Overview of the CubeSat Kit™

speaker:
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PART I

A Design Partnership of

PUMPKIN INCORPORATED

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MASSIF
Pumpkin, Inc.

- An embedded solutions company
- Established 1995 in San Francisco, California
- Focused on providing highest-quality tools for embedded system designers
- Active in both hardware and software design for a variety of end-user clients
- Source for Salvo™, a unique commercial RTOS designed expressly for single-chip microcontrollers with <= 4KB RAM
design MASSIF

● An industrial design and engineering consultant

● Established in 1992 in Mountain View, California; operating near Placerville, California since 1994

● Specializing in product design for low volume manufacturing, usually with high-precision elements, yet solutions are cost-effective and on budget

● Typical clients are startup companies

● Onsite machine shop and welding equipment enables prototype parts to be quickly fabricated, essential to early product development stages

● Parametric CAD solid modeling is utilized for product visualization, and allows for design updates to be seamlessly integrated
CubeSat Kit Design Objectives

- Affordable
- Complete conformance with CubeSat specifications
- Lightweight
- Minimal structural and Flight Module intrusion into available volume
- Minimal use of wires and cables
- Highly user-configurable
- Standard bus
- Ultra-low power consumption (<10mW operational, <250µW sleep)
- Powerful and comprehensive development environment (for CubeSat hardware and software) for rapid development
PART II

Chassis, Flight Module & Software Components
Sheet Metal Aluminum Chassis

- Affords designers considerable freedom in conforming to CubeSat specifications
- Lightweight, yet strong
- Maximizes available internal volume
- Minimal use of fasteners
- Very low parts count
- Manufacturing tolerances are +/- 0.005"
- Modular – 1U, 2U and 3U CubeSats all part of same family
- Available in two different flavors:
  - Skeletonized
  - Solid-wall
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CubeSat Kit Base Plate (detail)

Figure 1: Dimensional Detail, CubeSat Kit Base Plate
Flight Module

- Minimal weight and volume
- Extremely low power consumption
- Accepts external power
- USB support
- μC CPU's I/O pins available on standardized connectors
- Can serve as primary or secondary mission CPU
- PC/104 form factor and stackability
- Sufficient MIPS for low-to-moderate mission complexity
- Integrated 2.4GHz spread spectrum transceiver support
- Direct debugging support
Figure 2: Semi-Exploded View, CubeSat Kit, Illustrating PCB Stacking and Bus Interconnect Scheme
Salvo – A Unique RTOS

- Minimal on-chip resource requirements
- Designed expressly for use in single-chip µC's
- Event-driven, priority-based, cooperative multitasking
- Certified for use with all major MSP430 compilers:
  
  ![QIAR Systems](QIAR Systems.png)  ![MECraft](MECraft.png)  ![Quadravox](Quadravox.png)  ![RA](RA.png)

- Available in different flavors:
  - Salvo Lite freeware / demo / evaluation
  - Salvo tiny included with some compilers / IDEs
  - Salvo SE available from certain compiler vendors
  - Salvo LE all supported functionality
  - Salvo Pro Salvo LE + source code

- Portable (cross-compiler and cross-target)
- Highly configurable (written 98% in C)
- Easy to learn
- Royalty-free
A Highly Challenging Design Exercise

- Existing CubeSat specification highly constrains many aspects of CubeSat Kit's design goals
- Size of Microhard MHX-2400 spread spectrum transceiver conflicts with CubeSat basic 10x10x10cm dimensions
- Size of high-current (10A) launch and remove-before-flight switches complicates packaging
- Required locations of remove-before-flight pin and USB connector constrain placement options and have far-reaching consequences on other components
- Density of components on Flight Module dictates 6-layer PCB
- PCB-stacking options have ramifications for packaging density
- Hard-anodizing (non-conductive) incompatible with desire for chassis as Faraday cage
Figure 3: CubeSat Kit Face Dimensional Details

Figure 4: CubeSat Kit Face Oblique View
PART III

The CubeSat Kit™
Figure 5: Solid-wall and Skeletonized Assembled CubeSat Kit Flight Models
Figure 6: Disassembled CubeSat Kit Flight Models
All Design Objectives Reached, Including

- Chassis
  - Consists of 3 major single-piece assemblies (body, base plate, end plate) and 7 machined aluminum feet (two types – simple, and with spring plunger)
  - Alodyned for electrical conductivity, except for hard-anodizing on wear surfaces
  - All fasteners stainless steel for uniform thermal expansion and resistance to corrosion
  - 10 M3 screws hold entire chassis together
  - 9 smaller screws and 4 nuts affix feet and hold launch and remove-before-flight switches in place
  - Remove-before-flight pin securing system very strong, with audible and tactile engagement and disengagement
  - PCB stacks assembled via 15 & 25mm M3 threaded standoffs

- Masses\(^1\), resulting in a minimum of 690g for payload, etc:
  - Chassis, complete, skeletonized\(^2\) 190g
  - FM430 Flight Module +50g
  - MHX-2400 spread spectrum transceiver +70g
  - Total 310g
• **System**
  
