Design Considerations for High Power Spacecraft Electrical Systems

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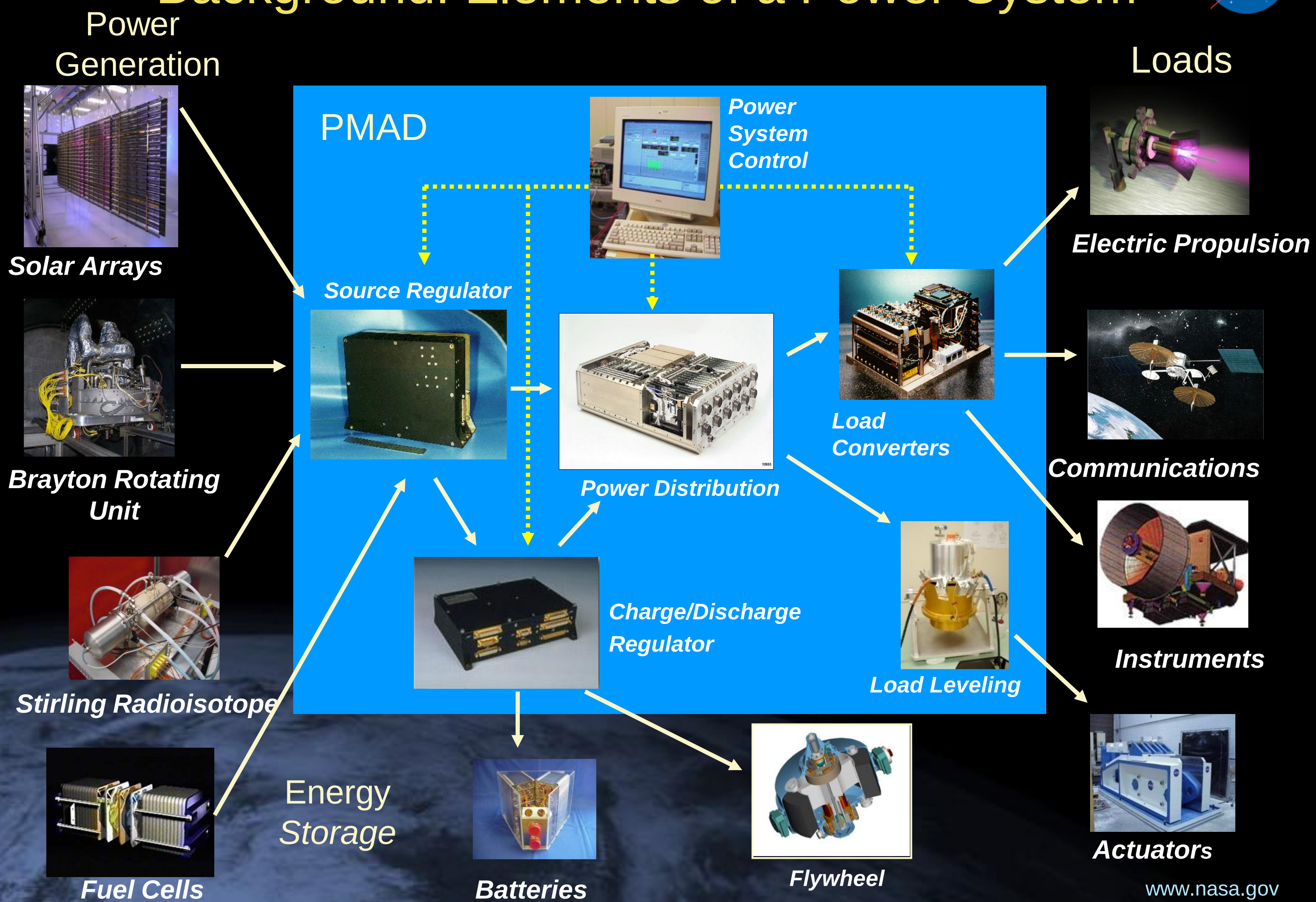
Outline

- Space Power Challenge
- Background
- Trends is Space Power Requirements
- Future Space Systems
- Challenges and Driving Requirements
- Modular Power Systems
- Advanced Power Technologies
- Conclusions
- Credits

