Small Satellite Research Laboratory

Franklin College of Arts and Sciences

UNIVERSITY OF GEORGIA

Towards an Integrated GPU Accelerated SoC as a Flight Computer for Small Satellites

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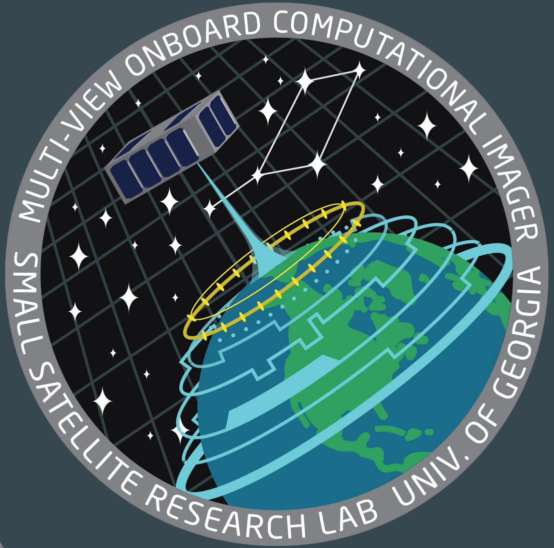
Overview

- UGA SSRL
- The MOCI Mission
- What we have done
- What we're doing
- (if time permits) Applications

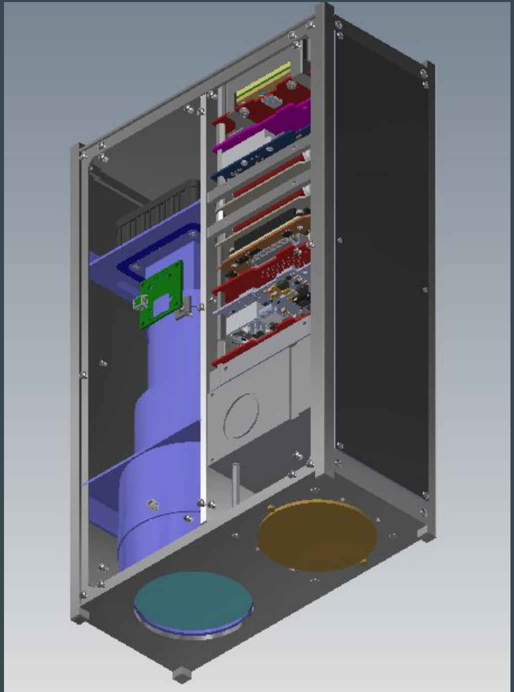
UGA SSRL

- Founded in 2016 by a team of Undergrads
  - How hard could it be?
- Faculty supported
- 2 funded cubesat missions
  - MOCI - AFRL UNP
  - SPOC - NASA USIP
- Advanced topics in remote sensing
- 5 Grad Students

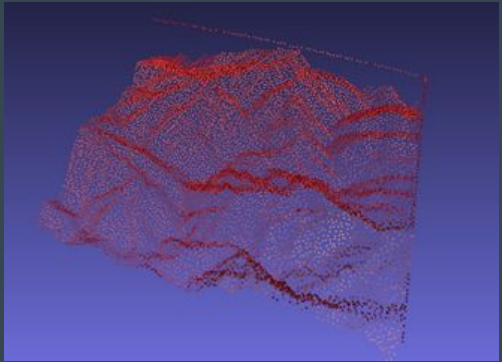


The MOCI Mission

- **M**ultiview **O**nboard **C**omputational **I**mager
- 6U cube satellite
- ~450km orbit - ~6m GSD
- Goal is to generate 3D terrain models in near real-time
- Flying an Nvidia Tegra X2i GPU SoC
- Funded by AFRL



