Designing for Success:
Choosing CubeSat Components Wisely

Andrew E. Kalman, Ph.D.
Introduction

• Andrew E. Kalman
  ▪ President and CTO, Pumpkin, Inc.
  ▪ Author of Salvo
    The RTOS that runs in tiny places.
  ▪ Creator of the CUBE SAT KIT
  ▪ 20+ years of embedded systems design and programming experience.
  ▪ Contact: aek@pumpkininc.com
Outline

• Overview: Presentation Goals
• Part I: Building vs. Buying
• Part II: Extreme Timelines
• Part III: Examples
• Part IV: Suggested Guidelines
Overview

• This presentation is targeted at educators, students and project managers who are working to rapidly develop hardware & software for CubeSat missions.

• With over 30 Pumpkin CubeSat Kits in customer hands, we have seen customers faced with a variety of design decisions as their CubeSat projects progress towards completion.

• We examine three critical areas that will affect every CubeSat project – PCB fabrication, connectors and software – and supply examples of choices to be made for the sake of efficiency.

• Finally, we provide some guidelines to aid in successfully designing for CubeSat missions within the relatively short timeframes available.
Part I: Building vs. Buying

• Advantages of building something from scratch:
  ▪ Pride in building something yourself.
  ▪ Educational experience.
  ▪ Custom size / power / functionality requirements.
  ▪ Exactly what you wanted.

• Advantages of buying off-the-shelf (COTS) components:
  ▪ Much faster design & integration process.
  ▪ Often cheaper, especially when time is factored in.
  ▪ Effort is the same for 1 or 100 units.
  ▪ Let someone else worry about the details.
  ▪ Often built for interoperability via standards.
  ▪ You’re not alone.
Building vs. Buying (cont’d)

• Disadvantages of building something from scratch:
  ▪ Expertise may be lacking.
  ▪ Ramp-up time may not be available.
  ▪ Substantial NRE in labor, tools & materials.
  ▪ Design iterations take time. Early revisions are likely to have errors, esp. as complexity increases.
  ▪ Resulting product may be a dead end.

• Disadvantages of buying off-the-shelf components:
  ▪ Advertised cost & availability may not reflect reality.
  ▪ Generally not designed for space use (e.g. temp. ratings).
  ▪ Dependent on supplier for support.
  ▪ Often not an “ideal fit” to your architecture or plans.
  ▪ Higher apparent cost.
Building vs. Buying (cont’d)

• A CubeSat will likely be a combination of COTS (i.e. bought) components and custom (i.e. built) components. The trick is to choose wisely ...

• For proof-of-concept work – where mass, volume and power constraints are not an issue – “going all COTS” saves lots of time.
Building vs. Buying (cont’d)

• Building and buying are both affected by parts availability:
  ▪ RoHS and WEEE have recently caused many parts sourcing difficulties, esp. in the USA. Most parts are now Pb-free, etc.
  ▪ *Parts obsolescence* is unavoidable in the electronics industry. Microcontrollers and commodity discretes have relatively long lifespans. Other, more specialized components are often subject to availability and/or allocation, or are simply phased out. Designers must deal with these issues on a regular basis. Parts can become unavailable overnight.
  ▪ Increasing miniaturization forces PCB redesigns to keep up with newer package offerings.
  ▪ Because of their small numbers and their low parts costs, CubeSats have little or no clout with parts manufacturers and are at the mercy of bigger market forces.

• One advantage of CubeSats is their relatively low internal parts cost. Therefore *lifetime buys* of critical components should be seriously considered, thereby alleviating worries about availability.
Part II: Extreme Timelines

• 12 to 18 months appears to be the current desired timeframe for CubeSat development within educational settings. Projects with larger scopes can take much longer.

• Since students pass in and out of CubeSat projects relatively quickly, it is imperative to organize their efforts to yield a sense of ownership and accomplishment for each student. At the end of a term, each student or team of students should deliver a complete, functional and well-documented CubeSat module (hardware and software) that can be integrated into the whole with a minimum of further changes.

