Power Electronics for the Next Generation

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Where We Have Been
So You Need Power?

• Who Gives a Watt?
  – And what does that Watt Cost you?
Workhorse of a Spacecraft Power System

• NiCad Battery
  – 22 Watt Hour / kg
    • TRMM Spacecraft  2 batteries with total weight of 278 Pounds (126 kg)

• Nickel Hydrogen
  – 30 to 40 Watt Hour / kg
    • HST  6 Batteries with a total weight of 930 Pounds (421 kg)

• Lithium Ion
  – 80 Watt Hour / kg
    • SDO 1 Battery with a total weight of 97 Pounds (44 kg)

Note: Mixing of Units
Battery Weight Does Not Include

• Solar Arrays
• Power Handling Electronics
• Harness
• Spacecraft Structure to Handle the Weight of the Batteries
• Cooling Equipment
Crude Voltage Estimates for Batteries Over One Orbit

• NiCad Battery
  – End of Day: 33V   End of Eclipse: 26.4V   \( \Delta V = 6.6V \)

• Nickel Hydrogen
  – End of Day: 33V   End of Eclipse: 26.4V   \( \Delta V = 6.6V \)

• Lithium Ion
  – End of Day: 32V   End of Eclipse: 28.8V   \( \Delta V = 3.2V \)
Allowed Voltage Variation on Electronic Logic

• Neon Logic
  – 95v to 500v allowed ripple: 15 volts – 20 volts

• CD4000 Logic
  – 5v to 20v allowed ripple: 1 volt at 5 volt input.

• 74HC Logic
  – 2v to 7v Allowed ripple: 0.5 volt at 4 volt input.

• FPGA’s
  – 3.14v to 3.45 and 1.43v to 1.57v Allowed ripple: 0.015 volt input.
Problems in Developing What We Have.
Top 5 Problems

• Lack of Requirements / Requirements Creep.
• Overloading and UNDERLOADING: Both are bad, underloading is less understood.
• Thermal
• Robustness (Distinct from Redundancy)
• Parts Design Changes and Thermal Instability Issues
Where We are Going
Getting Power to Your Parts

Solar Array

Battery

+ Spacecraft Power Distribution

Box Level Power Conversion

Backplane

Load

Load
Getting Power to Your Parts
Harness Drop and Voltage Variations.

20 Watt Load
(1 Watt in Harness)

ΔV=6V

26.4 V

0.8 A

25.1 V

Logic Level Voltage Drop Allowed
Resistances Needed to Remain in Specification Due to Logic.

20 Watt Load

<table>
<thead>
<tr>
<th>Logic Family</th>
<th>Volts</th>
<th>Ripple</th>
<th>Current</th>
<th>Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neon Bulb</td>
<td>150.0</td>
<td>20.0</td>
<td>0.1</td>
<td>150.0</td>
</tr>
<tr>
<td>CD4000</td>
<td>5.0</td>
<td>1.0</td>
<td>4.0</td>
<td>0.3</td>
</tr>
<tr>
<td>54HC</td>
<td>4.0</td>
<td>0.5</td>
<td>5.0</td>
<td>0.1</td>
</tr>
<tr>
<td>FPGA</td>
<td>3.3</td>
<td>0.04</td>
<td>6.1</td>
<td>0.007</td>
</tr>
<tr>
<td>Core FPGA</td>
<td>1.5</td>
<td>0.015</td>
<td>13.3</td>
<td>0.001</td>
</tr>
</tbody>
</table>
Power Delivery Internal to a Box

<table>
<thead>
<tr>
<th>Logic Family</th>
<th>Resistance</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neon Bulb</td>
<td>150.0</td>
<td>Lay out the board</td>
</tr>
<tr>
<td>CD4000</td>
<td>0.3</td>
<td>Be careful in board layout</td>
</tr>
<tr>
<td>54HC</td>
<td>0.1</td>
<td>Ground Plains, Extra Pins, Filtering</td>
</tr>
<tr>
<td>FPGA</td>
<td>0.007</td>
<td>?</td>
</tr>
<tr>
<td>Core FPGA</td>
<td>0.001</td>
<td>?</td>
</tr>
</tbody>
</table>

If you can not get there from here.....
Power Delivery Internal to a Box

If you can not get there from here.....

Go somewhere else first!
Point of Load Converters
The JWST ICDH Approach

• James Webb Space Telescope’s Instrument Command and Data Handling Box has 20 FPGA’s.

• The Approach was to use Low Drop-out Linear regulators near each FPGA.
Point of Load Converters
The JWST ICDH Approach

• Low Drop-out Linear Regulators had problems with Radiation.

• Changed for Homemade Linear Regulator, which took up too much space and was complex.

• Final Approach was to use “Standard” Linear regulators. (5.0 Volt to 1.5 Volt) With over all efficiency of 30%.
Note on Homemade Linear Regulator.

- Late in the development cycle on JWST it was learned at GSFC that there is a **Thermal Instability** with MOSFETs when Vgs is below ~ 7 volts (Linear Region).

  - As manufactures work to make their MOSFETs faster and lower in On-Resistance, the problem is already causing failures and is becoming worse.
Thermal Instability
The MOSFET Technical Bulletin (10-01) has been reviewed by Export Control and deemed Non-ITAR. This document is now available on the NRB PBMA at http://secureworkgroups.grc.nasa.gov/nesc-review-board?go=396207.

http://ntrs.nasa.gov/search.jsp?R=699181&id=1&as=false&or=false&qs=Ntt%3Dmosfet%26Ntk%3Dall%26Ntx%3Dmode%2Bmatchall%26Ns%3DHarvestDate%257c1%26N%3D0
Point of Load
The Next Step

• With the drive for MORE Current, Smaller Input Voltages, and Higher Efficiencies.

• The Next Step is a Switching Regulator
Point of Load Switching Converters

• Non-isolation Converters (Input & Output Grounds are Common)
• High Efficiency (80% to 97%)
• Small (1.5 inches square)

• Commercial Vendors are starting to be interested in manufacturing Point of Load Converters. These are Hybrid Converters
Plans to Qualify Point of Load’s

- Obtaining Point of Load’s from several vendors.
- Test converters to determine what they can / can not do.
- Bring Manufacturing up to Flight Standard’s
- Testing will be done according to the NESC paper on DC – DC Converters. [http://standards.nasa.gov/](http://standards.nasa.gov/)
  - Keyword -or- Document Number search on “DC/DC Converter”
Plans to Qualify Point of Load’s Key Tests

• Performance under low loads and high loads
  – Stability
  – Efficiency

• Performance with dynamic loading on input as well as output.

• EMI