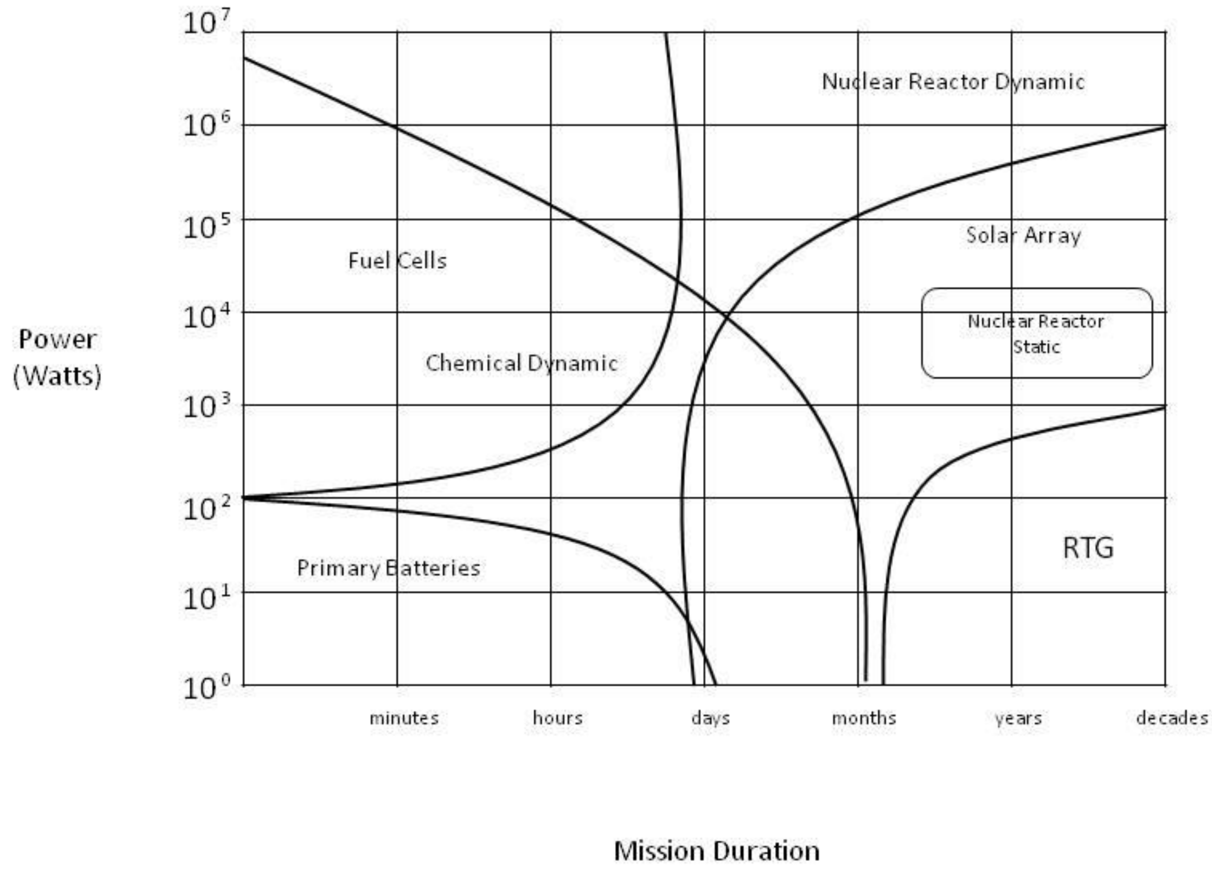
Space Power Grand Challenge

- Needs: Abundant, Reliable and Affordable Power
  - NASA's future missions of science and human exploration require abundant, reliable and affordable energy generation, storage and distribution.
  - Power needs grow exponentially as we look at extending human presence beyond near earth.
- Problem: Today's space power systems limit our ability to conduct human exploration beyond LEO.
  - Current spacecraft power systems key driving requirements become even more critical as we look at meeting growing power needs.

Background: Elements of a Power System



Background: Types of Space Power Systems



Traditional Space Power Systems

- Power Level ≤ 15kW
- PMAD Distribution Voltage ≤ 120V
- Custom systems created from one-of-a-kind components.
- Limited or no growth potential.
- Require extensive infrastructure for verification and operation.
- Limited or no autonomous operation.

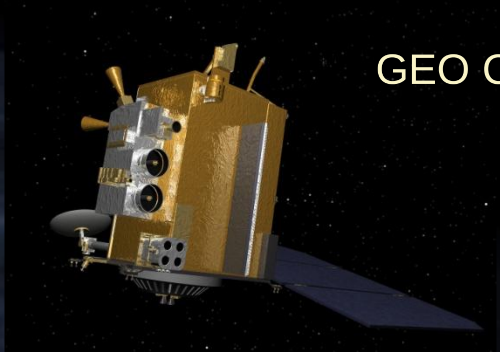
STS Orbiter

Rovers

Crew Vehicle (Orion)

