Tools to predict Single Event Effects

Soft Error Rate Estimation by Simulation

A Leading Provider of Smart, Connected and Secure Embedded Control Solutions

Aerospace and Defense
David Truyen - Technology Hardening Team

13rd December 2022

SMART | CONNECTED | SECURE

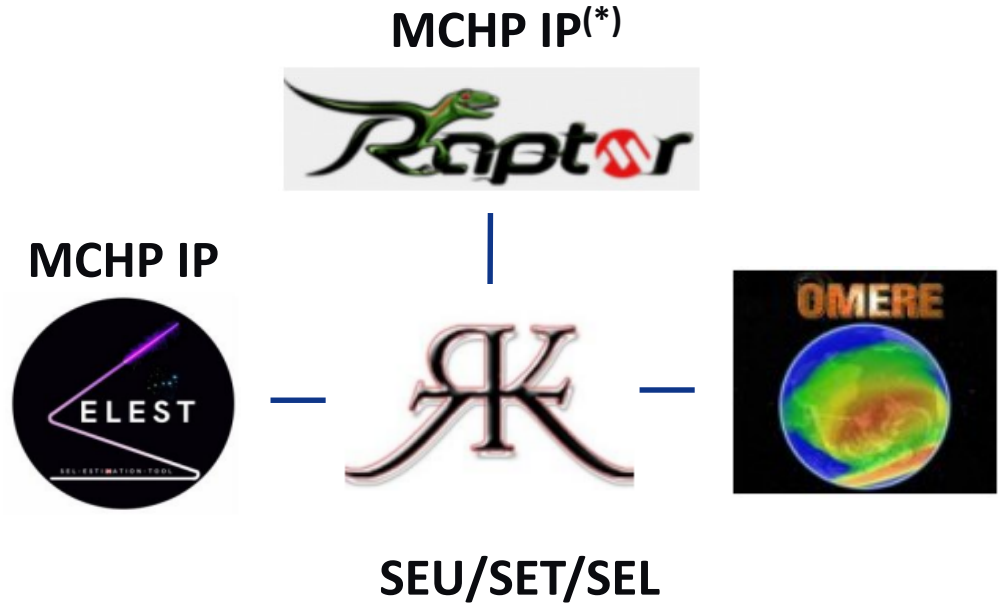
Introduction

Objectives

- **Soft & hard Errors caused by radiations is a major concern for electronic components**
- **The Technology Hardening team developed methodologies and tools to predict the radiation sensitivity of the products and provide mitigation guidelines**
  - Evaluate technologies
  - Evaluate the operational risk of the cells & circuit before testing
  - Improve the reliability and efficiency of the devices (std cells)
  - Evaluate full custom IPs, clock/reset trees
  - Highlight critical parameters (process, design) and propose hardening solution

Radiation Tool Kit (RTK)

- **Suite of software tool dedicated to SEL/SEU/SET radiation effects**
  - **TCAD 2D** and **3D** simulator by Synopsys
  - **RAPTOR** for SEU/SET Simulations
  - **SELEST** for SEL simulations
  - **OMERE** for SER calculation



- **RTK does not address SEFI**
  - Design & Application dependent
- **… and TID ?**
  - Not yet available, but the feasibility of a TID predictive tool is in progress

(*) RAPTOR is a MCHP tool co-developed with the ONERA (include the code MUSCA)

