PUMPKIN™
REAL-TIME SOFTWARE

Overview of the CubeSat Kit™

CUBE SAT KIT

speaker:

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PART I

A Design Partnership of

PUMPKIN™ INCORPORATED

&

design 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

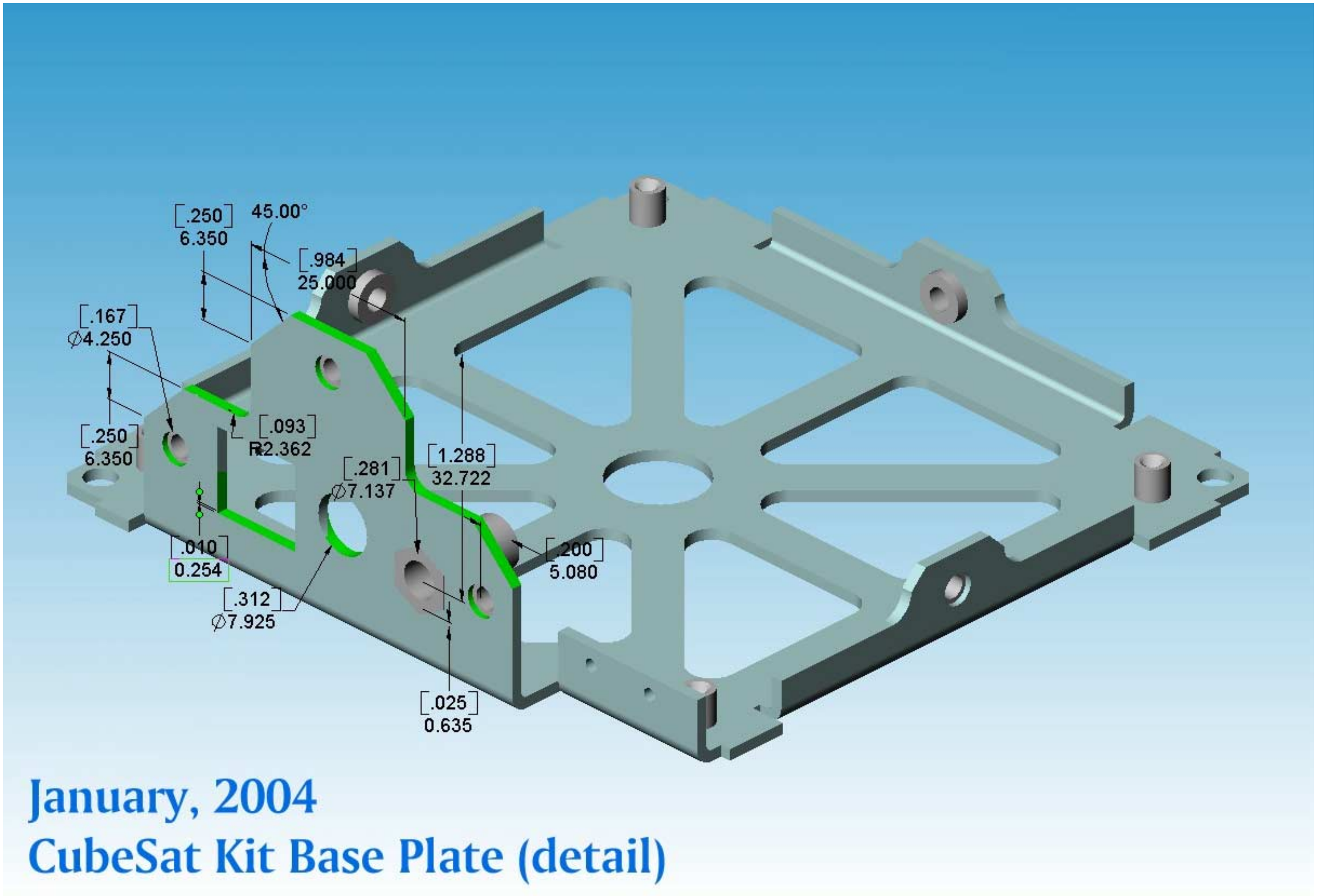


Figure 1: Dimensional Detail, CubeSat Kit Base Plate

