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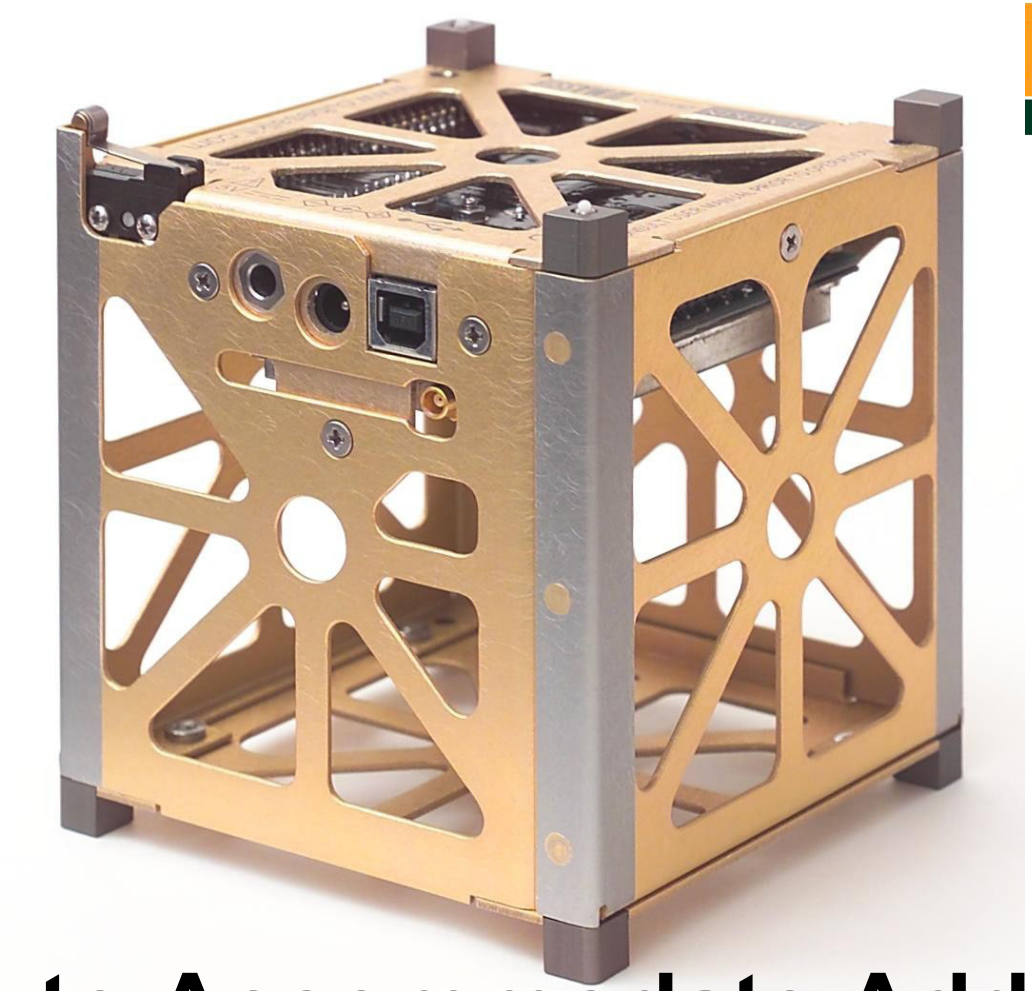

How to Accommodate Additional Processors in the CubeSat Kit™

Andrew E. Kalman, Ph.D.

Introduction

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- 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

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- Part I: CubeSat Kit Architecture & Processor
- Part II: Choosing Processors
- Part III: Interfacing Additional Processors
- Part IV: Going it Alone
- Part V: Examples
- Part VI: Summary

CubeSat Kit Architecture & Processor

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- Versatile MCU-based architecture:
  - Modular approach w/ 90 x 96mm PCB form factor.
  - 104-pin stackable CSK Bus connectors form a backplane:
    - I/O, power, control, status, network, xcvr, switching, user-defined.
  - 48 I/O pins directly on CSK Bus.
  - +5V, +3.3V, V_{BATT} & V_{BACKUP} all on CSK Bus.
  - For uni- or multi-processor implementations.
- Every CSK module has full access to entire CSK Bus:
  - C&DH: source & endpoint for many signals.
  - EPS: deliver power to bus, status & control to C&DH.
  - COMM: handle Tx & Rx, use +3.3V for I/O, +5V for transmitter.
  - Payload: interface between C&DH and payload / experiment.

