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Cross-Layer Early Reliability Evaluation for the Computing cOntinuum

SEVENTH FRAMEWORK PROGRAMME

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Soft-Error Vulnerability Evolution: A 4D study (bulk/SOI, planar/FinFET)

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RAFES Workshop, Cluj-Napoca (Romania) 28/05/2015

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Objectives

- Analyze trends in raw failure rates of current and future technologies for:
  - Memories (SRAM, DRAM, NVRAM)
  - Logic Gates (AND, OR, NOT, …)
- Provide a sensitivity analysis to operating conditions:
  - Temperature
  - Voltage
  - Location
- Provide a framework for fast characterization

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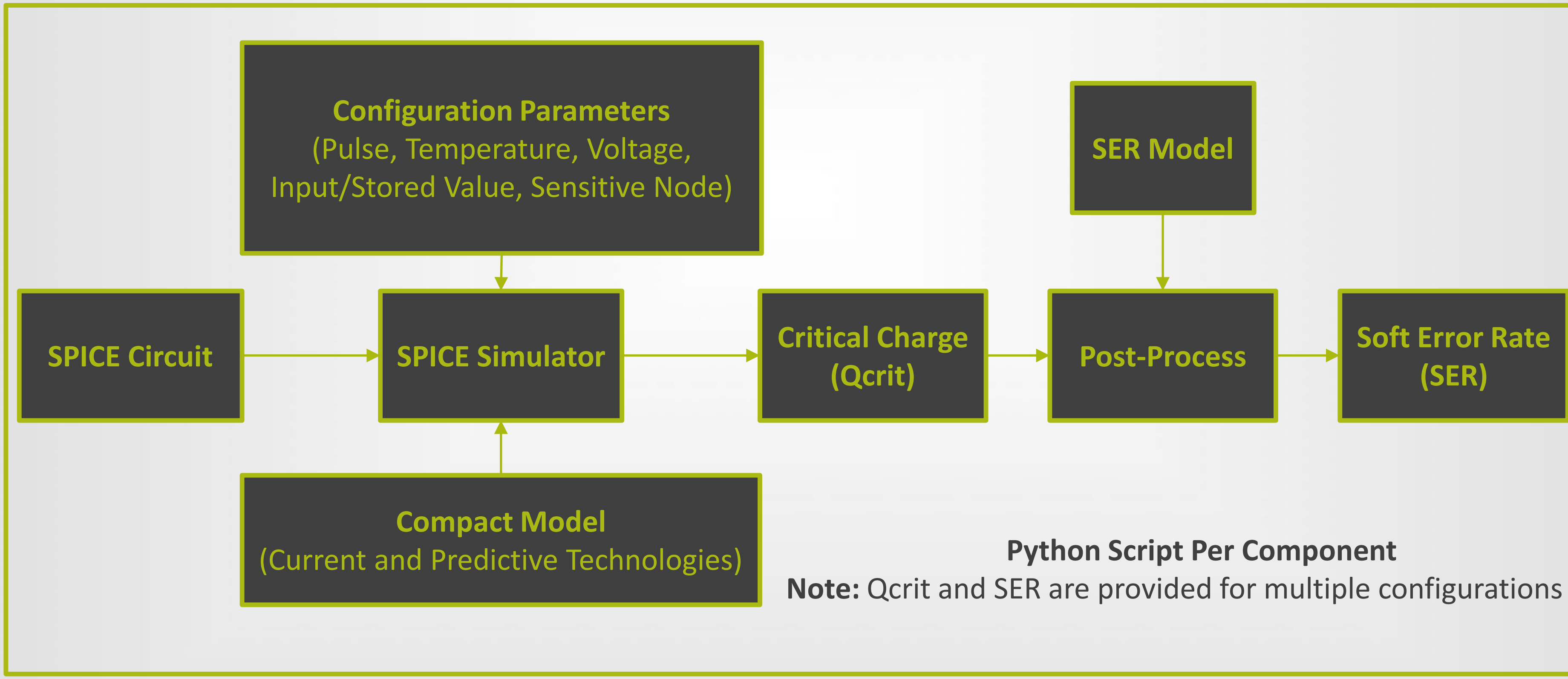
Description - Technologies and Components

Circuits	Technology (CMOS)	Technology Nodes
SRAM Cells 6T/8T/10T	Bulk Planar (ASU PTM Models)	16nm (Bulk Planar)
Flip Flop - D	Bulk FinFET (ASU PTM Models)	22nm (Bulk Planar)
Latch	SOI Planar (UTSOI Model)	14nm (Bulk FinFET)
Logic Gates (AND, OR, NOT…)	SOI FinFET (Ongoing Work)	20nm (Bulk FinFET)
	III-V HEMT (Ongoing Work)	22nm (SOI Planar)

