A Dual-Redundant CubeSat Flight Computer Based on Raspberry Pi

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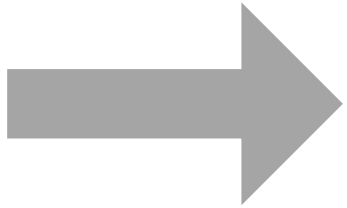
Overview

- Context: The AAReST Mission
- Why use Raspberry Pi?
- DualPi OBC Evolution
- System Overview
- Functional Breakdown
- Characteristics
- Getting Involved
- Q&A

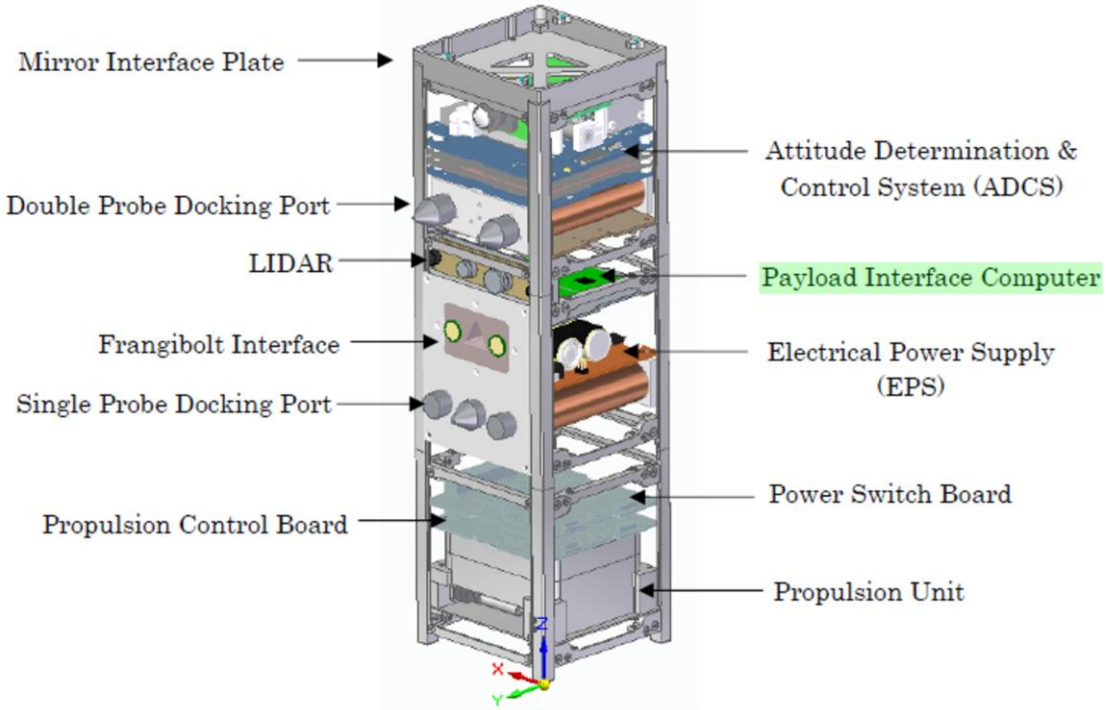


- *System Monitoring*
- *Ethernet Cross-Link*
- *Wi-Fi Intersatellite Link*
- *Raspberry Pi Camera Support*

Context: The AAReST Mission

"Autonomous Assembly of a Reconfigurable Space Telescope"

C. Underwood et al, "AAReST Autonomous Assembly Reconfigurable Space Telescope Flight Demonstrator," in *69th International Astronautical Congress*, Bremen, Germany, 2018.



- Payload **UART** (Deformable Mirror Payload)
- Payload **I2C** (master, docking systems)
- Platform **I2C** (slave, ADCS bundle)
- LiDAR **USB** → *Raspberry Pi Camera*
- Intersatellite Link **Wi-Fi**

Why use Raspberry Pi?

Advantages

- ARM Microprocessor
- Inexpensive
- Simplifies Development
- Community Support
- GPU – AOCS, Image Processing

Disadvantages

- Vulnerable to radiation effects
- Partial Proprietary (Broadcom)
- Physical Integration
- High Power Consumption

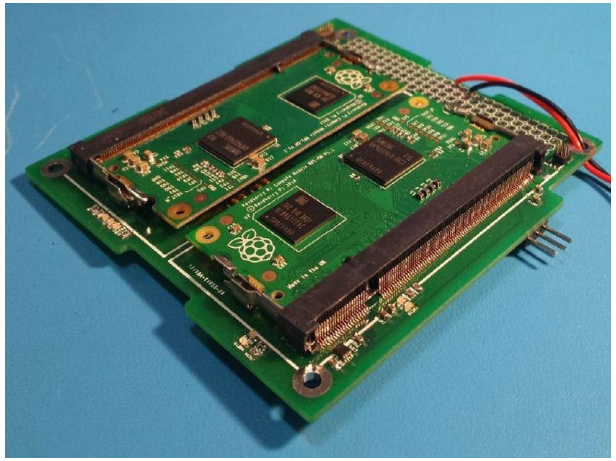
Solution:

Redundant Raspberry Pis + support circuitry on one board

Raspberry Pi Compute Module - easier to integrate

DualPi OBC Evolution

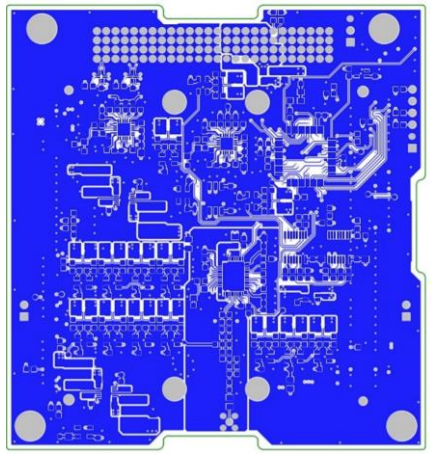
2015
O. Launchbury-Clark



Version 1

2x RPi Compute Module 1
(Cold-Redundant)
MSP430 FRAM MCU (FR6989)
Anti-latchup circuitry
I2C

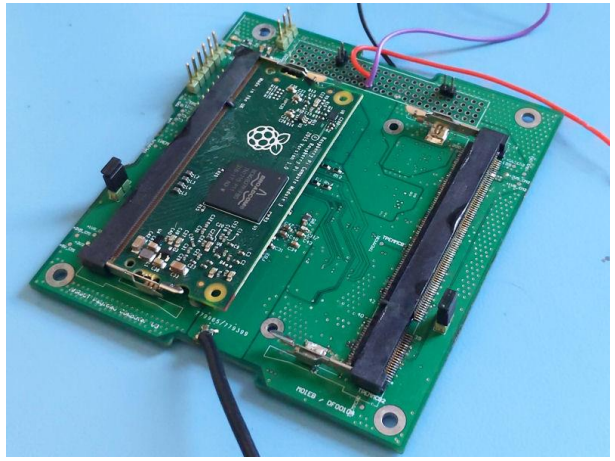
2017
P. Ramaprakash



Version 2 (design only)

2x RPi Compute Module 3*
(Cold-Redundant)
Xilinx CPLD (XC9572XL)
Digital supply monitoring
2x I2C, UART, USB
ISL Wi-Fi

