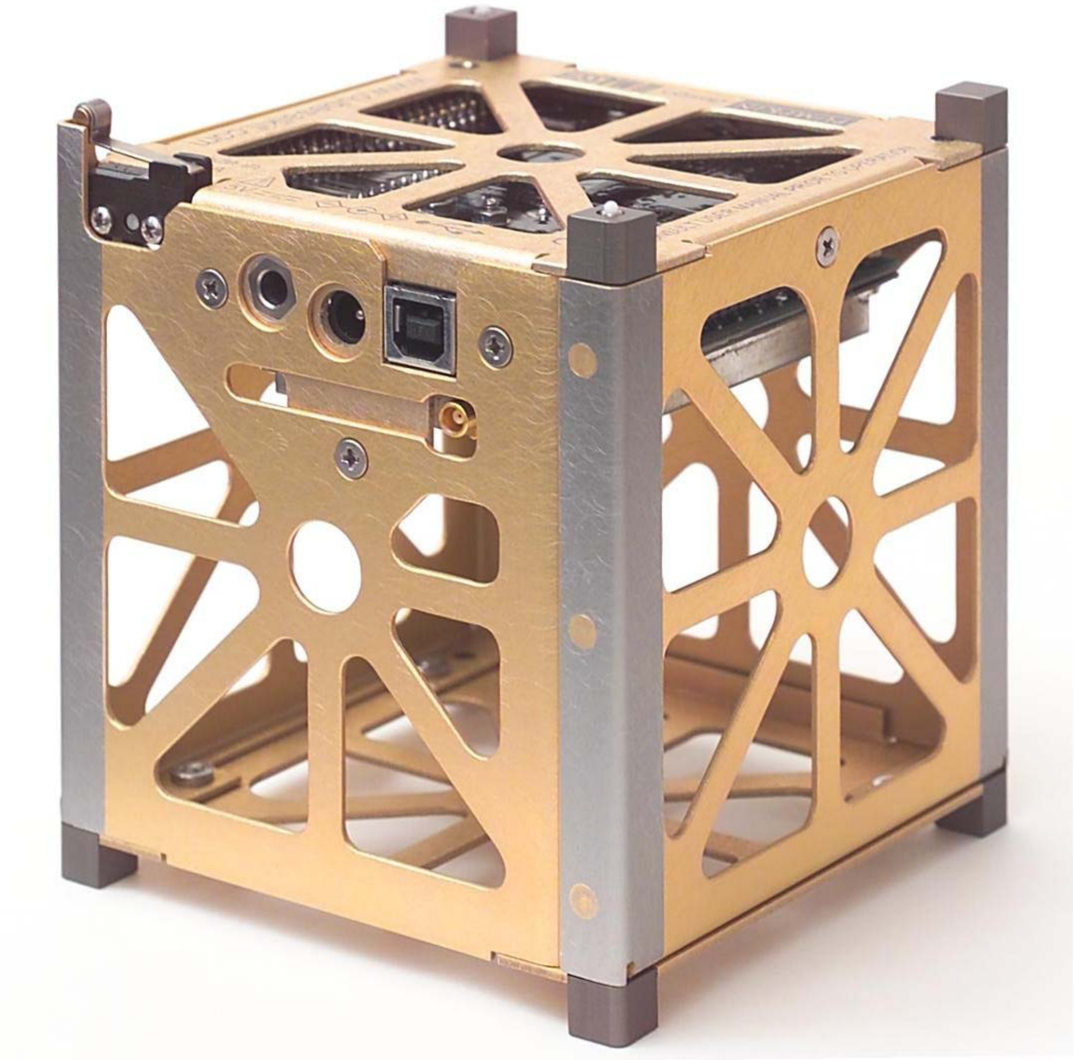

Designing for Success:
Choosing CubeSat Components Wisely

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 CubeSat Kit
  - 20+ years of embedded systems design and programming experience.
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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. 1^{st} 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. G*reater demand for CubeSat-specific components can substantially reduce their per-unit cost* by reducing the impact of NRE for custom fabrication.

