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STUDY OF POWER MANAGEMENT TECHNOLOGY FOR ORBITAL MULTI-100KWe APPLICATIONS

VOLUME 2 ✦ STUDY RESULTS

GENERAL DYNAMICS
Convair Division

STUDY OF POWER MANAGEMENT TECHNOLOGY FOR ORBITAL MULTI-100 KWe APPLICATIONS

VOLUME 1 • EXECUTIVE SUMMARY
VOLUME 2 • STUDY RESULTS
VOLUME 3 • REQUIREMENTS

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16. Abstract

This study examines mid-to-late 1980's power management technology needs to support development of a general purpose space platform, capable of supplying 100 to 250 KWe to a variety of users in LEO.

To that end, a typical, Shuttle assembled and supplied space platform is illustrated, along with a group of payloads which might reasonably be expected to use such a facility. Examination of platform and user power needs yields a set of power system requirements used to evaluate power management options for life cycle cost effectiveness.

The most cost-effective AC/DC and DC systems are evaluated, specifically to develop system details which lead to technology goals, including: array; and transmission voltage, best frequency for AC power transmission, and advantages and disadvantages of AC and DC system for this application.

Finally, system and component requirements are compared with the state of the art to identify areas where technological development is required.

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FOREWORD

This final report was prepared by General Dynamics Convair Division for NASA Lewis Research Center (LeRC) in accordance with contract NAS3-21757. It consists of three volumes: Volume 1, a brief executive summary, Volume 2, a comprehensive set of study results, and Volume 3, a compilation of requirements which includes a preliminary power management system (PMS) specification and a typical 250 KWe space platform description.

The principal results were developed throughout 1979 with reviews at LeRC on 8 May 1979, 31 July 1979, and 13 December 1979, and at NASA Headquarters on 22 January 1980.

Because of the scope of the study, many individuals contributed technical assistance. General Dynamics Convair personnel who significantly contributed to the study include:

Study Manager	J.W. Mildice
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Technology Gap Analysis	C. Foster
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This is Volume 2 of the three volumes comprising the final report.

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FIGURES (Contd)

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SUMMARY

The primary objective of this study is to identify and define for NASA the preliminary requirements and technology advances required for cost-effective space power management systems for multi-100 kilowatt requirements. This study effort evaluated, defined, and analyzed power management systems (PMS) as defined by technical study tasks 1A, 1B, 2, and 3 outlined in the contract work statement.

1.1 TASK 1A

Task 1A defines overall system requirements, evaluates system design candidates and defines one or two system topologies which appear most promising from a cost-effective point of view for detailed analysis during the remainder of the study.

This study element defined system requirements by establishing a baseline space platform in the 250 KWe power range, examining typical user loads and interfaces and providing a PMS requirements specification documenting important parameters of the system, based on the source and load interfaces.

It also selected two PMS configurations from a candidate list of approximately eighty possible options (which preliminary analysis showed had possibilities to provide low life cycle cost) for detailed trade-offs and analysis in study part 1B. We judged that these systems met the study goals and together, contained all the important power system technologies which should be evaluated. They are:

a. Centralized D-C distribution and control system, including
   (1) Hardwired DC array
   (2) Slip rings for rotary joint power transfer
   (3) Battery or fuel cell conditioning
   (4) Centralized regulator unit
   (5) Payload interface units containing only switching provisions for load isolation
   (6) High voltage dc power transmission between solar array, batteries, and the central PMS unit.

b. Distributed A-C distribution and control system, including
   (1) Hardwired DC array
   (2) Energy storage on array side of rotary joint, including battery or fuel cell conditioning
   (3) Integrated inverter/regulator/rotary transformer

(4) High voltage three-phase AC power transmission across rotary joint and throughout satellite
(5) Distributed power conditioning and isolation at each load interface unit

1.2 TASK 1B

Task 1B provides the detailed analysis to determine the best approach for cost-effective performance and to define the requirements for major system components. It includes analyses and trade studies involving life cycle costs, with consideration given to approaches to lower PMS weights and improve efficiencies. Of the seventeen separate analysis topics identified, the most critical design parameters identified for detailed analysis include: (1) increased distribution voltages and space plasma losses, (2) the choice between AC and DC distribution systems, (3) shuttle servicing effects on reliability, life cycle costs, and (4) frequency impacts to PMS and payload systems for AC transmission.

These evaluations resulted in the recommendation that the first choice for a power management system for this kind of application and size range is a hybrid AC/DC combination (pictured in Figure 1-1) with the following major features:

a. Modular design and construction - sized for minimum weight/life-cycle-cost

b. High voltage transmission (1000 Vac RMS)

c. Medium voltage array ($\leq$ 440 Vdc)

d. Resonant inversion

e. Transformer Rotary Joint

f. High frequency power transmission line ($\geq$20 KHz)

g. Energy storage on array side of rotary joint

h. Fully redundant

i. 10-year life with minimal replacement and repair

Since DC would be a second choice for this application and have specific applications for other space vehicles and payloads, it is necessary to also include important dc technologies and the alternate DC system has been refined and evaluated in the later parts of the study. It is pictured in Figure 1-2 and has the following major features:

a. Modular design and construction - sized for minimum weight/life-cycle-cost

b. High voltage transmission, storage, and array (750 Vdc)

c. Fully redundant

d. 10-year life through minimal replacement and repair

e. Power system isolation must be provided by the payloads and users.

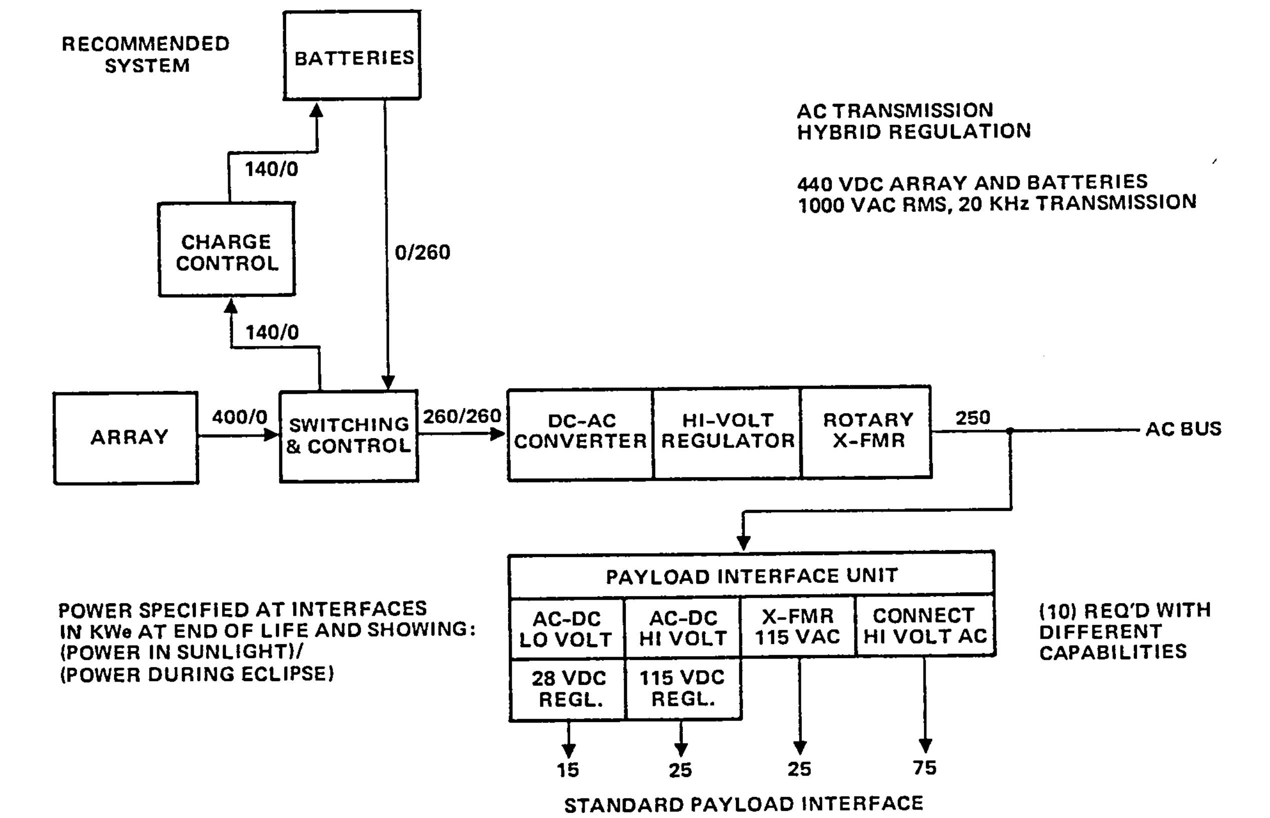


Figure 1-1. Hybrid AC/DC system.

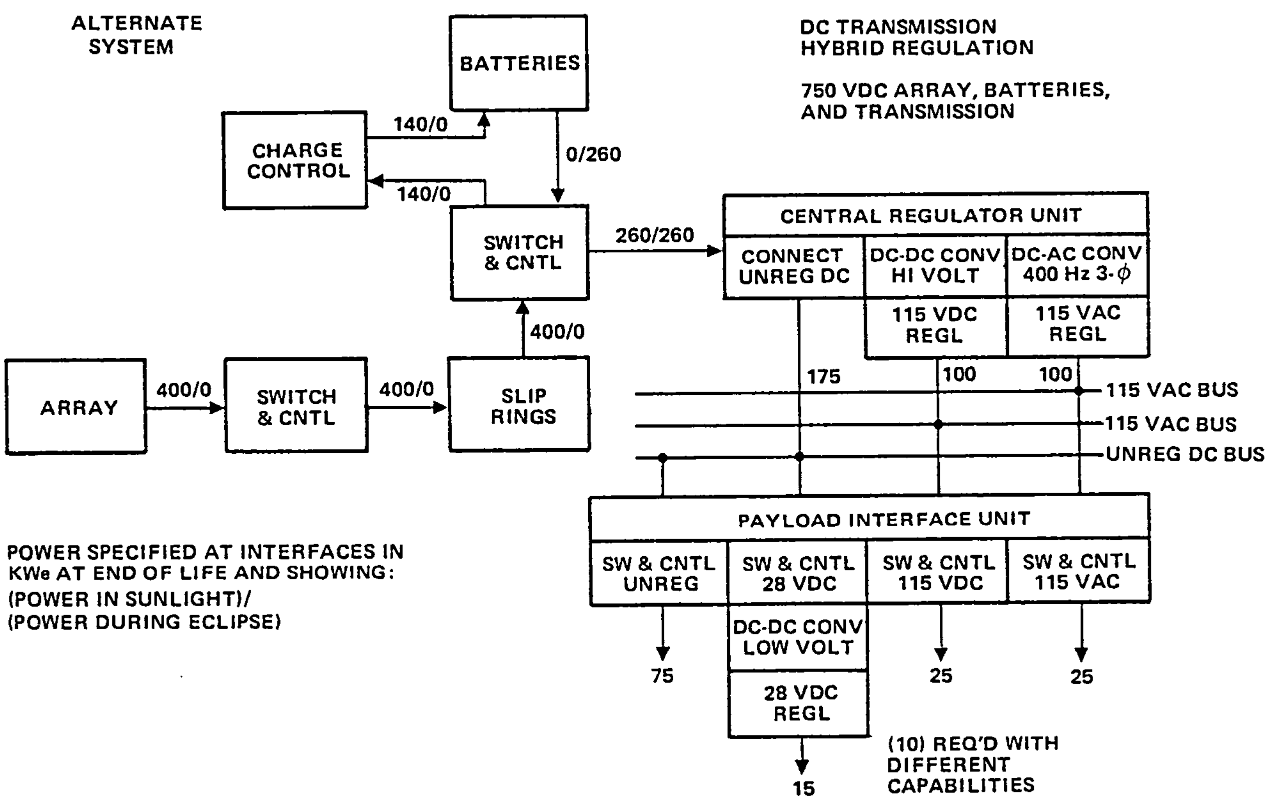


Figure 1-2. All DC system.

1.3 TASK 2

Task 2 evaluates the PMS requirements resulting from Task 1 and identifies technology gaps. The technology gaps identified were then analyzed to determine those technologies which can be available between 1984 and the late 1980s. Development cost and schedule are provided for technologies that can be available with NASA assistance by 1984, with a separate category showing those ready in the mid-to-late 1980s. Technology development candidates identified were also ranked with respect to cost-effective benefits, and long-lead items identified for high priority tasks.

Thirty-one separate, applicable technology gaps were identified as follows: four were judged to not need NASA assistance because normal industry progress would close them in a timely way. Three were judged too large to meet a late 1980s technology readiness even with NASA support. All are non-critical, non-enabling technologies. The remaining twenty-four were prioritized and estimates of costs and schedules leading to technology readiness in the mid-to-late 1980s were developed. The highest priority items on the list are:

a. AC System
   (1) Integrated "split" resonant DC-AC-DC/AC converter system development
   (2) Rotary transformer development
   (3) Payload connector development
   (4) Coaxial transmission line development
   (5) Remote power controller improvement

b. DC System
   (1) Improved performance semiconductor switch elements
   (2) Remote power controller improvement

1.4 TASK 3

Task 3 provides for reporting, including technical, financial, and schedular progress throughout the study.

It has provided monthly reports, three reviews at LeRC, a final briefing at NASA headquarters in Washington, D. C., and this final report.

1.5 CONCLUSION

In conclusion, it is recommended that the NASA pursue the technologies related to both AC and DC power management systems. Since each system type fits different mission needs, this approach will allow a choice to be made at some future date, so that it will best fit the mission requirements as defined at that time.

2

INTRODUCTION

Space station studies have identified missions and configurations requiring a significant increase in electrical power compared to that of existing spacecraft. The power systems required for these missions represent a large step forward in physical size as well as electrical power. Recent space station studies (References 1 and 2) have concentrated on the candidate power sources and the load requirements, but have not defined the requirements for distribution and processing. Earlier power distribution and processing studies for aircraft and/or spacecraft (Ref. 3-7) have indicated the general direction for technology advances. The recommended technology advances from these studies included the use of higher voltages, solid state power switching, automatic remote computer control, multiplexed control signals, and continuous computer checkout. These advances are expected to yield significant improvements in reliability, weight, and cost. But these studies did not contain detailed information that is needed to identify specific characteristics and technology needs for a space station. These characteristics and technology needs must be identified and developed so that they are available when needed for space station application. This study determines the required characteristics and technology needs of multi-100 kW power transmission, distribution, processing, and conditioning for cost effective, near term space station applications.

The study is divided into three separate tasks, and this report is divided into sections consistent with those tasks.

2.1 TASK 1, PART A

Task 1, Part A develops basic system requirements, then sifts the large number of possible system topologies to select one or two of the most cost-effective ones which satisfy the requirements. Cost-effectiveness was considered to be a primary driver, here and throughout the study.

2.2 TASK 1, PART B

Task 1, Part B does detailed trade-offs to select system operational parameters and provide component requirements and characteristics. Detailed life cycle costs are developed and a recommended and alternate system are chosen. The chosen systems are evolved versions of the Part A ones, with improvements based on the detailed analyses.

2.3 TASK 2

Task 2 assesses the state of the art of the supporting technologies compared to the component requirements and identifies the areas where gaps exist. It then examines the efforts needed to close the gaps by the mid-to-late 1980s, and provides cost and schedule estimates in those where the NASA must be active to assure a timely completion.

2.4 TASK 3

Task 3 examines each contract task above in detail and reports the technical details, results, conclusions, and recommendations for each work statement/work plan item. It is organized in the same chronology as the contract work statement to ease evaluations and comparisons with requirements.

NOTE: In each report section, introductions enclosed in quotation marks (") represent quoted requirements from the contract work statement.

3

STUDY RESULTS

3.1 TASK 1, PART A

Task 1, Part A; system analysis and definition, establishment of approaches. This part of the study was performed as shown in Figure 3-1.

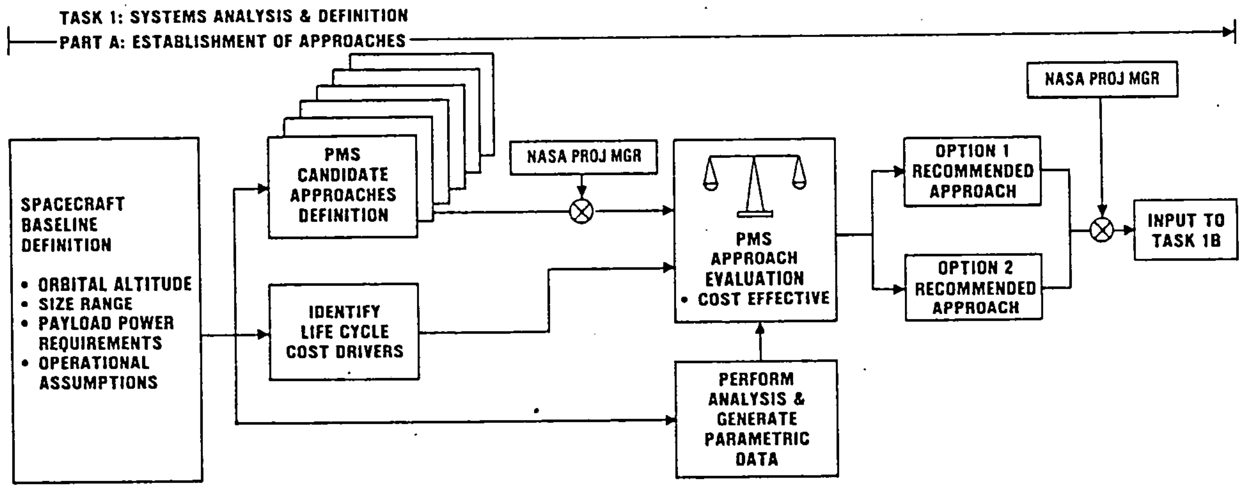


Figure 3-1. Task 1, Part A methodology.

3.1.1 SYSTEM REQUIREMENTS. The first step in the development of Power Management System (PMS) approaches is the definition and documentation of a set of system requirements against which candidate system topologies can be measured. The contract specifies broad, overall requirements:

a. Space platform in low earth orbit

b. Mid-to-late 1980s technology readiness

c. Ten-year useful life

d. Shuttle launch

e. On-orbit maintenance/repair/retrieval capability

f. Planar, silicon photovoltaic array

g. Array and storage sizing based on continuous operation of load power in the study range of 100-250 KWe (average)

h. Clean sheet approach — no combining of several smaller power systems

i. Approach consistent with extended visits by man

For proper system evaluation, a more detailed specification is required. It needs to include quantities such as payload interface characteristics, physical sizes and equipment positions, typical load profiles, etc. Using the data from References 1 through 7, appropriate NASA specifications (References 8 through 14), and data from Convair in-house studies, such a detailed PMS specification was created and used for system synthesis and evaluation. This specification is included in this report as Volume 3. Figures 3-2, 3-3, and 3-4 summarize some important overall results.

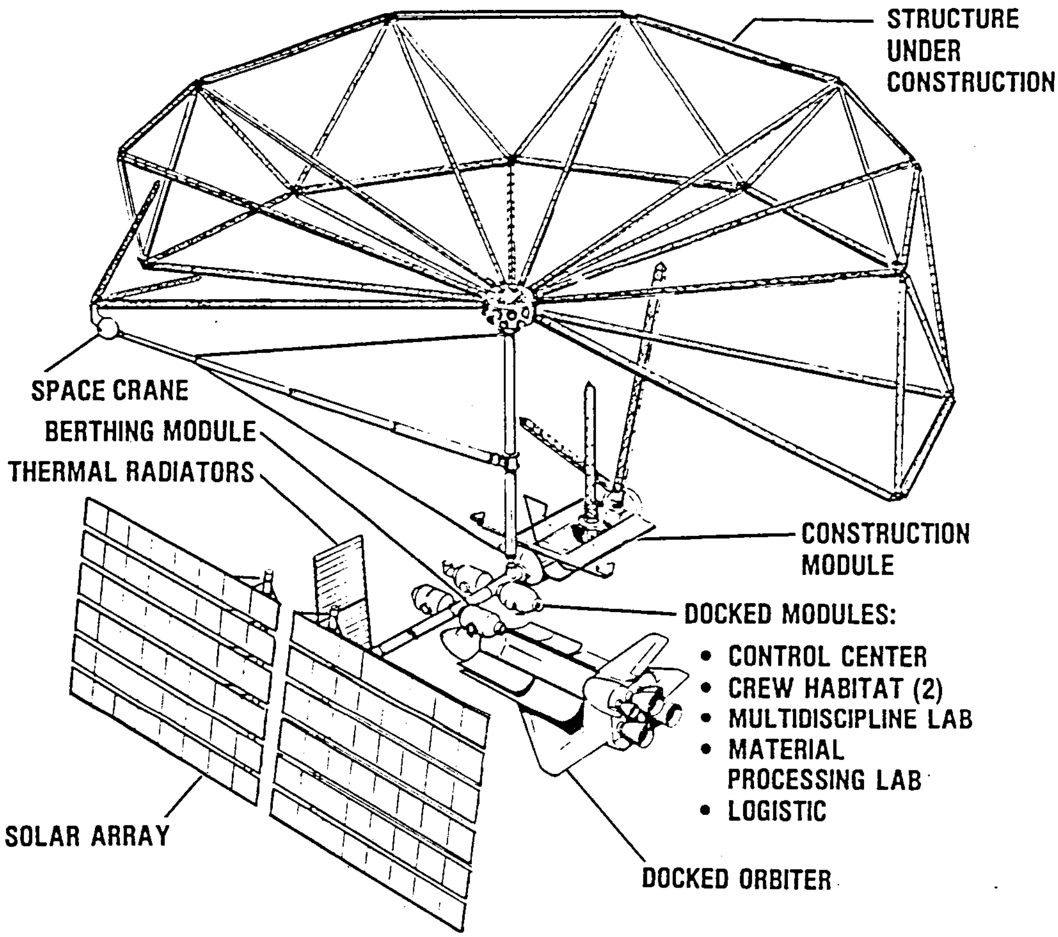


Figure 3-2. Baseline space platform configuration.

3.1.2 <u>SYSTEM CANDIDATES FOR PRELIMINARY EVALUATION.</u> Major candidates for overall system topologies may be broken down into two broad techniques, or combinations of them. They are:

a. Central (or lumped) distribution, where power conditioning, power storage, and switching functions are grouped and centrally located near the loads.

b. Distributed, where part or all equipment required for conditioning, storage, and switching is distributed about the space platform and located at the load interfaces. A variation of this latter approach may include incorporating portions of this equipment within the Load Equipment package even though it is part of the PMS and accounted for and costed as such.

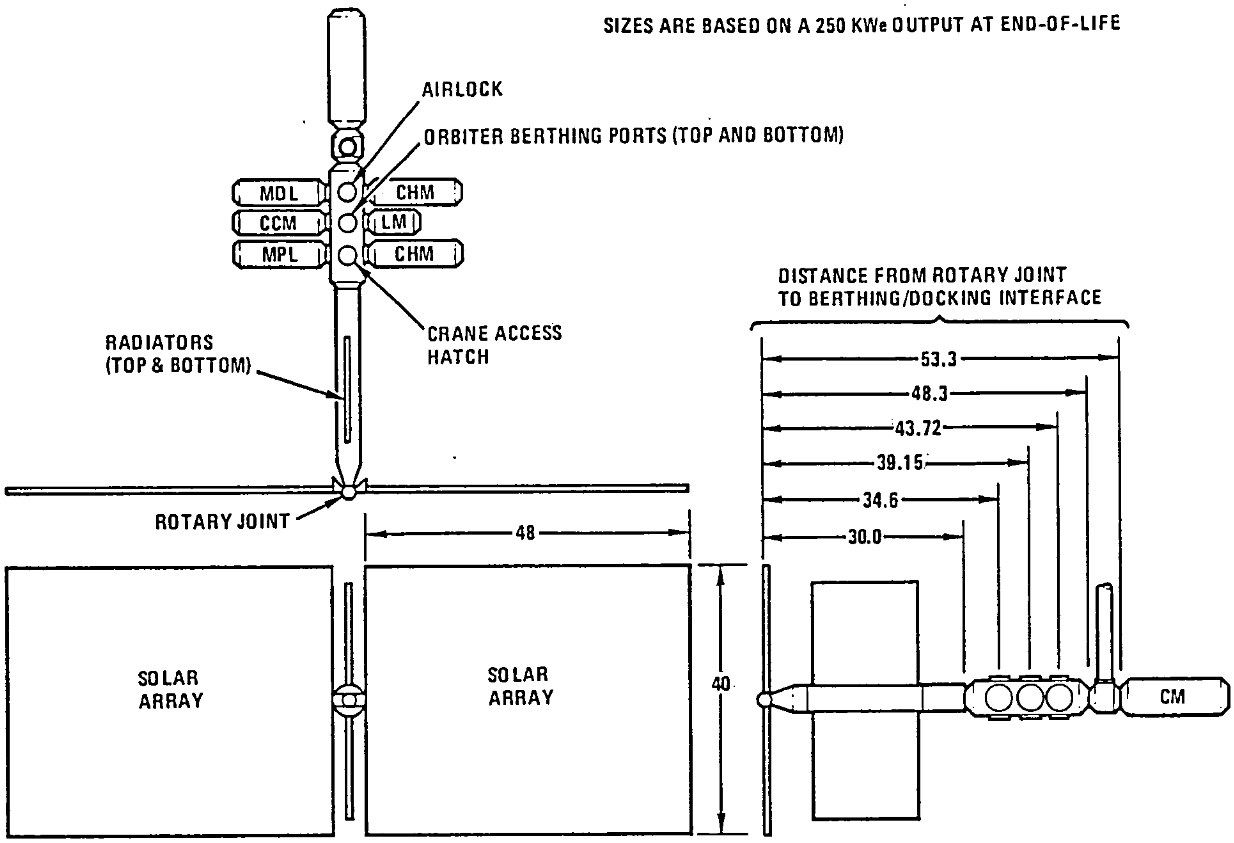


Figure 3-3. PMS spatial relationships (all distances in meters).

ALL POWER IN kW

LOAD LOCATION	HIGH VOLTAGE REGULATED 115 ± 5 VDC	HIGH VOLTAGE UNREGULATED TBD	LOW VOLTAGE REGULATED 28 ± 4 VDC	400 ± 1 Hz, 3φ 115/200 VAC
MULTI-DISCIPLINE LAB	20	(500)(1)	15	20
MATERIALS/PROCESSING LAB	20	60	10	20
CONSTRUCTION MODULE	20	(75)(2)	10	20
CRANE	5	—	2	5
CONTROL CENTER	20	—	10	20
CREW HABITAT #1	3	—	4	2
CREW HABITAT #2	3	—	4	2
BERTHING MODULE	15	50(3)	20(4)	5
LOGISTICS MODULE	—	—	2	—
POWER MANAGEMENT	5	—	10	5

NOTES:
(1) INTERMITTENT 500 kW FOR PLASMA PHYSICS EXPERIMENT
(2) INTERMITTENT 75 kW FOR MICROWAVE POWER TRANSMISSION ANTENNA TEST
(3) CONTINUOUS 50 kW FOR O_2/H_2 RELIQUEFACTION EQUIPMENT
(4) INCLUDES 14 kW FOR ORBITER SUPPORT

Figure 3-4. Payload voltage types & maximum* power levels.
(*Not all connected simultaneously)

The question of central vs. distributed systems applies to the power sources as well as to the loads. At present, the conventional approach has treated the solar array essentially as a single source, with power busses connected to the vehicle through some rotating joint arrangement. Other options are clearly available, even desirable, for large systems. For example, array-located PMS components can include power conditioning equipment/circuits, switch gear for PMS reconfiguration, and possibly even energy storage devices if array structure and temperatures permit.

A third category of candidate approaches consists of adaptive PMS and non-adaptive PMS design concepts. In the conventional non-adaptive approach, power management control would be limited to switching in or switching out PMS components and busses to various loads. In the adaptive approach, the PMS would be designed to allow automatic or directed reconfiguring to meet the needs of changing space platform operational requirements. Benefits from the adaptive approach may include:

a. Real-time automated reconfiguration or load shedding to counteract failures or other anomalies.

b. Ability to easily reconfigure the space platform to accept changes in payload functions and/or power requirements throughout the life of the platform. It is expected that ten years in orbit will see many new payloads and experiments requiring different power types and distributions.

c. Ability to reconfigure to maintain service while portions of the array or energy storage hardware are undergoing repair or maintenance.

Additionally, there are options in high level details which can apply to any of the above major categories, thereby creating many possible detailed system configurations. They include:

a. DC or AC or a combination of both

b. High voltage or low voltage transmission, generation, storage, or distribution

c. If AC, single phase or multiphase

d. If AC, power line frequency and characteristics

Therefore, we have created the following list representing the possible system major design alternatives. They are hereby presented, without regard to priority or desirability. Letters in parentheses are shorthand notations used on later matrix charts.

a. Centralized conditioning and storage equipment (CC&S)
b. Centralized source power from array (CA)
c. Distributed conditioning and storage equipment (DC&S)
d. Distributed source power from array (DA)

e. Non-adaptive control (NA)
f. Adaptive configuration control (A)
g. Direct current (DC)
h. Alternating current (AC)
i. Multi phase AC (MØ)
j. Single phase AC (1Ø)
k. Low frequency AC - 60 Hz (LF)
l. High frequency AC > 400 Hz (HF)
m. High voltage transmission > 440 V (HV)
n. Low voltage transmission < 440 V (LV)

These approaches and parameters can be combined in a matrix as shown in Figure 3-5a, yielding 80 possible system configurations.

This maximum number of combinations can be distilled into a more manageable number as follows:

a. System voltages will be determined by analysis of plasma effects and load requirements as a later part of this study and will not effect basic topological decisions. Therefore, columns A and B can be combined into "DC with the appropriate voltage". Columns C through K can be treated similarly.

b. Since the choice of AC system frequency affects detailed component design and has no significant effect on overall system configuration, it can also be treated in this manner.

c. Row 2, defining a totally centralized adaptable system was removed from further consideration since the inherent inflexibility of this approach makes it complex and excessively expensive.

d. The inherent flexibility of a totally distributed system and its easy adaptability make Row 7 non-competitive with the other options, since it still carries the extra hardware penalty of the distributed approach, while eliminating one of the major advantages.

Therefore, Figure 3-5b can be drawn as a distillation of Figure 3-5a, and it represents a more reasonable matrix of 18 possible systems.

At this point in the study, we decided to evaluate the separable options independent of one-another rather than defining a reduced number of total system concepts. The most promising of these were combined into the one or two candidate approaches developed in Task 1, Part A.

	A. DC - HV	B. DC - LV	C. AC - HV - HF - MØ	D. AC - HV - HF - 1Ø	E. AC - HV - LF - MØ	F. AC - HV - LF - 1Ø	G. AC - LV - HF - MØ	H. AC - LV - HF - 1Ø	J. AC - LV - LF - MØ	K. AC - LV - LF - 1Ø
1. LC&S - LA - NA										
2. LC&S - LA - A	† REMOVED - COMPLEX AND EXPENSIVE									
3. LC&S - DA - NA										
4. LC&S - DA - A	COMBINED IN COLUMN A	COMBINED IN COLUMNS B & C								
5. DC&S - LA - NA	3-5b	3-5b								
6. DC&S - LA - A										
7. DC&S - DA - NA	*REMOVED - NON-COMPETITIVE WITH (6) AND (8)									
8. DC&S - DA - A										

Figure 3-5a. System option matrix.

	A. DC - Appr. Volt.	B. AC - 1Ø - Appr. Volt & Freq	C. AC - MØ - Appr. Volt & Freq
1. LC&S - LA - NA			
2. LC&S - DA - NA			
3. LC&S - DA - A			
4. DC&S - LA - NA			
5. DC&S - LA - A			
6. DC&S - DA - A			

Figure 3-5b. Reduced system option matrix.

The system elements examined in detail were:

a. Distributed array element interconnection with integral regulation and conditioning vs. conventional hardwired busses.

b. Centralized regulator/conditioning/distribution equipment vs. distributed configuration with control at or integral with the loads.

c. Adaptive switching and control.

d. All DC system.

e. All AC system (1Ø and multi Ø).

f. DC-AC hybrid system.

3.1.3 ESTABLISHMENT OF APPROACHES. In order to further reduce the number of options for cost effective system designs that meet the performance requirements of subsection 3.1.1, the work statement for this element of the study lists seven specific topics for evaluation of candidate systems. This section will present each of those seven along with the results and conclusions about each of them. In order of the contract, they are:

3.1.3.1 "Identify and evaluate the major electrical power system life cycle cost drivers (e.g., acquisition cost, transportation (to orbit) cost, maintenance cost) involving the PMS in order to identify a cost effective approach."

If we assume that only one platform is built and flown, major cost drivers are, in order of their importance:

a. Design/Development Costs (45%)

b. Production/Hardware Costs (43%)

c. Operations and Transportation Costs (10%)

d. Maintenance Costs (2%)

In this portion of the study, comparative costs were estimated using cost estimating relationships (CERs) developed by Convair (see Reference 19) from past experience and cost analysis studies for design and manufacturing, and the "STS User Handbook" for transportation and operations costs.

At this point, it is important to note that the costs calculated were preliminary estimates, based on configuration data for typical units for the types of components making up the various system options. Therefore, while they are useful to determine the relative cost effectiveness of the candidate system approaches, they could not be used to assess the real, absolute costs of that hardware. In order to avoid the confusion of multiple sets of cost data, all numbers used in this part of the study are normalized so there will be no conflicts with the detailed cost data calculated in study Task 1, Part B. The CERs used in this case for this class of equipment were: (Ref. 19)

<u>Design Cost</u> $= 0.016\ F_D\ W^{0.799}$

where: 0.016 is a scaling constant based on empirical data for this class of power control equipment, normally between 0.012 and 0.020

W is unit weight

0.779 (the weight factor exponent) is based on empirical data reflecting the average economy of scale for this class of equipment

F_D is the design complexity factor, nominally 1.0 and a function of:

a. Packaging density requirements (D_P)
b. Number of interconnections/interfaces (N_C)
c. Incorporation of off-the-shelf components (N_{OSC})
d. Degree of modularity (M_{OD})
e. Reliability Requirements (R_L)
f. Degree of redundancy & redundancy management methods (R_D)
g. Assembly location (ground or orbital) (L_A)
h. Storage interface requirements (S_T)
i. Amount of DET & QUAL Testing required (T_D)
j. Load characteristics & uniformity (C_L)
k. Crew safety requirements (S_C)

And the magnitude of F_D was calculated according to the equation:

$$F_D = 1 + (D_P + N_C + N_{OSC} + 0.5\,M_D + R_L + 1.5\,R_D + L_A + S_T + 0.5\,T_D + 1.25\,C_L + 1.5\,S_C)$$

Where each constant in the above equation is assigned a value as follows:

-0.2	Major contribution to lower cost
-0.1	Intermediate contribution to lower cost
0	No cost difference for subject trade
+0.1	Intermediate contribution to higher cost
+0.2	Major contribution to higher cost

<u>Hardware/manufacturing costs</u> $= 0.005\ F_M\ W^{0.921}$

where F_M is the manufacturing complexity factor, nominally 1.0 and a function of:

a. Package Density (D_P)
b. Number of connectors & interconnections (N_C)
c. Off-the-shelf components (N_{OSC})
d. Modularity (M_{OD})

e. Special testing costs to verify reliability and/or redundancy (T_P)
f. Number of units (N_{UP})
g. Assembly location (ground or orbital) (L_A)
h. Load uniformity (special thermal requirements) (C_L)
i. Crew safety requirements (S_C)

And the magnitude of F_M was calculated according to the equation:

$$F_M = 1.0 + (D_P + N_C + N_{OSC} + 1.25 M_{OD} + 0.50 T_P + 0.5 N_{UP} + L_A + 0.5 C_L + S_C)$$

Where each constant in the above equation is assigned a value as follows:

-0.2	Major contribution to lower cost
-0.1	Intermediate contribution to lower cost
0	No cost difference for subject trade
+0.1	Intermediate contribution to higher cost
+0.2	Major contribution to higher cost

All the other constants are derived in the same way as the ones for design cost.

It can be observed that the above equations (CERs) identify weight as a major correlating factor related to cost. However, this does not imply that we think that power management hardware is sold by the pound. If we use the appropriate constant and exponent to scale the equation, our experience has shown that weight closely correlates with the magnitude of the design effort and the amount of hardware to be built or raw material to be bought, for a particular class of equipment, based on its complexity and function. A combination of analysis and historical data (Ref. 19) has provided CERs appropriate to equipment used in space systems. See Table 3-1 for a list of design CERs, and Table 3-2 for manufacturing.

Transportation to Orbit Costs

Since this family of equipment is significantly more dense that the optimum of 105 kg/m^3 (6.54 lb/ft^3) for shuttle payloads, weight is directly used to determine transportation to orbit costs. Based on data from the "STS User Handbook", we used \$1000/kg (\$444/lb) for this part of the study.

Maintenance Costs

For reasonable quality units (MIL-SPEC level), individual unit MTBFs are high enough so that maintenance costs are small enough to be nearly negligible for modularized functions and preliminary cost analysis of this accuracy.

Cost analysis results are summarized in Table 3-3 (page 3-19).

Table 3-1. Design cost CERs (all calculations in 1979 dollars $\times 10^6$).

EQUIPMENT CLASS	CER	REMARKS
GUIDANCE & NAVIGATION	$1.55\ FW^{0.68}$	F = COMPLEXITY FACTOR
COMMUNICATIONS	$0.16\ FW^{0.89}$	W = WEIGHT IN POUNDS
SOLAR ARRAY	$1.43\ P^{0.93}$	P = POWER CAPACITY (kW)
BATTERIES	$0.03\ FR^{0.087}$	R = RATING IN WATT-HRS F = 1.0 SOA NiCd (OFF SHELF) 14.0 NEW DESIGN NiCd 56.0 NiH_2
FUEL CELL	$0.43\ FW^{0.67}$	
ELECTRICAL DIST & CONV	$0.016\ FW^{0.799}$	
MECHANISMS	$0.06\ FW^{0.5}$	
CONTROLS	$0.1\ FW^{0.5}$	

Table 3-2. Manufacturing cost CERs (first unit costs). All calculations in 1979 dollars $\times 10^6$

EQUIPMENT CLASS	CER	REMARKS
GUIDANCE & NAVIGATION	$0.03\ FW^{0.93}$	F = COMPLEXITY FACTOR
COMMUNICATIONS	$0.05\ FW^{0.79}$	
SOLAR ARRAY	$0.85\ FP^{0.85}$	P = POWER (kW)
BATTERIES	8.8×10^{-4} $FNR^{0.578}$	R = RATING IN WATT-HRS F = 1.0 NiCd 2.5 NiH_2 N = NO. OF BATTERIES W = WEIGHT IN POUNDS
FUEL CELL	$0.02\ FW^{0.74}$	
ELECTRICAL DIST & CONV	$0.005\ FW^{0.921}$	
MECHANISMS	$0.004\ FW^{0.667}$	
CONTROLS	$0.006\ FW^{0.667}$	

Table 3-3. Preliminary cost comparisons.

System Option	Hardware Quantity* (Equiv. KWe)	Weight (kg)	Normalized Cost†		
			Design	Mfg	Total
1. Centralized DC	420	1512	0.53	0.47	1.00
2. Distributed DC	520	1872	0.66	0.57	1.23
3. Distributed AC (Docking Module Storage)	1140	4320	1.06	0.99	2.05
4. Distributed AC (Array Side Storage)	780	2340	0.79	0.70	1.49

*Total system hardware capacity expressed in kW, allowing for complexities of various elements.

†Costs normalized to total cost of Centralized DC.

As a result of the above described analysis, the top four system configurations, from the point of view of minimum ten year life cycle costs (LCC) were picked and are listed below:

a. Centralized regulation and control; DC power transmission and mixed distribution.

b. Distributed regulation and control; AC power transmission and distribution.

c. Centralized regulation and control; AC power transmission and mixed distribution.

d. Distributed regulation and control; DC power transmission and distribution.

3.1.3.2 "Compare an all DC system to a mixed AC-DC system including effects on the loads."

From the preceding preliminary cost analysis, we can conclude that the lowest cost DC system costs 33% less than the least expensive mixed AC-DC system. However, the two systems do not provide equal capability, particularly at the load interfaces.

A system which utilizes AC distribution takes advantage of its full potential by providing distributed power conditioning at each payload interface. In this way, transformer coupling can be used to provide the maximum degree of flexibility to match source and load equirements and to allow simple DC power system isolation. A large degree of AC isolation can also be provided by adding tuned transformers to reject all frequencies except the power line frequency.

The less expensive DC system utilizes centralized power conditioning and control, providing several outputs (probably four) to meet average payload requirements. Because of the shared busses, a particular payload interface cannot be modified without effecting the others sharing the bus. In addition, no inherent isolation is provided at the interface.

A DC system having the same capability as the AC one demands a distributed approach with DC to DC converters at each payload. The addition of this more complex hardware form nearly removes the DC cost advantage. Even with that, a routine analysis of the two systems would show the DC one to be cheaper and more efficient primarily due to the added hardware converting DC on the array to AC for transmission and distribution.

Our preliminary analysis has shown that incorporation of creative system changes (such as moving the energy storage hardware to the DC/array side of the rotary joint, and the use of high frequencies, greater than 10 kHz) coupled with design improvements in power conditioning hardware can make the mixed AC-DC system cost competitive with the least expensive DC system.

3.1.3.3 "Voltage Changes."

a. "Evaluate the advantages and disadvantages of increased power system voltage levels (including first order effects on source, storage, and loads) for DC and mixed AC-DC systems. Examine the effects on the PMS of increasing the solar array output voltage to levels up to 1000 volts."

   On a first order basis, it is obviously safe to say that within practical limits, PMS weight, efficiency, and, therefore, cost improve with increased voltage. Higher voltage and its corresponding lower current reduce bus weights and improve efficiency by reducing switching losses. Efficiency improvements reduce solar array, battery, and thermal management requirements, thereby decreasing total space platform weight and costs.

   Voltage limiting effects include component voltage ratings and plasma effects which will be analyzed and traded-off with the above positive voltage drivers in detail in study Part 1B.

b. "Examine the desirability of voltage step-up and/or step-down to minimize transmission losses."

   Voltage step-up and/or step-down at the solar array and load interface has the capability to minimize the conflict between the benefits of high voltage and the problems associated with component ratings and plasma losses. The array could be wired to maximize reliability and minimize plasma losses, independent of output voltage. At the load end, control and/or conditioning hardware could be designed to take the best advantage of component voltage and current ratings, independent of transmission voltage. Therefore, step-up/step-down is obviously good, providing that the implementation hardware does not add its own efficiency penalties larger than the savings.

   For an AC system, with its built-in transformer coupling, step-up or step-down can cost almost nothing if the system designer is creative. Therefore, it is an option worth adding in this case.

However, DC systems must use specific active hardware to change voltages such as a CDVM. Preliminary analysis on the step-up side shows that this can add losses in the neighborhood of 5% in the best case, and a more detailed analysis must be performed to see if this can be offset by other system improvements. At this level of analysis, we have preliminarily determined that the most cost and weight efficient DC system would have the source, storage, and load power conditioning inputs operating at the same high voltage. However, the longer strings of series solar cells or panels and battery cells to generate the higher voltage represent a reliability compromise that must be included in the trade-offs of Task 1, Part B.

c. "Evaluate combinations of (a) and (b)."

Obviously the system combinations discussed in (b) are appropriate for combinations involving step-up/step-down at either end or both or for portions of the system, and final recommendations must await the detailed trade-offs of Task 1, Part B.

3.1.3.4 "Identify and evaluate approaches to voltage regulation and how the varying requirements of different loads could be met."

Three major categories of regulation approaches were evaluated as part of an overall system topological investigation which considered approximately 80 possible configurations. They are:

a. Distributed regulation at the payload interfaces

b. Centralized regulation at the platform docking module

c. On-array regulation integral with the solar panels

Selection of specific hardware implementations or components was not considered during this study phase as outputs of that nature are inherent in the early phases of Task 1, Part B.

Evaluation of load profiles and patterns documented in the system requirements specification of Volume 3, has shown that the economies of shared operation of control and regulation hardware make the centralized approach attractive for this type of multi-purpose space platform with a wide variety of loads and duty cycles. On the other hand, requirements for load isolation and system flexibility make the distributed approach a still viable candidate, even though a simple system design would show it initially contained more hardware. Fewer changes during the system's lifetime and fewer restrictions on system users could ultimately make total system life cycle costs lower.

Our IRAD programs investigating on-array-regulation have shown that there are many technical questions which are currently unanswered. For example, management of the energy storage interface and integration of on-array control hardware onto thin solar blankets require significant technical development which puts this technology beyond the time frame of consideration for this study.

Final system selection used both a. and b. above and is documented later in this section, in subsection 3.1.3.8.

3.1.3.5 "Investigate the degree of modularity and commonality suitable for the various approaches. The contractor shall include in his investigation both a central station approach and a distributed system approach."

For any approach considered for this system design, a high degree of modularity is required. The major justifications are:

a. System maintenance and repair can be accomplished without total system shutdown. Branches and modules can be turned off and disconnected for test or removal and replacement with some reduction in system capability only, since modular failures will still occur in highly reliable systems. (See b., below.)

b. Acceptable ten-year reliability for single high power units (100-250 kW) is not possible with mid-to-late 1980s components. Even if units are redundant at the component level, typical MTBFs are less than five years. Lower power modules (5-25 kW) can be sufficiently reliable for MTBFs to exceed 20 years in parallel combinations of smaller modules, and appropriate spares can provide reliabilities sufficient to minimize the problem of maintenance.

c. System life cycle costs can be optimized by optimizing modular size and cost for each class of application.

d. Module size and mass must be limited to allow for handling in orbit by the station crew. Requirements will be examined in the modular size determination paragraphs of Task 1, Part B.

Therefore, all systems evaluated during this study were aggregates of smaller modules with individual module sizes optimized based on ten year life cycle costs.

3.1.3.6 "The contractor shall consider the following types of storage for this application:

1. Advanced NiCd

2. NiH_2

3. Regenerative fuel cells - water electrolysis

Determine the impact of storage choices above on the PM approach and whether the different power management approaches favor certain storage methods."

Evaluation of the character of the three choices has shown that the basic nature of the PMS control for those options is the same. The interface is DC, and the controlling device is a regulator acting as a current source by utilizing current feedback as its control parameter.

The major difference in characteristics is charge-discharge (C/D) efficiencies. We can project that advanced batteries of either type, operating to 70% depth of discharge (DOD) will have C/D efficiencies greater than 90%. The best we can expect from a water electrolysis cell/fuel cell combination will probably not exceed 50%. Therefore, in PMS configuration, batteries would be better than fuel cells, since approximately half of the PMS C/D hardware would be required.

Looking at today's battery life characteristics makes predictions of 70% DOD for batteries seem somewhat optimistic. A typical life-cycle/DOD curve for NiCd batteries is shown in Figure 3-6 for current hardware. Life cycle cost optimizations using this type of current data indicate that the best DODs for this type of mission lie in the 30% region. Significant battery improvement work is now under way and manufacturers are informally claiming equivalent life times with DODs above 60% in the late 1980s if individual cell control is used. Even if these expectations are not realized, and 30% was used in an actual system, average C/D efficiencies would still be in the range approaching 80% and the basic conclusions about the PMS preferring batteries instead of fuel cells are still valid.

From the other point of view, the inherent flexibility of an AC system makes it easier to interface with electrolysis cell/fuel cell systems since their input parameters are, at this point, not very flexible. Even though long series strings of battery cells are possible, better combinations based on reliability and operational charge control hardware are possible through the flexibility offered by AC system design.

In summary, reduction of the quantity of PMS hardware favors batteries (either type); and the flexibility at the energy storage interface favors AC.

3.1.3.7 "Identify those crew safety factors that affect the selection of the PMS approach."

The problem of crew safety has been addressed by examination of the two major NASA specifications covering the design of manned systems: MSFC-STD-512A and JSC 11123 (see references list for complete titles and dates). The requirements apply equally to all the suggested system topologies and do not provide design difficulties for one more than another. Therefore, there are no drivers associated with crew safety that lead toward a particular topology at this level of selection.

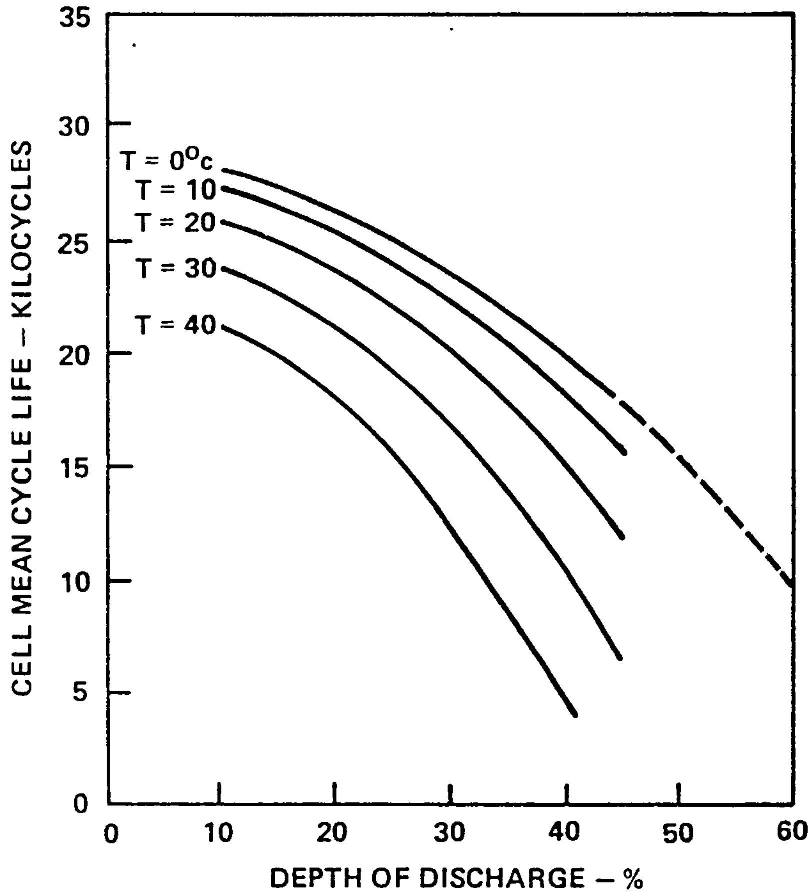


Figure 3-6. Battery cyclic life curves.

3.1.3.8 Part A - Establishment of Approaches - Summary. "The contractor shall propose candidate approaches to space platform power management which shall be submitted to the NASA Project Manager for approval prior to their further study. For the approved candidates the contractor shall perform analyses on the major cost and design drivers of the power management system (PMS) and recommend not more than two cost effective approaches."

The major separable system elements were evaluated as described in subsections 3.1.3.1 through 3.1.3.7, above to: identify lowest life cycle cost, look at advantages of AC and DC, evaluate the use of high voltages, decide on appropriate topologies for regulation, establish a level of modularity, and to assess the impact of storage hardware and crew safety requirements. The results of each of these are described in the preceding paragraphs addressing the contract work statement items.

In addition, we evaluated candidate approaches containing the technical options by: measuring them against system requirements, evaluating preliminary size and weight, and considering technical and operational advantages, including versatility, adaptability, and growth potential.

Since the contract establishes the importance of cost effective approaches, the primary system selected was the lowest cost one meeting the system requirements. It is:

DC transmission and distribution system with centralized regulation and control (Figure 3-7) including:

a. Hardwired DC array,

b. Slip rings for rotary joint transfer,

c. Battery or fuel cell conditioning,

d. Centralized regulator unit,

e. Payload interface units containing only switching provisions for load isolation,

f. High voltage DC power transmission between sources and central unit.

With NASA concurrence, we included a second, alternate system to be evaluated in the detailed trade-offs and evaluations of the next major study sections. It is:

AC transmission and distribution system with centralized AC inversion on the array side of the rotary joint and distributed regulation and control at each payload interface (Figure 3-8) including:

a. Hardwired DC array,

b. Energy storage on array side of rotary joint, including battery or fuel cell conditioning,

c. Integrated inverter/regulator/rotary transformer,

d. High voltage three phase AC power transmission across rotary joint and throughout satellite,

e. Distributed power conditioning and isolation at each load interface unit.

System evaluation showed good and sufficient reasons to include this second system for further evaluation.

a. It has significant operational and technical advantages. It is the best system with regard to versatility, adaptability, payload isolation, and growth potential.

b. It has the potential to be competitive with DC for cost, weight, size, and efficiency through creative system design (such as b., above) and improved PMS component design (such as c., above), even though cost analysis shows it to be more expensive at this point. See Table 3-3 for cost comparisons of the primary candidates.

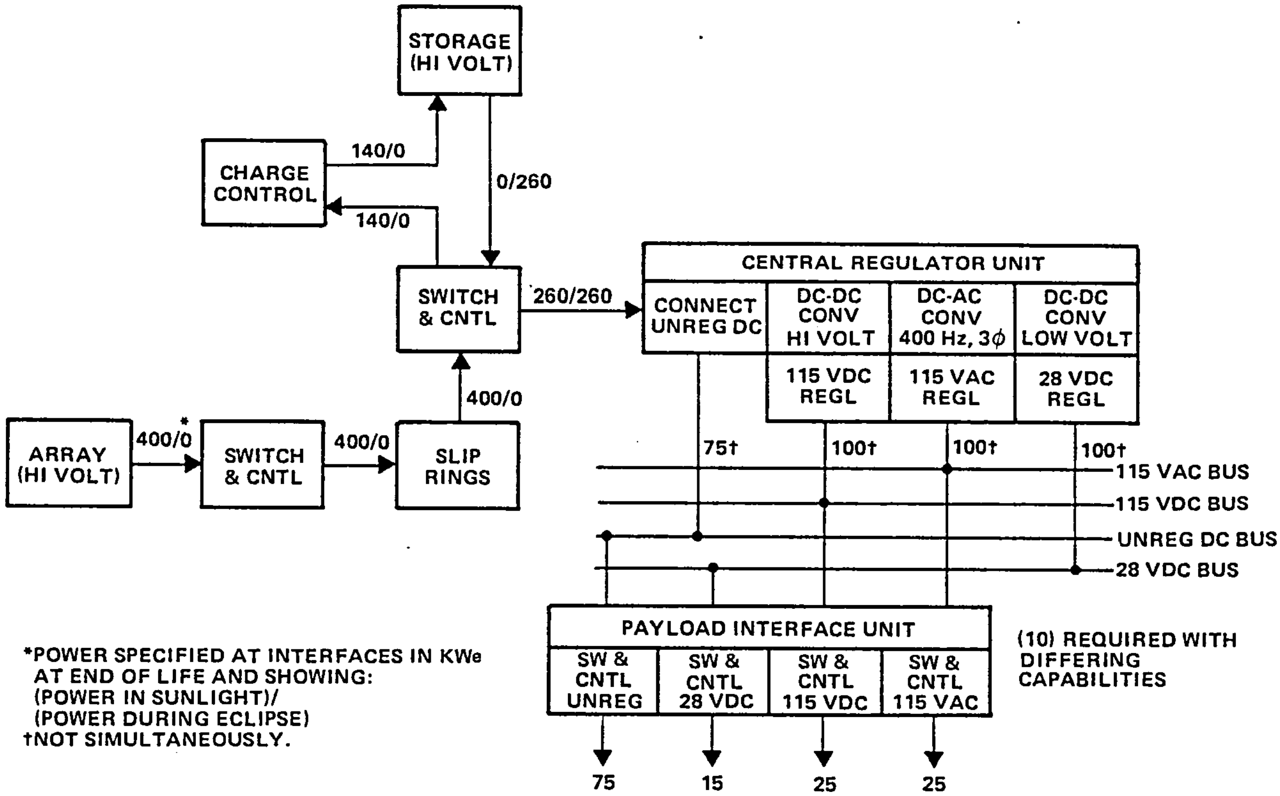


Figure 3-7. Centralized DC distribution system.

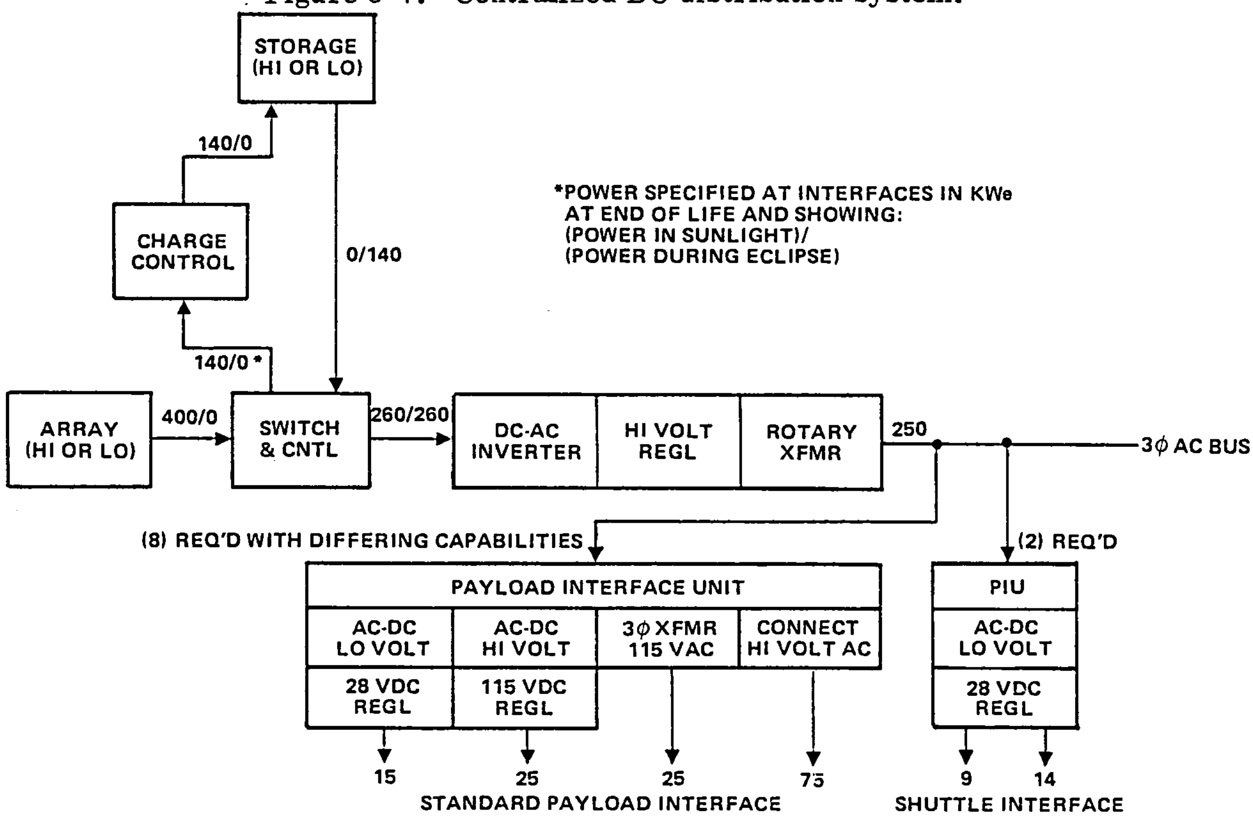


Figure 3-8. Distributed AC distribution system.

3.2 TASK 1, PART B, SYSTEM ANALYSIS AND DEFINITION, PMS REQUIREMENTS DEFINITION

As in the preceding section, results and conclusions will be presented in the order of the contract work statement to facilitate review. That work statement for this study element says:

> "Following approval of the Part A approach(es), the contractor shall perform detailed parametric and tradeoff analyses in order to define the preliminary requirements of the PMS and major PM components (Table 1) that promise cost effective performance. These efforts include development of new procedures, techniques, and analysis not directly related to component development. The major interactions involving the PMS with the source, storage, and loads shall be identified and evaluated in order to arrive at a cost effective power system. The contractor shall perform and document analyses and show conclusions that lead to the identification of PM technology advancements."

This part of the study was performed as shown on the block diagram of Figure 3-9. Overall requirements for component blocks were extracted from the requirements specification of Part 1A. They are shown on the block diagram of Figures 3-10 and 3-11 for the two systems. Since optimum module sizes were determined as a result of the cost analysis and technical trades of this part of the study, actual module requirements were determined later and documented in the requirements section of the "PMS components characteristic data sheet". A complete set of these sheets is included as Appendix 1.

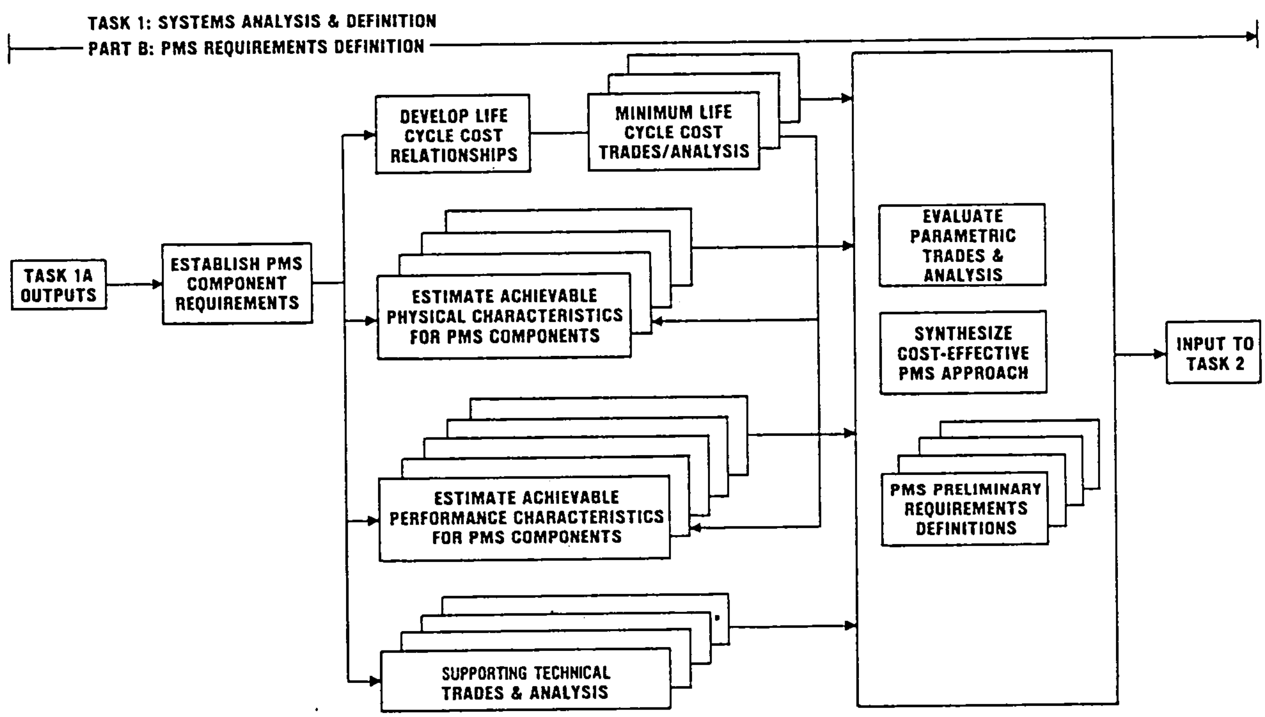


Figure 3-9. Task 1, Part B methodology.

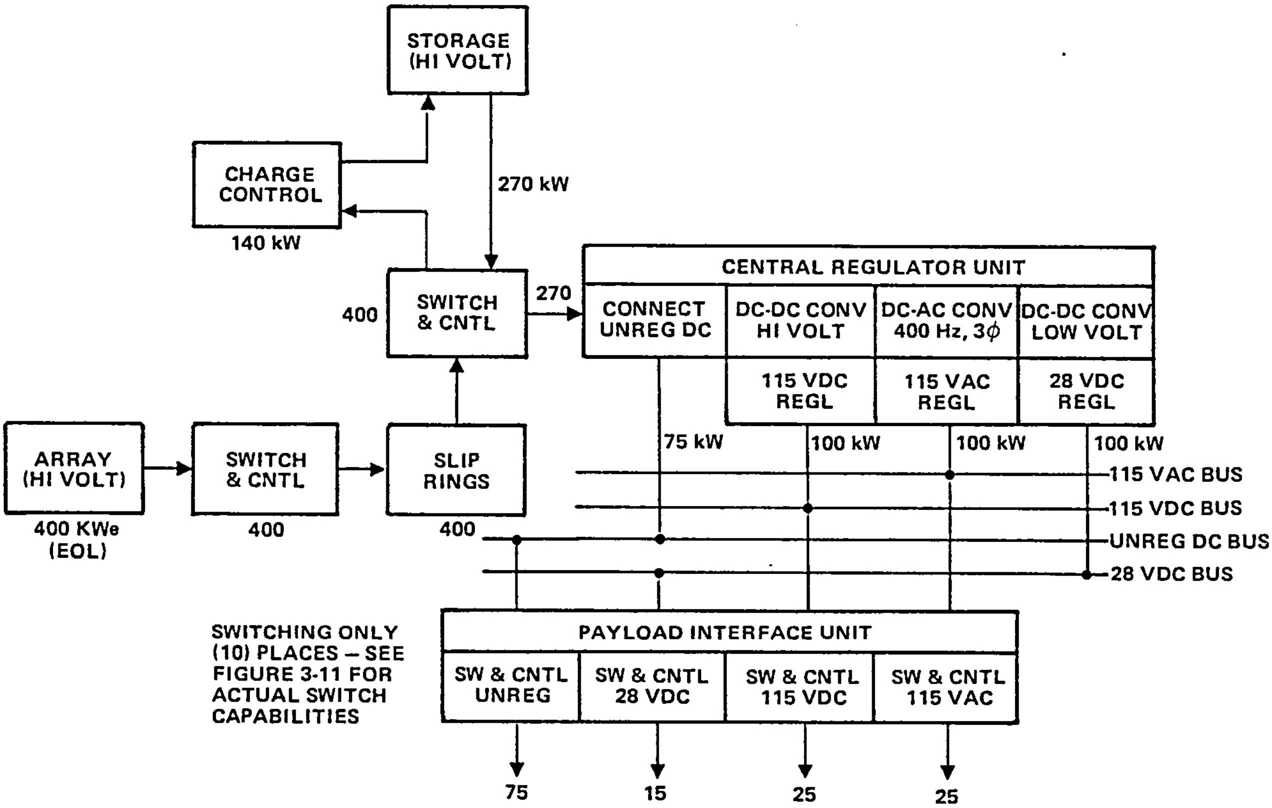
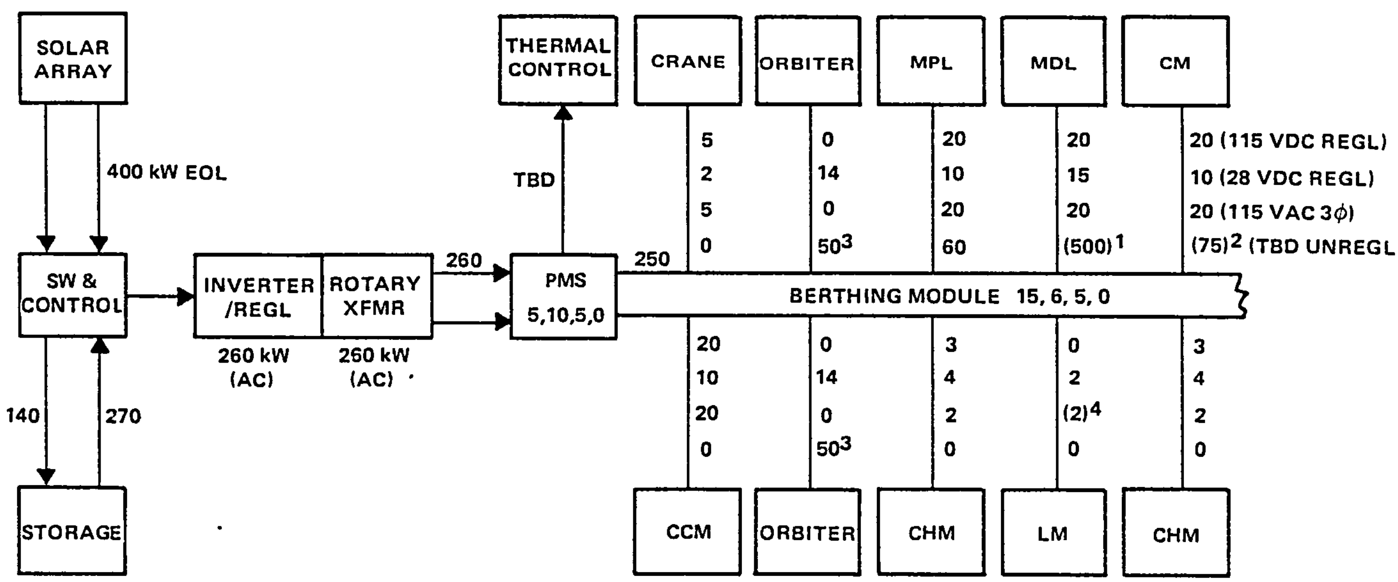


Figure 3-10. Component block requirements (centralized DC).



1. INTERMITTENT 500 kW FOR PLASMA EXPERIMENT.
2. INTERMITTENT 75 kW FOR MICROWAVE POWER TRANSMISSION TEST.
3. CONTINUOUS 50 kW FOR H_2/O_2 RELIQUEFACTION EQUIPMENT.
4. COULD REPLACE 2 kW 28 VDC REGL.

Figure 3-11. Component block requirements - AC.

The interrelated middle blocks of the diagram comprise the detailed evaluations of this study element and are documented in subsections 3.2.1 through 3.2.17, presented below, preceded by the appropriate work statement task description.

3.2.1 "Develop cost relationships and perform tradeoff analyses to minimize electrical power system life cycle cost."

Since the final calculation of total system costs is an iterative process, interlinked with the technical trades, this paragraph will discuss the general methods, models, and tools that were used, and final cost data will be presented at the end of Section 3.2 where the reader will have a better understanding of the system details, final configurations, and their evolution.

General Dynamics recognizes the importance of cost to the viability of future NASA programs in general and space platform concepts in particular. Accordingly, cost considerations were an integral part of this study of the power management system to ensure selecting optimum and low cost concepts and the technology required to support them.

Final cost calculations were accomplished through the use of subsystem level life cycle cost models to structure estimates of development, production, and operations costs of the PMS, together with the impact of those costs on space platform total program costs.

To ensure that mission costs are minimized, we developed a model that estimated, organized, and displayed PMS costs, accounted for related array and storage costs, and used that model to guide and support the trades and analyses.

Figure 3-12 depicts our cost estimating process. We developed a hardware-oriented work breakdown structure (WBS) that included all significant PMS elements and the other affected space platform elements. Component unit and development cost estimates were derived from in-house data, vendor/supplier sources, and extrapolations from current prices. Comprehensive data from our study of cost drivers was used. Parametric cost estimating relationships (CERs) were established as appropriate. By aggregating and factoring these costs into the PMS life cycle, total PMS costs were computed by the life cycle cost (LCC) model. The resulting costs are analyzed to support the trades and analyses. At the conclusion of the process, LCC is minimized, and the costs are published.

The WBS (Figure 3-13) provided visibility of the system cost elements and their interrelationships. It also shows the impact of PMS costs on other space platform cost elements reflecting the cost buildup that otherwise might be visible only in a complete space system cost estimate.

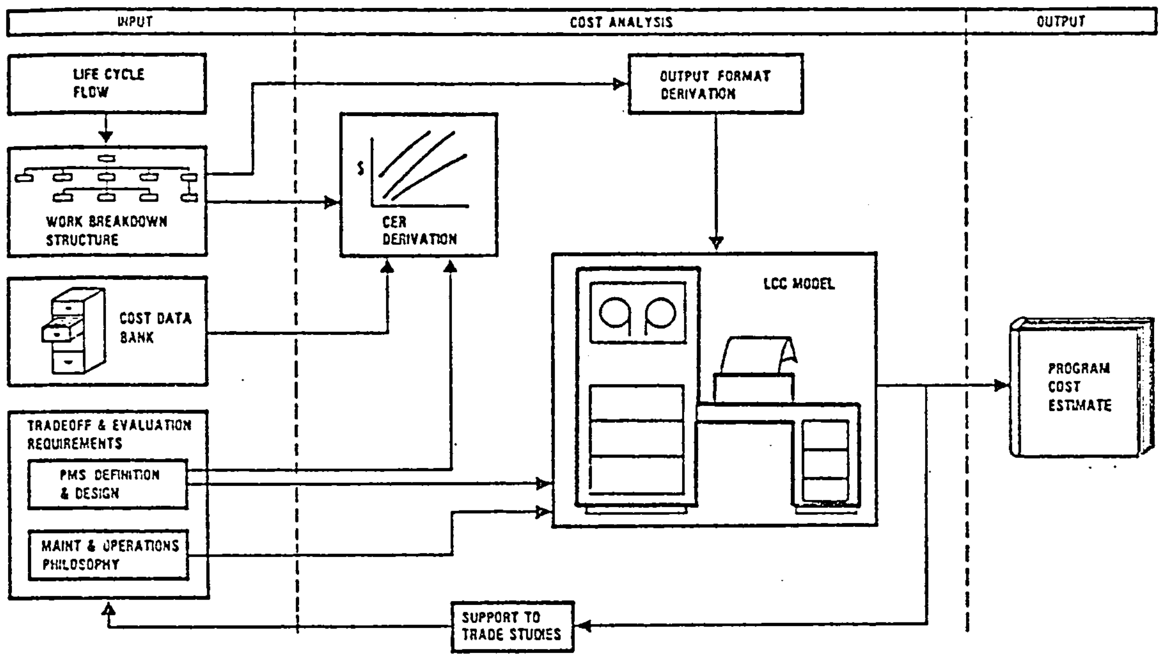


Figure 3-12. System costs estimating.

