ANALYSIS OF SINGLE EVENT TRANSIENT EFFECTS IN ANALOGUE TOPOLOGIES

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CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

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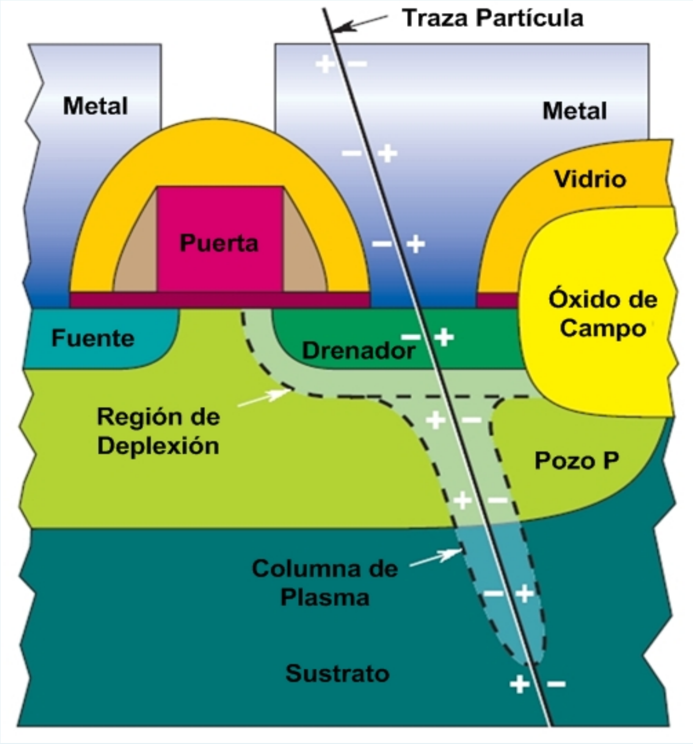
Outline

- Introduction
- Motivation
- Description of the implemented tool
  - SET emulation models
  - Single Event Simulation Analyzer methodology
  - Examples of tool performance
- Conclusions and future work

Introduction

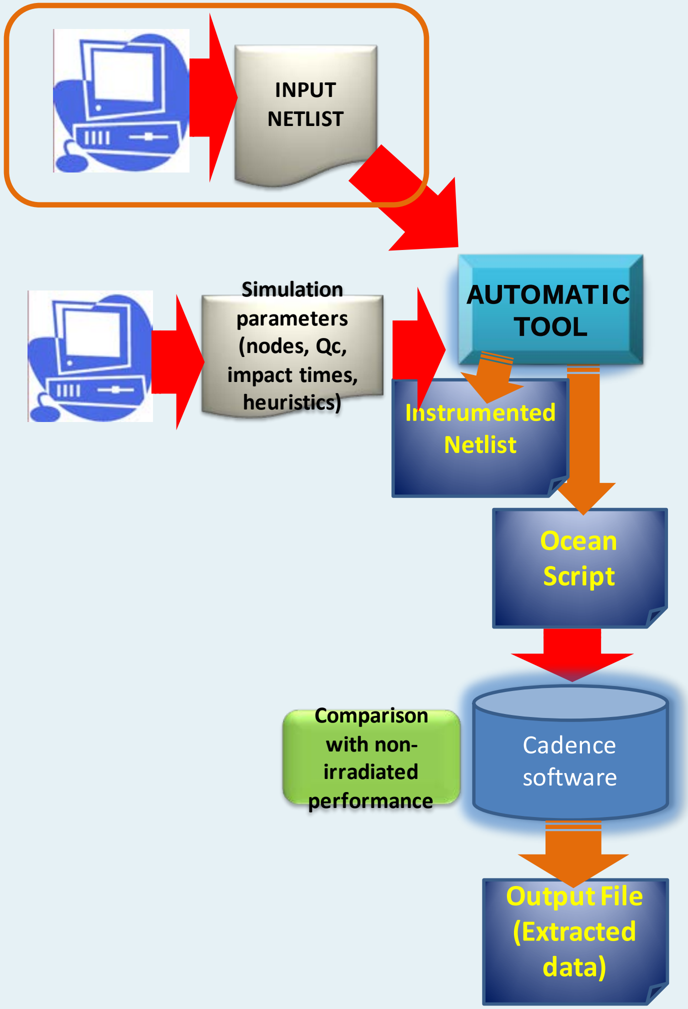
- High-energy particle impacts become critical as technology shrinks.
- Single Event Effects (SEE) are a major concern not only in digital domain but also in analogue cells.
- Dealing with the analysis of analogue circuits is a challenging tread as the number of transistors increases.