The MOCI satellite with front panel and UHF antenna removed

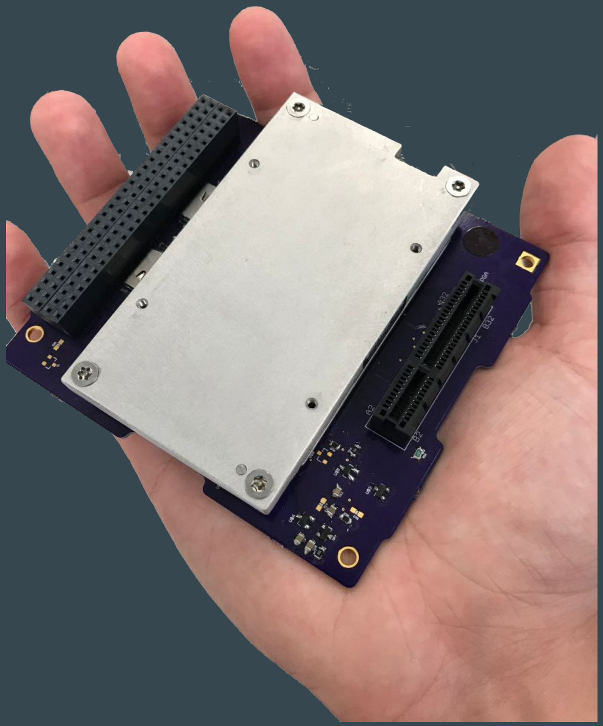


Simulated computations of mountain ranges

Current MOCI optical layout

The CORGI Board

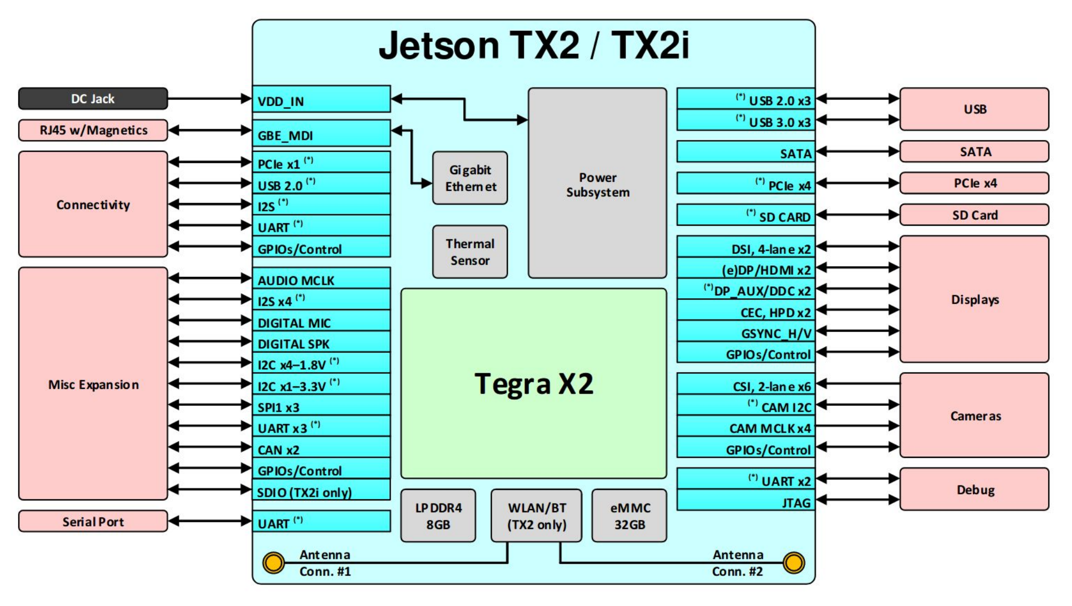
- **C**ore **G**PU **I**nterface Board
- An additional primary OBC is still needed
  - Clyde Space OBC us currently used
    - Contains ARM Cortex M3
- Designed for Cubesats
  - PC/104+ standard
- Compatible with the Nvidia TX2 and TX2
- Standard Procedures: Conformal Coating, Outgassing, Staking, etc...



The Nvidia TX2i mounted onto the UGA SSRL's CORGI board

Nvidia Jetson TX2i

- Pascal GPU - 256 CUDA cores
- ARMv8
  - Nvidia Denver 2 (dual-core)
  - ARM Cortex A57 MPCore Module (quad-core)
- 8GB LPDDR4 - 28 GB/s peak memory bandwidth
- 32GB eMMC Flash Memory
- Software enabled ECC



The Nvidia TX2 / TX2i IO and Block Diagram

Minimizing the TX2i OS

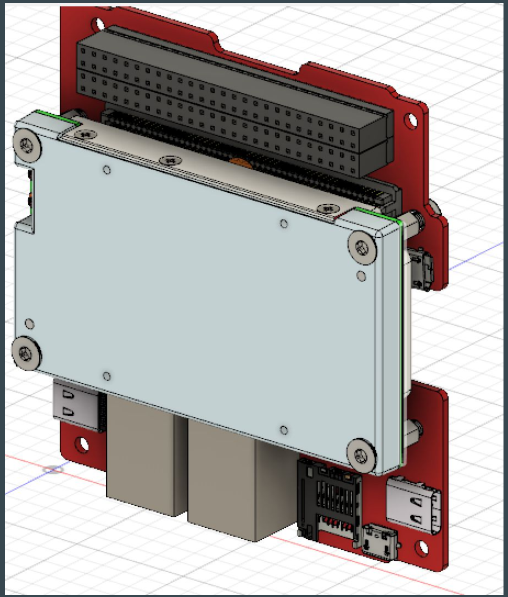
- Ubuntu 16.04 LTS based
- Busybox Jetson Root FS
- JHU Dart team has solutions we are moving to
  - We used to script FS generation and dependency population
- Hardest parts are
  - maintaining all packages needed
  - maintaining CUDA compatibility

CORGI Software & Telem Monitoring

- Connects OBC to TX2i via 500Kb/s TTL UART
  - OBC will act as 'Master' initiating all communications to the TX2i
- API implemented on each side allowing for the OBC to send commands when needed and receive telemetry when requested
- Upon detection of anomalous behavior the OBC has the ability to hard reset the TX2i

CORGI Watchdog

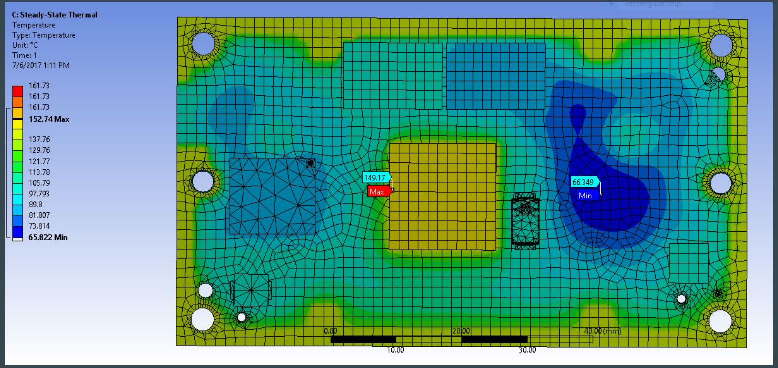
- The OBC will use telemetry received from the TX2i to monitor its state.
    - If communication is lost or commanded actions take too long OBC will force a hard reset
- OBC will model the TX2i by implementing a Finite State Machine that will keep track of the TX2i state and take corrective action if necessary