SEL Prediction by Simulation

SEL EStimation Tool

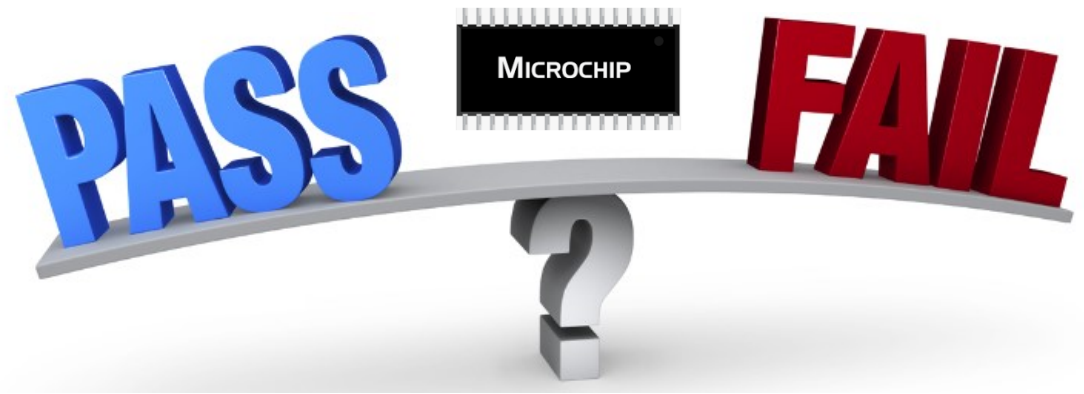
Co-funded by the CNES

Aerospace & Defense Group

MICROCHIP

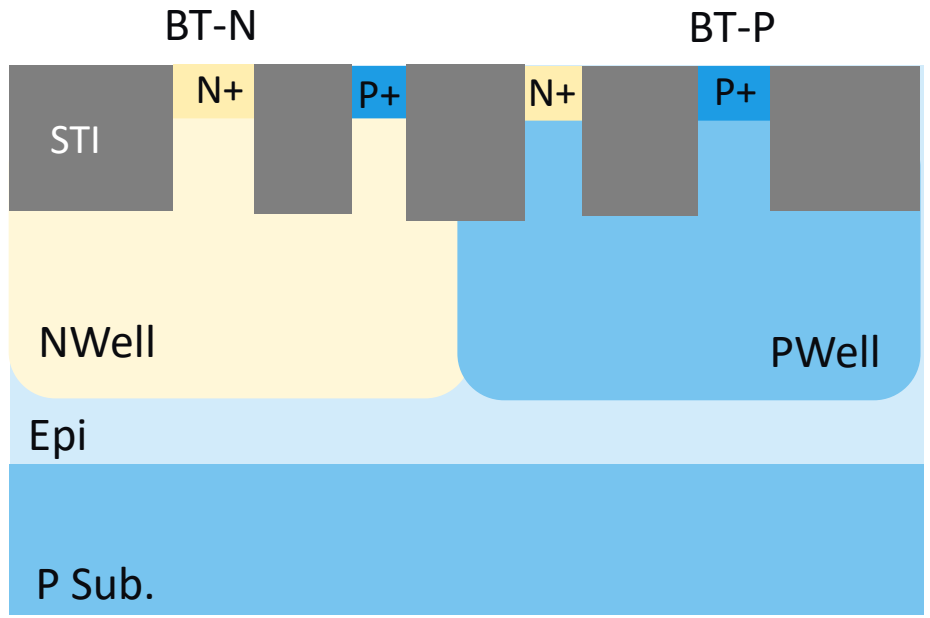
SELEST – Goal

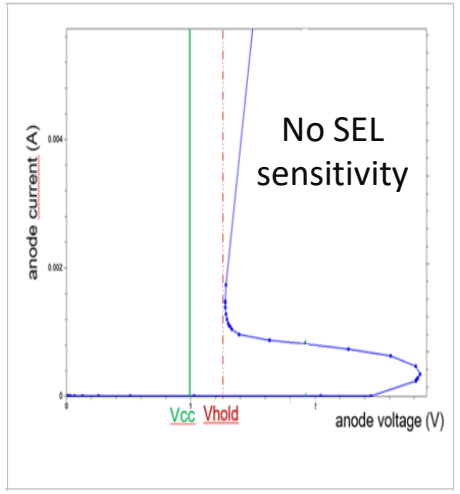
- **Assistant tool to select commercial components able to address the new-space market**
- **Estimate the SEL sensitivity of the products before performing tests with a tradeoff between time & accuracy**
- **Provide hardening solutions against SEL**