Motivation: SET sensitivity evaluation

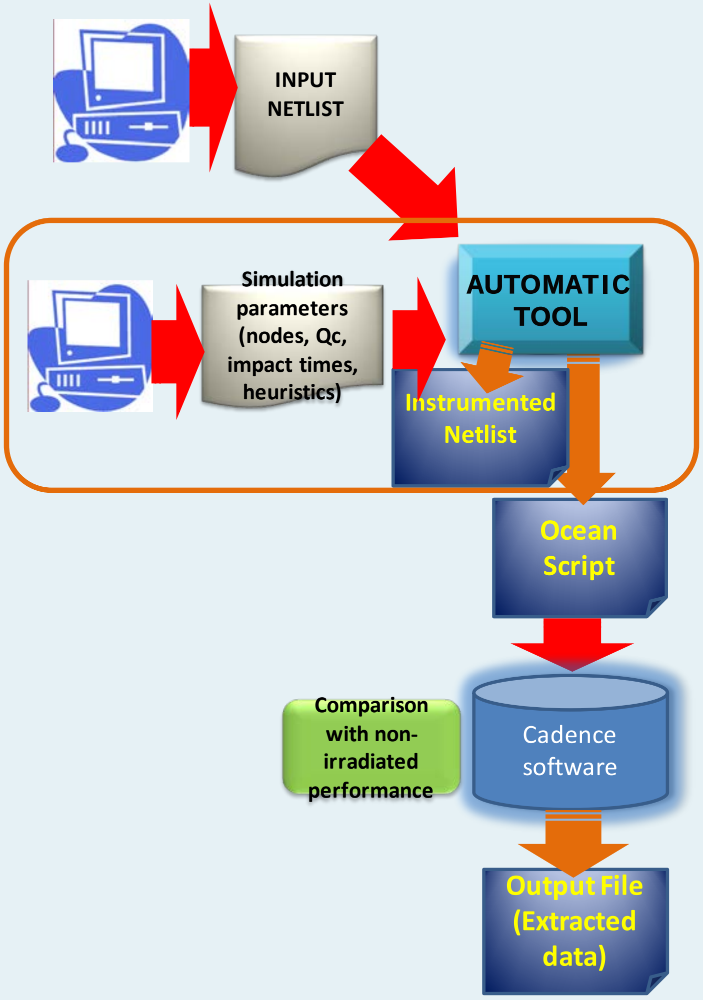
- The work presented has been carried out in colaboration with IMB-CNM and Arquimea.
  - Need for a SET sensitivity evaluation in a reconfigurable System-on-chip for radiation-hardening purposes.
- A tool to evaluate the SET sensitivity at transistor level in complex circuits.
  - Provide a useful information about critical nodes of the circuit under test to the analog designer.
  - Easy to use by the circuit designer.
- Development of the tool will be continued under FT-Unshades (digital SEU sensitivity evaluation)

Single Event Simulation Analyzer



- The circuit designer has to define the test-bench of the circuit under test:
  - A netlist that describes the circuit is required as an input.
- The tool automatically creates an instrumented netlist.
  - SET models for impacts emulation are added to every possible target.
  - The user provides configuration parameters for simulation and analysis of the circuit.
- A simulation script is automatically created.
  - Compares an ideal (non-irradiated) output and the signal affected by injected SETs.
  - Results of the analysis of circuit's vulnerabilities are extracted.