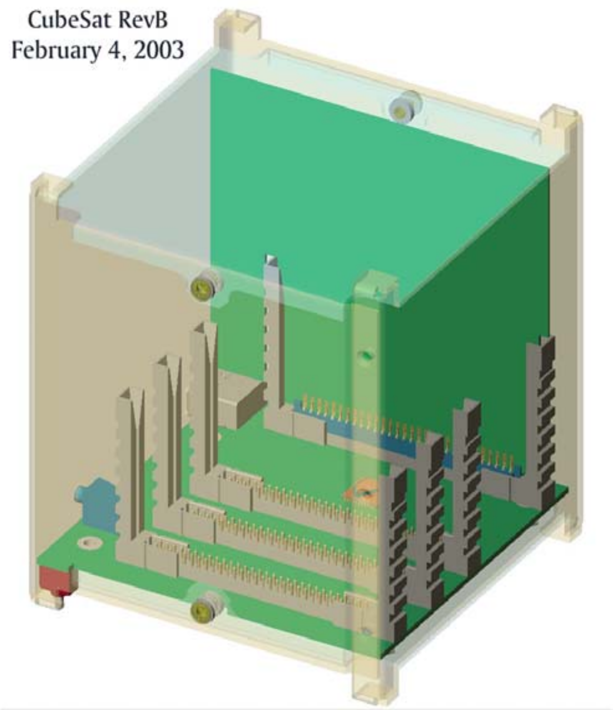
Part III: Examples (cont'd)

- Connectors:

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

Part III: Examples (cont'd)

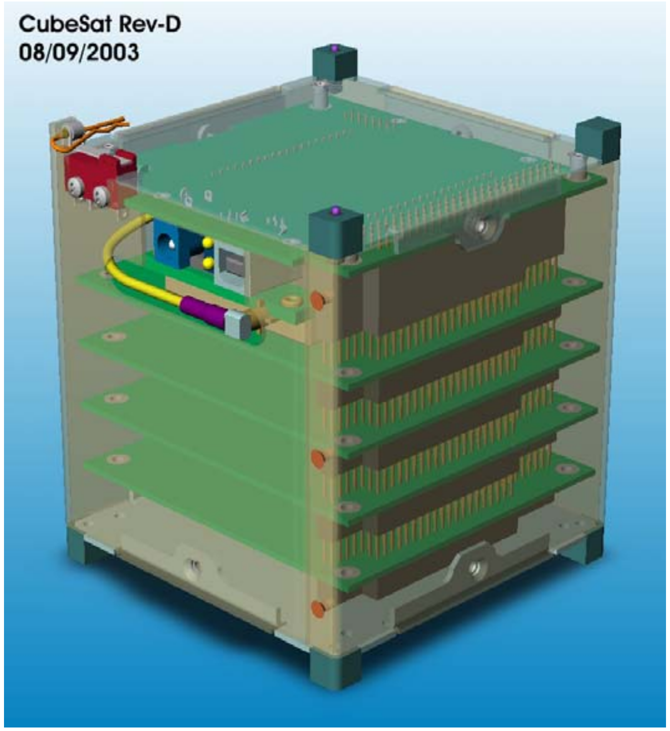
- Connectors (cont'd):
  - A CubeSat is likely to employ several types of connectors, based on their unique strengths, e.g.
    - Point-to-point wiring to attach Solar Panel PCBs to EPS.
    - PC/104 stackable connectors as a backbone.
    - Inter-board stacking connectors to attach complex daughter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

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

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 2nd & 3rd 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

