Spacecraft Bus Voltage Selection

2015 Space Power Workshop

May 12 – 14, 2015

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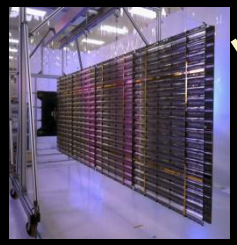
Discussion Topics

- Spacecraft Power System
- Spacecraft Systems – Why do a Voltage Trade
- What are the Voltage Trade Drivers
- Heritage Spacecraft Operating Voltage
- Technical Issues
- Architecture
- Voltage Trade Approach
- Conclusions
- Credits and Acknowledgments

Spacecraft Power System

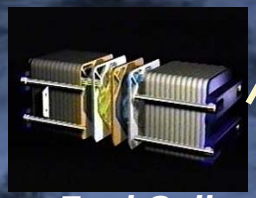
Power Generation



Solar Arrays

Brayton Rotating Unit

Stirling Radioisotope

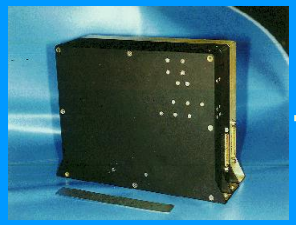


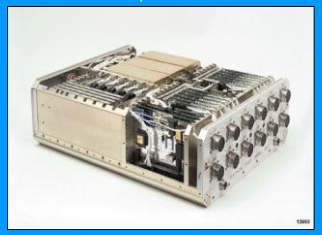
Fuel Cells

PMAD

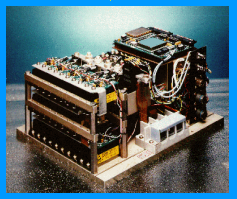
Power System Control

Source Regulator





Power Distribution



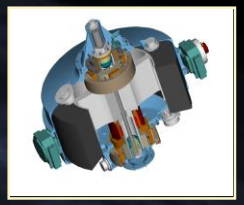
Load Converters

Charge/Discharge Regulator

Load Leveling

Energy Storage

Batteries



Flywheel

Loads

Electric Propulsion

Communications

Instruments

Actuators

www.nasa.gov

How to Select a Voltage - Voltage Trade?

The Need

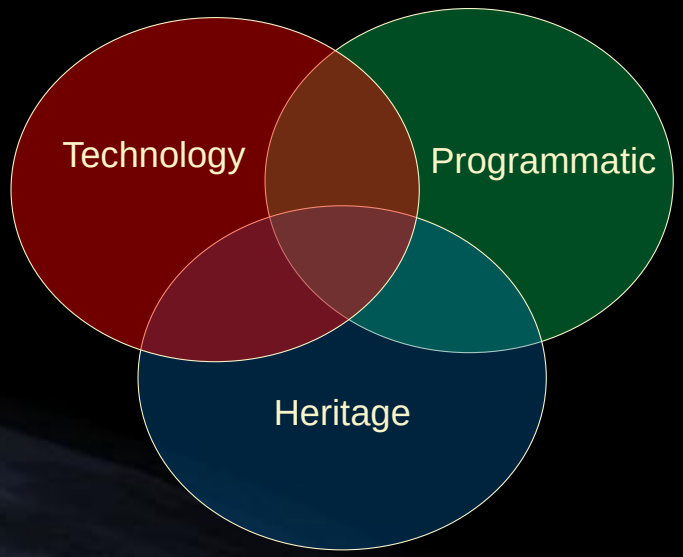
- **Spacecraft power levels are increasing to meet the needs for exploration and commercial**
  - **Driven by need for Solar Electric Propulsion**