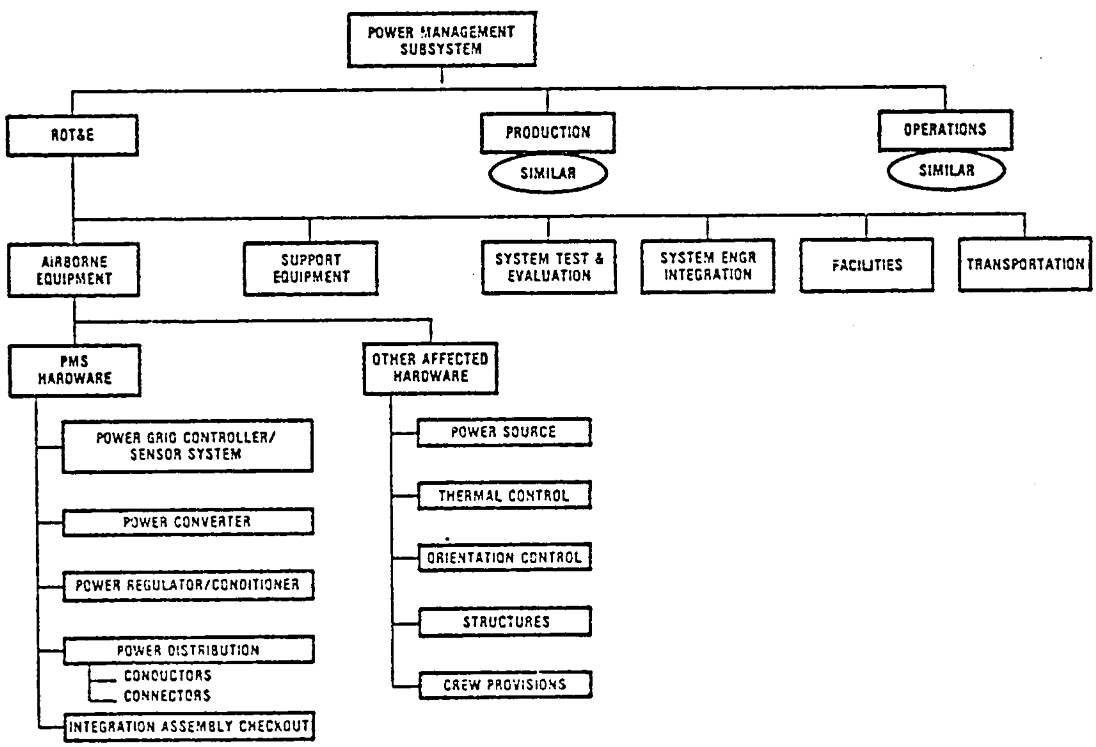
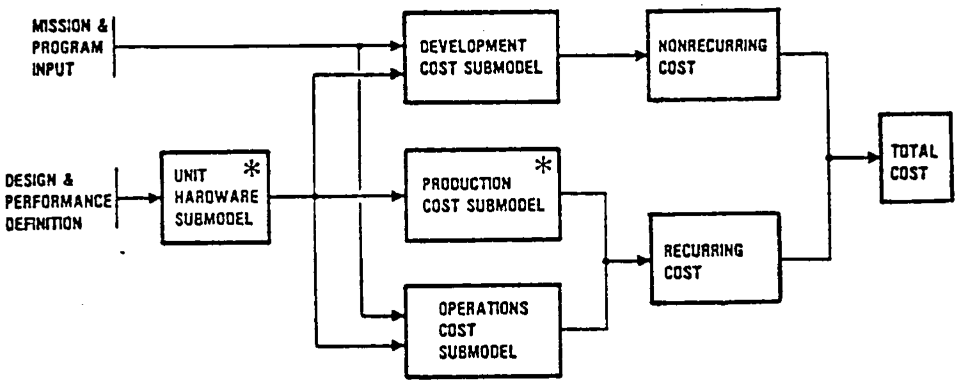


Figure 3-13. Work breakdown structure (WBS).

The RCA PRICE (Ref. 20) model was used to estimate the costs of PMS modules. CERs were used that parametrically relate cost to the characteristics of the hardware (e.g., transformer rating). We used factors for the costs of PMS integration, assembly, and test, based upon the size, cost, and complexity of the components. Maintenance costs were estimated from considerations of unit costs, MTBF, and system usage.

At the heart of the cost estimating process is the cost model (Figure 3-14) that calculates, organizes, sums, and prints the PMS life cycle cost. A computerized LCC model specifically tailored to the PMS was developed as an outgrowth of our space system cost modeling experience.



NOTE: THE RCA "PRICE" MODEL WAS USED TO CALCULATE COSTS FOR THE TWO BLOCKS MARKED (*), "UNIT HARDWARE SUBMODEL" AND "PRODUCTION COST SUBMODEL". SEE REFERENCE 20.

Figure 3-14. PMS cost model.

The system payloads data and analysis (SPDA) cost model (Ref. 21) is a unique tool generally applicable to a wide variety of shuttle payloads that provides hardware development and fabrication costs as well as operational phase costs. Of particular interest is the cost data synthesis methodology developed for the payload ground operations/integration activities, which is based on detailed analysis of the individual tasks involved.

The PMS cost model was adapted from the SPDA model. It identified cost elements, CER requirements, input requirements cost estimate format, and model logic for proper calculation and accumulation of costs. Because the model is based on the WBS, all cost elements are directly relatable to both the hardware activities and services required for the program and are sorted to each of the program life cycle time phases.

The model calculates the cost for each cost element using CERs, throughputs of point estimates, or detailed estimates based on task manpower. These costs are then accumulated for a total estimate. This output is then provided to evaluate trade studies of concept selection or for PMS mission cost projections. Figures 3-15 through 3-31 show the modular cost results.

PRODUCTION COSTS DC-AC INVERTER 250 kW + (1) SPARE

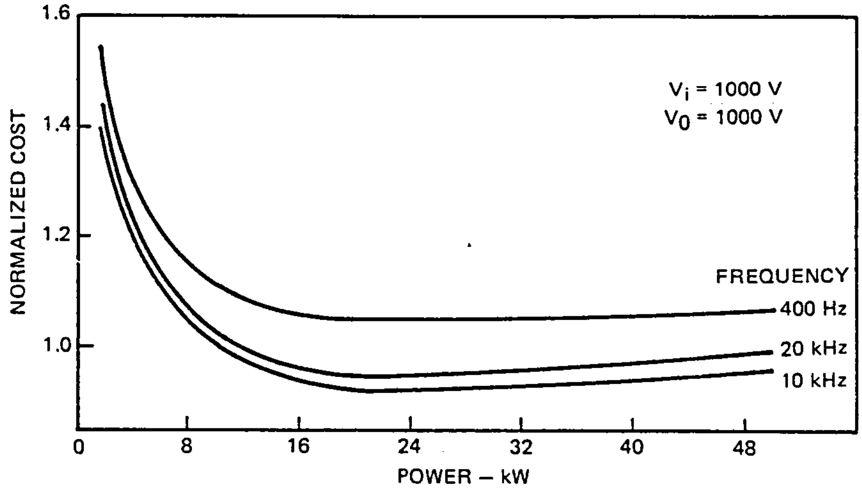


Figure 3-15. Power output relationships.

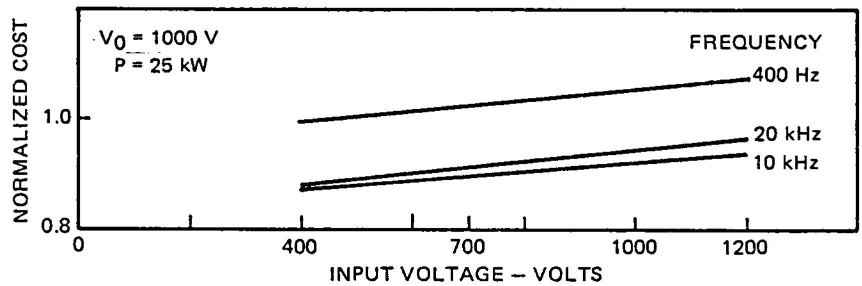


Figure 3-16. Voltage relationships.

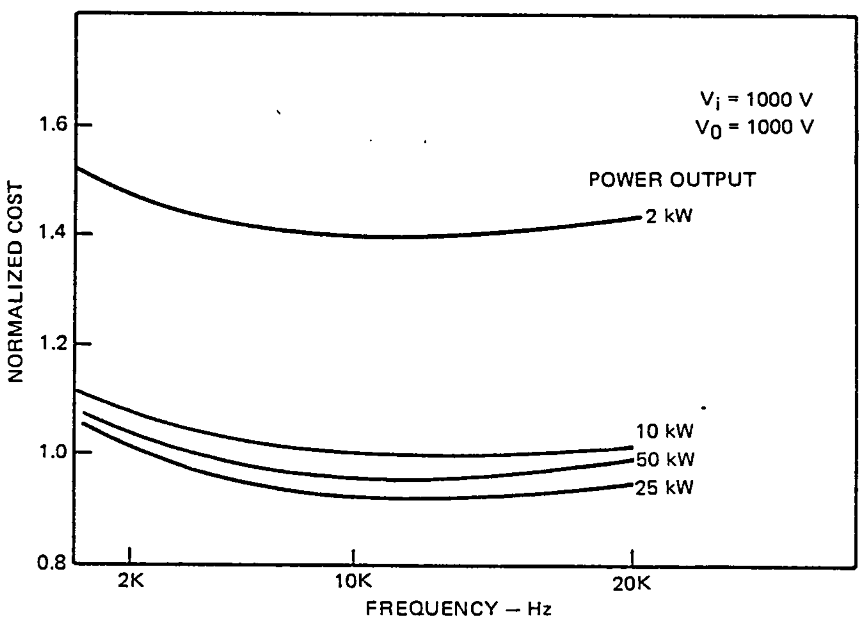


Figure 3-17. Frequency relationships.

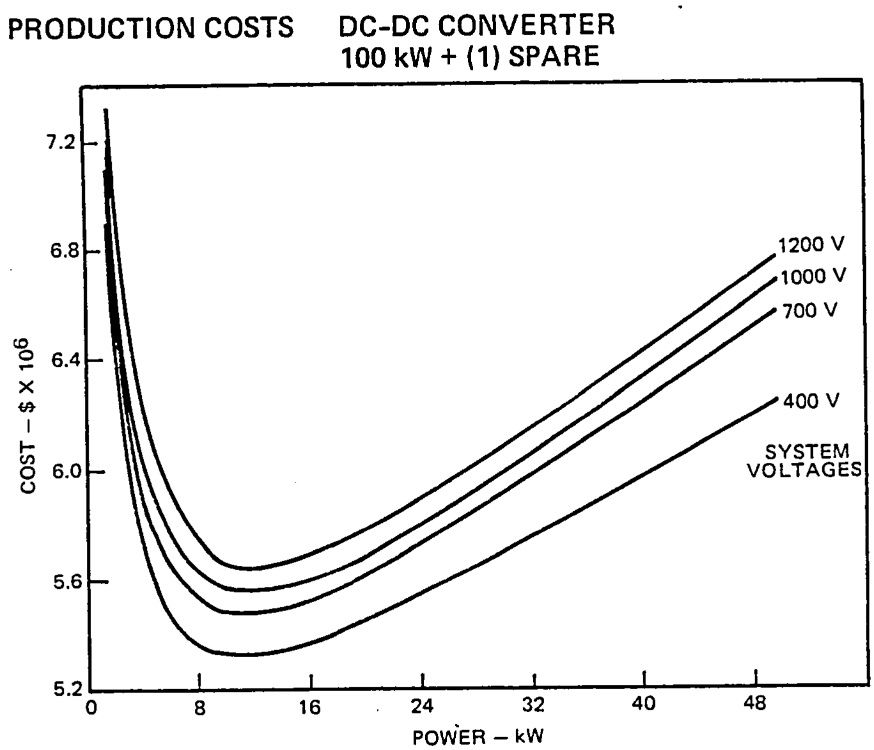


Figure 3-18. Power output relationships.

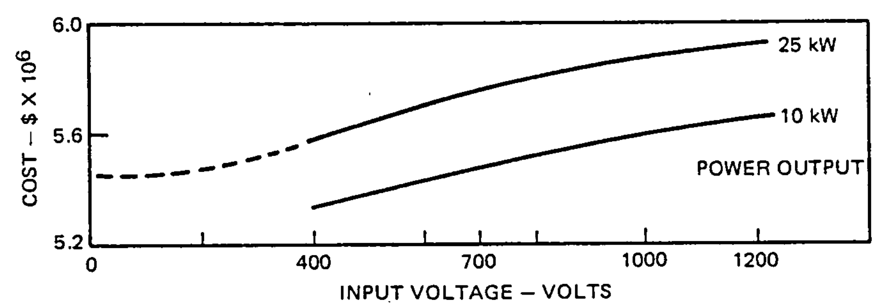


Figure 3-19. Voltage relationships.

PRODUCTION COSTS DC-AC INVERTER 100 kW + (1) SPARE

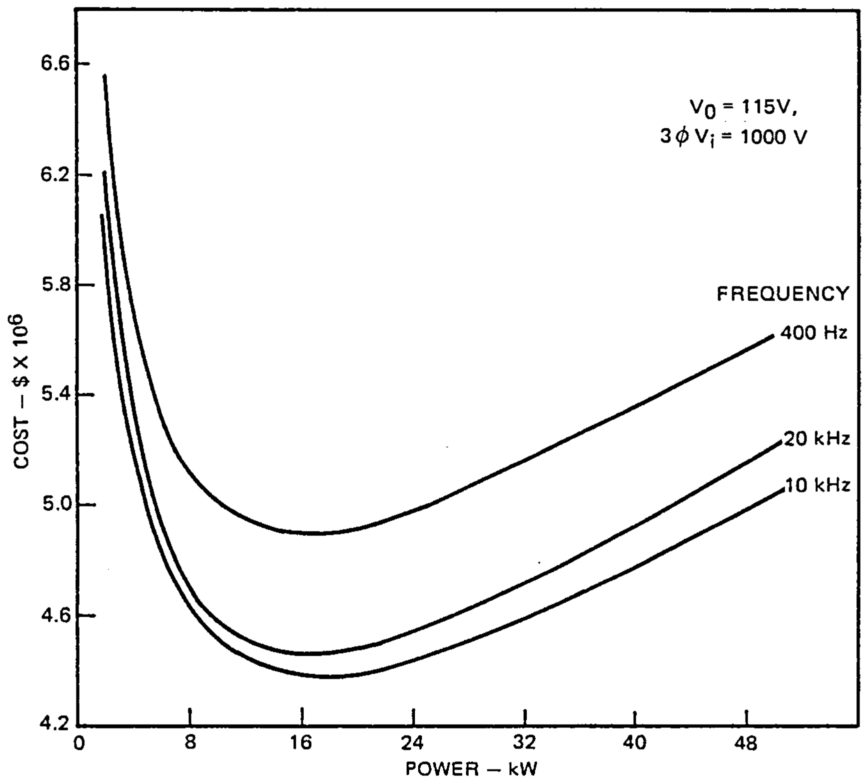


Figure 3-20. Power relationships.

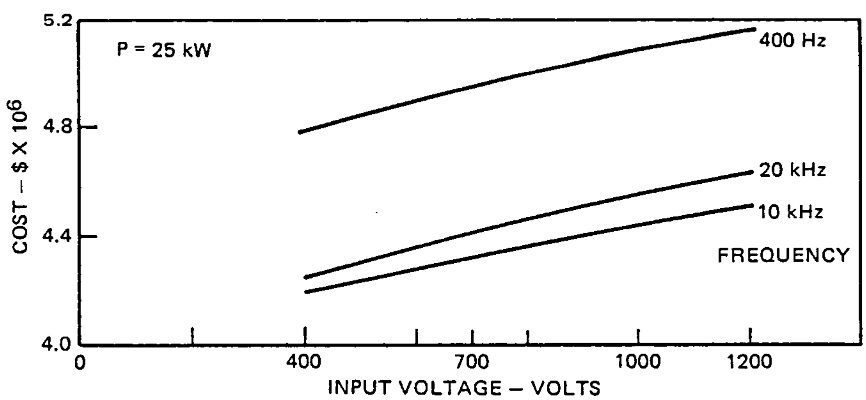


Figure 3-21. Input voltage relationships.

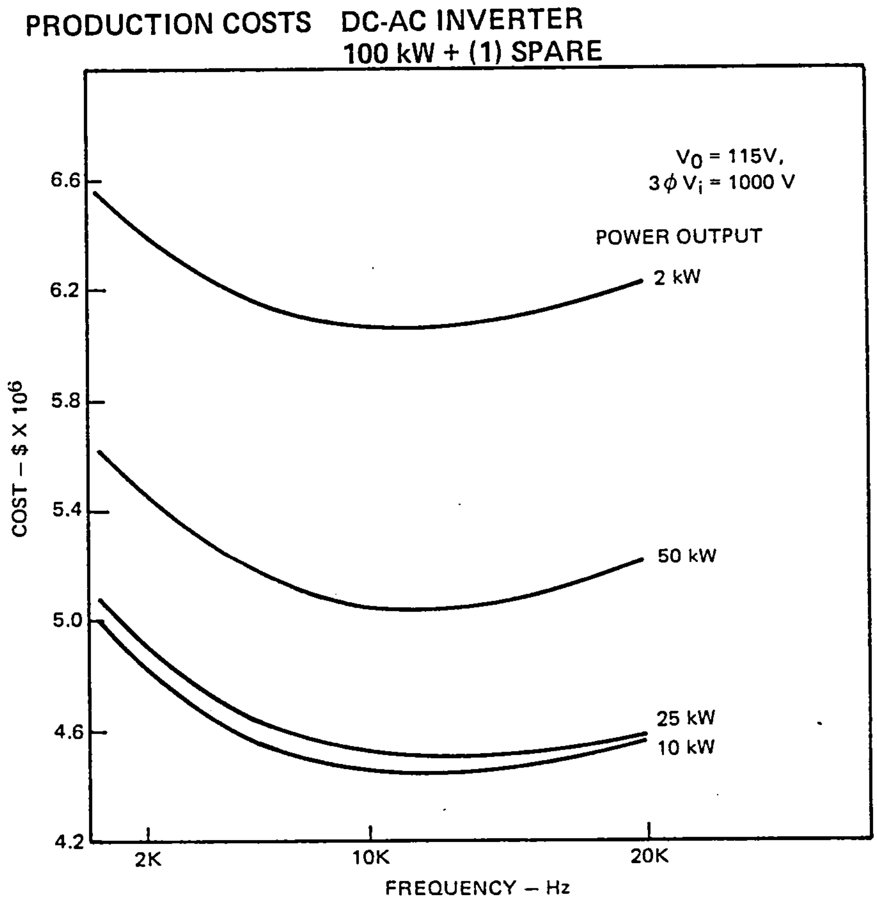


Figure 3-22. Frequency relationships.

PRODUCTION COSTS AC-DC CONVERTER
25 kW TOTAL + (1) SPARE

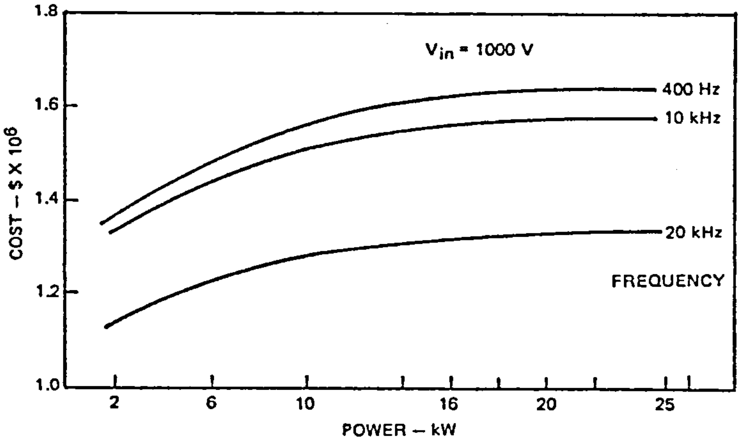


Figure 3-23. Power relationships.

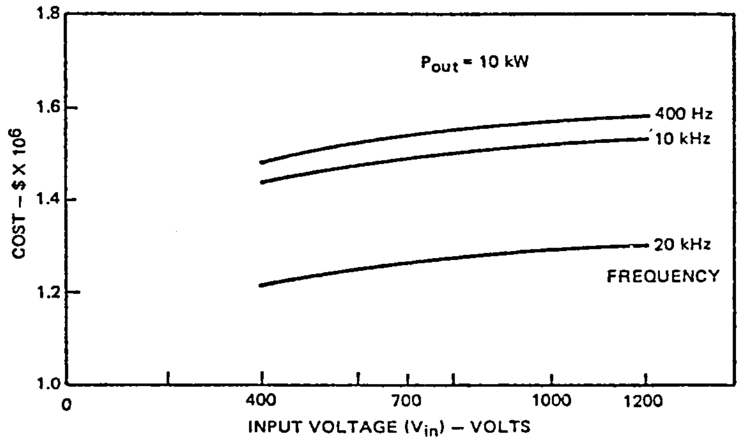


Figure 3-24. Voltage relationships.

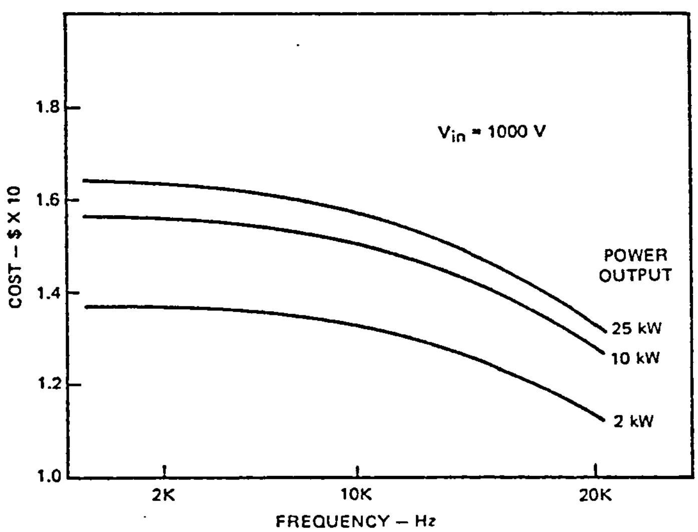


Figure 3-25. Frequency relationships.

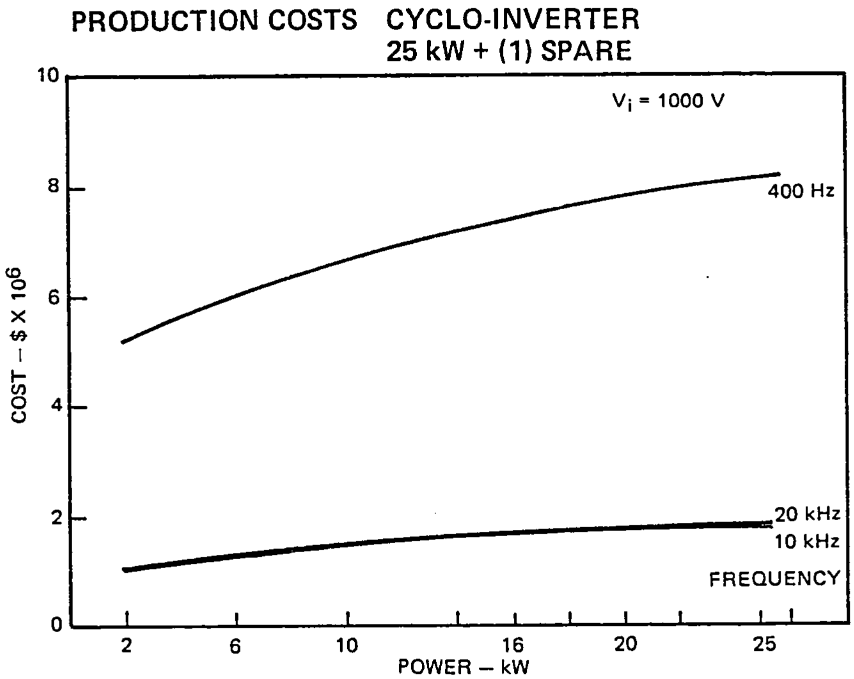


Figure 3-26. Power relationships.

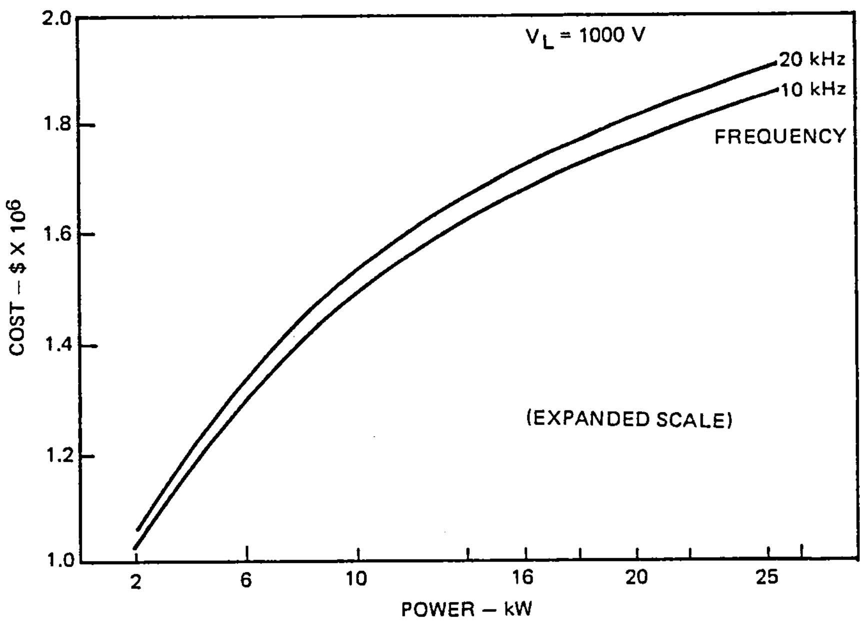


Figure 3-27. Expanded scale power relationships.

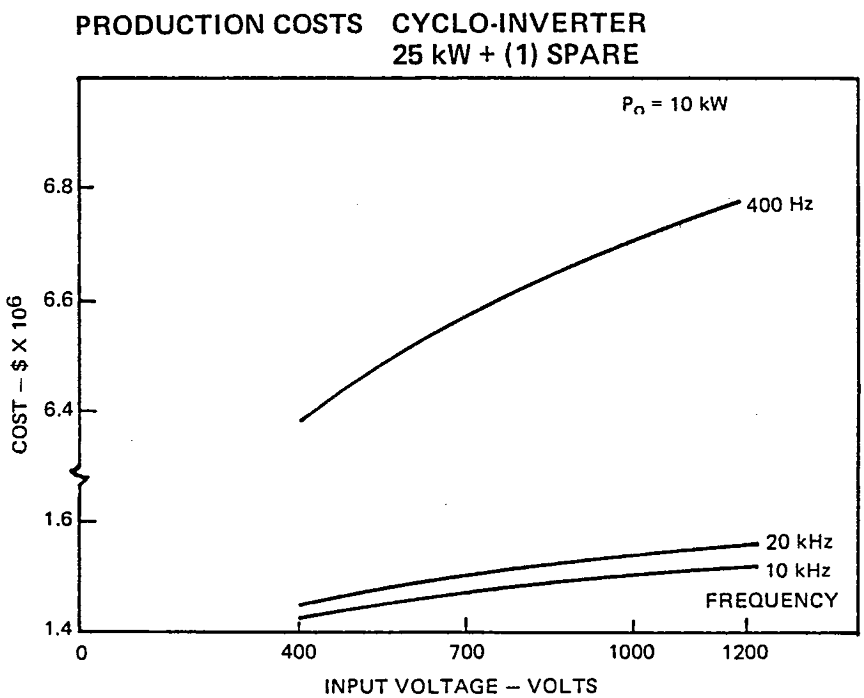


Figure 3-28. Voltage relationships.

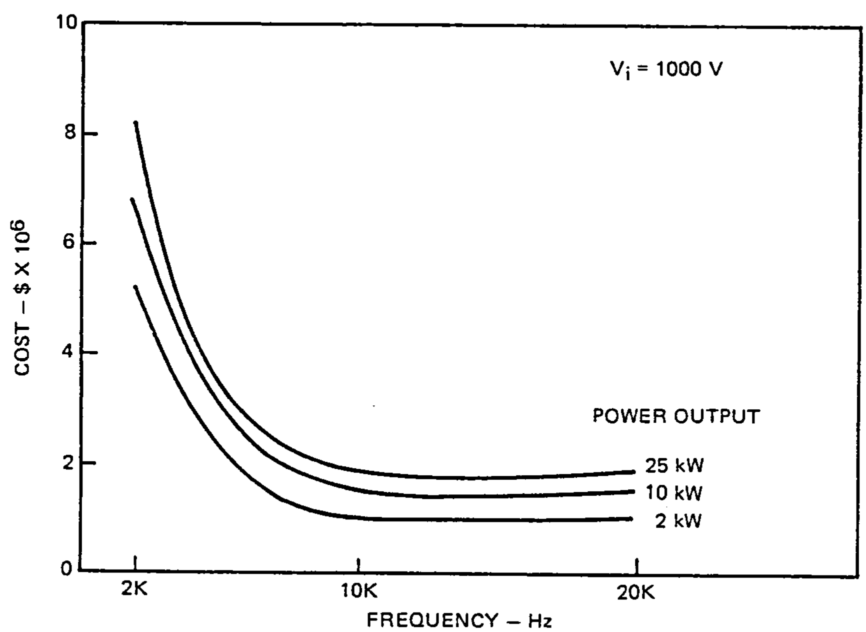
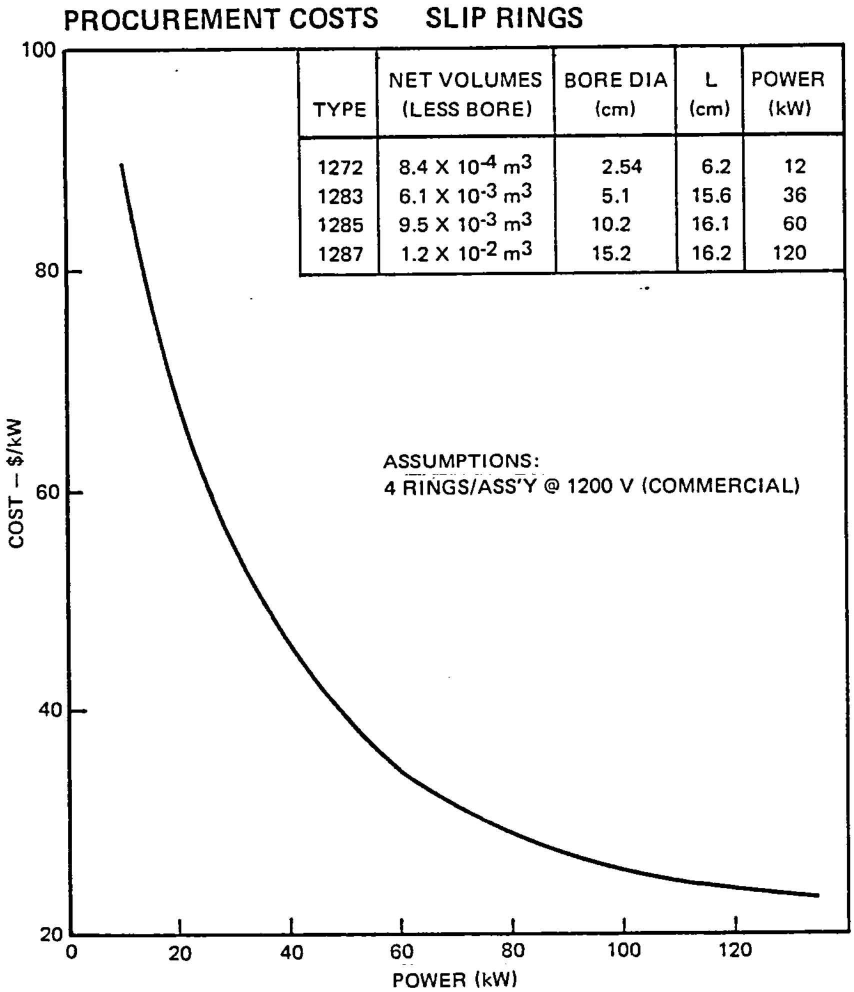


Figure 3-29. Frequency relationships.



TYPE	NET VOLUMES (LESS BORE)	BORE DIA (cm)	L (cm)	POWER (kW)
1272	8.4×10^{-4} m^3	2.54	6.2	12
1283	6.1×10^{-3} m^3	5.1	15.6	36
1285	9.5×10^{-3} m^3	10.2	16.1	60
1287	1.2×10^{-2} m^3	15.2	16.2	120

Figure 3-30. Power relationships.

PROCUREMENT COSTS POWER DISTRIBUTION SWITCHES (PER SWITCH) (FROM COMMERCIAL VENDOR DATA)

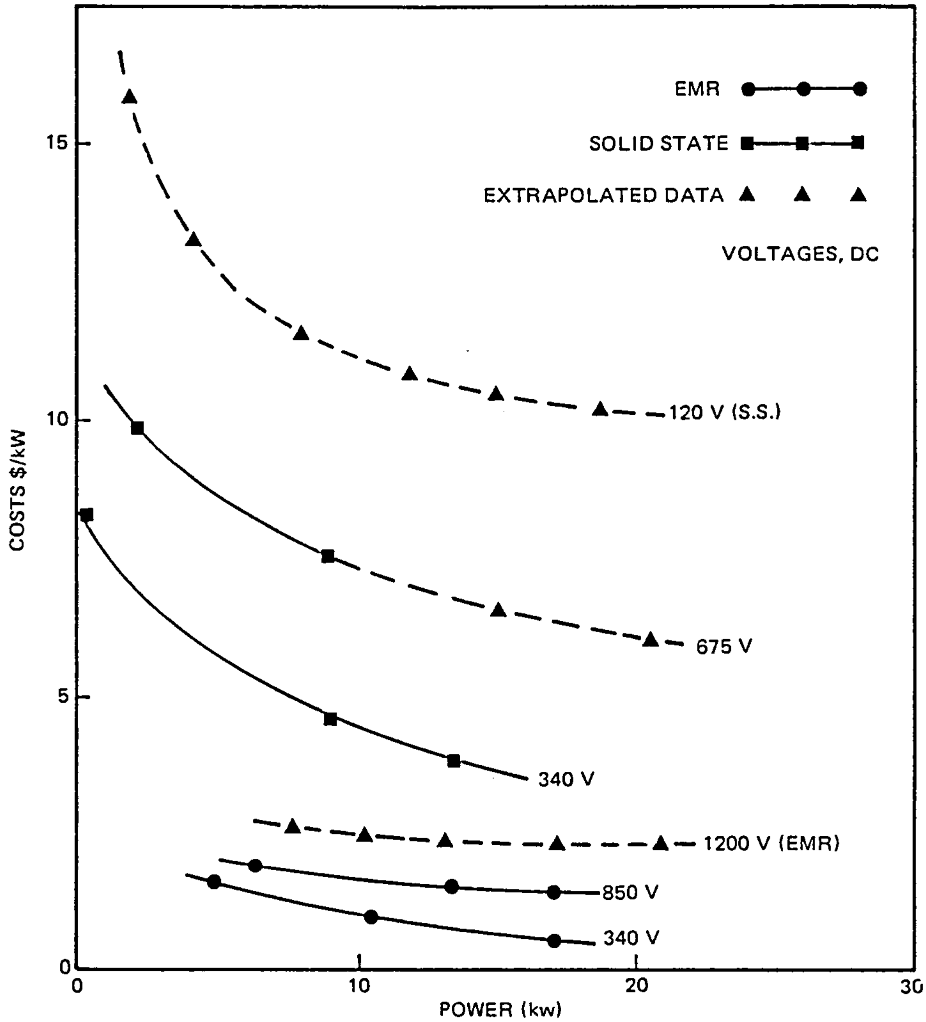


Figure 3-31. Power relationships.

Final total system costs are discussed in Subsection 3.3.4, Final Cost Analysis, beginning on page 3-93. Costs for the two selected systems are shown in Tables 3-12 and 3-13 in that subsection. Table 3-14 is a cost summary for the two systems and their major variations. Final cost conclusions are deferred to Subsection 3.3.4 so that they can be better integrated with the technical trades.

3.2.2 "Estimate the achievable weight and volume characteristics of the PMS and each of its major components. Determine any first order weight and volume effects on systems or subsystems other than the PMS caused by tradeoffs involving the PMS."

In this task, typical designs for the major components of the power management system were examined to estimate weight and volume as a function of power output. Sizes and weights of components, housings, heat sinks, etc., were estimated and unit predesigns based on complexity and component count were developed. Unit sizes and weights were then calculated. Using assessments of the state of the art and rates at which the various technologies are currently moving, estimates of weights and volumes, projected into the mid-to-late 1980s were provided. The outputs were normalized and plotted as specific mass and specific volume as a function of power output and are presented in Figures 3-32 and 3-33 for the major components in question. The non-structural portions of a rotary transformer are presented in Figure 3-34. Current slip-ring designs, as determined from published vendor data, are adequate to meet the needs of a system of this size and their catalog data are presented in Figures 3-35 and 3-36. Switchgear is shown in Figures 3-37 and 3-38.

Once a strategy for sizing modules composing system functional blocks has been adopted, an optimum size submodule can be found, based on weight or cost as described in subsection 3.2.1. The strategy for this system is developed in subsections 3.2.9 and 3.2.10 on reliability and life and provides for sufficient modules to supply the full power output for any function plus one operational spare. Using the specific mass data and cost models then allows the calculation of cost to supply the full required output as a function of modular size. The minimum of this curve is the most cost-effective modular size for the function in question. Figure 3-15 shows this curve for a 250 kWe DC-AC resonant inverter. Tables 3-4, 3-5, 3-6, and 3-7 list optimum modular sizes and major characteristics (based on minimum life cycle costs) for each functional block in our candidate systems. The data for individual modules is documented on the "PMS components characteristics data sheets" (Appendix 1).

CONCLUSION: Component sizes and weights are moving in the right direction for space platform applications as a natural consequence of improved design. Component weights are approaching acceptable values and will certainly meet mid-to-late 1980s requirements. Equipment densities are almost an order of magnitude higher than what is ideal for STS payloads, therefore, decreasing weight at the expense of increased volume is a worthwhile trade for power management equipment.

First order weight and volume effects on other PMS related space platform elements are evaluated and documented in the sections where they are important. See subsections 3.2.6, 3.2.7, and 3.2.8 for the major impact areas. Obviously, losses and efficiency are the driving parameters, since they directly impact requirements for capacity of solar arrays, batteries, and thermal management.

NOTE: NUMBERS IN ( ) ARE % INCREASES TO RAISE THE RELIABILITY OF A 10 kW UNIT FROM THE SIMPLEX BASE NUMBER SHOWN IN FIGURE 3-53a TO A VALUE OF 0.99.

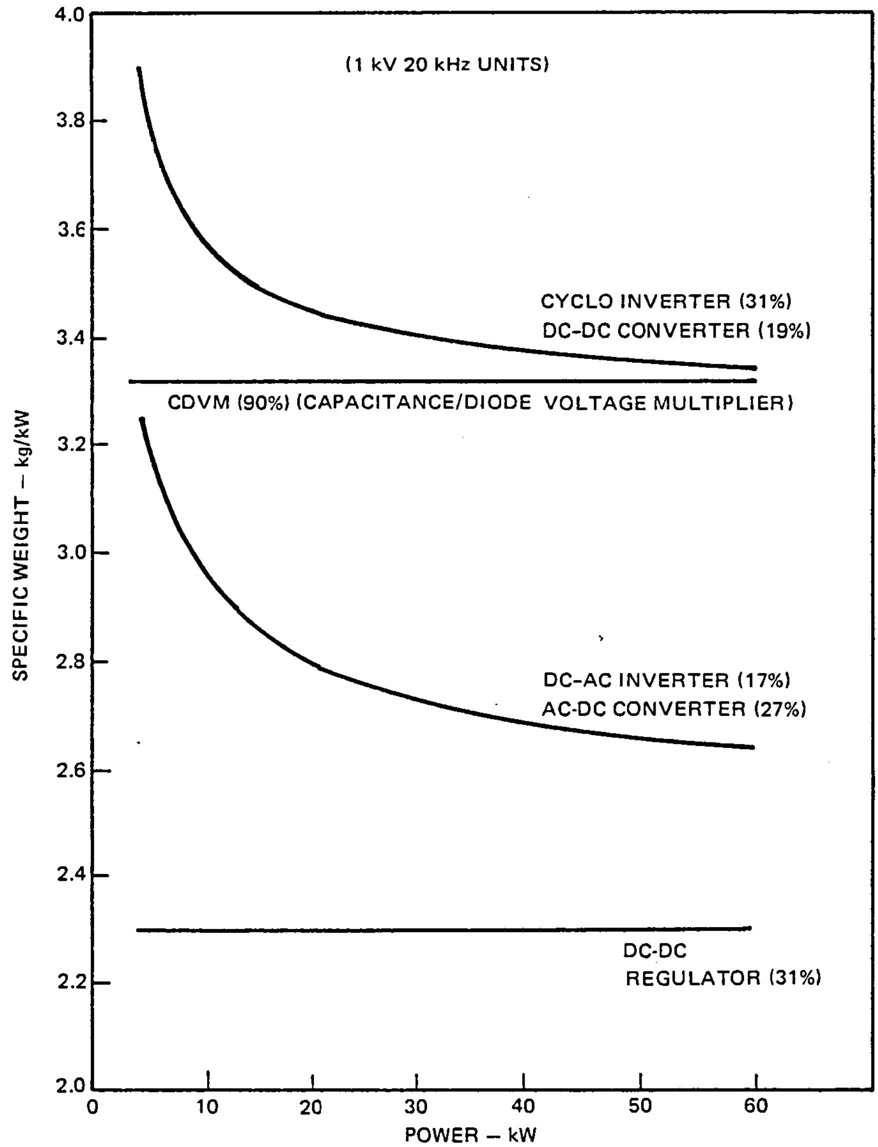


Figure 3-32. Specific mass relationships for PMS major components.

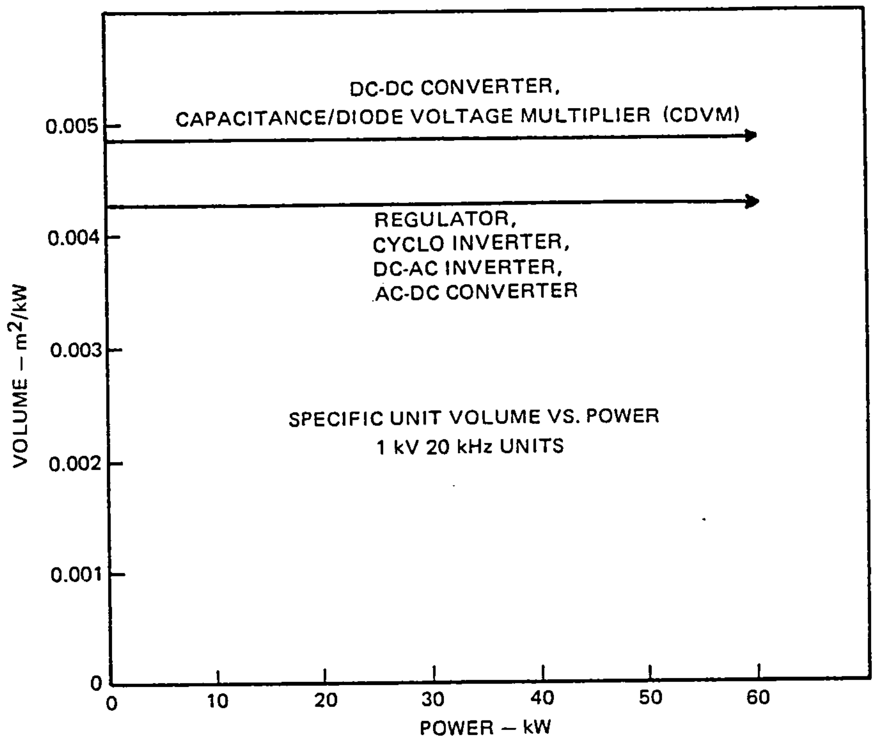


Figure 3-33. Specific volume relationships for PMS major components.

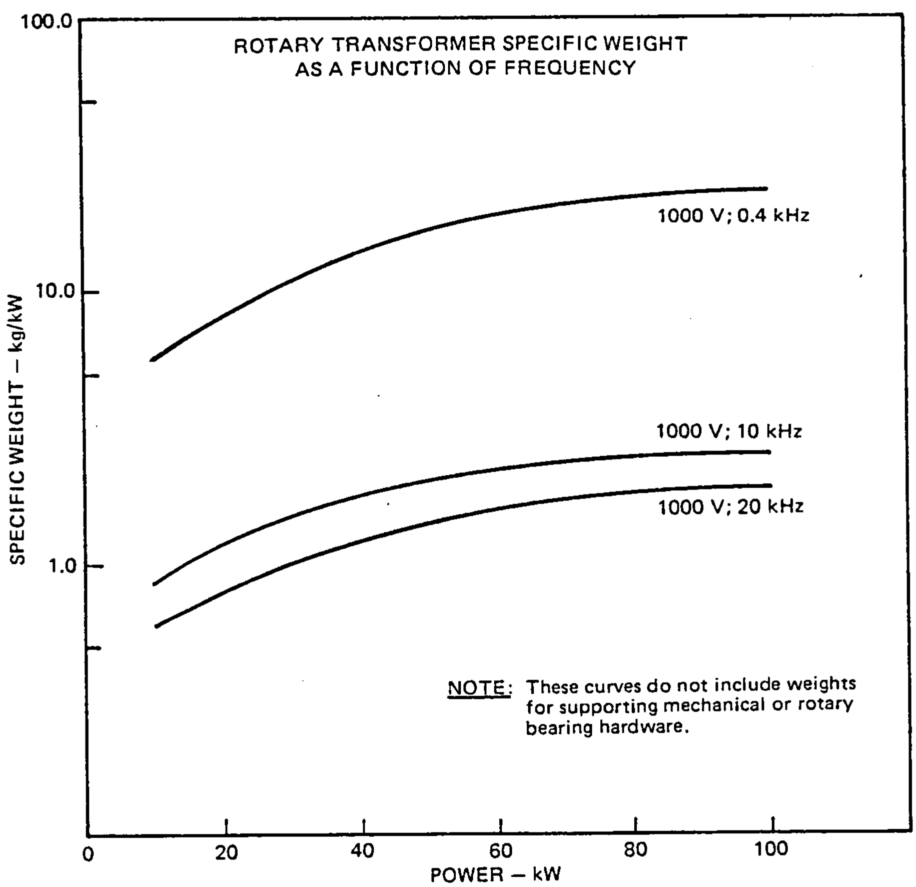
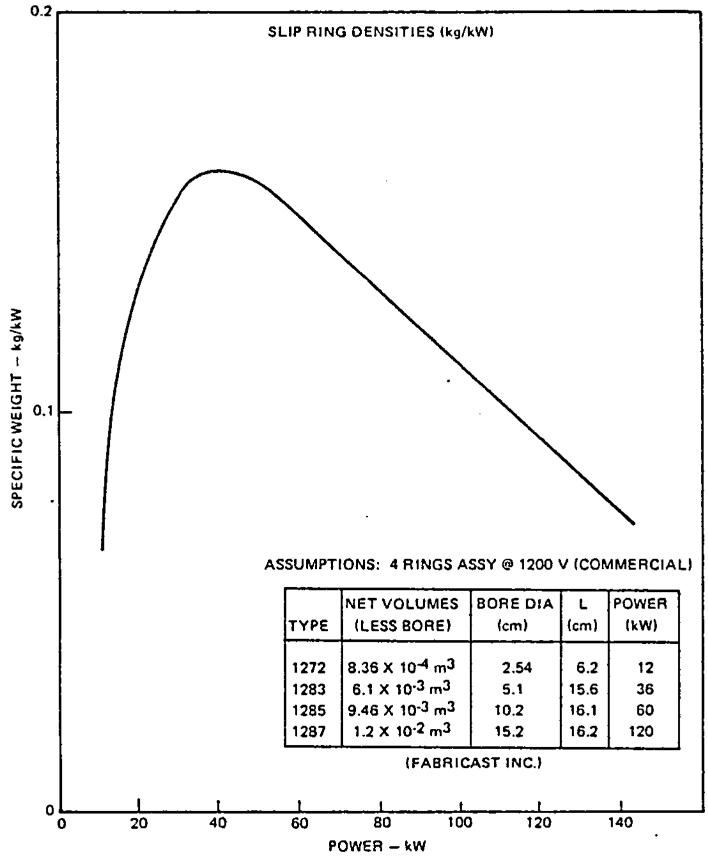
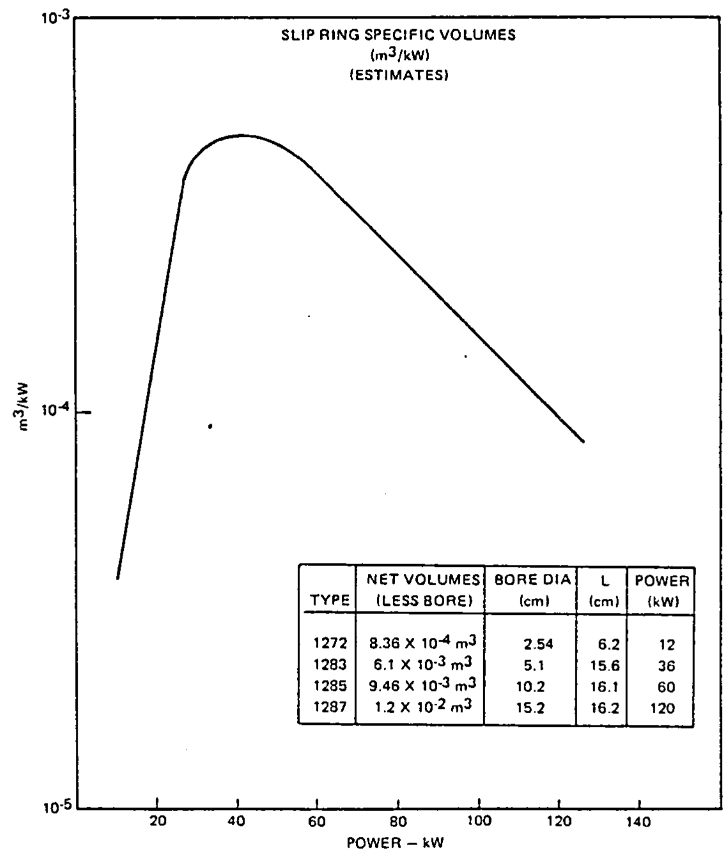


Figure 3-34. Specific mass relationships for rotary transformer electrical hardware.



TYPE	NET VOLUMES (LESS BORE)	BORE DIA (cm)	L (cm)	POWER (kW)
1272	8.36×10^{-4} m^3	2.54	6.2	12
1283	6.1×10^{-3} m^3	5.1	15.6	36
1285	9.46×10^{-3} m^3	10.2	16.1	60
1287	1.2×10^{-2} m^3	15.2	16.2	120

Figure 3-35. Slip ring mass relationships.



TYPE	NET VOLUMES (LESS BORE)	BORE DIA (cm)	L (cm)	POWER (kW)
1272	8.36×10^{-4} m^3	2.54	6.2	12
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1285	9.46×10^{-3} m^3	10.2	16.1	60
1287	1.2×10^{-2} m^3	15.2	16.2	120

Figure 3-36. Slip ring volume relationships.

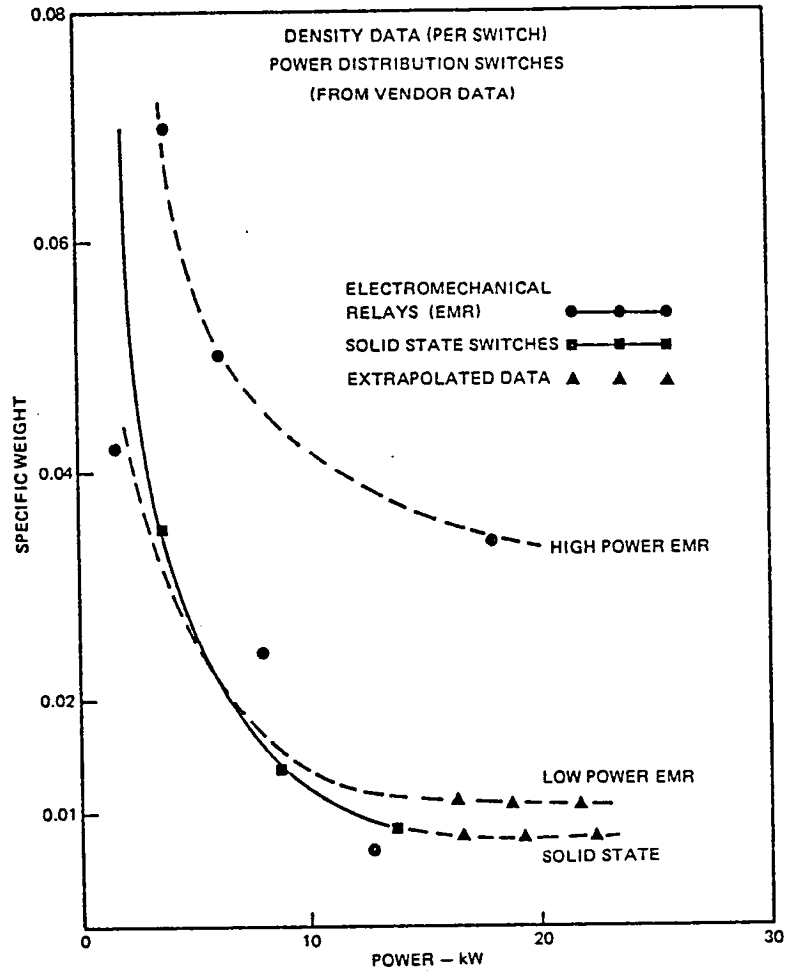


Figure 3-37. Switchgear mass relationships.

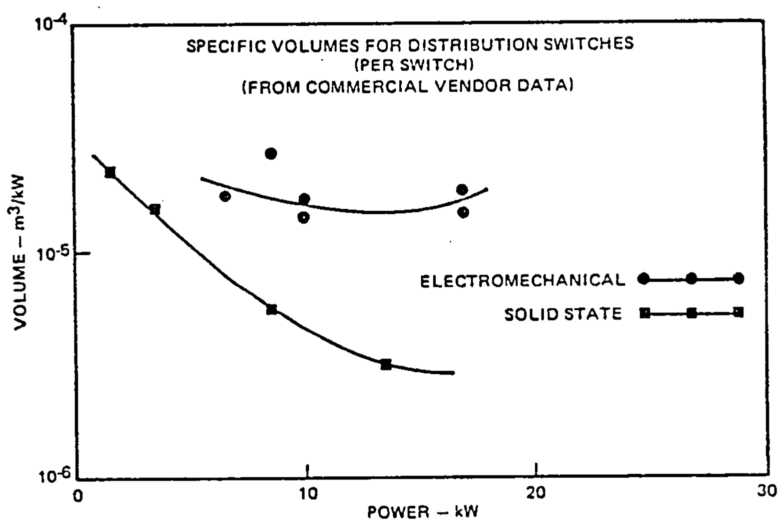


Figure 3-38. Switchgear volume relationships.

Table 3-4. Optimum module size based on weight and life cycle cost (DC system).

Module Type	Total Power	Optimum Size	Total Modules	Remarks
Slip Rings	400 kW	100 kW	4 + 4 Spares	Totally Redundant
Battery Charger	135 kW	13.5 kW	10 + 1	
DC Regulator (115 V)	100 kW	10.0 kW	10 + 1	
DC-AC Inverter	100 kW	16.7 kW	6 + 1	
DC-DC Conv (28 V)	15 kW	5.0 kW	20 + 10	Distrib Worst Case @ PIU
Switchgear (DPDT)	—	10.0 kW	10 + 1	Hi Volt Bus Isolation
Switchgear (DPDT)	—	10.0 kW	10 + 1	Lo Volt Bus Isolation
Switchgear (DPDT)	—	5.0 kW	20 + 10	Distrib DC-DC Isolation
Switchgear (SPDT)	—	13.5 kW	44	Sized from Battery Charger
Switchgear (DPDT)	20 kW	5.0 kW	90	Payload Isolation

Table 3-5. Optimum module size based on weight and life cycle cost (AC system).

Module Type	Total Power	Optimum Size	Total Modules	Remarks
DC-AC Inverter	250 kW	25.0 kW	10 + 1 Spare	
Rotary Transformer	250 kW	25.0 kW	10 + 1	Matches Inverter Outputs
Battery Charger	135 kW	13.5 kW	10 + 1	
AC-DC Conv (28V)	15 kW	5.0 kW	20 + 10	Worst Case at Dist. PIU
AC-DC Conv (115V)	20 kW	5.0 kW	20 + 10	Worst Case at Dist. PIU
Output Transformer	20 kW	5.0 kW	20 + 10	Worst Case at Dist. PIU
Switchgear (DPDT)	—	5.0 kW	90	PIU Input Isolation
Switchgear (DPDT)	75 kW	15.0 kW	16	Worst Case at Dist. PIU
Switchgear (SPDT)	—	25.0 kW	33	Matches Inverter Inputs

Table 3-6. Parameters of the major DC system components.

Module	Power Per Unit	Weight Per Unit	Average Volume Per Unit	Eff. (%)	Average* Cost Per Unit	Total Units Used	Total Cost	Remarks
1 Slip Rings	100 kW	11.3 kg	0.020 m^3	99.9	11.6 K	8	92.8 K	Not incl struct
2 Battery Charger	13.5 kW	31.1 kg	0.065 m^3	97.6	30.5 K	11	336 K	
3 DC Regl 115 V	10.0 kW	23.0 kg	0.048 m^3	97.6	35.7 K	11	393 K	
4 DC-AC Inverter	16.7 kW	49.3 kg	0.080 m^3	96.1	53.6 K	7	375 K	3 Phase
5 DC-DC Converter*	5.0 kW	11.5 kg	0.048 m^3	97.6	20.2 K	30	606 K	
6 Switchgear DPDT	5.0 kW	0.26 kg	**	99.6	0.26 K	30	8 K	Distrib. 28 VDC
7 Switchgear DPDT	10.0 kW	0.52 kg	**	99.6	0.62 K	30	16 K	Conv Interface
8 Switchgear DPDT	10.0 kW	0.52 kg	**	99.0	0.52 K	22	12 K	Bus Isolation
9 Switchgear SPDT	13.5 kW	0.35 kg	**	99.6	0.35 K	44	15 K	Source Control
10 Switchgear DPDT	5.0 kW	0.26 kg	**	99.0	0.26 K	90	23 K	Payload Isolation

*Average cost is based on a production run of 100 units and an 85% learning curve.
**Small enough to be neglected compared to other PMS hardware.

Table 3-7. Parameters of the major AC system components.

Module	Power Per Unit	Weight Per Unit	Average Volume Per Unit	Eff. (%)	Average* Cost Per Unit	Total Units Used	Total Cost	Remarks
1 DC-AC Inverter	25.0 kW	43.0 kg	0.063 m^3	97.95	74.1 K	11	815 K	
2 Rotary Transformer	25.0 kW	8.8 kg	NA	99.0	10.9 K	11	120 K	Not incl struct.
3 Battery Charger	13.5 kW	31.1 kg	0.065 m^3	97.6	30.5 K	11	336 K	
4 AC-DC Converter (28 VDC)	5.0 kW	8.6 kg	0.013 m^3	97.75	15.2 K	30	455 K	
5 AC-DC Converter (115 VDC)	5.0 kW	8.6 kg	0.013 m^3	97.75	15.2 K	30	455 K	
6 Output Transformer	5.0 kW	0.3 kg	NA	99.0	1.0 K	30	30 K	
7 Switchgear DPDT	5.0 kW	0.23 kg	$10 \times 10^{-5} m^3$	99.8	0.26 K	90	23 K	Bus Isolation
8 Switchgear DPDT	15.0 kW	0.69 kg	$13.8 \times 10^{-5} m^3$	99.8	0.75 K	16	12 K	Non-Reg Control
9 Switchgear SPDT	25.0 kW	1.15 kg	$10 \times 10^{-5} m^3$	99.5	0.64 K	33	21 K	Source Control

*Average cost is based on a production run of 100 units and a learning curve of 85%.

3.2.3 "Estimate the achievable performance characteristics of the PMS and each of its major components."

Using the optimum module sizes found in subsection 3.2.2, the general performance requirements are calculated and documented on Part B of the "PMS components characteristics data sheets" (Appendix 1).

The current state-of-the-art was then assessed for each major component and current capabilities were documented in the "state-of-the-art" column on the data sheets in Appendix 1.

Where current technology does not meet or exceed the PMS requirement for the major units, the improvements possible from "normal development programs" have been evaluated and estimated to provide "technology readiness" in the mid-to-late 1980s. This evaluation is a combination of Convair experience, vendor opinions, general industry interest, degree of device design maturity, historical data, and the rate-of-change of the current important parameters. The results are presented in the "achievable capability" column of the summary sheets in Appendix 1.

Some requirements, such as voltage and frequency are optimized in later sections of this report and justifications are presented there.

<u>CONCLUSIONS:</u> The information on the summary sheets forms the basis for the component technology gap analysis of Task 2. There are no gaps in major component technology which cannot be remedied by normal development programs for mid-to-late 1980s technology readiness.

3.2.4 "Estimate the effect of the load power range (100-250 KWe) on the major PMS characteristics."

This load power range was found to have little impact on the design of a modularized system with the modules sized in the ranges specified in Tables 3-6 and 3-7. Power requirements for individual modules are low enough so that no major changes in design and construction techniques are required for optimum sized modules as system capacity grows from 100 to 250 KWe.

Increases in cost are, therefore, linearly related to increases in power with the usual economies of scale as power increases over this range. (See Figure 3-32.) The cost curves are smooth with no discontinuities showing a demand for technological change for system components. Therefore, it was concluded that the most cost-effective system (on a per-kilowatt basis) is at 250 KWe, and 250 kW technology is not much different from 100 kW technology. Other study elements were then based on 250 KWe with the knowledge that the general conclusions would also be valid for the lower end.

3.2.5 "Estimate the peak power capability of the electrical power system. The technology impacts (on the PMS) of supplying peak power to experiments shall be examined."

The maximum power capabilities of both AC and DC systems have been analyzed under three different sets of conditions, and the limiting parameter/hardware has been identified. The limiting paths are shown in Figures 3-39 and 3-40. They are:

a. No system changes to supply maximum, continuous power; no component derated design value exceeded.

   For the DC system, the first limit occurs at approximately 500 kW, which is the maximum power that the pair of redundant power bus systems (250 kW each) would be designed for.

   In the AC system, the limiting hardware is the inverter and rotary transformer transmitting power across the array/space platform rotary joint. Using the 10 plus 1 modules shown in Table 3-5 yields a maximum design power level of 275 kW for this hardware.

b. No system changes to supply maximum, continuous power; no component absolute maximum rating exceeded. All conservative electronic/electrical designs provide maximum worst case capabilities which are derated from the manufacturer's maximum component ratings to allow a safety factor and improve reliability. It is conceivable that this sort of hardware could be operated for short periods at its maximums without any serious impact. On that basis, the limiting hardware of a., above, could supply the following peak powers, assuming the usual half-power deratings:

   DC system - 1000 kW (steady state)
   AC system - 600 kW (steady state)

   Thermal characteristics of individual designs would have to be evaluated to see what length of time could be used before temperatures got high enough to compromise reliability.

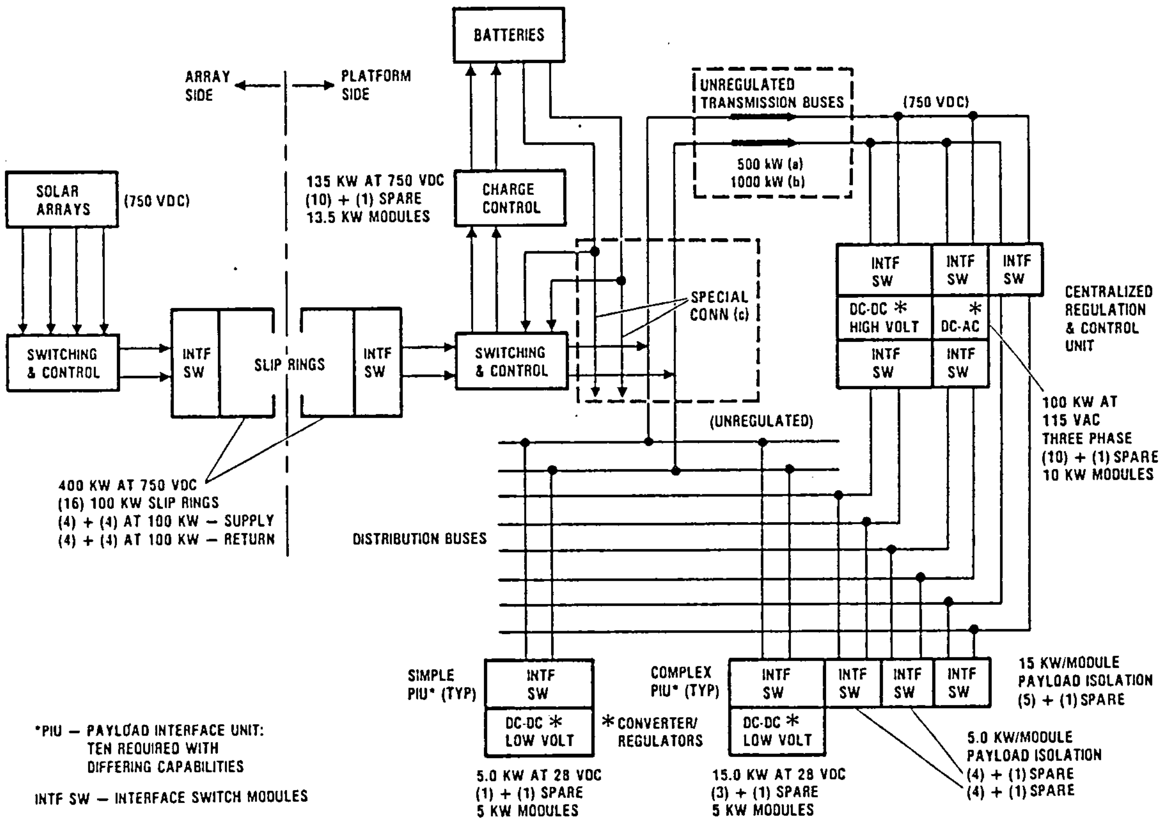


Figure 3-39. DC system block diagram.

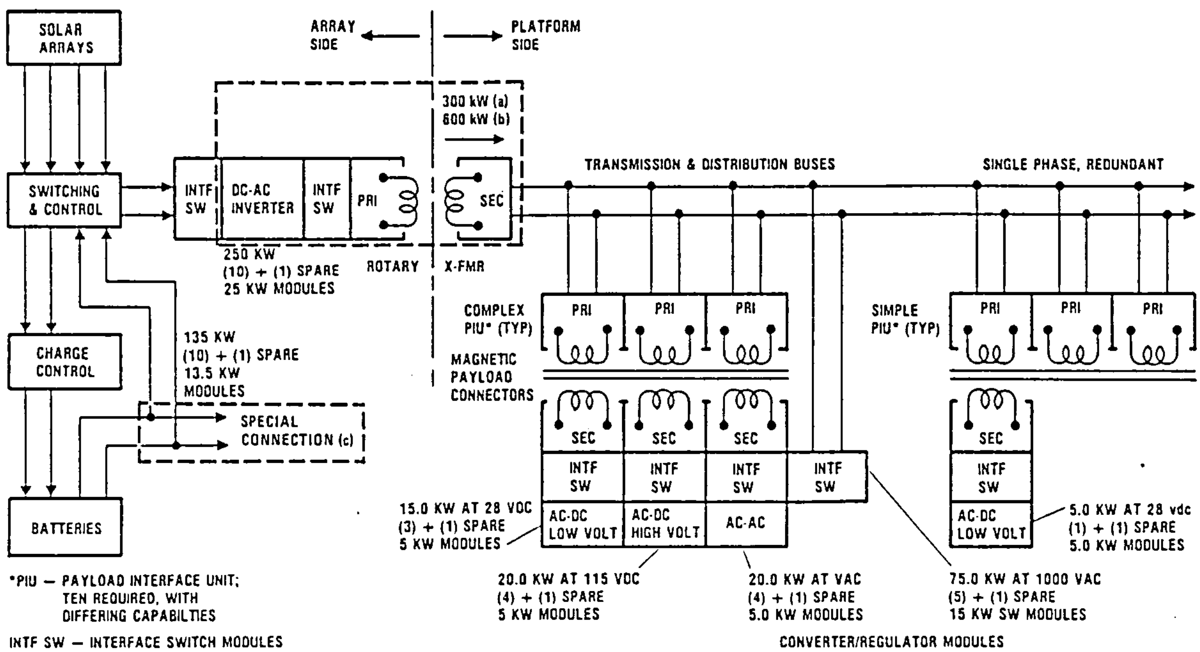


Figure 3-40. AC-DC hybrid resonant system block diagram.

c. Supplementary hardware added to take advantage of maximum energy available on the space platform. In this case, the batteries are used to supply their maximum safe transient discharge current into a special experiment or load by connecting them to it via supplementary cables and switchgear supplied as part of the experiment. This power is added to the normal solar array power to calculate the maximum available.

   DC system - 3.6 MW for three minutes
   AC system - 3.4 MW DC for three minutes (supplied directly from the batteries)

   In the AC system, the supplementary cables must bridge the rotary joint since the batteries are on the array side. This will put special constraints on the satellite motions during the time of the experiment.

CONCLUSION: Significant amounts of power can be supplied above the normal system rating with small reliability compromises and some system changes. The major source is the energy from a fully charged set of batteries, discharged at a higher than normal rate.

3.2.6 "Examine the effect of increased conversion equipment internal switching frequency."

This study element was expanded to examine the frequency question from two points of view. The first evaluates internal switching frequencies for system components such as DC-DC converters, switching regulators, etc. Because an AC transmission and distribution system was proposed as a system alternative, its transmission frequency was addressed as a second topic under this work statement paragraph.

3.2.6.1 Converter Internal Switching Frequency. There are two major frequency considerations for these devices. Weight and transportation to orbit cost decrease when frequency increases, since magnetic component and filter element sizes and weights decrease rapidly with increasing frequency.

For conventional, non-resonant conversion equipment, efficiency increases in the lower frequency range and then begins to decrease as the output device frequency response causes the switching time to be a significant percentage of the output duty cycle. Figure 3-41 shows this relationship for the major items of PMS equipment. Decrease in efficiency translates into added costs due to added thermal control hardware, solar arrays, and batteries. From the curves, it can be observed that the most efficient frequencies lie in the 10 kHz to 50 kHz range. Figure 3-42 shows the unit mass as a function of frequency. Because of the close correlation of cost and weight, the best life cycle cost devices appear to need frequencies in the 20 kHz to 30 kHz range. It is also clear that there is a need for faster power devices to move the efficiency curve to the right for a truly optimum design.

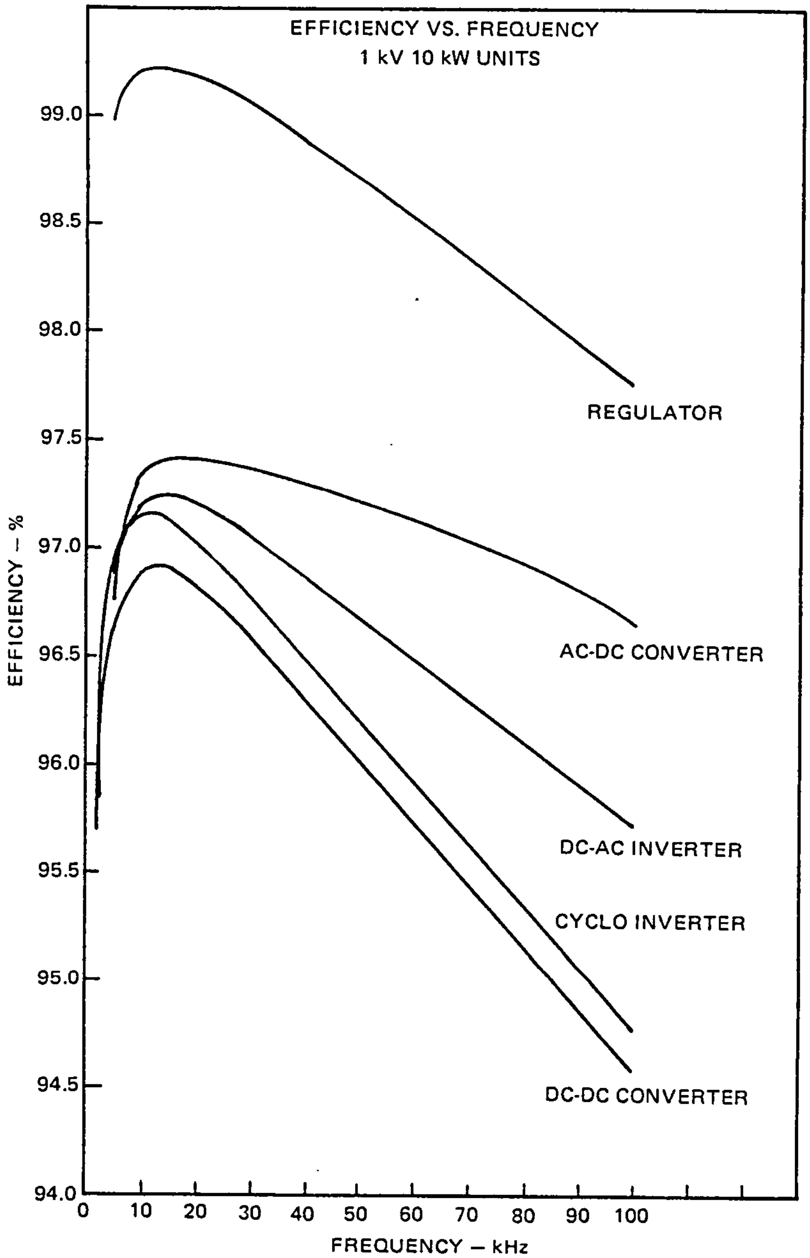


Figure 3-41. Conventional PMS major component efficiencies.