Part I (cont'd)

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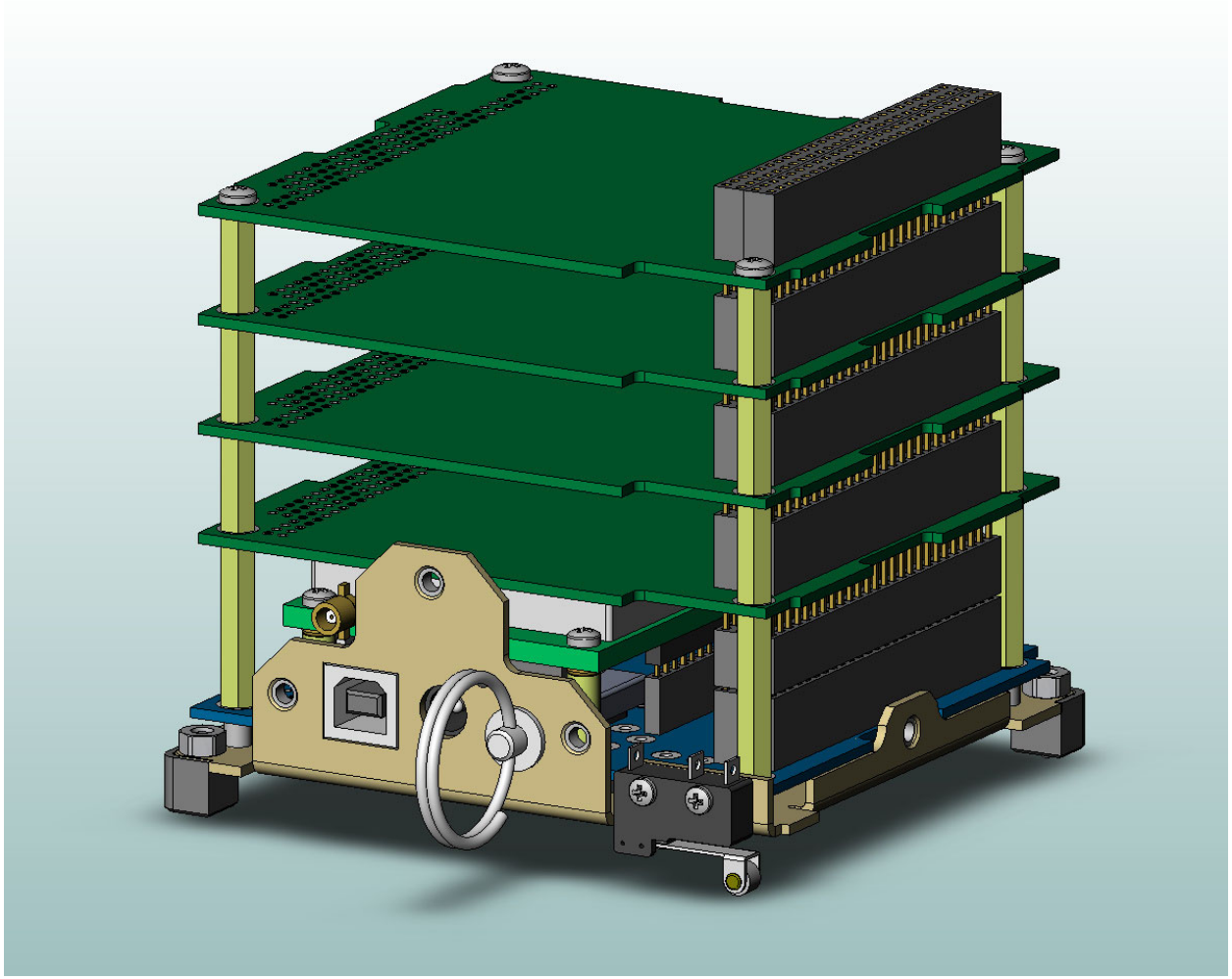

CubeSat Kit Module Stack Example

Part I (cont'd)