Challenges

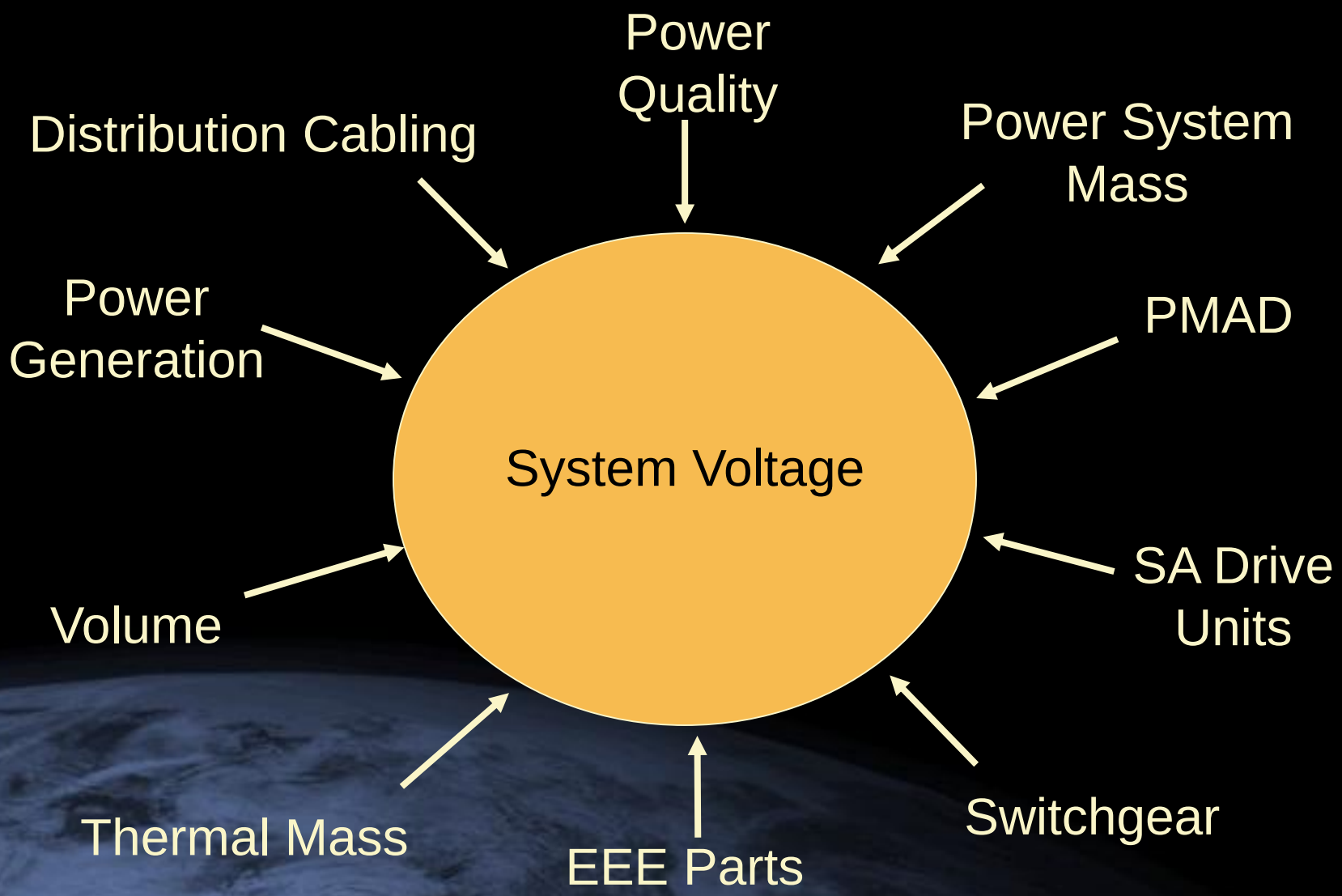
- **Power system mass must be kept within reasonable levels**
- **Component availability must be addressed**
- **Environmental interactions must be accommodated**

What are the Voltage Trade Drivers?

- Programmatic Issues
  - Schedule Risk
  - Cost Risk
  - Technical Risk
- Heritage
  - Reluctance to change from previous experience
- Technical Issues
  - Power System Mass
  - Cable Sizing
  - Switchgear Sizing
  - Parts Availability
  - Power Quality Requirements
  - Architecture
  - Energy Storage Control
  - Environmental Interactions



