arranged similarly, with a spacecraft weight and power budget by subsystem and a detailed breakdown of the constituents of the transponder, the transponder feed assembly, and the communications antenna compliment. There are two weight summaries, one for UHF and one for L-Band communications. Each of the subsystem weight and power summary tables includes the weight budgets for all spacecraft subsystems as well as power consumption by subsystem for the two cases of spacecraft in direct sunlight and spacecraft in eclipse.

The spacecraft transfer orbit weight was held fixed at 5800 pounds (the performance limit of the RCA SCOTS subsystem) for the cases of minimum, 50%, and 100% payload operations during eclipse. This was done to allow an evaluation of relative channel capacity of the different configurations as antenna aperture and percent payload eclipse operations were varied. The Series 4000 spacecraft payload weight and power tradeoff curves for a 5800-pound GTO weight spacecraft are given in Figure 4-52; the weights of the reflector, masts, feed assembly, radiators, and electronics are included in the payload weight.

In the cases of zero channel capacity and bandwidth limited capacity, the GTO weight was allowed to vary as the demands from the communications payload dictated. In these cases of varying GTO weight, mass scaling was accomplished on the structure, mechanical assemblies, AKM, and propellant in addition to the scaling associated with the antenna diameter, transponder configuration, and power subsystem included for the various configurations.

Mass scaling of AKM and PKM was assumed without identifying specific motors for instances of GTO weight beyond 5800 pounds. Although these cases also employ power consumptions beyond present capabilities, mass scaling was still employed to determine overall spacecraft weight.

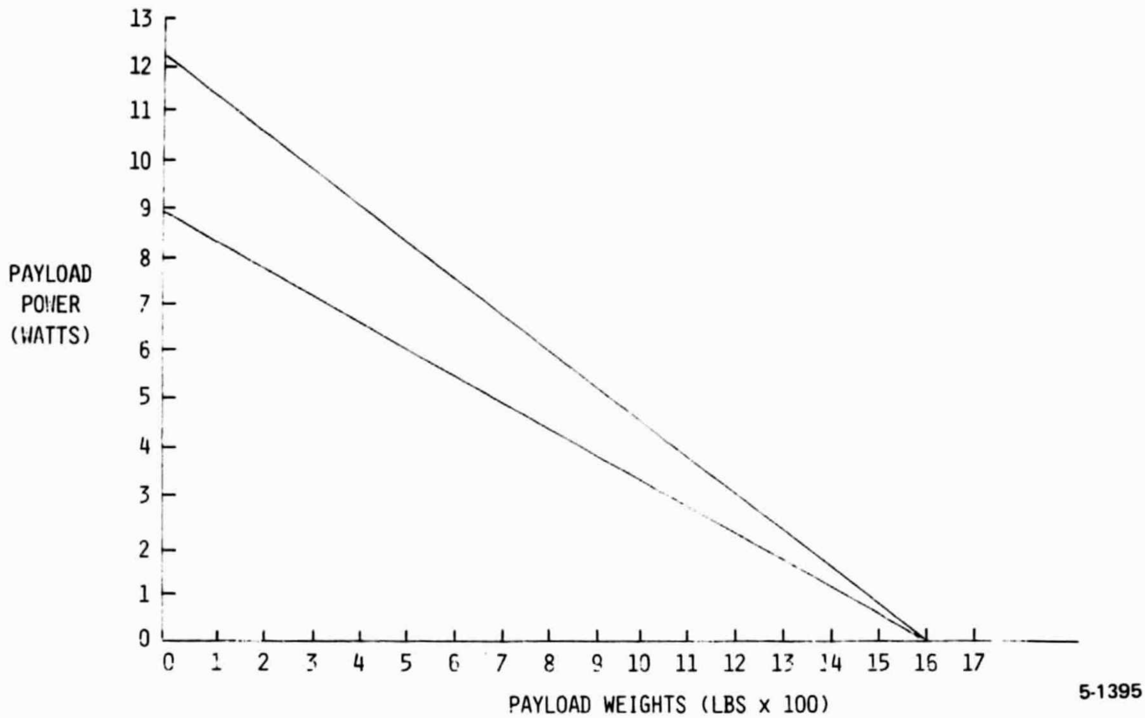

Figure 4-52. Series 4000 Spacecraft Payload Weight as a Function of Payload Power

The detailed breakdowns of the transponder, transponder feed assembly, and antenna given in Table 4-18 provide, in addition to the results of mass scaling of the structural elements, (a) the numbers of components of each type unit in the transponder for each antenna aperture case and (b) the impact of RF power demand on power amplifier size and on thermal radiator weight required to maintain equipment temperatures at 45°C maximum. Therefore, the feed assembly weight varies principally due to radiation area requirements.

Within the feed assembly, the weight of the feed itself is listed separately from the feed panel support. For the case of the UHF 20-meter antenna, there is no weight allocated for the feed panel support because configuration of the feed is self-supporting and the structure of the feed assembly is sized to support this large feed. Since the sizes and weights of all other feeds are less than the 20-meter UHF case, they require a support panel to allow mounting on the fixed size of the feed assembly.

4.3.1 UHF SPACECRAFT CONFIGURATION

Tables 4-18 through 4-27 present the results of the scaling study for the UHF spacecraft. Examination of the three cases of minimum, 50%, and 100% payload operations during eclipse show that the maximum channel capacity occurs for the case of a 15-meter antenna. The reasons for this occurrence are that the increase in weight of the reflector, support structure, and transponder occur faster than the decrease in power system weight caused by the reduced RF power demand which is the result of fewer watts per channel required for the larger antenna configuration.

TABLE 4-18. UHF TRANSPONDER CONFIGURATION AND WEIGHT SUMMARY FOR MINIMUM ECLIPSE CAPABILITY

Parameter	Values for Antenna Aperture of 10 meters	15 meters	20 meters
Eclipse Operation (percent)	40	38	31
Channels Supported	3175	6050	5300
RF Power per Channel (watts)	0.36	0.16	0.09
RF Power per Beam (watts)	142.9	80.7	19.9
Beams	8	12	24
Beam Electronics Installed	12	18	32
Amplifier Efficiency (percent)	25	26	26
Life (years)	7	7	7
Margin (pounds)	237	201	184
GTO Weight (pounds)	5800	5800	5800

Unit	Weight Summary (pounds) Unit Wt.	Qty.	S/C Wt.	Unit Wt.	Qty.	S/C Wt.	Unit Wt.	Qty.	S/C Wt.
Transponder Feed Assembly:									
Structure	149.0	1	149.0	149.0	1	149.0	149.0	1	149.0
Radiator Panels	125.8	1	125.8	103.2	1	103.2	58.4	1	58.4
Feed Panel	19.8	1	19.8	26.2	1	26.2	64.4	1	64.4
Feed Panel Support	35.7	1	35.7	30.6	1	30.6	0.0	1	0.0
Hinges	12.0	1	12.0	12.0	1	12.0	12.0	1	12.0
TOTAL			342.3			321.0			283.8
Transponder:									
Ku-Band Diplexer	0.6	1	0.6	0.6	1	0.6	0.6	1	0.6
Ku-Band Receiver	1.1	3	3.3	1.1	3	3.3	1.1	3	3.3
Signal Splitter	0.7	1	0.7	0.7	1	0.7	0.7	1	0.7
UHF Receiver/Frequency Translator	0.4	12	4.8	0.4	18	7.2	0.4	32	12.8
UHF Transmitter	16.8	12	201.9	9.1	18	163.3	5.8	32	186.6
UHF Diplexer	6.0	8	48.0	6.0	12	72.0	6.0	24	144.0
UHF Downlink Receiver	0.9	12	10.8	0.9	18	16.2	0.9	32	28.8
Signal Combiner	0.7	1	0.7	0.7	1	0.7	0.7	1	0.7
Ku-Band Upconverter	1.2	3	3.5	1.2	3	3.5	1.2	3	3.5
Ku-Band Preamplifier	1.0	3	3.0	1.0	3	3.0	1.0	3	3.0
Ku-Band SSPA (incl. EPC)	2.3	3	6.8	4.3	3	13.0	3.8	3	11.4
Waveguide Switches	0.3	12	3.6	0.3	12	3.6	0.3	12	3.6
Coaxial Switches	0.2	20	4.0	0.2	32	6.4	0.2	60	12.0
EPC (Up & Down Translator)	5.3	3	15.9	5.3	3	15.9	5.3	3	15.9
Master Oscillator	2.0	3	6.0	2.0	3	6.0	2.0	3	6.0
Miscellaneous	8.0	1	8.0	8.0	1	8.0	8.0	1	8.0
TOTAL			321.5			323.2			440.7
Communications Antenna:									
Reflector	78.4	1	78.4	137.1	1	137.1	208.8	1	208.8
Small Boom (incl. Can)	41.3	1	41.3	58.6	1	58.6	75.9	1	75.9
Large Boom (incl. Can)	82.5	1	82.5	117.2	1	117.2	151.8	1	151.8
Ku-Band Reflector (incl. Feed)	12.0	1	12.0	12.0	1	12.0	12.0	1	12.0
TOTAL			214.2			324.8			448.5

