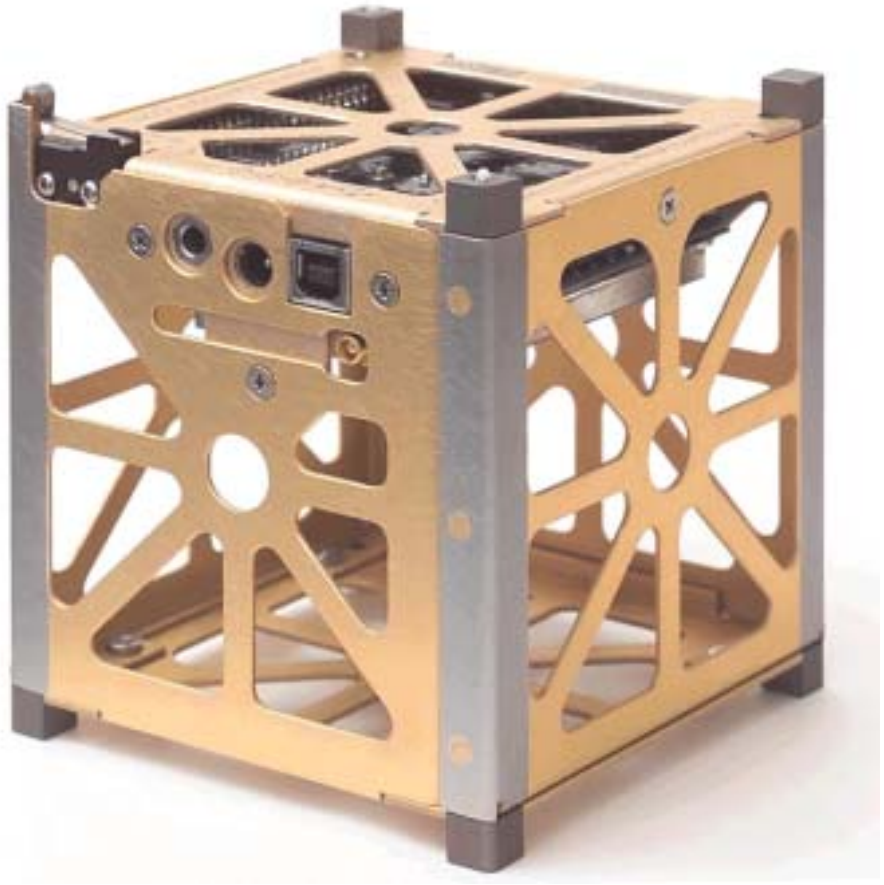
Recent Advances in the CubeSat Kit™ Family of Picosatellites



speaker:

Andrew E. Kalman, Ph.D.
President, Pumpkin, Inc.

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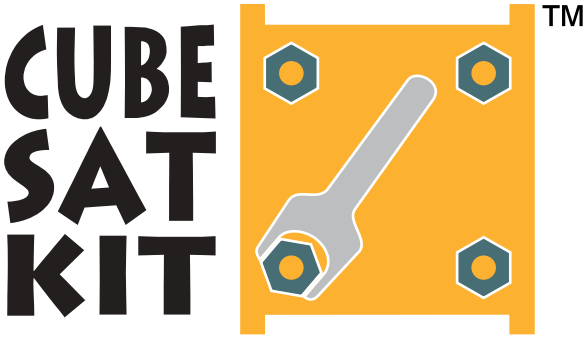
Part I



Overview

What is the CubeSat Kit™?

- The CubeSat Kit consists of hardware and software to be employed as the foundation for a CubeSat mission, from initial development to final deployment.

Who should use the CubeSat Kit?

- University / research, educational, governmental and commercial CubeSat programs who intend to launch CubeSats.

What are the advantages of using the CubeSat Kit?

- It provides a hardware and software CubeSat development environment for in-lab use. Add mission-specific hardware, software and payload to complete your CubeSat.
- The launch-ready FM430 Flight Model (included) fully conforms to the CubeSat specification via a strong, lightweight and space-efficient structure.
- The on-board electronics have been designed for maximum utility with minimal power consumption and ease of use.
- The CubeSat Kit's modular design affords the user great flexibility when designing mission-specific modules.
- It's affordable and available *now* as an off-the-shelf item.