• When succeeding students & teams do not build upon previous efforts, timelines are invariably stretched out.

• Even student-led projects appear to develop NIH syndrome …
Part III: Examples

- PCB Fabrication:
  - 2 Layer, FR4, 4” x 4” (10cm x 10cm), Cu Wt: 1 oz, Trace/Space: 0.008”, Holes: 300, Small Hole: 0.015”, SMD: Both Sides, Pitch: 0.025”, SMD Pads: 300, Mask: Both Sides, Silkscreen: Top Side, 0 Gold Fingers, 0 Cutouts/Slots, Individual, No Testing, Delivery: 7 days:
    - 30g for 0.062” (1.5mm). Using “Proto Special Pricing”, $10 ea. for qty 10, + $10 shipping = $110 total, i.e. $11 per PCB.
    - 15g for 0.031” (0.75mm). Price rises to $22.27 ea. for qty 10, + $100 tooling + $10 shipping = $332.70 total, i.e. $33.27 per PCB.
Part III: Examples (cont’d)

• PCB Fabrication (cont’d):
  - Idea is to take advantage of “best buys” for prototyping and proof-of-concept, and then optimize design for CubeSat specifications in following iteration(s). Parametric changes (e.g. PCB thickness) can have far-reaching implications. 1st revision often has errors!
  - Going from 0.062” (1.5mm) to 0.031” (0.75mm) Solar Panel PCBs saves nearly 100g (10% of CubeSat’s mass) for six sides! Therefore “slight deviations from the norm” (here, the norm is 0.062” PCB thickness) are often highly desirable.
  - The demands of the CubeSat specification (esp. low mass) push the prices of fabrication (e.g. PCB fab) out of the mainstream and into the higher-cost custom region.
  - With increased standardization amongst CubeSats, these costs can be reduced as manufacturing volumes increase. Greater demand for CubeSat-specific components can substantially reduce their per-unit cost by reducing the impact of NRE for custom fabrication.
### Part III: Examples (cont’d)

- **Connectors:**

<table>
<thead>
<tr>
<th>Type / Method</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Point-to-point wiring</td>
<td>No unused pins, <em>can be implemented anywhere</em></td>
<td><em>Heavy</em>, require larger volume than most connectors, require desoldering or end connectors for disassembly, easily damaged</td>
</tr>
<tr>
<td>Flat cable</td>
<td>Connectors are very small, few unused pins, 3-D <em>bendable</em>, generally interchangeable across manufacturers</td>
<td><em>Not designed for vibration or extreme temps</em>, not volume-efficient (single row), limited insertion cycles</td>
</tr>
<tr>
<td>High-density board-to-board interconnects</td>
<td><em>Low mass &amp; volume</em>, few unused pins, rugged, positive engagement, well-suited for card-cage architectures</td>
<td>Generally single-sourced, <em>inflexible stacking heights and arrangements</em>, expensive, low-to-moderate currents</td>
</tr>
<tr>
<td>PC/104-style</td>
<td><em>Industrial-grade</em>, readily available, rated for high currents, <em>wide range of stacking heights</em>, all modules have same pinout</td>
<td><em>Moderate mass &amp; volume</em>, potentially many unused semi-exposed pins</td>
</tr>
</tbody>
</table>
Part III: Examples (cont’d)

- Connectors (cont’d):
  - A CubeSat is likely to employ several types of connectors, based on their unique strengths, e.g.
    - Point-to-point wiring to attach Solar Panel PCBs to EPS.
    - PC/104 stackable connectors as a backbone.
    - Inter-board stacking connectors to attach complex daughter boards, etc.

