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Administration

MSFC Electrical Power Systems for Cubesats

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November 9, 2018

Agenda

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Typical Cubesat Subsystems

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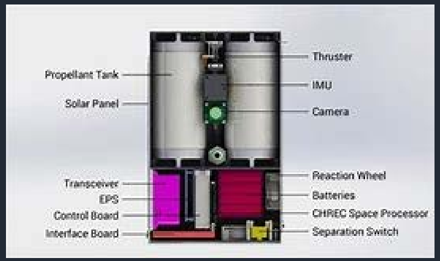
Systems

Propulsion and/or Reaction Control (RCS)

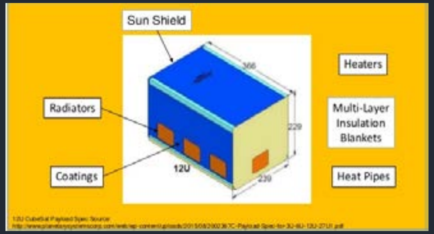


Guidance, Navigation, and Control (GN&C)

Communications (Comm)

Command and Data Handling (C&DH)

Structures and Mechanisms

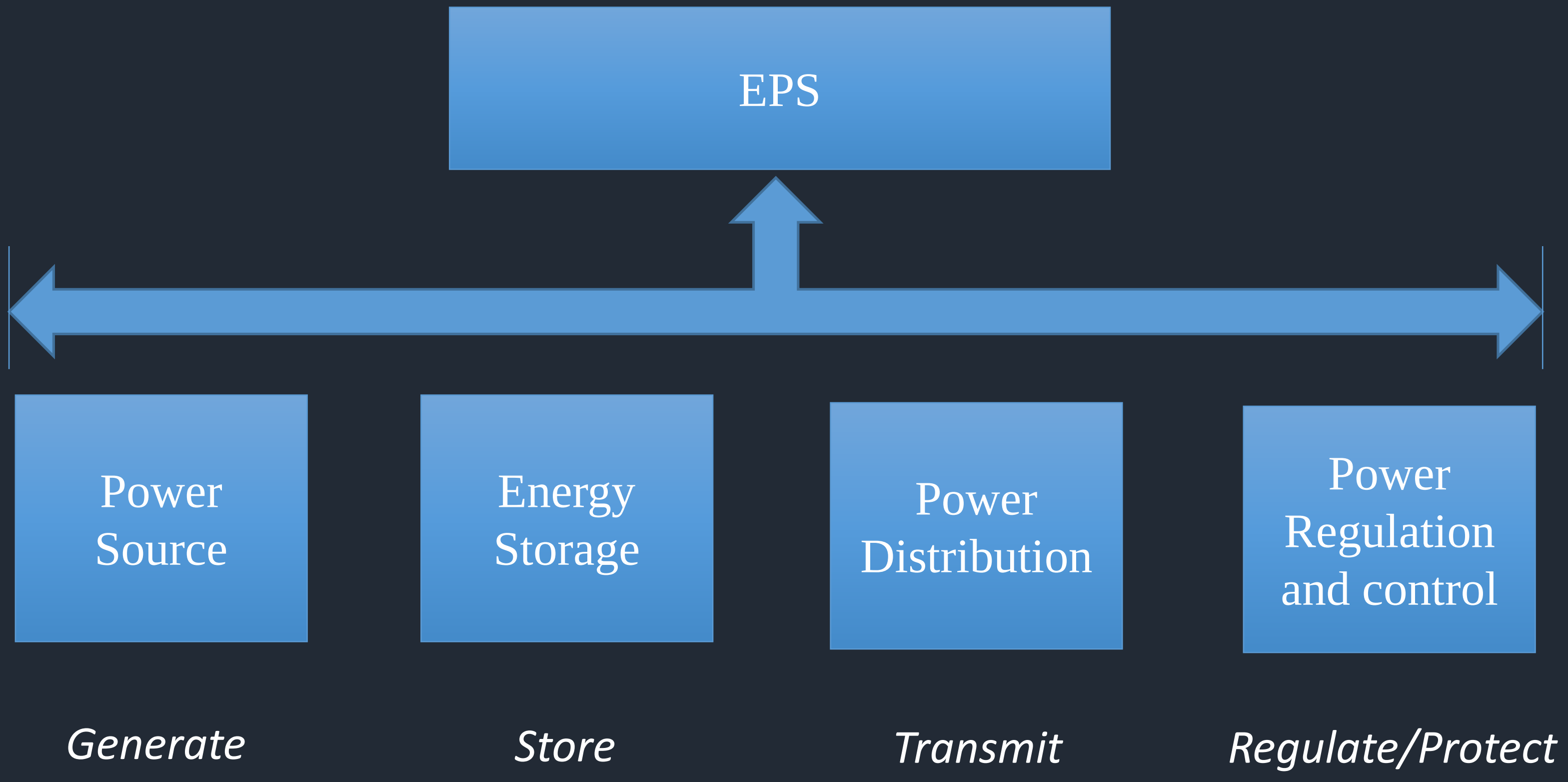


Thermal Control (TCS)

Electrical Power System (EPS)

Mission Payloads

Typical EPS Subsystems



Power System Definitions

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Power (Watts)

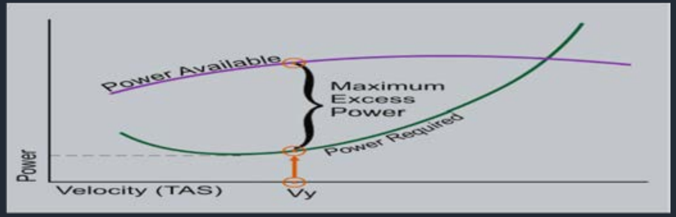
Energy (Watt-hours)

Electrical Power System

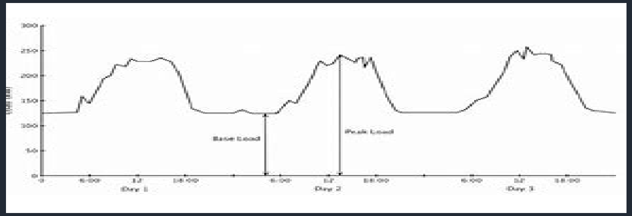
Power Efficiency (n)

Power Equipment List (PEL)

Power Margin

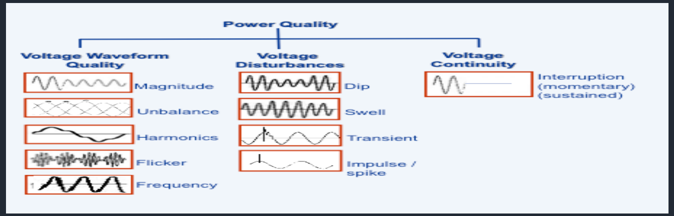


Power Profile



Power Protection

Power Quality (PQ)



Requirements Flowdown

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NASA Requirements: Traceability Matrix
(1 of 2)

Category	Science Objectives	Scientific Measurement Requirements	Instrument Functional Requirem	Mission Functional Requirements	Level 2 Data Products
Surface WaTER	WatER Science Objectives: Determine surface water storage change and discharge to predict the land surface branch of the global hydrologic cycle; Measure flood hydraulics; assess the role of fresh water storage as a regulator of biogeochemical cycle such as carbon and nutrients. [A	Global monitoring of storage change b measuring changes in water body height and spatial extent with time. Derivation of river discharge from measurements of slope and spatial extent within a hydrodynamic model assimilation. Revisit time ~2 weeks in the tropics and less than 1 week in the Arctic.	Ka-band Interferometer Requirements: Height accuracy 5cm. Slope accuracy 10urad (1cm/km). Spatial resolution finer than a 100 m posting. 120 km total swath.	Orbit /repeat (14 days in the tropics, less than 7 days in the Arctic). Exact repeat is not required, rather samples anywhere within the swath are sufficient for describing water height. Precise orbit determination required.	Global maps of water surface elevations and area are expecte after every period of global coverage (e.g., ~weekly). Individual swaths will be useful fo local water managers. Hydrologists need derived products that are global maps of water storage change and discharge. Hydraulic engineers will need maps of h, dh/dt, dh/d and area.
		3 year baseline operation, with a 5 yea goal.	3 year reliability, with a 5 year goal.	Minimum 1 year, with a 3 year baseline mission, with a 5 year goal.	
Sea Surface Topography	Hydrosphere Mapper Science Objectives: Measure mesoscale activity, including fronts, eddies, and boundary currents; eddy mean-flow interactions, eddy transports, and the role of eddies in climate; physical-biological interactions and the role of eddie in the carbon cycle; coastal tides and open ocean internal tides; and coastal currents [B]	Monitor global mesoscale activity through the measurement of sea surface height (SSH) with a spatial resolution of 1 km x 1 km with random noise no greater than 1.5 cm. In the open ocean 30 km away from th coast, the SSH accuracy shall be less than 4.6 cm (1) at wavelengths shorter than 500 km; the total SSH accuracy (all scales included) shall be less than 5.1 cm (2). Within 30 km from the coast, the SSH accuracy at wavelengths shorter than 500 km shall be less than 4.9 cm (3) and the total SSH accuracy shall be les than 5.3 cm (4). Wind speed measurement shall have a accuracy of 2 m/s.	Ka-band Interferometer: 1.5 cm precision with 2 km x 2 km resolution. Nadir Radiometer: Resolve tropospheric correction with 1.2 cm accuracy. GPS: Determine orbit with radial accuracy of 2 cm.	Orbit repeat periods shall be between 10-25 days. Non-sun-synchronous orbit is required. Exact repeat ground tracks with cross-track separation less than +/- 1 km. The attitude of the Ka-band interferometer shall be maintain steady (no yaw-steering) Fully calibrated and validated science data are required within 30 days. Quick-look data with less quality are required within 1 day for coastal and other operational applications.	Fully calibrated, validated science data: Geolocated, calibrated interferometer strip data of sea surface height on a per orbit basi on a 2 km grid near coastlines. Wind speed strip data on a simila grid. Both products with less tha 30 day latency. Quick look data: Geolocated, partially calibrated interferomete strip data of sea surface height o a per orbit basis on a 2 km grid near coastlines. Wind speed stri data on a similar grid. Both products with less than 1 day latency.
		Global coverage of sea surface height measurements for ice free oceans with a repeat cycle less than 25 days. Aliased periods of the eight leading tid components (M2, S2, K1, K2, P1, Q1, N2, O1) shall be separated from one another with maximum period less tha one year.	Ka-band Interferometer provide above measurement accuracy over a total swath of [120] km.		
		3 year baseline operation, with a 5 yea goal.	3 year reliability, with a 5 year goal.	3 year baseline mission, with a 5 year goal.	

Apr24_06HM_pollardCharts_2.ppt

Mission Requirements

- Primary mission,
- Science needs,
- Mission length,
- Cost, schedule, and reliability constraints

Spacecraft Requirements

- Orbit definition,
- Mission life,
- System architecture,
- Environments,
- Size and weight constraints,
- Basic power / energy needs (PEL)

EPS Requirements

- Power profile
- Power margin
- Bus voltage level
- Cycling / charging
- EPS component definition
  - Battery size
  - Solar array end of life power
  - Other Subsystem needs (steady state and peak)

Typical EPS System Requirements

Supply continuous Electrical Power to subsystems as needed during entire mission life (including nighttime and eclipses).

Safely distribute and control all of the power generated.

Provide enough power with margin for both average and peak loads.

Provide downstream power converters for different voltage loads.

Provide bus isolation between upstream and downstream loads.

Provide EPS Health and Status (voltage, current, temperature, etc.)

Provide and protect itself and others from EMI, transients, bus faults and load faults (filtering, overvoltage, short circuit protection, etc.)

Typical EPS Derived Requirements

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Determine average power from the Power Equipment List (PEL).

Determine peak power from the Power Profile.

Evaluate Mission Requirements.

Evaluate Orbital or Site Parameters.

Major Interacting Subsystems

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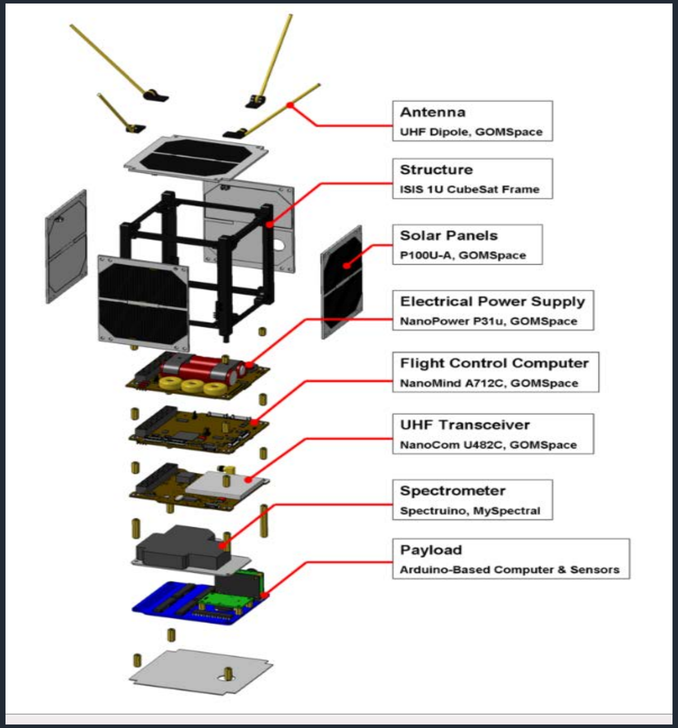
Thermal

Structures

Command and Data Handling

Payloads



Where to Start – System Level

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Typical Trades

DC Bus voltage

Power source

There is no power grid in Space!

Where to Start – Component Level

Typical Trades

Energy storage type

Charging method

Power Conversion techniques COTS/Custom

Electrical, Electronic, and Electromechanical (EEE) Parts Grade

Radiation (Rad) environment

Where to Start – EEE Part Level

Typical Trades

- *Radiation Hardening*
- *Radiation Tolerant Designs*
- *Commercial Off the Shelf (COTS) Subsystems*
- *Risk*
- *Derating*

Why Derating

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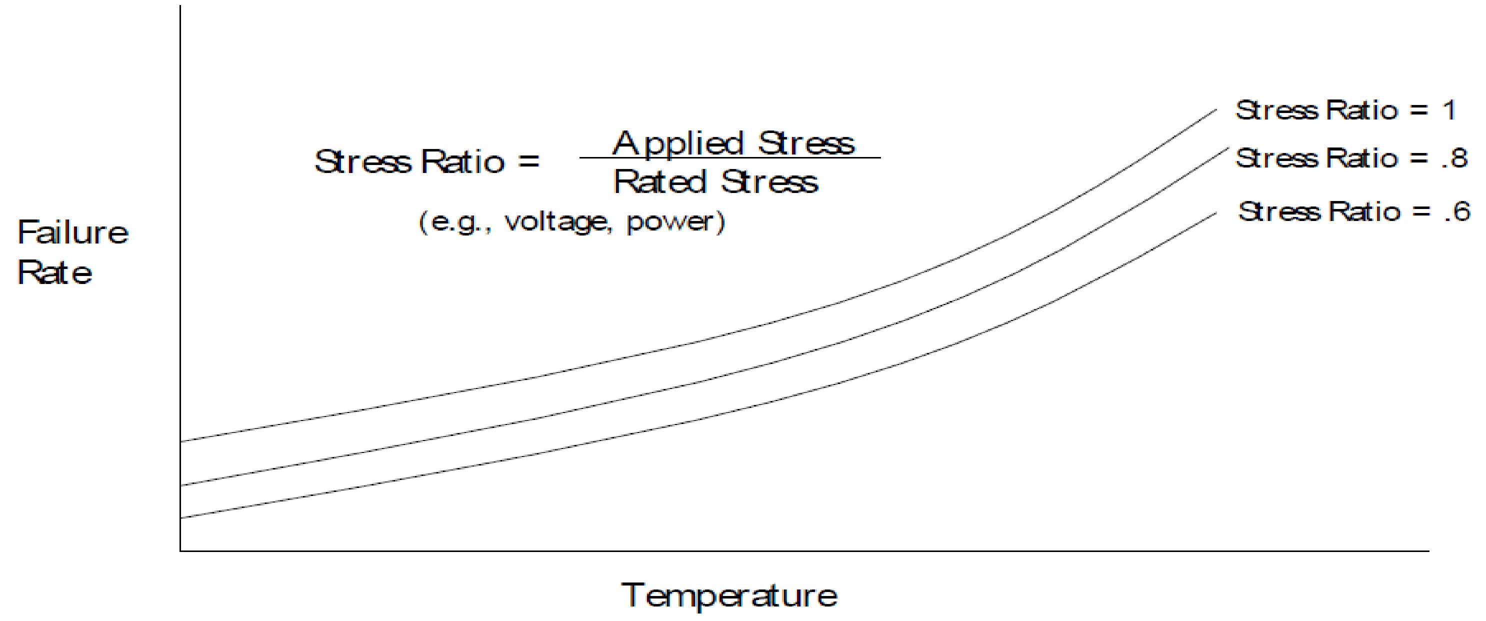

Figure 1. Piece-part Failure Rate vs. Temperature

PREFERRED RELIABILITY PRACTICES PRACTICE NO. PD-ED-1201
EEE PARTS DERATING
GODDARD
SPACE FLIGHT
CENTER

Before we get to design particulars here are some Safety or Reliability Considerations

– Solar arrays can be easily damaged. Special care is recommended during all phases of design.

– Batteries are full of energy. Be careful not to short the leads.

–Many components are Electrostatic Discharge (ESD) sensitive. Only work on ESD sensitive components on an ESD grounded bench.

– Lead free solder and lead free parts may cause tin whiskers to grow. If possible, use solder that contains at least 3 % lead. Also, if use lead free parts, then may still need to deal with whisker mitigation techniques

– Some types of stranded wire (such as Teflon) can cold flow. Be sure to select wire and parts to meet the application (outgassing, etc.)