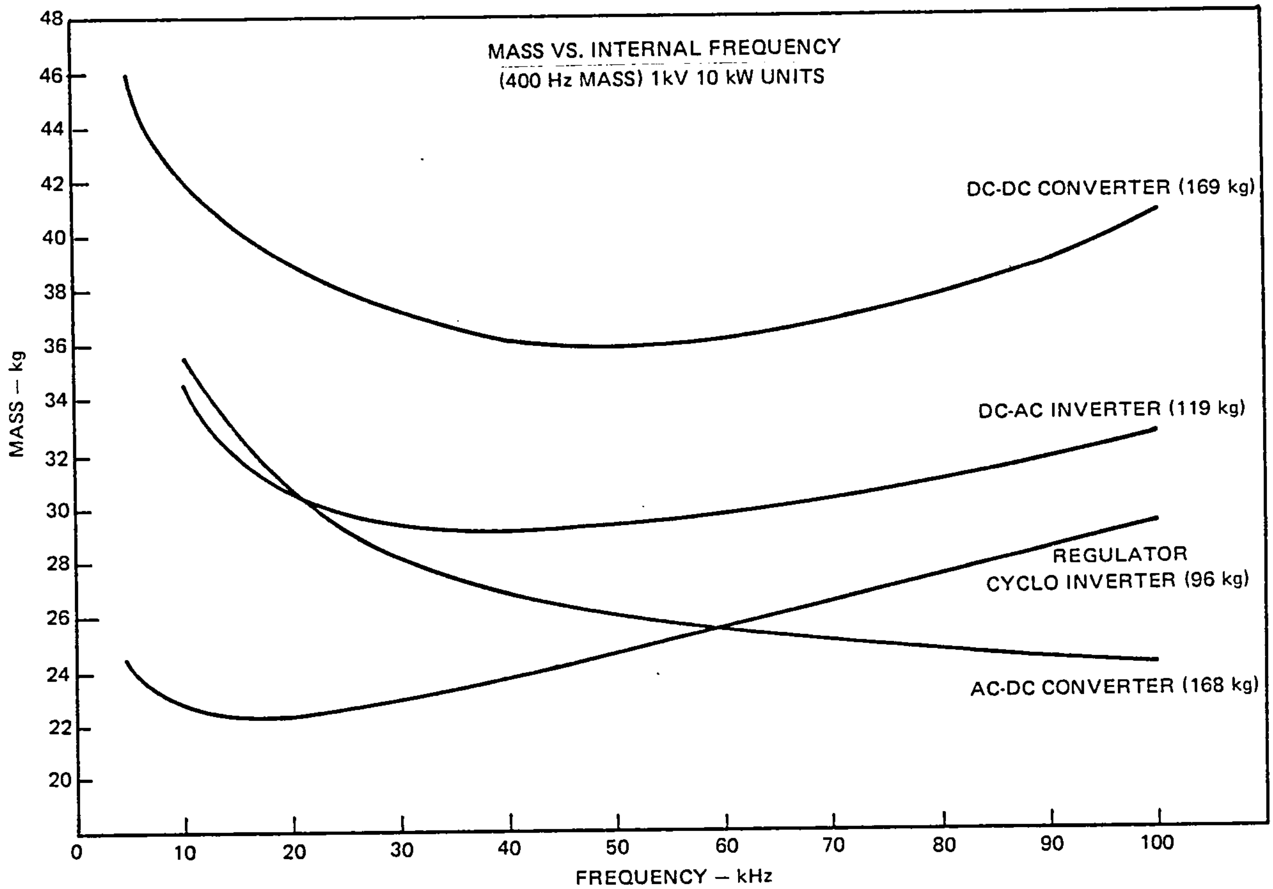


Figure 3-42. Conventional PMS component masses.

Since this non-resonant class of components will most likely have only limited application in modern high power systems, further analysis of costs and drivers was not accomplished. The improved inherent efficiencies of resonant devices makes them the logical first choice.

Resonant converter (Reference 15) efficiencies show the same sizable decrease in mass as non-resonant ones. These data have been calculated for the various major devices and are shown in Figure 3-43. Since the switching in this family of devices occurs at the current zero crossing point of the AC waveform, dynamic switching losses are virtually eliminated over a reasonable frequency range (less than 100 kHz). This is shown in Figure 3-44.

Cost analysis has shown that recurring costs to produce hardware rise slowly at the higher frequencies. Therefore, an optimum module cost can be calculated based on the trade-off of transportation costs and manufacturing and hardware costs.

The AC system proposed for this application is really one large, distributed resonant converter with a distributed driver, a transformer coupled resonant link which is the transmission line, and transformer coupled distributed load conditioners. Its theory of operation is described fully in Subsection 3.2.18 and Reference 15. Because of that, the following analysis for the "best" AC system frequency also applies to the general family of resonant converters addressed by this portion of the study.

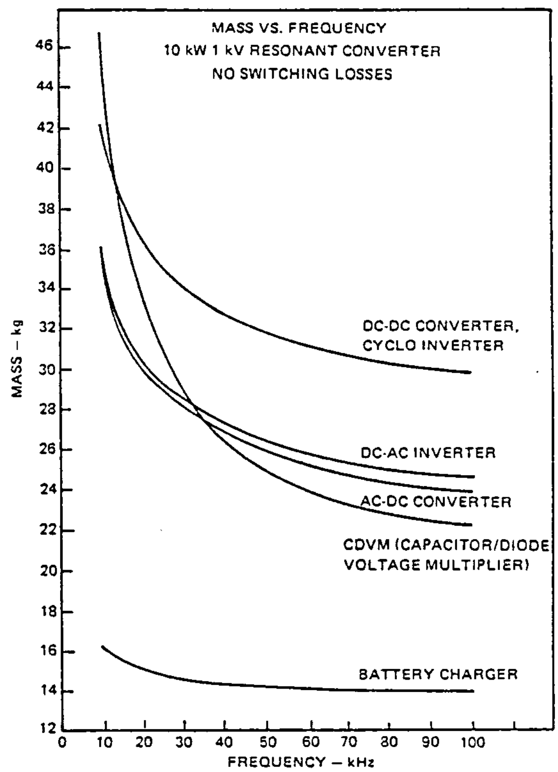


Figure 3-43. Resonant major PMS component masses.

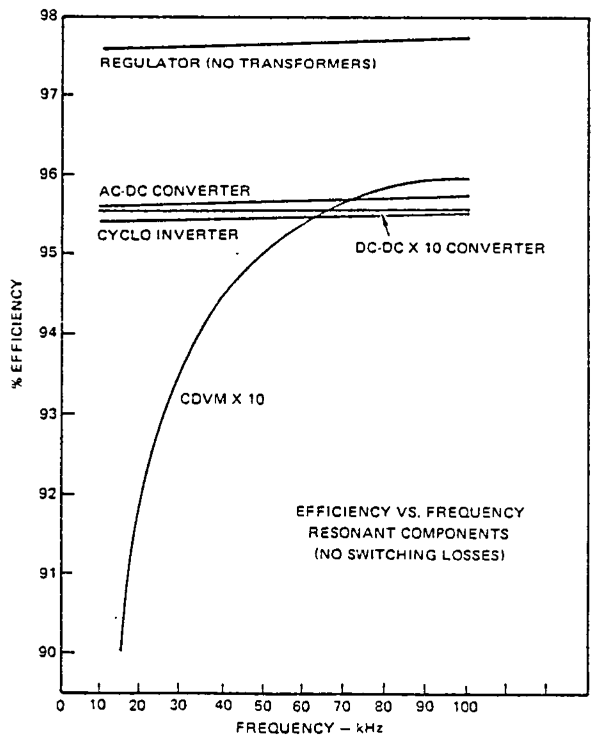


Figure 3-44. Resonant major PMS component efficiencies.

3.2.6.2 Optimum AC Transmission Frequency. Our evaluation of system costs as a function of frequency has shown that two major items must be considered for AC system frequency optimization.

Hardware costs, while not a strong function, are a large enough percentage of the total that they must be included. Shown in Figures 3-45 and 3-46, they decrease slightly as increased frequency causes unit sizes to decrease until frequency gets high enough so that special attention must be given to noise, pick-up, spacing and layout, special low-loss components, etc. Thereafter, costs increase on a slowly rising curve.

The primary driver is hardware weight. As frequency increases, transformers and energy storage components used in filters and resonant networks, rapidly decrease in size and weight, causing significant improvements in PMS component size and weight. This is reflected in "Transportation to Orbit" costs, also shown in Figures 3-45 and 3-46.

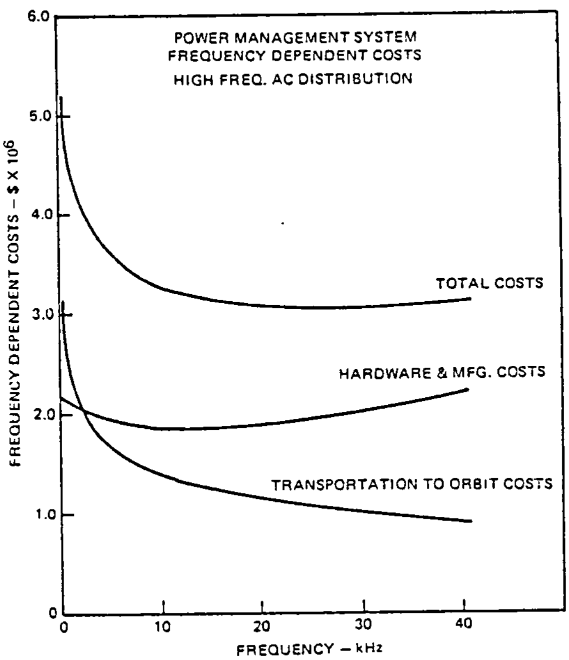


Figure 3-45. Frequency-dependent PMS hardware costs (MIL-grade components).

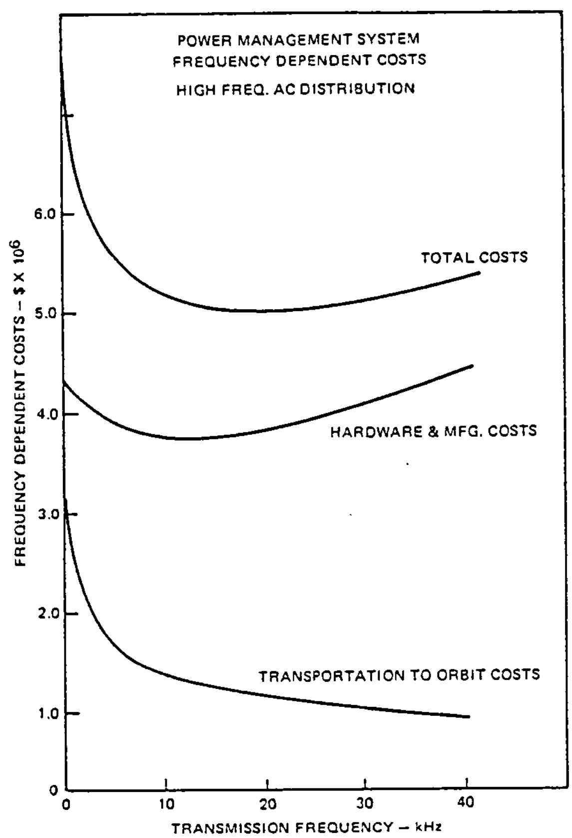


Figure 3-46. Frequency-dependent PMS hardware costs (space-qualified components).

Two sets of cost data are presented. The curves title "MIL-Grade Components" represent a quality level, including piece-parts, manufacturing, and test usually found in typical military electronic hardware. "Space-Qualified" represents the hardware usually used for non-repairable, high-reliability, or man-rated space missions.

While analysis has shown that MIL-grade components will satisfy the statistical reliability requirements in our modular system approach, there will be pressures to move toward man-rated components for this type of platform. The result will most likely be a cost curve somewhere between the two. At the same time, technology advancement will probably move the manufacturing cost curves to the right even more than predicted by the basically conservative PRICE model, pushing the minimums toward somewhat higher frequencies by 1985.

Since the entire AC power transmission system is a distributed resonant converter, conversion switching occurs at zero crossings and frequency dependent switching losses do not become important until much higher frequencies are used.

For optimum transformer designs, core losses are still low enough below 100 kHz (less than 0.1% for ferrites) that they are negligible.

Therefore, total significant frequency dependent costs are plotted in Figures 3-45 and 3-46 for MIL-grade and space-qualified components, respectively. The corresponding cost-effective frequencies are 26 kHz and 20 kHz. From a human engineering point of view, it is best to stay above the audio range, so we would establish a working minimum of 20 kHz and pick a nominal based on the worst case frequency variation of such a system, expecting that it would come out somewhere in the 20 kHz to 26 kHz range.

Since the valleys in these curves are broad, costs are not adversely affected by moderate frequency variations.

While not directly related to cost effectiveness, there are two items strongly related to frequency that should be discussed.

These frequencies are high enough so that non-uniform current distribution in busses becomes important. Skin effects are a major driver and dictate that for a frequency of 20 kHz, the power bus will be a hollow tube or its equivalent having a wall thickness/diameter ratio of approximately 1:40.

Since the recommended frequencies are in the range where natural plasma resonant frequencies can occur in LEO, a bus configuration must be chosen to minimize coupling of energy to the surrounding plasma. At these frequencies and at maximum loads, bus inductance also becomes important. These two factors make a coaxial bus configuration the appropriate choice. This bus design will be discussed in more detail in subsection 3.2.14.

CONCLUSION: Frequencies in the low ultrasonic range (20-30 kHz) are the most cost effective choice for this type of system. This selection demands additional investigation in the areas of bus design to minimize inductance and plasma coupling.

3.2.7 "Examine the effect of transmission line length on the PMS characteristics."

For both AC and DC cases, simply stated, line characteristics are all proportional to length. Line resistance, optimum weight, reactance, losses, are all directly proportional to length. For stations of this size (requiring approximately 50 meters of transmission line), transmission line weight can be made less than 5% of active system weight with only moderately high (~1000 V) voltage, making variations in length only second order effects.

Since there is a trade-off between line weight and losses, and losses require added solar array and battery capability, weight and, therefore, cost can be optimized by interrelating those major items. This has been done by NASA and documented in "Power Management and Control for Space Systems". (See Reference 17 for additional details.) The basic relationship turns out to be:

$$W_{TLopt} = \frac{2 P \ell}{V} \sqrt{\rho d \, (\alpha_{HR} + \alpha_{PG})}$$

where: W_{TLopt} = Optimum transmission line weight
P = Power to be transmitted
ℓ = Transmission line length
V = Transmission line volume
ρ = Resistivity of line material
d = Density of line material
α_{HR} = Constants related to the specific masses of
α_{PG} solar arrays and batteries

Figure 3-47 plots this relationship for the primary bus material candidates. An important conclusion which can be drawn from examination of that figure is that the bus weights at higher voltages are small and high voltage removes the demand for exotic materials or designs.

Since the AC system operates at high frequency (for a power system), line inductance becomes an important quantity since it affects phase and resonant link frequency. As line length increases, it becomes more important to use low inductance designs, and that length and other variables be controlled. The bus design for this high frequency approach is discussed in detail in subsection 3.2.14.

CONCLUSION: Transmission line length is not a major driver for typical space platforms served by this size power system. Cost and weight can be easily optimized for both AC and DC systems. High frequency resonant considerations in AC systems make inductance control and, therefore, length second order concerns.

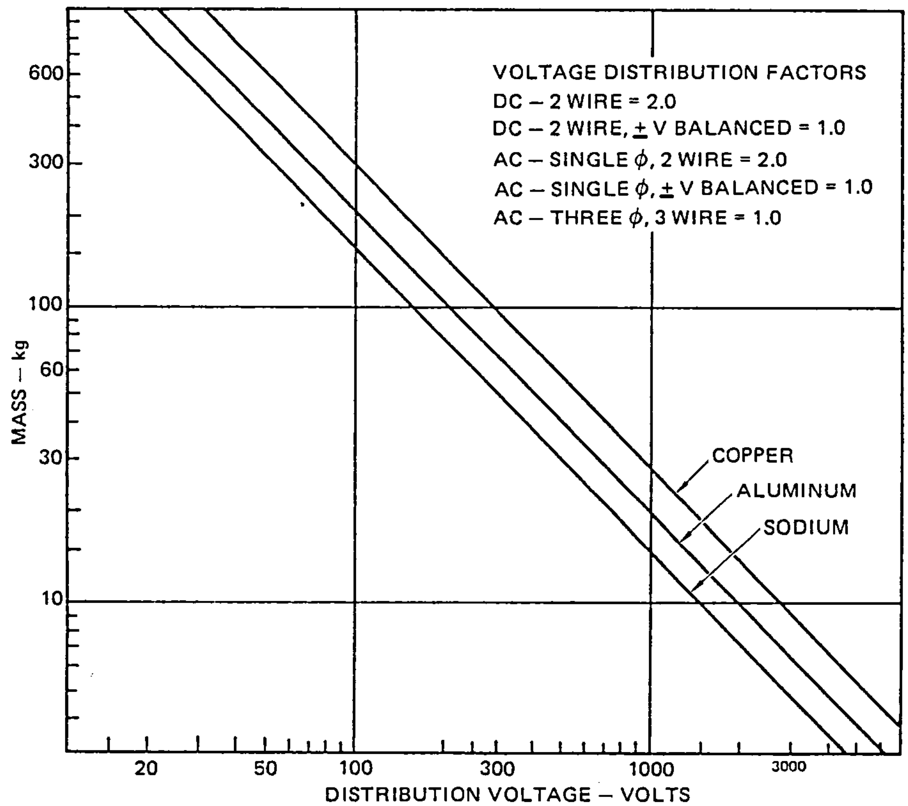


Figure 3-47. Optimum bus parameters for a 250 kW, 50 m, distribution system show effects of increased voltage.

3.2.8 "Evaluate the effects of increased power system voltage including corona problems and recommend voltage levels as a function of power range."

In general, PMS system losses decrease as transmission and distribution voltages increase, due to lower I^2R losses and improved switching efficiencies. On the other side of the ledger, recurring hardware costs increase due to higher voltage provisions, such as high voltage components and added insulation or voltage isolation provisions. In addition, high solar array voltages promote a DC conduction directly through the surrounding plasma at LEO which must be accounted for as another system loss. This study element examines and trades these quantities to optimize system voltage for both AC and DC.

3.2.8.1 Plasma Effects. Losses to the surrounding plasma have been evaluated by computer modeling techniques which are fully documented and explained in a separate report attached as Appendix 2. Typical results from that portion of the study are shown in Figure 3-48.

As expected, power loss directly to the surrounding plasma increases with increasing solar array voltage. At the worst case altitude, it varies from 0.8% at 440 V, to 1.4% at 750 V, to 2.2% at 1200 V and rises to 6.7% at 3000 V. These losses provide a driver to be considered in the system voltage choice, pushing toward lower voltage.

The second section of Appendix 2 examines the problems associated with high voltage lines and components. Even though most elements of the PMS will be housed in the space platform's docking module, which will be pressurized most of the time, we assumed that all components should be capable of operating in the space plasma environment in case of a pressurization failure or to provide the option of unpressurized systems for periods when the platform might be unmanned. Briefly, it was concluded that insulated transmission lines are not a problem, the discharge question within units needs further modeling and testing, and a high frequency AC system has the potential to interract with plasma resonant frequencies and additional testing and modeling is recommended to study this phenomenon.

For additional details and backup data, the reader is directed to Appendix 2.

3.2.8.2 Optimum Transmission Voltage - AC System. Since there are no significant operational and system design drivers affecting the choice of voltage for the transmission system, a cost and weight analysis was performed to pick the best voltage for the recommended AC system.

The major costs involved are contained in procurement and manufacture of the PMS components; and as we would reasonably expect, the "PRICE" estimating model shows a slowly rising cost curve as voltage increases. (See Figure 3-49.) Since the curve has no knee, the region examined contains no upper voltage limiting factors. There is, of course, a low end flat area which our data just approaches where voltage is not a driver which we expect to move to the right for the period of the mid-1980s. The effect of such movement will be discussed later.

The contrary factors in the voltage-cost relationship have to do with system efficiencies. Component efficiencies, switching losses, and bus losses all improve with increasing voltage. System efficiencies can be directly translated into added solar array and battery hardware with the attendant cost and weight penalties.

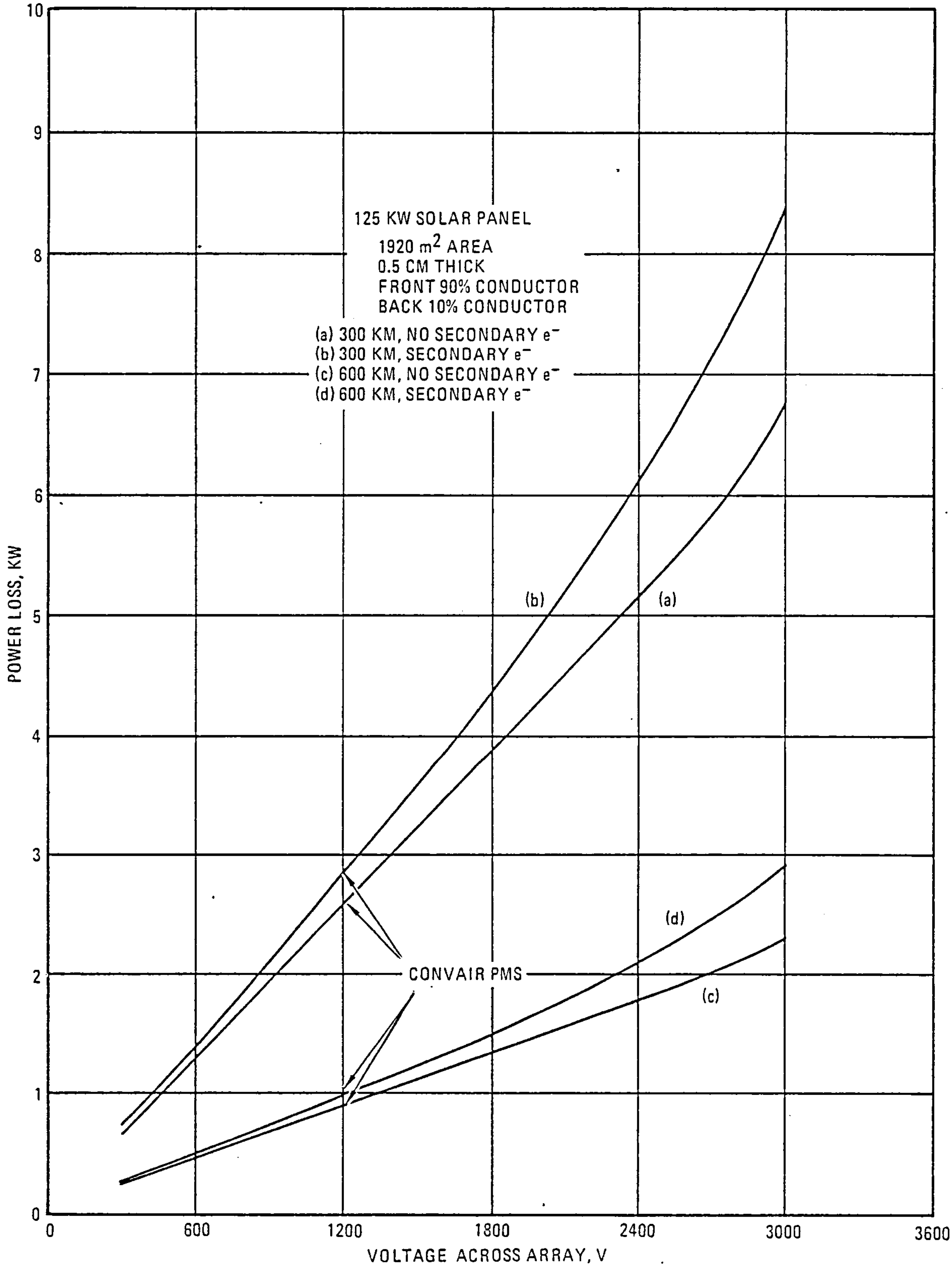


Figure 3-48. Solar array power loss with voltage.

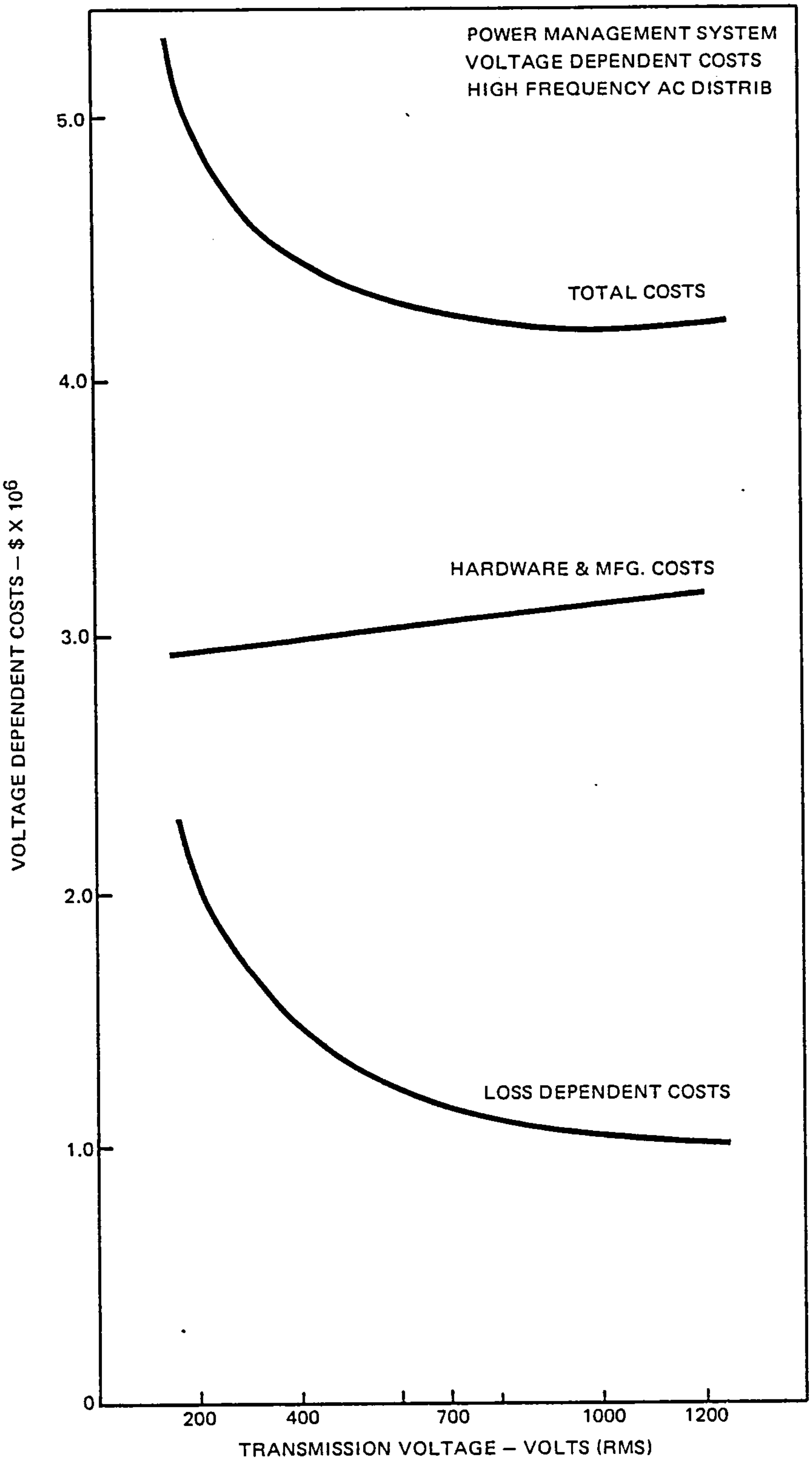


Figure 3-49a. Voltage dependent costs for AC (MIL-grade components).

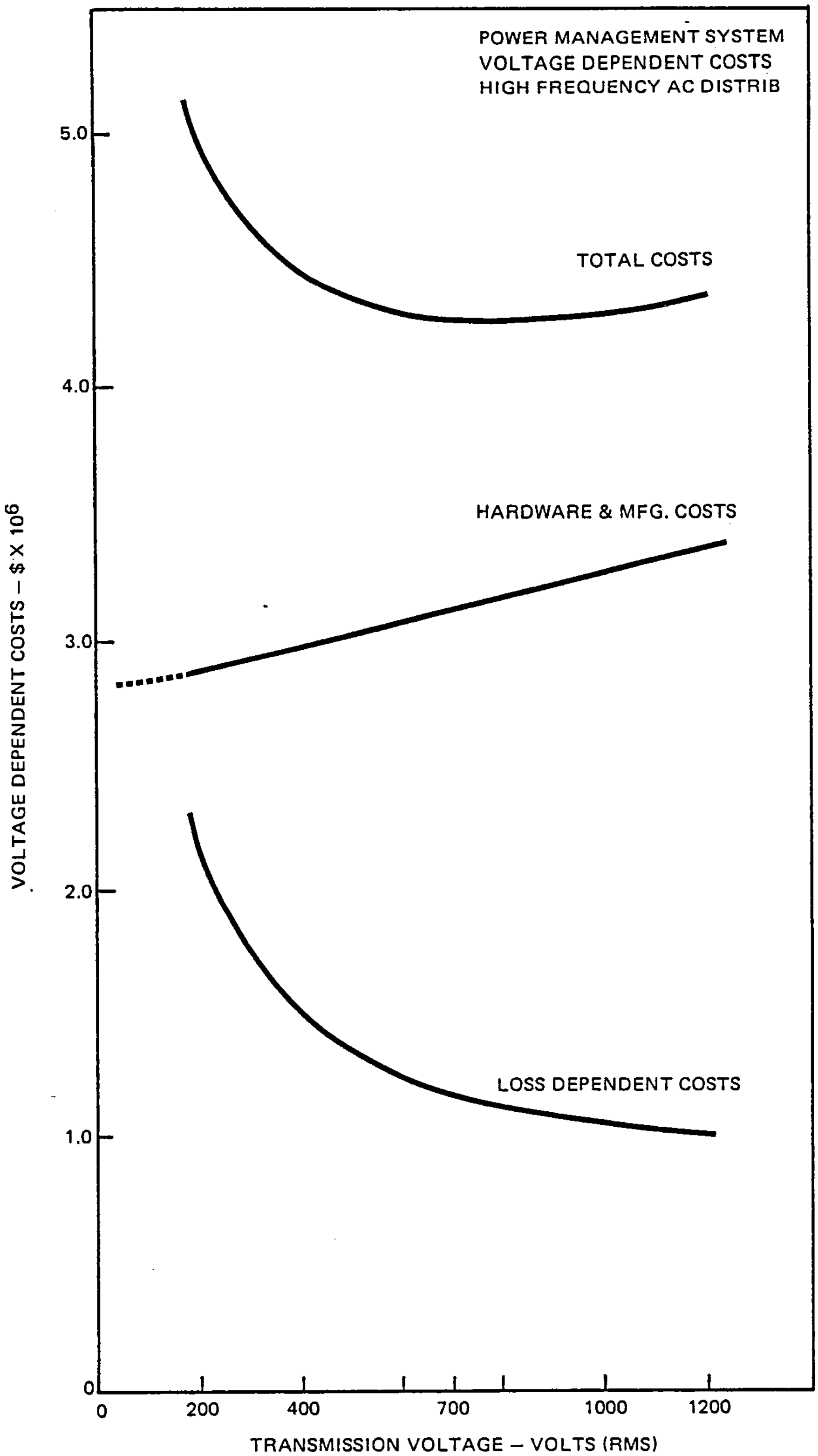


Figure 3-49b. Voltage dependent costs for AC (space-qualified components).

By and large, PMS component weights are not strongly influenced by voltage since weight improvements due to lower currents and losses are approximately offset by increases due to added insulation, increased spacing requirements, and similar high voltage considerations. However, bus sizes and weights are strongly affected by voltage and the transportation costs associated with the total added weight of busses, solar arrays, and batteries becomes important in calculating system costs. The total costs associated with system losses as a function of voltage form a falling curve which becomes reasonably flat above 1000 V RMS. (See Figure 3-49a.) The factors and data used to plot the above curves are listed in Table 3-8.

Table 3-8. AC system — costs affecting transmission voltage — $\$(10^6)$.

SYSTEM	PRODUCTION (%) DC-DC CONVERTER	TRANSPORTATION (%) DC-DC CONVERTER	PRODUCTION (%) DC-DC CONVERTER	TRANSPORTATION (%) DC-DC CONVERTER	TOTAL VOLTAGE DEPENDENT COSTS FOR PMS HARDWARE		TOTAL VOLTAGE DEPENDENT COST HARDWARE + LOSSES	
X-MISSION	25 Kw UNITS	WT @ 3.42 Kg/Kw	5 Kw UNITS	WT @ 3.903				
VOLTAGE	300 Kw TEST (SOURCE)	513 Kg-CONST (SOURCE)	300 Kw TEST (LOAD)	585 Kg (100)	SPACE-QUAL	MIL-QUAL	SPACE-QUAL	MIL-QUAL
200V	1.981	0.513	2.794	0.585	5.873	2.937	8.092	5.156
400	2.021		2.850		5.969	2.985	7.474	4.490
700	2.065		2.952		6.115	3.058	7.289	4,232
1000	2.114		3.053		6.265	3.113	7.311	4.179
1200	2.144	0.513	3.113	0.585	6.355	3.178	7,370	4.193

	CONVERTER % LOSS	SWITCHING % LOSS	TOTAL	POWER LOSS	PRODUCTION ADDED ARRAY & BATT COST (.0414)/Kw	TRANSPORTATION ADDED ARRAY & BATT COST ($1.0K/Kg) (11.32 Kg/Kw)	PROB. + TRANSP. (ARRAY+BATT+BUSS)	PROD. + TRANSP. HEAT REJECTION HARDWARE	TOTAL COSTS ATTRIB. TO LOSSES $\$(10^6)$
200V	5.75%	2.0 %	7.75%	19.38 Kw	0.802	0.219	1.110	0.098	2.219
400	4.98	1.5	6.48	16.20	0.670	0.183	0.567	0.085	1.505
700	4.67	1.3	5.97	14.93	0.618	0.169	0.308	0.079	1.174
1000	4.50	1.2	5.70	14.25	0.590	0.161	0.219	0.076	1.046
1200	4.47	1.17	5.64	14.10	0.583	0.160	0.196	0.076	1.015

The total, combined cost/voltage relationship is also plotted in Figure 3-49a. It has a minimum at about 1000 V RMS with a broad valley, just starting to rise at 800 V and 1200 V.

Figure 3-49b represents all the same basic quantities using "Space-Qualified" components appropriate to man-rated systems. Different relative costs and slopes make this minimum occur between 800 V and 900 V.

While we believe that MIL-grade components will satisfy the statistical reliability requirements in our modular system approach, there will be pressures to move toward man-rated components for this type of platform. The result will most likely be a cost curve somewhere between the two. (See Figure 3-50.) At the same time, technology advancement will probably move the manufacturing cost curves to the right even more than predicted by the basically conservative PRICE model, pushing the minimums toward somewhat higher voltages by 1985.

CONCLUSION: The most cost effective transmission voltage for an AC system of this size will be between 800 V RMS and 1200 V RMS and we recommend using 1000 V RMS as a reasonable mid-point working value for further development work.

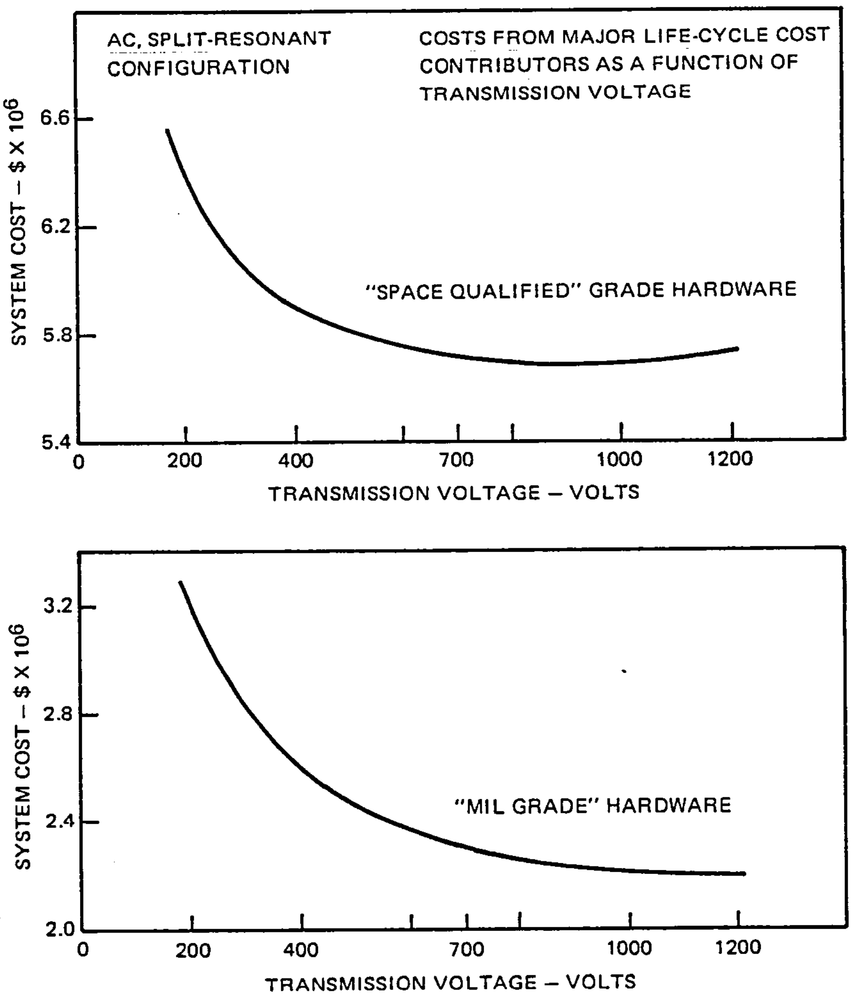


Figure 3-50. Component grade cost comparisons for AC.

Because of the flexibility inherent in transformer-coupled AC systems of this type, voltage and current can be adjusted to take best advantage of component and piece-part ratings. Therefore, no major piece-part development is required for the AC system at the 250 kWe level beyond that already in progress. Higher level development work will be required on devices such as rotating transformers, magnetic disconnects, and coax transmission busses.

3.2.8.3 Optimum Transmission Voltage - DC System. DC system components have the same sort of slowly rising curve of hardware/manufacturing costs as a function of voltage, as shown in Figure 3-51. Loss terms have the same source and, therefore, generate the same general shape curve as the AC case. (See Figure 3-51.)

For the DC system, transmission system voltages increase directly with solar array voltages if efficiency is maximized, and plasma losses from the array increase with increasing voltage, providing another strong voltage/loss related cost driver. Our analysis has shown that interposing a voltage step-up device (such as a CDVM) in the system to keep array voltages low always results in higher losses than the plasma related ones, providing the voltage is kept to a moderate value (<2000 VDC). Plasma effects are, therefore, also shown for the DC case in Figure 3-51.

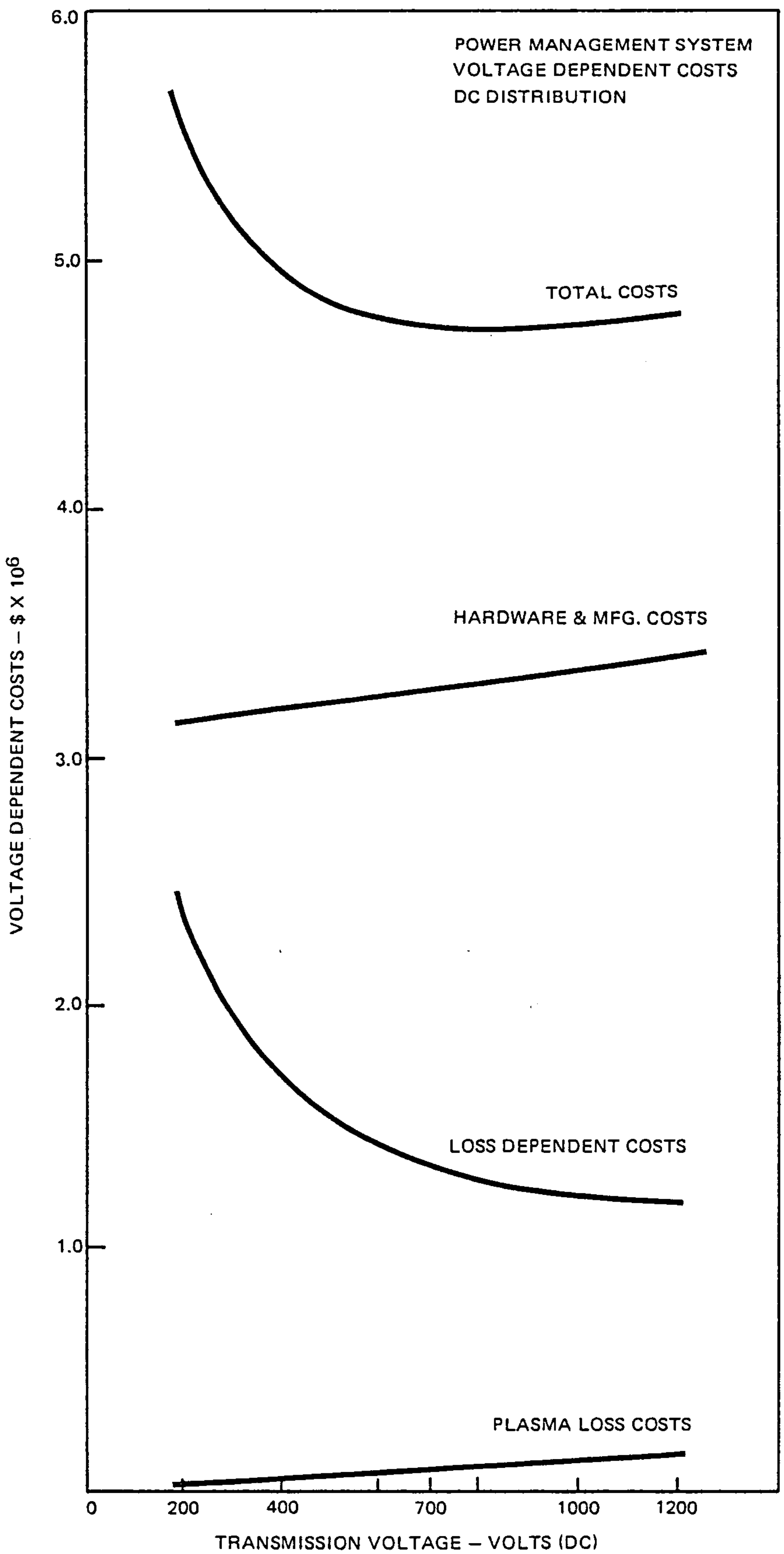


Figure 3-51. Voltage dependent costs for DC (MIL-grade components).

The three major contributors are then added to form the total cost-voltage optimization curve also plotted in Figure 3-51.

The same "MIL-grade" and "space-qualified" considerations that were discussed in the AC case apply for DC, and Figure 3-52 shows the same basic quantities depicted in Figure 3-51 for the higher cost space-qualified case. The factors and data used to plot the above curves are listed in Table 3-9.

Table 3-9. DC system — costs affecting transmission voltage — $\$(10^6)$.

	DC-DC CONVERTER	DC-DC REGULATOR	DC-AC CONVERTER	WEIGHT TOTAL	PMS HARDWARE COST		TOTAL PMS COSTS	
VOLTAGE	5 Kw @ 150 Kw 3.903 Kg/Kw	100 Kw 2.30 Kg/Kw	100 Kw 2.96 Kg/kw	(Kg)	SPACE-QUAL	MIL	SPACE-QUAL	MIL
200V	2.794	1.075	1.324	1.113	6.303	3.152	8.705	5.554
400	2.850	1,092	1.344		6.399	3.199	8.121	4.921
700	2.952	1.124	1.385		6.574	3.287	8.007	4.720
1000	3.053	1.141	1.426		6.733	3.364	8.079	4.713
1200	3.113	1.158	1.447		6.831	3.416	8.178	4.763

VOLTAGE	CONV LOSS % OF 150	INV LOSS % OF 100	REG LOSSES % OF 100	AUG PMS LOSS	SWITCHING % LOSS	TOTAL (%)	POWER LOSS (Kw)	PROD & TRANSP. BATT & ARRAY (.0517/Kw)	BUSSES	HEAT REJECTION HARDWARE	TOTAL COSTS ATTRIB TO LOSSES
200V	5.75%	4.75%	3.22%	4.74%	4.0 %	8.74%	21.85	1.151	1.110	0.110	2.371
400	4.98	4.25	2.75	4.13	3.5	7.65	19.13	1.008	0.567	0.097	1.672
700	4.67	4.00	2.50	3.86	3.3	7.16	17.90	0.943	0.308	0.091	1.342
1000	4.50	3.94	2.42	3.75	3.2	6.95	17.38	0.916	0.219	0.088	1.223
1200	4.47	3.92	2.40	3.72	3.17	6.89	17.23	0.908	0.196	0.087	1.191

VOLTAGE	PLASMA LOSSES (%)	POWER LOSS (Kw)	ADDED ARRAY COST (.0235/Kw)	ADDED ARRAY W/ TRANSP. COST	PLASMA LOSS COSTS TOTAL
200V	0.46%	1.15 Kw	0.027	0.004	0.031
400	0.74	1.84	0.043	0.007	0.050
700	1.36	3.40	0.079	0.012	0.091
1000	1.84	4.60	0.107	0.016	0.123
1200	2.32	5.80	0.135	0.021	0.156

CONCLUSIONS: Examination of the "Total Cost" curves shows that the addition of voltage-dependent plasma losses causes them to rise sooner than for the AC case. The best cost effective MIL-grade voltage occurs just above 800 VDC and the optimum for space-qualified is just below 700 VDC. Using the same logic used for the AC case yields a reasonable working value of 750 VDC for further hardware investigations for this size system.

This voltage choice demands continued development of semiconductor devices to meet the voltage and current rating requirements. Present capability (D60T transistor) must be more than doubled to effectively be used for the DC system.

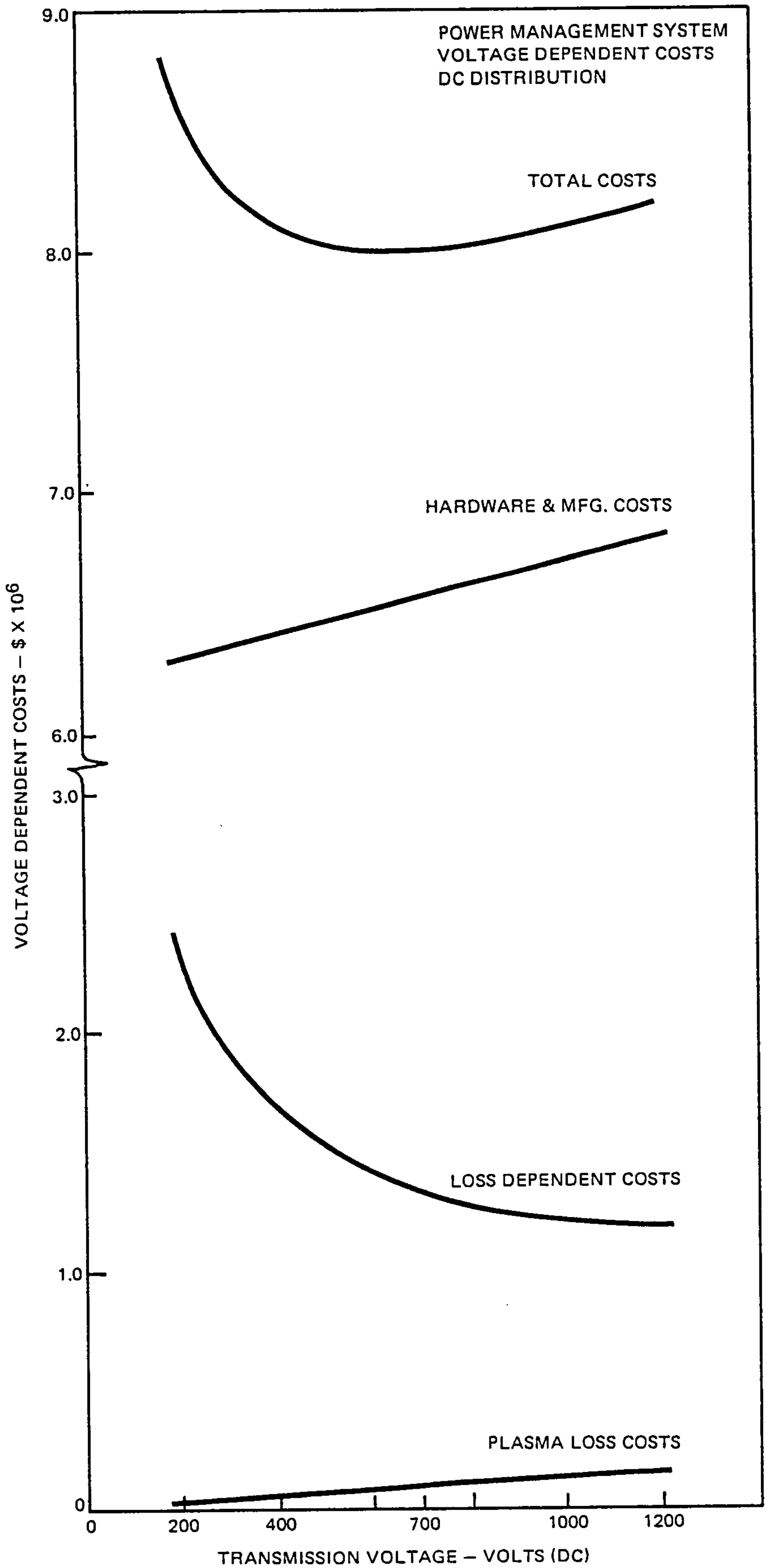


Figure 3-52. Voltage dependent costs for DC (space-qualified components).

3.2.9 "Evaluate the technology implications of the platform 10 year useful lifetime requirements."

3.2.10 "Examine the impact of Shuttle servicing capability on the cost of reliability."

Both of these topics are interrelated through the cost-of-repair/cost-of-reliability trade-offs and, therefore, must be treated together to develop a cost-effective strategy for unit reliability requirements for ten years, allocation of spares and repair capability, and logistics planning.

The first step was to evaluate the ten year reliabilities of the various major items of equipment found in the PMS. MIL-HNDBK-217B was used to provide the evaluation methods and the statistical failure rate data. Figures 3-53a, 3-53b, and 3-53c show the results of those calculations for each major module type as a function of power output.

Our analysis creating these curves used the following constraints and inputs:

a. Average equipment duty cycle = 40% ± 20%

b. Environmental Use Factor = 1.0. This is the normal factor (S_F) for equipment operating in zero g, in orbit.

c. Typical junction or active element temperatures = 85°C. This value is derived from a normal conservative thermal design for electronic hardware. Such a process would project a maximum heat sink/radiator temperature of 85°C under the worst possible combination of worst case parameters and conditions. Good thermal/mechanical design would then put maximum junction temperatures at approximately 125°C under the same conditions, allowing a typical 40°C rise. It is reasonable to evaluate failure rates at typical, not worst case temperature conditions, and Convair experience with this type of hardware has shown that the above worst case design generates typical temperatures approximately 40°C lower. Therefore, typical junction or active element temperatures are 85°C and heat sink/radiator temperatures are approximately 45°C.

d. Quality factors for each component family assumed the parts used were the equivalent of JAN TXV.

To understand the meaning of these reliabilities, we can examine a typical module in a unit in the DC system:

Adding up the total requirements for AC power, in the Requirements Document (Vol. 3), yields a maximum of 100 kW for a centralized DC-AC inverter. Extrapolating the curve of Figure 3-53a, a single 100 kW unit has a 10 year reliability = 0.32, corresponding to an MTBF = 76,970 hours. This is obviously inadequate for an 87,660 hour mission, and provides the basic reliability justification for a modular approach.

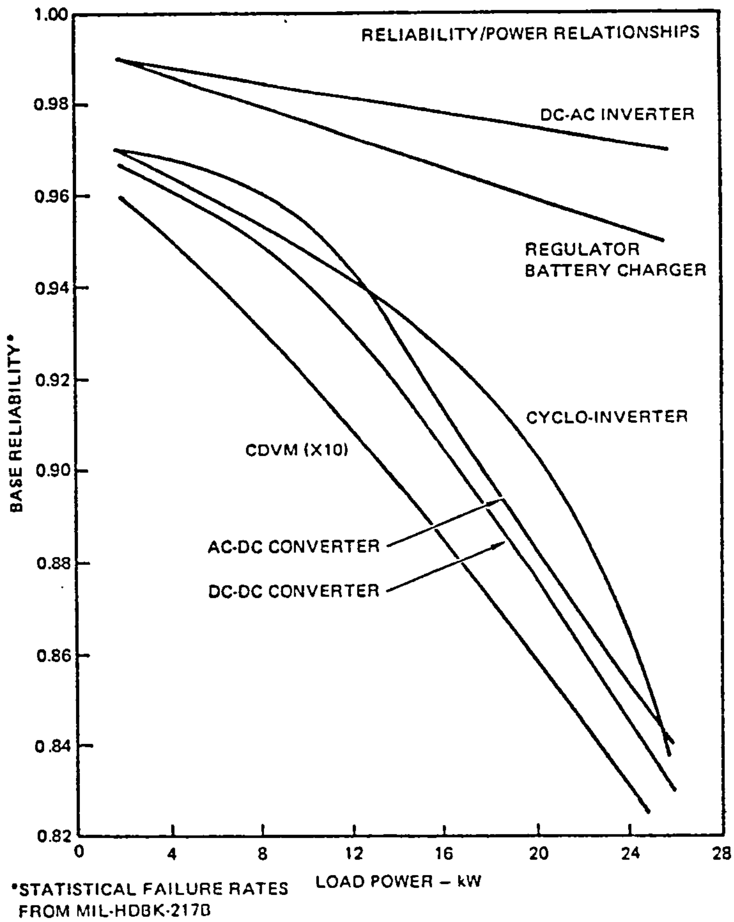


Figure 3-53a. Reliability/power relationships.

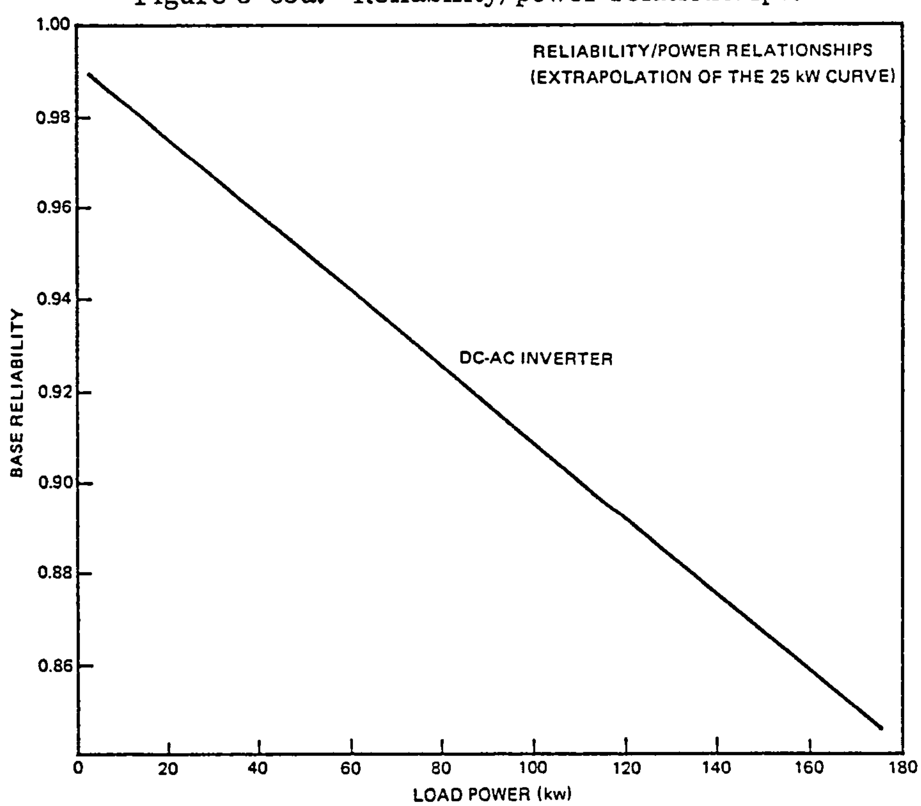


Figure 3-53b. Reliability/power relationships (extrapolation of the 25 kW curve).

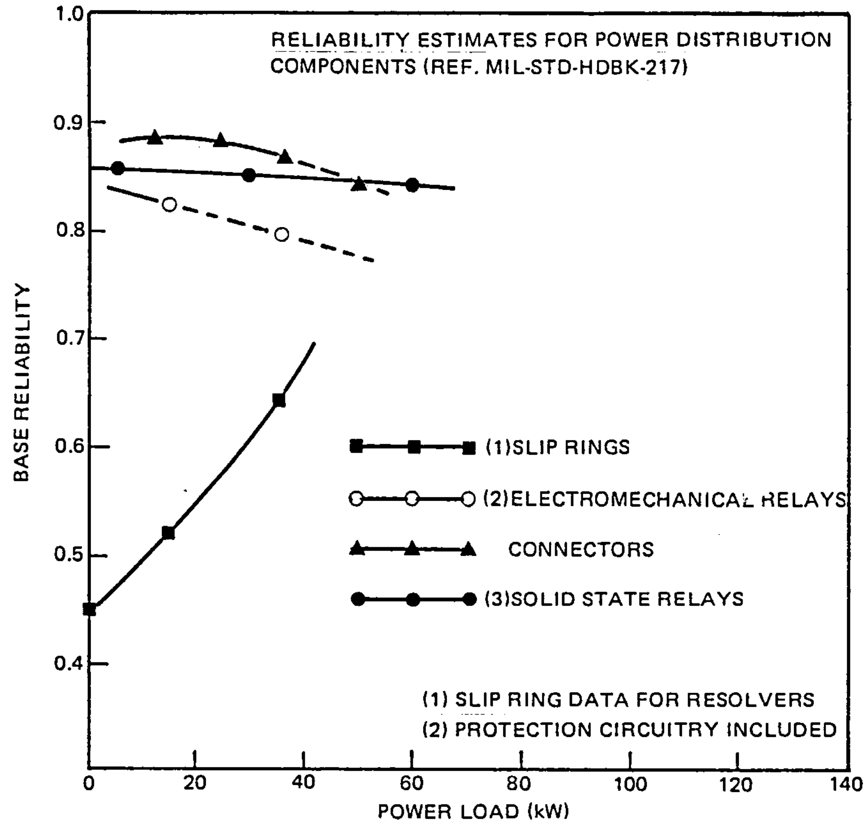


Figure 3-53c. Reliability estimates for power distribution components. (Ref. MIL-STD-HDBK-217)

Because of the basic nature of space logistics, spare units will always be built and flown, independent of the statistics of reliability. Therefore, an operational strategy has been recommended which maximizes the utility of those spares. That is: every output will be served by a full complement of modules to supply the total requirement plus one operational spare. That being the case, full output is still provided with one failed module and very impressive reliabilities can be realized. In addition, module sizes can be optimized on the basis of cost, and, in fact, have been in the modular breakdowns of Tables 3-4 and 3-5 shown on page 3-38.

Returning to our example, the 100 kW functional capability is supplied by ten 10 kW modules plus one spare.

The reliability of a 10 kW module = 0.9550 corresponding to an MTBF = 1.93×10^6 hours. Since there are eleven modules, one will fail every $(1.93 \times 10^6)/11 = 0.175 \times 10^6$ hours, or on the average, every 20 years.

The probability of having ten of eleven units operating (and supplying the full 10 kW output) for the platform's ten year life is 0.930 (using a 90% confidence factor).

The probability of having at least nine of eleven units operating (with no repair of a previously failed module) is 0.992 for the same conditions.

These reliability relationships are documented in Figures 3-54, 3-55, 3-56, and 3-57.

The reliabilities and MTBFs have been calculated for all the module families and are documented on the data sheets of Appendix 1.

Because the STS will service this space platform and crew members will be available to effect repairs, a trade was performed to evaluate the use of lower quality hardware and allow for more frequent repair.

Since good design practice and good factory quality control would not normally be compromised for this type of hardware, the major source of reduced cost and higher failure rates would be lower quality piece-parts. An infinity of possibilities exists for units comprised of mixtures of military grade parts and lower quality commercial parts and, therefore, there must be some configuration that realizes a small cost saving. However, the idea of commercial parts and more repairs was found to be a poor one. Consider the following example using the same reliability analysis method described in the preceding paragraphs.

Examining a 10 kW, DC-DC converter module

- Simplex Design, Commercial Parts, R (Reliability) = 0.42
- Redundant Design, Commercial Parts, R = 0.64
- Simplex Design, Military Parts, R = 0.94
- Redundant Design, Military Parts, R = 0.99

For this kind of unit, piece-parts typically cost 20% of the recurring total; assembly and test labor costs account for the remaining 80%, for parts built to military standards. Commercial parts usually cost approximately one-tenth as much as military parts.

Therefore, normalized costs can be compared:

Simplex, Military - unit	=	(0.80) + (0.20) = 1.00
Simplex, Commercial - unit	=	(0.80) + (0.20) (0.1) = 0.82
Redundant, Commercial - unit	=	(0.80) + (0.20) (0.1) (1.19) = 0.824

The baseline system would fly eleven Simplex Military units with R = 0.94 and average one failure in ten years.

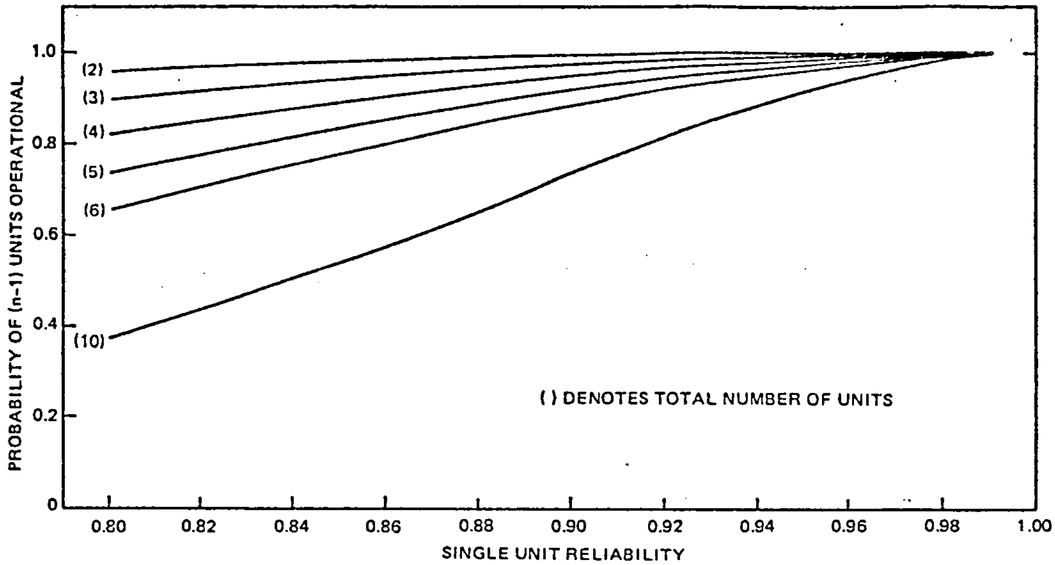


Figure 3-54. Reliability of multiple units - one failure allowed.

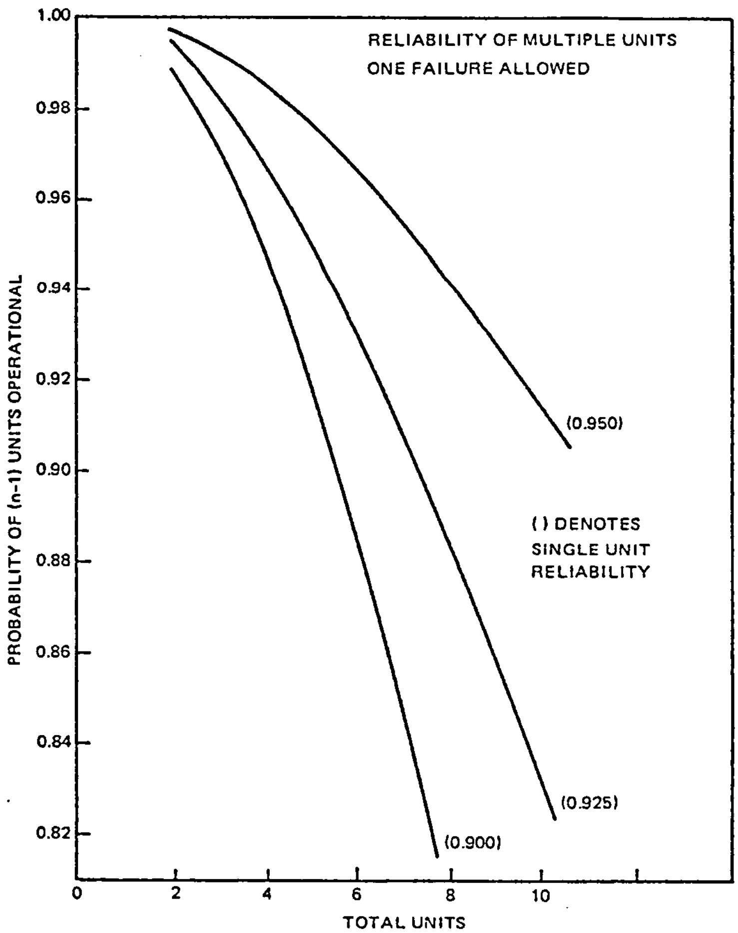


Figure 3-55. Reliability of multiple units - one failure allowed.

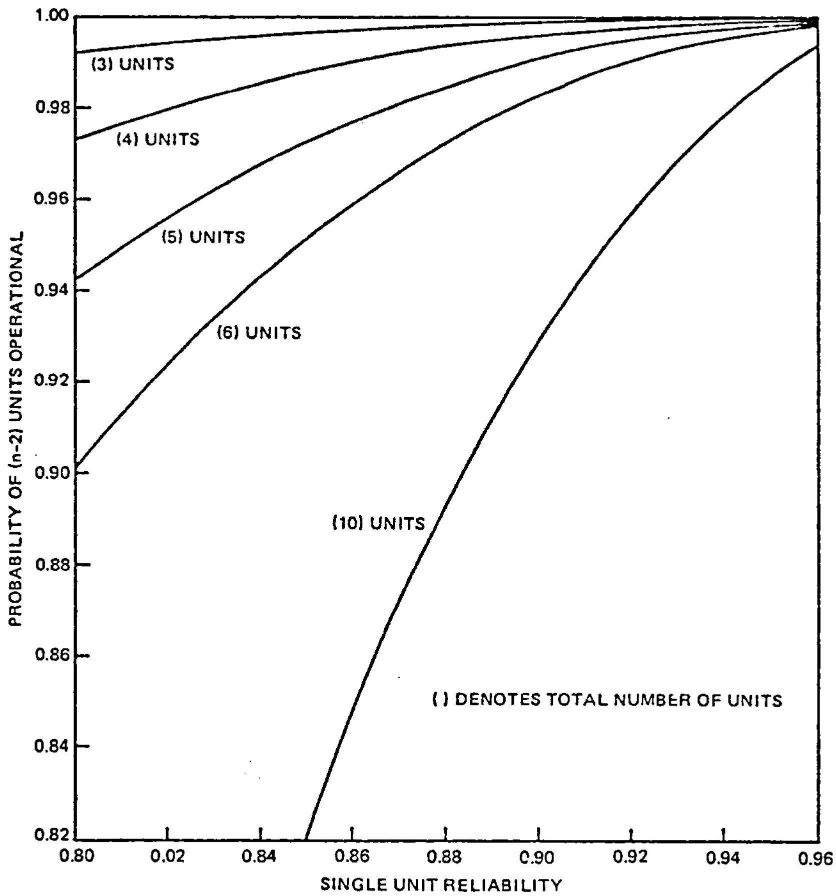


Figure 3-56. Reliability of multiple units - two failures allowed.

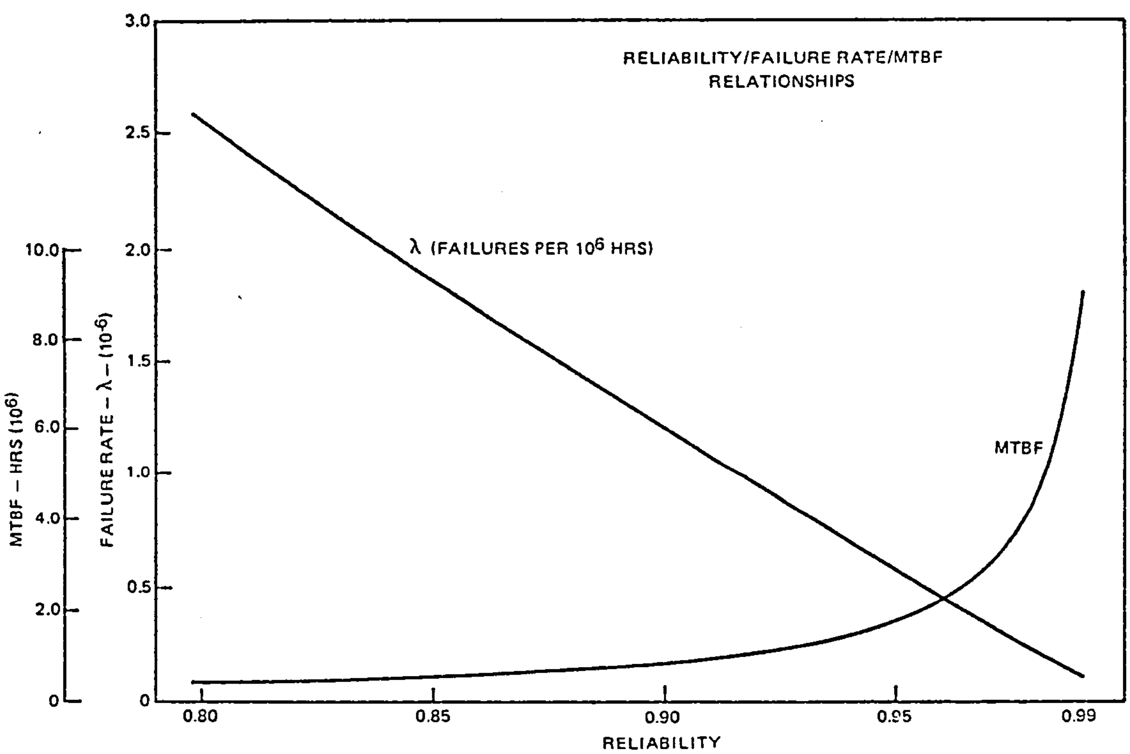


Figure 3-57. Reliability/failure rate/MTBF relationships ($R = e^{-\lambda t}$).

If we substituted eleven redundant commercial units with R = 0.64, the system would average four failures in ten years.

Military Unit Cost = (11) (1.0) + (1) (1.0) = 12.0
Commercial Unit Cost = (11) (0.824) + (4) (0.824) = 12.36

Therefore, lower reliability costs more, even without considering the added costs of transportation to orbit and repair and replacement in orbit. The baseline Military units are more cost effective at this level of analysis and mixes of parts in detailed designs will not be considered.

CONCLUSION: Ten year life places demands on the reliability of PMS units that are beyond the capability of current technology for full capacity. PMS functions can be accomplished using parallel combinations of smaller units and including operational spare capability (one module). Those modular units can meet reliability requirements when they are sized for minimum life cycle cost. Minimal replacement and repair will be required in orbit (an average of one failure for each module family in ten years) and Simplex military-quality units provide the best quality/repair compromise. Component and functional MTBFs are shown in the block diagrams of Figures 3-58 and 3-59.

Examining piece-part failure rates which are the largest contributors to PMS component failure rates yields results that are no different from those that designers and reliability engineers have come to expect. Output semiconductors handling large amounts of power and capacitors with high amounts of ripple current are the primary offenders. While none of the designs evaluated experiences premature failures due to these causes and specific reliability improvements are not required for this type of modular system, improved individual unit reliabilities can be improved as shown in Figure 3-32 through piece-part level redundancy or reliability improvement in these two main areas.

3.2.11 "Estimate the environmental excursions and thermal dissipations of the PM components. Recommend a cooling concept."

3.2.11.1 Without some thermal control through intentional power dissipation, thermal excursions of PMS hardware can be very wide.

On the hot side, good thermal design will limit piece-part junction or active element temperatures to 125°C on a worst case basis. As explained in subsection 3.2.10, this approach will result in real maximums in the 85°C area with average thermal heat sink/radiator temperatures of 45°C.

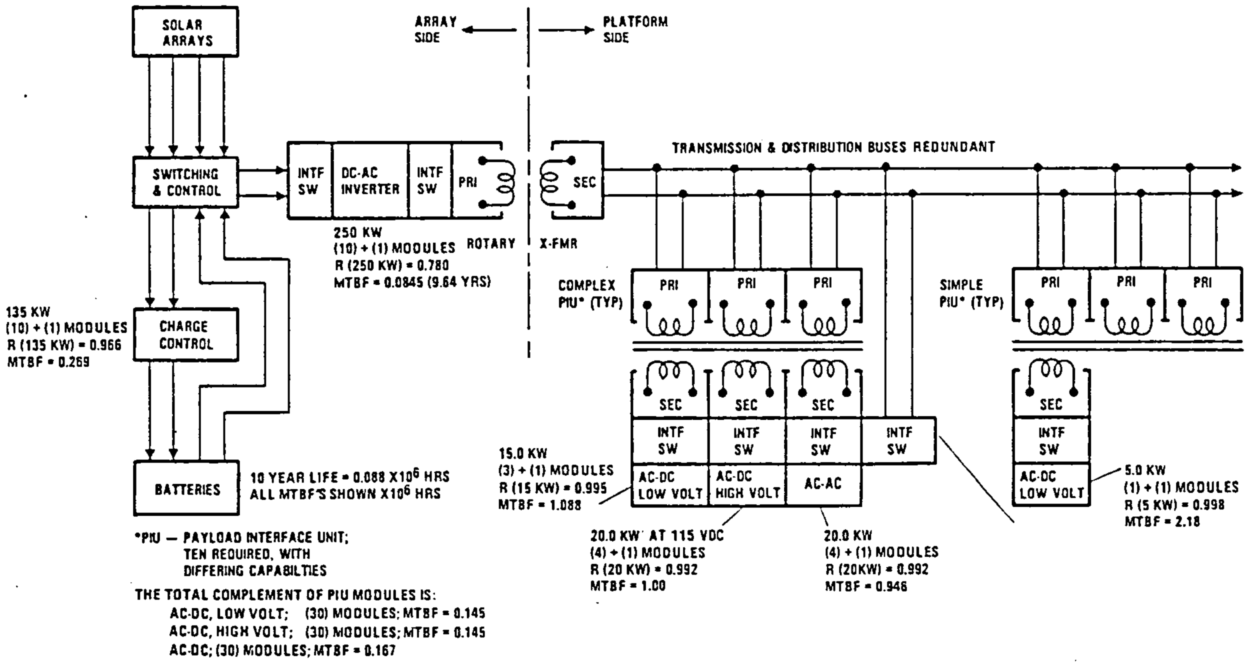


Figure 3-58. AC system modular reliability.

