Single-Event Upset in the PowerPC 7400 Microprocessor

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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 compare to conventional processors which generally execute one to three instructions per cycle.

* *G. M. swift, et al., IEEE Trans. Nucl. Sci., vol. 48, no. 6, pp. 1822-1827,2001*

Introduction

Summary of Motorola's PowerPC Family of Advanced Processors

Device	Feature Size (μm)	Die Size (mm^2)	Core Voltage (V)	Max. Operating Freq. (MHz)
MPC603 (G2)	0.50	196	2.5	300
MPC750 (G3)	0.29	67	2.5	350
MPC7400 (G4)*	0.20	83	1.8	500
MPC7450 (G4)*	0.18	106	1.6	867
MPC7455 (G4)*#	0.18	TBD	1.6	1000

*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

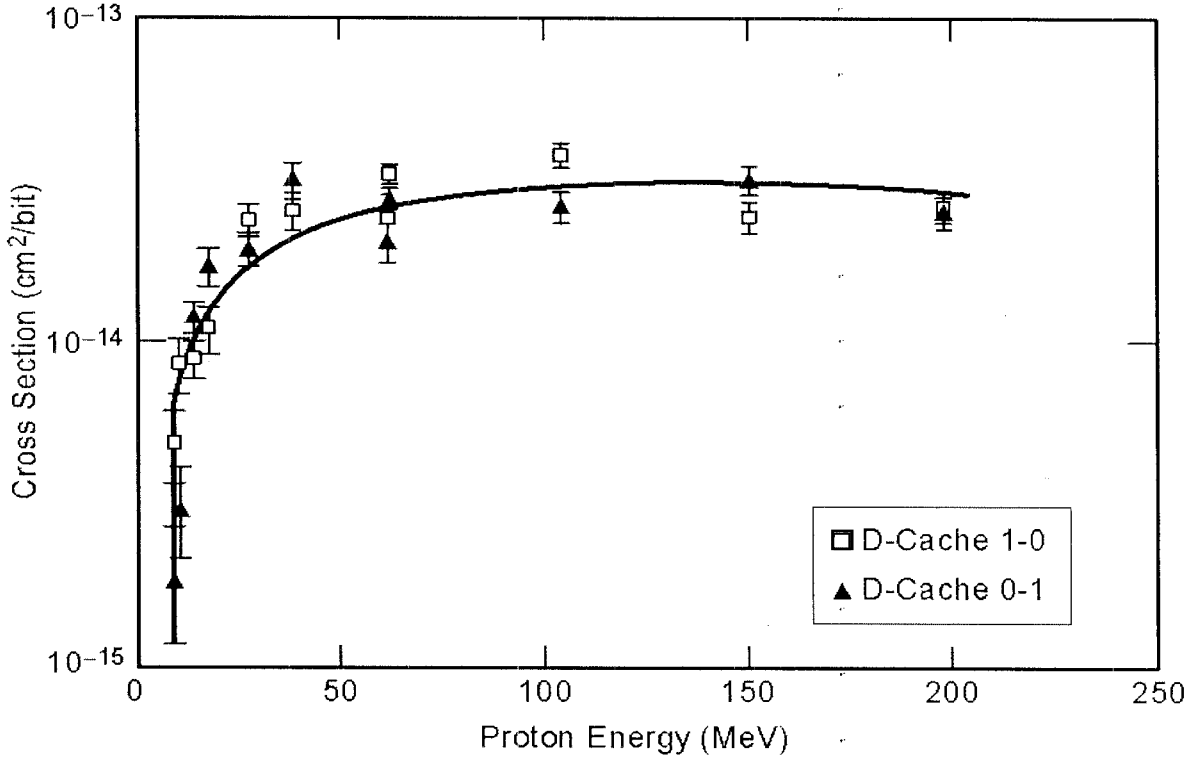
Experimental Method

- 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 decrementer interrupt
- After the irradiation, an external interrupt triggers a program to count state changes in internal registers or the data cache