Voltage Trade Drivers



Heritage Spacecraft Operating Voltage

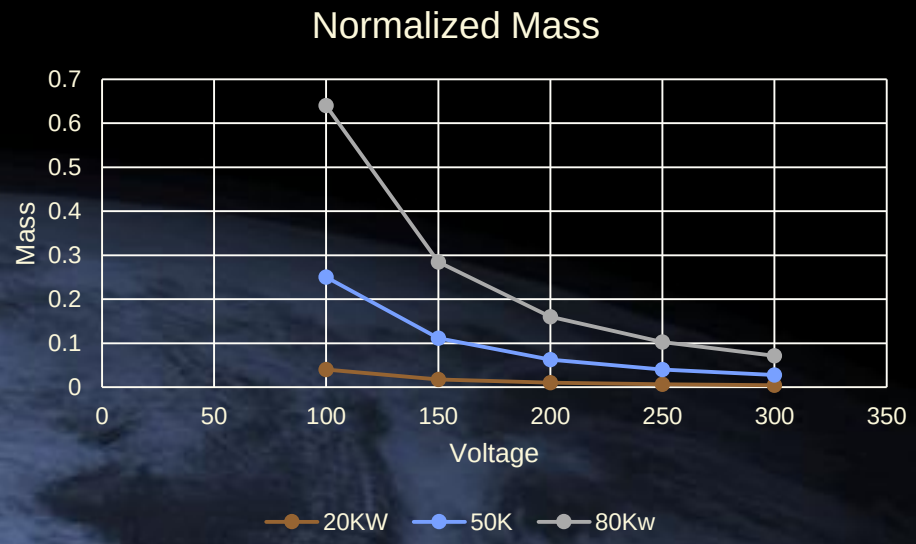
- Low power spacecraft use well-established low voltage systems ($28V_{DC}$) with well understood interactions in space environment
- Larger (>10kW) commercial communication satellites distribute 70 and 100 V_{DC}

- International Space station regulates solar array voltage at 160 V_{DC}
  - Distribution voltage is 120 V_{DC}

- NASA is currently developing other architecture for $120V_{DC}$.

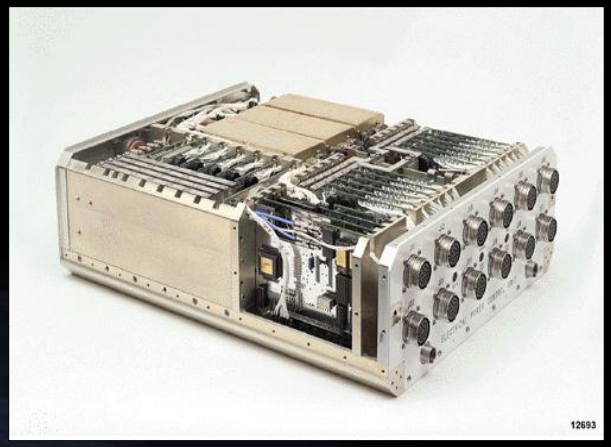
Technical Issues – Power System Mass

- **High distribution currents need to be kept manageable**
- **As power levels go up eventually the voltage must go up to minimize the currents and mass**
- **Cable mass is proportional to:**
  (power/voltage)^2
- **For systems as large as ISS (80kW) the majority of the mass benefits are realized between 150 to 200 volts**



Technical Issue – Cable Sizing

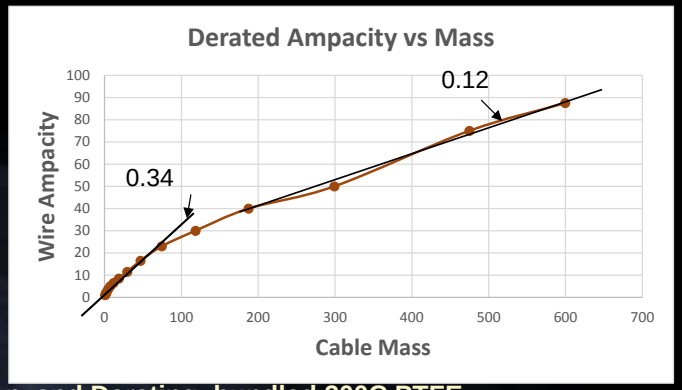
- Wire size is limited by mechanical properties
  - Minimum wire gauge – Brittlement/breakage #24
  - Limits on the maximum wire gauges – bend radius
- Losses in cable need to be minimized for power quality and to reduce thermal load
  - I^2R Loss for thermal
  - IR Loss for voltage (Power Quality)
- Losses can be reduced through:
  - Channelization – Distribution only
  - Increasing voltage



