DATE 16
DESIGN, AUTOMATION & TEST IN EUROPE
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A Detailed Methodology to Compute Soft Error Rates in Advanced Technologies

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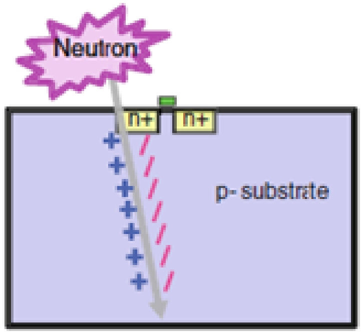
Cross-Layer Early Reliability Evaluation for the Computing cOntinuum
SEVENTH FRAMEWORK PROGRAMME

Introduction

- **Soft errors can be produced due to different types of sources:**
  - **Alpha Particles from packaging**
  - **Neutrons from the Atmosphere**
- **If the charge produced by a particle strike 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**
- **Alpha particles are already well known and can be threaten in different ways by changing the packaging of the chip**
- **Neutron strikes produce 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)

Objectives

- Analyze trends in raw failure rates of current and future technologies for:
  - Memories (SRAM, DRAM, Latch)
  - Logic Gates (AND, OR, NOT, …)

- Provide a sensitivity analysis to operating conditions:
  - Temperature
  - Voltage
  - Location

Outline

- Introduction
- Objectives
- **Technologies and Components**
- **Methodology**
- **Results**
- **Conclusions**

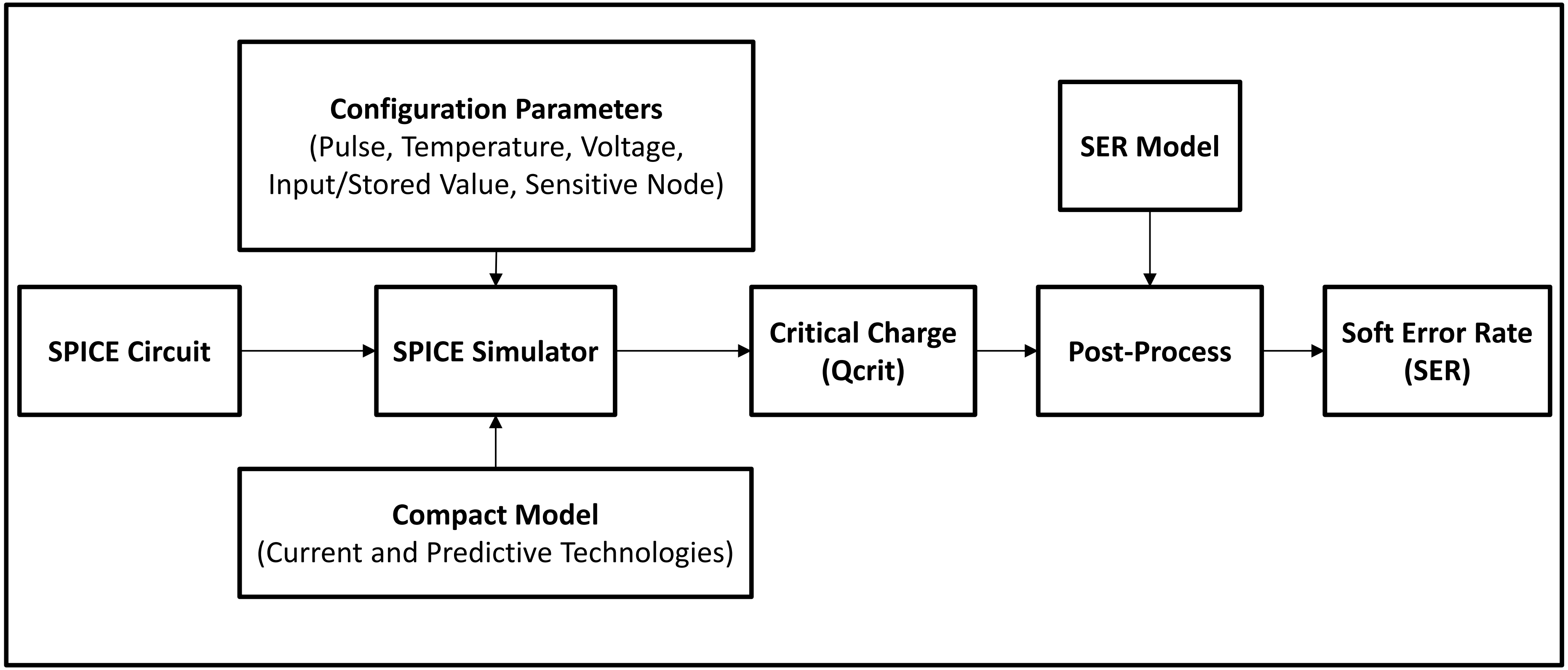
Description - Technologies and Components