Experimental Method

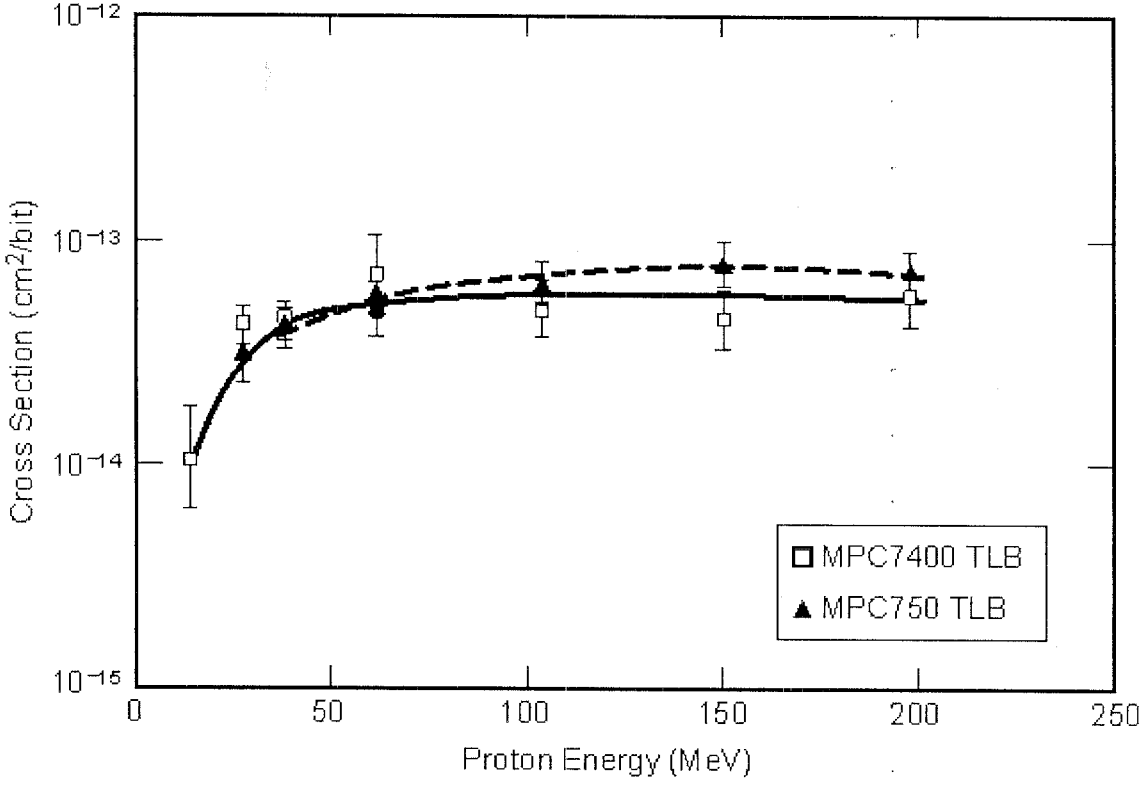
- Proton tests with energies above 65 MeV were performed at IUCF
- Tests at lower energies were done at UC Davis.
- Heavy-ion tests were performed at the TAM using ions with 25 and 40 MeV/amu
- Because of limited range of heavy-ion beams, we ground down the back surface of the PowerPC 7400
  - Reduced 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



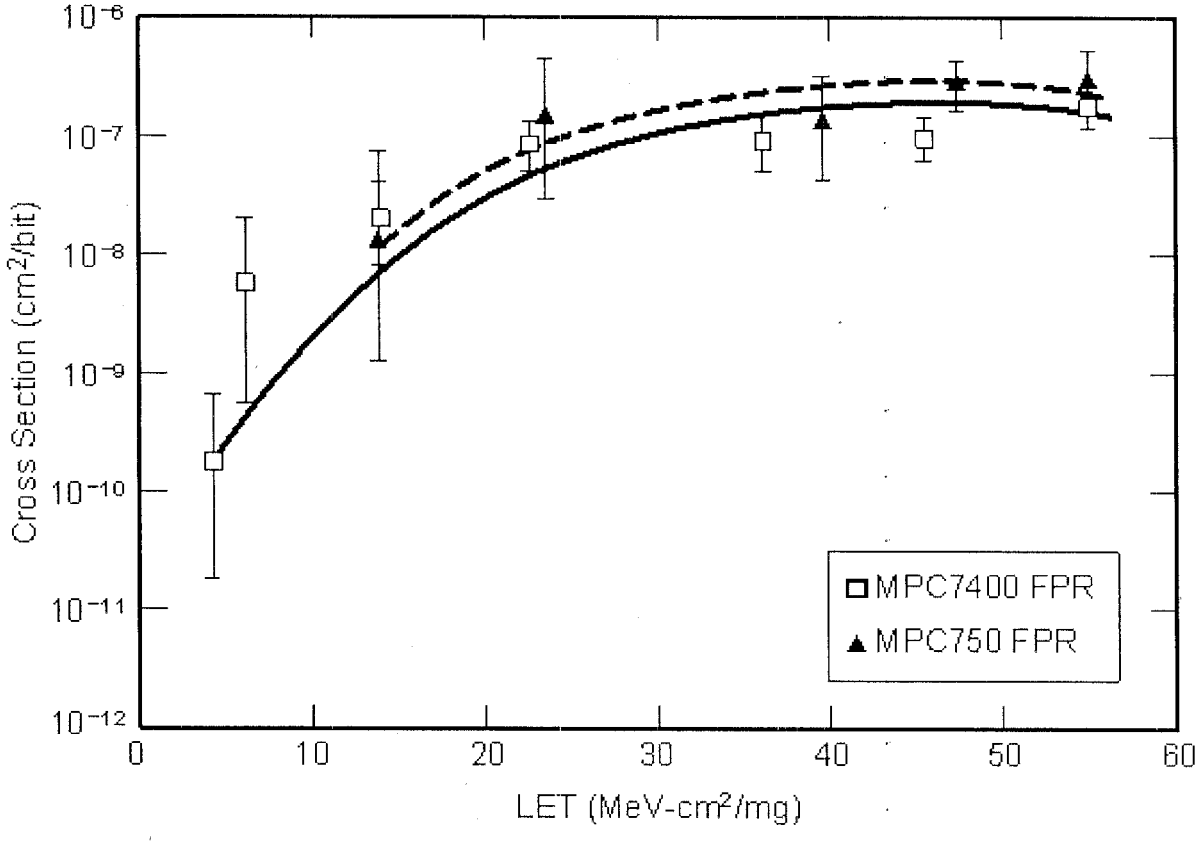
- **Cross section for transitions between "1" and "0" are statistically identical**
- **Threshold is 5-7 MeV**
- **Saturated cross section is about 3×10^{-14} cm^2/bit, which is in agreement with data for the PowerPC 750 with its feature size of 0.29 µm**

