MSFC
Electrical Power Systems for Cubesats

ES30/Karen Cunningham
ES44/John Carr
ES44/Brandon Lewis

November 9, 2018
Agenda

Typical Cubesat Subsystems
Typical EPS Subsystems
Power System Definitions
Requirements
Major Interacting Subsystems
Where to Start
Why Derating
Safety and Reliability Considerations
Other Key Considerations
Subsystems Design
  Power Generation
  Energy Storage
  Power Distribution, Regulation and Control
  EPS Bus Design and Integration
Testing
Pre Launch / Launch Site Considerations
Summary
Contact Information
Typical Cubesat Subsystems

Systems

Propulsion and/or Reaction Control (RCS)

Guidance, Navigation, and Control (GN&G)

Communications (Comm)

Command and Data Handling (C&DH)

Structures and Mechanisms

Thermal Control (TCS)

Electrical Power System (EPS)

Mission Payloads
Typical EPS Subsystems

- Power Source
- Energy Storage
- Power Distribution
- Power Regulation and control

Generate | Store | Transmit | Regulate/Protect
Power System Definitions

- Power (Watts)
- Energy (Watt-hours)
- Electrical Power System
- Power Efficiency (n)
- Power Equipment List (PEL)
- Power Margin
- Power Profile
- Power Protection
- Power Quality (PQ)
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

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

Thermal

Structures

Command and Data Handling

Payloads
Where to Start – System Level

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

![Graph showing the relationship between failure rate and temperature with different stress ratios.](image)

**Figure 1.** Piece-part Failure Rate vs. Temperature

---

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

11/9/18
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

*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?*
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?*
Solar Constant Ratio to Earth Versus A.U.

- Mars (0.431)
- Saturn (0.011)
- Neptune (0.00111)
EOL Array performance vs. Temperature

- **Array power output (W)**
- **Temperature (°C)**
- **Array voltage output mpp (V)**

Lines represent:
- Light blue: UTJ Power (W)
- Dark gray: ZTJ Power (W)
- Red: UTJ Voltage (V)
- Orange: ZTJ Voltage (V)

11/9/18
Time vs Power for Octagonal Cell Configuration
@ 10% CIGS efficiency

- Case 1, 0deg Orbit
- Case 2, 51.4deg Orbit
- Case 4, 75deg Orbit

Array 90 deg Sun (entering shadow)
Array 90 deg Sun (exiting shadow)

Power (Watts)

0 1000 2000 3000 4000 5000 6000
Time (sec)
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

Current through String-2/Cell-2

Current through String-2/Cell-1

Primary Arc Current
Impact at 24,500 km/h

18 cm

1.2 cm
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

<table>
<thead>
<tr>
<th>Sun angle degrees</th>
<th>Mathematical cosine value</th>
<th>Kelly cosine value</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>0.866</td>
<td>0.866</td>
</tr>
<tr>
<td>50</td>
<td>0.643</td>
<td>0.635</td>
</tr>
<tr>
<td>60</td>
<td>0.500</td>
<td>0.450</td>
</tr>
<tr>
<td>80</td>
<td>0.174</td>
<td>0.100</td>
</tr>
<tr>
<td>85</td>
<td>0.087</td>
<td>0.000</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar constant from environment:</td>
<td>1366.1 W/m²</td>
</tr>
<tr>
<td>Solar Cell Efficiency:</td>
<td>28.3 %</td>
</tr>
<tr>
<td>Solar Cell Temperature Coefficient:</td>
<td>88.0 %</td>
</tr>
<tr>
<td>Solar Cell EOL Environment:</td>
<td>93.0 %</td>
</tr>
<tr>
<td>Solar Panel Packing Density:</td>
<td>90.0 %</td>
</tr>
<tr>
<td>Solar Panel AOI:</td>
<td>99.0 %</td>
</tr>
<tr>
<td>MPPT efficiency, line loss, diode etc.:</td>
<td>85.0 %</td>
</tr>
<tr>
<td>Power delivered to EPS:</td>
<td>239.6 W/m²</td>
</tr>
<tr>
<td>Average power needed from PEL/Profile:</td>
<td>120.0 W</td>
</tr>
<tr>
<td>Add in growth margin:</td>
<td>20.0 %</td>
</tr>
<tr>
<td>Solar array area needed:</td>
<td>0.601 m²</td>
</tr>
<tr>
<td>Add in designers margin:</td>
<td>10.0 %</td>
</tr>
<tr>
<td>Total solar array area needed:</td>
<td>0.661 m²</td>
</tr>
</tbody>
</table>
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

