Next on the Pad – “RadSat”
A Radiation Tolerant Computer System

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Objective of the RadSat Mission

Demonstrate a Single Event Effect (SEE) Mitigation Strategy

- The computer delivers radiation tolerance through a reconfigurable/redundant architecture.
- The computer delivers low cost using COTS parts.
- The computer delivers higher performance (computation & power efficiency) by exploiting modern process nodes (Artix-7).
Why Does the SmallSat Community Care?

Computation

• SmallSats are doing more and more on-board data processing (e.g., images, sensor data, communications).

Radiation Tolerance

• Cutting edge process nodes (28nm) provide increased computation but are becoming more susceptible to radiation induced faults (SEEs).
• As SmallSat missions achieve longer duration and move into deep space, radiation becomes more and more of a concern (both TID & SEE).

Cost

• Any SmallSat computing solution must be cost effective to align with SmallSat theme.

(i.e., “launch more, inexpensive, satellites”)
Single Event Effects (SEE)

- Electron/hole pairs created by a single particle passing through semiconductor.
- Primarily due to heavy ions and high energy protons.
- Excess charge carriers cause current pulses.
- Creates a variety of destructive and non-destructive damage.

“Critical Charge” = the amount of charge deposited to change the state of a gate

![Diagram showing heavy ion particle track, proton nuclear reactions, and short-range recoil produces ionization.]
How We Currently Deal with Radiation

Dealing with Single Event Effects

- **Architecture: Triple Module Redundancy**
  - Triplicate each circuit
  - Use a majority voter to produce output

- **Background Memory Checking: Scrubbing**
  - Compare contents of a memory device to a “Golden Copy”
  - Golden Copy is contained in a radiation immune technology (fuse-based memory, MROM, etc…)

**Note:** TMR+Scrubbing is the recommended mitigation approach for FPGA-based aerospace computers
Our Approach

Fault Tolerance Through Abundant Spares

1. TMR + Spares
   • 3 Tiles run in TMR with the rest reserved as spares

2. Spatial Avoidance and Background Repair
   • If TMR detects a fault, the damaged tile is replaced with a spare and foreground operation continues
   • The tile is “repaired” in the background via partial reconfiguration (PR).

3. Scrubbing
   • Blind scrubbing continually runs through tiles (fast)
   • Readback scrubbing periodically runs through rest of fabric (slower)

Precedent: Shuttle Flight Computer (TMR + Spare)

9 MicroBlaze Processors on Artix-7
Our Approach

Why do it this way?

With Spares, it basically becomes a flow-problem:

- TMR produces the right output, but repair is inevitable.
- Partial Reconfiguration is faster than Full Reconfiguration.
- Bringing on a spare is faster than Partial Reconfiguration.
- If the repair rate is faster than the incoming fault rate, you’re safe.
- If the repair rate is slightly slower than the incoming fault rate, spares give you additional time.
- The additional time can accommodate varying flux rates.
- Abundant resources on an FPGA enable dynamic scaling of the number of spares.
Our Approach

Modeling: Is this an improvement to TMR+Scrubbing?

- We use a Markov Model to predict *Mean-Time-Before-Failure*.
- We want to see if it improves MTBF over non-redundant & TMR+scrubbing.
- The fault rate was extracted from CREME96 for 4 different orbits for Virtex-6 FPGA.
- The repair rate was found empirically.
History of Technology Maturation

10 years…

TRL 3 – Proof of Concept
2008-2009: Prototype demonstration at MSFC.

TRL 4 – Subsystem Validation in Laboratory

TRL 5 – Subsystem Validation in Relevant Environment

TRL 6 – Subsystem Demonstration in Relevant End-to-End Environment

TRL 7 – System Demonstration in an Operational Environment
2014-16: Internal ISS Demonstration using NanoRacks CubeLab Experiment Locker (HTV6 Launch).
The Design

FPGA Experiment Stack

9-Tile MicroBlaze System
(TMR + 6 Spares)
The Design

Integrated with Avionics into 3U Satellite
Mission Concept

Use ISS-based, NanoRacks CubeSat Deployer

- Manifested on ELaNa-23, OA-9 CRS Mission.
- Cygnus/Antares II flight out of Wallops Flight Facility.
- March 14, 2017.
- Operated from SSEL Ground Station in Bozeman, MT.
Questions

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RadSat