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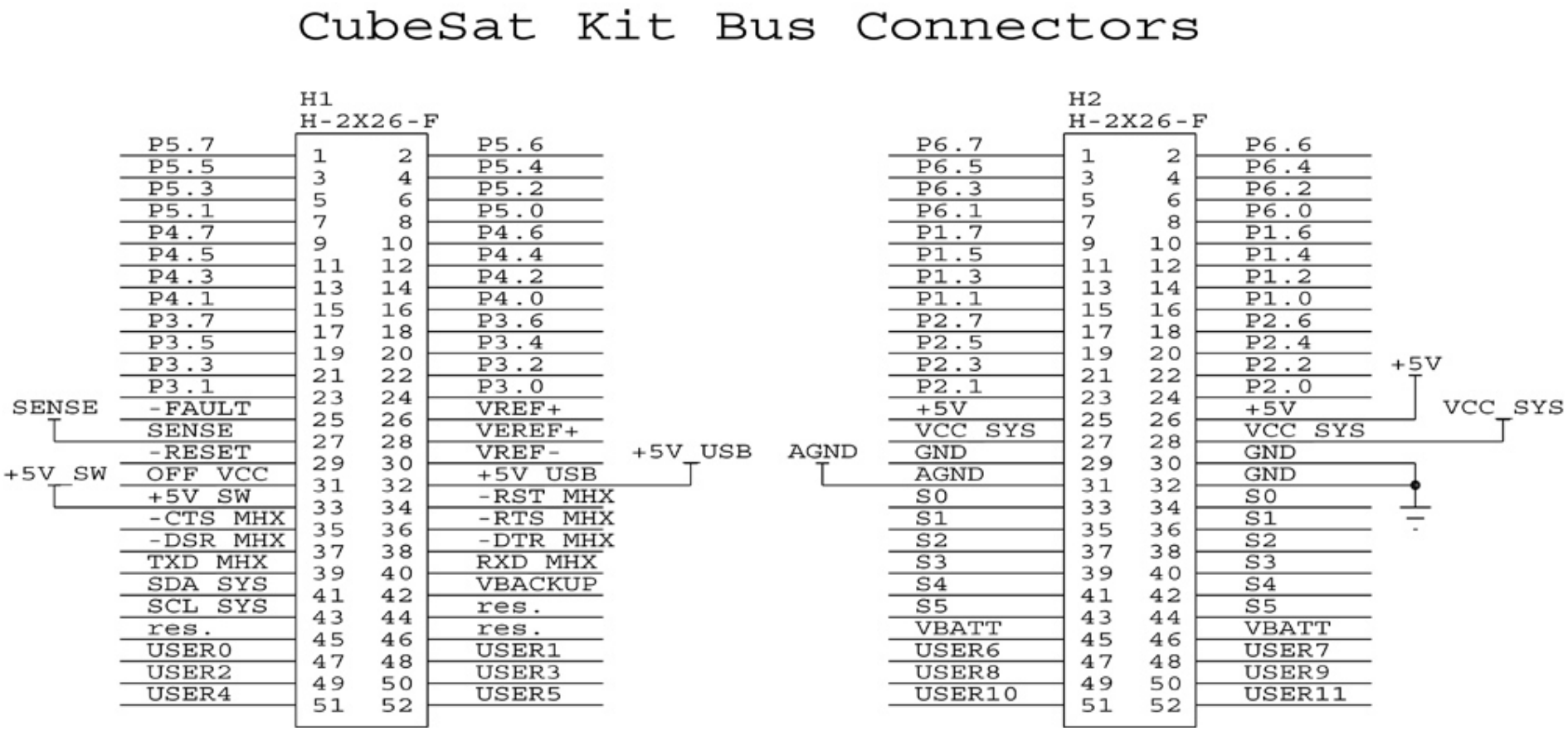

Part I (cont'd)

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- CSK FM430 Flight Module features:
  - +5V supply, +3.3V core & I/O, reset via supervisor @ < +3.1V.
  - MSP430F1612 MCU w/5KB RAM & 55KB Flash, 48 +3.3V I/O (36 unallocated).
  - Extremely low-power operation (< 5mA run, < 40μA sleep).
  - 3 clocks: 32.768kHz, DCO (0-850kHz), 7.3728MHz.
  - Overcurrent, overvoltage, undervoltage & latch-up protection.
  - System-wide resources:
    - Flight MCU.
    - SD card (mass storage) interface.
    - Transceiver (MHX socket) / zero-power USB interface.
    - Launch & Remove-Before-Flight switches.
  - +5V external power jack, JTAG programming / debug interface.