What's included in the CubeSat Kit?

- **Development Board, Salvo™ multitasking RTOS software, Flight Model (with FM430 Flight Module inside), software programming / debugging adapter, USB cable, R-B-F pin, lab power supply.**

Figure 1: 1U solid-wall CubeSat Kit contents.

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What else is required to get started with a CubeSat Kit?

- A Salvo-certified compiler for TI's MSP430 ultra-low-power 16-bit RISC MCU:

- A PC for software development.
- Transceiver(s) of your choice. The CubeSat Kit accepts the Microhard™ MHX-2400 2.4GHz spread-spectrum transceiver as a drop-in option.[1]
- Mission-specific hardware (e.g. solar cells, antenna(e), user modules, payload).

How much does a CubeSat Kit cost?

- The 1U (10x10x10cm) CubeSat Kit as shown above is priced at $5,000.[2]

Part II

The CUBE SAT KIT™ Family Evolves

Milestones:

- **December 2000:** Proposal for CubeSat Kit first placed on WWW.
- **December 2002:** First serious customer interest.
- **Summer 2003:** Top-to-bottom redesign of CubeSat Kit to take advantage of technology updates.
- **December 2003:** First three CubeSat Kits delivered to customer #1.
- **Fall-Winter 2004-2005:** Demand for larger structures (e.g. 2U, 3U) leads to Rev B chassis design. Rev B electronics introduce new features (e.g. mass storage).
- **Spring 2005:** First 3U chassis delivered to customer. 2U & 3U designs finalized. ½U and 1½U designs also possible.
- **Summer 2005:** CubeSat Kit product catalog expanding with additional family add-ons.

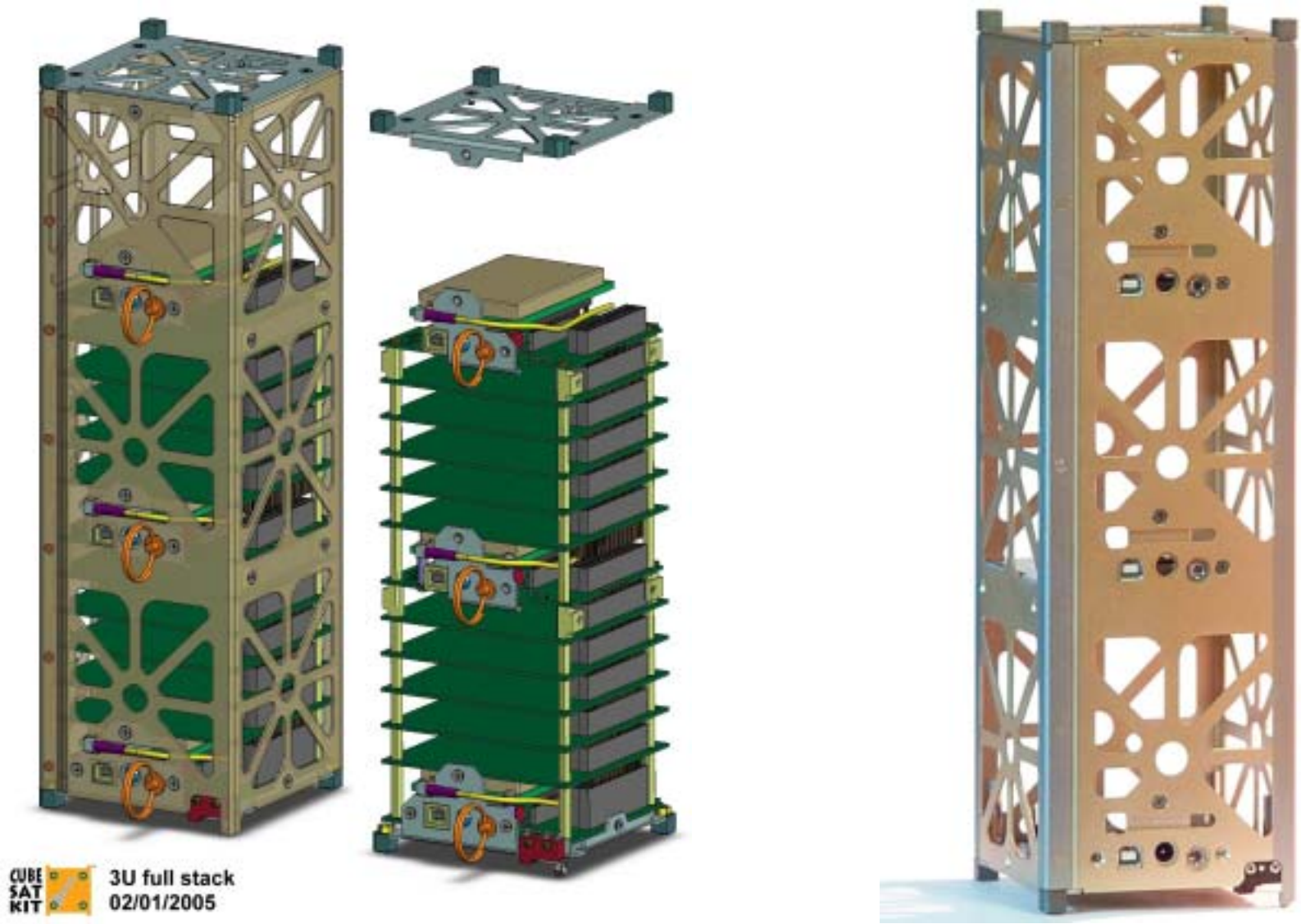
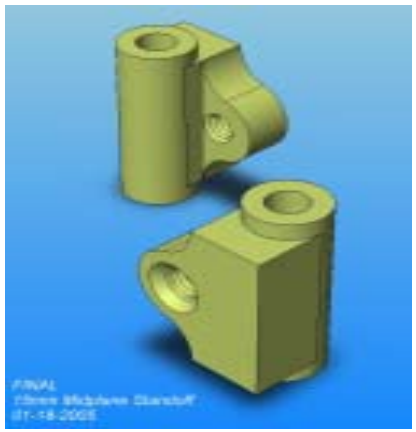


