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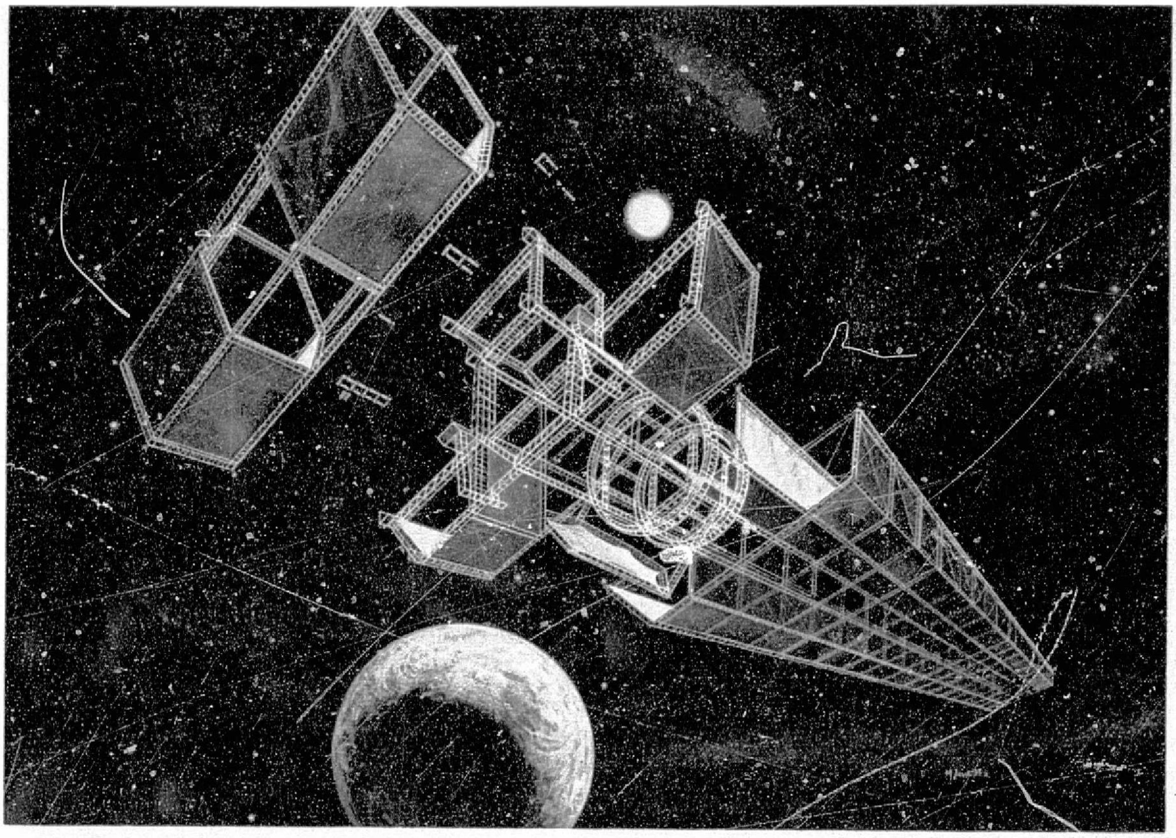

Satellite Power Systems (SPS) Concept Definition Study

FINAL REPORT

VOLUME II

SPS SYSTEM REQUIREMENTS

April 1978

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Rockwell International
Space Division

FOREWORD

This document, *SPS System Requirements*, is Volume II of the SPS Concept Definition Study (Contract NAS8-32475), Exhibits A and B, and also incorporates results of NASA/MSFC in-house effort. Other volumes of the final report that provide additional detail are listed below.

Volume	
I	Executive Summary
III	SPS Concept Evolution
IV	SPS Point Design Definition
V	Transportation and Operations Analysis
VI	SPS Technology Requirements and Verification
VII	SPS Program Plan and Economic Analysis

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1.0 SCOPE/GENERAL REQUIREMENTS

1.0 SCOPE/GENERAL REQUIREMENTS

1.1 INTRODUCTION

This volume of Satellite Power Systems (SPS) Concept Definition Study Final Report summarizes the basic requirements used as a guide to systems analysis and is a basis for the selection of candidate SPS point design(s). Initially, these collected data reflected the level of definition resulting from the evaluation of a broad spectrum of SPS concepts. As the various concepts matured these requirements were updated to reflect the requirements identified for the projected satellite system/subsystem point design(s).

The first half of the study established several candidate concepts which were presented to the NASA for their review and to provide a basis for the selection of one or two approaches that would be given a more comprehensive examination. The two selected concepts were expanded and constitute the selected system point designs. This volume emphasizes the identified system/subsystem requirements and provides information on the selected point design only where it was felt to be necessary to clarify the stated subsystem requirements. A more detailed presentation on the selected point designs is given in Volume IV of the SPS Final Report.

Figure 1.1-1 establishes the relationship of the satellite system data presented in this document with other elements of the SPS program. Discussions relative to these associated program elements (rectenna, transportation, etc.) are provided only, and to the extent necessary, to clarify or define subsystems forming the satellite system.

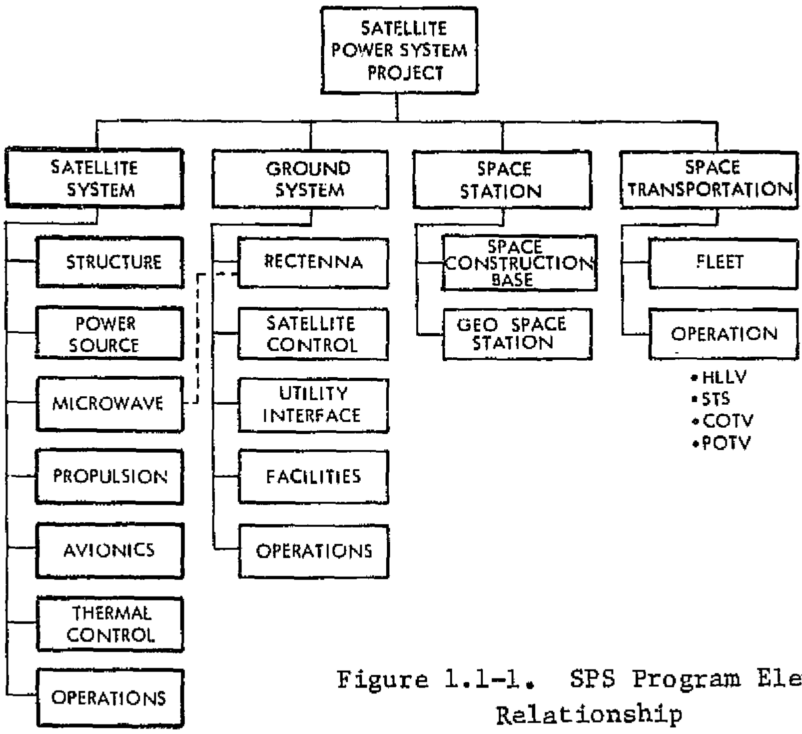

Figure 1.1-1. SPS Program Element Relationship

Figure 1.1-2 indicates various subsystems and their relationship to the satellite and to each other. The rectenna system is identified and shown to

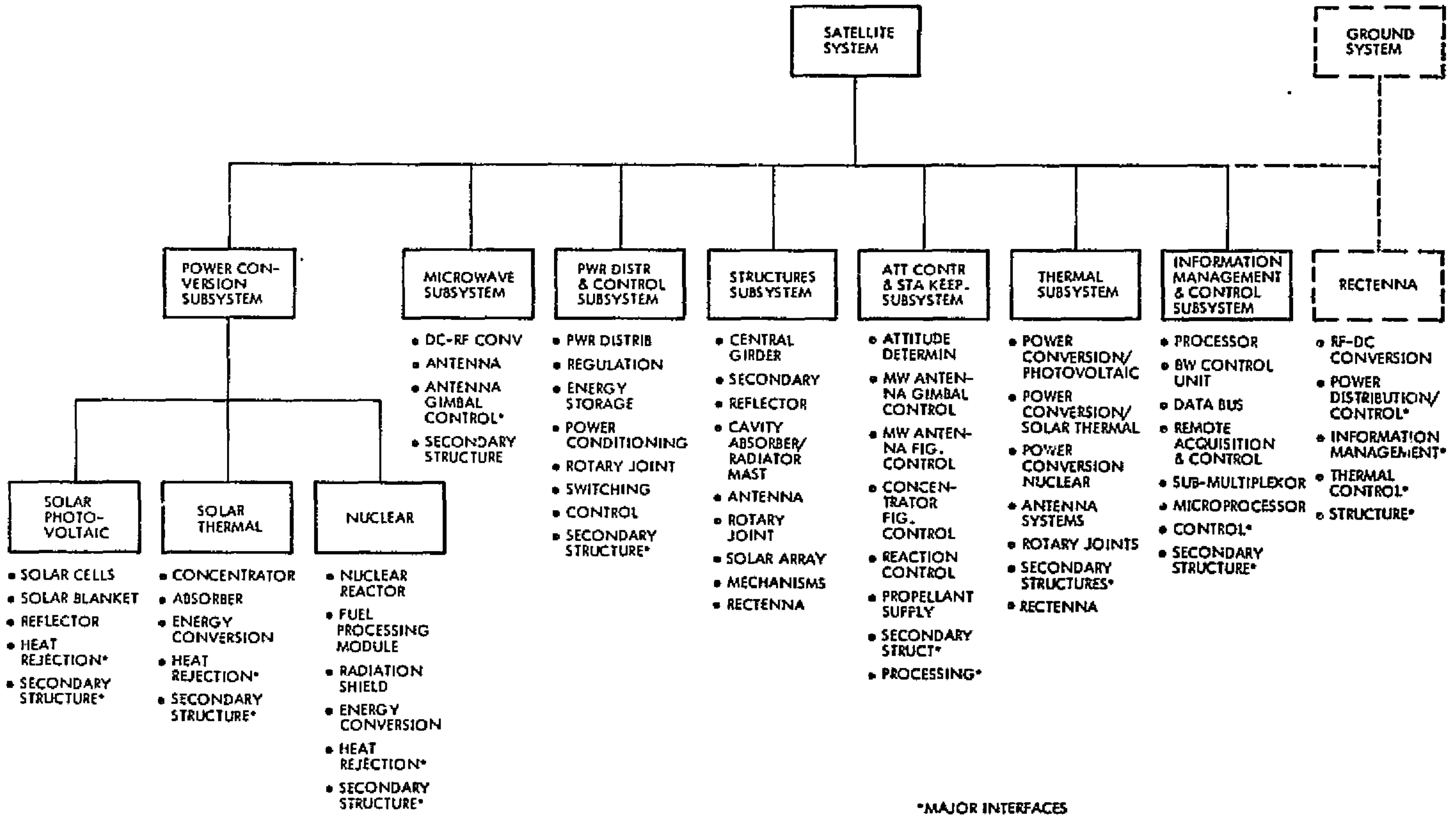

Figure 1.1-2. Subsystem/Satellite System Relationship

have an indirect (dotted) relationship to the orbiting satellite. Major assemblies comprising each subsystem are identified. Unique factors such as elements of one subsystem that are integrated with another (for example, thermal radiators, subsystem control, etc.) are also identified. This document will also identify supporting subsystems, including the transportation system and SPS related ground facilities where these elements have been identified and evaluated.

1.2 SATELLITE POWER SYSTEM CONCEPTS

1.2.1 CANDIDATE CONCEPTS

Six satellite concepts were identified for consideration at the mid-term briefing. These concepts are shown in Figure 1.2-1. A single rectenna farm concept was assumed, applicable to all satellite concepts.

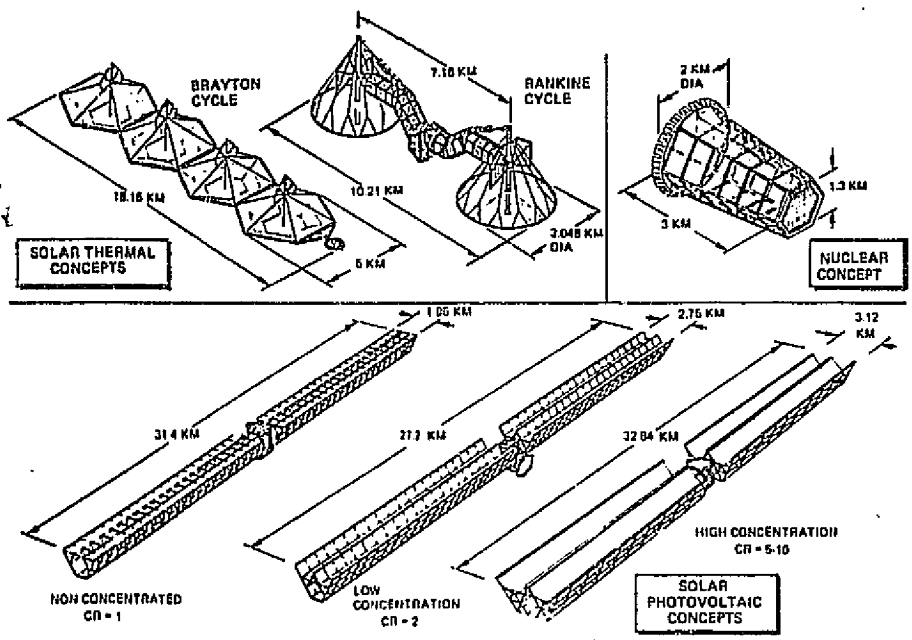

Figure 1.2-1. SPS Conceptual Configuration (Mid-Study)

<u>Solar Photovoltaic (CR-1)</u>

Figure 1.2-2 illustrates the solar photovoltaic (CR-1) satellite power system concept. The CR-1 system was a planar array and had an overall planform dimension of 2.0x28.58 km. The depth of the satellite was 1.17 km. This system required 48.99 km^2 of deployed solar cell area and had a total mass of 37.3×10^6 kg, including a 30.7 percent growth factor. The major advantages of the CR-1 configuration were its simplicity of design; it did not require reflectors; and its relative insensitivity to misorientation angles of as much as $\pm$ 3 degrees. The CR-1 configuration would have had the largest solar cell area and mass in orbit.

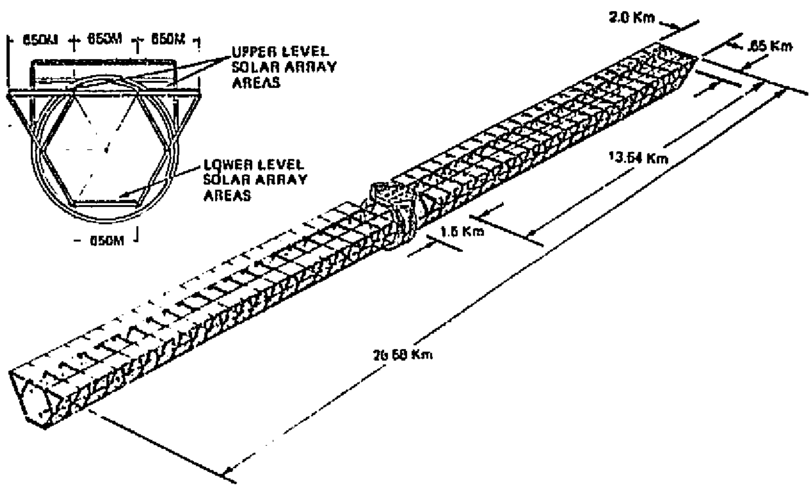

Figure 1.2-2. Solar Photovoltaic Satellite (CR-1) (Mid-Study)

Solar Photovoltaic (CR-2)

Figure 1.2-3 illustrates the solar photovoltaic (CR-2) satellite power system concept. The CR-2 system used reflector membranes to concentrate solar energy on the cells. The satellite had two "Vee" troughs per wing. The overall planform dimensions were 2.75x27.16 km, and the depth was 1.2 km. This system required 23.76 km^2 of deployed solar cell area and had a total

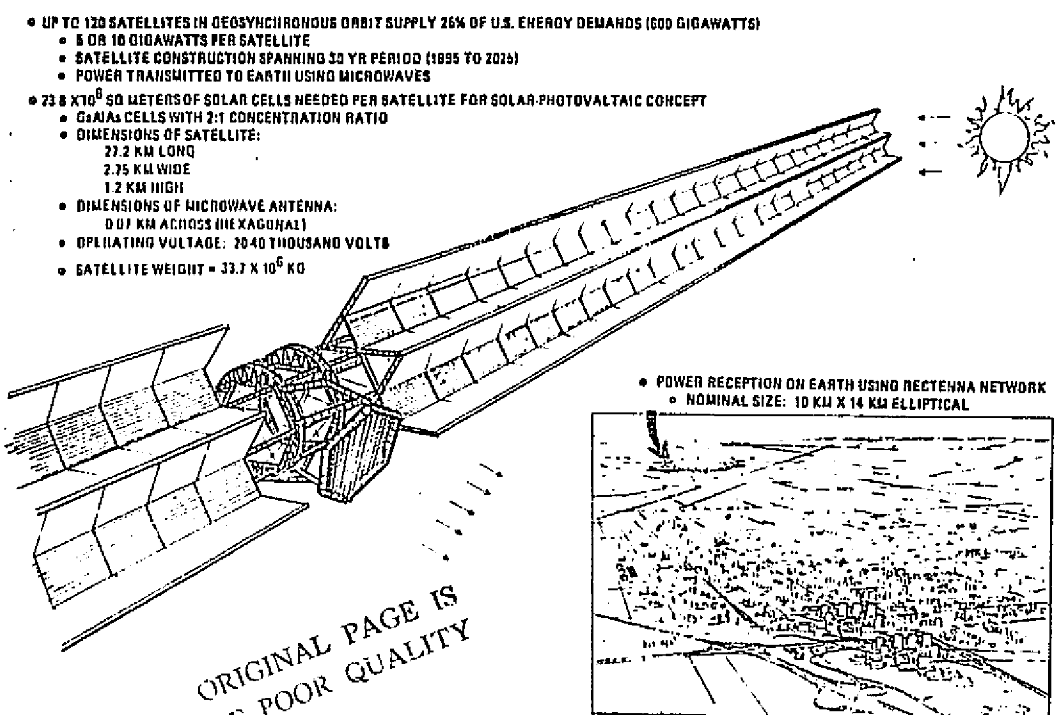

Figure 1.2-3. Solar Photovoltaic Satellite (CR-2) (Mid-Study)

mass of 33.7×10^6 kg, including a 30-percent growth factor. The major advantages of the CR-2 configuration were the reduced requirement for solar cells and low weight which reduced overall cost. The disadvantages were the planform of the satellite was higher than for CR-1 and the system was sensitive to misorientation. A $\pm$ 1 degree misorientation of the solar array required an additional 7.9 percent of reflector surface area. The reflective membranes for the GEO environment was not available, and reflectivities of 90 percent at the beginning of life and 72 percent at the end of life were used in the design.

Solar Photovoltaic (CR-5)

Figure 1.2-4 illustrates the solar photovoltaic (CR-5) satellite power system concept. The CR-5 system had two troughs per wing and used reflector membranes to concentrate solar energy on the cells. The satellite had the overall planform dimension of 3.12x32.84 km and the depth was 1.4 km. This system required 10.4 km^2 of deployed solar cell area and had a total mass of 37.4×10^6 kg, including a 31.2-percent growth factor. The CR-5 system required the lowest solar cell area. The CR-5 configuration was very sensitive to misorientation angles of only $\pm$ 1 degree. At a geometric concentration ratio of 5, an increase in reflector surface of 43 percent was required to compensate for a misorientation of $\pm$ 1 degree.

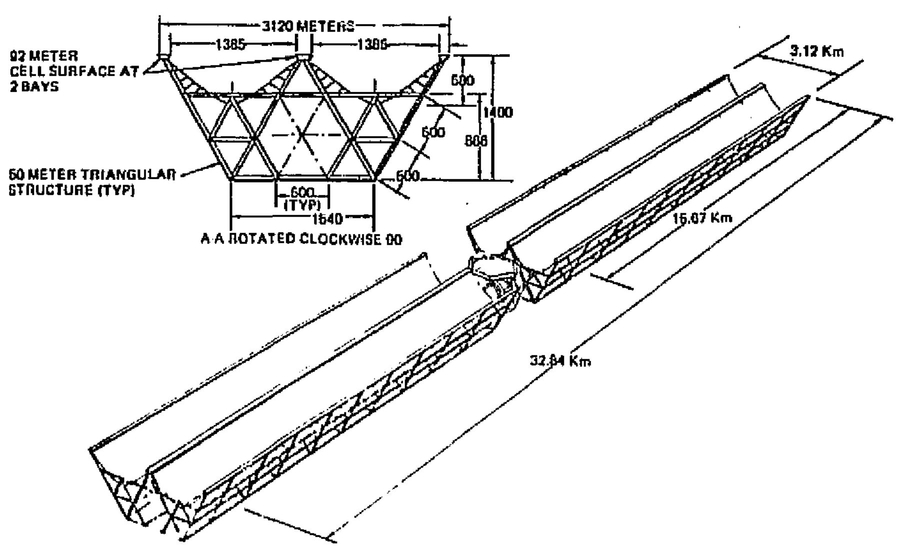

Figure 1.2-4. Solar Photovoltaic Satellite (CR-5) (Mid-Study)

Solar Thermal - Brayton

Figure 1.2-5 shows one Boeing concept for a 10-GW solar thermal SPS. It used four concentrator modules, each composed of thousands of planar facets which reflect sunlight into a cavity absorber. Ceramic tubing in the absorber heated pressurized helium to 1379°C (2514°F) which was supplied to a Brayton cycle power module comprised of a turbine, regenerator, cooler, compressor, and electrical generator. Heat rejected from the cycle was dissipated by

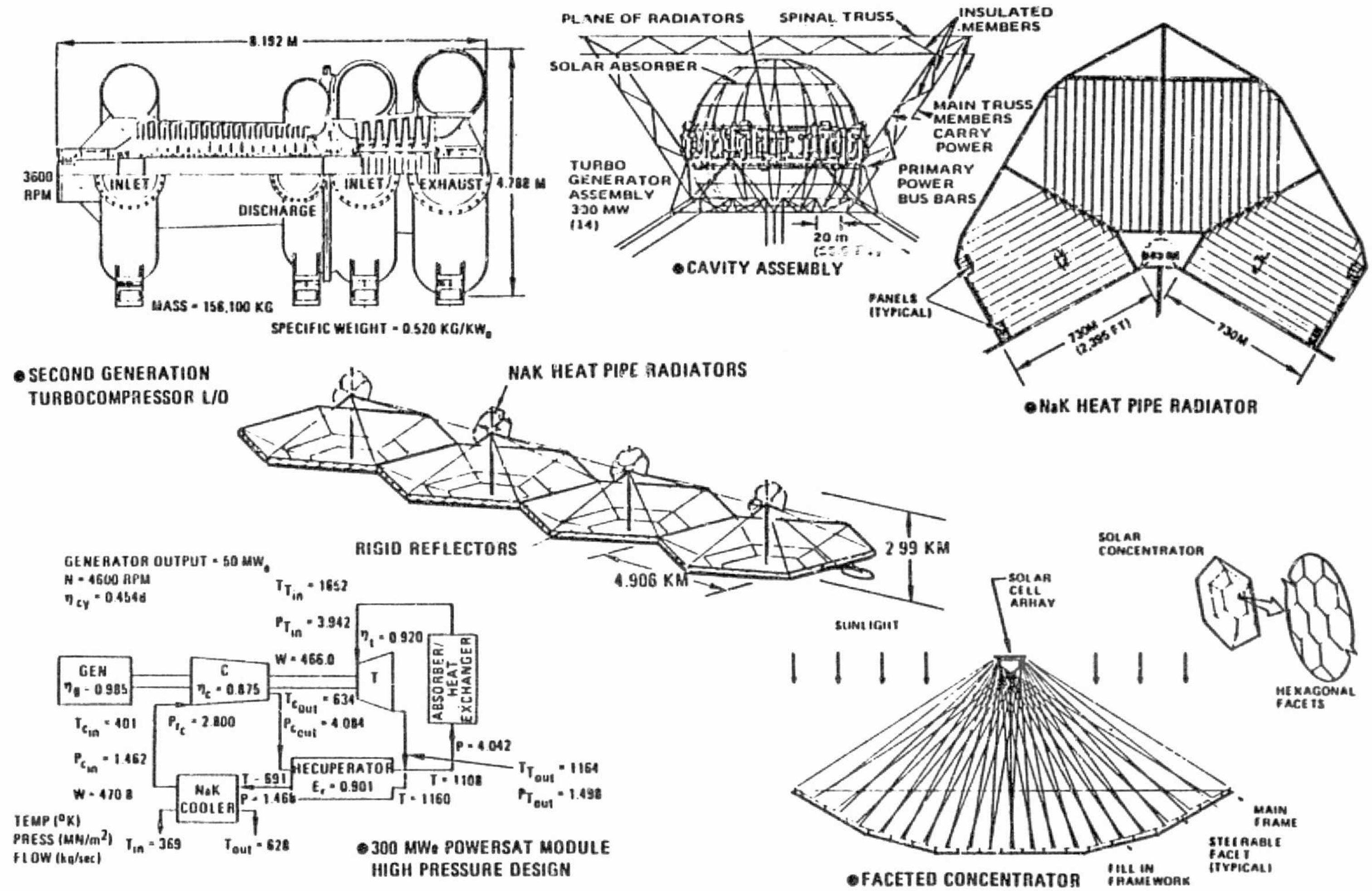

Figure 1.2-5. Solar Thermal Brayton (Boeing) 10 GW

means of a NaK loop to a heat pipe/fin radiator. Microwave power was transmitted from a single antenna at the end of the satellite.

Solar Thermal - Rankine

Figure 1.2-6 shows a Rockwell concept for a 5-GW solar thermal SPS using a cesium Rankine cycle. The two concentrators were inflatable, using aluminized plastic film with a transparent canopy. Sunlight was concentrated on an open-disc absorber (cesium boiler) which provides cesium vapor at 1038°C (1900°F) to cesium turbines. Exhaust from the cesium turbines was condensed at 400°F in a tube/fin radiator. Each of the concentrator modules was hinged to permit seasonal tracking of the sun without imposing gravity gradient torques on the satellite. The beam connecting the two modules was offset to locate the rotary joint at the satellite center of gravity.

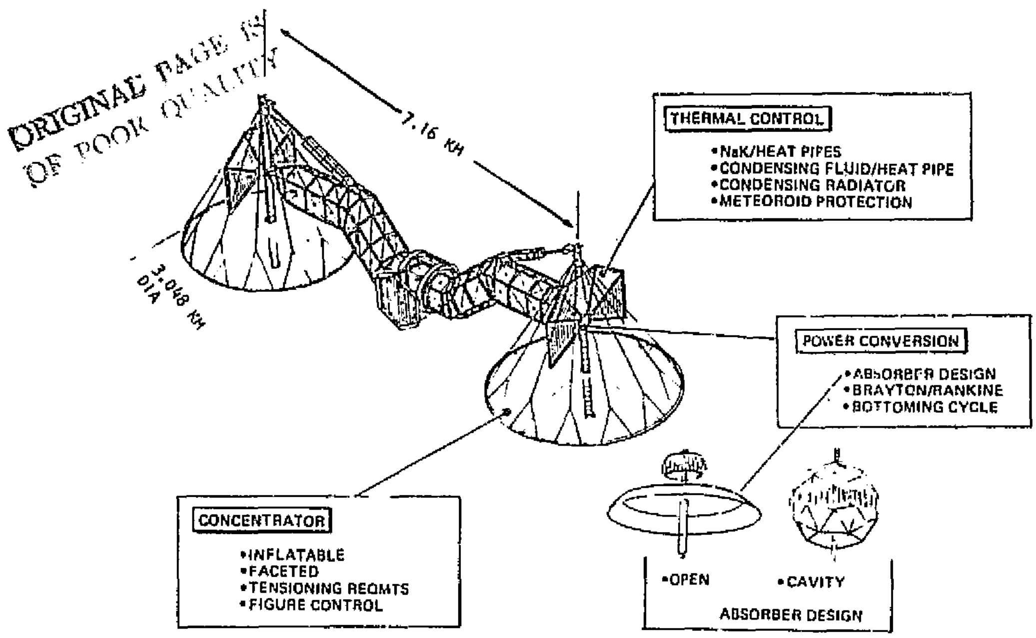

Figure 1.2-6. Solar Thermal - Rankine (Mid-Study)

Nuclear - Brayton

Figure 1.2-7 illustrates the nuclear-powered satellite power system concept. The nuclear Brayton powered SPS consisted of 26 power modules configured in a circular array 2 km in diameter. The antenna was separated by a distance of 3 km from the power modules. In this manner, reactor shadow shielding and reactor-close plane separation distance were combined to reduce nuclear radiation at the antenna to a level acceptable to maintenance personnel. Each power module generated 344 MW_e to provide the required power at the distribution bus as well as its own housekeeping requirements. Brayton

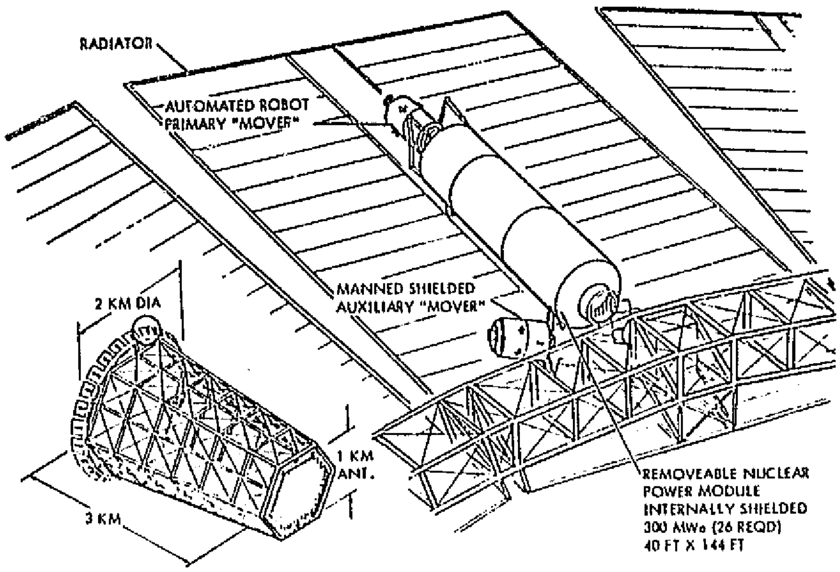

Figure 1.2-7. Nuclear - Brayton

cycle waste heat was rejected by a square radiator measuring 227 meters (750 feet) on each side (26 required). Each power module was approximately 40 feet in diameter and 144 feet in length, and contained one nuclear reactor with shadow shield, fuel reprocessing assembly, and two closed Brayton cycle power conversion units. The power module could be removed from the radiator for replacement by remotely operated equipment.

Mass Properties

Tables 1.2-1 through 1.2-3 present the summary weights for the six initial candidate satellite concepts. The solar thermal weight summary illustrates the known weight elements for both potassium-(K) and cesium-(Ce) based Rankine thermal cycles.