Part I (cont'd)

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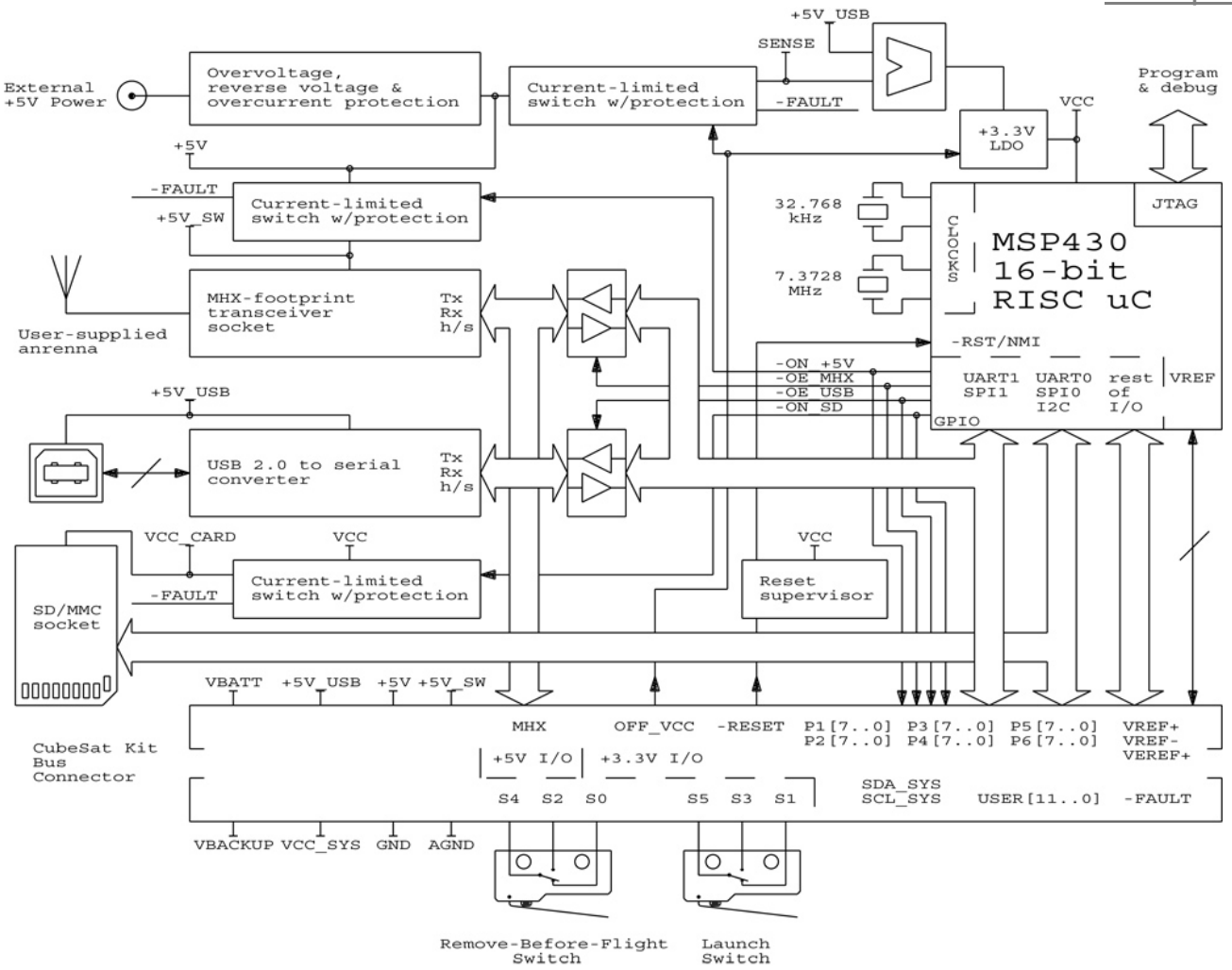

CubeSat Kit FM430 Rev C Block Diagram

Part I (cont'd)