  - Accepts a minimum of four additional PC/104-sized user modules (PCBs)
  - Plug-in support for MHX-2400 spread-spectrum transceiver
  - Easily expanded via Flight Module's CubeSat Bus Connectors
  - Powered from on-board power supply, external +5V or USB
  - Multiple remove-before-flight and launch switch wiring options
  - Less than 8cm of high-current wiring required solely for launch and remove-before-flight switches

• **Flight Module**
  
  - Meets all low-power requirements
  - Easy to Program
  - Only a small number of I/O pins have permanently dedicated functions – rest are free for user
What's Included

- **Development Board**
  - Duplicates Flight Module, but in a more convenient form factor
  - Important chip(s) socketed
  - Greater accessibility (e.g. for probing)
  - Multiple power source options
  - Separate breadboard / prototyping area
  - Additional circuitry not on Flight Module (e.g. extra RS-232 transceiver)

- **CubeSat Chassis**

- **Flight Module**

- **Power Supply**

- **JTAG Debugger / Emulation Tool**

- **Salvo Pro RTOS Software & Example / Demo / Test Code**

- **Manuals**

- **Misc. Cables, etc.**
PART IV

FM430
Flight Module
MSP430F149-based Flight Module

- **Hardware Details:**
  - P6 shared between:
    - USB / transceiver handshake / control interface
    - Transceiver isolation
    - Analog sampling channels (e.g. temp sensors)
  - USART1 shared between:
    - Serial-to-USB converter
    - 2.4GHz spread-spectrum wireless transceiver
    - User (off-board)
  - Mixed +3.3V / +5V design:
    - Level translators & buffers provide isolation, incl. unpowered states
    - USB (+5V, bus-powered) interfaces to MCU at +3.3V via isolator
    - Transceiver (+5V) interfaces to MCU via isolators & level-shifters
    - MCU controls OE's on isolators & level-shifters
    - MCU controls power to +5V transceiver
  - Low-Power:
    - Sleep at < 30µA, operate at < 2mA, Tx (occasionally) at > 750mA
    - Powered via internal +5V or via USB
• Block Diagram:
● **Software Requirements (implemented as a Salvo application):**

  ● **USART1:**
    ● Manage isolation & interface to USB / transceiver / user to avoid contention
  
  ● **USB:**
    ● Detect when USB I/F is present
    ● Acquire & release USB interface
  
  ● **Transceiver:**
    ● Tx / Rx when requested
    ● Acquire & release transceiver interface, including the control of transceiver power when Tx'ing / Rx'ing
  
  ● **P6:**
    ● Sample at a variety of rates via A/D inputs
    ● Handshake control to USB / transceiver interface
  
  ● **Other Processes:**
    ● Perform a myriad of other simultaneous operations (e.g. data processing, system status reporting, storing and retrieving data to / from external NVRAM, etc.)
  
  ● **Power Consumption:**
    ● Sleep whenever no activity is warranted
Completing the Application

- Use additional binary semaphores and task priorities to manage access to resources:
  - Analog sampling tasks wait for P6 (shared with USB / transceiver interface) to be available before proceeding
  - User USART1 task waits for USART1 (used by TaskTalkUSB() and TaskTalkMHX()) to be available before proceeding

- Run additional periodic tasks at multiples of system tick period

- Use messages and message queues for intertask communications:
  - Multiple, asynchronous sampling tasks pass data to a single task that logs captured data to NVRAM
  - Highest-priority tasks wait on critical events

- Use free-running system timer for timestamps

- Handle lost events via wait-with-timeout
Example Application Results

- **Application Configured For / Uses:**
  - 10ms system tick period
  - LPM1
  - `sprintf()`, 16-bit multiply & divide
  - Subsystems:
    - Timer_A, USART0, USART1, ADC12, WDT, Digital I/O

- **Salvo Configured For:**
  - 16-bit delays
  - Binary semaphores
  - 32-bit system timer
  - Priority-based multitasking
  - 15 tasks
  - 1 event

- **Salvo's Memory Requirements** on MSP430F149 for this Application:
  - 1132 bytes ROM (1.8%) for Salvo services
  - 171 bytes RAM (8.3%) for Salvo's global objects
  - Default of 90 bytes RAM (4.4%) for stack is more than sufficient

- **Application's Power Consumption:**
  - Over 97% of the time in LPM
PART V

Pricing
Complete CubeSat Kit with FM430 Flight Module

- 1U (10x10x10cm): US $5,000
- 2U (10x10x20cm): TBD
- 3U (10x10x30cm): TBD

N.B. Additional flight models and other spare parts will be available to existing CubeSat Kit customers
Thank you for your interest in Pumpkin's
Speaker Information

Dr. Kalman is Pumpkin's president and chief software architect. 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. He has also been involved in a variety of other hardware and software projects.

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All specifications subject to change without notice.

1 Preliminary, subject to real-world adjustments.
2 For solid-wall chassis, add 85g.
3 A bus-powered USB device is one that gets its power from the USB host (i.e. over the USB cable).
4 This is the total system sleep current, and includes the quiescent current of voltage regulators, leakage across power-control and level-shifting FETs, etc.
5 IAR MSP430 C v2.10A
6 With skeletonized or solid-wall chassis.