Rectenna

The ground receiver or rectenna transforms the transmitted radio frequency energy to dc current for distribution into the utility network. The area covered by a 5-gigawatt (GW) delivered power rectenna rate is shown for a typical city (Figure 1.2-3). The rectenna formed an ellipse that is approximately 6x10 km. An additional 4 km in radial length was provided to the security fence to assure a safe level of radiation outside the fence.

1.2.2 SELECTED SYSTEM CONCEPTS

The two concepts selected for further evaluation and definition were a photovoltaic (CR-2) approach and a variation of the proposed Rockwell Solar Thermal satellite. A summary description of the two selected point designs are given in the following two paragraphs. Both these concepts are described in greater detail in Volume IV, Point Design, of the SPS Final Report.

In addition the selected rectenna point design which differs slightly from the previous concept is briefly described below and in more expanded form in Volume IV.

Table 1.2-1. Solar Photovoltaic Weight Summary (GaAlAs Solar Cells) (Mid-Study)

CONCENTRATION RATIO	CR = 5 10^6 KG	CR = 2 10^6 KG	CR = 1 10^6 KG	GROWTH %
COLLECTOR ARRAY (NON ROT.)	(18.363)	(15.465)		(38.3)
PRIM./SEC. STRUCT./MECH.	9.306	3.993	2.805	25.0
ATTITUDE CONTROL	.300	0.212	.375	30.0
SOLAR CELLS	3.297	5.990	12.343	24.7
REFLECTORS	2.182	2.052	N/A	15.0
POWER CONDIT.	.387	.387	.387	50.0
WIRE HARNESS/SLIP RING	2.891	2.891	2.469	97.0
ANTENNA (ROTATING)	(9.794)	9.794	9.794	(23.1)
PRIM./SEC. STRUCT./MECH.	.268			25.0
COOLING	.200			50.0
PWR CONVERTERS	5.690			20.0
WIRING/SLIP RING	.096	SAME	SAME	94.0
WAVEGUIDES	3.540			20.0
IMS EQMT/CABLING	.240	.240	.240	88.0
PROPELLANT/YEAR	.100	.100	.100	0
SUBTOTAL SATELLITE SYST.	28.497	25.599	28.513	
GROWTH ALLOWANCE	8.882	8.115	8.766	31.2
TOTAL SATELLITE SYST.	37.379	33.714	37.279	

COMPARABLE SILICON CR = 1
WEIGHT = 48.589 X 10^6 KG

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Table 1.2-2. Solar Thermal Weight Summary (Mid-Study)

CONVERSION CONCEPT	BRAYTON (10^6 KG)	RANKINE POTASSIUM (10^6 KG)	RANKINE CESSIUM (10^6 KG)	RANKINE GROWTH %
COLLECTOR ARRAY (NON-NOT)	(22.846)	(31.178)	(22.559)	
PRIM./SEC. STRUCT./MECH.	2.217	2.217	2.139	25.0
ATTITUDE CONTROL	.200	.200	.200	30.0
SOLAR COLLECTOR	.878	1.200	1.109	24.4
SOLAR ABSORBER	2.600	.230	.230	30.0
TURBO-EQUIP /GEN	4.990	14.100	5.650	30.0
POWER CONDIT	1.839	1.839	1.839	50.0
WIRE HARNESS/SLIP RING	1.262	1.262	1.262	100
RADIATORS	8.860	10.130	10.130	30.0
ANTENNA (ROT)	9.794	9.794	9.794	23.1
IMS EQMT/CABLING	.240	.240	.240	75.0
PROPELLANT/YEAR	.100	.100	.100	0
SUBTOTAL SATELLITE SYST	32.980	41.312	32.693	
GROWTH ALLOWANCE	10.182	12.566	10.087	30.8
TOTAL SATELLITE SYST	43.162	53.878	42.780	

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Table 1.2-3. Nuclear Reactor Concept Weight Summary

	(10^6 KG)		GROWTH %
PRIMARY STRUCTURE	0.361		25.0
SEC. STRUCT.	1.112		25.0
ATTITUDE CONTROL	0.20		30.0
SHEILDING	0.54		30.0
REACTORS (26)	2.06		30.0
FUEL PROCESSING	1.01	20.73*	30.0
TURBO-EQUIPMENT	3.34		30.0
GENERATORS	1.83		30.0
RADIATORS	11.94		30.0
POWER CONDIT.	1.839		50.0
WIRE HARDNESS	0.60		100
ANTENNA	9.88		23.1
IMS EQUIP.	0.061		50.0
IMS CABLING ITS	0.179		100
PROPELLANT/YEAR	0.10		0
SUBTOTAL	35.052		–
GROWTH ALLOWANCE	10.411		29.6
TOTAL SATELLITE SYST.	45.463		

CONCEPT WEIGHT COMPARISONS			
POWER CONVERSION CONCEPT	BASE WEIGHT (10^6 KG)	GROWTH (%)	TOTAL WEIGHT (10^6 KG)
CR = 1	28.513	30.7	37.279
2	25.599	30.0	33.714
5	28.497	31.2	37.379
RANKINE CS/STEAM	26.386	31.2	34.605
NUCLEAR	35.056	29.6	45.465

*GASEOUS CORE REACTOR/MHD COULD POTENTIALLY REDUCE THIS TO 1.99 X 10^6 KG – REFERENCE: 8TH IECEC PAPER 739018, 1973

RADIATOR OPTIMIZATION COULD POTENTIALLY REDUCE THIS TO 14.95 X 10^6KG - CONDENDING STEAM RADIATOR (LOWER TEMPERATURE)

Solar Photovoltaic (CR-2)

The GaAlAs photovoltaic point design satellite power system concept is shown in Figure 1.2-8. The system utilizes aluminized reflector membranes to concentrate the solar energy on the cells. The satellite solar reflectors produce a concentration ratio of CR-2. The satellite employes the "Vee trough" configuration and has three troughs per wing. The system has an overall efficiency of 6.08% and delivers 5 GW of electrical energy to the utility company on the ground. The overall planform dimensions are 3.85x21.3 km, and the depth is 1.69 km. The satellite has a mass of 36.56×10^6 kg which includes a 30% growth factor for the mass. The system requires $30.6 \times 10^6 m^2$ of solar cells and $61.2 \times 10^6 m^2$ of reflector surface. The solar cells for the point design are GaAlAs cells rated at 20% efficiency at AMO and 28°C. The solar array blanket mass is 0.2525 kg/m^2.

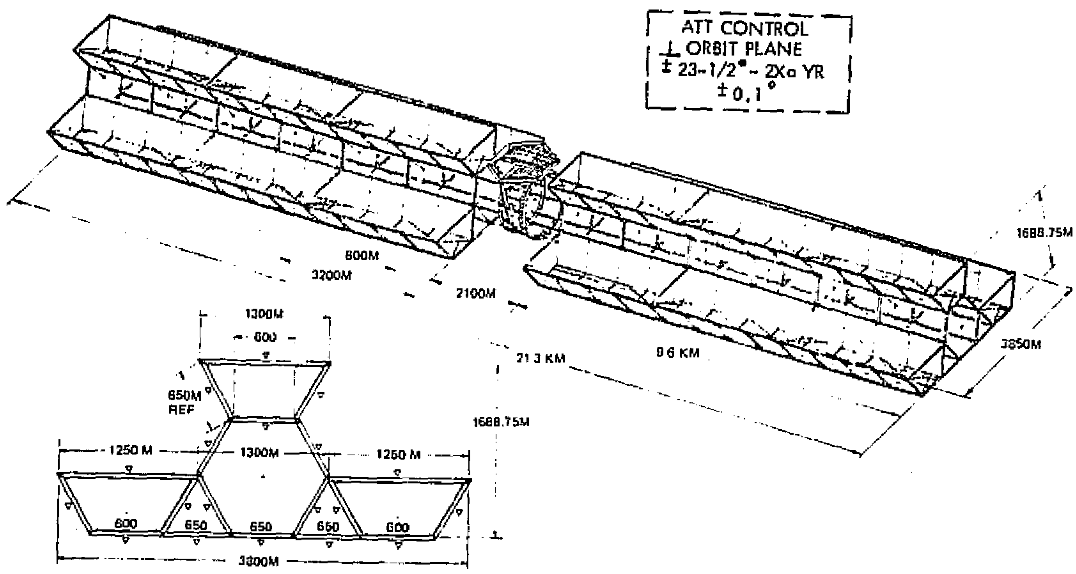


Figure 1.2-8. Solar Photovoltaic Satellite (CR-2) 5 GW

Solar Thermal - Rankine

Figure 1.2-9 shows the Rockwell point design concept of a 5-GW solar thermal SPS using a cesium/steam Rankine cycle. The two concentrators are of an inflatable design, using aluminized plastic film with a transparent canopy. Sunlight is concentrated on an open-disc absorber (cesium boiler) which provides cesium vapor at 1260°C (2300°F) to cesium turbines. Exhaust from the cesium turbines is condensed at 593°C (1100°F) on the outside of steam boiler tubes which produce steam at 538°C (1000°F) and 16.6 kN/m^2 (2400 psia) to a bottoming steam turbine. Exhaust from the steam turbines is condensed at 204°C (400°F) in a tube/heat pipe/fin radiator.

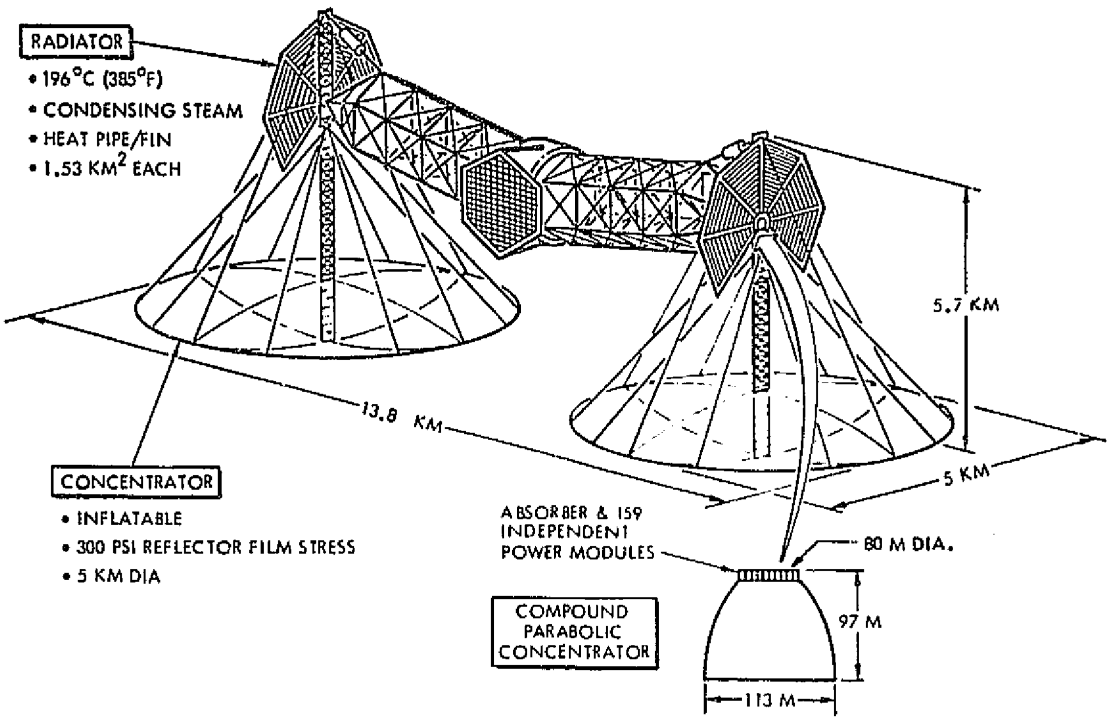


Figure 1.2-9. Solar Thermal - Rankine (5 GW)

Each of the concentrator modules is hinged to permit seasonal tracking of the sun without imposing gravity gradient torques on the satellite. The beam connecting the two modules is offset to locate the rotary joint at the satellite center of gravity. This permits mounting of thrusters on the rotary joint and facilitates their orientation during LEO/GEO orbital transfer.

Rectenna

The rectenna concept selected for further definition is illustrated in Figure 1.2-10. The receiving antenna forms an eclipse with major and minor axis of 13 km and 10 km respectively. The major axis is aligned along the N-S geographic line. Figure 1.2-11 illustrates the general site concept recommended by the study to date.

Mass Properties

Table 1.2-4 and 1.2-5 present a summary of the estimated weight for the two point design concepts.

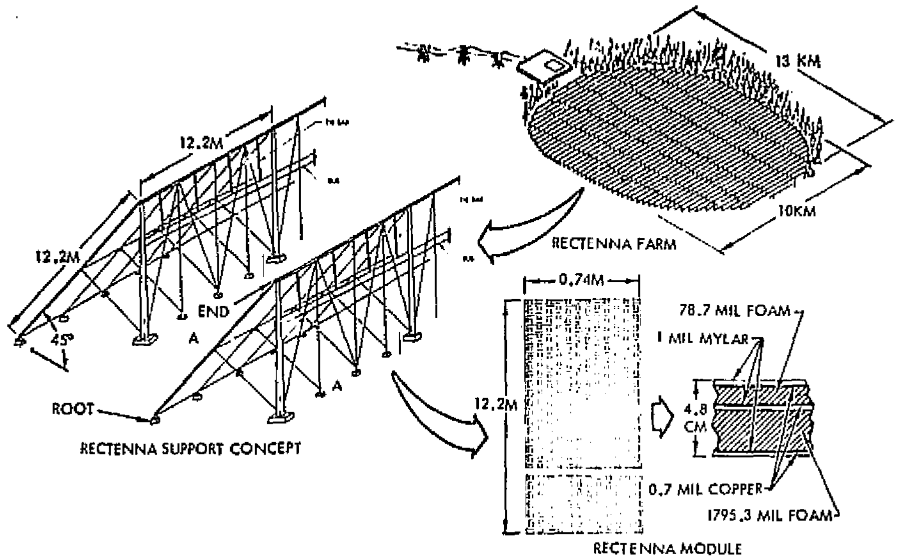


Figure 1.2-10. Microwave Transmission Subsystem - Rectenna

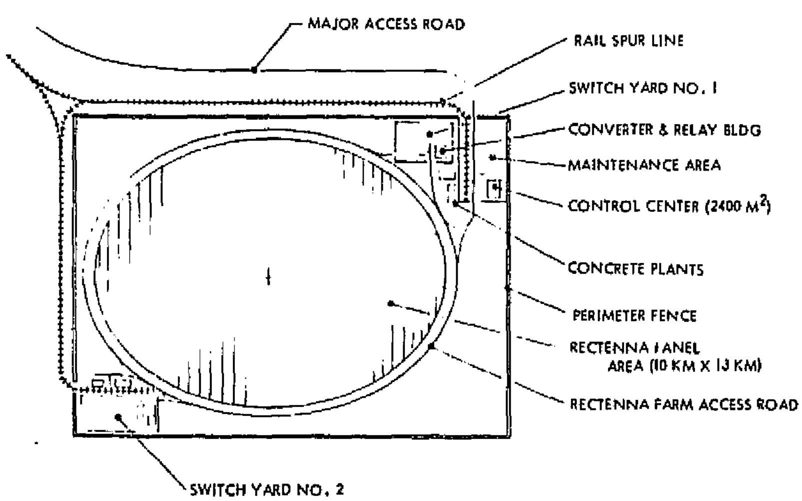


Figure 1.2-11. Rectenna Site Concept

Table 1.2-4. Photovoltaic (CR-2) Satellite Mass Statement - Point Design

Subsystem	Weight (Million kg)
Collector array	
Structure and mechanisms	3.777
Power source	8.831
Power distribution and control	1.166
Attitude control	0.095
Information management and control	0.050
Total array (dry)	(13.919)
Antenna section	
Structure and mechanisms	1.685
Thermal control	1.408
Microwave power	7.012
Power distribution and control	3.469
Information management and control	0.630
Total antenna section (dry)	(14.204)
Total SPS dry weight	28.123
Growth (30%)	8.437
Total SPS dry weight with growth	36.560
Propellant per year	0.040

Table 1.2-5. Solar Thermal Satellite Mass Statement - Point Design

SUBSYSTEM	WEIGHT (MILLION KG)
COLLECTOR ARRAY	
STRUCTURE AND MECHANISMS	1.661
POWER SOURCE	3.120
POWER DISTRIBUTION AND CONTROL	4.304
ATTITUDE CONTROL	0.095
THERMAL CONTROL	8.786
INFORMATION MANAGEMENT AND CONTROL	0.050
TOTAL ARRAY (DRY)	(18.016)
ANTENNA SECTION	
STRUCTURE AND MECHANISMS	1.685
THERMAL CONTROL	1.408
MICROWAVE POWER	7.012
POWER DISTRIBUTION AND CONTROL	3.469
INFORMATION MANAGEMENT AND CONTROL	0.630
TOTAL ANTENNA SECTION	(14.204)
TOTAL SPS DRY WEIGHT	32.220
GROWTH (30%)	9.666
TOTAL SPS DRY WEIGHT WITH GROWTH	(41.886)
PROPELLANT PER YEAR	0.040

1.3 TRANSPORTATION SYSTEM

Figure 1.3-1 illustrates one of several candidate transportation flight operations designed to deliver cargo to geosynchronous (GEO) orbit for SPS construction. The system consists of two types of vehicles, the Heavy Lift Launch Vehicle (HLLV) and the Cargo Orbital Transfer Vehicle (COTV). The HLLV is an aeromaneuverable boost vehicle employing both airbreathing and LO_2/LH_2 engines, which takes off and lands in the horizontal position. Its payload capability of 91,000 kg (30m x 10m x 6m) is sized to carry cargo and stages of the COTV. For each payload package delivered to GEO orbit, three HLLV missions are required to low earth orbit (LEO) (300 nmi at zero-degree inclination), two to transport the COTV stages to orbit, and one to boost the payload package. The two COTV stages and the payload are then mated and boosted to GEO orbit. Each COTV stage returns to LEO orbit and is picked up by a later (empty) HLLV for return to earth, where it and the HLLV are refurbished for future missions. The transportation concepts selected for further evaluation are described in Final Report, Volume V.

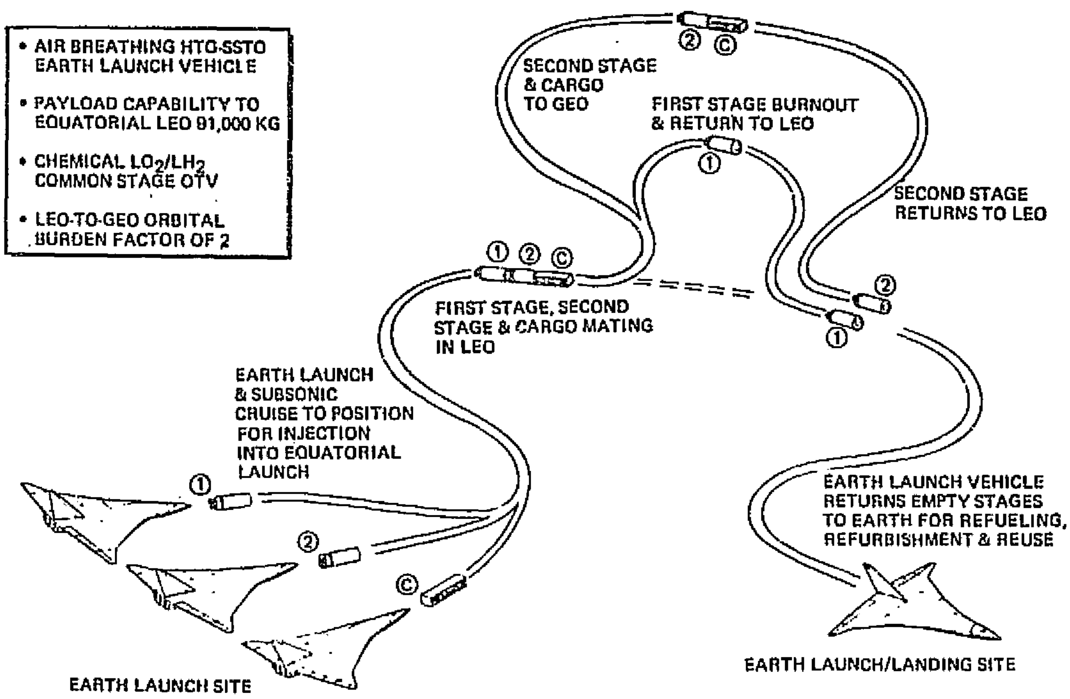


Figure 1.3-1. Transportation System (Typical)

1.4 PROGRAM GROUND RULES

Table 1.4-1 shows the program ground rules that affected the development of requirements. Table 1.4-2 shows the general requirements describing the overall SPS program.

Table 1.4-1. Program Ground Rules

IOC Date:	1998
Maximum Program Size:	2005 - 170 GW 2025 - 600 GW
Medium Program Size:	2005 - 55 GW 2025 - 335 GW
Minimum Program Size:	2005 - 40 GW 2025 - 140 GW
30 Year System Life	
Costs - 1977 Constant Dollars (7.5% Discount Rate)	
1985 Technology Base	
Systems available in the 1980's: - Shuttle - IUS - OTV	

Table 1.4-2. General Requirements Describing the Overall SPS Program

Programmatic	Technology
ENERGY SOURCE - Solar and/or nuclear	*OUTPUT POWER* - Power level is defined as constant power level (except during solar eclipse) at utility interface (5 GW)
CAPACITY - Assume 4 to 5 units per year after initial buildup to 600 GW	*MAXIMUM RADIATION LEVELS* - Maximum radiation level at rectenna is 23 mW/cm^2; maximum radiation level at perimeter fence line is 1 mW/cm^2
LIFETIME - 30 years with minimum planned maintenance (should be capable of extended life beyond 30 years with replacement)	*WEIGHT GROWTH* - (TBD)
IOC - 1998	*TOTAL WEIGHT* - All summary weight (totals) will be in term of kg/kW_e
BUILDUP - Provide (TBD) power buildup rate to utility interface	*ENERGY STORAGE* - To support on-board satellite system operations only
OPERATIONS - Geosynchronous orbit; 0-degree inclination, circular (35,786-km altitude)	*CONSTELLATION* - Satellite space, 3 degrees
RESOURCES - Minimum use of critical resources	*FAILURE CRITERIA* - No single point failure may cause total loss of SPS function
COMMERCIALIZATION - Compatible with United States utility networks	*ENERGY PAYBACK* - Less than 3 years × 10 percent of total generated power
DEVELOPMENT - Evolutionary, with provisions for incorporating later technology	*COST* - Competitive with ground-based power generation within lifetime of SPS project
	STORAGE - One year on-board storage without resupply
	CONSTRUCTION - (TBD)
	STARTUP/SHUTDOWN - (TBD)

2.0 FUNCTIONAL FLOW BLOCK DIAGRAMS (SATELLITE)

2.0 FUNCTIONAL FLOW BLOCK DIAGRAMS (SATELLITE)

2.1 INTRODUCTION

The functional flow diagrams as presented in this section are intended to provide two types of information. The first is a simplified block diagram identifying the basic flow path of the end product, in this case electrical energy, from the point of origin (power generation) to the interface where the energy leaves the satellite (microwave antenna). The corresponding information for the rectenna has not been established at this time. The flow diagrams also identify the interfaces between the various primary and support subsystem and the signal flow paths within the various subsystem concepts. The flows are, at the present time, limited to the active paths necessary for vehicle operations. Passive elements or subsystems, e.g., the structural fasteners and fastening concepts, are not addressed in this section of the requirements document.

The second type of information provided is a summary of the requirements imposed by, imposed upon, and/or derived within the various subsystem configurations.

Examples of the type of information presented (when available) include operating temperatures, pressures, flow rates, voltage and current, pointing limits, etc.

The operating relationship between the various subsystems is illustrated by the block diagram shown in Figure 2.1-1. Operational control of the satellite is provided by the Information Management and Control Subsystem (IMCS).

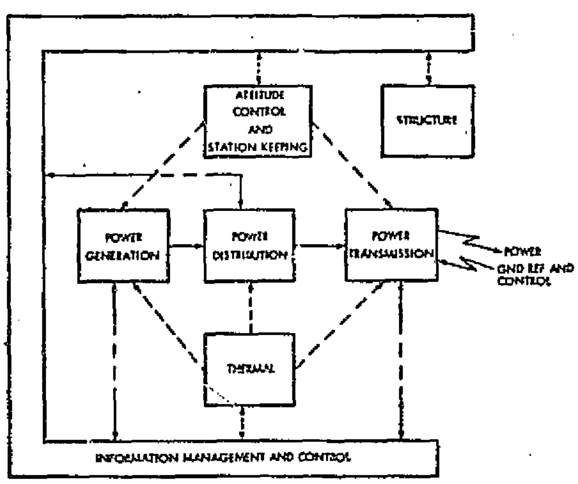


Figure 2.1-1. SPS Satellite Subsystem Functional Relationships

The IMCS also provides subsystem processing support for all but the very special functions. The only specific case of a special function identified at the present time is the beam programmer element in the microwave antenna subsystem. The man-machine interface has also been established to be at computer-generated display/control terminals. The display/control terminals have not, as yet, been defined -- nor will they be during this contract.

Mechanical interfaces (between structure subsystem and the other subsystems) have not been shown to simplify the diagrams.

2.2 SUBSYSTEM IDENTIFICATION

The following paragraphs briefly describe specific details of each of the two subsystem concepts, defined to date. Important parameters are summarized where appropriate. Most specific details of each subsystem element will be discussed in greater length in Section 3.0 of this document.

2.2.1 POWER GENERATION

Figures 2.2-1 and 2.2-2 present the basic power generation concepts for the photovoltaic and solar thermal, respectively. The photovoltaic concept shown is for a concentration ratio of 2 (CR=2). Switch gear for inter-segment connections are considered part of the power generation group. The solar thermal concept shown specifies temperatures and pressures for the Rankine cycle.

2.2.2 POWER DISTRIBUTION

Figure 2.2-3 presents the functional block diagrams for the satellite power distribution subsystem. This figure represents the distribution system for both the photovoltaic and the solar thermal based power satellite systems. The supplementary power source is required during eclipse periods to power critical support systems and to sustain temperature-sensitive subsystem elements such as the MW antenna klystrons.

Preliminary power estimates for supplementary power indicates a need for a 1-40 MW storage capacity. Although subsystem power conditioning and dc-dc conversion is shown as being combined into a single unit, these functions are in actuality composed of many dc-dc converters (or dc-ac converters, if necessary) located throughout the vehicle and/or MW antenna structure. Dc-dc bias voltage converters are located at two locations on the antenna structure and supply the 6 high voltages needed to operate the Klystron. The maximum number of high voltage dc-dc converters on the antenna is estimated to be 32.

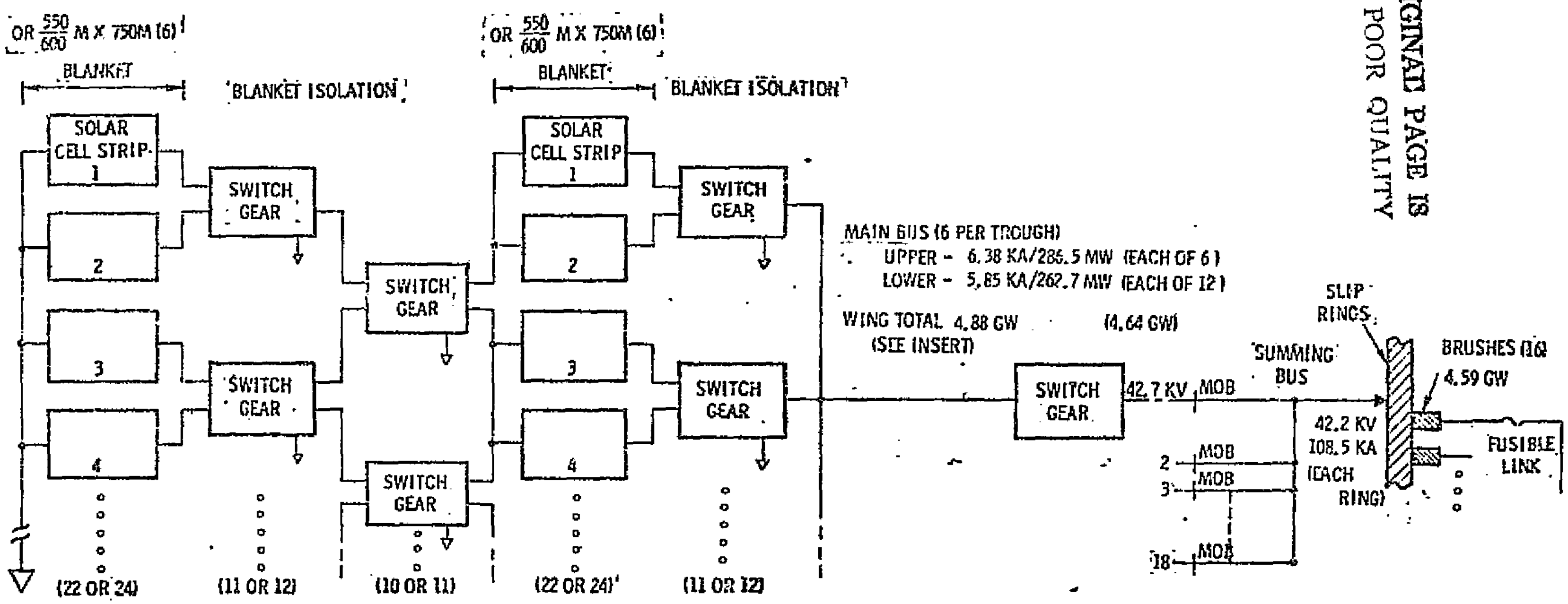


Figure 2.2-1. Power Generation - Photovoltaic (CR=2)

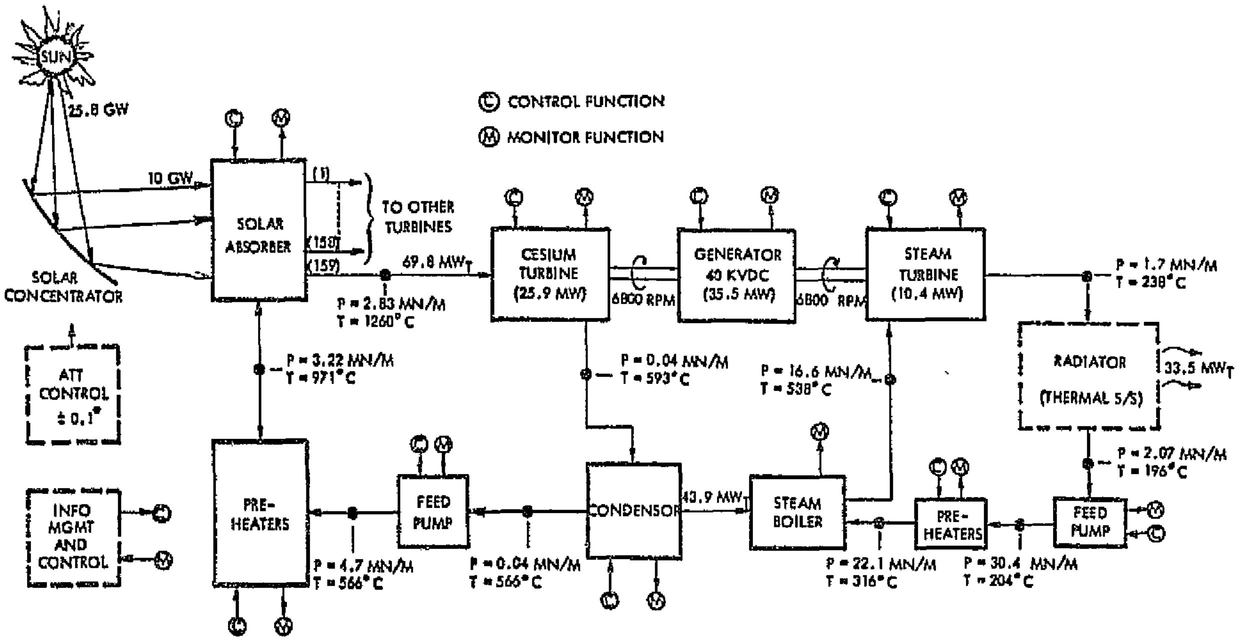


Figure 2.2-2. Power Generation - Solar Thermal (Rankine)

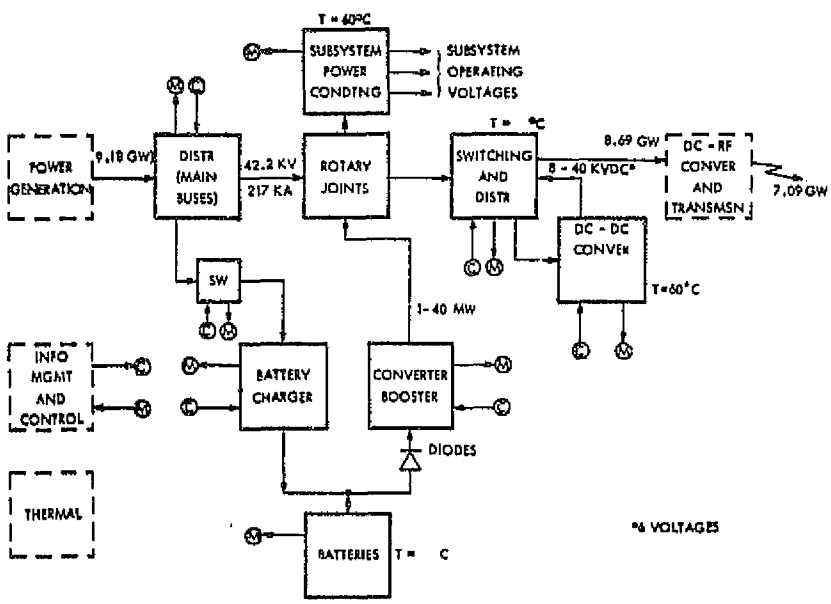
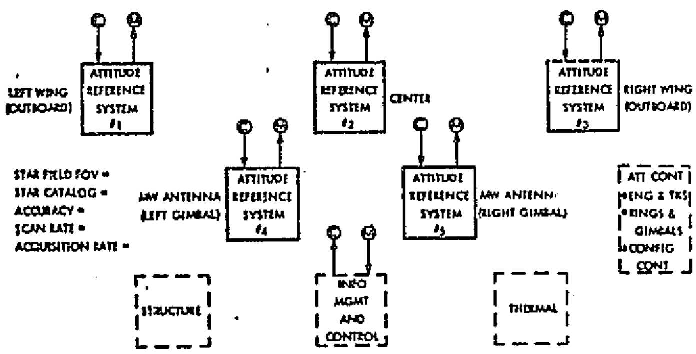


Figure 2.2-3. Power Distribution

2.2.3 ATTITUDE CONTROL AND STATIONKEEPING

Figures 2.2-4 through 2.2-6 present the subsidiary systems that make up the attitude control and stationkeeping subsystem for the photovoltaic SPS satellite concepts. These three systems are the attitude reference (platform) system, the microwave antenna pointing system (ring drive and gimbal drives), and the tank and engine systems. The pointing system shown is also applicable to the solar thermal concept.