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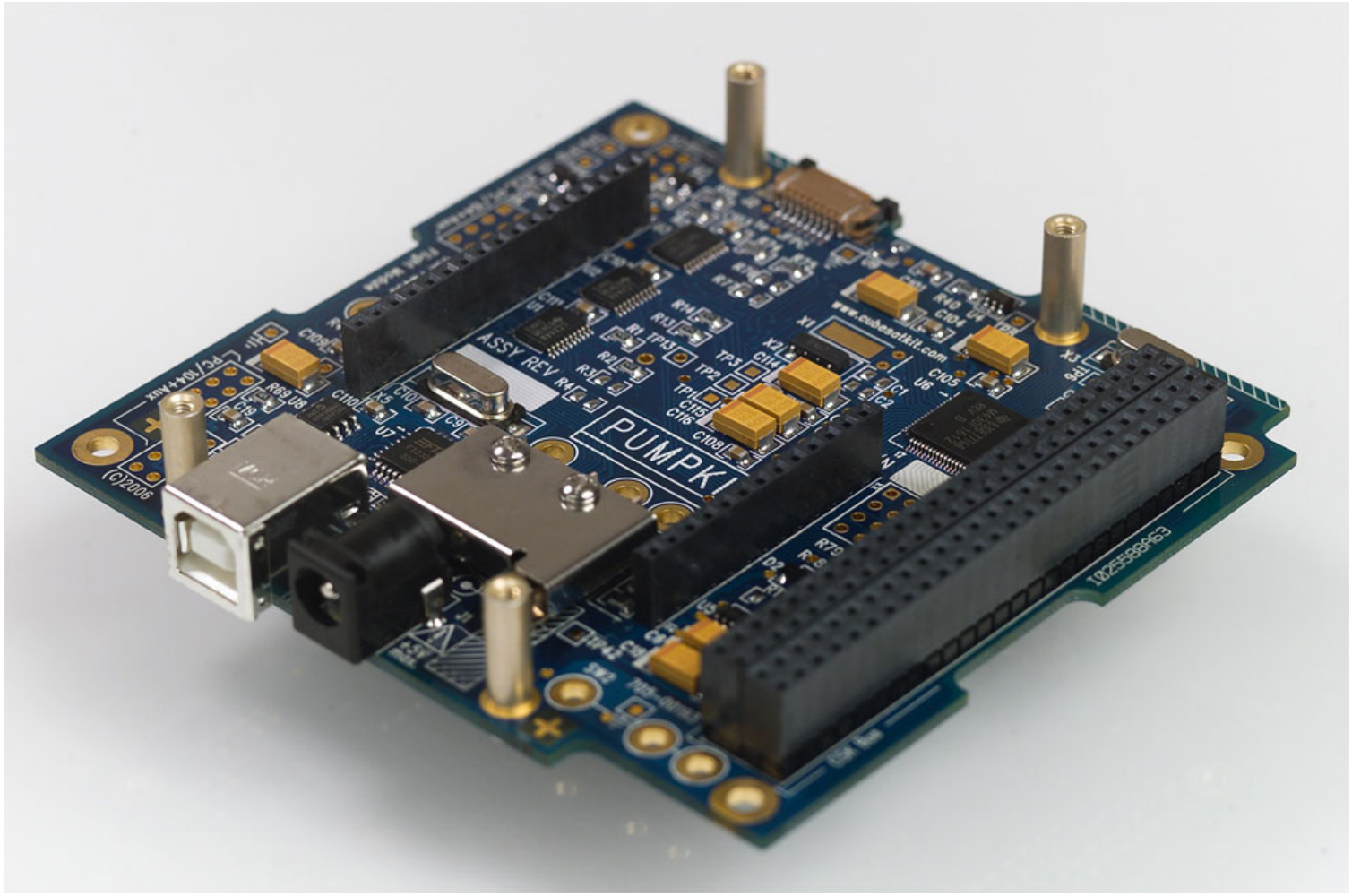

CubeSat Kit FM430 Flight Module Rev C

Choosing Processors

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- TI's 16-bit MSP430 RISC MCU
- Benefits:
  - Lowest-power MCU available, startup in 6μs.
  - Low-cost JTAG debugger & development boards.
  - Very C-friendly, good code density (esp. vs. 8-bit).
  - Versatile I/O, easy configuration, vectored interrupts.
  - Well supported, good tools & example code available.
  - Widely available (through distribution and as samples).
  - Good peripheral mix: USARTs (UART, SPI, I2C), DMA, ADC, DAC, WDT, counter/timers, etc.
- Limitations:
  - 64KB address space (MSP430X up to 1MB), no external memory.
  - Max clock 8MHz (new families 16 to 25MHz).
  - +3.6V max V_{CC}, < 2mA output drive, no +5V-tolerant I/O.
  - No PC host-like functions available (e.g. USB host, Ethernet).

