Nano-Satellite Electrical Power Sub-System Architecture

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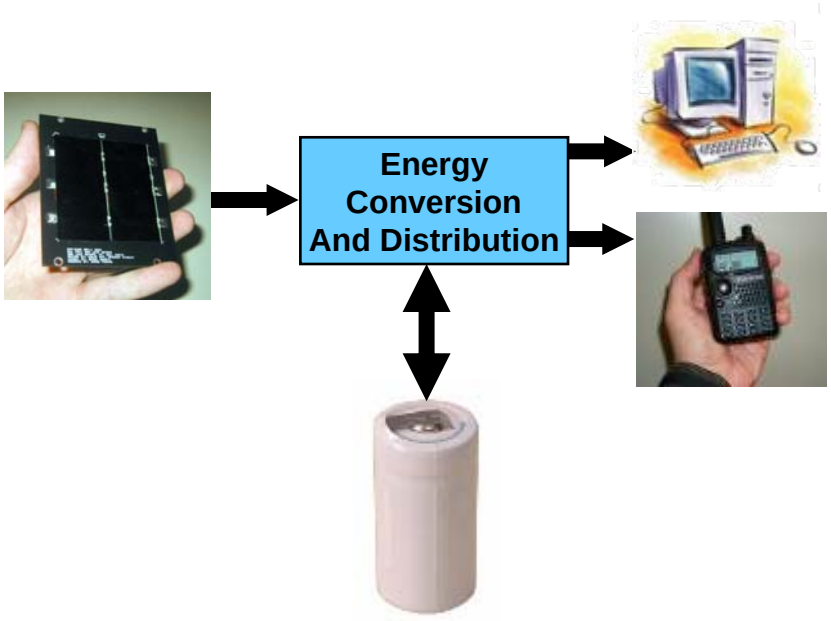
Sound Electrical Power Sub-System (EPS) Design

- Essential for Mission Success

- Previously Observed EPS Design Failures
  - Charging system
  - Over-current protection
  - Battery pack failure

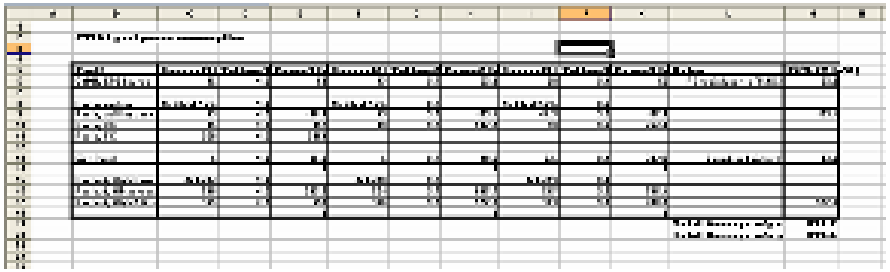


- Good Design Practices
  - Design for redundancy in high failure rate components
    - Batteries and charge controllers
    - Design with multiple power branches to isolate failures and keep core systems functional
    - Design with margin, preferably 50% or more
  - Test, test, test…
    - Test the system with available circuits as early as possible
    - The easiest problems to solve are the problems found early
    - Test at worst case limits
      - » At least once
      - » Whenever possible
    - Thoroughly test subsystems together

Power Budget Key to Design

- Starting Point in EPS design

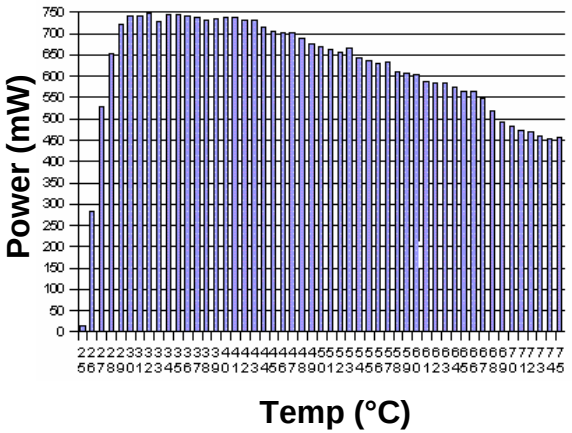
- Basic Concept - Capture details of power input and power output in a spreadsheet for analysis
- Design Considerations
  - Solar cells may operate hotter and at a lower power than the datasheet specifies (usually around 28°C)
  - Consider the power consumed by devices (especially microcontrollers) while in both sleep mode and active mode
  - Include margins to accommodate unknowns and inaccuracies with datasheet information
  - Also create a (peak) power budget for each mode of operation
  - Account for beginning of life and end of life power production and requirements
  - Increase the number of Power Modes to increase fidelity