Further examination of the transponder weight shows a driver to be the required beam-dependent equipment. The number of beams doubles between the 15- and 20-meter reflector cases. One might expect the transponder weight to double in this case; however, it goes up only by approximately 35 percent due to the number of items in the back haul SHF portion and the decrease in power amplifier size and weight.

Although not a subject of the study, the factors surrounding the use of lower aperture antennas due to economic reasons (cost per channel year) may be totally offset by spectrum conservation considerations when determining the antenna aperture selected for system implementation.

4.3.2 L-BAND SPACECRAFT CONFIGURATION

Tables 4-28 through 4-37 present the results of the scaling study for the L-Band spacecraft. In comparison to the UHF spacecraft cases, examination of the three cases of minimum, 50%, and 100% eclipse payload operations show that the maximum channel capacity occurs, in all instances, for the 15-meter antenna. The reasons for this occurrence are the same at L-Band as for UHF in that the increase in weight of the reflector, support structure, and transponder occur faster than the decrease in power system weight caused by the reduced RF power demand of the larger aperture antenna. Further increases in antenna aperture were not studied; however, the same characteristic of decreased channel capacity with increased antenna aperture is anticipated.

TABLE 4-19. UHF SUBSYSTEM WEIGHT AND POWER SUMMARY FOR MINIMUM ECLIPSE CAPABILITY

Parameter	Values for Antenna Aperture of 10 meters			15 meters			20 meters		
Channels Supported	3175			6050			5300		
Eclipse Operation	40%			38%			31%		
Unit	Weight (lbs.)	Sunlight Power (watts)	Eclipse Power (watts)	Weight (lbs.)	Sunlight Power (watts)	Eclipse Power (watts)	Weight (lbs.)	Sunlight Power (watts)	Eclipse Power (watts)
Structure	339			359			389		
Mech. Assemblies	52			62			70		
Transponder Feed Assembly	342			321			284		
Transponder	321	4815	2039	323	3972	1691	441	2198	949
Communications Antenna	214			325			449		
CR&T	98	55	55	98	55	55	98	55	55
Attitude Control	91	31	31	91	31	31	91	31	31
Power Subsystem	672	31	31	582	31	31	357	31	31
Thermal	58	48	58	55	48	67	49	48	55
Propulsion	70			70			70		
AKM Assembly	2989			2989			2989		
Harness	123	146	73	131	122	61	122	70	35
Propellant	143			143			143		
Balance	50			50			50		
SUBTOTAL	5563	5126	2286	5599	4258	1935	5599	2433	1156
Margin	237			201			201		
GTO Weight	5800			5800			5800		

TABLE 4-20. UHF SUBSYSTEM WEIGHT AND POWER SUMMARY FOR 50% ECLIPSE CAPABILITY

Parameter	Values for Antenna Aperture of								
	10 meters			15 meters			20 meters		
Channels Supported	3090			5675			4675		
Eclipse Operation	50%			50%			50%		
Unit	Weight (lbs.)	Sunlight Power (watts)	Eclipse Power (watts)	Weight (lbs.)	Sunlight Power (watts)	Eclipse Power (watts)	Weight (lbs.)	Sunlight Power (watts)	Eclipse Power (watts)
Structure	339			359			389		
Mech. Assemblies	52			62			70		
Transponder Feed Assembly	338			315			278		
Transponder	314	4663	2425	315	3727	2005	438	1973	1173
Communications Antenna	214			325			449		
CR&T	98	55	55	98	55	55	98	55	55
Attitude Control	91	31	31	91	31	31	91	31	31
Power Subsystem	688	31	31	593	31	31	361	31	31
Thermal	57	48	52	54	48	52	48	48	52
Propulsion	70			70			70		
AKM Assembly	2989			2989			2989		
Harness	122	142	71	129	114	57	119	63	31
Propellant	143			143			143		
Balance	50			50			50		
SUBTOTAL	5566	4970	2665	5592	4006	2231	5591	2200	1374
Margin	234			208			209		
GTO Weight	5800			5800			5800		

TABLE 4-21. UHF TRANSPONDER CONFIGURATION AND WEIGHT SUMMARY FOR 50% ECLIPSE CAPABILITY

Parameter	Values for Antenna Aperture of		
	10 meters	15 meters	20 meters
Eclipse Operation (percent)	50	50	50
Channels Supported	3090	5675	4675
RF Power per Channel (watts)	0.36	0.16	0.09
RF Power per Beam (watts)	139.1	75.7	17.5
Beams	8	12	24
Beam Electronics Installed	12	18	32
Amplifier Efficiency (percent)	25	26	26
Life (years)	7	7	7
Margin (pounds)	237	208	209
GTO Weight (pounds)	5800	5800	5800

Unit	Weight Summary (pounds)								
	Unit Wt.	Qty.	S/C Wt.	Unit Wt.	Qty.	S/C Wt.	Unit Wt.	Qty.	S/C Wt.
Transponder Feed Assembly:									
Structure	149.0	1	149.0	149.0	1	149.0	149.0	1	149.0
Radiator Panels	121.7	1	121.7	96.8	1	96.8	52.5	1	52.5
Feed Panel	19.8	1	19.8	26.2	1	26.2	64.4	1	64.4
Feed Panel Support	35.7	1	35.7	30.6	1	30.6	0.0	1	0.0
Hinges	12.0	1	12.0	12.0	1	12.0	12.0	1	12.0
TOTAL			338.2			314.6			277.9
Transponder:									
Ku-Band Diplexer	0.6	1	0.6	0.6	1	0.6	0.6	1	0.6
Ku-Band Receiver	1.1	3	3.3	1.1	3	3.3	1.1	3	3.3
Signal Splitter	0.7	1	0.7	0.7	1	0.7	0.7	1	0.7
UHF Receiver/Frequency Translator	0.4	12	4.8	0.4	18	7.2	0.4	32	12.8
UHF Transmitter	16.2	12	194.6	8.6	18	155.6	5.8	32	185.3
UHF Diplexer	6.0	8	48.0	6.0	12	72.0	6.0	24	144.0
UHF Downlink Receiver	0.9	12	10.8	0.9	18	16.2	0.9	32	28.8
Signal Combiner	0.7	1	0.7	0.7	1	0.7	0.7	1	0.7
Ku-Band Upconverter	1.2	3	3.5	1.2	3	3.5	1.2	3	3.5
Ku-Band Preamplifier	1.0	3	3.0	1.0	3	3.0	1.0	3	3.0
Ku-Band SSPA (incl. EPC)	2.3	3	6.6	4.1	3	12.2	3.3	3	10.0
Waveguide Switches	0.3	12	3.6	0.3	12	3.6	0.3	12	3.6
Coaxial Switches	0.2	20	4.0	0.2	32	6.4	0.2	60	12.0
EPC (Up & Down Translator)	5.3	3	15.9	5.3	3	15.9	5.3	3	15.9
Master Oscillator	2.0	3	6.0	2.0	3	6.0	2.0	3	6.0
Miscellaneous	8.0	1	8.0	8.0	1	8.0	8.0	1	8.0
TOTAL			314.0			314.7			438.1
Communications Antenna:									
Reflector	78.4	1	78.4	137.1	1	137.1	208.8	1	208.8
Small Boom (incl. Can)	41.3	1	41.3	58.6	1	58.6	75.9	1	75.9
Large Boom (incl. Can)	82.5	1	82.5	117.2	1	117.2	151.8	1	151.8
Ku-Band Reflector (incl. Feed)	12.0	1	12.0	12.0	1	12.0	12.0	1	12.0
TOTAL			214.2			324.8			448.5