Figure 2: Design Study and First Article of 3U Skeletonized CubeSat Kit Chassis

Evolution of CubeSat Kit Structure:

- Original design now proven to be on-target in all critical respects (strength, mass, internal volume, parts count, fastener count, flexibility, conformance to CubeSat standard, etc.)
- Very minor changes for Rev B chassis.
- Larger (e.g. 2U and 3U) chassis get additional Midplane Standoffs and two additional Cover Plate fastening points to rigidize heavier internal module stacks.
- Most Rev B structure components interchangeable & backwards-compatible with Rev A components.
- Various schemes analyzed for fasteners used in module stacking (M/F standoffs vs. threaded rod + spacers, material choices, etc.)
- Major effort to keep costs inline with CubeSat Kit's affordability.



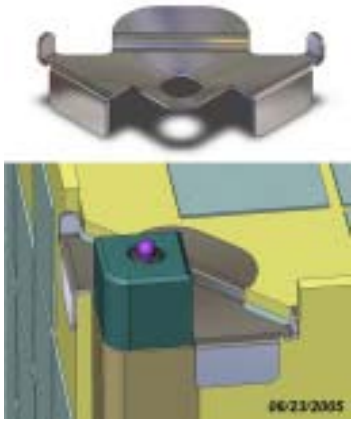


Figure 3: 3D CAD Design Studies of various new CubeSat Kit Elements

Evolution of CubeSat Kit Electronics:

- Ride TI's MSP430 upgrade path from original MSP430F149 (60K flash, 2K RAM, no I2C, no DAC, no DMA) to MSP430F169/1611/1612 (60/48/55K flash, 2/10/5K RAM, I2C, 12-bit DAC, 3xDMA).
- Rev B electronics get additional protection on +5V input, SD/MMC interface, other minor changes.
- Two pins on CubeSat Kit Bus freed for user applications.
- With MSP430F16x/161x, USART0 now operates in up to three modes: USART (off-board), SPI (to on-board SD/MMC and off-board) and I2C (off-board).
- Having all MSP430 I/O on CubeSat Kit Bus means that fixes and upgrades to overall architecture do not obsolete the Development Board.
- All major subsystems (e.g. transceiver on USART1, USB and SD/MMC interface) continue to have explicit power control via FM430 Flight Module.
- Still has a minimum of 32 I/O pins and most peripherals unconditionally free to user

Evolution of CubeSat Kit Flight Model Packaging:

- New electronics features (e.g. SD/MMC interface, MaxStream adapter) fit within existing volume footprint of FM430 Flight Module.
- Midplane Standoffs for 2U and 3U chassis occupy same space as inter-module standoffs, weigh only 6g.
- FM430 Flight Module options enable various choices for CubeSat Kit Bus connector, including stackthrough.