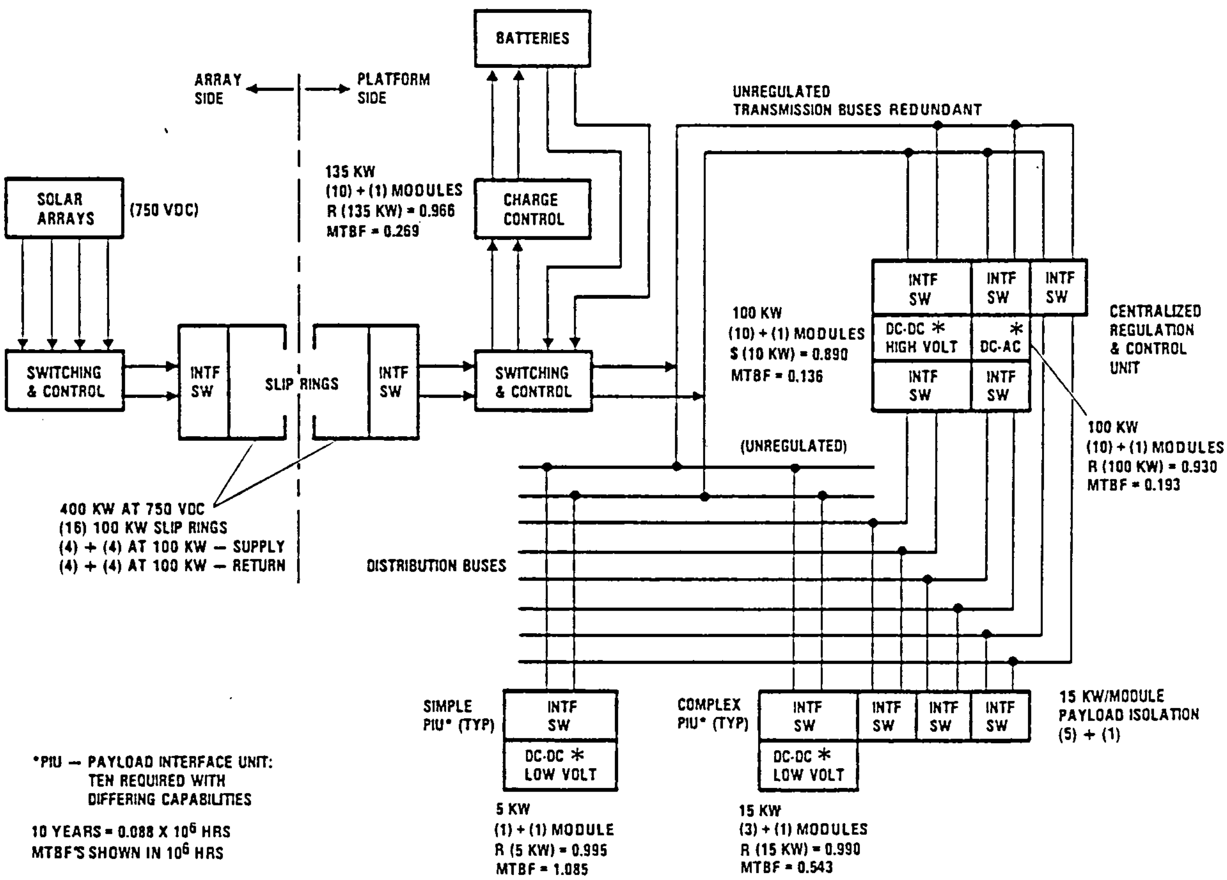


Figure 3-59. DC system modular reliability.

The low temperature end of the excursion caused by eclipse periods is a different problem. If a thermally isolated module (at an unused payload interface, for example) were simply left off, its temperature would stabilize at its deep space radiator temperature which could be below -200°C. While electrical components could be designed to meet this kind of extreme temperature range, current technology is, in general, capable of -65°C to 125°C. An extensive program of materials development for thermal matching over wide ranges is clearly not justified when another obvious, simple solution is available. That is, to allow the system controller to provide for some power dissipation in isolated, normally off functions. For such a thermal control arrangement, mechanical layout of the modules could minimize the requirement for "thermal" power by arranging to have an "on" module close to an "off" one on the same heat sink, eliminating the need to heat the "off" module internally. In addition, there is no effect on full-load dissipation or efficiency, since "thermal" power is not required there and plenty of power is available when needed at light loads.

Therefore, good system management can maintain component temperatures in the -65°C to 125°C range which current devices can accommodate, and there is no need for funding to develop more capable devices.

3.2.11.2 Based on projected component efficiencies, Figures 3-60 and 3-61 list the full-load efficiencies of the individual modules which make up the PMS functions.

3.2.11.3 From an operational point of view, a totally passive thermal radiator cooling concept is the preferred way to operate. In that way, a failure in the active system serving the platform and payloads would not disable the power system and would allow full operation of critical systems such as life support.

Assuming an overall system full-load efficiency of 92.5% yields a full-load system dissipation of 18.75 kW. From thermal design considerations, under normal conditions, the PMS heat sink/radiator temperature would be 45°C to maintain the components at their maximum 85°C.

The classical thermal radiation equation has been used:

$$Q_R = 0.171\, F_E\, F_A\, A \left[\left(\frac{T_1}{100}\right)^4 - \left(\frac{T_2}{100}\right)^4\right] \quad \text{Btu/hr}$$

with the following assumptions:

F_E (emissivity factor) = 0.8 to 0.9
F_A (view factor) = 0.5 (including sun, earth, reflection, and radiation)
A (area) = ft^2

and the radiator size requirement becomes approximately 506 ft^2 or 47 m^2.

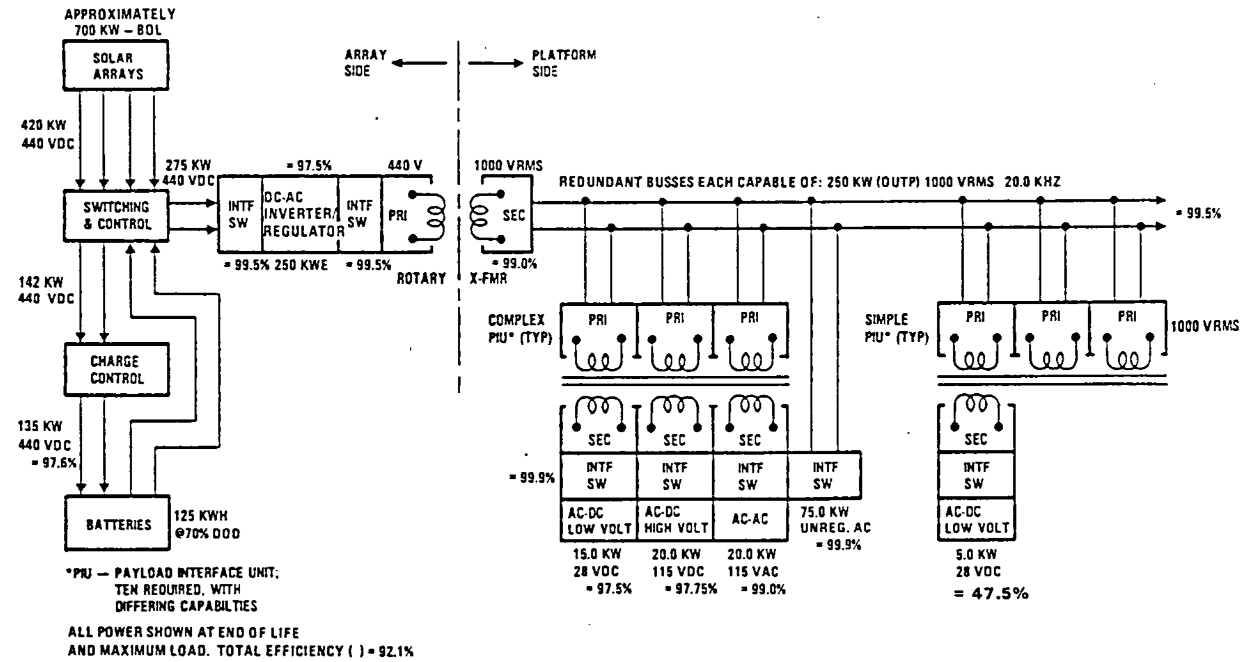


Figure 3-60. AC system efficiencies.

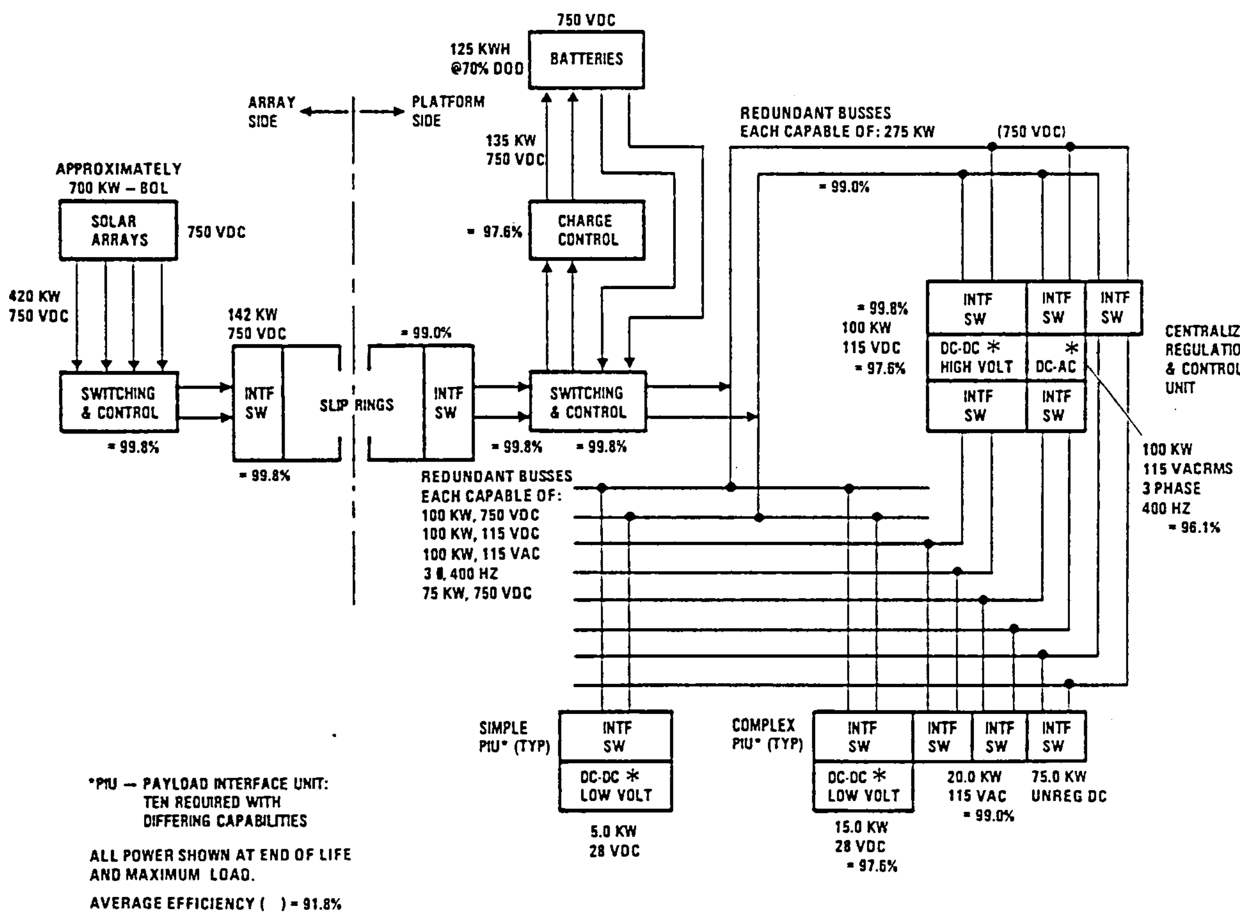


Figure 3-61. DC system efficiencies.

The docking module is 18 m long × 4 m in diameter having a surface area of 226 m^2. Therefore, if we use approximately 25% of the docking module surface for thermal radiation, it can provide PMS cooling by direct conduction from hardware mounted on the inside surface. Looking at the docking port layout in the requirements document shows that at least this much area is available.

CONCLUSION: Units of this type would normally be designed for cold-plate cooling. That cold plate can be the outside surface of a portion of the space platform docking module. It would allow for maximum surface temperatures of 45°C under worst case conditions with lower temperatures during normal operation.

There are no major technical drivers influencing system choice from thermal considerations since both AC and DC systems have similar efficiencies.

3.2.12 "Establish accessibility requirements for maintenance and replacement of PM components."

EVA cost estimates from the STS User's Handbook of $60,000 to $100,000 for each six-hour activity are a strong driver to make all PMS components accessible from inside the space platform. The preceding paragraph suggests an appropriate approach.

PMS component modules are distributed around and mounted to the inner surface of the docking module. In this way, they are accessible from inside the module and can have heat transfer surfaces in contact with the outer skin of the module for direct radiation to space.

For maintenance and replacement or repair, astronauts would simply enter the docking module with an air environment and isolate the module to be removed by operation of a mechanical switch. It is proposed that the signal connections be via conventional low power or optical connectors and the main power connection be bolt-down terminals. Mechanical mounting would be a system of bolts providing the necessary pressure at the thermal/cold plate interface.

While it sounds inconvenient, this "low technology" approach is appropriate to this application since it does not demand new development and the statistics of reliability predict fewer than ten failures for the total complement of modules, for the system's ten year life.

Since both AC and DC systems would use the same design approach with equal ease, there are no significant technology drivers from mechanical design, maintenance, or replacement considerations.

Both systems would likewise be affected equally by mass and size restrictions, and ground handling and maintenance would be a stronger driver than the zero-g problems in orbit. Assuming that two astronauts would likely manipulate heavy or bulky equipment in orbit, it is not unreasonable to expect that they could handle 100 kg and/or 1.0 m^3. The same two men, when on the ground at 1.0 g might reasonably be expected to move and control 50 kg without special handling equipment. The largest individual modules in the DC system are the 400 Hz inverter modules at 16.7 kW and 49.8 kg. AC system high frequency inverter modules are 25.0 kW and 43.0 kg. Therefore, neither system provides a discriminator in this area.

3.2.13 "For the storage alternatives chosen for study, identify requirements for charging and discharging."

Basic charging techniques are essentially the same for all three storage options: programmable constant-current source regulators with appropriate limit controls and overrides (i.e., pressure, temperature). Charge/discharge efficiencies make sizes and capacities significantly different, with fuel cell systems requiring approximately twice the input power as either battery system.

For the worst case orbit, the space platform is in the sun for 62% of its period. To provide full power during eclipse requires 250 kW for 38%. Battery input power is, therefore:

$$P_{BIN} = (250\ \text{kW}) \left(\frac{38\%}{62\%}\right) \Big/ \ 90\%\ \text{(Battery Efficiency)} = 170\ \text{kW}$$

For fuel cells, the power becomes:

$$P_{FC} = (250\ \text{kW}) \left(\frac{38\%}{62\%}\right) \Big/ \ 45\%\ \text{(Fuel/Electrolysis Cell Efficiency)} = 340\ \text{kW}$$

Fuel cells have more stable output voltage characteristics than batteries, but both are significantly better than solar cell output voltages from beginning to end of life and share the same regulators; therefore, discharge characteristics are not a driver for PMS design.

Strictly from a PMS point of view, batteries (of either type) are the best choice, since they require about half of the charging hardware. From a total platform perspective, battery life, quantities, and cost for ten years must be traded-off against fuel cell life and cost, with PMS hardware only part of the equation.

CONCLUSION: Since both AC and DC systems can use either batteries or fuel cells, there is no major driver here. However, since the AC system voltages are more flexible, it removes the need for high voltage interface with batteries or fuel cells. Because of the significant reduction in power management hardware, this study will assume batteries in all subsequent work.

3.2.14 "Examine alternative power conductor, return conductor, and grounding concepts."

3.2.14.1 Overall supply, return, and grounding concepts have been examined from the point-of-view of external electric and magnetic field interractions (both generated and induced) and noise generation and pick-up. While definitive magnitudes for the above effects cannot be established without a rigorous analysis of a specific configuration, some general conclusions (sufficient for the depth required of this study) can be made from the defined baseline space platform.

To minimize system and payload interraction, noise, pick-up, and field effects, each major load should have its current return through a bus which is physically close to its supply (i.e., coaxial or twisted). This, then, demands a single point ground in the docking module and does not allow using the uncertainties of a return through the vehicle structure.

3.2.14.2 For the voltage levels selected in subsection 3.2.8, bus currents are low enough so that bus weights can be kept small compared to other system weights and, therefore, losses are low. They are estimated to be on the order of 0.5% for the two redundant bus systems combined and operating at full load, for a total dissipation of 1.25 kW, distributed along approximately 200 m (two-each 50 m supply and return) of total bus length. Average bus temperature would be maintained below 85°C for a bus radiating width of less than 2 cm. Since the AC coaxial bus has about 10 cm and any conventional DC bus would be larger than 2 cm, passive cooling is adequate for this application.

3.2.14.3 For the DC transmission system, conventional solid wires in a coaxial or twisted pair configuration are adequate.

For the AC case, there are bus effects influencing overall system design which drive the bus design. Since the transmission system becomes part of the AC resonant converter link in this system approach, inductance must be minimized, which dictates a choice of coaxial design. For a 100 m round trip, a coax has stray inductance of approximately 25 μh, while a conventional approach would have 175 μh.

The second major consideration has to do with skin effect at these frequencies. Figure 3-62 plots depth of penetration as a function of frequency and Figure 3-63 shows the resistance as a function of frequency for hollow cylindrical shapes with various aspect ratios and constant metallic cross section.

From these considerations, an appropriate typical bus design is shown in Figure 3-64. It provides a flat side for good thermal conduction to the platform outside wall/radiating surface, coaxial configuration for minimum inductance, and hollow conductors to account for high frequency skin effects. Dimensions and notes are typical for this application.

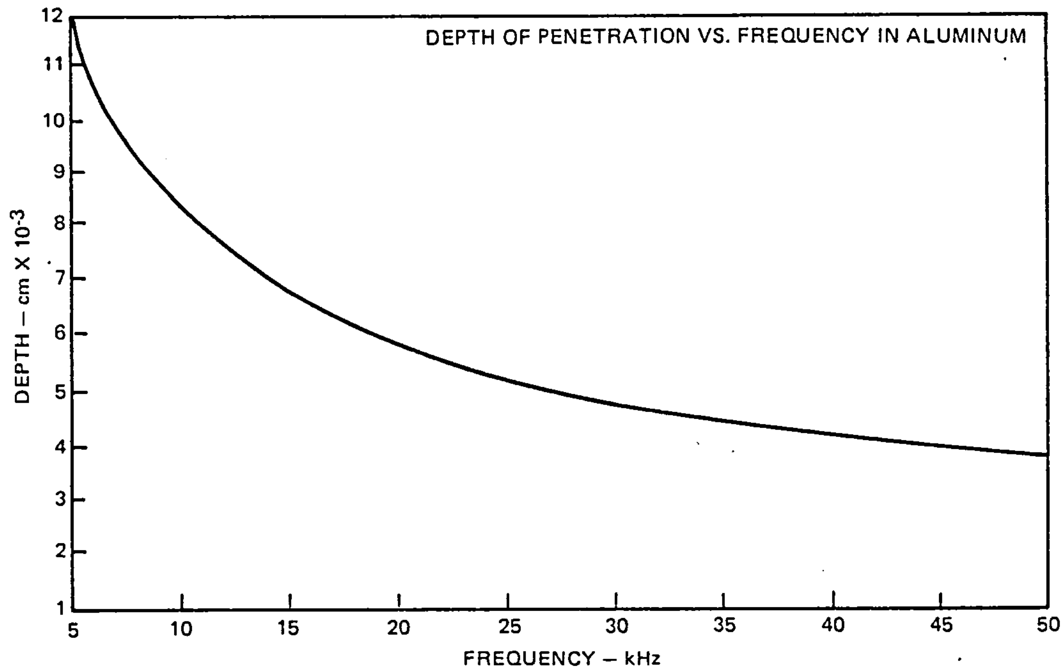


Figure 3-62. Depth of penetration vs. frequency in aluminum.

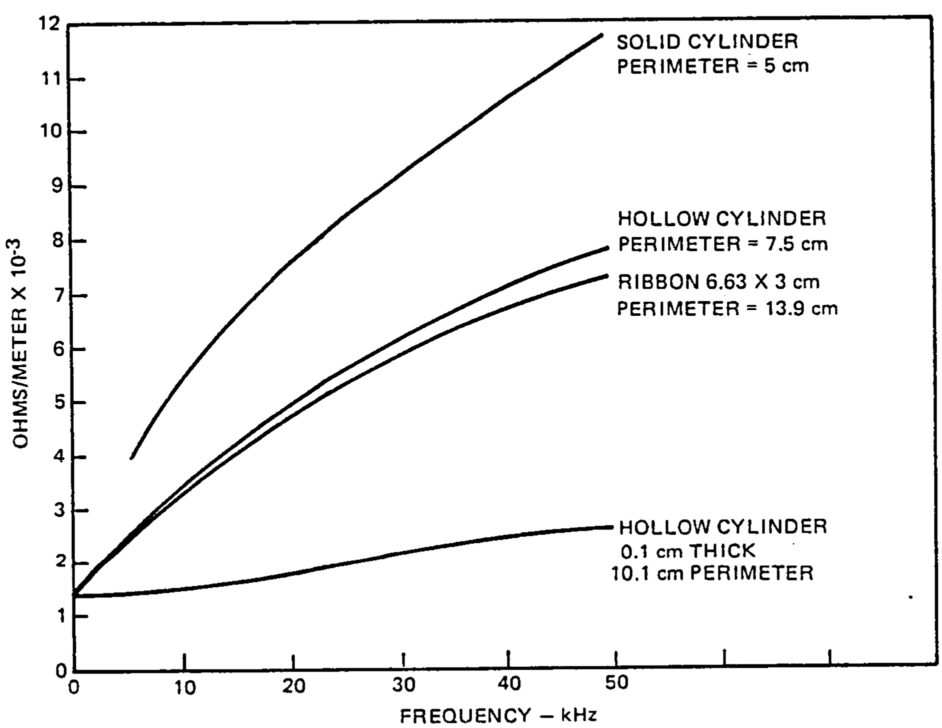


Figure 3-63. Resistance vs. frequency in Aluminum at 20°C. (2 cm^2 cross section)

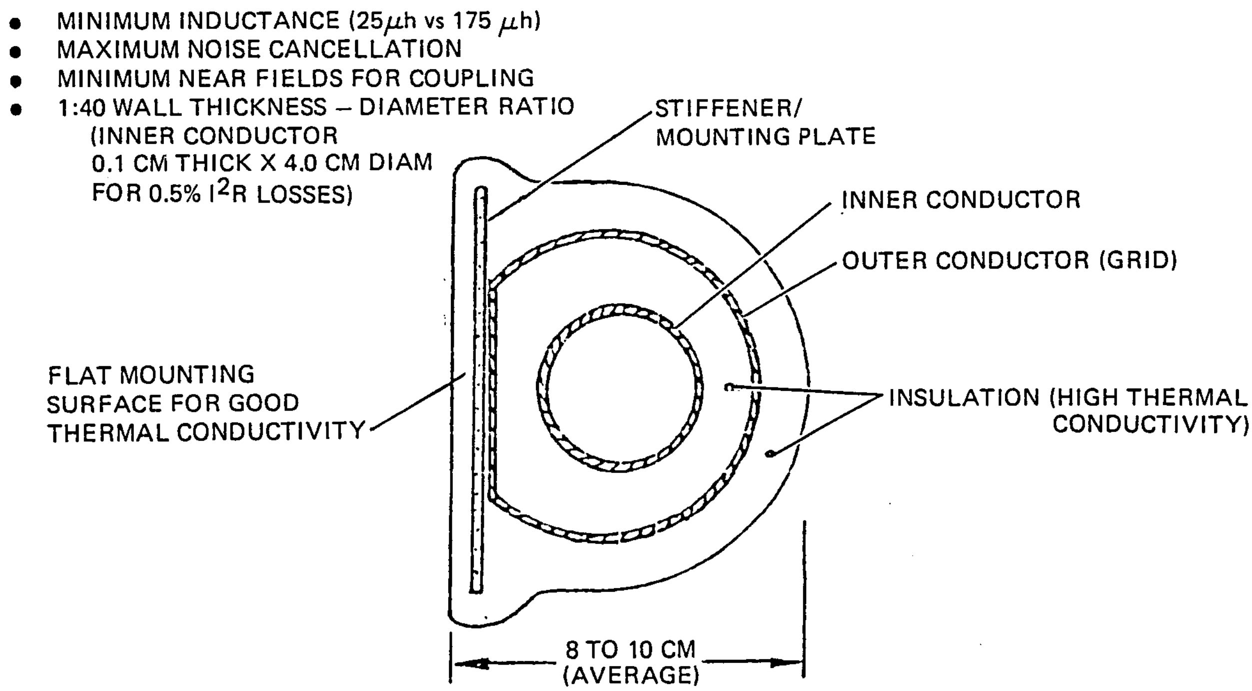


Figure 3-64. Preliminary power transmission line design (cross section).

CONCLUSIONS: Main busses for either system will be semi-rigid and firmly fastened in place because of conductor sizes and the requirements to control the parameters such as inductance and coupling. Branch and interconnect busses feeding individual loads will be flexible for maximum convenience. Bus interconnections, added taps, and growth provisions are sufficiently complex considerations so that additional, more detailed work is recommended, directed at those subjects.

3.2.15 "Identify the requirements for the protection equipment and protection circuits including overload capability and including typical circuit arrangements and sizing of distribution branches."

In general, good engineering practice for the design of the class of equipment we would fly in this kind of system would derate individual components between 25 and 50% based on maximum allowable junction or element temperatures. Therefore, steady-state short term overloads up to 50% could be tolerated without triggering any immediate new failure mechanisms. The momentary decrease in reliability associated with increased dissipation and temperature during the overload has no statistical significance on 10 year system reliability. Higher transient overloads (on the order of one device or bus thermal time constant) can certainly be accommodated. Actual values will depend on the individual thermal masses involved in actual designs, so definitive numbers cannot be supplied except for a few representative examples.

In practice, overload protection would be under control of the system computer, through sensed voltage and current for each major load or distribution branch. An allowable energy threshold will be established (power-time product) and a branch turned off when it is exceeded. As LSI capability increases over the next few years, this function could be included in RPC design for better response. At these power levels, it is our opinion that conventional output limiting (load-line limiting, etc.) will require enough thermal overdesign to take care of dissipation during an overload to make RPCs containing such features unattractive from a size and weight point of view.

However, RPC design must still be sufficient to accommodate short term overloads up to and including shorted outputs, for as long as it takes to be sensed and turned off either locally or remotely. On a worst-case basis, that time could approach 200 micro-seconds.

General operational requirements for RPCs operating in AC or DC systems will be the same, with the obvious power form differences. Switching hardware can, therefore, have basic differences, with thyristors meeting the AC system needs without further development and transistors applied to DC interfaces. Transistor capability must be improved for application in this size system, as documented in Appendix 3.

Distribution branch sizes will be based on payload needs and modular breakdowns for PMS major components. As an example, each payload breakout from the 250 kW, 1000 V, main bus will have a total capacity of 140 kW which will be split into 4 sub-busses to feed the distributed interface hardware as follows:

a. 25 kW to 115 VDC, (5) 5 kW circuits into the payload

b. 25 kW to 115 VAC, (5) 5 kW circuits into the payload

c. 15 kW to 28 VDC, (3) 5 kW circuits into the payload

d. 75 kW unregulated, (6) 15 kW circuits into the payload

3.2.16 "Investigate automated methods of power system control and monitoring which minimize crew involvement. Include an examination of automatic load shedding features. Identify impacts of automatic control on PM components."

Normal system control will be accomplished by a multiple, federated group of microcomputers distributed about the vehicle and communicating over standard data links, using protocols similar to those currently being developed for communications in the Digital Integrated Subsystem (DIS) (see Reference 22). Hardware and software is being developed for this and similar systems, and the power management problem will be only one detailed sub-element of that development. Therefore, the control system design to solve the problems of system control, communication, redundancy management, self test, etc. is being addressed in great detail and need not be a concern of PMS development.

For PMS control, loads will be prioritized and controlled, based on a predetermined set of algorithms which will react to satellite energy supply conditions, system status, mission status and demands, and payload conditions and demands.

Specific impacts on power management components concern data and command interfaces, so PMS hardware is compatible with DIS type protocols and standard data links such as MIL-STD-1553, which are expected to be optical by the mid-to-late 1980s.

In more detail, RPCs would be expected to take commands in serial digital form, decode them, and execute the appropriate function. Data required for system management or instrumentation (i.e., voltage, current) must be digitized, formatted, and transmitted when requested on the same serial data bus communication system. Other system components (converters, regulators, etc.) would interface with the command and control subsystem in the same way.

Therefore, there is no driver of significance affecting the design of the PMS itself or the selection of system type from the control considerations.

3.2.17 "Investigate electromagnetic interference problems that require new technology."

The intent of current specifications such as MIL-STD-1541 is generally applicable to these types of systems. For our primary and backup systems, there are many particulars which require additional data.

3.2.17.1 AC System

a. Characteristics of ultrasonic power line frequencies are not addressed. The major intent of the specification appears to assume frequencies in the 60 Hz to 400 Hz range. System impacts of ultrasonic power need to be evaluated, and new values for conducted and radiated interference in this domain must be specified.

b. To meet the general requirements, several system technology questions must be addressed:

    1. Zero current switching is possible with AC systems and is a simple method to eliminate switching noise which can cause EMI noise. Methods to implement it in practical systems must be evaluated.

    2. Low loss, high line frequency EMI filter components must be developed. New dielectric materials for large capacitors and for transmission line insulation must be provided specifically for the ultrasonic region to minimize losses and component heating. (See Appendix 2, Sheet C-5.)

3. High voltage filter components are required. While not really beyond the state of the art, system voltages are higher than those commonly proposed for space power applications, and qualified, physically efficient components must be provided.

3.2.17.2 DC System

a. Rise and fall time limited switching. A major noise source in DC power systems is the transients which occur during switching in converters and load changing. With multi-kW individual switches, the only practical way to reduce this is to control the rate-of-change of line current to an acceptable value. RPC designs will have to include controls on current during turn-on and turn-off and allow for the increased transient power dissipation in their thermal design.

b. High voltage filter components are required for the same reasons as AC and the AC discussion is, therefore, valid for this DC case also.

3.2.18 RESONANT SYSTEM DESIGN. Since the resonant design approach is the main development which enables the AC PMS to compete favorably with DC from a size, weight, efficiency, and cost point of view, a clear understanding of its operation is important to justify the recommendation of AC over DC.

Referring to Figure 3-65a, if switch S1 is closed the circuit will be excited and "ring" at its natural frequency as determined by the values of L and C. The current will have a waveform as determined by the circuit constants and shown in Figure 3-65b. If the resonant circuit is now excited from a pair of opposite polarity sources through a pair of toggled switches operating at the natural frequency, a sustained AC wave can be developed, as shown in Figures 3-66a and 3-66b. Alternatively, a single source and four switches arranged in the usual "bridge" configuration and using thyristors as the switches (Figure 3-67a) will produce the same results. The load can be transformer coupled (Figure 3-67b) and any isolated output AC power can be provided. Component sizes make this approach to inverter design impractical for reasonable amounts of power and typical power line frequencies (60 Hz or 400 Hz). However, component sizes become manageable when AC frequencies above 10 kHz are used. Of course, this is not very practical with today's equipment.

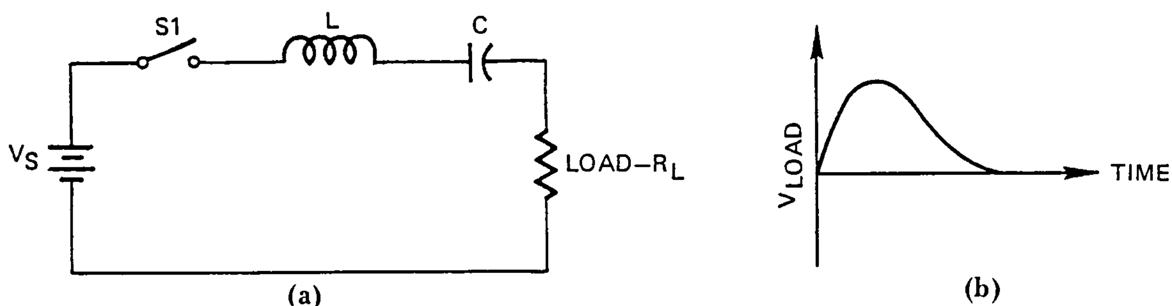
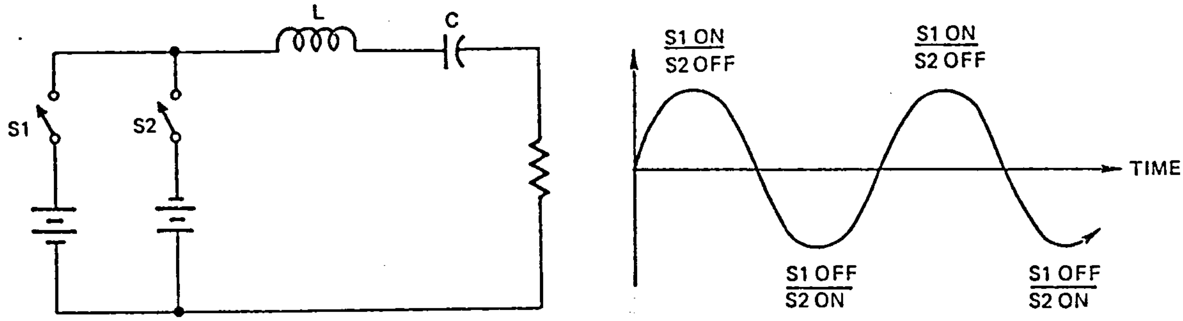
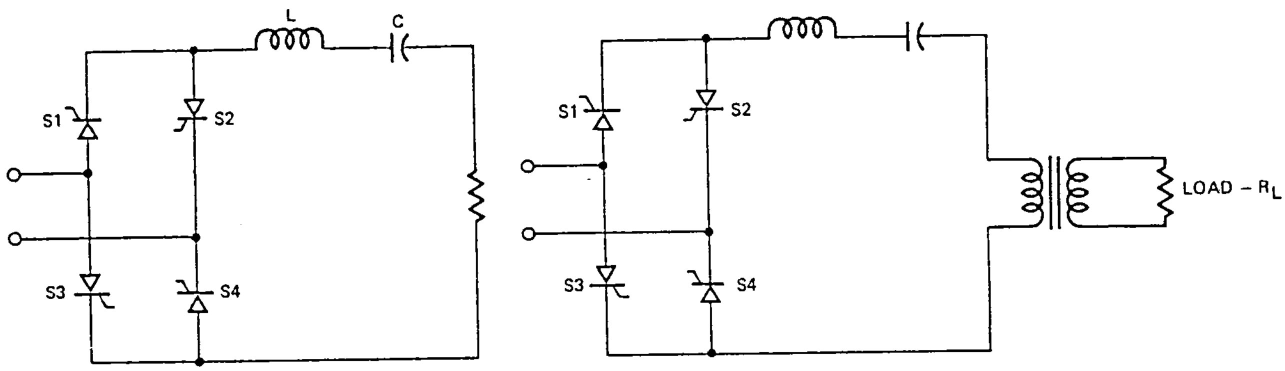


Figure 3-65. Basic resonant circuit.



(a) (b)

Figure 3-66. Dual polarity resonant circuit.



(a) (b)

Figure 3-67. Bridge driven resonant circuit.

Consider one additional system modification. If the simple load resistor is replaced by a "bridge-connected" set of switches (see Figure 3-68) driving the load, they can be operated as a synchronous demodulator to supply the load with DC power of either polarity, controlled by the transformer ratio and the demodulator duty cycle. In fact, with appropriate duty cycle control, low frequency output AC can be provided if its frequency is sufficiently lower than the carrier frequency.

Using this technique, a practical power system can be designed that takes any voltage DC, changes it to high frequency AC (20 kHz), transformer couples it to any appropriate transmission voltage, transformer couples it to any load voltage, and demodulates it to any voltage DC or low-frequency (60 Hz or 400 Hz) AC to an individual load. The major elements of one such system, in a modularized form, are shown in Figure 3-69.

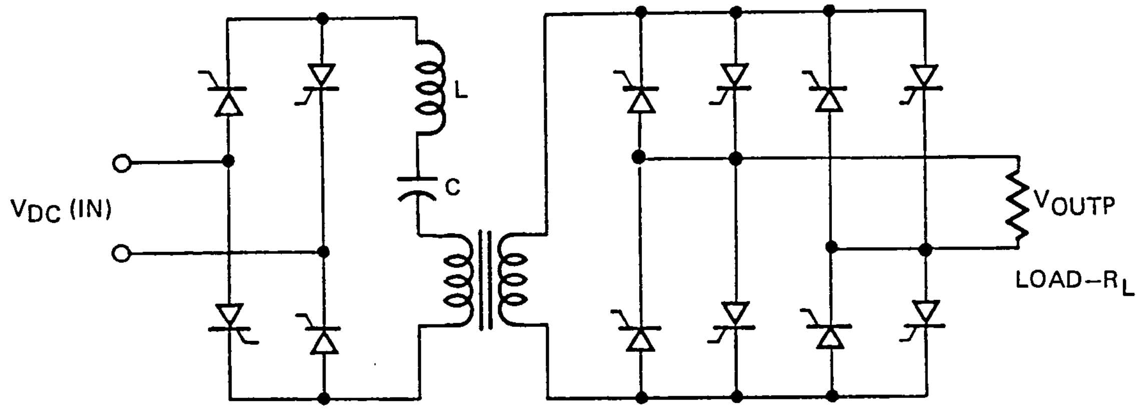


Figure 3-68. Bridge driven resonant circuit with transformer coupled, demodulator controlled load.

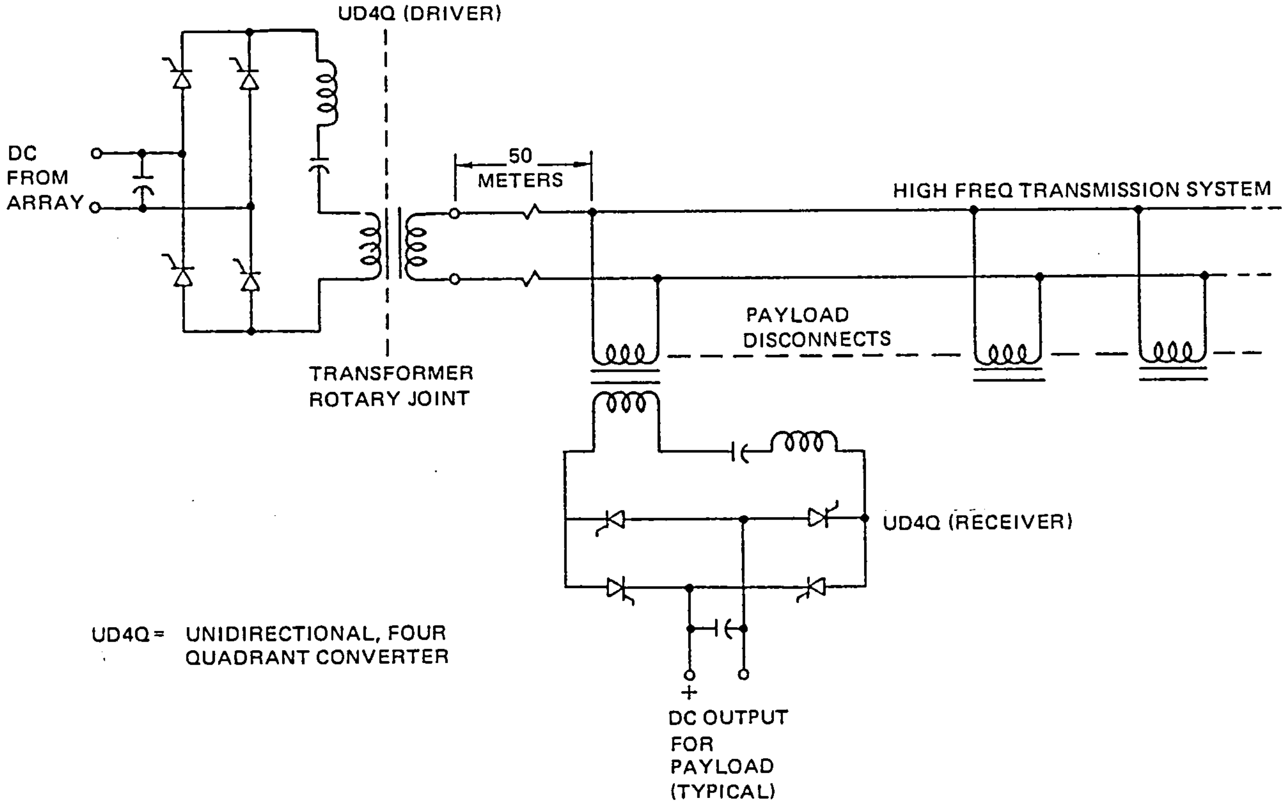


Figure 3-69. Simplified system schematic representation showing major power elements only.

This resonant approach to power conversion has significant advantages over conventional designs, whether it is used for a total system or for power conversion in a single unit.

a. Improved Efficiency - All switching is done when the current waveform passes through zero, thereby eliminating dynamic switching losses which are significant in conventional approaches. Power can be transmitted and switched at its most efficient voltage and current, independent of input and output interfaces. Solar array voltages can be kept low, minimizing plasma losses for LEO space platforms.

b. Reduced Size and Weight - Reactive components for filters and voltage or current transformation are designed for high frequency, making them significantly smaller than in conventional systems. Total power handling hardware required (for both ends) is about the same as any DC-DC converter. Lower losses result in reduced demands for solar arrays, batteries, and thermal management hardware.

c. Coupling transformers perform multiple functions - A rotary transformer in the system eliminates the need for slip rings at the rotary joint. The load transformer has been designed to provide the interconnect function, eliminating the need for spacecraft high voltage, high current, connectors. Total source/line/load/ground is inherently provided.

Since this discussion is intended to describe the general theory and concepts of resonant AC power systems, the data and schematics presented are simplified for clarify. For example, switch drive circuits are not included, and closed loop control circuitry has not been addressed. For a complete discussion of the engineering and technical details of such a system see Reference 15.

In summary, this resonant AC system approach has been recommended for this application because of its versatility, low losses, high physical efficiency, and operational advantages.

3.3 TASK 1 - FINAL RESULTS

Task 1, Part A yielded two system configurations to be examined in detail. They have herein been called DC-centralized and AC-distributed. The seventeen specific topics of Task 1, Part B addressed detailed trade-offs which affected system design. Part B also documented and defined system hardware. That overall process led to the evolution of AC and DC system topologies and more detailed technical descriptions of system elements and parameters. Detailed characteristics and requirements for major system components have been defined and documented in Appendix 1, Volume II, and the differences between data in the "state of the art" and "PMS requirements" columns form the basis for the technology gap analysis of Task 2.

To better understand the source of the requirements and to provide a coherent picture of the major results of study Task 1, the following finalized system descriptions are provided along with final recommendations about the "big questions" addressed.

3.3.1 AC SYSTEM. This system configuration evolved from the basic AC-distributed topology (presented in subsection 3.1.3) into a hybrid system with the following significant features.

a. Modular configuration, with each major module group providing full specification power capability plus one operational spare module, sized for minimum life cycle costs. See Figure 3-70 for a block diagram showing major module groups and breakdowns.

b. Hybrid DC-AC design, with solar array and energy storage interface hardware and conditioning equipment DC and all contained in a PM module on the array side of the platform rotary joint. That module also contains an inverter to drive the AC transmission and distribution system on the payload side of a rotary transformer type joint.

c. Hybrid regulation and control, with the system inverter providing general AC regulation as a centralized unit with AC-DC converter/regulator modules providing those functions at each payload interface as required. Figure 3-70 is a system block diagram showing this general configuration.

d. Resonant, high voltage, high frequency transmission and distribution. The system design is not a conventional AC inverter/transmission/converter system with the usual module designs for those functions. To save weight and cost and to improve efficiency, the entire system is designed as a single distributed resonant converter. The single device prototype which was used as the starting point for this approach was developed by F. C. Schwarz on NASA Contract NAS3-30363 and is described in detail in Reference 15.

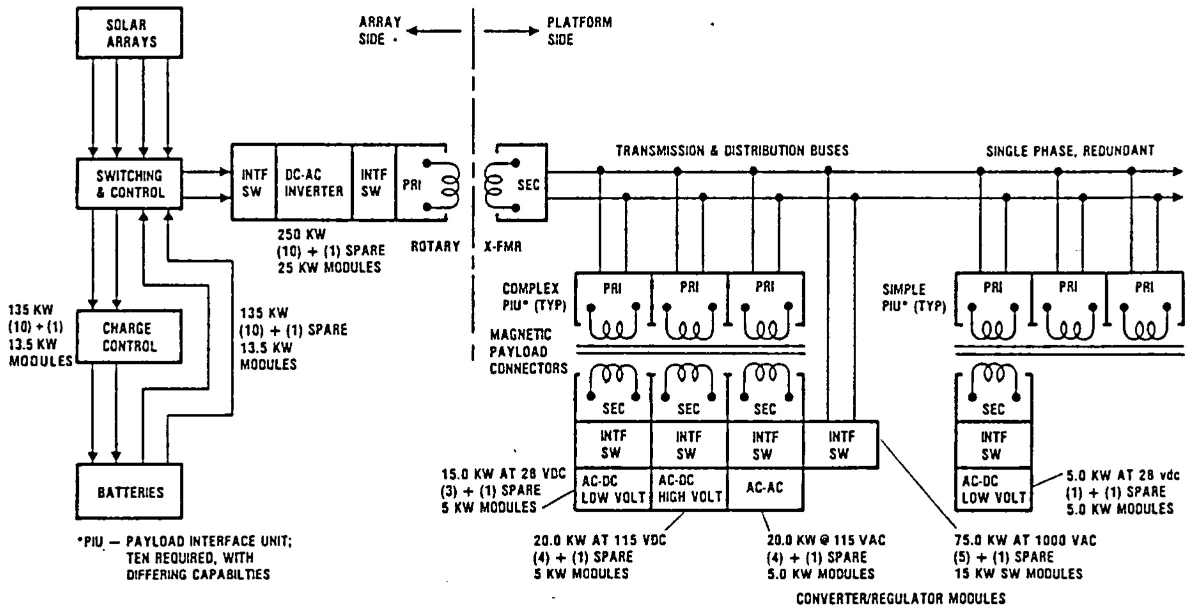


Figure 3-70. Resonant DC-AC-DC/AC system block diagram.

This approach uses a modular, transformer-coupled driver as a DC to AC inverter which is only the switch element bridge half of the usual converter or cyclo inverter. The transformer-coupled transmission line is the usual resonant link. The switch element bridge-connected type receivers are distributed at the payload interfaces and transform the line high frequency power to whatever is required by the individual payloads. These receivers are also only half of the usual hardware. For those payloads capable of using high frequency AC directly, only transformer coupling would be required.

The trade-offs of subsections 3.2.6 and 3.2.8 selected a frequency equal to or greater than 20 kHz and a system voltage of 1000 V RMS, respectively. Parameter variations in drivers and loads may cause the line frequency to vary as much as ±20%, but since line frequency is in no way critical to any system operational parameter, there would be no impact.

e. Because of the flexibility offered by transformer coupling at both ends, solar array and battery voltages are kept low to improve reliability and minimize plasma interractions. (Refer to Appendix 2.) The value selected is less than or equal to 440 VDC, a voltage that is low enough for this application and for which much power control equipment has already been developed. Voltages at the load interface hardware are adjusted to take best advantage of currently available hardware such as the D60T transistor, eliminating the requirement for new transistor development for this size system. Figure 3-60 showed system voltages, powers, and other important electrical quantities.

f. This distributed resonant converter approach provides good efficiency, size, weight, and cost. Figures 3-60 and 3-71 show these quantities. Costs displayed are average production (recurring) costs per unit based on building 100 modules (for more than one platform) with an 85% learning curve.

g. This modular breakdown provides for the appropriate reliability for ten years with only minimal repair. Figure 3-58 listed the reliabilities and MTBFs of the various functions.

h. Table 3-10 is a table of functional and technical advantages of this AC/DC hybrid system approach.

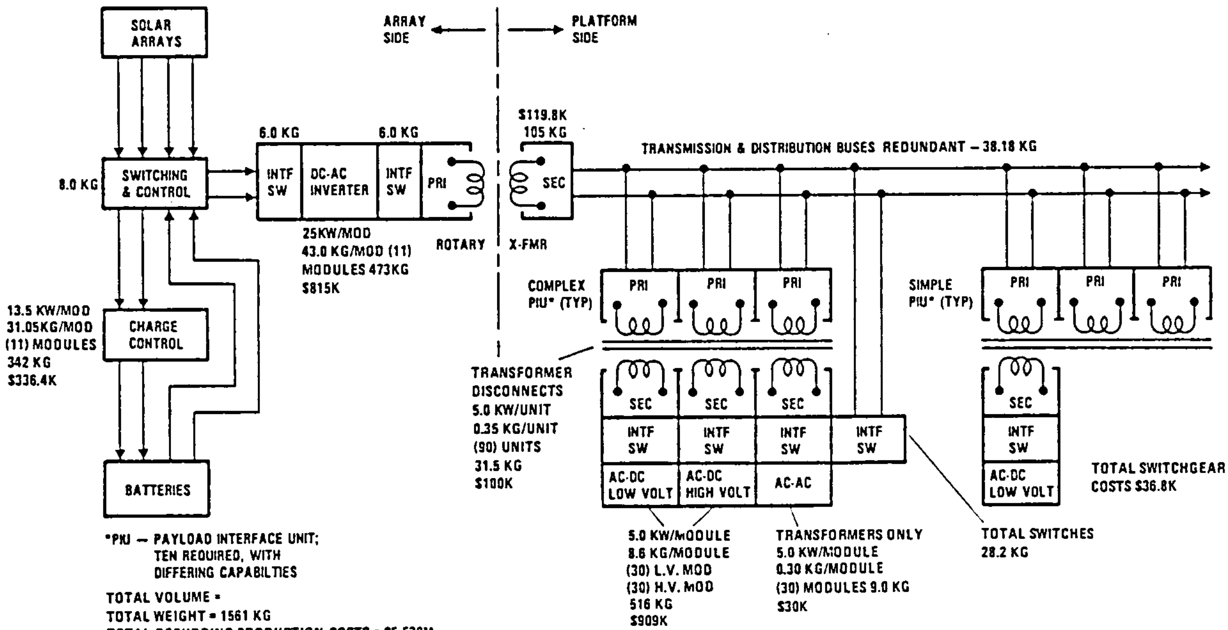


Figure 3-71. AC system modular costs.

3.3.2 <u>DC SYSTEM.</u> The DC system configuration presented is also an evolution from the basic topology presented at the conclusion of Task 1, Part A. While it uses DC throughout, it is also a hybrid from the control and regulation point of view, containing the following major features.

a. Modular configuration, with each major module group providing full specification capability plus one operational spare module, sized for minimum life cycle costs. See Figure 3-72 for a block diagram showing major module groups and breakdowns.

Table 3-10. AC system advantages and disadvantages.

MAJOR ADVANTAGES

- High degree of flexibility for general purpose platform
- Simple power system isolation
- Reduced plasma losses for low-voltage array
- Components more mature
- Simplified storage interface (fuel cells and batteries)
- Growth potential
- Noncontact interfaces and devices
- No inherent voltage ceiling

MAJOR DISADVANTAGES — None

ADDITIONAL DEVELOPMENT REQUIRED

- System proof of concept required
- System design required
- High-frequency user equipment development
- Ultrasonic interference and plasma coupling must be evaluated

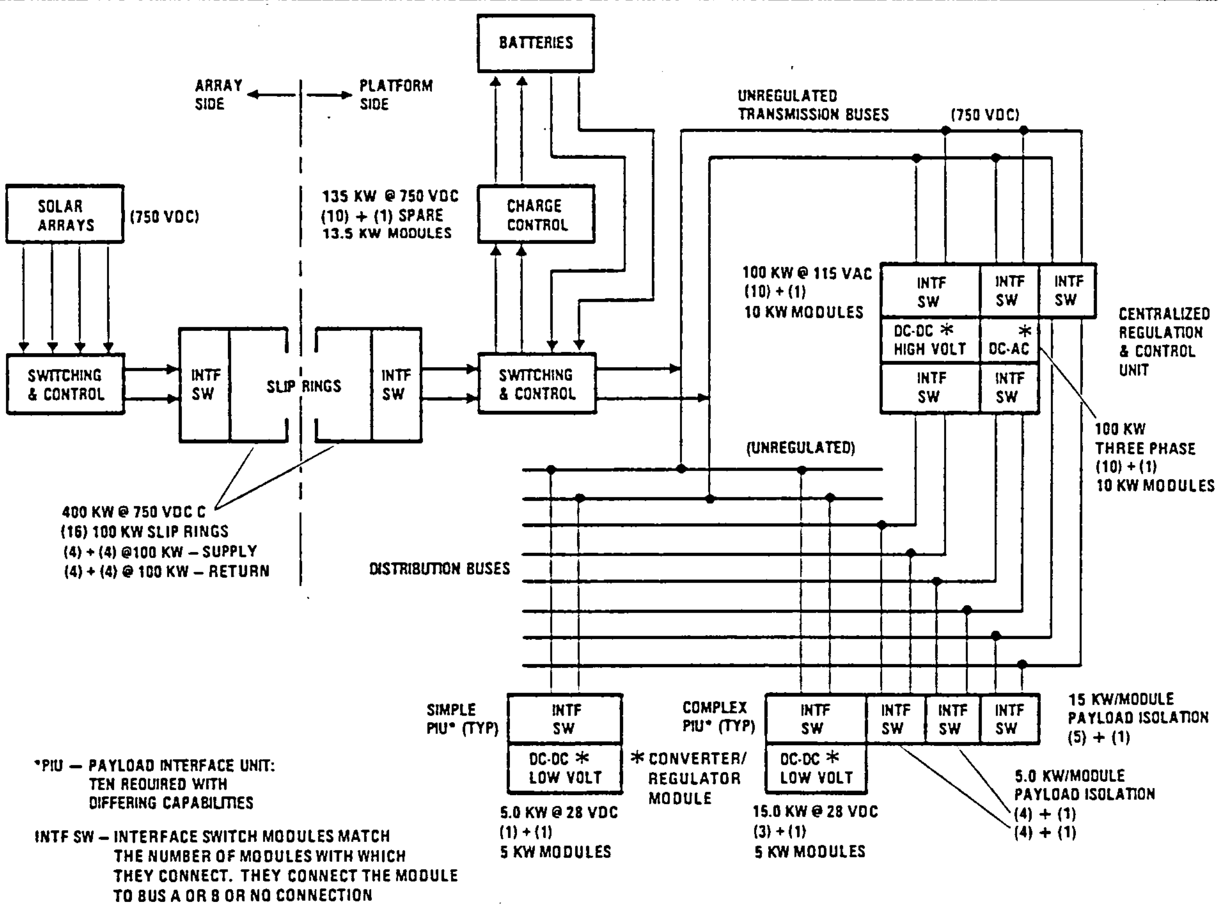


Figure 3-72. DC system block diagram.

b. Solar array, energy storage, and transmission busses all at the same voltage, which is a compromise between plasma losses and system losses as developed in subsection 3.2.8. The value selected by those trade-offs is 750 VDC. It is not efficient to operate the solar arrays and energy storage hardware at a lower voltage, as even the most efficient DC step-up hardware (a CDVM) would provide approximately 5% losses, about twice what is lost by the recommended approach. Only about 2.5% is lost from the solar arrays to the surrounding plasma at the DC system voltage of 750 VDC. Figure 3-61 shows important electrical parameters.

c. Hybrid regulation and control. Evaluation of system losses for the centralized approach of subsection 3.1.3 showed that the high currents associated with the switching and distribution of 28 VDC required by the payloads (approximately 4000 amperes, worst case), created major system losses. Therefore, a configuration was chosen which maintained centralized regulation and control for the higher voltage AC and DC payload requirements and utilized distributed regulation and control located at each payload interface for 28 VDC, as shown in Figure 3-61. Figure 3-73 lists the sizes, weights, and costs. Costs displayed are average production (recurring) costs per unit based on building 100 modules (for more than one platform) with an 85% learning curve.

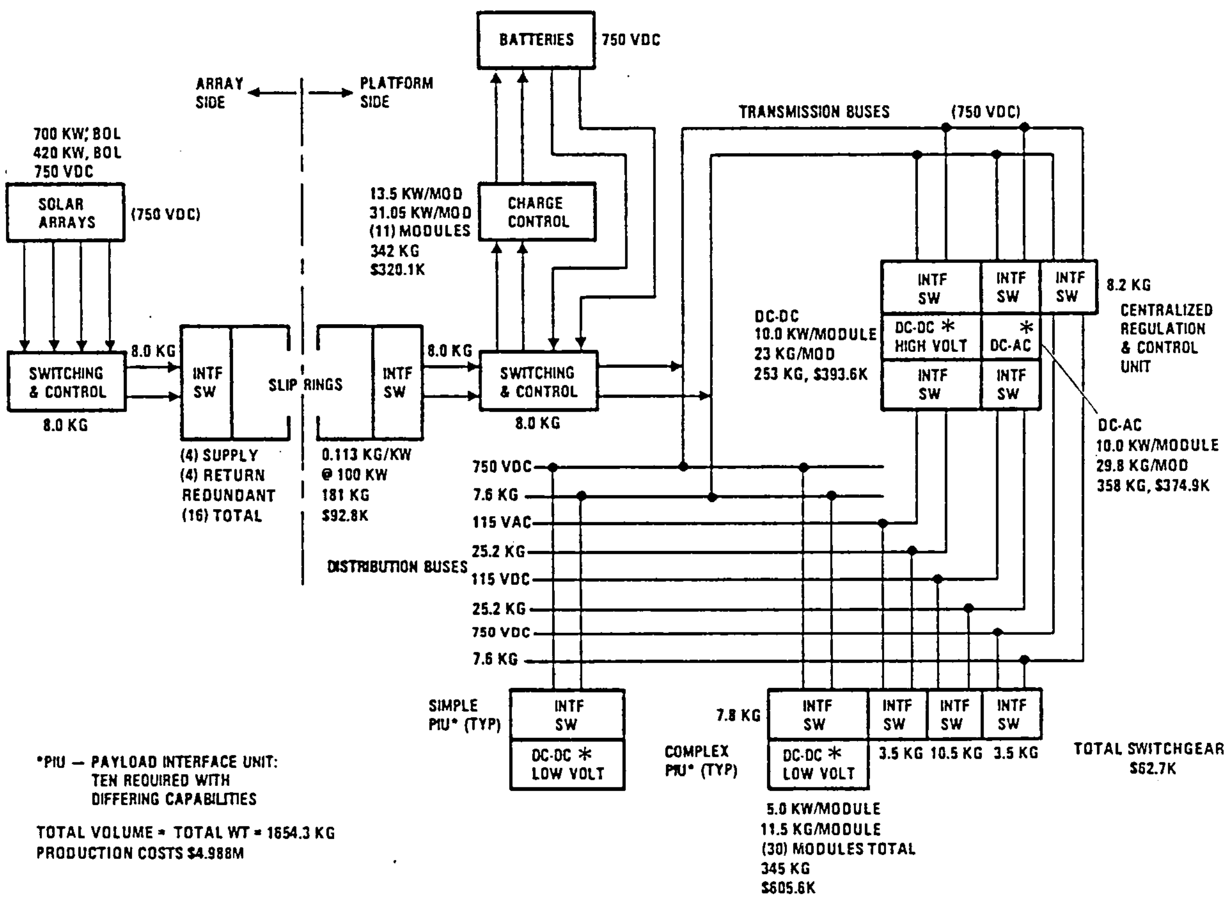


Figure 3-73. DC system modular costs.

d. This DC system is the "least expensive" system from a life cycle cost point of view. As such, it does not inherently provide power system isolation at the payload interfaces and, if required, it must be provided by the user.

e. This modular breakdown provides for the appropriate reliability for ten years, with only minimal repair. Figure 3-59 lists the reliabilities and MTBFs of the various functions.

f. Table 3-11 is a table of functional and technical advantages of this DC hybrid system approach.

Table 3-11. DC system advantages and disadvantages.

<u>MAJOR ADVANTAGES</u>
• Mature system design
• AC conversion not required
<u>MAJOR DISADVANTAGES</u>
• User interface flexibility through complex hardware
• Difficult power system isolation
• High array voltage to minimize PMS losses increases plasma problems
• Voltage ceiling of approximately 1000 V
• Rubbing contact interfaces and devices
<u>ADDITIONAL DEVELOPMENT REQUIRED</u>
• Higher rating components

3.3.3 <u>FINAL RECOMMENDATIONS.</u> At this point in the study, the system recommended as the primary one is the AC/DC hybrid with hybrid regulation and control for the reasons summarized below.

3.3.3.1 Interface Design Contributes:

a. High flexibility with simple, efficient hardware

b. Simple user isolation with high frequency transformers for noise immunity and special grounding of critical circuits and assemblies.

c. Transformer payload connector has no open connections and has rugged hardware to simplify docking interface by using a magnetic disconnect designed by General Dynamics.

3.3.3.2 System AC allows:

a. Minimum component development of semiconductor piece-parts due to ability to adjust voltage and current with transformers.

b. Contact-free interfaces and user equipment (switches, motors, etc.)

c. Total voltage/current flexibility to take advantage of hardware characteristics and ratings.

d. Easy growth to higher powers because of lack of voltage ceiling.

e. Simple modular interface for improved reliability and redundancy management.

f. Battery interface which matches battery characteristics most closely.

g. Significant transient EMI reduction by using zero cross-over switching for the AC current waveform.

h. Fault switching at the zero cross over for safer fault counteraction.

3.3.3.3 Resonant converter designs have improved system size, weight, efficiency, and reliability.

3.3.3.4 The all-DC system is being continued into Task 2 as an alternate recommendation so that important technology gaps and technology requirements unique to DC will not be ignored in future planning, since DC could still be the correct answer for a different application.

3.3.4 FINAL COST ANALYSIS. At this point, sufficient detail is available on both the primary recommended AC system and alternate DC system to provide full cost analyses of both. Table 3-12 is the cost breakdown for AC and Table 3-13 is for the DC system.

It should be noted that these two systems represent the least expensive AC system and the least expensive DC system for this application, even though they do not have equivalent capabilities. Section 3.3 has presented a thorough discussion of their capabilities in terms of advantages and disadvantages. To better understand the differences and their cost impacts, a final cost summary is presented in Table 3-14 and includes the totals for a conventional AC system and a DC system which is operationally equivalent to the recommended AC one. Block diagrams of those additional configurations are presented as Figures 3-74 and 3-75, respectively.

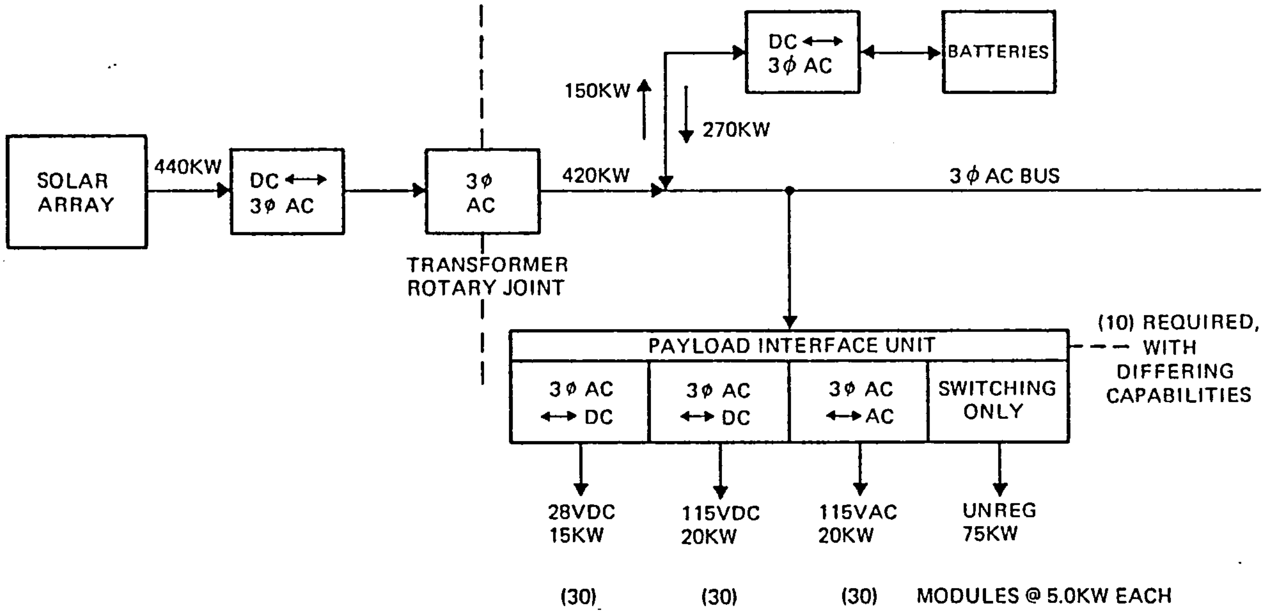


Figure 3-74. Standard, distributed 3-phase AC power system.

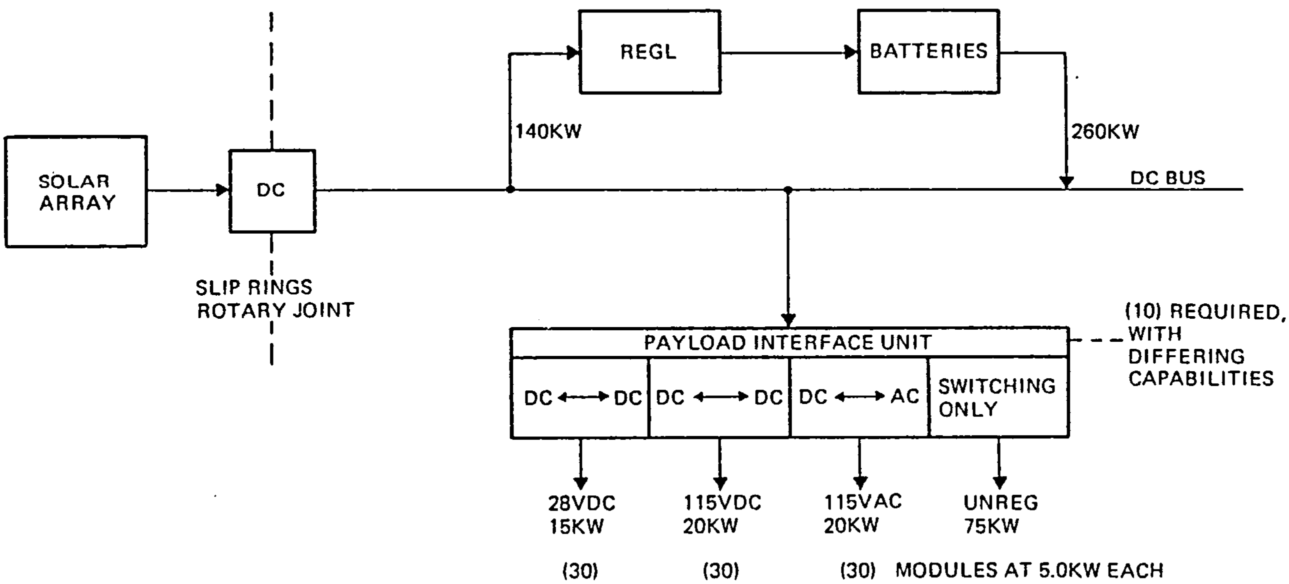


Figure 3-75. Distributed DC power system.

Table 3-12. AC power system cost hybrid regulation.

	COST 1979 $ K*				
	Design	First Unit	Production	Operations	Totals
Power Management System	6778.3	N/A	5538.8	1572.4	12889.5
Flight Hardware	4237.9	N/A	2849.6	–	7087.5
Power Transmission	148.0	N/A	149.8	–	297.8
Conductors	TBD	TBD	TBD	–	TBD
Slip Rings	–	–	–	–	–
Coupling Transformer	19.0	1.0	30.0	–	49.0
Rotary Transformer	129.0	6.9	119.8	–	248.8
Distribution Control	N/A	N/A	N/A	–	N/A
Processing	N/A	N/A	N/A	–	N/A
Conditioning	2665.9	N/A	2117.2	–	4783.1
DC-DC Converter	–	–	–	–	–
DC-AC Converter	1224.0	242.0	815.0	–	2039.0
AC-DC Converter	660.0	108.0	909.0	–	1569.0
Charge/Discharge	726.0	109.0	336.4	–	1062.4
Switchgear	55.9	19.6	56.8	–	97.2
Thermal Control	1424.0	266.0	266.0	–	1690.0
IA & CO	673.8	–	316.6	–	316.6
Subsystem Design & Integ.	673.8	–	–	–	673.8
Software	TBD	TBD	TBD	TBD	TBD
Tooling	TBD	–	TBD	–	TBD
Sustaining Engineering	–	–	427.4	750.0	1177.4
System Test	1060.0	–	–	–	1060.0
GSE	423.8	–	–	–	423.8
Facilities	0	–	–	0	–
Training	60.0	–	–	150.0	210.0
Spares	–	–	253.3	253.3	506.6
Initial			253.3	–	
Consumption			–	253.3	
Ground Operations	–	–	–	83.0	83.0
Maintenance/Refurb	–	–	–	78.0	78.0
Life Support	–	–	–	–	–
Transportation (to orbit)	–	–	1832.0	183.2	2015.2
Program Management	322.8	–	176.5	74.9	574.2

*"Costs" represent total life cycle costs excluding technology development.

Table 3-13. DC power system cost hybrid regulation.

	COST 1979 $ K*				
	Design	First Unit	Production	Operations	Totals
Power Management System	6717.1	N/A	4988.3	1524.6	13230.8
Flight Hardware	4199.6	N/A	2380.2	–	6579.8
Power Transmission	160.0	39.0	92.8	–	252.8
Conductors	TBD	TBD	TBD	–	TBD
Slip Rings	160.0	39.0	92.8	–	252.8
Coupling Transformer	–	–	–	–	–
Rotary Transformer	–	–	–	–	–
Distribution Control	N/A	N/A	N/A	–	N/A
Processing	N/A	N/A	N/A	–	N/A
Conditioning	2615.6	N/A	1756.9	–	4372.5
DC-DC Converter	446.0	75.6	605.6	–	1051.6
DC-AC Inverter	695.0	117.0	374.9	–	1069.9
AC-DC Converter	696.0	134.0	393.6	–	1089.6
Charge/Discharge	726.0	109.0	320.1	–	1046.1
Switchgear	52.6	18.3	62.3	–	115.3
Thermal Control	1424.0	266.0	266.0	–	1690.0
IA & CO	–	N/A	264.5	–	264.5
Subsystem Design & Integ.	667.7	–	–	–	667.7
Software	TBD	–	–	TBD	TBD
Tooling	TBD	–	TBD	–	TBD
Sustaining Engineering	–	–	357.0	750.0	1107.0
System Test	1049.9	–	–	–	1049.9
GSE	420.0	–	–	–	420.0
Facilities	0	–	–	0	–
Training	60.0	–	–	150.0	210.0
Spares	–	–	211.6	211.6	423.2
Initial			311.6	–	
Consumption			–	211.6	
Ground Operations	–	–	–	83.0	83.0
Maintenance/Refurb	–	–	–	78.0	78.0
Life Support	–	–	–	–	–
Transportation (to orbit)	–	–	1802.0	180.2	1982.2
Program Management	319.9	N/A	237.5	72.6	630.0

*"Costs" represent total life cycle costs excluding technology development.

Table 3-14. Costs for the primary system options.

System	Research and Technology Costs ($ M)	Design Costs ($ M)	Recurring Costs (Prod. & Oper.) ($ M)	Life Cycle Costs Totals ($ M)
Non-Isolated DC System (Lowest Cost DC)	2.3	6.72	6.52	15.54
Fully Isolated DC System*	2.4	6.72	10.28	19.40
Conventional AC System	2.0	6.78	11.53	20.31
Resonant, H.F. AC System* (Recommended)	3.0	6.78	7.11	16.89

- CONCLUSION: For equivalent capability systems (marked *), the recommended AC system costs $2.51 M less.

3.4 TASK 2, TECHNOLOGY ADVANCEMENT

Task 2 methodology is shown in Figure 3-76 and the work statement for this task says:

> "The contractor shall use the outputs of Task 1 to identify the gaps in electrical, thermal, and mechanical technology for power management. Technology advancement efforts shall then be identified to eliminate these gaps. Estimates of development cost and schedule shall be made for those technology efforts that can meet Mid-to-Late 1980's technology need dates with a normal development effort.
>
> "The contractor shall identify those technology advancements which are capable of meeting a 1984 technology need date. For those technology advancements which cannot meet the 1984 date, estimate the dates that the technology could be available. The Contractor shall rank these technology advancement efforts in order of priority with respect to their effect on life cycle costs. For the higher priority efforts, critical long lead items shall be identified and further defined. Those technology advancement efforts, which, after study, were considered to be unachievable by the Mid-to-Late 1980's but which are capable of producing benefits shall also be identified except that estimates of program cost and schedule shall not be required."

