Power Budgets for Mission Success

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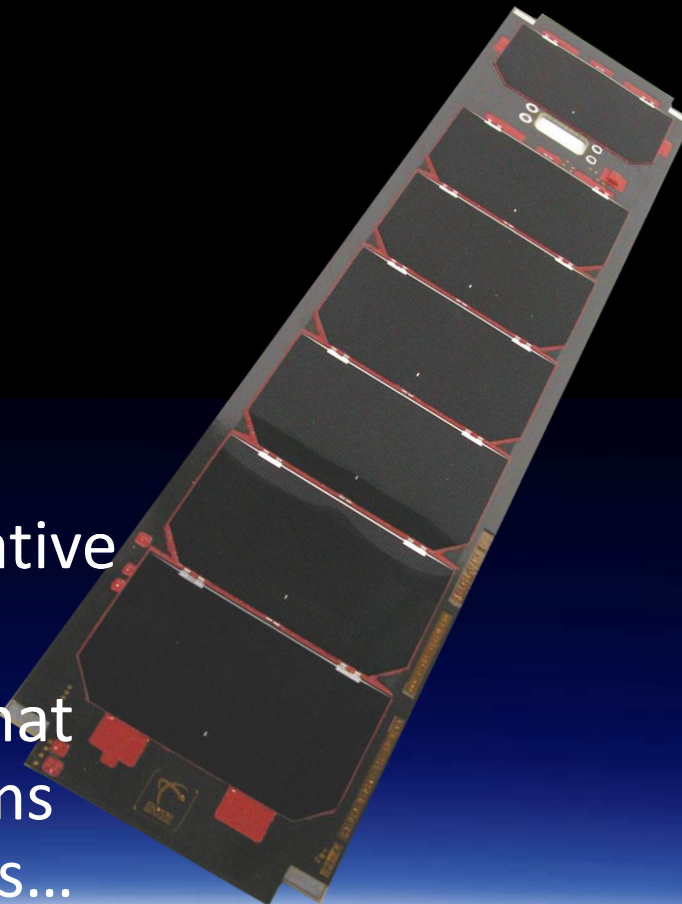
Outline

1. The CubeSat power challenge
2. Estimating orbit average power
3. Power usage
4. Load control and unloading function
5. Conclusion

CUBESAT POWER CHALLENGE

‘P’ stands for Precious

- No matter the size of the CubeSat, or the configuration, power is always precious on a CubeSat.
- In practice, this means that power usage must be moderated and managed.
- A CubeSat mission should never be allowed to fail due to having a negative power budget.
- There are some simple measures that can be incorporated into the systems and spacecraft design to ensure this…



Energy in = Energy out

- Power on a spacecraft is a bit like filling up a bath with water with the plug out.
  - The bigger the plug hole, the more water needs to be poured in to maintain a sufficient water level.
  - If this is not possible, the only other thing you can do is reduce the size of the plug hole.
- If a mission doesn't have a way to actively control the power draw from the bus, it is in danger of completely discharging the battery.

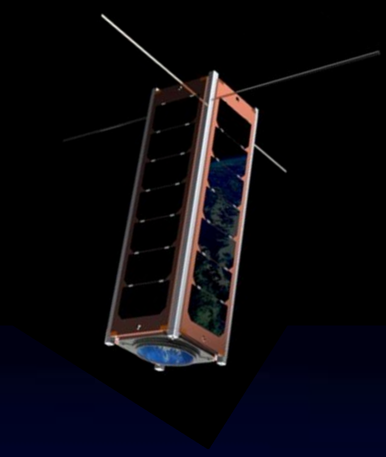
ESTIMATING ORBIT AVERAGE POWER

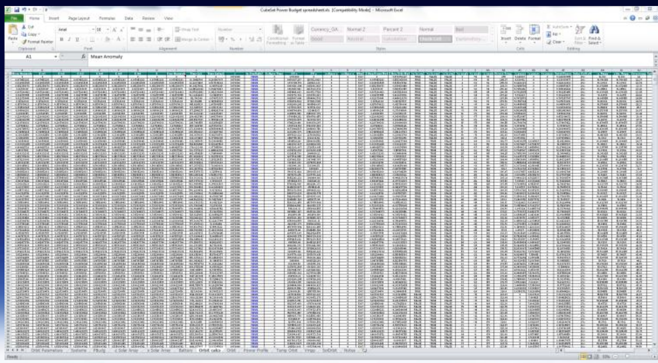
Orbit Average Power (OAP)