Single Event Simulation Analyzer



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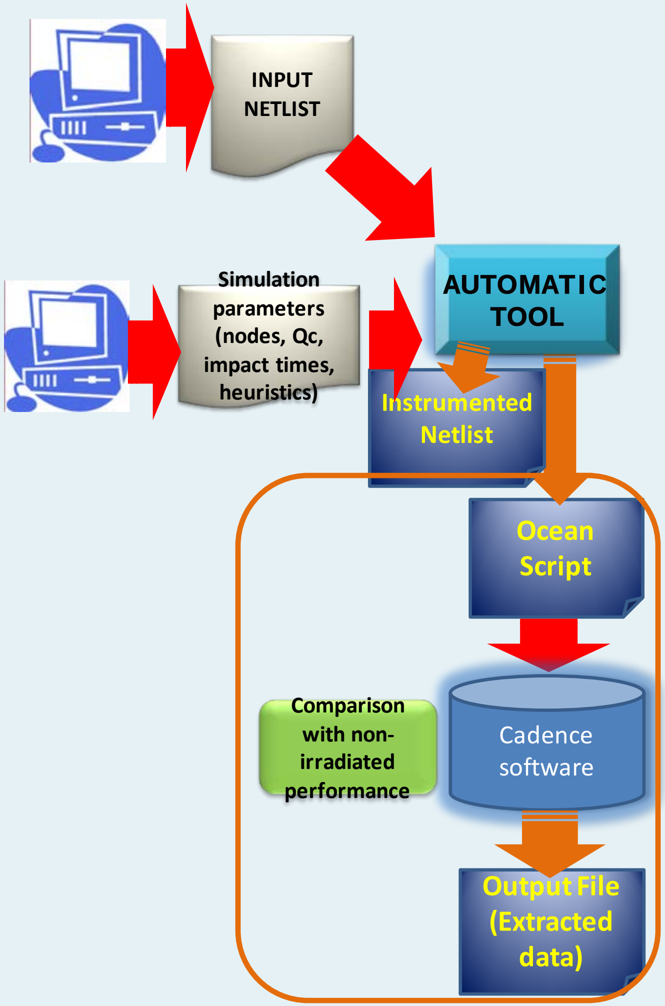

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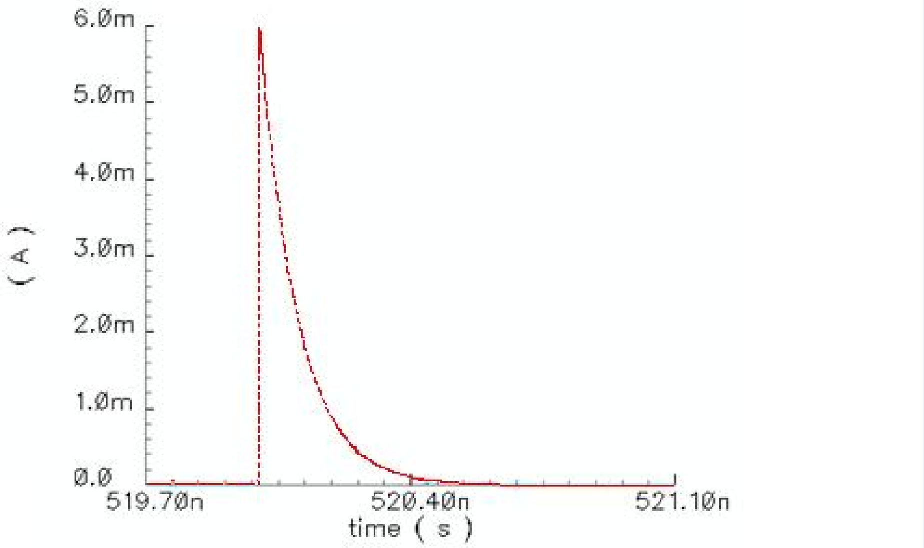
SET emulation

- SET emulation based on charge injection models:
  - Current sources with double exponential dynamics*
  - Use of configurable parameters (AHDL implementation)



$$I_{rad} = \frac{Q_C}{\tau_d - \tau_r}\left(e^{-\frac{\tau}{\tau_d}} - e^{-\frac{\tau}{\tau_r}}\right)$$

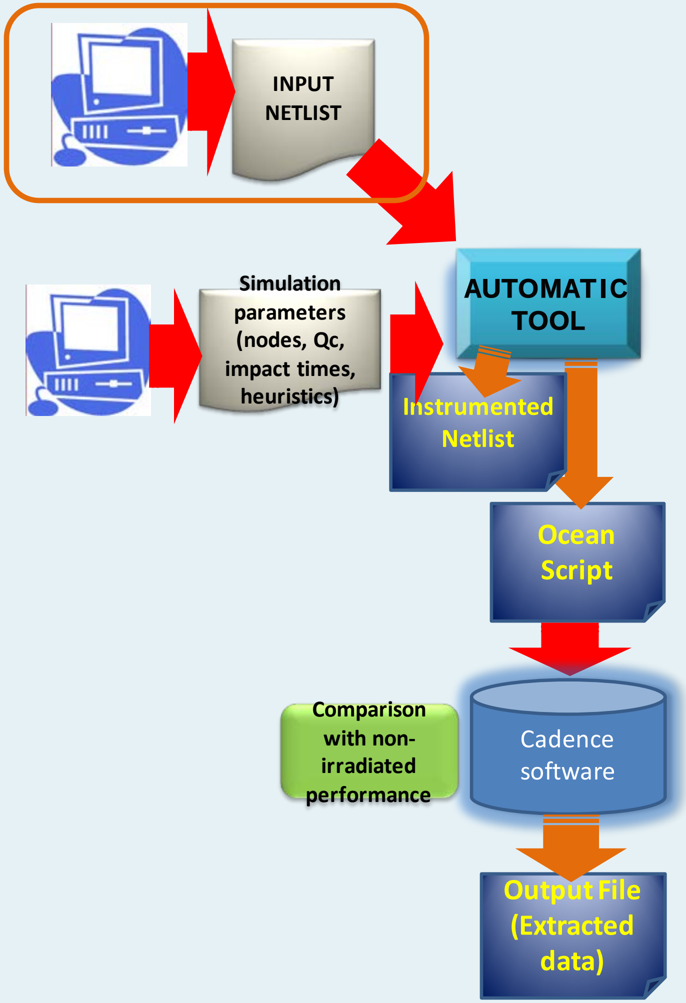
$$Q_c = \frac{\rho \cdot LET \cdot d}{3.6}$$