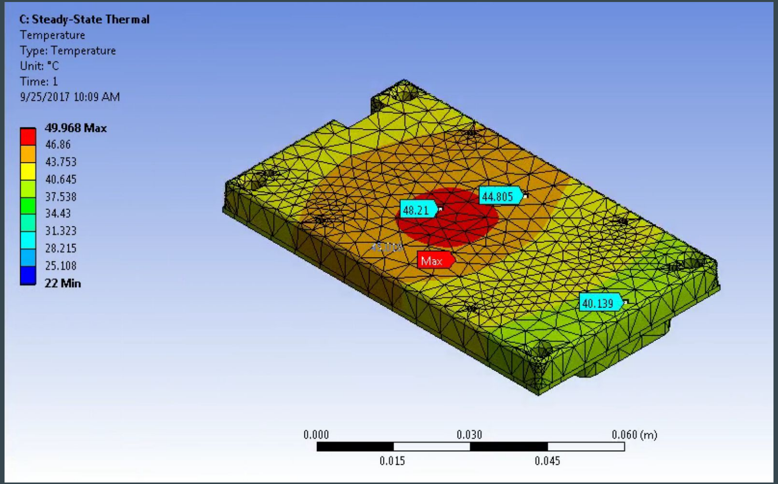


An older version of the AFC / CORGI concept

Thermal Analysis

- We assume a lot of bad things here
  - TDP of 15 Watts
  - Realistic load of 7.5 Watts
- We have a TVac chamber we will kills some boards in
- Boards modeled as FR-4
- Ansys + Simplified Model
- Aluminium 6063-T5
- Carbice Space TIM used
  - Low CVCM and TML
- Goes from 160 C to 50 C with TIM and mount to frame





Ansys Thermal Simulations of the Nvidia TX2i

Lowering Power

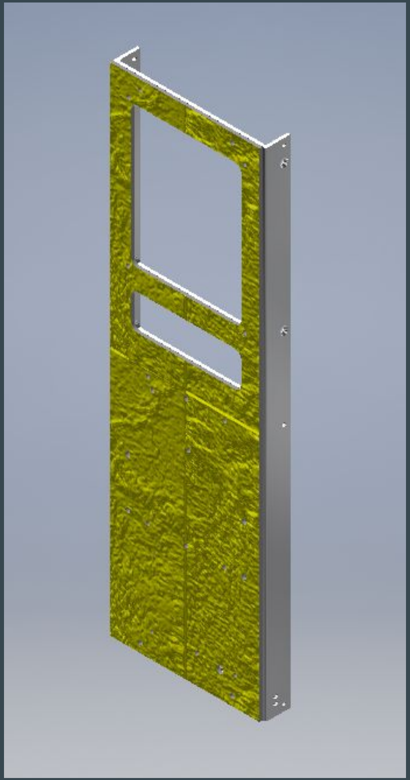
- Easiest Way to improve Thermals!
  - For me as a software guy at least
- Shut off cores with `$ sudo nvpmodel #` and set modes to minimize power
- decrease clock frequency/self throttle
- Choice of mode is design decision
- We get between 3 and 7.5 Watts doing this

Mode	Name	Denver 2	Hz	ARM A57	Hz	GPU Hz
0	Max-N	2	2.0	4	2.0	1.3
1	Max-Q	0	-	4	1.2	0.85
2	Max-P Core-All	2	1.4	4	1.4	1.12
3	Max-P ARM	0	-	4	2.0	1.12
4	Max-P Denver	1	2.0	1	2.0	1.12

TX2 / TX2i power modes

Physical Radiation Mitigation

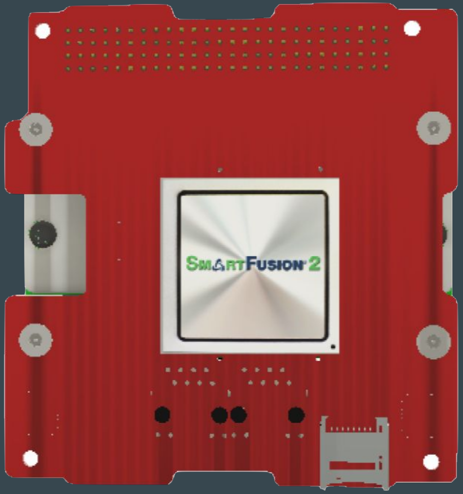
- Dunmore Aerospace Satkit
- SIGNIFICANT future work in this section
  - Working with JHU APL, using facilities at University of Washington
- Aluminum block around the TX2i
- Cheap LEO/cubesat solutions

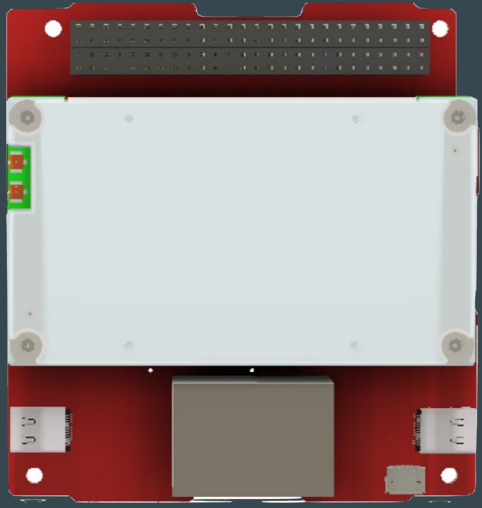


Aluminized Kapton shielding on a 3U face

AFC - Moving Towards a Flight Computer

- The AFC (Accelerated Flight Computer)
  - Currently a tangled mess of wires in our ESD area
- An upgraded CORGI - (this is outside the scope of MOCI mission)
- We Need to:
  - Develop Radiation Mitigation Techniques
  - Diversify Interfaces
  - Implement Watchdog
  - Add Persistent Memory
  - Improve Thermals
  - Lower The Power Consumption





AFC rendering

System Specs Overview

Nvidia Tegra X2i
2x Denver ARM Cortex A57
256 Pascal Arch GPU
8GB LPDDR4
32GB ECC support