Part II (cont'd)

The FM430 Flight Module's MCU is well-suited to the C&DH role. With multitasking software it can handle:

- COM interface @ 19,200bps.
- SPI, I2C & async serial payload peripherals.
- FAT-based reading and writing to SD card mass memory.
- Control & monitoring of EPS & system power & health.
- Some PWM-based tasks (motor control, audio waveform output).
- More …

- However, heavy computational loads involving e.g. non-integer divides / matrix inversions (e.g. for GPS waypoint calculations) or DSP-like signal processing exceed the MSP430's real-time capabilities.

Part II (cont'd)

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Possible multiprocessor architectures in the CubeSat Kit:

- Multiple "lesser or equal" low-power MCUs (e.g. small PICs or AVRs or even MSP430s) offload end-node computing. E.g. network of I2C or SPI slaves with FM430's MSP430 Flight MCU as the master.
- "Coprocessor approach" where one or more powerful (and consequently power-hungry) processors are onboard to perform dedicated functions at low duty cycle (e.g. < 10%) under FM430's command. PC/104, other SBC, ARM7/ARM9, PowerPC, DSP, gumstix, etc. running Linux or Windows or other OS. In these designs the FM430's role may be secondary.
- Multiple FM430s in one CubeSat Kit (1.5U or larger) using wired or wireless connectivity between them.

Part II (cont'd)

Other reasons for adding additional processors:

- Already part of (sub-)payload hardware.
- Existing COTS software + hardware is ideally suited to a particular mission, or is only available solution.
- Processor testbeds (e.g. flight qualification of new processors).
- Sponsor- or partner-driven.
- Redundancy.

- Power requirements of additional processors will largely dictate how they are used, esp. in 1U CubeSats (1 - 5W total power). Most additional processors will spend their time asleep or powered off.
- Consider that from a mass and power standpoint, it's often more efficient to pack more functionality into a single processor than to spread it amongst multiple processors. K.I.S.S.

Interfacing Additional Processors

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- CubeSat Kit module design is relatively straightforward:
  - Required:
    - Conform to CSK PCB module specification (footprint).
    - Power from +5V and/or +3.3V, reset properly (e.g. via supervisor).
    - All I/O to FM430 must be +3.3V, avoid overcurrent (> 2mA).
    - If used, limit +5V_USB draw to available (< 500mA).
  - FM430 Interface:
    - Standard I2C, SPI and async serial interfaces (all +3.3V I/O).
    - User-defined for unallocated I/O from/to FM430 or other devices.
    - Handshaking required to access FM430's local resources (e.g. SD card, USB).
  - Optional:
    - Drive +5V I/O to MHX transceiver, control +5V_SW.
    - Interface to –RESET, OFF_VCC & -FAULT (o.c.), etc.
    - Use USER[11..0] bus in any way you want … need not be +3.3V.

Part III (cont'd)

- FM430 hardware design for additional processors:
  - None – FM430 architecture is already defined.
  - Any additional h/w (e.g. for RS422) must be implemented in the I/O space on another (i.e. user) module. Shared I/O must be pinned out properly on user modules!
- FM430 software design for additional processors:
  - Largely user-defined:
    - Native serial interfaces (I2C, SPI, simple async serial devices) are ready to go.
    - Non-native interfaces & protocols (e.g. RS422, CAN, SLIP) will require software protocol(s) to pass data among processors and share control of bus signals where necessary.

Part III (cont'd)

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- A properly designed additional processor module will:
  - Conform to the CSK PCB module specification.
  - Fit inside a maximum volume of 90 x 96 x 15x(n+10)mm.
  - Run on +5V and/or +3.3V directly from the CSK Bus.
  - Connect to the minimum number of CSK Bus pins required to power the module and communicate with the FM430 and/or other processors at +3.3V.
  - Pass all unused CSK Bus pins on to other modules.
  - Be an enabling element of the responsive space approach that typifies CubeSats in particular and nanosatellites in general.