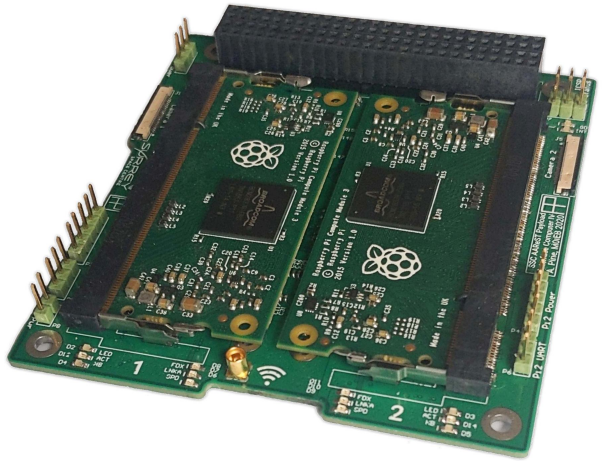
2018
D. Frangopoulos



Version 3

1x RPi Compute Module 3
(Cold-Redundant)
Xilinx CPLD (XC95144XL)
Digital supply monitoring
2x I2C, UART, USB
ISL Wi-Fi

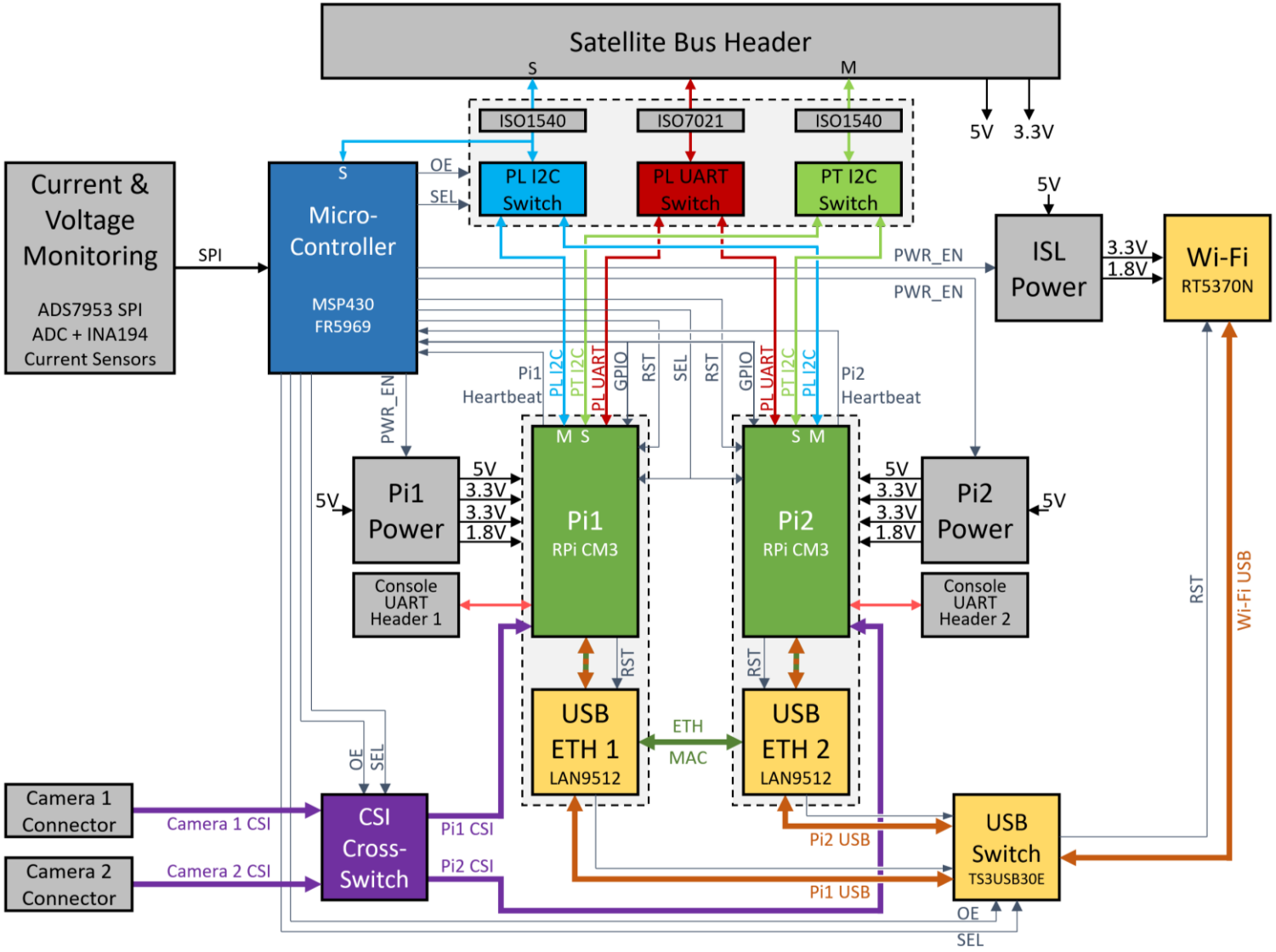
2020
A. Pirie

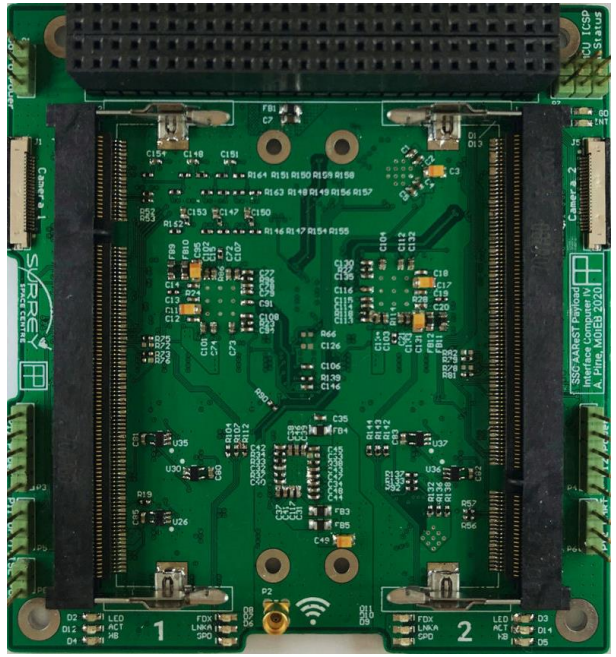


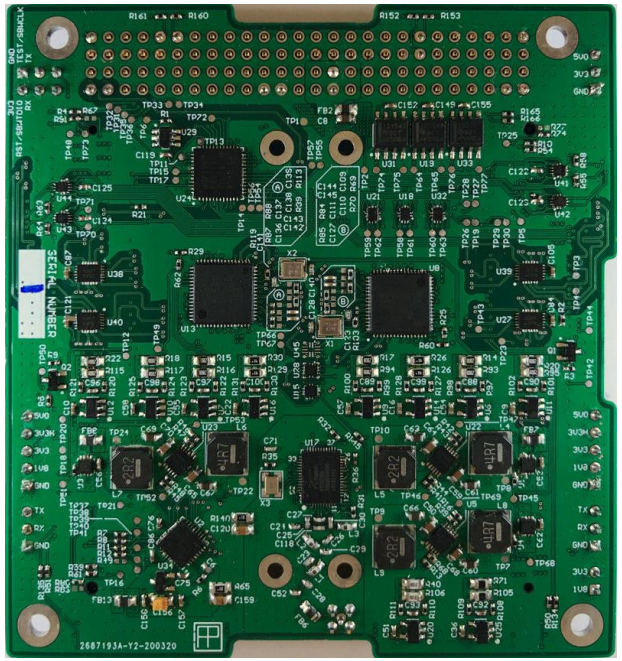
Version 4

2x RPi Compute Module 3
(Cold/Warm/Hot-Redundant)
MSP430 FRAM MCU (FR5969)
Digital supply monitoring
2xI2C, UART, (USB)
ISL Wi-Fi, 2x RPi Camera

