Single-Event Upset in the PowerPC 7400 Microprocessor

Farokh Irom, Gary M. Swift, Farhad Farmanesh
Jet Propulsion Laboratory

and

Doug Millward
Millward Research

The research in this paper was carried out by the Jet Propulsion laboratory, California Institute of Technology out under contract with the National Aeronautics and Space Administration (NASA) code AE.
Introduction

Why are we interested in commercial Processors?

- Increased performance compared to hardened processors
- Potential applications for instruments and data processing
  - Particularly critical for autonomous instruments
  - Simplified data transmission in deep space
Introduction

Summary of Motorola’s PowerPC Family of Advanced Processors

- The PowerPC750 was co-designed by IBM and Motorola.
- We have previously reported single-event measurements on Motorola and IBM PowerPC 750 processors.*
- The PowerPC 74xx series incorporates a more advanced processing unit (AltiVec).
- The PowerPC 74xx series with AltiVec unit can execute 20 operations per clock cycle compared to conventional processors which generally execute one to three instructions per cycle.

## Introduction

### Summary of Motorola’s PowerPC Family of Advanced Processors

<table>
<thead>
<tr>
<th>Device</th>
<th>Feature Size (μm)</th>
<th>Die Size (mm²)</th>
<th>Core Voltage (V)</th>
<th>Max. Operating Freq. (MHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPC603 (G2)</td>
<td>0.50</td>
<td>196</td>
<td>2.5</td>
<td>300</td>
</tr>
<tr>
<td>MPC750 (G3)</td>
<td>0.29</td>
<td>67</td>
<td>2.5</td>
<td>350</td>
</tr>
<tr>
<td>MPC7400 (G4)</td>
<td>0.20</td>
<td>83</td>
<td>1.8</td>
<td>500</td>
</tr>
<tr>
<td>MPC7450 (G4)</td>
<td>0.18</td>
<td>106</td>
<td>1.6</td>
<td>867</td>
</tr>
<tr>
<td>MPC7455 (G4)</td>
<td>0.18</td>
<td>TBD</td>
<td>1.6</td>
<td>1000</td>
</tr>
</tbody>
</table>

*AltiVec processing unit

#SOI
Basic Approach

- Test facilities
  - IUCF and UC Davis - protons
  - TAM - Heavy-ion
- Irradiating from back
- The protons have sufficient range to penetrate the package
- Heavy-ion tests were done on specially prepared units that were thinned
- Upsets measured in
  - Altivec registers
  - L1 data cache and their tags
  - L2 tags
  - Translation Lookaside Buffer TLB
- Overall results for processor functionality
Experimental Method

- Radiation testing was done using a development board from Motorola known as “Yellowknife”
- Basic PROM-based system monitor instead of a complex operating system
- Small daughter card for processor and cache with no active components underneath (important for proton beam penetration)
- External communication with serial connection and JTAG port
- An Agilent Technology 5900B JTAG probe was used
  - Many nodes of interest, e.g. GPR, FPR, Caches, etc. can be read indirectly through the JTAG port
  - It is able to interrogate the processor even when unexpected events occurred
Single-Event Upset in the PowerPC 7400 Microprocessor

Experimental Method

- Fill internal registers or data cache with recognizable pattern
- Perform a one word instruction in a small infinite loop
- Write a register or changes in data cache snapshot to a strip chart in the physical memory every half second using decremener interrupt
- After the irradiation, an external interrupt triggers a program to count state changes in internal registers or the data cache
Experimental Method

- Proton tests with energies above 65 MeV were performed at IUCF.
- Tests at lower energies were done at UC Davis.
- Heavy-ion tests were performed at the TAM using ions with 25 and 40 MeV/amu.
- Because of limited range of heavy-ion beams, we ground down the back surface of the PowerPC 7400
  Reduced thickness from 720 to 50-200 μm
  No impact on electrical characteristics
- A custom heat sink with a hole for the processor die was used to contact heat away from the package.
Proton Test Results for Cache

- Cross section for transitions between "1" and "0" are statistically identical
- Threshold is 5-7 MeV
- Saturated cross section is about $3 \times 10^{-14}$ cm$^2$/bit, which is in agreement with data for the PowerPC 750 with its feature size of 0.29 μm
Proton Test Results for TLB

- Results of cross section per bit measurement for TLB of the PowerPC 7400 MMU versus proton energy
- For comparison we show our previous measurements for the PowerPC 750
- The saturated cross section is about $5 \times 10^{-14}$ cm$^2$/bit
- The threshold energy is 15 MeV
- Agreement with results for PowerPC 750
Heavy Ion Test Results for FPR

- Results of cross section for PowerPC 7400 FPR for “1” to “0” transitions
- The LET threshold is about 5 MeV-cm²/mg
- The saturated cross section is about 1x10⁻⁷ cm²/bit
- The cross section for “1” to “0” is the same as for “0” to “1” transitions
- There is a good agreement for results obtained from different thicknesses
- Agreement with results for PowerPC 750
Heavy Ion Test Results for TLB

- The saturated cross section is about 4x10^{-8} cm^2/bit
- The saturated cross section is slightly lower than PowerPC 750
- This might be related to smaller die size for MMU unit in the PowerPC 7400
- We plan to do measurements at lower LET to compare the threshold cross section with results for PowerPC 750
Conclusions

- Although the PowerPC 7400 has smaller, geometry, lower internal core voltage and design advances, its proton and heavy ion upset susceptibility are somewhat lower than PowerPC 750
  - PC7400 0.20 μm, 1.8 V
  - PC750 0.29 μm, 2.5 V
- The low space rates, immunity to latchup, and relatively low power consumption, allow them to be used successfully in many space environments
- They can be used in data analysis or instrument control applications where occasional malfunctions or errors from single-event upset can be tolerated and corrected