MicroSD Operational Experience
and Fault Mitigation Techniques

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  • Interface (e.g. memory, imaging devices, ...)
  • Data acquisition (e.g. AIS, video, hyperspectral imagery, ...)
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• Some goals:
  • Robust
  • Affordable
  • Low power, small size
  • Fast application memory
  • Computationally capable
  • Accommodate (almost) arbitrary interfaces
  • Familiar S/W development and runtime environments (e.g. Linux, Yocto)
Background

To achieve these goals Xiphos cards feature:

- General purpose CPUs and programmable logic
- Low power RAM
- NOR flash to store application configuration (bootloaders, kernel, rootfs, logic bitstream)
- High density, high speed NAND flash in the form of MicroSD cards to store application data
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  • Xilinx Spartan 6
  • One or more Microblaze soft processors
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- Example: Q7 processor card (2014)
  - Xilinx Zynq-7020 (2 x ARM Cortex-A9, Artix-7 FPGA)
  - 1 x 512 MB and 1 x 256 MB LPDDR2 RAM, 2 x 32 GB MicroSD
Q7 Top

- Power input
- RJ45 Gigabit Ethernet
- Micro-AB USB 2.0 OTG
- RTC
- Low-power RAM
- Xilinx Zynq AP SoC
- High Efficiency Power Supply
- PIM Interface (incl. RSXXX)
- High Reliability System Controller
- QSPI Flash (NOR)
Q7 Bottom

- Up to 32 GB of Flash
- Another 32 GB of Flash
- Mezzanine Connectors (incl. RSXXX & USB)
NAND Flash, MicroSD

- NAND vs. NOR: NAND flash is a relatively high density memory
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  - Controllers that implement error correction and wear leveling
  - Memory areas that store error correcting codes and FTL controller configuration
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- These mitigations are appropriate for the terrestrial, COTS use-case but additional errors occur in space
  - Core NAND flash components?
  - FTL controller?
  - FTL controller configuration memory?
Xiphos Experience

*In Orbit Observations*

- Xiphos has supplied spacecraft developers with (Micro)SD equipped processors for LEO applications since 2006. Examples:
  - Cameras systems for SpaceQuest and Bigelow Aerospace Genesis-1/2
  - AIS payload processors for SpaceQuest
  - Payload monitoring and networking for the OSTEO-4 experiment on ISS
- Failures are rare but do occur
- Symptom: card information and status register queries result in responses but corrupted values
- Vendor feedback: controller firmware corruption resulting in device factory reset
- Perfect correlation: a rise in power consumption of ~100 mA @ 3.3 V
- This rise is about twice the expected peak current during SD write operations but much lower than the threshold required to trip standard latch-up protection
- This is a condition known as “low-current latch-up”
Xiphos Experience

Radiation Test Observations

- Xiphos tested (Micro)SD cards and Xiphos processor cards against the Proton Irradiation Facility (PIF) at TRIUMF in 2004, 2011, 2012, 2014

- Test goals:
  - Detect weaknesses in Xiphos designs
  - Characterise the radiation events that produce SD card failures
  - Characterise the SD card failures themselves

- Observed failures:
  - Temporary, transient write errors (low-current latch-up)
  - Temporary, multi-sector data corruption (low-current latch-up)
  - Destruction (one observation) (30 krad TID)

- Radiation:
  - Transient errors can occur at relatively low doses e.g. 2 – 5 krad
  - One campaign actively sought to find some “sweet spots” e.g. errors occur within 100 s under a 63 MeV bean at 6 nA
Xiphos Experience

Radiation Tests
Xiphos Experience

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Radiation Tests
Xiphos Fault Mitigation Techniques

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- These are predicated on both flight and test experience
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• Software-based, robust storage mechanism:
  • Linux kernel module implementation (xdm_replicate)
  • Provides a robust virtual block device via combination of multiple non-robust devices
  • Detects and repairs corrupted sectors
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• Low-current latch-up detection:
  • ProASIC3 monitors MicroSD card power consumption
  • Automatic shutdown is triggered when the overcurrent condition is detected
  • Reaction time is < 1 microsecond
  • Extremely effective according to the 2014 TRIUMF test campaign

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Xiphos Experience

Low-Current Latch-Up Detection

AP-001 #11 - Power-Off

SD Current (mA)

Time (sec)

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Xiphos Fault Mitigation Techniques

- MicroSD FTL controller reconfiguration
  - With MicroSD manufacturer cooperation it may be possible to modify/reconfigure FTL controller firmware “in the field”
  - Xiphos has had positive response from one manufacturer and is looking at ways to develop this capability
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• Robust design!
  • Store critical firmware and software in redundant, error corrected NOR flash
  • Store payload data to redundant MicroSD cards
  • Keep MicroSD cards unpowered when not in use
Summary

- Xiphos...
  - Has flown SD and MicroSD cards for almost 10 years
  - Observed SD card failures in orbit
  - Tested SD cards at TRIUMF since 2004
  - Designed techniques to protect SD card data from radiation upsets
    - Low-current latch-up detection
    - Software-based robust storage mechanism for corrupted sector detection and repair
    - FTL controller firmware reconfiguration (in progress)
  - Tested low-current latch-up detection and software-based robust storage
- Xiphos is confident that event detection techniques and robust design elements can permit long term and reliable use of MicroSD cards in orbit

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