

Single Event Upset (SEU) in Field Programmable Devices: a problem for future experiments?

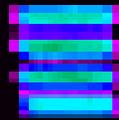
Torino

Complex Systems of
Hadrons and Nuclei

October, 2005

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Overview

- SEU: Single Event Upset
- SOURCES OF SEU FAILURES
- EXPERIMENTAL TEST
- OUTLOOK



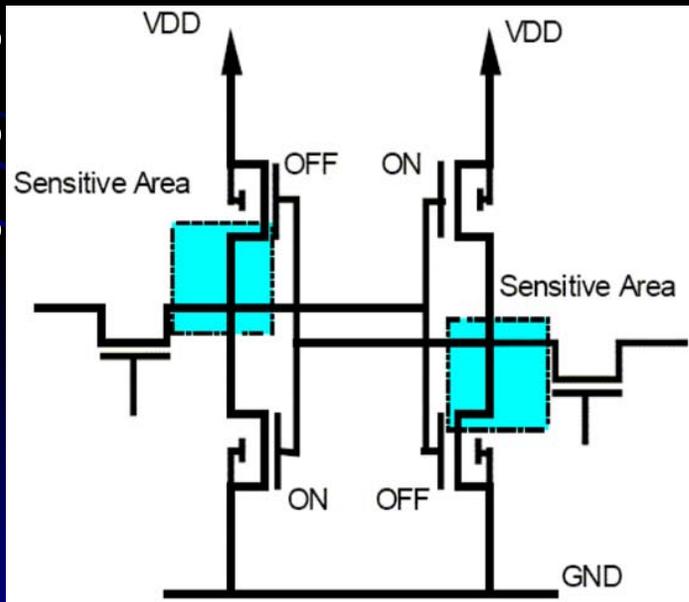
What Field Programmable Gate Array (FPGA) is.....

- Cheap device with low cost
- High gate density
- Configuration by downloading a bit stream
- Digital electronic
- Important for i.e. pattern recognition



SEU definition

Single event upset is:



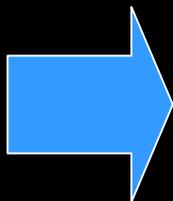
SEU can happen when a particle can strike key node within a device, resulting in a ionization well localized that can cause a state change by flipping a bit

lose their energy by ionizing

SEU

- Charge deposition by ionizing particle can lead to a change in the state of a logic circuit
- Charge deposition $Q_{dep} = E_{dep} \cdot q / w_{ehp}$
 w_{ehp} = electron-hole pair creation energy (Si: $w_{ehp} = 3.6$ eV)

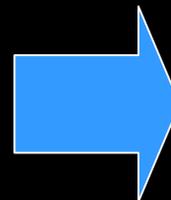
$Q_{dep} > Q_{crit} :$
 LET_{th}



SEU

• $LET_{threshold}$ (estimation for Xilinx device) \approx
 200 keV/mg/cm²

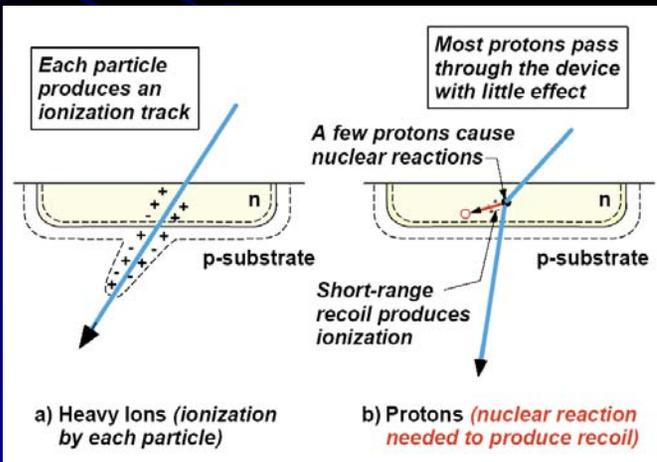
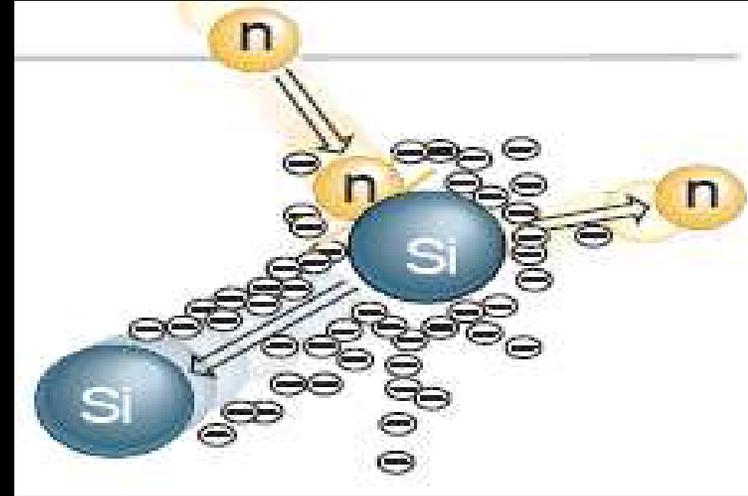
• i.e. $LET(30$ MeV proton in Si) =
 15 keV/mg/cm²