Going it Alone

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- An alternative uni- or multiprocessor approach is to use module(s) other than the CubeSat Kit's FM430 Flight Module, i.e. use just the CubeSat Kit mechanicals (structure, etc.)
  - Drawbacks:
    - Available 90 x 96mm footprint limits choices (many PC/104 modules will not fit).
    - Design costs and times, lack of Pumpkin support, etc.
    - Useful FM430 features (extremely low power, USB, SD card) may not be present.
    - Inability to use other CSK modules (e.g. Clyde Space EPS).
    - Cannot draw support from CubeSat Kit community.
- 90 x 96mm PCB in the CubeSat Kit module / PC/104 footprint is mechanically compatible with the family of CubeSat Kit structures.

Examples

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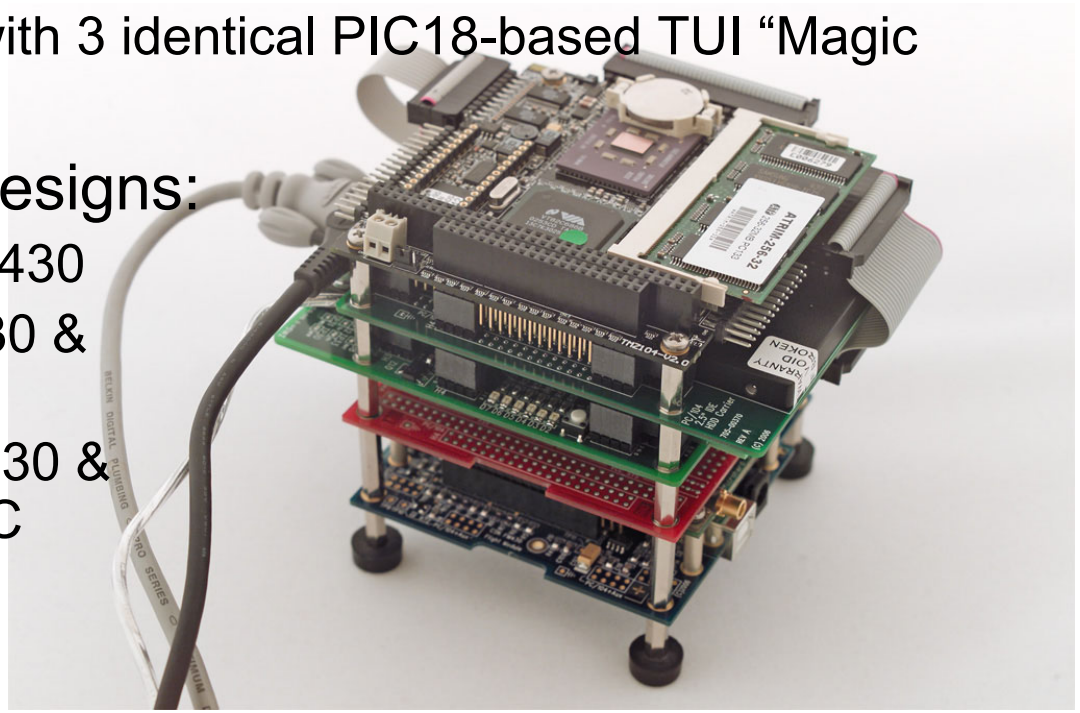
- Earlier CubeSat designs:
  - QuakeSat: 3U, with underclocked Linux PC/104 SBC
  - GeneSat-1: 3U, with PIC18-based C&DH & separate payload processor
  - MAST: separable 3U, with 3 identical PIC18-based TUI “Magic Boards”
- Current CubeSat Kit designs:
  - Libertad-1: 1U, with FM430
  - Delfi-C3: 3U, with FM430 & multiple I2C slaves
  - BioLaunch-1: with FM430 & TMZ104 low-power SBC running Windows XP