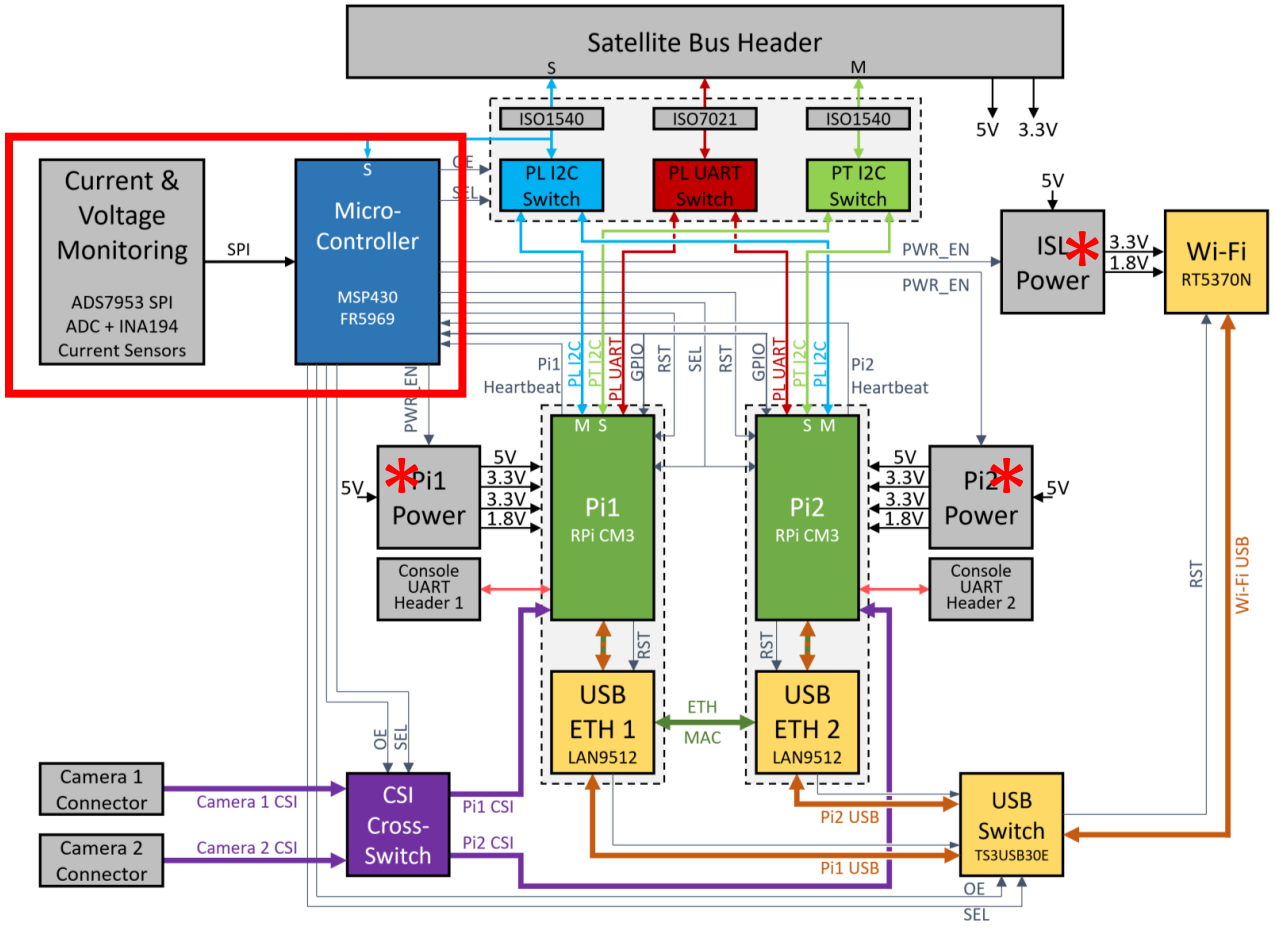
System Overview

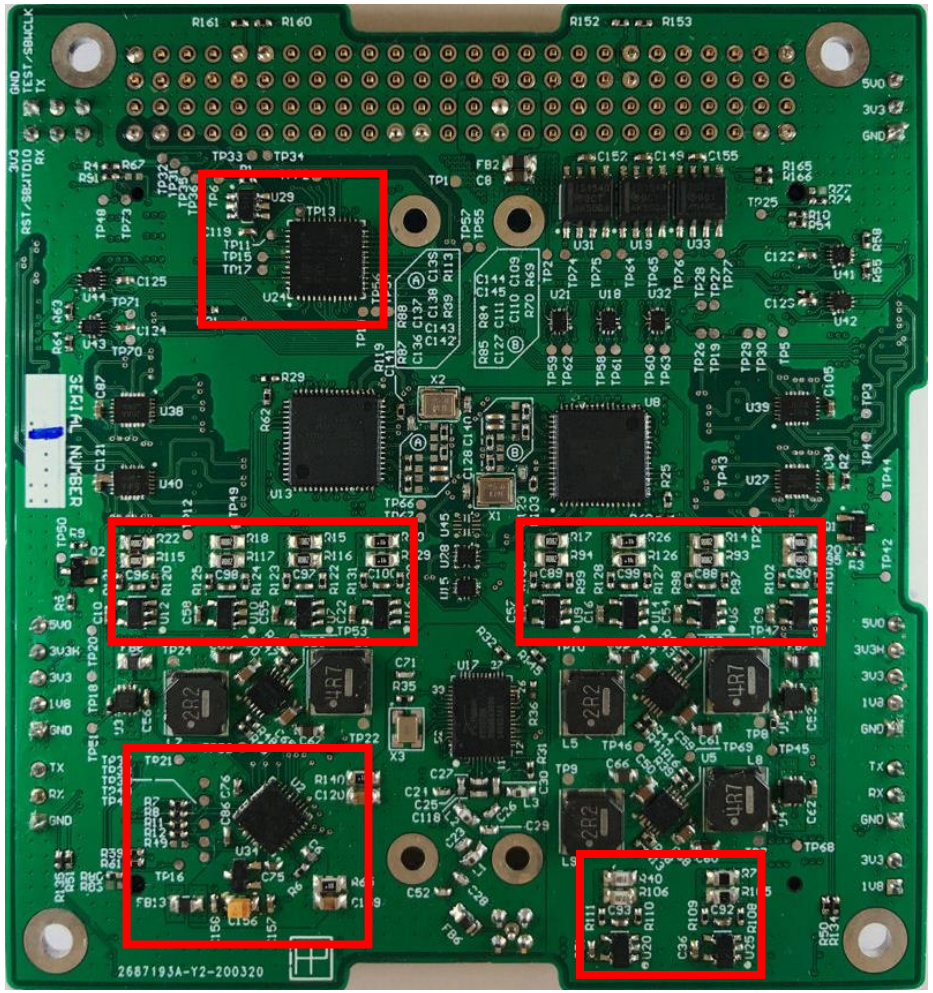






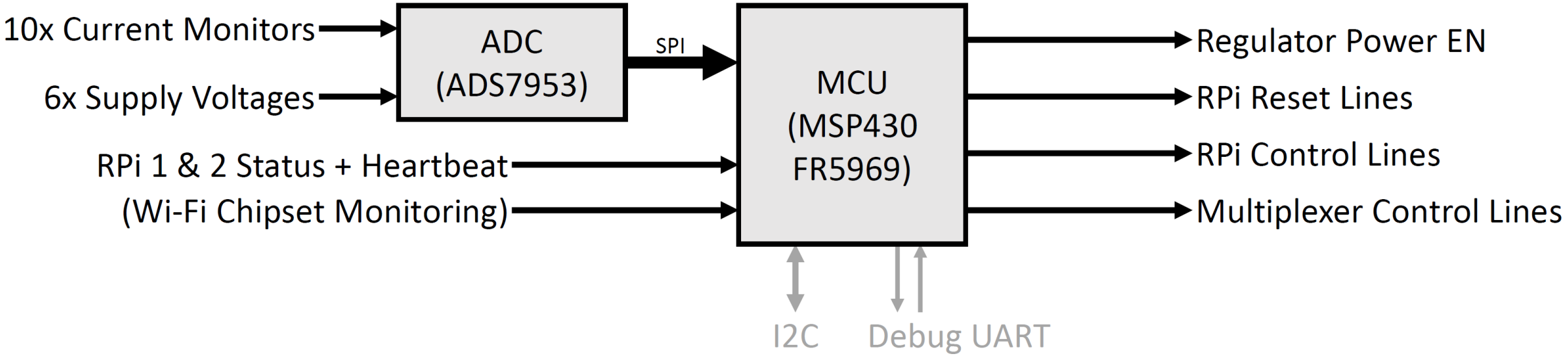
System Monitoring





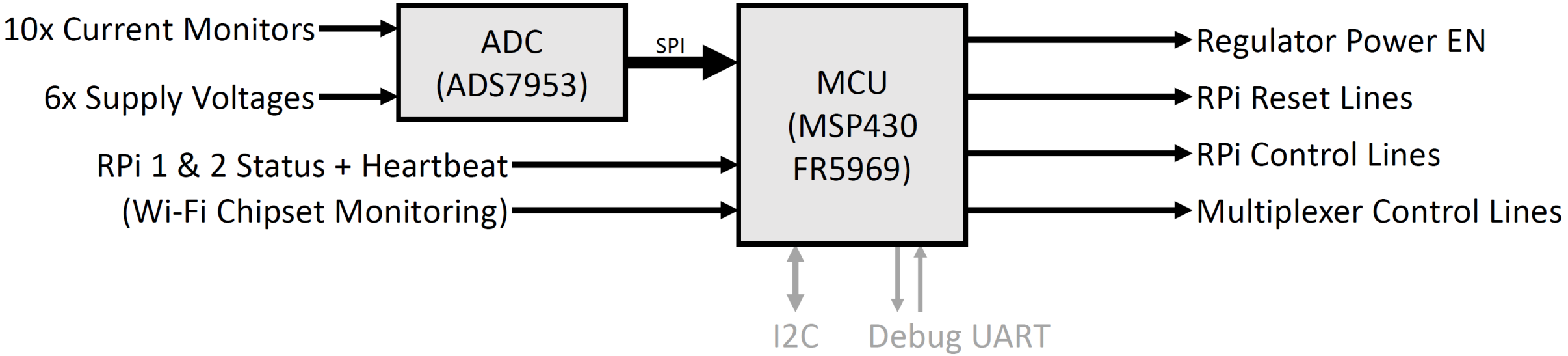
System Monitoring

- Supply I-V monitoring
  - Current sensors (INA194)
  - 16-channel SPI ADC (ADS7953)
  - Measurements at ~1 ksps/channel
- State-of-health monitoring
  - Signals from Raspberry Pis
    - Status line
    - Heartbeat signals
  - Wi-Fi chipset status monitoring