(Part of attitude determination)

Figure 2.2-4. Attitude Control and Stationkeeping - Photovoltaic Attitude Reference System

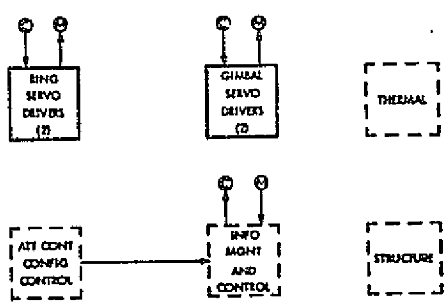


Figure 2.2-5.
Attitude Control and Stationkeeping -
Photovoltaic and Solar Thermal,
MW Antenna Pointing System

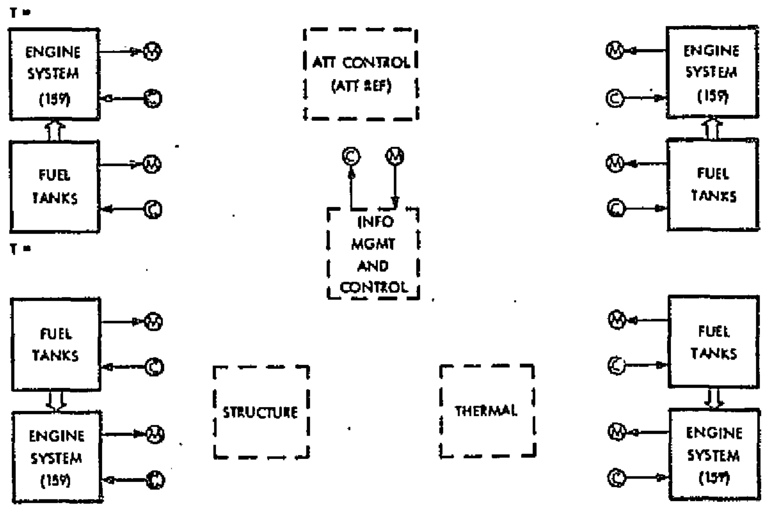


Figure 2.2-6. Attitude Control and Stationkeeping - Photovoltaic Tank and Engine System

2.2.4 STRUCTURE

Figure 2.2-7 presents the only active (instrumentation) portion of the structures subsystem defined to date. The depicted system monitors the location of corner reflectors so as to establish the degree of distortion existing in reflectors, mirrors, and other elements of the entire satellite configuration. Each of the 35 laser transits is assumed capable of scanning and calculating the location of at least 100 to 200 reflectors distributed over the surface of the mirror, solar arrays, and primary support structure.

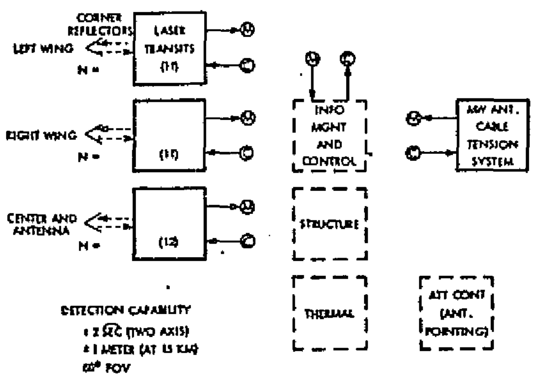


Figure 2.2-7. Structure - Configuration Monitor - Photovoltaic (CR-2)

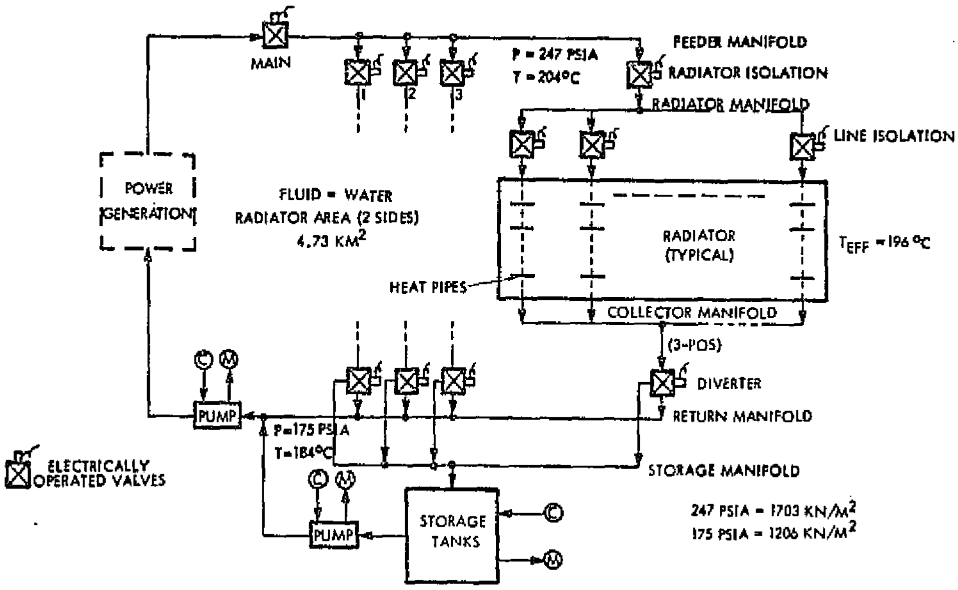


Figure 2.2-9. Thermal - Solar Thermal (Rankine) Radiator

2.2.6 MICROWAVE ANTENNA

Figure 2.2-10 presents the beam generation and control portion of the microwave antenna subsystem. Most of the paths shown operate at frequencies of approximately 2.45 GHz and are, therefore, either coaxial cable, strip lines, or wave guides. The beam programmer is a special-purpose dedicated processor design to accomplish high-speed RF pointing control via the digital diode phase shifter. External processing is limited to much slower, large element antenna pointing and performance monitoring and control.

2.2.7 INFORMATION MANAGEMENT AND CONTROL

This subsystem provides for overall satellite operational control, as well as performing system status monitoring.

Figure 2.2-11 depicts the overall processor hierarchy appropriate to the basic photovoltaic (CR-2) configuration. Except for the possibility of unique requirements (not as yet identified), it is expected that this block diagram can be considered typical for both concepts selected.

Figure 2.2-12 presents the typical architecture of the microwave antenna IMCS system.

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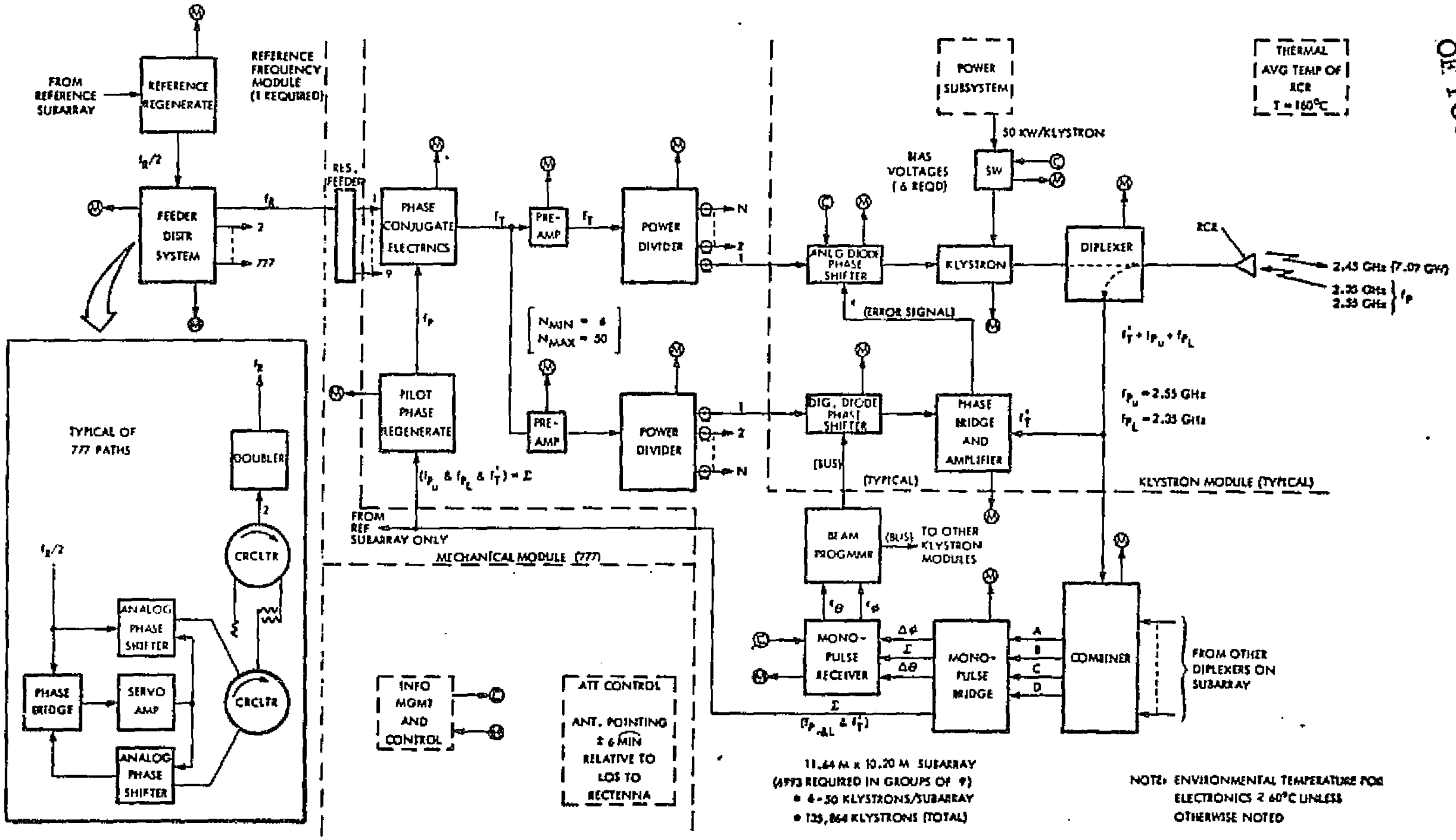


Figure 2.2-10. Microwave Antenna - Beam Generation and Control

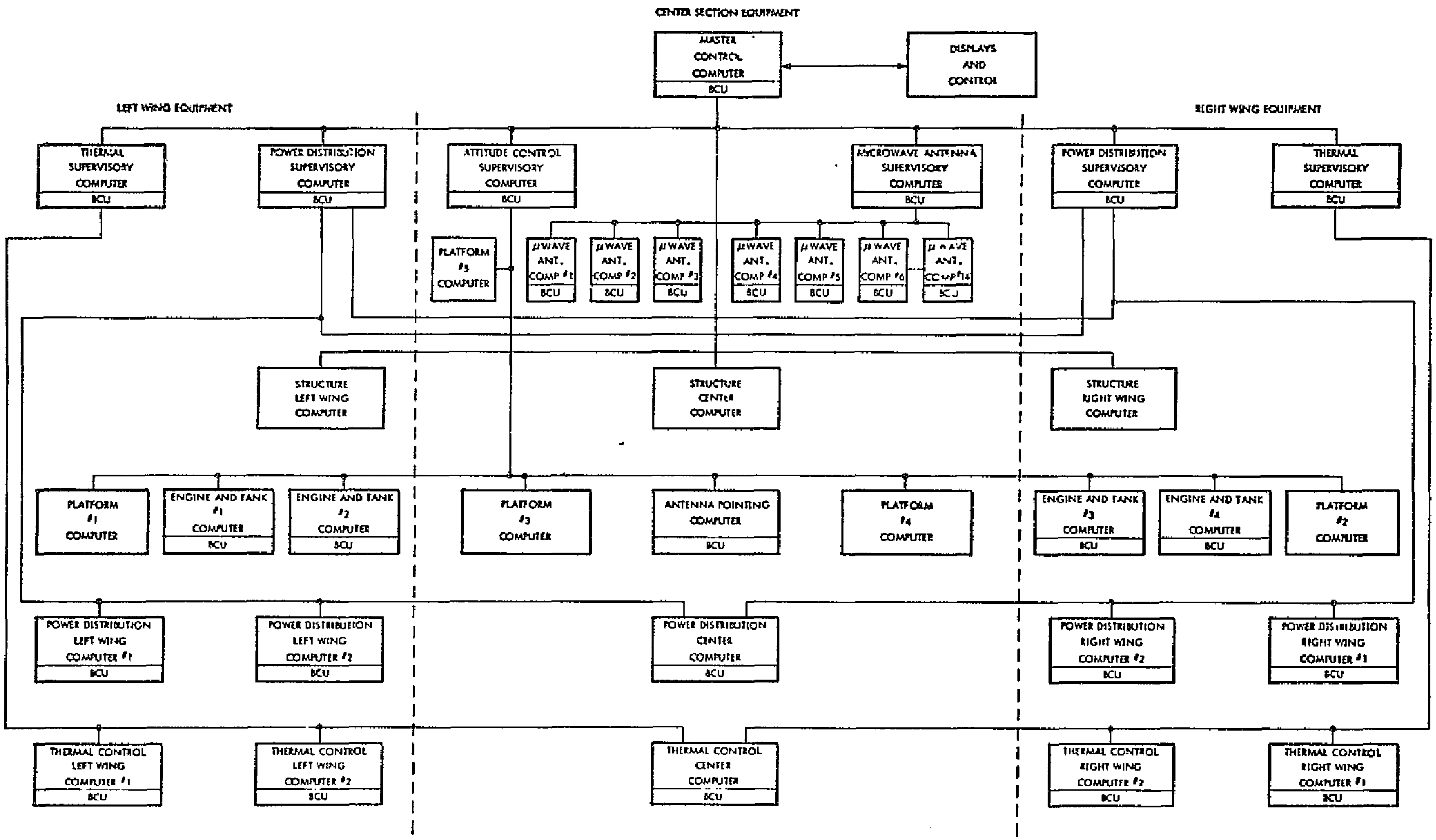
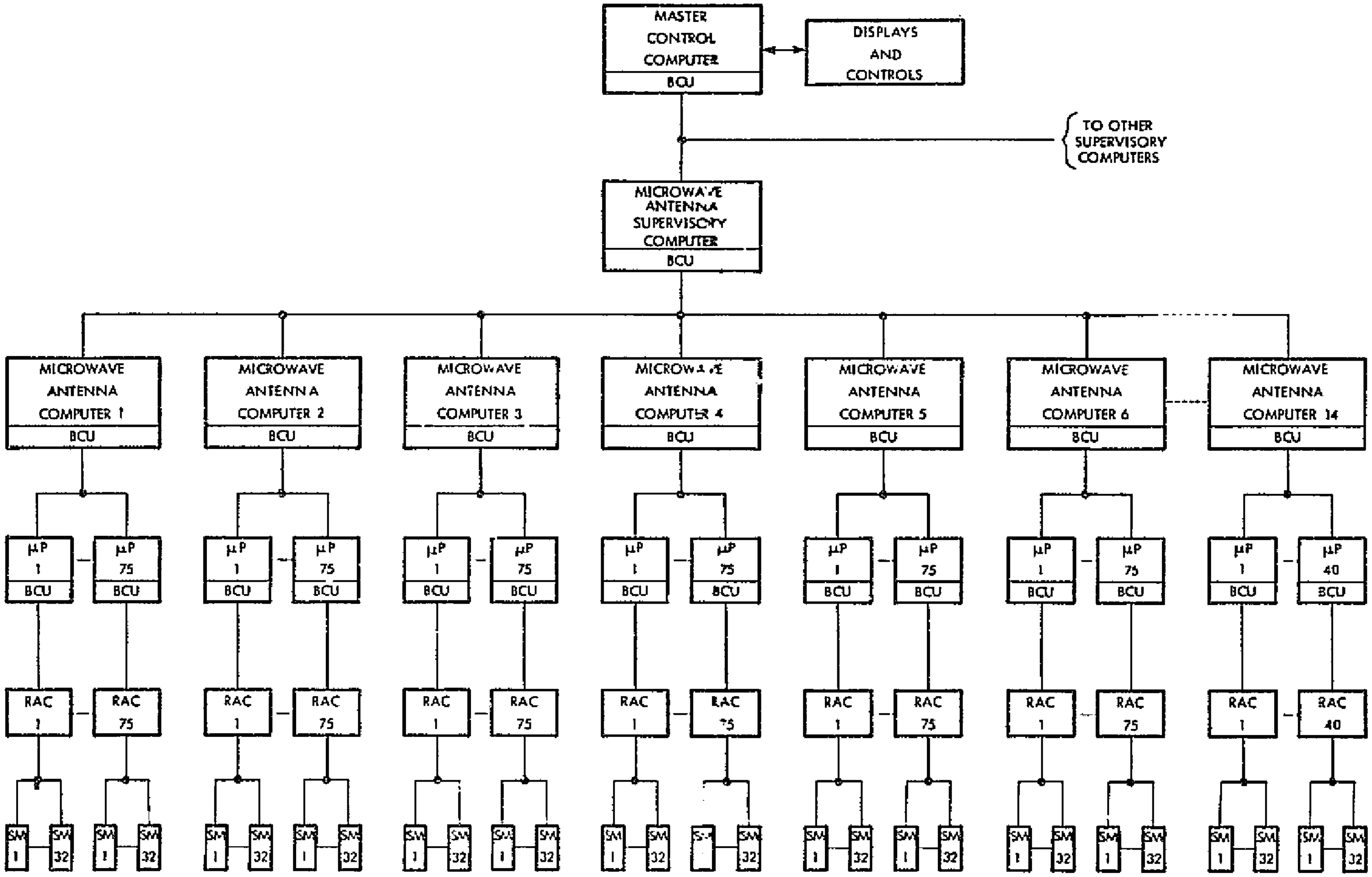


Figure 2.2-11. SPS IMCS Top-Level Block Diagram



RAC - REMOTE ACQUISITION AND CONTROL UNIT
SM - SUB-MULTIPLEXER
μP - MICRO-PROCESSOR
BCU - BUS. CONTROL UNIT

Figure 2.2-12. IMCS - Microwave Antenna

3.0 SUBSYSTEM

3.0 SUBSYSTEM

3.0 SUBSYSTEM

The following subsections of this document describe the requirements, the major assemblies, characteristics, and definitions for the seven subsystem groups which were developed during the initial SPS evaluation. These subsystems (or subsystem groups) are listed below.

- Power Conversion
  - Photovoltaic
  - Solar Thermal
- Microwave Transmission
- Power Distribution and Control
- Structure
- Attitude Control and Stationkeeping
- Thermal Control
- Information and Management Control

3.1 POWER CONVERSION

3.1.1 SOLAR PHOTOVOLTAIC POWER SUBSYSTEM

The solar photovoltaic power subsystem consists of the solar cells, blankets, attachment devices and, for the concentrator-type system, includes the reflector membranes and attachment devices. Gallium aluminum arsenide (GaAlAs) cells have been selected as the reference solar cell. The cell is fastened to a thin-film Kapton substrate with an FEP adhesive. The photovoltaic power conversion subsystem is designed for a geometric concentration ratio of 2.

Functional Requirements and Block Diagrams

The functional requirements for the photovoltaic power subsystems are listed in Table 3.1-1. The system efficiency block diagram is shown in Figure 3.1-1. Shown in the figure are power levels, efficiencies, degradation factors and solar cell area requirements. A simplified integrated block diagram for the CR-2 concept is presented in Figure 3.1-2.

Table 3.1-1. Solar Array Functional Requirements

PROGRAMMATIC

ENERGY SOURCE - Solar
CAPACITY - 5 GW delivered to utility networks
LIFETIME - 30 years with minimum planned maintenance (should be capable of extended life beyond 30 years with replacement)
IOC DATE - 1998
OPERATIONS - Geosynchronous orbit; 0-degree inclination, circular (35,786 km altitude)
RESOURCES - Minimum use of critical resources
COMMERCIALIZATION - Compatible with United States utility networks
DEVELOPMENT - Evolutionary, with provisions for incorporating later technology

TECHNOLOGY

OUTPUT POWER - Power level is defined as constant power level (except during solar eclipse)
WEIGHT GROWTH - 30 percent
ENERGY STORAGE - To support on-board satellite system operations only
FAILURE CRITERIA - No single-point failure may cause total loss of SPS function
ENERGY PAYBACK - Less than 3 years
COST - Competitive with ground-based power generation within lifetime of SPS project
STORAGE - One year on-board storage without resupply

OPERATION

Mode	Assembly	Functions
CONSTRUCTION	Subsystem	None
INTERORBIT TRANSFER	Subsystem	None
OPERATIONS	Subsystem	Steady-state operation
	Reflector	Sized for end-of-life (EOL) power rating
ECLIPSE	Subsystem	Shut down before entering eclipse
		Standby (zero power)
		Turn on after leaving eclipse and arrays reach equilibrium temperature
	Batteries	Supply power for essential functions
FAILURE/MAINTENANCE	Subsystem	Redundant operation, auto shutdown, manual startup
	Power module*	Shut down and isolate failed module; replace solar cell blanket and/or reflector
CHECKOUT	Subsystem	Fail-safe checks; control response

*Solar cell/blanket/reflector module

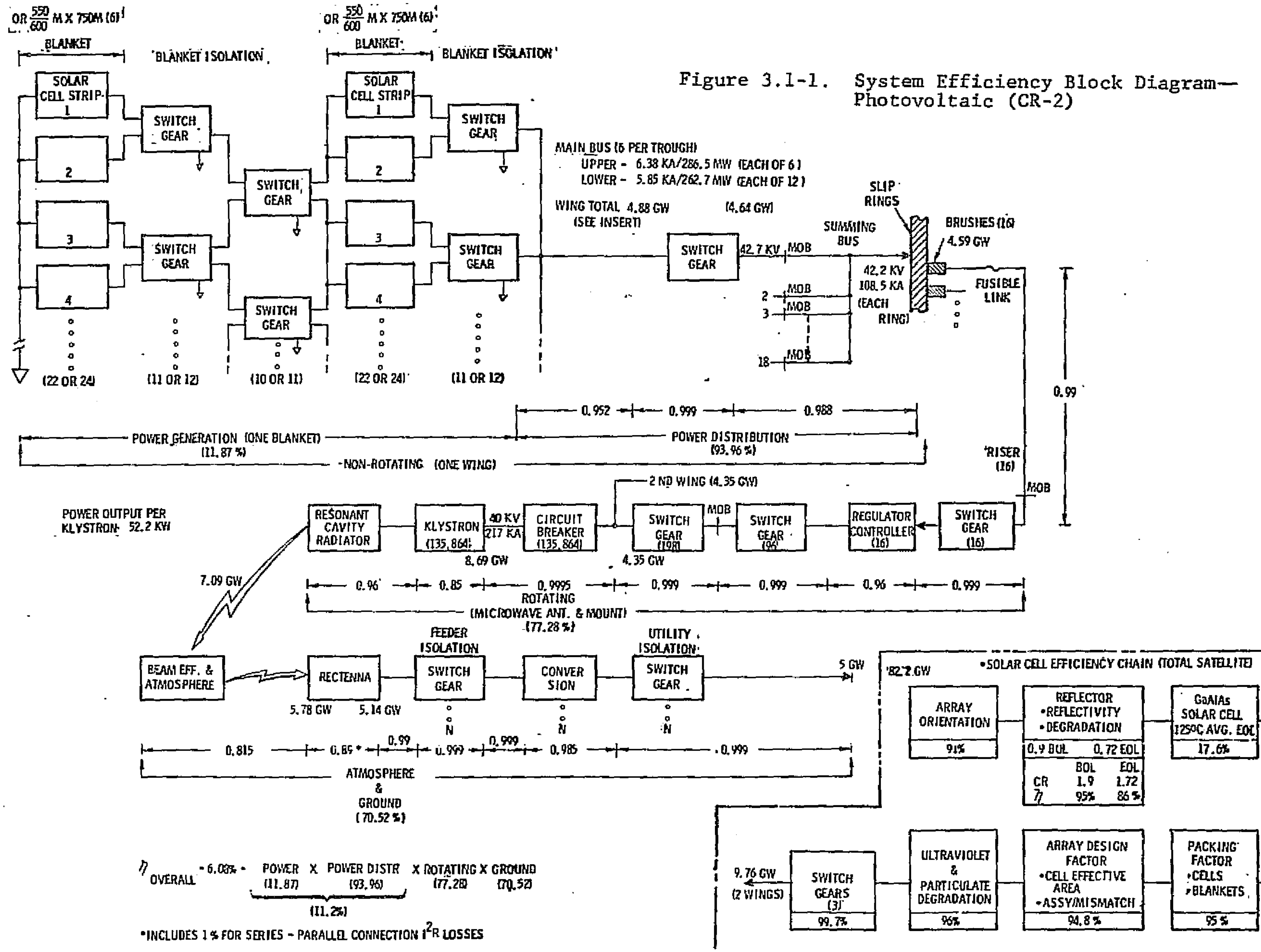


Figure 3.1-1. System Efficiency Block Diagram—Photovoltaic (CR-2)

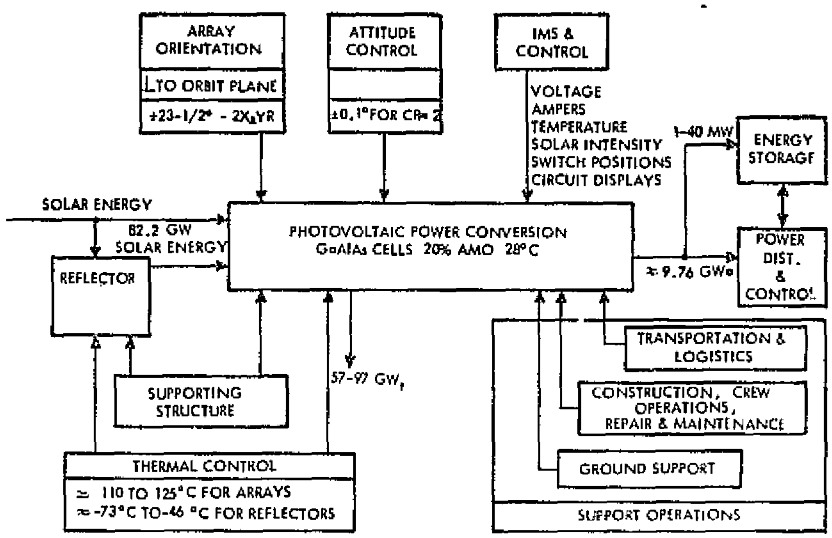


Figure 3.1-2. Simplified Integrated Block Diagram - Photovoltaic (CR-2)

Major Assemblies

The major assemblies and components that are required for the photovoltaic subsystem are shown in Figure 3.1-3.