Technology (CMOS)	Technology Nodes
Bulk Planar (ASU PTM Models)	22nm and 16nm
Bulk FinFET (ASU PTM Models)	20nm and 14nm
SOI Planar (UTSOI Model)	22nm

X

Circuits
SRAM Cells 6T/8T/10T
Flip Flop - D
Latch
Logic Gates (AND, OR, NOT)

Work Flow - Setup



Configuration Parameters
(Pulse, Temperature, Voltage,
Input/Stored Value, Sensitive Node)

SER Model

SPICE Circuit

SPICE Simulator

Critical Charge
(Qcrit)

Post-Process

Soft Error Rate
(SER)

Compact Model
(Current and Predictive Technologies)

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: 0.7-1.2V tested
  - Temperature: 25, 50, 75 and 100 Cº tested

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:

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

Where:

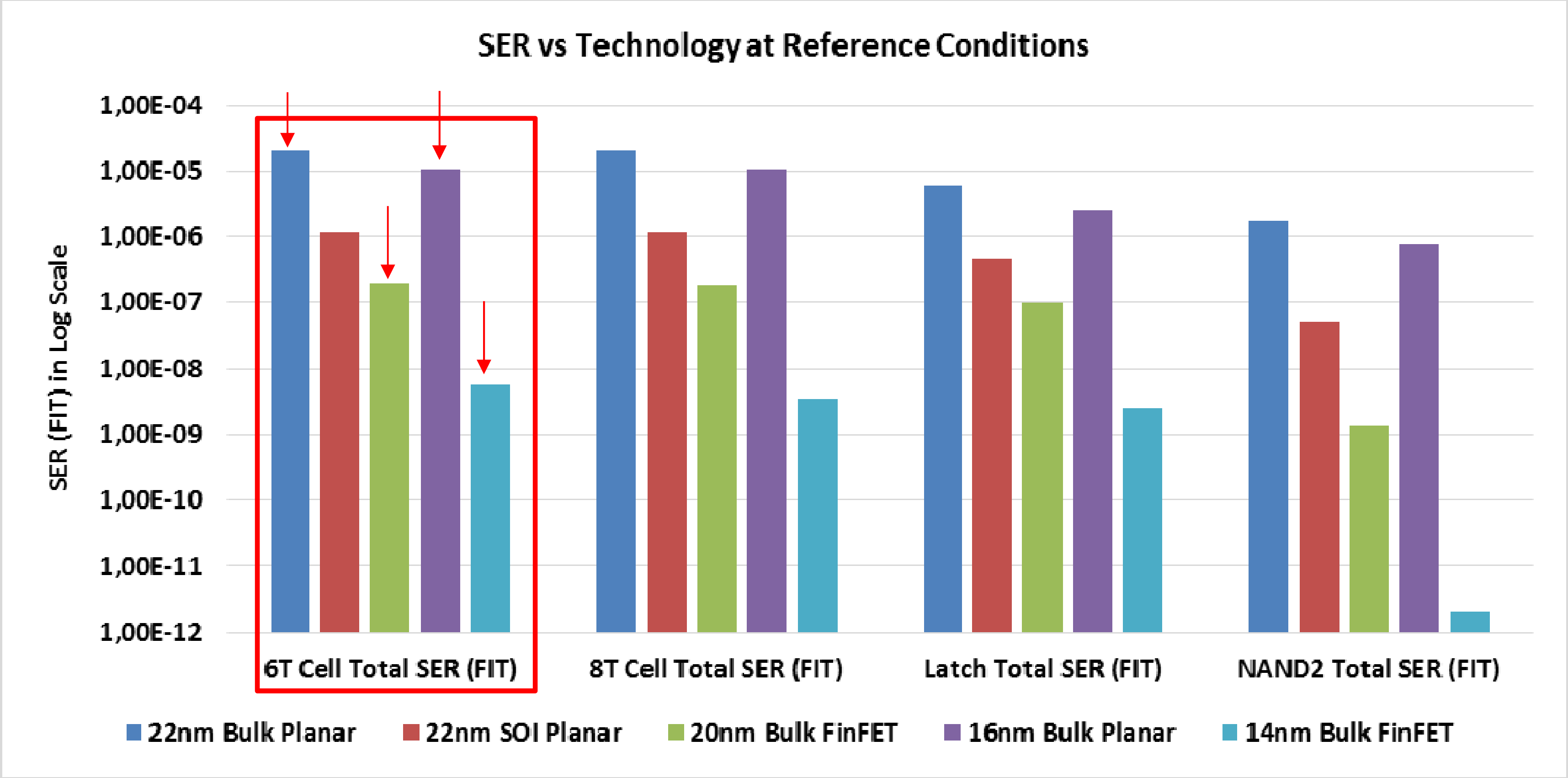
K: Constant (Technology independent parameter)
Flux: Reference Neutron Flux from NYC
Area: Sensitive Area to neutron strikes
Qs: Charge Collection Efficiency (Technology dependent parameter)
Qcrit: Critical Charge