Deep Space Spacecrafts

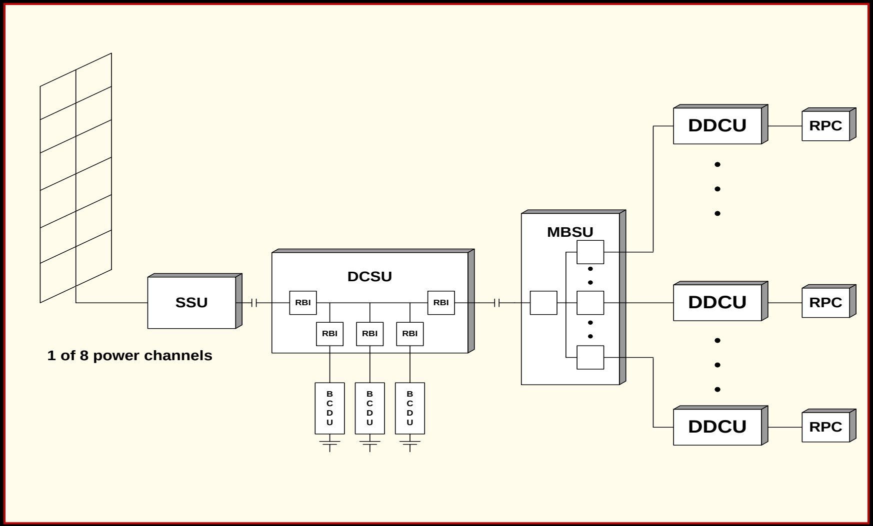
Hubble Telescope



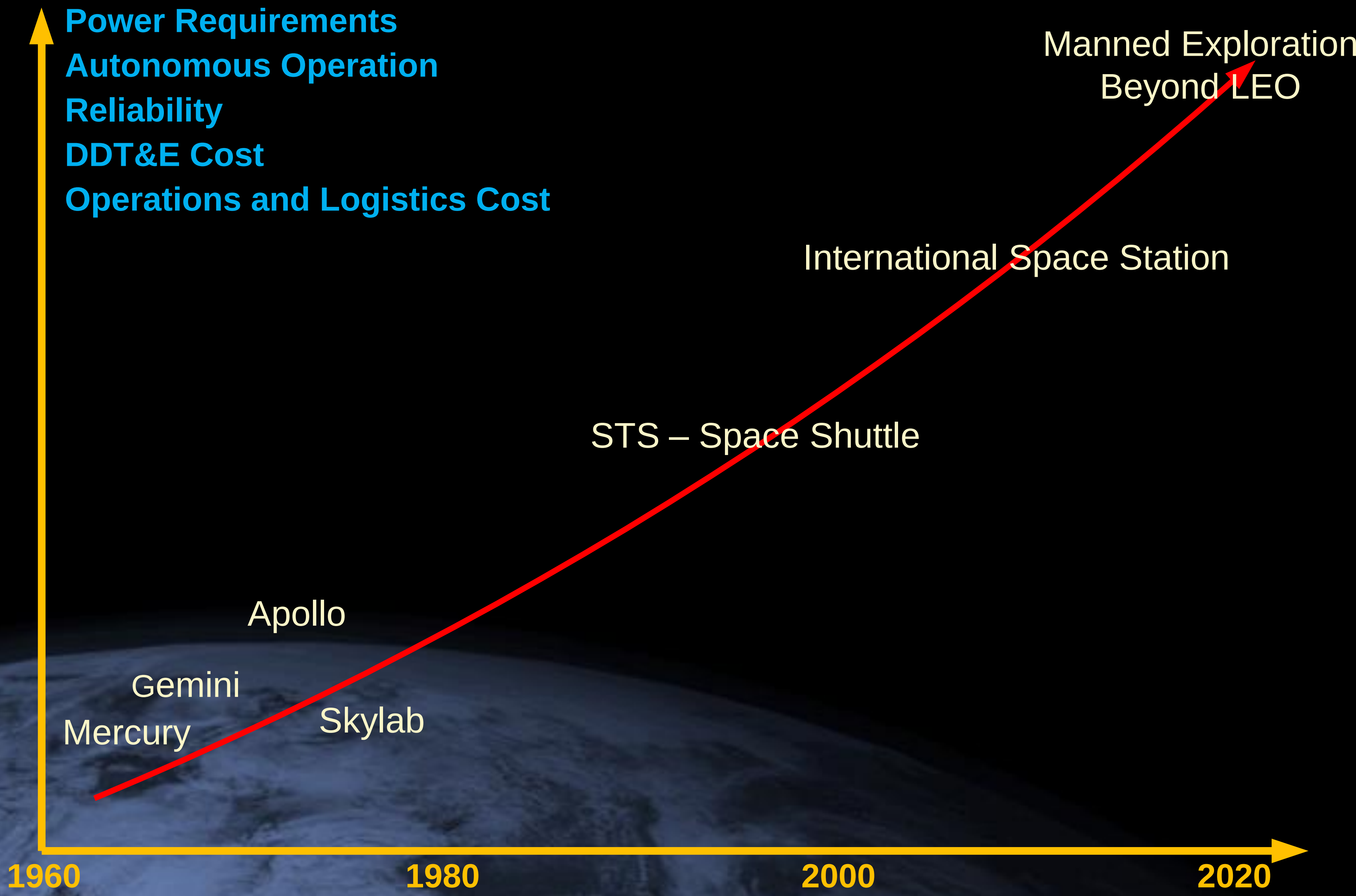
GEO ComSats

International Space Station EPS

- Power Source
  - Largest ever space solar array
  - 8 solar array wings on space station (2 per PV module)
  - Nominal electrical power output ~ 30 kW per PV wing BOL for ~ 240 kW total power
- Energy Storage
  - 24 NiH2 Batteries NiH2
  - Nominal storage capacity is ~4 kW-hr
- Power Distribution
  - Power Level 75 kW
  - 8 power channels
  - Distribution Voltage
    - 116-170 V primary
    - 120 V secondary



Trends in Space Power Systems



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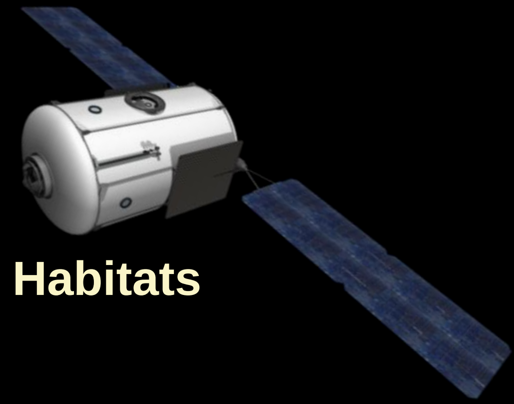
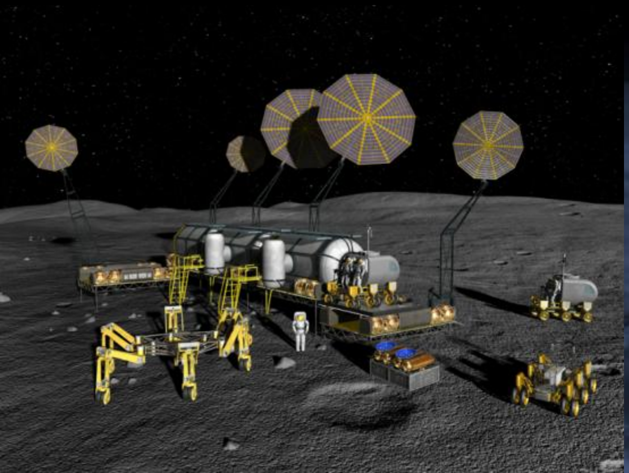