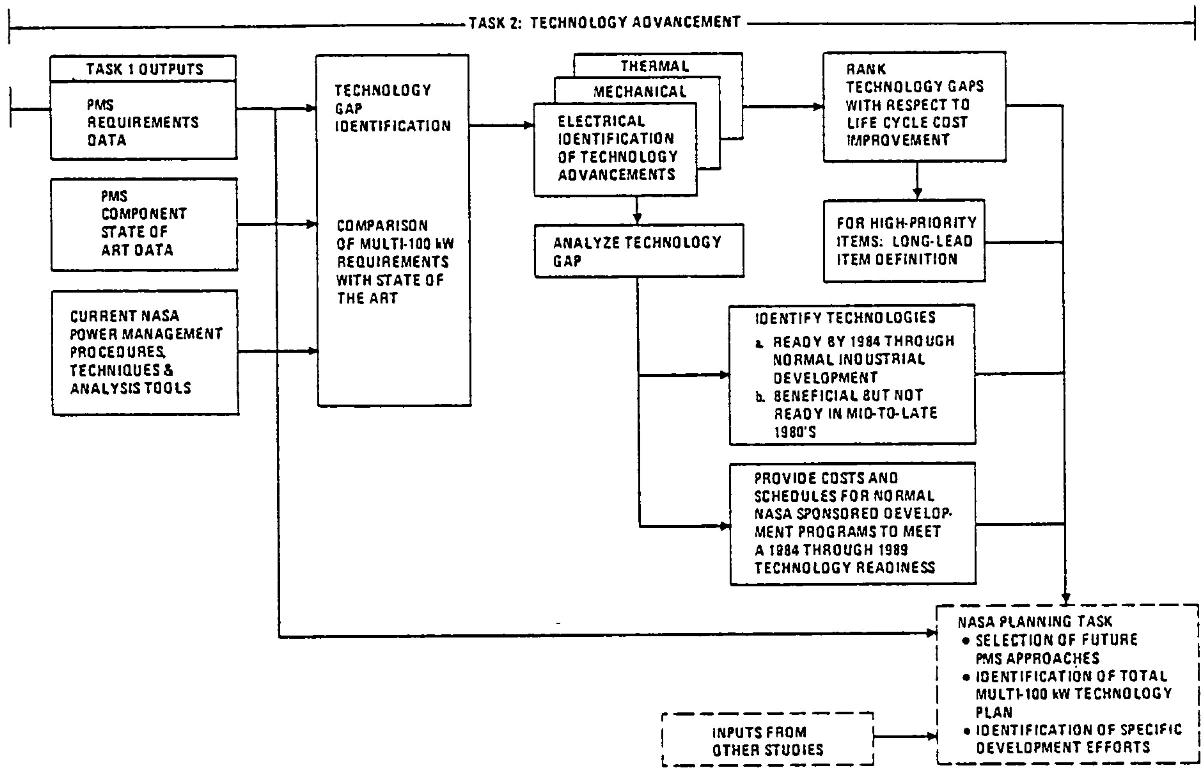


Figure 3-76. Task 2 methodology.

3.4.1 ELECTRICAL. The data sheets of Task 1 (Volume II Appendix 1) were each examined to compare "State-of-the-Art capability" with "PMS requirements" and all areas where differences existed were identified at the major component level. These are listed in Table 3-15. An analysis of each major component gap was then performed to determine which component(s) or technologies caused the limit. The "basic" gaps were then documented on Page 1 of the "Definition of Technology Requirement" data sheets. The complete set of these documentation sheets along with their second and third pages is included as Appendix 3. The sheets are numbered C-1 through C-19 (for component technology).

General system analysis considerations identified other technology items not obvious from the component level evaluations described above. An example of one such item is a proof-of-concept analysis and demonstration of the AC resonant system design. This and similar technological developments are identified and documented in Appendix 3 on data sheets numbered S-1 through S-5 (for system or high-level component technology).

Table 3-15. General areas where technology gaps have been identified.

- AC system design for low weight and high efficiency (high voltage, high frequency)
- High-frequency power transmission and power components
- High-voltage, high-current semiconductor switch elements for DC applications
- High-frequency user components
- Rotary joint hardware
- Transmission lines for the space environment

Finally, a third category of gap has been identified where there is a basic lack of the physics data to complete necessary analyses. There are several topics in the plasma interraction area that fit this category. In addition, there are some components which could fulfill PMS needs which are commercial developments and additional MIL-type qualification will be required. These are included in Appendix 3, numbered D-1 through D-8 (for data).

Data Sheet page 2 documents the evaluation of the options and alternatives and looks at whether or not the gap is expected to be filled by already planned programs or undisturbed industrial technology advancement. Historical data showing prior development to today's status, the slope of the technology development curve, and the history of similar devices, coupled with assessments of general needs and industry preceptions of the demands of the market, were used to project the normal industrial development future.

When a technology is identified as necessary for cost-effective PMS design, and the information on Page 2 (above) indicates that it will not be ready by the Mid-to-Late 1980s without some sort of government encouragement or assistance, Page 3 is prepared to document an analysis which determines the extent of NASA sponsorship that is required. Estimates of schedule and funding are provided for those technologies where a normal NASA-funded development program will produce "Technology Readiness" by the mid-to-late 1980s.

Finally, there are some useful technologies that will not be ready in this time frame, even with NASA help on a normal development basis. These are identified without detailed schedule or funding information and important long-lead items are highlighted to provide information for long-lead type technology planning.

Tables 3-16, 3-17, and 3-18 summarize the results presented on the data sheets of Appendix 3. Table 3-16 contains a list of those technologies which will probably be available through normal industrial development or through other programs now in progress. Table 3-17 presents those technologies which are necessary for cost-effective power management systems, and in which NASA must sponsor work, if they are to be ready to support the design of a system of this size in the mid-to-late 1980s. Table 3-18 contains those technology developments which are not expected to be available by the required time, even with a NASA-sponsored program. Table 3-17 is prioritized according to program benefit with those items which represent the greatest cost saving having the highest priority. Three major groups are also defined and members of those groups are identified with Roman numerals I, II, or III. Group I represents those items requiring immediate starts because they are key technologies or have long lead times. Group II represents those which are important, but whose lead times are short enough to allow later starts. Group III are those which are necessary, but non-critical and may be worked when time and funding allow.

Table 3-16. Available technologies, mid-to-late 1980s*.

- High current, fast recovery rectifiers
- Improved performance triacs
- Improved performance bipolar semiconductors
- Environmental radiation effects on PMS design
- Standard optical data bus interface hardware
- Federated computer system hardware
- Federated computer system software for general operation and redundancy management

*Technologies judged to be available in the mid-to-late 1980s through normal industry development or development that has already been started.

Table 3-17. Technology development priorities*.

GROUP**	PRIORITY RANKING	TECHNOLOGY DEVELOPMENT
I	1.	Integrated "split" resonant DC-DC/DC-AC converter system development.
I	2.	Rotary transformer development.
I	3.	Payload connector development a. AC, magnetic connector b. DC, high voltage, high current
I	4.	Improved performance semiconductor switch elements a. Improved ratings for power FETs b. Improved ratings for bipolar transistors
I	5.	Coaxial transmission line development
I	6.	Remote Power Controller (RPC) improvement a. Data/command interface b. Improved performance (voltage, current) c. Multi-pole, multi-throw configurations d. Incorporation of new devices e. Transient overload control
II	7.	Plasma Characteristic Research a. Special tests for irregular shapes/transmission lines/small components (AC and DC) b. AC energy coupled into the plasma as a function of voltage and frequency (AC) c. Expanded flat-plate testing for plates with voltage gradients (AC and DC) d. Arcing phenomena characterization (AC and DC) e. Surface damage through sputtering (AC and DC)
II	8.	Optical data bus rotary joint
II	9.	Insulating materials with low dielectric loss at high frequencies
II	10.	Analysis of total platform dynamics
III	–	Assessment of high frequency power line impact on "standard" user equipment a. Motors b. Power supplies
III	–	New/updated EMI-EMC specifications for high frequency power systems
III	–	Thermal management system technology
III	–	Micrometeorite protection for insulated components
III	–	Space-qualified thyristors/triacs
III	–	Space-qualified slip rings for high power and data transmission

*Priorities for important technology developments that NASA should sponsor in the early 1980s.

**GROUP I Immediate start required
II Shorter lead time will allow later start
III Necessary items, non-critical start times

Table 3-18. Unavailable technologies*.

• On-array power conditioning and control
• Superconducting energy storage
• Magnetic dipole attitude control

*Technologies judged not to be available in time to support design starts in the mid-to-late 1980s. (5)

3.4.2 THERMAL. Insofar as the power management system is concerned, no major thermal design gaps have been identified. PMS equipment for this size system can be cold-plate mounted with some internal heat pipe thermal conduction augmentation. Reasonable platform design would allow the PMS cold plates to be passively cooled by radiating their heat energy directly to space, as part of the docking module skin. This is not to say that the PMS cold plates could not receive active cooling assistance if it is available and convenient. However, some passive cooling capability must be retained so that the power system is not totally disabled by a thermal management system failure, and is totally isolated from any pumped fluid system failure.

This does not mean that there is no technology work remaining in space platform thermal management. Payload and life support heat loads are certainly significant and the space radiator and total thermal management problems are far from solved. It is only concluded that PMS thermal control is not necessarily part of these problems.

3.4.3 MECHANICAL. The major impact of mechanical design technology improvements is on unit size and weight. Size and weight of Shuttle payloads affects transportation to orbit costs which, in turn, affects life cycle costs.

While it is certainly a desirable goal to make this class of equipment smaller and lighter, transportation costs are only about 15% of the total life cycle cost of a power system. Magnetic and filter components are perhaps the most massive components used in these systems and major improvements have already been made in their size and weight through the use of high frequencies, both for the AC power transmission system and the DC devices' internal frequency links.

The industry, in general, is now moving toward smaller, lighter components. Additional NASA-sponsored technology programs in this area would have poor benefit-to-cost ratios, and are, therefore, not recommended for Shuttle-launched payloads.

Finally, power equipment has high densities, perhaps more than ten times the ideal Shuttle payload bay utilization density of 6.25 lb/ft^3. Therefore, it is obvious that design trades that show that weight can be saved at the expense of added volume, should decide in favor of lower weight.

3.4.3 TASK 2 CONCLUSIONS

a. While a 250 kWe space power system could theoretically be "brute force" designed with today's technologies, NASA must sponsor key technology developments to make it cost-effective.

b. With NASA sponsorship on normal development programs, there are no key technologies that will not meet mid-to-late 1980s need dates.

c. The recommended AC system has technology gaps primarily in the proof-of-concept, system design, and high level component areas.

d. The alternate DC system has technology gaps primarily in the detailed component and piece-part areas. Actual component design and maximum electrical performance and ratings must be improved.

e. Thermal considerations related to the PMS alone do not show any significant technology gaps.

f. There are no significant technology gaps in mechanical design areas for power hardware in a system of this size.

4

STUDY CONCLUSIONS

4.1 The DC-AC-DC/AC system with hybrid regulation and control and resonant conversion provides the "best" cost-effective approach to power management for this type of general purpose space platform, operating in low earth orbit, in the power range of 100 to 250 kWe.

4.2 All-DC systems are a second choice, but could be a first choice in applications with fixed loads, fewer payload variables, and different demands and parameters. Therefore, technologies in support of all-DC systems should continue to be developed along with those unique to AC.

4.3 High voltages (750 V for DC and 1000 V for AC) and high frequencies (low ultrasonic) are appropriate to systems and components in the power management of space platforms in this power range.

4.4 Power management hardware is expected to cost in the neighborhood of $30.00 per peak watt, on a recurring basis, on orbit, for this size system and application. This represents total life cycle costs for a ten-year-life space platform, excluding technology development and design costs.

4.5 An opportunity exists to improve overall satellite design by moving more mass to the solar array portion of the system which maintains a more nearly fixed position in inertial space, thereby reducing stationkeeping requirements.

4.6 Ten year life is a reasonable expectation for PMS hardware in this size modular system.

4.7 While a 250 kWe space power management system could theoretically be "brute force" designed with today's technology, NASA must sponsor key technology developments to make it cost-effective.

4.8 With NASA sponsorship on normal development programs, all key technologies will meet mid-to-late 1980s need dates.

4.9 NASA now has two attractive options for space platform power management, where only one was considered to be cost-effective prior to this work, and that choice of options will provide systems better suited to specific applications.

5

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APPENDIX 1

PMS COMPONENTS CHARACTERISTICS

DATA SHEETS

INTRODUCTION

The individual data sheets in this appendix document major components making up both AC and DC versions of a 250 KWe space platform power management system.

The data is presented in two parts: Part A shows physical data and Part B documents electrical performance. General descriptive data and mechanical and electrical interface requirements are presented along with specific mechanical and performance data in three categories:

1. PMS Requirements - what is needed based on system design, tradeoffs, and modular breakdowns.
2. State of the Art - what is currently available in a state of technology readiness.
3. Achievable Capability - our evaluation and estimate of what can be ready in 1984 or the mid-to-late 1980's.

Finally there is a block summarizing the results of the analysis and the significant conclusions about the technology involved in each component.

Where required, physical data curves are included for clarity. Switchgear is presented by using a summary, a curve, and a table for individual units for both electromechanical and solid state types, and individual electrical performance (Part B) charts for each switch.

PMS COMPONENTS CHARACTERISTIC DATA SHEET
PART A — PHYSICAL

COMPONENT NAME AC-DC CONVERTER (AC RESONANT SYSTEM)

FUNCTION CONVERTS HIGH VOLTAGE, HIGH FREQUENCY, AC BUS POWER INTO PAYLOAD DC POWER AT EACH DISTRIBUTED PAYLOAD INTERFACE ADAPTER.
(28 VDC OUTP)

PHYSICAL DESCRIPTION

SEMICONDUCTOR POWER DEVICES, MEDIUM POWER DRIVERS, AND MSI/LSI CONTROL, COMMAND, AND DATA INTERFACE CIRCUITRY MOUNTED IN A NON-SEALED HOUSING/HEATSINK STRUCTURE. PASSIVE THERMAL DESIGN AUGMENTED BY HEAT PIPES WHERE NECESSARY.

PARAMETRIC ANALYSIS RESULTS

SPECIFIC VOLUME IS APPROX. CONSTANT OVER THE POWER RANGE. (SEE ATTACHED CURVE)

SPECIFIC MASS DECREASES EXPONENTIALLY WITH INCREASING POWER (SEE ATTACHED CURVE)

PHYSICAL DEVELOPMENT PROJECTIONS

CHARACTERISTIC	STATE OF THE ART	PMS REQUIREMENT	ACHIEVABLE CAPABILITY
Size	$0.05 M^3$	$0.025 M^3$	$0.025 M^3$
Weight	22.7 Kg	9.75 Kg	9.75 Kg
Mass	4.5 Kg/KW	1.95 Kg/KW	1.95 Kg/KW
Cooling Requirements	375 W	115 W	115 W
Operating Temp	T_J MAX = 125°C (WORST CASE); 85°C T_J MAX (TYPICAL)		
Space Radiation Damage	OK	3×10^{12} e/cm^2	SOTA OK
Pressurization	—	NON-PRESSURIZED	NON-PRESSURIZED
Vibration	SHUTTLE LAUNCH ENV. OK	SHUTTLE LAUNCH REQUIREMENTS	SHUTTLE LAUNCH ENV. OK.

PHYSICAL INTERFACE REQUIREMENTS/CHARACTERISTICS UNIT DESIGNED TO MOUNT TO A COLD PLATE WITH LOW THERMAL IMPEDANCE. HIGH VOLTAGE AND CONVENTIONAL CONNECTORS REQUIRED.

MATERIAL CONSIDERATIONS

MATERIAL FOR HOUSING SELECTED FOR LIGHT WEIGHT AND GOOD THERMAL CONDUCTIVITY. ALUMINUM OR MAGNESIUM PROBABLE SELECTION.

PMS COMPONENT CHARACTERISTIC DATA SHEET

PART B — PERFORMANCE

COMPONENT NAME AC-DC CONVERTER (AC RESONANT SYSTEM)

FUNCTIONAL CHARACTERISTICS 5.0 KW MODULE DESIGNED TO BE PARALLELED WITH ONE TO FOUR OTHERS AT EACH PAYLOAD INTERFACE FOR DISTRIBUTED 28 VDC CONVERSION. PROVIDES PART OF THE PAYLOAD END OF THE "DISTRIBUTED AC RESONANT CONVERTER SYSTEM". HIGH FREQUENCY, HIGH VOLTAGE, AC INPUT; LOW VOLTAGE DC OUTPUT

PERFORMANCE DEVELOPMENT PROJECTIONS

CHARACTERISTIC	STATE OF THE ART (INP. / OUTP.)	PMS REQUIREMENT (INP. / OUTP.)	ACHIEVABLE CAPABILITY (INP / OUTP.)
Voltage Level	1000VACRMS / 28VDC	1000VACRMS / 28VDC	1000VACRMS / 28VDC
Peak Voltage	1500VPK / 56VPK	2000VPK / 56VPK	2000VPK / 56VPK
Current Capability	5AMP / 180AMP	5AMP / 180AMP	5.0AMP / 180AMP
Peak Load	5.0KW	5.0KW	5.0KW
Efficiency	92.5%	97.75%	97.75%
Reliability	0.979	0.944	0.979
MTBF (Hours)	4.20×10^6	1.58×10^6	4.20×10^6
Peak Load Capability	6.0KW	6.0KW	6.0KW
Operating Frequency	20-40KHz / DC	20-40KHz / DC	20-40KHz / DC
Magnetic Field	OK.	0.47 GAUSS, MAX	OK
Regulation %	5%	5.0%	5.0%
Transient Capability	IN ACCORDANCE WITH THE INTENT OF MIL-STD-1541		
Stability	± 2.0% / 2 YEARS	5.0% / 10 YEARS	5.0% / 10 YEARS
Redundancy	ACCOMPLISHED AT THE 5.0KW MODULE LEVEL		

INTERFACE REQUIREMENTS

Control/Monitor SERIAL DATA BUS - WIRED OR OPTICAL; MIL-STD-1553 TYPE

Operational/Safety REDUNDANT SERIAL DATA BUSSES SHARED WITH ABOVE FUNCTIONS

Maintainability/Repair TOTAL 5.0KW MODULE REMOVED AND REPL. FOR SYSTEM REPAIR

Other BUILT-IN-TEST PROVISIONS, COMMANDED AND MONITORED VIA THE DATA BUS INTERFACE.

PARAMETRIC ANALYSIS RESULTS

TRANSFORMER COUPLING ALLOWS VOLTAGE AND CURRENT ADJUSTMENT TO SUIT COMPONENT CAPABILITIES.

NO NEW PIECE-PARTS REQ'D, D60T IS AN ADEQUATE OUTP. DEVICE.

PMS COMPONENTS CHARACTERISTIC DATA SHEET
PART A — PHYSICAL

COMPONENT NAME AC-DC CONVERTER (AC RESONANT SYSTEM)

FUNCTION CONVERTS HIGH VOLTAGE, HIGH FREQUENCY, AC BUS POWER INTO PAYLOAD DC POWER AT EACH DISTRIBUTED PAYLOAD INTERFACE ADAPTER.
(115VDC OUTP)

PHYSICAL DESCRIPTION

SEMICONDUCTOR POWER DEVICES, MEDIUM POWER DRIVERS, AND MSI/LSI CONTROL, COMMAND, AND DATA INTERFACE CIRCUITRY MOUNTED IN A NON-SEALED HOUSING/HEATSINK STRUCTURE. PASSIVE THERMAL DESIGN AUGMENTED BY HEAT PIPES WHERE NECESSARY.

PARAMETRIC ANALYSIS RESULTS

SPECIFIC VOLUME IS APPROX. CONSTANT OVER THE POWER RANGE. (SEE ATTACHED CURVE)

SPECIFIC MASS DECREASES EXPONENTIALLY WITH INCREASING POWER (SEE ATTACHED CURVE)

PHYSICAL DEVELOPMENT PROJECTIONS

CHARACTERISTIC	STATE OF THE ART	PMS REQUIREMENT	ACHIEVABLE CAPABILITY
Size	$0.05 M^3$	$0.025 M^3$	$0.025 M^3$
Weight	22.7 Kg	9.75 Kg	9.75 Kg
Mass	4.5 Kg/KW	1.95 Kg/KW	1.95 Kg/KW
Cooling Requirements	350 W	115 W	115 W
Operating Temp	T_J MAX = 125°C (WORST CASE) ; 85°C T_J MAX (TYPICAL)		
Space Radiation Damage	OK	3×10^{12} e/cm²	SOTA OK
Pressurization	—	NON-PRESSURIZED	NON-PRESSURIZED
Vibration	SHUTTLE LAUNCH ENV. OK	SHUTTLE LAUNCH REQUIREMENTS	SHUTTLE LAUNCH ENV. OK.

PHYSICAL INTERFACE REQUIREMENTS/CHARACTERISTICS UNIT DESIGNED TO MOUNT TO A COLD PLATE WITH LOW THERMAL IMPEDANCE. HIGH VOLTAGE AND CONVENTIONAL CONNECTORS REQUIRED.

MATERIAL CONSIDERATIONS

MATERIAL FOR HOUSING SELECTED FOR LIGHT WEIGHT AND GOOD THERMAL CONDUCTIVITY. ALUMINUM OR MAGNESIUM PROBABLE SELECTION.

PMS COMPONENT CHARACTERISTIC DATA SHEET

PART B — PERFORMANCE

COMPONENT NAME AC-DC CONVERTER (AC RESONANT SYSTEM)

FUNCTIONAL CHARACTERISTICS 5.0 KW MODULE DESIGNED TO BE PARALLELED WITH ONE TO FOUR OTHERS AT EACH PAYLOAD INTERFACE FOR DISTRIBUTED 115 VDC CONVERSION. PROVIDES PART OF THE PAYLOAD END OF THE "DISTRIBUTED AC RESONANT CONVERTER SYSTEM". HIGH FREQUENCY, HIGH VOLTAGE, AC INPUT ; LOW VOLTAGE DC OUTPUT

PERFORMANCE DEVELOPMENT PROJECTIONS

CHARACTERISTIC	STATE OF THE ART (INP. / OUTP.)	PMS REQUIREMENT (INP. / OUTP.)	ACHIEVABLE CAPABILITY (INP. / OUTP.)
Voltage Level	1000 V / 115VDC	1000VACRMS / 115VDC	1000VACRMS / 115VDC
Peak Voltage	1500VPK / 230VPK	2000VPK / 230VPK	2000VPK / 230VPK
Current Capability	5 AMP / 43 AMP	5 AMP / 43 AMP	5.0 AMP / 43 AMP
Peak Load	5.0KW	5.0 KW	5.0KW
Efficiency	93.0%	97.75%	97.75%
Reliability	0.979	0.944	0.979
MTBF (Hours)	4.20 x 10^6	1.58 x 10^6	4.20 x 10^6
Peak Load Capability	6.0KW	6.0KW	6.0KW
Operating Frequency	20-40 KHz / DC	20-40KHz / DC	20-40KHz / DC
Magnetic Field	OK	0.47 GAUSS, MAX	OK
Regulation %	5%	5.0%	5.0%
Transient Capability	IN ACCORDANCE WITH THE INTENT OF MIL-STD-1541		
Stability	± 2.0% / 2 YRS	5.0% / 10 YEARS	5.0% / 10 YEARS
Redundancy	ACCOMPLISHED AT THE 5.0KW MODULE LEVEL		

INTERFACE REQUIREMENTS

Control/Monitor SERIAL DATA BUS - WIRED OR OPTICAL ; MIL-STD-1553 TYPE

Operational/Safety REDUNDANT SERIAL DATA BUSSES SHARED WITH ABOVE FUNCTIONS

Maintainability/Repair TOTAL 5.0KW MODULE REMOVED AND REPL. FOR SYSTEM REPAIR

Other BUILT-IN-TEST PROVISIONS, COMMANDED AND MONITORED VIA THE DATA BUS INTERFACE.

PARAMETRIC ANALYSIS RESULTS

TRANSFORMER COUPLING ALLOWS VOLTAGE AND CURRENT ADJUSTMENT TO SUIT COMPONENT CAPABILITIES.

NO NEW PIECE PART REQ'D. D60T TRANSISTOR IS AN ADEQUATE OUTPUT DEVICE

3652 ??

PMS COMPONENTS CHARACTERISTIC DATA SHEET
PART A — PHYSICAL

COMPONENT NAME DC - AC INVERTER (AC RESONANT SYSTEM)

FUNCTION CONVERTS DC ARRAY POWER TO HIGH FREQUENCY AC TO BE TRANSMITTED AND DISTRIBUTED TO SPACE PLATFORM LOADS VIA THE RESONANT TRANSMISSION BUS SYSTEM.

PHYSICAL DESCRIPTION

SEMICONDUCTOR POWER DEVICES, MEDIUM POWER DRIVERS, AND MSI / LSI CONTROL, COMMAND AND DATA INTERFACE CIRCUITRY MOUNTED IN A NON-SEALED HOUSING / HEAT SINK STRUCTURE. PASSIVE THERMAL DESIGN AUGMENTED BY HEAT PIPES IF NECESSARY.

PARAMETRIC ANALYSIS RESULTS

SPECIFIC VOLUME IS APPROX CONSTANT OVER THE POWER RANGE. (SEE ATTACHED CURVE)

SPECIFIC MASS DECREASES EXPONENTIALLY WITH INCREASING POWER. (SEE ATTACHED CURVE)

PHYSICAL DEVELOPMENT PROJECTIONS

CHARACTERISTIC	STATE OF THE ART	PMS REQUIREMENT	ACHIEVABLE CAPABILITY
Size	$0.12\ M^3$	$0.063\ M^3$	$0.063\ M^3$
Weight	100 Kg	43.0 Kg	43.0 Kg
Mass	4.0 Kg / KW	1.72 Kg / KW	1.72 Kg / KW
Cooling Requirements	1130 WATTS	565 WATTS	565 WATTS
Operating Temp	125°C Tj MAX (WORST CASE); 85°C Tj MAX (TYPICAL)		
Space Radiation Damage	OK	$3 \times 10^{12}\ e/cm^2$	SOTA OK
Pressurization	—	NON - PRESSURIZED	NON - PRESSURIZED
Vibration	SHUTTLE LAUNCH ENV. OK	SHUTTLE LAUNCH REQUIREMENTS	SHUTTLE LAUNCH ENV. OK

PHYSICAL INTERFACE REQUIREMENTS/CHARACTERISTICS UNIT DESIGNED TO MOUNT TO A COLD PLATE WITH LOW THERMAL IMPEDANCE. HIGH VOLTAGE AND CONVENTIONAL CONNECTORS REQUIRED.

MATERIAL CONSIDERATIONS MATERIAL FOR HOUSING SELECTED FOR LIGHT WEIGHT AND GOOD THERMAL CONDUCTIVITY. ALUMINUM OR MAGNESIUM ALLOYS PROBABLE SELECTION.

PMS COMPONENT CHARACTERISTIC DATA SHEET

PART B — PERFORMANCE

COMPONENT NAME DC-AC INVERTER (AC RESONANT SYSTEM)

FUNCTIONAL CHARACTERISTICS THIS IS THE DC-AC HALF OF A DISTRIBUTED RESONANT CONVERTER WHICH MAKES UP THE DISTRIBUTION AND CONDITIONING COMPONENTS OF THE PMS. ITS INPUT IS LOW VOLTAGE DC, ITS OUTPUTS ARE HIGH VOLTAGE, HIGH FREQUENCY, SINGLE PHASE A.C.

SPECIFICATIONS ARE FOR A 25.0KW MODULE USED WITH (10) OTHERS FOR A 250KW SYSTEM, WITH A DISTRIBUTED PAYLOAD INTERFACE.

PERFORMANCE DEVELOPMENT PROJECTIONS

CHARACTERISTIC	STATE OF THE ART	PMS REQUIREMENT	ACHIEVABLE CAPABILITY
Voltage Level	INP / OUTP 200-400VDC / 1000VAC	INP / OUTP 200-400VDC / 1000VAC	INP / OUTP 200-400VDC / 1000VAC
Peak Voltage	400-800VDC / 1200VAC	400-800VDC / 1200VAC	400-800VDC / 1200VAC
Current Capability	125-62.5A / 25A	125-62.5A / 25AMP	125-62.5A / 25AMP
Peak Load	25.0KW	25.0KW	25.0KW
Efficiency	95.7%	97.75%	97.75%
Reliability	0.910	0.913	0.910
MTBF (Hours)	0.90×10^6	0.96×10^6	0.90×10^6
Peak Load Capability	30.0KW	30.0KW	30.0KW
Operating Frequency	20-40KHZ	20-40KHZ	20-40KHZ
Magnetic Field	OK	0.41 GAUSS, MAX	OK
Regulation %	5.0%	5.0%	5.0%
Transient Capability	IN ACCORDANCE WITH THE INTENT OF MIL-STD-1541		
Stability	1.0% / YEAR	5.0% / 10 YEARS	5.0% / 10 YEARS
Redundancy	ACCOMPLISHED AT THE MAJOR MODULE LEVEL		

INTERFACE REQUIREMENTS

Control/Monitor SERIAL DATA BUS — WIRED OR OPTICAL; MIL-STD-1553 TYPE

Operational/Safety REDUNDANT SERIAL DATA BUSSES SHARED WITH ABOVE FUNCTIONS

Maintainability/Repair TOTAL 25.0KW MODULE REMOVABLE FOR SYSTEM REPAIR

Other BUILT-IN-TEST PROVISIONS, COMMANDED AND MONITORED VIA THE DATA BUS INTERFACE.

PARAMETRIC ANALYSIS RESULTS

TRANSFORMER COUPLING ALLOWS VOLTAGE AND CURRENT ADJUSTMENT TO SUIT COMPONENT CAPABILITIES.

NO NEW PIECE PARTS REQ'D.

D60T TRANSISTOR IS AN ADEQUATE OUTPUT DEVICE

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PMS COMPONENTS CHARACTERISTIC DATA SHEET

PART A — PHYSICAL

COMPONENT NAME DC-DC CONVERTER (DC SYSTEM)

FUNCTION CHANGE DC VOLTAGE LEVELS (UP OR DOWN) WITH LARGE DIFFERENCES BETWEEN SOURCE AND LOAD VOLTAGES AND/OR WHEN GROUND ISOLATION IS REQUIRED

PHYSICAL DESCRIPTION

COMBINATION OF HIGH POWER SEMICONDUCTORS, MEDIUM POWER DRIVERS, AND MSI/LSI CONTROL, COMMAND, AND DATA INTERFACE CIRCUITRY, MOUNTED IN A NON-SEALED HOUSING/HEAT SINK STRUCTURE. PASSIVE THERMAL DESIGN AUGMENTED BY HEAT PIPES IF NECESSARY.

PARAMETRIC ANALYSIS RESULTS

SPECIFIC VOLUME REMAINS APPROX. CONSTANT WITH INCREASING POWER. (SEE ATTACHED CURVE)

SPECIFIC MASS DECREASES EXPONENTIALLY WITH INCREASING POWER. (SEE ATTACHED CURVE)

PHYSICAL DEVELOPMENT PROJECTIONS

CHARACTERISTIC	STATE OF THE ART	PMS REQUIREMENT	ACHIEVABLE CAPABILITY
Size	$0.05\ M^3$	$0.025\ M^3$	$0.025\ M^3$
Weight	40.0 Kg	11.5 Kg	11.5 Kg
Mass	8.0 Kg/KW	2.3 Kg/KW	2.3 Kg/KW
Cooling Requirements	450 WATTS	215 WATTS	215 WATTS
Operating Temp	125°C T_J MAX (WORST CASE);	85°C T_J MAX (TYPICAL)	
Space Radiation Damage	OK	$3 \times 10^{12}\ e/cm^2$	SOTA OK
Pressurization	—	NON-PRESSURIZED	NON-PRESSURIZED
Vibration	SHUTTLE LAUNCH ENV. O.K.	SHUTTLE LAUNCH REQUIREMENTS	SHUTTLE LAUNCH ENV. O.K.

PHYSICAL INTERFACE REQUIREMENTS/CHARACTERISTICS

UNIT DESIGNED TO MOUNT TO COLD PLATE WITH GOOD THERMAL CONDUCTIVITY. HIGH VOLTAGE AND CONV. CONNECTORS

MATERIAL CONSIDERATIONS

MATERIAL FOR HOUSING - SELECTED FOR LIGHT WEIGHT AND GOOD THERMAL CONDUCTIVITY. ALUMINUM OR MAGNESIUM ALLOYS PROBABLE SELECTION.

PMS COMPONENT CHARACTERISTIC DATA SHEET

PART B — PERFORMANCE

COMPONENT NAME DC-DC CONVERTER

FUNCTIONAL CHARACTERISTICS 5.0 KW MODULE DESIGNED TO BE PARALLELED WITH ONE TO FOUR OTHERS AT EACH PAYLOAD INTERFACE FOR DISTRIBUTED 28VDC CONVERSION. HIGH VOLTAGE D.C. INPUT; LOW VOLTAGE D.C. OUTPUT

PERFORMANCE DEVELOPMENT PROJECTIONS

CHARACTERISTIC	STATE OF THE ART	PMS REQUIREMENT	ACHIEVABLE CAPABILITY
Voltage Level	INP DC / OUTP DC 500V	INP DC / OUTP DC 750V / 28V	INP DC / OUTP DC > 750V / 28V
Peak Voltage	500V	900V / 36V	900V / 36V
Current Capability (MAX W.C.)	7.4A / 200A	7.4A / 200A	> 7.4A / 200A
Peak Load	10 KW	5.0KW	> 5.0KW
Efficiency	85 %	95.7 %	95.7%
Reliability	0.959	0.944	0.959
MTBF (Hours)	2.15×10^6	1.58×10^6	2.15×10^6
Peak Load Capability	6.0KW	6.0KW	6.0KW TYP
Operating Frequency	> 20KHZ	> 20 KHZ	> 20KHZ
Magnetic Field	OK	0.47 GAUSS, MAX	OK
Regulation %	± 5%	± 5.0%	± 5.0%
Transient Capability	IN ACCORDANCE WITH THE INTENT OF MIL-STD-1541		
Stability	± 2.0%/ 2 YRS	± 5.0% /10 YRS	± 5.0% /10 YRS
Redundancy	ACCOMPLISHED AT THE 5 KW MODULE LEVEL		

INTERFACE REQUIREMENTS

Control/Monitor SERIAL DATA BUS - WIRED OR OPTICAL; MIL-STD-1553 TYPE

Operational/Safety REDUNDANT SERIAL DATA BUSSES SHARED WITH ABOVE FUNCTIONS

Maintainability/Repair TOTAL 5.0KW MODULE REMOVABLE FOR SYSTEM REPAIR

Other BUILT-IN-TEST PROVISIONS COMMANDED AND MONITORED VIA THE DATA BUS INTERFACE

PARAMETRIC ANALYSIS RESULTS

INPUT VOLTAGE TOO HIGH FOR CURRENT TRANSISTORS.

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PMS COMPONENTS CHARACTERISTIC DATA SHEET
PART A — PHYSICAL

COMPONENT NAME DC- AC INVERTER (DC SYSTEM)

FUNCTION PROVIDE THREE PHASE AC POWER FOR PAYLOADS, DERIVED FROM HIGH VOLTAGE DC BUS.

PHYSICAL DESCRIPTION

COMBINATION OF HIGH POWER SEMICONDUCTORS, MEDIUM POWER DRIVERS, AND MSI / LSI CONTROL, COMMAND, AND DATA INTERFACE CIRCUITRY, MOUNTED IN A NON-SEALED HOUSING / HEAT SINK STRUCTURE. PASSIVE THERMAL DESIGN AUGMENTED BY HEAT PIPES IF REQUIRED.

PARAMETRIC ANALYSIS RESULTS

SPECIFIC VOLUME REMAINS APPROX. CONSTANT WITH INCREASING POWER. (SEE ATTACHED CURVE)

SPECIFIC MASS DECREASES EXPONENTIALLY WITH INCREASING POWER (SEE ATTACHED CURVE)

PHYSICAL DEVELOPMENT PROJECTIONS

CHARACTERISTIC	STATE OF THE ART	PMS REQUIREMENT	ACHIEVABLE CAPABILITY
Size	0.09 M^3	0.044 M^3	0.044 M^3
Weight	70.0 Kg	29.8 Kg	29.8 Kg
Mass	7.0 Kg / KW	2.98 Kg / KW	2.98 Kg / KW
Cooling Requirements	800 WATTS	400 WATTS	400 WATTS
Operating Temp	125°C T_J, MAX (WORST CASE)	85°C T_J, TYPICAL	
Space Radiation Damage	OK	3×10^{12} e/cm²	SOTA OK
Pressurization	—	NON-PRESSURIZED	NON-PRESSURIZED
Vibration	SHUTTLE LAUNCH ENV. OK	SHUTTLE LAUNCH REQUIREMENTS	SHUTTLE LAUNCH ENV. OK

PHYSICAL INTERFACE REQUIREMENTS/CHARACTERISTICS UNIT DESIGNED TO MOUNT TO COLD PLATE WITH GOOD THERMAL CONDUCTIVITY. HIGH VOLTAGE AND CONVENTIONAL CONNECTORS REQ'D.

MATERIAL CONSIDERATIONS MATERIAL FOR HOUSING SELECTED FOR LIGHT WEIGHT AND GOOD THERMAL CONDUCTIVITY. ALUMINUM OR MAGNESIUM ALLOYS PROBABLE SELECTION.

PMS COMPONENT CHARACTERISTIC DATA SHEET

PART B — PERFORMANCE

COMPONENT NAME DC-AC INVERTER

FUNCTIONAL CHARACTERISTICS 10 KW MODULE DESIGNED TO BE PARALLELED WITH (11) OTHERS FOR A CENTRALIZED 100 KW INVERTER. HIGH VOLTAGE D.C. INPUT; LOW VOLTAGE 3 ϕ AC OUTPUT

PERFORMANCE DEVELOPMENT PROJECTIONS

CHARACTERISTIC	STATE OF THE ART	PMS REQUIREMENT	ACHIEVABLE CAPABILITY
Voltage Level	INP. DC 500 V ; OUTP AC 115VRMS	INP DC. 750 V ; OUTP. AC 115V RMS	INP DC 750 V ; OUTP AC 115VRMS
Peak Voltage	500 V , 200V PK	900 V ; 200V PK	900 V ; 200V PK
Current Capability	40 A ; 200 A	13.3 A ; 87.0 A	>13.3 A ; 87.0 A
Peak Load	20 KW	10.0 KW	> 10.0 KW
Efficiency	92%	96%	96%
Reliability	0.955	0.918	0.955
MTBF (Hours)	1.93×10^6	0.8×10^6	1.93×10^6
Peak Load Capability	12.0 KW TYP	12.0 KW TYP	12.0 KW TYP
Operating Frequency	≥ 20-30 KHz	20-30 KHz	≥ 20-30 KHz
Magnetic Field	OK	0.47 GAUSS, MAX	OK
Regulation %	± 50%	± 5%	± 5%
Transient Capability	IN ACCORDANCE WITH THE INTENT		MIL-STD-1541
Stability	± 2% / 2 YRS	± 5% / 10 YEARS	± 5% / 10 YEARS
Redundancy	ACCOMPLISHED AT THE MAJOR MODULE LEVEL		

INTERFACE REQUIREMENTS

Control/Monitor SERIAL DATA BUS - WIRED OR OPTICAL MIL-STD-1553 TYPE

Operational/Safety REDUNDANT SERIAL DATA BUSSES AS ABOVE.

Maintainability/Repair TOTAL 10KW MODULE REMOVABLE FOR SYSTEM REPAIR

Other BUILT-IN-TEST PROVISIONS COMMANDED AND MONITORED VIA THE DATA BUS INTERFACE

PARAMETRIC ANALYSIS RESULTS

INPUT VOLTAGE TOO HIGH FOR PRESENT DEVICES.

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PMS COMPONENTS CHARACTERISTIC DATA SHEET
PART A — PHYSICAL

COMPONENT NAME DC REGULATOR (DC SYSTEM)

FUNCTION PROVIDES A REDUCED, CONTROLLED VOLTAGE FOR HIGH VOLTAGE DC FROM THE HIGH VOLTAGE TRANSMISSION BUS WITHOUT GROUND ISOLATION

PHYSICAL DESCRIPTION

COMBINATION OF HIGH POWER SEMICONDUCTORS, MEDIUM POWER DRIVERS AND MSI / LSI CONTROL, COMMAND, AND INTERFACE CIRCUITRY, MOUNTED IN A NON-SEALED HOUSING / HEAT SINK STRUCTURE. PASSIVE THERMAL DESIGN AUGMENTED BY HEAT PIPES IF REQUIRED.

PARAMETRIC ANALYSIS RESULTS

SPECIFIC VOLUME REMAINS APPROX. CONSTANT WITH INCREASING POWER (SEE ATTACHED CURVE)

SPECIFIC MASS REMAINS APPROX. CONSTANT WITH INCREASING POWER (SEE ATTACHED CURVE)

PHYSICAL DEVELOPMENT PROJECTIONS

CHARACTERISTIC	STATE OF THE ART	PMS REQUIREMENT	ACHIEVABLE CAPABILITY
Size	$0.09\ M^3$	$0.044\ M^3$	$0.044\ M^3$
Weight	60 Kg	23 Kg	23 Kg
Mass	6.0 Kg / Kw	2.3 Kg / Kw	2.3 Kg / Kw
Cooling Requirements	600 WATTS	350 WATTS	350 WATTS
Operating Temp	125°C Tj MAX (WORST CASE)	85°C Tj MAX (TYPICAL)	
Space Radiation Damage	OK	$3 \times 10^{12}\ e/cm^2$	SOTA OK
Pressurization	—	NON-PRESSURIZED	NON-PRESSURIZED
Vibration	SHUTTLE LAUNCH ENV. OK	SHUTTLE LAUNCH REQUIREMENTS	SHUTTLE LAUNCH ENV. OK

PHYSICAL INTERFACE REQUIREMENTS/CHARACTERISTICS UNIT DESIGNED TO MOUNT TO COLD PLATE WITH GOOD THERMAL CONDUCTIVITY. HIGH VOLTAGE AND CONVENTIONAL CONNECTORS REQUIRED.

MATERIAL CONSIDERATIONS
HOUSING MATERIAL SELECTED FOR LIGHT WEIGHT AND GOOD THERMAL CONDUCTIVITY. ALUMINUM OR MAGNESIUM ALLOYS PROBABLE SELECTION.

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PMS COMPONENT CHARACTERISTIC DATA SHEET

PART B — PERFORMANCE

COMPONENT NAME DC REGULATOR

FUNCTIONAL CHARACTERISTICS 10 KW MODULE DESIGNED TO BE PARALLELED WITH (10) OTHERS FOR A CENTRALIZED 100 KW DC REGULATOR. HIGH VOLTAGE DC INPUT; LOWER VOLTAGE (115V) DC OUTPUT; NO GROUND ISOLATION

PERFORMANCE DEVELOPMENT PROJECTIONS

CHARACTERISTIC	STATE OF THE ART	PMS REQUIREMENT	ACHIEVABLE CAPABILITY
Voltage Level	INP / OUTP 200V / 115V	INP / OUTP 750V / 115V	INP / OUTP >750V / 115V
Peak Voltage	500V	900V / 130V	> 900V / 130V
Current Capability	40 A / 200 A	13.3 A / 87.0 A	>13.3 A / 87.0 A
Peak Load	10KW	10KW	10KW
Efficiency	94%	97.52%	97.5%
Reliability	0.983	0.918	0.983
MTBF (Hours)	7.5×10^6	1.05×10^6	7.5×10^6
Peak Load Capability		12.0 KW	12.0 KW
Operating Frequency	NA	NA	NA
Magnetic Field	OK	0.47 GAUSS, MAX	OK
Regulation %	5%	5%	5%
Transient Capability	IN ACCORDANCE	WITH THE INTENT	OF MIL-STD-1541
Stability	±2.0% / 2 YRS	5% / 10 yr	5% / 10 yr.
Redundancy	ACCOMPLISHED	AT THE MAJOR	MODULE LEVEL

INTERFACE REQUIREMENTS

Control/Monitor SERIAL DATA BUS - WIRED OR OPTICAL, MIL-STD-1553 TYPE

Operational/Safety REDUNDANT SERIAL DATA BUSSES, SHARED WITH ABOVE FUNCTIONS

Maintainability/Repair TOTAL 10.0 KW MODULE REMOVED AND REPL FOR SYSTEM REPAIR

Other BUILT-IN-TEST FUNCTIONS COMMANDED AND MONITORED VIA THE DATA BUS INTERFACE

PARAMETRIC ANALYSIS RESULTS

INPUT VOLTAGE TOO HIGH FOR PRESENT DEVICES

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PMS COMPONENTS CHARACTERISTIC DATA SHEET
PART A — PHYSICAL

COMPONENT NAME REGULATOR / BATTERY CHARGER (AC OR DC SYSTEM)

FUNCTION DC REGULATOR, OPERATED IN THE CURRENT FEEDBACK MODE TO PROVIDE A CURRENT SOURCE TYPE OUTPUT FOR BATTERY CHARGING

PHYSICAL DESCRIPTION

COMBINATION OF HIGH POWER SEMICONDUCTORS, MEDIUM POWER DRIVERS, AND MSI/LSI CONTROL, COMMAND, AND INTERFACE CIRCUITRY, MOUNTED IN A NON-SEALED HOUSING/HEAT SINK STRUCTURE, PASSIVE THERMAL DESIGN AUGMENTED BY HEAT PIPES IF REQUIRED.

PARAMETRIC ANALYSIS RESULTS

SPECIFIC VOLUME REMAINS APPROX. CONSTANT WITH INCREASING POWER. (SEE ATTACHED CURVES)

SPECIFIC MASS REMAINS APPROX. CONSTANT WITH INCREASING POWER (SEE ATTACHED CURVE)

PHYSICAL DEVELOPMENT PROJECTIONS

CHARACTERISTIC	STATE OF THE ART	PMS REQUIREMENT	ACHIEVABLE CAPABILITY
Size	$0.122\ M^3$	$0.059\ M^3$	$0.059\ M^3$
Weight	81 Kg	31.05 Kg	31.05 Kg
Mass	6.0 Kg/KW	2.3 Kg/KW	2.3 Kg/KW
Cooling Requirements	810 WATTS	335 WATTS	335 WATTS
Operating Temp	125°C TJ MAX (WORST CASE), 85°C TJ MAX (TYPICAL)		
Space Radiation Damage	OK	$3 \times 10^{12}\ e/cm^2$	SOTA OK
Pressurization	—	NON-PRESSURIZED	NON-PRESSURIZED
Vibration	SHUTTLE LAUNCH ENV. OK	SHUTTLE LAUNCH REQUIREMENTS	SHUTTLE LAUNCH ENV. OK

PHYSICAL INTERFACE REQUIREMENTS/CHARACTERISTICS UNIT DESIGNED TO MOUNT TO COLD PLATE WITH GOOD THERMAL CONDUCTIVITY. HIGH VOLTAGE AND CONVENTIONAL CONNECTORS REQUIRED.

MATERIAL CONSIDERATIONS

HOUSING MATERIAL SELECTED FOR LIGHT WEIGHT AND GOOD THERMAL CONDUCTIVITY. ALUMINUM OR MAGNESIUM ALLOYS PROBABLE SELECTION.

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PMS COMPONENT CHARACTERISTIC DATA SHEET

PART B — PERFORMANCE

COMPONENT NAME REGULATOR/BATTERY CHARGER (AC SYSTEM)

FUNCTIONAL CHARACTERISTICS 13.5KW DC REGULATOR MODULE DESIGNED TO BE PARALLELED WITH (10) OTHERS AND OPERATED IN A CURRENT FEEDBACK MODE TO ACT AS A CENTRALIZED CONTROL FOR CURRENT SOURCE BATTERY CHARGING. LOW VOLTAGE INPUT AND OUTPUT TO MATCH BEST BATTERY CHARACTERISTICS AND SERIES/PARALLEL COMBINATIONS FOR RELIABILITY.

PERFORMANCE DEVELOPMENT PROJECTIONS

CHARACTERISTIC	STATE OF THE ART	PMS REQUIREMENT	ACHIEVABLE CAPABILITY
Voltage Level	> 200-400V	200-400V	> 200-400V
Peak Voltage	> 220-440V	220-440V	> 220-440V
Current Capability	> 67.5A - 33.8A	67.5A - 33.8A	> 67.5A - 33.8A
Peak Load	20KW	13.5KW	> 13.5KW
Efficiency	94%	97.5%	97.5%
Reliability	0.983	0.918	0.983
MTBF (Hours)	7.5×10^6	1.05×10^6	7.5×10^6
Peak Load Capability	20.0KW	15KW	15KW
Operating Frequency	>20KHz	> 20KHz	> 20KHz
Magnetic Field	OK	0.47 GAUSS, MAX	OK
Regulation %	5%	5%	5%
Transient Capability	IN ACCORDANCE	WITH THE INTENT	OF MIL-STD-1541
Stability	±2.0%/2YRS	5%/10yr	5%/10yr
Redundancy	ACCOMPLISHED AT	THE MAJOR MODULE	LEVEL

INTERFACE REQUIREMENTS

Control/Monitor SERIAL DATA BUS; WIRED OR OPTICAL; MIL-STD-1553 TYPE

Operational/Safety REDUNDANT SERIAL DATA BUSSES, SHARED WITH ABOVE FUNCT.

Maintainability/Repair TOTAL 13.5KW MODULES REMOVED AND REPL. FOR SYSTEM REPAIR

Other BUILT-IN-TEST FUNCTIONS COMMANDED AND MONITORED VIA THE DATA BUS INTERFACE

PARAMETRIC ANALYSIS RESULTS

NO NEW PIECE PARTS REQUIRED.

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PMS COMPONENT CHARACTERISTIC DATA SHEET

PART B — PERFORMANCE

COMPONENT NAME REGULATOR / BATTERY CHARGER (DC SYSTEM)

FUNCTIONAL CHARACTERISTICS 13.5 KW DC REGULATOR MODULE DESIGNED TO BE PARALLELED WITH (10) OTHERS AND OPERATED IN A CURRENT FEEDBACK MODE TO ACT AS A CENTRALIZED CONTROL FOR CURRENT SOURCE BATTERY CHARGING. HIGH VOLTAGE INPUT AND OUTPUT BASED ON OVERALL SYSTEM CONSTRAINTS AND COMPROMIZES.

PERFORMANCE DEVELOPMENT PROJECTIONS

CHARACTERISTIC	STATE OF THE ART	PMS REQUIREMENT	ACHIEVABLE CAPABILITY
Voltage Level	500V	750 V	750V
Peak Voltage	500 V	900V	900 V
Current Capability	18 A	18 A	18 A
Peak Load	20.0 KW	13.5 KW	13.5 KW
Efficiency	94%	97.5%	97.5%
Reliability	0.983	0.918	0.983
MTBF (Hours)	7.5×10^6	1.05×10^6	7.5×10^6
Peak Load Capability	20.0 KW	15 KW	15 KW
Operating Frequency	> 20 KHZ	> 20 KHZ	> 20 KHZ
Magnetic Field	OK	0.47 GAUSS, MAX	OK
Regulation %	5%	5%	5%
Transient Capability	IN ACCORDANCE	WITH THE INTENT	OF MIL-STD-1541
Stability	± 2.0% / 2 yr.	5% / 10 yr	5% / 10 yr
Redundancy	ACCOMPLISHED AT	THE MAJOR MODULE	LEVEL

INTERFACE REQUIREMENTS

Control/Monitor SERIAL DATA BUS; WIRED OR OPTICAL; MIL-STD-1553 TYPE

Operational/Safety REDUNDANT SERIAL DATA BUSSES, SHARED WITH ABOVE FUNCT.

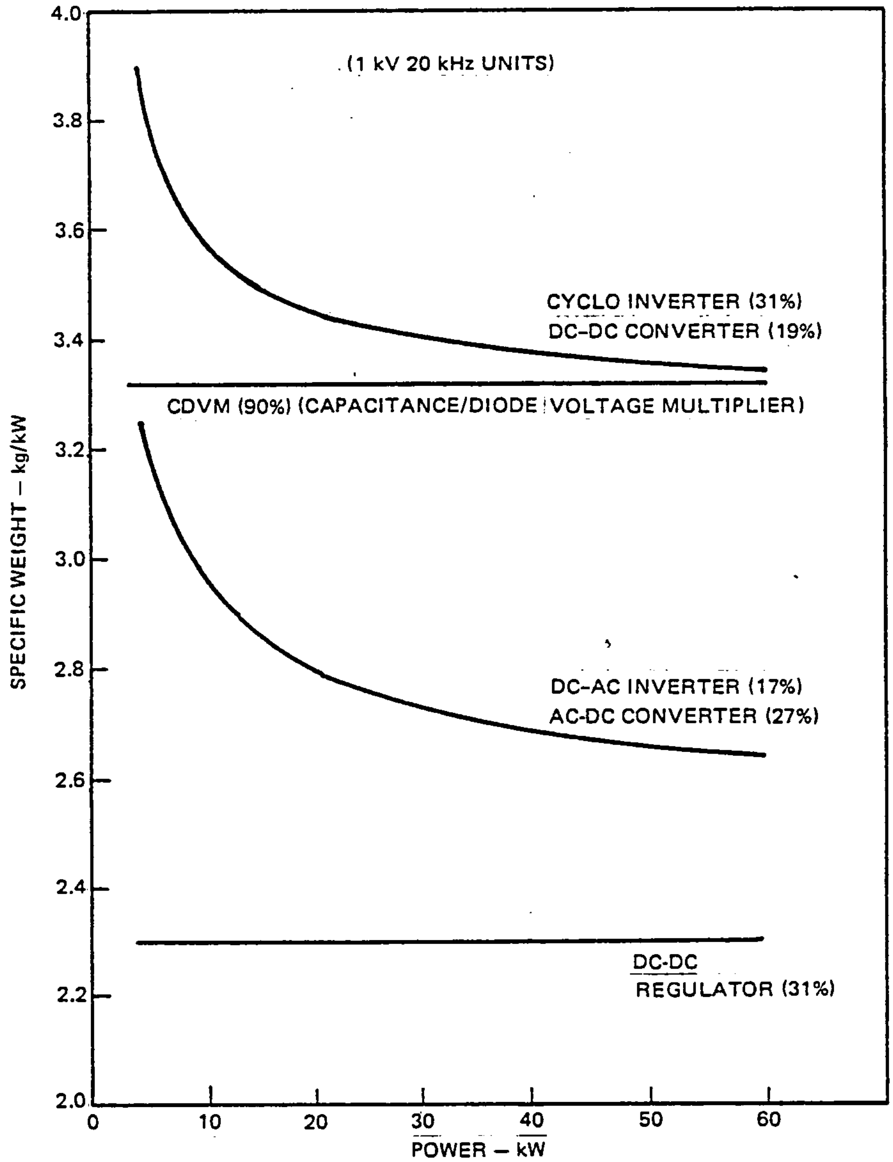
Maintainability/Repair TOTAL 13.5 KW MODULES REMOVED AND REPL. FOR SYSTEM REPAIR

Other BUILT-IN-TEST FUNCTIONS COMMANDED AND MONITORED VIA THE DATA BUS INTERFACE

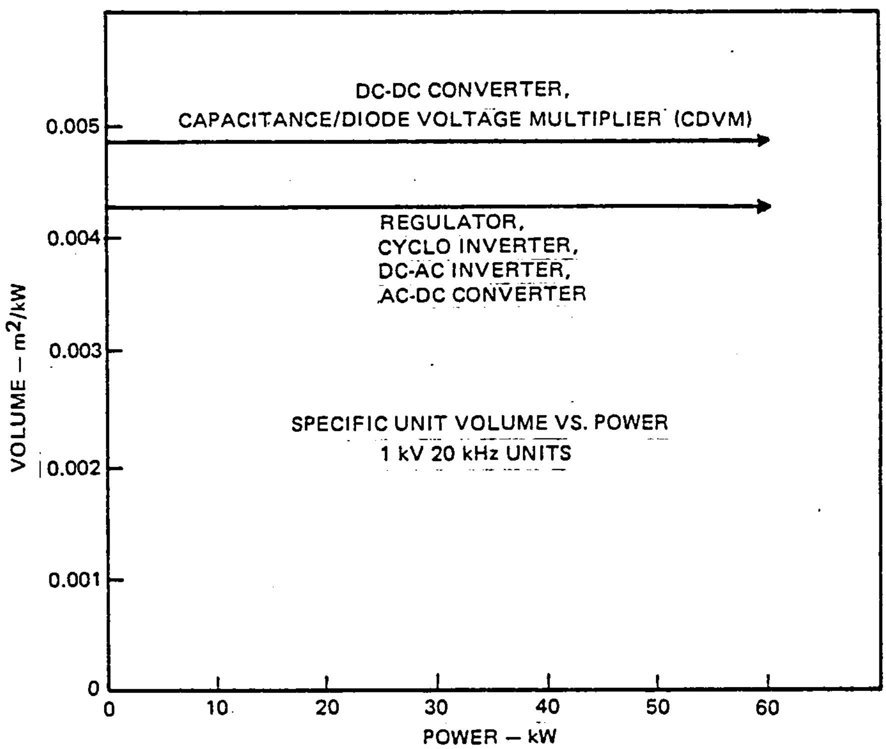
PARAMETRIC ANALYSIS RESULTS

INPUT VOLTAGE TOO HIGH FOR PRESENT DEVICES

NOTE: NUMBERS IN ( ) ARE % INCREASES TO RAISE THE RELIABILITY OF A 10 kW UNIT FROM THE SIMPLEX BASE NUMBER SHOWN IN FIGURE 3-53a TO A VALUE OF 0.99.



Specific mass relationships for PMS major components.



Specific volume relationships for PMS major components.

PMS COMPONENTS CHARACTERISTIC DATA SHEET
PART A — PHYSICAL

COMPONENT NAME SLIP RINGS

FUNCTION PROVIDE ROTARY JOINT POWER TRANSFER FROM SOLAR ARRAY WINGS TO MAIN BODY OF SPACE PLATFORM.

PHYSICAL DESCRIPTION

ASSEMBLY OF TWO GROUPS OF FOUR SLIP RINGS EACH, TO PROVIDE REDUNDANT POWER TRANSFER ACROSS THE SPACE PLATFORM ROTARY JOINT. EACH HALF SUPPLIES ONE SIDE OF A REDUNDANT BUS SYSTEM CAPABLE OF CARRYING THE FULL LOAD, BUT NOMINALLY CARRYING HALF LOAD.

PARAMETRIC ANALYSIS RESULTS

SPECIFIC MASS DECREASES APPROX. LINEARLY WITH POWER IN THE RANGE OF INTEREST.

SPECIFIC VOLUME DECREASES APPROX. LINEARLY WITH POWER IN THE RANGE OF INTEREST.

PHYSICAL DEVELOPMENT PROJECTIONS

CHARACTERISTIC	STATE OF THE ART	PMS REQUIREMENT	ACHIEVABLE CAPABILITY
Size (TOTAL - 8 RINGS)	0.168 M^3	0.168 M^3	< 0.168 M^3
Weight (TOTAL - 8 RINGS)	90.4 Kg.	90.4 Kg	< 90.4 Kg.
Mass (NOT INCL. STRUCT. SUPP)	0.113 Kg/KW	0.113 Kg/KW	< 0.11 Kg/KW
Cooling Requirements	100 W	100 W	100 W
Operating Temp	OK	−200 TO +125°C	SOTA OK
Space Radiation Damage	OK	3×10^{12} e/cm²	SOTA OK
Pressurization	MAJOR ASSEMBLY NON-PRESSURIZED		
Vibration	OK	SHUTTLE LAUNCH REQUIREMENTS	OK

PHYSICAL INTERFACE REQUIREMENTS/CHARACTERISTICS

MECHANICAL DESIGN MUST BE PART OF AN INTEGRATED SPACE PLATFORM ROTARY JOINT STRUCTURE.

MATERIAL CONSIDERATIONS

NOT A SIGNIFICANT DRIVER

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PMS COMPONENT CHARACTERISTIC DATA SHEET

PART B — PERFORMANCE

COMPONENT NAME SLIP RINGS

FUNCTIONAL CHARACTERISTICS EIGHT SLIP RINGS IN TWO FUNCTIONAL GROUPS OF FOUR EACH. EACH INDIVIDUAL SLIP RING IS CAPABLE OF TRANSMITTING 100KW AT 750 VDC AT END OF LIFE OR 100KW AT 1500 VDC AT BEGINNING OF LIFE. UNDER "NO - FAILURE" CONDITIONS, THE NOMINAL LOAD WILL BE 50KW.

PERFORMANCE DEVELOPMENT PROJECTIONS (PER SINGLE SLIP RING)

CHARACTERISTIC	STATE OF THE ART	PMS REQUIREMENT	ACHIEVABLE CAPABILITY
Voltage Level	1200 VDC	750 VDC	> 1200 VDC
Peak Voltage	1200 VDC	1500 VDC	>1500 VDC
Current Capability	100 AMP	133 AMP	> 150 AMP
Peak Load	120 KW	100 KW	225 KW
Efficiency	99.9 %	99.9 %	99.9 %
Reliability	0.85	0.938	> 0.94 *
MTBF (Hours)	0.53×10^6	1.40×10^6	$> 1.4 \times 10^6$
Peak Load Capability	120 KW	120 KW	> 120 KW
Operating Frequency	DC	DC	DC
Magnetic Field	OK	0.47 GAUSS, MAX	OK
Regulation %	NA	NA	NA
Transient Capability	IN ACCORDANCE WITH THE INTENT OF MIL-STD-1541		
Stability	10 YEARS	10 YEAR LIFE	> 10 YEARS
Redundancy	ACCOMPLISHED BY REDUNDANT SLIP RINGS		

INTERFACE REQUIREMENTS

Control/Monitor PROVISIONS TO MONITOR CURRENT AND VOLTAGE

Operational/Safety ASTRONAUT PROTECTION DURING ASSEMBLY REPAIR.

Maintainability/Repair INTEGRATED STRUCTURE SHOULD BE DESIGNED FOR REMOVAL AND REPLACEMENT OF A FAILED SLIP RING IN ORBIT

Other MONITOR FUNCTIONS SHOULD BE COMPATABLE WITH THE DATA BUS COMMUNICATION SYSTEM.

PARAMETRIC ANALYSIS RESULTS

PRESENT STATE OF THE ART IS NEARLY ADEQUATE FOR THIS APPLICATION.

QUALIFICATION TESTS AND OTHER SIMILIAR PROOFS OF DESIGN ADEQUACY AND LIFE WILL BE REQUIRED.

* VENDORS OPINION - PROOF OF RELIABILITY WILL BE REQUIRED

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PMS COMPONENTS CHARACTERISTIC DATA SHEET
PART A — PHYSICAL

COMPONENT NAME SWITCHGEAR (ELECTRO-MECHANICAL)

FUNCTION PROVIDE SWITCH FUNCTIONS FOR CONFIGURATION CHANGES, MODULE CONNECTION, REDUNDANCY MANAGEMENT, BATTERY CONTROL, POWER ON/OFF, MODULAR ISOLATION

PHYSICAL DESCRIPTION

SEMICONDUCTOR POWER SWITCHING DEVICES, MEDIUM POWER DRIVERS, AND MSI/LSI CONTROL, COMMAND, AND DATA INTERFACE CIRCUITRY MOUNTED IN A NON-SEALED HOUSING/HEAT SINK STRUCTURE. PASSIVE THERMAL DESIGN AUGMENTED BY HEAT PIPES IF NECESSARY.

PARAMETRIC ANALYSIS RESULTS

SPECIFIC MASS AND VOLUME DECREASE EXPONENTIALLY (DIFFERENT) WITH INCREASING POWER. (SEE ATTACHED CURVES)

PHYSICAL DEVELOPMENT PROJECTIONS

CHARACTERISTIC	STATE OF THE ART	PMS REQUIREMENT	ACHIEVABLE CAPABILITY
Size	SEE ATTACHED	TABLE	
Weight	SEE ATTACHED	TABLE	
Mass	SEE ATTACHED	TABLE	
Cooling Requirements	SEE ATTACHED	TABLE	
Operating Temp	125°C T_J MAX (WORST CASE),	85°C T_J	MAX (TYPICAL)
Space Radiation Damage	OK	3×10^{12} e/cm^2	SOTA OK
Pressurization	MAJOR ASSEMBLY	NON-PRESSURIZED	
Vibration	SHUTTLE LAUNCH ENV. OK	SHUTTLE LAUNCH REQUIREMENTS	SHUTTLE LAUNCH ENV. OK

PHYSICAL INTERFACE REQUIREMENTS/CHARACTERISTICS UNIT DESIGNED TO MOUNT TO COLD PLATE WITH GOOD THERMAL CONDUCTIVITY. HIGH VOLTAGE AND CONVENTIONAL CONNECTORS REQ'D. MULTIPLE RPC'S MAY BE MOUNTED IN A SINGLE UNIT.

MATERIAL CONSIDERATIONS

MATERIAL FOR HOUSING SELECTED FOR LIGHT WEIGHT AND GOOD THERMAL CONDUCTIVITY. ALUMINUM OR MAGNESIUM ALLOYS PROBABLE SELECTION.

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Table 1. Switchgear physical characteristics - electromechanical switches.

POWER	AC/DC	FORM	FUNCTION	SIZE ($m^3 \times 10^{-3}$)	WEIGHT (kg)	MASS (kg/kW) (SPST)	DISSIPATION (WATTS)
AC SYSTEM							
25.0 kW	DC	DPDT	Inv. Inpt. Isol.	1.0	1.55	0.031	250
25.0 kW	AC	DPDT	Inv. Mod. Outp. Isol.	1.0	1.55	0.031	250
5.0 kW	AC	DPDT	Payl. Mod. Inpt. Isol.	0.2	0.56	0.056	50
15.0 kW	AC	DPDT	Payl. Unreg. Pwr. Isol.	0.6	1.05	0.035	150
DC SYSTEM							
100.0 kW	DC	SPDT	Slip Ring Inp/Outp. Isol.	—	—	NA	—
15.0 kW	DC	DPDT	Payl. Unreg. Pwr. Isol.	0.6	1.05	0.035	150
10.0 kW	DC	DPDT	Conv/Reg. Inp. Isol.	0.4	0.84	0.042	100
10.0 kW	DC	DPDT	Conv/Reg. Outp. Isol.	0.4	0.84	0.042	100
10.0 kW	AC	3PDT	AC Inv. Outp. Isol.	0.6	1.26	0.042	100
5.0 kW	DC	DPDT	DC Bus Payl. Isol.	0.2	0.56	0.056	50
5.0 kW	AC	3PDT	AC Bus Payl. Isol.	0.3	0.84	0.056	50
5.0 kW	DC	DPDT	Distr. Payl. Conv/Regl. Isol.	0.2	0.56	0.056	50
AC OR DC SYSTEM							
13.5 kW	DC	DPDT	Batt Chg Inp/Outp Isol.	0.54	0.945	0.035	135

PMS COMPONENT CHARACTERISTIC DATA SHEET
PART B — PERFORMANCE

COMPONENT NAME SWITCHGEAR (ELECTRO MECHANICAL)

FUNCTIONAL CHARACTERISTICS FORM: DPDT (ON-OFF-ON)
POWER TYPE: HIGH VOLTAGE D.C.
RATING: POWER - 10.0KW VOLTAGE - 750VDC
SYSTEM FUNCTION: INPUT ISOLATION FROM TRANSMISSION BUSSES FOR CONVERTER/REGULATOR MODULES (DC SYSTEM)
PROVISIONS TO MONITOR VOLTAGE AND CURRENT; DATA AND COMMANDS TRANSMITTED VIA SERIAL DATA BUS

PERFORMANCE DEVELOPMENT PROJECTIONS

CHARACTERISTIC	STATE OF THE ART	PMS REQUIREMENT	ACHIEVABLE CAPABILITY
Voltage Level	1500 VDC	750 VDC	> 1500 VDC
Peak Voltage	1500 VDC	1500 VDC	> 1500 VDC
Current Capability	17 A DC	13.3 ADC	> 17 A DC
Peak Load	25.0 KW	10.0 KW	> 25.0 KW
Efficiency	99.9%	99.9%	99.9%
Reliability	0.932	0.944	> 0.944
MTBF (Hours)	1.3×10^6	1.58×10^6	$> 1.58 \times 10^6$
Peak Load Capability	25.0 KW	12.0 KW	> 25.0 KW
Operating Frequency	OK	HALF CYCLE @ 25 KHZ	OK
Magnetic Field	OK	0.47 GAUSS, MAX	OK
Regulation %	NA	NA	NA
Transient Capability	IN ACCORDANCE WITH	THE INTENT OF	MIL-STD-1541
Stability	NA	NA	NA
Redundancy	ACCOMPLISHED AT	THE MAJOR MODULE LEVEL	

INTERFACE REQUIREMENTS

Control/Monitor SERIAL DATA BUS - WIRED OR OPTICAL; MIL-STD-1553 TYPE

Operational/Safety REDUNDANT SERIAL DATA BUSSES SHARED WITH ABOVE FUNCTIONS.

Maintainability/Repair EACH SWITCH UNIT (OR RPC) REMOVABLE AND REPLACED FOR SYSTEM REPAIR.

Other BUILT-IN-TEST PROVISIONS COMMANDED AND MONITORED VIA THE DATA BUS INTERFACE.

PARAMETRIC ANALYSIS RESULTS

STATE OF THE ART EXCEEDS REQUIREMENTS

3652-72

PMS COMPONENT CHARACTERISTIC DATA SHEET

PART B — PERFORMANCE

COMPONENT NAME SWITCHGEAR (ELECTROMECHANICAL)

FUNCTIONAL CHARACTERISTICS FORM: DPDT (ON-OFF-ON)
POWER TYPE: HIGH VOLTAGE, DC
RATING: POWER - 15.0 KW VOLTAGE - 750 VDC
SYSTEM FUNCTION: UNREGULATED POWER PAYLOAD ISOLATION FROM DISTRIBUTION SYSTEM. (DC SYSTEM)
PROVISIONS TO MONITOR VOLTAGE AND CURRENT; DATA AND COMMANDS TRANSMITTED VIA SERIAL DATA BUS

PERFORMANCE DEVELOPMENT PROJECTIONS

CHARACTERISTIC	STATE OF THE ART	PMS REQUIREMENT	ACHIEVABLE CAPABILITY
Voltage Level	1500 VDC	750 VDC	> 1500 VDC
Peak Voltage	1500 VDC	1500 VDC	> 1500 VDC
Current Capability	17 ADC	20 ADC	> 20 ADC
Peak Load	25.0 KW	15.0 KW	25.0 KW
Efficiency	99.9%	99.9%	99.9%
Reliability	0.925	0.900	SOTA OK
MTBF (Hours)	1.2×10^6	0.80×10^6	SOTA OK
Peak Load Capability	25.0 KW	18.0 KW	> 25.0 KW
Operating Frequency	OK	HALF CYCLE @ 25 KHZ	OK
Magnetic Field	OK	0.47 GAUSS, MAX	OK
Regulation %	NA	NA	NA
Transient Capability	IN ACCORDANCE WITH	THE INTENT OF	MIL-STD-1541
Stability	NA	NA	NA
Redundancy	ACCOMPLISHED AT	THE MAJOR MODULE	LEVEL

INTERFACE REQUIREMENTS

Control/Monitor SERIAL DATA BUS - WIRED OR OPTICAL; MIL-STD-1553 TYPE

Operational/Safety REDUNDANT SERIAL DATA BUSSES SHARED WITH ABOVE FUNCTIONS.

Maintainability/Repair EACH SWITCH UNIT (OR RPC) REMOVABLE AND REPLACED FOR SYSTEM REPAIR.

Other BUILT-IN-TEST PROVISIONS COMMANDED AND MONITORED VIA THE DATA BUS INTERFACE.

PARAMETRIC ANALYSIS RESULTS

STATE OF THE ART EXCEEDS REQUIREMENTS

3662-92

PMS COMPONENT CHARACTERISTIC DATA SHEET
PART B — PERFORMANCE

COMPONENT NAME SWITCHGEAR (ELECTROMECHANICAL)

FUNCTIONAL CHARACTERISTICS FORM: SPDT (ON-OFF-ON)
POWER TYPE: HIGH VOLTAGE, DC
RATING: POWER - 100 KW VOLTAGE - 750 VDC
SYSTEM FUNCTION: INDIVIDUAL SLIP RING INPUT ISOLATION FROM SOLAR ARRAY BUSSES (DC SYSTEM)
PROVISIONS TO MONITOR VOLTAGE AND CURRENT; DATA AND COMMANDS TRANSMITTED VIA SERIAL DATA BUS

PERFORMANCE DEVELOPMENT PROJECTIONS

CHARACTERISTIC	STATE OF THE ART	PMS REQUIREMENT	ACHIEVABLE CAPABILITY
Voltage Level	850 VDC	750 VDC	> 750 VDC
Peak Voltage	850 VDC	1500 VDC	> 1500 VDC
Current Capability	150 A DC	133 AMP DC	> 133 ADC
Peak Load	113 KW	100 KW	> 100 KW
Efficiency	99.9 %	99.9 %	99.9 %
Reliability	0.808	0.938	0.85
MTBF (Hours)	0.4×10^6	1.40×10^6	0.52×10^6
Peak Load Capability	113 KW	120 KW	< 120 KW
Operating Frequency	OK	HALF CYCLE @ 25 KHZ	OK
Magnetic Field	OK	0.47 GAUSS, MAX	OK
Regulation %	NA	NA	NA
Transient Capability	IN ACCORDANCE WITH	THE INTENT OF	MIL-STD-1541
Stability	NA	NA	NA
Redundancy	ACCOMPLISHED AT THE MAJOR MODULE LEVEL		

INTERFACE REQUIREMENTS

Control/Monitor SERIAL DATA BUS - WIRED OR OPTICAL; MIL-STD-1553 TYPE

Operational/Safety REDUNDANT SERIAL DATA BUSSES SHARED WITH ABOVE FUNCTIONS.

