Using Built-in Sensors to Cope with Long Duration Transient Faults in Future Technologies

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Outline

- Motivation
- Drawbacks of Previous Mitigation Techniques
- The Proposed Approach
- Results
- Final Remarks
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Motivation

- Radiation effects are becoming more critical in nanometer technologies.

- Reduced node capacitance
- Reduced voltage supply
- Low critical charge

\( \alpha \) particles, protons, heavy ions
Motivation

Transient Effect Faults (soft errors):

- **Single Event Upset (SEU):** bit-flip in a sequential logic element
- **Single Event Transient (SET):** transient voltage pulse in the combinational logic
Motivation

Transient Effect Faults (soft errors):

- **Single Event Upset (SEU):** bit-flip in a sequential logic element
- **Single Event Transient (SET):** transient voltage pulse in the combinational logic

• Logical masking
• Electrical masking
• Latch window masking

![Sequential and combinational logic diagram]
Soft Error Rate increases with the increase of the frequency

[Narasimham et al., IEEE TNS 2006]
Transient Width Measurements under Radiation Ground Testing

[Dodd et al., IEEE TNS 2004]  [Gadlage et al., IEEE TNS 2004]
Challenges in Nanometer Technology

- **SET Transient Width (TW)** may vary from a few hundreds picoseconds to a few nanoseconds, according to LET.

Increase the probability of capturing a SET

- Electrical masking
- Latch window masking
Challenges in Nanometer Technology

- **SET Transient Width (TW)** may be longer than one clock cycle.

![Graph showing SET behavior across different technologies.](image-url)

SET of 400ps can last for 2 clock cycles in 90 nm CMOS technologies (5 GHz)
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Previous SET Mitigation Approaches

- They all present some limitations in:
  - AREA
    - Full Triple Modular Redundancy (TMR)
  - PERFORMANCE
    - Time redundancy (time filtering) with voter
SET Mitigation Approaches

FULL TMR

Long pulse → X

majority voter → OK
SET Mitigation Approaches

Time Redundancy with recovery scheme

Problem: delay must be larger than the SET width in order to filter the SET

Very Low frequency circuits
Recomputation

- Recomputation is good for performance because it adds penalty according to the soft error rate.

- The challenge is how to detect the faults in order to ask for recomputation with a low area overhead and low performance penalty!
SET Mitigation Approaches

Duplication with comparison with recovery scheme

Detection and recovery system

100% area overhead for fault detection
**SET Mitigation Approaches**

**Time Redundancy with recovery scheme**

**Problem:** delay must be larger than the SET duration width in order to filter the SET

Low frequency circuits
Goal

- Method to detect the faults in order to ask for recomputation with:
  - a low area overhead
  - low performance penalty

- General method that can be applied in any design.
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Proposed Approach

- Use a built-in current sensor (BICS) to detect the ionization caused by an energetic particle.
Bulk Built-in Current Sensor

Bulk Built-in Current Sensor

Bulk (VDD')

Bulk (Gnd')

output N-BICS

output P-BICS

nRST

pRST

V_{DD}

V_{DD}

ionization

bulk BICS

bulk BICS

α particles, protons, heavy ions
Bulk-BICS Behavior for **short SETs**

Faulty cycles

1. Vdd/2

2. Recomputing_status

3. Reset_BICS
Bulk-BICS Behavior for long SETs

Faulty cycles

clk

SET

BICS

recomputing_status

reset_BICS
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Case-Study: adders

4-bit carry look-ahead Adder
CMOS 32 nm PTM

Fault injection performed by Spice level simulations.

<table>
<thead>
<tr>
<th>Adder Width</th>
<th>Maximum Frequency</th>
<th>Cycle Time (T)</th>
<th># of transistors</th>
<th>area (µm²)</th>
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<tbody>
<tr>
<td>8 bits</td>
<td>5.714 GHz</td>
<td>175 ps</td>
<td>448</td>
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<tr>
<td>16 bits</td>
<td>2.857 GHz</td>
<td>350 ps</td>
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<td>32 bits</td>
<td>1.429 Ghz</td>
<td>700 ps</td>
<td>1,792</td>
<td>128.4</td>
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Area Overhead: Bulk-BICS for response time = 0.5 T

- And SET varying from 30% of the clock cycle (0.3T) to two clock cycles (2.0T)
# Area Overhead: Bulk-BICS for response time = 0.5 T

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### Area Overhead: Bulk-BICS for response time = 2 T

**Diagram:**
- clk: Clock signal
- SET: SET waveform
- Vdd/2: Voltage level at Vdd/2
- 2T: Time duration

**Table: Case Analysis**

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- The use of bulk-BICS as sensors to detect SET combined to the recomputing capability can mitigate long duration transients.

- The time for recomputation can be adjusted according to duration of the SET and the application.
Final Remarks

- Bulk-BICS approach leads to area overhead varying from 50% to 2.1% according to the sensitivity of the sensor and to the required time response.

- Bulk-BICS does not affect the normal operation frequency of the system.
Thank you!
Questions?

Contact: Fernanda Kastensmidt
fglima@inf.ufrgs.br