Now the Good Stuff:
How to select and size the subsystems

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Power Generation Subsystems

Energy Storage Subsystems

Power distribution, regulation and control Subsystems with special emphasis on Converters

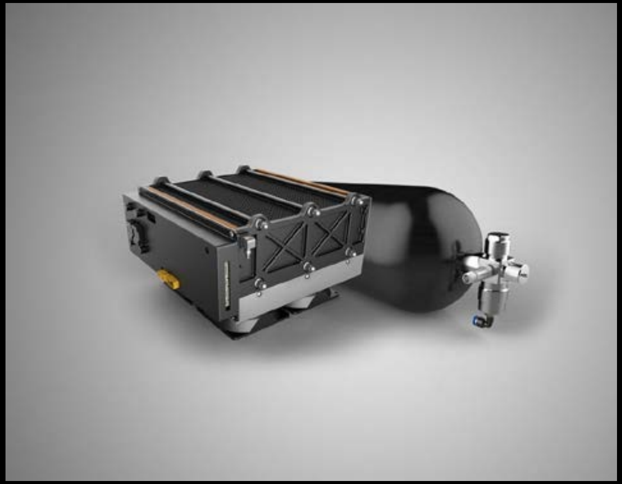
EPS Bus and Integration

Power Generation: Introduction

Power Generation Subsystem: provides unconditioned power to the EPS.

Power Generation Definitions

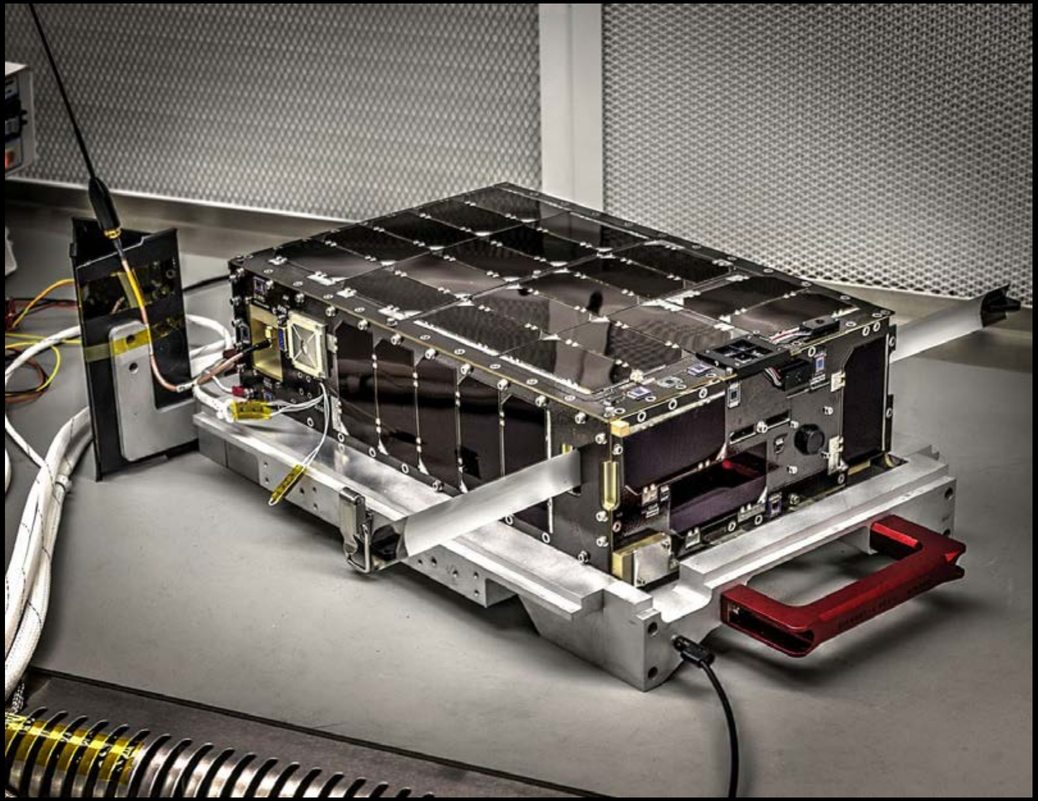
Batteries	Fuel Cell	Radioisotope	Solar

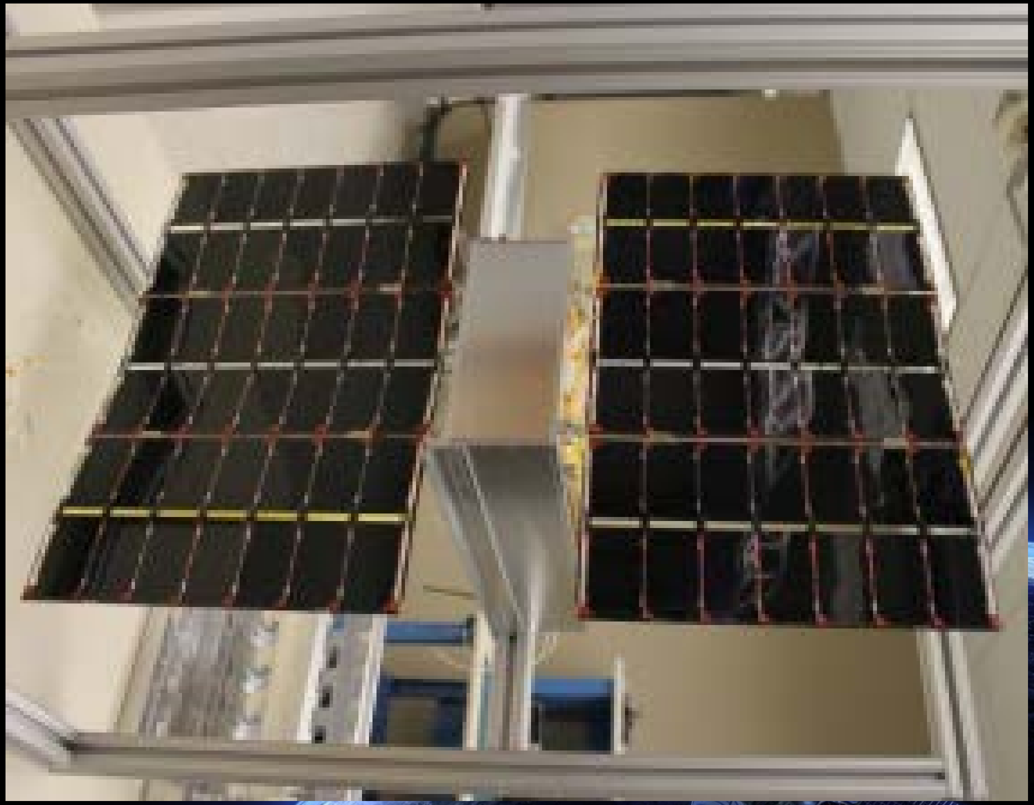


Solar Array: photovoltaic module that absorbs sunlight and generates DC electricity.

Solar array comprised of series and parallel interconnected solar cells which are covered with a protected coating and adhered to a mechanical substrate:

Body mounted or deployed





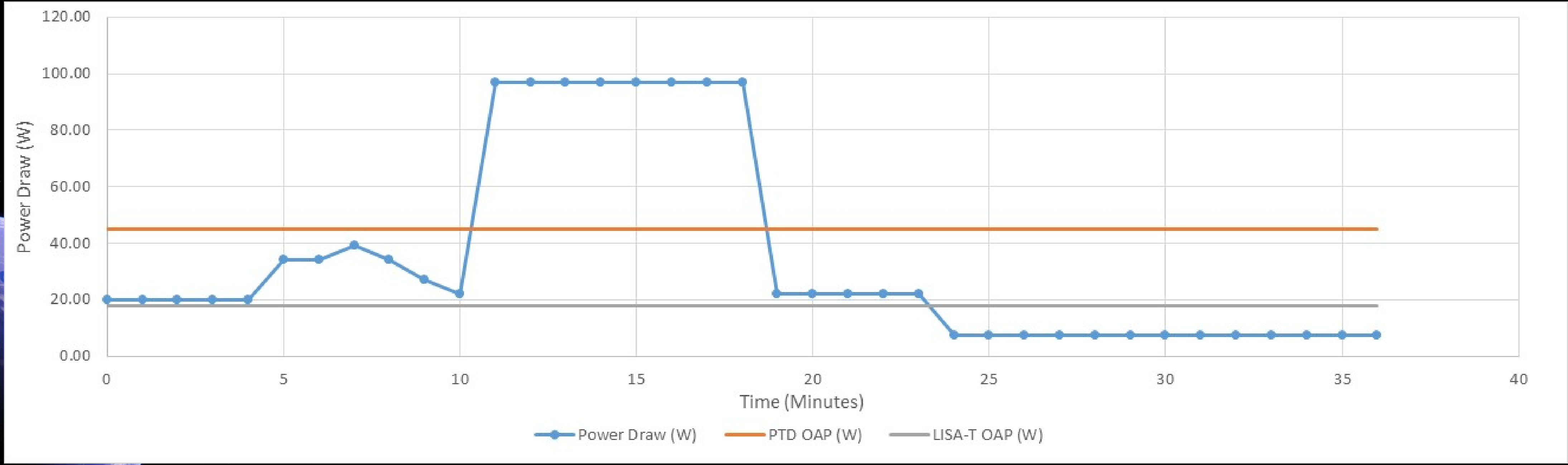
Actively articulated, spacecraft articulated, or non-articulated

Power Generation: Solar Array Design Considerations

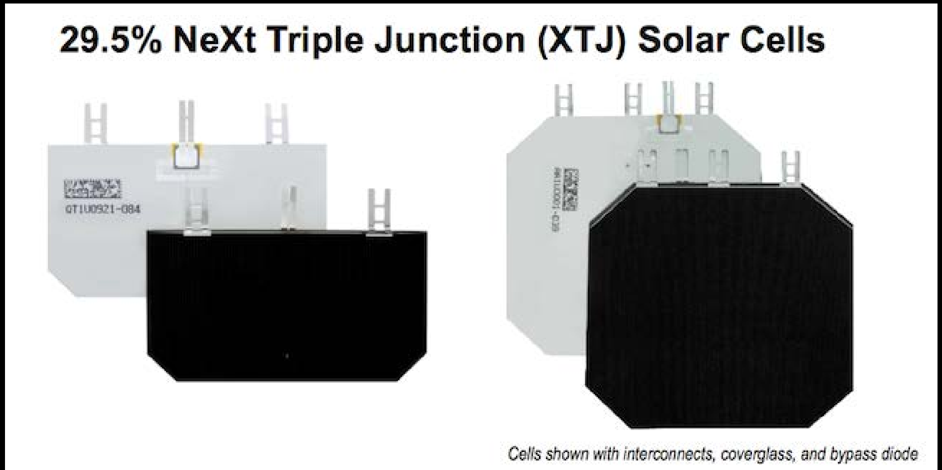
Start with PEL and Power Profile: *How much power does the spacecraft need and when does it need it?*

INPUTS									
		Current Draw (Amps)							
	Voltage	Standby/Charge	Thrust	Pre Heat	Post Heat	Comm	Momentum Dump	Margin	DC/DC Eff
Cortex 130 SA Input	28.000	0.110	0.110	0.110	0.110	0.110	0.110	30.00%	90.0%
Cortex 130 SA Input	28.000	0.110	0.110	0.110	0.110	0.110	0.110	30.00%	90.0%
Battery Management Board	28.000	0.200	0.200	0.200	0.200	0.200	0.200	30.00%	70.0%
PPU Switch	28.000	0.000	0.000	0.000	0.000	0.000	0.000	30.00%	100.0%
PPU	28.000	0.110	10.236	0.614	0.614	0.110	0.110	15.00%	98.0%
Flight Computer	28.000	0.210	0.210	0.210	0.210	0.210	0.210	30.00%	90.0%
Thruster Camera (Electronics)	5.000	0.000	0.100	0.100	0.100	0.000	0.000	30.00%	50.0%
Thruster Camera (Heater)	5.000	0.110	0.110	0.110	0.110	0.110	0.000	30.00%	50.0%
Magnetometer	10.000	0.068	0.068	0.068	0.068	0.068	0.068	30.00%	50.0%

Power Calculations					
Power Draw (Watts)					
Standby/Charge	Thrust	Cathode Pre Heat	Line Pre/Post Heat	Comm	Momentum Dump
4.45	4.45	4.45	4.45	4.45	4.45
4.45	4.45	4.45	4.45	4.45	4.45
10.40	10.40	10.40	10.40	10.40	10.40
0.00	0.00	0.00	0.00	0.00	0.00
3.61	336.33	20.17	20.17	3.61	3.61
8.49	8.49	8.49	8.49	8.49	8.49
0.00	1.30	1.30	1.30	0.00	0.00
1.43	1.43	1.43	1.43	1.43	0.00
1.77	1.77	1.77	1.77	1.77	1.77



Determine type of solar cell to be used: *How efficiently will the array convert sunlight to electricity?*