- 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)

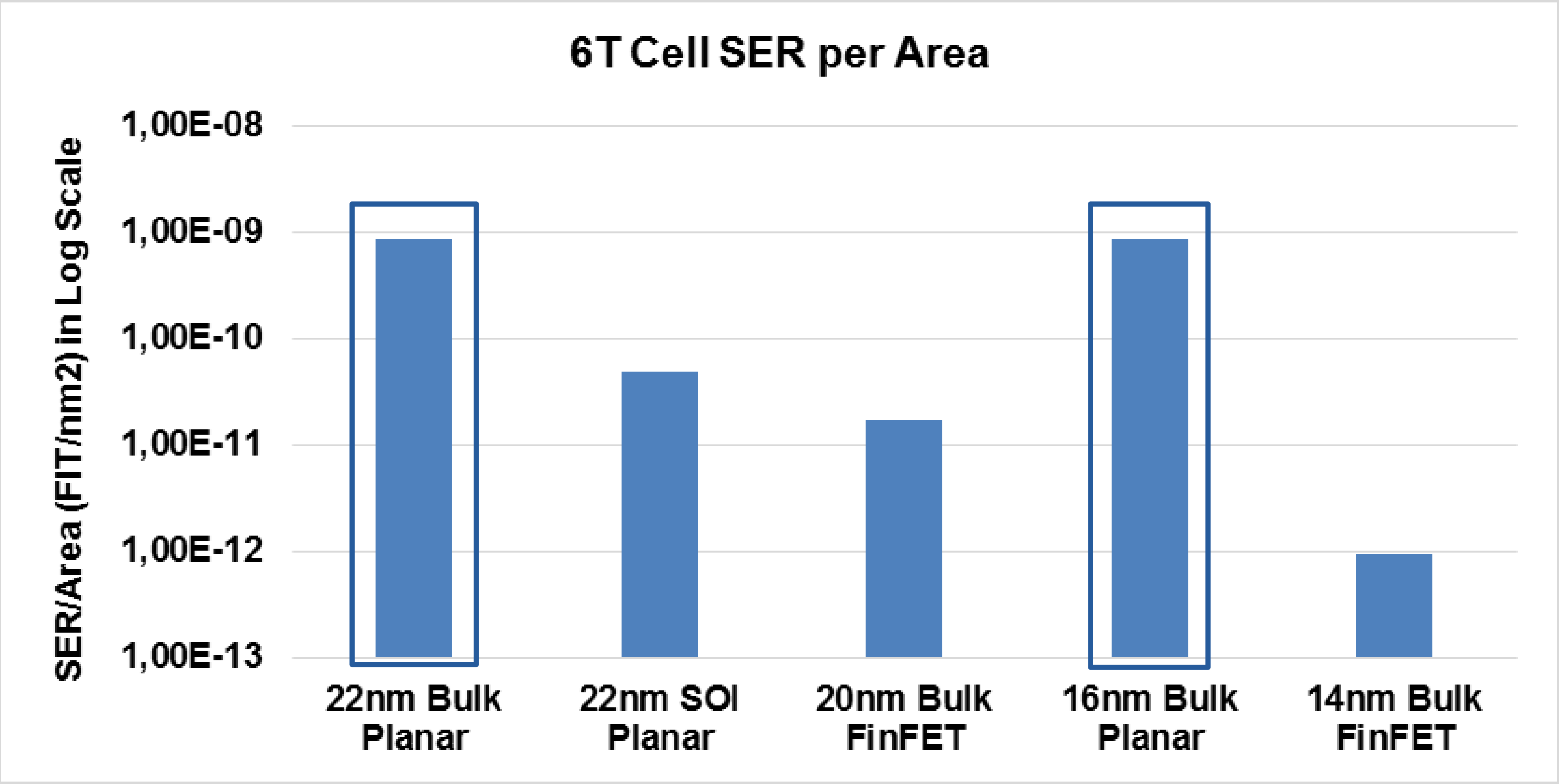
Results

- We have 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

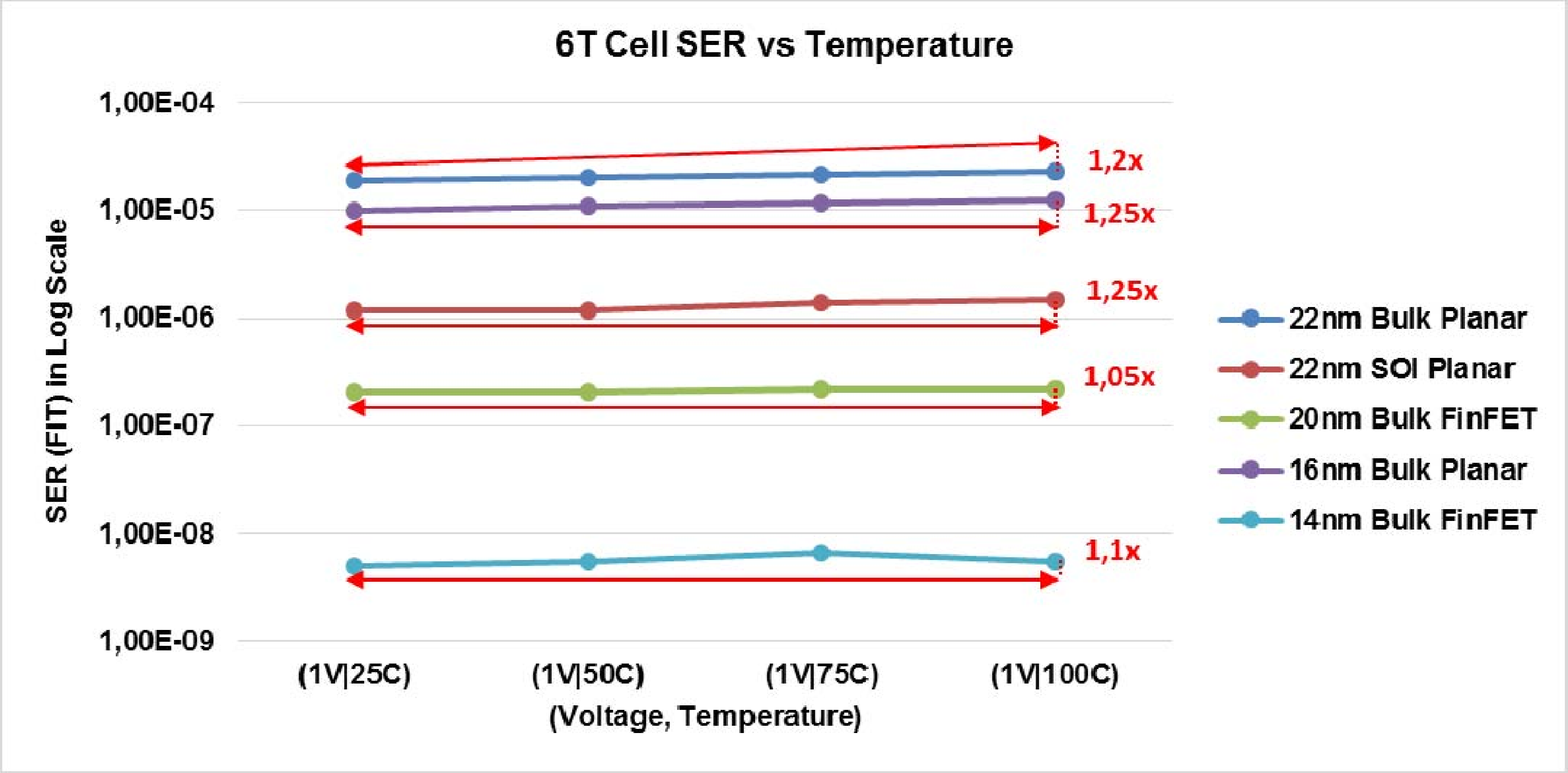
Results: Technology Comparison



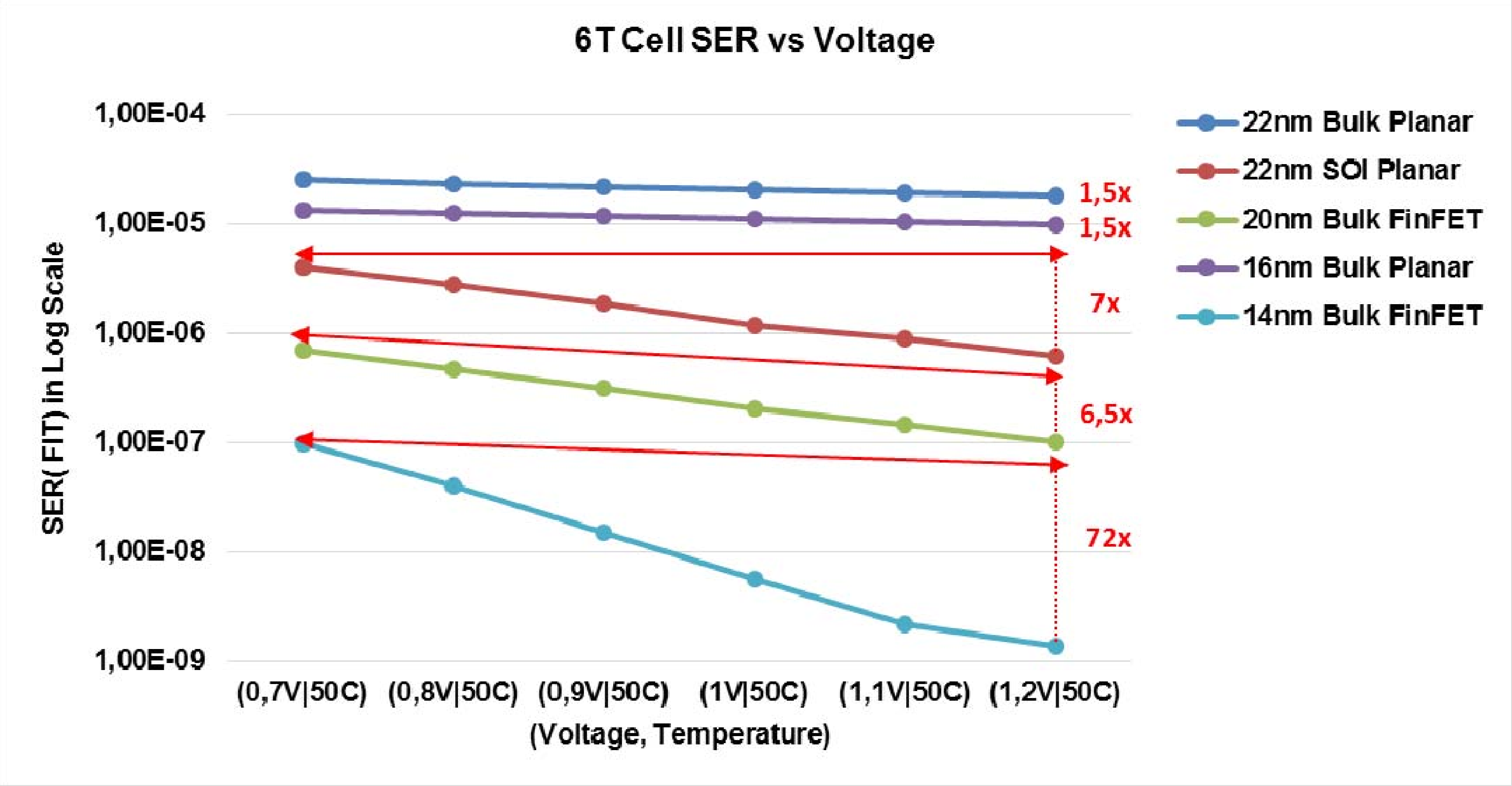
Results: SER per Area



