Small Satellite Research Laboratory

Franklin College of Arts and Sciences

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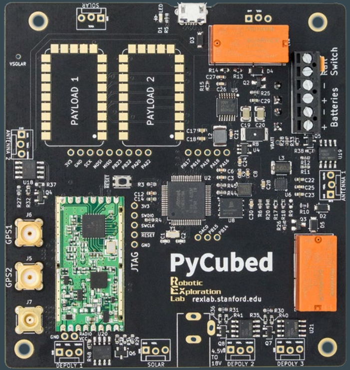
Design, Simulation, and Testing of a Custom Co-Processor for Cubesatellites in LEO

Justin Heimerl

Introduction - Current State

- Current rad-tolerant compute systems in LEO are several generations behind.
  - Hard to do things like real time image processing on a traditional rad hard system.
- Various attempts being made to place more modern (but cheap) compute systems in space. (PyCubed - SAMD51, NASA PhoneSat - Snapdragon, probably Starlink)



Introduction - CORGI

- CORGI - Core GPU Interface
  - NVIDIA TX2i Carrier Board/Dev Board
  - Plug and play with PC/104+ stack
  - Flying on Multiview On Board Computational Imager (MOCI) mission in 2022.
- NVIDIA TX2i
  - NVIDIA SoM (System on Module)
  - 256 CUDA Cores (Parallel Processors)
  - 64bit quad core ARM A57 Complex (Super Scaler, DSP, FPU, L1 ECC)
  - 8GB 128 bit - LPDDR4 with ECC

Design - Peripherals

- Final revision will contain various peripherals.

Peripheral	**Purpose**
1x SD Card	Modified filesystem/Mass storage
2x USB A 3.0	Payload Interface (Dual Imager)
1x SPI	OBC Interface
1x UART (115200 8N1)	OBC Interface
1x HDMI	Development Interface

Design - Layout

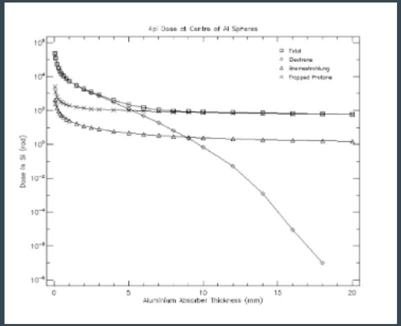
- Need to be careful with high speed signals (rule of thumb >1GHz).
    - Impedance (capacitance/inductance) MUST be taken into account. Can use online calculators or field solver.
    - If concerned over impact of vias or other discontinuities, like stubs, consider rise times (See High Speed Digital Design - Johnson)
- Large copper area for power planes.
    - More capacitance is better. TX2i requires little oscillation in main power rail.
    - Ground planes are all one continuous plane. Breaking this rule is quite bad, especially if routing a high speed signal over the plane. Energy travels in the dielectric.

Design - Component Selection

- Use temperature stable passives. (EX: X7R capacitors)
- High Speed Digital Components
  - We avoid common mode chokes. Can use if EMI is a problem.
  - Small as possible AC coupling capacitors, low ESR/ESL. (We use 0402, board house will charge extra to place 0204).
  - RCLAMP524PA for ESD protection.
  - AC coupling capacitors should be close as possible to transmitter to minimize effect of reflections.

Radiation - Total Ionizing Dose

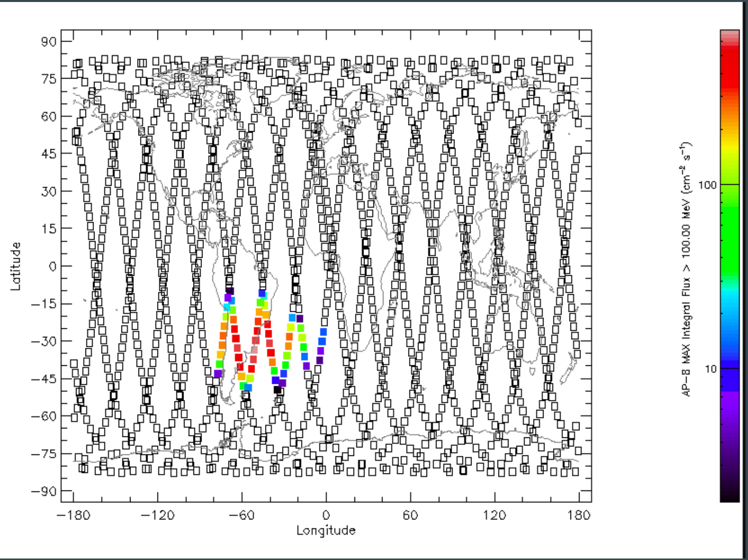
- No TID testing published on TX2i (hopefully coming soon).
- Testing has been done on Jetson Nano (Slater).
  - Device can likely survive 20 krad.
- Testing also carried out on NVIDIA 600 series chipset (Steele).
  - Devices all survive past 6 krad.



