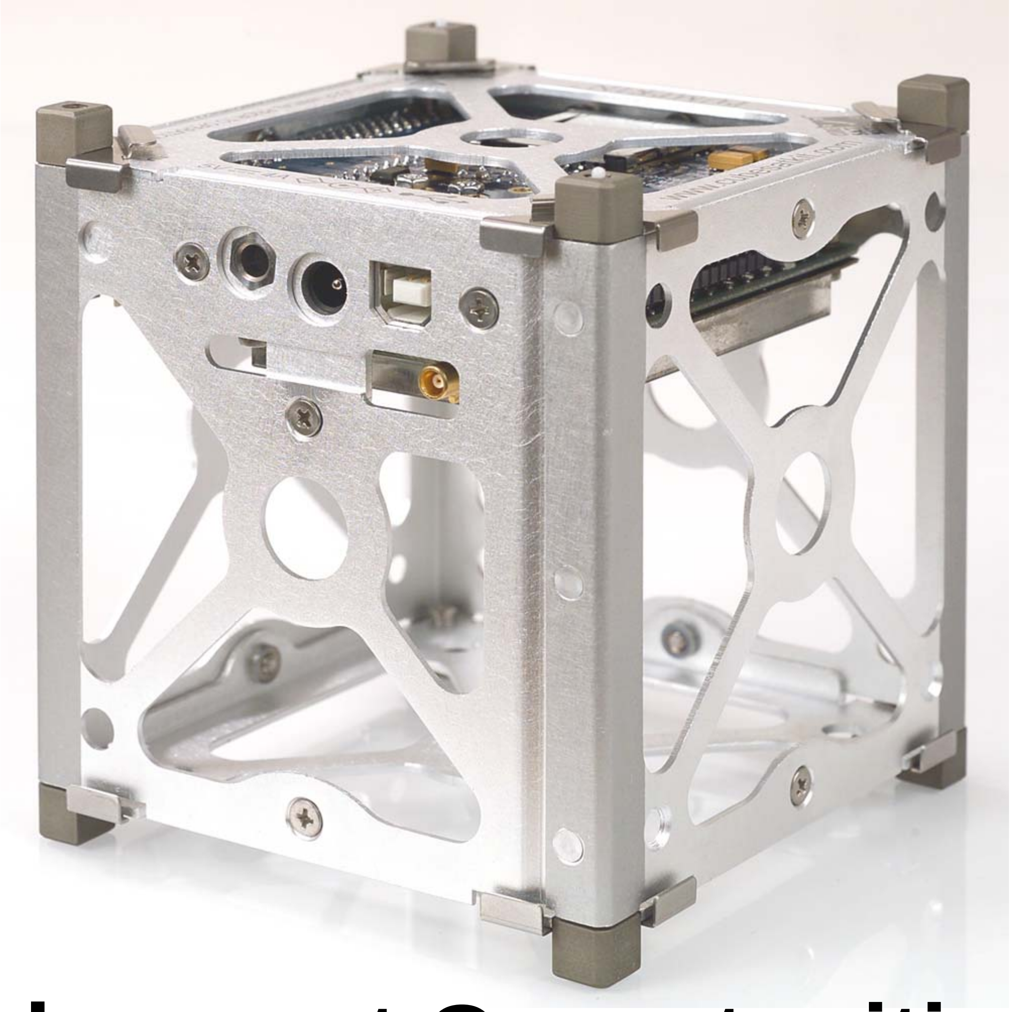

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Development Opportunities within the CubeSat Kit Architecture

Andrew E. Kalman, Ph.D.