Work Flow - Setup



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Critical Charge (Qcrit)

- Qcrit is the minimum charge needed to cause a bit flip
- Qcrit is computed with HSPICE by injecting a current pulse in the sensitive nodes
- A double exponential pulse is used since HSPICE supports it:

$$I(t) = (Q/(\tau f - \tau r)\,[exp(-t/\,\tau f) \,-\, exp(-t/\tau r)]$$

- Factors that impact Qcrit:
  - Supply Voltage
  - Temperature

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Soft Error Rate (SER) Model

- Once Qcrit is computed it needs to be mapped into a SER expressed in FIT
- The model of Hazucha and Svensson is used:

$$Circuit\ SER = K \cdot\ Flux \cdot\ Area \cdot\ e^{-\frac{Qcrit}{Qs}}$$

Where:

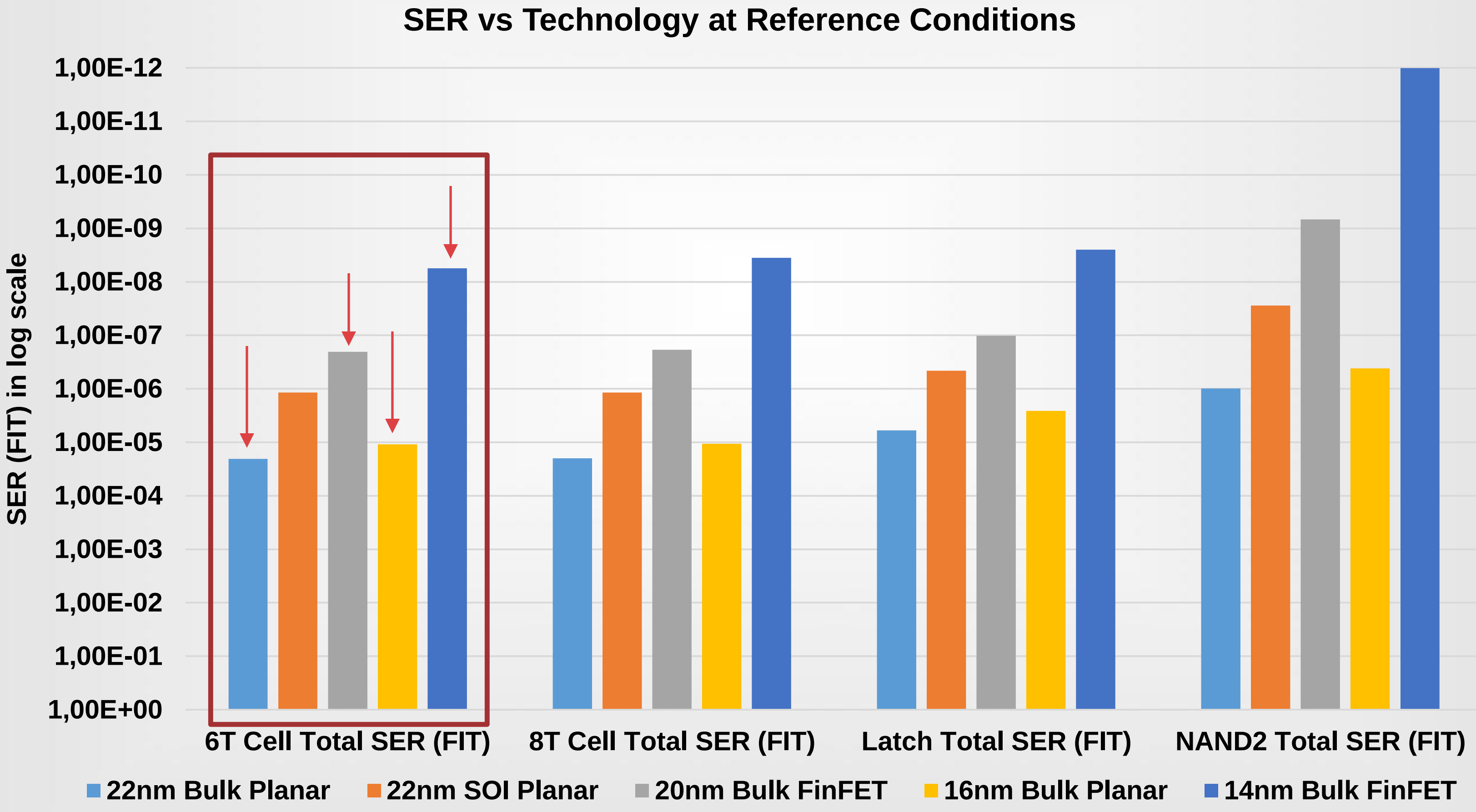
K: Constant (Technology independent parameter)
Flux: Neutron Flux
Area: Sensitive Area to neutron strikes
Qs: Charge Collection Efficiency (Technology dependent parameter)
Qcrit: Critical Charge