CubeSat Kit Evolution Summary:

Feature / Spec	Rev A	Rev B
Sizes available	1U	½U, 1U, 1½U, 2U, 3U
Stacking hardware	M/F standoffs	M/F standoffs or threaded rod with spacers
Flight MCU	MSP430F149	MSP430F169/1611/1612
Mass Storage	n/a	SD/MMC
External +5V protection	none	overvoltage
FM430 VCC bus isolation	no	yes
I/O pins free to user[3]	33	32[4]
Mounting location of FM430 Flight Module	bottom only	anywhere via Remote Mount Kit
FM430 Flight Module stacking options	bottom of stack	anywhere in stack

Table 1: Evolution of CubeSat Kit Features

Real-world CubeSat Kit Measurements:

Configuration	Mass	Notes
1U skeletonized chassis, complete[5]	165g	With Launch Switch. Add 85g for solid-wall chassis.
+ FM430 Flight Module and MHX-series transceiver	300g	No antenna. Using M/F standoffs.
+ Solar Panel Kit	479g	0.062" (1.5mm) bare PCBs on all six faces
+ Linear EPS w/Li-Ion iPod batteries	602g	In Slot 2
+ Experiment Board A	672g	In Slot 3, no antenna

- **300-400g remain for user payload and antenna(e).**
- **50-70g per user module / slot seems typical.**
- **Further weight reduction via thinner PCBs (e.g. 0.031" (0.75mm)) for solar panels and user modules is possible.**
- **Conventional M/F chrome-plated brass M3 standoffs weigh 10g per 15mm slot, 17g per 25mm slot. Rod-and-spacer weigh 6g per 25mm slot, etc. Roughly 30g overall savings per 1U CubeSat Kit.**

Part III

New CUBE SAT KIT™ Products

Linear EPS Module:

- Simple battery-powered linear +5V power supply module for CubeSat Kit. Can take four, five or six AAA batteries of various types (alkaline, NiMH, NiCad, Lithium, etc.) or two 3.7V 1700mAh Li-Ion iPod batteries. Especially useful when low-noise measurements (e.g. transceiver testing) is required. Flexible power switching via Remove-Before-Flight Switches and Launch. Voltage sense to Flight MCU. iPod battery life @ 65mA draw is approximately 24hrs.

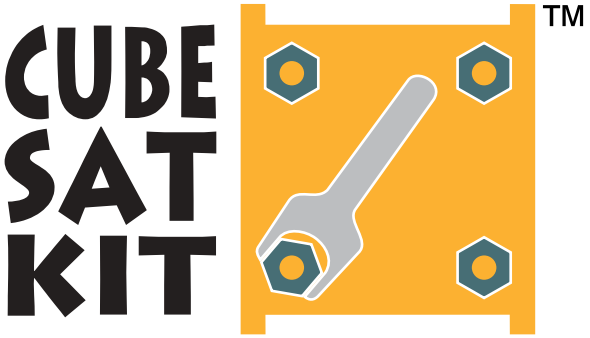
Experiment Board A:

- CubeSat Kit module with plug-in support for Trimble® Lassen® iQ GPS module. With battery-backup. Also with CdS cell to Flight MCU for simple sun sensor, etc.

Solar Panel Kit:

- New scheme for mounting solar panels requires one additional fastener and 8 custom clips, and weighs only 11g for all six faces combined. Includes clips to fit all Rev A and Rev B CubeSat Kits, and six example solar panel PCBs to cover an entire 1U CubeSat.