Outline

- Part I: Historical Overview & Observations
- Part II: Internal Module Stacking
- Part III: Underutilized Volume
- Part IV: External Payloads
- Part V: Connectors
- Part VI: Mass Reduction
- Part VII: Software
- Part VIII: The Future

Overview & Observations

- About to deliver 100th Flight Module & Development Board (December 2003 – April 2008)
- 1U & 3U configurations most popular, 2U gaining ground
- Solid-wall structures now deprecated due to inherent mass penalty. Still available by special order
- New CubeSat Kit 3D CAD models online
- Popular third-party compatible offerings:
  - Clyde Space EPS & solar panels
  - HCC-Embedded EFFS-THIN FAT file system
  - StenSat Group VHF/UHF radio
- Predict up to 4 CubeSat Kit-based nanosatellites to be launched in 2008
- CubeSat mass limit more critical than volume limit

Part I (cont'd)

- Customers often:
  - Want to model
  - Have aggressive schedules
  - Ask lots and lots of questions
  - Appreciate off-the-shelf availability
  - Are buying from multiple, specialized vendors
  - Often have little or no previous experience in space
  - Benefit from the dedicated Dev Board for development
  - Encounter a non-trivial learning curve for embedded programming

Part I (cont'd)

- Sometimes, customers:
  - Underestimate "real" costs and production times
  - Still spend a lot of time in the planning stages
  - Read too much into specifications (or a lack thereof)
  - Do not fully appreciate the beauty of the CubeSat specification
  - Want to roll their own solutions when a similar one is already available
  - Fail to take advantage of various CubeSat Kit architectural features
  - Underestimate how much software is required, and how much functionality can be accomplished by a lowly 16-bit microcontroller

Internal Module Stacking

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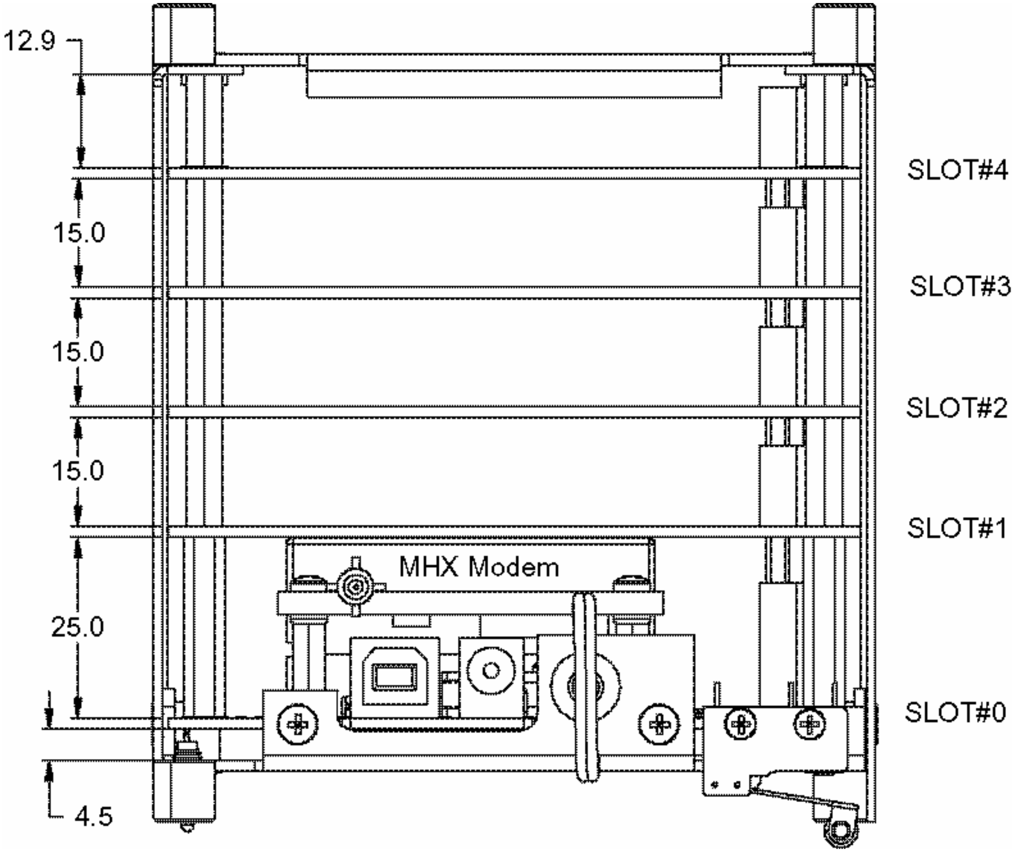
- Internal modules stacked with 15mm + (n x 10mm) between PCBs:



Typical layout of internal modules in the CubeSat Kit. Minimum inter-PCB distance with CubeSat Kit Bus connectors is 15mm. Pre-release Rev B structure shown.