TABLE 4-22. UHF SUBSYSTEM WEIGHT AND POWER SUMMARY FOR FULL ECLIPSE CAPABILITY

Parameter	Values for Antenna Aperture of								
	10 meters			15 meters			20 meters		
Channels Supported	2580			4680			3725		
Eclipse Operation	100%			100%			100%		
Unit	Weight (lbs.)	Sunlight Power (watts)	Eclipse Power (watts)	Weight (lbs.)	Sunlight Power (watts)	Eclipse Power (watts)	Weight (lbs.)	Sunlight Power (watts)	Eclipse Power (watts)
Structure	339			359			389		
Mech. Assemblies	49			59			70		
Transponder Feed Assembly	315			298			277		
Transponder	274	3807	3807	295	3089	3089	435	1631	1631
Communications Antenna	214			325			449		
CR&T	98	55	55	98	55	55	98	55	55
Attitude Control	91	31	31	91	31	31	91	31	31
Power Subsystem	797	31	31	649	31	31	376	31	31
Thermal	54	48	52	52	48	52	48	48	52
Propulsion	70			70			70		
AKM Assembly	2989			2989			2989		
Harness	117	117	58	123	96	48	114	53	26
Propellant	143			143			143		
Balance	50			50			50		
SUBTOTAL	5600	4089	4034	5600	3349	3305	5597	1848	1826
Margin	200			200			203		
GTO Weight	5800			5800			5800		

TABLE 4-23. UHF TRANSPONDER CONFIGURATION AND WEIGHT SUMMARY FOR FULL ECLIPSE CAPABILITY

Parameter	Values for Antenna Aperture of		
	10 meters	15 meters	20 meters
Eclipse Operation (percent)	100	100	100
Channels Supported	2580	4680	3725
RF Power per Channel (watts)	0.36	0.16	0.09
RF Power per Beam (watts)	116.1	62.4	14.0
Beams	8	12	24
Beam Electronics Installed	12	18	32
Amplifier Efficiency (percent)	26	26	26
Life (years)	7	7	7
Margin (pounds)	200	200	203
GTO Weight (pounds)	5800	5800	5800

Unit	Weight Summary (pounds)								
	Unit Wt.	Qty.	S/C Wt.	Unit Wt.	Qty.	S/C Wt.	Unit Wt.	Qty.	S/C Wt.
Transponder Feed Assembly:									
Structure	149.0	1	149.0	149.0	1	149.0	149.0	1	149.0
Radiator Panels	98.9	1	98.9	80.2	1	80.2	51.3	1	51.3
Feed Panel	19.8	1	19.8	26.2	1	26.2	64.4	1	64.4
Feed Panel Support	35.7	1	35.7	30.6	1	30.6	0.0	1	0.0
Hinges	12.0	1	12.0	12.0	1	12.0	12.0	1	12.0
TOTAL			315.3			297.9			276.7
Transponder:									
Ku-Band Diplexer	0.6	1	0.6	0.6	1	0.6	0.6	1	0.6
Ku-Band Receiver	1.1	3	3.3	1.1	3	3.3	1.1	3	3.3
Signal Splitter	0.7	1	0.7	0.7	1	0.7	0.7	1	0.7
UHF Receiver/Frequency Translator	0.4	12	4.8	0.4	18	7.2	0.4	32	12.8
UHF Transmitter	12.9	12	155.2	7.6	18	137.6	5.7	32	183.8
UHF Diplexer	6.0	8	48.0	6.0	12	72.0	6.0	24	144.0
UHF Downlink Receiver	0.9	12	10.8	0.9	18	16.2	0.9	32	28.8
Signal Combiner	0.7	1	0.7	0.7	1	0.7	0.7	1	0.7
Ku-Band Upconverter	1.2	3	3.5	1.2	3	3.5	1.2	3	3.5
Ku-Band Preamplifier	1.0	3	3.0	1.0	3	3.0	1.0	3	3.0
Ku-Band SSPA (incl. EPC)	1.8	3	5.5	3.3	3	10.0	2.7	3	8.0
Waveguide Switches	0.3	12	3.6	0.3	12	3.6	0.3	12	3.6
Coaxial Switches	0.2	20	4.0	0.2	32	6.4	0.2	60	12.0
EPC (Up & Down Translator)	5.3	3	15.9	5.3	3	15.9	5.3	3	15.9
Master Oscillator	2.0	3	6.0	2.0	3	6.0	2.0	3	6.0
Miscellaneous	8.0	1	8.0	8.0	1	8.0	8.0	1	8.0
TOTAL			273.5			294.6			434.5
Communications Antenna:									
Reflector	78.4	1	78.4	137.1	1	137.1	208.8	1	208.8
Small Boom (incl. Can)	41.3	1	41.3	58.6	1	58.6	75.9	1	75.9
Large Boom (incl. Can)	82.5	1	82.5	117.2	1	117.2	151.8	1	151.8
Ku-Band Reflector (incl. Feed)	12.0	1	12.0	12.0	1	12.0	12.0	1	12.0
TOTAL			214.2			324.8			448.5

TABLE 4-24. UHF SUBSYSTEM WEIGHT AND POWER SUMMARY FOR ZERO CHANNEL CAPABILITY

Parameter	Values for Antenna Aperture of								
	10 meters			15 meters			20 meters		
Channels Supported	0			0			0		
Eclipse Operation	40%			40%			40%		
Unit	Weight (lbs.)	Sunlight Power (watts)	Eclipse Power (watts)	Weight (lbs.)	Sunlight Power (watts)	Eclipse Power (watts)	Weight (lbs.)	Sunlight Power (watts)	Eclipse Power (watts)
Structure	272			306			368		
Mech. Assemblies	36			50			63		
Transponder Feed Assembly	237			246			277		
Transponder	181	140	140	250	182	182	425	296	296
Communications Antenna	214			325			449		
CR&T	98	55	55	98	55	55	98	55	55
Attitude Control	91	31	31	91	31	31	91	31	31
Power Subsystem	119	31	31	121	31	31	127	31	31
Thermal	43	48	52	44	48	52	48	48	52
Propulsion	70			70			70		
AKM Assembly	2050			2209			2695		
Harness	93	9	4	94	10	5	97	14	7
Propellant	124			128			137		
Balance	50			50			50		
SUBTOTAL	5600	313	313	4084	357	356	4995	474	471
Margin	200			201			200		
GTO Weight	5800			4285			5195		

TABLE 4-25. UHF TRANSPONDER CONFIGURATION AND WEIGHT SUMMARY FOR ZERO CHANNEL CAPABILITY

Parameter	Values for Antenna Aperture of		
	10 meters	15 meters	20 meters
Channels Supported	0	0	0
RF Power per Channel (watts)	0.36	0.16	0.09
RF Power per Beam (watts)	0.0	0.0	0.0
Beams	8	12	24
Beam Electronics Installed	12	18	32
Amplifier Efficiency (percent)	26	26	26
Life (years)	7	7	7
Margin (pounds)	200	201	200
GTO Weight (pounds)	3880	4285	5195