Silicon recoil and
Secondary particle
Production dominant !

Source of failures

- Logic Configuration
 - Altered logic definition
 - Always persistentUsually results in undesirable operation

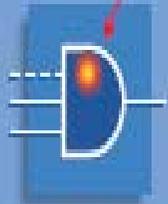


- Routing
 - Statistically most probable
 - Always persistent

Routing

Critical points !!!

Critical points !!!



Incoming Neutron Causes Firm Error in Logic Modules Leading to

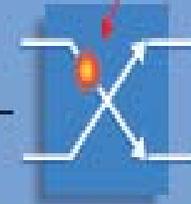
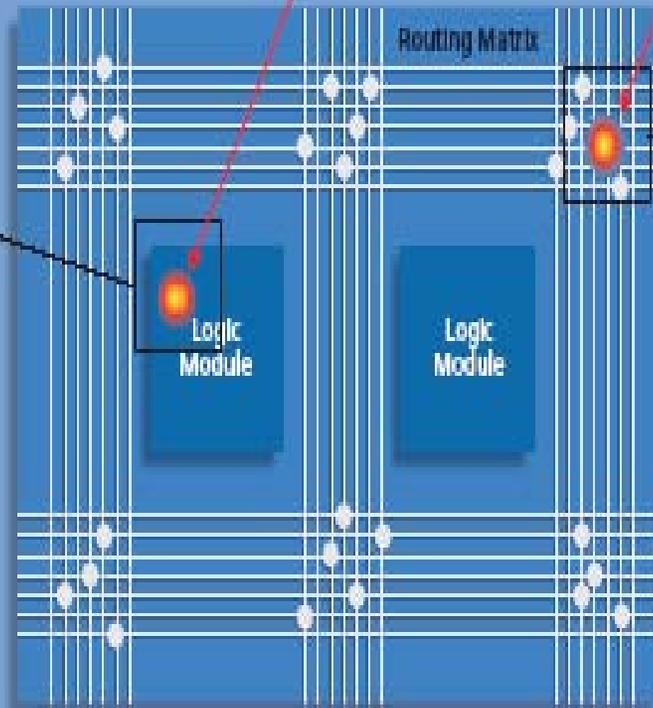