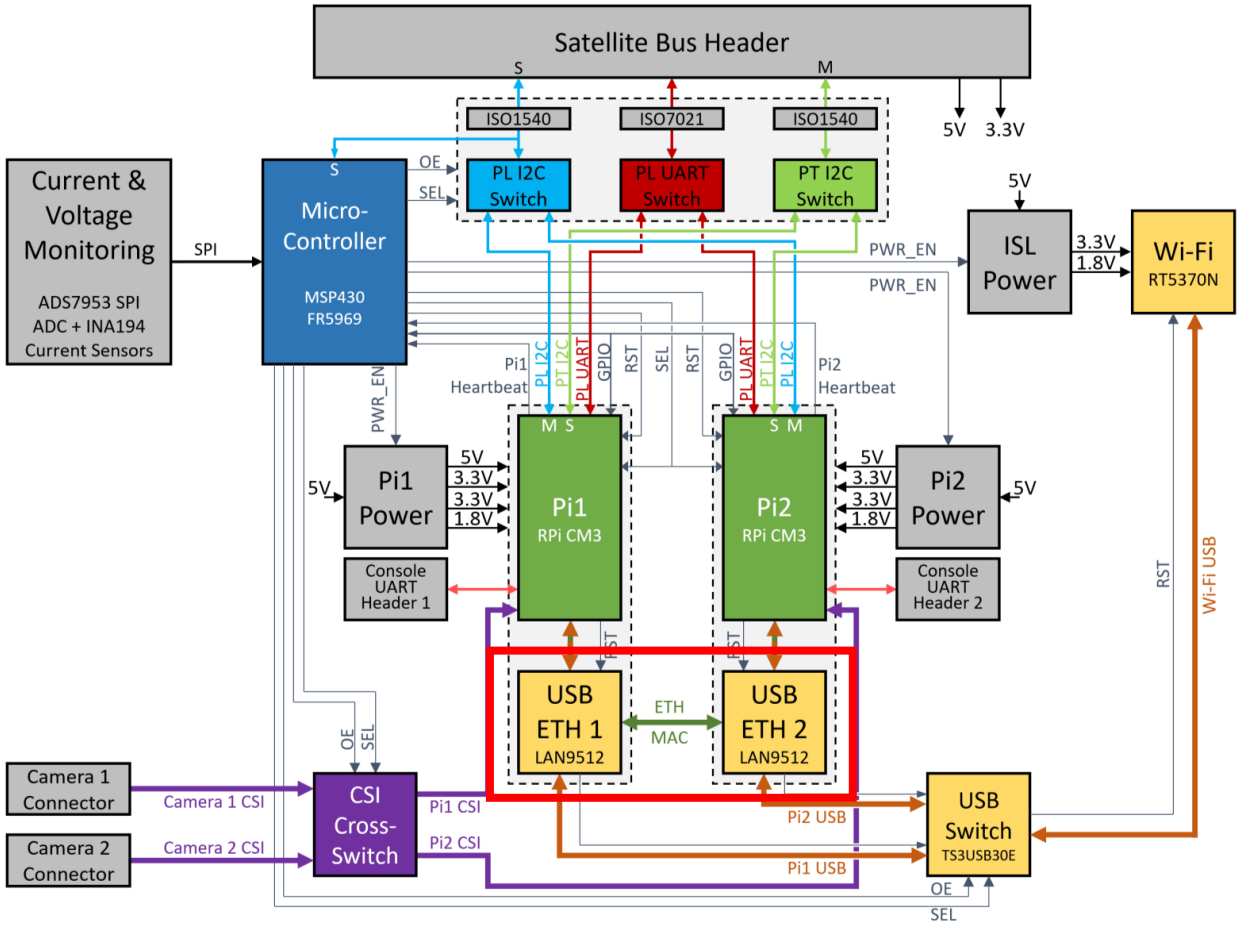


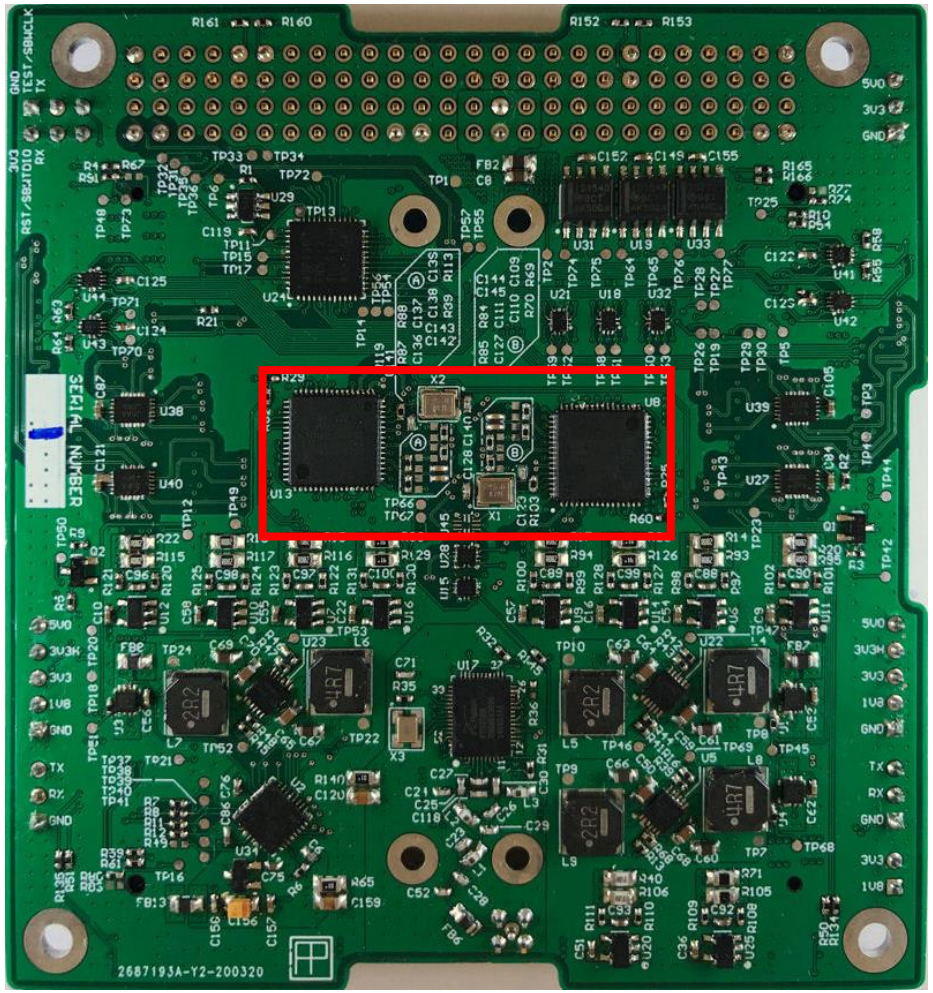
System Monitoring

- MSP430FR5969
  - FRAM-based MCU
  - Pin-compatible rad-hardened variant MSP430FR5969-SP:
    - *50krad(Si)*
    - *72MeV-cm^2/mg*
- Implements redundancy scheme
  - Enable/disable power domains
  - Soft- or hard-reset RPis
  - Assign active device
  - Control all multiplexers