Part II (cont'd)

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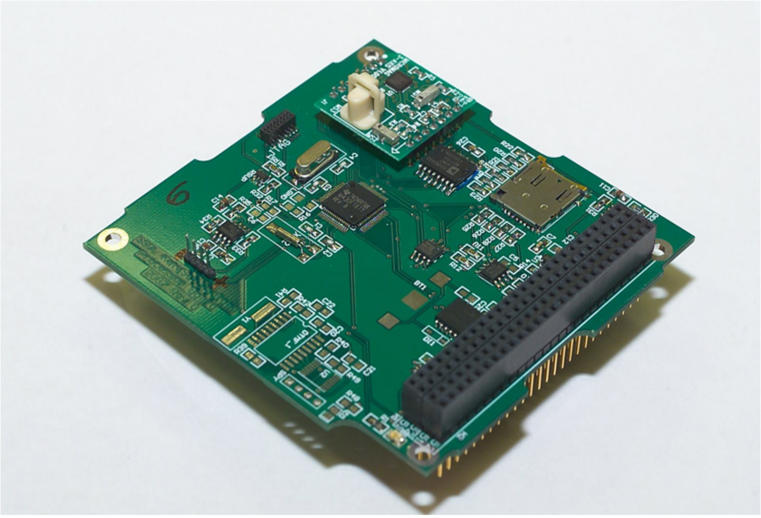

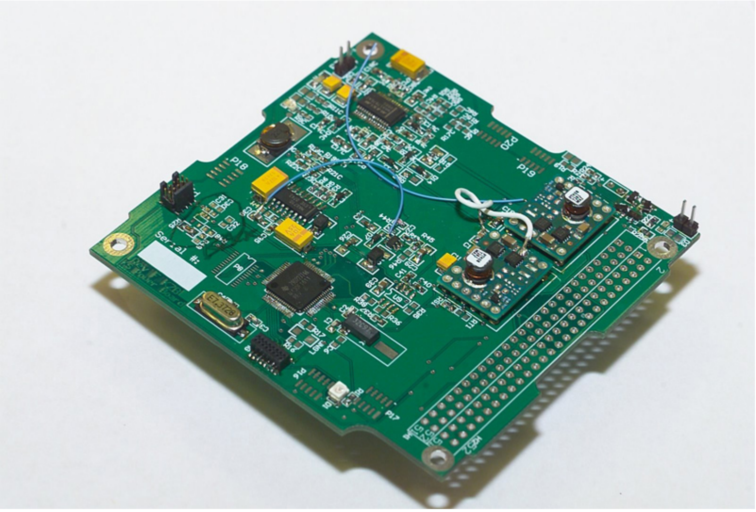

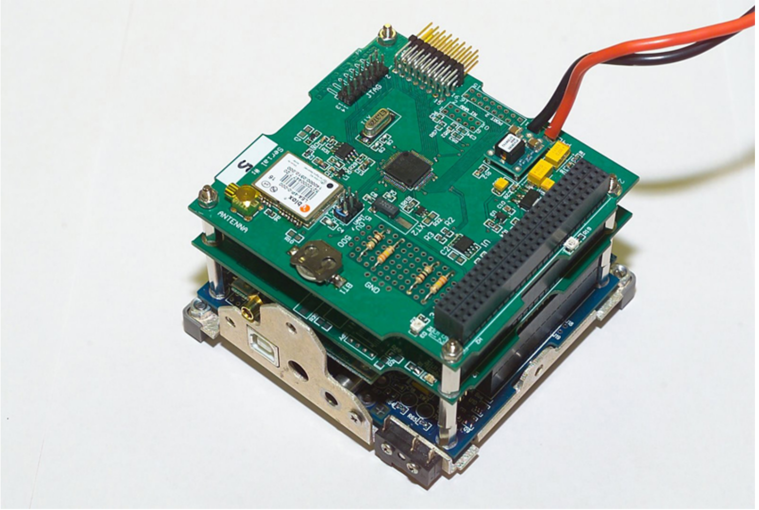

A selection of CubeSat Kit-compatible internal modules under development at Stanford's SSDL.