Part IV



Field Experience

In-class use of the CubeSat Kit:

- Stanford University's AA236A SpaceCraft Design Fundamentals class had students build autonomous rovers with the CubeSat Kit's Development Board running the Salvo RTOS on the MSP430F149:
  - Students with little or no previous embedded programming experience were able to deliver rovers that reported status, sensed an obstacle, and executed commands received over a wireless link.
  - Students transformed existing CubeSat Kit demo application (with built-in RS-232 and A/D services) into their own rover code.
  - Drop-in MaxStream radio compatibility was a big time-saver.
  - Lack of knowledge of assembly programming and MSP430 peripherals was no major handicap. All code was written in C with little dependence on on-board peripherals beyond those supported in demo application. Programming naivety (e.g. use of FP math for curve fitting) led to code more suited to a PC than to a 16-bit embedded µC with only 60K program memory. Yet resulting application ran on MSP430F149 with memory to spare.
  - Independent nature of tasks in an RTOS application allowed students to develop and debug each rover feature independently, then combine all of them into a single application.
  - Coding (and hardware – e.g. H-bridge motor drivers – integration) took 8 4-hour labs.

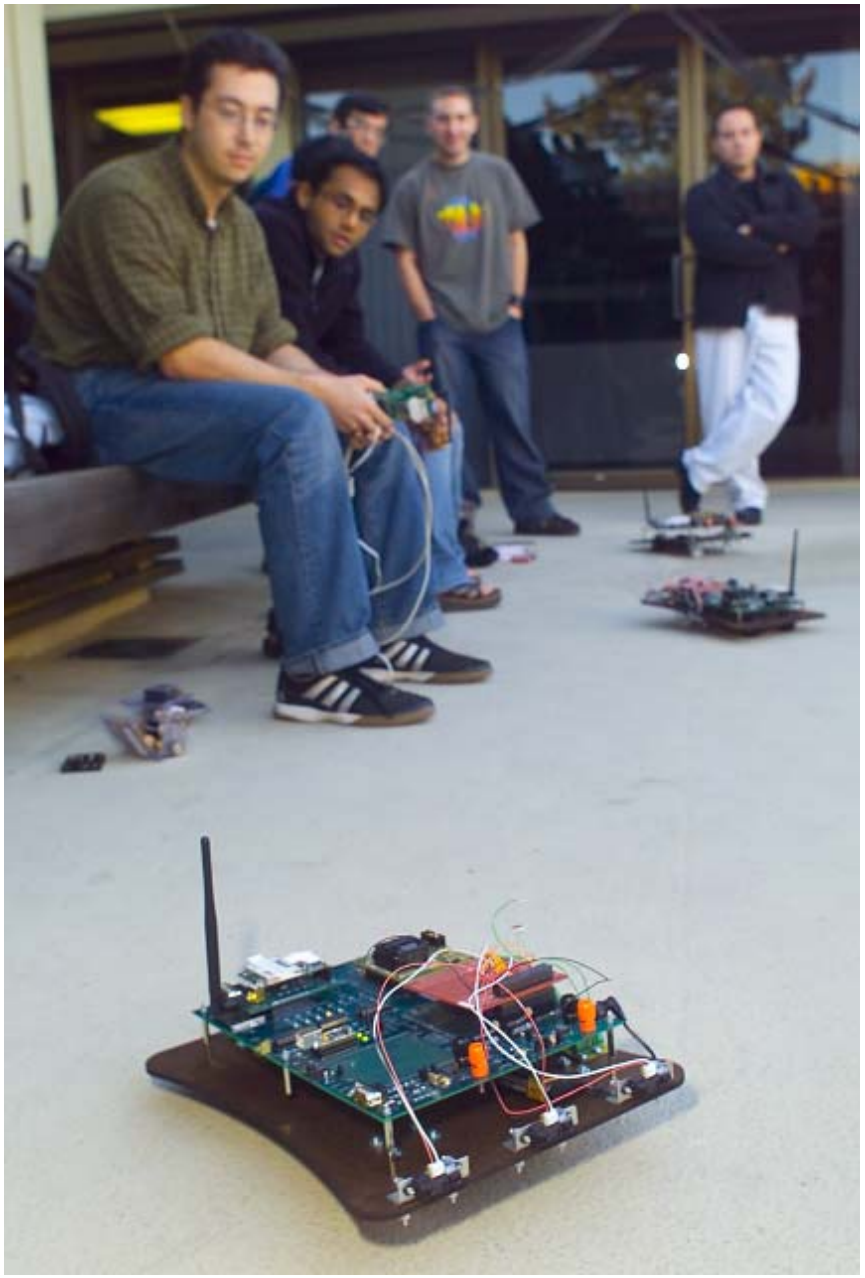


Figure 4: AA236A Final Exam – CubeSat Kit Development Board on Motorized Chassis w/Sensors