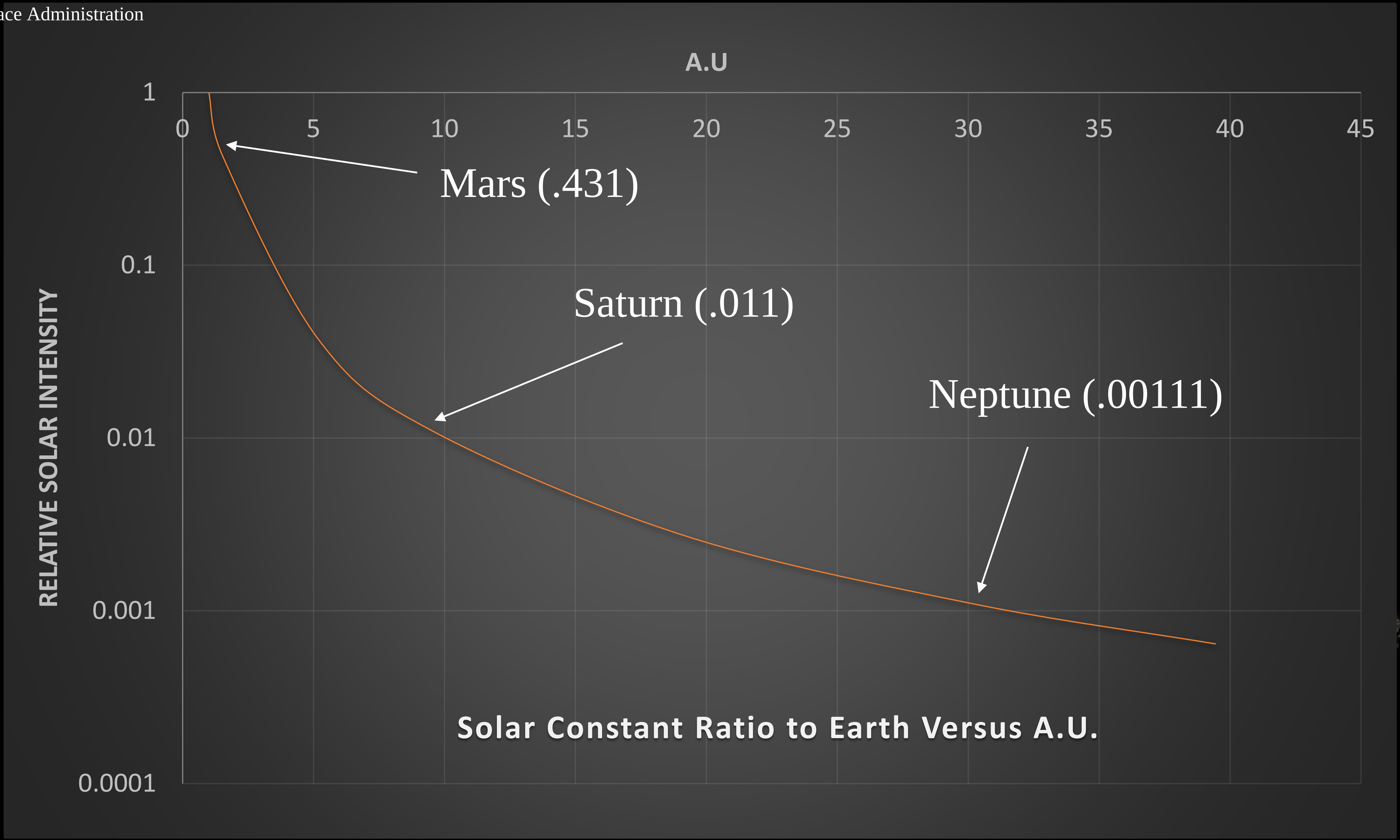


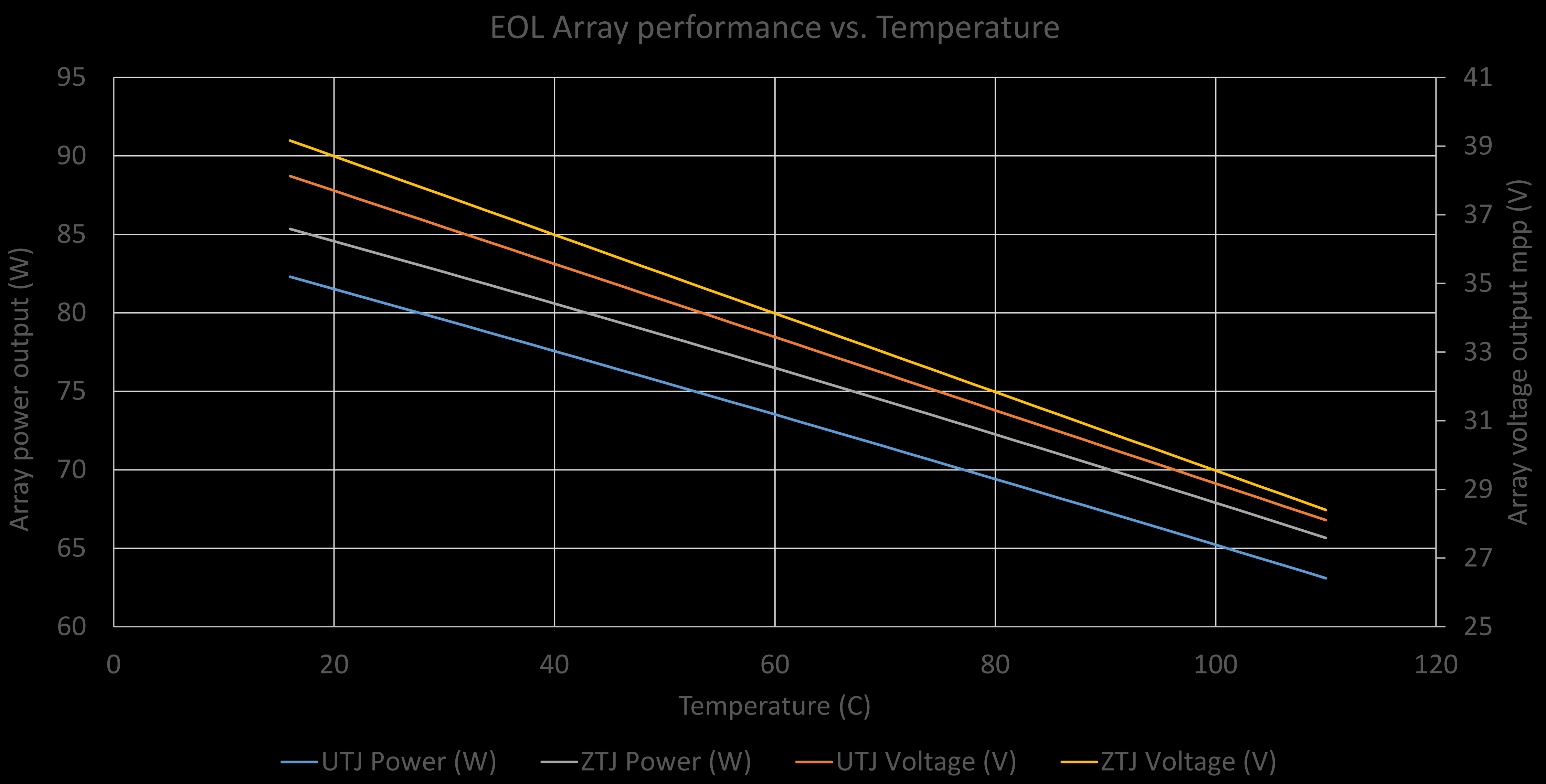
TJ III-V space cells; 29.5% PCE

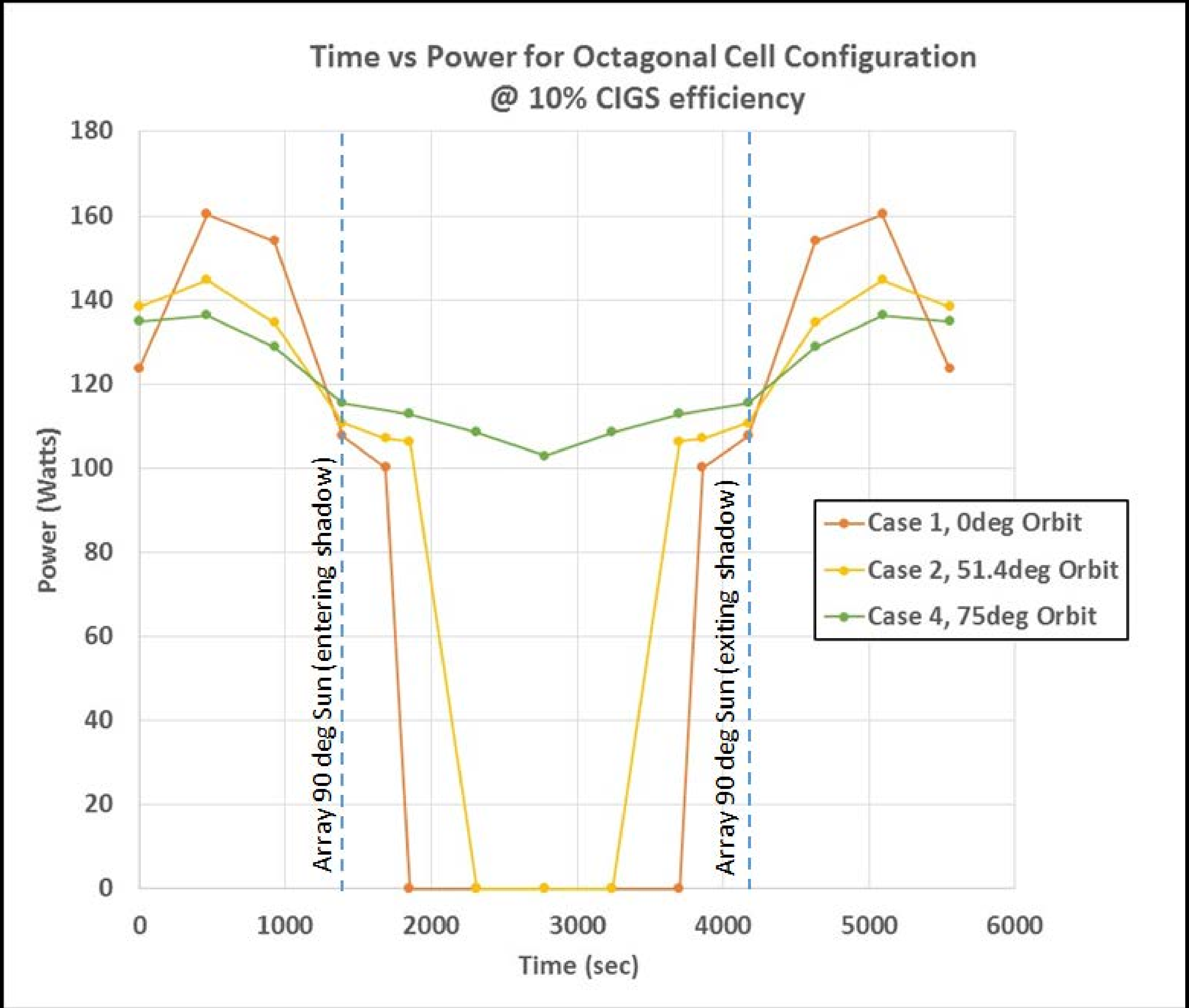
Silicon 17-21% PCE

Thin-films 12-33% PCE

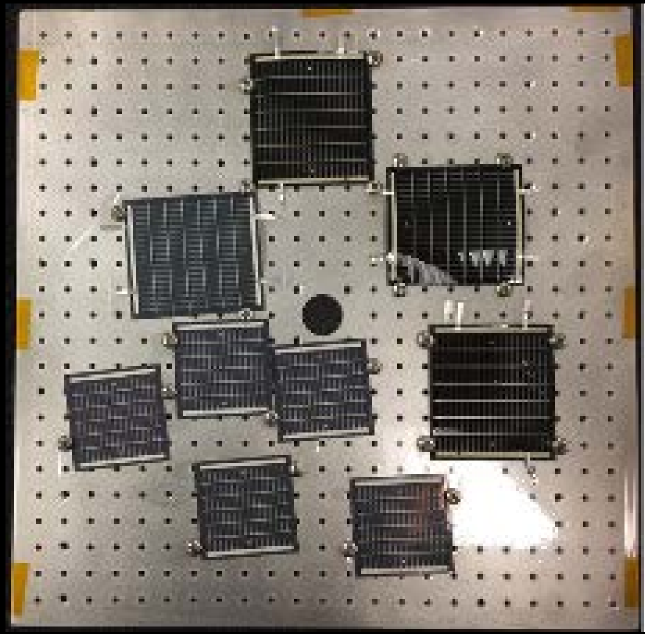
Determine the operational environment: *where in space must the solar cells operate?*

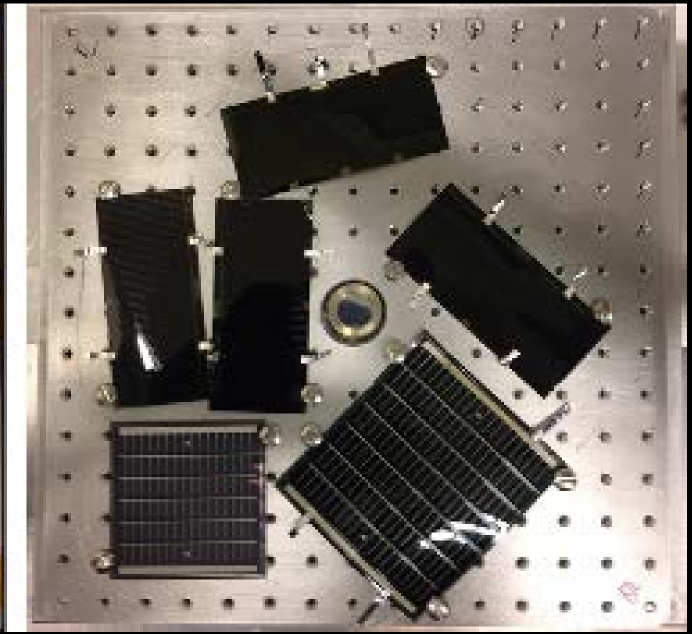

A.U
0
5
10
15
20
25
30
35
40
45
1
0.1
0.01
0.001
0.0001
RELATIVE SOLAR INTENSITY
Mars (.431)
Saturn (.011)
Neptune (.00111)
Solar Constant Ratio to Earth Versus A.U.

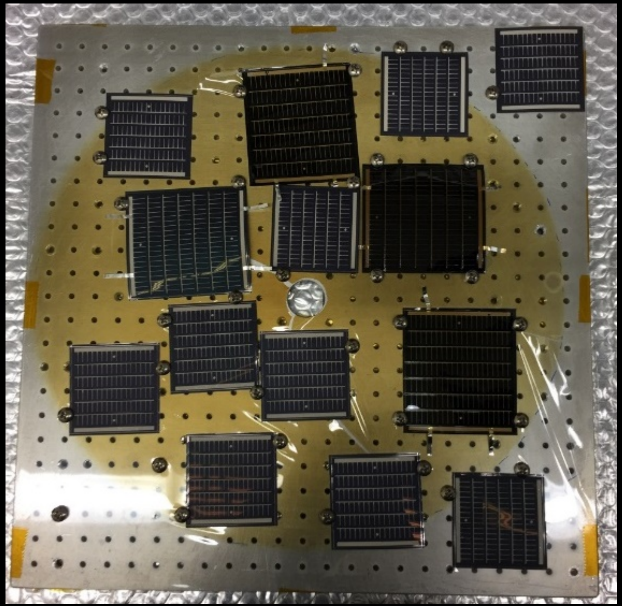

EOL Array performance vs. Temperature
95
90
85
80
75
70
65
60
41
39
37
35
33
31
29
27
25
Array power output (W)
Array voltage output mpp (V)
0
20
40
60
80
100
120
Temperature (C)
UTJ Power (W)
ZTJ Power (W)
UTJ Voltage (V)
ZTJ Voltage (V)

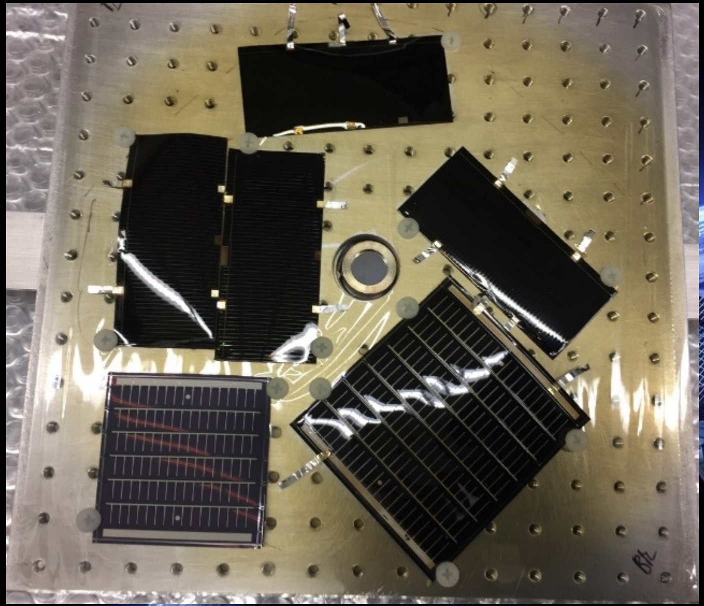


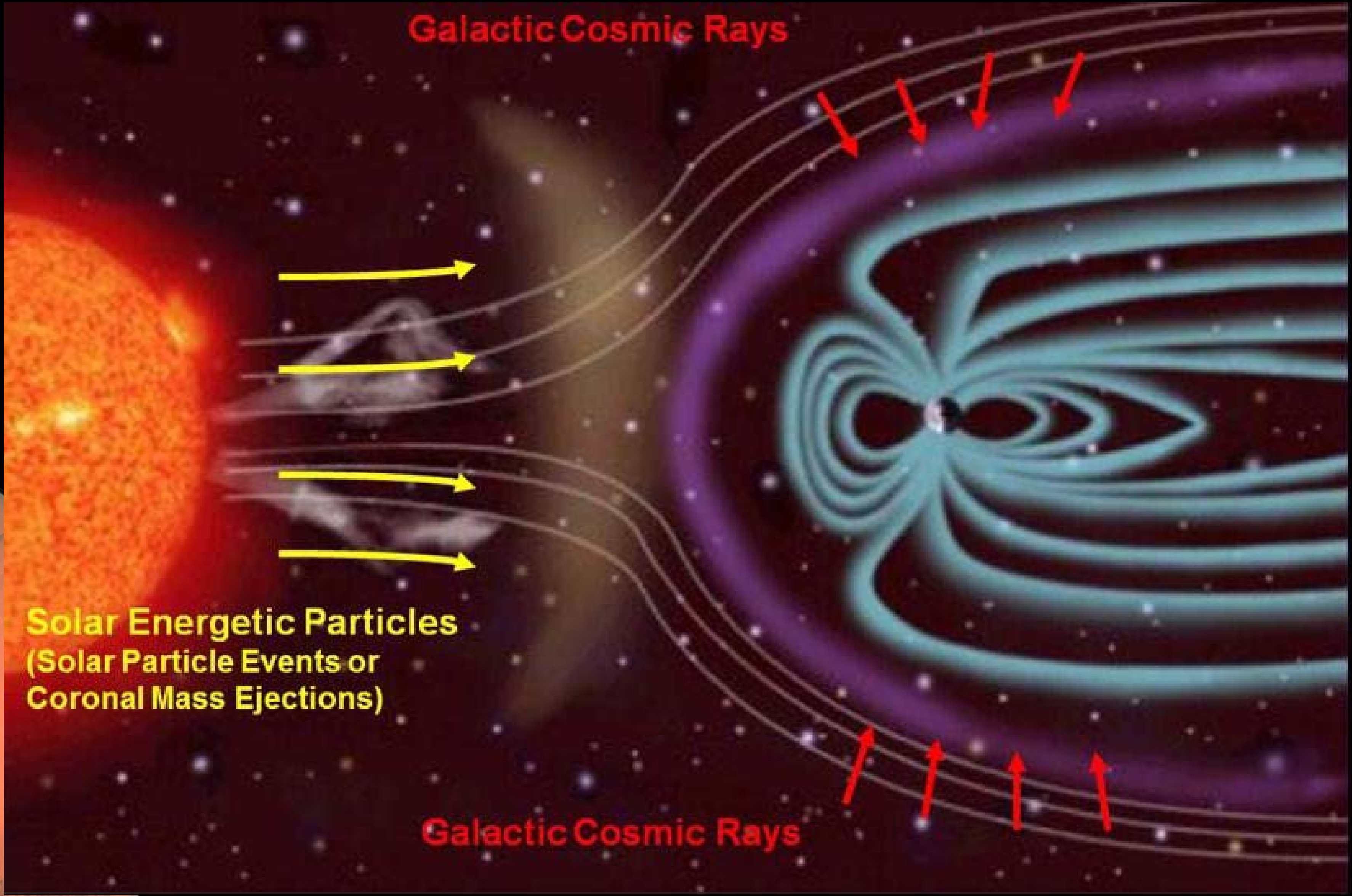
Time vs Power for Octagonal Cell Configuration
@ 10% CIGS efficiency
Power (Watts)
Time (sec)
0
20
40
60
80
100
120
140
160
180
0
1000
2000
3000
4000
5000
6000
Array 90 deg Sun (entering shadow)
Array 90 deg Sun (exiting shadow)
Case 1, 0deg Orbit
Case 2, 51.4deg Orbit
Case 4, 75deg Orbit