Some multi-level component stacking present. Note low utilization of available 90 x 96 x 15mm volume. Functionality of multiple modules can be combined into a single module.

Underutilized Volume

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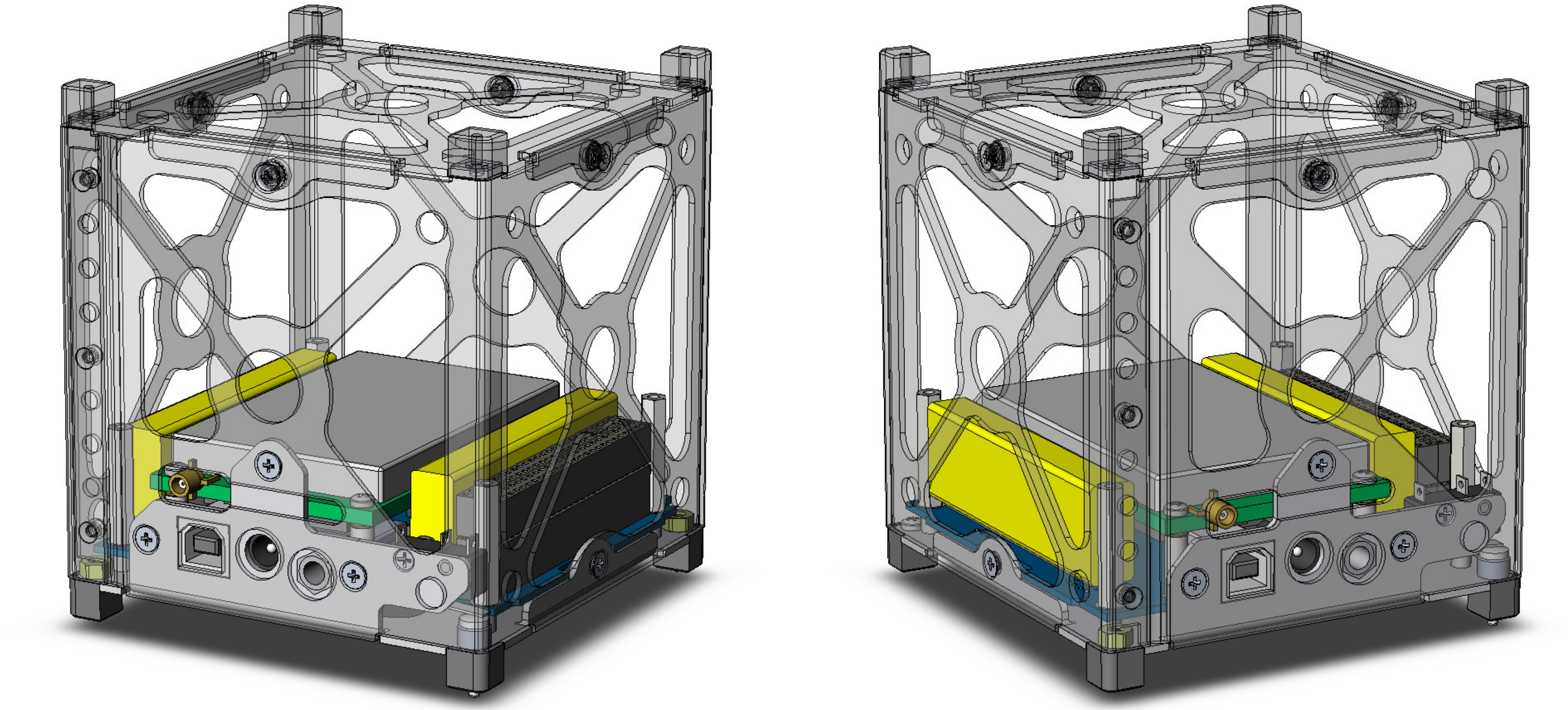
- Ever since first production CubeSat Kit, two underutilized volumes have existed between Slot 0 and Slot 1 …