Bypass diodes from the unshaded cells are reverse biased and have no impact.

Current from string of cells is limited by lowest current cell. If some cells are shaded, then the extra current from the good cells in the string forward biased these cells.

Bypass diode from shaded string is forward biased and conducts current +0.6V.

If the terminals of the module are connected (module ISC), the power from the unshaded cells is dissipated across the shaded cell.
Blocking Diodes
A note on deployment…
Power Generation: Make or Buy My Solar Array?
COST vs. RISK vs. BENEFIT vs. SCHEDULE
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

**Batteries (Batt)**

**Ampere-Hours**

<table>
<thead>
<tr>
<th>Current (amp)</th>
<th>1 amp draw</th>
<th>2 amp draw</th>
<th>3 amp draw</th>
<th>4 amp draw</th>
<th>5 amp draw</th>
<th>6 amp draw</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 hour</td>
<td>1 hour</td>
<td>30 min</td>
<td>1 hour</td>
<td>40 min</td>
<td>1 hour</td>
<td>60 min</td>
</tr>
<tr>
<td>30 amp hour</td>
<td>30 min</td>
<td>2 hours</td>
<td>1 hour</td>
<td>1 hour</td>
<td>30 min</td>
<td>30 min</td>
</tr>
<tr>
<td>40 amp hour</td>
<td>40 min</td>
<td>1 hour 20 min</td>
<td>1 hour</td>
<td>1 hour</td>
<td>40 min</td>
<td>40 min</td>
</tr>
<tr>
<td>50 amp hour</td>
<td>50 min</td>
<td>2 hours 30 min</td>
<td>1 hour 40 min</td>
<td>1 hour 15 min</td>
<td>1 hour 50 min</td>
<td></td>
</tr>
<tr>
<td>60 amp hour</td>
<td>60 min</td>
<td>3 hours</td>
<td>2 hours</td>
<td>1 hour 30 min</td>
<td>1 hour 12 min</td>
<td>1 hour 1 hour</td>
</tr>
</tbody>
</table>

**Energy Balance**

**Minimum Stored Energy**

**Primary Cell/Battery**

**Secondary Cell/Battery**
Key Design Considerations

Safety
Intended use
Launch site handling

Key Loss Factors
Mechanical stresses
Separator deterioration
Battery Chemistries…and Thermal Requirements and Packaging

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

11/9/18
Battery Cell Voltage Discharge Characteristics

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

Cell Voltage

Time

A, B, C – Mirror Images of the Discharge Curve
Battery Design /Sizing Example

Battery Efficiency ($\eta_{batt}$) and Recharge Ratio (RR)

$$\eta_{batt} = \frac{\text{integral}(t_2 \text{ to } t_3) \times I \, dt}{\text{integral}(t_1 \text{ to } t_2) \times I \, dt} = \frac{\text{A-hrs Out}}{\text{A-hrs In}}$$

where $t_1$ to $t_2$ = charge
$t_2$ to $t_3$ = discharge and $t_1$ capacity = $t_3$ capacity

$$RR = \frac{1}{\eta_{batt}} = \frac{\text{A-hrs In}}{\text{A-hrs Out}}$$

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

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

$$DOD = \frac{40 \times (30/60)}{100} = 0.2 \text{ or } 20\%$$
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

Vout = 1.475 * 21 = 30.975 V
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
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
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/Protection Components
EMI Filters

Power Control
Power Diode
Power Distribution
Power Distribution, Regulation, and Control Definitions (continued)

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.