Unit	Weight Summary (pounds)								
	Unit Wt.	Qty.	S/C Wt.	Unit Wt.	Qty.	S/C Wt.	Unit Wt.	Qty.	S/C Wt.
Transponder Feed Assembly:									
Structure	149.0	1	149.0	149.0	1	149.0	149.0	1	149.0
Radiator Panels	20.4	1	20.4	28.6	1	28.6	51.2	1	51.2
Feed Panel	19.8	1	19.8	26.2	1	26.2	64.4	1	64.4
Feed Panel Support	35.7	1	35.7	30.6	1	30.6	0.0	1	0.0
Hinges	12.0	1	12.0	12.0	1	12.0	12.0	1	12.0
TOTAL			236.9			246.4			276.6
Transponder:									
Ku-Band Diplexer	0.6	1	0.6	0.6	1	0.6	0.6	1	0.6
Ku-Band Receiver	1.1	3	3.3	1.1	3	3.3	1.1	3	3.3
Signal Splitter	0.7	1	0.7	0.7	1	0.7	0.7	1	0.7
UHF Receiver/Frequency Translator	0.4	12	4.8	0.4	18	7.2	0.4	32	12.8
UHF Transmitter	5.7	12	68.4	5.7	18	102.6	5.7	32	182.4
UHF Diplexer	6.0	8	48.0	6.0	12	72.0	6.0	24	144.0
UHF Downlink Receiver	0.9	12	10.8	0.9	18	16.2	0.9	32	28.8
Signal Combiner	0.7	1	0.7	0.7	1	0.7	0.7	1	0.7
Ku-Band Upconverter	1.2	3	3.5	1.2	3	3.5	1.2	3	3.5
Ku-Band Preamplifier	1.0	3	3.0	1.0	3	3.0	1.0	3	3.0
Ku-Band SSPA (incl. EPC)	0.0	3	0.0	0.0	3	0.0	0.0	3	0.0
Waveguide Switches	0.3	12	3.6	0.3	12	3.6	0.3	12	3.6
Coaxial Switches	0.2	20	4.0	0.2	32	6.4	0.2	60	12.0
EPC (Up & Down Translator)	5.3	3	15.9	5.3	3	15.9	5.3	3	15.9
Master Oscillator	2.0	3	6.0	2.0	3	6.0	2.0	3	6.0
Miscellaneous	8.0	1	8.0	8.0	1	8.0	8.0	1	8.0
TOTAL			181.2			249.6			425.2
Communications Antenna:									
Reflector	78.4	1	78.4	137.1	1	137.1	208.8	1	208.8
Small Boom (incl. Can)	41.3	1	41.3	58.6	1	58.6	75.9	1	75.9
Large Boom (incl. Can)	82.5	1	82.5	117.2	1	117.2	151.8	1	151.8
Ku-Band Reflector (incl. Feed)	12.0	1	12.0	12.0	1	12.0	12.0	1	12.0
TOTAL			214.2			324.8			448.5

TABLE 4-26. UHF SUBSYSTEM WEIGHT AND POWER SUMMARY FOR BANDWIDTH LIMITED CAPABILITY

Parameter	Values for Antenna Aperture of								
	10 meters			15 meters			20 meters		
Channels Supported Eclipse Operation	2280 100%			3420 100%			6840 100%		
Unit	Weight (lbs.)	Sunlight Power (watts)	Eclipse Power (watts)	Weight (lbs.)	Sunlight Power (watts)	Eclipse Power (watts)	Weight (lbs.)	Sunlight Power (watts)	Eclipse Power (watts)
Structure	328			343			414		
Mech. Assemblies	49			56			73		
Transponder Feed Assembly	303			277			298		
Transponder	253	3338	3338	274	2299	2299	448	2757	2757
Communications Antenna	214			325			449		
CR&T	98	55	55	98	55	55	98	55	55
Attitude Control	91	31	31	91	31	31	91	31	31
Power Subsystem	685	31	31	498	31	31	600	31	31
Thermal	52	48	52	49	48	52	51	48	52
Propulsion	70			70			70		
AKM Assembly	2835			2770			3427		
Harness	114	103	52	115	72	36	129	86	43
Propellant	140			139			151		
Balance	50			50			50		
SUBTOTAL	5283	3606	3559	5156	2536	2504	6349	3008	2969
Margin	200			194			201		
GTO Weight	5483			5350			6550		

TABLE 4-27. UHF TRANSPONDER CONFIGURATION AND WEIGHT SUMMARY FOR BANDWIDTH LIMITED CAPABILITY

Parameter	Values for Antenna Aperture of								
	10 meters			15 meters			20 meters		
Eclipse Operation (percent)	100			100			100		
Channels Supported	2280			3420			6840		
RF Power per Channel (watts)	0.36			0.16			0.09		
RF Power per Beam (watts)	102.6			45.6			25.7		
Beams	8			12			24		
Beam Electronics Installed	12			18			32		
Amplifier Efficiency (percent)	26			27			26		
Life (years)	7			7			7		
Margin (pounds)	200			194			200		
GTO Weight (pounds)	5483			5350			6550		
Unit	Weight Summary (pounds)								
	Unit Wt.	Qty.	S/C Wt.	Unit Wt.	Qty.	S/C Wt.	Unit Wt.	Qty.	S/C Wt.
Transponder Feed Assembly:									
Structure	149.0	1	149.0	149.0	1	149.0	149.0	1	149.0
Radiator Panels	86.5	1	86.5	59.6	1	59.6	72.9	1	72.9
Feed Panel	19.8	1	19.8	26.2	1	26.2	64.4	1	64.4
Feed Panel Support	35.7	1	35.7	30.6	1	30.6	0.0	1	0.0
Hinges	12.0	1	12.0	12.0	1	12.0	12.0	1	12.0
TOTAL			303.0			277.4			298.3
Transponder:									
Ku-Band Diplexer	0.6	1	0.6	0.6	1	0.6	0.6	1	0.6
Ku-Band Receiver	1.1	3	3.3	1.1	3	3.3	1.1	3	3.3
Signal Splitter	0.7	1	0.7	0.7	1	0.7	0.7	1	0.7
UHF Receiver/Frequency Translator	0.4	12	4.8	0.4	18	7.2	0.4	32	12.8
UHF Transmitter	11.3	12	135.5	6.7	18	120.2	6.0	32	190.5
UHF Diplexer	6.0	8	48.0	6.0	12	72.0	6.0	24	144.0
UHF Downlink Receiver	0.9	12	10.8	0.9	18	16.2	0.9	32	28.8
Signal Combiner	0.7	1	0.7	0.7	1	0.7	0.7	1	0.7
Ku-Band Upconverter	1.2	3	3.5	1.2	3	3.5	1.2	3	3.5
Ku-Band Preamplifier	1.0	3	3.0	1.0	3	3.0	1.0	3	3.0
Ku-Band SSPA (incl. EPC)	1.6	3	4.9	2.4	3	7.3	4.9	3	14.7
Waveguide Switches	0.3	12	3.6	0.3	12	3.6	0.3	12	3.6
Coaxial Switches	0.2	20	4.0	0.2	32	6.4	0.2	60	12.0
EPC (Up & Down Translator)	5.3	3	15.9	5.3	3	15.9	5.3	3	15.9
Master Oscillator	2.0	3	6.0	2.0	3	6.0	2.0	3	6.0
Miscellaneous	8.0	1	8.0	8.0	1	8.0	8.0	1	8.0
TOTAL			253.2			274.5			447.9
Communications Antenna:									
Reflector	78.4	1	78.4	137.1	1	137.1	208.8	1	208.8
Small Boom (incl. Can)	41.3	1	41.3	58.6	1	58.6	75.9	1	75.9
Large Boom (incl. Can)	82.5	1	82.5	117.2	1	117.2	151.8	1	151.8
Ku-Band Reflector (incl. Feed)	12.0	1	12.0	12.0	1	12.0	12.0	1	12.0
TOTAL			214.2			324.8			448.5

TABLE 4-28. L-BAND SUBSYSTEM WEIGHT AND POWER SUMMARY FOR MINIMUM ECLIPSE CAPABILITY

Parameter	Values for Antenna Aperture of								
	5 meters			10 meters			15 meters		
Channels Supported	950			3260			4600		
Eclipse Operation	40%			36%			24%		
Unit		Sunlight	Eclipse		Sunlight	Eclipse		Sunlight	Eclipse
	Weight (lbs.)	Power (watts)	Power (watts)	Weight (lbs.)	Power (watts)	Power (watts)	Weight (lbs.)	Power (watts)	Power (watts)
Structure	329			339			359		
Mech. Assemblies	44			52			59		
Transponder Feed Assembly	363			341			310		
Transponder	290	5663	2470	338	4702	1945	458		
Communications Antenna	116			214			325		
CR&T	98	55	55	98	55	55	98	55	55
Attitude Control	91	31	31	91	31	31	91	31	31
Power Subsystem	786	31	31	666	31	31	444	31	31
Thermal	100	48	60	90	48	52	76	48	60
Propulsion	66	23	23	66	23	23	66	23	23
AKM Assembly	2989			2989			2989		
Harness	110	171	86	122	143	72	123	97	49
Propellant	143			143			143		
Balance	50			50			50		
SUBTOTAL	5575	6000	2732	5599	5010	2185	5590	3410	1363
Margin	225			201			210		
GTO Weight	5800			5800			5800		