Orbit	Heliosynchronous
Apogee	500 km
Perigee	500 km
Inclination	97.4 degrees

Radiation - Single Event Effects

- SEE data is available for TX2. (Wyras)
    - Devices have the same GPU, CPU, Memory Architecture. TX2i has ECC.
    - Device tested with 200 MeV protons.
    - Functional Interrupts experienced quickly, but mostly fixed by reset.
- How often are particles with these energies encountered?
    - Not so often. (Only in South Atlantic Anomaly)
    - Simulated flux ~7 orders of magnitude less than experiment above.



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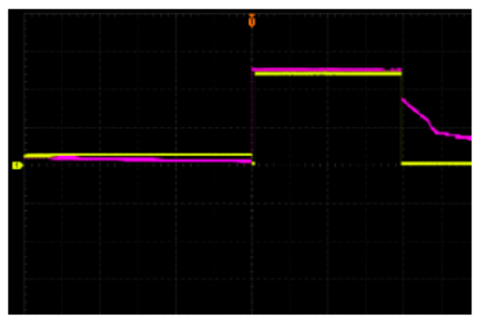
Radiation - Mitigation

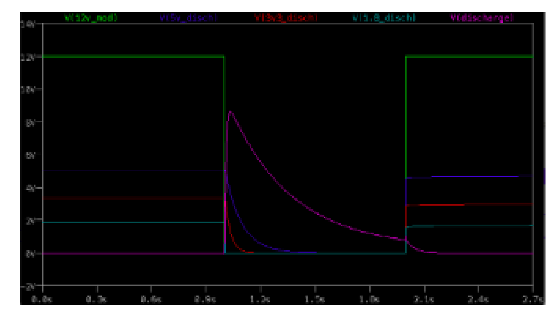
- Currently use Dunmore Aerospace SatKit.
  - .1mm thick, 99% aluminum.
- TX2i contains SBE correct DBE detect capability in the DRAM.
  - This is unique to TX2i.
- We use a triplicated filesystem.
  - Image hash computed at boot to find uncorrupted filesystem.
- Onboard computer (SmartFusion 2) also serves as remote watchdog with reset capability.

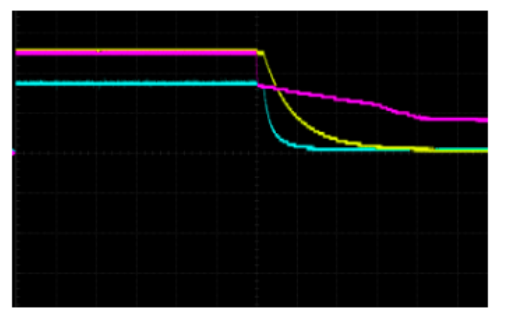
Simulation and Test - Power Circuitry

- TX2i requires power handling circuitry to function correctly.
    - Board designer needs to implement dirty power detection circuit and discharge circuit.
    - Circuit simulation in LTSpice. System tested with Clyde Space

Net	R Ω	C µF	τ ms
1.8V_SYS	37 Ω	3	0.1
3V3_SYS	48	660	31.6
5V_SYS	101	904	91.3







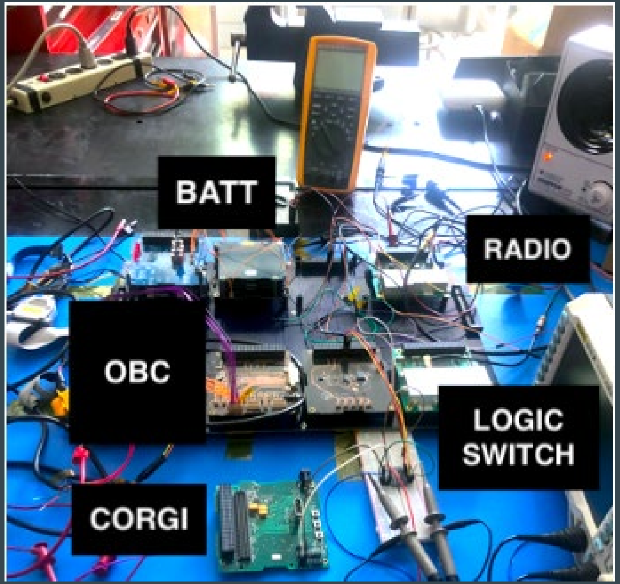
Simulation and Test - Communications

- Current revision of the board only has UART available to communicate with OBC. SPI to be added.
  - Tested file transfer speeds with 115200 baud 8N1.
  - System is ready to be used with arbitrary OBC, however UART is slow.