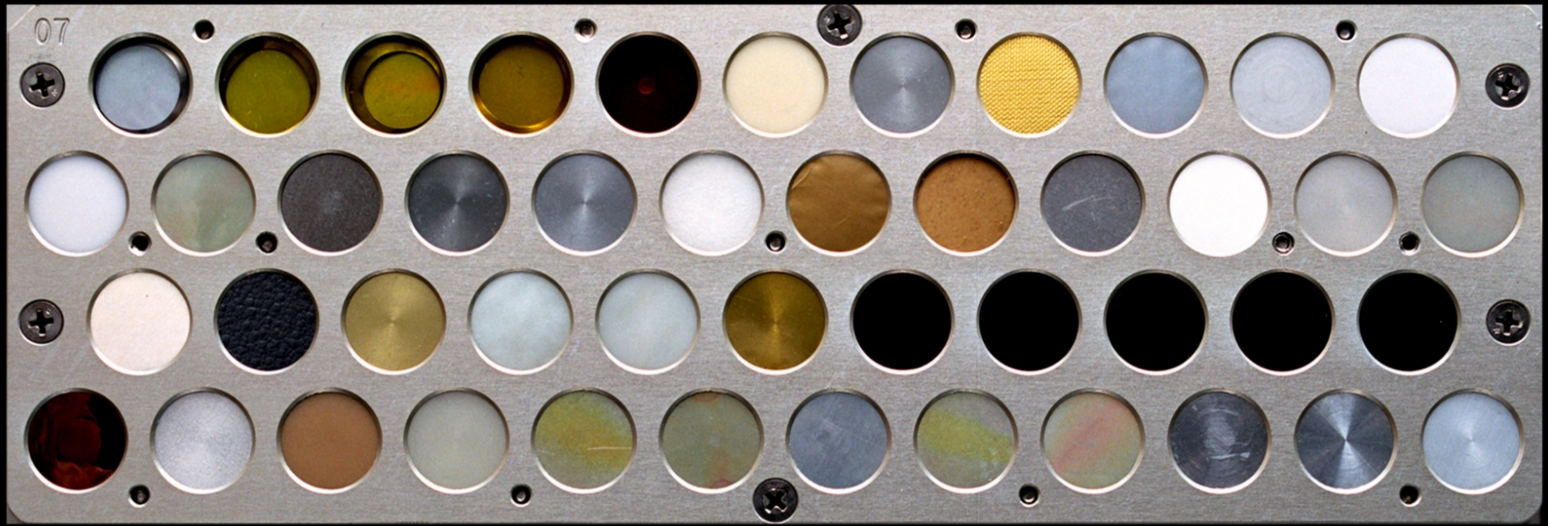






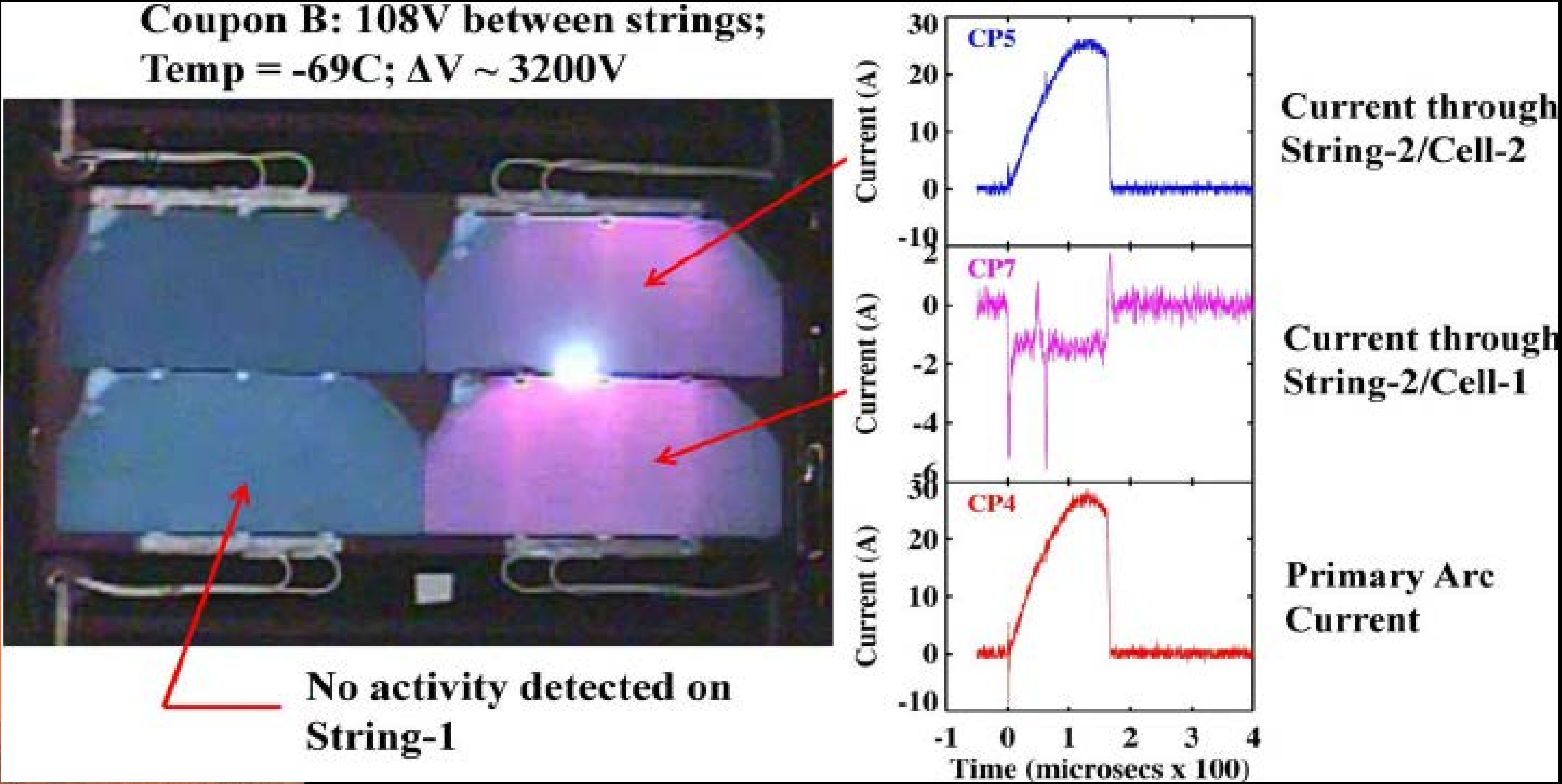

Galactic Cosmic Rays
Solar Energetic Particles
(Solar Particle Events or
Coronal Mass Ejections)
Galactic Cosmic Rays

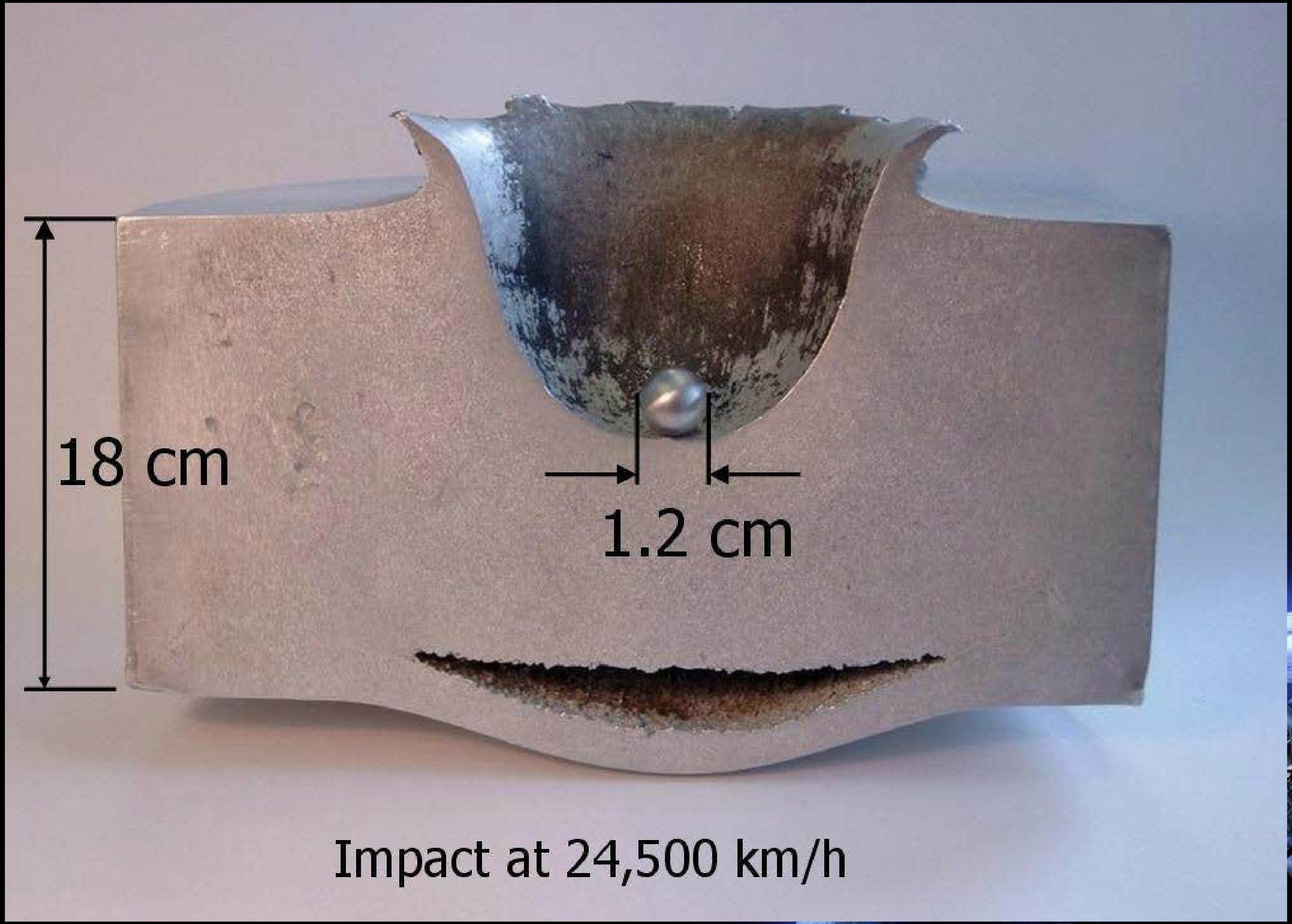
MISSE-2 Atomic Oxygen Erosion



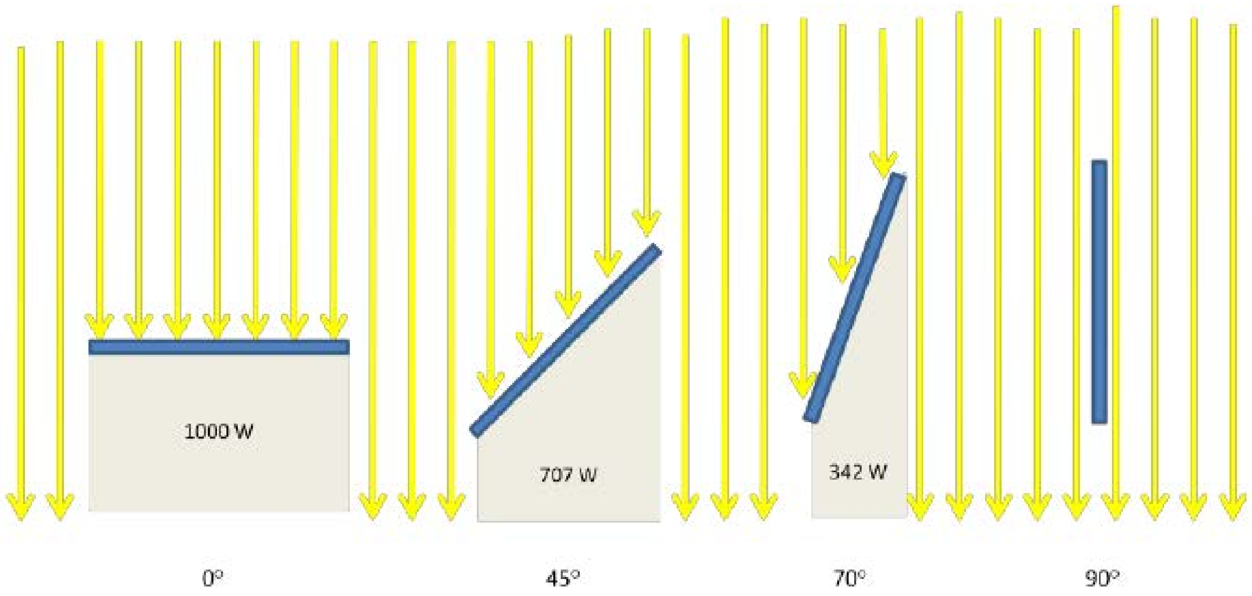
Above: Pre-Flight Samples

Post-Flight Samples after four years of space exposure


Coupon B: 108V between strings;
Temp = -69C; ΔV ~ 3200V
No activity detected on
String-1
CP5
CP7
CP4
Current (A)
Current (A)
Current (A)
Time (microsecs x 100)
Current through
String-2/Cell-2
Current through
String-2/Cell-1
Primary Arc
Current

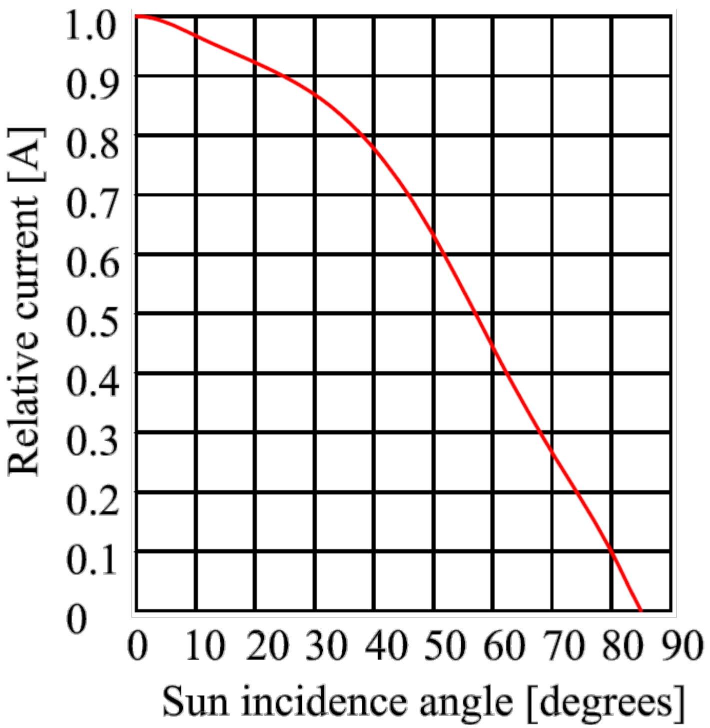

18 cm
1.2 cm
Impact at 24,500 km/h

Mission Lifetime then determines how long the solar array must endure these environments, giving a total EOL degradation.



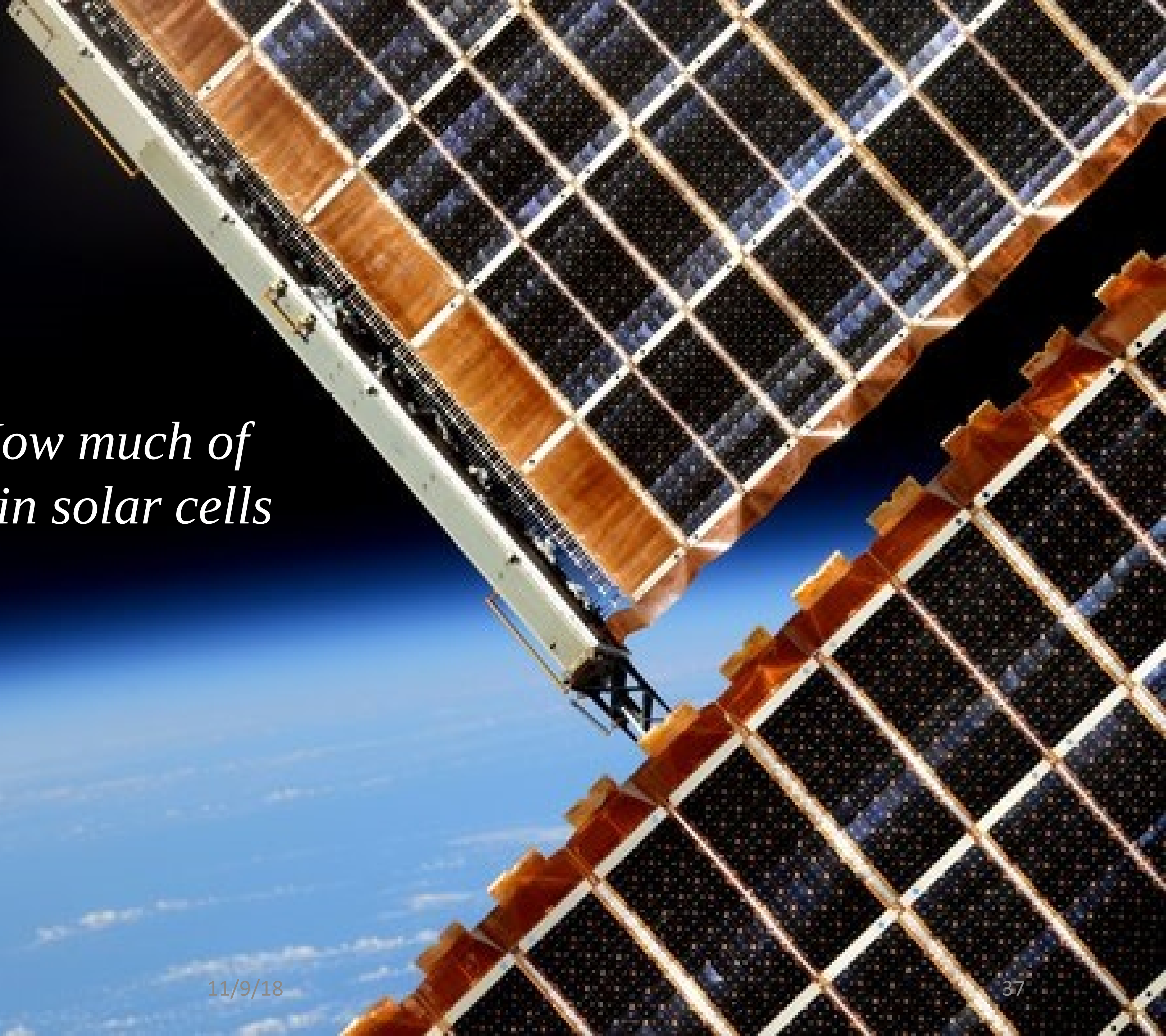
Determine Angle of Incidence:

Off-normal angle between incident light and solar panels



Kelly Cosine Values of the Photocurrent in Silicon Cells		
Sun angle degrees	Mathematical cosine value	Kelly cosine value
30	0.866	0.866
50	0.643	0.635
60	0.500	0.450
80	0.174	0.100
85	0.087	0.000

Determine Packing Factor: *How much of the substrate can be covered in solar cells*



Determine other inefficiencies: *Battery recharge, MPPT, power conversions, etc.*

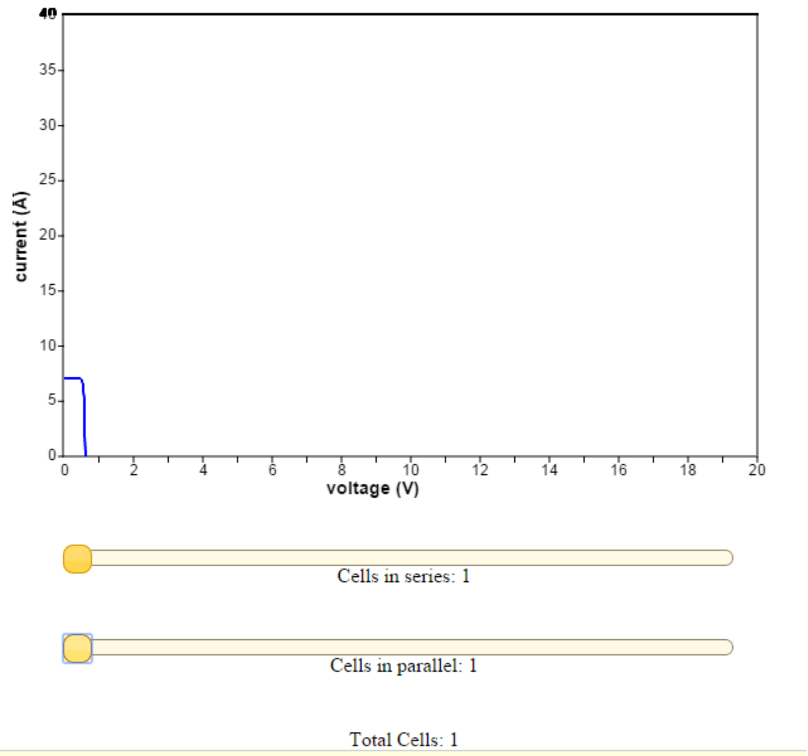
Determine margin philosophy: *How much extra to add to the numbers as a safety net.*