TABLE 4-29. L-BAND TRANSPONDER CONFIGURATION AND WEIGHT SUMMARY FOR MINIMUM ECLIPSE CAPABILITY

Parameter	Values for Antenna Aperture of		
	5 meters	10 meters	15 meters
Eclipse Operation (percent)	40	36	24
Channels Supported	950	3260	4600
RF Power per Channel (watts)	1.45	0.36	0.16
RF Power per Beam (watts)	172	49	15
Beams	8	24	49
Beam Electronics Installed	12	28	56
Amplifier Efficiency (percent)	25	26	27
Life (years)	7	7	7
Margin (pounds)	225	201	210
GTO Weight (pounds)	5800	5800	5800

Unit	Weight Summary (pounds)								
	Unit Wt.	Qty.	S/C Wt.	Unit Wt.	Qty.	S/C Wt.	Unit Wt.	Qty.	S/C Wt.
Transponder Feed Assembly:									
Structure	149.0	1	149.0	149.0	1	149.0	149.0	1	149.0
Radiator Panels	149.7	1	149.7	125.0	1	125.0	89.5	1	89.5
Feed Panel	5.3	1	5.3	16.3	1	16.3	37.6	1	37.6
Feed Panel Support	47.3	1	47.3	38.5	1	38.5	21.4	1	21.4
Hinges	12.0	1	12.0	12.0	1	12.0	12.0	1	12.0
TOTAL			363.3			340.8			309.5
Transponder:									
Ku-Band Diplexer	0.6	1	0.6	0.6	1	0.6	0.6	1	0.6
Ku-Band Receiver	1.1	3	3.3	1.1	3	3.3	1.1	3	3.3
Signal Splitter	0.7	1	0.7	0.7	1	0.7	0.7	1	0.7
UHF Receiver/Frequency Translator	0.4	12	4.8	0.4	28	11.2	0.4	56	22.4
UHF Transmitter	17.2	12	206.7	6.9	28	191.9	3.8	56	212.1
UHF Diplexer	2.0	8	16.0	2.0	24	48.0	2.0	49	98.0
UHF Downlink Receiver	0.9	12	10.8	0.9	28	25.2	0.9	56	50.4
Signal Combiner	0.7	1	0.7	0.7	1	0.7	0.7	1	0.7
Ku-Band Upconverter	1.2	3	3.5	1.2	3	3.5	1.2	3	3.5
Ku-Band Preamplifier	1.0	3	3.0	1.0	3	3.0	1.0	3	3.0
Ku-Band SSPA (incl. EPC)	0.7	3	2.0	2.3	3	7.0	3.3	3	9.9
Waveguide Switches	0.3	12	3.6	0.3	12	3.6	0.3	12	3.6
Coaxial Switches	0.2	20	4.0	0.2	48	9.6	0.2	98	19.6
EPC (Up & Down Translator)	5.3	3	15.9	5.3	3	15.9	5.3	3	15.9
Master Oscillator	2.0	3	6.0	2.0	3	6.0	2.0	3	6.0
Miscellaneous	8.0	1	8.0	8.0	1	8.0	8.0	1	8.0
TOTAL			289.5			338.0			457.5
Communications Antenna:									
Reflector	32.7	1	32.7	78.4	1	78.4	137.1	1	137.1
Small Boom (incl. Can)	23.9	1	23.9	41.3	1	41.3	58.6	1	58.6
Large Boom (incl. Can)	47.9	1	47.9	82.5	1	82.5	117.2	1	117.2
Ku-Band Reflector (incl. Feed)	12.0	1	12.0	12.0	1	12.0	12.0	1	12.0
TOTAL			116.5			214.2			324.8

TABLE 4-30. L-BAND SUBSYSTEM WEIGHT AND POWER SUMMARY FOR 50% ECLIPSE CAPABILITY

Parameter	Values for Antenna Aperture of								
	5 meters			10 meters			15 meters		
Channels Supported	900			3125			3915		
Eclipse Operation	50%			50%			50%		
Unit	Weight (lbs.)	Sunlight Power (watts)	Eclipse Power (watts)	Weight (lbs.)	Sunlight Power (watts)	Eclipse Power (watts)	Weight (lbs.)	Sunlight Power (watts)	Eclipse Power (watts)
Structure	329			339			359		
Mech. Assemblies	41			52			59		
Transponder Feed Assembly	355			336			299		
Transponder	281	5346	2869	333	4510	2469	445	2724	1627
Communications Antenna	116			214			325		
CR&T	98	55	55	98	55	55	98	55	55
Attitude Control	91	31	31	91	31	31	91	31	31
Power Subsystem	835	31	31	681	31	31	495	31	31
Thermal	97	48	52	88	48	52	72	48	52
Propulsion	66	23	23	66	23	23	66	23	23
AKM Assembly	2989			2989			2989		
Harness	109	162	81	121	137	69	119	85	42
Propellant	143			143			143		
Balance	50			50			50		
SUBTOTAL	5599	5673	3119	5600	4812	2707	5608	2974	1838
Margin	201			200			192		
GTO Weight	5800			5800			5800		

TABLE 4-31. L-BAND TRANSPONDER CONFIGURATION AND WEIGHT SUMMARY FOR 50% ECLIPSE CAPABILITY

Parameter	Values for Antenna Aperture of		
	5 meters	10 meters	15 meters
Eclipse Operation (percent)	50	50	50
Channels Supported	900	3125	3915
RF Power per Channel (watts)	1.45	0.36	0.16
RF Power per Beam (watts)	163.1	46.9	12.8
Beams	8	24	49
Beam Electronics Installed	12	28	56
Amplifier Efficiency (percent)	25	26	27
Life (years)	7	7	7
Margin (pounds)	201	200	192
GTO Weight (pounds)	5800	5800	5800

Unit	Weight Summary (pounds)								
	Unit Wt.	Qty.	S/C Wt.	Unit Wt.	Qty.	S/C Wt.	Unit Wt.	Qty.	S/C Wt.
<u>Transponder Feed Assembly</u>:									
Structure	149.0	1	149.0	149.0	1	149.0	149.0	1	149.0
Radiator Panels	141.3	1	141.3	120.0	1	120.0	78.5	1	78.5
Feed Panel	5.3	1	5.3	16.3	1	16.3	37.6	1	37.6
Feed Panel Support	47.3	1	47.3	38.5	1	38.5	21.4	1	21.4
Hinges	12.0	1	12.0	12.0	1	12.0	12.0	1	12.0
TOTAL			354.9			335.8			298.5
<u>Transponder</u>:									
Ku-Band Diplexer	0.6	1	0.6	0.6	1	0.6	0.6	1	0.6
Ku-Band Receiver	1.1	3	3.3	1.1	3	3.3	1.1	3	3.3
Signal Splitter	0.7	1	0.7	0.7	1	0.7	0.7	1	0.7
UHF Receiver/Frequency Translator	0.4	12	4.8	0.4	28	11.2	0.4	56	22.4
UHF Transmitter	16.5	12	198.1	6.7	28	186.8	3.6	56	200.6
UHF Diplexer	2.0	8	16.0	2.0	24	48.0	2.0	49	98.0
UHF Downlink Receiver	0.9	12	10.8	0.9	28	25.2	0.9	56	50.4
Signal Combiner	0.7	1	0.7	0.7	1	0.7	0.7	1	0.7
Ku-Band Upconverter	1.2	3	3.5	1.2	3	3.5	1.2	3	3.5
Ku-Band Preamplifier	1.0	3	3.0	1.0	3	3.0	1.0	3	3.0
Ku-Band SSPA (incl. EPC)	0.6	3	1.9	2.2	3	6.7	2.8	3	8.4
Waveguide Switches	0.3	12	3.6	0.3	12	3.6	0.3	12	3.6
Coaxial Switches	0.2	20	4.0	0.2	48	9.6	0.2	98	19.6
EPC (Up & Down Translator)	5.3	3	15.9	5.3	3	15.9	5.3	3	15.9
Master Oscillator	2.0	3	6.0	2.0	3	6.0	2.0	3	6.0
Miscellaneous	8.0	1	8.0	8.0	1	8.0	8.0	1	8.0
TOTAL			280.8			332.7			444.6
<u>Communications Antenna</u>:									
Reflector	32.7	1	32.7	78.4	1	78.4	137.1	1	137.1
Small Boom (incl. Can)	23.9	1	23.9	41.3	1	41.3	58.6	1	58.6
Large Boom (incl. Can)	47.9	1	47.9	82.5	1	82.5	117.2	1	117.2
Ku-Band Reflector (incl. Feed)	12.0	1	12.0	12.0	1	12.0	12.0	1	12.0
TOTAL			116.5			214.2			324.8