Maintainability/Repair EACH SWITCH UNIT (OR RPC) REMOVABLE AND REPLACED FOR SYSTEM REPAIR.

Other BUILT-IN-TEST PROVISIONS COMMANDED AND MONITORED VIA THE DATA BUS INTERFACE.

PARAMETRIC ANALYSIS RESULTS

ACHIEVABLE CAPABILITY MEETS REQUIREMENTS, NORMAL INDUSTRIAL DEVELOPMENT.

STATISTICAL RELIABILITY MAY DEMAND REDUNDANT SWITCHES.

3652-75

PMS COMPONENT CHARACTERISTIC DATA SHEET

PART B — PERFORMANCE

COMPONENT NAME SWITCHGEAR (ELECTRO MECHANICAL)

FUNCTIONAL CHARACTERISTICS FORM : DPDT (ON-OFF-ON)
POWER TYPE : MEDIUM VOLTAGE DC
RATING : POWER - 25.0KW VOLTAGE - 440 VDC, MAX
SYSTEM FUNCTION : INPUT ISOLATION FOR AC INVERTER MODULES AT SOLAR ARRAY BUSSES (AC SYSTEM)
PROVISIONS TO MONITOR VOLTAGE AND CURRENT; DATA AND COMMANDS TRANSMITTED VIA SERIAL DATA BUS

PERFORMANCE DEVELOPMENT PROJECTIONS

CHARACTERISTIC	STATE OF THE ART	PMS REQUIREMENT	ACHIEVABLE CAPABILITY
Voltage Level	850 VDC	440 VDC MAX	> 850 VDC
Peak Voltage	850 VDC	800 VDC	> 850 VDC
Current Capability	150 ADC	60 AMP	150 ADC
Peak Load	113 KW	25.0KW	113 KW
Efficiency	99.9%	99.9%	99.9%
Reliability	0.911	0.913	SOTA OK
MTBF (Hours)	$0,9 \times 10^6$	$0,96 \times 10^6$	SOTA OK
Peak Load Capacility	113 KW	30.0KW	113KW
Operating Frequency	OK	HALF CYCLE @ 25 KHz	OK
Magnetic Field	OK	0.47 GAUSS, MAX	OK
Regulation %	NA	NA	NA
Transient Capability	IN ACCORDANCE WITH THE INTENT OF MIL-STD-1541		
Stability	NA	NA	NA
Redundancy	ACCOMPLISHED AT THE MAJOR MODULE LEVEL		

INTERFACE REQUIREMENTS

Control/Monitor SERIAL DATA BUS - WIRED OR OPTICAL ; MIL-STD-1553 TYPE

Operational/Safety REDUNDANT SERIAL DATA BUSSES SHARED WITH ABOVE FUNCTIONS.

Maintainability/Repair EACH SWITCH UNIT (OR RPC) REMOVABLE AND REPLACED FOR SYSTEM REPAIR.

Other BUILT-IN-TEST PROVISIONS COMMANDED AND MONITORED VIA THE DATA BUS INTERFACE.

PARAMETRIC ANALYSIS RESULTS

STATE OF THE ART EXCEEDS REQUIREMENTS

PMS COMPONENT CHARACTERISTIC DATA SHEET

PART B — PERFORMANCE

COMPONENT NAME SWITCHGEAR (ELECTRO MECHANICAL)

FUNCTIONAL CHARACTERISTICS FORM: DPDT (ON-OFF-ON)
POWER TYPE: MEDIUM VOLTAGE, AC
RATING: POWER - 25.0KW VOLTAGE - 440 VAC, PK
SYSTEM FUNCTION: MODULE OUTPUT ISOLATION FOR DC-AC INVERTER MODULES AT ROTARY TRANSFORMER (AC SYSTEM)
PROVISIONS TO MONITOR VOLTAGE AND CURRENT; DATA AND COMMANDS TRANSMITTED VIA SERIAL DATA BUS

PERFORMANCE DEVELOPMENT PROJECTIONS

CHARACTERISTIC	STATE OF THE ART	PMS REQUIREMENT	ACHIEVABLE CAPABILITY
Voltage Level	850 VDC	440 VAC PK	850 V AC PK
Peak Voltage	850 VDC	800 VAC PK	850 V AC PK
Current Capability	150 ADC	60 AMP	150 A
Peak Load	113 KW	25.0 KW	113 KW
Efficiency	99.9%	99.9%	99.9%
Reliability	0.911	0.913	SOTA OK
MTBF (Hours)	0.9×10^6	0.96×10^6	SOTA OK
Peak Load Capability	113 KW	30.0 KW	113 KW
Operating Frequency	OK	HALF CYCLE @ 25 KHZ	OK
Magnetic Field	OK	0.47 GAUSS, MAX	OK
Regulation %	NA	NA	NA
Transient Capability	IN ACCORDANCE WITH THE INTENT OF MIL-STD-1541		
Stability	NA	NA	NA
Redundancy	ACCOMPLISHED AT THE MAJOR MODULE LEVEL		

INTERFACE REQUIREMENTS

Control/Monitor SERIAL DATA BUS - WIRED OR OPTICAL; MIL-STD-1553 TYPE

Operational/Safety REDUNDANT SERIAL DATA BUSSES SHARED WITH ABOVE FUNCTIONS.

Maintainability/Repair EACH SWITCH UNIT (OR RPC) REMOVABLE AND REPLACED FOR SYSTEM REPAIR.

Other BUILT-IN-TEST PROVISIONS COMMANDED AND MONITORED VIA THE DATA BUS INTERFACE.

PARAMETRIC ANALYSIS RESULTS

STATE OF THE ART EXCEEDS REQUIREMENTS

3652-95

PMS COMPONENT CHARACTERISTIC DATA SHEET

PART B — PERFORMANCE

COMPONENT NAME SWITCH GEAR (ELECTROMECHANICAL)

FUNCTIONAL CHARACTERISTICS FORM : DPDT (ON-OFF-ON)
POWER TYPE : MEDIUM VOLTAGE , AC
RATING : POWER - 5.0KW VOLTAGE - 440 VAC PK. MAX
SYSTEM FUNCTION : ARRAY INTERFACE UNIT MODULE ISOLATION FROM DISTRIBUTION BUS SYSTEM (AC SYSTEM)
PROVISIONS TO MONITOR VOLTAGE AND CURRENT ; DATA AND COMMANDS TRANSMITTED VIA SERIAL DATA BUS

PERFORMANCE DEVELOPMENT PROJECTIONS

CHARACTERISTIC	STATE OF THE ART	PMS REQUIREMENT	ACHIEVABLE CAPABILITY
Voltage Level	850 V PK	440 VAC PK.	> 850 VPK
Peak Voltage	850 VPK	500 VAC PK	> 850 VPK
Current Capability	150 A	12 AMP	> 150 A
Peak Load	113 KW	5.0 KW	> 113 KW
Efficiency	99.9%	99.9%	99.9%
Reliability	0.938	0.92	SOTA OK
MTBF (Hours)	1.4×10^6	1.08×10^6	SOTA OK
Peak Load Capability	113 KW	6.0 KW	> 113 KW
Operating Frequency	OK	HALF CYCLE @ 25 KHZ	OK
Magnetic Field	OK	0.47 GAUSS, MAX	OK
Regulation %	NA	NA	NA
Transient Capability	IN ACCORDANCE WITH	THE INTENT OF	MIL-STD-1541
Stability	NA	NA	NA
Redundancy	ACCOMPLISHED AT	THE MAJOR MODULE	LEVEL

INTERFACE REQUIREMENTS

Control/Monitor SERIAL DATA BUS - WIRED OR OPTICAL ; MIL-STD-1553 TYPE

Operational/Safety REDUNDANT SERIAL DATA BUSSES SHARED WITH ABOVE FUNCTIONS.

Maintainability/Repair EACH SWITCH UNIT (OR RPC) REMOVABLE AND REPLACED FOR SYSTEM REPAIR.

Other BUILT-IN TEST PROVISIONS COMMANDED AND MONITORED VIA THE DATA BUS INTERFACE.

PARAMETRIC ANALYSIS RESULTS

STATE OF THE ART EXCEEDS REQUIRMENTS

3652-75

PMS COMPONENT CHARACTERISTIC DATA SHEET

PART B — PERFORMANCE

COMPONENT NAME SWITCHGEAR (ELECTROMECHANICAL)

FUNCTIONAL CHARACTERISTICS FORM: DPDT (ON-OFF-ON)
POWER TYPE: HIGH VOLTAGE, AC
RATING: POWER - 15.0 KW VOLTAGE - 1000 VAC RMS
SYSTEM FUNCTION: UNREGULATED POWER PAYLOAD ISOLATION FROM DISTRIBUTION BUS SYSTEM (AC SYSTEM)
PROVISIONS TO MONITOR VOLTAGE AND CURRENT; DATA AND COMMANDS TRANSMITTED VIA SERIAL DATA BUS

PERFORMANCE DEVELOPMENT PROJECTIONS

CHARACTERISTIC	STATE OF THE ART	PMS REQUIREMENT	ACHIEVABLE CAPABILITY
Voltage Level	2500 VRMS	1000 VAC RMS	2500 VRMS
Peak Voltage	2500 VRMS	1700 V PK.	2500 VRMS
Current Capability	10.0 A	15 AMP RMS	> 15 A
Peak Load	25.0 KW	15.0 KW	25.0 KW
Efficiency	99.9%	99.9%	99.9%
Reliability	0.925	0.900	SOTA OK
MTBF (Hours)	1.2×10^6	0.8×10^6	SOTA OK
Peak Load Capability	25.0 KW	18.0 KW	25.0 KW
Operating Frequency	OK	HALF CYCLE @ 25 KHZ	OK
Magnetic Field	OK	0.47 GAUSS, MAX	OK
Regulation %	NA	NA	NA
Transient Capability	IN ACCORDANCE WITH THE INTENT OF MIL-STD-1541		
Stability	NA	NA	NA
Redundancy	ACCOMPLISHED AT THE MAJOR MODULE LEVEL		

INTERFACE REQUIREMENTS

Control/Monitor: SERIAL DATA BUS - WIRED OR OPTICAL; MIL-STD-1553 TYPE

Operational/Safety: REDUNDANT SERIAL DATA BUSSES SHARED WITH ABOVE FUNCTIONS.

Maintainability/Repair: EACH SWITCH UNIT (OR RPC) REMOVABLE AND REPLACED FOR SYSTEM REPAIR.

Other: BUILT-IN-TEST PROVISIONS COMMANDED AND MONITORED VIA THE DATA BUS INTERFACE.

PARAMETRIC ANALYSIS RESULTS

ACHIEVABLE CAPABILITY MEETS REQUIREMENTS THROUGH NORMAL INDUSTRY DEVELOPMENT.

3662 75

PMS COMPONENT CHARACTERISTIC DATA SHEET

PART B — PERFORMANCE

COMPONENT NAME SWITCHGEAR (ELECTROMECHANICAL)

FUNCTIONAL CHARACTERISTICS FORM: DPDT (ON-OFF-ON)
POWER TYPE: LOW VOLTAGE, DC
RATING: POWER - 10.0KW VOLTAGE - 115VDC
SYSTEM FUNCTION: OUTPUT ISOLATION FROM DISTRIBUTION BUSSES FOR CONV/REGL MODULES (DC SYSTEM)
PROVISIONS TO MONITOR VOLTAGE AND CURRENT; DATA AND COMMANDS TRANSMITTED VIA SERIAL DATA BUS

PERFORMANCE DEVELOPMENT PROJECTIONS

CHARACTERISTIC	STATE OF THE ART	PMS REQUIREMENT	ACHIEVABLE CAPABILITY
Voltage Level	120 VDC	115 VDC	> 120 VDC
Peak Voltage	160 VDC	140 VDC	> 160 VDC
Current Capability	90 ADC	87 ADC	> 90 ADC
Peak Load	12.0 KW	10.0 KW	> 12.0 KW
Efficiency	99.9%	99.9%	99.9%
Reliability	0.932	0.918	SOTA OK
MTBF (Hours)	1.3×10^6	0.8×10^6	SOTA OK
Peak Load Capability	12.0 KW	12.0 KW	> 12.0 KW
Operating Frequency	OK	HALF CYCLE @ 25 KHZ	OK
Magnetic Field	OK	0.47 GAUSS, MAX	OK
Regulation %	NA	NA	NA
Transient Capability	IN ACCORDANCE WITH	THE INTENT OF	MIL-STD-1541
Stability	NA	NA	NA
Redundancy	ACCOMPLISHED AT	THE MAJOR MODULE LEVEL	

INTERFACE REQUIREMENTS

Control/Monitor SERIAL DATA BUS - WIRED OR OPTICAL; MIL-STD-1553 TYPE

Operational/Safety REDUNDANT SERIAL DATA BUSSES SHARED WITH ABOVE FUNCTIONS.

Maintainability/Repair EACH SWITCH UNIT (OR RPC) REMOVABLE AND REPLACED FOR SYSTEM REPAIR.

Other BUILT-IN-TEST PROVISIONS COMMANDED AND MONITORED VIA THE DATA BUS INTERFACE.

PARAMETRIC ANALYSIS RESULTS

STATE OF THE ART EXCEEDS REQUIREMENTS

3654 #3

PMS COMPONENT CHARACTERISTIC DATA SHEET

PART B — PERFORMANCE

COMPONENT NAME SWITCHGEAR (ELECTRO MECHANICAL)

FUNCTIONAL CHARACTERISTICS FORM: 3PDT (ON-OFF-ON)
POWER TYPE: LOW VOLTAGE, AC, 3 PHASE
RATING: POWER - 5.0KW VOLTAGE - 115 VAC RMS
SYSTEM FUNCTION: PAYLOAD ISOLATION FROM 3Φ AC DISTRIBUTION BUS SYSTEM (DC SYSTEM)
PROVISIONS TO MONITOR VOLTAGE AND CURRENT; DATA AND COMMANDS TRANSMITTED VIA SERIAL DATA BUS

PERFORMANCE DEVELOPMENT PROJECTIONS

CHARACTERISTIC	STATE OF THE ART	PMS REQUIREMENT	ACHIEVABLE CAPABILITY
Voltage Level	120 VAC RMS	115 VAC RMS	> 120 VAC RMS
Peak Voltage	200 V PK	200 V PK	> 200 VPK
Current Capability	90 ARMS	25 ARMS	> 90 ARMS
Peak Load	12.0 KW	5.0 KW	> 12.0 KW
Efficiency	99.9%	99.9%	99.9%
Reliability	0.938 /SW	0.944	SOTA OK
MTBF (Hours)	1.4 X 10 6	1.58 X 10 6	SOTA OK
Peak Load Capability	12.0 KW	6.0 KW	> 12.0 KW
Operating Frequency	OK	HALF CYCLE @ 25 KHZ	OK
Magnetic Field	OK	0.47 GAUSS, MAX	OK
Regulation %	NA	NA	NA
Transient Capability	IN ACCORDANCE WITH THE INTENT OF MIL-STD-1541		
Stability	NA	NA	NA
Redundancy	ACCOMPLISHED AT THE MAJOR MODULE LEVEL		

INTERFACE REQUIREMENTS

Control/Monitor SERIAL DATA BUS - WIRED OR OPTICAL; MIL-STD-1553 TYPE

Operational/Safety REDUNDANT SERIAL DATA BUSSES' SHARED WITH ABOVE FUNCTIONS.

Maintainability/Repair EACH SWITCH UNIT (OR RPC) REMOVABLE AND REPLACED FOR SYSTEM REPAIR.

Other BUILT-IN-TEST PROVISIONS COMMANDED AND MONITORED VIA THE DATA BUS INTERFACE.

PARAMETRIC ANALYSIS RESULTS

STATE OF THE ART EXCEEDS REQUIREMENTS

3652-72

PMS COMPONENT CHARACTERISTIC DATA SHEET

PART B — PERFORMANCE

COMPONENT NAME SWITCHGEAR (ELECTRO MECHANICAL)

FUNCTIONAL CHARACTERISTICS FORM: DPDT (ON-OFF-ON)
POWER TYPE: HIGH VOLTAGE, DC
RATING: POWER - 5.0KW VOLTAGE - 750. VDC
SYSTEM FUNCTION: LOW VOLTAGE DISTR. CONV/REGL INPUT
ISOLATION AT THE PAYLOAD INTERFACE UNITS (DC SYSTEM)
PROVISIONS TO MONITOR VOLTAGE AND CURRENT; DATA AND
COMMANDS TRANSMITTED VIA SERIAL DATA BUS

PERFORMANCE DEVELOPMENT PROJECTIONS

CHARACTERISTIC	STATE OF THE ART	PMS REQUIREMENT	ACHIEVABLE CAPABILITY
Voltage Level	1500 VDC	750 VDC	> 1500 VDC
Peak Voltage	1500 VDC	1500 VDC	> 1500 VDC
Current Capability	17 ADC	6.7 ADC	> 17 ADC
Peak Load	25.0 KW	5.0 KW	> 25.0 KW
Efficiency	99.9%	99.9%	99.9%
Reliability	0.938	0.967	> 0.967
MTBF (Hours)	1.4×10^6	2.6×10^6.	$> 2.6 \times 10^6$
Peak Load Capability	25.0 KW	6.0 KW	> 25.0 KW
Operating Frequency	OK	HALF CYCLE @ 25 KHZ	OK
Magnetic Field	OK	0.47 GAUSS, MAX	OK
Regulation %	NA	NA	NA
Transient Capability	IN ACCORDANCE WITH THE INTENT OF MIL-STD-1541		
Stability	NA	NA	NA
Redundancy	ACCOMPLISHED AT THE MAJOR MODULE LEVEL		

INTERFACE REQUIREMENTS

Control/Monitor SERIAL DATA BUS - WIRED OR OPTICAL; MIL-STD-1553 TYPE

Operational/Safety REDUNDANT SERIAL DATA BUSSES SHARED WITH ABOVE FUNCTIONS.

Maintainability/Repair EACH SWITCH UNIT (OR RPC) REMOVABLE AND REPLACED FOR SYSTEM REPAIR.

Other BUILT-IN-TEST PROVISIONS COMMANDED AND MONITORED VIA THE DATA BUS INTERFACE.

PARAMETRIC ANALYSIS RESULTS

STATE OF THE ART EXCEEDS REQUIREMENTS

PMS COMPONENT CHARACTERISTIC DATA SHEET

PART B — PERFORMANCE

COMPONENT NAME SWITCHGEAR (ELECTROMECHANICAL)

FUNCTIONAL CHARACTERISTICS FORM: DPDT (ON-OFF-ON)
POWER TYPE: HIGH VOLTAGE, DC
RATING: POWER - 13.5KW VOLTAGE - 750VDC
SYSTEM FUNCTION: BATTERY / CHARGER ISOLATION FROM TRANSMISSION BUS SYSTEM (DC SYSTEM)
PROVISIONS TO MONITOR VOLTAGE AND CURRENT; DATA AND COMMANDS TRANSMITTED VIA SERIAL DATA BUS

PERFORMANCE DEVELOPMENT PROJECTIONS

CHARACTERISTIC	STATE OF THE ART	PMS REQUIREMENT	ACHIEVABLE CAPABILITY
Voltage Level	1500VDC	750 VDC	>750 VDC
Peak Voltage	1500VDC	1500 VDC	>1500 VDC
Current Capability	17 ADC	18 ADC	> 18 ADC
Peak Load	25.0 KW	13.5 KW	>13.5KW
Efficiency	99.9%	99.9%	99.9%
Reliability	0.926	0.918	SOTA OK
MTBF (Hours)	1.2×10^6	1.05×10^6	SOTA OK
Peak Load Capability	25.0KW	16.2KW	25.0KW
Operating Frequency	OK	HALF CYCLE @ 25KHZ	OK
Magnetic Field	OK	0.47 GAUSS, MAX	OK
Regulation %	NA	NA	NA
Transient Capability	IN ACCORDANCE WITH THE INTENT OF MIL-STD-1541		
Stability	NA	NA	NA
Redundancy	ACCOMPLISHED AT THE MAJOR MODULE LEVEL		

INTERFACE REQUIREMENTS

Control/Monitor SERIAL DATA BUS - WIRED OR OPTICAL; MIL-STD-1553 TYPE

Operational/Safety REDUNDANT SERIAL DATA BUSSES SHARED WITH ABOVE FUNCTIONS.

Maintainability/Repair EACH SWITCH UNIT (OR RPC) REMOVABLE AND REPLACED FOR SYSTEM REPAIR.

Other BUILT-IN-TEST PROVISIONS COMMANDED AND MONITORED VIA THE DATA BUS INTERFACE.

PARAMETRIC ANALYSIS RESULTS

STATE OF THE ART MEETS REQUIREMENTS

3652 -5

PMS COMPONENT CHARACTERISTIC DATA SHEET

PART B — PERFORMANCE

COMPONENT NAME SWITCHGEAR (ELECTROMECHANICAL)

FUNCTIONAL CHARACTERISTICS FORM: DPDT (ON-OFF-ON)
POWER TYPE: MEDIUM VOLTAGE, DC
RATING: POWER - 13.5KW VOLTAGE - 440 VDC
SYSTEM FUNCTION: BATTERY / CHARGER ISOLATION FROM TRANSMISSION BUS SYSTEM (AC SYSTEM)
PROVISIONS TO MONITOR VOLTAGE AND CURRENT; DATA AND COMMANDS TRANSMITTED VIA SERIAL DATA BUS

PERFORMANCE DEVELOPMENT PROJECTIONS

CHARACTERISTIC	STATE OF THE ART	PMS REQUIREMENT	ACHIEVABLE CAPABILITY
Voltage Level	440 VDC	440 VDC	> 440 VDC
Peak Voltage	680 VDC	800 VDC	> 800 VDC
Current Capability	80 ADC	31 A DC	> 80 A DC
Peak Load	54 KW	13.5KW	54 KW
Efficiency	99.9 %,	99.9 %	99.9 %
Reliability	0.926	0.918	SOTA OK
MTBF (Hours)	1.2×10^6	1.05×10^6	SOTA OK
Peak Load Capability	54 KW	16.2 KW	54 KW
Operating Frequency	OK	HALF CYCLE @ 25 KHZ	OK
Magnetic Field	OK	0.47 GAUSS, MAX	OK
Regulation %	NA	NA	NA
Transient Capability	IN ACCORDANCE WITH THE INTENT OF MIL-STD-1541		
Stability	NA	NA	NA
Redundancy	ACCOMPLISHED AT THE MAJOR MODULE LEVEL		

INTERFACE REQUIREMENTS

Control/Monitor SERIAL DATA BUS - WIRED OR OPTICAL; MIL-STD-1553 TYPE

Operational/Safety REDUNDANT SERIAL DATA BUSSES SHARED WITH ABOVE FUNCTIONS.

Maintainability/Repair EACH SWITCH UNIT (OR RPC) REMOVABLE AND REPLACED FOR SYSTEM REPAIR.

Other BUILT-IN-TEST PROVISIONS COMMANDED AND MONITORED VIA THE DATA BUS INTERFACE.

PARAMETRIC ANALYSIS RESULTS

ACHIEVABILITY CAPABILITY MEETS REQUIREMENTS.

3652-95

PMS COMPONENT CHARACTERISTIC DATA SHEET

PART B — PERFORMANCE

COMPONENT NAME SWITCHGEAR (ELECTROMECHANICAL)

FUNCTIONAL CHARACTERISTICS FORM: 3PDT (ON-OFF-ON)

POWER TYPE: LOW VOLTAGE, 3 PHASE, AC

RATING: POWER - 10.0KW VOLTAGE - 115VAC RMS

SYSTEM FUNCTION: OUTPUT ISOLATION FROM DISTRIBUTION BUSSES FOR AC INV/REGL MODULES (DC SYSTEM)

PROVISIONS TO MONITOR VOLTAGE AND CURRENT; DATA AND COMMANDS TRANSMITTED VIA SERIAL DATA BUS

PERFORMANCE DEVELOPMENT PROJECTIONS

CHARACTERISTIC	STATE OF THE ART	PMS REQUIREMENT	ACHIEVABLE CAPABILITY
Voltage Level	120 VAC RMS	115VAC RMS	>120VAC RMS
Peak Voltage	200 V PK	200V PK	> 200 VPK
Current Capability	90 A	50 A RMS	> 90 A RMS
Peak Load	12.0KW	10.0KW	> 12.0KW
Efficiency	99.9 %	99.9 %	99.9 %
Reliability	0.932 / SW	0.918	SOTA OK
MTBF (Hours)	1.3×10^6	0.80×10^6	SOTA OK
Peak Load Capability	12.0 KW	12.0 KW	> 12.0KW
Operating Frequency	OK	HALF CYCLE @ 25 KHZ	OK
Magnetic Field	OK	0.47 GAUSS, MAX	OK
Regulation %	NA	NA	NA
Transient Capability	IN ACCORDANCE WITH	THE INTENT OF	MIL-STD-1541
Stability	NA	NA	NA
Redundancy	ACCOMPLISHED AT	THE MAJOR	MODULE LEVEL

INTERFACE REQUIREMENTS

Control/Monitor SERIAL DATA BUS - WIRED OR OPTICAL; MIL-STD-1553 TYPE

Operational/Safety REDUNDANT SERIAL DATA BUSSES SHARED WITH ABOVE FUNCTIONS.

Maintainability/Repair EACH SWITCH UNIT (OR RPC) REMOVABLE AND REPLACED FOR SYSTEM REPAIR.

Other BUILT-IN-TEST PROVISIONS COMMANDED AND MONITORED VIA THE DATA BUS INTERFACE.

PARAMETRIC ANALYSIS RESULTS

STATE OF THE ART EXCEEDS REQUIREMENTS

PMS COMPONENT CHARACTERISTIC DATA SHEET
PART B — PERFORMANCE

COMPONENT NAME SWITCH GEAR (ELECTRO MECHANICAL)

FUNCTIONAL CHARACTERISTICS FORM: DPDT (ON-OFF-ON)
POWER TYPE: LOW VOLTAGE, DC
RATING: POWER - 5.0 KW VOLTAGE - 115 VDC
SYSTEM FUNCTION: PAYLOAD ISOLATION FROM DISTRIBUTION BUS SYSTEM (DC SYSTEM)
PROVISIONS TO MONITOR VOLTAGE AND CURRENT; DATA AND COMMANDS TRANSMITTED VIA SERIAL DATA BUS

PERFORMANCE DEVELOPMENT PROJECTIONS

CHARACTERISTIC	STATE OF THE ART	PMS REQUIREMENT	ACHIEVABLE CAPABILITY
Voltage Level	120 VDC	115 VDC	> 120 VDC
Peak Voltage	160 VDC	140 VDC	> 160 VDC
Current Capability	90 ADC	44 ADC	> 90 ADC
Peak Load	12.0 KW	5.0 KW	> 12.0 KW
Efficiency	99.9 %	99.9 %	99.9 %
Reliability	0.938	0.944	SOTA OK
MTBF (Hours)	1.4×10^6	1.52×10^6	SOTA OK
Peak Load Capability	12.0 KW	6.0 KW	> 12.0 KW
Operating Frequency	OK	HALF CYCLE @ 25 KHZ	OK
Magnetic Field	OK	0.47 GAUSS, MAX	OK
Regulation %	NA	NA	NA
Transient Capability	IN ACCORDANCE WITH THE INTENT OF MIL-STD-1541		
Stability	NA	NA	NA
Redundancy	ACCOMPLISHED AT THE MAJOR MODULE LEVEL		

INTERFACE REQUIREMENTS

Control/Monitor SERIAL DATA BUS - WIRED OR OPTICAL; MIL-STD-1553 TYPE

Operational/Safety REDUNDANT SERIAL DATA BUSSES SHARED WITH ABOVE FUNCTIONS.

Maintainability/Repair EACH SWITCH UNIT (OR RPC) REMOVABLE AND REPLACED FOR SYSTEM REPAIR.

Other BUILT-IN-TEST PROVISIONS COMMANDED AND MONITORED VIA THE DATA BUS INTERFACE.

PARAMETRIC ANALYSIS RESULTS

STATE OF THE ART EXCEEDS REQUIREMENTS

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PMS COMPONENTS CHARACTERISTIC DATA SHEET

PART A — PHYSICAL

COMPONENT NAME SWITCHGEAR (SOLID STATE)

FUNCTION PROVIDE SWITCH FUNCTIONS FOR CONFIGURATION CHANGES, MODULE CONNECTION, REDUNDANCY MANAGEMENT, BATTERY CONTROL, POWER ON/OFF, MODULAR ISOLATION

PHYSICAL DESCRIPTION

SEMICONDUCTOR POWER SWITCHING DEVICES, MEDIUM POWER DRIVERS, AND MSI / LSI CONTROL, COMMAND, AND DATA INTERFACE CIRCUITRY MOUNTED IN A NON-SEALED HOUSING / HEAT SINK STRUCTURE. PASSIVE THERMAL DESIGN AUGMENTED BY HEAT PIPES IF NECESSARY.

PARAMETRIC ANALYSIS RESULTS

SPECIFIC MASS AND VOLUME DECREASE EXPONENTIALLY (DIFFERENT) WITH INCREASING POWER. (SEE ATTACHED CURVES)

PHYSICAL DEVELOPMENT PROJECTIONS

CHARACTERISTIC	STATE OF THE ART	PMS REQUIREMENT	ACHIEVABLE CAPABILITY
Size	SEE ATTACHED	TABLE	
Weight	SEE ATTACHED	TABLE	
Mass	SEE ATTACHED	TABLE	
Cooling Requirements	SEE ATTACHED	TABLE	
Operating Temp	125°C T_J MAX (WORST CASE),	85°C T_J	MAX (TYPICAL)
Space Radiation Damage		3×10^{12} e/cm²	SOTA OK
Pressurization	MAJOR ASSEMBLY	NON-PRESSURIZED	
Vibration	SHUTTLE LAUNCH ENV. OK	SHUTTLE LAUNCH REQUIREMENTS	SHUTTLE LAUNCH ENV. OK

PHYSICAL INTERFACE REQUIREMENTS/CHARACTERISTICS UNIT DESIGNED TO MOUNT TO COLD PLATE WITH GOOD THERMAL CONDUCTIVITY. HIGH VOLTAGE AND CONVENTIONAL CONNECTORS REQ'D. MULTIPLE RPC'S MAY BE MOUNTED IN A SINGLE UNIT.

MATERIAL CONSIDERATIONS

MATERIAL FOR HOUSING SELECTED FOR LIGHT WEIGHT AND GOOD THERMAL CONDUCTIVITY. ALUMINUM OR MAGNESIUM ALLOYS PROBABLE SELECTION.

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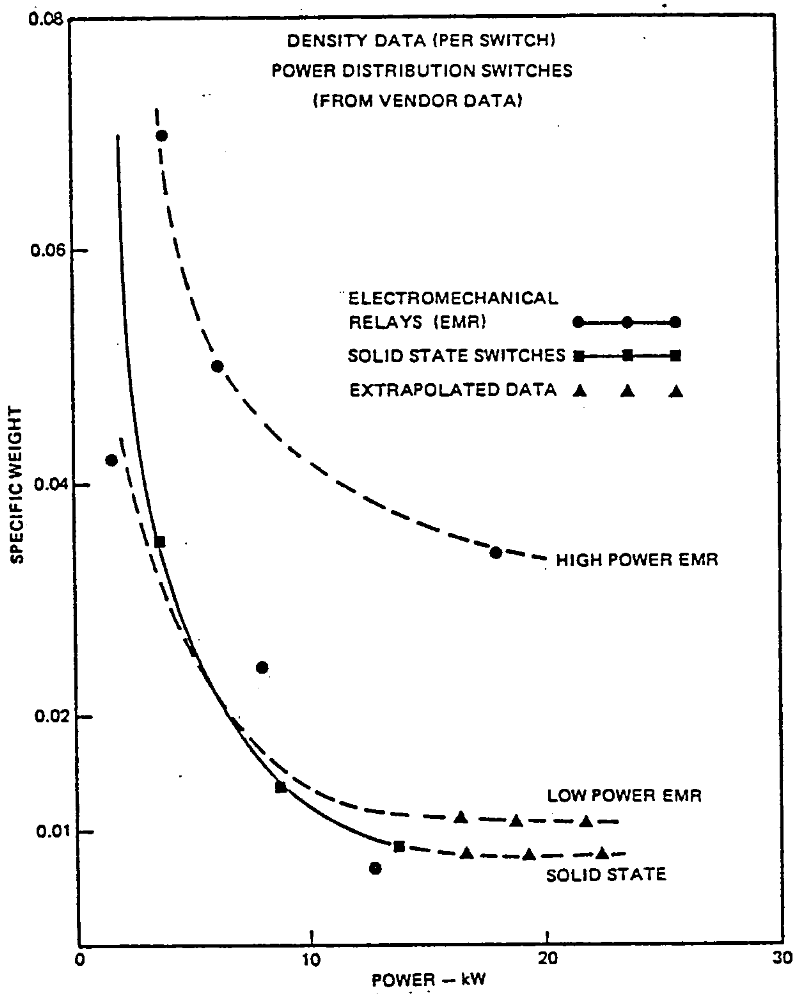
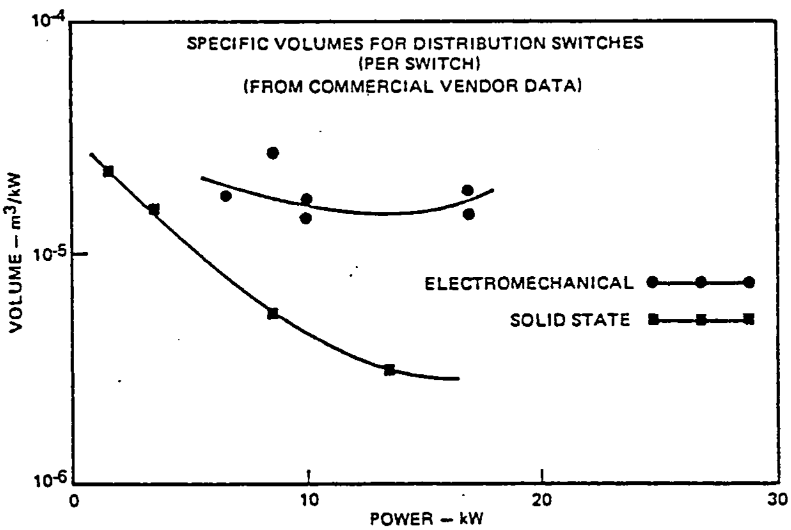
Table 1. Switchgear physical characteristics - solid-state switches.

POWER	AC/DC	FORM	FUNCTION	SIZE ($m^3 \times 10^{-3}$)	WEIGHT (kg)	MASS (kg/kW) (SPST)	DISSIPATION (WATTS)
AC SYSTEM							
25.0 kW	DC	DPDT	Inv. Inpt. Isol.	0.200	0.40	0.008	
25.0 kW	AC	DPDT	Inv. Mod. Outp. Isol.	0.200	0.40	0.008	
5.0 kW	AC	DPDT	Payl. Mod. Inpt. Isol.	0.100	0.26	0.026	
15.0 kW	AC	DPDT	Payl. Unreg. Pwr. Isol.	0.076	0.27	0.009	
DC SYSTEM							
100.0 kW	DC	SPDT	Slip Ring Inp/Outp. Isol.	—	—	NA	
15.0 kW	DC	DPDT	Payl. Unreg. Pwr. Isol.	0.076	0.27	0.009	
10.0 kW	DC	DPDT	Conv/Reg. Inp. Isol.	0.140	0.24	0.012	
10.0 kW	DC	DPDT	Conv/Reg. Outp. Isol.	0.140	0.24	0.012	
10.0 kW	AC	3PDT	AC Inv. Outp. Isol.	0.210	0.36	0.012	
5.0 kW	DC	DPDT	DC Bus Payl. Isol.	0.100	0.26	0.026	
5.0 kW	AC	3PDT	AC Bus Payl. Isol.	0.150	0.39	0.026	
5.0 kW	DC	DPDT	Distr. Payl. Conv/Regl. Isol.	0.100	0.26	0.026	
AC OR DC SYSTEM							
13.5 kW	DC	DPDT	Batt Chg Inp/Outp Isol.	0.135	0.24	0.009	



Switchgear mass relationships.



Switchgear volume relationships.

PMS COMPONENT CHARACTERISTIC DATA SHEET
PART B — PERFORMANCE

COMPONENT NAME SWITCHGEAR (SOLID STATE)

FUNCTIONAL CHARACTERISTICS FORM: DPDT (ON-OFF-ON)
POWER TYPE: MEDIUM VOLTAGE, AC
RATING: POWER - 25.0KW VOLTAGE - 440 VAC, PK
SYSTEM FUNCTION: MODULE OUTPUT ISOLATION FOR DC-AC INVERTER MODULES AT ROTARY TRANSFORMER (AC SYSTEM)
PROVISIONS TO MONITOR VOLTAGE AND CURRENT; DATA AND COMMANDS TRANSMITTED VIA SERIAL DATA BUS

PERFORMANCE DEVELOPMENT PROJECTIONS

CHARACTERISTIC	STATE OF THE ART	PMS REQUIREMENT	ACHIEVABLE CAPABILITY
Voltage Level	2600 VPK	440 VAC PK	SOTA OK
Peak Voltage	2600 VPK	800 VAC PK	SOTA OK
Current Capability	2000 AMP	60 AMP	SOTA OK
Peak Load	500 KW	25.0 KW	SOTA OK
Efficiency	99.5 %	99.5 %	99.5 %
Reliability	0.952	0.913	SOTA OK
MTBF (Hours)	1.8×10^6	0.96×10^6	SOTA OK
Peak Load Capability	10,000 AMP	30.0 KW	SOTA OK
Operating Frequency	OK	HALF CYCLE @ 25 KHZ	OK
Magnetic Field	OK	0.47 GAUSS, MAX	OK
Regulation %	NA	NA	NA
Transient Capability	IN ACCORDANCE WITH THE INTENT OF MIL-STD-1541		
Stability	NA	NA	NA
Redundancy	ACCOMPLISHED AT THE MAJOR MODULE LEVEL		

INTERFACE REQUIREMENTS

Control/Monitor: SERIAL DATA BUS - WIRED OR OPTICAL; MIL-STD-1553 TYPE

Operational/Safety: REDUNDANT SERIAL DATA BUSSES SHARED WITH ABOVE FUNCTIONS.

Maintainability/Repair: EACH SWITCH UNIT (OR RPC) REMOVABLE AND REPLACED FOR SYSTEM REPAIR.

Other: BUILT-IN-TEST PROVISIONS COMMANDED AND MONITORED VIA THE DATA BUS INTERFACE.

PARAMETRIC ANALYSIS RESULTS

RPC WITH THYRISTOR OUTP. DEVICES CAN BE DESIGNED TO MEET PMS REQUIREMENTS, FOR AC SWITCHING

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PMS COMPONENT CHARACTERISTIC DATA SHEET

PART B — PERFORMANCE

COMPONENT NAME SWITCHGEAR (SOLID STATE)

FUNCTIONAL CHARACTERISTICS FORM: DPDT (ON-OFF-ON)
POWER TYPE: MEDIUM VOLTAGE DC
RATING: POWER - 25.0KW VOLTAGE - 440 VDC, MAX
SYSTEM FUNCTION: INPUT ISOLATION FOR AC INVERTER MODULES AT SOLAR ARRAY BUSSES (AC SYSTEM)
PROVISIONS TO MONITOR VOLTAGE AND CURRENT; DATA AND COMMANDS TRANSMITTED VIA SERIAL DATA BUS

PERFORMANCE DEVELOPMENT PROJECTIONS

CHARACTERISTIC	STATE OF THE ART	PMS REQUIREMENT	ACHIEVABLE CAPABILITY
Voltage Level	500VDC	440 VDC MAX	500VDC
Peak Voltage	500VDC	800VDC	800VDC
Current Capability	40.0 AMP	60 AMP	60.0 AMP
Peak Load	20.0KW	25.0KW	25.0 KW
Efficiency	99.5%	99.5%	99.5%
Reliability	0.952	0.913	SOTA OK
MTBF (Hours)	1.8×10^6	0.96×10^6	SOTA OK
Peak Load Capability	20.0KW	30.0KW	30.0 KW
Operating Frequency	OK	HALF CYCLE @ 25 KHZ	OK
Magnetic Field	OK	0.47 GAUSS, MAX	OK
Regulation %	NA	NA	NA
Transient Capability	IN ACCORDANCE WITH	THE INTENT OF	MIL-STD-1541
Stability	NA	NA	NA
Redundancy	ACCOMPLISHED AT	THE MAJOR MO	DULE LEVEL

INTERFACE REQUIREMENTS

Control/Monitor SERIAL DATA BUS - WIRED OR OPTICAL; MIL-STD-1553 TYPE

Operational/Safety REDUNDANT SERIAL DATA BUSSES SHARED WITH ABOVE FUNCTIONS.

Maintainability/Repair EACH SWITCH UNIT (OR RPC) REMOVABLE AND REPLACED FOR SYSTEM REPAIR.

Other BUILT-IN-TEST PROVISIONS COMMANDED AND MONITORED VIA THE DATA BUS INTERFACE.

PARAMETRIC ANALYSIS RESULTS

MODERATE INCREASE IN OUTPUT SWITCH CAPABILITY FOR RPC REQUIRED.

REQUIRES POWER TRANSISTOR (BIPOLAR OR FET) IMPROVEMENT

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PMS COMPONENT CHARACTERISTIC DATA SHEET

PART B — PERFORMANCE

COMPONENT NAME SWITCHGEAR (SOLID STATE)

FUNCTIONAL CHARACTERISTICS FORM: DPDT (ON-OFF-ON)
POWER TYPE: MEDIUM VOLTAGE, AC
RATING: POWER - 5.0KW VOLTAGE - 440 VAC PK. MAX
SYSTEM FUNCTION: PAYLOAD INTERFACE UNIT MODULE ISOLATION FROM DISTRIBUTION BUS SYSTEM (AC SYSTEM)
PROVISIONS TO MONITOR VOLTAGE AND CURRENT; DATA AND COMMANDS TRANSMITTED VIA SERIAL DATA BUS

PERFORMANCE DEVELOPMENT PROJECTIONS

CHARACTERISTIC	STATE OF THE ART	PMS REQUIREMENT	ACHIEVABLE CAPABILITY
Voltage Level	2600 VPK	440 VAC PK.	SOTA OK
Peak Voltage	2600 VPK	500 VAC PK	SOTA OK
Current Capability	2000 AMP	12 AMP	SOTA OK
Peak Load	500 KW	5.0 KW	SOTA OK
Efficiency	99.5%	99.5%	99.5%
Reliability	0.957	0.92	SOTA OK
MTBF (Hours)	2.0×10^6	1.08×10^6	SOTA OK
Peak Load Capability	10,000 AMP	6.0 KW	SOTA OK
Operating Frequency	OK	HALF CYCLE @ 25 KHZ	OK
Magnetic Field	OK	0.47 GAUSS, MAX	OK
Regulation %	NA	NA	NA
Transient Capability	IN ACCORDANCE WITH	THE INTENT OF	MIL-STD-1541
Stability	NA	NA	NA
Redundancy	ACCOMPLISHED AT	THE MAJOR MODULE	LEVEL

INTERFACE REQUIREMENTS

Control/Monitor SERIAL DATA BUS - WIRED OR OPTICAL; MIL-STD-1553 TYPE

Operational/Safety REDUNDANT SERIAL DATA BUSSES SHARED WITH ABOVE FUNCTIONS.

Maintainability/Repair EACH SWITCH UNIT (OR RPC) REMOVABLE AND REPLACED FOR SYSTEM REPAIR.

Other BUILT-IN-TEST PROVISIONS COMMANDED AND MONITORED VIA THE DATA BUS INTERFACE.

PARAMETRIC ANALYSIS RESULTS

RPC WITH THYRISTOR OUTPUT DEVICES CAN BE DESIGNED TO MEET ALL PMS REQUIREMENTS, FOR AC SWITCHING

3652-93

PMS COMPONENT CHARACTERISTIC DATA SHEET
PART B — PERFORMANCE

COMPONENT NAME SWITCHGEAR (SOLID STATE)

FUNCTIONAL CHARACTERISTICS FORM: DPDT (ON-OFF-ON)
POWER TYPE: HIGH VOLTAGE, AC
RATING: POWER - 15.0 KW VOLTAGE - 1000 VAC RMS
SYSTEM FUNCTION: UNREGULATED POWER PAYLOAD ISOLATION FROM DISTRIBUTION BUS SYSTEM (AC SYSTEM)
PROVISIONS TO MONITOR VOLTAGE AND CURRENT; DATA AND COMMANDS TRANSMITTED VIA SERIAL DATA BUS

PERFORMANCE DEVELOPMENT PROJECTIONS

CHARACTERISTIC	STATE OF THE ART	PMS REQUIREMENT	ACHIEVABLE CAPABILITY
Voltage Level	2600 VPK	1000 VAC RMS	SOTA OK
Peak Voltage	2600 V PK	1700 V PK.	SOTA OK
Current Capability	2000 AMP	15 AMP RMS	SOTA OK
Peak Load	500 KW	15.0 KW	SOTA OK
Efficiency	99.9%	99.9%	99.9%
Reliability	0.954	0.900	SOTA OK
MTBF (Hours)	1.9×10^6	0.80×10^6	SOTA OK
Peak Load Capability	10,000 AMP	18.0 KW	SOTA OK
Operating Frequency	OK	HALF CYCLE @ 25 KHZ	OK
Magnetic Field	OK	0.47 GAUSS, MAX	OK
Regulation %	NA	NA	NA
Transient Capability	IN ACCORDANCE WITH THE INTENT OF MIL-STD-1541		
Stability	NA	NA	NA
Redundancy	ACCOMPLISHED AT THE MAJOR MODULE LEVEL		

INTERFACE REQUIREMENTS

Control/Monitor SERIAL DATA BUS - WIRED OR OPTICAL; MIL-STD-1553 TYPE

Operational/Safety REDUNDANT SERIAL DATA BUSSES SHARED WITH ABOVE FUNCTIONS.

Maintainability/Repair EACH SWITCH UNIT (OR RPC) REMOVABLE AND REPLACED FOR SYSTEM REPAIR.

Other BUILT-IN TEST PROVISIONS COMMANDED AND MONITORED VIA THE DATA BUS INTERFACE.

PARAMETRIC ANALYSIS RESULTS

RPC WITH THYRISTOR OUTPUT DEVICES CAN BE DESIGNED TO MEET ALL PMS REQUIREMENTS FOR AC SWITCHING.

3652-95

PMS COMPONENT CHARACTERISTIC DATA SHEET
PART B — PERFORMANCE

COMPONENT NAME SWITCHGEAR (SOLID STATE)

FUNCTIONAL CHARACTERISTICS FORM : SPDT (ON-OFF-ON)
POWER TYPE : HIGH VOLTAGE, DC
RATING : POWER - 100 KW VOLTAGE - 750 VDC
SYSTEM FUNCTION : INDIVIDUAL SLIP RING INPUT ISOLATION FROM SOLAR ARRAY BUSSES (DC SYSTEM)
PROVISIONS TO MONITOR VOLTAGE AND CURRENT ; DATA AND COMMANDS TRANSMITTED VIA SERIAL DATA BUS

PERFORMANCE DEVELOPMENT PROJECTIONS

CHARACTERISTIC	STATE OF THE ART	PMS REQUIREMENT	ACHIEVABLE CAPABILITY
Voltage Level	500 V	750 VDC	1000 VDC
Peak Voltage	500 V	1500 VDC	1000 VDC
Current Capability	40 AMP	133 AMP DC	150 ADC
Peak Load	20 KW	100 KW	100 KW
Efficiency	99.8 %	99.8 %	99.8 %
Reliability	0.931 (EXTR)	0.938	SOTA OK
MTBF (Hours)	1.3×10^6	1.40×10^6	SOTA OK
Peak Load Capability	20 KW	120 KW	100 KW
Operating Frequency	OK	HALF CYCLE @ 25 KHZ	OK
Magnetic Field	OK	0.47 GAUSS, MAX	OK
Regulation %	NA	NA	NA
Transient Capability	IN ACCORDANCE WITH	THE INTENT OF	MIL-STD-1541
Stability	NA	NA	NA
Redundancy	ACCOMPLISHED AT	THE MAJOR MODULE	LEVEL

INTERFACE REQUIREMENTS

Control/Monitor SERIAL DATA BUS - WIRED OR OPTICAL ; MIL-STD-1553 TYPE

Operational/Safety REDUNDANT SERIAL DATA BUSSES SHARED WITH ABOVE FUNCTIONS.

Maintainability/Repair EACH SWITCH UNIT (OR RPC) REMOVABLE AND REPLACED FOR SYSTEM REPAIR.

Other BUILT-IN-TEST PROVISIONS COMMANDED AND MONITORED VIA THE DATA BUS INTERFACE.

PARAMETRIC ANALYSIS RESULTS

LARGE IMPROVEMENT IN RPC OUTPUT CAPABILITY REQUIRED.

BIPOLAR OR FET TRANSISTOR IMPROVEMENT

3652-95

PMS COMPONENT CHARACTERISTIC DATA SHEET
PART B — PERFORMANCE

COMPONENT NAME SWITCHGEAR (SOLID STATE)

FUNCTIONAL CHARACTERISTICS FORM : DPDT (ON-OFF-ON)
POWER TYPE : HIGH VOLTAGE, DC
RATING : POWER - 15.0KW VOLTAGE - 750 VDC
SYSTEM FUNCTION : UNREGULATED POWER PAYLOAD ISOLATION FROM DISTRIBUTION SYSTEM. (DC SYSTEM)
PROVISIONS TO MONITOR VOLTAGE AND CURRENT; DATA AND COMMANDS TRANSMITTED VIA SERIAL DATA BUS

PERFORMANCE DEVELOPMENT PROJECTIONS

CHARACTERISTIC	STATE OF THE ART	PMS REQUIREMENT	ACHIEVABLE CAPABILITY
Voltage Level	500V	750 VDC	1000 VDC
Peak Voltage	500V	1500VDC	1000 VDC
Current Capability	40 AMP	20 ADC	40 ADC
Peak Load	20KW	15.0 KW	40KW
Efficiency	99.8%	99.8%	99.8%
Reliability	0.954	0.900	SOTA OK
MTBF (Hours)	1.9×10^6	0.80×10^6	SOTA OK
Peak Load Capability	20 KW	18.0KW	SOTA OK
Operating Frequency	OK	HALF CYCLE @ 25 KHZ	OK
Magnetic Field	OK	0.47 GAUSS, MAX	OK
Regulation %	NA	NA	NA
Transient Capability	IN ACCORDANCE WITH	THE INTENT OF	MIL-STD-1541
Stability	NA	NA	NA
Redundancy	ACCOMPLISHED AT	THE MAJOR MODULE LEVEL	

INTERFACE REQUIREMENTS

Control/Monitor SERIAL DATA BUS - WIRED OR OPTICAL ; MIL-STD-1553 TYPE

Operational/Safety REDUNDANT SERIAL DATA BUSSES SHARED WITH ABOVE FUNCTIONS.

Maintainability/Repair EACH SWITCH UNIT (OR RPC) REMOVABLE AND REPLACED FOR SYSTEM REPAIR.

Other BUILT-IN-TEST PROVISIONS COMMANDED AND MONITORED VIA THE DATA BUS INTERFACE.

PARAMETRIC ANALYSIS RESULTS

LARGE VOLTAGE RATING IMPROVEMENT FOR RPC OUTPUT. REQUIRED.

BIPOLAR OR FET TRANSISTOR IMPROVEMENT

3652-95

PMS COMPONENT CHARACTERISTIC DATA SHEET

PART B — PERFORMANCE

COMPONENT NAME SWITCHGEAR (SOLID STATE)

FUNCTIONAL CHARACTERISTICS FORM: DPDT (ON-OFF-ON)
POWER TYPE: HIGH VOLTAGE D.C.
RATING: POWER - 10.0KW VOLTAGE - 750VDC
SYSTEM FUNCTION: INPUT ISOLATION FROM TRANSMISSION BUSSES FOR CONVERTER/REGULATOR MODULES (DC SYSTEM)
PROVISIONS TO MONITOR VOLTAGE AND CURRENT; DATA AND COMMANDS TRANSMITTED VIA SERIAL DATA BUS

PERFORMANCE DEVELOPMENT PROJECTIONS

CHARACTERISTIC	STATE OF THE ART	PMS REQUIREMENT	ACHIEVABLE CAPABILITY
Voltage Level	500V	750 VDC	1000VDC
Peak Voltage	500V	1500 VDC	1000VDC
Current Capability	40.0A	13.3 ADC	40 A DC
Peak Load	20 KW	10.0 KW	40KW
Efficiency	99.8%	99.8%	99.8%
Reliability	0.955	0.944	SOTA OK
MTBF (Hours)	1.9×10^6	1.58×10^6	SOTA OK
Peak Load Capability	20 KW MIN	12.0 KW	SOTA OK
Operating Frequency	OK	HALF CYCLE @ 25 KHZ	OK
Magnetic Field	OK	0.47 GAUSS, MAX	OK
Regulation %	NA	NA	NA
Transient Capability	IN ACCORDANCE WITH	THE INTENT OF	MIL-STD-1541
Stability	NA	NA	NA
Redundancy	ACCOMPLISHED AT	THE MAJOR MODULE LEVEL	

INTERFACE REQUIREMENTS

Control/Monitor SERIAL DATA BUS - WIRED OR OPTICAL; MIL-STD-1553 TYPE

Operational/Safety REDUNDANT SERIAL DATA BUSSES SHARED WITH ABOVE FUNCTIONS.

Maintainability/Repair EACH SWITCH UNIT (OR RPC) REMOVABLE AND REPLACED FOR SYSTEM REPAIR.

Other BUILT-IN-TEST PROVISIONS COMMANDED AND MONITORED VIA THE DATA BUS INTERFACE.

PARAMETRIC ANALYSIS RESULTS

LARGE VOLTAGE RATING IMPROVEMENT FOR PPC OUTPUT REQUIRED.

BIPOLAR OR FET TRANSISTOR IMPROVEMENT.

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PMS COMPONENT CHARACTERISTIC DATA SHEET
PART B — PERFORMANCE

COMPONENT NAME SWITCHGEAR (SOLID STATE)

FUNCTIONAL CHARACTERISTICS FORM: DPDT (ON-OFF-ON)
POWER TYPE: LOW VOLTAGE, DC
RATING: POWER - 10.0KW VOLTAGE - 115VDC
SYSTEM FUNCTION: OUTPUT ISOLATION FROM DISTRIBUTION BUSSES FOR CONV/REGL MODULES (DC SYSTEM)
PROVISIONS TO MONITOR VOLTAGE AND CURRENT; DATA AND COMMANDS TRANSMITTED VIA SERIAL DATA BUS

PERFORMANCE DEVELOPMENT PROJECTIONS

CHARACTERISTIC	STATE OF THE ART	PMS REQUIREMENT	ACHIEVABLE CAPABILITY
Voltage Level	250 V	115 VDC	SOTA OK
Peak Voltage	250 V	140 VDC	SOTA OK
Current Capability	120 A	87 ADC	SOTA OK
Peak Load	30 KW	10.0 KW	SOTA OK
Efficiency	99.0 %	99.0 %	99.0 %
Reliability	0.955	0.918	SOTA OK
MTBF (Hours)	1.9×10^6	0.8×10^6	SOTA OK
Peak Load Capability	30 KW MIN	12.0 KW	SOTA OK
Operating Frequency	OK	HALF CYCLE @ 25 KHZ	OK
Magnetic Field	OK	0.47 GAUSS, MAX	OK
Regulation %	NA	NA	NA
Transient Capability	IN ACCORDANCE WITH THE INTENT OF MIL-STD-1541		
Stability	NA	NA	NA
Redundancy	ACCOMPLISHED AT THE MAJOR MODULE LEVEL		

INTERFACE REQUIREMENTS

Control/Monitor SERIAL DATA BUS - WIRED OR OPTICAL; MIL-STD-1553 TYPE

Operational/Safety REDUNDANT SERIAL DATA BUSSES SHARED WITH ABOVE FUNCTIONS.

Maintainability/Repair EACH SWITCH UNIT (OR RPC) REMOVABLE AND REPLACED FOR SYSTEM REPAIR.

Other BUILT-IN TEST PROVISIONS COMMANDED AND MONITORED VIA THE DATA BUS INTERFACE.

PARAMETRIC ANALYSIS RESULTS

STATE OF THE ART EXCEEDS REQUIREMENTS

3652-95

PMS COMPONENT CHARACTERISTIC DATA SHEET

PART B — PERFORMANCE

COMPONENT NAME SWITCHGEAR (SOLID STATE)

FUNCTIONAL CHARACTERISTICS FORM : 3PDT (ON-OFF-ON)
POWER TYPE : LOW VOLTAGE, 3 PHASE, AC
RATING : POWER - 10.0KW VOLTAGE - 115VAC RMS
SYSTEM FUNCTION : OUTPUT ISOLATION FROM DISTRIBUTION BUSSES FOR AC INV/ REGL MODULES (DC SYSTEM)
PROVISIONS TO MONITOR VOLTAGE AND CURRENT ; DATA AND COMMANDS TRANSMITTED VIA SERIAL DATA BUS

PERFORMANCE DEVELOPMENT PROJECTIONS

CHARACTERISTIC	STATE OF THE ART	PMS REQUIREMENT	ACHIEVABLE CAPABILITY
Voltage Level	2600 VPK	115V AC RMS	SOTA OK
Peak Voltage	2600 VPK	200V PK	SOTA OK
Current Capability	2000 AMP	50 A RMS	SOTA OK
Peak Load	800 KW	10.0 KW	SOTA OK
Efficiency	99.0 %	99.0 %	99.0%
Reliability	0.955	0.918	SOTA OK
MTBF (Hours)	1.9×10^6	0.80×10^6	SOTA OK
Peak Load Capability	10,000 AMP	12.0 KW	SOTA OK
Operating Frequency	OK	HALF CYCLE @ 25 KHZ	OK
Magnetic Field	OK	0.47 GAUSS, MAX	OK
Regulation %	NA	NA	NA
Transient Capability	IN ACCORDANCE WITH THE INTENT OF MIL-STD-1541		
Stability	NA	NA	NA
Redundancy	ACCOMPLISHED AT THE MAJOR MODULE LEVEL		

INTERFACE REQUIREMENTS

Control/Monitor SERIAL DATA BUS - WIRED OR OPTICAL ; MIL-STD-1553 TYPE

Operational/Safety REDUNDANT SERIAL DATA BUSSES SHARED WITH ABOVE FUNCTIONS.

Maintainability/Repair EACH SWITCH UNIT (OR RPC) REMOVABLE AND REPLACED FOR SYSTEM REPAIR.

Other BUILT-IN-TEST PROVISIONS COMMANDED AND MONITORED VIA THE DATA BUS INTERFACE.

PARAMETRIC ANALYSIS RESULTS

STATE OF THE ART EXCEEDS REQUIREMENTS

3652-95

PMS COMPONENT CHARACTERISTIC DATA SHEET
PART B — PERFORMANCE

COMPONENT NAME SWITCHGEAR (SOLID STATE)

FUNCTIONAL CHARACTERISTICS FORM: DPDT (ON-OFFON)
POWER TYPE: LOW VOLTAGE, DC
RATING: POWER - 5.0KW VOLTAGE - 115VDC
SYSTEM FUNCTION: PAYLOAD ISOLATION FROM DISTRIBUTION
BUS SYSTEM (DC SYSTEM)
PROVISIONS TO MONITOR VOLTAGE AND CURRENT; DATA AND
COMMANDS TRANSMITTED VIA SERIAL DATA BUS

PERFORMANCE DEVELOPMENT PROJECTIONS

CHARACTERISTIC	STATE OF THE ART	PMS REQUIREMENT	ACHIEVABLE CAPABILITY
Voltage Level	250V	115VDC	SOTA OK
Peak Voltage	250V	140VDC	SOTA OK
Current Capability	120 A	44 ADC	SOTA OK
Peak Load	30 KW	5.0KW	SOTA OK
Efficiency	99.0%	99.0%	99.0%
Reliability	0.957	0.944	SOTA OK
MTBF (Hours)	2.0×10^6	1.58×10^6	SOTA OK
Peak Load Capability	30 KW MIN	6.0KW	SOTA OK
Operating Frequency	OK	HALF CYCLE @ 25KHZ	OK
Magnetic Field	OK	0.47 GAUSS, MAX	OK
Regulation %	NA	NA	NA
Transient Capability	IN ACCORDANCE WITH	THE INTENT OF	MIL-STD-1541
Stability	NA	NA	NA
Redundancy	ACCOMPLISHED AT	THE MAJOR MODULE LEVEL	

INTERFACE REQUIREMENTS

Control/Monitor SERIAL DATA BUS - WIRED OR OPTICAL; MIL-STD-1553 TYPE

Operational/Safety REDUNDANT SERIAL DATA BUSSES SHARED WITH ABOVE FUNCTIONS.

Maintainability/Repair EACH SWITCH UNIT (OR RPC) REMOVABLE AND REPLACED FOR SYSTEM REPAIR.

Other BUILT-IN-TEST PROVISIONS COMMANDED AND MONITORED VIA THE DATA BUS INTERFACE.

PARAMETRIC ANALYSIS RESULTS

STATE OF THE ART EXCEEDS REQUIREMENTS

3652-95

PMS COMPONENT CHARACTERISTIC DATA SHEET
PART B — PERFORMANCE

COMPONENT NAME SWITCHGEAR (SOLID STATE)

FUNCTIONAL CHARACTERISTICS FORM: 3PDT (ON-OFF-ON)
POWER TYPE: LOW VOLTAGE, AC, 3 PHASE
RATING: POWER - 5.0KW VOLTAGE - 115 VAC RMS
SYSTEM FUNCTION: PAYLOAD ISOLATION FROM 3Φ AC DISTRIBUTION BUS SYSTEM (DC SYSTEM)
PROVISIONS TO MONITOR VOLTAGE AND CURRENT; DATA AND COMMANDS TRANSMITTED VIA SERIAL DATA BUS

PERFORMANCE DEVELOPMENT PROJECTIONS

CHARACTERISTIC	STATE OF THE ART	PMS REQUIREMENT	ACHIEVABLE CAPABILITY
Voltage Level	2600 VPK	115 VACRMS	SOTA OK
Peak Voltage	2600 VPK	200 V PK	SOTA OK
Current Capability	2000 AMP	25 ARMS	SOTA OK
Peak Load	500 KW	5.0 KW	SOTA OK
Efficiency	99.0%	99.0%	99.0%
Reliability	0.957	0.944	SOTA OK
MTBF (Hours)	2.0×10^6	1.158×10^6	SOTA OK
Peak Load Capability	10,000 AMP	6.0 KW	SOTA OK
Operating Frequency	OK	HALF CYCLE @ 25 KHZ	OK
Magnetic Field	OK	0.47 GAUSS, MAX	OK
Regulation %	NA	NA	NA
Transient Capability	IN ACCORDANCE WITH	THE INTENT OF	MIL-STD-1541
Stability	NA	NA	NA
Redundancy	ACCOMPLISHED AT	THE MAJOR MODULE LEVEL	

INTERFACE REQUIREMENTS

Control/Monitor SERIAL DATA BUS - WIRED OR OPTICAL; MIL-STD-1553 TYPE

Operational/Safety REDUNDANT SERIAL DATA BUSSES SHARED WITH ABOVE FUNCTIONS.

Maintainability/Repair EACH SWITCH UNIT (OR RPC) REMOVABLE AND REPLACED FOR SYSTEM REPAIR.

Other BUILT-IN-TEST PROVISIONS COMMANDED AND MONITORED VIA THE DATA BUS INTERFACE.

PARAMETRIC ANALYSIS RESULTS

STATE OF THE ART EXCEEDS REQUIREMENTS

3652-95

PMS COMPONENT CHARACTERISTIC DATA SHEET

PART B — PERFORMANCE

COMPONENT NAME SWITCHGEAR (SOLID STATE)

FUNCTIONAL CHARACTERISTICS FORM: DPDT (ON-OFF-ON)
POWER TYPE: HIGH VOLTAGE, DC
RATING: POWER - 5.0KW VOLTAGE - 750. VDC
SYSTEM FUNCTION: LOW VOLTAGE DISTR. CONV/REGL INPUT ISOLATION AT THE PAYLOAD INTERFACE UNITS (DC SYSTEM)
PROVISIONS TO MONITOR VOLTAGE AND CURRENT; DATA AND COMMANDS TRANSMITTED VIA SERIAL DATA BUS

PERFORMANCE DEVELOPMENT PROJECTIONS

CHARACTERISTIC	STATE OF THE ART	PMS REQUIREMENT	ACHIEVABLE CAPABILITY
Voltage Level	750V	750 VDC	1000VDC
Peak Voltage	750V	1500 VDC	1500 VDC
Current Capability	5.0 A	6.7 ADC	10.0 ADC
Peak Load	3.8KW	5.0KW	15KW
Efficiency	99.8%	99.8%	99.8%
Reliability	0.957	0.967	SOTA OK
MTBF (Hours)	2.0×10^6	2.6×10^6	SOTA OK
Peak Load Capability	3.8KW	6.0KW	15KW
Operating Frequency	OK	HALF CYCLE @ 25KHZ	OK
Magnetic Field	OK	0.47 GAUSS, MAX	OK
Regulation %	NA	NA	NA
Transient Capability	IN ACCORDANCE WITH THE INTENT OF MIL-STD-1541		
Stability	NA	NA	NA
Redundancy	ACCOMPLISHED AT THE MAJOR MODULE LEVEL		

INTERFACE REQUIREMENTS

Control/Monitor SERIAL DATA BUS - WIRED OR OPTICAL; MIL-STD-1553 TYPE

Operational/Safety REDUNDANT SERIAL DATA BUSSES SHARED WITH ABOVE FUNCTIONS.

Maintainability/Repair EACH SWITCH UNIT (OR RPC) REMOVABLE AND REPLACED FOR SYSTEM REPAIR.

Other BUILT-IN-TEST PROVISIONS COMMANDED AND MONITORED VIA THE DATA BUS INTERFACE.

PARAMETRIC ANALYSIS RESULTS

LARGE VOLTAGE IMPROVEMENT IN RPC OUTPUT CAPABILITY REQUIRED.

BIPOLAR OR FET TRANSISTOR IMPROVEMENT.

3652-95

PMS COMPONENT CHARACTERISTIC DATA SHEET
PART B — PERFORMANCE

COMPONENT NAME SWITCHGEAR (SOLID STATE)

FUNCTIONAL CHARACTERISTICS FORM: DPDT (ON-OFF-ON)
POWER TYPE: HIGH VOLTAGE, DC
RATING: POWER - 13.5KW VOLTAGE - 750VDC
SYSTEM FUNCTION: BATTERY / CHARGER ISOLATION FROM TRANSMISSION BUS SYSTEM (DC SYSTEM)
PROVISIONS TO MONITOR VOLTAGE AND CURRENT; DATA AND COMMANDS TRANSMITTED VIA SERIAL DATA BUS

PERFORMANCE DEVELOPMENT PROJECTIONS

CHARACTERISTIC	STATE OF THE ART	PMS REQUIREMENT	ACHIEVABLE CAPABILITY
Voltage Level	750V	750 VDC	1000 VDC
Peak Voltage	750V	1500 VDC	1500 VDC
Current Capability	5.0 A	18 ADC	20 ADC
Peak Load	3.75 KW	13.5 KW	30 KW
Efficiency	99.8 %	99.8 %	99.8 %
Reliability	0.955	0.918	SOTA OK
MTBF (Hours)	1.9×10^6	1.05×10^6	SOTA OK
Peak Load Capability	3.75 KW	16.2 KW	30.0 KW
Operating Frequency	OK	HALF CYCLE @ 25 KHZ	OK
Magnetic Field	OK	0.47 GAUSS, MAX	OK
Regulation %	NA	NA	NA
Transient Capability	IN ACCORDANCE WITH	THE INTENT OF	MIL-STD-1541
Stability	NA	NA	NA
Redundancy	ACCOMPLISHED AT	THE MAJOR MO	DULE LEVEL

INTERFACE REQUIREMENTS

Control/Monitor SERIAL DATA BUS - WIRED OR OPTICAL; MIL-STD-1553 TYPE

Operational/Safety REDUNDANT SERIAL DATA BUSSES SHARED WITH ABOVE FUNCTIONS.

Maintainability/Repair EACH SWITCH UNIT (OR RPC) REMOVABLE AND REPLACED FOR SYSTEM REPAIR.

Other BUILT-IN-TEST PROVISIONS COMMANDED AND MONITORED VIA THE DATA BUS INTERFACE.

PARAMETRIC ANALYSIS RESULTS

LARGE VOLTAGE IMPR. IN RPC OUTPUT CAPABILITY REQUIRED.

FET OR BIPOLAR TRANSISTOR IMPROVEMENT.

3662-95

PMS COMPONENT CHARACTERISTIC DATA SHEET

PART B — PERFORMANCE

COMPONENT NAME SWITCHGEAR (SOLID STATE)

FUNCTIONAL CHARACTERISTICS FORM : DPDT (ON-OFF-ON)
POWER TYPE : MEDIUM VOLTAGE, DC
RATING : POWER - 13.5KW VOLTAGE - 440 VDC
SYSTEM FUNCTION : BATTERY / CHARGER ISOLATION FROM
TRANSMISSION BUS SYSTEM (AC SYSTEM)
PROVISIONS TO MONITOR VOLTAGE AND CURRENT ; DATA AND
COMMANDS TRANSMITTED VIA SERIAL DATA BUS

PERFORMANCE DEVELOPMENT PROJECTIONS

CHARACTERISTIC	STATE OF THE ART	PMS REQUIREMENT	ACHIEVABLE CAPABILITY
Voltage Level	500 V	440 VDC	1000 VDC
Peak Voltage	500 V	800 VDC	1000 VDC
Current Capability	40 A	31 A DC	40 ADC
Peak Load	20 KW	13.5KW	40KW
Efficiency	99.5%	99.5%	99.5%
Reliability	0.955	0.918	SOTA OK
MTBF (Hours)	1.9×10^6	1.05×10^6	SOTA OK
Peak Load Capability	20 KW MIN	16.2 KW	SOTA OK
Operating Frequency	OK	HALF CYCLE @ 25 KHZ	OK
Magnetic Field	OK	0.47 GAUSS, MAX	OK
Regulation %	NA	NA	NA
Transient Capability	IN ACCORDANCE WITH THE INTENT OF MIL-STD-1541		
Stability	NA	NA	NA
Redundancy	ACCOMPLISHED AT THE MAJOR MODULE LEVEL		

INTERFACE REQUIREMENTS

Control/Monitor SERIAL DATA BUS - WIRED OR OPTICAL ; MIL-STD-1553 TYPE

Operational/Safety REDUNDANT SERIAL DATA BUSSES SHARED WITH ABOVE FUNCTIONS.

Maintainability/Repair EACH SWITCH UNIT (OR RPC) REMOVABLE AND REPLACED FOR SYSTEM REPAIR.

Other BUILT-IN-TEST PROVISIONS COMMANDED AND MONITORED VIA THE DATA BUS INTERFACE.

PARAMETRIC ANALYSIS RESULTS

LARGE VOLTAGE IMPR. IN PPC OUTPUT CAPABILITY REQUIRED

FET OR BIPOLAR TRANSISTOR IMPROVEMENT.

3652-95

APPENDIX 2

REPORT FOR

NAS 3-21757

November 1979

PART I

SOLAR ARRAY POWER LOSS TO THE IONOSPHERE

PART II

HIGH VOLTAGE LINES AND COMPONENTS

John Valerio

James Treglio

PART I

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PART I

SOLAR ARRAY POWER LOSS TO THE IONOSPHERE

ABSTRACT

We investigated the interaction of high-voltage solar arrays (HVSAs) with the ionospheric plasma encountered in low-earth orbit (LEO). First, an analytical model was used to estimate the power loss of an HVSA to the ionosphere through the collection of plasma currents assuming array surfaces of high electrical conductivity and a linear voltage gradient across the length of the array. Then, a more detailed computer model was used that included the effects of insulated surfaces and secondary electron emission. For comparison, a computer calculation of the analytical model, including insulation effects, was also performed. These computer models were developed as part of General Dynamics IRAD 111-2209-202, "Power Systems for Large Spacecraft." Consideration was given to some of the insulation effects found by other investigators in laboratory experiments.

Power loss calculations of the analytical and computer models were compared for a 1200V HVSA with conducting surfaces at LEO altitudes between 200 km and 1000 km. Lower power loss estimates of about 1.6 percent of payload power requirement (250 kw) by the analytical model with insulation were attributed to neglect of secondary electron emission and edge effects. Parametric studies of solar array power losses versus altitude, operating voltage, and insulation covering were performed with the computer model. Peak power loss of 2.2 percent for a 1200V HVSA occurs at about 300 km altitude, and falls sharply for higher and lower altitudes. Power losses are found to increase nonlinearly with voltage, but decrease as the fractional area covered by insulation increases. However, complications arise from the use of insulation in the form of increased frequency of electrical discharges and current collection through insulation perforations.

We recommend that further experimental and theoretical work be done to understand the mechanism responsible for electrical discharge of HVSA surfaces that are exposed to the space plasma. An important measurement is the secondary electron emission coefficient by O^+ ion impact on solar array materials. Finally we recommend a theoretical calculation of the wake behind the solar array to explore possible focusing of plasma currents on to the array.

SECTION 1

INTRODUCTION AND SUMMARY

1.1 INTRODUCTION

Use of high-voltage solar arrays in large-space power platforms could effect substantial cost savings and reduced payload weights. Space platform transmission lines, electromagnetic machinery, and power converters can be made lighter at higher voltages.

The potential difference developed along the array, however, cannot be increased indefinitely because the charged particle flux from the ionospheric plasma to the array can serve as a power leakage path. If the power loss is to be a small fraction of the generated power (about 100 watt/m^2), then the maximum voltage of the array with respect to the plasma will be limited. A straightforward method for reducing the surface field by electrical insulation can be used at the expense of added spacecraft weight.