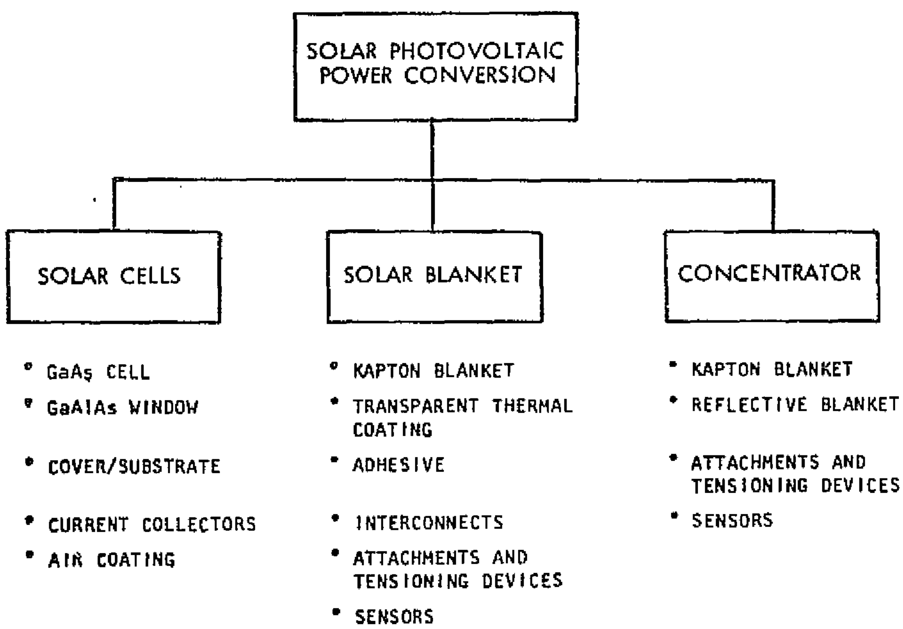


Figure 3.1-3. Assembly Tree

Solar Cells. The solar cell used in the SPS design is a GaAlAs cell having an efficiency of 20 percent at Air Mass Zero (AMO) and 28°C. The cell consists of the GaAlAs junction, GaAlAs window, cover/substrate, current collectors, and an anti-reflection coating. The basic cell design is the inverted GaAs/sapphire design having a weight of 0.252 kg/m^2. The various cell designs and the selected design are shown in Figure 3.1-4. The design cell has a 20-μm sapphire substrate upon which is grown a 5-μm single crystal GaAs junction. A 500-Å GaAlAs window is then deposited on the 5-μm junction. The voltage and current characteristics of the cell as a function of operating temperature are shown in Figure 3.1-5. The cell build up to form a submodule for the solar blanket is shown in Figure 3.1-6.

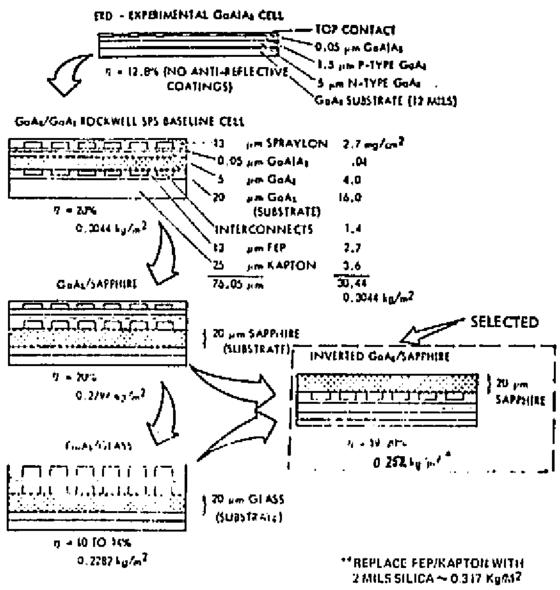


Figure 3.1-4. Alternate Solar Cell Design

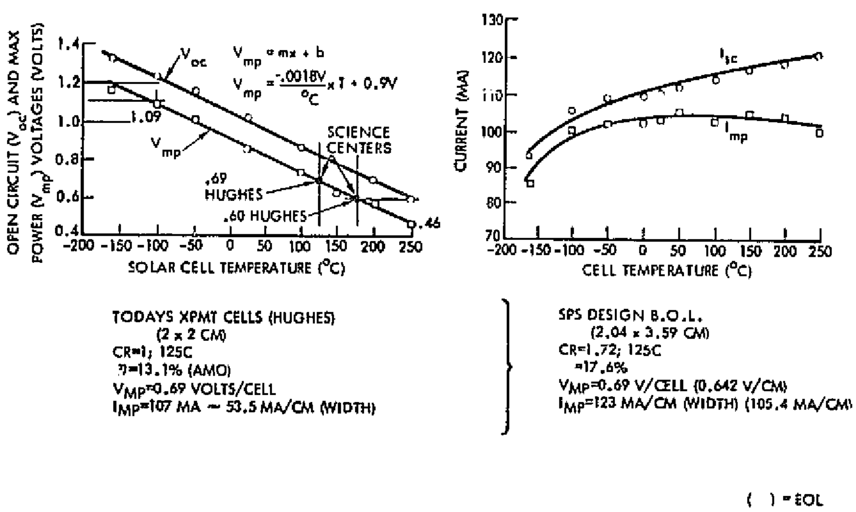
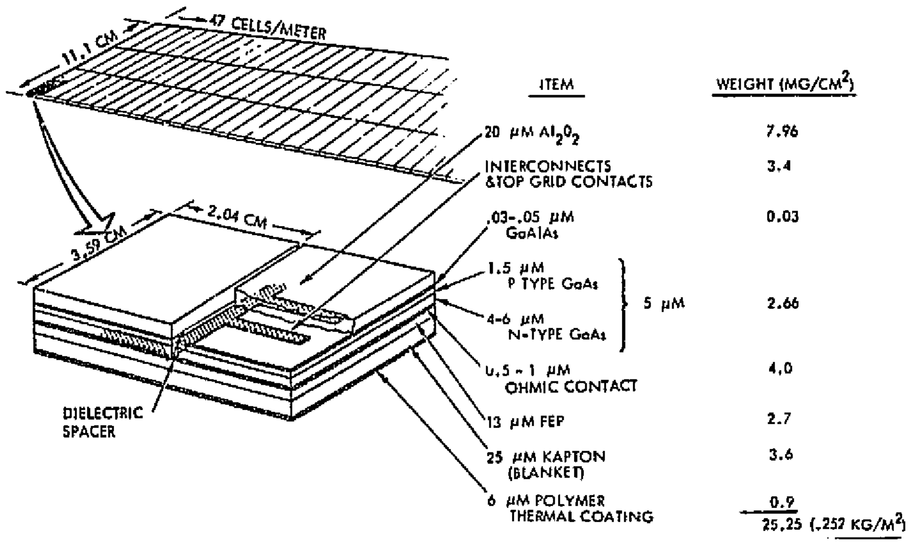
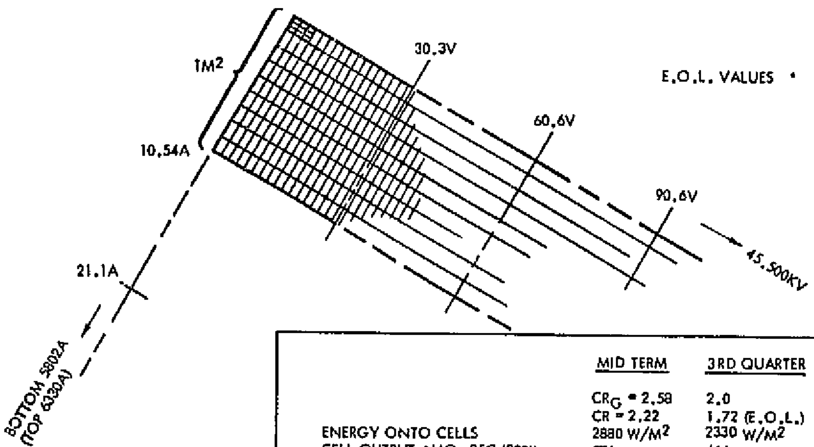


Figure 3.1-5. GaAlAs Solar Cell Voltage
And Current Characteristics



3.1-6. GaAlAs Solar Cell Blanket
Cross Section

Solar Blanket. The solar blanket consists of a 25-μm Kapton membrane upon which the cells are fastened with a thermosetting FEP adhesive. Also included in the blanket are the interconnects, transparent thermal coating as may be required for thermal control, attachments, tensioning devices, and sensors. The solar cell blankets will be manufactured in blanket form and the solar cells attached. This assembly will then be rolled up on a drum type canister. It is postulated that the blankets will be 25 m wide by approximately 750 m in length. The canisters are then transported to orbit where the blankets are deployed via a roll-out deployment-type operation. The solar blanket consists of 1 square meter modules that are hooked together in series and parallel and the voltage, current, power output and a typical layout is shown in Figure 3.1-7.



	MID TERM	3RD QUARTER
	CR_G = 2.58	2.0
	CR = 2.22	1.72 (E.O.L.)
ENERGY ONTO CELLS	2880 W/M^2	2330 W/M^2
CELL OUTPUT AMO, 25C (20%)	576	466
ARRAY DESIGN FACTOR	(.876)505	(.89)415
SEASONAL VARIATION	(.91)460	(.91) 379
TEMP. LOSS FACTOR (.88)	437	333
ENVIRON. DEGR. FACTOR	(.92)403 W/M^2	(.96) 320 W/M^2

*B.O.L. FACTOR = 1.15=> 368 W/M^2

3.1-7. Solar Panel Power Output - Watts/m^2

Reflectors. Thin reflector membranes are used on the SPS to reflect the sun onto the solar cell surfaces and obtain a nominal concentration ratio of 2. The reflector is made of 12.5 μm (0.5 mil) aluminized Kapton. Reflectivity of the reflector was taken at 0.9 BOL and 0.72 EOL. The reflector membrane has a mass of 0.018 kg/m^2. The reflective membranes are mounted on the structure using attachments and tensioning devices. Tensioning based on structural limit of the existing beam design (with safety factor of 1.5) indicates that tensioning of up to 75 psi can be used.

Design and Performance Characteristics

The design and performance characteristics of the photovoltaic system are presented in Tables 3.1-2 and 3.1-3. Operational parameters, materials of construction, deployed and planform areas and weights are presented for the subsystem.

Table 3.1-2. GaAlAs Solar Cell and Blanket Preliminary Specification (CR-2)

Item	Characteristic
Array intercepted energy	82.20 GW
Cell η at 28°C, AMO	20%
Cell η at 125°C, AMO	17.6%
Array output to distribution bus EOL	9.76 GW
Array output voltage	45 kV
Cell output voltage at 125°C	0.69 V
Cells in series	65,217
Solar cell subpanel size	
Top 24	600×750 m
Bottom 48	550×750 m
Number of bays per SPS	72
Array design factors	
Assembly and mismatch	97.7%
Interconnect and fatigue	97%
Packing factor	
Cells	96%
Blanket	99%
Reflectivity and degradation	0.90 BOL, 0.72 EOL
Concentration ratio	
Geometric	2
BOL	1.9
EOL	1.72
Solar cell construction	
Cover	20 μm sapphire
Cell	5 μm GaAlAs
Interconnect	12.5 μm silver mesh
Substrate	
Adhesive	12.5 μm FEP
Film	25 μm Kapton
Transparent thermal coating	6 μm polymer
Specific weight	0.2525 kg/m^2 (0.0516 lb/ft^2)
Deployed cell and blanket area planform	61.2 km^2
Solar cell area	30.6 km^2
Reflector surface area	61.2 km^2
Weight (kg)	
Solar cells	7.722×10^6
reflectors	1.108×10^6
Total weight	8.83×10^6 kg

Table 3.1-3. SPS Reflector Preliminary Specification (CR-2)

Item	Characteristic
Material	Aluminized Kapton
Kapton thickness	12.5 μm
Kapton specific gravity	1.42 (0.018 kg/m^2)
Aluminized coating thickness	400 angstrom units
Weight of aluminized coating	96 kg/km^2
Reflector surface protective film coating	Quartz or calcium fluoride
Reflector subpanel size	
Top 24	600×750 m
Bottom 48	550×750 m
Number of reflector panels	144
Reflector reflectivity/degradation	0.90 BOL, 0.72 EOL
Concentration ratio geometric	2.0
Concentration ratio	1.9 BOL, 1.72 EOL
Reflector slant angle from horiz.	60 degrees
Operating temperature	
Top reflectors	-52°C
Inboard bottom reflectors	-46°C
Outboard bottom reflectors	-73°C
Total area of reflectors	61.2×10^6 m^2
Total weight of reflectors	1.012×10^6 kg

Subsystem Definition and Interfaces

The subsystem interfaces are shown in Figure 3.1-3 and Table 3.1-4 for the photovoltaic conversion subsystem. The major interfaces include the array orientation, attitude control, IMS and control, energy storage, power distribution, structure, thermal control, and support operations. The major component interface parameters are also shown in the figure.

Table 3.1-4. Solar Array Interfaces

Subsystem Interface	Interface Requirement	Value or Comment
Power distribution	Voltage Power (EOL)	45 kV 9.76 GW
Thermal Array Reflector	 Temperature Temperature	 125°C -46°C to -73°C
Attitude control	Misorientation and misalignment angle Orientation	0.1° maximum Long axis perpendicular to orbital plane
Structure	Loads Deflections	Apply forces to adequately tension array and reflector up to 75 psi Reflector deflections/misalignment <0.1°; array deflection/misalignment <3°
IMS	Control and monitoring of power subsystem	TBD

3.1.2 SOLAR THERMAL POWER SUBSYSTEM

A solar thermal system generates power by concentrating sunlight (solar energy) upon a thermal absorber. The absorber consists of a series of tubular passages containing pressurized cesium fluid that is heated to an elevated temperature which, in turn, is used to drive a cesium turbine. Cycle efficiency for this form of power generation is 52 percent. Waste heat from this turbine is used to produce steam in a boiler which drives a steam turbine. Waste heat from the steam turbine exhaust is dissipated to space by means of a radiator subsystem (part of the thermal subsystem network), after which the working fluid is returned to absorber pressure by means of a pump/compressor. Both turbines drive single electrical generators.

Functional requirements for various operating modes are listed in Table 3.1-5. A simplified block diagram for the cesium/steam Rankine subsystem is shown in Figure 3.1-8. Included on the block diagram are typical values of pressure, temperature, and component efficiency. A system efficiency block diagram is shown in Figure 3.1-9.

Table 3.1-5. Solar Thermal Power Conversion Subsystem - Operating Modes - Brayton or (Rankine)

Mode	Assembly	Functions
Construction	Subsystem	None
Inter-Orbit Transfer	Subsystem	Self-power for electric propulsion
Operations	Subsystem Concentrator	Steady-state operation Defocus to match absorber input to load
Eclipse	Subsystem Absorber	Standby (zero power) Rankine fluid drained
	Energy Conversion Loop	Turbogenerators motoring at operating temp, reduced rpm, low fluid pressure (Battery power input 0.1%)
Failure/ Maintenance	Subsystem	Redundant operation, auto shutdown, manual startup
	Concentrator Absorber	Emergency defocus Drain and isolate panels
	Energy Conversion Loop	Shut down and isolate failed turbogenerator loops; no major repair
Checkout	Subsystem	Fail-safe checks, leak checks, control response

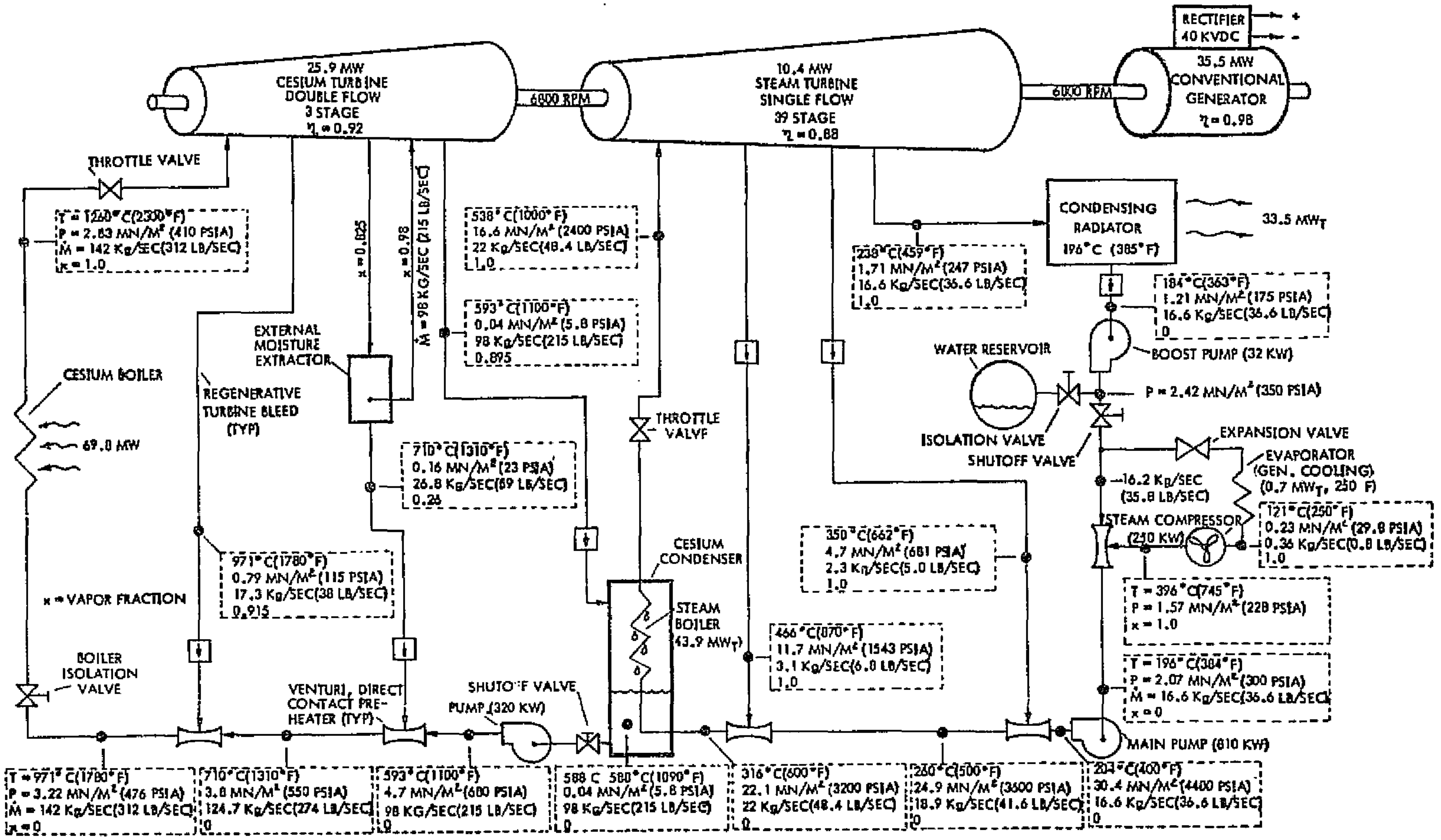


Figure 3.1-8. Cesium/Steam Rankine Cycle Schematic

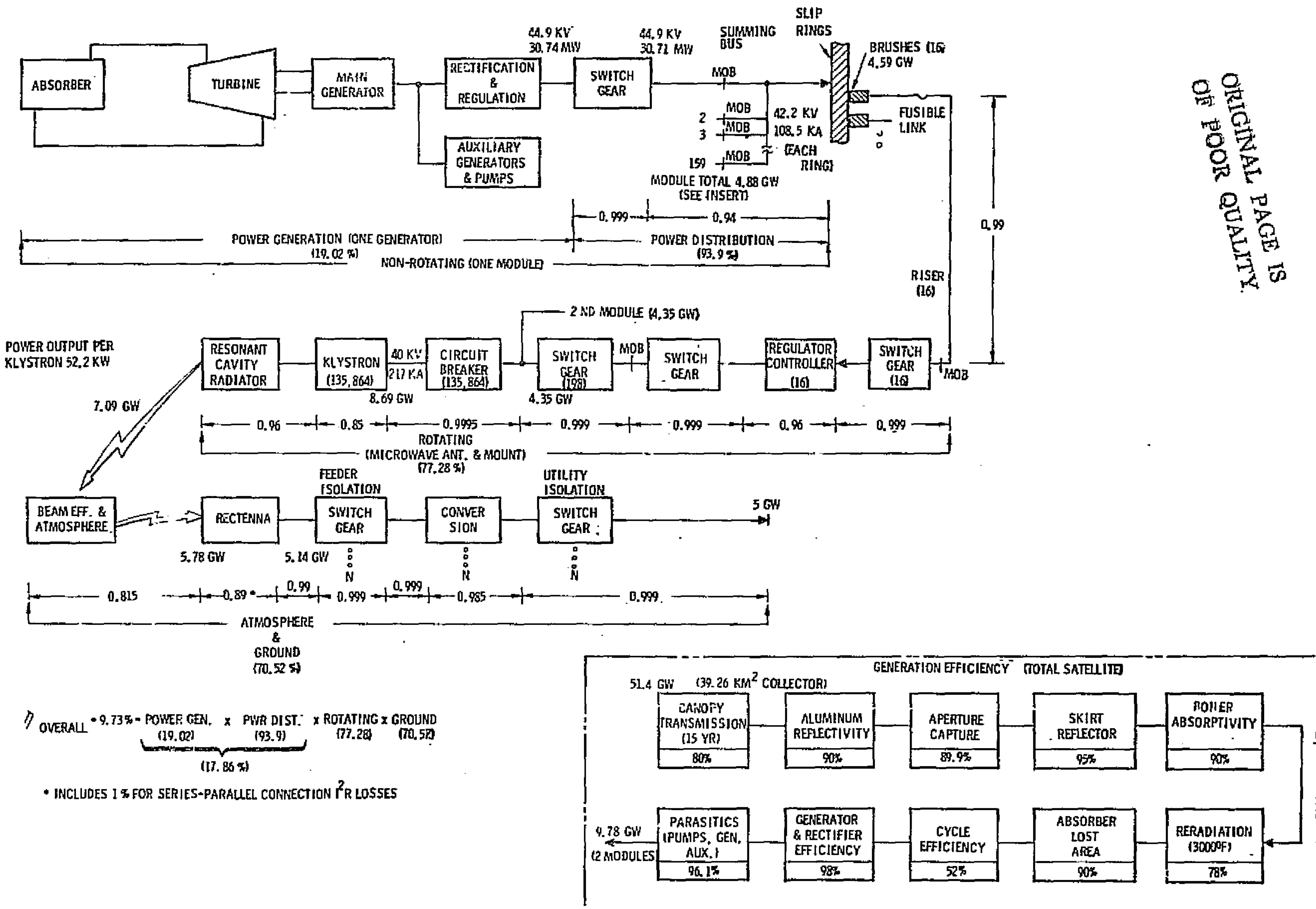


Figure 3.1-9. System Efficiency Block Diagram - Solar Thermal (Rankine)

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Figure 3.1-10 identifies the major assemblies comprising the solar thermal subsystem.

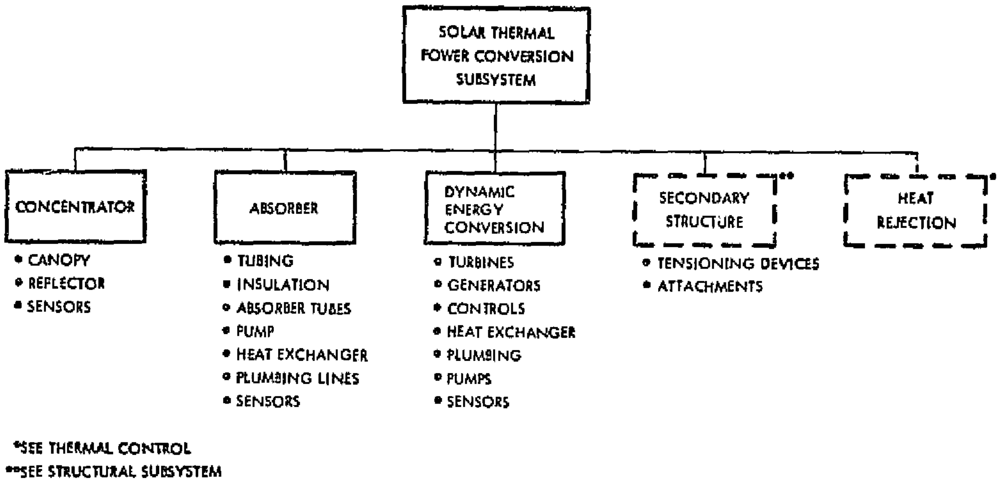


Figure 3.1-10. Assembly Tree

Concentrator

Two solar concentrators are provided for each solar power satellite. These concentrators are inflatable and consist of a parabolic reflector (aluminized 1/2-mil Kapton, 5.0 km in diameter), and a transparent FEP canopy joined at the circumference. Special sensors monitor the pointing and focusing accuracy of each concentrator. The mass of hydrogen pressurizing gas required is estimated to be approximately 20 kg per concentrator.

Absorber

Each concentrator (see above) focuses light onto a solar absorber containing passages (tubes) in which a working fluid is heated for use in the power conversion loop. The absorber includes its associated plumbing and a network of temperature sensors.

Energy Conversion

The energy conversion system consists of 318 independent power loops, each with turbines, regenerators, condenser, pumps, compressors, associated sensors (temperature, flow, pressure, rpm, etc.) and necessary controls. Each power module also includes a 35.5 MW generator interfacing with the power distribution subsystem.

Design and Performance Characteristics

Design and performance characteristics are shown in Table 3.1-6 for the cesium/steam rankine point design of Figure 3.1-8. Small, high-speed turbines and generators (35.5 MW) are used to minimize specific weight of these machines (Table 3.1-7).

Table 3.1-6. Solar Thermal Power System

GENERAL	
POWER TO UTILITY (GW)	5.0
SATELLITE SIZE - LENGTH (KM)	13.8
- DEPTH (KM)	5.7
NUMBER OF MODULES	2
CONCENTRATION RATIO (ACTUAL)	2250
REFLECTOR, TOTAL PLANE AREA (KM^2)	39.26
GENERATOR, TOTAL OUTPUT - NET (GW)	9.78
INTERCEPTED SOLAR ENERGY (GW)	51.4
OVERALL SYSTEM EFFICIENCY (%)	9.73
CYCLE EFFICIENCY (%)	52
SYSTEM EFFICIENCY - EXCLUDING POWER CONVERSION (%)	38.9
TOTAL SYSTEM WEIGHT (KG)	32.2×10^6
TOTAL SYSTEM WEIGHT (KG)*	42.0×10^6
SYSTEM SPECIFIC WEIGHT (KG/GW)*	8.4×10^6
SATELLITE ORIENTATION	PERPENDICULAR TO SUN
LIFETIME (YEARS)	30
IOC DATE	1998
ASSEMBLY ORBIT (KM)	LEO, 435
ASSEMBLY ORBIT INCLINATION (DEG)	0
ELECTRICAL	
GENERATOR SIZE, NOMINAL (MW)	35.5
GENERATORS, QTY	318
GENERATOR TYPE	CONVENTIONAL
NUMBER OF POLES	8
RPM	6800
FREQUENCY (Hz)	454 - 3 Ø
GENERATOR VOLTAGE (KV)	40
POWER DISTRIBUTION	DC
TRANSMISSION VOLTAGE (KV)	40
TYPE OF CONDUCTOR	NON-STRUCT.
BUS MATERIAL	Al
POWER CONVERSION	
WORKING FLUIDS	CESIUM/STEAM
CESIUM TURBINE INLET TEMPERATURE - °C (°F)	1260 (2300)
STEAM TURBINE INLET TEMPERATURE - °C (°F)	538 (1000)
CESIUM TURBINE INLET PRESSURE - KN/M^2 (PSIA)	2830 (410)
CESIUM TURBINE DISCHARGE PRESSURE - KN/M^2 (PSIA)	40 (5.8)
STEAM TURBINE INLET PRESSURE - KN/M^2 (PSIA)	16,600 (2400)
STEAM TURBINE DISCHARGE PRESSURE - KN/M^2 (PSIA)	1710 (247)
TURBINE REHEAT	NONE
TURBINE TYPE	AXIAL
TURBINE BLADING	REFRACTOR METAL
CESIUM TURBINE SIZE (MW)	25.9
CESIUM TURBINE EFFICIENCY (%)	92
STEAM TURBINE SIZE (MW)	10.4
STEAM TURBINE EFFICIENCY (%)	88
TURBINE SPEED (RPM)	6800
COMPRESSOR/PUMP, TYPE	CENTRIFUGAL
COMPRESSOR/PUMP EFFICIENCY (%)	75/85
REGENERATOR TYPE	DIRECT CONTACT
CESIUM CONDENSING TEMPERATURE - °C (°F)	593 (1100)
STEAM CONDENSING TEMPERATURE - °C (°F)	204 (400)
TURBINE PRESSURE RATIO (CESIUM/STEAM)	70.6/9.7
NUMBER OF TURBINE STAGES (CESIUM/STEAM)	3/39

*WITH WEIGHT ALLOWANCE (APPROX. 30 PERCENT)

Table 3.1-6. Solar Thermal Power System (Continued)

POWER CONVERSION (CONT.)	
NUMBER OF TURBINE REGEN BLEEDS (CESIUM/STEAM)	2/2
TURBINE EXTERNAL MOISTURE REMOVAL	CESIUM ONLY
BOILER PRESSURE RATIO (CESIUM/STEAM)	1.16/1.33
CESIUM TURBINE MASS FLOW - INLET (KG-SEC/LB-SEC)	142/312
CESIUM TURBINE MASS FLOW - OUTLET (KG-SEC/LB-SEC)	98/215
STEAM TURBINE MASS FLOW - INLET (KG-SEC/LB-SEC)	22/48.4
STEAM TURBINE MASS FLOW - OUTLET (KG-SEC/LB-SEC)	16.6/36.6
CESIUM PUMP POWER (MW_e)	0.32
WATER PUMP POWER - MAIN + BOOST (MW_e)	0.842
STEAM COMPRESSOR - GEN. COOLING (MW_e)	0.25
TURBINE SPEED CONTROL	INLET THROTTLE
TURBINE EXIT QUALITY (CESIUM/STEAM)	0.895/SUPERHEATED
CONCENTRATOR	
TYPE	CONTINUOUS, INFLATED
FOCAL LENGTH (APPROX)	0.6
CONCENTRATION RATIO (ACTUAL)	2250
COLLECTION EFFICIENCY (%)	64.9
COLLECTOR DIAMETER - 2 EACH (KM)	5.0
REFLECTOR MATERIAL	ALUMINIZED KAPTON
FILM STRESS (MN/M^2 (PSI)	2.07 (300)
POINTING ACCURACY (DEG)	0.1
DEFOCUSING RESPONSE (SEC)	10
INFLATION PRESSURE - N/M^2 [MICRONS] (PSF)	8.9×10^{-3} [2.4] (1.2×10^{-4})
ABSORBER	
TYPE	DISC/CPC SKIRT
OVERALL DIAMETER (M)	80
BOILER TUBE MATERIAL	T2M MOLY
PRESSURE DROP (%)	12
ABSORBER EFFICIENCY - 10% AREA LOSS (%)	60
TUBE I.D. - CM (IN.)	0.76 (0.3)
TUBE LENGTH - M (FT)	1.08 (3.3)
SKIRT CAPTURE HALF-ANGLE (DEG)	45
RADIATOR *(REFERENCE ONLY -- PART OF THERMAL SUBSYSTEM)*	
TYPE	CONDENSING STEAM
CONSTRUCTION	HEATPIPE/FIN
TEMPERATURE, EFFECTIVE - °C (°F)	196 (385)

Table 3.1-7. Solar Thermal Subsystem Weights (Millions of kg)

STRUCTURES AND MECHANISMS (KG)	1.661×10^6
CONCENTRATOR/ABSORBER	3.12
POWER CONVERSION	(3.397)
TURBOMACHINES	1.16
PUMPS, COMPRESSOR	0.145
PLUMBING, INSULATION	0.145
CONDENSER	0.283
POWER LOOP FLUID	0.105
GENERATORS, WITH COOLING	1.3
ELECT. POWER CONDITIONING	0.259
RADIATOR, WITH PUMPS (BOL)	8.786*

*REFERENCE ONLY--PART OF THERMAL SUBSYSTEM

Subsystem Definition and Interfaces

Subsystem interfaces are shown in Section 2.2 (Figure 2.2-2). Note that the distribution subsystem requires 35.5 MW (electrical) from each of 318 generators while the thermal radiator subsystem must be capable of dissipating 33.5 MW (thermal) of excess heat.