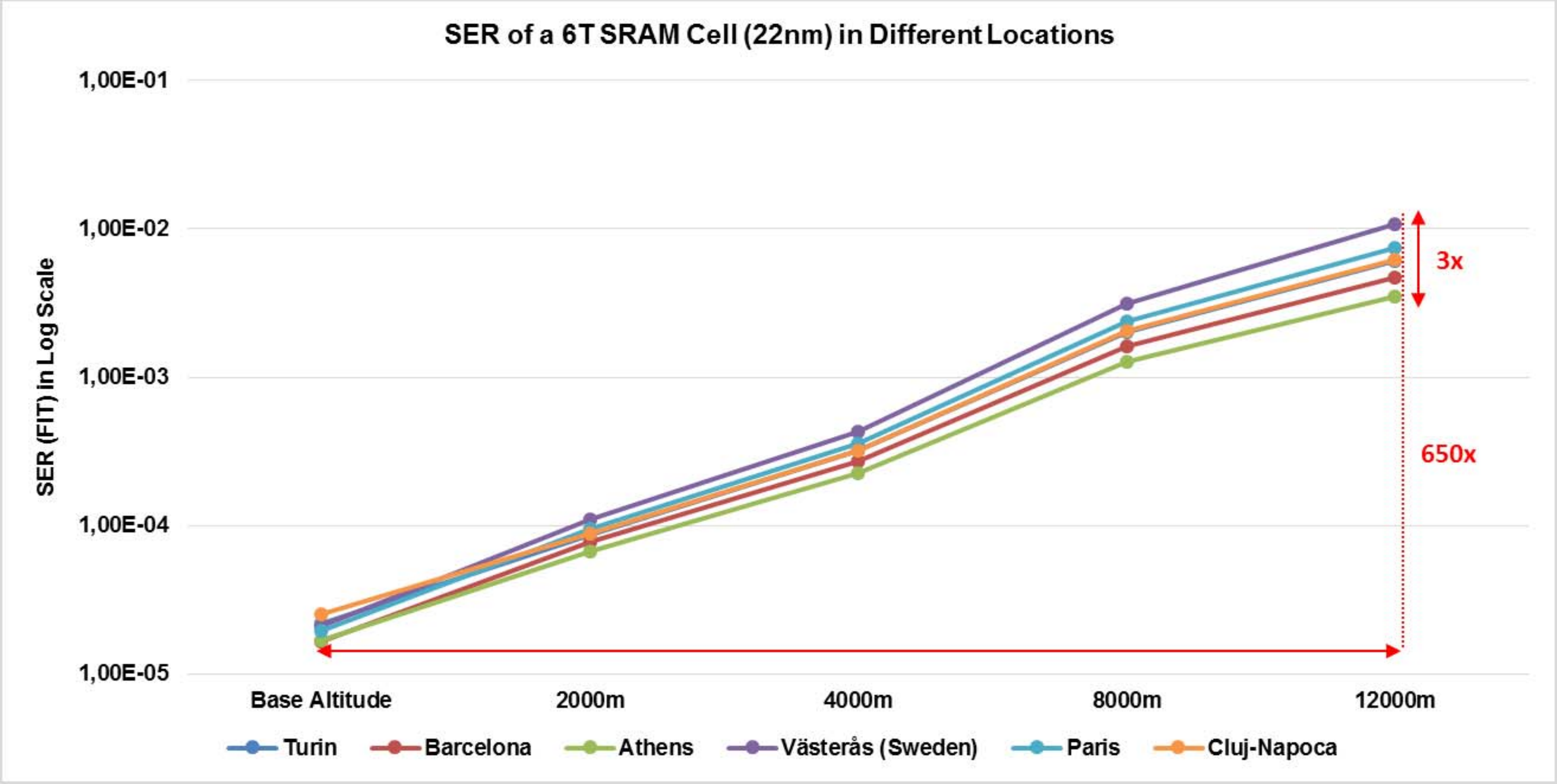
Results: Temperature Trend



Results: Voltage Trend



Results: Location Comparison



Conclusions

- We have managed to model SER FIT for new technologies with a methodology that allows performing a comprehensive comparison
- Our method also allows studying a number of critical parameters
- Our results show that:
  - Bulk planar is becoming more vulnerable to soft errors
  - Bulk FinFET reduces SERs up to 100x
  - SOI Planar reduces SERs up to 20x
  - 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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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**