*REF: **G. Messenger,** "Collection of Charge on junction nodes from ion tracks", *IEEE Transactions on nuclear science*, vol.29, nº 6, Dec. 1982

Single Event Simulation Analyzer

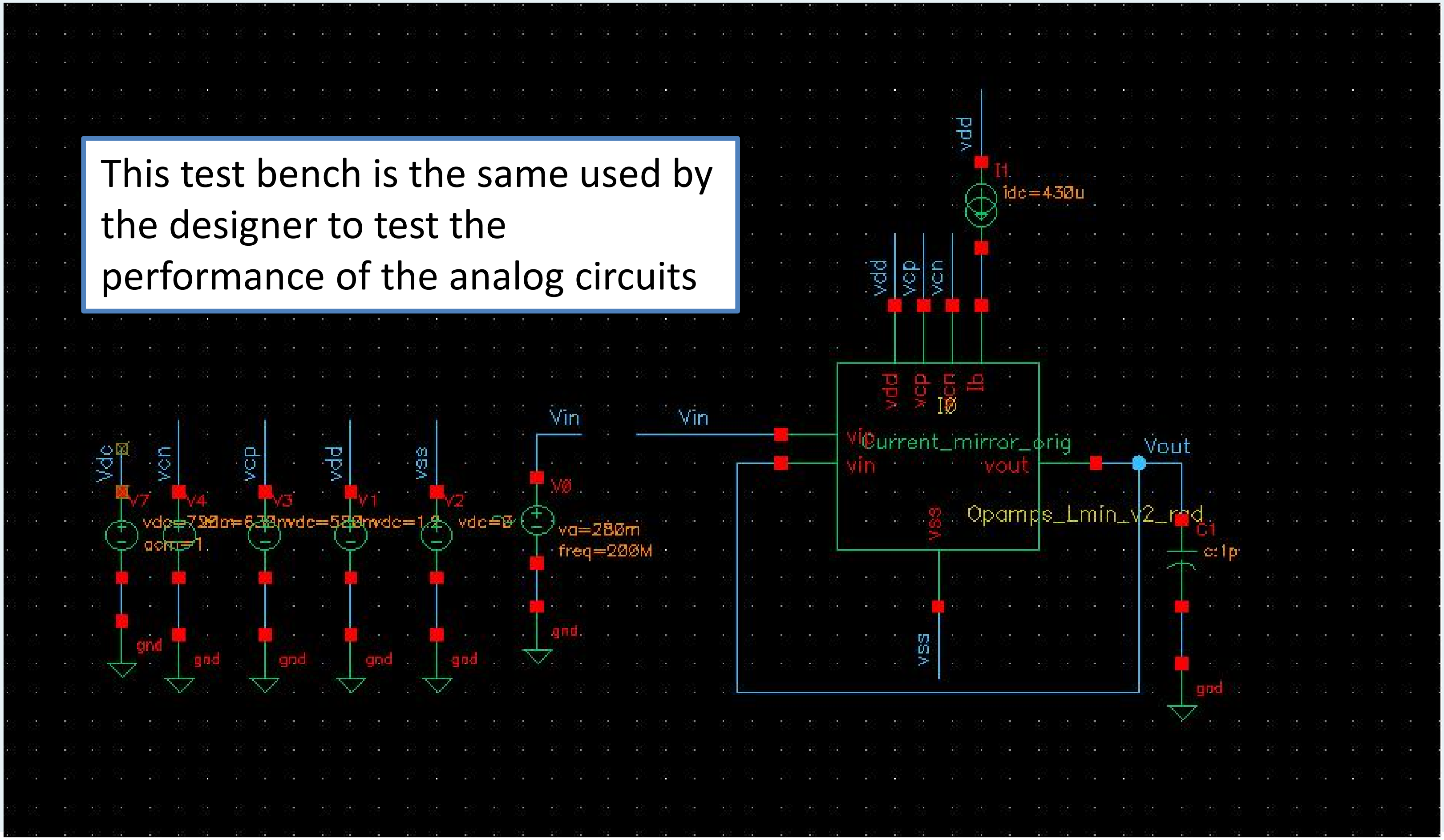
- Starting point:
  Input netlist

  - To extract the Spectre netlist, the tool requires a test-bench for the analog scheme under test.



Single Event Simulation Analyzer

- Starting point: circuit test-bench



This test bench is the same used by the designer to test the performance of the analog circuits