11/9/18
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

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

- Solar Array
- Voltage Regulator
- Distribution & Protection
- Power Diode
- Transmission Line
- Battery
- Solar Array
- SR
- Loads
Topology options

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

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

- Solar Array
- PPT
- Battery Discharger and Charger
- Transmission Line
- Voltage Regulator
- Distribution & Protection
- Battery
- Loads

11/9/18
Design example

*Calculating top level EPS efficiency*

EPS Efficiency $\eta_t$ is Found By

$$\eta_t = \frac{P_{out}}{P_{in}} \times 100\%$$

where $P_{out}$ is the Load Power and $P_{in}$ 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, $\varepsilon_s$,

$$\varepsilon_s = \left( \frac{t_e}{\eta_d \cdot \eta_b} \right) \cdot PL$$

where $\eta_d$ is the Battery Discharge Efficiency and $\eta_b$ is the Battery Efficiency or $1/(the\ Recharge\ Ratio)$
The Minimum Power Required to Recharge the Battery (During the Day), \( PR \), is

\[
PR = \frac{\varepsilon_s}{t_d \eta_c} = PL \left( \frac{t_e}{\eta_c \eta_d \eta_b t_d} \right)
\]

where \( \eta_c \) = Battery Charger Efficiency

Therefore, the Total Source Power Required, \( P_{sa} \), is

\[
P_{sa} = PL + PR = PL \left( 1 + \frac{t_e}{\eta_c \eta_d \eta_b t_d} \right)
\]

where \( \eta_c \) = Battery Charger Efficiency

Except, We have to account for the Other Efficiencies and the Final Total Source Power Required, \( P_{sa} \), is

\[
P_{sa} = PL + PR = \frac{PL}{\eta_r} \left( 1 + \frac{t_e}{\eta_c \eta_d \eta_b t_d} \right)
\]

where \( \eta_{dist} \) = Remaining Efficiencies not Related to the Energy Storage
EPS Sizing example

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

\[ \eta_{\text{diode}} = 0.99 \]
\[ \eta_{\text{tl}} = 0.99 \]
\[ \eta_{\text{b}} = 0.91 \]
\[ \eta_{\text{chg}} = 0.92 \]
\[ \eta_{\text{vr}} = 0.88 \]
\[ \eta_{\text{sa}} = 20\% \]
\[ \eta_{\text{d}} = 0.88 \]
\[ \eta_{\text{dist}} = 0.99 \]

\[ \text{Psa} = PL + PR = PL/\eta_{\text{diode}} \times \eta_{\text{tl}} \times \eta_{\text{vr}} \times \eta_{\text{dist}}[1 + (te/\eta_{\text{c}} \times \eta_{\text{d}} \times \eta_{\text{b}} \times \eta_{\text{td}})] \]

\[ \text{Psa(min)} = 1000/0.99 \times 0.99 \times 0.88 \times 0.99[1 + (30/0.92 \times 0.88 \times 0.91 \times 60)] \]

\[ = 1966.0 \text{ Watts} ** \]
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

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

Unique to some EPS components

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

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).


Launch site handling can be a major consideration.
ES44/John Carr  john.a.carr@nasa.gov  (solar arrays, EPS)
ES30/Karen Cunningham  karen.cunningham@nasa.gov  (electronics, power supplies)
ES44/Brandon Lewis  brandon.l.lewis@nasa.gov  (batteries, cubesat power)
ES44/Jeff Brewer  jeff.brewer@nasa.gov  (Branch Chief, Electrical Integration and Power Subsystems)
ES36/Delisa Wilkerson  delisa.l.Wilkerson@nasa.gov  Branch Chief, Electronic Design)

References
https://www.jpl.nasa.gov/cubesat/
http://www.cubesat.org/