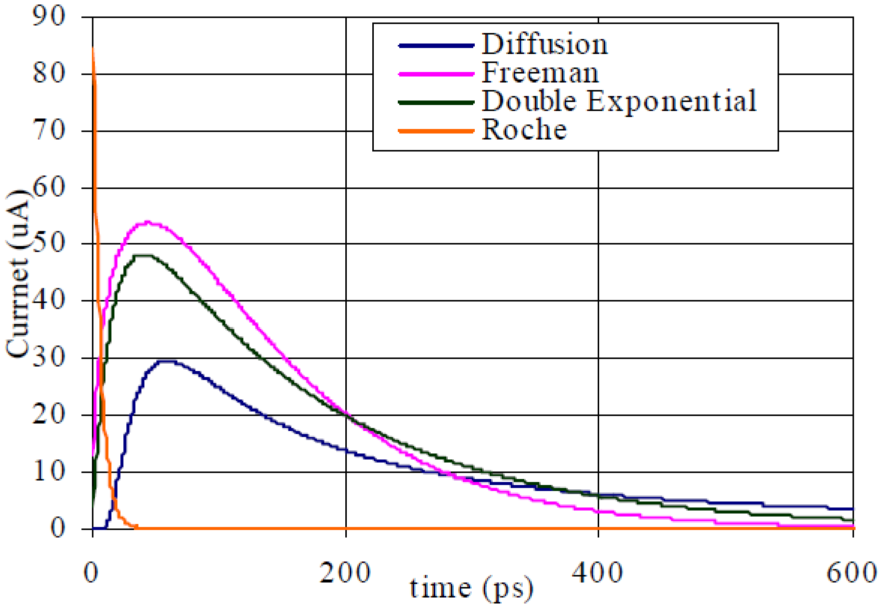


Figure 1: Current Pulse Profiles

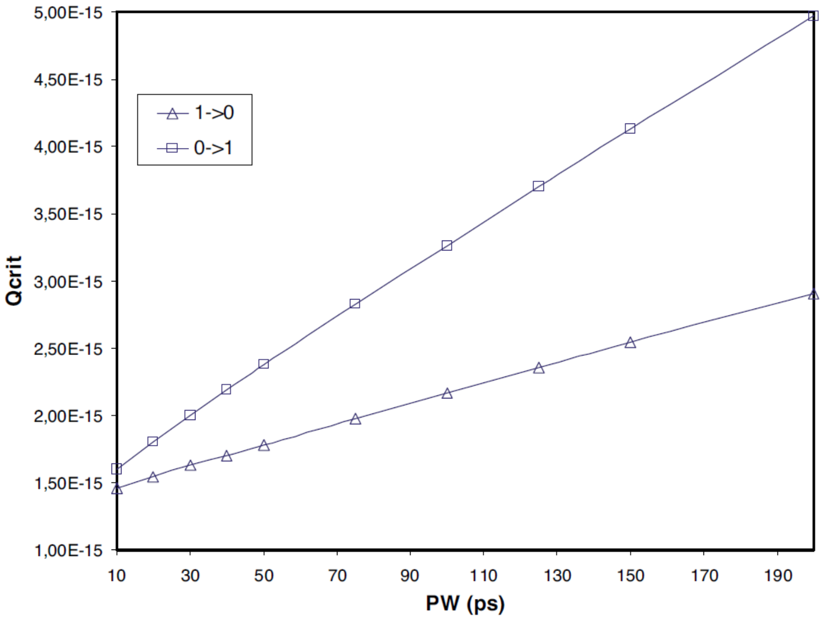