- Qcrit and Area can be easily computed but K and Qs are derived empirically
- K is technology independent so the value provided by Hazucha can be used
- Qs scales linearly with the Length Gate (Lg) so we scaled it from experimental data

Results

- We have already obtained SER results for:
  - 6T SRAM Cell
  - 8T SRAM Cell
  - Latch
  - Various logic gates such as the NAND2
- Results include the following comparisons:
  - Technologies
  - Voltages
  - Temperatures
  - Locations

Results: Technology Comparison



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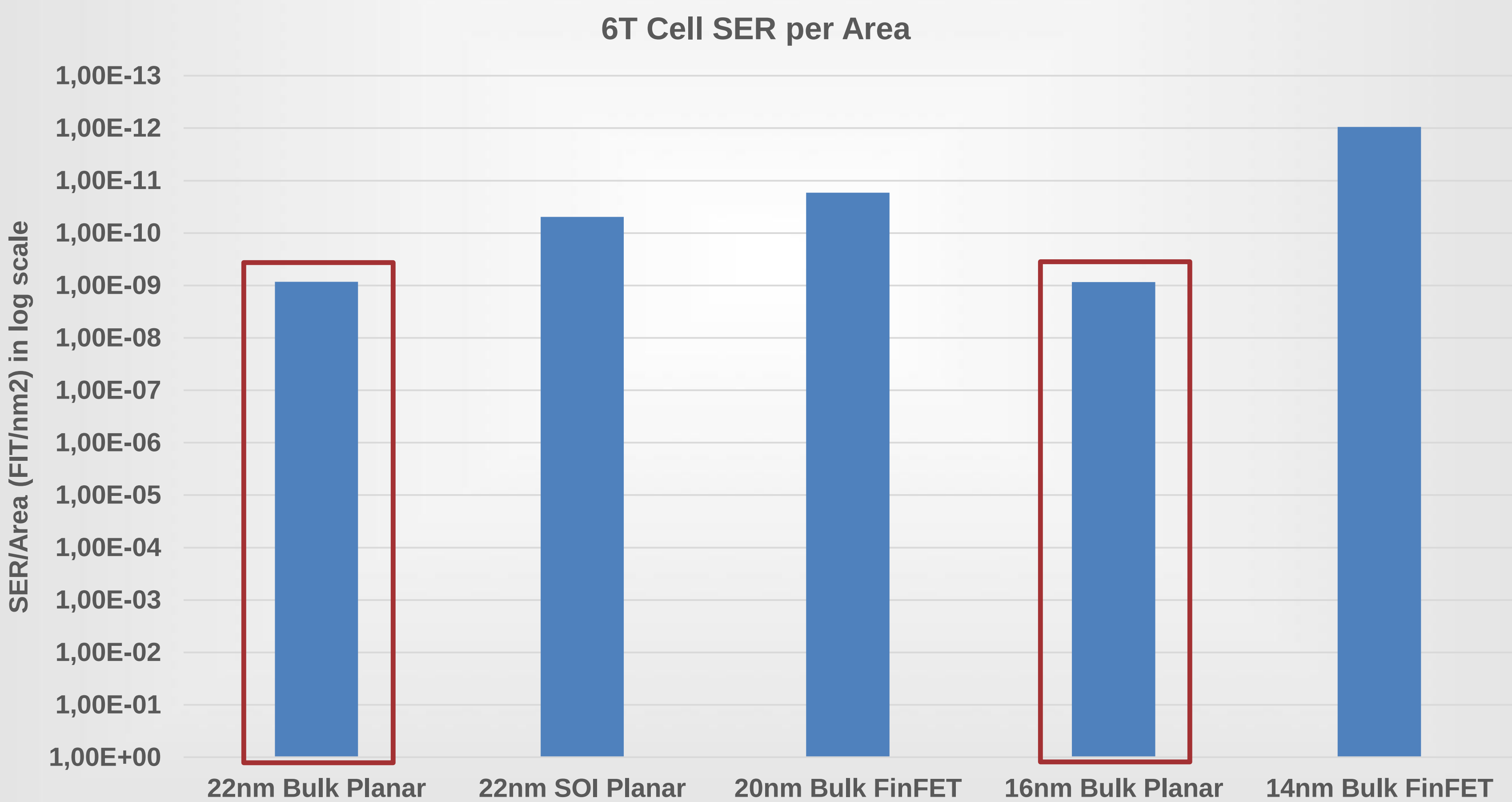
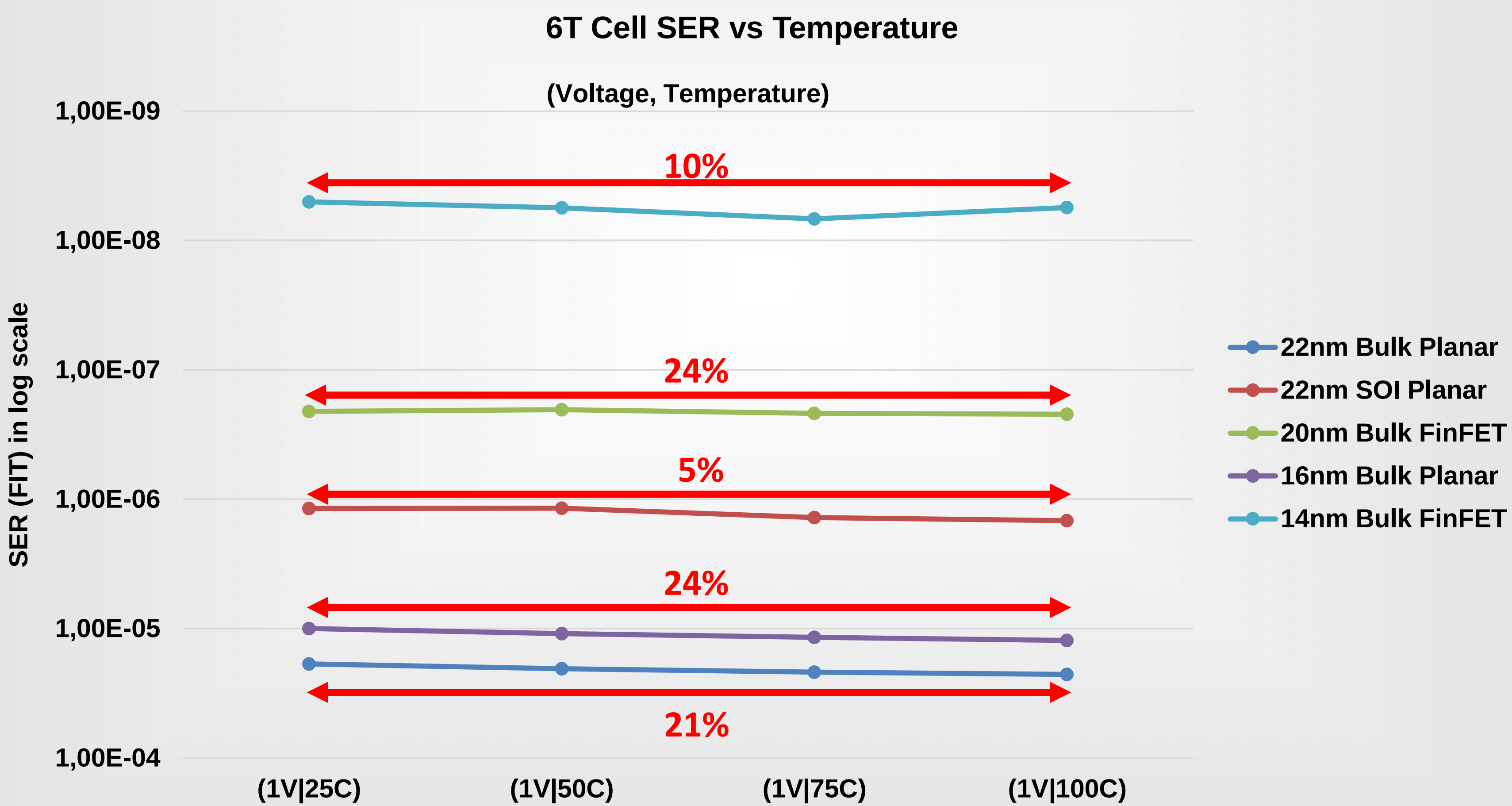
Results: SER per Area