Underutilized volumes in Rev D skeletonized CubeSat Kits. Each volume lies above Slot 0 (where the FM430 resides) and below Slot 1. Shown with MHX transceiver module in place, consistent with Slot 1 located 25mm above Slot 0.

Part III (cont'd)

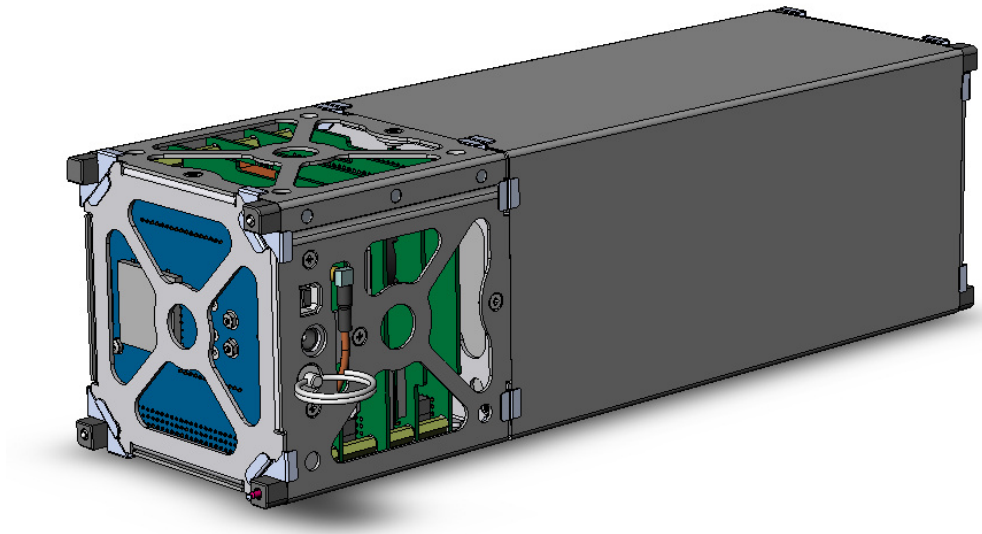
- Specifications of underutilized volumes:

location	Slot 1 @	approx. dimensions[1]	approx. volume
Left	15mm	72 x 15 x 13mm	14cc
	25mm	72 x 15 x 23mm	25cc
Right	15mm	80 x 12 x 11mm	11cc
	25mm	80 x 12 x 21mm	20cc

1. Dimensions assume no components on underside of Slot 1 module (I.e. smooth underside of Slot 1 PCB in affected areas).

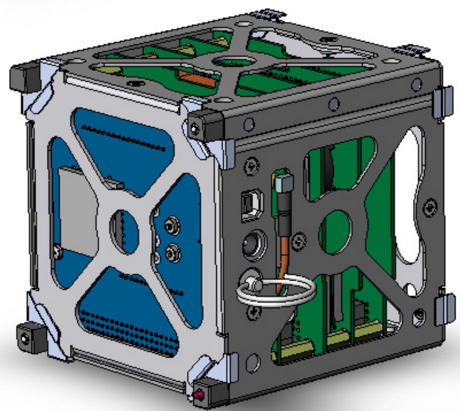
- Possible applications:
  - Beacon
  - Batteries
  - Cold gas tanks
  - DTMF decoder
  - Secondary radio(s)
  - Accelerometers & magnetometers