3.2 MICROWAVE POWER TRANSMISSION SYSTEM

The microwave power transmission (MPT) system consists of a set of dc-microwave conversion devices, feeding a microwave array and a ground array of antenna/rectifier assemblies for microwave-dc conversion (rectenna).

The array is phased by means of a pilot beam formed at the rectenna which is received by the array and used to form the power converter drive signals.

3.2.1 FUNCTIONAL REQUIREMENTS AND BLOCK DIAGRAMS

A functional block diagram of the satellite array assembly is shown in Figure 3.2-1. The requirements for the various operating modes are listed in Table 3.2-1.

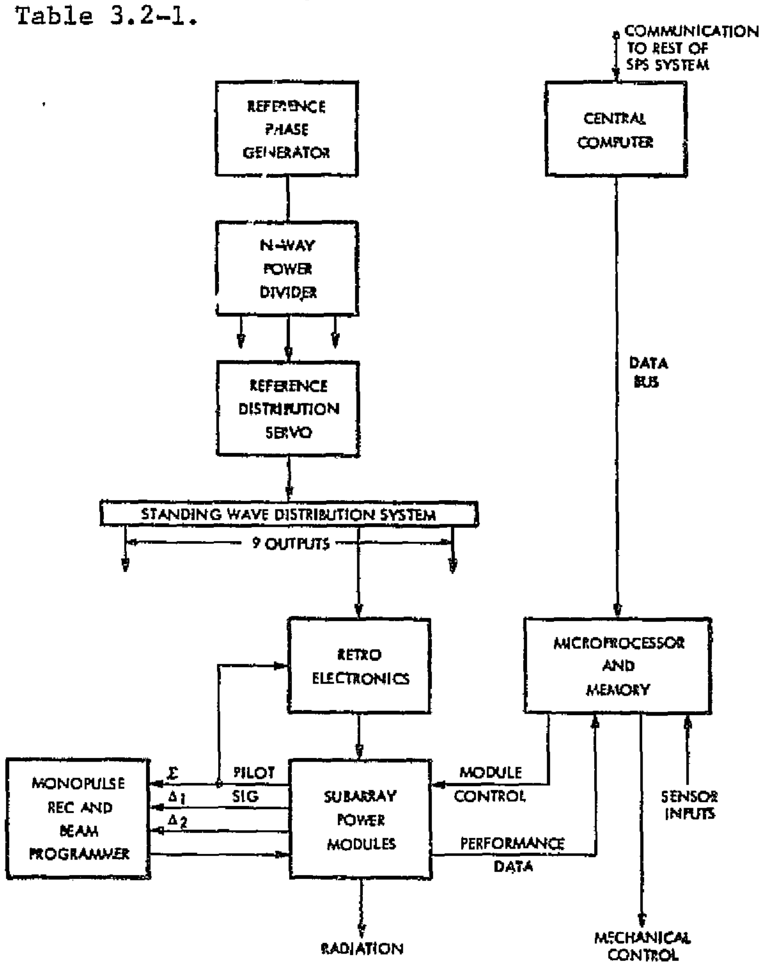


Figure 3.2-1. Functional Block Diagram

Table 3.2-1. Microwave Antenna - Operating Modes

Mode	Assembly	Function
Construction	N/A	N/A
Inter-Orbit Transp.	N/A	N/A
Operations	Subsystem	Steady-state transmission
Eclipse	Subsystem	Shutdown/startup
Transition	N/A	N/A
Failure/Maintenance	Subsystem	Redundant operation Auto shutdown Manual startup
Checkout	Subsystem	Performance Phasing tests Rectenna tests Environmental checks

Figure 3.2-2 shows how the array is formed of mechanical assemblies supported by two grids of catenaries anchored to the hexagon frame. These assemblies consist of nine 10.2 m by 11.64 m subarrays. Each subarray is formed of a variable number of power converter/radiator modules, depending on the power density required.

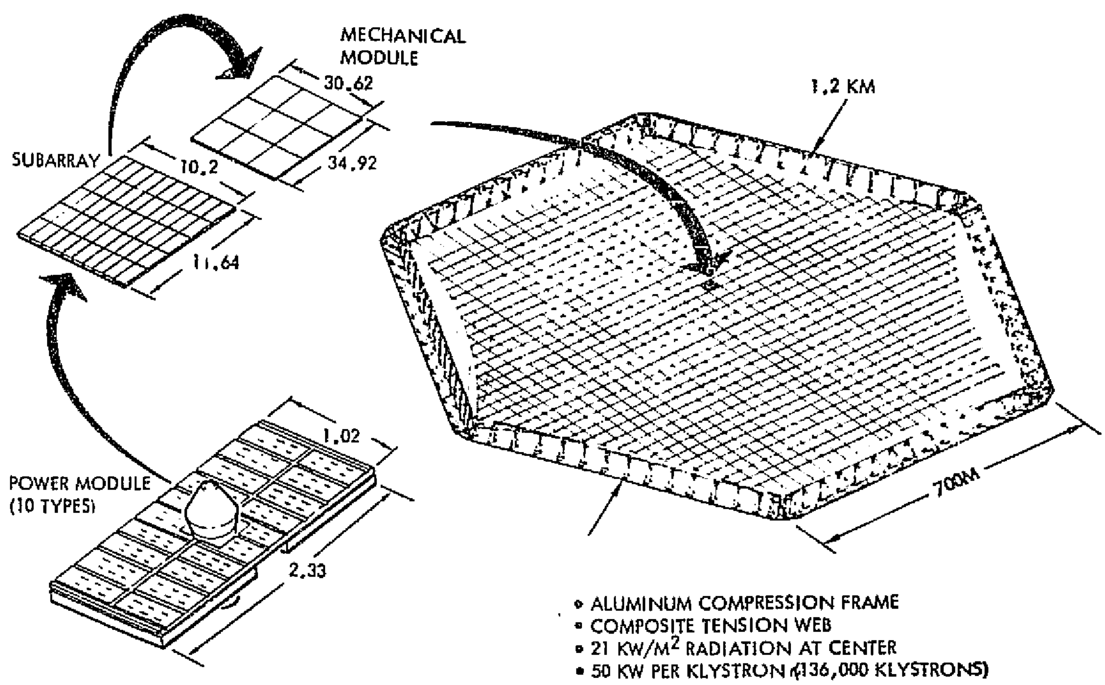


Figure 3.2-2. Satellite Antenna Array Assembly

3.2.2 MAJOR ASSEMBLIES

Figure 3.2-3 illustrates the major assemblies comprising the MPTS. Figure 3.2-4 shows a high-density module at the array center.

The selected power converters are nominally 50-kW klystrons, mounted in the center of the resonant cavity radiators (RCR). The klystron collector radiates downward in the direction of the microwave rectenna, as shown in Figure 3.2-5. Heat pipes remove heat from the klystron body and transfer it to the RCR face. The pipes lie between the radiating slots of the RCR.

Figure 3.2-6 shows an alternate power module using a stripline signal distribution panel feeding transistor amplifiers. These amplifiers drive an array of dipole radiators.

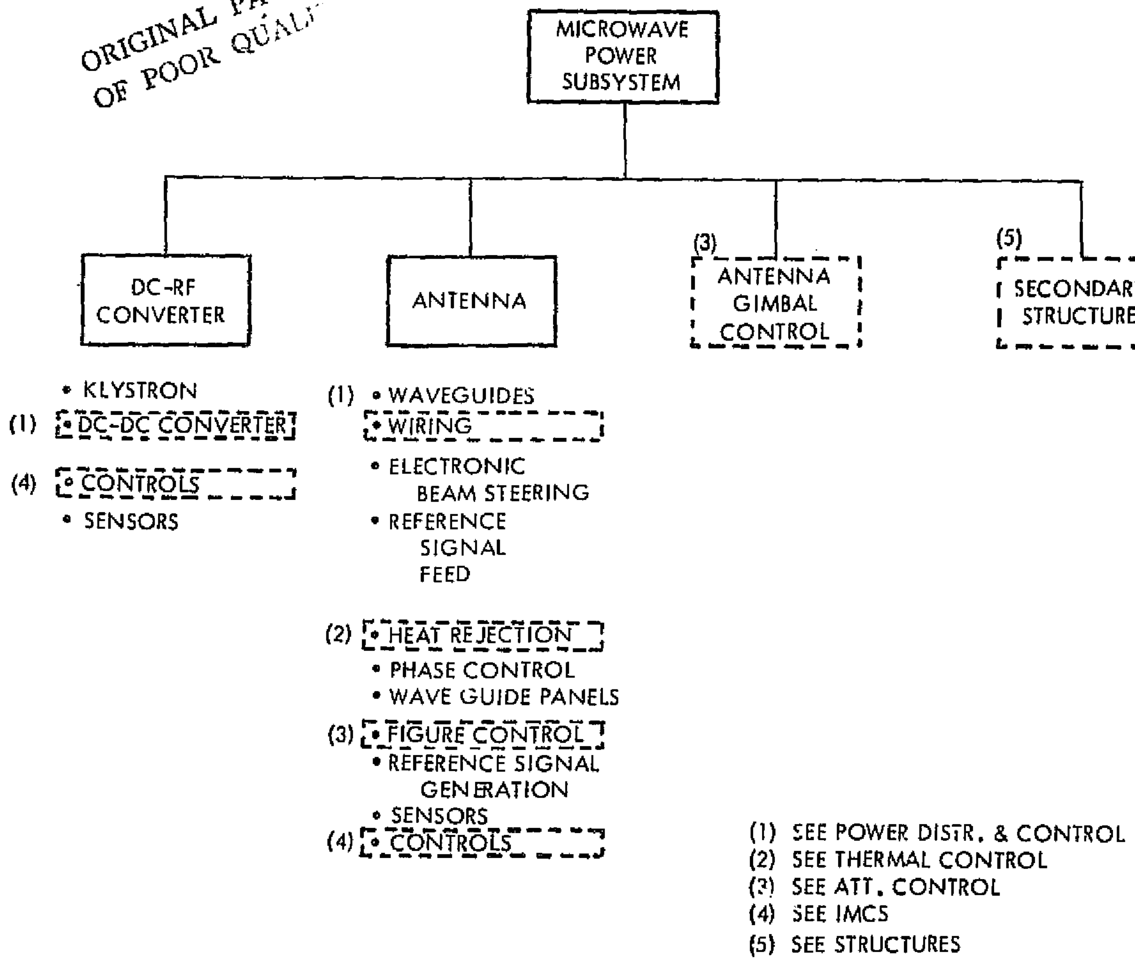


Figure 3.2-3. Assembly Tree

TYPE PWR DENSITY	1.	21.05 KW/M2
• NO. OF KLYSTRONS/ SUBARRAY · ARRANGEMENT	50	10 x 5
• PWR MOD SIZE • HINGED CONFIG • SHIPPING SIZE & WT.	1.02 x 2.33 10.2M x 2.33 2.35 x 1.02 x 2.33	 16.8 KG

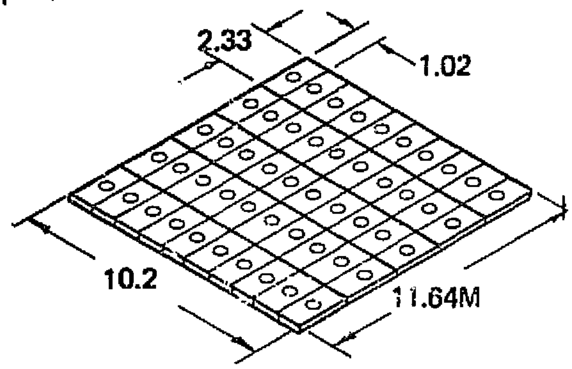


Figure 3.2-4. Klystron Subarray Assembly

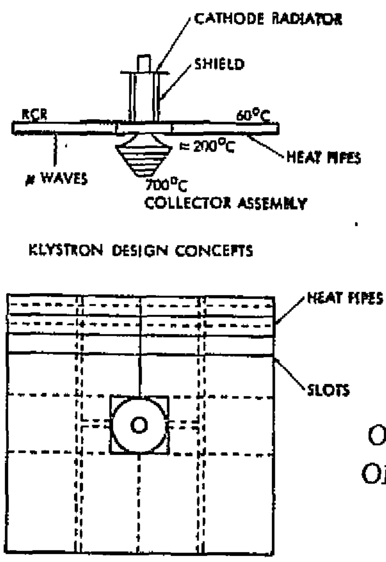


Figure 3.2-5. Heat Radiators on Array Face

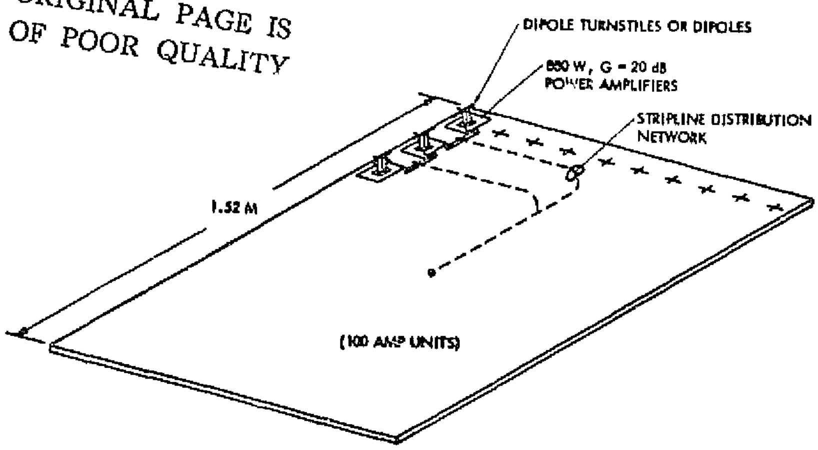


Figure 3.2-6. Transistor Power Module

The transmitted signal is formed from the pilot beam by means of the retroelectronics shown previously in Figure 2.2-10; there is one of these circuits per subarray. Figure 3.2-7 shows a servo system for transferring the required reference phase from a central point to a mechanical module, where it is distributed to the nine subarrays.

Figure 3.2-8 illustrates the power supply system required for each 50-kW klystron. Note that the "mod anode" is a low-current electrode. It would

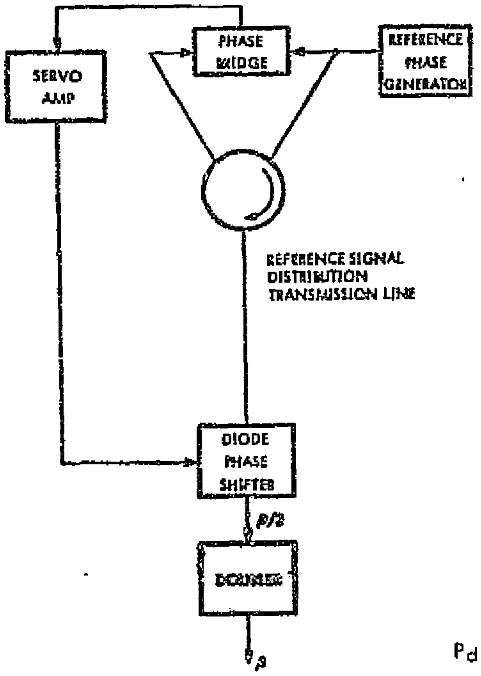


Figure 3.2-7.
Reference Phase Distribution System

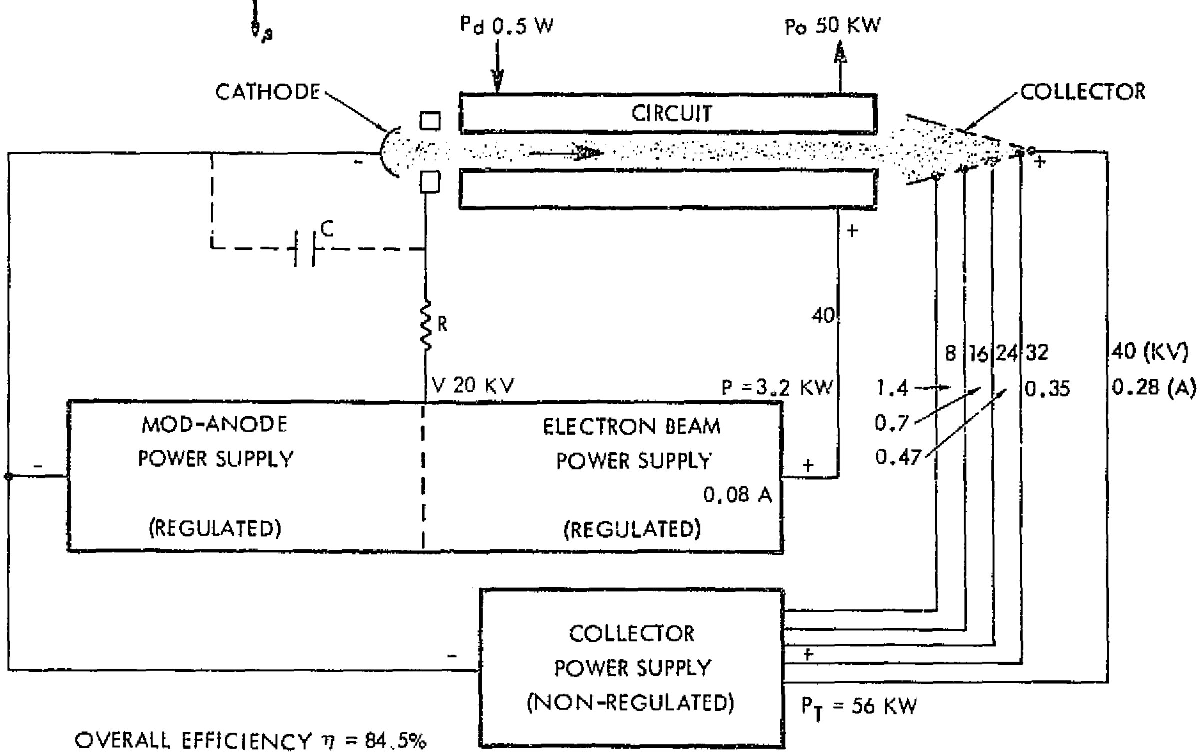


Figure 3.2-8. Klystron Power Requirements (Preliminary)

be supplied by a separate circuit capable of varying its potential to control klystron power.

Figure 3.2-9 is a layout and perspective view of the microwave integrated circuit (MIC) assembly which forms the transistor amplifier used for the alternate power conversion method. Figure 3.2-10 shows a circuit schematic of the amplifier which consists of a puch-pull emitter follower driving a common base push-pull final amplifier. All four transistors are formed on a single chip as shown in Figure 3.2-11.

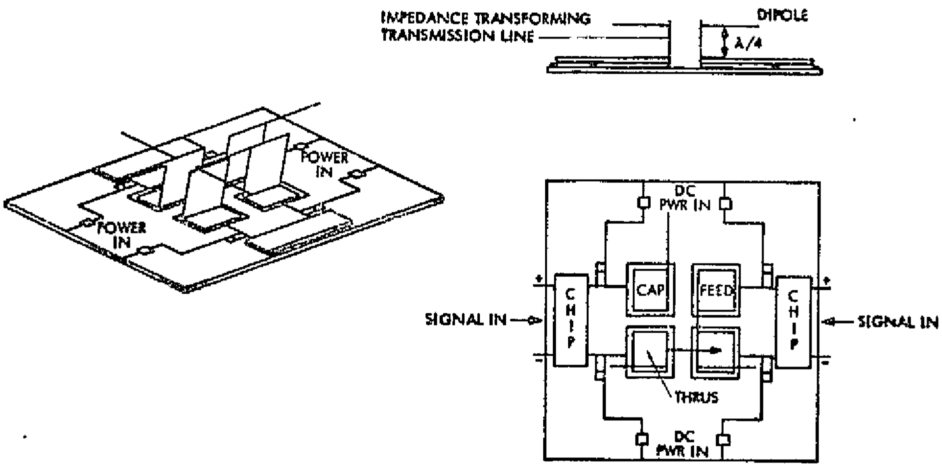


Figure 3.2-9. Transistor MIC Amplifier

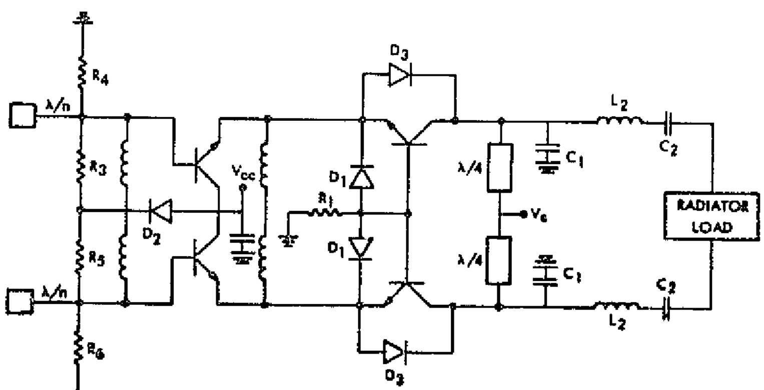
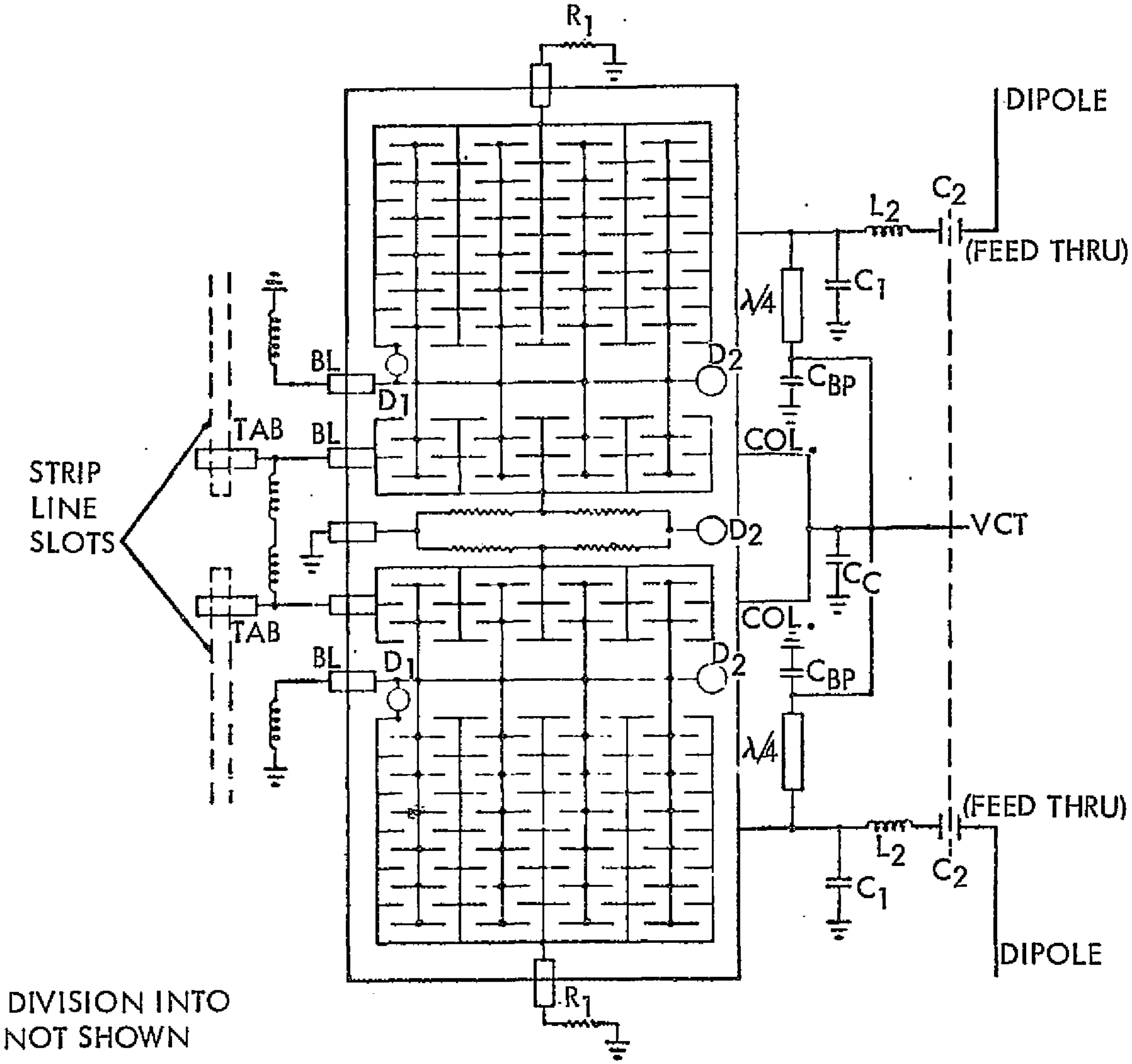


Figure 3.2-10. Transistor Power Circuitry



NOTE: DIVISION INTO
CELLS NOT SHOWN

Figure 3.2-11. Transistor Chip Layout

The rectenna portion of the system is shown in Figure 3.2-12. It consists of receiving arrays which drive a diode rectifier through a filter used to suppress harmonic re-radiation. The filter also acts as a tank circuit which stores energy during the non-conducting half of the dipole cycle. The rectifier outputs are smoothed by a filter and added. The individual module outputs are summed and fed to a central location. There, the individual power lines add their outputs in a converter assembly. The output of the converter(s) is delivered to one or more power grids.

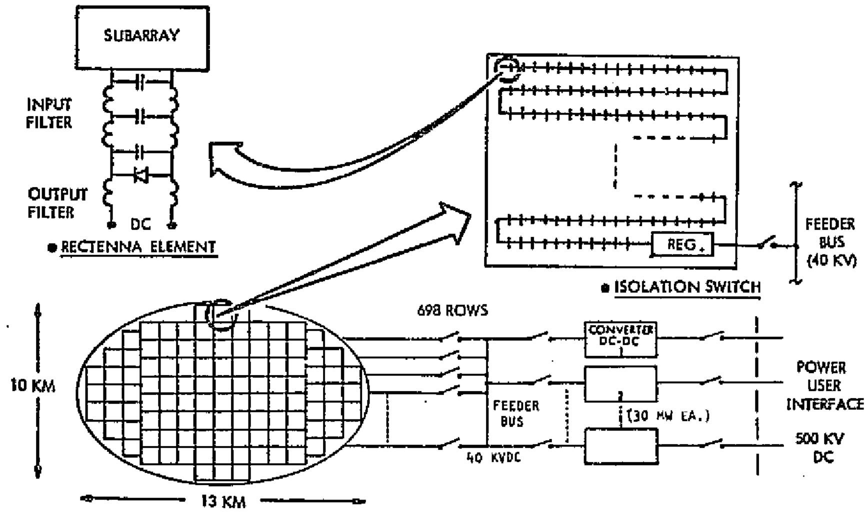


Figure 3.2-12. Rectenna System Model

3.2.3 DESIGN AND PERFORMANCE CHARACTERISTICS

The functional requirements for the MPTS system are shown in Table 3.2-2 through 3.2-7. Table 3.2-2 summarizes the system functional requirements; Table 3.2-3 shows the prime power requirements for the array; Table 3.2-4 shows a phase error budget for the retroelectronics; Table 3.2-5 shows the array characteristics; Table 3.2-6 shows the characteristics of the klystron power module; and Table 3.2-7 shows the characteristics of the alternate transistor power module.

3.2.4 SUBSYSTEM DEFINITION AND INTERFACES

Subsystem interfaces are shown in Figure 2.2-10. The concept/subsystem illustrated will be identical regardless of which satellite concept is selected for further consideration.

Table 3.2-2. Functional Requirements

Power conversion efficiency (dc-RF)	.85
Array radiation efficiency	.96
Array beam efficiency	.85*
Atmosphere transmission efficiency	.98
Rectenna conversion efficiency	.88
Total MTS efficiency	.543
Harmonic level required, dB	TBD
AM noise decrease required, dB/kHz	TBD
PM noise decrease required, dB/kHz	TBD
Maximum power density	TBD
Temperature at back of array, deg	60
Array mass	TBD

*Includes 3% beam blockage factor

Table 3.2-3. Design and Performance Characteristics

Device	Freq.	Voltage (kV)	Current A	Power (kW)	Regulation (%)
Collector 1		40	0.28	11.2	None
Collector 2		32	0.35	11.2	None
Collector 3		24	0.47	11.2	None
Collector 4		16	0.70	11.2	None
Collector 5		8	1.40	11.2	None
Klystron body		40.0	0.08	3.2	10
Mod anode		20.0			10
Cath. heater		20 V		0.1	1
Solenoid	(1)	20		0.5	1
Computer	(1)	20		0.1	1
Retroelect.	(1)	20 V		0.1	1
			Total	59.2	84.5

(1) Not included in determining klystron efficiency.

Table 3.2-4. Phase Error Budget

500:1 power divider	6°
Ref. Ø dist. link	6°
Zone feeder	6°
Retroelectronics	6°
Klystron Ø shifter loop	3°
Subarray pointing loop	3°

Total RMS phase error = 13°

Table 3.2-5. Array Characteristics

Operating frequency	2.45 GHz
Operating wavelength	12.2 cm
Mechanical module size	34.92×30.62 m
Subarray size	11.64×10.2 m
Subarray beamwidth	0.73°
Subarray RMS phase error	5°-10°
Amplitude weighting	10 dB Gaussian taper
Amplitude quantitization	10, 1-dB steps
Subarray weighting	Uniform
Electronic steering limit, 1/8 subarray beamwidth =	0.1° (RMS)
Mech. subarray pointing accuracy	0.07° (RMS)
Mech. module pointing accuracy	0.07°
Total RMS subarray electronic pointing accuracy	0.1°
Polarization	Linear
Beam efficiency	0.85
Radiation efficiency (0.2 dB feed + 0.2 dB RCR Ω loss)	0.96
First sidelobe level	-25 dB
Electronic subarray steering accuracy, 1/30 (0.73°) =	.024°
(Pointing Loss = -.005 dB)	

Table 3.2-6. Klystron Power Module

Output power, kW	50	Overall efficiency, %	85
Input power, W	0.5	Collector power dissipated, kW	5.0
Gain, dB	50	Body power dissipated, kW	3.3
Basic tube efficiency, %	85.8	Second harmonic level, dB	-40
Prime power, kW	58.3	AM noise, dB/kHz	-140
Auxiliary power, kW	0.70	PM noise, dB/kHz	-130
Total power, kW	59		

Table 3.2-7. Transistor

Amp output power, W	120
Gain, dB (two stages)	20
Input power, W	1.2
Collector efficiency	.83
Overall efficiency	.78
Second harmonic level, dB	-40
AM noise, dB/kHz	>-140
PM noise, dB/kHz	>-130
Number of amplifiers	100
Power module output, kW	12

3.3 POWER DISTRIBUTION AND CONTROL

The power distribution and control subsystem (PDS) receives power from the power generation subsystem, and provides the regulation and switching required to deliver regulated power from distribution to the antenna system (Klystrons) and the various subsystems (Attitude Control, IMCS, etc.). During the ecliptic periods, batteries will be utilized to supply the minimum required power to the various subsystems. The feeders, and power cabling of all SPS subsystems, are included in the PDS. The grounding, electromagnetic interference control, and shielding requirements of the SPS are also included as part of the PDS. The life expectancy of the PDS is 30 years with the exception of the energy storage (batteries), which has a life expectancy of 10 years. Resupply of the PDS will be as needed.