File	Size *bytes*	Average time *sec*	σ *sec*
"alice29.txt" Canterbury Corpus	152089	13.41	0.00452
"plrabn12.txt" Canterbury Corpus	481861	41.33	0.00798
"pi.txt" Miscellaneous Corpus	1000000	1:24.98	0.01892

Simulation and Test - GPU - Power

- Total system power draw measured.
  - When idle approximately 5000-6000mW.
  - When GPU is actively computing total draw maxes out around 9100mW.
- Two power tests carried out:
  - VGG-19 Jetson Benchmark (NVIDIA).
  - Linux “stress” tool with gpu_burn utility (Timonen).
- Tests also need to be carried in TVAC in the future.



VGG-19 Parameters and Results

- GPU placed in max throughput mode, clock speed of 1.122 GHz, workspace size of 1024. 3 runs total were carried out.

GPU RESULTS

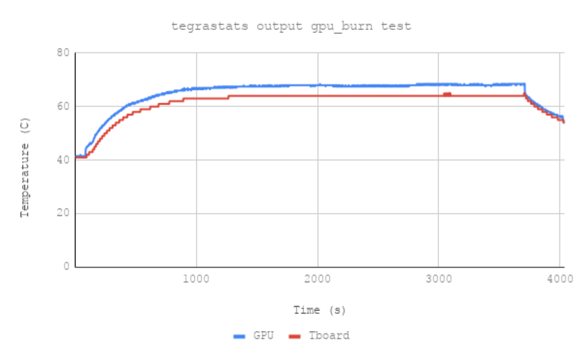
Run #	FPS	VDD SYS GPU (W)	VDD SYS SOC (W)	VDD IN (W)
1	27	3.032	0.912	9.051
2	28	3.032	0.913	9.048
3	25	3.198	0.912	9.044

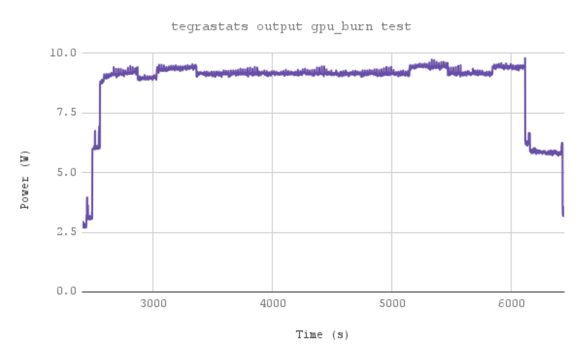
CPU Results

Run #	FPS	VDD SYS CPU (W)	VDD SYS DDR (W)
1	27	2.284	1.318
1	28	2.302	1.318
1	25	2.285	1.319

gpu_burn Parameters and Results

- Tool used in conjunction with Linux stress tool.
  - All CPU cores at 100% utilization for 3600 seconds.
  - Room temperature.
  - GPU temperature and board temperature reach 68.5 ℃ and 65 ℃ respectively. (TX2i operating range from -40 ℃ to 85 ℃)





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Simulation and Test - GPU - Bandwidth

- CUDA Bandwidth Test was utilized to determine Host to Device (CPU to GPU), Device to Host (GPU to CPU), and Device to Device (GPU to GPU) bandwidth.
  - Test run for 2.1 minutes/run.
  - Tests run after power tests to measure stress, no off nominal results from unstressed TX2i.

Run #	H2D BW (MB/s)	D2H BW (MB/s)	D2D (MB/s)
1	15407.1	15527.1	23063.8
2	15501.9	15523.4	23840.1
3	15456.3	15525.3	23100.9

Conclusions

- Board can currently serve as development environment in a PC/104+ stack.
  - Allows access to far more compute resources for parallel tasks than are traditionally available without utilizing an FPGA.
- External communications, power sequencing, command and control tested and verified.
- Currently at TRL 4 - Appropriate for use as an engineering model.
- Need TID results and TVAC testing. System will fly on MOCI satellite in 2022.

Thank You!

Authors: Justin Heimerl, Alex Lin, Allen Spain, David Cotten, Ph.D.

Email: jpheimerl@gmail.com, alexandria.lin@ngc.com, allen.spain@crosstrac.com, dcotte1@uga.edu

Web: http://smallsat.uga.edu/

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Citations

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3. E.J Wyras. Proton Testing of an NVIDIA Jet- son TX2. National Aeronautics and Space Administration, 2019.

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