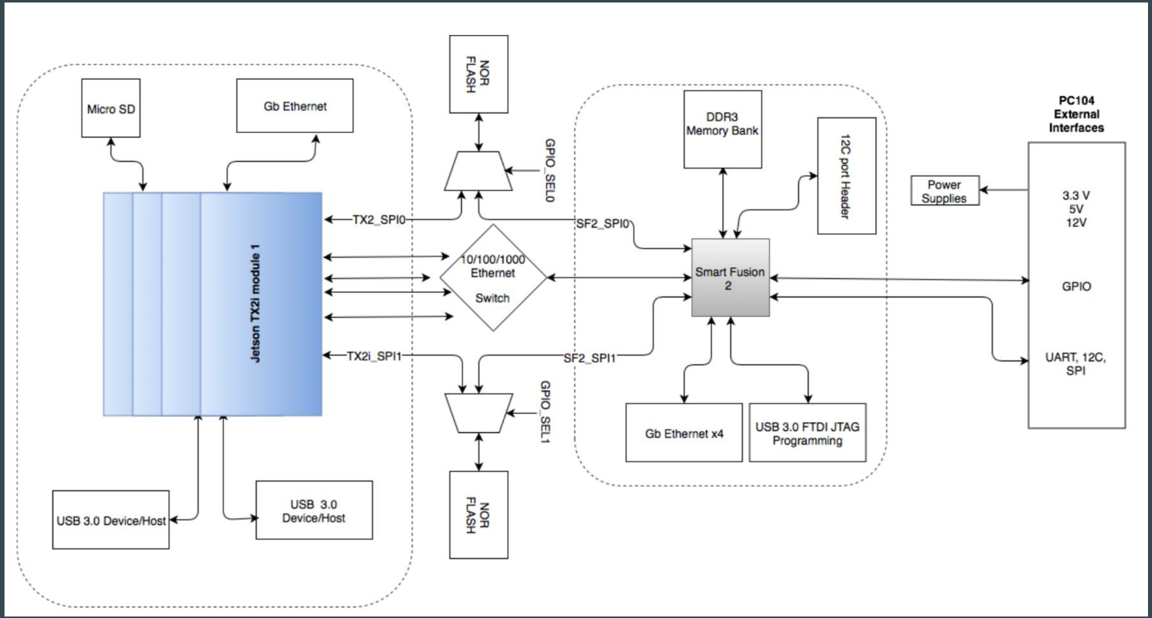
SmartFusion2
ARM Cortex M3
ARM Cortex M3 SoC FPGA
4x256 DDR3 Memory Bank

I/O
PC/104+, I2C, SPI, GPIO
QSPI Expansion Header
2x RJ-45
2x USB type C
Micro USB (FTDI)

Both
2GB (Cypress CYRS16B256)
1 Gb SPI Flash on SPI 0*
1 Gb SPI Flash on SPI 1*

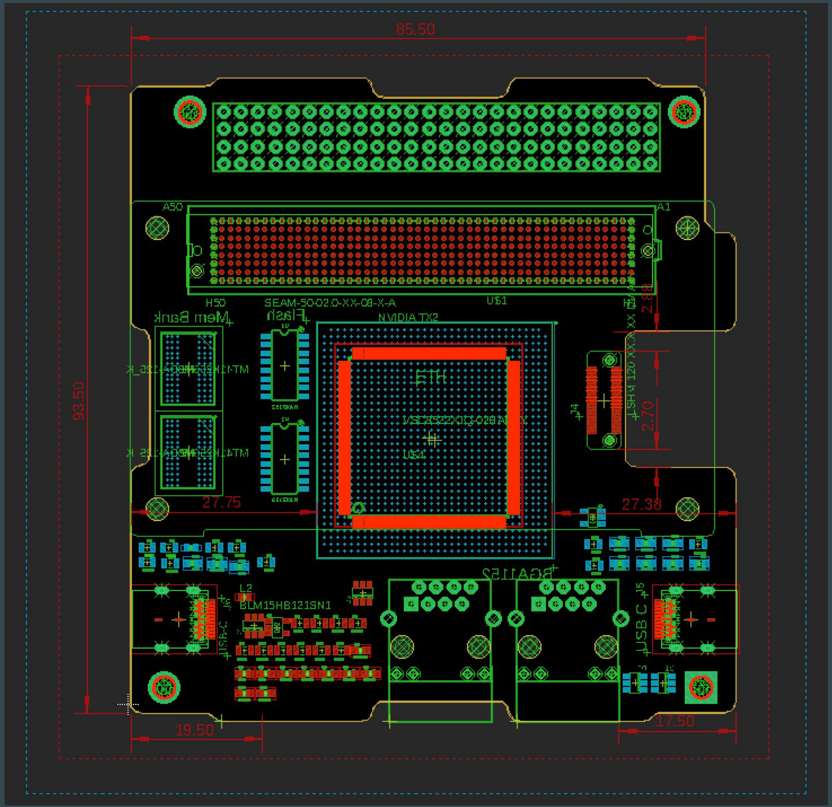
Architecture Overview

- SF2 controls TX2i over eth
- Shared NAND flash between SF2 and TX2i
- Power supply through Sat stack
- Eth. is primary communications for additional Jetson modules
- SD card only for development



Integration Overview

- Bidirectional Logic shifters needed
  - convert 1.8v (CMOS) TX2i logic to 3.3v (LVTTL) SF2
- Shifters required for (onboard) serial data transfer
- Power discharge circuitry
- USB and SD card interfaces
- More in extra slides