Potential Future Missions & Applications

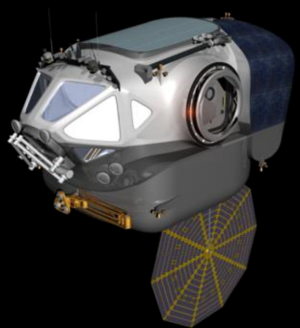
SEP Propulsion Stage



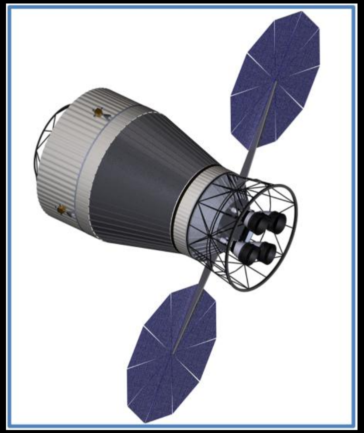
Deep Space Habitats

Space Outposts





Multi-mission Space Exploration Vehicle



Advanced Cryo Propulsion Stage

Challenges for Space Power Systems

- Environment
  - Radiation
  - Thermal
- Cost
- Wide Range of Spacecraft Configurations
  - Unique Requirements promotes “one of a kind” design.
- Long Term Operation with minimal human intervention
  - Health Monitoring
  - Power Management

- Space Power System Design Drivers:
  - Efficiency/Power density
  - Safety/Reliability
  - Radiation Hardness
  - Thermal requirements
  - Autonomous operation
  - Mass/Volume
  - DDT&E cost
  - Operations cost