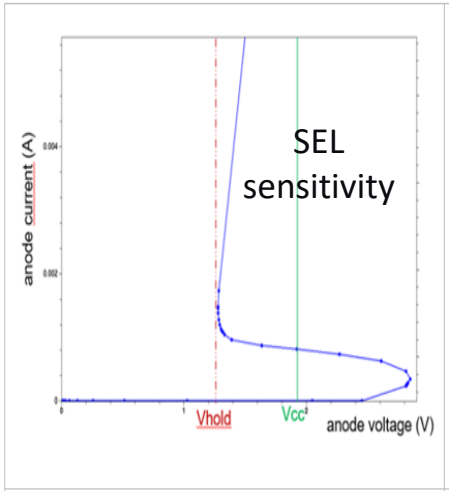


SELEST – Strategy

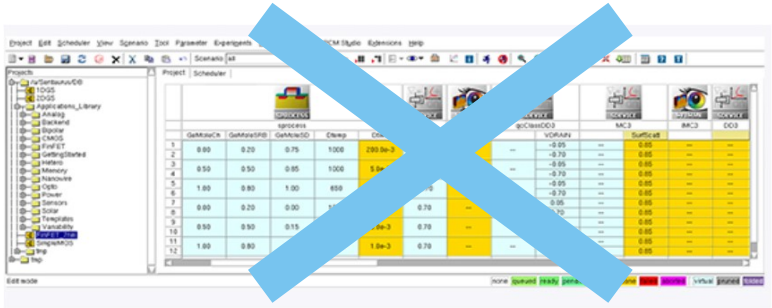
- Define an analytical model based on TCAD simulation
- Define the SEL sensitivity by estimating the $P(V_{hold}) > V_{CC}$
- Develop analytical prediction models per technologies
- Include hardening by process parameters
- Model the effect of the temperature and power supply







Technical challenges



- **Run a huge number of simulations (> 20 000) with an acceptable time frame**
  - Run simulations by scripts instead of Interactive mode
- **Extract and analyze a huge number of TCAD results**
  - Classify the different simulation status
  - Relaunch failed simulations and update of the *output* file with new results
- **Consolidate the results**
  - Initiate dedicated TCAD studies to classify some ambiguous results
  - Check of incomplete simulations
- **Development of the model**
  - Identify the PASS-FAIL cases
  - Create a classification model by using JMP and/or Neural designer tools…
  - Optimization of the model (neural, DOE analysis, …)
  - Include the experimental results
- **Development of a GUI interface**

Design of Experiment of TCAD Simulations

Inputs and values

- **Inputs**
  - **Process**: consider the doping profiles, resistivities, Epi, Bulk,…
  - **Topology**: consider spacings, widths, based on DRC rules of the technology
  - **Electrical**: range of the power supply Vs technology (min, max, typical)
  - **Temperature** : $85°C \leq T \leq 125°C$
- **Some figures about the DoE:**
  - **Number of cases**: **~20k cases** per technology
  - **Duration of TCAD simulations**: 3min/simu => **~6 weeks** non-stop

Analysis & Consolidation of TCAD Results

- **Classification of Status**

Status	Comment
LATCHUP_DETECTED	Vhold, Vtrig extracted
NO_LATCHUP	No Vhold, Vtrig (NA)
DOUBLE_S_DETECTED MULTIPLE_S_DETECTED	Vhold, Vtrig, Vhold_reverse, Vtrig_reverse, extracted
SDE_LICENSE_ERROR SNMESH_LICENSE_ERROR SDEVICE_LICENSE_ERROR	Could not get a license. Jumped to next experiment simulation.
NO_MESH_FILE	sde or snmesh failed
SDEVICE_FAILURE	sdevice failed (no convergence)
NO_PLOT_FILE	No plot file found
INCOMPLETE_SIMULATION	Neither max_vstress nor max_istress were reached in plot file (convergence problem)
HIGH_CURRENT_AT_VDD	High anode current at VDD
NEED_CHECK	Plot analysis found an incoherence
KO	Plot analysis could not conclude
GOT_NO_STATUS	Something went wrong in flow, but what ?