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

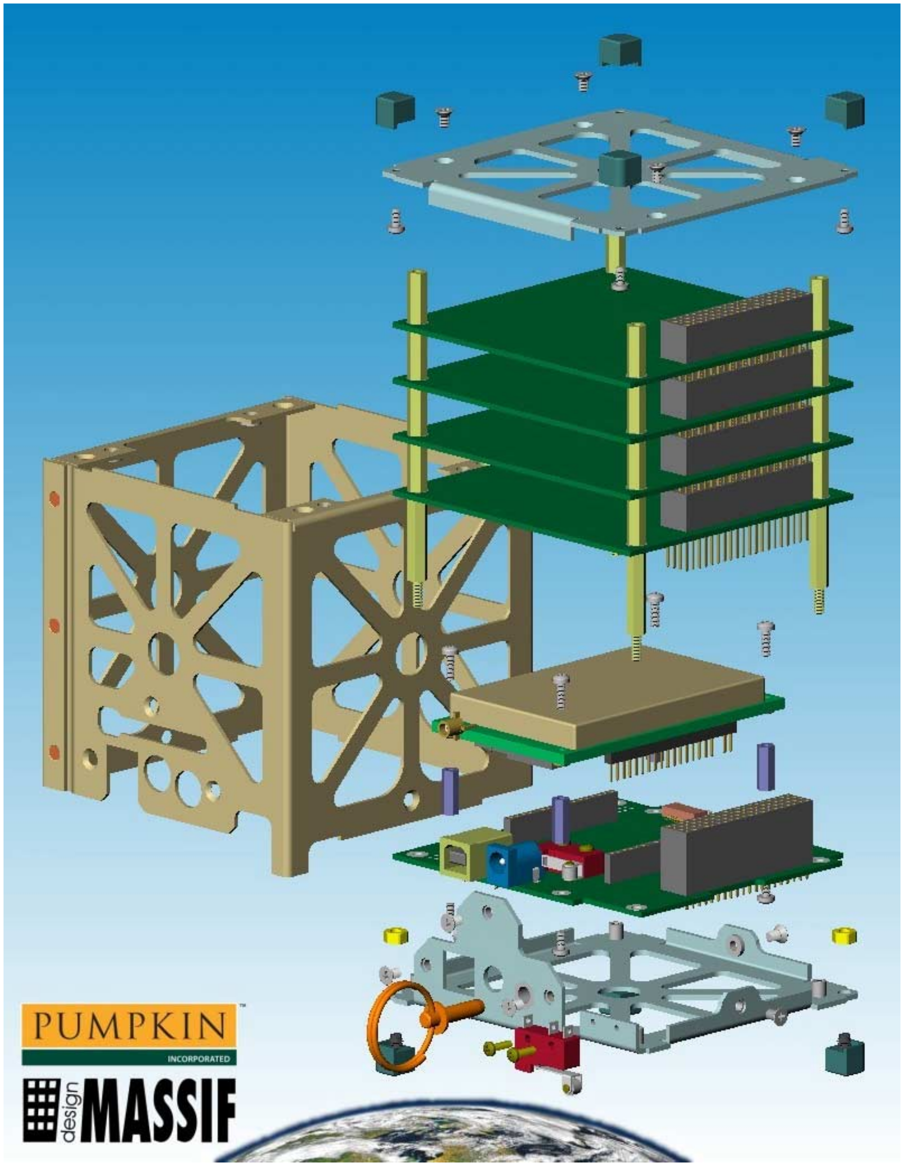


Figure 2: Semi-Exploded View, CubeSat Kit, Illustrating PCB Stacking and Bus Interconnect Scheme

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:
- 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