Given these challenges

What should be our focus…

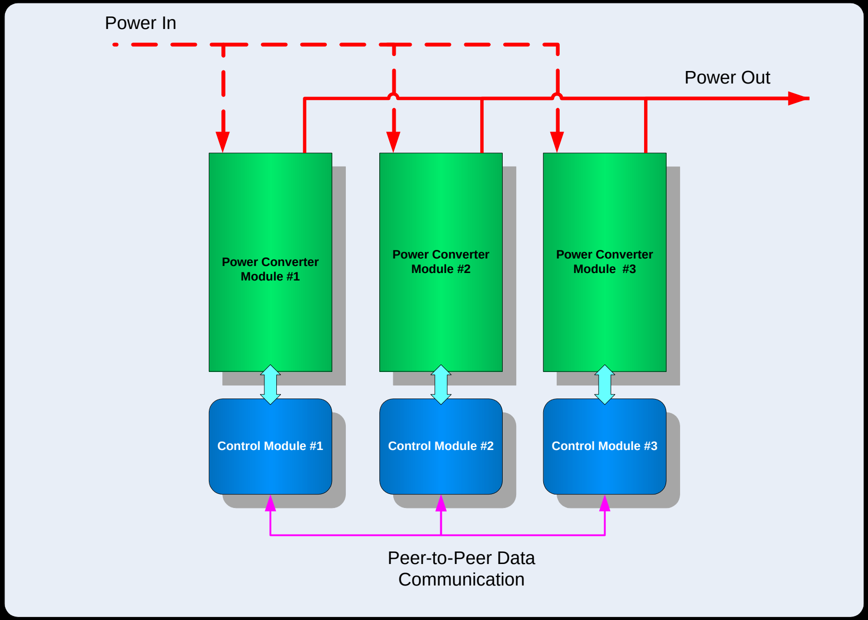
Modular Power System Concept

- Develop a set of modular power components that can be mixed and matched to meet “unique” requirements for different applications
  - Reduces DDT&E cost through design reuse
  - Reduces logistics cost across missions through reduction of vehicle unique components.
- “Monolithic” EPS functional units are replaced by collections of common “smart modules”.
- The power system can be “modularized” at various levels.
  - Module Level
    - Uses common devices with master-less intelligent controllers to create “smart modules” to build EPS functional units (converters, switchgear, batteries, etc.).
  - System Level
    - Integrate “smart modules” into sub-systems (power generation, storage, and distribution).

Modular PMAD - Hardware

Description

- Reusable building block(s) that can be configured in series and parallel arrangements for power management and distribution.



Key Issues to Address

- Mechanical packaging and interconnects.
- Low mass – complexity – parasitic.
- Control/configuration for multi-function, series, and/or parallel operation.

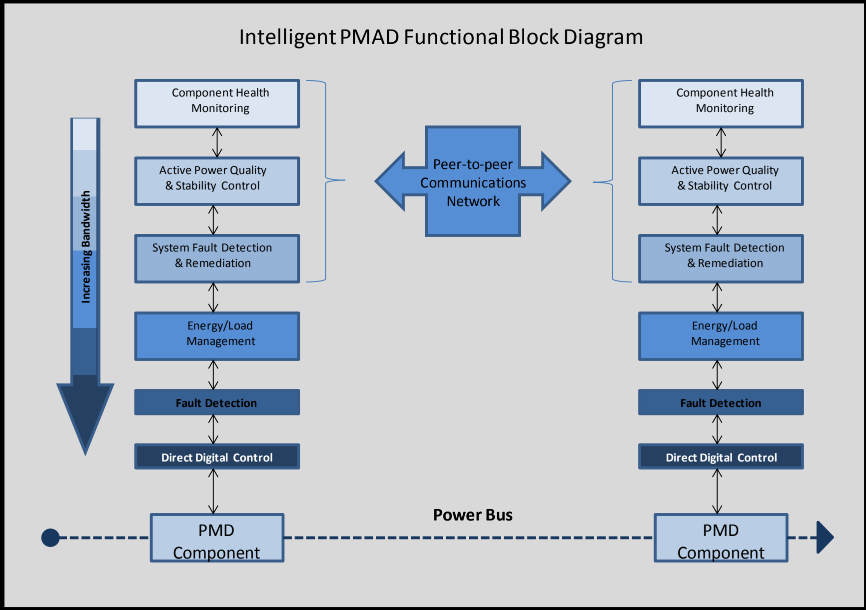
Key Benefits

- Reduced DDT&E and logistics costs.
- Enables high voltage/high power conversion and conditioning

Modular PMAD - Controls
Intelligent Control Systems

Description

- Replaces a traditional, hierarchical control system with peer-to-peer cooperating elements with each power module for enhanced operational effectiveness.