13/0 Cols

	BulkRes	DBodyTieN	DBodyTieP	Spacing_AC	STI_SAC	Temperature	Vdd	Vtrig	Vhold	Vtrig_reverse	Vhold_reverse	Status	Status_SEL
	15	30	30	15	2.5	125	1.32	7.81	7.39	1.92	7.61	LATCHUP_DETECTED	0
										1.92		DOUBLE_S_DETECTED	1
										1.93		NO_LATCHUP	
										1.95		SDEVICE_FAILURE	
										1.96		INCOMPLETE_SIMULATION	
	3	0.1	0.1	0.12	0.32	85	1	1.74	0.9	2 241 others	1.17	MULTIPLE_S_DETECTED	
58	3	0.1	0.1	5	1	105	1	•	•	•	•	SDEVICE_FAILURE	1
59	3	0.1	0.1	10	1	105	1	•	•	•	•	NO_LATCHUP	1
60	3	0.1	0.1	15	1	105	1	•	•	•	•	NO_LATCHUP	1
61	3	0.1	0.1	0.12	1	105	1.1	2.516	2.51	•	•	LATCHUP_DETECTED	1
62	3	0.1	0.1	0.3	1	105	1.1	2.639	2.57	•	•	LATCHUP_DETECTED	1
63	3	0.1	0.1	1	1	105	1.1	2.865	2.77	•	•	LATCHUP_DETECTED	1
64	3	0.1	0.1	5	1	105	1.1	5.429	5.00	•	•	LATCHUP_DETECTED	1
65	3	0.1	0.1	10	1	105	1.1	•	•	•	•	NO_LATCHUP	1
66	3	0.1	0.1	15	1	105	1.1	•	•	•	•	NO_LATCHUP	1
67	3	0.1	0.1	0.12	1	105	1.32	2.770	2.72	•	•	LATCHUP_DETECTED	1

- **Identification of errors**
  - 15 type of errors have been classified
  - 900 simulations have been relaunched (convergence issues)
- **Consolidation of the results**
- **For the 65nm technology, the full 27864 simulations have been considered to define the prediction models**

Development of the Model - Epi

- **Model PASS/FAIL for EPI process**

Model NTanH(9)

Training

SEL P/F

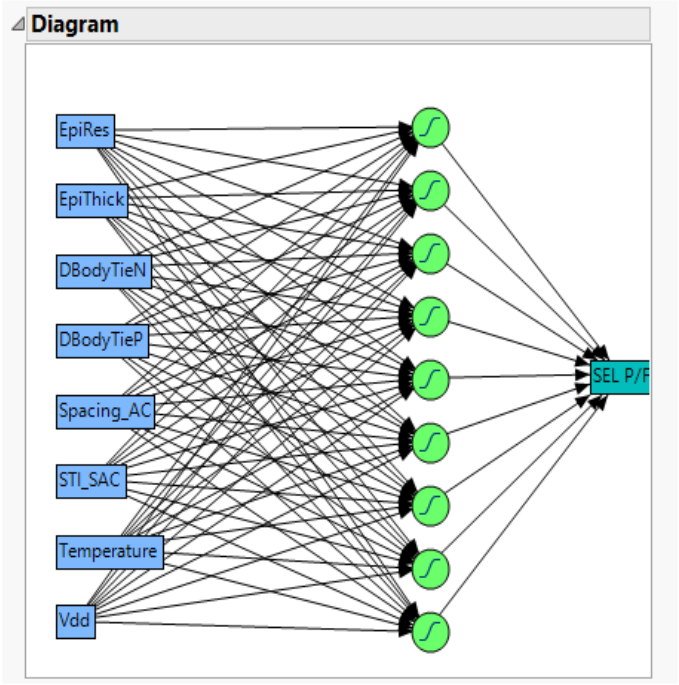
Measures	Value
Generalized RSquare	0.9823804
Entropy RSquare	0.9796418
RASE	0.0257404
Mean Abs Dev	0.002455
Misclassification Rate	0.0008333
-LogLikelihood	31.651364
Sum Freq	10800