Proton Test Results for TLB



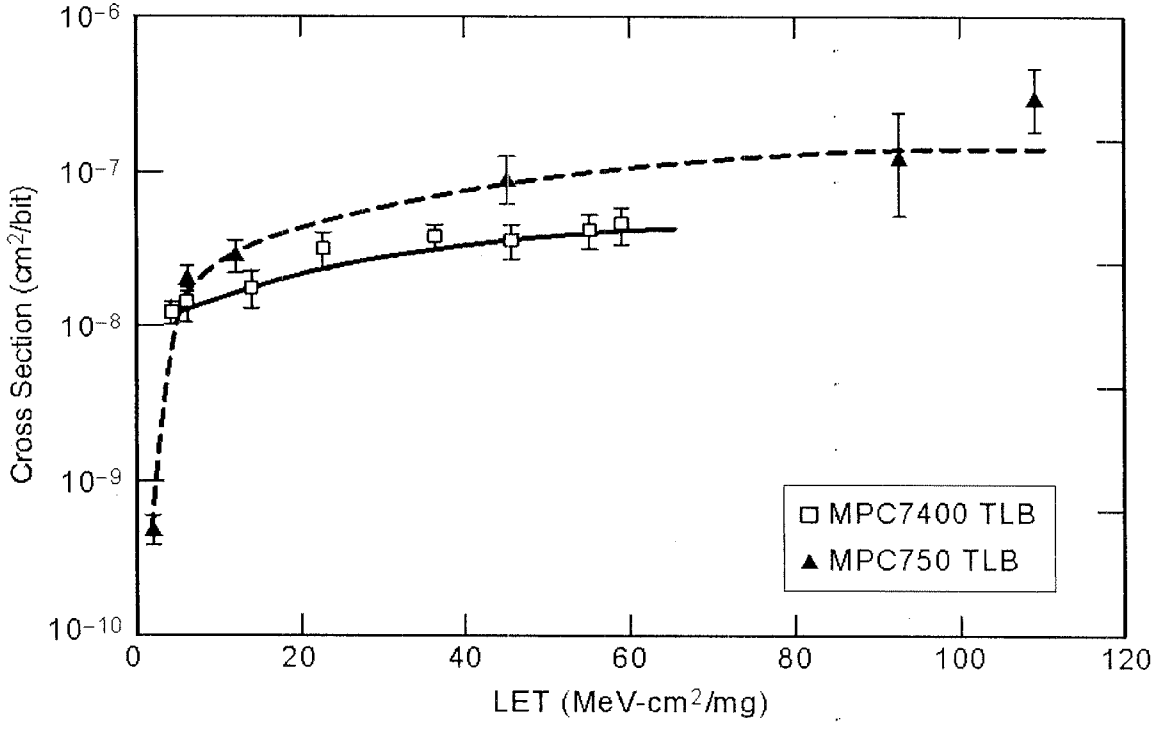
- Results of cross section per bit measurement for TLB of the PowerPC 7400 MMU versus proton energy
- For comparison we show our previous measurements for the PowerPC 750
- The saturated cross section is about 5×10^{-14} cm²/bit
- The threshold energy is 15 MeV
- Agreement with results for PowerPC 750

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-cm^2/mg
- The saturated cross section is about 1x10^{-7} cm^2/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 cm2/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