CubeSat Kit Module Stack with TMZ104 above FM430

Summary

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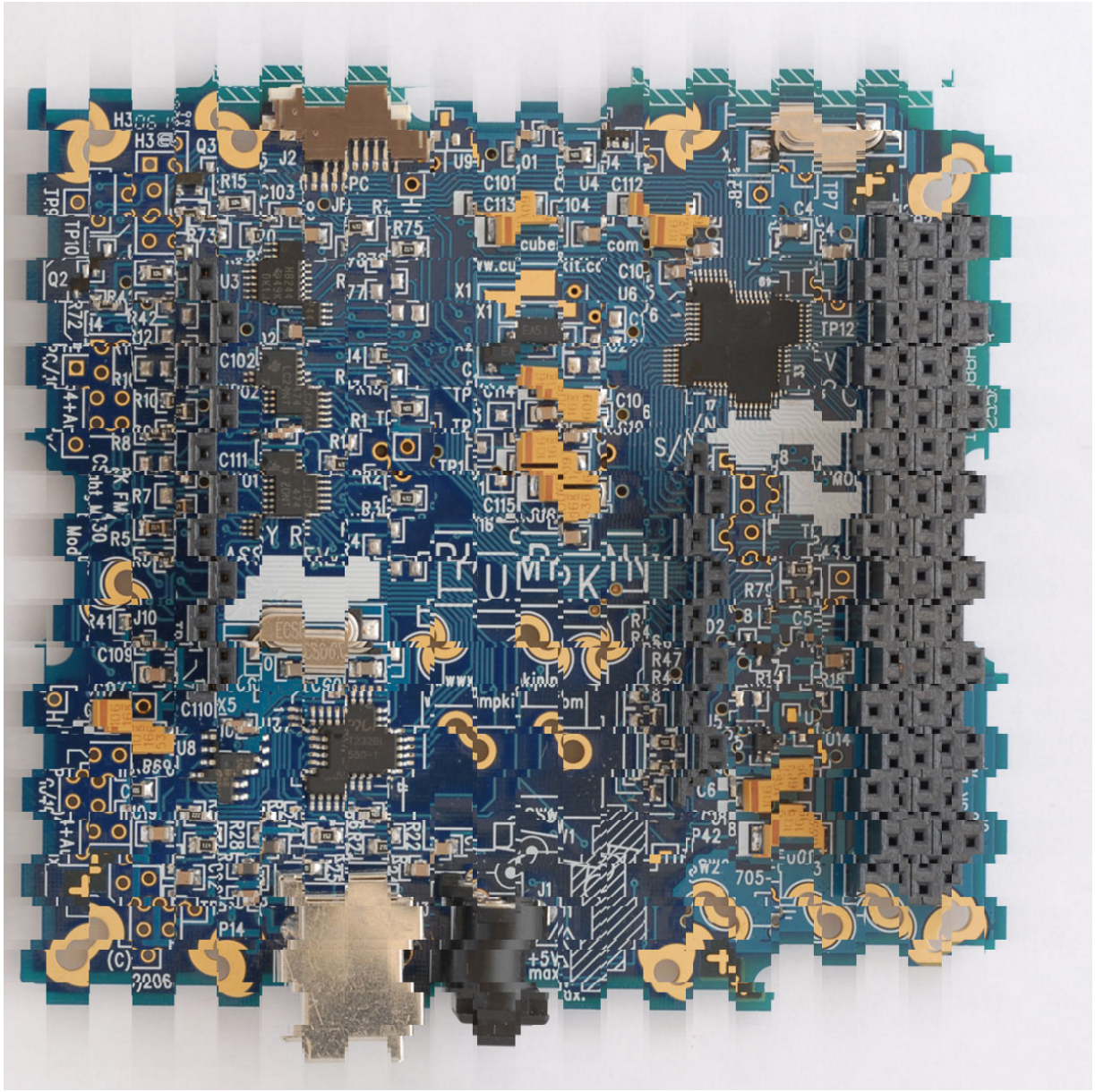
- The CubeSat Kit architecture can easily accommodate additional processors.
- A variety of multiprocessor architectures are possible.
- The rules for harmonious multiprocessor operation are relatively simply satisfied.



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Q&A Session

Thank you for attending this Pumpkin seminar at the CubeSat Workshop Developers' Conference 2007!

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Suggested Reading

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1. *MSP430x15x, MSP430x16x, MSP430x161x Mixed Signal Microcontroller*, Texas Instruments Datasheet SLAS368D, October 2002.
2. *MSP430x1xx Family User's Guide Revision F*, Texas Instruments SLAU049F, 2006.
3. *Salvo User Manual*, Pumpkin, Inc., 2003.
4. *CubeSat Kit FM430 Flight Module datasheet*, Pumpkin, Inc., 2007.

Appendix

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- 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.
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First presented at the CubeSat Workshop Developers' Conference in Huntington Beach, California on April 19-21, 2007.