Confusion Matrix

Actual	Predicted Count
SEL P/F	
0	
1	

Confusion Rates

Actual	Predicted Rate
SEL P/F	
0	
1	



FAIL - Latchup: $V_{hold} < Vcc$

PASS - No latchup: $V_{hold} > Vcc$

SEL : 5 erroneous predictions on 353 cases (error of 1.4%)

No SEL: 4 erroneous predictions on 10447 cases (error < 0.1%)

Validation of the Models

- **Selest Vs Experiments**

Technology	Node (nm)	Product	Manufacturer	Manuf. Location	Device	Supply (V)	Temperature (°C)	Exp LETth (MeV.cm²/mg)	SEL Prediction by SELEST	
CMOS	65	Product 1	Manuf. 1	Fab1	SRAM	1.26	125	**< 16**	Model Bulk 65nm LV	**SEL**
CMOS	65	Product 2	Manuf. 1	Fab1	SRAM	1.26	125	**< 16**		**SEL**
CMOS	65	Product 3	Manuf. 1	Fab1	Std cells	1.26	125	**> 65**		**No SEL**
CMOS	65	Product 4	Manuf. 1	Fab1	Std cells	1.40	125	**> 62**		**no SEL**
CMOS	65	Product 5	Manuf. 1	Fab1	Std cells	1.30	125	**> 62**		**No SEL**
CMOS	65	Product 6	Manuf. 1	Fab1	SRAM	1.00	125	**> 62**		**No SEL**
CMOS	65	Product 7	Manuf. 2	Fab2	SRAM	1.32	125	**TBD**		**SEL**
CMOS	65	Product 7	Manuf. 2	Fab2	Std cells	1.32	125	**TBD**		**SEL**