1.2 SUMMARY

In our investigation, we estimate power loss from a high-voltage solar array to the plasma by first assuming the array is a bare conductor. Complications that arise from the addition of an insulating surface will be reviewed in Section 2, where laboratory experiments on electrical wiring are discussed. In Section 3, we present the analytical model for power loss that is applicable to low-earth orbits (LEOs) between 200 km and 1000 km. Consideration of the array as a bare conductor is believed to represent the conditions of maximum power loss to the plasma environment. A more detailed computational model capable of treating both conductor and insulator surfaces is given in Section 4. A comparison of computational model predictions to experimental results and the simpler analytical model is given in Section 5. A parametric analysis of solar array power loss versus voltage is carried out and the effect of partial array coverage by insulation is also studied. Section 6 considers areas such as arcing, secondary emission, and wake effects that require further study. Conclusions reached in this study and recommendations for future work are given in Section 7.

SECTION 2

EXPERIMENTAL DATA

Laboratory experiments on the interaction of plasma with material surfaces used in spacecraft have been conducted by several groups. Experiments relevant to our effort have been conducted at NASA - Lewis Research Center (LeRC), NASA - Johnson Space Center (JSC), and the Boeing Company. We will give a brief summary of the current collection and electrical arcing phenomena observed by the experimenters.

2.1 LeRC EXPERIMENTS

The NASA - LeRC group (Reference 1) exposed a stainless steel disc, a similar disc mounted on Kapton, and a solar array segment to a 1.0 eV nitrogen plasma. Positive and negative voltages relative to the plasma were applied to each target system.

Current collection by the plain steel disc for bias voltages up to ±1.0 kV was consistent with theoretical predictions. Essentially the same current-voltage characteristic was observed for the disc-on-Kapton system when the voltage bias was negative, but significant differences occurred with positive bias. Below +100 V, the Kapton insulation assumes a slightly negative (-6 V) potential relative to the plasma. Electron collection by the disc is slightly reduced from the plain disc value by the overlap of the Kapton field at the disc edge. Above +100 V, the disc electric field appeared to expand over the Kapton surface until, at sufficiently high bias voltage, the entire Kapton surface area collected current. Consequently, current collection at high positive bias greatly exceeds the values for the plain steel disc. A theoretical description of this interaction has not yet been formulated.

Interaction of nitrogen plasma with the solar array segment produced large variations of current collection with positive bias and arcing at high negative voltage. As with the disc-on-Kapton system, current suppression is observed for positive voltage less than +100 V and the enhanced area collection is fully effective above +200 V. At low positive potential, the cover slides restrict current collection to the interconnects. As the array potential is increased, the slide potential rises toward the interconnect values to allow the plasma sheaths about the interconnects to expand over the cover slides.

For negative voltage bias, the current-voltage characteristic of the interconnect area resembles the plain disc up to a potential where arcing occurs. The negative voltage required to trigger arcing appears to increase as the plasma density is decreased. Electric fields, as in the disc-on-Kapton system, are mostly confined to the interconnect region up to the discharge potential. Reliable prediction for the onset of arcing is not presently possible.

2.2 JSC EXPERIMENTS

The NASA - JSC group (Reference 2) exposed a 1.0 m by 10 m panel in a large vacuum chamber to an argon plasma with 15-25 eV flow energy and 0.5-2 eV electron temperature. One square meter of the panel consisted of solar cells and the remaining area was covered by a conductive plastic that could support 4 kV along its length. Test of this large panel under conditions that simulated a high-voltage solar array in LEO was another step toward the development of scaling relationships that can be extrapolated to large space systems. Although current collection may submit to scaling, arcing seems independent of overall size.

Three electrical configurations for the panel were used in the experiments: a linear voltage drop along the panel in a floating configuration that approximates the situation in space; one end connected to the chamber wall, the other end to a high-voltage supply; and operation of the entire panel at a constant high-voltage. We are most interested in the results obtained from the floating configuration.

Consistent with theory (see Section 3), the electrically floating panel was observed to operate about 3 percent positive and 97 percent negative relative to the plasma potential. Power loss to the plasma was about 5.6 percent at an operating voltage of 4000 V.

Arcing was observed at frequent intervals in the experiments. Some areas were small but others resulted in the complete discharge of the panel. Arcs originated on insulator surfaces only when voltages were above +400 V and below -1000 V. Contrary to the LeRC group's finding, the voltage for arcing fluctuated widely from day to day, with similar plasma densities.

2.3 BOEING EXPERIMENTS

High-voltage solar array experiments were conducted at Boeing (Reference 3) in 1973 to investigate plasma current collection, arcing, and dielectric properties. These experiments used plain samples of dielectric materials, biased metal plates covered by insulation with pinholes, and biased solar array segments. Many of the findings at Boeing are consistent with the later work of LeRC and JSC summarized above.

The most significant finding was the large electron current that can be collected through a pinhole in the insulation over an electrode that is biased positively relative to the plasma. Similar to the disc-on-Kapton experiment at LeRC, the insulation area about the pinhole becomes increasingly effective for current collection above +100 V. The spread of the electric field from the pinhole over the surrounding insulation is believed to collect current along the insulator surface. Damage to Kapton insulation occurred at power levels between 0.5 W and 5 W per pinhole.

Solar panels segments biased positive relative to the plasma collected the bulk of the plasma currents at the interconnects. Covering the interconnects with insulation greatly reduced the current, but the expense for insulation was high. Any break in the insulation or development of a pinhole negated the effect of insulation. Negative biased solar array segments experienced frequent arcing below -400 V at the interconnect locations. Insulation of the interconnects was found to reduce arcing.

2.4 SUMMARY OF FINDINGS

High-voltage conductors exposed to plasma appear to collect currents proportionate to their surface area. Plasma current collection can be substantially reduced by completely covering a high-voltage conductor with insulation. However, if a pinhole or crack develops in the insulation, then the effect of the insulation is essentially defeated. If the underlying conductor has a high positive potential relative to the plasma, the entire insulated area appears to collect and redirect electrons toward the pinhole. If the underlying conductor is at a high negative potential relative to the plasma, electrical discharges occur that disrupt the voltage distribution and often damage the insulation.

SECTION 3

ANALYTICAL MODEL

3.1 PHYSICAL PHENOMENA

The computation of power leakage should consider (1) the flow of thermal ions and electrons to the array, (2) the ion ram current arising from satellite motion, (3) the charge particle flow to the array due to satellite wake effects or accumulated charge, (4) the photoelectron emission by the solar flux, (5) secondary electron emission, and (6) the effect of the geomagnetic field on electron flow. The geomagnetic field greatly reduces the transport of electrons normal to the field direction and is also responsible for the development of a potential gradient along the array as the satellite traverses the field. The latter phenomena is known as the $\underline{v} \times \underline{B}$ effect, where $\underline{v}$ is the satellite velocity and $\underline{B}$ is the geomagnetic field. We do not consider depreciation of solar cell capacity due to excess current.

The most important charging mechanisms are the collection of electrons, the collection of ions, and secondary electron emission. Ion collection is dominated by the ram component below 2000 km orbital altitude but wake effects should also be considered. The large sheath structure formed plus the potential gradients in the wake could significantly modify ion collection. Since photo-electron production becomes important above a 1000 km altitude, we did not incorporate it in our LEO model. Consideration of the $\underline{v} \times \underline{B}$ effect was also omitted because the magnitude of the potential gradient developed is about 1 percent of gradient along the array.

The contribution of electrons from secondary emission by ion impact is included in the computational model (see Section 4) but is omitted in the analytical model for simplicity. Current contribution by secondaries is usually a few percent. Secondary emission by electron impact on the (high) positive potential surfaces is not modeled. Modeling of secondary electron emission from surface area of low positive potential (with respect to the plasma) could be quite complex, since only a fraction of the emitted electrons will be reabsorbed. In this case, knowledge of the secondary electron distribution in energy and angle is required. Fortunately, we can sidestep this complication since the fraction of array area near the plasma potential is negligibly small.

3.2 LEO ENVIRONMENT

The characteristics of the ionosphere between 200 km and 1000 km varies with altitude, geographic location, time of day, season of the year, and sunspot cycle. Any statement of the ionospheric properties must be considered to be indicative and not definitive because of the wide variations in the measured properties.

In Table 3-1 we list, at selected altitudes, the magnitudes of electron density, electron temperature, and ion temperature characteristic of the ionosphere during the day at maximum solar sunspot cycle. Use of these values should provide an estimate for the maximum power loss as a function of altitude since the electron densities are maximum under these conditions. The very maximum power loss, of course, is expected near 300 km altitude.

Table 3-1. Daytime Ionospheric Conditions at Maximum Sunspot Activity (Reference NASA SP-8049)

Altitude (km)	Electron Density (m^{-3})*	Electron Temperature (eV)	Ion Temperature (eV)	Satellite Velocity (m/sec)*
200	4.5 (11)	0.075	0.060	7.80 (3)
250	9.0 (11)	0.140	0.063	7.78 (3)
300	2.0 (12)	0.190	0.069	7.74 (3)
350	1.8 (12)	0.205	0.078	7.71 (3)
400	1.5 (12)	0.215	0.083	7.68 (3)
500	1.1 (12)	0.230	0.115	7.63 (3)
600	6.8 (11)	0.245	0.155	7.57 (3)
700	4.0 (11)	0.255	0.210	7.52 (3)
800	2.8 (11)	0.265	0.241	7.47 (3)
900	1.9 (11)	0.272	0.259	7.42 (3)
1000	1.2 (11)	0.282	0.282	7.36 (3)

*Numbers in parentheses represent powers of 10.

3.3 PHYSICAL MODEL

The equilibium state of the solar array with the plasma is reached when the net electrical current to the array is zero. That is, $J_i A_- = -J_e A_+$ where J_i is the ion current density, J_e the electron current density, A_- the negative potential area, and A_+ the positive potential area. The array floats with respect to the plasma with some voltage distribution fixed by the solar cells. Since the electron current density is usually 10 to 100 times the ion current density, the floating negative voltage area of the array is expected to be 10 to 100 times the positive voltage area. The array under consideration here will assume a constant voltage gradient along the length of the array and uniform potential normal to the length. Figure 3-1 is a qualitative illustration of a solar array with a linear voltage distribution and the expected current leakage variation.

If the current collecting surface is flat and has dimensions large compared to the thickness of the plasma sheath formed, then the ion current density and electron current density are nearly uniform over the negative and positive portions of the array, respectively. The portion of the array near space potential is subject to large changes in current density. However, the region is limited to an area with potential ±5 times the electron thermal potential (kT_e/e). For 2 cm solar cells that develop 0.5 V, the dimension of rapid change in current density is about 40 cm for a 1.0 eV electron temperature.

The sheath structure about a solar array in Low Earth Orbit (LEO) is schematically illustrated in Figure 3-2 with the satellite velocity v_o normal to plane array. A wake is formed behind the negative portion of the array as the ambient ions stream around the panel. Ions of the positive ion sheath are primarily supplied by the ram motion of

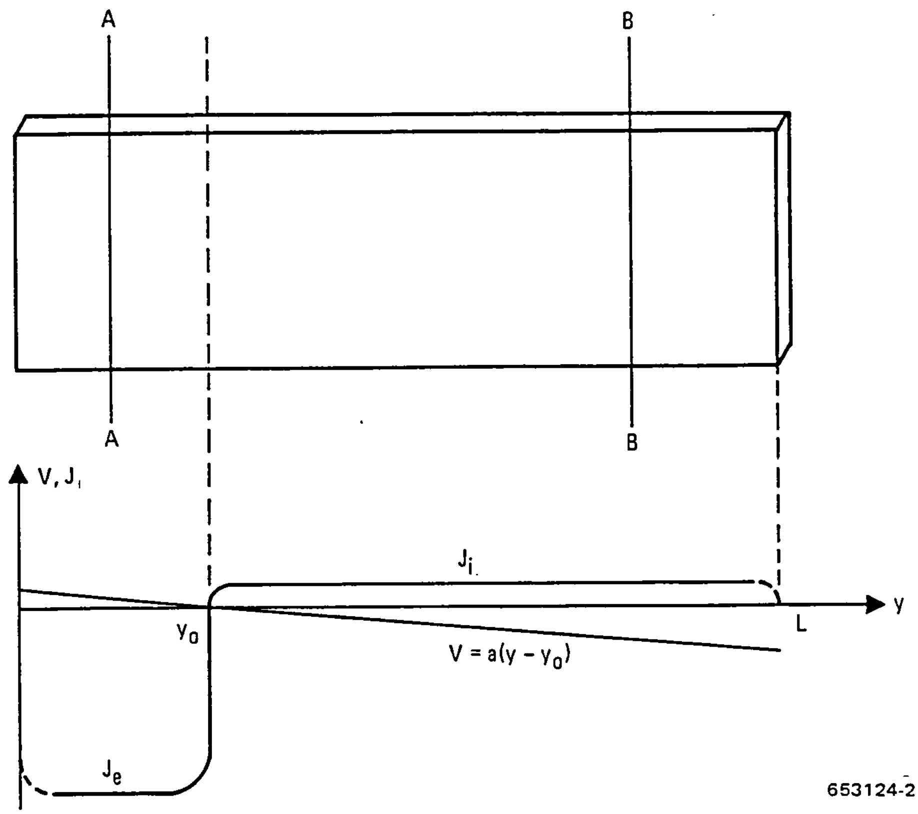

Figure 3-1. Distribution of Electron and Ion Current Densities Along a Floating Solar Array. y_o is at Plasma Potential for an Array with a Linear Voltage Gradient

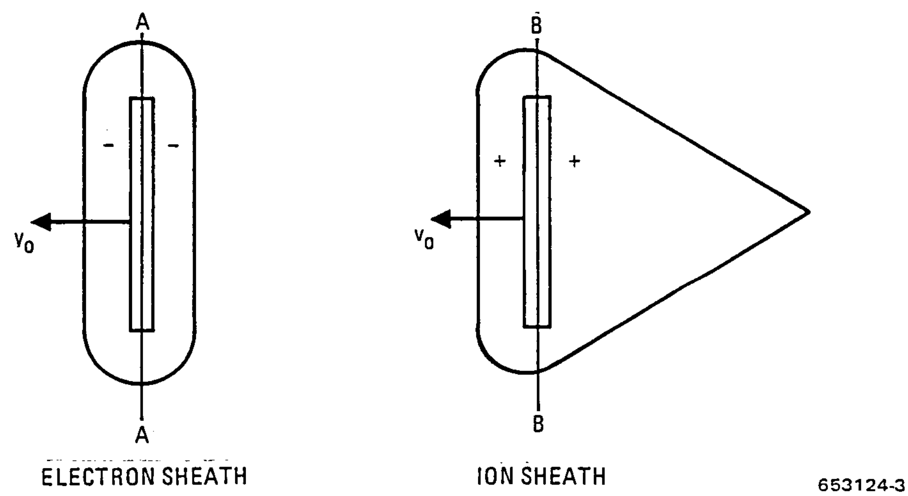

Figure 3-2. Electron (A-A) and Ion (B-B) Sheath Cross Sections about a Solar Array Moving at Velocity v_o

the satellite since the mean thermal ion velocity $\langle v_i \rangle$ is much less than the satellite velocity. Electrons are simply repelled by the negative potential. The electron sheath structure about the positive portion of the array is not expected to exhibit much of a wake because the mean electron thermal velocity $\langle v_e \rangle$ is much greater than the satellite velocity. Here, the ions are repelled by the positive potential. Consequently, the electron sheath thickness is governed by the array potential and the electron thermal current.

If the length and width of the flat current collection surface are large compared to the thickness of the potential sheath, a space charge-limited current will flow from the plasma to the solar array. Edges of the solar array, which have a characteristic dimension determined by the thickness of the array (about 0.5 cm), will form half-cylindrical sheaths. Ignoring edge effects we can compute the sheath thickness, d, from the Langmiur-Child expression for the plasma diode current density (Reference 4):

$$J = \frac{4\epsilon_o}{9}\left(\frac{2e}{m}\right)^{1/2} \frac{|V|^{3/2}}{d^2} \tag{3-1}$$

where V is the potential with respect to the plasma, m is the particle mass, e is the charge on an electron, and $\epsilon_o = 8.85 \times 10^{-12}$ F/m^2. The sheath thickness can be found from Eq 3-1 as

$$d = \begin{cases} 1.53 \times 10^{-3} \; |V_e|^{3/4} \, J_e^{-1/2} & \\ 2.36 \times 10^{-4} \, M^{-1/4} \; |V_i|^{3/4} \, J_i^{-1/2} & \text{for ions} \end{cases} \tag{3-2}$$

once J_e or J_i is obtained. The ion mass number is given by M.

The maximum value (or saturation value) for J_e available from the plasma edge of the sheath is the thermal current

$$J_e = 1/4 \; ne \; \langle v_e \rangle = ne\left(\frac{kT_e}{2\pi m_e}\right)^{1/2} \tag{3-3}$$

where n is the electron (or ion density) in the plasma, T_e is the electron temperature, and $k = 1.38 \times 10^{-23}$ J/K. Ion current density on one side of the solar array is dominated by the ram current

$$J_i = ne \; v_o \cos\alpha; \quad 0 \leq \alpha \leq 90° \tag{3-4}$$

where v_o is the satellite velocity and α is the angle between the satellite velocity and the surface normal. On the wake side of the array, the ion current density decreases to

$$J_i = \max \begin{cases} ne\left(\frac{kT_i}{2\pi m_i}\right)^{1/2} & ; \; T_i \geq T_e \\ 1/2 \, ne\left(\frac{kT_e}{m_i}\right)^{1/2} & ; \; T_i < T_e \end{cases} \tag{3-5}$$

However, when an ion wake is present the planar sheath Eq 3-2 does not apply on the wake side. But this is of little consequence because most of the ion current is incident on the front surface.

If the satellite velocity is assumed normal to the array, Eqs 3-2 through 3-4 can be used to estimate the sheath thickness using the reasonable values $v_o = 10^4$ m/sec, $V_e = 1.0$ kV, $V_i = -10$ kV, M = 16, and the plasma properties given in Table 3-1. Computed sheath thicknesses, which are listed in Table 3-2 with the saturation current densities, show the planar approximation has a high degree of validity up to 600 km altitude provided the smaller dimension of the array exceeds about 38 meters. The General Dynamics Convair Power Management System (PMS) arrays, with proposed 40 m by 48 m dimensions and expected maximum potentials of $V_e \approx 100$ V and $V_i \approx$ 1100 V, may validly use the planar approximation to 1000 km since $d_e \approx 4.0$ m and $d_i \approx 6.0$ m there.

Table 3-2. Electron Current Densities, Ion Current Densities, and Sheath Thicknesses (see text for voltage conditions)

Altitude (km)	J_e (A/m^2)*	d_e (m)	J_i (A/m^2)*	d_i (m)
200	3.3 (-3)	4.7	7.2 (-4)	4.4
300	2.3 (-2)	1.8	3.2 (-3)	2.1
600	7.9 (-3)	3.0	9.6 (-4)	3.8
1000	1.6 (-4)	22.0	1.8 (-5)	28.0

*Numbers in parentheses represent powers of 10.

Other factors that can affect the power loss to the plasma at higher altitudes are of lesser importance in LEO altitudes. Current contribution through photoelectron emission is usually neglible below 1000 km, but secondary electron emission may contribute over 20 percent of the saturation current density at higher voltages. Secondary emission will be included in the computational model presented in Section 4.

Modification of the ion current by the geomagnetic field is also neglible since the ion gyro radius is large compared to the dimensions of the array. However, the geomagnetic field can decrease the electron current collected by one-half when the field is oriented parallel to the array surface. The time-averaged effect of the magnetic field will be considerably less than this because of the changing orientation of the array to the field through orbital motion. Magnetic field effects will not be included in our model.

3.4 POWER LOSS

A first estimate for power loss from the array to the plasma can be computed analytically provided the assumption of a thin plane sheath holds. If we consider the array to be a good electrical conductor free of any insulator surfaces, we should approximate the upper limit for power loss when the satellite velocity is normal to the array surface. Application of insulation material to high-voltage elements (provided arcing can be controlled) should lower the overall power loss to the plasma. The average power leakage $\langle P \rangle$ per unit area A (that is $A_+ + A_-$) of the solar array can be written as

$$\frac{\langle P \rangle}{A} = \frac{1}{L}\int_0^{y_o} dy\ J_e(y)\ V(y) + \frac{1}{L}\int_{y_o}^{L} dy\ \ J_i(y)\ V(y) \tag{3-6}$$

$$= \frac{\langle P_e \rangle}{A} + \frac{\langle P_i \rangle}{A} \tag{3-7}$$

where y_o is the location on the panel that is at plasma potential (see Figure 3-1), y is the distance from the positive potential end of the array, V(y) is the potential at position y, $J_e(y)$ is the net current density collected on positive portion of array (mainly electrons) at y, $J_i(y)$ is the net current density collected on the negative portion of the array (mainly ions), and L is the length of the array. The current densities are (front and back):

$$J_e(y) = -nev_o + 1/2\ ne\ \langle v_e \rangle\ ; \quad 0 \leq y \leq y_o \tag{3-8}$$

$$J_i(y) = -nev_o + 1/2\ ne\ \langle v_e \rangle \exp\left[-\ \frac{ae}{kT_e}\ \ (y - y_o)\right]\ ; \ \ y_o < y < L \tag{3-9}$$

and the linear potential variation chosen is

$$V(y) = -a\ (y - y_o)\ ; \quad a > 0, \ \ 0 \leq y \leq L. \tag{3-10}$$

Substitution of Eqs 3-8 and 3-9 into Eq 3-6 and carrying out the indicated integrations produces the desired power leakage expressions

$$\frac{\langle P_e \rangle}{A} = \frac{nea}{2L}\, y_o^2 \left(\langle v_e \rangle /2 - v_o \right) \tag{3-11}$$

and

$$\frac{\langle P_i \rangle}{A} = \frac{nea}{2L} \left\{ v_o (L - y_o)^2 + \langle v_e \rangle \frac{kT_e}{ae} (L - y_o) \exp\left[- \frac{ae}{kT_e} (L - y_o) \right] - \langle v_e \rangle \left(\frac{kT_e}{ae} \right)^2 \left(1 - \exp\left[- \frac{ae}{kT_e} (L - y_o) \right] \right) \right\} \tag{3-12}$$

which reduces to

$$\frac{\langle P_i \rangle}{A} = \frac{nea}{2L} \left[v_o (L - y_o)^2 - \langle v_e \rangle \left(\frac{kT_e}{ae} \right)^2 \right] \tag{3-13}$$

since the argument of the exponent is large.

Equation 3-11 represents the areal power loss due to electron collection minus the power gain due to ion collection on the positive portion of the array. Equation 3-13 gives the areal power loss due to ion collection on the negative portion of the array minus the power gain from electron collection over a small region near y_o where the potential reverses.

In order to compute the power leakage we must first determine the value of y_o. Recalling that the total current to the array must be zero at equilibrium, we can write

$$J_e A_+ + J_i A_- = 0 \tag{3-14}$$

or

$$\frac{A}{L} \int_0^{y_o} dy\, J_e(y) + \frac{A}{L} \int_{y_o}^{L} dy\, J_i(y) = 0 \tag{3-15}$$

Carrying out the indicated integration produces a transcendental equation in y_o

$$v_o L - 1/2 \langle v_e \rangle y_o - 1/2 \langle v_e \rangle \frac{kT_e}{ae} \left\{ 1 - \exp\left[- \frac{ae}{kT_e} (L - y_o) \right] \right\} = 0 \tag{3-16}$$

For LEO the exponential term is extremely small, consequently a good approximation is

$$\frac{y_o}{L} = \frac{2\, v_o}{\langle v_e \rangle} - \frac{kT_e}{aeL} \tag{3-17}$$

where the second term may also be neglected when the product $aL >> 1$. For the arrays under consideration, the inequality is usually satisfied.

The maximum voltage (or length) for a solar array that is formed solely with conducting surfaces is limited by the power production capability of the array; i.e., approximately 100 W/m^2. An estimate of the maximum voltage (without use of insulation) can be found from the inequalities

$$-J_i\, V(L) < 100 \quad \text{and } J_e\, V(0) < 100 \tag{3-18}$$

for the negative or positive ends of the array. At the peak of the F-region of the ionosphere (300 km) we find, with the aid of Table 3-1, the voltage maximums

$$V(L) > -31 \text{ kV} \quad \text{and } V(0) < 2.2 \text{ kV} \tag{3-19}$$

which correspond to $L < 1.25$ km when a voltage gradient $a = 25$ V/m is used. In practice, the likely requirement to limit power loss below 100 W/m^2 at the array ends would proportionately reduce the allowed maximum voltage and length of the array. Alternatively, a dielectric covering might be used to insulate the high voltage from the plasma.

The highest voltage expected in the General Dynamics Convair PMS is limited by the 48 m array length. At 300 km and $a = 25$ V/m, we find $V(L) = -1116$ V and $V(0) = 84$ V assuming conducting surfaces only. This corresponds to less than 4 W/m^2 power loss at each end. Total power leakage to the plasma, given by the sum of Eqs 3-11 and 3-13, is 5.7 kW or 2.2 percent of the 250 kW system at an altitude of 300 km during solar maximum conditions. Total power loss computed includes both arrays, each with dimensions 40 m by 48 m. Insulation should reduce these losses further. At higher or lower orbital altitudes, the array will experience lower power losses. For example, we expect the power loss at 1000 km to decrease by a factor of 17 from the amount at 300 km.

SECTION 4

DESCRIPTION OF COMPUTER MODEL

To estimate the effects of insulation and the variation of power loss with array voltage and altitude, a flexible computer code was used to perform the power loss calculation. This code, called SPACE, was developed as part of the space power system IRAD, and includes consideration of secondary electron emission. Currently, the code is designed for altitudes between 200 and 1000 km where photoelectron emission is unimportant.

4.1 COMPUTATIONAL MODEL

The solar panel is modeled in the current version of SPACE as a series of 2 cm cells with 0.5 V across each of them. Cells are arranged in the array so that voltage increases in only one dimension to produce a voltage gradient of 25 V/m. For voltages positive relative to the plasma, the current and power loss are calculated by summing the contribution from strips 2 cm by W, where W is the array width. Each strip along the array has a voltage V_n where n is the position index. For voltages below the plasma potential, the strip sizes are increased to 20 cm by W since the ion contribution to the power loss per unit area is much less than the electron contribution. The last strip, which is usually less than 20 cm across, is divided into 2 cm segments.

The program selects a position on the array, the cross-over point, at which the voltage relative to the plasma is zero (i.e., the ion current equal to the electron current), and then calculates currents collected on all the strips. If the ion current does not equal the electron current, a new cross-over point is determined and the currents are recomputed. This procedure is repeated until the ion and electron currents are within a specified tolerance (say 5%), at which time the code computes power loss for the entire array.

4.2 TREATMENT OF PLASMA SHEATH

The code has been constructed to treat solar array panels when the plasma sheath thickness is small compared to array dimensions. The model employed assumes that a flat sheath covers the 2 cm by W area strips with 2-cm-long half cylinders around the edges of the W dimension. Current to each strip is computed from a calculation of the sheath structure appropriate to the voltage of each strip. The radius r_n of the n^{th} cylindrical edge sheath is computed using the Langmuir solution for the current of a cylindrical diode, Reference 4 (compare Eq 3-2),

$$r_n = \begin{cases} 2.34 \times 10^{-6} \ |V_n|^{3/2} / (a\beta^2 J_e) \ ; V_n > 0 \\ 5.45 \times 10^{-8} \ |V_n|^{3/2} / (a\beta^2 J_i M) \ ; V_n < 0. \end{cases} \qquad (4\text{-}1)$$

Here M, J_e, and J_i are defined as in Eqs 3-2 through 3-5. V_n is the voltage of the n^{th} strip, a is the radius of a cylinder with the same surface area as the strip edge, and β is given by an infinite series. In this calculation, β was approximated by the first four terms of the series (Reference 4):

$$\beta \approx b - \frac{2}{5} b^2 + \frac{11}{120} b^3 - \frac{47}{3300} b^4 \qquad (4\text{-}2)$$

where

$$b = \ln (a/r_n) \qquad (4\text{-}3)$$

This expression for β results in the use of a sheath radius somewhat smaller than that given by the exact value of β. However, in the worst case of very large sheaths, the sheath radius is only underestimated by 20 percent.

Orbit calculations are usually required to properly determine surface currents when large sheaths are present, since only part of the current entering the sheath is collected. If the impact parameter

$$p = a \left[1 + |eV| / \ kT \right]^{1/2} \qquad (4\text{-}4)$$

is smaller than the sheath radius, the normal practice is to replace the sheath radius with p. In the code used, this procedure is inadequate.

To understand the difficulty, consider the particle orbits in Figure 4-1. In orbit A, the incident particle has an impact parameter at infinity less than p, and thus strikes the surface. But a particle in orbit B has an impact parameter at infinity greater than p, so it misses the collecting surface even though it passes through the sheath. Note, however, orbit C. Even though its impact parameter is greater than p, it still strikes the collecting surface. All particles in C orbits will be collected since those orbits hit the array. Thus, substitution of p for the sheath radius will underestimate the collected current because half the incident particles have orbits that pass to the array side of the half-cylinder sheath on the edge. Consequently, current collected includes particles with impact parameters less than p plus half the incident particles that pass through the sheath with impact parameters greater than p.

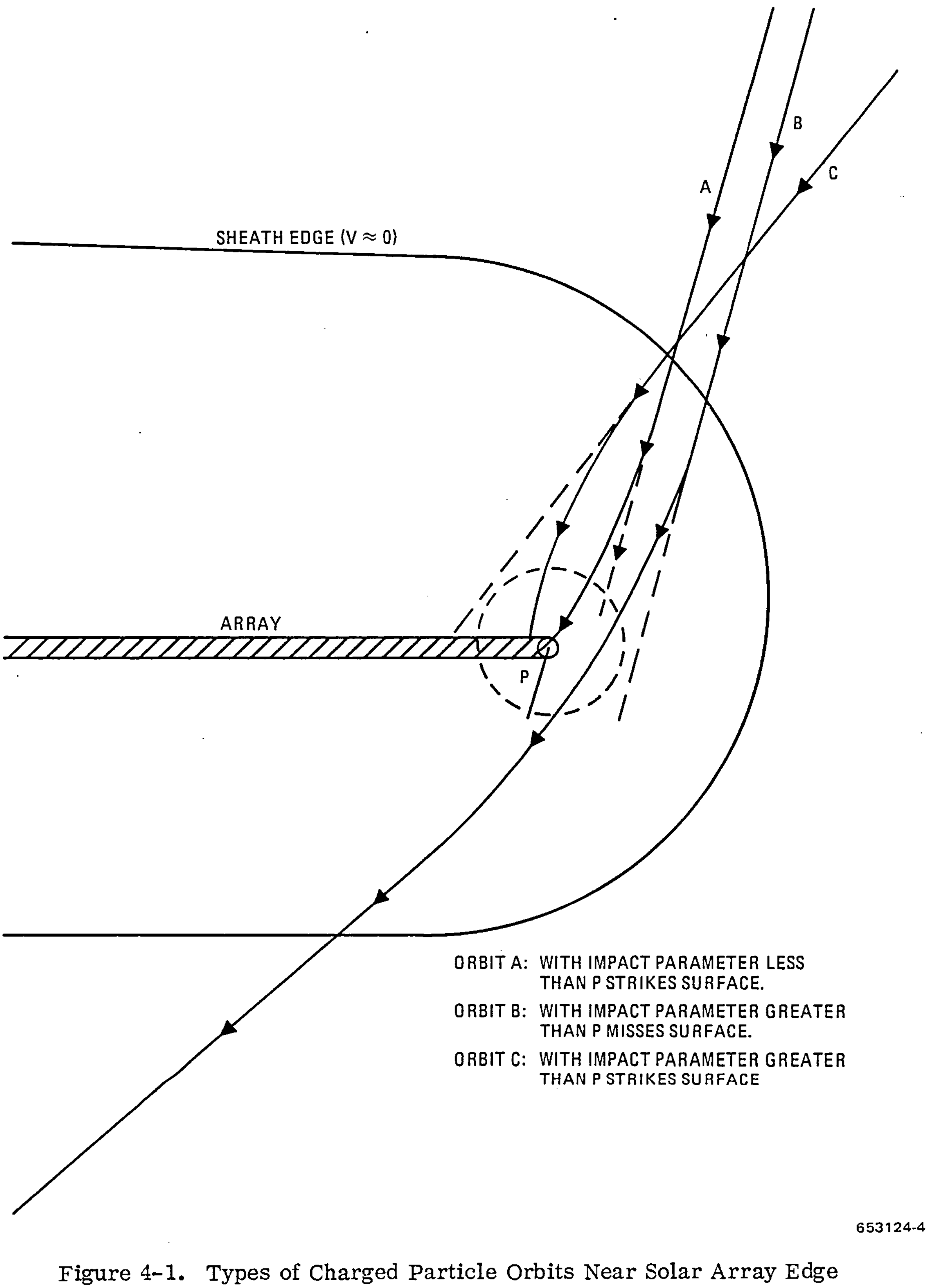

Figure 4-1. Types of Charged Particle Orbits Near Solar Array Edge

4.3 EFFECTS OF INSULATION

The code uses a straightforward method to calculate power loss from a solar array when part of the surface is covered with insulating material. Experiments (see Section 2, references 1 and 2,) find that, for $V < 0$, the current collected is proportional to the exposed conductor area. The same holds true when $0 > V > 200$ V, but dramatic current increases occur as the voltage rises above 200 V until the collected current becomes proportional to the total surface area, conductor plus insulator.

For array voltages negative relative to plasma potential, the code assumes that only conductor surfaces collect current. In the calculation of the sheaths, it has been found (Reference 5) appropriate to replace ϵV for V where ϵ is the ratio of conductor surface area to total surface area. For positive array voltages, the code assumes the entire surface is a conductor.

The last assumption for positive surfaces differs from that of other investigators (Reference 6). They assume the conductor area alone collects current for $V < 200$ V whereas the entire surface is allowed to collect current at higher voltages. In addition, the sheath is computed as if the surface voltage was reduced by 50 V. These model refinements have negligible effect on the power loss computation for high voltage solar arrays.

4.4 SECONDARY EMISSION

The preponderant ion species at low earth orbit altitudes is O^+. Experiments have not yet been conducted to determine secondary electron emission coefficients for O^+ on solar array materials. Available data (Reference 7) for O^+ on Mo has been fit by a power law between 200 eV and 8 keV as

$$\gamma = 0.179E^{0.8} \qquad (4\text{-}5)$$

where γ is the secondary electron emission coefficient and E is the ion energy in keV. Eq 4-5 is used in the code to provide a first estimate for the effect of secondary electron emission on solar array power loss.

The secondary emission coefficient used reaches unity at about 9 keV. Calculated power losses from surfaces that accelerate O^+ to this voltage will be twice the value found if secondary emission were not included. The need for good values of O^+ secondary electron emission coefficients on solar array materials is evident.

SECTION 5

RESULTS OF ANALYSIS

5.1 COMPARISON OF ANALYTIC AND COMPUTER MODELS

Power loss for the 40 m by 48 m proposed General Dynamics Convair solar array panel was calculated by the computer code SPACE. First the computation was made assuming a panel with conducting surfaces alone without secondary electron emission, and computed again with the effects of secondary emission included. Without secondary emission, the SPACE code prediction for power loss exceeded the analytical model of Section 3 with insulation effects considered by about 10 percent for most altitudes between 250 km and 1000 km. Since all the conditions and plasma properties were the same (see Section 3), the increased power loss found by SPACE is attributed to the cylindrical sheath structure used to account for edge effects. Inclusion of secondary electron emission increases the computed power loss by an additional 6 percent.

5.2 JSC EXPERIMENT

The SPACE code was used to model the floating panel experiment conducted by the NASA - JSC group (Reference 2). Midrange values for the argon plasma temperature and flow velocity were employed. We calculated a 62 W power loss to the plasma when the operating voltage was 4000 V, which is about 11 percent higher than the measured 56 W loss. In view of the large uncertainties of the plasma properties, the computed power loss may be considered consistent with the experimental value.

5.3 PARAMETER STUDIES

Parametric calculations of power loss were performed for a solar array panel with 1920 m^2 area, a 25 V/m voltage gradient along one dimension, and 0.5 cm panel thickness. Power loss was calculated over the altitude range 200 km to 1000 km and over an operating voltage range of 300 V to 3000 V using the daytime plasma conditions given in Table 3-1. In the voltage variation study, the total area remains constant as the length and width dimensions change to accommodate the changing operating voltage developed by the fixed voltage gradient.

Figure 5-1 is a plot of array power loss to the ambient plasma as a function of altitude. The array surface that receives the ion ram current is designated as the front surface by convention. Three different percentage coverings by insulation illustrate the decreasing power loss with diminishing conductor surface. The front-back conductor surfaces exposed are 90% - 10%, 60% - 10%, and 30% - 10%. Secondary electron emission is not included in these calculations.

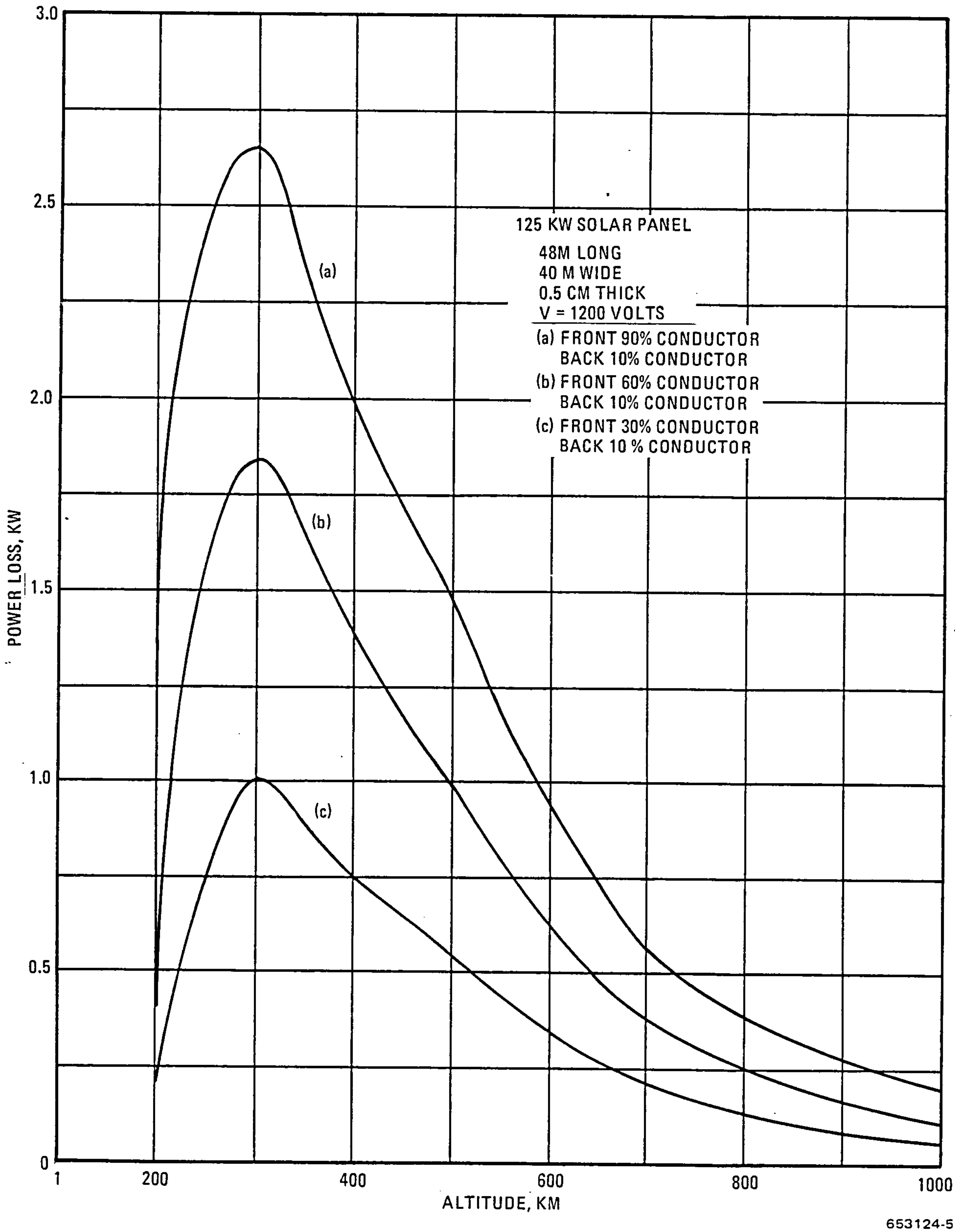

Figure 5-1. Solar Array Power Loss with Altitude: Three Different Fractional Areas of Conductors

In Figure 5-2, the power loss is plotted as a function of array operating voltage. The results are given for 300 km and 600 km altitude, with and without the secondary electron emission. Secondary emission appears to increase in importance with increasing voltage. We must remember that the secondary emission coefficient used is for O^+ on a clean Mo surface. The correct magnitude of the coefficient for O^+ on actual solar array materials may be quite different.

Power loss to the plasma is plotted in Figure 5-3 as a function of altitude for the solar panel to show the effects of secondary emission. Secondary electron emission produces an incremental power loss of about 6 percent for most altitudes shown when the panel is operated at 1200 V. Maximum power loss is less than 2.3 percent of the generated power at 300 km, decreasing with altitude to below 0.2 percent at 1000 km. As shown in Figure 5-1, these losses may be reduced further by appropriate use of insulation. Recall, that these power losses represent a worst case; namely, we assume daytime plasma conditions that occur at maximum sunspot activity, and the least insulated array surface intercepts the ion ram current at normal incidence.

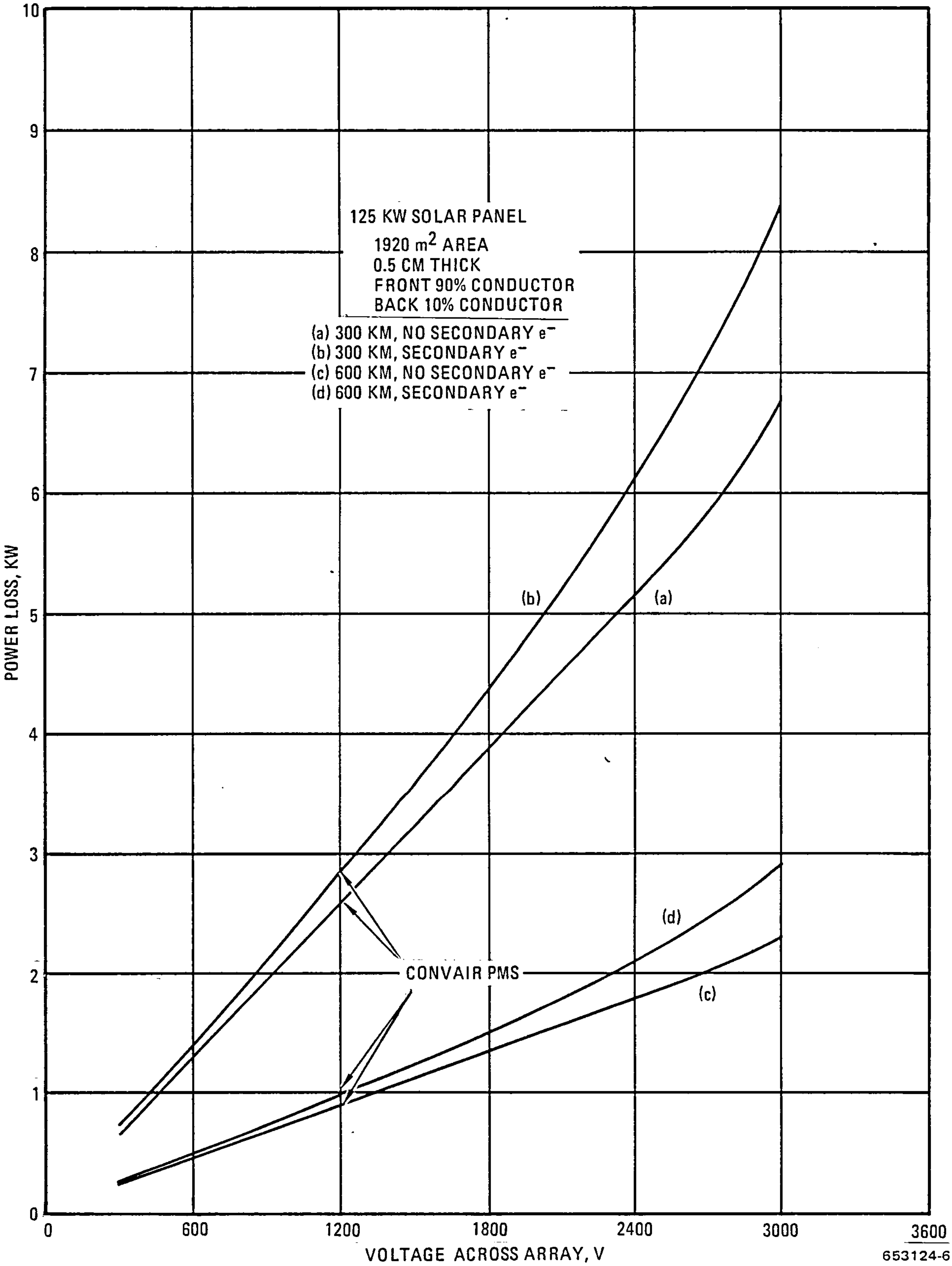

Figure 5-2. Solar Array Power Loss with Voltage. Power Loss With and Without Secondary Electron Emission at 300 km and 600 km Altitude. Values for General Dynamics Convair's Power Management System (PMS) are Identified

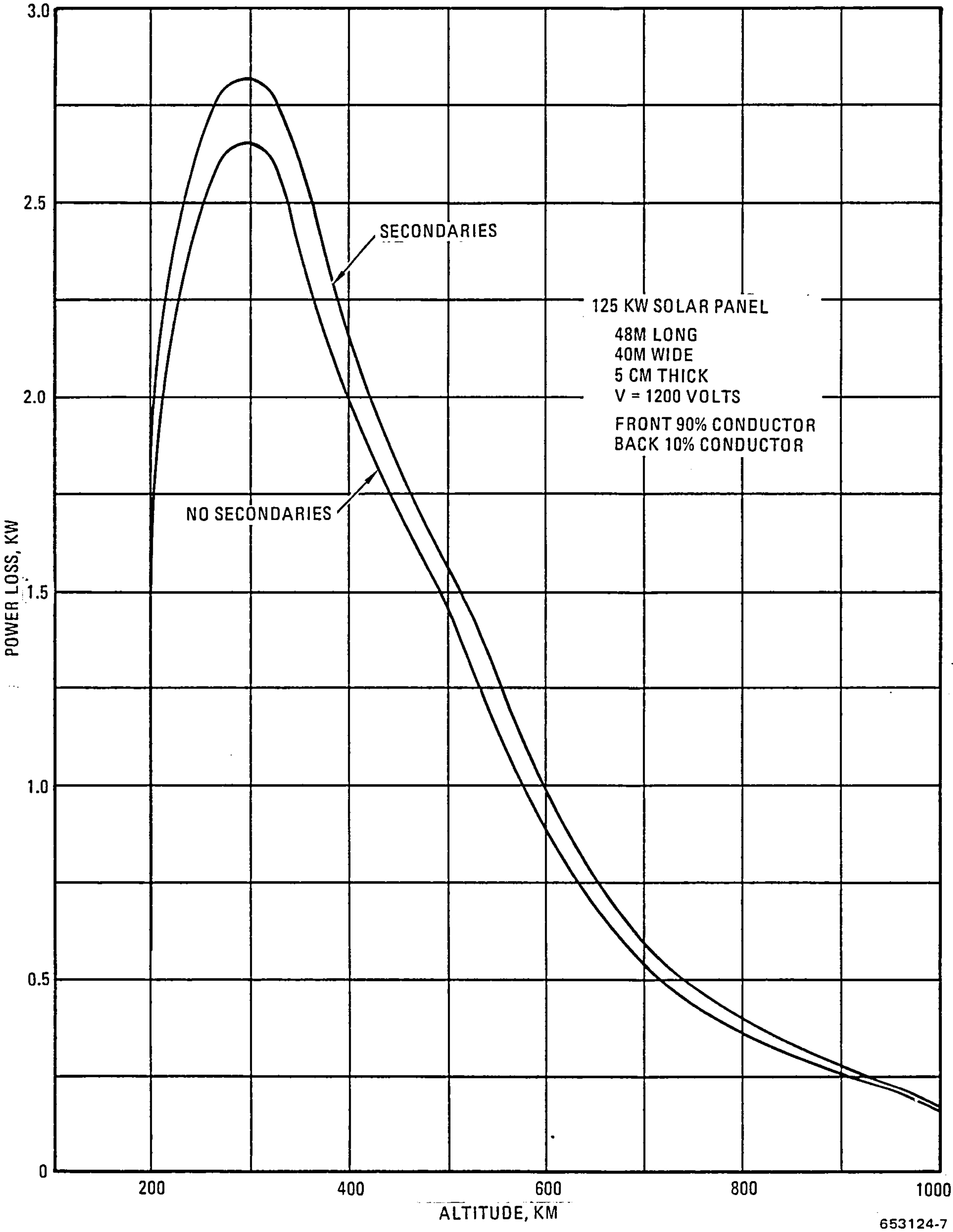

Figure 5-3. Effects of Secondary Electron Emission. Solar Array Power Loss as a Function of Altitude With and Without Secondary Emission

SECTION 6

AREAS FOR FURTHER STUDY

Further work, both experimental and theoretical, is required before high-voltage solar arrays can be confidently designed for reliable operation in the LEO space plasma. We will confine our attention to the phenomena of electrical discharges, secondary emission, and the wake structure.

6.1 ARCING

The occurrence of electric discharges from spacecraft surfaces constitutes one of the major problems for high-voltage solar arrays. Breakdown appears to originate at imperfections or edges, but the precise trigger mechanism remains unknown. Understanding of the discharges will probably require an improved characterization of such spacecraft materials as Al, Mg, SiO_2, Au, Teflon, and Kapton. Material properties needed include secondary electron yields, charge particle reflection coefficients, and surface resistivities under space plasma and solar flux exposure. Development of high electric fields on an insulator surface with small radius of curvature (e.g., on edge) may set the stage for an electric discharge. But, to trigger an arc, a flow of charge must begin by some process and continue to propagate by the same or some other process. Secondary electron emission in the vicinity of the high electric field strength may act as the trigger, whereas ionization of gas evolved from a surface heated by the charge flow may serve as the propagation mechanism. Experiments needed to investigate the arcing mechanism should measure surface heating during breakdown, gas pressures and evolved species near the arc, and the change of surface resistivity during breakdown.

6.2 SECONDARY EMISSION

Our discussion in Section 4.4 pointed out the lack of experimental data of secondary electron emission yield coefficients for O^+ on spacecraft materials from 0.2 keV to 20 keV. Good values for these coefficients will not only allow an improved calculation of spacecraft charging, but may help to understand electric discharges in spacecraft materials. Measurement of secondary electron yield of O^+ on solar array materials should be pursued.

6.3 WAKE EFFECTS

The shape of the wake behind an orbiting spacecraft is geometry dependent. Down stream from the negative voltage portion of a solar array, the wake resembles a wedge-shaped region that extends a considerable distance behind the array. Ions are expected to diffuse into the wake for eventual collection by the array, while electrons will be repelled by the high negative surface potential. Collected ion current will be limited by the thermal ion saturation current density through the wake boundary area. Although the wake area is much larger than the array area, ion current collected by the wake will still be less than the ion ram current in LEO.

Ion flow downstream from the positive portion of the array is also expected to produce a disturbance in the ambient plasma, but the disturbance is expected to have little effect on electron collection by the high positive potential surface. An electron sheath is expected to form immediately about the array surface almost independent of the complex potential structures further downstream. Thermal electron diffusion will be sufficient to provide the normal electron saturation current characteristic of the plasma to form the high voltage sheath.

Detailed calculation of the wake structure should be performed. Although wake effects are probably unimportant for power loss calculations, possible ion and electron focusing in the region of voltage crossover may reveal important enhanced currents to the array that might cause damage.

SECTION 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

Interaction of high voltage solar arrays with the LEO space plasma can give rise to power system loss through the collection of plasma currents and by electrical discharges from surfaces with high negative potentials relative to the plasma. Fortunately, the 250 kW Power Management System proposed by General Dynamics Convair is designed to operate under 1200 V where effects of power loss and arcing are manageable.

Solar array panels with a linear voltage gradient acquire a positive potential relative to the plasma at one end and a negative potential on the remainder of the panel. This comes about because the net current collected by the floating array must be zero. Less than 5 percent of the array area is positive for the proposed Convair array at altitudes over 300 km.

Peak power loss through plasma current collection for the proposed Convair 1200 V array was calculated as 2.2 percent of the total generated power at 300 km altitude, and drops sharply for higher and lower altitudes. Higher operating voltages could be employed at the expense of higher power loss to the plasma and increased incidence of electrical discharges. Use of higher voltage without suffering these penalties might be achieved, of course, through use of proper insulation. Desirable properties of the ideal insulator include high bulk resistivity, low surface resistivity and the ability to heal pinholes or other insulation deterioration. An insulator with all these properties is not yet available.

Most arcs observed in laboratory experiments appear to originate from insulator surfaces that are near conductors held at high negative potentials relative to the ambient plasma. A practical method to control discharges over long spacecraft lives has not yet been found, but may well require the development of new spacecraft materials. Understanding the triggering and propagation mechanisms of electrical discharges requires a considerable amount of experimental and theoretical work.

7.2 RECOMMENDATIONS

Experiments should be conducted to identify the trigger mechanism and the mode of propagation of electrical discharges on solar cell segments. We believe the measurements should include determination of the evolved species, the gas pressure in the vicinity of the discharge, the amount of surface heating, and change of surface resistivity during breakdown.

Yield and energy dependence of secondary electron emission produced by O^+ on spacecraft materials are needed. We recommend these measurements be performed on fabrication grade spacecraft materials of Al, Mg, SiO_2, Au, Teflon, and Kapton with O^+ ion energies from 0.2 keV to 20 keV.

We recommend doing a theoretical calculation of the wake structure downstream from a high-voltage solar array moving in the ionosphere. It is important to determine the effect of charged particle focusing that might produce local damage to a solar array.

SECTION 8

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Part II

Table of Contents

Section 1

Introduction

Previous work was concerned with the power loss to the ambient plasma by the large, high voltage solar arrays of the PMS. In this work we consider problems associated with the high voltage lines connecting the arrays to the spacecraft, and high voltage components within the spacecraft. It is shown that the power loss to the plasma from the transmission lines is going to be very small. The primary problem will be arcing. A simple model suggests separation of transmission lines should exceed one meter. Similar work was not attempted for spacecraft components due to their greater geometric complexity.

If a. c. transmission lines are used, frequencies should be chosen so as not to coincide with natural plasma frequencies, such as the ion plasma frequency and the lower hybrid frequency.

Section 2

Discussion

2.1 Transmission Line Separation Distances

The problem of arcing cannot be treated in an all - inclusive manner, as will be further explained in Section 3. Nonetheless, it is possible, for a geometrically simple system, to define a separation distance between two high-voltage components such that the probability of a damaging discharge is small. In this section we treat the specific problem of power transmission lines.

Consider two parallel cylindrical transmission lines at voltages of +100V and -1100V with respect to the plasma. These voltages are approximately those calculated for the PMS solar array. Assume that both lines have radius a. We seek an estimate of the minimum separation distance d, measured from the center of the two cables, such that the probability of a damaging arc will be small.

With no intervening plasma, the potential will vary linearly from one surface to the next along the line joining the centers of the cables. If an electron in emitted from the line at -1100V, it will accelerate uniformly to the 110V line were the lines in an absolute vacuum. With gas between, the electron will undergo elastic and inelastic collisions with the gas molecules. If the electron ionizes any of the gas, the ions and electrons will accelerate to the lines, creating more electron-ion pairs. In simplest terms, a discharge will occur when electrons flowing from one line to the other ionize enough of the intermediary gas to establish a breakdown path through the gas.

In the presence of a plasma, the potential will no longer vary linearly between the cables. The plasma will polarize about the lines such that in the vicinity of the negative electrode there will be an excess of ions, and an excess of electrons near the positive electrode. The potentials will fall off more rapidly than linearly and, if the cables are sufficiently far apart, there will exist an intermediate region between the cables where the potential is essentially zero. In this region, ion-electron pairs caused by ionization of the background gas will not accelerate to the transmission lines.

In effect, the plasma shields one line from the other. Breakdown paths will thus terminate in the plasma, not at the other line. The plasma is only a relatively small source of energy to feed the arc, so such breakdowns will do substantially less damage than those which travel between power lines. It is possible for a complete circuit between the lines to be formed if breakdown occurs simultaneously between both lines and the plasma, but this can be expected to have a low probability.

Thus we can establish a simple criterion for reducing damaging discharges. This criterion is that the separation distance should be such that the plasma sheaths of the lines do not overlap.

Returning to our initial statement of the problem, the separation distance, d, should be greater than r the sum of the sheath radii for the two conductors. These are given by[1]

$$r_+ = 2.34 \times 10^{-16} |V|^{3/2} (a \beta^2 J_e) \qquad (2\text{-}1)$$

$$r_- = 5.45 \times 10^{-8} |V|^{3/2} (a \beta^2 J_i M) \qquad (2\text{-}2)$$

where r_+ is the sheath around the positively charged cylinder, r- about the negative, V is the potential with respect to the plasma, a the cylinder radius, J_e the electron current density, J_i the ion current density, M the ion mass number, and β is a parameter given by an infinite series. We can approximate by taking the first four terms of the series:

$$\beta \approx b - \frac{2}{5} b^2 + \frac{11}{120} b^3 - \frac{47}{3300} b^4 \qquad (2\text{-}3)$$

where

$$b = \ln\left(r_{\pm} / a \right) \qquad (2\text{-}4)$$

J_e and J_i are functions of altitude, time of day, and spacecraft direction. J_e is given by

$$J_e = ne \left(\frac{kT_e}{2 \pi M_e} \right)^{1/2} \qquad (2\text{-}5)$$

where

n = plasma density
e = electron charge
J_e = electron temperature in eV
and M_e = electron mass.

For the ion saturation current, the problem is complicated by the fact that the ion mean velocity is less than the satellite velocity. For the purpose of this calculation, we will assume that the rest of the spacecraft will shield the lines from ram effects. Then the ion current density will be given by 1-5 with T_i, the ion temperature, replacing T_e and M_i, the ion mass, replacing M_e.

It must be understood that the presence of the plasma enhances the probability of discharge, not diminishes it. Among other effects, plasma provides a large flux of charged particles to create ionization paths. Thus, the higher the plasma density, the greater the probability of a discharge. On the other hand, the higher the plasma density the smaller the plasma sheath.

For this report, we calculate the separation distance assuming daytime conditions where the saturation current densities are maximum. It should be recognized that the separation distance calculated will not prevent sheath overlap for low plasma density conditions.

In Figure 1 we show the separation distance, d, as a function of transmission line radius, a. The separation distance is given by

$$d = r_+ + r_- \tag{2-6}$$

Table 1 lists the parameters used in the calculation. From the figure it can be seen that the separation distance varies slowly with line radius. A safe distance seems to be on the order of one meter.

It must be stated that the phenomenon of arcing is quite complex. Gas density, plasma density, plasma temperature, electrode shape, surface irregularity, materials, and the earth's magnetic field all play a role in determining the probability of a discharge. The criteria we have chosen treats only one aspect of this complex problem.

2.2 Transmission Line Power Loss

We consider the power lost by the transmission lines of the PMS satellite to the ambient plasma. Consider a pair of lines with radius of two centimeters, fifty meters long, at +100V and -1100V respectively. Unlike section 2.1, we assume that the ion current density is altered by ram effects, and is given by:

$$J_i = ne\,V_o \tag{2-7}$$

where V_o is the satellite velocity and n and e are as defined in section 2.1. We assume that the lines are separated by a distance greater than d as calculated in section 2.1. Maximum power loss will be for an altitude of 300 km with ion current density given by eq. 2-7 for the entire line. At 300 km this is $J_i = 3.2 \times 10^{-3}$ A/m^2, and $J_e = 2.3 \times 10^{-2}$ A/m^2.

Table 1: Sheath thicknesses and minimum separation distances for 300 and 600 km altitudes.

h = 300km, $J_e = 2.3 \times 10^{-2}$ A/m^2, $J_i = 8.1 \times 10^{-5}$ A/m^2

a (cm)	r+ (cm)	r- (cm)	d (cm)
0.25	12	42.5	54.5
0.5	13	44	57
1	15	47	62
2	18	51.5	69.5
5	23.5	62	85.5
7.5	27.5	68	95.5
10	31	74	105

h = 600km, $J_e = 7.9 \times 10^{-3}$ A/m^2, $J_i = 3.67 \times 10^{-5}$ A/m^2

a (cm)	r+ (cm)	r-(cm)	d (cm)
0.25	19.5	63	82.5
0.5	21	64	85
1	23	67	90
2	26.5	67	90
5	33.5	84	117.5
7.5	38.5	92	130.5
10	42.5	98.5	141

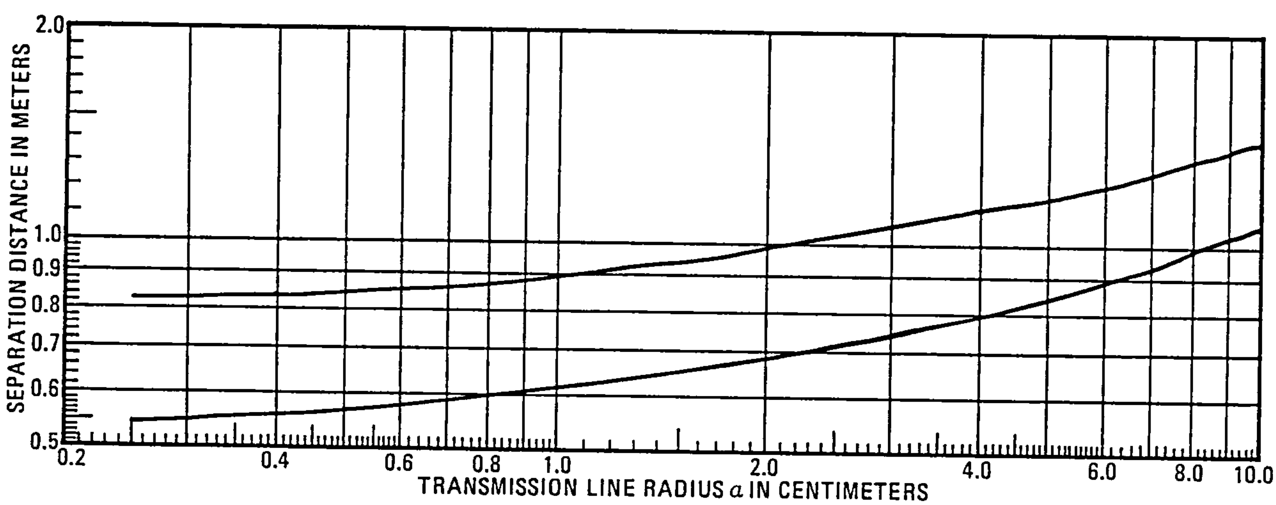

Figure 1

The powerloss is given by

$$P_{L_{e,i}} = VI = 2\pi r_{+,-} J_{e,i} L |V| \qquad (2\text{-}8)$$

The total power loss comes to 267 watts. For a 250 kw PMS system, this comes to only 0.1% of the payload power, or 5% of that lost by the solar array.

2.3 Spacecraft High Voltage Components

Within the spacecraft there will be a number of components which will be at a high voltage with respect to nearby surfaces. During normal operation it is anticipated that the spacecraft will be pressurized, so the system will not be exposed to the ionosphere. However, should the spacecraft lose pressure it is possible that high voltage components will come into contact with the ambient plasma.

In the pressurized condition, the standard techniques for holding off high voltages will suffice. In the case where the system is exposed to the plasma, these techniques may not be adequate to prevent damaging discharges. There are these points to consider:

1) the environment in which the components will reside is highly variable, especially with respect to plasma and neutral gas densities;

2) the component geometries are neither uniform nor simple;

3) the components will be constructed of a variety of materials with very different properties;

and 4) there may be components unconnected electrically from the remainder of the spacecraft, and thus floating with respect to the plasma.

Under such conditions, it is unlikely that any general set of design criteria can be established beyond those which are required to hold voltage in the case where the spacecraft is pressurized.

It would be possible that, given a reasonable geometry and an appropriate set of environmental conditions, a computational model would yield the requirements for preventing breakdown. However, the confidence factor of such an activity must be considered low. On the other hand, for reasonably small components, there exist a large number of facilities where a specific component can be subjected to a sufficient variety of conditions to assure adequate performance in space. In other words, an experimental test procedure is to be preferred over an analytical/computational.

2.4 Alternating Current Effects

High frequency transmission lines may be used as the power bus from the solar array to the spacecraft. Such lines may couple to the ambient plasma by operating at frequencies which will excite natural modes in the plasma. The result can be a rather large power drain.

One can calculate the effect of high frequency lines in the space plasma by performing a particle-in-cell plasma simulation of the system. The general behavior of the system is that of a harmonic oscillator (the plasma) with a harmonic driving force (the power supply). When the driving frequency matches the natural frequency of the oscillator, the system is resonant and the power absorbed increases to infinity. Damping effects and power supply limitations will prevent this; however, the power absorption can still be quite great.

While detailed calculations have not been made, it is clear from the above that it is wise to avoid use of frequencies near any of the natural modes of the ionospheric plasma. Those frequencies to be avoided include the ion plasma frequencies, the ion cyclotron frequencies, and the lower hybrid frequency. The electron cyclotron and plasma frequencies are in the MHz range, well beyond any desired operational frequency.

The ion plasma frequency, in MKS units, is given by

$$\omega_{pi} = q \left(n_i / M_i \epsilon_o \right)^{1/2} \tag{2-9}$$

where q is the ion charge, n_i the ion density, M_i the ion mass, and ϵ_o the permitivity of free space. Because the plasma frequency depends on density, the frequency zone in which operation should be avoided will be quite wide.

For operation at $\sim$300km, the plasma frequency varies from 23KHz at nighttime solar minimum to 74KHz at daytime solar maximum. For 600km, the numbers are 7KHz and 43KHz, respectively.

The ion cyclotron frequency is given by

$$\omega_{ci} = \frac{qB}{M_i} \tag{2-10}$$

where q, M_i are as defined above and B is the earth's magnetic field. At 300km, B varies from $\sim$0.3 gauss to 0.5 gauss, depending on colatitude, so ω_{ci} varies from 28.5Hz to 47.5Hz. At 600km, the variation is from 24Hz to 38Hz.

The lower hybrid frequency is given by

$$\omega_{LH} \cong \left(\omega_{ci}\ \omega_{ce}\right)^{1/2} = \left(\frac{eqB^2}{M_e M_i}\right)^{1/2} \tag{2-11}$$

where ω_{ce} is the electron cyclotron frequency, e the electron charge, and M_e the electron mass. At 300km the lower hybrid varies from 6KHz to 10KHz; at 600km from 5KHz to 8KHz.

The above numbers demonstrate that there is no "safe" frequency in the KHz range below about 80KHz at which the line can operate. However, an operating frequency can be chosen in this range when operational altitudes are determined.

We make the following additional points: 1) The actual power loss will be when the plasma density is greatest. Thus, it is better to operate near the low end of the plasma frequency range than the high end. 2) The satellite is not stationery. The motion of the satellite will effect the coupling. The simulation will be more difficult because of this effect.

Section 3

Conclusions and Recommendations

3.1 Conclusions

The problem of arcing is quite complex and should properly be treated by laboratory work. Simple considerations of arcing mechanisms allow calculations to be made with respect to safe separation distances. For transmission lines of reasonable cross-section connecting the PMS solar array to the spacecraft, separation distances should be on the order of one meter. The power loss to the ambient plasma from such transmission lines will be neligible.

No simplifying assumptions can be made with respect to small high voltage components within the spacecraft.

For a.c. lines, there exists a frequency window between lower hybrid and ion plasma frequencies at which the system can operate without special bus designs. At 300km the window ranges from 10 to 23KHz. At about 600km the window is gone.

3.2 Recommendations

Since analytical models cannot provide sufficient information for the design of the smaller high voltage components within the spacecraft, we recommend that a high vacuum, space plasma simulation facility be made available for testing components, and that it be made available to the design teams. A similar facility should be made available to test alternative transmission line designs.

A computer simulation of the space plasma in contact with an a.c. transmission line at frequencies at or near plasma natural frequencies should be attempted to determine if operation is feasible at those frequencies.

Section 4

References

1) F. F. Chen, "Electric Probes," Plasma Diagnostic Techniques, Academic Press, New York, 1965.

APPENDIX 3

DEFINITION OF TECHNOLOGY REQUIREMENTS

S-1 THROUGH S-5	SYSTEMS
C-1 THROUGH C-19	COMPONENTS
D-1 THROUGH D-8	DATA

INTRODUCTION

The data sheets in this appendix present the details about the recommdations and final conclusions in the text of the study report.

Each set of data sheets has three pages:

1. The basic technology descriptions and the justification for the recommendation.

2. The technical options, and alternatives, and already-planned programs and status.

3. Schedules, references, and an indication of the state of the art of the technology. Page 3 is included only for those technologies that NASA must take a hand in developing if they are to be ready to support 1984 or mid-to-late 1980's design starts for PMS hardware to support a space platform of this size.

This appendix is organized in three separate sections:

"S" (1 through 5) for systems level technologies.

"C" (1 through 19) for components that require further development.

"D" (1 through 8) for places where devices exist but additional test or qualification data is required.

DEFINITION OF TECHNOLOGY REQUIREMENT No. S-1

1. TECHNOLOGY REQUIREMENT (TITLE): Distributed/Split DC-AC-DC/AC Resonant Converter Page 1 of 3

2. TECHNOLOGY CATEGORY: System Design

3. OBJECTIVE/ADVANCEMENT REQUIRED: Development/extension of the basic Schwarz Resonant Converter to an entire system concept using the resonant section for power transmission.

4. CURRENT STATE OF ART: Basic Resonant Converter developed as a single-output/single-function device.

5. DESCRIPTION OF TECHNOLOGY: Design of the total Power Management System (PMS) as a single, multi-function, multi-output, resonant converter. This integrated system would use the resonant techniques developed by Schwartz and expand them into a "Device" having a distributed resonant link and multiple input-output ports.

6. RATIONALE AND ANALYSIS: Resonant Converter designs have been investigated by Schwarz and others because of their high efficiency. They eliminate switching losses through AC switching at the zero-crossing; and have been developed as single-function devices (i.e., DC-DC, DC-AC, AC-DC conv. etc.). A system operating as a single, complex resonant converter will offer significant weight and efficiency improvements over a conventional approach. (60% weight reduction and 57% loss reduction).

3652-96

1. TECHNOLOGY REQUIREMENT (TITLE): Distributed/Split DC-AC-DC/AC Resonant Converter

7. TECHNOLOGY OPTIONS: (Other than proposed system)

Conventional AC or DC system design with lower efficiency and approximately 40% higher cost and weight.

8. TECHNICAL PROBLEMS:

No significant problems - proof of extended design concept required. Investigate frequency drift as a function of load. Investigate effects of direct AC loading.

9. POTENTIAL ALTERNATIVES:

Conventional design - (See 7).

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

None Planned

11. RELATED TECHNOLOGY REQUIREMENTS:

Rotary Transformer (C-); Transformer Payload Disconnect (C-); Coax Transmission Line Dev. (C-); Plasma Resonant Frequency Coupling Study (D-); Energy Storage on the array side (S02).

3652-97

DEFINITION OF TECHNOLOGY REQUIREMENT	No. S-1

1. TECHNOLOGY REQUIREMENT (TITLE): Distributed/Split DC-AC-DC/AC Resonant Converter

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95		
TECHNOLOGY																			
1. Proof of concept																			
2. B1B design and test																			
3. Component development and specification																			
4. Final qual and hndbk publication																			
FUNDING LEVEL (In $1,000, 1978 dollars)			200	200	100	50													

13. USAGE SCHEDULE:

	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	TOTAL
TECHNOLOGY NEED DATE							▲											
NUMBER OF LAUNCHES																		

14. REFERENCES

NASA CR-159660; B1-Directional, Four Quadrant (BDQ4) Power Converted Development; Final Report, Contract NAS3-30363; F. C. Schwarz, Power Electronics Assoc. Inc., Lincoln, MA. 01773.

15. LEVEL OF STATE OF THE ART:

1. Basic phenomena observed and reported
2. Theory formulated to describe phenomena
3. Theory tested by physical experiment or mathematical model
4. Pertinent functions or characteristic demonstrated, e.g.. material, component
5. Component or breadboard tested in relevant environment in laboratory
6. Model tested in aircraft environment
7. Model tested in space environment
8. New capability derived from a much lesser operational model
9. Reliability upgrading of an operational model
10. Lifetime extension of an operational model

3652-93

DEFINITION OF TECHNOLOGY REQUIREMENT — No. S-2

1. TECHNOLOGY REQUIREMENT (TITLE): Space Platform Dynamic Analysis for "Heavy" Array.

2. TECHNOLOGY CATEGORY: System Design

3. OBJECTIVE/ADVANCEMENT REQUIRED: Analysis of control dynamics function for attitude control of a space station having inverters and batteries on the solar array.

4. CURRENT STATE OF ART: Solar array hardware is a lightweight appendage of major satellite systems.

5. DESCRIPTION OF TECHNOLOGY: Preliminary analysis suggests that increasing the mass of a satellite on the solar array side of the rotary joint which generally remains fixed in inertial space may simplify the attitude control problem and reduce energy expended for attitude. Computer simulation type analyses of this configuration are required to confirm or deny this opinion.

6. RATIONALE AND ANALYSIS: We can maximize the cost effectiveness and minimize size and weight of an AC power system if the power used to charge batteries and battery discharge control is on the array side of the inverter and rotary joint. This approach reduces the size of the inverter and rotary transformer, and the batteries share regulation and control hardware with the solar array.