Figure 5: AA236A Command Central – Issuing Motion Commands over Wireless Link

In-class use of the CubeSat Kit (cont'd):

- Stanford's AA236B class has students developing an entire CubeSat mission (KatySat) in under 12 months. From this we have observed:
  - Successful student cooperation with a third party to design a plug-in VHF/UHF radio module for the CubeSat Kit. This module will be used in multiple CubeSat missions.
  - Certain complex hardware peripherals (e.g. I2C) remain a challenge for students to integrate from scratch. Shared libraries among CubeSat Kit users would be very beneficial to the CubeSat Kit community.
  - Mission-specific PCBs (e.g. EPS board with multiple switchers, solar panels with unusual part decals not present in PCB CAD libraries, etc.) rapidly gain a level of complexity that outpaces student abilities.
  - No good off-the-shelf antenna solutions.
  - Each project should have an "architecture czar" to manage the use of resources (e.g. on-chip peripherals, I/O pins on bus, etc.) intelligently.
  - Development Board is very robust – no field failures reported.
  - Additional debugging tools (e.g. Development Board's monitor port and CrossWorks for MSP430 IDE's `debug_puts()`) extremely useful in helping students visualize system behavior while developing and debugging.
  - MSP430 proving to be a very versatile µC with powerful peripherals.
  - Students encounter many time & experience vs. $ tradeoffs.