Misconnected Signal

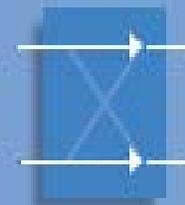
or



Functional Change



Incoming Neutron Causes Firm Error in Routing Matrix Leading to



Misrouted Signal

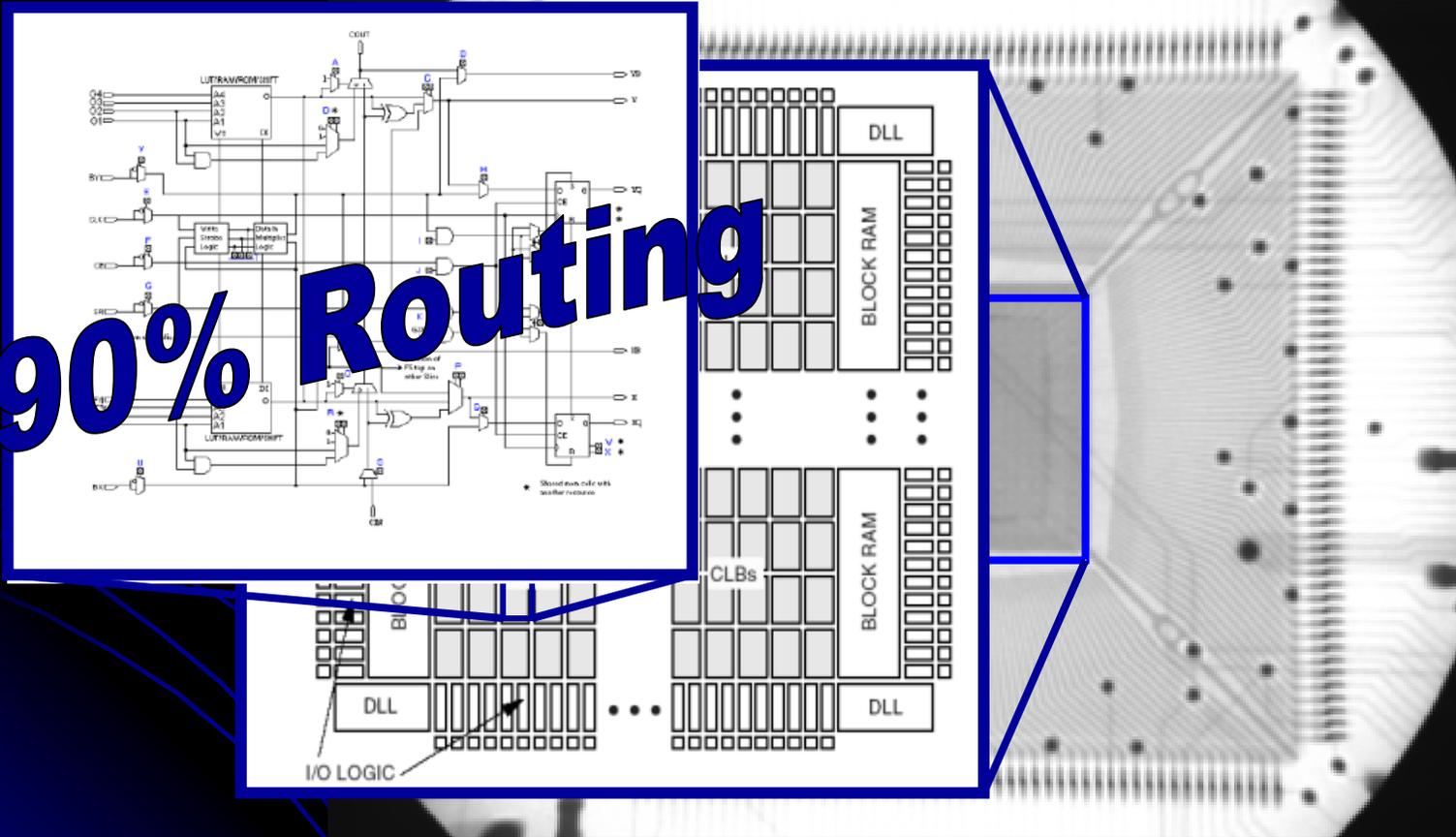
or



Missing Signal

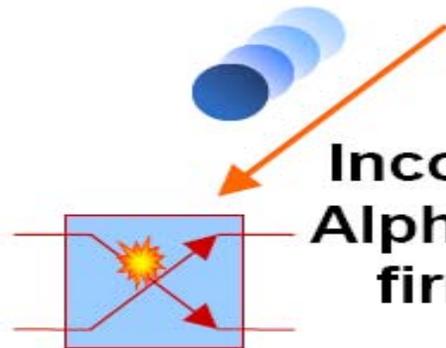
Source of failures

90% Routing



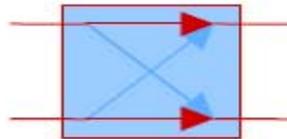
Mux create routing Multiplexer Multiplexer

Error:



Incoming neutron or
Alpha particle causes
firm error in GRM

Firm error leads to . . .