Technical Issue – Cable Optimization

- Cables optimization is necessary
- Ampacity and wire gauge are not linear
- Cable sizes greater than 4 carry a higher mass penalty
  - Wire size #8 to #16 are capable of higher current densities per unit mass than large kcmil conductors
    - #12 wire can carry 390A/kg[1]
    - #6 wire can carry 253A/kg[1]
- High current requires large distribution cables resulting in unacceptable mass

Generally the smallest wire gauges used for spacecraft power is #24 due to it's limited mechanical strength



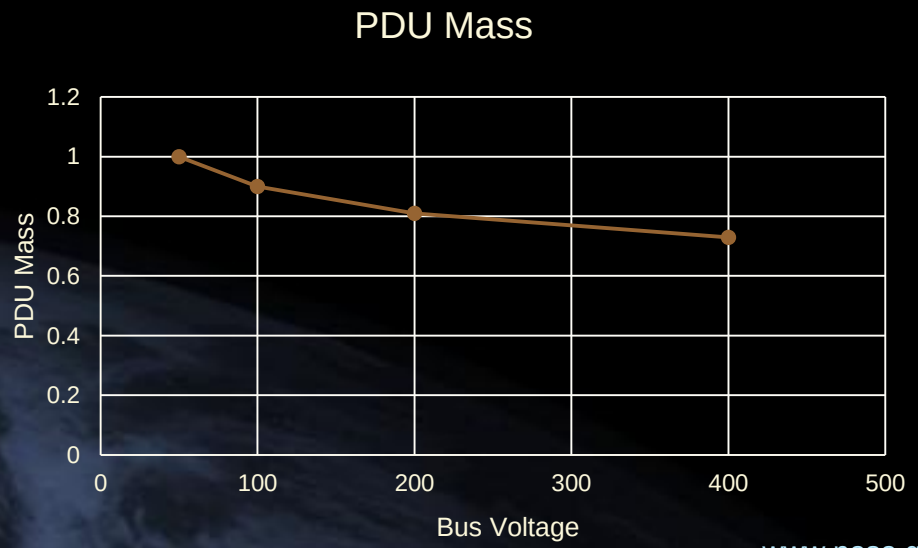
1- Per **EEE-INST-002: Instructions for EEE Parts Selection, Screening, Qualification, and Derating, bundled 200C PTFE**

Technical Issues - Parts Availability

- All components of the power system are impacted by voltage selection
- SOA parts – Availability of Si power semiconductors with good performance, radiation tolerance, and flight heritage is limited
  - Transistors
  - Diodes
- Advanced parts – Silicon carbide has good high voltage performance, high voltage ratings but lack heavy ion radiation tolerance
- Developing "Rad-Hard" high voltage parts is costly
- Some ceramic and film capacitors are available
  - Could be stacked for higher voltage with volume impact
- Insulation Systems

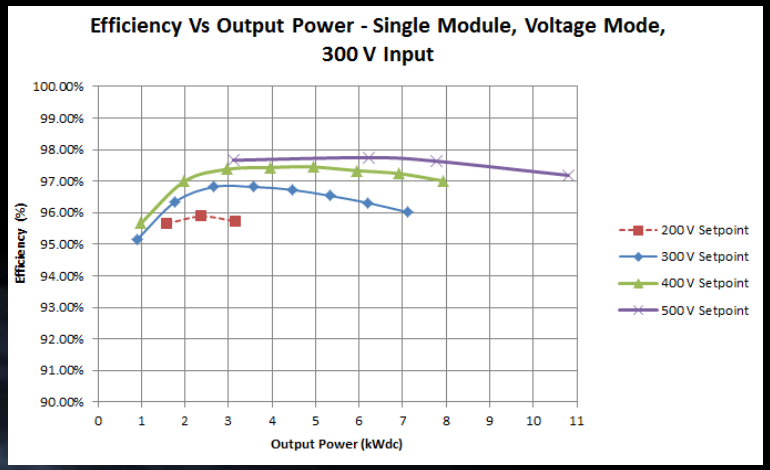
Technical Issues – Switchgear Sizing

- **Voltage and current will impact the size of the switchgear and power distribution components**
- **For the same power level, doubling the distribution voltage, resulting in very high current levels, only reduces the PDU mass by 10%**
- **Currents and voltages need to be kept to a reasonable level for wire size and component ratings respectively**