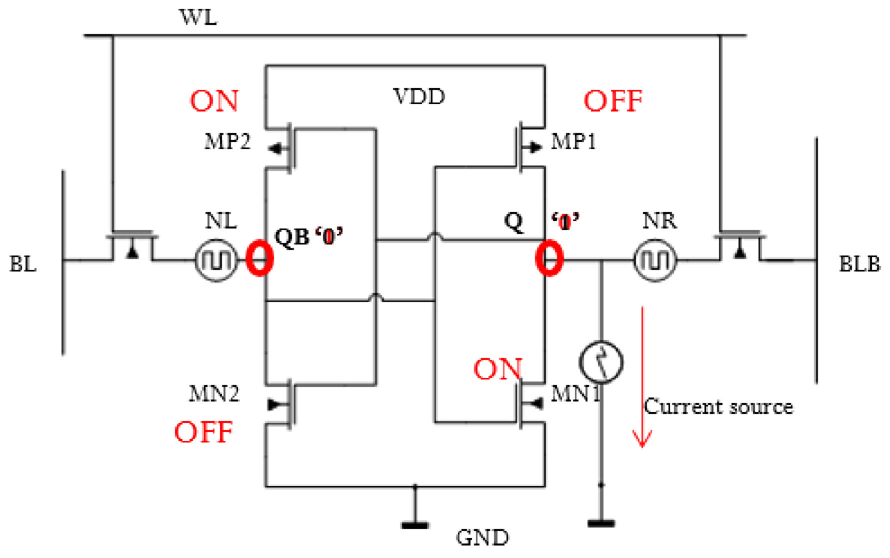
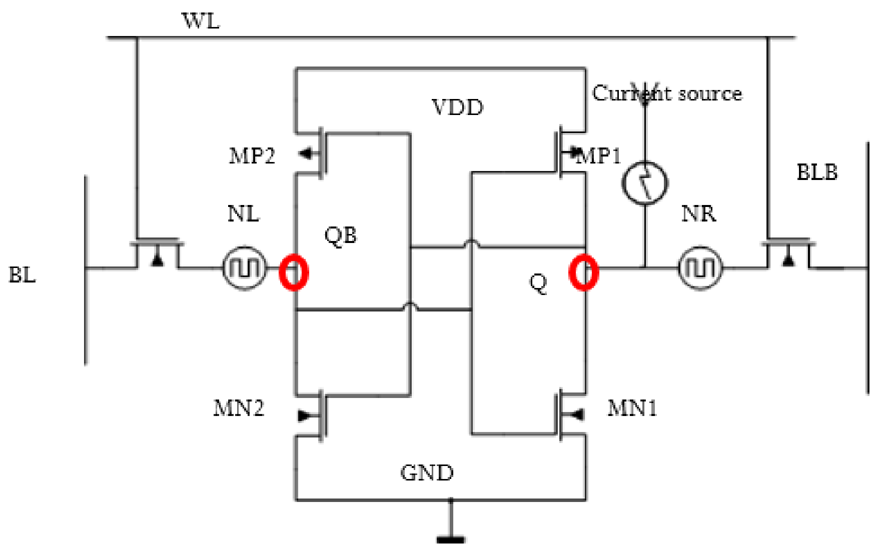