misrouted
signal



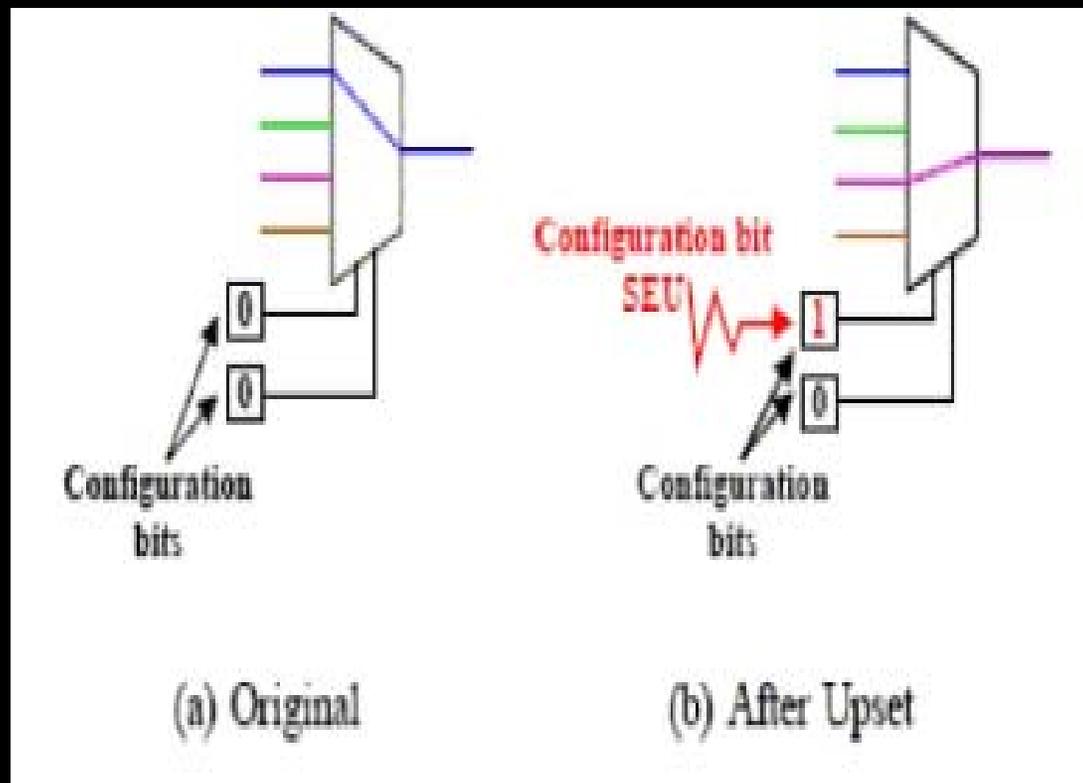
or missing
signal



Mux create routing

Immediately around the two slices within a logic element are collection of input muxes (imuxes) and output muxes (omuxes) which are used to route input and output signals to and from the elements.

Figure provides an exploded view of this form of programmable routing



Why are these errors getting more important...

- The dimensions and operating voltages of modern semiconductor devices are getting smaller, following the commercial trend of higher density, lower power, and lower cost.
- In deep submicron technologies the smaller feature sizes have smaller critical charge levels and large voltage disturbances can be caused from small amounts of deposited charge.