Good correlation between Estimations and experiments

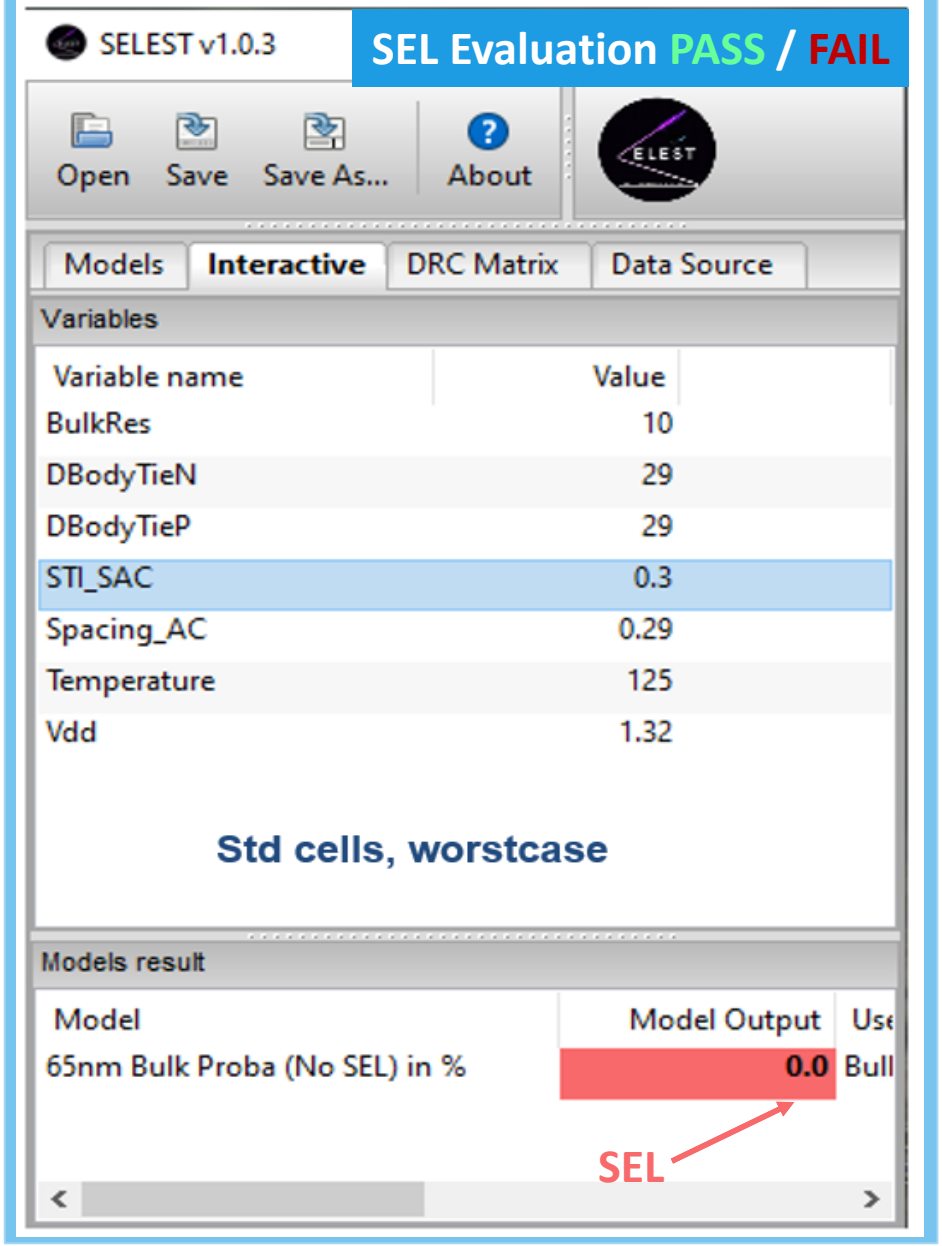
Criteria: LET_{th} > 60 MeV.cm²/mg → No SEL

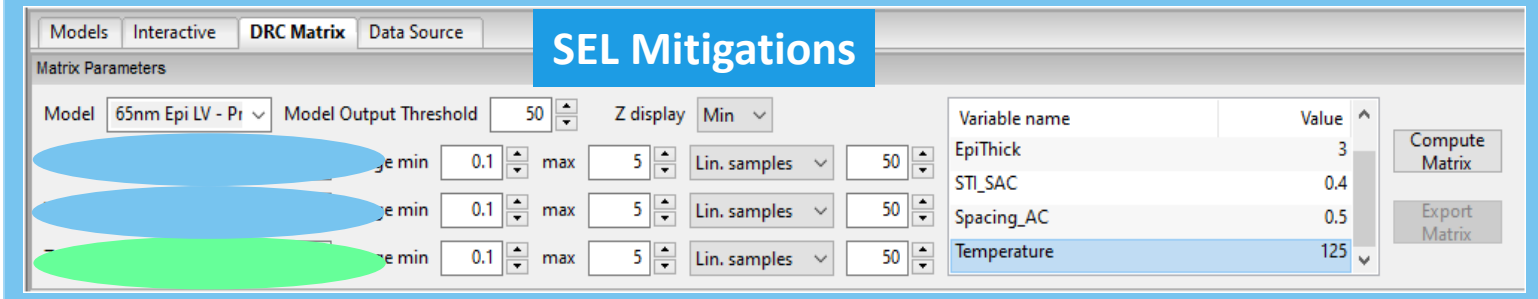
Pending experimental results of 65nm Epi process