TABLE 4-32. L-BAND SUBSYSTEM WEIGHT AND POWER SUMMARY FOR 100% ECLIPSE CAPABILITY

Parameter	Values for Antenna Aperture of								
	5 meters			10 meters			15 meters		
Channels Supported	718			2415			3275		
Eclipse Operation	100%			100%			100%		
Unit		Sunlight	Eclipse		Sunlight	Eclipse		Sunlight	Eclipse
	Weight (lbs.)	Power (watts)	Power (watts)	Weight (lbs.)	Power (watts)	Power (watts)	Weight (lbs.)	Power (watts)	Power (watts)
Structure	329			339			359		
Mech. Assemblies	38			49			59		
Transponder Feed Assembly	325			310			288		
Transponder	248	4210	4365	304	3509	3594	432	2331	2391
Communications Antenna	116			214			325		
CR&T	98	55	55	98	55	55	98	55	55
Attitude Control	91	31	31	91	31	31	91	31	31
Power Subsystem	929	31	31	742	31	31	523	31	31
Thermal	85	48	52	78	48	52	68	48	52
Propulsion	66	23	23	66	23	23	66	23	23
AKM Assembly	2989			2989			2989		
Harness	105	129	64	115	108	54	115	73	37
Propellant	143			143			143		
Balance	50			50			50		
SUBTOTAL	5613	4504	4598	5587	3782	3817	5606	2569	2596
Margin	187			213			194		
GTO Weight	5800			5800			5800		

TABLE 4-33. L-BAND TRANSPONDER CONFIGURATION AND WEIGHT SUMMARY FOR 100% ECLIPSE CAPABILITY

Parameter	Values for Antenna Aperture of		
	5 meters	10 meters	15 meters
Eclipse Operation (percent)	100	100	100
Channels Supported	718	2415	3275
RF Power per Channel (watts)	1.45	0.36	0.16
RF Power per Beam (watts)	130.1	36.2	10.7
Beams	8	24	49
Beam Electronics Installed	12	28	56
Amplifier Efficiency (percent)	25	27	27
Life (years)	7	7	7
Margin (pounds)	187	213	194
GTO Weight (pounds)	5800	5800	5800

Unit	Weight Summary (pounds)								
	Unit Wt.	Qty.	S/C Wt.	Unit Wt.	Qty.	S/C Wt.	Unit Wt.	Qty.	S/C Wt.
Transponder Feed Assembly:									
Structure	149.0	1	149.0	149.0	1	149.0	149.0	1	149.0
Radiator Panels	111.3	1	111.3	94.0	1	94.0	68.3	1	68.3
Feed Panel	5.3	1	5.3	16.3	1	16.3	37.6	1	37.6
Feed Panel Support	47.3	1	47.3	38.5	1	38.5	21.4	1	21.4
Hinges	12.0	1	12.0	12.0	1	12.0	12.0	1	12.0
TOTAL			324.9			309.8			288.4
Transponder:									
Ku-Band Diplexer	0.6	1	0.6	0.6	1	0.6	0.6	1	0.6
Ku-Band Receiver	1.1	3	3.3	1.1	3	3.3	1.1	3	3.3
Signal Splitter	0.7	1	0.7	0.7	1	0.7	0.7	1	0.7
UHF Receiver/Frequency Translator	0.4	12	4.8	0.4	28	11.2	0.4	56	22.4
UHF Transmitter	13.8	12	165.9	5.7	28	160.1	3.4	56	189.8
UHF Diplexer	2.0	8	16.0	2.0	24	48.0	2.0	49	98.0
UHF Downlink Receiver	0.9	12	10.8	0.9	28	25.2	0.9	56	50.4
Signal Combiner	0.7	1	0.7	0.7	1	0.7	0.7	1	0.7
Ku-Band Upconverter	1.2	3	3.5	1.2	3	3.5	1.2	3	3.5
Ku-Band Preamplifier	1.0	3	3.0	1.0	3	3.0	1.0	3	3.0
Ku-Band SSPA (incl. EPC)	0.5	3	1.5	1.7	3	5.2	2.3	3	7.0
Waveguide Switches	0.3	12	3.6	0.3	12	3.6	0.3	12	3.6
Coaxial Switches	0.2	20	4.0	0.2	48	9.6	0.2	98	19.6
EPC (Up & Down Translator)	5.3	3	15.9	5.3	3	15.9	5.3	3	15.9
Master Oscillator	2.0	3	6.0	2.0	3	6.0	2.0	3	6.0
Miscellaneous	8.0	1	8.0	8.0	1	8.0	8.0	1	8.0
TOTAL			248.2			304.4			432.4
Communications Antenna:									
Reflector	32.7	1	32.7	78.4	1	78.4	137.1	1	137.1
Small Boom (incl. Can)	23.9	1	23.9	41.3	1	41.3	58.6	1	58.6
Large Boom (incl. Can)	47.9	1	47.9	82.5	1	82.5	117.2	1	117.2
Ku-Band Reflector (incl. Feed)	12.0	1	12.0	12.0	1	12.0	12.0	1	12.0
TOTAL			116.5			214.2			324.8

TABLE 4-34. L-BAND SUBSYSTEM WEIGHT AND POWER SUMMARY FOR ZERO CHANNEL CAPABILITY

Parameter	Values for Antenna Aperture of								
	5 meters			10 meters			15 meters		
Channels Supported	0			0			0		
Unit	Weight (lbs.)	Sunlight Power (watts)	Eclipse Power (watts)	Weight (lbs.)	Sunlight Power (watts)	Eclipse Power (watts)	Weight (lbs.)	Sunlight Power (watts)	Eclipse Power (watts)
Structure	250			276			321		
Mech. Assemblies	23			36			50		
Transponder Feed Assembly	226			241			266		
Transponder	110	70	225	206	211	296	370	347	407
Communications Antenna	116			214			325		
CR&T	98	55	55	98	55	55	98	55	55
Attitude Control	91	31	31	91	31	31	91	31	31
Power Subsystem	158	31	31	165	31	31	172	31	31
Thermal	45	48	52	50	48	52	59	48	52
Propulsion	66	23	23	66	23	23	66	23	23
AKM Assembly	1874			2063			2408		
Harness	91	7	3	93	11	6	96	15	8
Propellant	121			125			133		
Balance	50			50			50		
SUBTOTAL	3320	241	397	3775	387	470	4504	527	583
Margin	200			200			201		
GTO Weight	5520			3975			4705		

TABLE 4-35. L-BAND TRANSPONDER CONFIGURATION AND WEIGHT SUMMARY FOR ZERO CHANNEL CAPABILITY

Parameter	Values for Antenna Aperture of		
	5 meters	10 meters	15 meters
Eclipse Operation (percent)	100	100	100
Channels Supported	0	0	0
RF Power per Channel (watts)	1.45	0.36	0.16
RF Power per Beam (watts)	0.0	0.0	0.0
Beams	8	24	49
Beam Electronics Installed	12	28	56
Amplifier Efficiency (percent)	27	27	27
Life (years)	7	7	7
Margin (pounds)	200	200	201
GTO Weight (pounds)	3520	3975	4705