- Orbit Average Power (or OAP) is one of the most important figures derived from the spacecraft systems design.
  - It defines how much power is available per orbit
  - It determines how much power you can use.
- A power budget is basically your OAP minus Average Power Used.
  - A negative power budget is where you use more power than is available per orbit.
  - A positive power budget means you have power left over.
- It is possible to operate a spacecraft with a negative power budget for a few orbits
  - This is typically as part of an operation strategy
  - But is risky and requires the spacecraft to have a positive power budget for several subsequent orbits.

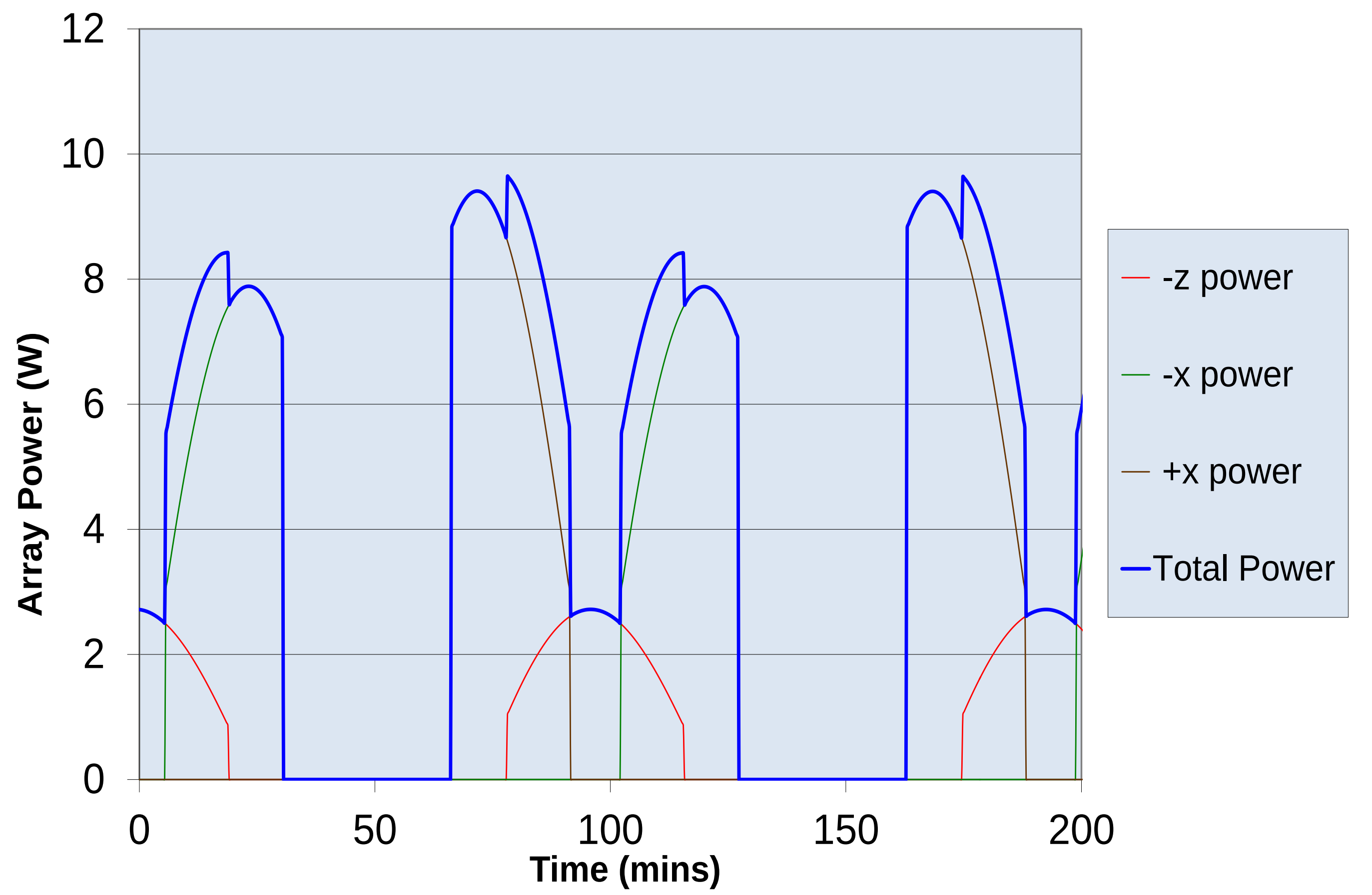
How to calculate OAP

- A simple box satellite with 4 solar panels (X/Y facets) in LEO:
  - Rule of thumb is OAP = 60% * Power from one panel.
  - FOUR 8W panels means an OAP of 4.8W.
- Orbit models can be used to give more accurate results
  - Important when using complex array configurations.
  - Excel is adequate for this, but tools are available such as STK.





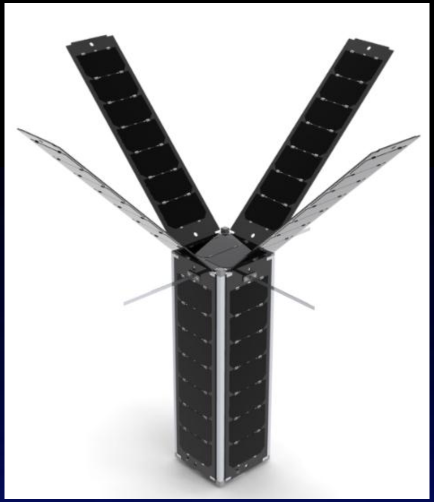
Example 3U Power Profile



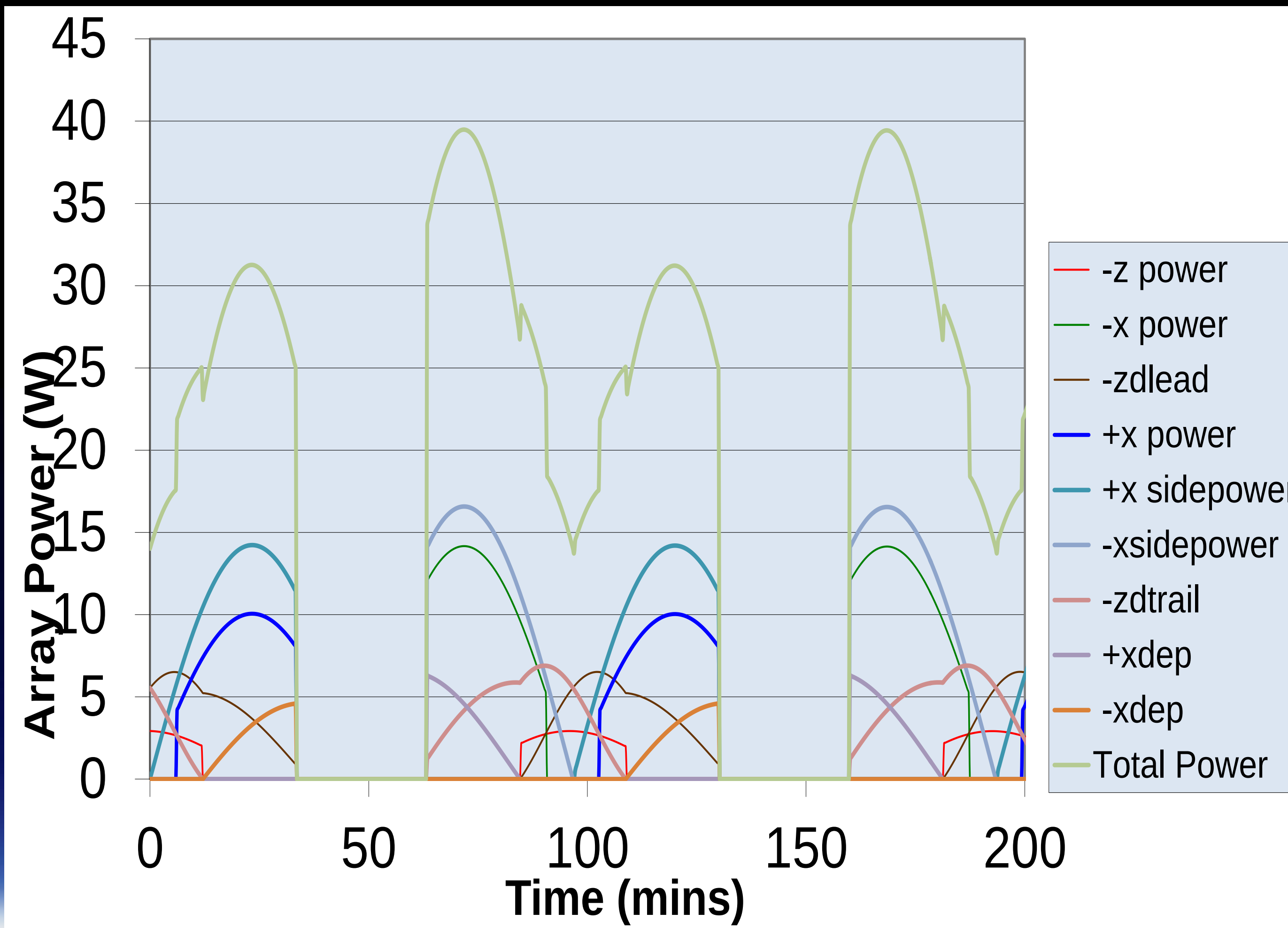
- From complex Excel orbit model
- Orbit average power of 4.9W (including 10% Albedo).
- Peak power is 9W over the poles.
- Concurs with ‘rule of thumb’ estimate.