Note: Multi Bit Upsets (MBU) are not included

Results: Temperature Trend



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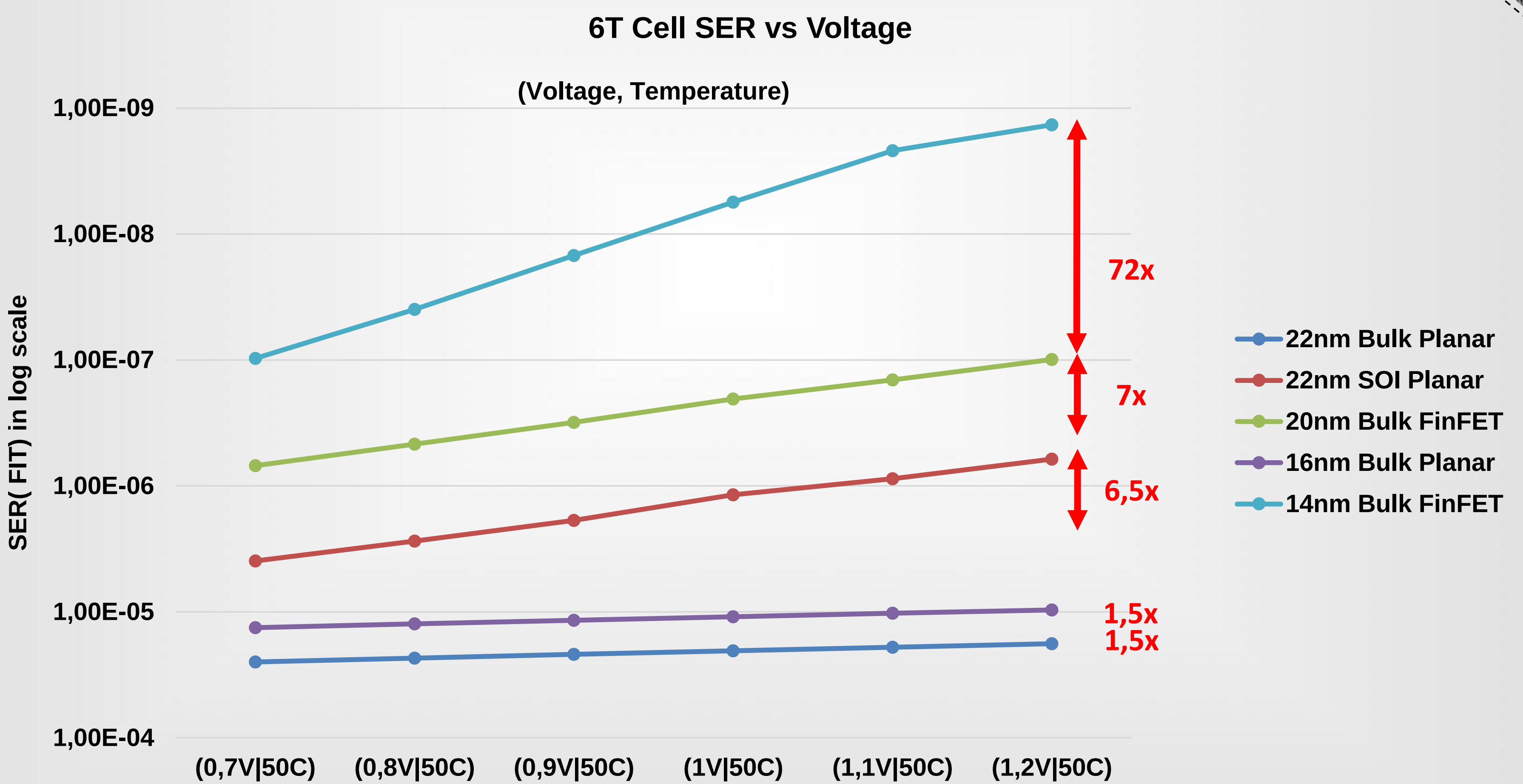
Results: Voltage Trend