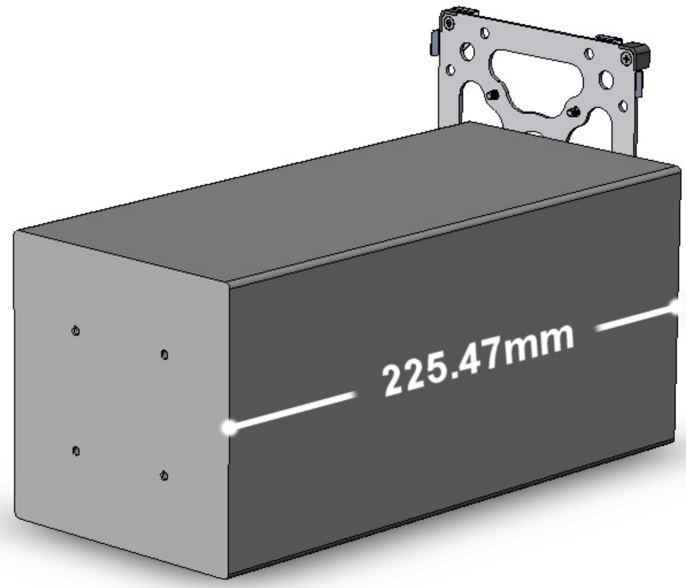
External Payloads



3U CubeSat Kit constructed from a single 1U skeletonized CubeSat Kit (w/ C&DH, radio, EPS & internal payloads) and a 2U external payload (100 x 100 x 225 mm).

Total length is 340.50 mm.





Connectors

- The CubeSat Kit Bus uses PC/104-style connectors
- Benefits:
  - High current
  - High reliability
  - Readily available
  - Multiple stacking heights
  - Any number of rows available
  - Height-extendable in 10mm increments
  - On 0.100” (2.54mm) centers, easy to route
  - Low impact on PCB real estate (stackthrough)
- Drawbacks:
  - Relatively large (16cc per 104 pins)
  - Relatively heavy (16g per 104 pins)
  - Minimum inter-module (i.e. stacking) spacing of 15mm
  - Not all modules need all pins, yet all pins are carried through

Part V (cont'd)

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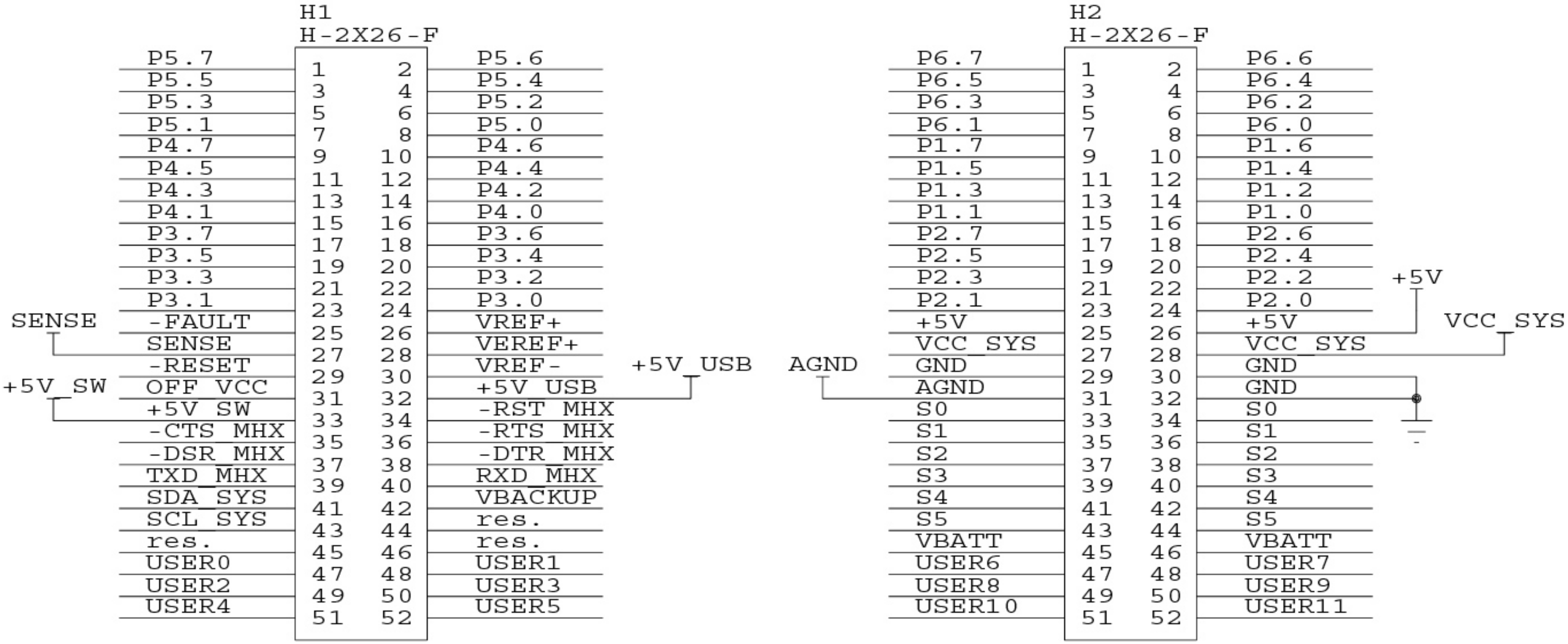
CubeSat Kit Bus Connectors