By adopting a PC/104-centric connector scheme for the CubeSat Kit, our customers are able to use components 15mm and higher in any module slot, instead of having per-slot height restrictions.
### Part III: Examples (cont’d)

- **Software:**

<table>
<thead>
<tr>
<th>Type / Method</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do-It-Yourself</td>
<td><em>No up-front cost</em>, exciting to create something new, may have size or speed advantage, can be quick to implement</td>
<td><em>Can take much more time than originally anticipated</em>, unlikely to be well-tested, often poorly documented, often feature-poor, no support, unique code</td>
</tr>
<tr>
<td>Find Something Free on the ‘Net</td>
<td><em>Reputed to work</em>, may be just what you’re looking for, often comes with source code, commonality across users</td>
<td><em>Usually no direct support</em>, quality varies wildly, copyright / IP issues</td>
</tr>
<tr>
<td>Purchase</td>
<td><em>Proven rack record</em>, good support and documentation, fully-featured, clear licensing, commonality across users</td>
<td><em>Expensive</em>, might not be exactly what you wanted, may not include source code</td>
</tr>
</tbody>
</table>
Part III: Examples (cont’d)

- Software (cont’d):
  - The Rev B CubeSat Kit introduced an SD/MMC card socket.
    - At first, we thought we might write the interface code (SD, FAT12, etc.) ourselves. But time pressures and lack of expertise made us conclude we could not economically deliver a robust solution.
    - Next, we found and made available to our customers an example project (a university class final project) using the same processor (MSP430) with rudimentary SD card I/O and FAT features. It does not appear to have proven very popular …
    - Currently, we are investigating licensing a commercial, small-footprint SD card software solution in library / object form for our customers, as a CubeSat Kit add-on.
Part IV: Suggested Guidelines

• Don’t be afraid to employ non-mainstream components in novel ways as long as you can justify their use over simpler, mainstream components. *CubeSats are about innovation in a small space.*

• Often, unique components will be required. If you must single-source (e.g. from Maxim), secure a lifetime buy’s worth of components before committing to the design.

• Wherever possible, choose multiply-sourced and popular parts. A part that Digi-Key® has 2,000+ pieces of in stock is usually a better choice than one that requires special sourcing.

• Avail yourself of the manufacturer’s technical support.

• Budget time for 2\textsuperscript{nd} & 3\textsuperscript{rd} revisions to work all your bugs out and optimize your design. Iterate. There will be unexpected delays.

• Reaching the 1kg mass target may add extra costs. Plan ahead.

• Build only what you must. Buy what you can. Leverage the help of others, even when it isn’t free. You must work efficiently and accurately.
Notice

This presentation is available online in Microsoft® PowerPoint® and Adobe® Acrobat® formats at:

www.pumpkininc.com/content/doc/press/Pumpkin_SmallSat-2006.ppt

and:

www.pumpkininc.com/content/doc/press/Pumpkin_SmallSat-2006.pdf
Q&A Session

Thank you for attending the workshop!
Notes & References

3. PCB price quotes via [http://www.pcb4u.com](http://www.pcb4u.com) (Accutrace, Inc.).
4. For connectors of many different types (including PC/104 and inter-board), please see [http://www.samtec.com](http://www.samtec.com).
5. Digi-Key is at [http://www.digi-key.com](http://www.digi-key.com).
Appendix

• Speaker information
  - Dr. Kalman is Pumpkin’s president and chief technology architect. He entered the embedded programming world in the mid-1980's. After co-founding Euphonix, Inc – the pioneering Silicon Valley high-tech pro-audio company – he founded Pumpkin to explore the feasibility of applying high-level programming paradigms to severely memory-constrained embedded architectures. He holds two United States patents and is a consulting professor at Stanford University.

• Acknowledgements
  - Stanford Professors Bob Twiggs' and Jamie Cutler’s continued support for the CubeSat Kit, and their inputs on enhancements and suggestions for future CubeSat Kit products, are greatly appreciated.
  - Pumpkin’s Salvo and CubeSat Kit customers, whose real-world experience with our products helps us improve and innovate.

• Salvo, CubeSat Kit and CubeSat information
  - More information on Pumpkin’s Salvo RTOS and Pumpkin’s CubeSat Kit can be found at http://www.pumpkininc.com/ and http://www.cubesatkit.com/, respectively.
  - More information on the open CubeSat standard and the CubeSat community can be found at http://www.cubesat.info/

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