AFC electronics in eagle CAD

Bootloader TMR

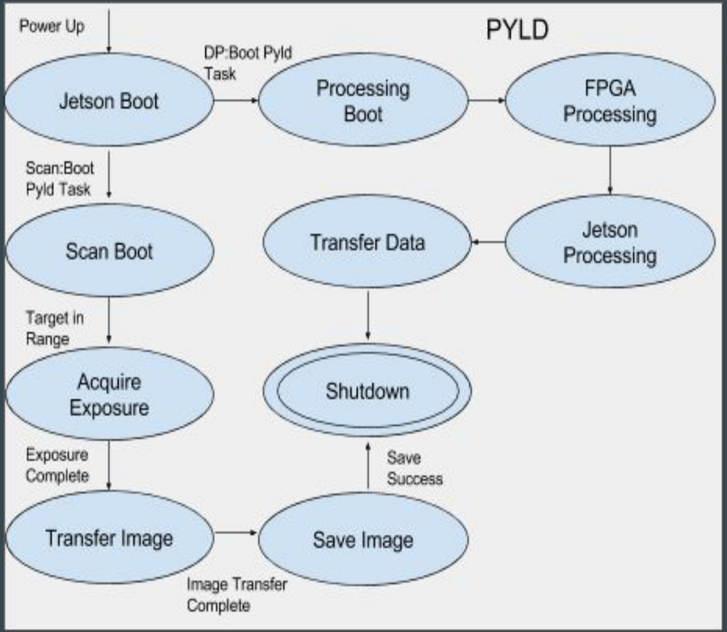
- Using U-Boot to add custom boot time functionality to the TX2i
  - The principle of TMR safeguards against catastrophic OS corruption
- 3 identical OS images stored in memory, along with hashes of the images
  - Hashes used to determine if an image has been corrupted by radiation
  - Hash stored in triplicate to protect against hash corruption
- If corruption is detected on all 3, bootloader will try to reconstruct a valid image
  - Uses principle of majority voting to determine which parts of the images are corrupted
  - Relies on unlikeliness of the exact same bit being corrupted on each image

Unifying Memory

- Tx2i and Smartfusion 2 both share persistent SPI flash memory
    - Shifter (MUX) required (controlled by SF2)
    - Added overall system storage
        - Radiation hardened
    - Data can be accessed when coprocessor (TX2i) is powered off
    - Sharing mutually relevant files

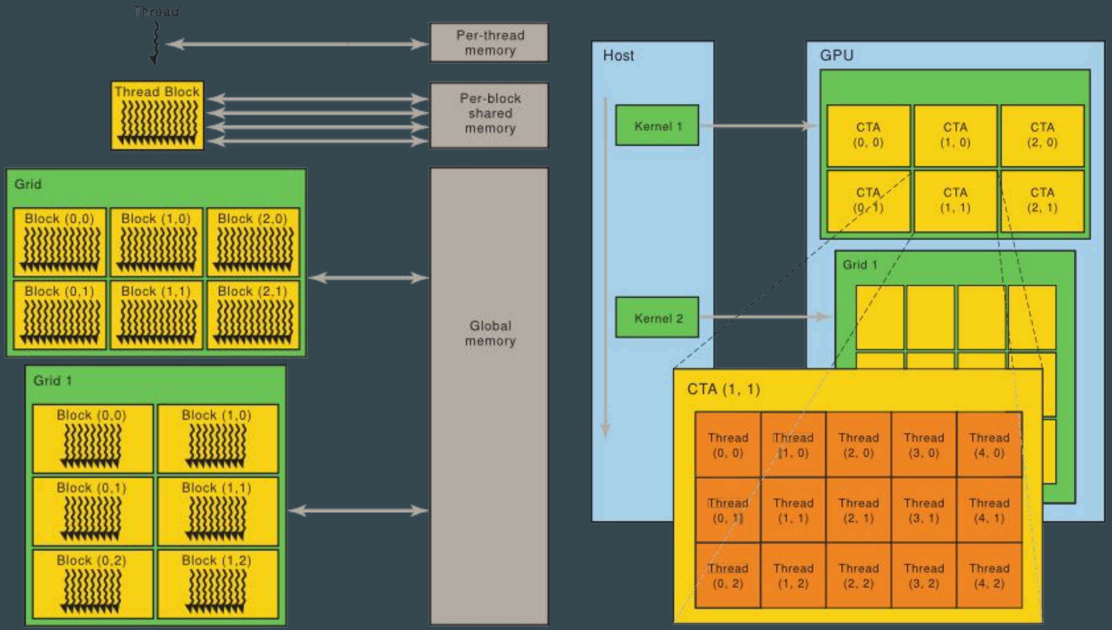
FPGA as a Watchdog

- FPGA contains a Finite State Machine
  - updated via regular telemetry from the system
- Will have the ability to hard or soft reset the TX2 upon detection of an anomalous state
- IO is tested against simple checks to continue



PTX overview

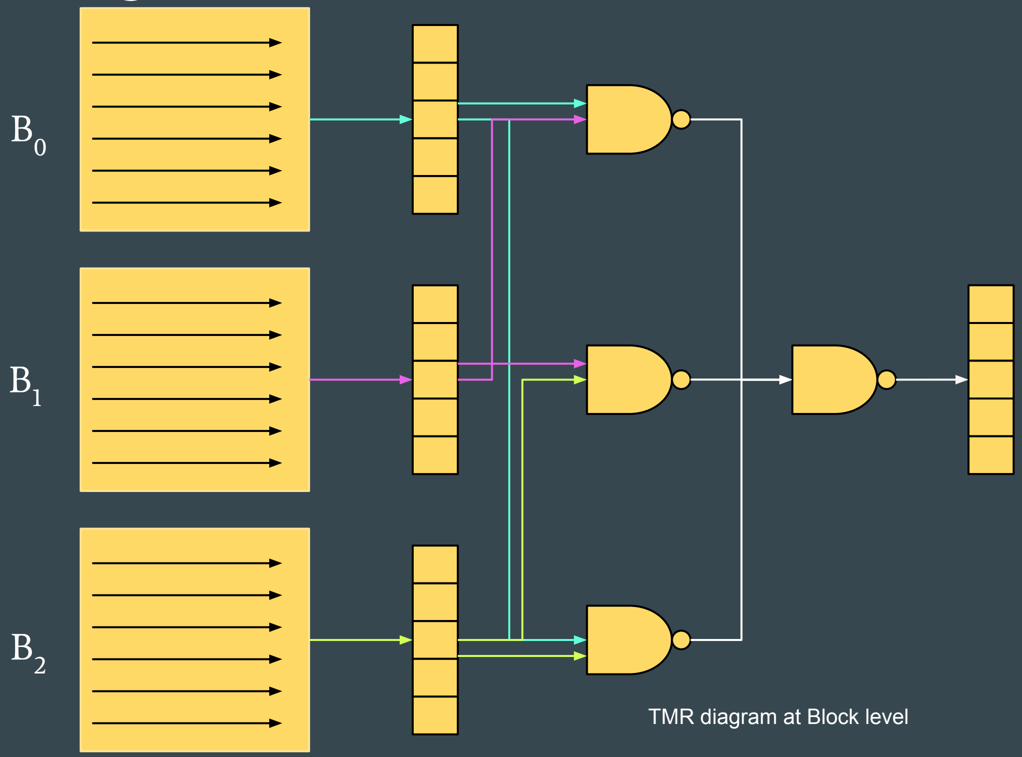
- PTX is a low level VM (Virtual Machine) and ISA (Instruction Set Architecture).
- Compatible with all CUDA capable GPUs
- Written like any other assembly language
- Breaks into CTAs (Cooperative Thread Arrays) = Thread Blocks
- PTX programs specify the actions of a given thread in a specific thread array
- CUDA compiles into PTX and can be used within CUDA kernels