3.3.1 FUNCTIONAL REQUIREMENTS AND BLOCK DIAGRAMS

Functional requirements for various operating modes are listed in Table 3.3-1. A smplified block diagram for the photovoltaic concept is presented in Figure 3.3-1. The solar thermal concept replaces the solar arrays with the power module consisting of concentrators, absorbers, and electromechanical power generation.

Table 3.3-1. Power Distribution and Control Subsystem
- Operating Modes

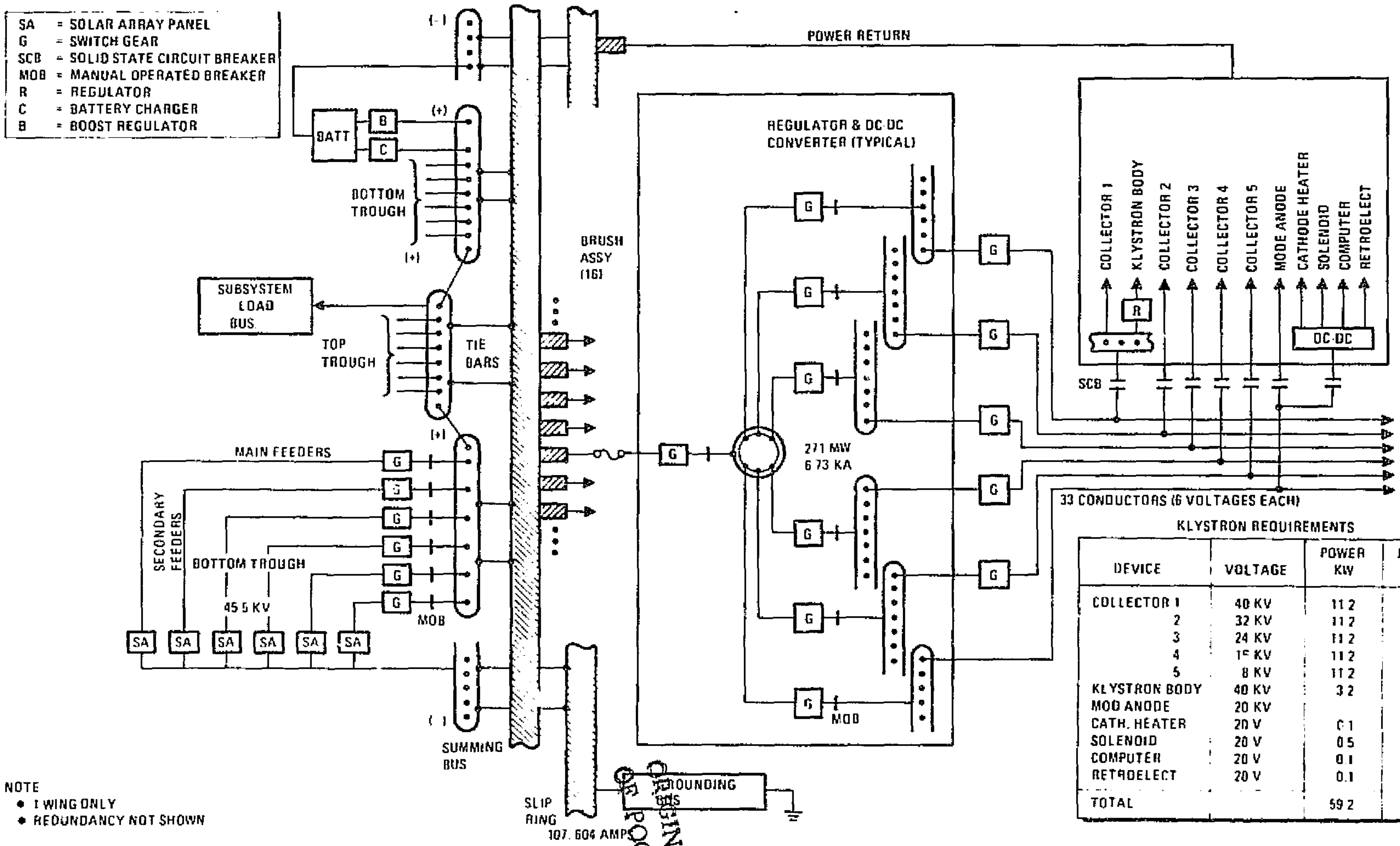
Mode	Assembly	Function
Construction	N/A	N/A
Inter-orbit transportation	Subsystem	Power for elec. prop. system (configured for low voltage)
Operation	Subsystem	Steady-state operation
Eclipse	Subsystem	Shutdown/startup and minimum energy supplied to subsystems
Transition (from construction transport.)	Subsystem	Startup/shutdown thruster power
Failure maintenance	Subsystem	Redundant operation, auto shutdown
Checkout	Subsystem	Continuity, insulation resistance

3.3.2 MAJOR ASSEMBLIES

Figure 3.3-2 illustrates the major assemblies comprising the power distribution and control subsystem (PDS). The assemblies are essentially similar for both SPS concepts.

Power Distribution

The power distribution subsystem consists of the main feeders, secondary feeders, summing busses, tie bars, and power interface cabling for the various subsystems. The main feeders are generally sized to minimize the combined mass of itself and the solar array mass, considering power requirements, efficiency, and the variation in resistivity with operating temperature. The power distribution system utilizes flat aluminum (6001-T6) feeders where feasible, and round conductors for those subsystems where flat conductors are



KLYSTRON REQUIREMENTS

DEVICE	VOLTAGE	POWER KW	REGUL ATION
COLLECTOR 1	40 KV	11 2	
2	32 KV	11 2	
3	24 KV	11 2	
4	1[illegible] KV	11 2	
5	8 KV	11 2	
KLYSTRON BODY	40 KV	3 2	1%
MOD ANODE	20 KV		1%
CATH. HEATER	20 V	0 1	1%
SOLENOID	20 V	0 5	1%
COMPUTER	20 V	0 1	1%
RETRODELECT	20 V	0.1	1%
TOTAL		59 2	

Figure 3.3-1. Power Distribution - Simplified Block Diagram

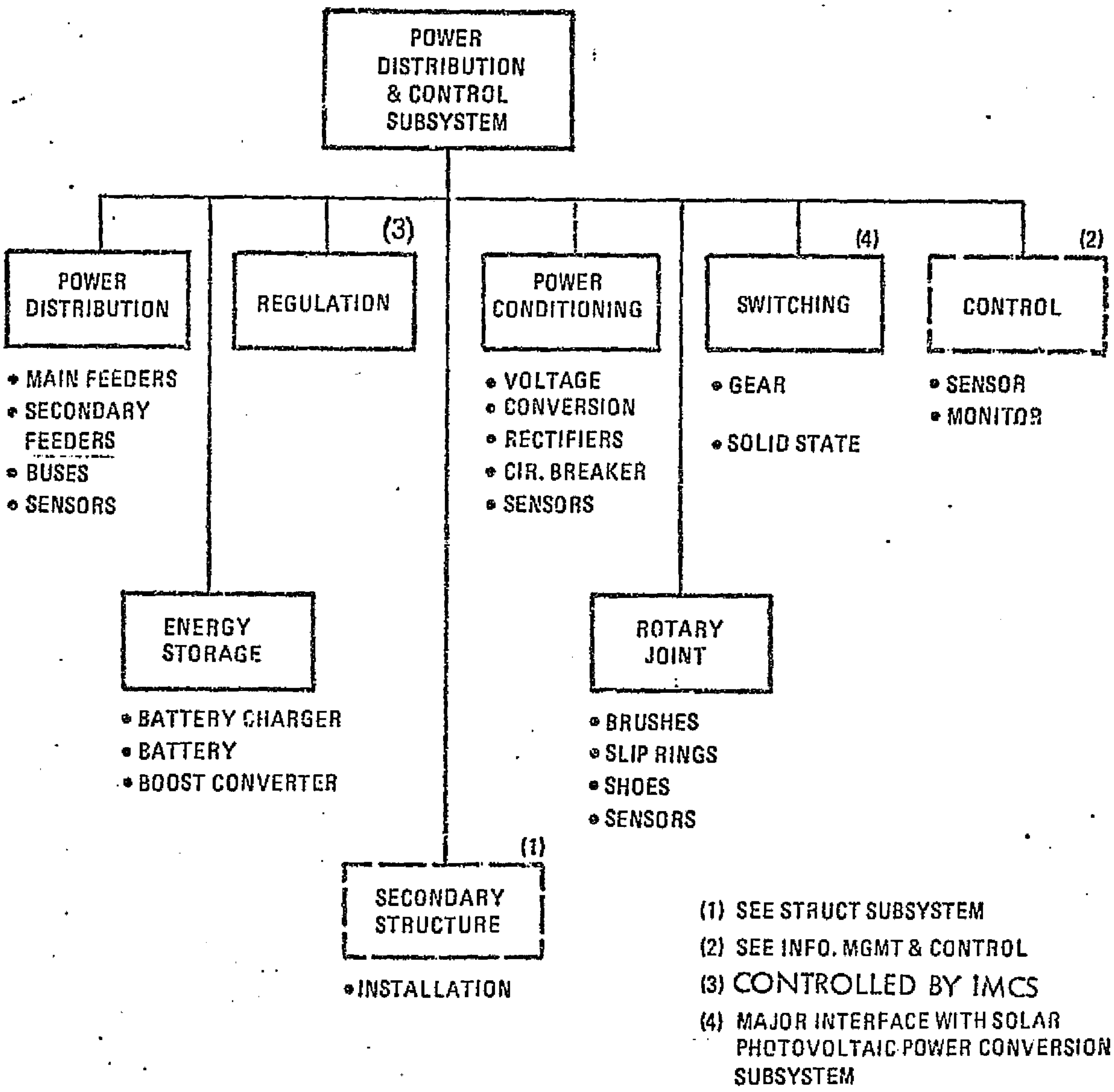


Figure 3.3-2. Assembly Tree

not feasible. The flat conductors are not considered part of the main structure; they will normally be passively cooled by radiation to free space.

Regulation

The solar array output will be regulated so as to prevent line surges when switching the solar array power on to the main feeders. The regulation function is accomplished by selective control of intra-blanket switching managed by the information management and control subsystem (IMCS). The regulators on the solar thermal system are an integral part of each generator complex.

Power Converters and Conditionings

The power converter and conditioners convert the existing bus voltages to the subsystem voltage required for the various subsystem loads. The output tolerances will be based on the using subsystem interface requirements. The power converters are utilized in the GEO and ecliptic modes of operation.

Switch Gears

Switch gears are used for:

- Isolation of solar array blankets or rotating generator sets due to systematic element failure
- Isolation of solar array blankets or rotating generator sets when performing maintenance work
- Prevention of large line transients upon startup and shutdown and during ecliptic periods

The switch gears will be solid-state to reduce the overall mass of switches. The voltages and currents being handled by these switches will be monitored by the IMCS to determine their status and to establish a need for the opening and closing of these switches. The switches are generally held in the closed state during the steady-state mode of operation. During the startup and shutdown operations, the switches will be monitored by the IMCS and when certain voltage levels are reached a command signal will open or close switches as required.

Energy Storage

Batteries will be utilized during ecliptic periods to provide the minimum energy required by the various subsystems. The batteries will be a sodium chloride type, having a density of at least 200 Wh/kg.

Rotary Joint

The rotary joint is utilized to transfer energy through slip-rings and brushes from the SPS fixed member to the SPS rotating member upon which the microwave antenna is located. The power transferred includes both that required to operate antenna-mounted equipment, as well as that to be transmitted to the ground.

Control

The PDS control concept is a simple, continuous monitoring system performed by the on-board IMCS computer system. The IMCS monitors the bus as well as the converter voltages, currents and temperatures, and compares these with preset levels stored in the computer(s). In the event of a voltage/current level disagreement with the preset conditions, the IMCS will initiate a command signal to regulate the faulted area by opening up or closing the associated switch gear(s).

Secondary Structures

Secondary structures consist of mounting brackets, clamps, and installation structures as needed. It is assumed that a delta of 10 percent of the PDS mass would be sufficient for such purposes.

3.3.3 DESIGN AND PERFORMANCE CHARACTERISTICS

The design and performance characteristics for the power distribution system are listed in Table 3.3-2. The characteristics have been generalized to show a range of performance requirements encompassing both concepts.

3.3.4 SUBSYSTEM DEFINITION AND INTERFACES

Subsystem interfaces are shown in Figure 2.2-1 for the photovoltaic concept. A similar interface would be applicable to the solar thermal concept. The power required from the photovoltaic power source is 9.76 GW, while the solar thermal power source must supply 9.79 GW to account for differing distribution/conversion losses.

Table 3.3-2. Design and Performance Characteristics

Major Assembly	Requirements	Technology Issue
GENERAL		
Mass	Configuration dependent	
MTBF	Subsystem dependent	
Life	30 years	
Efficiency	88-98% (config. dependent)	
Resupply and maintenance	As needed	
POWER DISTRIBUTION (PD)	Mostly flat conductor	Further study is required to determine feasibility of superconductivity for reduction of mass.
Mass	Configuration dependent	
Material	Aluminum 6001-T6	
Insulation	1-mm Kapton	
Efficiency	88-98% (config. dependent)	
Subsystem cabling	Location and power dependent	
Resupply and maintenance	As required	
Life	30 years or greater	
POWER CONVERTER AND CONDITIONING		
Density	Approx. 0.1 kg/kW	Further analysis is required to specify design requirements and type.
Voltage	Subsystem dependent	
Current	Subsystem dependent	
Efficiency	96-98%	
Life	30 years	
Resupply and maintenance	As required	
SWITCH GEAR		
Density	Approx. 0.00086 kg/kW	Study is required to specify design requirements.
Type	Solid state	
Power rating	Configuration dependent	
Voltage	Config. and location dependent	
Efficiency	99-99.9%	
Life	30 years	
Resupply and maintenance	As required	
ENERGY STORAGE (BATTERY)		
Density	Approx. 200 Wh/kg	Further study to define charge/discharge cycle, size, volume, and installation is required.
Type	Sodium chloride	
Temperature	200°C	
Efficiency	80-95% (turnaround)	
Life	10-20 years	
Resupply and maintenance	As required	

Table 3.3-2. Design and Performance Characteristics (Cont.)

Major Assembly	Requirements	Technology Issue
SECONDARY STRUCTURE		
Mass	10% of PDS weight was considered to be required for mounting and installation.	
CONTROL		
Temperature sensors	No. of sensors config. dependent	
Current sensors	No. of sensors config. dependent	
Voltage sensors	No. of sensors config. dependent	
Switch gear control	Configuration dependent	
Overcurrent		
Overvoltage		
Undercurrent		
Undervoltage		
ROTARY JOINT		
Slip rings required for SPS	2 positive and 2 negative	
Operating voltage	40,000 V dc (nominal)	
Amps per ring assembly	108,500	
Total weight of four-ring and brush assemblies	173,392 kg	
Life	30 years	
Resupply and maintenance	As required	
SLIP RING		
Core of slip ring	Aluminum	
Cladding on slip ring	Coin silver	
Core size, cross-section	41.3 cm^2	
Diameter	1.13 km	
Length	3.55 km	
Weight	40,300 kg	
Total weight of all slip rings (4)	161,200 kg	
PICKUP SHOE-BRUSH		
Number required/each slip ring	8	
Material	75% M_oS_2, 25% M_o+ T_a	
Shoe size		
Dimension/shoe	17.8 × 12.7 cm × 6.1 m	
Contact surface area/shoe	1,651 cm^2	
Weight/shoe	381 kg	
Shoe travel velocity	2.47 m/min	
Wear rate per year	0.0156 cm	
Current density	7.75 amp/cm^2	
Operating temperature	90°C	
Contact pressure	0.705 kg/cm^2	
Total weight, all 32 shoes	12,192 kg	

3.4 STRUCTURES SUBSYSTEM

The primary SPS structure assemblies are made up, basically, of tribeam girders, tension cables, and joints. The fabrication and assembly of these structures are accomplished on orbit by beam machines and supporting auxiliary equipment. These structural elements must individually withstand the forces, torques, and dynamics imposed by the construction process. Once built up to an assembly level (e.g., solar array wing, rotary joint, etc.), the structure must have sufficient strength and stiffness to withstand forces, torques, and dynamics generated by the environment (gravity-gradient torques), the attitude control system (forces and frequencies) and the operational equipment (rotary joint torques, microwave induced thermal environment, etc.). The level of strength and stiffness are dictated by other subsystem requirements such as pointing accuracies and ACS bandwidth frequencies.

The secondary structure consists of the passive interface attachment between the primary structure and the operational subsystems. The structural mechanisms consist of active structural subassemblies that articulate, rotate, or otherwise cause or allow motion between the primary structure and other subsystem elements or between subsystem elements themselves.

3.4.1 FUNCTIONAL REQUIREMENTS AND BLOCK DIAGRAMS

Functional requirements for various operating modes are listed in Table 3.4-1. Since the structure is primarily a passive system (the exception is the figure monitoring system), no block diagrams exist. A simplified interface diagram is presented in Section 2.2.

Table 3.4-1. Structural Subsystem - Operating Mode

MODE	ASSEMBLY	FUNCTIONS
CONSTRUCTION	SYSTEM	MAINTAIN STRUCTURAL INTEGRITY OF STRUCTURAL SUBELEMENTS PRIOR TO OVERALL SYSTEM STABILIZATION.
PRE-INTER-ORBIT TRANSFER REORIENTATION	SYSTEM	WITHSTAND GRAVITY-GRADIENT/ACS TORQUE INTERACTION. DEVELOP MINIMUM FIRST BENDING MODE FREQUENCY DICTATED BY ACS.
INTER-ORBIT TRANSFER	SYSTEM	WITHSTAND G-LOADS ASSOCIATED WITH PROPULSION SYSTEM THRUST LEVEL WHILE MAINTAINING ADEQUATE RIGIDITY WITHIN POINTING TOLERANCES REQUIRED FOR POWER CONVERSION.
ECLIPSE		WITHSTAND THERMAL STRESS AND DISTORTIONS DUE TO EXTREME TEMPERATURE CHANGES.
OPERATION	ANTENNA STRUCTURE	POINT WITHIN $\pm 0.08°$ OF TARGET
	SOLAR ARRAY	MAINTAIN WIDTH DISTORTION $\leq \pm 0.3°$
	SOLAR THERMAL REFLECTOR STRUCT.	MAINTAIN PARABOLIC MOLDLINE $\leq$ 0.5°
FAILURE/MAINTENANCE	SYSTEM	PROVIDE FOR SUBELEMENT SECONDARY LOAD PATHS. WITHSTAND FORCES & TORQUES INTRODUCED BY MAINTENANCE OPERATIONS.

3.4.2 MAJOR ASSEMBLIES

Figure 3.4-1 depicts the major structural subsystem assemblies and tabulates the elements that make up each of these major assemblies. An example of this element breakdown is shown in Figure 3.4-2. The assemblies are photovoltaic peculiar, solar thermal peculiar, or common to both systems indicated.

3.4.3 DESIGN AND PERFORMANCE CHARACTERISTICS

The design and performance characteristics for the structures subsystem are listed in Table 3.4-2.

3.4.4 SUBSYSTEM DEFINITION AND INTERFACES

Subsystem interfaces are shown in Figure 2.2-3. The only active interface identified to date is the laser transit network, established to determine the satellite figure for the CR-2 photovoltaic satellite. It is expected that this network would be applicable to any photovoltaic concept. Equivalent networks would be derived for the other candidate concepts.

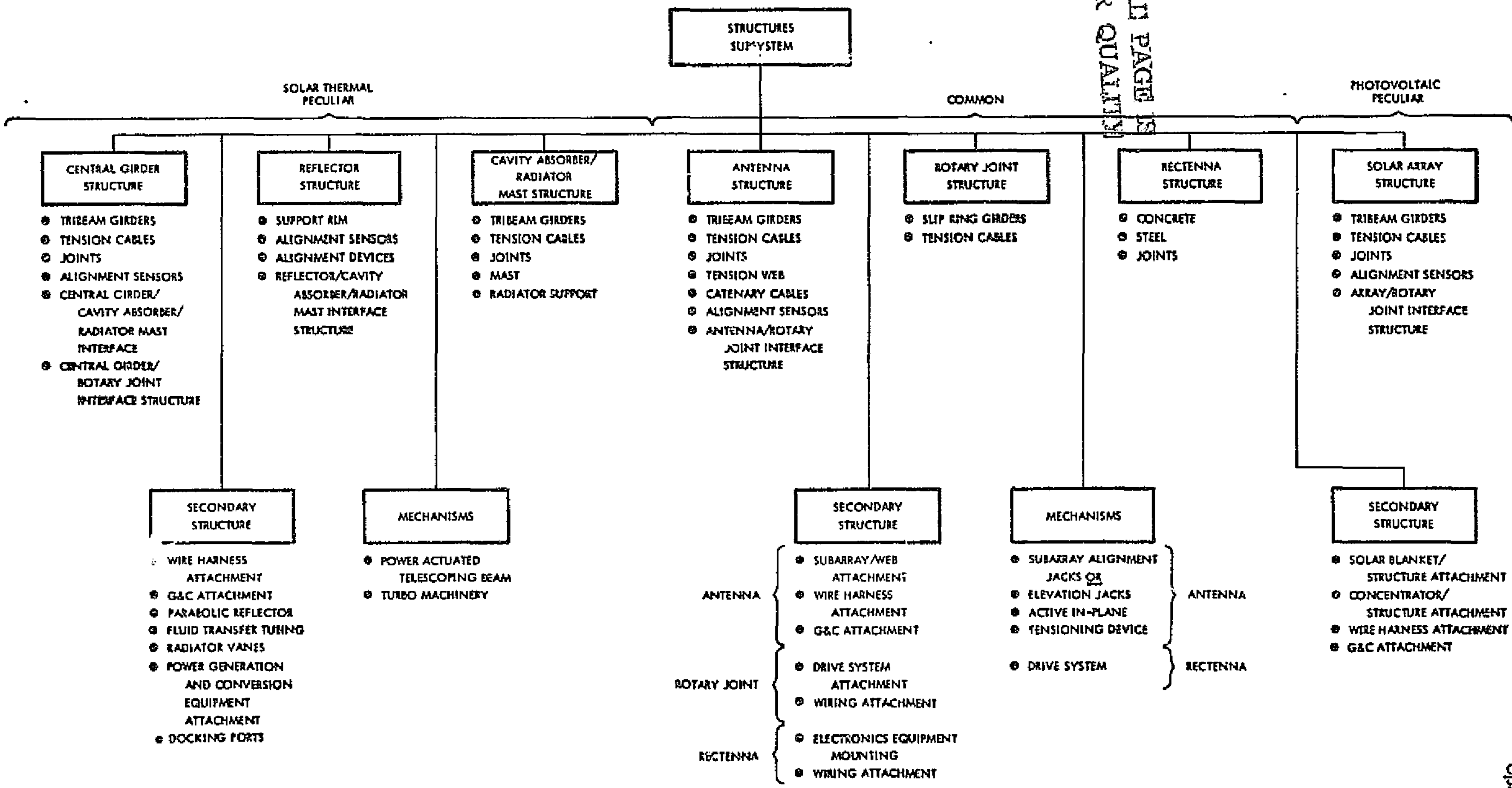


Figure 3.4-1. Assembly Tree

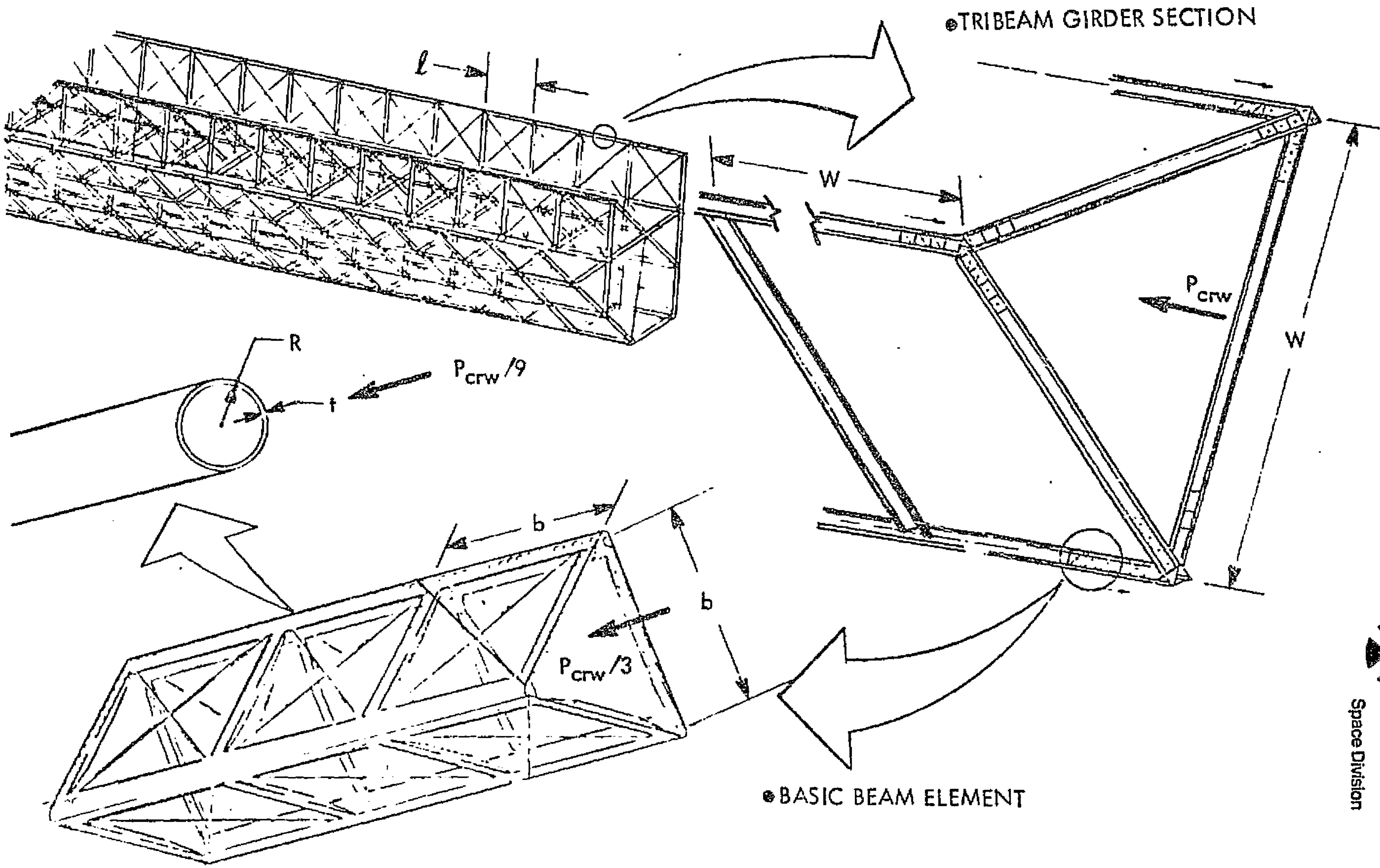


Figure 3.4-2. Structure Breakdown

Table 3.4-2. Design and Performance Characteristics

FACTOR	SOLAR THERMAL			COMMON			PHOTOVOLTAIC
	CENTRAL GIRDER STRUCTURE	REFLECTOR STRUCTURE	CAVITY ABSORB RADIATOR MAST STRUCT.	ANTENNA STRUCTURE	ROTARY JOINT STRUCTURE	RECTENNA STRUCTURE	SOLAR ARRAY STRUCTURE
CONSTRUCTION SITE	LEO	LEO	TBD	LEO/GEO	LEO/GEO	EARTH	GEO
CONSTRUCTION TECHNIQUE	BEAM MACHINE	TBD	BEAM MACHINE	BEAM MACH/ TBD	BEAM MACHINE	GROUND CONSTR.	BEAM MACHINE
MASS (KG)	TBD	TBD	TBD	$0.1\text{-}0.2\times10^6$	1.4×10^6	0.75×10^9	3.7×10^6
MATERIAL	ALUMINUM	ALUMINUM AL/KAPTON	ALUMINUM	METALLIC/ COMPOSITES	ALUMINUM	STEEL/ CONCRETE	ALUMINUM
MAX ALLOW OP TEMP (°C)	150	150	150	150/160	150	150	150
OPERATING STRESS LEVEL (μPa) *	$\sigma_{cc} = \sigma_{cn}$	TBD	$\sigma_{cc} = \sigma_{cn}$	$\sigma_{cc} = \sigma_{cn}$	TBD	138	$\sigma_{cc} = \sigma_{cn}$
FACTOR OF SAFETY	2.0	2.0	2.0	1.5	1.5	1.7 BASED ON F_{TY}	2.0
MIN NATURAL FREQ (CYCLES/HOUR)	1-10	1-10	1-10	2.0	TBD	N/A	10.0-LEO 1.0-GEO
ORIENTATION	X-POP	Z-SUN	X-SUN	NADIR	N/A	N/A	Y-POP Z-EQUATOR
TOLERANCES (OUT OF PLANE) ABOUT Y AXIS ABOUT X AXIS	TBD	TBD	TBD	±0.8°	TBD	TBD	0.3° 1.0°

$^*\sigma_{cc}$ = CRITICAL CRIPPLING STRESS; σ_{cn} = CRITICAL BUCKLING STRESS

3.5 ATTITUDE CONTROL AND STATIONKEEPING SUBSYSTEM

The attitude control and stationkeeping subsystem (ACSS) is an integrated system designed to satisfy the control and stationkeeping requirements for each of the SPS operational modes. The functional performance requirements of the ACSS are to provide: vehicle attitude stabilization, solar collector pointing and figure control (currently passive for the photovoltaic satellite), and microwave (MW) antenna pointing and figure control, and stationkeeping in geosynchronous orbit.

3.5.1 FUNCTIONAL REQUIREMENTS AND BLOCK DIAGRAM

Functional requirements for various operating modes are listed in Table 3.5-1. The functional flow diagram in Figure 3.5-1 illustrates the major ACSS component subsystems and information flow between the components to satisfy the control and stationkeeping requirements. The ACSS is integrated with the IMCS which provides the interconnections for all the ACSS elements and the computational capacity for the control algorithms. The basic information for the implementation of the control laws is provided by the sensors. The control forces and torques are furnished by the ion bombardment thrusters of the reaction control system (RCS). The MW antenna pointing is achieved with the rotary joint and antenna gimbal torques.