Complex model design

- Design of a power budget calculator is a great student project.
- Model must simulate the spacecraft orbit reasonably accurately.
  - Enough to obtain sun angles, eclipse and sunlight times.
- Must take into account power usage throughout orbit, power system efficiencies, design margins, degradation/losses and solar array configuration.



Models can get quite complex



- Orbit average power of 20.8W
- Peak power is 40W.

POWER USAGE

Basic System Model

- A power system model defines:
  - Every electrical subsystem and payload and the power consumption.
  - The duty cycle of the subsystem and payload
    - e.g.is it on 10% or 100% of the orbit?
    - TX units are typically on for 10%
    - RX units are on for 100%
  - Power margin
    - The greater the uncertainty, the higher the margin

Example System Model

			Orbit		Eclipse	
	Power	Number	Avg Duty Cycle	Watts	Avg Duty Cycle	Watts
	(W) each	Active	(%)		In Eclipse (%)	
PAYLOAD						
Payload	2.1	1	100	2.1	100	2.1
			Total	2.1	Total	2.1
PLATFORM SUB-SYSTEMS						
Communications						
UHF TX	1.9	1	10	0.2	10	0.2
VHF RX	0.15	1	100	0.2	100	0.2
ADCS						
ADCS Board	0.1	1	100	0.1	100	0.1
Magnetorquers	0.1	1	2	0.0	2	0.0
Sensors	0.01	1	100	0.0	100	0.0
On-Board Data Handling						
OBC	0.25	1	100	0.3	100	0.3
Thermal Control System						
Battery Heaters	2	1	0	0.0	0	0.0
Power						
Power System Electronics	0.05	1	100	0.1	100	0.1
Platform Subtotal				0.8		0.8
Margin (platform and payload)				20%		20%
			Total	**3.4**	**Total**	**3.4**

Power budget

- Things to remember:
  - The power from the arrays will suffer degradation with time and line losses.
  - Power system architecture has a massive impact (peak power tracker vs direct energy transfer).
  - The energy taken from the battery in eclipse needs to be replaced in sunlight + battery losses.
  - Albedo is a bonus not a certainty
    - I'd recommend not relying on it for your mission success; if you do then your power budget is too tight.