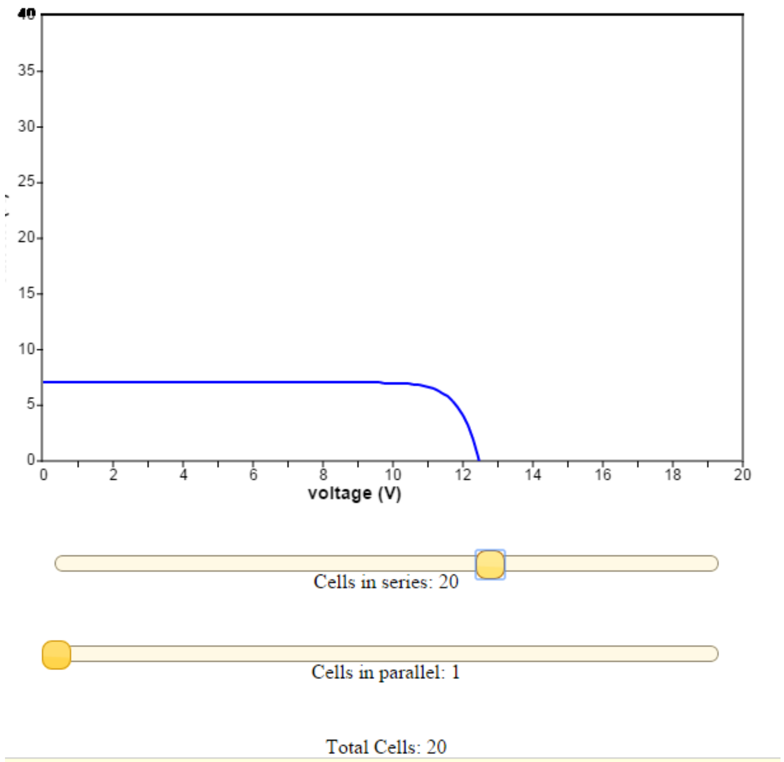
Power Generation: Solar Array Design

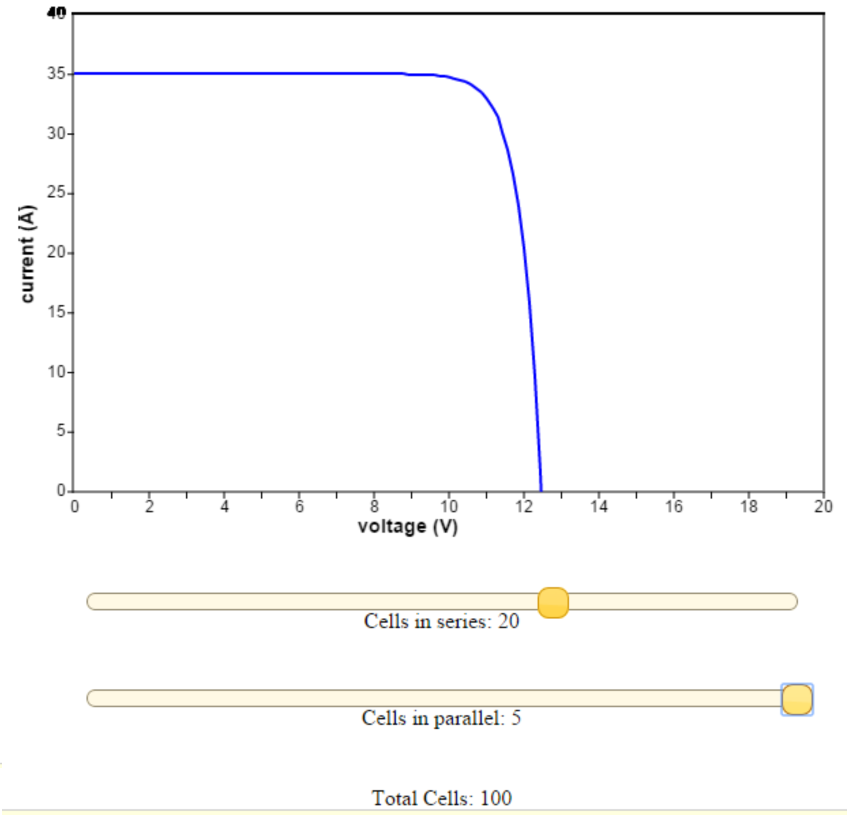
Basic Solar Array Sizing Calculation

Solar constant from environment:	1366.1	W/m^2
Solar Cell Efficiency:	28.3	%
Solar Cell Temperature Coefficient:	88.0	%
Solar Cell EOL Environment:	93.0	%
Solar Panel Packing Density:	90.0	%
Solar Panel AOI:	99.0	%
MPPT efficiency, line loss, diode etc.:	85.0	%
Power delivered to EPS:	239.6	W/m^2
Average power needed from PEL/Profile:	120.0	W
Add in growth margin:	20.0	%
Solar array area needed:	0.601	m^2
Add in designers margin:	10.0	%
Total solar array area needed:	0.661	m^2

A step further: voltage and current breakout…S&P



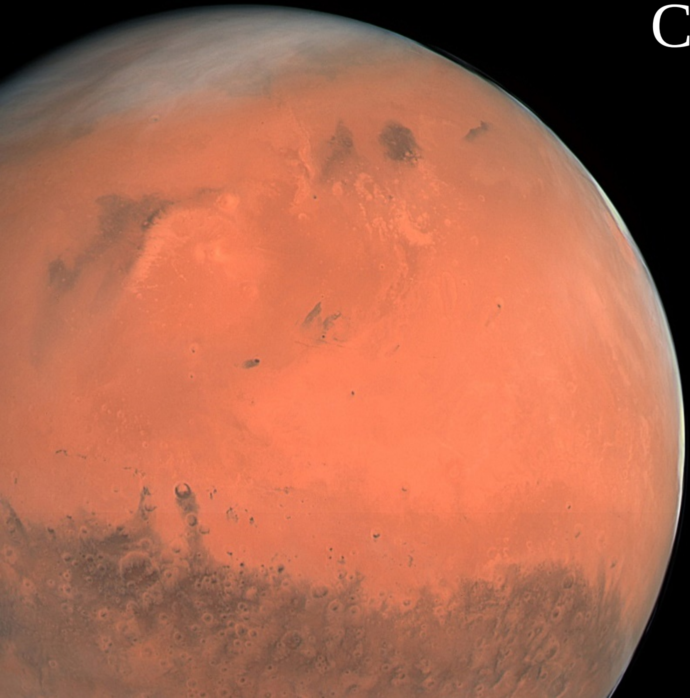




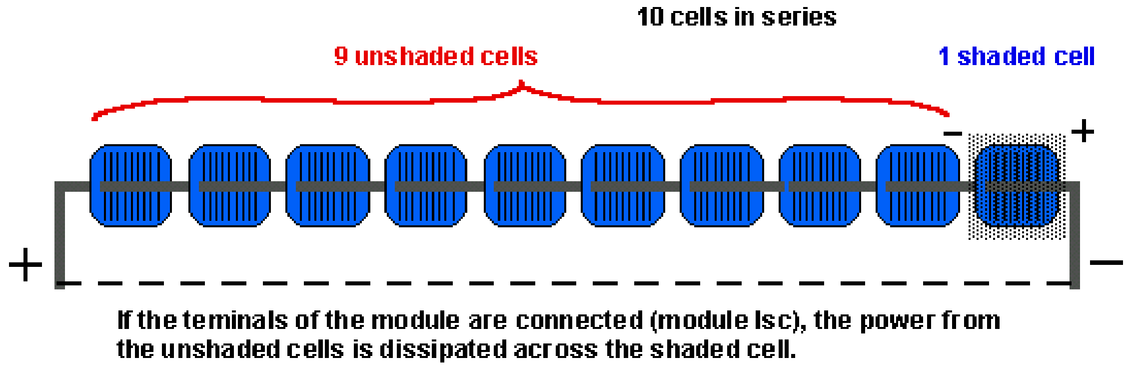
Most missions also need to recharge the battery; an additional load:

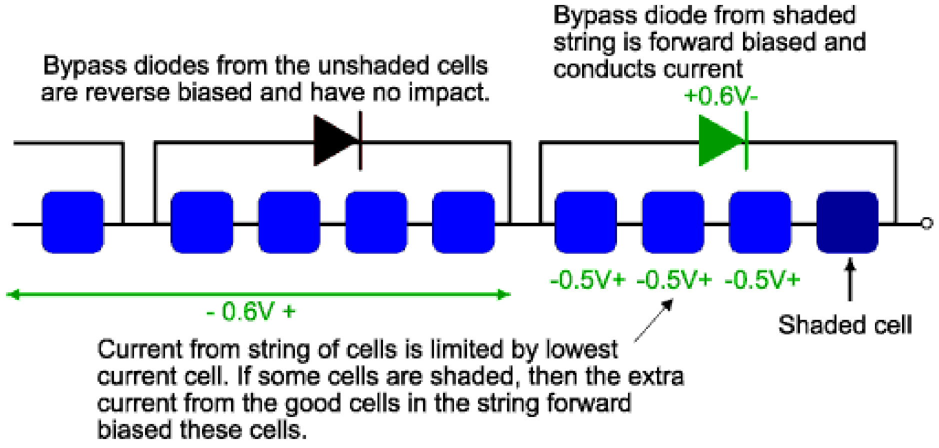
Pull eclipse load from PEL/Profile:	144.0	W
Determine eclipse time from environment:	30.0	min
Determine capacity drained from the battery:	72.0	W-hr
Determine capacity drained from the battery:	2.57	A-hr
Battery recharge efficiency, line loss, etc.:	112	%
Capacity needed to recharge:	2.88	A-hr

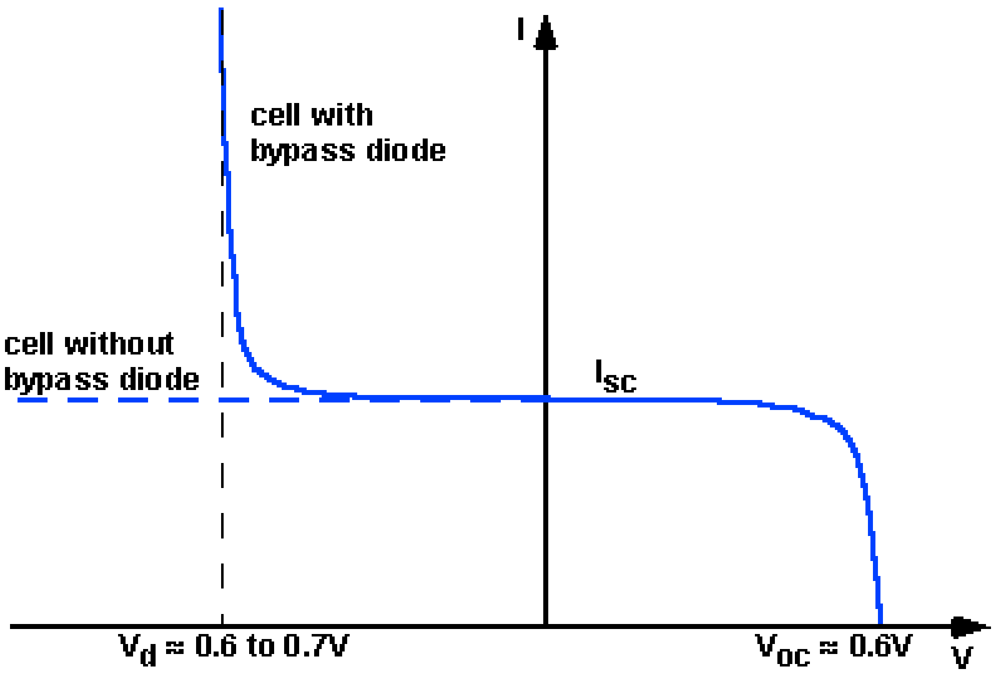
Recharge time from environment:	66	min
Array Current needed (@battery voltage)	2.62	A



Bypass Diodes







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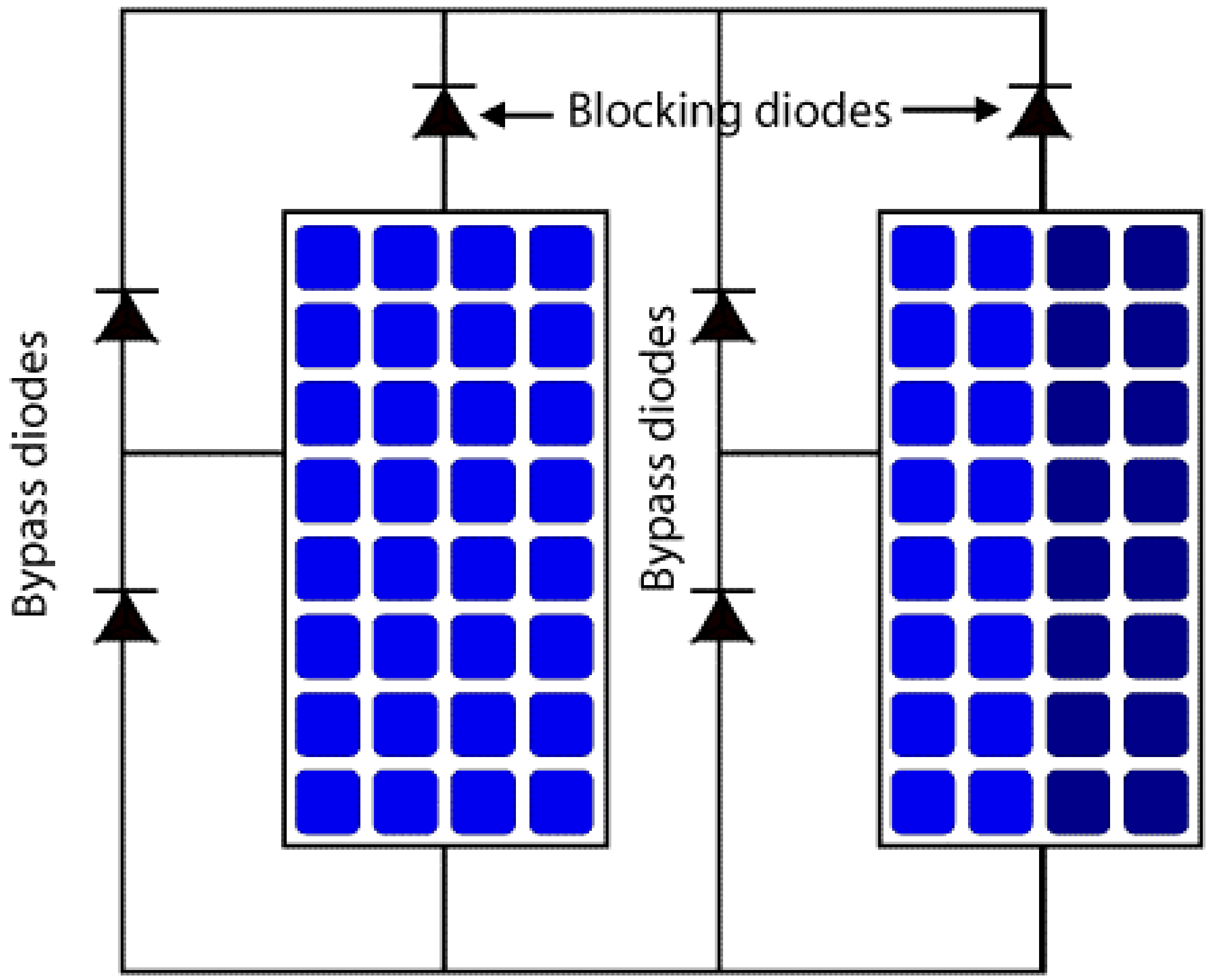
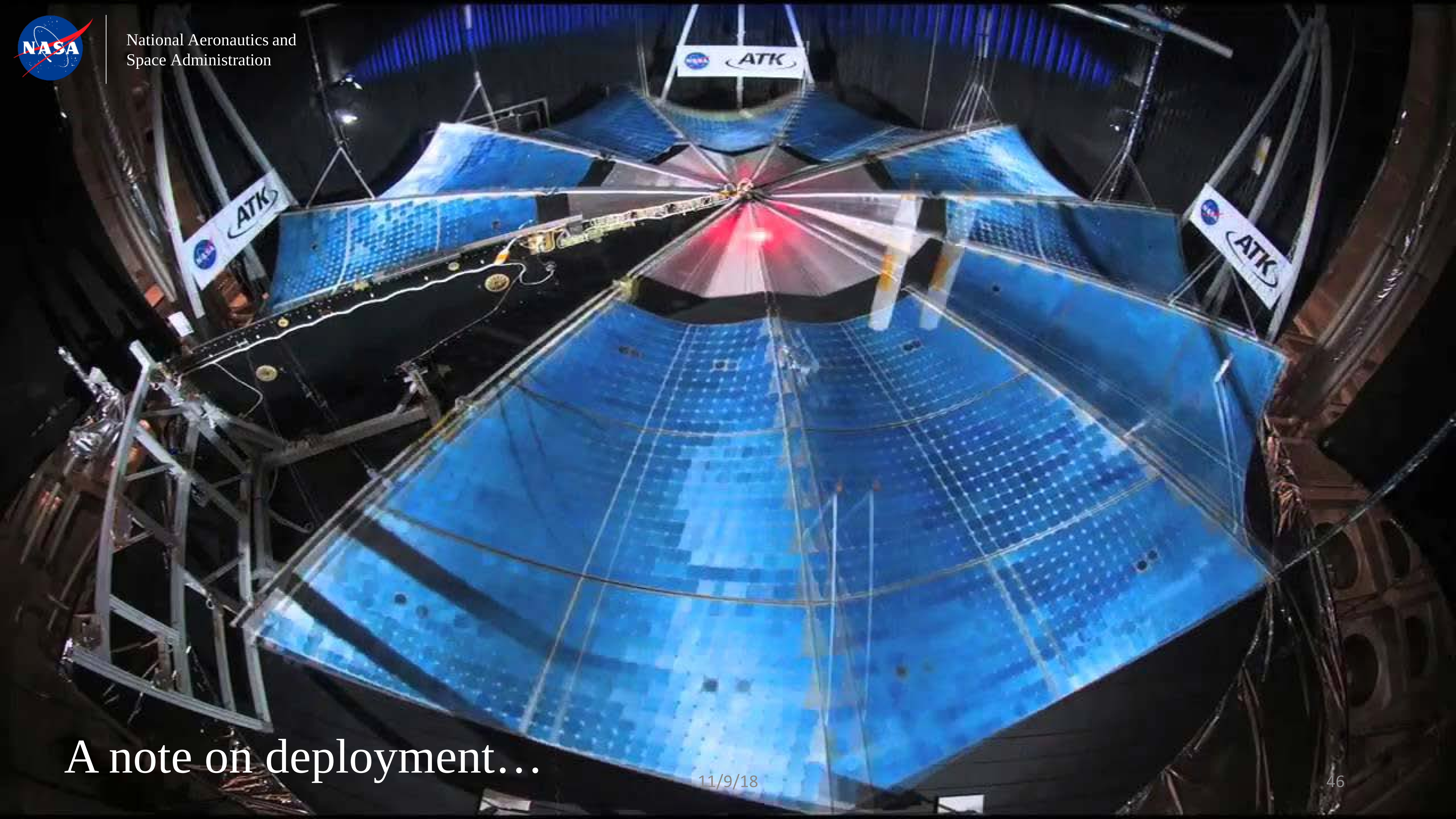
Blocking Diodes



pveducation.org



A note on deployment…

Power Generation: Make or Buy My Solar Array?