Table 3.5-1. Attitude Control and Stationkeeping - Operating Modes

MODE	FUNCTIONS
CONSTRUCTION	VEHICLE STABILIZATION DOCKING STATIONKEEPING
TRANSITION FROM CONSTRUCTION OPNS	REORIENT FROM CONSTRUCTION TO OPERATIONAL ATTITUDE
OPERATIONS	ATTITUDE CONTROLLED REFERENCE ORIENTATION ANTENNA POINTING FIGURE CONTROL STATIONKEEPING
ECLIPSE	ATTITUDE CONTROLLED TO REFERENCE ORIENTATION ANTENNA POINTING (STATIONKEEPING NOT REQUIRED)
FAILURE MAINTENANCE	FAIL-OPERATIONAL REDUNDANCY ON ALL ATTITUDE CONTROL FUNCTIONS MAINTENANCE INTERVAL, $\geq$ 1 YEAR
CHECKOUT	LEAK CHECKS SOLAR POINTING AND FIGURE CONTROL STATIONKEEPING DYNAMIC RESPONSE

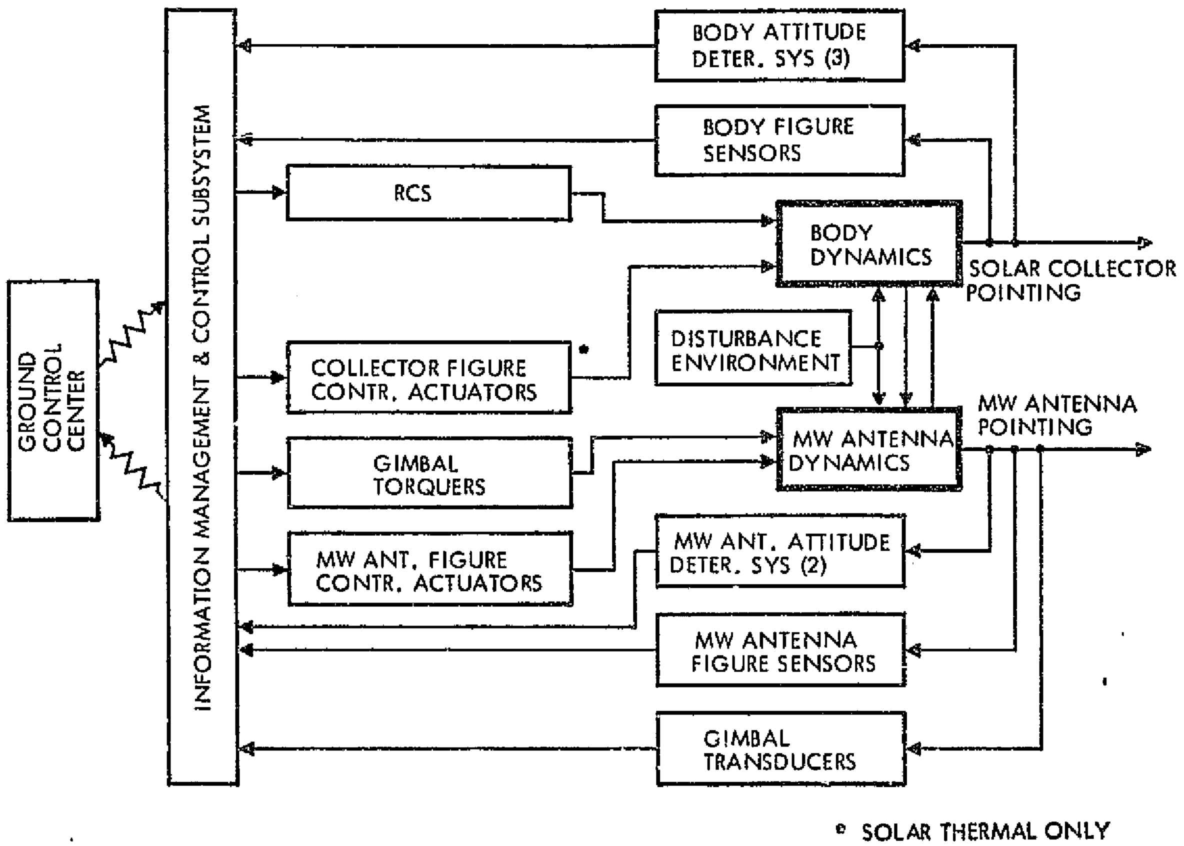


Figure 3.5-1. Functional Flow Diagram

Satellite Attitude Control Requirements

The attitude control system shall maintain vehicle stabilization and orientation accuracy in all three axes. The detailed performance requirements are given in Table 3.5-2. The coordinate systems used in the photovoltaic and solar thermal concepts are shown in Figure 3.5-2.

Table 3.5-2. Attitude Control Requirements

PARAMETER	SPS OPTIONS: PHOTO-VOLTAIC CR = 2	SPS OPTIONS: SOLAR THERMAL
ASSEMBLY ORBIT	GEO	LEO
ASSY CONTROL (GRAVITY-GRADIENT (STABLE)	Z-POP, Y-LV	Z-POP, Y-LV
CONTROL ACCURACY (DEG)	±0.5	±0.5
OPERATIONAL ATTITUDE CONTROL		
REFERENCE ATTITUDE	Y-POP,X-IOP	Y-POP,X-IOP
CONTROL ACCURACY (DEG)	±0.1	±0.1
CONTROL SYS BANDWIDTH (CYCLES/HR)	0.5	3.4
SATELLITE FIRST BENDING MODE FREQ (CYCLES/HR)	≥1.0	≥6.8

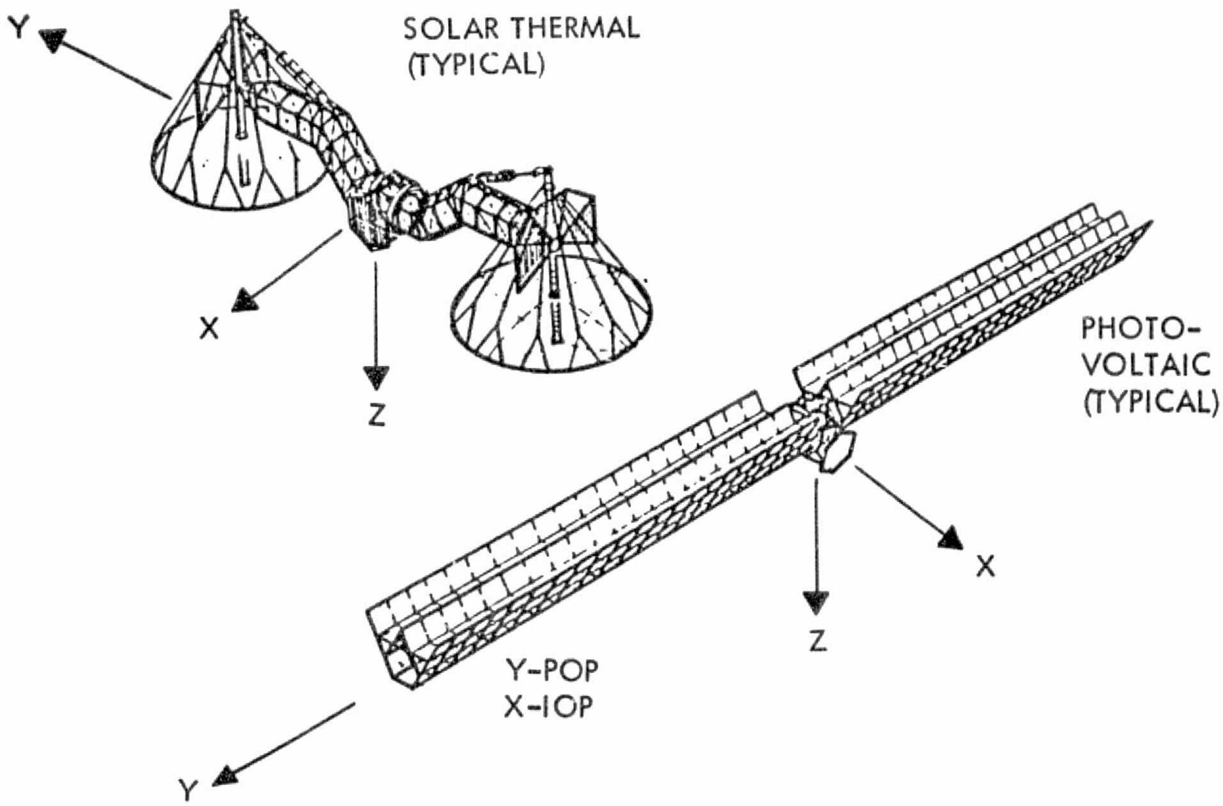


Figure 3.5-2. Satellite Coordinate Systems

Microwave Antenna Pointing Requirements

The MW beam steering is accomplished by a combination of mechanical antenna pointing and electronic beam steering. The requirements for the MW antenna gimbal pointing accuracy and the antenna figure control are the same for both SPS configuration options. The mechanical gimbal pointing accuracy requirement must be > 1 arc-min. The antenna must be stabilized to < 1 arc-min/sec. The antenna figure control shall be capable of pointing each of the 34.9x30.6-m elements to an accuracy better than < 6 arc-min. The electronic steering of the MW beam to provide the vernier pointing accuracy is accomplished in the MPTS.

Stationkeeping

The purpose of the stationkeeping system is to maintain a geostationary equatorial orbit and spacing with respect to the other satellites in the presence of disturbing perturbations. These perturbation forces include the effects of earth gravitational anomalies, lunar and solar gravitational perturbations and the solar pressure force acting on the spacecraft. The thrusters that provide the forces and torques for attitude control also provide the necessary thrust for stationkeeping maneuvers.

The equatorial orbit is selected in trade studies to minimize the impact of orbit inclination on rectenna size (and cost) requirements. This necessitates latitude (north-south) control.

The satellite longitude station must be selected within several degrees of its rectenna longitude in order to prevent an increase in rectenna size (and cost). The solar pressure induced perturbations are cyclical with an annual frequency and can be as large as ± 3.1° if uncorrected. In order to minimize the SPS space requirement in GEO and to prevent interference with other satellites which do not experience as large a solar pressure perturbation as the SPS, it is assumed that this perturbation must be corrected. Because of the large magnitude of this correction, means of alleviating it should be investigated further in future studies.

To minimize interference with the large number of other satellites expected to be using this orbit by the 2000 time frame a stationkeeping accuracy of ± 0.1 degree in longitude and latitude is adopted. The stationkeeping requirements are summarized in Table 3.5-3. No stationkeeping thruster firings should be performed during eclipse periods in order to minimize the thruster power requirements. Cyclic perturbations with a period less than or equal to one day need not be corrected.

Table 3.5-3. Stationkeeping Requirements

PERTURBATION SOURCES	ANNUAL REQUIREMENT*	
	ΔV/YR (~M/SEC)	PROP. (~KG/YR)
EARTH TRIAXIALITY (E-W)	2.1	430
SOLAR/LUNAR PERTURBATIONS (N-S)	53.3	11,000
SOLAR PRESSURE (E-W)	311	64,200
OTHERS	NEGLIGIBLE	NEGLIGIBLE

*BASED ON PHOTOVOLTAIC POINT DESIGN WITH MASS OF 28.65×10^6 KG AND I_{SP} = 13,000 SEC.

Collector Figure Control

Collector figure control for the solar collecting options may use passive techniques (i.e., continuously active servo control devices are not required). For the photovoltaic option (CR-2), the reflector/blanket dimensions and orientation tolerances must be maintained within 0.3 degree. The solar thermal Rankine figure control concept must maintain the collector surface to absorber alignment within 0.5 degree. The requirements include the effects of all thermal and dynamic disturbances as well as initial alignment errors.

Reaction Control System

The reaction control system (RCS) provides the necessary forces and torques for attitude control and stationkeeping. For the photovoltaic option the RCS consists of eight ion bombardment thruster modules with two modules mounted at each corner of the vehicle. The argon propellant is stored cryogenically. A refrigeration system is necessary to maintain the cryogenic temperatures. The thruster characteristics are given in Table 3.5-4.

Table 3.5-4. Electric Thruster Requirements

CHARACTERISTICS	VALUE
THRUST	1.75 N
SPECIFIC IMPULSE	13,000 SEC
PROPELLANT	ARGON
APERTURE	100 CM
OPERATING POWER	120 KW

3.5.2 MAJOR ASSEMBLIES

Figure 3.5-3 illustrates the major assemblies comprising the ACSS. The description of each assembly, as applicable to the photovoltaic option, is given in the preceding section.

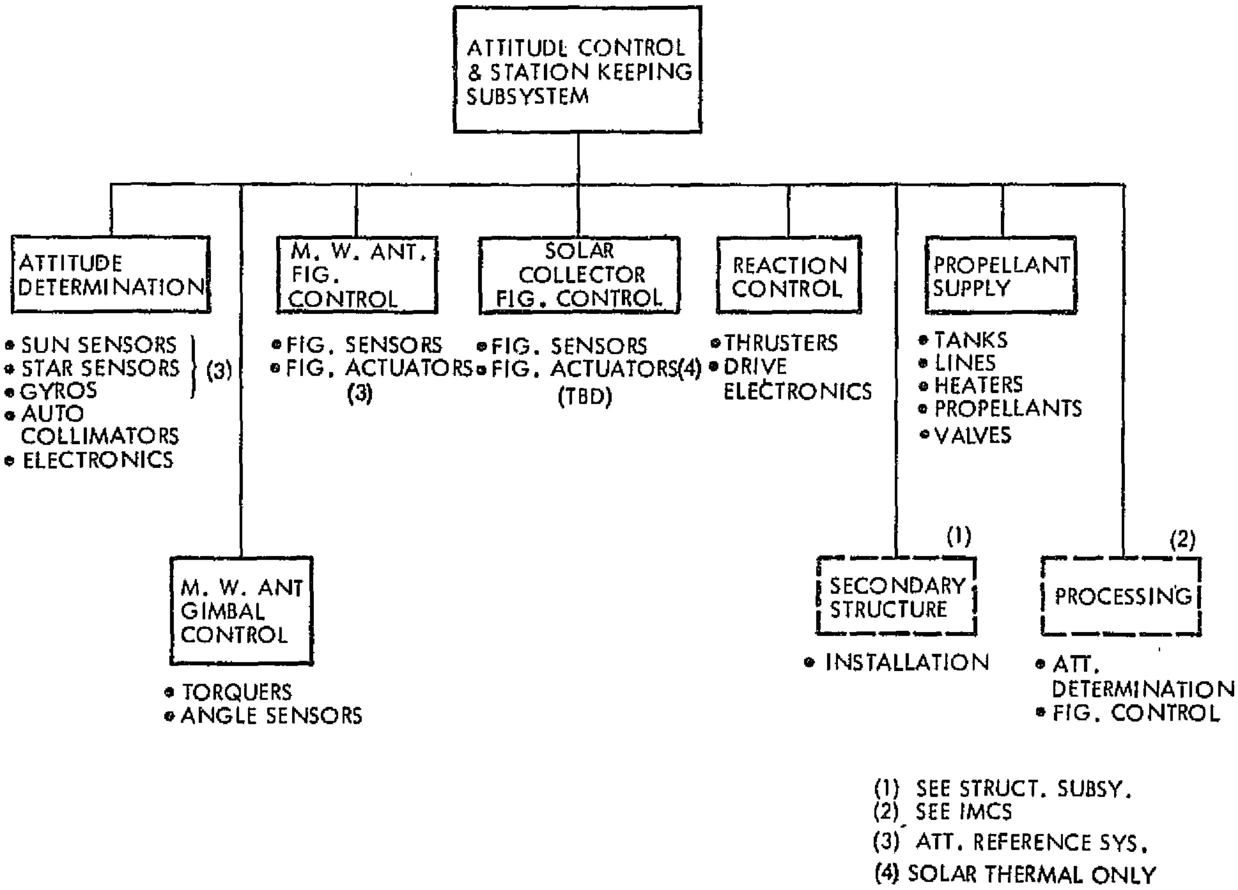


Figure 3.5-3. Assembly Tree

3.5.3 DESIGN AND PERFORMANCE CHARACTERISTICS

The point design ACSS is described in Volume IV.

3.5.4 SUBSYSTEM INTERFACES

The primary interfaces are the IMCS, the power distribution and control subsystem, and the structure. The IMCS, which functions as an integral part of the ACSS, also provides the interface for the ground support system to the ACSS. Figures 2.2-4 through 2.2-6 show the primary interfaces for the attitude reference system, the MW antenna pointing system, and the tank and engine system, respectively.

3.6 THERMAL CONTROL

The thermal control subsystem continuously maintains temperature levels within allowable extremes and provides equipment for heat dissipation, acquisition and temperature regulation where required. Both active and passive systems may be employed and components utilized include selective coatings, insulations, heaters, radiator networks, and specialized energy transport devices such as heat pipes. Thermal control impacts almost all satellite operations supporting power conversion, power distribution, the microwave generator and power transmission systems, the rotary joint, information management, primary and secondary structural design, and the ground receiving station.

3.6.1 FUNCTIONAL REQUIREMENTS AND BLOCK DIAGRAMS

The thermal control subsystem must satisfy functional requirements during all satellite operating phases indicated in Table 3.6-1. A simplified

Table 3.6-1. Thermal Control Subsystem - Operating Modes

Mode	Assembly	Functions
Construction	Subsystem	Maintain allowable temperature levels and gradients to restrict structural deformations/stresses and protect assemblies.
Inter-Orbit Transfer	Subsystem	Maintain allowable temperature levels and gradients: power required operation phases.
Operations	Subsystem	Support steady-state operation for all assemblies.
	P/C* Radiators	Reject waste heat generated by solar thermal system as required. Fluid line resistance to ensure repeated meteoroid impacts.
	Klystron Radiators	Reject klystron waste heat. Maintain required antenna temperature profiles. Restrict thermal stresses which could impair microwave transmission. Minimize heat transfer to rotary joint, antenna structure, and electronics' modules.
Eclipse	Subsystem	Guarantee integrity of all systems during extended cooling and return to steady state; assure continuous operation of resumption after shutdown as required.
	P/C* Radiators	Drain fluid as necessary and provide localized heating if required; smooth restart to steady-state operation.
	Klystron Radiators	Recover from fluid (heat pipe) freeze-up.
Failure/Maintenance	Subsystem	Redundant capability, where possible; e.g., heat pipes, pumps. Provide rapid access to down components.
	P/C* Radiators	Leak isolation through application of valves and heat pipes. Fluid in lines can be drained. Minimize particle impact failures by use of armor/bumper combination. Failure identification by sensors, or possibly by visual method.
	Klystron Radiators	Redundant heat pipes.
Checkout	Subsystem	Ground test where possible; leak check; verify control response.

*P/C = Power Conversion Subsystem

functional flow diagram of the thermal subsystem, indicating its relationship to other operating subsystems is illustrated in Figure 3.6-1. A simplified block diagram for the solar thermal (Rankine-cesium/steam) radiator system is shown in Section 2 (Figure 2.2-11). The klystron radiator heat pipe assembly is shown in Figure 3.6-2.

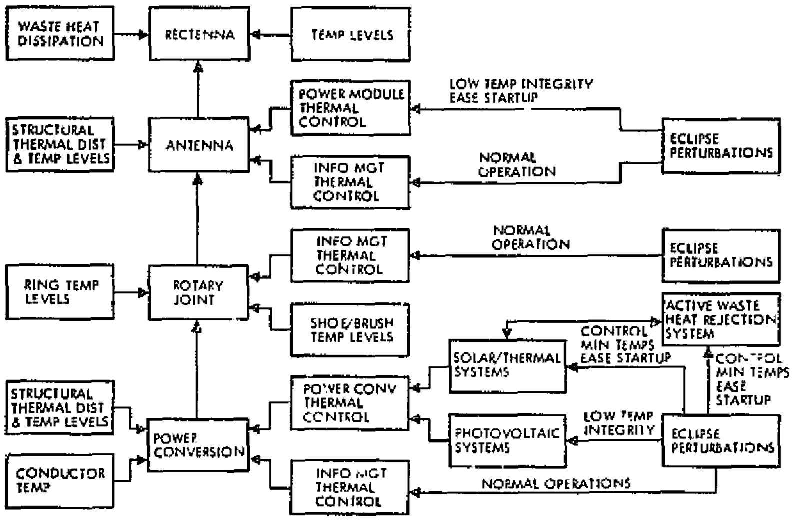


Figure 3.6-1. Thermal Control Functional Flow Diagram

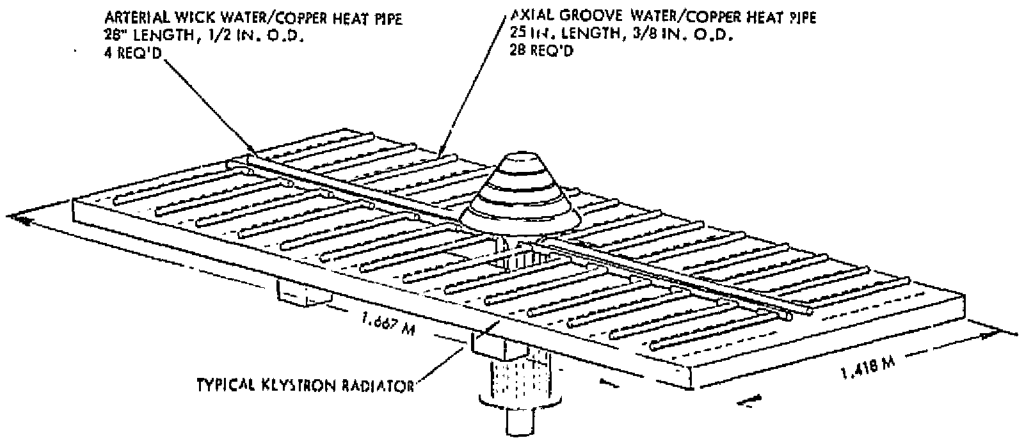


Figure 3.6-2. Klystron Radiator Configuration

3.6.2 MAJOR ASSEMBLIES

Figure 3.6-3 illustrates the major assemblies and components comprising the thermal control subsystem.

3.6.3 DESIGN AND PERFORMANCE CHARACTERISTICS

Design and performance characteristics are presented in Table 3.6-2 for the cesium/steam Rankine system. Design and performance data for the klystron radiators are presented in Table 3.6-3.

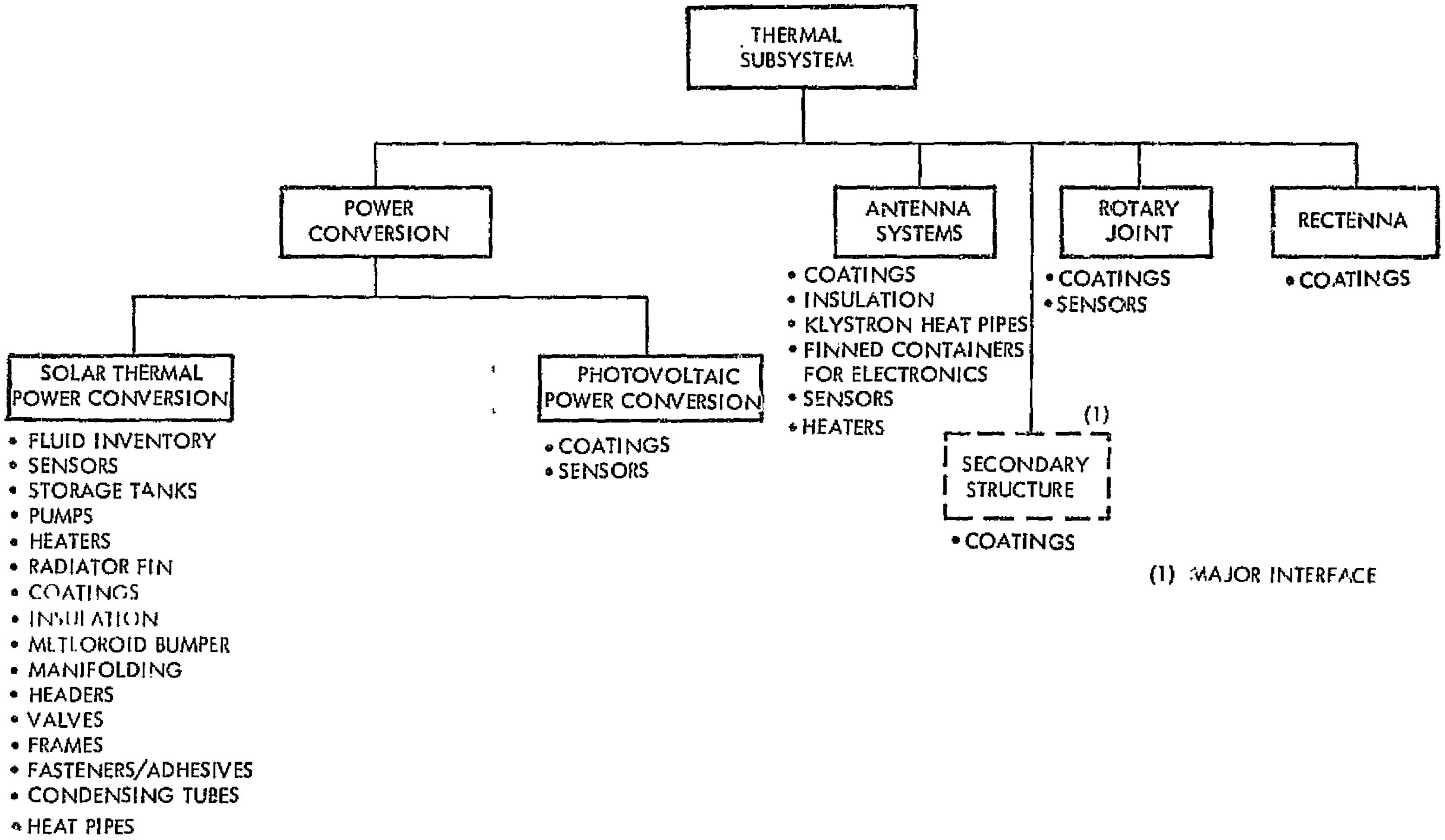


Figure 3.6-3. Assembly Tree

Table 3.6-2. Radiator Characteristic Performance Data

	Cesium/Steam (Rankine)
Waste heat (GW)	9.35
Heat transport mechanism	Condensing steam
Construction	Heat pipe/fin
Temp., eff. (°C)	196
Total panel area, one side (km^2)	2.37
Heat pipe	*
Radiator system weight (10^6 kg)	8.79
• Fins	1.80
• Heat pipe (+ armor)	5.07
• Fluid inventory + storage	0.89
• Piping (+ bumper and connections)	0.86
• Pumps	0.15
• Valves	0.02

*Radiator Heat Pipe Specification

Working fluid	Water
Material	Titanium liner (.0127 cm)/ aluminum outer tube (.0381 cm)
Wick	Flexible screen
Diameter (I.D.)	.9525 cm (0.375 in)
Diameter (O.D.)	1.0541 cm (0.415 in)
Evaporator section	12.45 cm
Adiabatic section	3.0 cm
Condenser section	98.5 cm
Q_{max}	260 watts
QL_{max}	160 w-m (6300 w-inches)
Tube spacing	3.53 diameters (based on OD)

Table 3.6-3. Klystron Cavity Radiators (Max. Intensity Region)

Total heat load (kW)	3.264
Driver cavities (kW)	0.206
Output cavity (kW)	2.308
Electromagnet (kW)	0.750
Radiator temperature (°C)	198
Radiator area, mine (m^2)	2.36
Fin material	Aluminum
Fin efficiency (%)	60
Coating (external)	Anodize (soft)
Coating (internal)	Anodize (hard)

Heat Pipes - Four high-performance, arterial wick copper/water heat pipes of 28-in. length each 1/2 in. O.D. Twenty-eight axial groove copper/water heat pipes, 25 inches long, each 3/8 in. O.D. (Container is actually copper liner encased in aluminum tube). Total heat pipe assembly weight = 6.18 kg.

3.7 INFORMATION MANAGEMENT AND CONTROL

The information management and control subsystem (IMCS) provides the interconnecting elements between and within all the various satellites and ground-based operational subsystems. The IMCS also provides operational control of both the satellite and ground systems as well as providing all subsystem processing support for all but very special functions.

The IMCS consists of the on-board and ground-based processing equipment [central processing units (CPU) and memories], the inter- and intra-subsystem data network (data busses), the man-machine interfaces (display/control), and inter-system communication links, including RF, but excepting those specifically provided for the control and transfer of primary power, and all elements provided to accommodate activities related to system security, safety, or any other operation necessary to the continuing operation of the SPS.

Because of the early stage of program analysis, only those requirements imposed upon the IMCS by a limited number of satellite operations have been identified. The identified requirements generally are limited to those associated with the immediate operations of an active satellite. Auxiliary functions such as ground/space communications, display/control, safety, security, etc., will be added when data become available.

3.7.1 FUNCTIONAL REQUIREMENTS AND BLOCK DIAGRAMS

The functional requirements for various operating modes are given in Table 3.7-1. The relationship of the IMCS to the other major subsystems is

Table 3.7-1. IMCS - Operating Modes

Mode	Assembly	Function
Construction	Subsystem	Temperature monitor Attitude monitor and control Safety monitor
Inter-Orbit Transportation	Subsystem	Power conversion and distribution Monitor and control Navigation Attitude monitor and control Subsystem monitor Configuration control MW pointing, gimbal pointing control
Operations	Subsystem	Steady-state monitor and control
Eclipse	Subsystem	Eclipse monitor Shutdown/startup monitor and control Subsystem standby monitor and control
Transition	Subsystem	Orientation monitor Subsystem monitor and control
Failure/Maintenance		Failure detection/isolation Redundancy management Auto shutdown/restart Override control Maintenance logging

depicted in Figure 2.1-1. Figure 2.2-13 illustrates a representative processor hierarchy as applied to a solar photovoltaic power-generating satellite concept. Initial analysis of the solar thermal power-generation concept has shown that this basic IMCS concept would also be applicable, although it would be desirable to alter the specific number, type, and location of the various hardware elements. The IMCS hierarchy applicable to the microwave antenna subsystem, attitude control and stationkeeping subsystem, and power distribution subsystems is presented in Figures 3.7-1 through 3.7-3, respectively. These hierarchies are established to the level at which the IMCS and the using subsystem interfaces are apparent (e.g., physical/electrical interface).

Table 3.7-2 summarizes the estimated number of data interfaces (not measurements) that must be accommodated by the IMCS. Note specifically that the microwave antenna subsystem is by far the major contributor to the determination of the complexity of the IMCS electrical interface. Table 3.7-3 provides a very preliminary estimate of the control interface that must be accommodated by the IMCS although the estimates for the other subsystems are not supported by an in-depth analysis. Again, the microwave antenna system predominates.

3.7.2 MAJOR ASSEMBLIES

Figure 3.7-4 identifies the major assemblies that form the IMCS. Six major assemblies have been identified at this time: (1) processors, (2) bus control units (BCU), (3) data bus, (4) remote acquisition and control units (RAC), (5) submultiplexers (SM), and (6) microprocessors (μp).