Figure 2: Pulse Width dependence of Qcrit

Soft Error Injection Example



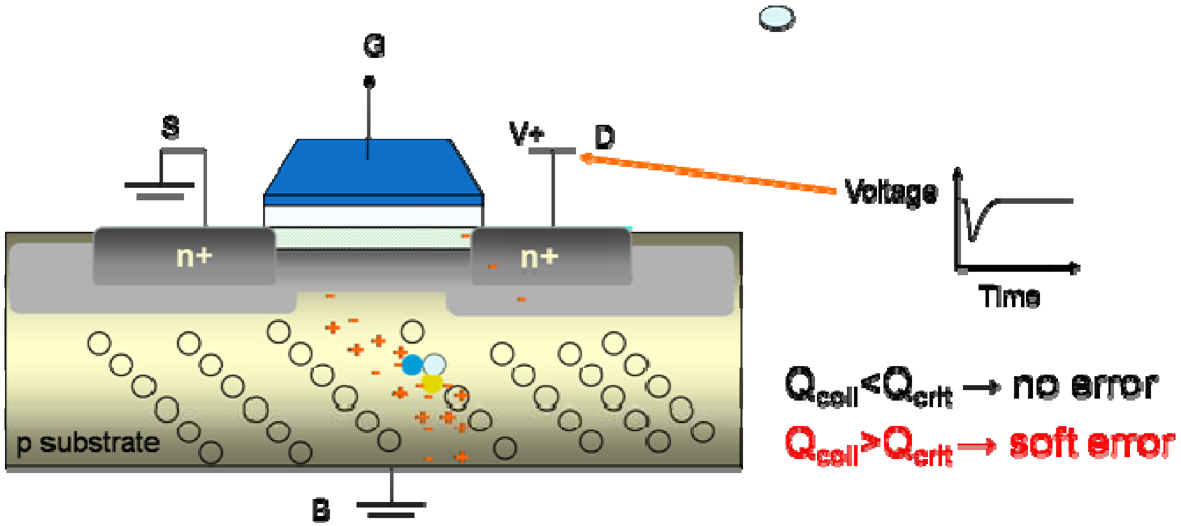
UPSET 1



UPSET 0

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 has been scaled down from experimental data and a technology factor has been applied



$Q_{coll} < Q_{crit}$ → no error

$Q_{coll} > Q_{crit}$ → soft error

Qcrit Computation

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

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

- Multiple Rise time constants used in the literature (2, 16, 33 and 90ps) tested
- Multiple Voltages (0,7-1,2V) and Temperatures (25, 50, 75 and 100 C^{o}) 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

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:

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

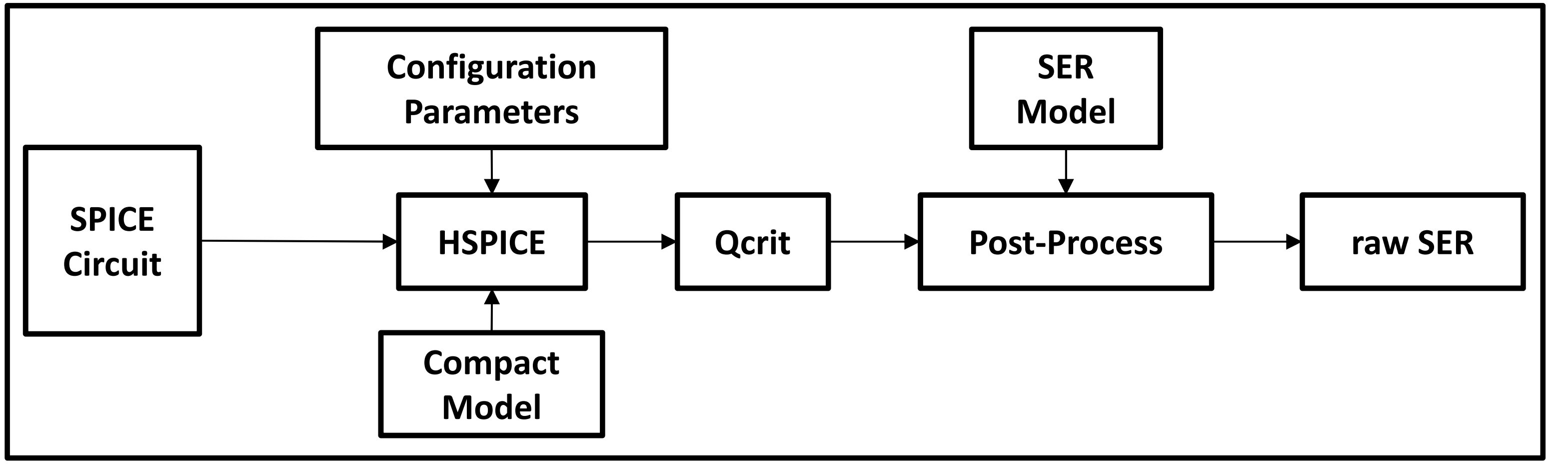
Where:

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

Evaluation Framework Summary

```
For each Technology Do
  For each Voltage Do
    For each Temperature Do
      For each Input or Stored value Do
        For each Sensitive Node Do
         Current=0;
         Flipped=0;
         While not flipped {
           Increase Current Injected;
           Generate SPICE Files;
           Simulate Element in HSPICE;
           Read Simulation Results;
           If Flip Detected {
             Flipped=1;
             Write Results in a CSV;
           }
           Clean Simulation Files;
```

Methodology Summary



Relative Neutron Flux Comparison