CubeSat Kit Bus Connectors. Rev C (104-pin bus) shown.

Part V (cont'd)

- Some customers taking advantage of architectural features:
  - EPS that use +5V_USB to charge batteries
  - Clyde Space allocating high-voltage bus to pair of USER pins for one particular end-user
  - Next revision of StenSat VHF/UHF radio to have +5V direct UART interface via TXD_MHX & RXD_MHX
- Un(der)utilized CubeSat Kit Bus features:
  - +5V_USB to power multiple processors via USB "umbilical"
  - Unused S[5..0] pairs for non-standard power bus, etc.
  - *_MHX for direct [+5V,0] interface to radio in MHX slot
  - VBACKUP for flexible location of RTC chip backup battery
  - SENSE and -FAULT signals for supervisor

Mass Reduction

- Rev D structures are probably close to the minimum mass for an Aluminum-based approach
- PCBs and connectors may provide biggest (and easiest) mass reductions. Suggestions:
  - Go from 0.062” (1.5mm) to 0.031” (0.75mm) PCBs wherever possible: Δ_m = -16g per 85cm^2 of PCB real estate. Module, daughterboard-on-module and solar panel PCBs are prime candidates
  - Combine multiple modules into one: Δ_m = -16g per 104 pins of CubeSat Kit Bus Connectors saved. Side-effect of more efficient module volume utilization
  - “Manage the reach” of each particular CubeSat Kit Bus signal in successively higher Slots within the CubeSat Kit. *Recommend that all module PCBs be laid out for full 104-pin pinout, however*
  - For external payloads, fork from CubeSat Kit Bus Connector to payload-specific connector / wiring

Software

- Not enough sharing of software among CubeSat Kit users.
- CubeSat Kit-specific & Pumpkin general software growing to provide libraries of driver-type routines
- HCC-embedded EFFS-THIN for CubeSat Kit:
  - Can run multiple MSP430s, each with FAT-based SD card for unlimited storage. E.g. for dedicated payload processors
  - File-based data exchange among multiple MSP430s
- RTOS-based approach enables simple module sharing:
  - E.g. ADC12 code from Linear EPS runs on FM430 as additional task

Future

- Customers and prospective customers continue to ask for:
  - Radios
  - Solar Panels
  - Ground Stations
  - Space-capable GPS
  - Software
  - and more …
- CubeSat Kit System Chart
  - Illustrates how everything fits together
  - COTS for CubeSats is a reality
  - Ready to accommodate future products & additional developers