Key Issues to Address

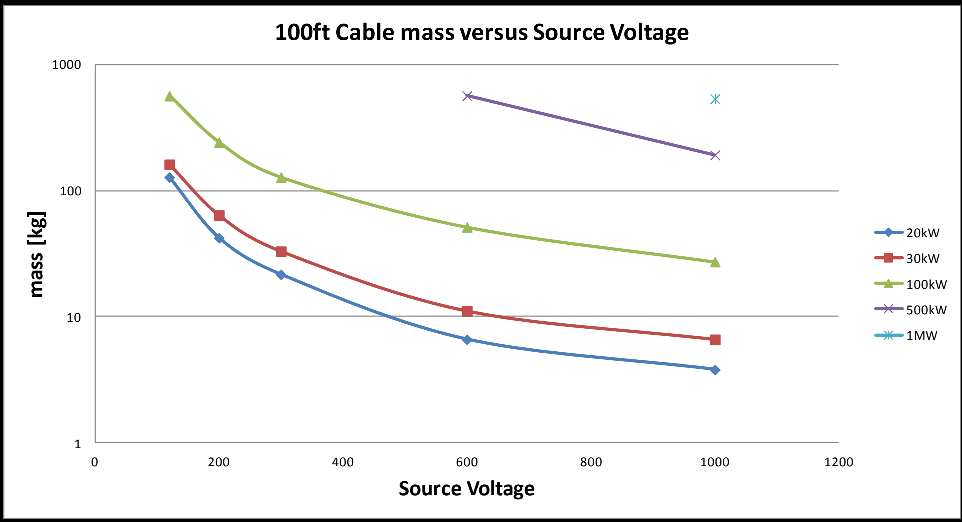
- Embedded controls in power elements.
- Collaborative agents in components for active power quality and stability control.
- Sensor web and distributed networks for health monitoring.
- Fault isolation and reconfiguration at the lowest levels.
- Reliable inter-module communication

Benefits

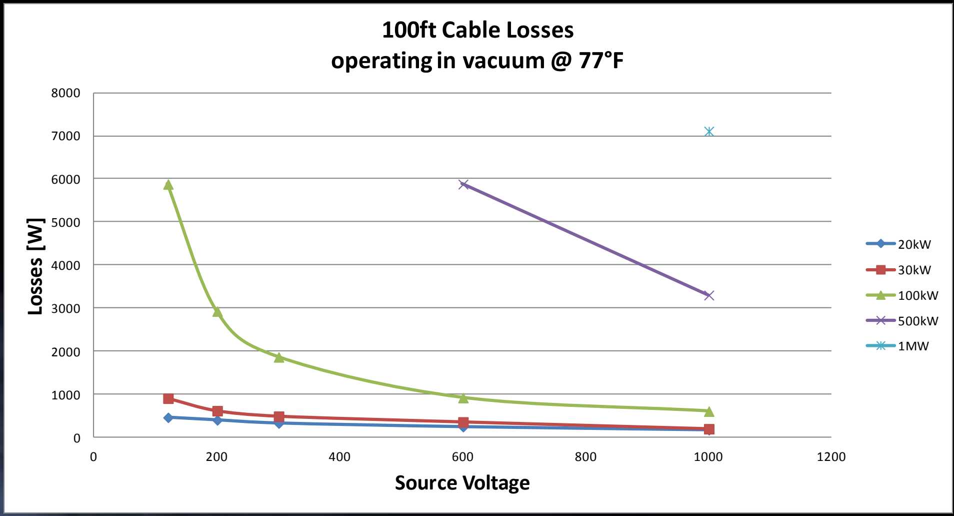
- Enhanced safety and reliability.
- Facilitates “plug & play” growth and system enhancement.
- Reduces cost of system verification and logistics.

PMAD - Power Distribution
High Voltage

Description
- AC or DC high voltage, > 300V, delivery of large power, >100kW, from source to load



Key Issues to Address
- Insulation stress.
- High current/power connectors.
- Corona management in certain environments.
- High current switching and fault control.
- Radiation tolerance.



Key Benefits
- High voltage distribution reduces cable mass and ohmic losses.
- Minimizes power conversion which maximizes efficiency.