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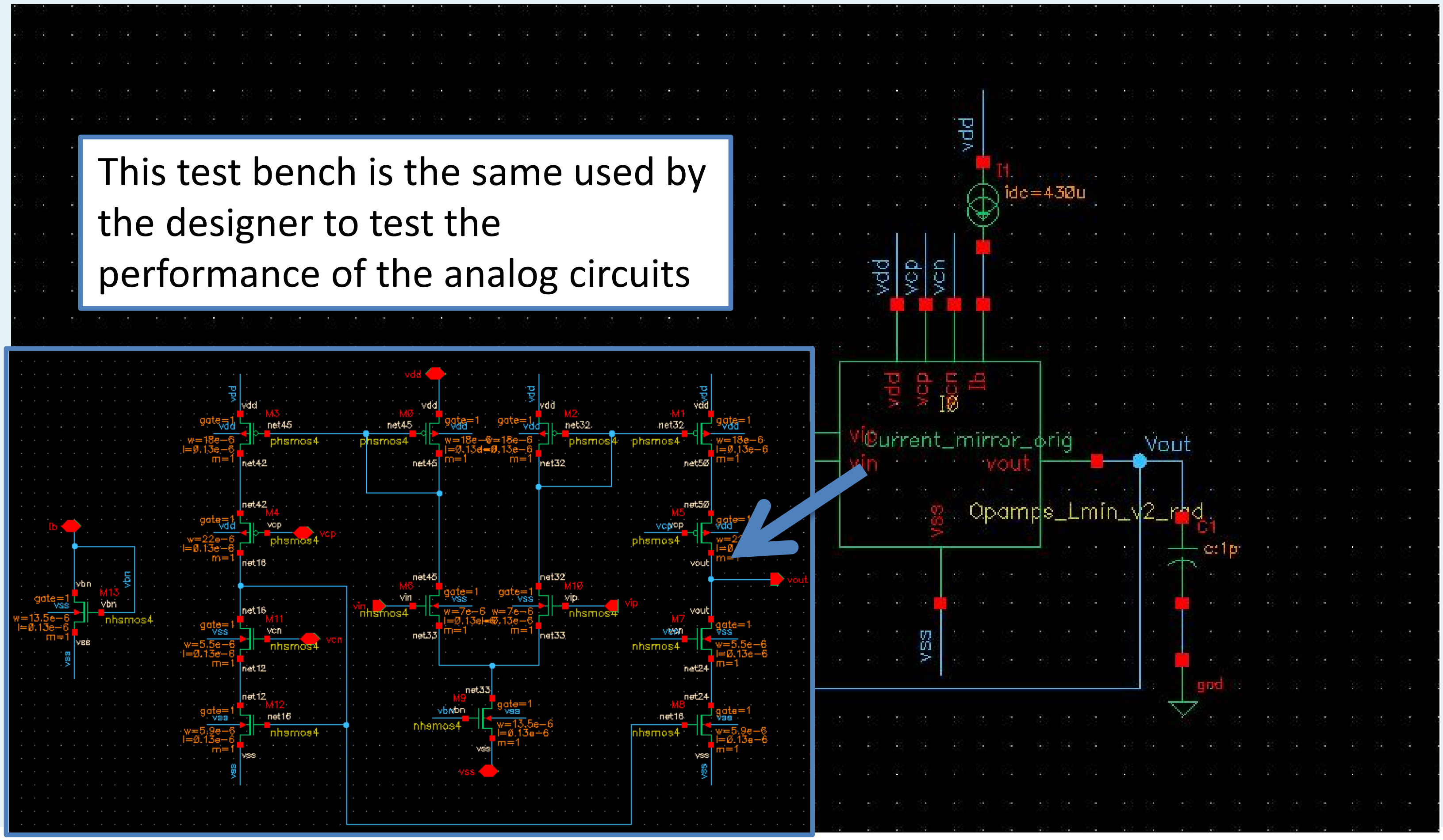