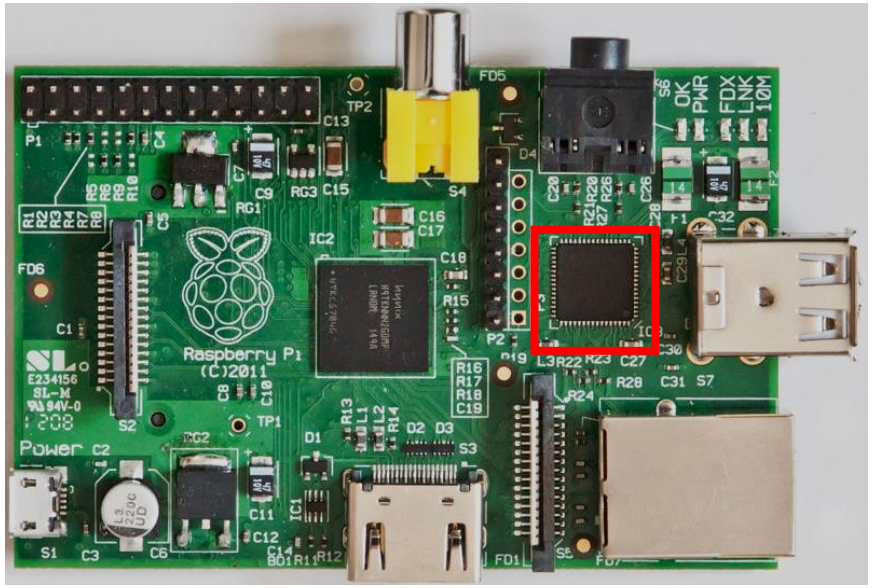
Ethernet Cross-Link





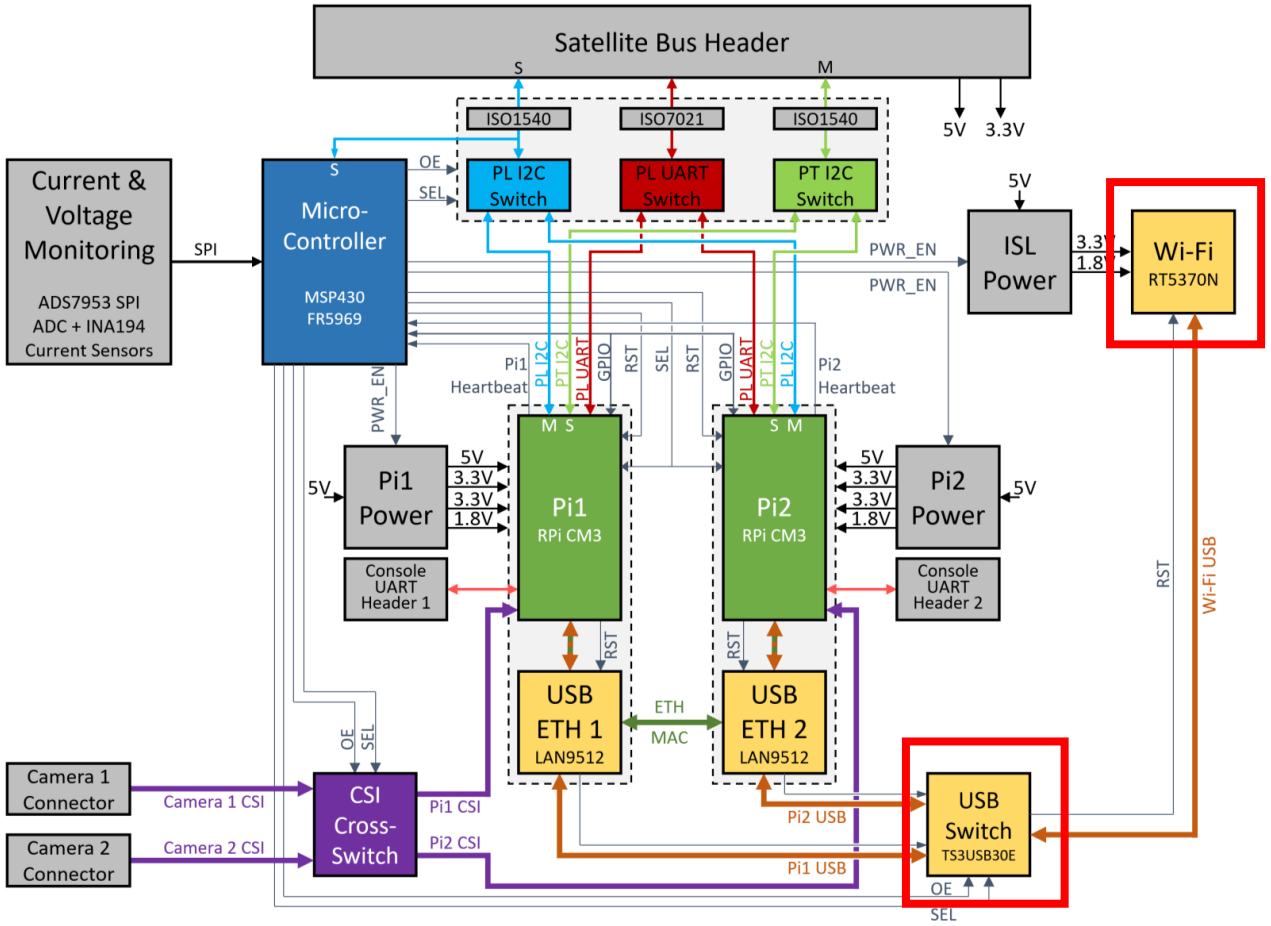
Ethernet Cross-Link

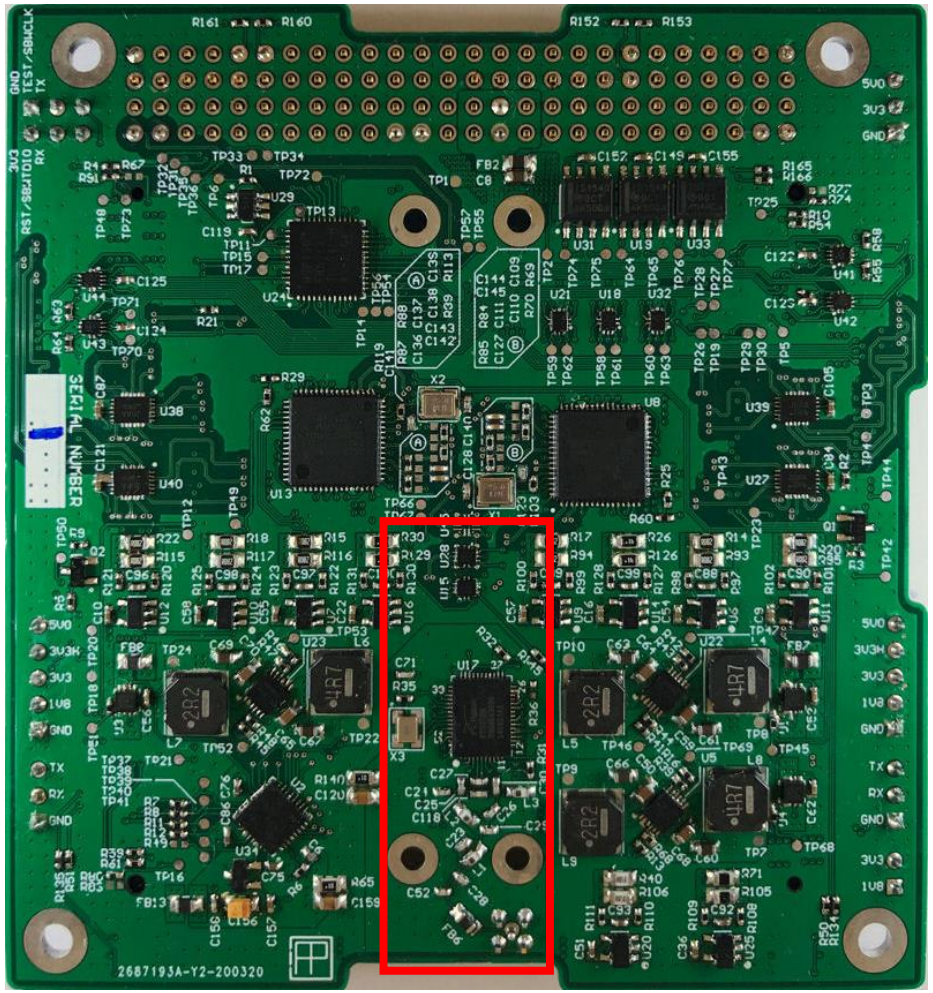
- Why?
  - Need a fast communication channel between Raspberry Pis
  - Excessive but low-risk approach
- LAN9512 USB Ethernet Hub
  - Adapted from RPi B schematics, expected to “just work”
  - *Transformer-less* implementation, capacitively coupled
- Operational 100Mbps-class link
  - Peer-to-peer network, static IP
  - 94.4Mbps observed (*iperf3*)