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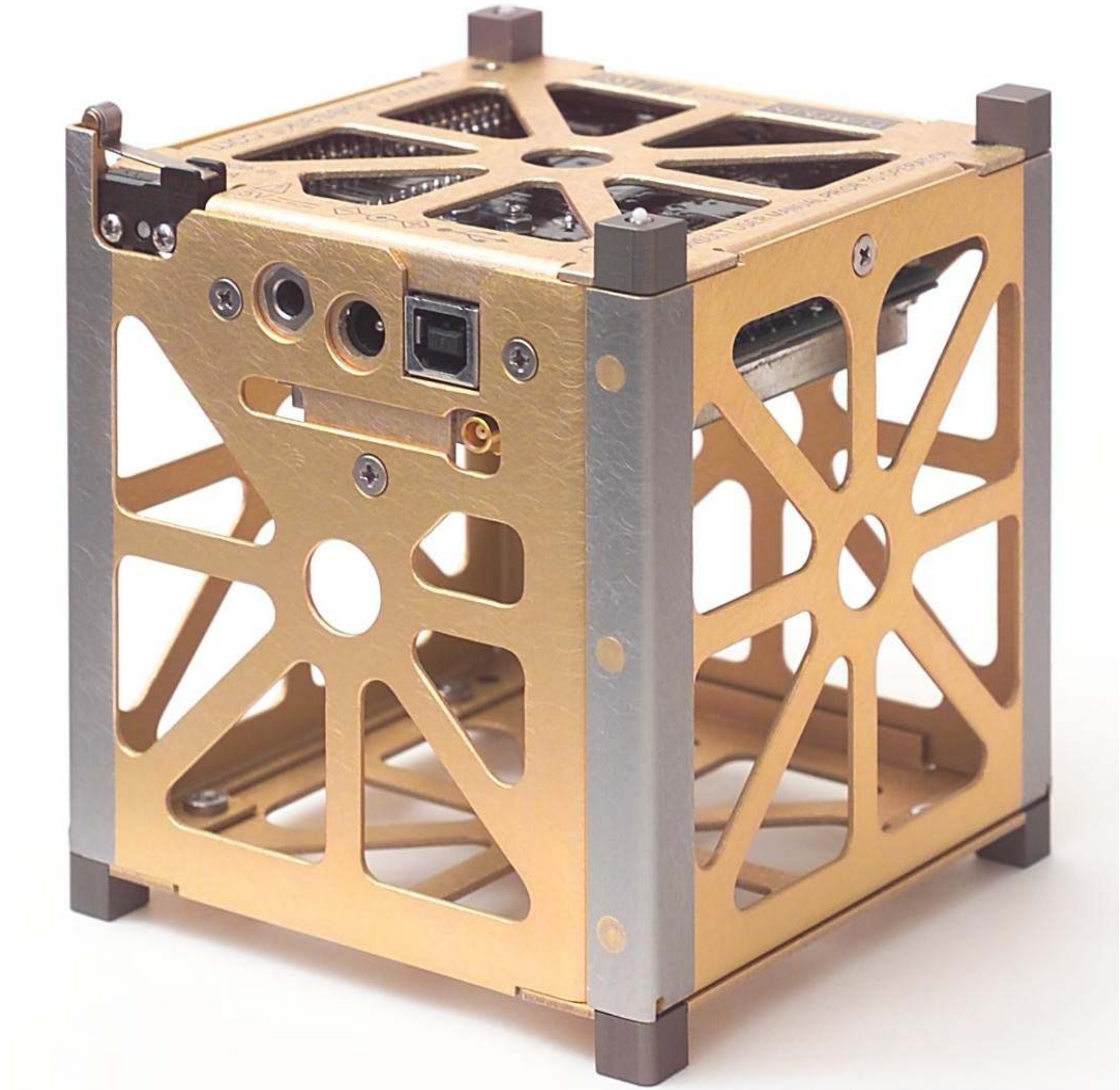

Q&A Session

Thank you for attending the workshop!

Notes & References

1. *CubeSat Design Specification*, www.cubesat.org .
2. *CubeSat Kit User Manual*, Pumpkin, Inc. 2005, www.pumpkininc.com.
3. PCB price quotes via 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 .
5. Digi-Key is at 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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