COST vs. RISK vs. BENEFIT vs. SCHEDULE

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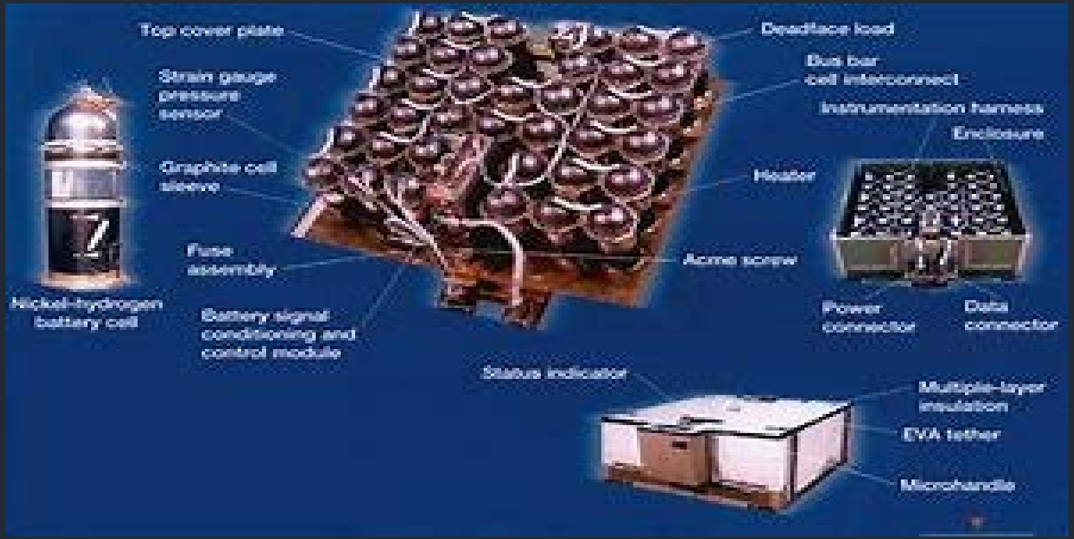
Energy Storage Subsystems:
Stores, as energy, some of the power generated by the power generation components, for use during an eclipse or some other period when the power generation components are unable to meet the load.



Energy Storage Definitions

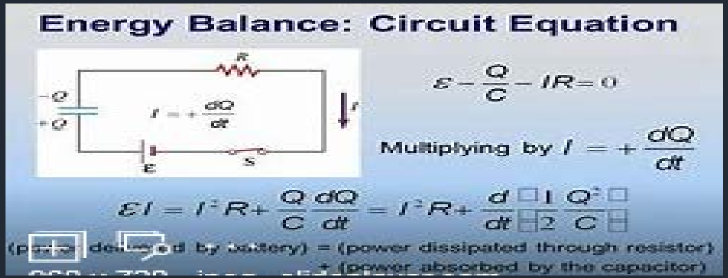
National Aeronautics and Space Administration

Batteries (Batt)

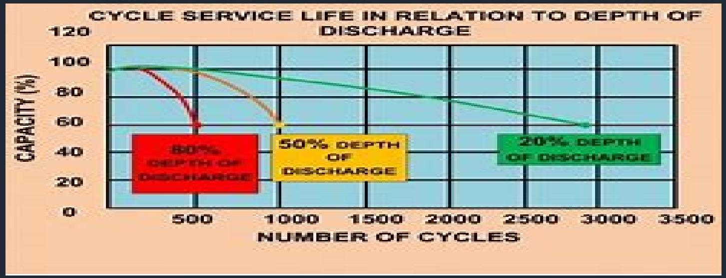
Ampere-Hours

	1 amp draw	2 amp draw	3 amp draw	4 amp draw	5 amp draw	6 amp draw
2.0 amp hour	2 hours	1 hour	40 min	30 min	24 min	20 min
3.0 amp hour	3 hours	1 hour 30 min	1 hour	45 min	36 min	30 min
4.0 amp hour	4 hours	2 hours	1 hour 20 min	1 hour	48 min	40 min
5.0 amp hour	5 hours	2 hours 30 min	1 hour 40 min	1 hour 15 min	1 hour	50 min
6.0 amp hour	6 hours	3 hours	2 hours	1 hour 30 min	1 hour 12 min	1 hour

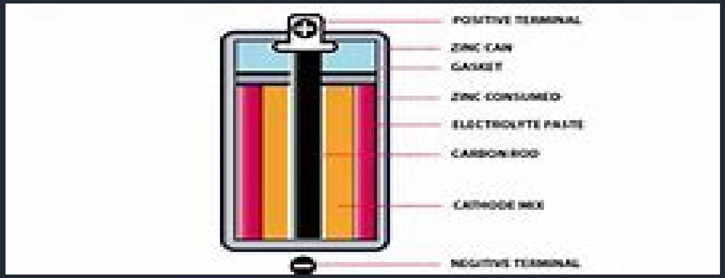
Energy Balance



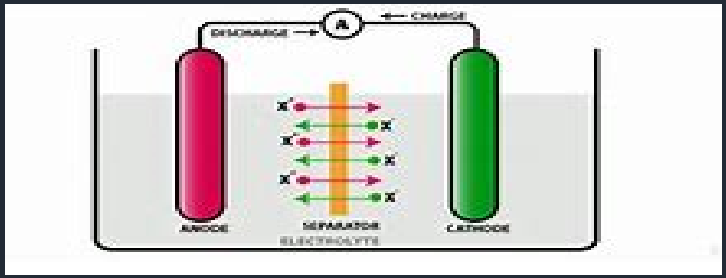
Minimum Stored Energy



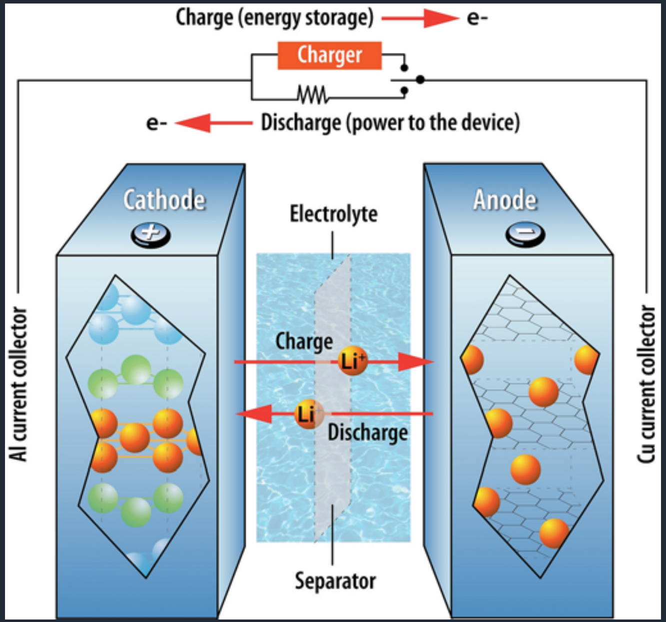
Primary Cell/Battery



Secondary Cell/Battery



Battery Design Considerations



Key Design Considerations

Safety

Intended use

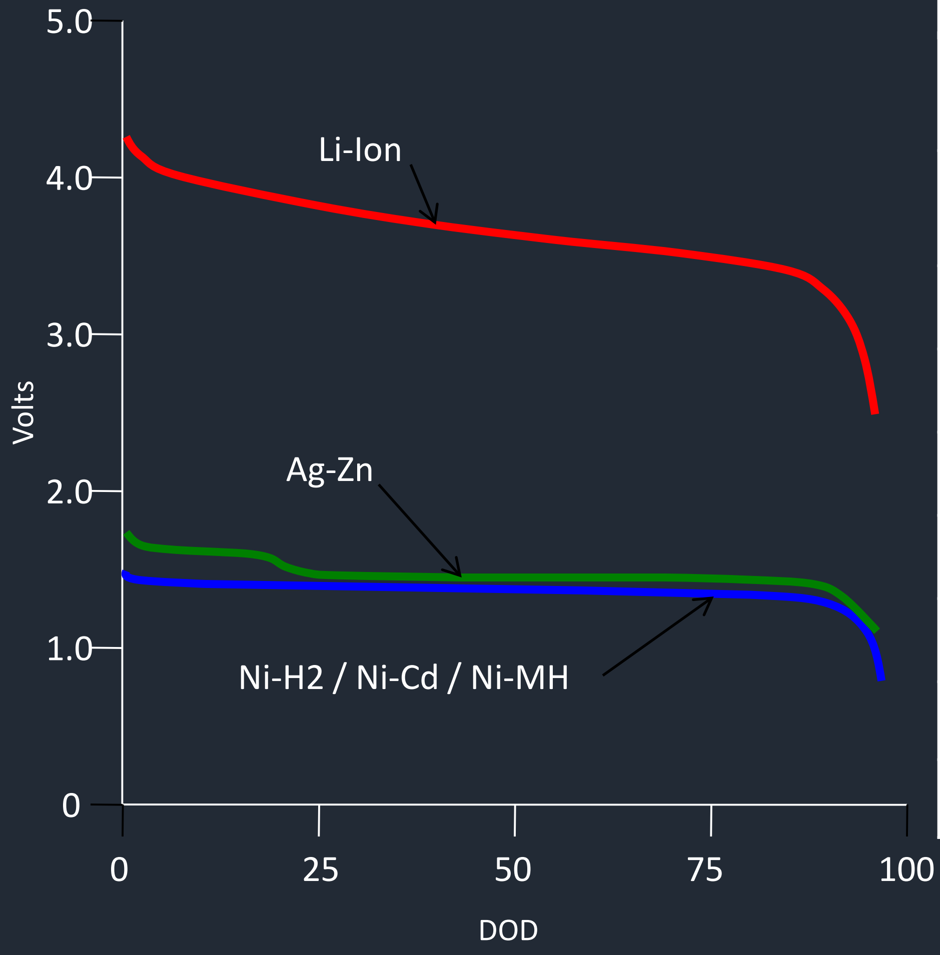
Launch site handling

Key Loss Factors

Mechanical stresses

Separator deterioration

Battery Chemistries…and Thermal Requirements and Packaging



	Ag-Zn	Ni-Cd	Ni-H2	Li-Ion
Specific energy (Wh/kg)	110	35	60	130
Energy density (Wh/l)	200	90	65	200
Rate capability	High	Med-High	Med-High	High
Cycle capability	Low	High	High	Med
Operating temp (C)	10-50	0-40	-20-30	0-60
Nominal cell V	1.5	1.3	1.3	3.6
Energy gauge	None	None	Pressure	Voltage
Shelf life	180 days	4-5 years	4-5 years	4-5 years
Cost	Low	Med-Low	High	Med-High

Battery Cell Voltage Discharge Characteristics

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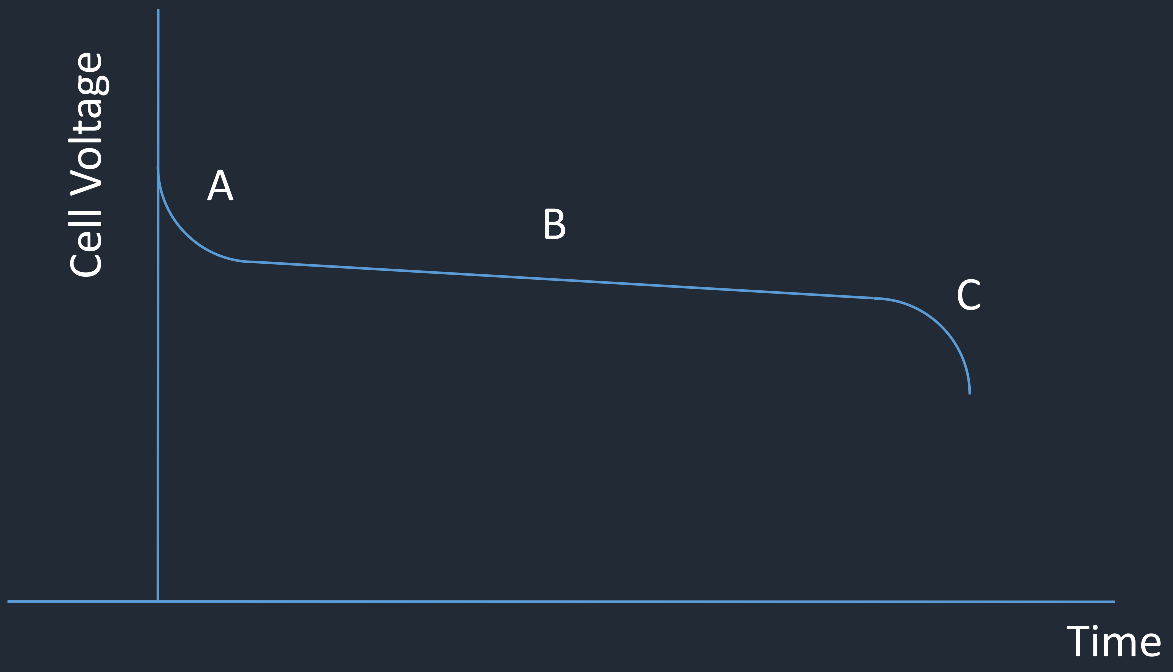

A – A Quick Drop from the Starting Voltage (Day to Night) (Seconds to < 5 Min)

B – Steady State Discharge Plateau (Minutes to Hours to Days)

Battery Charge Voltage Characteristics

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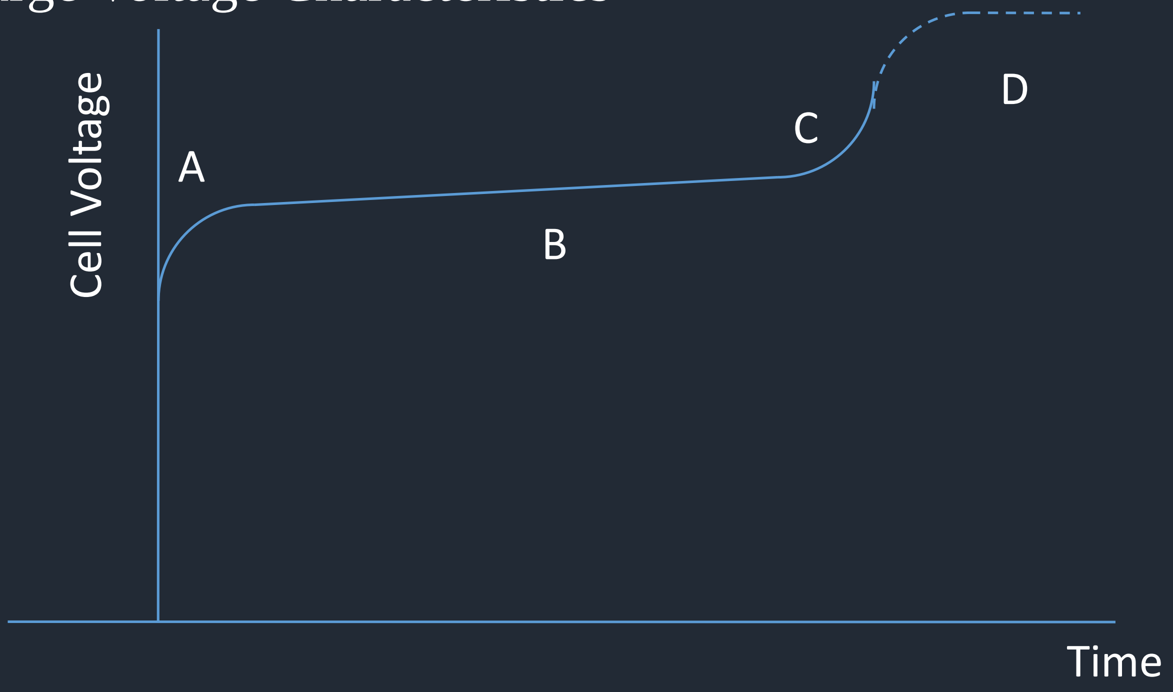