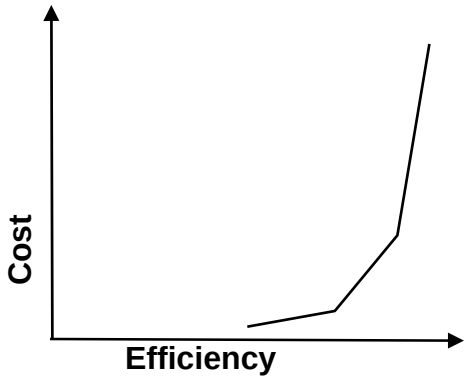


Integrating Solar Cells into EPS Architecture

- Considerations and Options

- Direct Energy Transfer (DET) vs. Maximum Power Point Tracking (MPPT)
  - MPPT allows operation at the solar panel's maximum power point and allows greater power production
  - DET is simpler and connects the solar arrays directly to the battery bus
- Solar panel operating power varies significantly with temperature
  - Typical solar cells in LEO reach around 67°C but many solar cell datasheets use a reference temperature of only 28°C
  - Temperature of the array nominally accounts for about 15% power degradation
- Solar cells cost vs efficiency considerations
  - Commercially available solar cell cost vs efficiency are generally inversely proportional
- Shunting circuitry may be required to limit peak solar panel voltages





Regulated / Unregulated Key Trade

- Power Converters Key to Efficient Design

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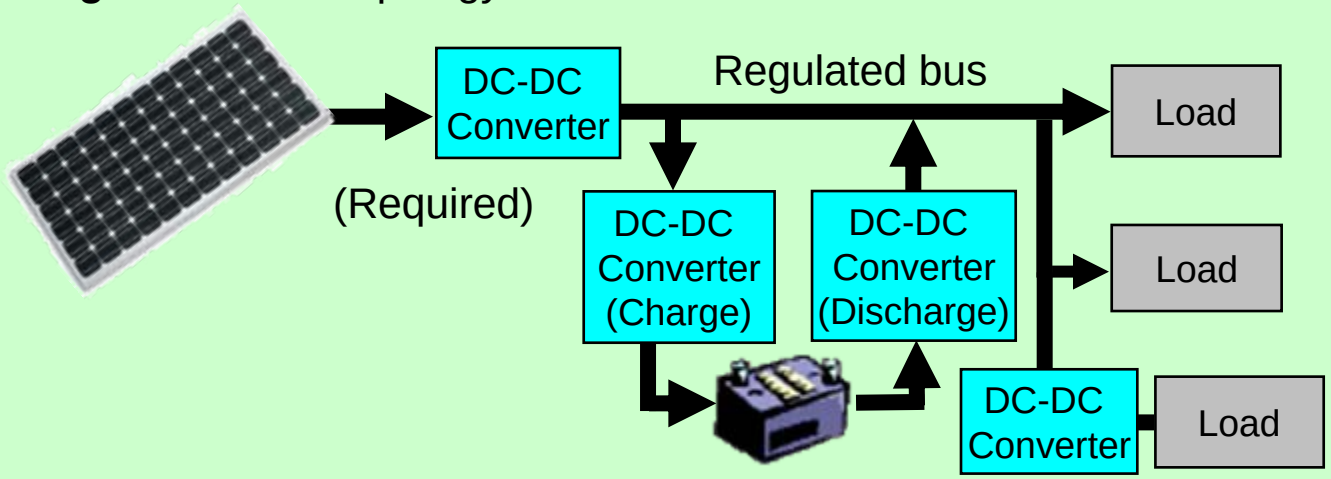
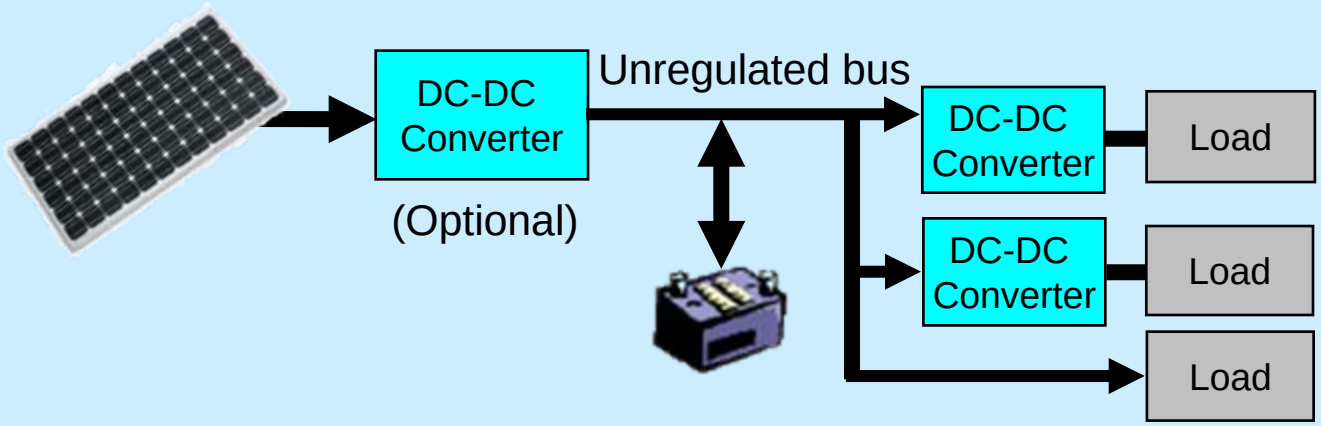
Regulated Bus Topology