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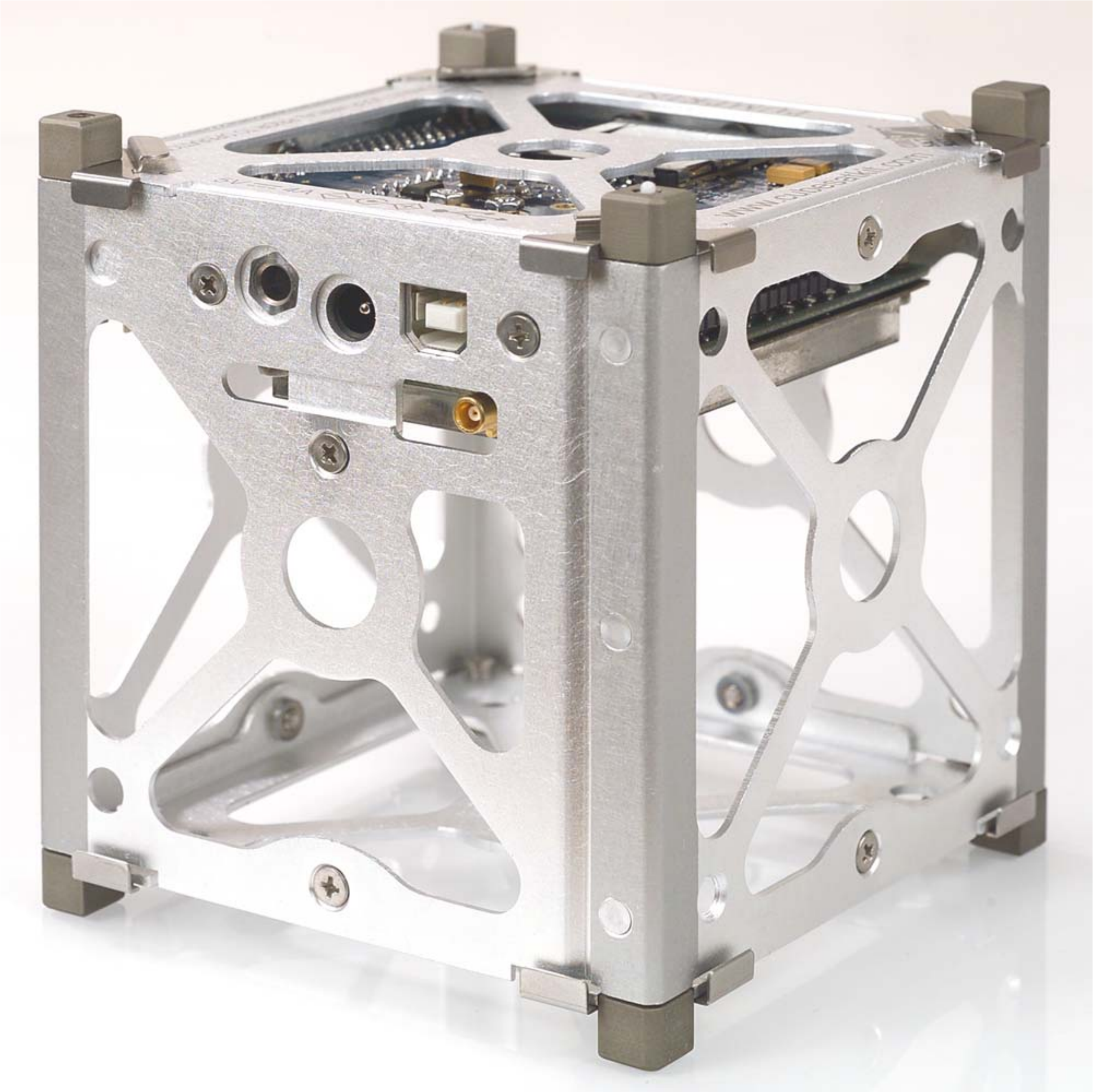

Q&A Session

Thank you for attending!

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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, Inc. to explore the feasibility of applying high-level programming paradigms to severely memory-constrained embedded architectures. He is the creator of the Salvo RTOS and the CubeSat Kit. He holds two United States patents and is a consulting professor in the Aero & Astro department at Stanford University. Contact Dr. Kalman at aek@pumpkininc.com.
- 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.
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