A, B, C – Mirror Images of the Discharge Curve

Battery Design /Sizing Example

Battery Efficiency (ηbatt) and Recharge Ratio (RR)

ηbatt = Integral (t2 to t3)*I dt / Integral (t1 to t2)*I dt = A-hrs Out / A-hrs In

where t1 to t2 = charge

t2 to t3 = discharge and t1 capacity = t3 capacity

RR = 1/ηbatt = A-hrs In / A-hrs Out

Depth of Discharge (DOD) - % of Total Battery Capacity Removed During Discharge

Ex. 100 A-hr Battery uses 40 Amps During a 30 Minute Night

DOD = 40 *(30/60) / 100 = 0.2 or 20%

Battery Sizing Example

To Reach the Bus Voltage need
Ns = Number of Cells in Series Where:

Ns = Vbus/Vcell then Round UP to the Nearest Whole Number

For this example, Let Vbattcell = 1.475 V:
Ns = 30 V/1.475 V/cell = 20.34 cells or 21 cells in series

Electrochemical Cells Do Not Combine in Parallel, therefore, need to Combine Batteries in Parallel To Reach the Bus Current/Time Requirement

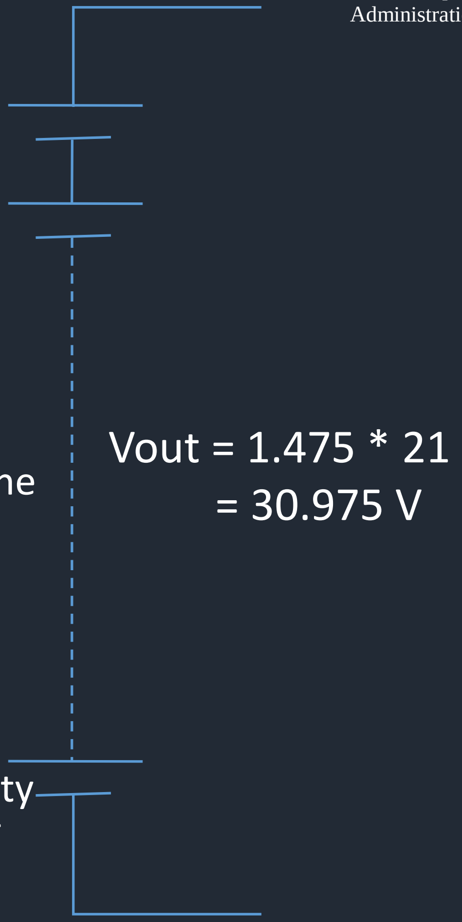
For this Example:
Assume Cell Rated at 1.475 V @ 12 A-hrs

Therefore, from above, the Battery will consist of 21 Cells @ 12 A-hrs Capacity
Now, to provide 100 A for 35 Minutes (assume) , would require a capacity of
100 A * 35/60 hrs = 58.33 A-hrs

and

Nbatteries = Capacity Needed/Battery Capacity and Rounded Up or

Nbatteries = 58.333/12 = 4.86 or 5



Battery Make or Buy

- Buy options include
  - Pumpkin
  - Blue Canyon
  - GomSpace
  - Clyde Space
  - Tyvak
- In house options
  - In house assembly process can be dangerous and is not recommended.

Battery Charger / Discharger

The Battery Charger/Discharger is the electronic components that provide a way to charge the battery when the solar arrays are illuminated and allows the battery to discharge while furnishing power to the loads when the solar arrays are in the dark (nighttime or eclipse).]

Options
- Constant voltage
- Constant current
- Etc.

Typical down select and why

Lithium cell charge scheme is typically constant current until desired voltage is reached, then switch to constant voltage mode.

Key Aspects for deep space

Types of parts are critical.

Make or Buy

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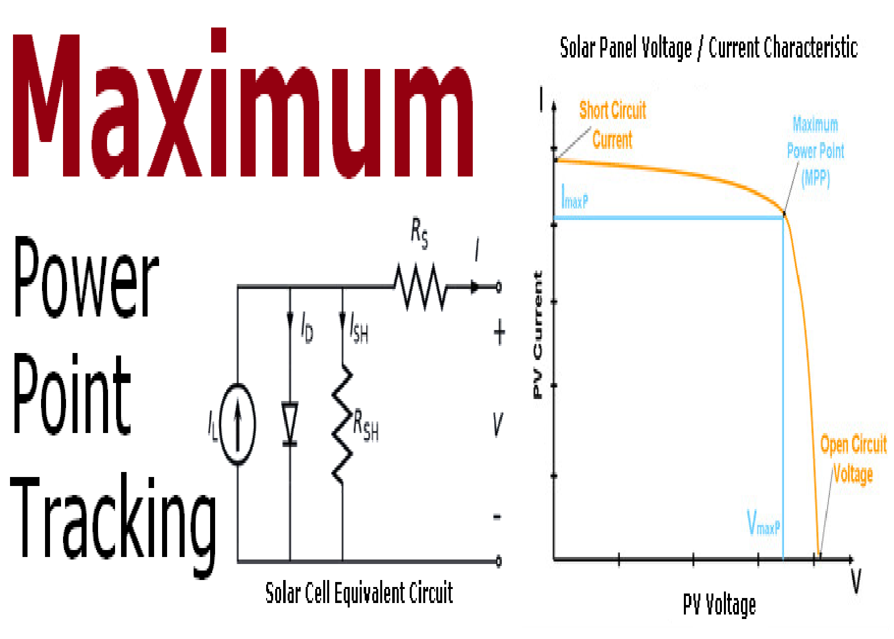
Maximum Power Point Tracking (MPPT):

MPPT is the technique used to maximize power extracted out of the solar arrays. Peak power trackers are used to maintain optimum power regulation out of the solar array. They typically consist of a high side and low side switch, depending on the design and algorithm selected.

Algorithm and design considerations

Key Aspects for deep space design

Make or Buy



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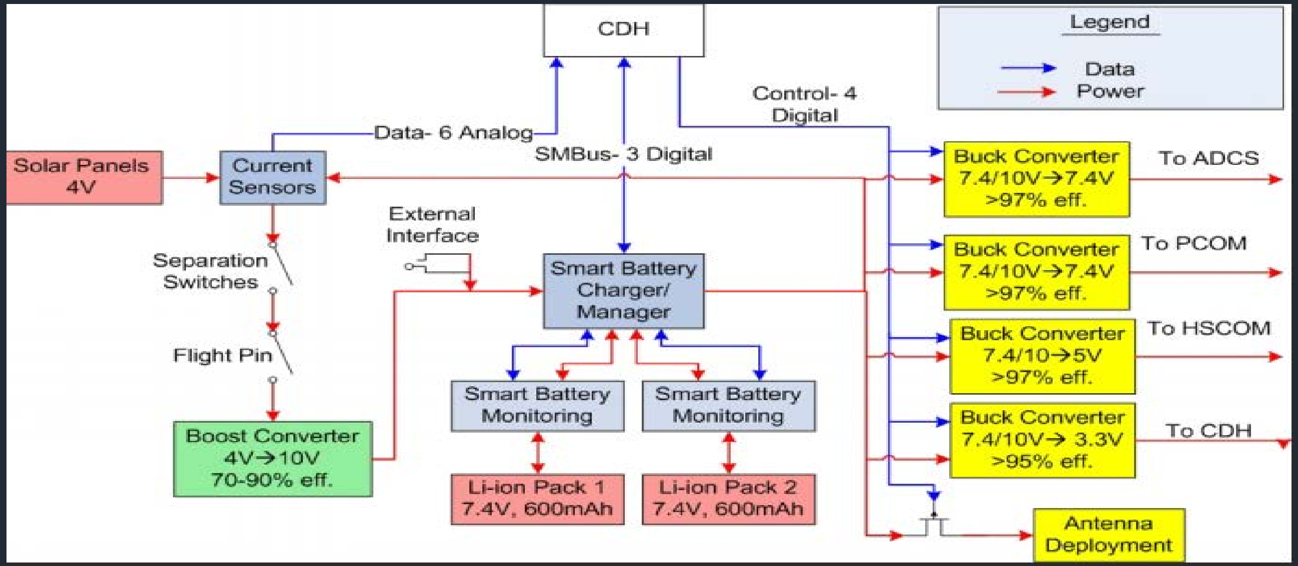
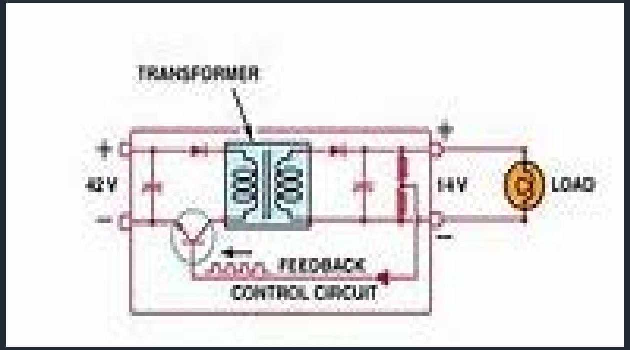
Power Distribution, Regulation and Control Subsystems

The Power distribution , regulation and control circuits are used to maintain energy balance, control battery charge/discharge, allow manual or automatic intervention, sense problems and react, protect , distribute power to the loads, and regulate load voltage.

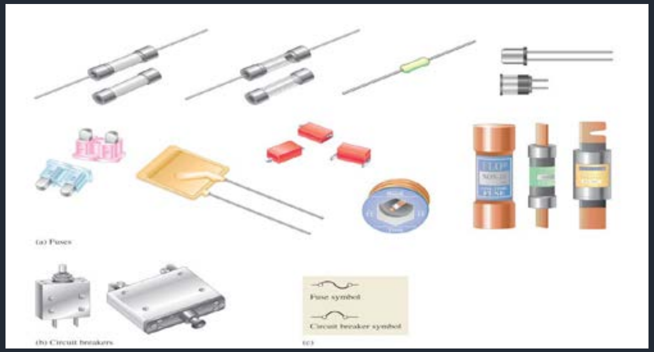


Power Distribution, Regulation, and Control Definitions

DC/DC Converters/Linear Regulators

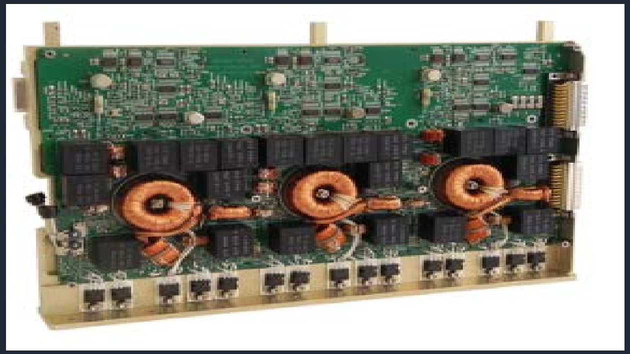


Distribution/Protections Components

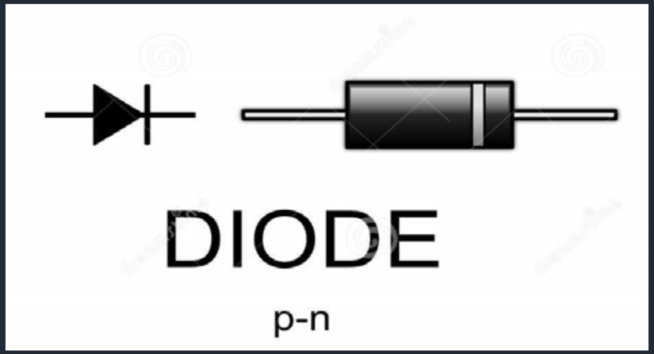


EMI Filters

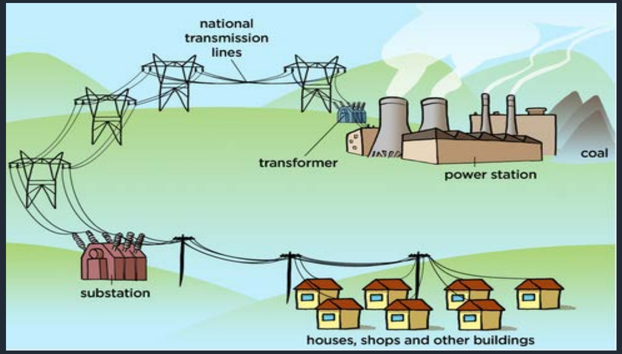
Power Control



Power Diode



Power Distribution



Power Distribution, Regulation, and Control Definitions (continued)

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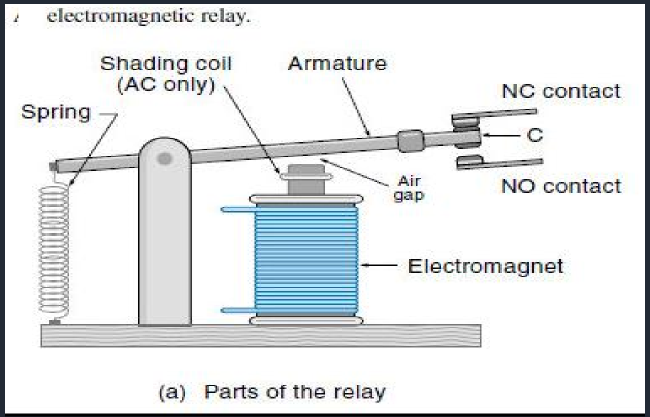
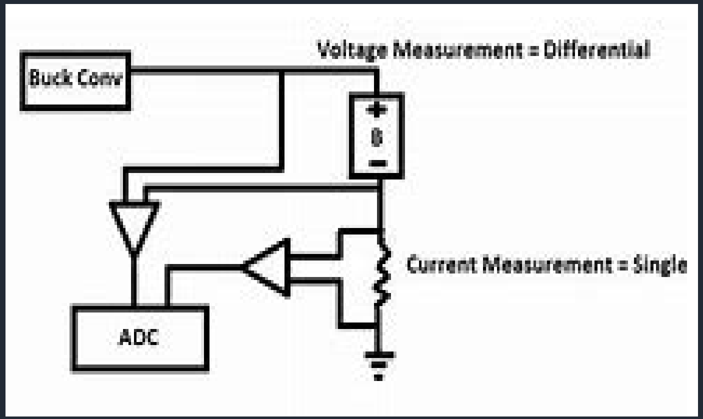
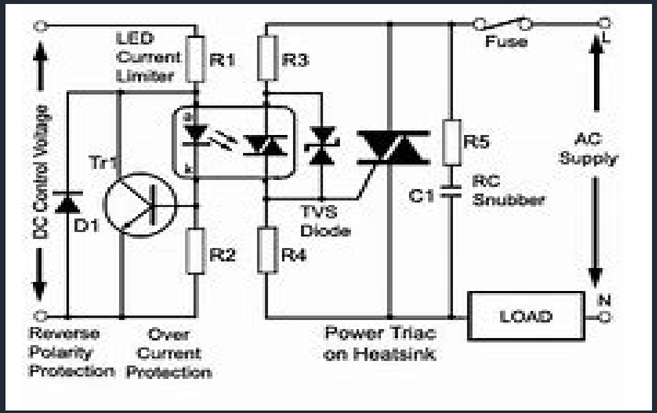
Relay



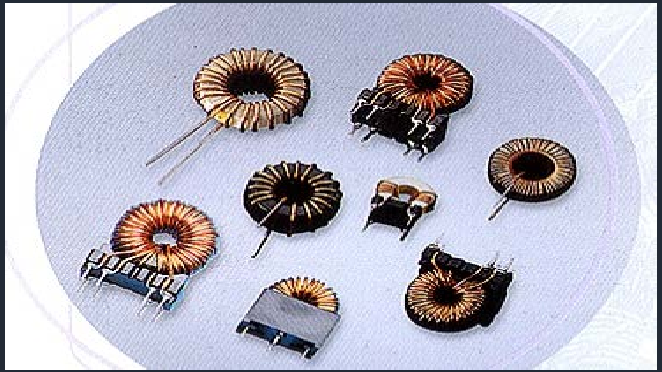
Sensors and Measurements



Solid State Relay



Transformers and Inductors



Wiring and Cabling

Design Considerations

For power regulation and control, we will mainly concentrate on selecting the type of converter to use. The remainder of the circuits required with a converter are usually built with typical circuits such as op amps, comparators, drivers, filters, etc.

There are many different types of DC/DC converter options including isolated switching converters or non-isolated point of load (POL) converters. For switching converters, there are many different topology options, depending on the output requirements.

– *Buck*
– *Boost*
– *Buck/Boost*
– *Parallel or Push-Pull Configuration*
– *Semi Resonant*

For Point of Load (POL) converters, most are linear regulators. Linear regulators are another method of creating an output voltage that is lower than the bus voltage. While linear regulators are usually much smaller than a DC/DC converter, linear regulators can incur higher power losses compared to a DC/DC converter. Use linear regulators judiciously.

Key Aspects for deep space design

The DC/DC converter should be selected to meet input voltage range requirements and deliver the maximum output current needed at the correct output voltage level.