- **Pros**
  - Low bus impedance
  - Fixed solar array working point
- **Cons**
  - Lower efficiency
  - More difficult to avoid single point failures

Unregulated (Battery Clamped) Topology



- **Pros**
  - Load is buffered from bus noise
  - Large currents are available
- **Cons**
  - Complex load regulation

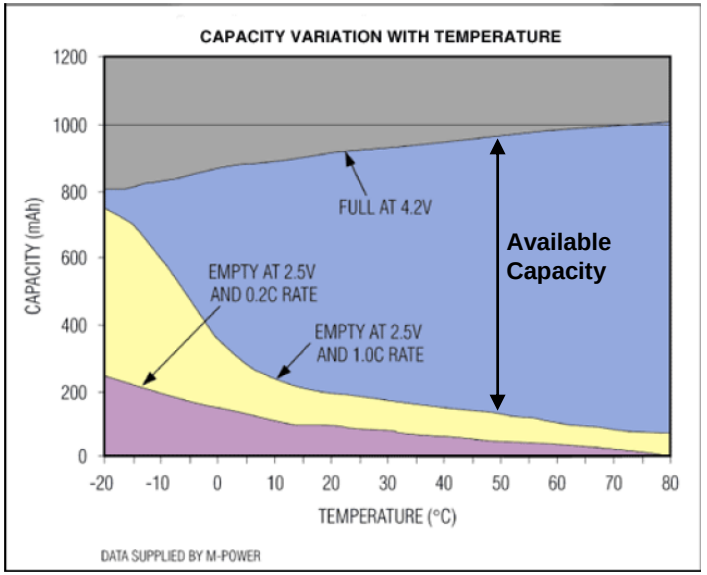
Battery Use Guidelines

- Care and Feeding Instructions for your Batteries

- References
  - Batteries in a Portable World - Isidor Buchmann, 2001
  - Handbook Of Batteries - David Linden, Thomas B. Reddy, 2001
- Shelf life
  - Life begins at the time of manufacture
  - Lower temperatures extend battery life
  - Lower state of charge extends battery life
- Cycle life
  - Increased Depth of Discharge (DOD) will decrease cycle life logarithmically
- Temperature considerations
  - Limited operating temperature range
  - Useable energy varies significantly over temperature

Effect of Charge and Temperature on Non-recoverable Battery Loss

Temperature	40% charge level (recommended storage charge level)	100% charge level (typical user charge level)
0°C	98% after 1 year	94% after 1 year
25°C	96% after 1 year	80% after 1 year
40°C	85% after 1 year	65% after 1 year
60°C	75% after 1 year	60% after 3 months



http://pdfserv.maxim-ic.com/en/an/AN3958.pdf
http://www.buchmann.ca

Choosing an appropriate Regulator
- *Depends on Application*

- Linear Regulator
  - Good for very low power loads
  - Good for noise sensitive loads
- Switching Converter (Switching Regulator)
  - Very energy efficient
  - For most loads, this is the best choice

Parameter	Linear (LDO)	Switching Converter
Noise and Electrical Ripple	**Low**	High
Energy Efficiency	Low	**High**
Physical Size	Small	Large
Heat Dissipation	High	Low
Transient Response	Fast	Average
Function	Only steps down	**Steps up or down**
Design Complexity	Low	Medium to High