Raspberry Pi Foundation

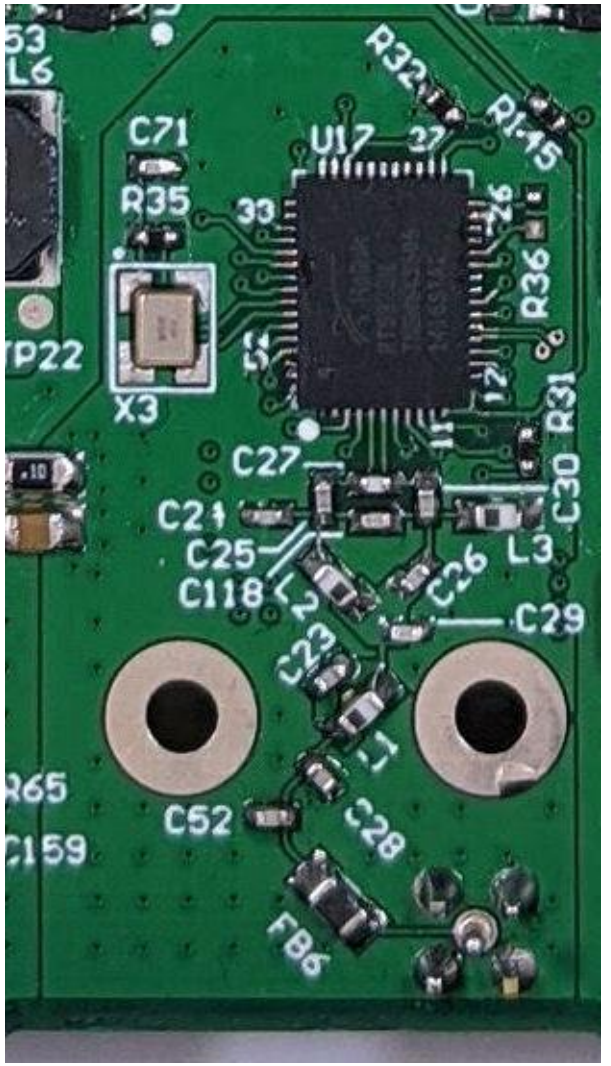
Wi-Fi Intersatellite Link



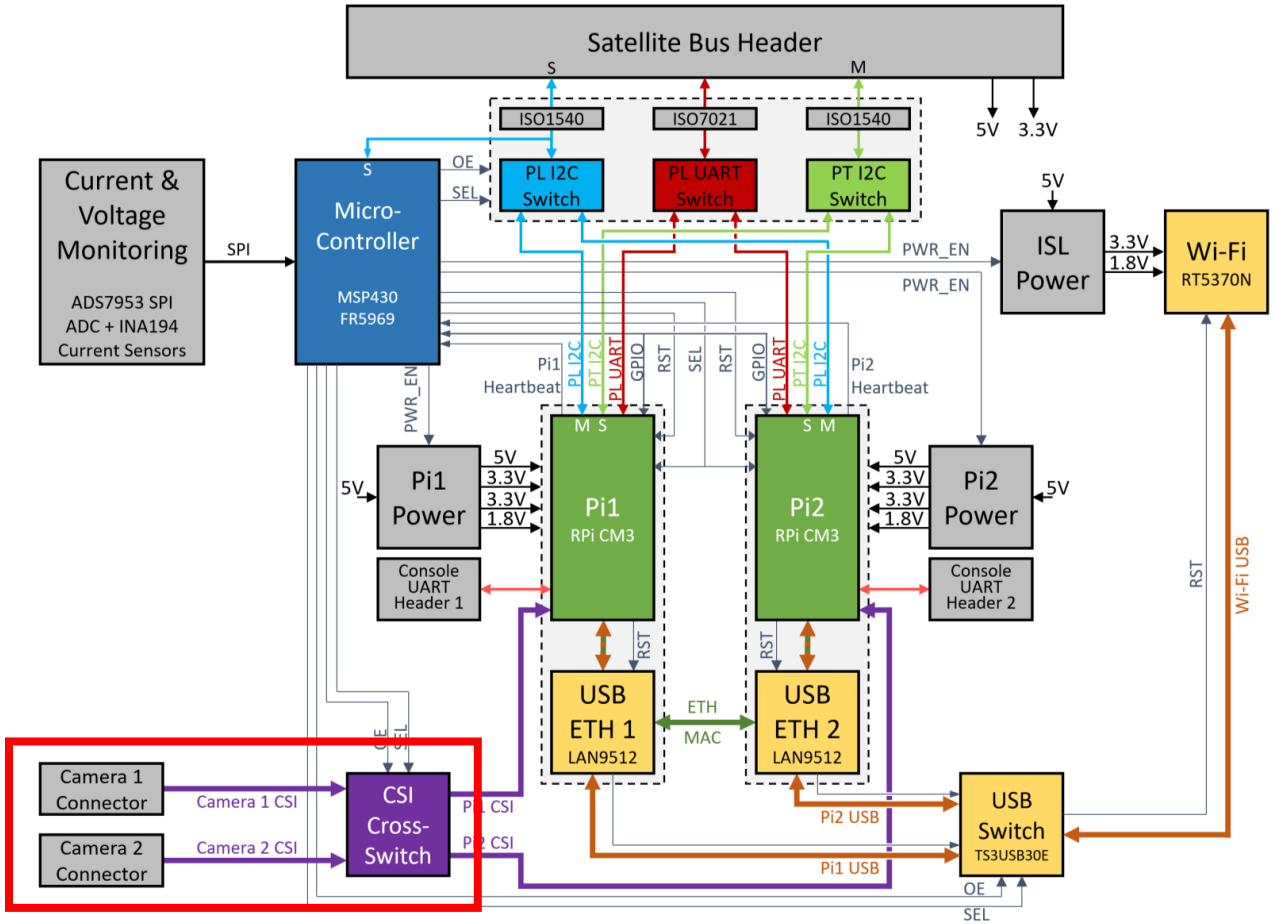


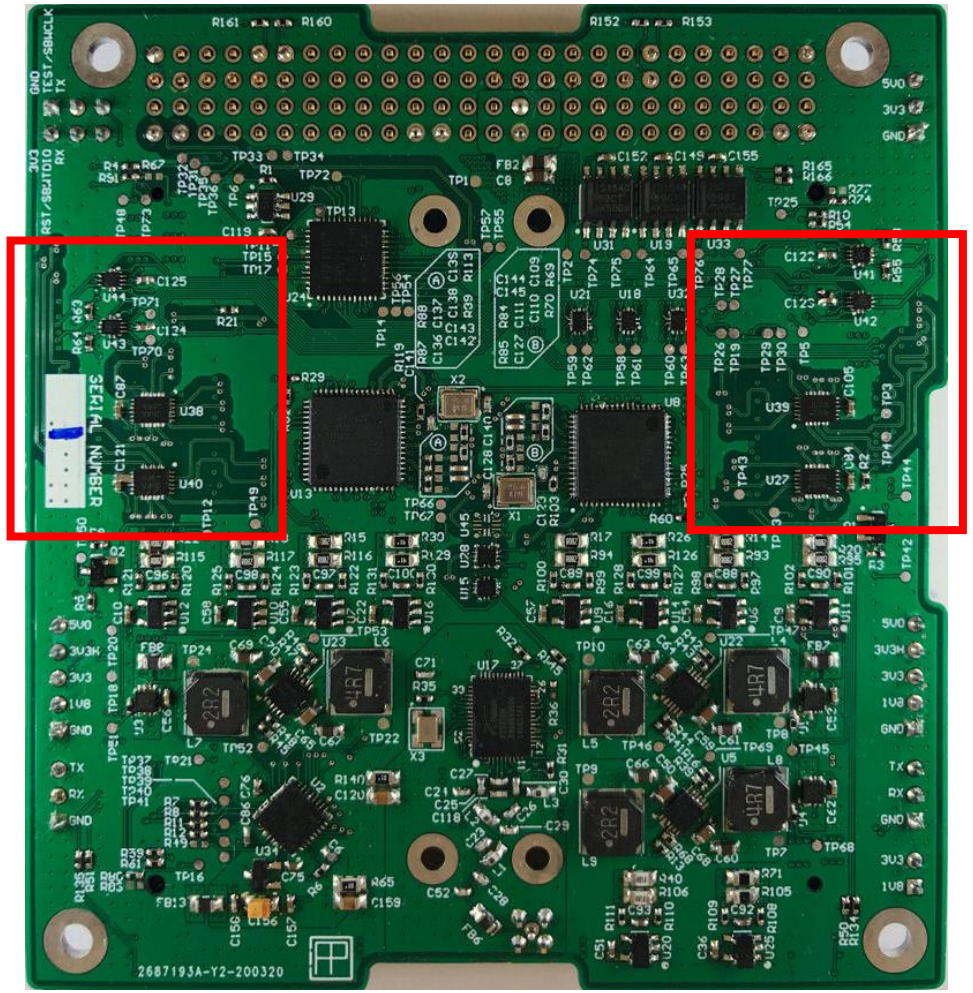
Wi-Fi Intersatellite Link

- Circuit based on Ralink RT5370N USB Wi-Fi dongle
  - Schematics available online
  - RPi compatibility assured – USB plug and play “just works”
  - Component sourced from China
- Multiplexed USB – TS3USB30E
  - Connects to RPi Compute Module USB hosts via Ethernet Chipsets
- Prelim tests (wire antenna)
  - 3.14Mbps observed (*iperf3*)
  - Pending further lab tests