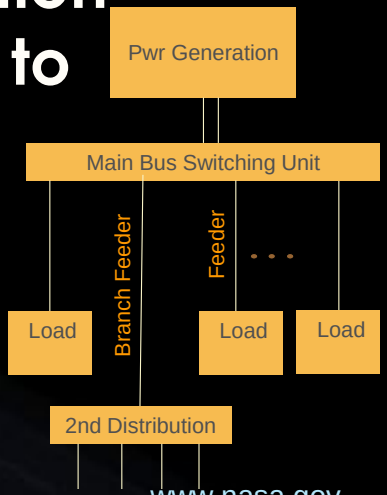
Technical Issues – Thermal Load

- **Systems with high losses burden the spacecraft thermal system**
- **Thermal system mass can quickly outpace any mass gains from the use of small conductors**
- **Thermal system is impacted by:**
  - **Distribution losses I^2R**
  - **Conduction and efficiency losses from electrical loads**



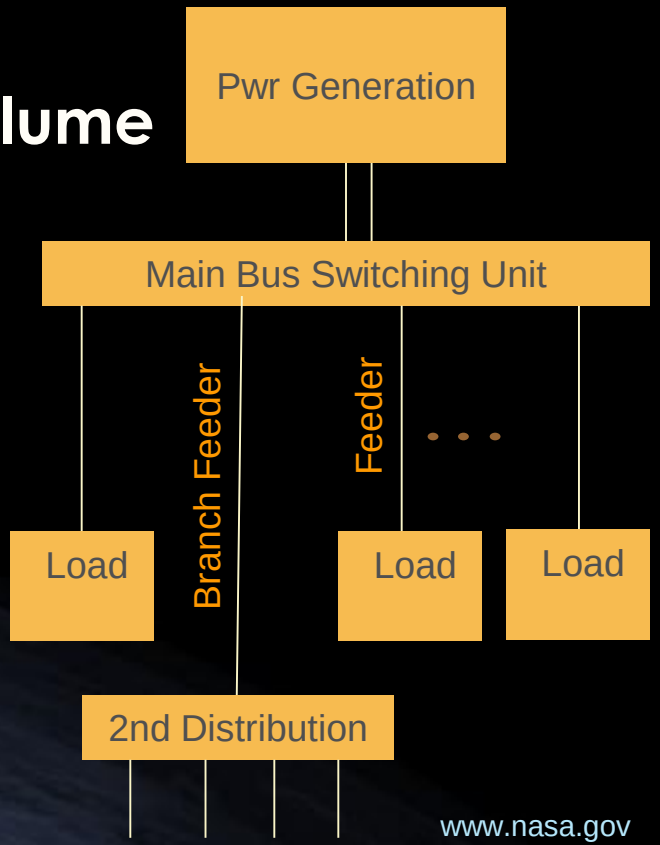
Architecture

- Power system, architecture consists of power generation, energy storage, and distribution systems
  - Generation and storage systems mass is primarily driven by power level
- Power distribution system permits the matching of energy stored and generated with the loads
  - Cable mass is primarily effected by voltage selection
- In some situations architecture channelization provides an additional degree of freedom to “optimize “ bus to bus cables