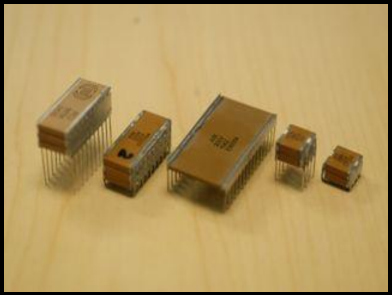
PMAD - Advanced Components

SiC Semiconductors

Description

- Components that can withstand the harsh environments, wide temperature variations, and high radiation of deep space.

Advanced Capacitors



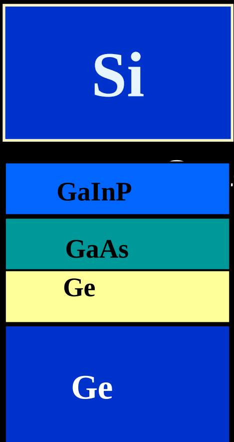
Key Issues to Address

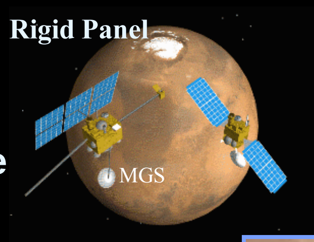
- Development of Silicon Carbide and Gallium Nitrate semiconductors.
- High current/high energy density capacitors.
- Low loss magnetic materials that can withstand high temperatures.

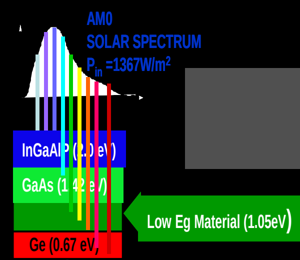
Key Benefits

- Facilitates high voltage switching.
- Increased radiation tolerance.
- Ruggedness improves safety and reliability.
- Lower mass/higher energy density.
- Increased operating temperature range.

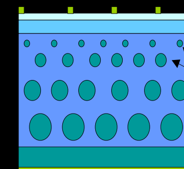
Power Generation: High Efficiency & Low Mass Photo-voltaic

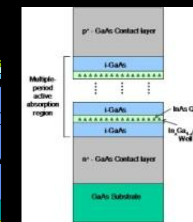




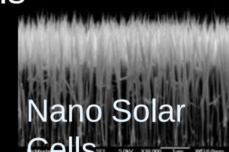


4 & 5 Junction Solar Cells

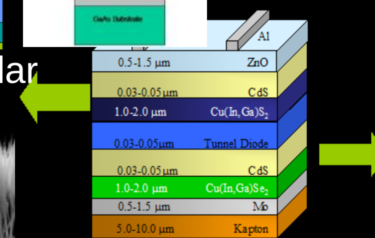




Quantum Dot Solar Cells



Nano Solar Cells



Thin Film Solar Cells

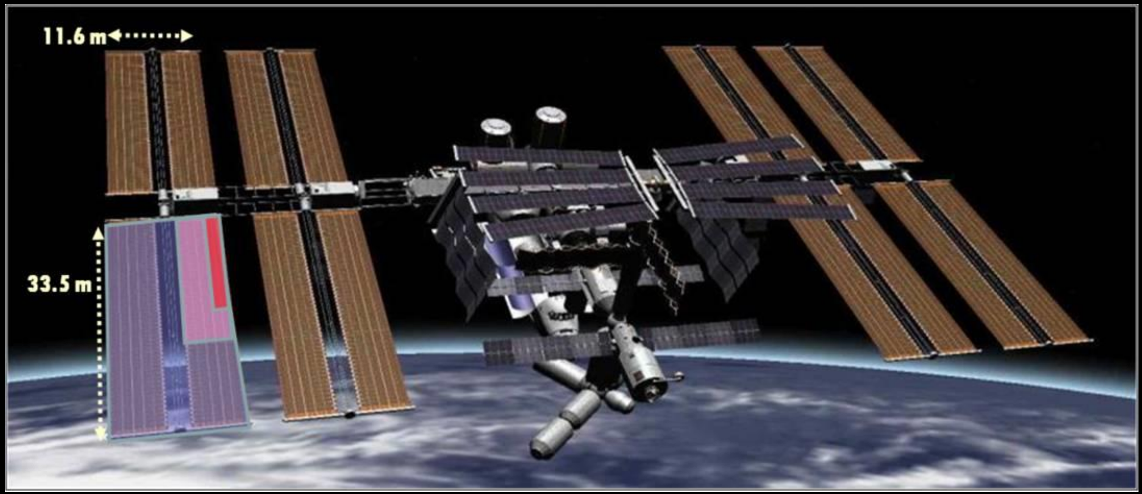
State of Practice

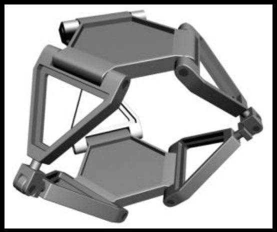
- Current Systems: Crystalline Si Cells; Triple Junction GaAs Solar Cells;
- Efficiency: Si Cells: 15%; MJ Cells: 31%
- Specific power: 50 to100 W/kg
- Array stowage volume: 5 to 15 kW/m³