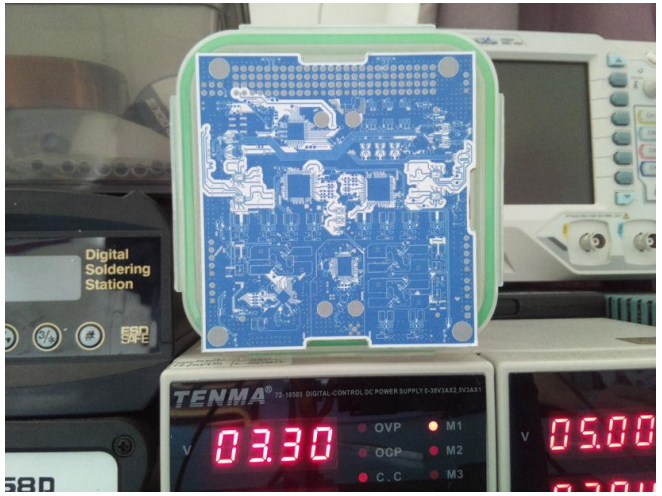
Raspberry Pi Camera Support

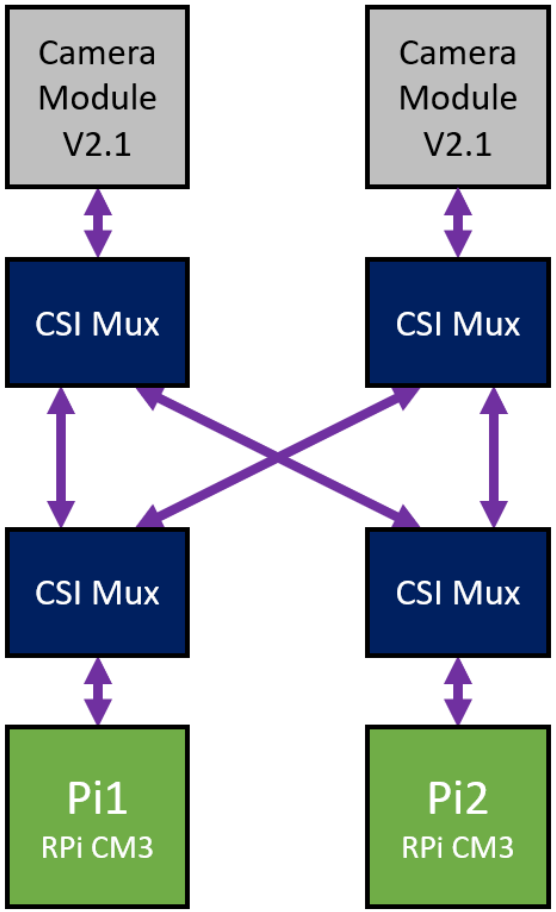




Raspberry Pi Camera Support

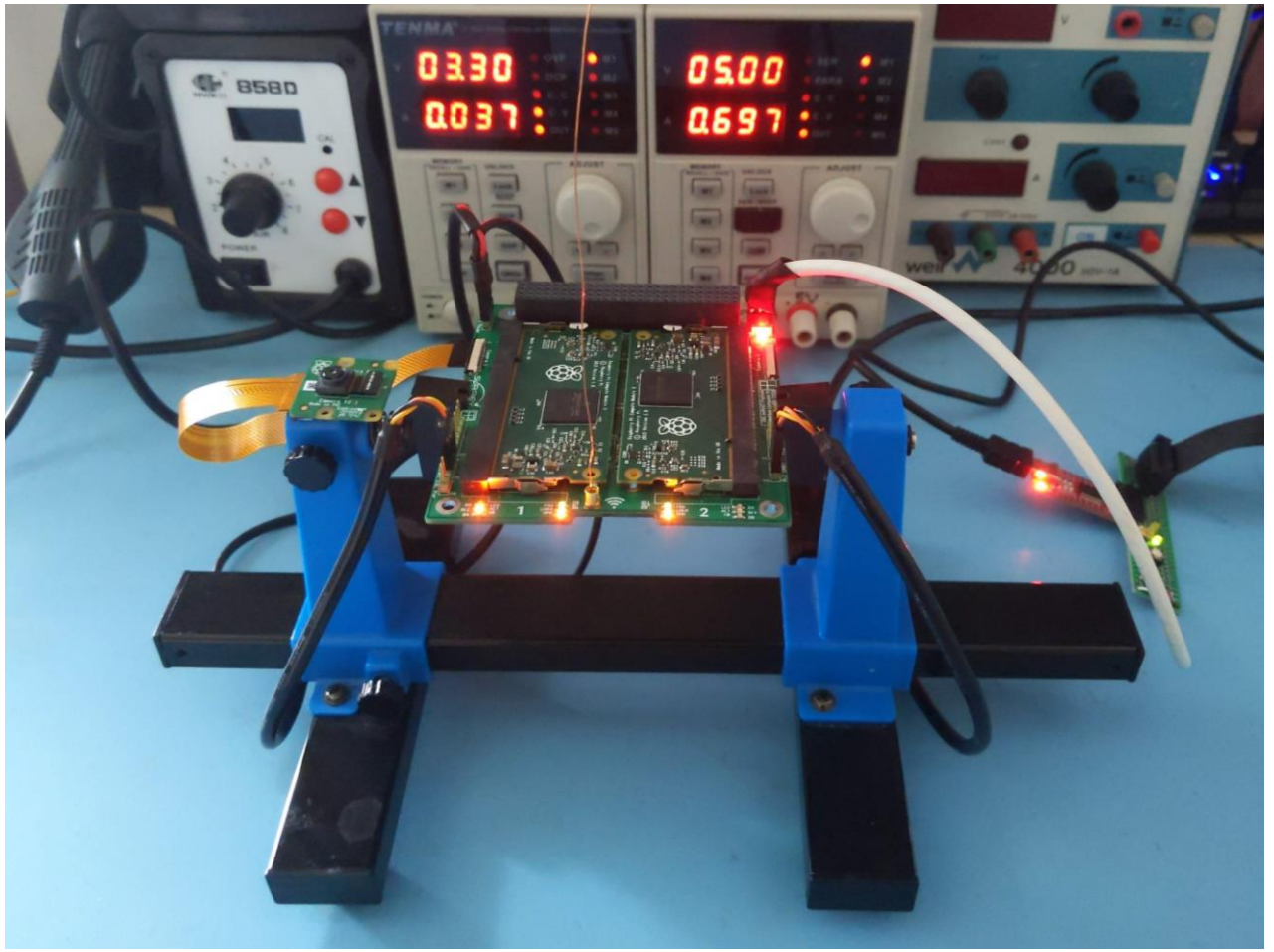
- Cross-Strapped Camera Modules
  - Flexible configuration (hot-swappable)
  - Camera hardware redundancy
  - Can support single or dual camera operations
- Buses
  - MIPI Camera Serial Interface (3x differential pairs)
  - I2C + GPIO x2
- Multiplexing
  - FSA642 (CSI)
  - TS3USB30E (I2C, GPIO)
- Functionally verified →





Characteristics

- CubeSat PC-104 form-factor
  - Board mass: 77g
- 3.3V and 5V dual-supply
  - 10W peak power draw (two RPis + two cameras)
  - ~90% of power from 5V supply
- Next Steps:
  - Thermal profiling
    - Aiming for Q1 2021
    - Initial characterisation complete
  - RF testing
  - Software development



Getting Involved

- Design files freely available
  - https://gitlab.eps.surrey.ac.uk/ap00789/aarest-obcviv/
- Boundaries to accessibility
  - Altium Designer file format
    - Free online viewer for file inspection
    - Tools exist to convert to KiCad, etc
  - Challenging soldering/assembly
    - 0402 [1005 metric] passives
    - Leadless QFN packages
    - Internal plane thermal behaviour
- Designed for JLCPCB fabrication process
  - 6-layer PCB + impedance control
  - Board price ~€70 for 10pcs
  - Components ~€100 (excluding Raspberry Pi Compute Modules and Cameras)