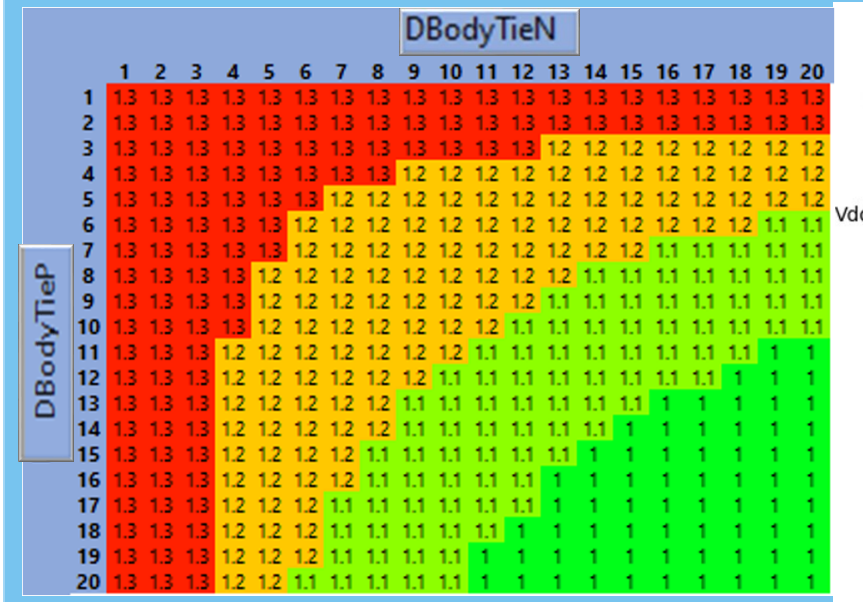
Aerospace & Defense Group

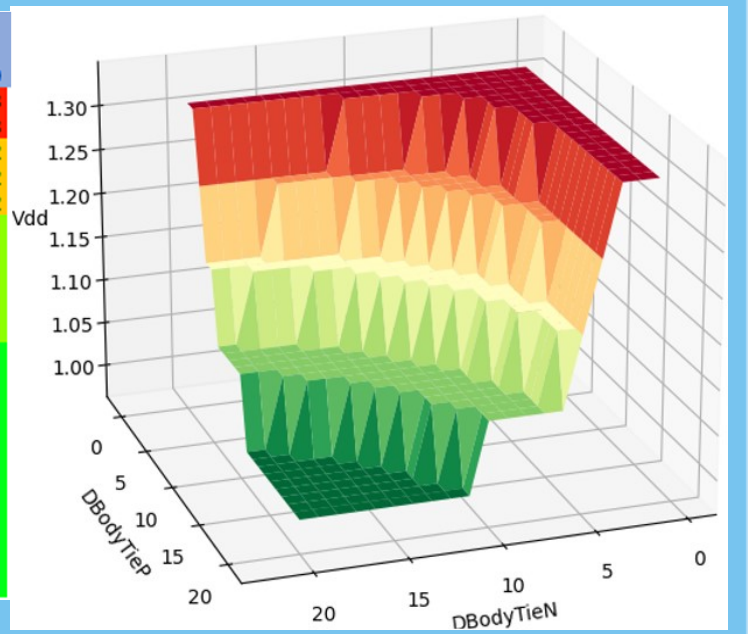
MICROCHIP

Development of a Graphical Interface









Example of Mitigation : Voltage derating Vs distance of body-ties

Aerospace & Defense Group
MICROCHIP

Thank you for your attention

Questions ??