	Weight Summary (pounds)								
Unit	Unit Wt.	Qty.	S/C Wt.	Unit Wt.	Qty.	S/C Wt.	Unit Wt.	Qty.	S/C Wt.
Transponder Feed Assembly:									
Structure	149.0	1	149.0	149.0	1	149.0	149.0	1	149.0
Radiator Panels	12.4	1	12.4	25.0	1	25.0	46.3	1	46.3
Feed Panel	5.3	1	5.3	16.3	1	16.3	37.6	1	37.6
Feed Panel Support	47.3	1	47.3	38.5	1	38.5	21.4	1	21.4
Hinges	12.0	1	12.0	12.0	1	12.0	12.0	1	12.0
TOTAL			226.0			240.8			266.3
Transponder:									
Ku-Band Diplexer	0.6	1	0.6	0.6	1	0.6	0.6	1	0.6
Ku-Band Receiver	1.1	3	3.3	1.1	3	3.3	1.1	3	3.3
Signal Splitter	0.7	1	0.7	0.7	1	0.7	0.7	1	0.7
UHF Receiver/Frequency Translator	0.4	12	4.8	0.4	28	11.2	0.4	56	22.4
UHF Transmitter	2.4	12	28.8	2.4	28	67.2	2.4	56	134.4
UHF Diplexer	2.0	8	16.0	2.0	24	48.0	2.0	49	98.0
UHF Downlink Receiver	0.9	12	10.8	0.9	28	25.2	0.9	56	50.4
Signal Combiner	0.7	1	0.7	0.7	1	0.7	0.7	1	0.7
Ku-Band Upconverter	1.2	3	3.5	1.2	3	3.5	1.2	3	3.5
Ku-Band Preamplifier	1.0	3	3.0	1.0	3	3.0	1.0	3	3.0
Ku-Band SSPA (incl. EPC)	0.0	3	0.0	0.0	3	0.0	0.0	3	0.0
Waveguide Switches	0.3	12	3.6	0.3	12	3.6	0.3	12	3.6
Coaxial Switches	0.2	20	4.0	0.2	48	9.6	0.2	98	19.6
EPC (Up & Down Translator)	5.3	3	15.9	5.3	3	15.9	5.3	3	15.9
Master Oscillator	2.0	3	6.0	2.0	3	6.0	2.0	3	6.0
Miscellaneous	8.0	1	8.0	8.0	1	8.0	8.0	1	8.0
TOTAL			109.6			206.4			370.0
Communications Antenna:									
Reflector	32.7	1	32.7	78.4	1	78.4	137.1	1	137.1
Small Boom (incl. Can)	23.9	1	23.9	41.3	1	41.3	58.6	1	58.6
Large Boom (incl. Can)	47.9	1	47.9	82.5	1	82.5	117.2	1	117.2
Ku-Band Reflector (incl. Feed)	12.0	1	12.0	12.0	1	12.0	12.0	1	12.0
TOTAL			116.5			214.2			324.8

TABLE 4-36. L-BAND SUBSYSTEM WEIGHT AND POWER SUMMARY FOR BANDWIDTH LIMITED CAPABILITY

Parameter	Values for Antenna Aperture of								
	5 meters			10 meters			15 meters		
Channels Supported	2280			6840			13965		
Eclipse Operation	100%			100%			100%		
Unit	Weight (lbs.)	Sunlight Power (watts)	Eclipse Power (watts)	Weight (lbs.)	Sunlight Power (watts)	Eclipse Power (watts)	Weight (lbs.)	Sunlight Power (watts)	Eclipse Power (watts)
Structure	521			468			498		
Mech. Assemblies	75			73			84		
Transponder Feed Assembly	594			479			465		
Transponder	494	14349	14504	476	9967	10052	633	9128	9188
Communications Antenna	116			214			325		
CR&T	98	55	55	98	55	55	98	55	55
Attitude Control	91	31	31	91	31	31	91	31	31
Power Subsystem	2695	31	31	1915	31	31	1760	31	31
Thermal	193	48	52	146	48	52	139	48	52
Propulsion	66	23	23	66	23	23	66	23	23
AKM Assembly	5861			4933			5085		
Harness	138	427	213	157	298	149	182	273	137
Propellant	199			181			184		
Balance	50			50			50		
SUBTOTAL	11191	14941	14886	9345	10429	10369	9660	9566	9494
Margin	199			200			200		
GTO Weight	11390			9545			9860		

TABLE 4-37. L-BAND TRANSPONDER CONFIGURATION AND WEIGHT SUMMARY FOR BANDWIDTH LIMITED CAPABILITY

Parameter	Values for Antenna Aperture of		
	5 meters	10 meters	15 meters
Eclipse Operation (percent)	100	100	100
Channels Supported	2280	6840	13965
RF Power per Channel (watts)	1.45	0.36	0.16
RF Power per Beam (watts)	413.3	102.6	45.6
Beams	8	24	49
Beam Electronics Installed	12	28	56
Amplifier Efficiency (percent)	23	26	26
Life (years)	7	7	7
Margin (pounds)	199	200	200
GTO Weight (pounds)	11390	9545	9860

Weight Summary (pounds)									
Unit	Unit Wt.	Qty.	S/C Wt.	Unit Wt.	Qty.	S/C Wt.	Unit Wt.	Qty.	S/C Wt.
Transponder Feed Assembly:									
Structure	149.0	1	149.0	149.0	1	149.0	149.0	1	149.0
Radiator Panels	380.4	1	380.4	262.7	1	262.7	245.4	1	245.4
Feed Panel	5.3	1	5.3	16.3	1	16.3	37.6	1	37.6
Feed Panel Support	47.3	1	47.3	38.5	1	38.5	21.4	1	21.4
Hinges	12.0	1	12.0	12.0	1	12.0	12.0	1	12.0
TOTAL			594.0			478.5			465.4
Transponder:									
Ku-Band Diplexer	0.6	1	0.6	0.6	1	0.6	0.6	1	0.6
Ku-Band Receiver	1.1	3	3.3	1.1	3	3.3	1.1	3	3.3
Signal Splitter	0.7	1	0.7	0.7	1	0.7	0.7	1	0.7
UHF Receiver/Frequency Translator	0.4	12	4.8	0.4	28	11.2	0.4	56	22.4
UHF Transmitter	34.0	12	408.0	11.5	28	322.6	6.6	56	367.2
UHF Diplexer	2.0	8	16.0	2.0	24	48.0	2.0	49	98.0
UHF Downlink Receiver	0.9	12	10.8	0.9	28	25.2	0.9	56	50.4
Signal Combiner	0.7	1	0.7	0.7	1	0.7	0.7	1	0.7
Ku-Band Upconverter	1.2	3	3.5	1.2	3	3.5	1.2	3	3.5
Ku-Band Preamplifier	1.0	3	3.0	1.0	3	3.0	1.0	3	3.0
Ku-Band SSPA (incl. EPC)	1.6	3	4.9	4.9	3	14.7	10.0	3	30.0
Waveguide Switches	0.3	12	3.6	0.3	12	3.6	0.3	12	3.6
Coaxial Switches	0.2	20	4.0	0.2	48	9.6	0.2	98	19.6
EPC (Up & Down Translator)	5.3	3	15.9	5.3	3	15.9	5.3	3	15.9
Master Oscillator	2.0	3	6.0	2.0	3	6.0	2.0	3	6.0
Miscellaneous	8.0	1	8.0	8.0	1	8.0	8.0	1	8.0
TOTAL			493.7			476.4			632.7
Communications Antenna:									
Reflector	32.7	1	32.7	78.4	1	78.4	137.1	1	137.1
Small Boom (incl. Can)	23.9	1	23.9	41.3	1	41.3	58.6	1	58.6
Large Boom (incl. Can)	47.9	1	47.9	82.5	1	82.5	117.2	1	117.2
Ku-Band Reflector (incl. Feed)	12.0	1	12.0	12.0	1	12.0	12.0	1	12.0
TOTAL			116.5			214.2			324.8

SECTION 5.0
COST ESTIMATES

5.1 MODELING TECHNIQUES AND ASSUMPTIONS

The Mobile Satellite Study cost modeling requirements were addressed using the RCA Heritage cost modeling technique, with specific new inputs in the antenna and transponder areas. The RCA Heritage cost modeling system is proprietary to RCA and draws heavily on the cost data generated on RCA commercial communications satellite programs. This model has proven to be a reliable predictor of space segment costs for both existing and new technology in communications satellite applications.

