Total Dose Effects on Single Event Transients in Digital CMOS and Linear Bipolar Circuits

S. Buchner, MEI/NASA-GSFC
D. McMorrow, NRL
M. Sibley, P. Eaton, D. Mavis, Micro-RDC
L. Dusseau, N. J-H. Roche, M. Bernard, Univ. of Montpellier

Presented by S. Buchner at SEE Symposium, San Diego, CA, April 2009
Introduction

• Exposure of ICs to ionizing radiation changes electrical parameters.

• TID effect observed in both CMOS and bipolar circuits:
  – In bipolar circuits, transistors exhibit gain degradation
  – In CMOS circuits, transistors exhibit threshold voltage shifts

• Changes in electrical parameters can cause changes in SEU/SET rates. Depending on effect, rates may increase or decrease.

• Therefore, measures taken for SEU/SET mitigation might work at the beginning of a mission but not at the end following TID exposure.

Presented by S. Buchner at SEE Symposium, San Diego, CA, April 2009
TID concerns arise during proton testing of circuits with small SEU cross-sections

- At 60 MeV, a fluence of 7x10^{11} p/cm^2 gives a TID of 100 krad(Si).
- For 10% statistics require 100 upsets or 3x10^{11} p/cm^2.
- Assume 50% charge yield in presence of electric field.
- Equivalent TID(e^-) = 20 krad.
- If part has a hardness of 50 krad, can measure 2 points before electrical parameters exceed manufacturer’s specifications and part must be changed.
- Schwank et al have investigated proton-induced TID effects in SRAMs (2004)

Presented by S. Buchner at SEE Symposium, San Diego, CA, April 2009
Introduction – Bipolar Transistors

TID causes charge buildup that distorts emitter/base junction field and degrades gain.

Schmidt et al, IEEE TNS 1996

Schrimpf, NSREC 2001 Short Course

Presented by S. Buchner at SEE Symposium, San Diego, CA, April 2009
Introduction – MOS transistors

TID causes charge buildup that shifts threshold Voltage and increases leakage currents.

N-channel MOSFET

J. Schwank, NSREC Short Course 2002

Presented by S. Buchner at SEE Symposium, San Diego, CA, April 2009
LINEAR BIPOLAR CIRCUIT
VOLTAGE COMPARATOR – LM139

Presented by S. Buchner at SEE Symposium,
San Diego, CA, April 2009
Voltage Comparator – LM139

- **LM139** - SETs become smaller with TID

Presented by S. Buchner at SEE Symposium, San Diego, CA, April 2009
LINEAR BIPOLAR CIRCUIT

Operational Amplifier – LM124

Presented by S. Buchner at SEE Symposium, San Diego, CA, April 2009
Operational Amplifier – LM124

- Used focused pulsed laser to inject charge into Q9 and R.

Presented by S. Buchner at SEE Symposium, San Diego, CA, April 2009
LM124 – Q9 VF

Amplitude (V)

Time (s)

Presented by S. Buchner at SEE Symposium, San Diego CA April 2009
LM124 – Q9 VF

Presented by S. Buchner at SEE Symposium,
San Diego, CA, April 2009
Presented by S. Buchner at SEE Symposium, San Diego, CA, April 2009
LM124 – Q9 VF

Presented by S. Buchner at SEE Symposium, San Diego, CA, April 2009
LM124 – Q9 VF

Amplitude (V) vs. Time (s)

-2.0E-05 0.0E+00 2.0E-05 4.0E-05 6.0E-05
-6.0 0.0 2.0E-05 4.0E-05 6.0E-05

0 krad
5 krad
10 krad
18 krad
28 krad
35 krad

Presented by S. Buchner at SEE Symposium,
San Diego, CA, April 2009
LM124 – Q9 VF

Amplitude (V) vs. Time (s)

Presented by S. Buchner at SEE Symposium, San Diego, CA, April 2009
LM124 – Slew Rate

<table>
<thead>
<tr>
<th>Total Ionizing Dose [krad(Si)]</th>
<th>Slew Rate</th>
<th>Exp. Fit</th>
<th>Slope of Q9</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.30</td>
<td>0.25</td>
<td>0.2</td>
</tr>
<tr>
<td>1</td>
<td>0.25</td>
<td>0.20</td>
<td>0.15</td>
</tr>
<tr>
<td>2</td>
<td>0.20</td>
<td>0.15</td>
<td>0.1</td>
</tr>
<tr>
<td>3</td>
<td>0.15</td>
<td>0.10</td>
<td>0.05</td>
</tr>
<tr>
<td>4</td>
<td>0.10</td>
<td>0.05</td>
<td>0.0</td>
</tr>
<tr>
<td>5</td>
<td>0.05</td>
<td>0.00</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Presented by S. Buchner at SEE Symposium, San Diego, CA, April 2009
LM124 – R1 (Inverter Mode)

Presented by S. Buchner at SEE Symposium, San Diego, CA, April 2009
LM124 – R1 (Inverter Mode)

Presented by S. Buchner at SEE Symposium,
San Diego, CA, April 2009
LM124 – R1 (Inverter Mode)

Presented by S. Buchner at SEE Symposium, San Diego, CA, April 2009
LM124 – R1 (Inverter Mode)

Presented by S. Buchner at SEE Symposium,
San Diego, CA, April 2009
LM124 – R1 (Inverter Mode)

Presented by S. Buchner at SEE Symposium, San Diego, CA, April 2009
LM124 – R1 (Inverter Mode)

Presented by S. Buchner at SEE Symposium, San Diego, CA, April 2009
LM124 – R1 (Inverter Mode)

Presented by S. Buchner at SEE Symposium,
San Diego, CA, April 2009
DIGITAL CMOS CIRCUIT

Test Circuit from Micro-RDC

Presented by S. Buchner at SEE Symposium,
San Diego, CA, April 2009
Digital Test Circuit

- Use pulsed laser to measure transient width

![Diagram of digital test circuit]

180 nm CMOS

Vin=1.8V

Presented by S. Buchner at SEE Symposium, San Diego, CA, April 2009
Digital Test Circuit

\[ R = (\tau_{pw} - T_{s-h}) \cdot f_{clk} \cdot f_{laser} \]

Pulse-width = \( \tau_{pw} = T_{s-h} + \frac{R}{f_{clk} \cdot f_{laser}} \)

Presented by S. Buchner at SEE Symposium, San Diego, CA, April 2009
Test Results

0 KRad, 300 MHz

Transistor Number

Number of Transients in 10 Secs

Input 0

Input 1

Presented by S. Buchner at SEE Symposium,
San Diego, CA, April 2009
Test Results

Presented by S. Buchner at SEE Symposium,
San Diego, CA, April 2009
Presented by S. Buchner at SEE Symposium, San Diego, CA, April 2009
Explanation

Presented by S. Buchner at SEE Symposium,
San Diego, CA, April 2009
Summary

- Exposure of ICs to ionizing radiation alters their electrical parameters and therefore their SET shapes and sensitivities.
- The effect occurs in both CMOS and bipolar circuits.
- Depending on effect, rates may increase or decrease.
- Effect of TID on SET rates should be considered if SETs cannot be tolerated.
- This work is being extended to other ICs such as a phase locked loop and memories.