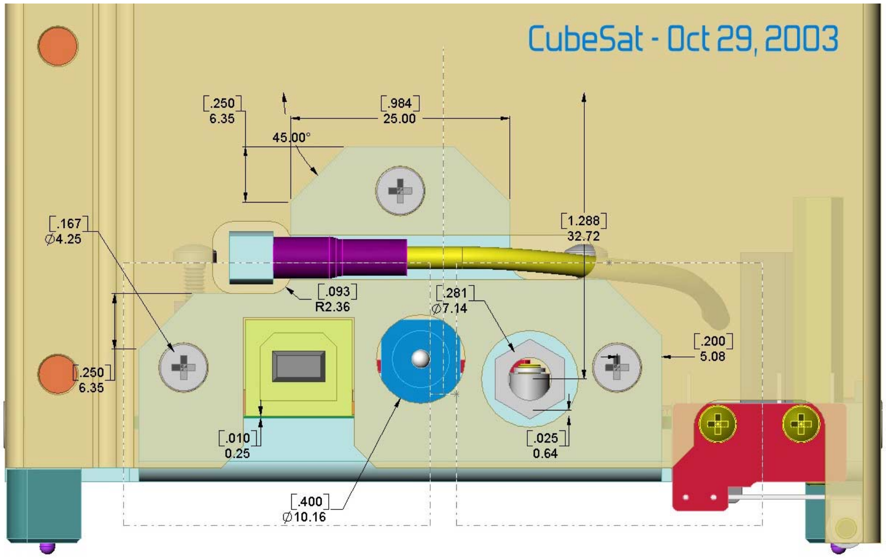


Figure 3: CubeSat Kit Face Dimensional Details

Figure 4: CubeSat Kit Face Oblique View

PART III

The CubeSat Kit™

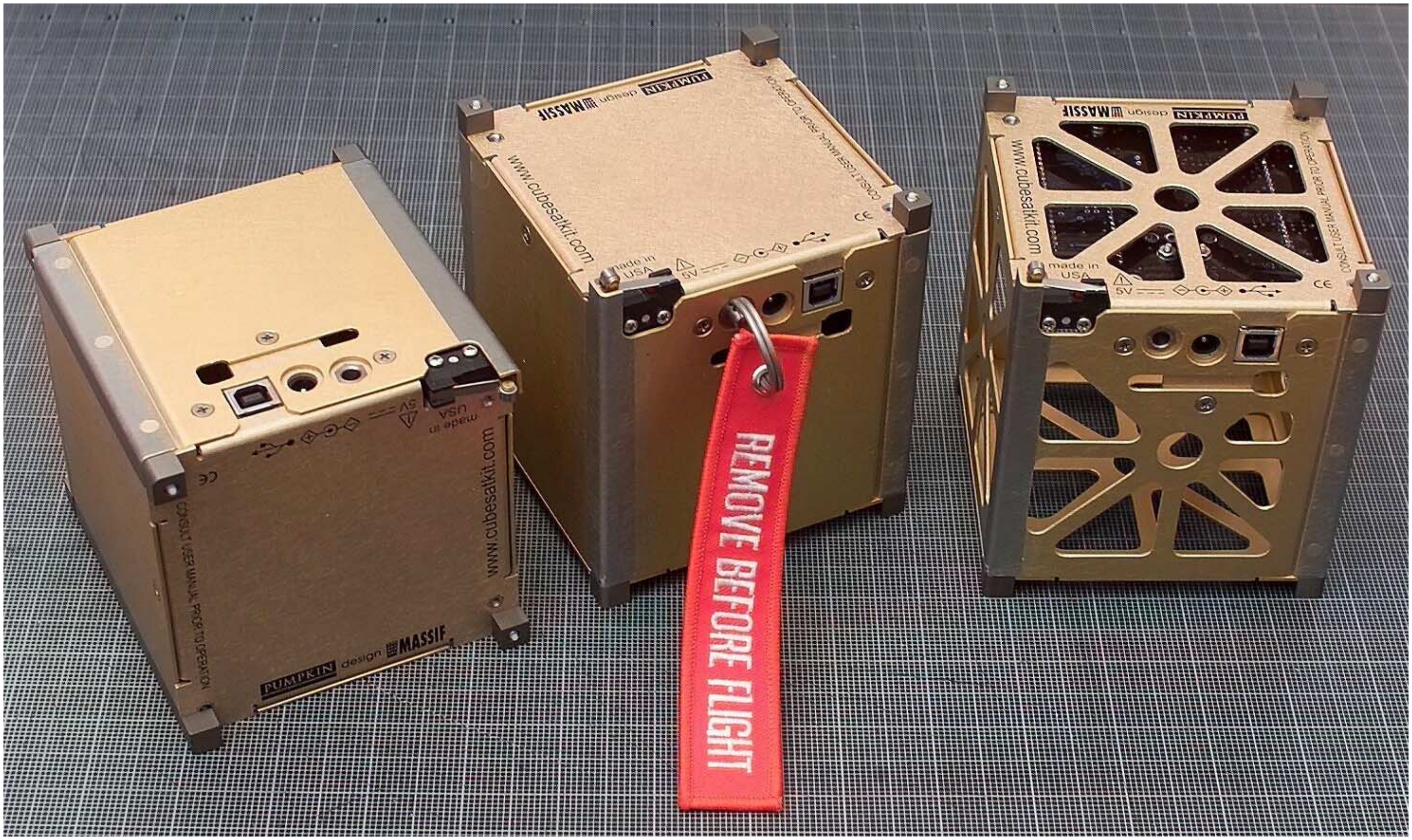


Figure 5: Solid-wall and Skeletonized Assembled CubeSat Kit Flight Models

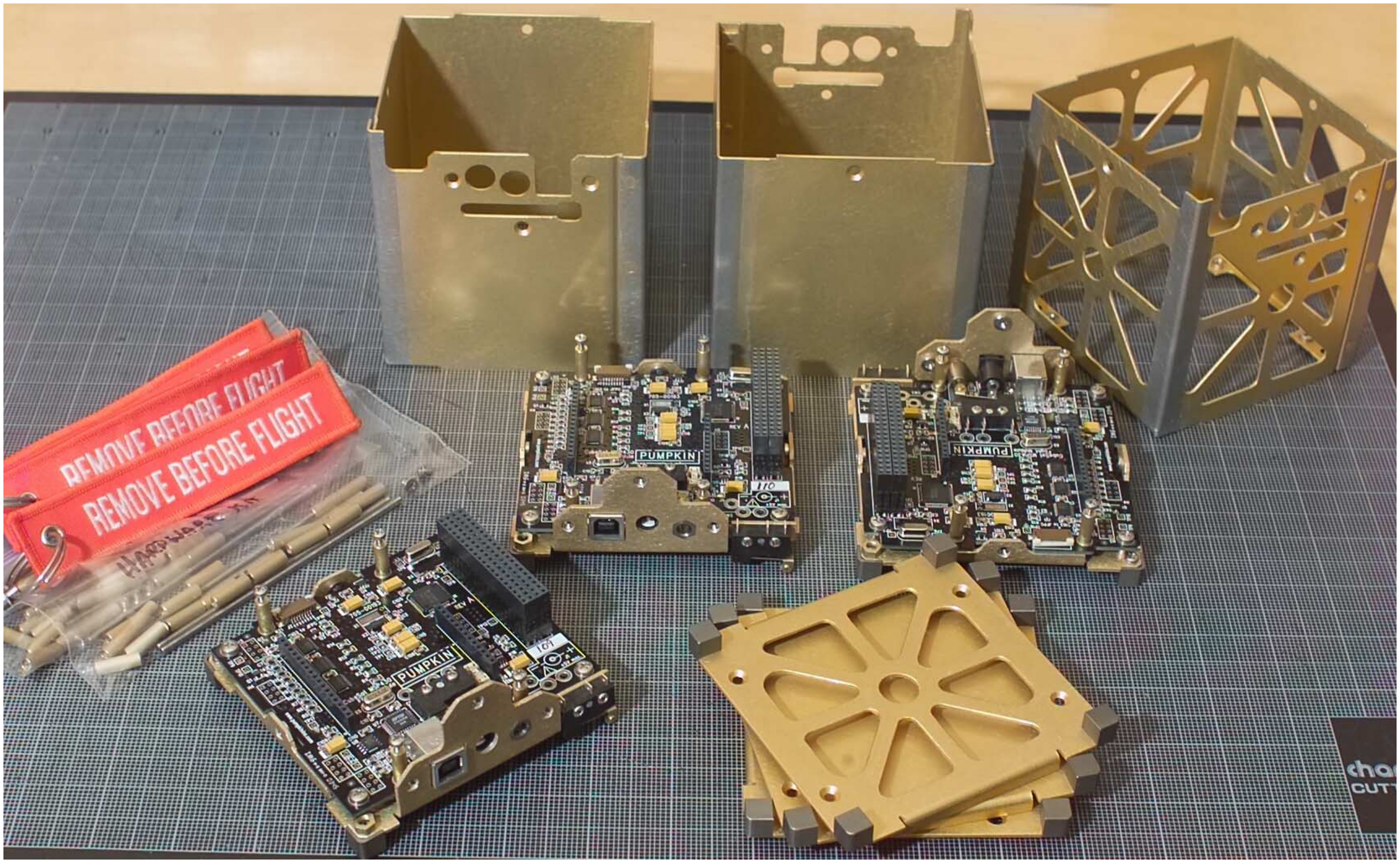


Figure 6: Disassembled CubeSat Kit Flight Models

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.**

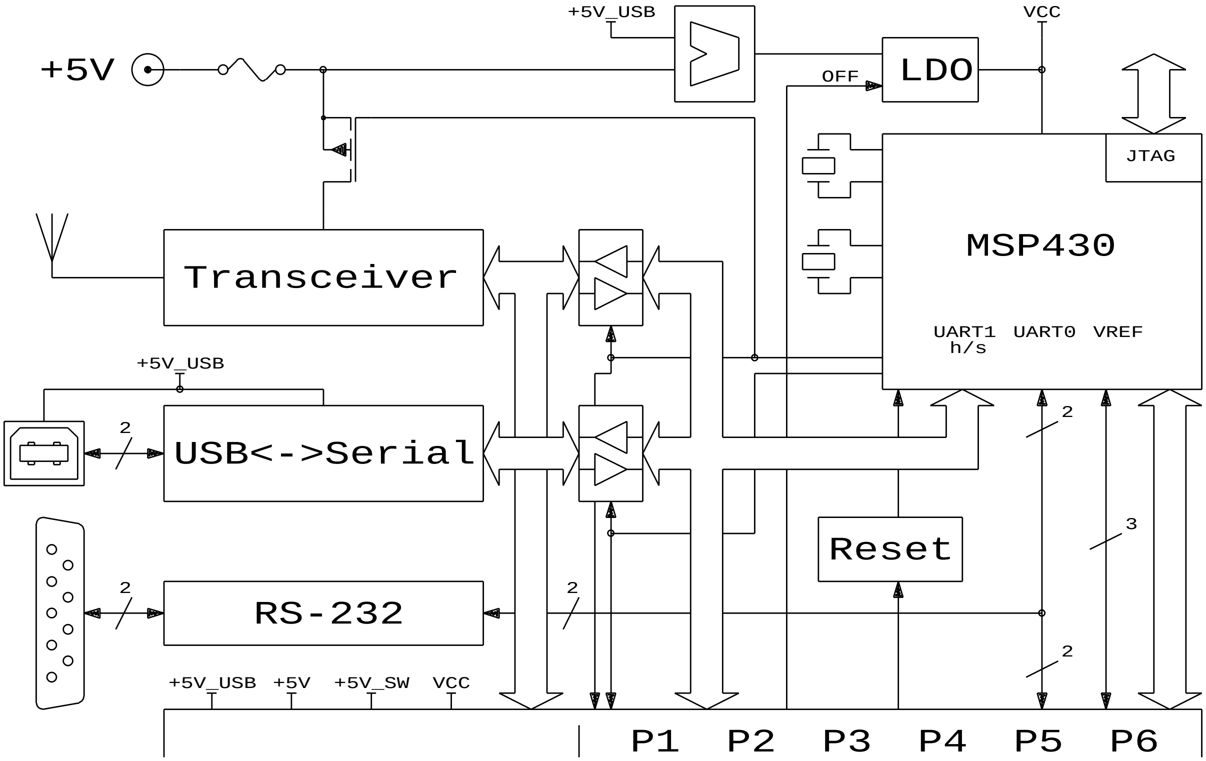
PART IV

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[3]) interfaces to MCU at +3.3V via isolator
    - Transceiver (+5V) interfaces to MCU via isolators & level-shifters
    - MCU controls −0E's on isolators & level-shifters
    - MCU controls power to +5V transceiver
  - Low-Power:
    - Sleep at < 30µA,[4] 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
  - Multiple interrupt sources
  - LPM1
  - MCLK, SMCLK
  - `sprintf()`, 16-bit multiply & divide
  - Subsystems:
    - Timer_A, USART0, USART1, ADC12, WDT, Digital I/O
- **Salvo Configured For:**
  - 16-bit delays
  - Priority-based multitasking
  - Binary semaphores
  - 15 tasks
  - 32-bit system timer
  - 1 event
- **Salvo's Memory Requirements[5] 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[6] 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

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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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[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.