The Mobile Satellite cost models were structured using constant 1985 dollars for all satellite and ground equipments and 1989 dollars for launch costs (to compensate for the anticipated 4-year delivery of the first satellite). All satellite baseline models assume the 5800-pound GTO constraint imposed by the RCA Shuttle Compatible Orbit Transfer System (SCOTS) as a limiting factor on payload capability and are based upon use of the RCA 4000 series satellite bus.

5.2 SPACE SEGMENT MODEL

RCA has modeled three satellite configurations in each frequency band (UHF and L-Band). The configurations modeled vary as a function of antenna diameter and resultant transponder content. In all cases the system output is limited by the SCOTS weight constraint, and a 50-percent eclipse operation capability has been assumed for costing purposes.

The Lockheed wrap-rib antenna was used as the estimating baseline for the satellite cost models. The prices quoted by Lockheed have been represented to RCA as being the same as those recently quoted to JPL in conjunction with the Lockheed/JPL antenna study contract. This antenna represents the major cost and schedule driver to the satellite program.

The results of the RCA cost model by configurations are as presented in Table 5-1 and include all costs associated with development, production, and launch of two flight satellites including perigee stages (SCOTS). Launch costs include contractor provision of all satellite control functions required to place the satellite at its intended orbit location.

5.3 LAUNCH COSTS

The launch costs for the Mobile Satellite program were based upon currently published STS pricing guidelines for the 1988-1989 time frame, which indicate a price base for a full Shuttle at 87 million dollars in 1982 equivalent dollars. Assuming an annual inflation rate in the 6 percent range, the expected 1989 price for a full Shuttle would be approximately 50 percent higher than the 1982 base cost, or 130.5 million dollars.

TABLE 5-1. JPL MOBILE SATELLITE COST MODEL OUTPUT BY CONFIGURATION

	UHF			L-BAND		
Parameter	A	B	C	D	E	F
Antenna Diameter	20 M	15 M	10 M	15 M	10 M	5 M
Active Transponder Channel and RF Power	24 @ 20 W	12 @ 81 W	8 @ 143 W	49 @ 13 W	24 @ 47 W	8 @ 163 W
Redundancy	32 for 24	18 for 12	12 for 8	56 for 49	32 for 24	12 for 8
Eclipse Capability	50%	50%	50%	50%	50%	50%
Spacecraft Weight (Pounds)	5800	5800	5800	5800	5800	5800
Life (Years)	7	7	7	7	7	7
Equivalent 5-kHz Channels/ Satellite	4675	5675	3090	3915	3125	900
Satellite Cost (2) (with SCOTS)	$169 M	$155M	$146 M	$194 M	$163 M	$141 M

The Mobile Satellite cargo element charge factor (CF_L) will be driven by the length of the satellite and will vary as a function of the communications antenna diameter selected. The calculated cost to launch a Mobile Satellite is shown in Table 5-2. Note that the calculated weights of the JPL element is approximately 19,000 pounds and that significant economies might be realized if the satellite were co-manifested with NASA payloads whose charge factors were highly driven by weight.

5.4 GROUND SEGMENT COSTS

The Ground Segment cost to support and operate the Mobile Satellite systems is made up of three major elements; namely, satellite control equipment (TT&C/ SCC), communications and processing equipment, and yearly operations cost. The ground segment costs are summarized in Table 5-3. Cost assumptions regarding the three elements listed above are as follows:

- Satellite Control - The Mobile Satellite system will require a Satellite Control Center (SCC) and a Telemetry, Tracking, and Command site similar

TABLE 5-2. MOBILE SATELLITE LAUNCH COSTS

Parameter	20 M Antenna	15 M Antenna	10 M Antenna	5 M Antenna
Required STS Length	29.0 ft	27.5 ft	26.0 ft	24.5 ft
STS CL_L	0.645	0.611	0.578	0.544
STS CF_W	0.39	0.39	0.39	0.39
1989 STS Launch Cost (per Satellite)	\$84.2 M	\$79.7 M	\$75.4 M	\$71.0 M
Allowable Cargo Element Weight*	31,400 lb	29,800 lb	28,200 lb	26,500 lb
Actual Cargo Element Weight	19,000 lb	19,000 lb	19,000 lb	19,000 lb

*Total weight allowable at selected charge factor (CF_L).

TABLE 5-3. MOBILESAT GROUND SEGMENT COST SUMMARY

Item	Cost (Million Dollars)					
Satellite Description (from Table 5-1)	A	B	C	D	E	F
TT&C/SCC Cost	12.0	12.0	12.0	12.0	12.0	12.0
Communications Equipment	21.3	24.9	14.5	17.9	14.8	5.8
Civil Works	2.0	2.0	2.0	2.0	2.0	2.0
7 Years Operation Cost	21.0	21.0	21.0	21.0	21.0	21.0
Total	56.3	59.9	49.5	52.9	49.8	40.8

in configuration to those employed by most commercial satellite operators (including communications test and monitoring equipment). These functions can be collocated to reduce land a building cots, and all in-orbit control functions can be accomplished using step track antennas. The cost model assumes that the land, civil works, and power (including an uninterruptable power supply) would be provided by the customer (at a cost of 1 million dollars), and all other equipments would be provided by the satellite contractor.

- Communications and Processing Equipment - The communications gateway station and other networking elements are peculiar to the Mobile Satellite system market and represent a program-peculiar requirement. The cost model assumes that this element of the ground system would be provided by the customer), and no contractor loadings or integrations have been included. The basic switching and processing equipment required for this element is similar to that used in a standard telephone system. The major variable cost is that associated with providing individual multiplexing for each 5-kHz channel in the system. The rule-of-thumb estimate in the telecommunication industry for this equipment is 4,000 dollars per channel. The cost model has been constructed using a fixed cost of 2.2 million dollars for switching and signal conditioning equipment, and a variable cost of 4,000 dollars per 5-kHz channel for multiplexing equipment. Land, building, and power were assumed to be furnished by the customer and are included in the amount of 1 million dollars.

- Yearly Operations - The operational phase is modeled as a customer operated effort and includes staffing on a 7-day per week around-the-clock basis for each major Ground Segment element. Normal maintenance for civil works, including heat and power, and routine maintenance of all Ground Segment equipment are included in the estimated cost of 3.0 million dollars per year for this function.

5.5 SUMMARY COST MODEL

The integrated cost model for the Mobile Satellite system is presented in Table 5-4. The total model represents the price to procure, launch, and operate a two-satellite system for a period of 7 years. The cost per channel year is based on only one satellite operating over the 7 years. Note that, to take advantage of the full channel capability of both satellites, the Ground Segment costs would have to be increased to provide for the increased channel capacity.

TABLE 5-4. MOBILESAT SYSTEM COST MODEL SUMMARY

Item	Value					
Satellite Configuration (From Table 5-1)	A	B	C	D	E	F
Space Segment Cost (2 Satellites)	\$169 M	\$155 M	\$146 M	\$194 M	\$163 M	\$141 M
Launch Cost (STS) (2 Launches)	\$168 M	\$159 M	\$151 M	\$159 M	\$151 M	\$142 M
Ground Segment Cost	\$ 56 M	\$ 60 M	\$ 50 M	\$ 53 M	\$ 50 M	\$ 41 M
Total	\$393 M	\$374 M	\$347 M	\$406 M	\$364 M	\$324 M
Number of 5-kHz Channels/Satellite	4675	5675	3090	3915	3125	900
\$ Per Channel Year (1 Satellite Operating)	\$11.8 K	\$9.4 K	\$16.0 K	\$14.8 K	\$16.5 K	\$51.0 K

APPENDIX A
REFERENCES

1. "Land Mobile Satellite Service (LMSS)", Part II, Technical Report, JPL Publication 82-19, Firouz Naderi, Editor, February 15, 1982.

2. M. K. Sue, "Second Generation Mobile Satellite System", August 29, 1984. (Internal JPL 23-page stapled document)

3. "A Brief Description of the Second Generation Mobile Satellite System, Its Operation, Requirements and Assumptions". (Internal document from JPL, 17 pages, stapled, provided to RCA August 29, 1984.)