This includes selecting for:

- *Worse case steady state and transient conditions of the output load and input bus*
- *Environmental requirements (especially radiation and temperature)*
- *Parts pedigree (reliability)*
- *Thermal requirements (conductive cooling (coldplate) or convective cooling (typically convective cooling methods such as fans are not used on cubesats))*
- *Protection circuit needs*
- *DC/DC Converter Stability*
- *Input and output EMI filtering for the DC/DC converters*

Converter make or buy

Some hybrid DC/DC manufacturers include

- *Crane Aerospace (Interpoint)*
- *Infineon (International Rectifier)*
- *VPT*
- *Vicor*

Some POL linear regulators manufacturers include

- *Linear Technology (Analog Devices)*
- *Infineon*
- *VPT*

Custom design

- *For cubesats, it is very difficult to design a custom DC/DC converter in such a small space. In addition, many cubesat EPS manufacturers include the converter as part of the EPS. If a custom design is required to optimize size and weight, many reference books exist on how to select the components based on the chosen topology.*

EPS Bus Design Considerations and Integration

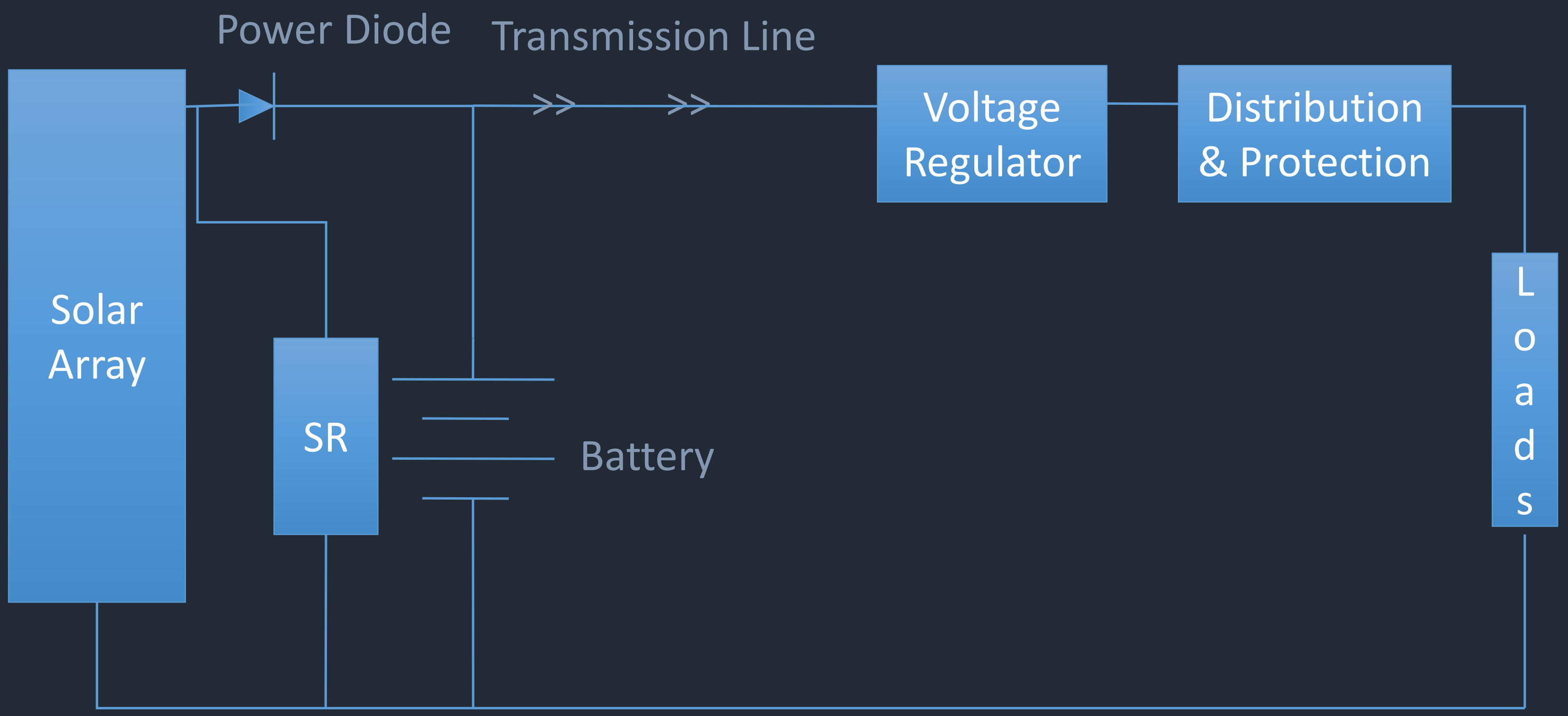
Battery Regulated Bus

Versus

Solar Array Regulated Bus

Topology options

Top Level Solar Array/Battery EPS – Direct Energy Transfer with an Unregulated Bus (Full Shunt)



Topology options

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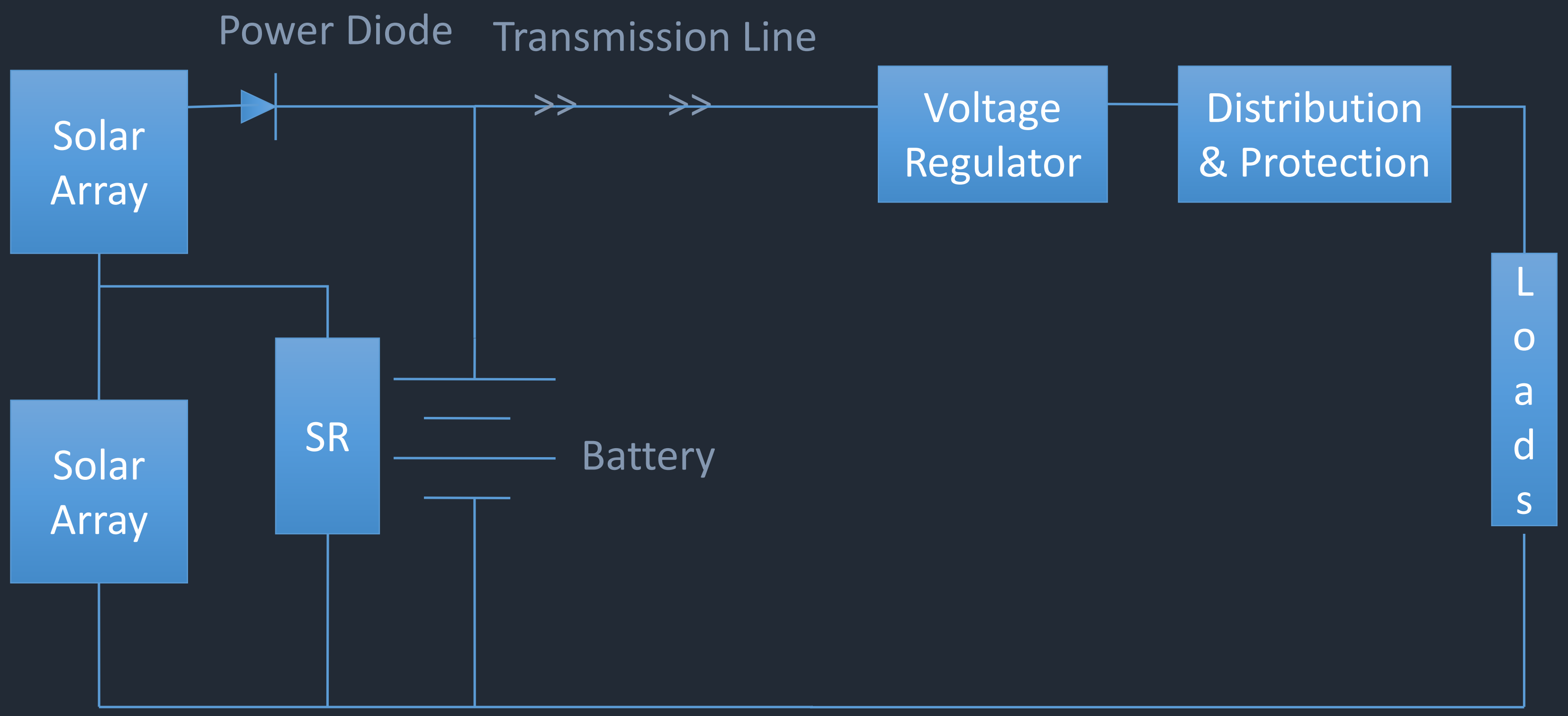
Top Level Solar Array/Battery EPS – Direct Energy Transfer with an Unregulated Bus (Partial Shunt)



Topology options

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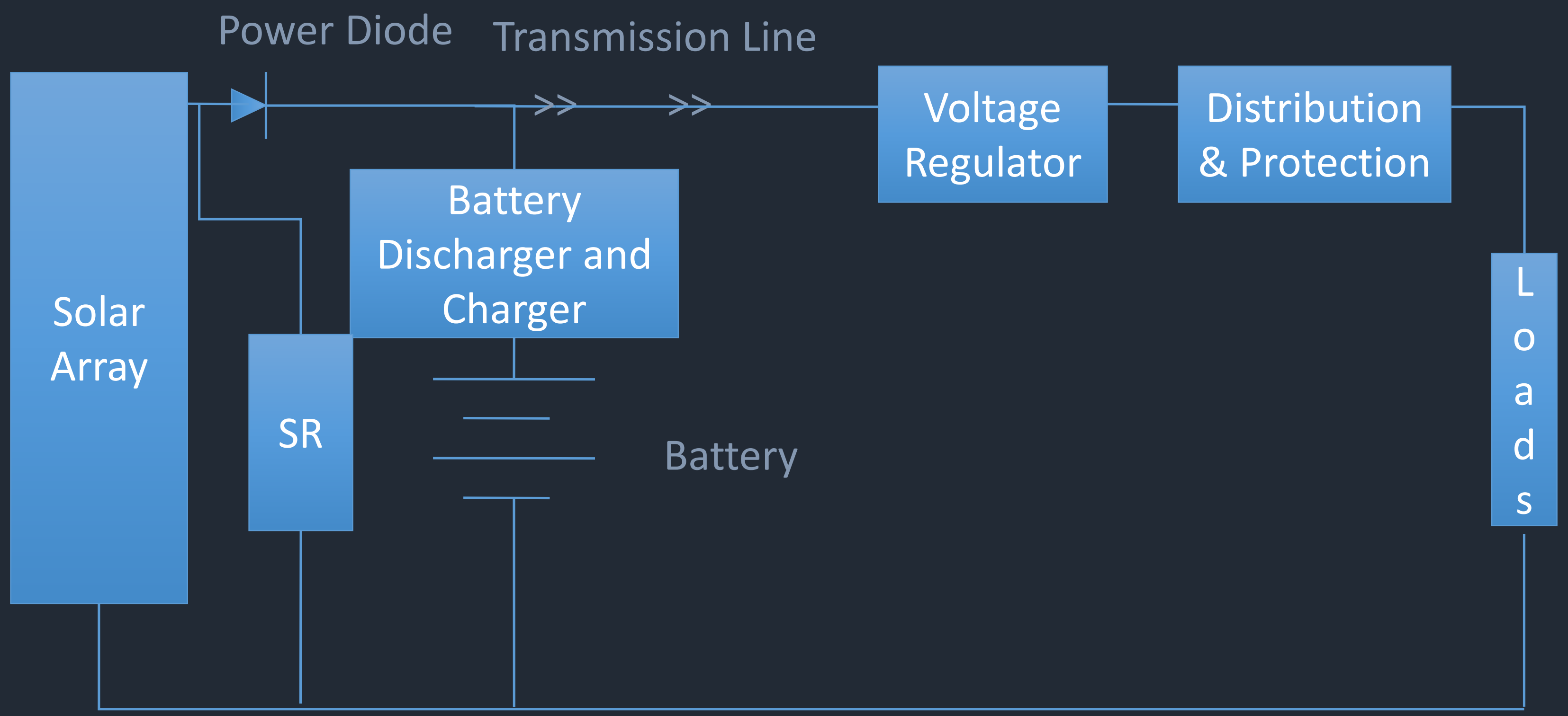
Top Level Solar Array/Battery EPS – Direct Energy Transfer with a Fully Regulated Bus



Topology options

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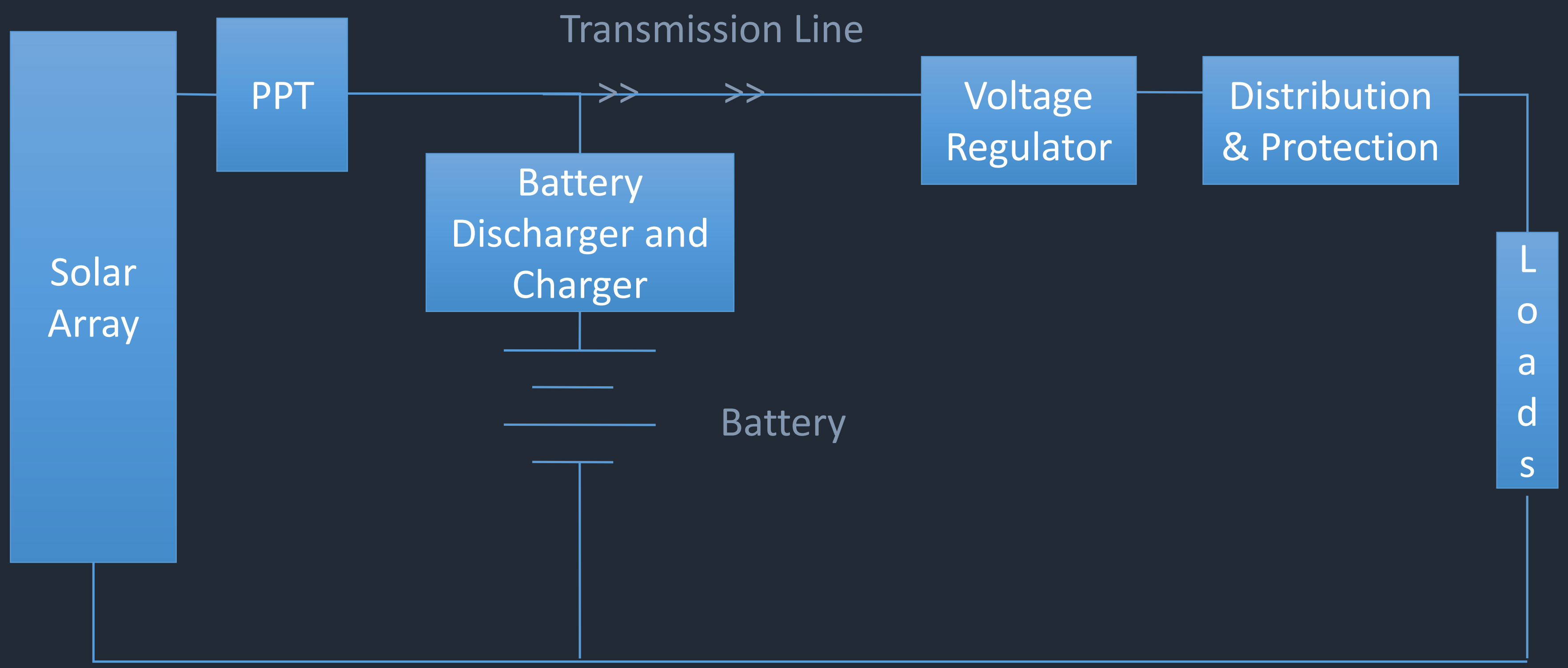
Top Level Solar Array/Battery EPS – Peak Power Tracker (PPT) with a Fully Regulated Bus



Design example

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Calculating top level EPS efficiency

EPS Efficiency η_t is Found By

$$\eta_t = P_{out}/P_{in} * 100\%$$

where Pout is the Load Power and Pin is the Solar Array Output

Assume a Constant Power Load, PL and an orbit of time

$t = t_e + t_d$ (te – eclipse period (night) and td - lighted period (day)

Then the Stored Energy Required, ε_s,

$$\varepsilon_s = (t_e/\eta_d * \eta_b) * P_L$$

where η_d is the Battery Discharge Efficiency and η_b is the Battery Efficiency or 1/(the Recharge Ratio)

Top level efficiency continued

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The Minimum Power Required to Recharge the Battery (During the Day), PR, is

$$PR = \varepsilon s/td*\eta c = PL*(te/(\eta c*\eta d*\eta b*td))$$

where ηc = Battery Charger Efficiency

Therefore, the Total Source Power Required, Psa, is

$$Psa = PL + PR = PL*(1 + te/(\eta c*\eta d*\eta b*td))$$

where ηc = Battery Charger Efficiency

Except, We have to account for the Other Efficiencies and the Final Total Source Power Required, Psa, is

$$Psa = PL + PR = PL/\eta r*(1 + te/(\eta c*\eta d*\eta b*td))$$

where ηdist = Remaining Efficiencies not Related to the Energy Storage

EPS Sizing example

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For this example, Let PL = 1000 W in a LEO (60 minute day, 30 minute night) and assume

$\eta diode = 0.99$

$\eta tl = 0.99$

$\eta b = 0.91$

$\eta chg = 0.92$

$\eta vr = 0.88$

$\eta sa = 20\%$

$\eta d = 0.88$

$\eta dist = 0.99$

Psa = PL + PR =

$PL/\eta diode*\eta tl*\eta vr*\eta dist[1 + (te/\eta c*\eta d*\eta b*td)]$

Psa(min) =

1000/0.99*0.99*0.88*0.99[1 + (30/0.92*0.88*0.91*60)]

= 1966.0 Watts **

EPS Make or Buy

- Buy options include
  - Pumpkin
  - Blue Canyon
  - GomSpace
  - Clyde Space
  - Tyvak
- In house options
  - Can build to spec and maximize efficiency.

Component Testing

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Depending on Budget and Risk…Qualification and Acceptance testing like any spacecraft component.

Unique to some EPS components

Solar Arrays	Batteries	Other Power Components

• Thermal cycling
• Deployment mechanism
• UV and atomic O2 effects characterization
• Post Final Installation
  First motion test
  Photovoltaic "aliveness" test
  Sensors and solar cell strings continuity testing
	• Capacity
	• Charge retention
	• Vacuum Leak check
	• Thermal cycling
	• Abuse tolerance
	• Post Final Installation
	  Load check
	  Sensor continuity testing
		• Continuity and isolation measurements prior to power up
		• Min/max line voltage swings (input voltage range)
		• Min/max load swings (output current range).
		• Control load sequencing and understand turn on and turn off transients.
		• Test over temperature and test protection circuitry when possible. Some protection circuitry such as fuses can't be tested without destroying the part.

Pre Launch/ Launch site Considerations

General EPS considerations revolve around controlling environments.

Ideally, integrate and store in an environmentally controlled area.

Solar Arrays are typically stowed until after launch.

Batteries often require additional attention.

Summary

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The EPS in all spacecrafts provides electrical power to all vehicle loads and is vital for the completion of the defined missions.

Most commonly used architectures for Cubesats are battery only or solar array / battery configurations.

Batteries must be treated as potential hazards as they combine stored energy with (sometimes) caustic materials.

Thermal and mechanical are the key subsystem interfaces with EPS as designs are developed (very iterative process).

Testing is key. "Test what you fly and fly what you test."

Launch site handling can be a major consideration.

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National Aeronautics and Space Administration

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ES36/Delisa Wilkerson delisa.l.Wilkerson@nasa.gov Branch Chief, Electronic Design)

References

https://www.jpl.nasa.gov/cubesat/

http://www.cubesat.org/