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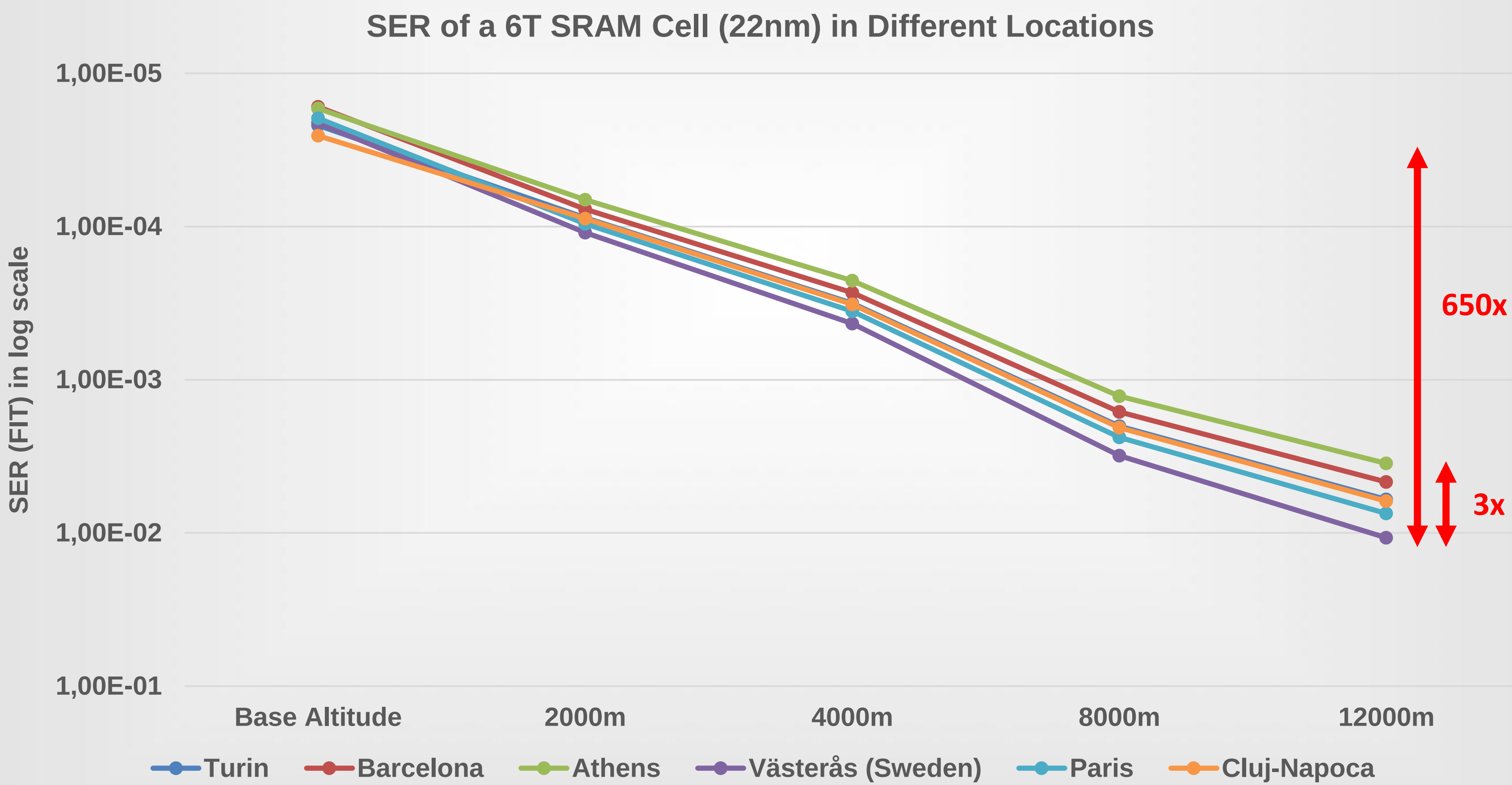
Results: Location Comparison



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Conclusions

- Bulk planar is becoming more vulnerable to soft errors:
  - Lower nodes increases the total SER since more components are introduced
- New technologies and materials can improve the reliability of the device:
  - Bulk FinFET reduces SERs up to 100x
  - SOI Planar reduces SERs up to 20x
- Environmental parameters and location also have a huge impact on SERs:
  - SERs can vary from 1,2x to 70x due temperature and voltage, with a stronger effect in voltage
  - SERs can increase up to 650x due the altitude

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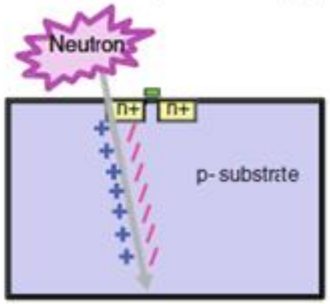
Fundamentals of Radiation Induced Faults (RIF)

- Produced due to Neutrons from the Atmosphere
- When a particle hits a transistor of an electronic device it produces a certain amount of electrical charge
- If the charge is high enough an off transistor may be activated producing different results:
  - **Storage element**: Stored value flipped losing the stored data
  - **Logic gates**: Glitch in the output value producing wrong results
- Neutron particle produces soft errors that are difficult to detect and have a high impact on the reliability of the device

Radiation Induced Fails

Caused by alpha particles (packaging) and neutrons (cosmic rays)



Output Glitches (Bit flips)

Loss of stored data (switching state)

Current Pulses

- Pulses in general have a rapid rise followed by a slow decay
- Figure 1 shows different types of pulses used to compute Qcrit
- Figure 2 shows the pulse width dependence of Qcrit
- Rise and fall times affect Qcrit to the point where each pulse model results in its own Qcrit