Figure 6: KatySat's Mike D'Ortenzio Developing Code for new UHF/VHF Module

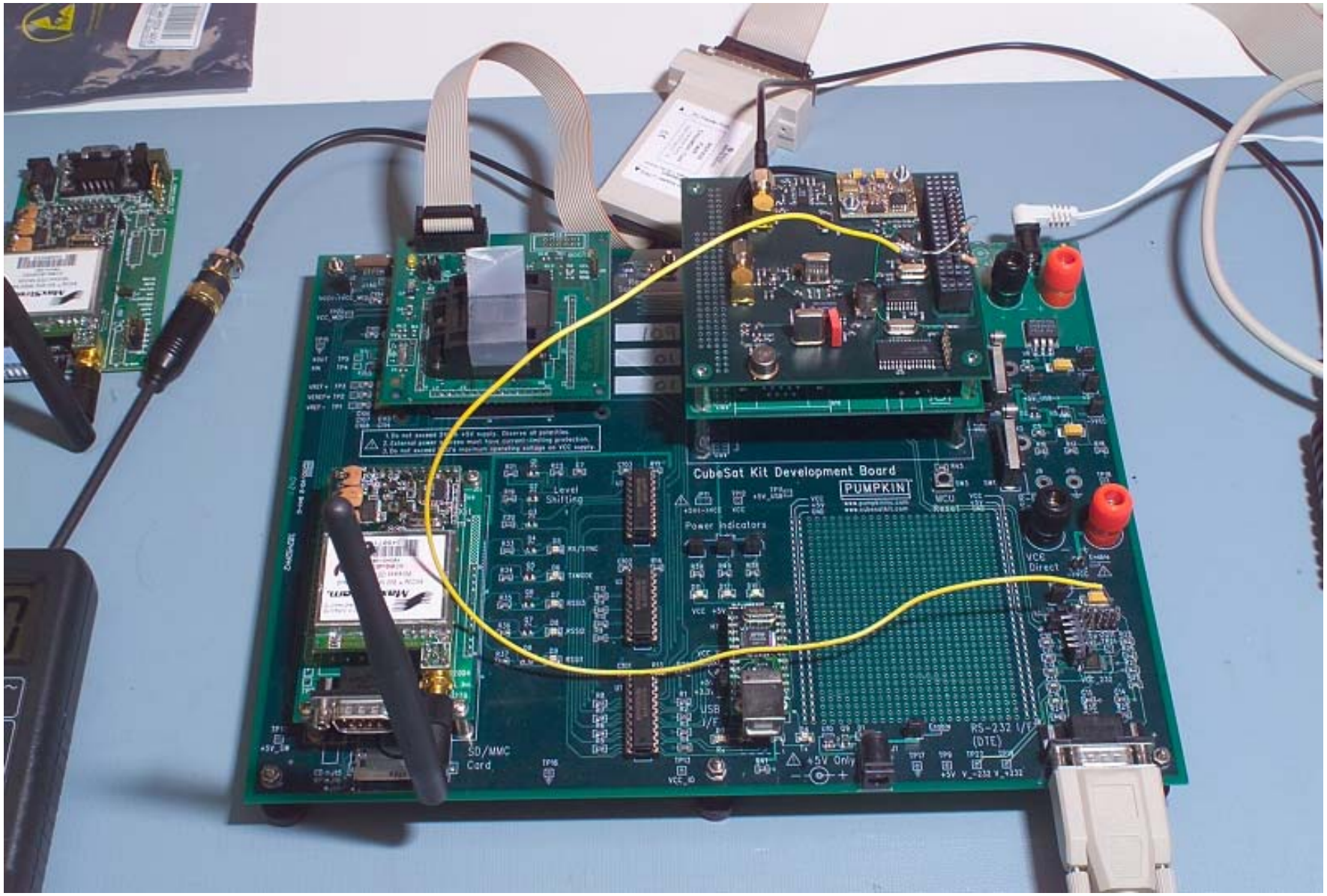


Figure 7: KatySat's New UHF/VHF Module on CubeSat Kit Development Board

Part V

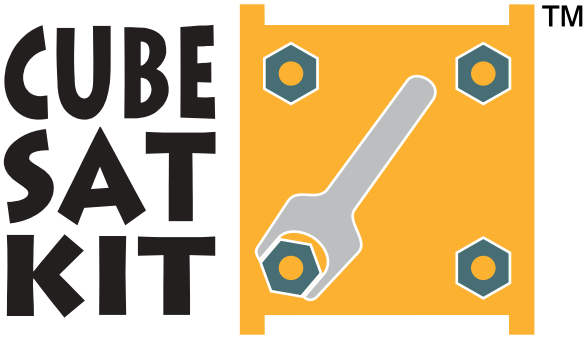
Conclusion

- **The CubeSat Kit delivers a flyable structure, a C&DH/COM/mass storage Flight Module, a Development Board and multitasking demonstration software at low cost and with great specs.**
- **The first 18 months of the CubeSat Kit COTS availability has resulted in its adoption on 5 continents as a COTS basis for CubeSat missions.**
- **Rev B delivers additional flexibility for missions that need more functionality and/or outgrow the 10x10x10cm confines of the original CubeSat specification while preserving customer investment.**
- **Future CubeSat Kit family products are likely to address the remaining non-payload issues that face our customers, including:**
    - Additional architectural enhancements
    - More CubeSat Kit-specific software
    - Solar panel solutions
    - EPS boards
    - Antennae
    - COTS user modules for experimenting (e.g. for GPS receivers)
    - COTS user modules with technology from other vendors (e.g. TUI's deorbiter)
    - Alternate launch vehicle kits (e.g. the RocketPod™ kit)
    - Customization services (e.g. the "1plus U" CubeSat Kit)
    - Launch-to-deorbit mission services (e.g. with 1Earth & SRI)

Salvo™

The RTOS that runs in tiny places.™

and the



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Speaker information

Dr. Kalman is Pumpkin's president, chief software architect and the inventor of the CubeSat Kit. He entered the embedded programming world in the mid-1980's. After co-founding a successful Silicon Valley high-tech startup, he founded Pumpkin with an emphasis on software quality and applicability to a wide range of microcontroller-based applications. He invented the CubeSat Kit out of a desire to see mass-production technologies applied to spacecraft design in order to substantially reduce cost. He is also involved in a variety of other hardware and software projects.

Acknowledgements

Adam "Close Tolerance" Reif's tireless work in developing the CubeSat Kit's 3D CAD models, turning those models into production parts, and overseeing the production and quality control of the CubeSat Kit's mechanical components have been crucial to the success of the CubeSat Kit.

Stanford Professor Bob Twiggs' continued support for the CubeSat Kit, and his input on enhancements and suggestions for future CubeSat Kit products, are greatly appreciated.

Copyright notice

End Notes

1 MHX-2400 transceiver kits are available through Pumpkin. Other transceivers can be adapted for use in the CubeSat Kit.
2 All prices in US $.
3 Assumes transceiver is on 100% of the time.
4 Assumes user is using the SD/MMC interface.
5 A similar 3U skeletonized CubeSat Kit chassis weighs in at 321g