Experimental Test

- 2 direct beams:
 π^- (1.17GeV/c) , π^+ and p

- products from reaction
Al (1GeV/a) + Ca

- A plastic scintillator placed behind the die

→ counting rate

- Stick moved by a motor, controlled by a remote system

→ Control the particle rate

- 2 different self checking programs

→ counter based

→ ram based



Experimental Test

Hades pre-shower



FPGA Board

High rate
Low rate

Approx. 1 error per 10^6 particles

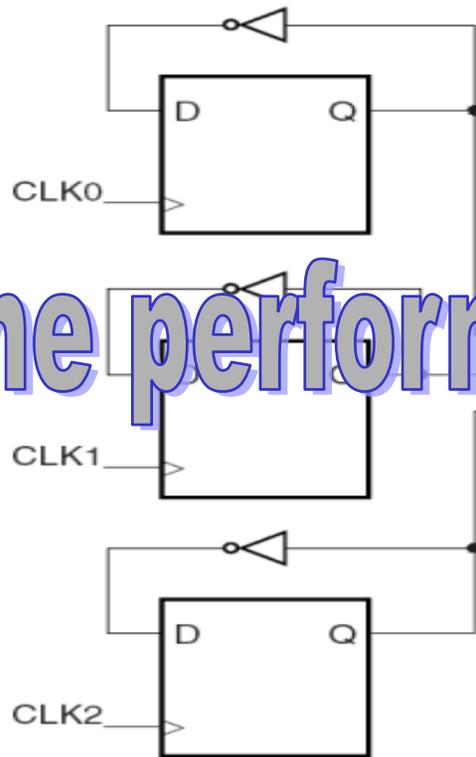
Outlook

Simple triple module redundancy (TMR)

- Three copies of user logic and voting
- Triple power consumption
- Triple logic utilization
- Slower operation
- No fully automated tool at present



Outlook



The performance impact of TMR is ~10%

TR0	TR1	TR2	sig_out
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	1
1	0	0	0
1	0	1	1
1	1	0	1
1	1	1	1

Outlook

Readback and Verify Configuration Data

- Read entire memory contents
 - Byte for Byte comparison.
 - Count number of frames to upset.
-
- If errors are detected, device is fully reconfigured
 - Applications that can tolerate errors if they are detected:::

**Non-Critical Applications
(Imaging, Data Processing)**

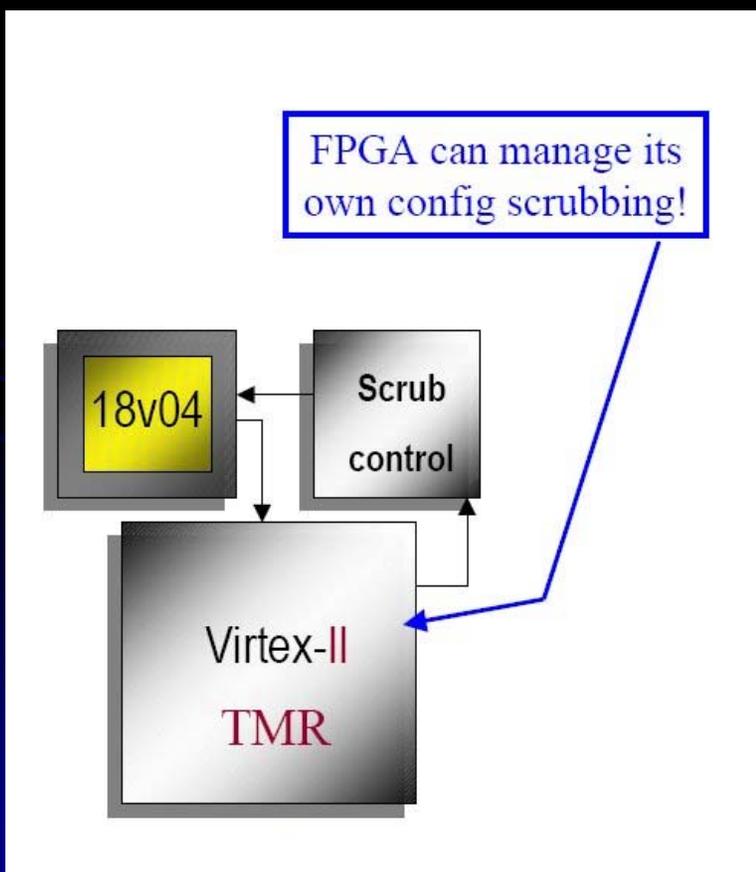
Outlook

- “Scrubbing” refreshes configuration memory through partial reconfiguration
- Repair SEUs by continuously reconfiguring part
- Two approaches:
 - readback, compare, repair (closed-loop scrubbing)
 - continuous reconfig (open-loop scrubbing)



Outlook

- **Readback/error detection can be incorporated into scrub controller**



- **Critical data processing Applications (Communications, Navigation)**

Numerous Missions

- **Satellite-based DSP modules**
- **Image Processing**
- **GPS Transceivers**