3652-96

DEFINITION OF TECHNOLOGY REQUIREMENT No. S-2

1. TECHNOLOGY REQUIREMENT (TITLE): Space Platform Dynamic Analysis for "Heavy" Array.

7. TECHNOLOGY OPTIONS: - N/A

Analysis only - verify simple theory.

8. TECHNICAL PROBLEMS:

None - Analysis only

9. POTENTIAL ALTERNATIVES:

None - Analysis only

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

None Planned

11. RELATED TECHNOLOGY REQUIREMENTS:

Distributed/Split DC-AC-DC/AC Resonant Converter (S-1).

8652-97

DEFINITION OF TECHNOLOGY REQUIREMENT	No. S-2

1. TECHNOLOGY REQUIREMENT (TITLE): Space Platform Dynamic Analysis for "Heavy" Array

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95		
TECHNOLOGY Perform dynamic analysis to verify comparative propellant useage for baseline 250 KWe configuration			—																
FUNDING LEVEL (In $1,000, 1978 dollars)			50																

13. USAGE SCHEDULE:

																		TOTAL
TECHNOLOGY NEED DATE																		
NUMBER OF LAUNCHES																		

14. REFERENCES

15. LEVEL OF STATE OF THE ART:

1. Basic phenomena observed and reported
2. Theory formulated to describe phenomena
3. Theory tested by physical experiment or mathematical model
4. Pertinent functions or characteristic demonstrated, e.g., material, component
5. Component or breadboard tested in relevant environment in laboratory
6. Model tested in aircraft environment
7. Model tested in space environment
8. New capability derived from a much lesser operational model
9. Reliability upgrading of an operational model
10. Lifetime extension of an operational model

3652-93

DEFINITION OF TECHNOLOGY REQUIREMENT No. S-3

1. TECHNOLOGY REQUIREMENT (TITLE): Radiation Effects on PMS Hardware Page 1 of 2

2. TECHNOLOGY CATEGORY: System Design

3. OBJECTIVE/ADVANCEMENT REQUIRED: Analysis of PMS Hardware for this power class to determine degradation due to long term exposure to space radiation and design changes to solve the problem.

4. CURRENT STATE OF ART: Significant body of data on short term high intensity exposures.

5. DESCRIPTION OF TECHNOLOGY: Development of a set of guidelines and ground rules active power circuit design and performance in the space radiation environment for periods in the 10 year range. They will include device performance and parametric changes, shielding methods and effectiveness, design approaches, etc.

6. RATIONALE AND ANALYSIS: Power system components may be significantly effected with regard to size, weight, and performance as a function of allowing for the effects of long term exposure to space radiation. Accurate predictions of effects will allow for optimum PMS designs.

3652-96

DEFINITION OF TECHNOLOGY REQUIREMENT No. S-3

1. TECHNOLOGY REQUIREMENT (TITLE): Radiation Effects on PMS Hardware Page 2 of 2

7. TECHNOLOGY OPTIONS:

a. Provide radiation-resistant components for PMS hardware design.

b. Provide shielding for sensitive components and harmful radiation types.

c. Provide "overdesign" for PMS hardware to allow for parameter degradation with long term exposure.

d. Repair and replace degraded hardware in orbit.

8. TECHNICAL PROBLEMS:

Semiconductor devices are all degraded by exposure to many forms of radiation. Degree of effect must be determined for large devices commonly found in large power systems.

9. POTENTIAL ALTERNATIVES:

No alternatives - All hardware must be compatible with the radiation environment.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

Many Air Force and NASA programs for radiation hardening. The only PMS action should be to survey their results periodically to check for applicability and incorporation into the PMS data base.

No page 3 required.

11. RELATED TECHNOLOGY REQUIREMENTS:

8652-97

DEFINITION OF TECHNOLOGY REQUIREMENT No. S-4

1. TECHNOLOGY REQUIREMENT (TITLE): Magnetic Dipole Attitude Control Page 1 of 2

2. TECHNOLOGY CATEGORY: System Design

3. OBJECTIVE/ADVANCEMENT REQUIRED: Evaluate the feasibility of space platform attitude control or control augmentation using the Earth's magnetic field.

4. CURRENT STATE OF ART: Small satellite considerations.

5. DESCRIPTION OF TECHNOLOGY: Use of the large currents flowing in the PMS to power magnets either parasitically or directly on a transient basic to aid in attitude control. Investigate possible force magnitudes and electrical implementation methods.

6. RATIONALE AND ANALYSIS: Large currents available on space platforms of this type allow for the creation of magnetic fields making the entire platform a magnetic dipole whose characteristics can be used to react with the Earth's magnetic field to aid in attitude control, thereby reducing the requirements for consumable propellants.

3652-96

DEFINITION OF TECHNOLOGY REQUIREMENT — No. S-4

1. TECHNOLOGY REQUIREMENT (TITLE): Magnetic Dipole Attitude Control — Page 2 of 2

7. TECHNOLOGY OPTIONS:

a. Large PMS currents used in differentially connected solenoid configurations to provide controllable net magnetic field.

b. Single solenoids with variable current control.

c. Multiple "crossed-axis" solenoids at satellite extremities to provide rational torques.

8. TECHNICAL PROBLEMS:

a. Design of high current, high field, low loss, magnets.

b. Effect of magnetic fields on other space platform systems.

9. POTENTIAL ALTERNATIVES:

a. Conventional hot or cold gas station keeping thrusters.

b. Ion engine thrusters

c. Inertial wheel/gyro type station keeping/attitude control system.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

No definitive programs planned, superconducting magnets would probably be required to solve the problems listed in (8). Not available by mid-to-late 1980's.

No page 3 required.

11. RELATED TECHNOLOGY REQUIREMENTS:

Superconducting energy storage. (S-5)

3652-97

DEFINITION OF TECHNOLOGY REQUIREMENT No. S-5

1. TECHNOLOGY REQUIREMENT (TITLE): Superconducting Energy Storage Page 1 of 2

2. TECHNOLOGY CATEGORY: System Design

3. OBJECTIVE/ADVANCEMENT REQUIRED: Investigate the viability of superconducting energy storage as an alternative to batteries or fuel cells.

4. CURRENT STATE OF ART: No detailed or serious investigation utilizing current or proposed technologies.

5. DESCRIPTION OF TECHNOLOGY: Superconducting magnets can be used to store large amounts of electrical energy. System evaluations and cost effectiveness comparisons with conventional systems are required; including: storage hardware size and weight, efficiency, PMS impacts and interfaces, and support systems (cooling or cryogenic).

6. RATIONALE AND ANALYSIS: Technological development of superconducting magnets has shown the promise of making this technique competitive with the conventional approaches. It can be integrated with magnetic dipole attitude control (No. S-4) for additional cost effectiveness.

3652-36

DEFINITION OF TECHNOLOGY REQUIREMENT No. S-5

1. TECHNOLOGY REQUIREMENT (TITLE): Superconducting Energy Storage Page 2 of 2

7. TECHNOLOGY OPTIONS:

a. Radiation/cryo cooled torroid, assembled in orbit.

b. Radiation/cryo cooled solenoid or series of solenoids used to store energy and provide magnetic field for station keeping and attitude control.

c. Is total radiation cooling feasible?

8. TECHNICAL PROBLEMS:

a. High weight in orbit.

b. Cooling system requirements.

9. POTENTIAL ALTERNATIVES:

a. Batteries

b. Fuel Cells

c. Inertia Wheels

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

Many large magnet programs in support of nuclear fusion research. No programs for superconducting magnets in space.

Cannot support mid-to-late 1980's technology readiness.

No page 3 required.

11. RELATED TECHNOLOGY REQUIREMENTS:

8652-97

DEFINITION OF TECHNOLOGY REQUIREMENT No. C-1

1. TECHNOLOGY REQUIREMENT (TITLE): Rotary Transformer Page 1 of 3

2. TECHNOLOGY CATEGORY: Components

3. OBJECTIVE/ADVANCEMENT REQUIRED: 250 KW; 20 KHz; 1 Ø; 1000 VRMS unit; possibly in 25.0K KW modules or with 25.0 KW separate primaries.

4. CURRENT STATE OF ART: Design study just beginning.

5. DESCRIPTION OF TECHNOLOGY: A device which can be integrated with the structure of the rotary joint between a space platform and its solar arrays, which is a high frequency transformer with primary and secondary free to rotate with respect to one-another.

Requirements: (a) continuous rotation at 360° in 24 hrs (b) 250 KW, 20 KHz, single phase, 440V; 1000 VACRMS. (c) multiple inputs from 25.0 KW modules, redundant outputs each caple of 250 KW, with a total max output of 250 KW.

6. RATIONALE AND ANALYSIS:

An AC power transmission system for power management allows the use of a transformer rotary joint energy coupling, thereby

(a) Eliminating sliding contacts (slip rings)

(b) Allowing for multiple 360° rotations, simplifying the station keeping problem.

3652-96

DEFINITION OF TECHNOLOGY REQUIREMENT	No. C-1
1. TECHNOLOGY REQUIREMENT (TITLE): Rotary Transformer	Page 2 of 3

7. TECHNOLOGY OPTIONS:

Flat type or armature type.

8. TECHNICAL PROBLEMS:

a. Exist in concept only, no actual design at this time.

b. Integration with rotary joint structure.

c. Integration with resonant inverter.

9. POTENTIAL ALTERNATIVES:

a. Slip rings with separate transformer.

b. Flexible cables with suitable space platform motions to "unwind" cables during eclipse periods.

c. Rotary capacitor.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

Inertial NASA sponsored design study now in work at General Electric.

See NASA Contract   for cost and schedule.

11. RELATED TECHNOLOGY REQUIREMENTS:

Integrated/split DC-AC-DC/AC Resonant Converter (S-1).

3652-97

DEFINITION OF TECHNOLOGY REQUIREMENT	No. C-1
1. TECHNOLOGY REQUIREMENT (TITLE): Rotary Transformer	Page 3 of 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95		
TECHNOLOGY																			
1. Design Feasibility		—	—																
2. Operating model and Testing			—	—															
FUNDING LEVEL (In $1,000, 1978 dollars)			50	50															

13. USAGE SCHEDULE:

																	TOTAL
TECHNOLOGY NEED DATE																	
NUMBER OF LAUNCHES																	

14. REFERENCES

15. LEVEL OF STATE OF THE ART:

1. Basic phenomena observed and reported
2. Theory formulated to describe phenomena
3. Theory tested by physical experiment or mathematical model
4. Pertinent functions or characteristic demonstrated, e.g., material, component
5. Component or breadboard tested in relevant environment in laboratory
6. Model tested in aircraft environment
7. Model tested in space environment
8. New capability derived from a much lesser operational model
9. Reliability upgrading of an operational model
10. Lifetime extension of an operational model

3652-98

DEFINITION OF TECHNOLOGY REQUIREMENT — No. C-2

1. TECHNOLOGY REQUIREMENT (TITLE): Remote Power Controller Improvement - Power Output

2. TECHNOLOGY CATEGORY: Components

3. OBJECTIVE/ADVANCEMENT REQUIRED: Improved output capability higher DC voltage and current; improved AC performance to 20KHz; multi-pole-multi-throw configuration.

4. CURRENT STATE OF ART: To 400V/60A; 500V/40A, DC, 60 and 400HZ, SPST.

5. DESCRIPTION OF TECHNOLOGY: Solid state, remotely commanded power controllers are required to provide various switch functions for both AC and DC systems.

The maximum requirements are:

DC System:	100KW, SPDT, 750V/133 A (DC)
	15.0KW, DPDT, 750V/20 A (DC)
	10.0KW, DPDT, 750V/13.3 A (DC)
	10.0KW, DPDT, 115V/87.0 A (DC)
AC System:	25.0KW, DPDT, 440V/57.0 A (DC)
	25.0KW, DPDT, 440 VPK/80 A RMS (AC)
	5.0KW, DPDT, 1000V/5.0 A RMS (AC)

6. RATIONALE AND ANALYSIS: Various switch functions are required for both AC and DC systems:

DC System: Slip ring input/output isolation, battery isolation, module isolation and redundancy management, payload fault isolation.

AC System: Inverter module input and output module isolation and redundancy management, payl oad regulator/ converter and payload fault isolation.

3652-96

DEFINITION OF TECHNOLOGY REQUIREMENT	No. C-2

1. TECHNOLOGY REQUIREMENT (TITLE): Remote Power Controller Improvement - Power Output

7. TECHNOLOGY OPTIONS:

a. Improved design solid-state RPC's.

b. Electro-mechanical switchgear now designed for the power industry.

c. Electro-magnetic-mechanical switchgear.

8. TECHNICAL PROBLEMS:

a. Output switching devices have ratings too low to meet DC requirements.

b. Power dissipation requires additional thermodynamic design and analysis.

c. Electro-mechanical switches have life problems in space environment.

9. POTENTIAL ALTERNATIVES:

None - Switchgear is an integral requirement of all PMS.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

RPC development programs sponsored by NASA LeRC.

11. RELATED TECHNOLOGY REQUIREMENTS:

Improved performance switching devices.

8652-97

DEFINITION OF TECHNOLOGY REQUIREMENT No. C-3

1. TECHNOLOGY REQUIREMENT (TITLE): Remote Power Controller Improvement - Data Interface

2. TECHNOLOGY CATEGORY: Components

3. OBJECTIVE/ADVANCEMENT REQUIRED: Provide a bus compatible input and output data interface for command and monitor functions.

4. CURRENT STATE OF ART: Single, non-multiplexed hardwired inputs and outputs.

5. DESCRIPTION OF TECHNOLOGY:

Develop a serial data bus compatible input/output port for each RPC to receive and transmit all command and data functions. Decide on a data/command protocol for error detection and correction and command verification and redundancy.

6. RATIONALE AND ANALYSIS:

Complex, large, power management systems such as this one will require too many individual switch functions and individual remote power controllers to have data and command information transmitted to and from them via individual signal wires.

Bus interface and logic hardware is now reaching sufficient levels of integration that it can be easily incorporated into FPC design.

Significant reductions in control system size, weight, and cost will result, since this approach is consistant with current control system designs.

3652-96

1. TECHNOLOGY REQUIREMENT (TITLE): Remote Power Controller Improvement - Data Interface

7. TECHNOLOGY OPTIONS:

a. Wired data input/output port similiar to MIL-STD-1553B or IEEE standard.

b. DIS type system integration.

c. Optical data interface port such as MIL-STD-1553FO

d. Several RPC's located around a single interface/decoder/controller unit.

8. TECHNICAL PROBLEMS:

a. Decision about which system type will be dominant in the mid-to-late 1980's.

b. Integration of the appropriate hardware into RPC design.

9. POTENTIAL ALTERNATIVES:

Hard wired system with individual lines to system controller.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

RPC development programs sponsored by NASA LeRC general, wide, industry and Government sponsored data transmission systems are in work. PMS programs must look to hardware integration.

11. RELATED TECHNOLOGY REQUIREMENTS:

Data interface hardware development.

3652-97

DEFINITION OF TECHNOLOGY REQUIREMENT — No. C-4

1. TECHNOLOGY REQUIREMENT (TITLE): Remote Power Controller Improvement - Overload Protection

2. TECHNOLOGY CATEGORY: Components

3. OBJECTIVE/ADVANCEMENT REQUIRED: Development of short term overload protection for PMS as part of an RPC function.

4. CURRENT STATE OF ART: No satisfactory problem solution in present devices.

5. DESCRIPTION OF TECHNOLOGY:

Remote power controllers which provide system protection by limiting fault currents for a short time (approx. 200 sec) until they can be commanded off by the system controller.

6. RATIONALE AND ANALYSIS:

Integrated system control requires time to monitor, analyze, and decide about system status to provide for fault isolation, load shedding, or section shutdown in case of a fault. A compromise to simplify RPC logic design and allow for reasonable control system response time is to provide for a simplified overload response (such as current limiting) in the RPC for the time it takes the system to respond.

3652-96

DEFINITION OF TECHNOLOGY REQUIREMENT — No. C-4

1. TECHNOLOGY REQUIREMENT (TITLE): Remote Power Controller Improvement - Overload Protection — Page 2 of 3

7. TECHNOLOGY OPTIONS:

a. Simple current limiting with appropriate thermodynamic design to provide heat sinking or thermal capacitance for the transient dissipation.

b. Load line limiting to reduce transient dissipation.

8. TECHNICAL PROBLEMS:

Thermodynamic design capable of keeping temperatures low enough for the dissipation/time product.

9. POTENTIAL ALTERNATIVES:

a. Overload shut-off function internal to the RPC with output flag to the system controller.

b. Fuse function with output flag to system controller to be reset and repaired by astronaut.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

RPC development programs sponsored by NASA LeRC.

11. RELATED TECHNOLOGY REQUIREMENTS:

Improved Thermodynamic design.

8652-97

DEFINITION OF TECHNOLOGY REQUIREMENT No. C-2/3/4

1. TECHNOLOGY REQUIREMENT (TITLE): Remote Power Controllers

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95		
TECHNOLOGY																			
1. Design																			
2. Prototype																			
3. Qual Unit & Testing																			
FUNDING LEVEL (In $1,000, 1978 dollars)																			
Development		100	120	100	100														

13. USAGE SCHEDULE:

																		TOTAL
TECHNOLOGY NEED DATE																		
NUMBER OF LAUNCHES																		

14. REFERENCES

15. LEVEL OF STATE OF THE ART:

1. Basic phenomena observed and reported
2. Theory formulated to describe phenomena
3. Theory tested by physical experiment or mathematical model
4. Pertinent functions or characteristic demonstrated, e.g., material, component
5. Component or breadboard tested in relevant environment in laboratory
6. Model tested in aircraft environment
7. Model tested in space environment
8. New capability derived from a much lesser operational model
9. Reliability upgrading of an operational model
10. Lifetime extension of an operational model

3652-92

DEFINITION OF TECHNOLOGY REQUIREMENT No. C-5

1. TECHNOLOGY REQUIREMENT (TITLE): Low Loss Dielectric Material for High Frequency EMI Filters and Transmission Lines Page 1 of 3

2. TECHNOLOGY CATEGORY: Components

3. OBJECTIVE/ADVANCEMENT REQUIRED: EMI filters with low loss at 1KV RMS and 20 KHz frequency.

4. CURRENT STATE OF ART: 400 HZ, 440 VRMS

5. DESCRIPTION OF TECHNOLOGY:

Low loss EMI components are required to support a 1KV 20 KHz power distribution system. These components should have low loss to maintain system efficiency and be effective filters at RF.

6. RATIONALE AND ANALYSIS:

Conventional EMI filters are suitable for power line frequencies up to 400 HZ and voltages around 120 VRMS. The development of these EMI components should be done in conjunction with the creation of a 20 KHz power distribution specification. Current components would not be suitable because of high dielectric losses at this frequency and voltage, which would result in higher system losses.

3652-96

DEFINITION OF TECHNOLOGY REQUIREMENT — No. C-5

1. TECHNOLOGY REQUIREMENT (TITLE): Low Loss Dielectric — Page 2 of 3

7. TECHNOLOGY OPTIONS:

a. Different ceramic materials

b. Different film materials.

8. TECHNICAL PROBLEMS:

a. Thermal operating range
b. Vacuum environment
c. Plasma effects
d. Dielectric heating

9. POTENTIAL ALTERNATIVES:

Use existing EMI filters and insulators and tolerate increased weight and dielectric heating losses.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

None planned

11. RELATED TECHNOLOGY REQUIREMENTS:

Possible development of suitable ceramic and/or film materials for this specific application.

3652-97

DEFINITION OF TECHNOLOGY REQUIREMENT	No. C-5

1. TECHNOLOGY REQUIREMENT (TITLE): Low Loss Dielectric — Page 3 of 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95		
TECHNOLOGY 1. Basic Research 2. Material Testing 3. Production																			
FUNDING LEVEL (In $1,000, 1978 dollars)			50	100	50														

13. USAGE SCHEDULE:

																	TOTAL
TECHNOLOGY NEED DATE																	
NUMBER OF LAUNCHES																	

14. REFERENCES

15. LEVEL OF STATE OF THE ART:

1. Basic phenomena observed and reported
2. Theory formulated to describe phenomena
3. Theory tested by physical experiment or mathematical model
4. Pertinent functions or characteristic demonstrated, e.g.. material, component
5. Component or breadboard-tested in relevant environment in laboratory
6. Model tested in aircraft environment
7. Model tested in space environment
8. New capability derived from a much lesser operational model
9. Reliability upgrading of an operational model
10. Lifetime extension of an operational model

3652-92

DEFINITION OF TECHNOLOGY REQUIREMENT No. C-6

1. TECHNOLOGY REQUIREMENT (TITLE): High Current, High Voltage Fast Recovery Rectifiers

2. TECHNOLOGY CATEGORY: Components

3. OBJECTIVE/ADVANCEMENT REQUIRED: 1500 PIV, 100A rectifier diodes with recovery times in the range of 500 nS

4. CURRENT STATE OF ART: 600V, 50A, 200 nS

5. DESCRIPTION OF TECHNOLOGY:

High current, High voltage, fast recovery rectifiers will be required to reduce the size, weight and cost of inverters and switching regulators while maintaining high efficiencies.

6. RATIONALE AND ANALYSIS:

Present day devices do not have sufficient peak inverse voltage (PIV) ratings for the desired applications. Stacking these devices to achieve higher PIV ratings requires equalization networks which slow the apparent recovery time, increase the apparent reverse leakage, and reduce the efficiency due to higher foreward voltage drops.

3652-96

DEFINITION OF TECHNOLOGY REQUIREMENT — No. C-6

1. TECHNOLOGY REQUIREMENT (TITLE): High Current, High Voltage Fast Recovery Rectifiers — Page 2 of 2

7. TECHNOLOGY OPTIONS:

a. Different materials

b. Different device geometries

8. TECHNICAL PROBLEMS:

Present day device geometries and manufacturing methods are not sufficient for the anticipated needs.

9. POTENTIAL ALTERNATIVES:

Stack (series) existing devices and tolerate higher losses and increased weight and bulk.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

Commercial program related to the power industry should provide acceptable components by the mid-to-late 1980's.

No page 3 required.

11. RELATED TECHNOLOGY REQUIREMENTS:

Semiconductor materials.

3652-97

DEFINITION OF TECHNOLOGY REQUIREMENT No. C-7

1. TECHNOLOGY REQUIREMENT (TITLE): High Frequency Motors Page 1 of 3

2. TECHNOLOGY CATEGORY: Components

3. OBJECTIVE/ADVANCEMENT REQUIRED: Development of a broad range of motors and controllers which will operate directly from a 20 KHz 3 Ø power source.

4. CURRENT STATE OF ART: 3 Ø motors

5. DESCRIPTION OF TECHNOLOGY:

Various sizes and speeds of motors will be required to run the mechanical, ventilating, environmental and experimental equipment aboard the spacecraft. It is desirable that these motors be able to run directly off of a 20 KHZ power system.

6. RATIONALE AND ANALYSIS:

Motors not running off of a 20 KHZ system would require cycloinverters or other methods of power conversion which would result in increased bulk, weight, and losses.

3652-96

DEFINITION OF TECHNOLOGY REQUIREMENT	No. C-7
1. TECHNOLOGY REQUIREMENT (TITLE): High Frequency Motors	Page 2 of 3

7. TECHNOLOGY OPTIONS:

a. New motor configurations

b. New fabrication techniques for conventional motor designs adapted for higher frequencies.

8. TECHNICAL PROBLEMS:

a. Present motor designs would not be suitable for 20 KHZ operation.

b. An increase in the number of poles by a factor of 50 is required to maintain reasonable rotational speeds.

9. POTENTIAL ALTERNATIVES:

Use existing motors with complex controllers or cycloinverters.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

None

11. RELATED TECHNOLOGY REQUIREMENTS:

Printed circuit motor windings.

3652-97

DEFINITION OF TECHNOLOGY REQUIREMENT	No. C-7

1. TECHNOLOGY REQUIREMENT (TITLE): High Frequency Motors

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95		
TECHNOLOGY																			
Evaluation of Approaches																			
Design																			
Prototype Evaluation																			
FUNDING LEVEL (In $1,000, 1978 dollars)			50	100	50	50													

13. USAGE SCHEDULE:

TECHNOLOGY NEED DATE																	TOTAL
NUMBER OF LAUNCHES																	

14. REFERENCES

15. LEVEL OF STATE OF THE ART:

1. Basic phenomena observed and reported
2. Theory formulated to describe phenomena
3. Theory tested by physical experiment or mathematical model
4. Pertinent functions or characteristic demonstrated, e.g.. material, component
5. Component or breadboard tested in relevant environment in laboratory
6. Model tested in aircraft environment
7. Model tested in space environment
8. New capability derived from a much lesser operational model
9. Reliability upgrading of an operational model
10. Lifetime extension of an operational model

3652-92

DEFINITION OF TECHNOLOGY REQUIREMENT — No. C-8

1. TECHNOLOGY REQUIREMENT (TITLE): High Frequency AC-DC Power Supplies — Page 1 of 3

2. TECHNOLOGY CATEGORY: Components

3. OBJECTIVE/ADVANCEMENT REQUIRED: Power supply design for use off of a 20 KHZ power distribution system.

4. CURRENT STATE OF ART: No known sources or designs.

5. DESCRIPTION OF TECHNOLOGY:

Power supplies which would run directly off of the main 20 KHZ power bus will be required. These should be available as OEM components and have standard (+15, -15, +5, +28) output voltages to power the equipment in which they are installed.

6. RATIONALE AND ANALYSIS:

High frequency power supplies would reduce the number of payload interface units. Using equipment which runs directly off of the 20 KHZ power line would increase overall efficiency and decrease the weight of both the spacecraft and the user equipment. Additionally many of the spacecraft supervisory and control system components could be placed at optimum locations without regard to proximity of a payload interface unit. Weight reductions of 90% in magnetic and filter components will probably reduce power supply weights by 75% compared to 60 HZ ones.

3652-96

DEFINITION OF TECHNOLOGY REQUIREMENT	No. C-8

1. TECHNOLOGY REQUIREMENT (TITLE): High Frequency AC-DC Power Supplies

7. TECHNOLOGY OPTIONS:

a. SCR synchronously commutated regulation

b. Convert to DC and regulate

8. TECHNICAL PROBLEMS:

No known technical problems.

9. POTENTIAL ALTERNATIVES:

Run equipment off of the standard power options available at the payload interfaces.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

None planned because 20 KHZ power systems do not exist.

11. RELATED TECHNOLOGY REQUIREMENTS:

High frequency, high power, low loss ferrites.

8652-97

DEFINITION OF TECHNOLOGY REQUIREMENT

No. C-8

1. TECHNOLOGY REQUIREMENT (TITLE): High Frequency AC-DC Power Supplies

Page 3 of 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95		
TECHNOLOGY																			
Design																			
Testing																			
FUNDING LEVEL (In $1,000, 1978 dollars)				50	50														

13. USAGE SCHEDULE:

																		TOTAL
TECHNOLOGY NEED DATE																		
NUMBER OF LAUNCHES																		

14. REFERENCES

15. LEVEL OF STATE OF THE ART:

1. Basic phenomena observed and reported
2. Theory formulated to describe phenomena
3. Theory tested by physical experiment or mathematical model
4. Pertinent functions or characteristic demonstrated, e.g., material, component
5. Component or breadboard tested in relevant environment in laboratory
6. Model tested in aircraft environment
7. Model tested in space environment
8. New capability derived from a much lesser operational model
9. Reliability upgrading of an operational model
10. Lifetime extension of an operational model

3652-98

DEFINITION OF TECHNOLOGY REQUIREMENT No. C-9

1. TECHNOLOGY REQUIREMENT (TITLE): Optical Data Bus Rotary Joint

2. TECHNOLOGY CATEGORY: Components

3. OBJECTIVE/ADVANCEMENT REQUIRED: Slip ring type devices which can couple optical data busses across a rotary joint.

4. CURRENT STATE OF ART: No known designs

5. DESCRIPTION OF TECHNOLOGY:

Optical slip rings are needed to couple the optical data busses to each side of the rotary joint. Due to physical constraints these devices may not be located in the center of the joint but must be around the perimeter. The devices may not resemble slip rings but must perform the same function.

6. RATIONALE AND ANALYSIS:

Optical data busses must cross the rotary joint to link all of the controllers and the central computer in the Power Management System. The devices used to couple across the joint must work over a full 360 degrees of rotation and may be rotated the same direction for up to one million rotations.

3652-96

DEFINITION OF TECHNOLOGY REQUIREMENT	No. C-9

1. TECHNOLOGY REQUIREMENT (TITLE): Optical Data Bus Rotary Joint — Page 2 of 3

7. TECHNOLOGY OPTIONS:

a. Mirror System

b. Light spreading termination

8. TECHNICAL PROBLEMS:

Reduction of coupling losses

9. POTENTIAL ALTERNATIVES:

Use RF (telemetry) link

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

None

11. RELATED TECHNOLOGY REQUIREMENTS:

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DEFINITION OF TECHNOLOGY REQUIREMENT — No. C-9

1. TECHNOLOGY REQUIREMENT (TITLE): Optical Data Bus Rotary Joint — Page 3 of 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95		
TECHNOLOGY																			
Trade Study																			
Design																			
Prototype Testing																			
FUNDING LEVEL (In $1,000, 1978 dollars)			50	50															

13. USAGE SCHEDULE:

																		TOTAL
TECHNOLOGY NEED DATE																		
NUMBER OF LAUNCHES																		

14. REFERENCES

15. LEVEL OF STATE OF THE ART:

1. Basic phenomena observed and reported
2. Theory formulated to describe phenomena
3. Theory tested by physical experiment or mathematical model
4. Pertinent functions or characteristic demonstrated, e.g.. material, component
5. Component or breadboard tested in relevant environment in laboratory
6. Model tested in aircraft environment
7. Model tested in space environment
8. New capability derived from a much lesser operational model
9. Reliability upgrading of an operational model
10. Lifetime extension of an operational model

3652-98

DEFINITION OF TECHNOLOGY REQUIREMENT — No. C-10

1. TECHNOLOGY REQUIREMENT (TITLE): Micrometeorite Protection for Insulated Components

2. TECHNOLOGY CATEGORY: Components

3. OBJECTIVE/ADVANCEMENT REQUIRED: Methods to provide high voltage insulation between conductive surfaces which will not be comprised by particle penetration.

4. CURRENT STATE OF ART: Provide shielding and sufficient thickness to prevent complete penetration.

5. DESCRIPTION OF TECHNOLOGY:

Methods are required to maintain the integrity of insulation between high voltage conductors in the face of penetrations by small particles, leaving "tracks" or holes which plasma or other material can fill, allowing for conduction.

6. RATIONALE AND ANALYSIS:

Orbital spacecraft have the probability of encountering micro-meteorites which are energetic enough to penetrate exterior surfaces. External components, such as solar arrays and busses will have high voltage surfaces near low voltage or structural ground surfaces with insulation between them, for simple structural design. If the insulation is penetrated, the hole provides the opportunity for a conductive path since it can fill with plasma or conductive products of thecolusion.

3652-96

DEFINITION OF TECHNOLOGY REQUIREMENT No. C-10

1. TECHNOLOGY REQUIREMENT (TITLE): Micrometeorite Protection for Insulated Components

7. TECHNOLOGY OPTIONS:

a. Provide configurations (i.e., Coax) where insulation shielding is inherent in the structure.

b. Provide separate micro-meteorite shields (not practical for solar arrays).

c. Provide more dense insulating material to reduce the likelihood of complete penetration.

d. Use viscous or chemically reacting insulating materials that could "heal" themselves.

8. TECHNICAL PROBLEMS:

a. High weight of shielding or dense insulating materials.

b. No practical concept for self-healing materials.

9. POTENTIAL ALTERNATIVES:

Provide space platform designs where surfaces with large electrical potentials between them are physically separated. (Typical distances would be on the order of 1.0 meter for 1000V).

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

None currently planned

11. RELATED TECHNOLOGY REQUIREMENTS:

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DEFINITION OF TECHNOLOGY REQUIREMENT	No. C-10

1. TECHNOLOGY REQUIREMENT (TITLE): Micormeteorite Protection for Insulated Components

Page 3 of 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95		
TECHNOLOGY																			
Trade Study																			
Predesign Protection Schemes																			
Breadboard and Test																			
FUNDING LEVEL (In $1,000, 1978 dollars)			25	50	50														

13. USAGE SCHEDULE:

																		TOTAL
TECHNOLOGY NEED DATE																		
NUMBER OF LAUNCHES																		

14. REFERENCES

15. LEVEL OF STATE OF THE ART:

1. Basic phenomena observed and reported
2. Theory formulated to describe phenomena
3. Theory tested by physical experiment or mathematical model
4. Pertinent functions or characteristic demonstrated, e.g., material, component
5. Component or breadboard-tested in relevant environment in laboratory
6. Model tested in aircraft environment
7. Model tested in space environment
8. New capability derived from a much lesser operational model
9. Reliability upgrading of an operational model
10. Lifetime extension of an operational model

3652-98

DEFINITION OF TECHNOLOGY REQUIREMENT — No. C-11

1. TECHNOLOGY REQUIREMENT (TITLE): Coaxial Power Transmission Line Development — Page 1 of 3

2. TECHNOLOGY CATEGORY: Components

3. OBJECTIVE/ADVANCEMENT REQUIRED: Development of a low loss, low inductance, low external field, high voltage, high power, transmission line.

4. CURRENT STATE OF ART: No development in this area.

5. DESCRIPTION OF TECHNOLOGY: Power Transmission line meeting the following requirements:

a. 250KW at 1000 VRMS AC at 20-30KHZ.

b. Minimum series inductance

c. Losses 1.0% at full load

d. Minimum external fields

e. Lenght - approx. 50 meters

f. "Party line connection of branching busses along its length to parallel loads.

g. Passive cooling

6. RATIONALE AND ANALYSIS:

The recommended AC system transmits power at 20-30KHZ and the line is part of a series L-C resonant link. High frequency and low weight considerations make the basic conductor choice hollow cylinders.

Minimum external field and minimum inductance (so as not to effect resonant link characteristics) creates a requirement making the cylinders concentric, effectively a coax.

See attached diagram for a typical configuration.

3652-96

DEFINITION OF TECHNOLOGY REQUIREMENT No. C-11

1. TECHNOLOGY REQUIREMENT (TITLE): Coaxial Power Transmission Line Development

7. TECHNOLOGY OPTIONS:

a. Concentric cylinders

b. Twisted hollow conductors, surrounded by a conventional woven or foil shield.

8. TECHNICAL PROBLEMS:

a. Losses to the surrounding plasma through resonant coupling.
b. Definition of inductance and characteristic impedance.
c. Insulating materials (good thermal conductivity).
d. Connections at the load branches/growth & taps.
e. Thermal gradients and analysis.

9. POTENTIAL ALTERNATIVES:

Conventional cables with increased losses and inductance.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

None planned.

11. RELATED TECHNOLOGY REQUIREMENTS:

Low loss dielectric materials (C-5), AC plasma coupling as a function of voltage and frequency (D-3), distributed/split DC-AC-AC/DC resonant converter (S-1).

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DEFINITION OF TECHNOLOGY REQUIREMENT	No. C-11
1. TECHNOLOGY REQUIREMENT (TITLE): Coaxial Power Transmission Line Development	Page 3 of 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	
TECHNOLOGY																		
Configuration Modeling			▬															
Final Configuration Development			▬															
Build Repr. 50 M. Line				▬														
FUNDING LEVEL (In $1,000, 1978 dollars)			50	25														

13. USAGE SCHEDULE:

	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	TOTAL
TECHNOLOGY NEED DATE			▲															
NUMBER OF LAUNCHES																		

14. REFERENCES

15. LEVEL OF STATE OF THE ART:

1. Basic phenomena observed and reported
2. Theory formulated to describe phenomena
3. Theory tested by physical experiment or mathematical model
4. Pertinent functions or characteristic demonstrated, e.g., material, component
5. Component or breadboard tested in relevant environment in laboratory
6. Model tested in aircraft environment
7. Model tested in space environment
8. New capability derived from a much lesser operational model
9. Reliability upgrading of an operational model
10. Lifetime extension of an operational model

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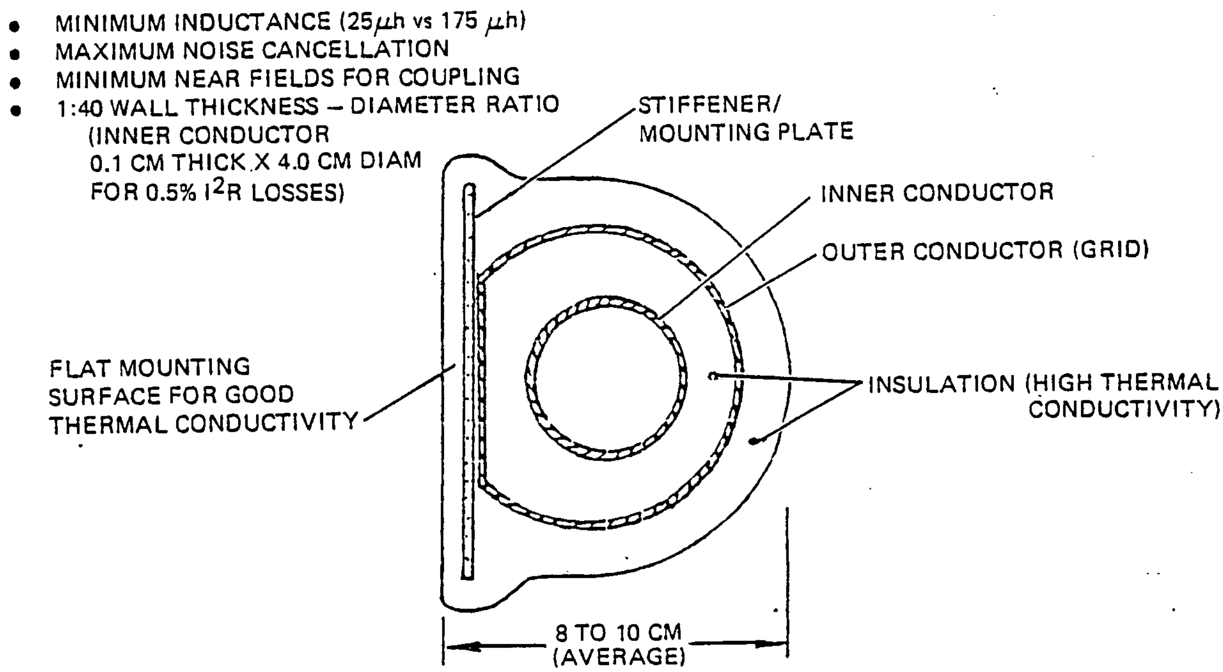

Preliminary power transmission line design (cross section).

DEFINITION OF TECHNOLOGY REQUIREMENT	No. C-12

1. TECHNOLOGY REQUIREMENT (TITLE): High Voltage, High Current Connectors (DC System) Page 1 of 3

2. TECHNOLOGY CATEGORY: Components

3. OBJECTIVE/ADVANCEMENT REQUIRED: High voltage, high current payload connector for use in plasma environment.

4. CURRENT STATE OF ART:

5. DESCRIPTION OF TECHNOLOGY:

High voltage, high current connectors will be needed to support the DC distribution system. Currently, manned spacecraft have been using multiple low current connector pins and low (28Vdc) voltages.

6. RATIONALE AND ANALYSIS:

The optimum voltage for the DC system is about 700 VDC. The power levels involved are such that 50 amp connector pins would also be needed to support this system.

3652-96

DEFINITION OF TECHNOLOGY REQUIREMENT No. C-12

1. TECHNOLOGY REQUIREMENT (TITLE): High Voltage, High Current Connectors

7. TECHNOLOGY OPTIONS:

a. Exlusion of plasma environment (similar to underwater connectors).

b. Multiple low current pins.

c. Physical separation of pins with opposite voltages.

8. TECHNICAL PROBLEMS:

Not enough is known about plasma problems to arrive at a final solution.

9. POTENTIAL ALTERNATIVES:

Hardwiring with bolts and bussbars.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

None planned

11. RELATED TECHNOLOGY REQUIREMENTS:

Plasma characteristics research

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DEFINITION OF TECHNOLOGY REQUIREMENT	No. C-12
1. TECHNOLOGY REQUIREMENT (TITLE): High voltabe, High Voltage Connectors	Page 3 of 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95		
TECHNOLOGY																			
Conceptual Analysis			—																
Materials Research				—															
Design					—	—													
Testing					—	—													
FUNDING LEVEL (In $1,000, 1978 dollars)			25	50	100	50													

13. USAGE SCHEDULE:

																		TOTAL
TECHNOLOGY NEED DATE																		
NUMBER OF LAUNCHES																		

14. REFERENCES

15. LEVEL OF STATE OF THE ART:

1. Basic phenomena observed and reported
2. Theory formulated to describe phenomena
3. Theory tested by physical experiment or mathematical model
4. Pertinent functions or characteristic demonstrated, e.g.. material, component
5. Component or breadboard tested in relevant environment in laboratory
6. Model tested in aircraft environment
7. Model tested in space environment
8. New capability derived from a much lesser operational model
9. Reliability upgrading of an operational model
10. Lifetime extension of an operational model

3652-98

DEFINITION OF TECHNOLOGY REQUIREMENT No. C-13

1. TECHNOLOGY REQUIREMENT (TITLE): Magnetic Power Disconnects (including circuit breaker applications) Page 1 of 3

2. TECHNOLOGY CATEGORY: Components

3. OBJECTIVE/ADVANCEMENT REQUIRED: Development of a "split" transformer - such that the secondary can be separated from the primary for purposes of module power connects.

4. CURRENT STATE OF ART:

5. DESCRIPTION OF TECHNOLOGY:

A safe, positive means for interconnecting the various modules of the spacecraft is required. An "interleaved" transformer concept would solve this problem because there would be no exposed conductors to accidentally short in case of a misalignment during docking. This technology could also be extended to include magnetically coupled circuit breakers which would not cause a plasma arc when operating an overloaded circuit.

6. RATIONALE AND ANALYSIS:

To date, no known manufacturers have addressed this problem. Standard electrical connectors may have increases in contact resistance over a 10 year anticipated life-span and cause intermittants if connected and disconnected very often. Since both parts of this device would be made of the same material, thermal problems should be reduced. This connector would provide the combined functions of disconnect, level load isolation, and load transformer, while keeping the interface fully protected from the environment.

3652-96

DEFINITION OF TECHNOLOGY REQUIREMENT — No. C-13

1. TECHNOLOGY REQUIREMENT (TITLE): Magnetic Power Disconnects — Page 2 of 3

7. TECHNOLOGY OPTIONS:

a. Interleaved primary and secondary with stacked cores.

b. Flat interface with gapped ferrite cores.

8. TECHNICAL PROBLEMS:

a. Thermal design and gradient effects.

b. Mate/demate mechanism and connector structural design.

c. External magnetic field of open connector.

d. Thermal cycling effect on structural design.

9. POTENTIAL ALTERNATIVES:

High voltage, plasma tolerant conventional connector.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

None planned

11. RELATED TECHNOLOGY REQUIREMENTS:

High flux, high frequency core materials.

8652-97

DEFINITION OF TECHNOLOGY REQUIREMENT

No. C-13

1. TECHNOLOGY REQUIREMENT (TITLE): Magnetic Power Disconnects

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	
TECHNOLOGY																		
Design Feasibility Study																		
Prototype Design & Test																		
Mechanical Concepts																		
FUNDING LEVEL (In $1,000, 1978 dollars)			25	50														

13. USAGE SCHEDULE:

																		TOTAL
TECHNOLOGY NEED DATE																		
NUMBER OF LAUNCHES																		

14. REFERENCES

15. LEVEL OF STATE OF THE ART:

1. Basic phenomena observed and reported
2. Theory formulated to describe phenomena
3. Theory tested by physical experiment or mathematical model
4. Pertinent functions or characteristic demonstrated, e.g.. material, component
5. Component or breadboard tested in relevant environment in laboratory
6. Model tested in aircraft environment
7. Model tested in space environment
8. New capability derived from a much lesser operational model
9. Reliability upgrading of an operational model
10. Lifetime extension of an operational model

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Example of detailed process - see article/etc.

DEFINITION OF TECHNOLOGY REQUIREMENT No. C-14

1. TECHNOLOGY REQUIREMENT (TITLE): Power FET's Page 1 of 3

2. TECHNOLOGY CATEGORY: Components

3. OBJECTIVE/ADVANCEMENT REQUIRED: Higher voltage (1KV) and higher current (100A) power FET's.

4. CURRENT STATE OF ART: 100V, 28A, 0.55 ohms

5. DESCRIPTION OF TECHNOLOGY:

High voltage (1KV) power FET's will be needed to decrease losses in switching type power conversion equipment.

6. RATIONALE AND ANALYSIS:

Conventional FET's such as the V-mos power FET and the newly announced HEXFET have undergone improvements since their introduction in mid-1977. The primary progress which has been made has been in the area of "on" resistance with the maximum Drain-to-Source voltage ratings remaining almost constant over the years. In order for these devices to be useful development of devices with higher Drain-to-Source voltage ratings is necessary. The inherent high speed and high gain of these devices makes FET's more desirable than bipolar devices for switching applications.

3652-96

DEFINITION OF TECHNOLOGY REQUIREMENT	No. C-14
1. TECHNOLOGY REQUIREMENT (TITLE): Power FET's	Page 2 of 3

7. TECHNOLOGY OPTIONS:

a. Different material

b. Different device geometry

8. TECHNICAL PROBLEMS:

a. Present FET devices do not have sufficient voltage ratings.

b. Present FET devices do not have sufficient current ratings.

9. POTENTIAL ALTERNATIVES:

a. Cascade available FET devices and accept increased losses in output and driver circuits.

b. Develop suitable bipolar devices.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

500V, 50A may be available by 1985.
Industry does not consider this a priority product line. Therefore, low priority development programs are underway.

11. RELATED TECHNOLOGY REQUIREMENTS:

Semiconductor (FET) manufacturing technology.

3652-97

DEFINITION OF TECHNOLOGY REQUIREMENT	No. C-14
1. TECHNOLOGY REQUIREMENT (TITLE): Power FET's	Page 3 of 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	
TECHNOLOGY																		
Define Problems																		
Define Materials																		
Optimize Material and Geometry																		
Pilot Runs																		
Qualification																		
Production																		
FUNDING LEVEL (In $1,000, 1978 dollars)																		
Development			50	100	100													
Qualification																		
Production																		

13. USAGE SCHEDULE:

																	TOTAL
TECHNOLOGY NEED DATE																	
NUMBER OF LAUNCHES																	

14. REFERENCES

15. LEVEL OF STATE OF THE ART:

1. Basic phenomena observed and reported
2. Theory formulated to describe phenomena
3. Theory tested by physical experiment or mathematical model
4. Pertinent functions or characteristic demonstrated, e.g., material, component
5. Component or breadboard tested in relevant environment in laboratory
6. Model tested in aircraft environment
7. Model tested in space environment
8. New capability derived from a much lesser operational model
9. Reliability upgrading of an operational model
10. Lifetime extension of an operational model

3652-92

DEFINITION OF TECHNOLOGY REQUIREMENT No. C-15

1. TECHNOLOGY REQUIREMENT (TITLE): Standard Optical Data Bus Interface Hardware Page 1 of 2

2. TECHNOLOGY CATEGORY: Components

3. OBJECTIVE/ADVANCEMENT REQUIRED: Standard interface for use at RPC's and other PMS components.

4. CURRENT STATE OF ART: Many independent companies competing for the business. Early version MIL-STD-1553FO released.

5. DESCRIPTION OF TECHNOLOGY:

Standard serial data bus communications interface capable of receiving commands and sending data; compatible with standard systems and formats; probably optical for this time period; in accordance with a later version of MIL-STD-1553FO or its successor.

6. RATIONALE AND ANALYSIS:

The many elements and automated control of a PMS for this size space platform will make direct, single wire interconnection for each function, command, and data input or output totally unmanageable. This makes serial data bus interconnection the only reasonable choice, thereby generating the need for a standard interface module.

3652-96

DEFINITION OF TECHNOLOGY REQUIREMENT	No. C-15

1. TECHNOLOGY REQUIREMENT (TITLE): Standard Optical Data Bus Interface Hardware — Page 2 of 2

7. TECHNOLOGY OPTIONS:

a. Optical Data Bus

b. Wired Data Bus

8. TECHNICAL PROBLEMS:

a. Selection of an appropriate standard.

9. POTENTIAL ALTERNATIVES:

Parallel hard-wired interconnection.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

Many, from many independent companies, many government contracts - make development imminent without additional assistance from PMS programs .

No Page 3 required.

11. RELATED TECHNOLOGY REQUIREMENTS:

3652-97

DEFINITION OF TECHNOLOGY REQUIREMENT No. C-16

1. TECHNOLOGY REQUIREMENT (TITLE): Federated Computer System Hardware

2. TECHNOLOGY CATEGORY: Components

3. OBJECTIVE/ADVANCEMENT REQUIRED: Development of a federated computer control/data system capable of managing the PMS.

4. CURRENT STATE OF ART: Many micro-computers and control systems now being developed.

5. DESCRIPTION OF TECHNOLOGY:

A group of small computers communicating with one-another and with other remote terminals to ascertain the status of, and issue commands to control and manage the PMS based on determinations of space platform status, power capability status, load demands and priorities, and manual inputs from astronaut/crew members.

6. RATIONALE AND ANALYSIS:

Control and communication systems for large, complex vehicles are rapidly moving toward this type of design. Rapid improvements in micro-computers and data communication hardware has made this approach cost effective and reliable; and it is suited to the integrated control of this type of space platform including PMS functions.

3652-96

DEFINITION OF TECHNOLOGY REQUIREMENT — No. C-16

1. TECHNOLOGY REQUIREMENT (TITLE): Federated Computer System Hardware — Page 2 of 2

7. TECHNOLOGY OPTIONS:

Many individual system architectures.

8. TECHNICAL PROBLEMS:

Selection of appropriate hardware.

9. POTENTIAL ALTERNATIVES:

Centralized computer control approach.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

Many now under way, DIS promises to provide exactly the type of system needed. No PMS funds need to be expended in this area, except to monitor developments.

No page 3 required.

11. RELATED TECHNOLOGY REQUIREMENTS:

Federated computer system software (C-17)

8652-97

DEFINITION OF TECHNOLOGY REQUIREMENT No. C-17

1. TECHNOLOGY REQUIREMENT (TITLE): Federated Computer System Software

Page 1 of 2

2. TECHNOLOGY CATEGORY: Components

3. OBJECTIVE/ADVANCEMENT REQUIRED: Development of general control software for the PMS computer control function.

4. CURRENT STATE OF ART: Many systems now working or under development.

5. DESCRIPTION OF TECHNOLOGY:

The software for the computer system to direct overall system operation and communication, and to provide redundancy management and control.

6. RATIONALE AND ANALYSIS:

This type of general purpose software is a basic system requirement, not dependent on the actual detailed PMS configuration, and can be developed as part of the general computer problem.

3652-96

DEFINITION OF TECHNOLOGY REQUIREMENT — No. C-17

1. TECHNOLOGY REQUIREMENT (TITLE): Federated Computer System Software — Page 2 of 2

7. TECHNOLOGY OPTIONS:

Many variations - depending on hardware chosen.

8. TECHNICAL PROBLEMS:

None

9. POTENTIAL ALTERNATIVES:

Centralized computer approach software.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

Many now under way. DIS promises to provide exactly the type of system required. No PMS funds need to be expended in this area except to monitor developments.

No page 3 required.

11. RELATED TECHNOLOGY REQUIREMENTS:

Federated computer system hardware (C-16).

8652-97

DEFINITION OF TECHNOLOGY REQUIREMENT No.C-18

1. TECHNOLOGY REQUIREMENT (TITLE): Improved Performance Triacs

2. TECHNOLOGY CATEGORY: Components

3. OBJECTIVE/ADVANCEMENT REQUIRED: AC switching components with improved parameters as shown below.

4. CURRENT STATE OF ART: $V_{DRM} = 600V$; $I_T = 40A$ RMS

5. DESCRIPTION OF TECHNOLOGY:

Bi-directional AC switching components with the following ratings:

$$V_{DRM} = 2000 \text{ VPK}$$

$$I_T = 50\text{A RMS}$$

6. RATIONALE AND ANALYSIS:

AC switch elements are required for redundancy management and high voltage isolation functions. Thyristor technology is developed to meet the necessary requirements.

Triacs are Bi-directional devices and therefore provide simpler implementation of AC switch functions than SCR's.

3652-96

DEFINITION OF TECHNOLOGY REQUIREMENT — No. C-18

1. TECHNOLOGY REQUIREMENT (TITLE): Improved Performance Triacs — Page 2 of 2

7. TECHNOLOGY OPTIONS:

a. Improved ratings

b. Parallel SCR's

8. TECHNICAL PROBLEMS:

9. POTENTIAL ALTERNATIVES:

a. Electro-mechanical switches

b. Transistor switches

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

Thyristor technology is capable of meeting these requirements; triacs, being more convenient implementations should progress toward SCR ratings.

No page 3 required.

11. RELATED TECHNOLOGY REQUIREMENTS:

8652-97

DEFINITION OF TECHNOLOGY REQUIREMENT No. C-19

1. TECHNOLOGY REQUIREMENT (TITLE): Improved Performance Bipolar Semiconductors Page 1 of 2

2. TECHNOLOGY CATEGORY: Components

3. OBJECTIVE/ADVANCEMENT REQUIRED: Increased current and voltage ratings for bipolar semiconductors.

4. CURRENT STATE OF ART: D60T transistor - 400V-60 Amp to 500V-40 Amp.

5. DESCRIPTION OF TECHNOLOGY:

Switching transitsor with ratings as follows:

a. $V_{CEO(SUS)} = 1000$ VDC

$I_{C(CONT)} = 25.0$ ADC

b. $V_{CEO(SUS)} = 600$ VDC

$I_{C(CONT)} = 70$ ADC

6. RATIONALE AND ANALYSIS:

Bipolar switches are required for output devices in several converter designs. The DC system will also require transistors for isolation and redundancy management switching as output devices for RPC's.

3652-96

DEFINITION OF TECHNOLOGY REQUIREMENT	No. C-19
1. TECHNOLOGY REQUIREMENT (TITLE): Improved Performance Bipolar Semiconductors	Page 2 of 2

7. TECHNOLOGY OPTIONS:

a. Improved designs

b. Series or parallel combinations of present devices

8. TECHNICAL PROBLEMS:

9. POTENTIAL ALTERNATIVES:

a. Change system voltages

b. Use electro-mechanical switches

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

LeRC has a continuing program which resulted in the development of the D60T and should be continued to provide the improvements shown.

No page 3 required.

11. RELATED TECHNOLOGY REQUIREMENTS:

8652-97

DEFINITION OF TECHNOLOGY REQUIREMENT No. D-1

1. TECHNOLOGY REQUIREMENT (TITLE): High Frequency Power for "Standard" Test Equipment

2. TECHNOLOGY CATEGORY: Data

3. OBJECTIVE/ADVANCEMENT REQUIRED: Assessment of impact on standard test equipment if the input power frequency increases 20KHZ.

4. CURRENT STATE OF ART: 60HZ equipment the rule with a little 400HZ equipment becoming available.

5. DESCRIPTION OF TECHNOLOGY:

Changes in power supply design to operate at frequencies in excess of 20KHZ. Changes in instrument character when line frequency functions are used. These are for "standard" laboratory type equipment such as scopes, meters, power supplies, counters, etc.

6. RATIONALE AND ANALYSIS:

High frequency magnetic components and filter elements offer significant advantages from a size and weight point of view. Components designed to run from AC power can realize the same benefits. The PMS and components can be more cost effective if there is no need to interpose a frequency-changing cycloinverter in the power interface to reduce the frequency to 60 or 400 HZ.

3652-96

DEFINITION OF TECHNOLOGY REQUIREMENT	No. D-1

1. TECHNOLOGY REQUIREMENT (TITLE): High Frequency Power for "standard" Test Equipment

Page 2 of 3

7. TECHNOLOGY OPTIONS:

a. Design "standard" equipment for use in orbit to be compatible with high frequency power inputs.

b. Provide a standard test equipment converter or replaceable plug-in module.

8. TECHNICAL PROBLEMS:

Current equipment not designed this way.

9. POTENTIAL ALTERNATIVES:

Provide system cycloinverters to supply 400 HZ or 60 HZ to the platform payloads.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

None planned - This program would be a survey only to define the problem in sufficient detail to make a decision to request manufacturere to provide new designs or incorporate cycloinverters into the PMS.

11. RELATED TECHNOLOGY REQUIREMENTS:

Integrated/split DC-AC-DC/AC Resonant Converter (S-1).

3652-97

DEFINITION OF TECHNOLOGY REQUIREMENT	No. D-1

1. TECHNOLOGY REQUIREMENT (TITLE): High Frequency Power for "Standard" Test Equipment

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95		
TECHNOLOGY																			
Perform Survey			▬																
FUNDING LEVEL (In $1,000, 1978 dollars)			25																

13. USAGE SCHEDULE:

																		TOTAL
TECHNOLOGY NEED DATE			▲															
NUMBER OF LAUNCHES																		

14. REFERENCES

15. LEVEL OF STATE OF THE ART:

1. Basic phenomena observed and reported
2. Theory formulated to describe phenomena
3. Theory tested by physical experiment or mathematical model
4. Pertinent functions or characteristic demonstrated, e.g.. material, component
5. Component or breadboard tested in relevant environment in laboratory
6. Model tested in aircraft environment
7. Model tested in space environment
8. New capability derived from a much lesser operational model
9. Reliability upgrading of an operational model
10. Lifetime extension of an operational model

3652-98

DEFINITION OF TECHNOLOGY REQUIREMENT No. D-2

1. TECHNOLOGY REQUIREMENT (TITLE): EMI-EMC Specifications for High Power, High Frequency Page 1 of 3

2. TECHNOLOGY CATEGORY: Data

3. OBJECTIVE/ADVANCEMENT REQUIRED: Creation of a spec of modification of current ones to address the system having high (20KHZ) Power line frequencies.

4. CURRENT STATE OF ART: Specs for AC power systems designed around 60HZ or 400HZ.

5. DESCRIPTION OF TECHNOLOGY:

New specifications required similiar to MIL-STD-1541 for this class of system. Specific recommendations to be added.

6. RATIONALE AND ANALYSIS:

Unique characteristics of space systems having power systems operating at these power levels and frequencies have not been addressed.

3652-96

DEFINITION OF TECHNOLOGY REQUIREMENT	No. D-2
1. TECHNOLOGY REQUIREMENT (TITLE): EMI-EMC Specifications for High Power, High Frequency	Page 2 of 3

7. TECHNOLOGY OPTIONS:

a. Modify present spec. (MIL-STD-1541)

b. Provide new spec.

8. TECHNICAL PROBLEMS:

None - Specification only

9. POTENTIAL ALTERNATIVES:

None - Specification only

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

None Planned

11. RELATED TECHNOLOGY REQUIREMENTS:

Distributed/split DC-AC-DC/AC Resonant Converter (S-1).

3652-97

DEFINITION OF TECHNOLOGY REQUIREMENT	No. D-2

1. TECHNOLOGY REQUIREMENT (TITLE): EMI-EMC Specifications for High Power, High Frequency

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95		
TECHNOLOGY																			
Solicit New Spec Inputs from Industry					▬														
Write New Spec Revision					▬														
FUNDING LEVEL (In $1,000, 1978 dollars)					25														

13. USAGE SCHEDULE:

	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	TOTAL
TECHNOLOGY NEED DATE					▲													
NUMBER OF LAUNCHES																		

14. REFERENCES

15. LEVEL OF STATE OF THE ART:

1. Basic phenomena observed and reported
2. Theory formulated to describe phenomena
3. Theory tested by physical experiment or mathematical model
4. Pertinent functions or characteristic demonstrated, e.g., material, component
5. Component or breadboard tested in relevant environment in laboratory
6. Model tested in aircraft environment
7. Model tested in space environment
8. New capability derived from a much lesser operational model
9. Reliability upgrading of an operational model
10. Lifetime extension of an operational model

3652-98

DEFINITION OF TECHNOLOGY REQUIREMENT No. D-3

1. TECHNOLOGY REQUIREMENT (TITLE): Power Loss to Ionosphere from A.C. Transmission Lines Page 1 of 3

2. TECHNOLOGY CATEGORY: HVSA

3. OBJECTIVE/ADVANCEMENT REQUIRED: Calculate power loss to ionosphere from an A.C. transmission line operating near or at the ion plasma frequency.

4. CURRENT STATE OF ART: Computer codes for plasma simulation are readily available from the magnetic fusion program.

5. DESCRIPTION OF TECHNOLOGY:

A computer simulation of the ionospheric plasma and transmission line is needed to determine the reaction of the plasma to the oscillating fields. Such a simulation will provide information as to power loss to the plasma, contours of equi-potential surfaces, and non-linear limitations.

6. RATIONALE AND ANALYSIS:

It has been found that operation in an A.C. mode at 20-40 KHZ is desired. However, this frequency range corresponds to the ion plasma frequency range for the operational altitudes. Thus, it is important to determine the power losses to be expected when the operational frequency matches the ion plasma frequency.

3552-96

DEFINITION OF TECHNOLOGY REQUIREMENT — No. D-3

1. TECHNOLOGY REQUIREMENT (TITLE): Power Loss to Ionosphere from A.C. Transmission Lines — Page 2 of 3

7. TECHNOLOGY OPTIONS:

a. Operate at frequencies which are not resonant with any plasma modes.

b. Use coaxial transmission lines. There will still be some need for the calculation in the event currents are not balanced.

8. TECHNICAL PROBLEMS:

The major complication will be inclusion of satellite motion, which will effectively change the problem from one-dimensional to two-dimensional, and inclusion of the Earth's magnetic field.

9. POTENTIAL ALTERNATIVES:

The alternative is to experimentally determine the power loss. However, it will be difficult to find a vacuum chamber in which one can have an effectively infinite plasma with ultra-high vacuum conditions.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

None identified.

11. RELATED TECHNOLOGY REQUIREMENTS:

Calculation of wake structure

8652-97

DEFINITION OF TECHNOLOGY REQUIREMENT	No. D-3

1. TECHNOLOGY REQUIREMENT (TITLE): Power Loss to Ionosphere from A.C. Transmission Lines

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95		
TECHNOLOGY																			
Test Program			▬																
FUNDING LEVEL (In $1,000, 1978 dollars)			140																

13. USAGE SCHEDULE:

																		TOTAL
TECHNOLOGY NEED DATE					▲													
NUMBER OF LAUNCHES																		

14. REFERENCES

15. LEVEL OF STATE OF THE ART:

1. Basic phenomena observed and reported
2. Theory formulated to describe phenomena
3. Theory tested by physical experiment or mathematical model
4. Pertinent functions or characteristic demonstrated, e.g.. material, component
5. Component or breadboard-tested in relevant environment in laboratory
6. Model tested in aircraft environment
7. Model tested in space environment
8. New capability derived from a much lesser operational model
9. Reliability upgrading of an operational model
10. Lifetime extension of an operational model

3652-98

DEFINITION OF TECHNOLOGY REQUIREMENT No. D-4

1. TECHNOLOGY REQUIREMENT (TITLE): Prevention of Arcing on High Voltage Spacecraft Components Page 1 of 2

2. TECHNOLOGY CATEGORY: HVSA

3. OBJECTIVE/ADVANCEMENT REQUIRED: Determine design criteria for high voltage spacecraft components to prevent damage due to arcing.

4. CURRENT STATE OF ART:

5. DESCRIPTION OF TECHNOLOGY:

The arcing phenomenon cannot be readily quantified. To assure optimum design of components will require an experimental program where high voltage elements are placed in a chamber with conditions similar to those expected in space. This should allow general information on component design and also provide a procedure for testing components before sending them into space.

6. RATIONALE AND ANALYSIS:

The high voltage components of the HVSA spacecraft will normally be shielded from the ambient plasma in a pressurized compartment. It is possible, should the compartment become depressurized, for these components to come into contact with the plasma, with the possibility of damaging electrical discharges between component surfaces. Such discharges have been observed experimentally.

3652-96

DEFINITION OF TECHNOLOGY REQUIREMENT	No. D-4

1. TECHNOLOGY REQUIREMENT (TITLE): Prevention of Arcing on High Voltage Spacecraft Components

7. TECHNOLOGY OPTIONS:

Keep components from coming in contact with ionosphere.

8. TECHNICAL PROBLEMS:

None Identified

9. POTENTIAL ALTERNATIVES:

Calculations can be performed, but reliability will be low and cost high.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

Studies of arcing are planned by NASA, but it is not known if these will include components under consideration. Further information will be obtained from satellites currently in NASA Planning.

No page 3 required.

11. RELATED TECHNOLOGY REQUIREMENTS:

a. Arcing between HVSA surfaces, HVSA surfaces and structures, and transmission lines.

b. Determination of secondary emission coefficients.

3652-97

DEFINITION OF TECHNOLOGY REQUIREMENT — No. D-5

1. TECHNOLOGY REQUIREMENT (TITLE): Secondary Emission from HVSA Surfaces — Page 1 of 2

2. TECHNOLOGY CATEGORY: High Voltage Solar Arrays

3. OBJECTIVE/ADVANCEMENT REQUIRED: Measurement of secondary emission coefficient for O_2^+ ions on solar array materials for energies from O, 2 KeV to 20 KeV

4. CURRENT STATE OF ART: Coefficients only known for O_2^+ on Mo, W.

5. DESCRIPTION OF TECHNOLOGY:

The equipment required to conduct this study is: a positive ion source, vacuum system accelerating and focusing electrodes, power supplies, and miscellaneous current and voltage recording devices. Briefly, the measurement consists of extracting an ion beam from the ion source, focusing the beam onto the surface to be studied, and measuring the current delivered to the target and the secondary electron current produced.

6. RATIONALE AND ANALYSIS:

Measurement of secondary emission coefficients is necessary for designing high voltage solar arrays for use at LEO. The data is needed to:

1. Calculate power loss from the solar arrays to the ambient plasma at LEO.
2. Determines design which will minimize damage to HVSA surfaces and thus improve performance and lifetime.

3652-96

DEFINITION OF TECHNOLOGY REQUIREMENT No. D-5

1. TECHNOLOGY REQUIREMENT (TITLE): Secondary Emission from HVSA Surfaces

7. TECHNOLOGY OPTIONS:

a. Operate at voltages where secondary emission is not expected to be very great.

b. Determine power loss from HVSA experimentally. This will be costly.

8. TECHNICAL PROBLEMS:

No serious thecnical problems should be encountered, as the measurement is quite straight-forward. The only problems that might arise are: precise definition of the surface, and build up of charge on an insulating surface that could impede or even prevent further ion bombardment.

9. POTENTIAL ALTERNATIVES:

None

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

Currently in NASA planning.

No page 3 required.

11. RELATED TECHNOLOGY REQUIREMENTS:

a. Secondary emission may contribute to arcing phenomena.

b. Power loss of solar array to ambient plasma.

3652-97

DEFINITION OF TECHNOLOGY REQUIREMENT No. D-6

1. TECHNOLOGY REQUIREMENT (TITLE): Prevention of Arcing on HVSA surfaces

2. TECHNOLOGY CATEGORY: High Voltage Solar Array

3. OBJECTIVE/ADVANCEMENT REQUIRED: Determine design criteria to prevent damage to HVSA systems due to electrical discharge.

4. CURRENT STATE OF ART: Laboratory experiments with current designs show extensive arcing at high voltage.

5. DESCRIPTION OF TECHNOLOGY:

Experiments are needed to investigate the mechanisms involved in arcing on HVSA surfaces. Specific areas of investigation include surface heating during breakdown, background gas pressure and species evolved near arc surfaces, and the change in surface resistivity during breakdown. To accomplish these studies, experimental apparatus includes a large high or ultra-high vacuum chamber, residual gas analyzer and a gas pressure measurement system.

6. RATIONALE AND ANALYSIS:

It has been found experimentally that high voltage solar arrays, in a plasma environment similar to conditions at LEO, will suffer from electrical discharges which may damage electrical components. Further experiments are needed to ascertain what characteristics of the space plasma environment and solar array structure lead to arcing. This information will allow design of dependable high voltage solar array systems.

3652-96

DEFINITION OF TECHNOLOGY REQUIREMENT	No. D-6

1. TECHNOLOGY REQUIREMENT (TITLE): Prevention of Arcing on HVSA Surfaces — Page 2 of 2

7. TECHNOLOGY OPTIONS:

a. Operate at low voltage (less than 1000V)

b. Insulate all conducting surfaces from space plasma. This might fail due to micrometeorite damage to insulation.

c. Overdesign power system to accommodate loss of components due to arcing.

8. TECHNICAL PROBLEMS:

It will prove difficult to perform these studies at gas pressures expected in the ionosphere. Also, measurement of gas pressure near the arcing surface will not be easy.

9. POTENTIAL ALTERNATIVES:

Prime alternative is to perform experiments in space. Such work is being conducted, however, it is very expensive.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

Currently NASA is performing a series of experiments in this area. It is not clear that the NASA programs will attempt work at higher vacuums, or will attempt all of the studies suggested herein. Further information is being obtained from actual satellite data currently in NASA planning.

No page 3 required.

11. RELATED TECHNOLOGY REQUIREMENTS:

a. Arcing between structural materials and array surface, transmission lines, and spacecraft components.

b. Power loss of solar array to ambient plasma.

c. Determination of secondary emission coefficients.

3652-97

DEFINITION OF TECHNOLOGY REQUIREMENT No. D-7

1. TECHNOLOGY REQUIREMENT (TITLE): Space Qualified Thyristors/ Triacs

Page 1 of 3

2. TECHNOLOGY CATEGORY: Data

3. OBJECTIVE/ADVANCEMENT REQUIRED: Provide for qualification of standard commercial devices now in use for the special stresses of the space environment.

4. CURRENT STATE OF ART: Devices now developed for commercial, terrestrial service.

5. DESCRIPTION OF TECHNOLOGY:

Provide data and qualification testing, where necessary, to verify that available, commercial devices will meet the unique environmental requirements for orbital service.

6. RATIONALE AND ANALYSIS:

The recommended AC system approach allows the opportunity to conveniently use this family of devices as switch elements (for isolation, etc) since turn-off is simplified. Terrestrial demand in AC utility systems will provide devices with sufficient capability for this application.

However, verification will be required to guarantee proper performance over their expected life (10 years) in the orbital environment.

3652-96

DEFINITION OF TECHNOLOGY REQUIREMENT	No. D-7

1. TECHNOLOGY REQUIREMENT (TITLE): Space Qualified Thyristors/ Triacs

7. TECHNOLOGY OPTIONS:

a. Provide for full MIL-qualification

b. Perform only those tests necessary to verify capability.

c. Qualify by analysis and comparison to other similar components.

8. TECHNICAL PROBLEMS:

None - Data only

9. POTENTIAL ALTERNATIVES:

Use other devices - Electro-mechanical switches, transistors, or power FET's.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

None planned.

11. RELATED TECHNOLOGY REQUIREMENTS:

Distributed/split DC-AC-DC/AC Resonant Converter (S-1).

3652-97

DEFINITION OF TECHNOLOGY REQUIREMENT	No. D-7

1. TECHNOLOGY REQUIREMENT (TITLE): Space Qualified Thyristors/ Triacs

Page 3 of 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95		
TECHNOLOGY																			
Qual Testing						—													
FUNDING LEVEL (In $1,000, 1978 dollars)						60													

13. USAGE SCHEDULE:

																			TOTAL
TECHNOLOGY NEED DATE						▲													
NUMBER OF LAUNCHES																			

14. REFERENCES

15. LEVEL OF STATE OF THE ART:

1. Basic phenomena observed and reported
2. Theory formulated to describe phenomena
3. Theory tested by physical experiment or mathematical model
4. Pertinent functions or characteristic demonstrated, e.g.. material, component
5. Component or breadboard tested in relevant environment in laboratory
6. Model tested in aircraft environment
7. Model tested in space environment
8. New capability derived from a much lesser operational model
9. Reliability upgrading of an operational model
10. Lifetime extension of an operational model

8652-98

DEFINITION OF TECHNOLOGY REQUIREMENT No. D-8

1. TECHNOLOGY REQUIREMENT (TITLE): Space Qualified Slip Rings for High Power

2. TECHNOLOGY CATEGORY: Data

3. OBJECTIVE/ADVANCEMENT REQUIRED: Provide for qualification of standard high power devices, for the orbital environment and life.

4. CURRENT STATE OF ART: 120 KW

5. DESCRIPTION OF TECHNOLOGY:

Provide data and qualification testing, where necessary, to verify that available devices will meet the unique environmental requirements for ten year orbital service.

6. RATIONALE AND ANALYSIS:

The alternate DC system approach requires a multiple slip ring assembly for redundant power transfer across the rotary joint. Approximately 400 KW is required and may be divided between as many rings as required without adding significant weight from the modular approach. Today's units are capable of 120 KW each with approximately 225 KW forecasted for 1985.

3652-96

DEFINITION OF TECHNOLOGY REQUIREMENT | No. D-8

1. TECHNOLOGY REQUIREMENT (TITLE): Space Qualified Slip Rings for High Power |

7. TECHNOLOGY OPTIONS:

a. Provide full MIL-qualification.

b. Perform only those tests necessary to verify capability.

c. Qualify by analysis and comparison to other similar components.

8. TECHNICAL PROBLEMS:

None - for gathering test data.
10 year life may be difficult to show.

9. POTENTIAL ALTERNATIVES:

a. AC system with rotary transformer.

b. Flexible cables with periodic "unwinding".

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

None

11. RELATED TECHNOLOGY REQUIREMENTS:

8652-97

DEFINITION OF TECHNOLOGY REQUIREMENT	No. D-8

1. TECHNOLOGY REQUIREMENT (TITLE): Space Qualified Slip Rings for High Power — Page 3 of 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95		
TECHNOLOGY Qual Testing and Analysis						—													
FUNDING LEVEL (In $1,000, 1978 dollars)						60													

13. USAGE SCHEDULE:

																		TOTAL
TECHNOLOGY NEED DATE						▲												
NUMBER OF LAUNCHES																		

14. REFERENCES

15. LEVEL OF STATE OF THE ART:

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8652-98

GENERAL DYNAMICS

Convair Division