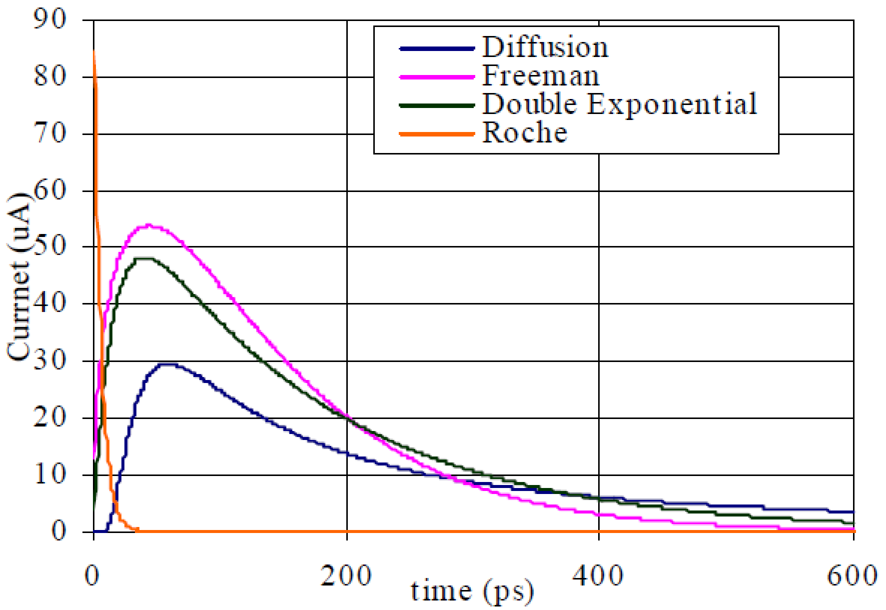


Figure 1: Current Pulse Profiles

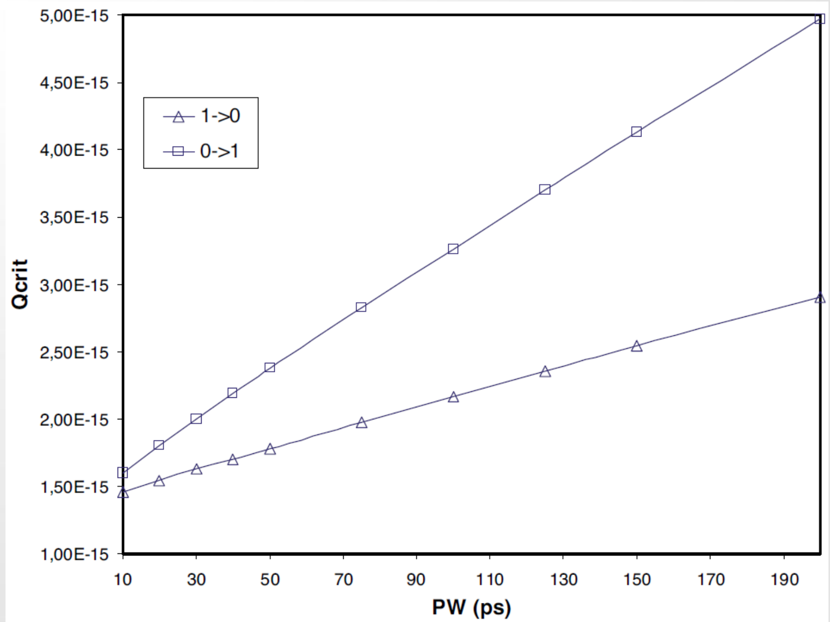


Figure 2: Pulse Width dependence of Qcrit

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Qcrit Computation

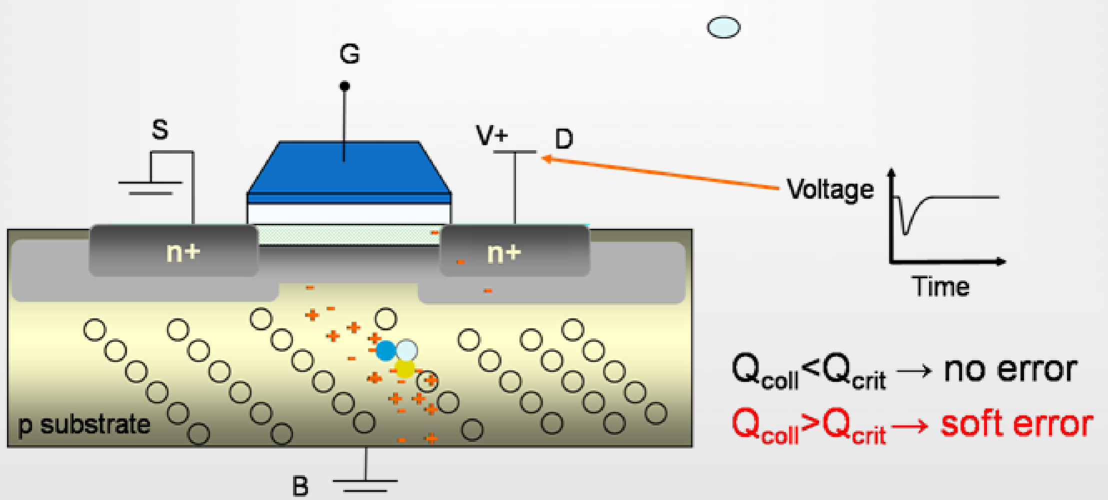
- A double exponential pulse is used since HSPICE only has this type:

$$I(t) = (Q/(\tau f - \tau r)\ [exp(-t/\ \tau f)\ -\ exp(-t/\tau r)]$$

- Multiple Rise time constants used in the literature (2ps, 16ps, 33ps and 90ps) tested
- Multiple Voltages (0,7-1,2V) and Temperatures (25, 50, 75 and 100 Cº) tested
- Pulse width (PW) defined from the start until the pulse decreases an 80% of its maximum which represents the spike of the pulse
- Then Qcrit is computed as the integral of the pulse in that range

Charge Collected (Qcoll/Qs)

- If Charge Collected (Qcoll) by a particle is greater than Qcrit a soft error is produced
- Charge Collection Efficiency (Qs) is the mean of Qcoll in a range of energy particles
- Qs is a parameter dependent of the technology that is usually computed experimentally
- Qs scales approximately linearly with the Length Gate (Lg)
- Qs has been scaled down from experimental data and a technology factor has been applied



Neutron Flux

- Reference neutron flux commonly used is from New York City at sea level
- Neutron flux depends on the location and is mainly affected by two parameters:
  - **Altitude**: Increases exponentially with the altitude
  - **Vertical Cutoff**: Parameter of the magnetic field of the earth
- Neutron Flux can be computed dependent of the location with Gordon's model:

$$F = F_{ref} \ x \ F_{alt}(d) \ x \ F_{BSYD}(Rc, d, I)$$

Where:

F_{ref}: Flux at a reference location (i.e.: Flux of New York City at sea level)
F_{alt}: Function describing the dependence on altitude
F_{BSYD}: Function describing the dependence on geomagnetic location and solar activity

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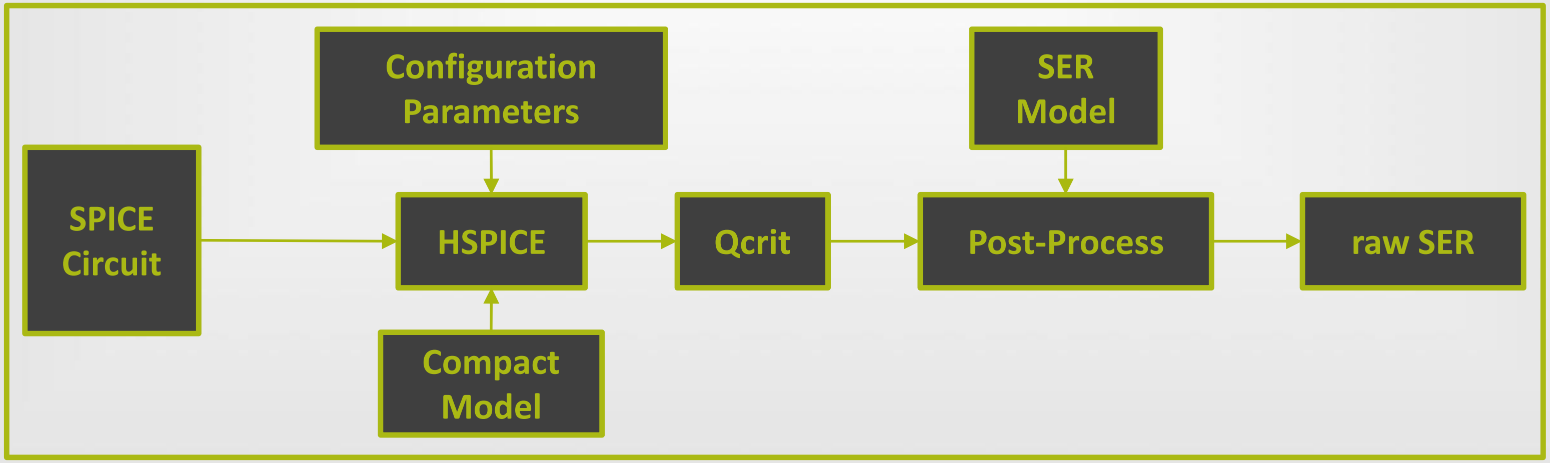
Methodology Summary

- Each script simulates an element with a variety of parameters and technology models
- Inner loop iterates the current injected until a flip or glitch is detected
- Simulations are done with HSPICE
- Charge from a pulse that causes a malfunction is stored and defined as Qcrit
- Each raw SER depends on a combination of environmental parameters



Relative Neutron Flux Comparison