Advanced Solar Arrays

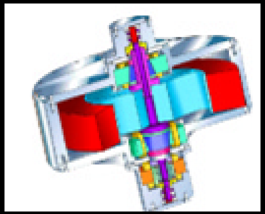
- 4-5 Junction Solar Cells; Quantum Dot Solar Cells; Thin-Film Solar Cells
- Efficiency >50%
- Specific Power > 500 W/kg
- Array stowage volume > 100 kW/m³

Power Generation: Low Mass Solar Arrays





Advanced Mechanism



State of Practice

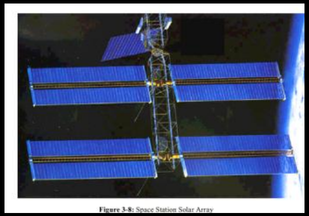
- Semi-rigid Deployment Mechanism
- Alpha and Beta Joints With Slip Rings or Roll Rings
- Truss Structure To Add Additional Solar Array Blankets
- Centralized Momentum Control

Advanced Solar Arrays

- Rigid Light Weight Deployment and Re-stowage Mechanism
- Lower Mass Pointing Mechanism Allowing Power and Thermal Transfer
- Integrated/Controlled Truss Structure With Distributed Momentum Control

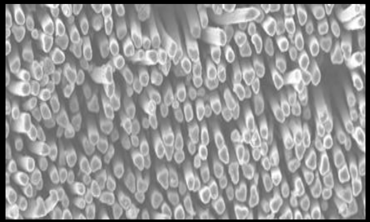
Energy Storage: Batteries

International Space Station

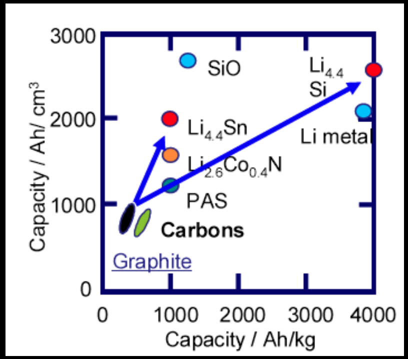


Space Shuttle

Lithium Metal / Alloy Anodes



Advanced Battery Materials



State of the Art

- Ni-H2: 30 Wh/kg at the cell level life > 10 years – ISS Application
- Li-Ion: 100 Wh/kg at the cell level life > 5 years

Advanced Batteries

- Li-ion: 160 - 200 Wh/kg at the cell level for > 2000 cycles -- Rover / Lander application
- Li-ion: 270 Wh/Kg at the cell level for > 100 cycles – EVA applications

Energy Storage

Li-Ion vs. NiH2 Batteries

Cell Characteristics	ISS NiH2	140Ah Li ion
Rated capacity	81 AH	134-144 A
Energy density	~65 wh/kg	~150 wh/kg
Discharge voltage	1.25 V	> 3.6 V
Self discharge rate	~7% per day (20ºC)	< 0.05% per day
Cycle life in LEO (20%-30%DOD)*	*~ 10 years (60,000-75,000 cycles) @ 20%-30% DOD*	*~ 10 years (58,000 cycles) @ 20%-25%DOD*
Spec Cycle life	6.5 years @ 35%	10 years @ ISS power levels
Storage life	4 years	6 years
Overcharge	Tolerant	Controlled by 2 FT design
Total Energy Storage (Important for contingency operations)	8 kW-hr (Two ORUs combined)	15 kW-hr (One ORU)
Battery Weight	744 lbs (Two ORUs)	415 lbs (One ORU)

Replacement of two NiH2 ORUs with one Li-ion ORU
Half the logistics flights
Fewer EVAs to replace batteries

Conclusions

- As human space exploration power needs increase, high power / high voltage systems will be required for future missions
- Power system technology development is critical for the future of human space exploration
- Spectrum of technology development will be needed to meet the increasing power needs of future manned missions

Credits

- Robert Scheidegger – NASA GRC
- James Soeder – NASA GRC
- Raymond Beach – NASA GRC
- Walter Santiago – NASA GRC
- Tom Kerslake – NASA GRC
- Penni Dalton – NASA GRC
- Jameka Humphrey – NASA GRC (SGT inc.)
- Azam Arastu – Boeing Space & Intelligence Systems