Nvidia PTX thread-batching, source: Nvidia

Block PTX checkpointing

- Simple TMR type design
  - Majority Gate
- Follows finite state machine on the FPGA
- Makes the execution much slower
- Where to place PTX checkpointing is a design choice on its own
  - Last stages of pipelines ideal
  - B_1 and B_2 of smaller size
- Writing inline PTX



TMR diagram at Block level

Adding Interfaces

- Ethernet - high speed data transfer, enables many devices on the same network in a peer to peer configuration.
- USB 2.0 (FTDI) - provides debug interface with the SF2
- USB 3.0 (Type C) - Jetson Tx2i command/control interface
  - Low profile
  - Backwards compatibility
  - Good data rate
  - Supports peripheral devices

Future Work

- Better PTX checkpointing
- Better PTX GPU memory bank monitoring
- Multi-Jetson computation
- Radiation Event Correction
- Flight!

Questions?

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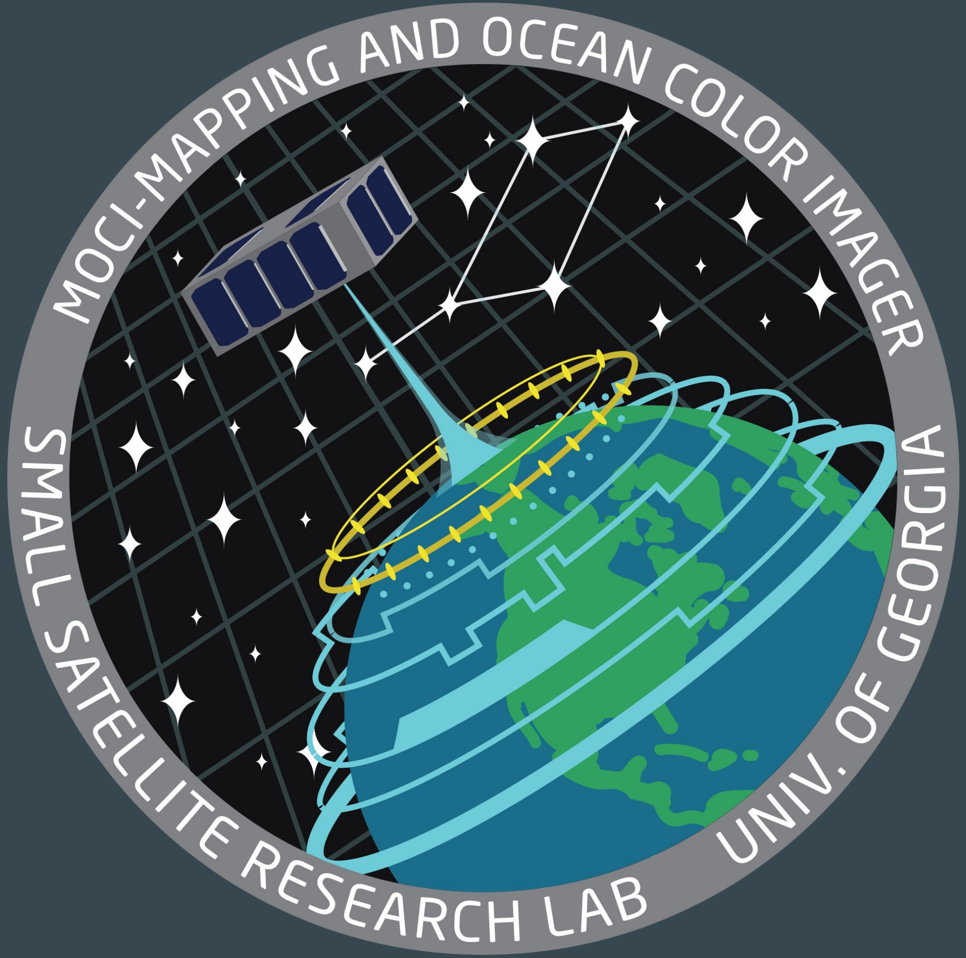
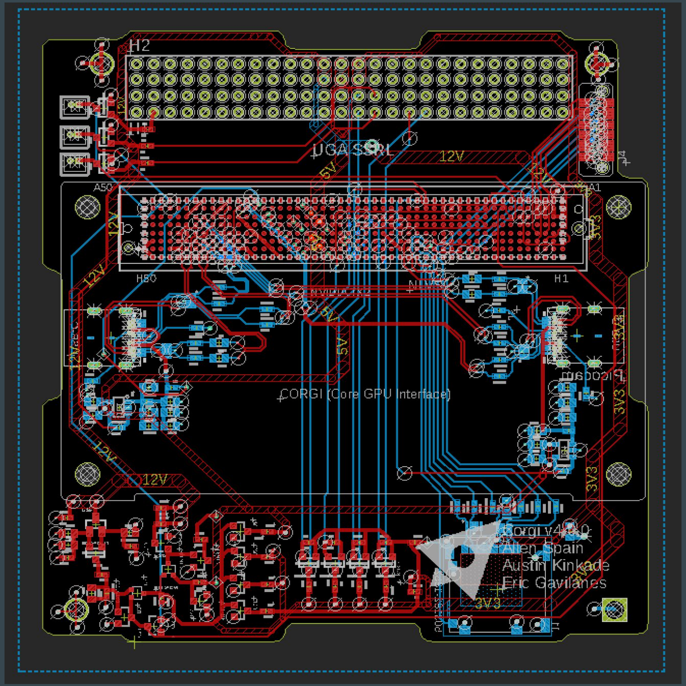
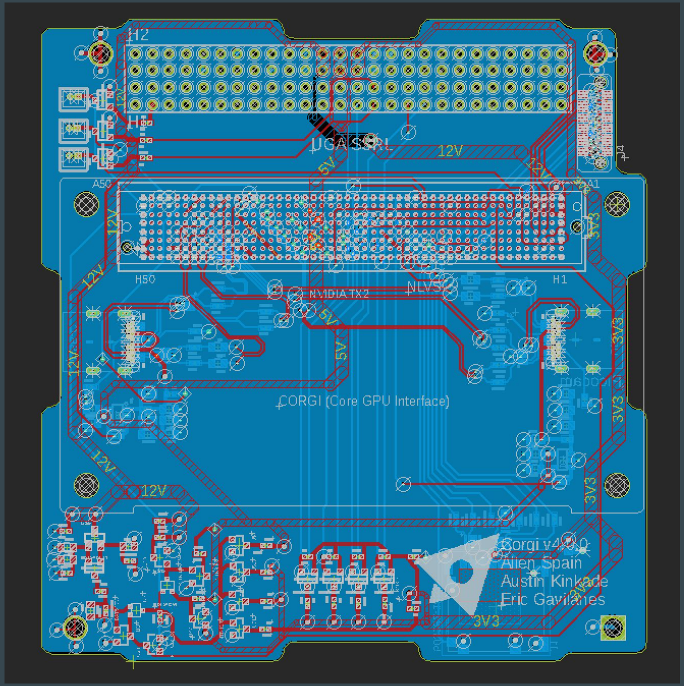
University of Georgia