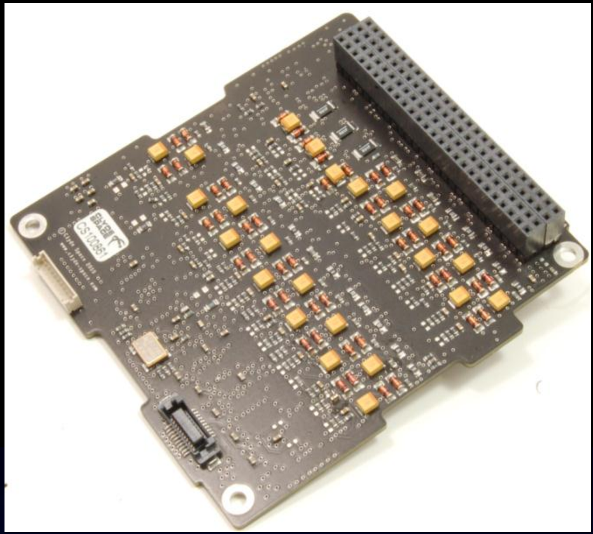
Example power budget

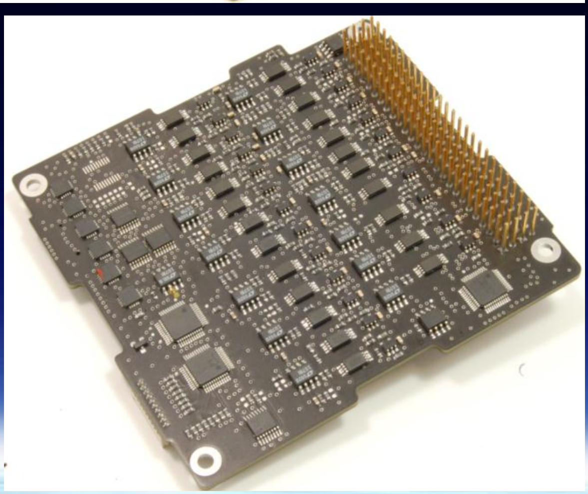
Orbit Average Power	6.76W
Power Reduction EOL and MPPT error	3%
Adjusted EOL OAP (at 28C)	6.56W
Average eclipse Power consumption	3.4W
Maximum Eclipse Period	30.1mins
Power requirments	1.7W
Battery Return Factor	1.1
Battery Capacity required	1.89Wh
Battery Capacity available	27.75Wh
Actual DoD	7%
Time in Sunlight	1.1hrs
Average Charge Power during sunlight	1.7W
Power System Efficiency Figures	
Path from Solar Arrays to Power Bus	90%
Path from Power Bus to Battery	100%
Path from Battery to Power Bus	100%
Path from Power Bus to Platform and Payload	99%
Power Budget Summary	
Power To Battery in Sunlight	1.7W
Available Solar Array Power at Bus (EOL)	5.9W
Remaining OAP Available	4.2W
OAP Required During Sunlight	5.2W
Margin (EOL)	14%
Margin (EOL)	0.75W

LOAD CONTROL
AND UNLOADING FUNCTION

The power of the switch

- The ‘power bus’ approach is quite unique to CubeSats.
  - Where load management is devolved.
- Most satellites have a ‘Power Distribution Module’ (PDM).
- PDM provides functions essential to mission survival in times of anomaly.
  - Over-current protection.
  - Load management (switch things ON and OFF)
  - Battery under-voltage protection (or Unloading Function).
- Switch Board opposite has 24 power switches at 4 different voltages.
  - (Note, our EPS protects each power bus with a switch and this has under-voltage protection)





Unloading function

- What is the unloading function and why is it so important?
  - All subsystems and payloads must be ‘switched’ individually (supplied by a switch).
  - Software safety task can monitor battery state of charge
    - Shut down subsystems if voltage is low in order of priority.
    - Can put spacecraft into ‘Safe-Mode’.
  - Hardware absolute minimum battery voltage is back-up to this safety task.
  - In the event of an anomaly resulting in an unsustainable power situation, the hardware back-up resets all of the power switches to nominal state.
    - If the software safety task is not functional, the battery discharges to a minimum voltage and the power system turns everything off until the battery has recharged to a reasonable level.
    - At this point the spacecraft will be in a safe configuration with only essential systems on and a positive power budget.
- **Without the Unloading Function, the spacecraft will remain in a negative power budget and will never recover!**

CONCLUSIONS

Conclusions

- Know the power limits of your mission and stay within them.
- A CubeSat launched with a known negative power budget is ‘space debris’.
- Have an understood power margin.
  - If you end up with more power on orbit you can increase payload operations …
- Make sure you can switch OFF non-essential subsystems and payloads
  - Your spacecraft will never recover from a negative power budget if the load cannot be removed.
- Finally: Design your safety features such that you can modify them if needed
  - i.e. software defined battery voltage safety limits

Questions?

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