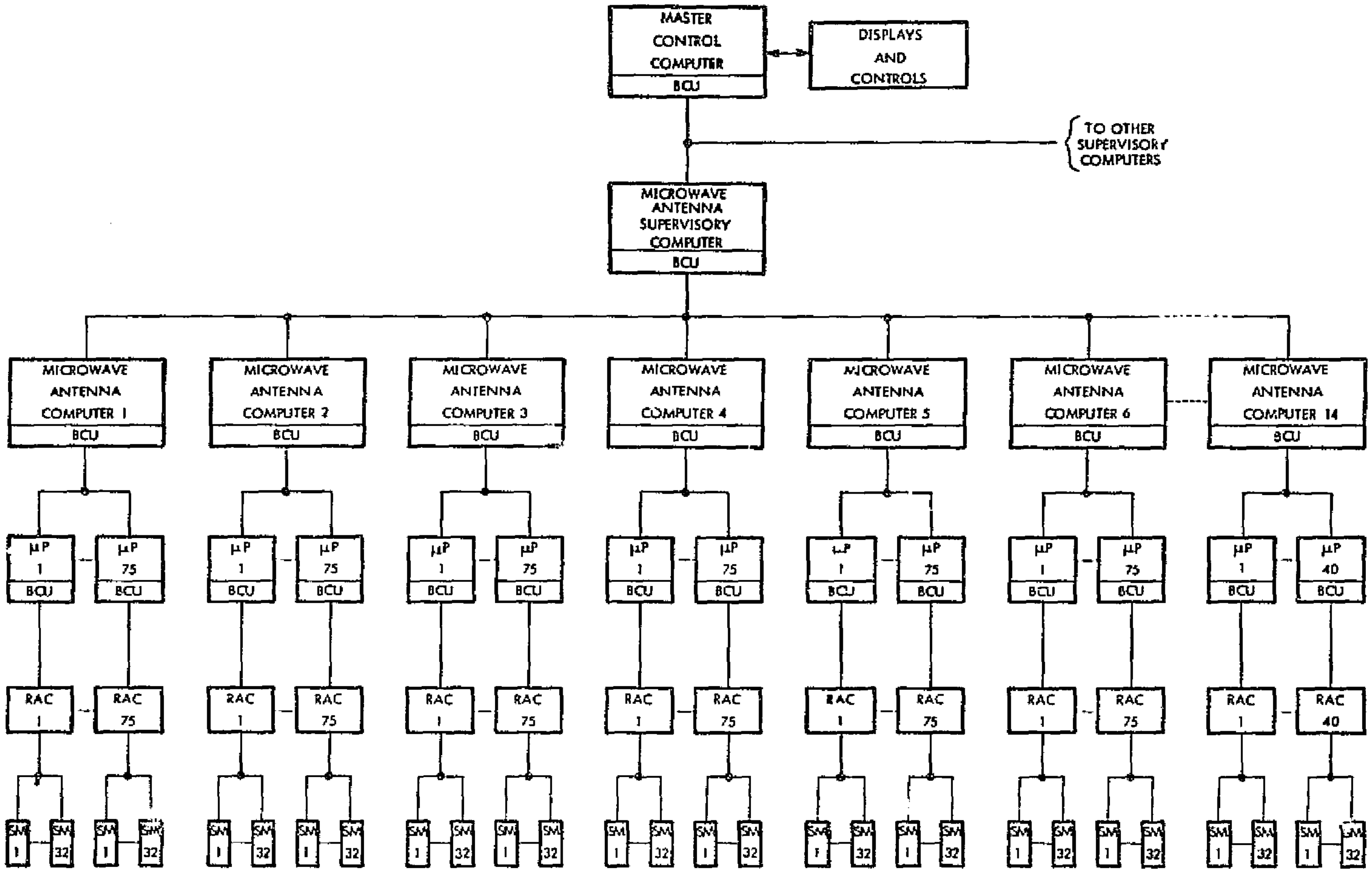
Processors

The satellite Master Control Computer (Figure 3.7-1) will operate with a 16-32 bit word format and have a 64K-128K word active memory plus a TBD billion word bulk storage facility. Second- and third-level processors (supervisory or local) will be 16-bit word assemblies and be limited to 16K-32K memories. In special cases, memory capacity may be increased to as much as 128K words. Assemblies or subassemblies identified as microprocessors (normally those units incorporated directly within the associated electronics) will incorporate an 8-bit-work format and use active 8K-64K word memories.

Bus Control Unit

The bus control unit (BCU) provides the control necessary for data/command transfer over the subsystem data bus network. The BCU accepts instructions and data (or commands) from its associated processor and translates these data from a processor-compatible format to one compatible with the data network. It also accepts bus-compatible data and converts these data to processor formats. In addition, the BCU monitors the data traffic--performing bit and word checks as well as health/status checks.

In addition to data bus control, the BCU will provide a computer-to-computer link where appropriate.



RAC - REMOTE ACQUISITION AND CONTROL UNIT
SM - SUB-MULTIPLEXER
μP - MICRO-PROCESSOR
BCU - BUS. CONTROL UNIT

Figure 3.7-1. IMCS - MW Antenna

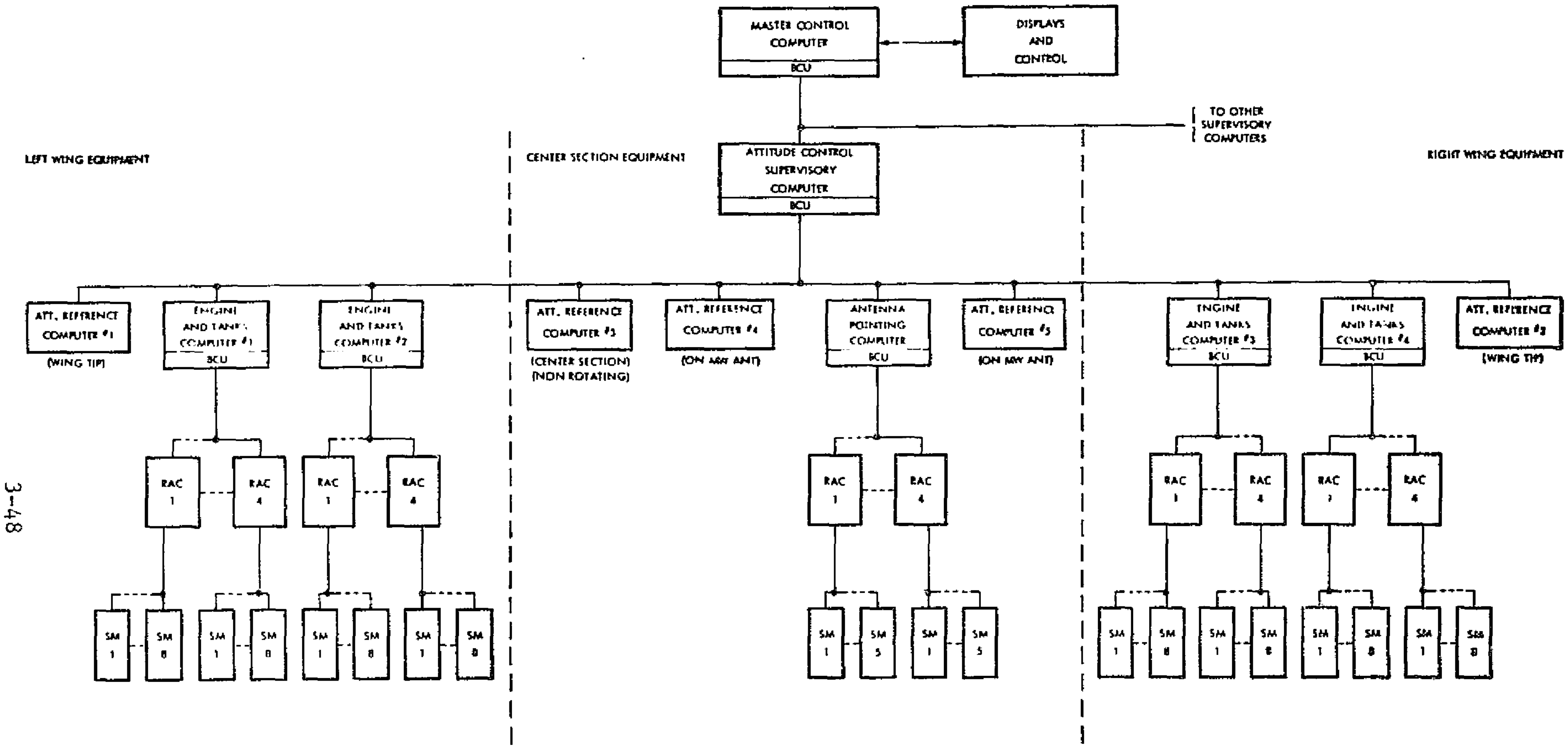


Figure 3.7-2. IMCS - Attitude Control

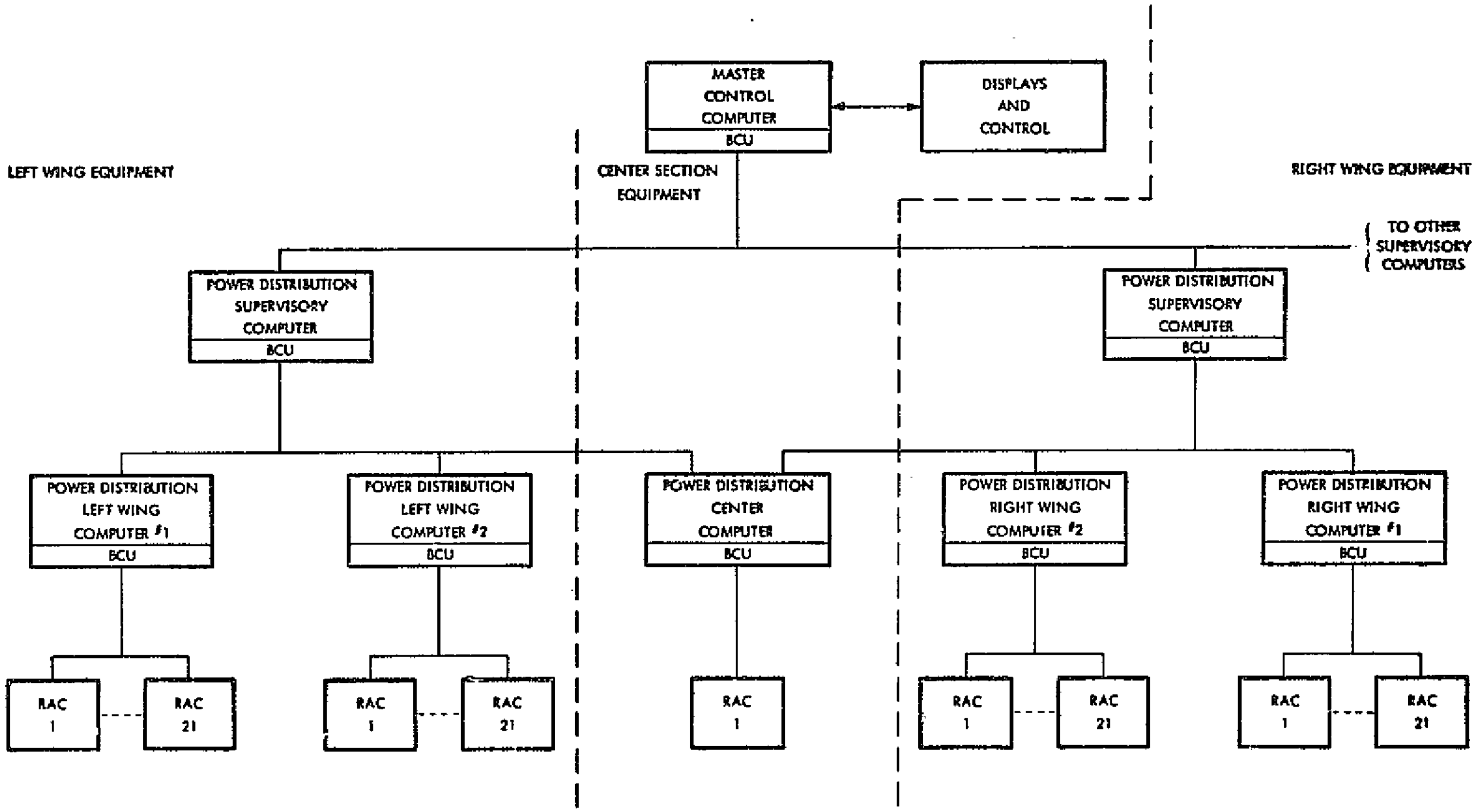


Figure 3.7-3. IMCS - Power Distribution

Table 3.7-2. Preliminary Data Interface Summary -
Photovoltaic (CR-2) Configuration

	ANALOG	DIGITAL	EVENT	TOTAL
MICROWAVE ANTENNA	6×10^6	1×10^6	2.1×10^6	$>9\times10^6$
OTHER SUBSYSTEMS				
STRUCTURE	35	35	35	>100
ATT. CONTROL & STATIONKEEPING	900	800	1000	~3000
POWER DISTRIBUTION	1000	100	2000	~3000
INFORMATION MANAGEMENT	-	~19,000	-	~19,000
THERMAL	16,000	-	-	16,000
LIFE SUPPORT	TBD	TBD	TBD	TBD
SAFETY AND SECURITY	TBD	TBD	TBD	TBD

Table 3.7-3. Preliminary Control Interface Summary
Photovoltaic (CR-2) Configuration

	PROPORTIONAL	EVENT	TOTAL
MICROWAVE ANTENNA	$<13.6\times10^4$	30×10^4	$<44\times10^4$
OTHER SUBSYSTEMS			
STRUCTURE	~35	~35	<100
ATTITUDE CONTROL & STATIONKEEPING	~100	>300	<500
POWER DISTRIBUTION	-	>300	>300
INFORMATION MANAGEMENT	-	>3000	>3000
THERMAL	-	-	-
LIFE SUPPORT	TBD	TBD	TBD
SAFETY AND SECURITY	TBD	TBD	TBD

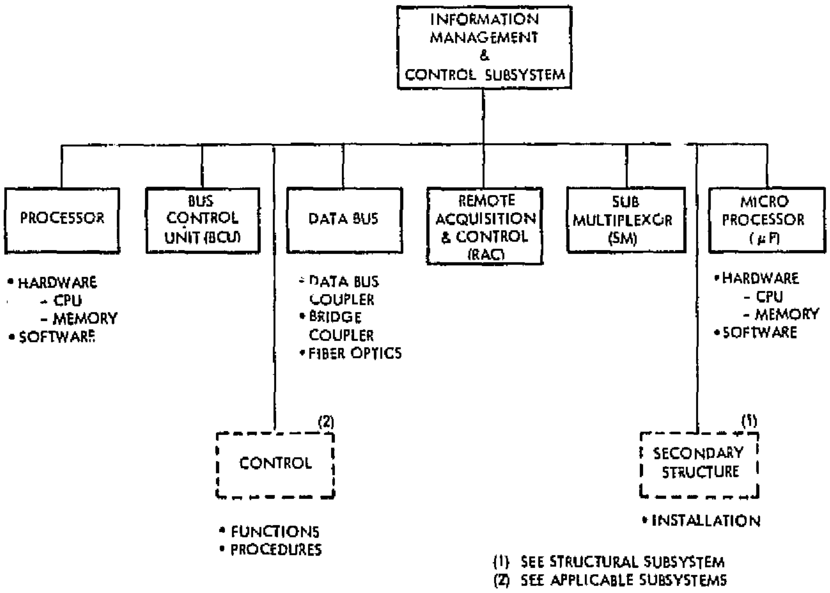


Figure 3.7-4. Assembly Tree

Data Bus

The data bus network accommodates multiplexed, digital data transmitted between the BCU and all other remotely located data acquisition and central devices associated with a specific processor/BCU combination. The bus link may utilize conventional wire techniques for short runs in low EMI areas or fiber-optic technology for long paths or through high EMI areas. Basic bit rate within the bus assembly is assumed to be 1.0 Mbps. Included in the data bus assembly are the data bus coupling devices used to connect the various remote units (one required per remote) as well as the bridge coupler required to transfer data across the microwave antenna rotary joints; the latter element is presently TBD.

Remote Acquisition and Control

The remote acquisition and control (RAC) assembly is the basic interface between the IMCS and the various operating subsystems. The RAC provides for data format conversion from the preconditioned analog, digital or event voltage/impedance levels, and converts these data into 8-bit digital, serial, equivalents. The RAC also accepts digital data words and outputs commands in a format compatible with the receiving subsystems.

Basic conversion (input/output) is assumed to be $\pm 1\%$ (e.g., 7-bit and sign). Voltage ranges and impedances are TBD.

Submultiplexers

The submultiplexer (SM) provides a means of expanding the capability of the RAC. The SM thus contains all of the capabilities of an RAC, but can only communicate with a single RAC rather than a given data bus. The number of SM's that can communicate with an RAC is presently TBD.

Microprocessor

The microprocessor (μp) elements provide local, front-end processing of data obtained from the various using systems. These processors will handle the bulk of the system's monitoring and control task, sending raw data up through the computer hierarchy only when the task-levels exceed preestablished limits, or when detected out-of-tolerance conditions exceed local control boundaries. These devices are solid state and could normally be integrated within the user electronics. When necessary, the μp can be located within the RAC's or SM's to provide local performance monitoring and control.

3.7.3 SUBSYSTEM DEFINITION AND INTERFACE

The subsystem interfaces for the three major subsystems are indicated in Figure 2.1-1 through 2.1-12. Table 3.7-4 summarizes the number of IMCS elements required for a typical photovoltaic configuration. Table 3.7-5 summarizes the physical (weight, power, volume) requirements for this system.

Table 3.7-4. Hardware Summary

HARDWARE ELEMENT	FUNCTION							
	MASTER CONTROL COMPUTER	DISPLAY AND CONTROL	SUPER-VISORY COMPUTER	REMOTE COMPUTER	MICRO-PROC.	BUS CONTROL UNIT	REMOTE ACQUIS. AND CONTROL	SUB-MUX
SATELLITE CONTROL	2	1	-	-	-	2	-	-
THERMAL CONTROL	-	-	2	5	-	7	85	1,352
STRUCT. ALIGN.	-	-	-	3	-	3	-	-
ATTITUDE CONTROL	-	-	1	10	-	11	28	148
POWER DISTRIB.	-	-	2	5	-	7	85	-
MICROWAVE ANTENNA CONTROL	-	-	1	14	777	792	787	29,500
TOTAL	2	1	6	37	777	822	985	31,000

Table 3.7-5. Weight/Power/Volume Summary - IMCS

HARDWARE ELEMENT	QUANTITY	UNIT MASS (Kg)	TOTAL MASS (Kg)	UNIT POWER (KW)	TOTAL POWER (KW)	UNIT VOLUME (m^3)	TOTAL VOLUME (m^3)
NON-ROTATING							
MASTER CONTROL COMPUTER	2	500	1,000	2	4	0.4	0.8
DISPLAY & CONTROL SET	1	200	200	0.9	0.9	0.72	0.72
SUPERVISORY COMPUTER	5	14	70	0.07	0.35	0.01	0.05
REMOTE COMPUTER	23	14	322	0.07	1.61	0.01	0.23
MICRO-PROCESSOR	–	5	–	0.02	–	0.003	–
BUS CONTROL UNIT	30	5	150	0.02	0.6	0.005	0.15
REMOTE ACQUISITION & CONTROL	198	5	990	0.02	3.96	0.005	0.99
SUB-MULTIPLEXOR	1,500	3	4,500	0.01	15.0	0.003	4.5
SUBTOTAL			7,232		26.42		7.44
ROTATING							
MASTER CONTROL COMPUTER	–	500	–	2	–	0.4	–
DISPLAY & CONTROL SET	–	200	–	0.9	–	0.72	–
SUPERVISORY COMPUTER	1	14	14	0.07	0.07	0.01	0.01
REMOTE COMPUTER	14	14	196	0.07	0.98	0.01	0.14
MICRO PROCESSOR	777	5	3,885	0.02	15.54	0.003	2.331
BUS CONTROL UNIT	792	5	3,960	0.02	15.84	0.005	3.96
REMOTE ACQUISITION & CONTROL	787	5	3,935	0.02	15.74	0.005	3.935
SUB MULTIPLEXOR	29,500	3	88,500	0.01	295.0	0.003	88.5
SUBTOTAL			100,490		343.17		98.876
TOTAL			108,000		369.6		106.3
CABLE							
NON-ROTATING–WIRE (22GA) FIBER OPTICS	1,200 KM 90 KM	12.0/KM 0.14/KM	14,000 12			2×10^{-5}/KM 2×10^{-6}/KM	0.48
ROTATING–WIRE FIBER OPTICS	33,000 KM 350 KM		279,000 50				
TOTAL			293,000				0.48

4.0 SUPPORT SYSTEMS

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4.0 SUPPORT SYSTEMS

4.1 GEO OPERATIONAL BASE

(TBD)

4.2 MAINTENANCE AND REFURBISHMENT FACILITY

(TBD)

4.3 SPS TRANSPORTATION SYSTEM REQUIREMENTS (PRELIMINARY)

The primary driver in establishing transportation system requirements is the high density SPS mass flow requirements to LEO and GEO. The expected number of earth launches required to support SPS construction ranges from 1500/year to 5000/year dependent upon satellite configuration and launch vehicle payload capability. The requirements contained herein are for a Heavy Lift Launch Vehicle (HLLV) capable of delivering a payload from the selected launch site(s) to LEO; a high thrust Orbital Transfer Vehicle (OTV) and a low thrust OTV, both of which are required to deliver a payload from LEO to GEO; and an on-orbit shuttle craft. The requirements as stated are based upon a mature program and may or may not be satisfied by a single transportation system configuration (i.e., a separate and distinct transportation system may be employed to satisfy personnel transfer requirements). Because the transportation system operations costs represent a significant percentage of overall SPS program costs, a primary objective is total system recovery/reusability with minimum maintenance, assembly and checkout requirements, consistent with the need for a high probability of mission completion and minimum risk of vehicle loss.

4.3.1 CONFIGURATION AND MISSION REQUIREMENTS

Although the selected satellite configuration may affect transportation system fleet size and launch rate requirements, it is not anticipated that the selection of an alternate SPS would lead to any significant changes in the overall approach to satisfying transportation system requirements (i.e., the total mass flow requirement is of sufficient magnitude that significant increases in mass flow would not be expected to change transportation system concepts).

Satellite Configuration

The reference SPS is a Solar Photovoltaic configuration with a CR of 2, a BOL power at the grid of 5 GW and an expected life of 30 years. The satellite mass is assumed to be $35x10^6$ kg (GEO Assembly) or $37x10^6$ kg (Partial LEO Assembly). The satellites are to be constructed at the rate of four per year (mature program) with a total requirement of 120 satellites. The satellite is to be constructed and/or assembled on-orbit. In addition to the satellite mass, the transportation system must also provide for the transfer of personnel and supplies to LEO and GEO. This requirement will lead to an additional mass flow of approximately 300 men and 125,000 kg/month.

Satellite Orbital Requirements

The ultimate operational destination of the SPS is a Geosynchronous Orbit (∿ 35,800 km equatorial). The LEO staging and/or construction orbit shall be selected to maximize operational flexibility (e.g., minimum radiation hazard and atmospheric drag with maximum opportunity for rendezvous by the HLLV and maximum opportunity of departure from LEO to GEO.

Flight Requirements

A primary transportation system objective is minimum earth and on-orbit operational requirements. Preferably methods of HLLV/OTV/payload handling would not require special orbital staging manpower/facilities. All elements of the transportation system should be sufficiently autonomous to require a minimum communication/data link between vehicle(s) and earth/orbital staging areas. For the purpose of analysis, it is assumed that at least 10 percent of the mass delivered to the satellite construction site will be structural mass required for satellite payload packaging and structural support; therefore, the transportation system shall provide a down-payload capability of at least 10 percent of the up-payload. Launch and reentry/recovery corridors shall be established to minimize restrictions and provide a maximum degree of flexibility in launch/recovery operations. All orbital elements of the transportation system shall be designed for a minimum orbital stay time commensurate with nominal turnaround requirements. All orbital elements of the transportation system shall have the capability of on-orbit propellant transfer to effect recovery in the event that the orbital stay-time exceeds the maximum allowed by system design.

Environmental Requirements

Specific environmental requirements are TBD. However, the overall impact on earth resources by transportation system materials and propellant selections must be considered. In addition, the overall levels of acoustic and toxic/noxious emissions must conform to generally accepted levels. The potential hazards of storing large quantities of propellants at the selected launch and orbital staging areas must also be addressed.

4.3.2 HEAVY LAUNCH LIFT VEHICLE(S) REQUIREMENTS

The HLLV must be capable of meeting the mass flow requirements of the Satellite Configuration section. In addition, the HLLV must transport the OTV and/or OTV propellants to LEO. Since HLLV operations are the major contributor to SPS transportation costs, specific attention must be given toward minimizing handling, checkout and assembly equipment requirements; facility and manpower requirements; replacement and/or refurbishment hardware; and any other factors which affect overall turnaround time requirements. As in the case of the Space Shuttle Transportation System, a "spaceline" (airline) concept is indicated.

Payload and Interfaces

Since the efficient delivery of payloads to LEO is the primary objective of the HLLV, then payload mass, configuration and interface requirements may strongly influence ELV design.

Payload Interface. For the purpose of HLLV synthesis, it may be assumed that all payloads will be prepackaged and self-contained. All payloads shall conform to a common HLLV mechanical interface and require minimum handling and installation equipment/operations. Those payloads requiring servicing (i.e., OTV propellant) shall be capable of servicing-deservicing after HLLV installation. The HLLV shall provide suitable launch and flight environmental protection for all payloads. The HLLV shall be capable of remote deployment of payloads in LEO and retrieval of empty payload modules and/or crew/OTV modules from LEO for return to Earth Base. All other HLLV/payload interfaces shall be avoided except where such interfaces will enhance mission accomplishment or are shown to be most cost-effective.

Payload Configuration. Specific payload weight and envelope requirements are dependent upon HLLV and OTV concept selection and potential environmental considerations. Because of the high mass flow requirement to support satellite construction, a minimum mix and manageable size of payload elements is desirable in order to reduce on-orbit operational requirements. The HLLV delivery concept and payload volume capability shall be such that a minimum payload density is required to meet maximum HLLV payload weight capability.

On-Orbit Docking Requirements. Except for the requirements specified in Payload Interface, above, HLLV on-orbit docking requirements are TBD.

Launch Site(s) Requirements

The predominant launch site requirement is in meeting the high launch/retrieval rates and mass flow requirements through the launch facility. Because of the high mass flow requirement, the launch site must be readily accessible by at least three of the four common means of earth transport (i.e., truck, rail, air and sea). In order to meet the high launch/retrieval rate requirement, launch site activities should be restricted to payload/HLLV mating, routine checkout/servicing and HLLV preparation for launch. The proximity of payload and transportation system maintenance and overhaul staging areas to the launch site are TBD. Because of the high demand for propellants, it may be assumed that a propellant processing facility will be at or in close proximity to the launch site. A candidate launch site is the Kennedy Spaceflight Center. Owing to the high probability of suspension of launch/retrieval operations for periods of up to two weeks due to inclement weather (especially if sea recovery of the HLLV is planned), an alternate, geographically isolated launch/retrieval site is indicated. A possible alternate to another launch site would be to increase the launch rate capability to provide for a two-week inventory of satellite construction elements on-orbit. However, the emergency return of orbital crew members would be precluded.

HLLV/Launch Site Interface Requirements. Except for the potential requirement for specialized checkout/maintenance equipment which might be employed in the HLLV staging area, physical launch site interfaces shall be restricted to consumables servicing and ground power requirements. Communication and data interface requirements are TBD.

Launch Site/Recovery Site Interface. The recovery site shall be in as close proximity to the launch site as practicable. Launch and recovery site operations shall be autonomous and require a minimum of communication/data links between one another. Launch and recovery operations shall be capable of being conducted simultaneously on a non-interference basis. Should alternate launch/landing sites be employed, the HLLV shall be readily capable of transport from one launch/recovery site to the other. Recovery site and method of recovery shall be selected to assure intact recovery of the HLLV with minimum turnaround maintenance/checkout requirements.

HLLV Performance Requirements

The HLLV shall provide the delta-V required to deliver the desired payload to the selected LEO staging area. The HLLV shall have the capability of performing all necessary orbital maneuvers to effect rendezvous with the LEO staging base and/or with down-payload modules and all necessary deorbit/reentry/landing maneuvers. The HLLV shall have sufficient performance reserves to satisfy TBD error analyses.

Abort Requirements

Abort requirements are TBD.

Design Life Requirements

As a design goal, the HLLV shall have the capability of accomplishing 300 missions. Life-limited components and/or components requiring periodic overhaul shall meet TBD line replaceable unit (LRU) requirements. Each LRU shall be capable of removal/replacement without materially affecting vehicle fleet size or turnaround requirements.

4.3.3 ORBITAL TRANSFER VEHICLE (HIGH THRUST)

The high-thrust OTV shall employ LOX/LH_2 propellant. The OTV must be capable of meeting the satellite mass flow requirements of the Satellite Configuration section. The OTV shall be capable of meeting the orbital transfer requirements defined in the Satellite Orbital Requirements section and the Flight Requirements section. In addition, the OTV shall have the capability of self-test and monitoring in order to evaluate status and readiness for operation.

Payload and Interfaces

In addition to satellite construction/operation mass requirements, the OTV shall be capable of orbital transfer of crew and supply modules.

Payload Interface. All payloads shall be prepackaged and self-contained, and conform to a common OTV mechanical interface. All other OTV/payload interfaces shall be avoided except where such interfaces may be shown to enhance mission accomplishment or to be more cost-effective.

Payload Configuration. Except for the interface requirement of Payload Interface, above, there are no payload configuration restrictions.

On-Orbit Docking Requirements. On-orbit docking requirements are TBD.

OTV/HLLV Interface Requirements. The OTV shall conform to the interface requirements of the Payload Interface and Payload Configuration sections.

OTV/Orbital Base Interface Requirements. OTV/Orbital base interface requirements are TBD.

OTV/Launch Site Interfaces. The OTV shall meet the interface requirements of the HLLV/Launch Site Interface Requirements section.

OTV Performance Requirements

The OTV shall provide the required delta-V capability to deliver the desired payload from the selected LEO staging base to the SPS GEO location and effect a return to the LEO staging base. The OTV shall provide a down-payload capability for crew/supply and empty satellite payload containers. The OTV shall have the capability of performing all necessary LEO/GEO rendezvous maneuvers and posses sufficient performance reserves to satisfy TBD error analysis.

Abort Requirements

Abort requirements are TBD.

Design Life Requirements

The OTV shall meet the Design Life Requirements section.

4.3.4 ORBITAL TRANSFER VEHICLE (LOW THRUST)

Low-thrust OTV requirements are TBD.

4.3.5 ON-ORBIT TRANSFER VEHICLE

The high traffic density and multiple rendezvous requirements indicate the possible need for an OOTV. OOTV requirements are TBD.

4.4 LEO OPERATIONAL BASE

(TBD)

4.5 CARGO AND PERSONNEL LAUNCH AND RECOVERY FACILITIES

(TBD)

4.6 BASE SUPPORT FACILITIES

(TBD)

4.7 LOGISTIC FACILITIES

(TBD)

4.8 SPS GROUND RECTENNA FACILITIES

(TBD)