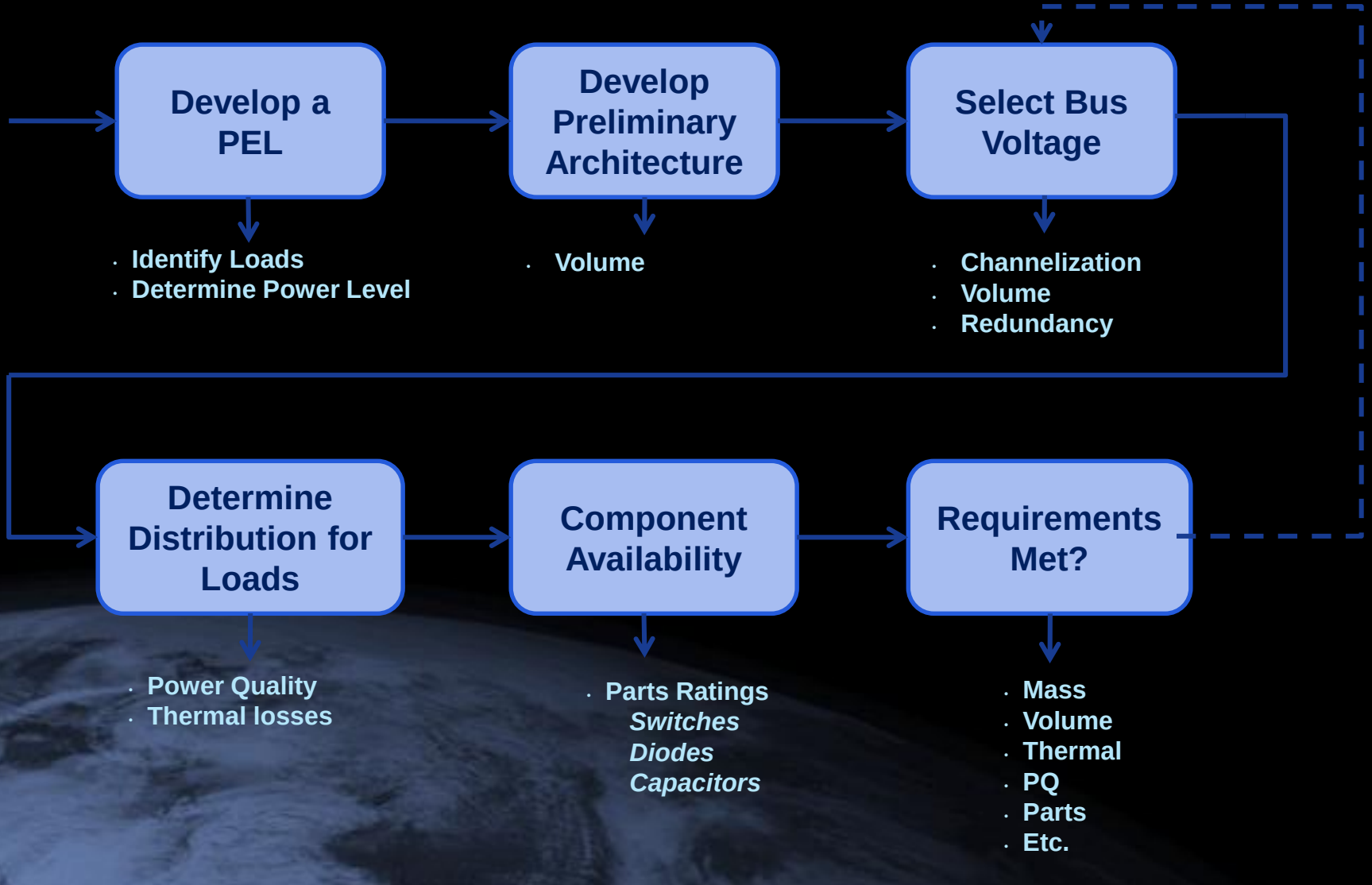


Architecture – Channelize & Volume

- Channelization is limited by the available spacecraft volume
  - Channelization requires more volume
  - Larger spanning structures are more amenable to channelization
- Spacecraft with less available volume must use other means



Voltage Trade Approach



Conclusions

- **Selection of a spacecraft bus voltage not trivial**

  "But it's just ohms law" ***L. Pinero***

- **System voltage decisions are often required early with limited data**
- **Selection of bus voltage is driven by the need to minimize distribution mass and I^2R loses**
- **Channelizing distribution needs to be considered to optimize bus to bus cable ampacity**
- **Voltage selection should optimize mass and available volume**
- **Ultimately voltage selection is limited based on parts availability, plasma interactions, heritage and safety**

As future spacecraft power exceed 50 kW system designers will be forced to increase bus voltages beyond the norm

References

- Kerslake, Thomas W, 2003, "Effect of Voltage Level on Power System Design for Solar Electric Propulsion Missions", NASA/TM-2003-212304
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Credits & Acknowledgments

- Luis Pinero – NASA Glenn Research Center
- Carolyn Storer – NASA Glenn Research Center