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

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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.
Introduction

TID concerns arise during proton testing of circuits with small SEU cross-sections

- At 60 MeV, a fluence of $7 \times 10^{11}$ p/cm$^2$ gives a TID of 100 krad(Si).
- For 10% statistics require 100 upsets or $3 \times 10^{11}$ 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)

![Graph showing upset cross-section vs proton energy](image-url)
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

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Introduction – MOS transistors

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

N-channel MOSFET

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LINEAR BIPOLAR CIRCUIT

VOLTAGE COMPARATOR – LM139

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Voltage Comparator – LM139

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

![Comparator Circuit Diagram](image)

![Graph](image)

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LINEAR BIPOLAR CIRCUIT

Operational Amplifier – LM124

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Operational Amplifier – LM124

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

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LM124 – Q9 VF

Amplitude (V)

Time (s)

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LM124 – Q9 VF

Amplitude (V)

Time (s)

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LM124 – Q9 VF

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LM124 – Slew Rate

Slew Rate

Exp. Fit

Slope of Q9

Slew Rate and Slope (V/us)

Total Ionizing Dose [krad(Si)]

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LM124 – R1 (Inverter Mode)

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DIGITAL CMOS CIRCUIT

Test Circuit from Micro-RDC

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Digital Test Circuit

• Use pulsed laser to measure transient width

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Digital Test Circuit

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

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

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Test Results

0 KRad, 300 MHz

Number of Transients in 10 Secs

Transistor Number

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Test Results

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Explanation

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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.