Extra Slides

CORGI BITS


H2
UGA SSRL
12V
5V
A50
A1
H50
H1
NVIDIA TX2
3V3
Picocam
CORGI (Core GPU Interface)
12V
Corgi v4.0.0
Allen Spain
Austin Kinkade
Eric Gavilanes
3V3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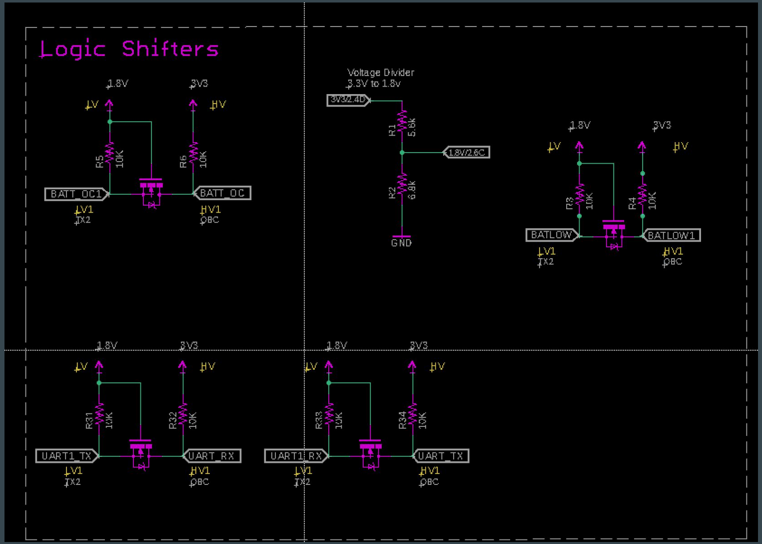
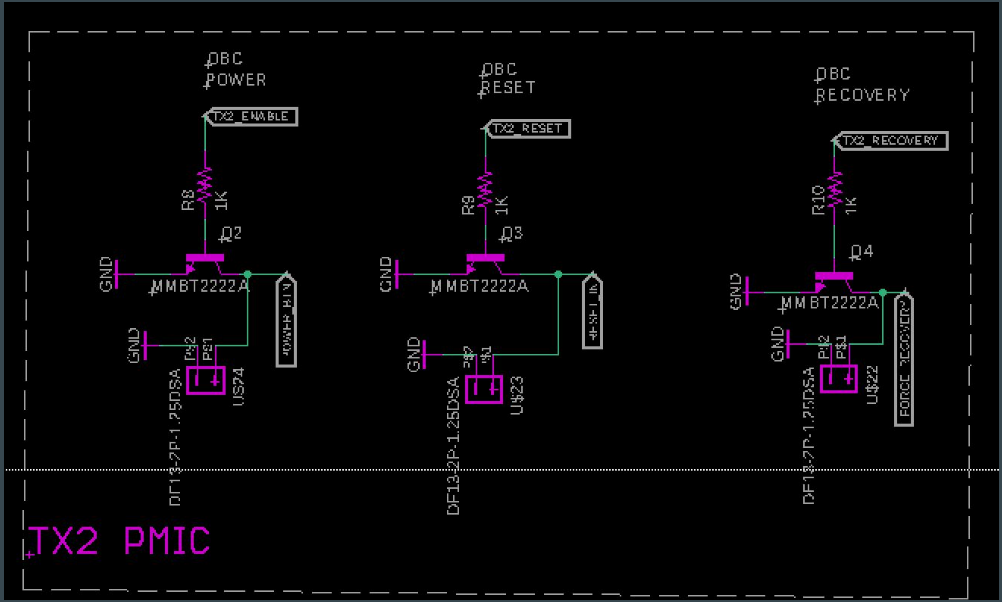
CORGI BITS