Selecting a Specific Switching Converter

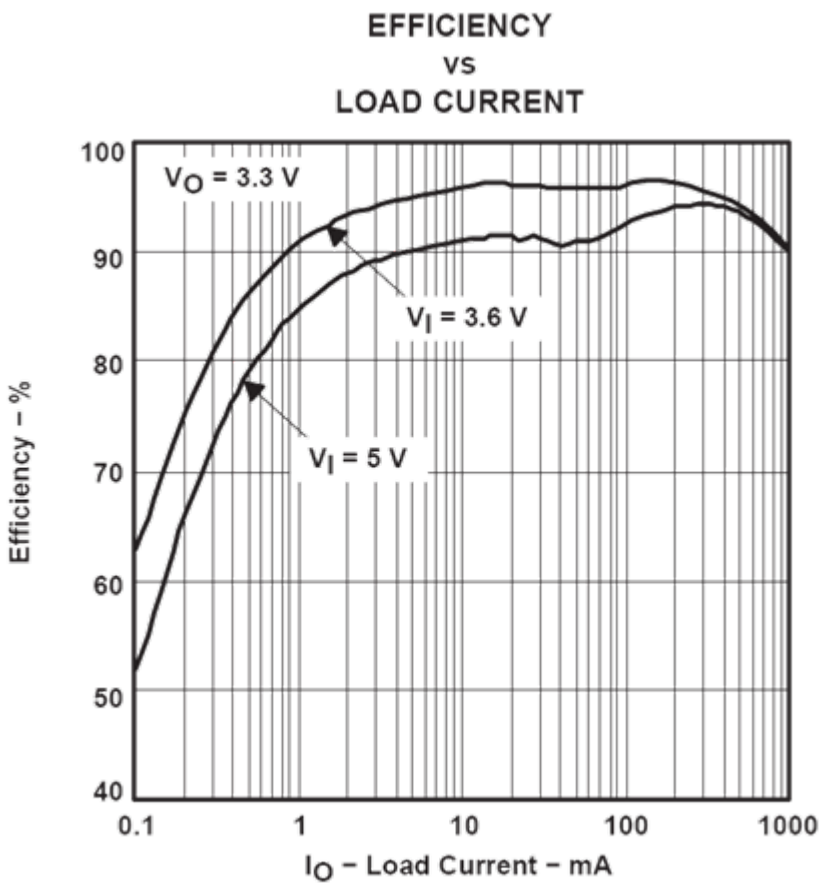
- Selecting a Switching Converter

- Choose carefully between switching converter topologies
  - Buck, Boost, Buck-Boost, and Flyback are popular topologies each with their own characteristics
  - Is electrical isolation required?
  - Is the voltage always being reduced, increased or could it be either?
- Synchronous rectification is optional
  - Increases efficiency
  - Can achieve 5% better efficiency
  - Uses extra MOSFETs
- Look for low quiescent current, low I_Q (Bad for engineers, good for converters)

Selecting a Specific Switching Converter

- *Suggestions in Selecting and Using a Switching Converter*

- Pay careful attention to control loop compensation –
  - Follow converter datasheets or
  - Find a seasoned engineer to help with more complex designs
- Pay careful attention to the performance listed in the datasheet
  - Efficiency drops at greater input to output voltage ratios
  - Note the efficiency drop off at low and high load currents



http://www.ti.com/lit/gpn/tps62000

Additional resources

- Suggestions for Future Reading

- **DC-DC converter design resources:**
  - http://focus.ti.com/docs/toolsw/folders/print/switcherpro.html
  - http://www.elecdesign.com/Articles/Index.cfm?AD=1&ArticleID=15826
  - http://www.recom-international.com/pdf/Application-Notes-2006-2nd-edition.pdf
  - http://www.maxim-ic.com/appnotes.cfm/appnote_number/2031/
  - http://focus.ti.com/lit/ml/sluw001a/sluw001a.pdf
  - http://www.maxim-ic.com/quick_view2.cfm/qv_pk/1837

- **General satellite EPS architecture**
  - http://www.aiaa.org/content.cfm?pageid=406&gTable=japaperimportPre97&gID=23224
  - http://insa.netquire.com/docs/Lessons_Learned_Fina.pdf
  - http://cubesat.atl.calpoly.edu/media/Documents/Papers/stensat_hist.pdf
  - http://ssdl.stanford.edu/classes/AA236/2005A/documents/aa236/PSIREX.pdf
  - http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=1488259

- **Batteries**
  - http://www.sciencedirect.com/science?_ob=MImg&_imagekey=B6TH1-460WHH7-5-G&_cdi=5269&_user=615015&_orig=search&_coverDate=09%2F18%2F2002&_sk=998889998&view=c&wchp=dGLbVlb-zSkzV&md5=a6598a3fb41af60ca5725eb82d0a5ee8&ie=/sdarticle.pdf
  - http://www.sciencedirect.com/science?_ob=MiamiImageURL&_imagekey=B6TH1-43X7V64-G-1J&_cdi=5269&_user=615015&_check=y&_orig=search&_coverDate=10%2F15%2F2001&view=c&wchp=dGLbVlb-zSkzV&md5=abb5472ea9c3c08608b13d0a2191445d&ie=/sdarticle.pdf
  - http://www.motorola.com/testservices/article1.htm
  - http://www.amazon.com/Handbook-Batteries-David-Linden/dp/0071359788/ref=pd_bbs_sr_1?ie=UTF8&s=books&qid=1204572533&sr=1-1

Questions?