Aerospace &
Defense Group

MICROCHIP

BACKUP

Aerospace &
Defense Group

MICROCHIP

Prospects

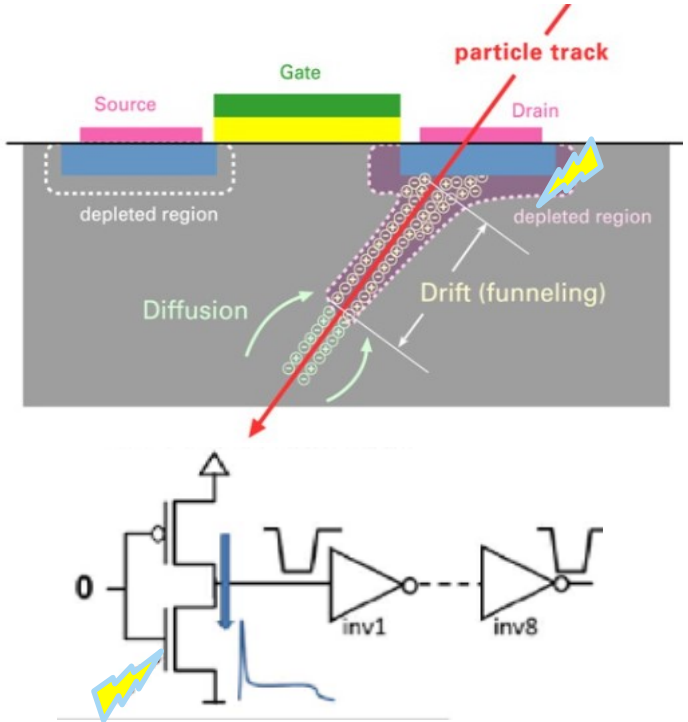
- **Development of next models :**
  - 180nm
  - 150nm SOI
  - 130nm
  - 110 nm (in progress)
  - 90nm
  - 28nm
  - 12nm FinFet

Single Event Effects

- **SEE are radiation induced errors due to a *single particle* (protons, heavy ions, neutrons, Alpha)**

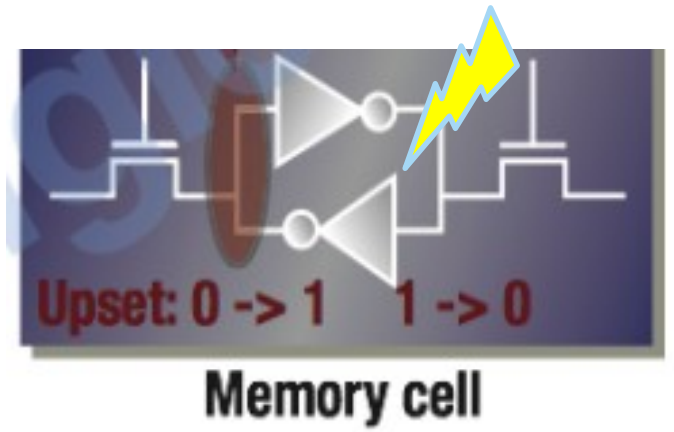
Single Event Transient

SET is a current pulse occurring at a circuit node

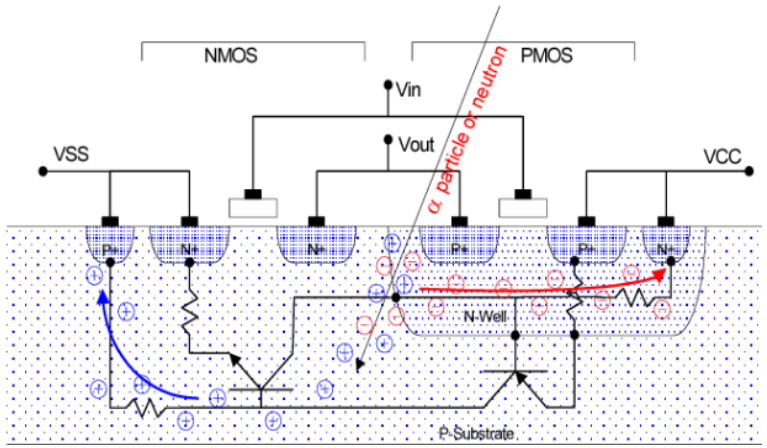


Single Event Upset

SEU is a change of state of memory cell



SEL is an abnormal high-current state in a device
=> May cause permanent damage to the device



MICROCHIP