Bidirectional Logic Shift

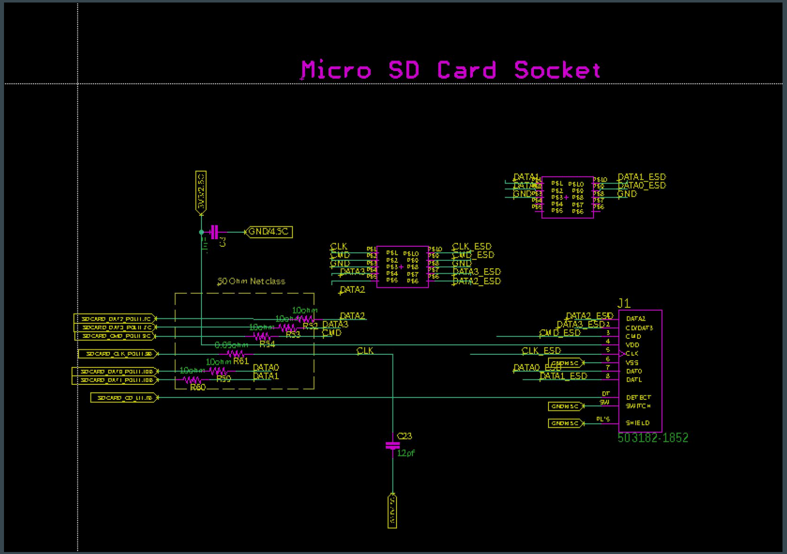


Power switch

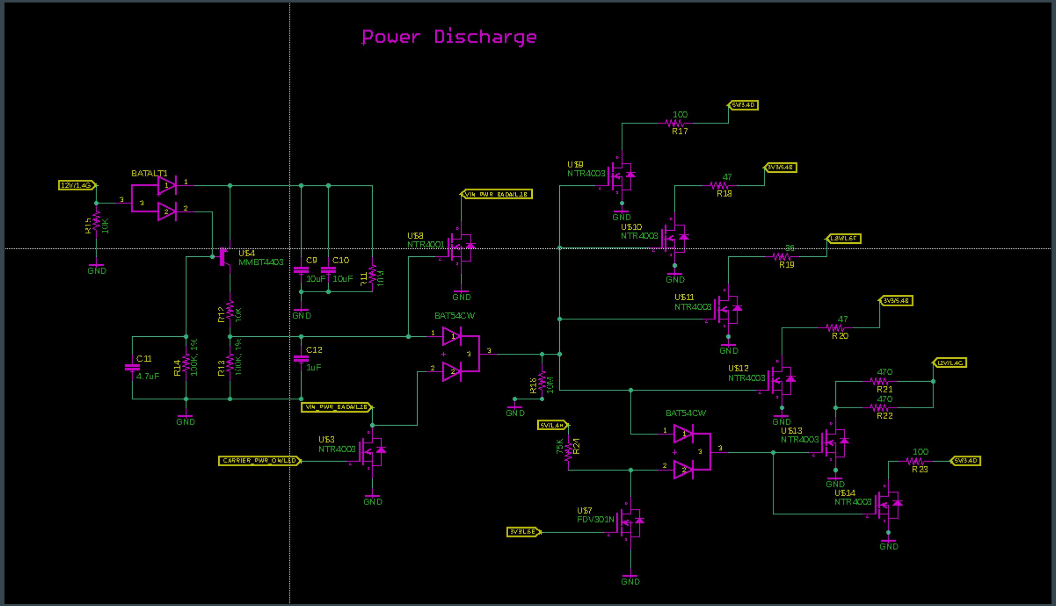


CORGI BITS

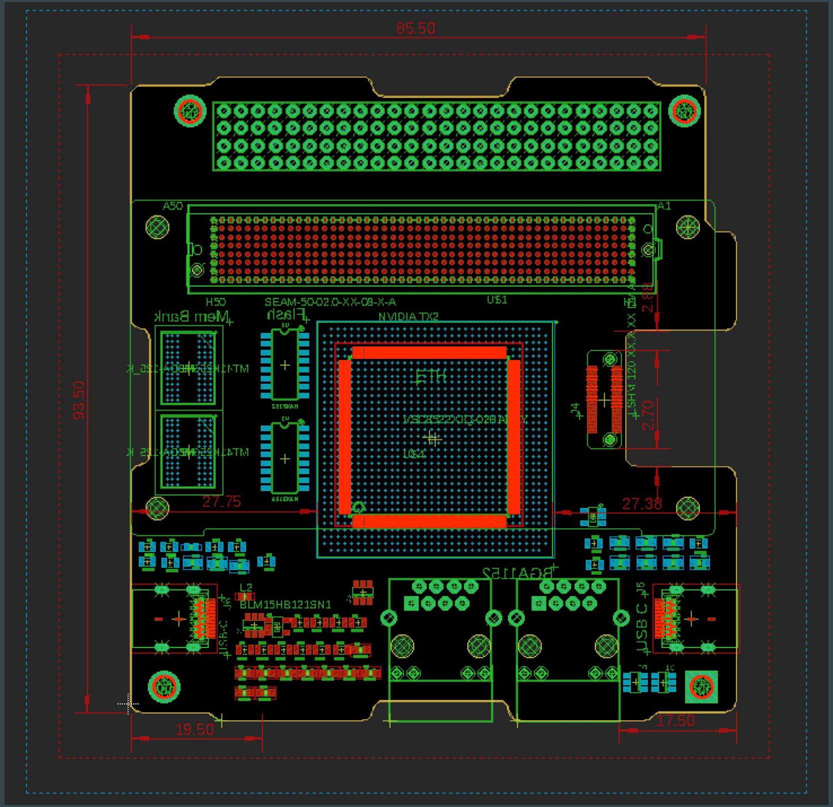
SD Card Interface



Power Discharge



AFC Design


85.50
93.50
A50
A1
H50
SEAM-50-02.0-XX-08-X-A
U31
Mem Bank
Flash
NVIDIA TX2
27.75
27.38
L2
BLM15HB121SN1
USB C
19.50
17.50