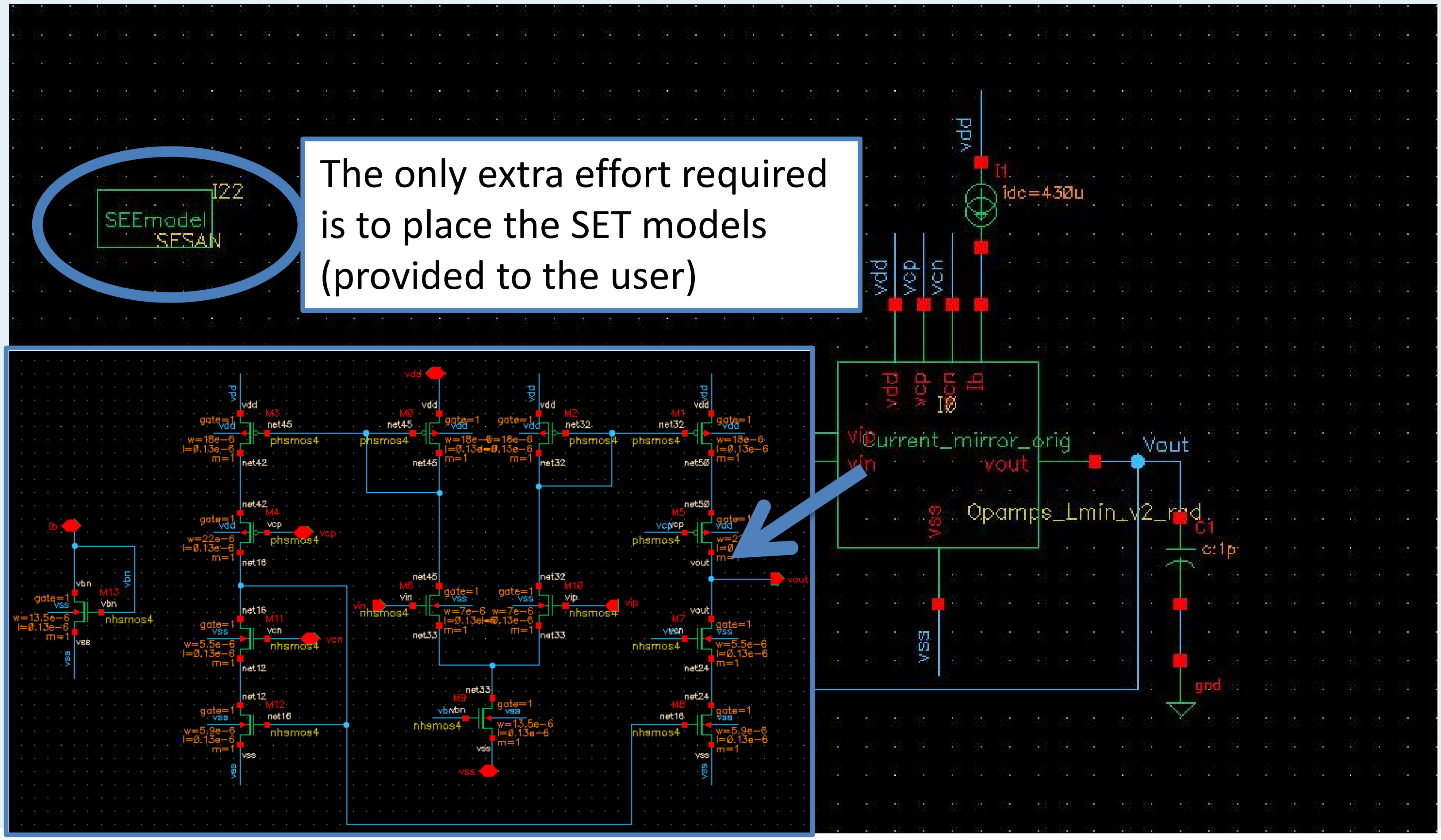


Single Event Simulation Analyzer

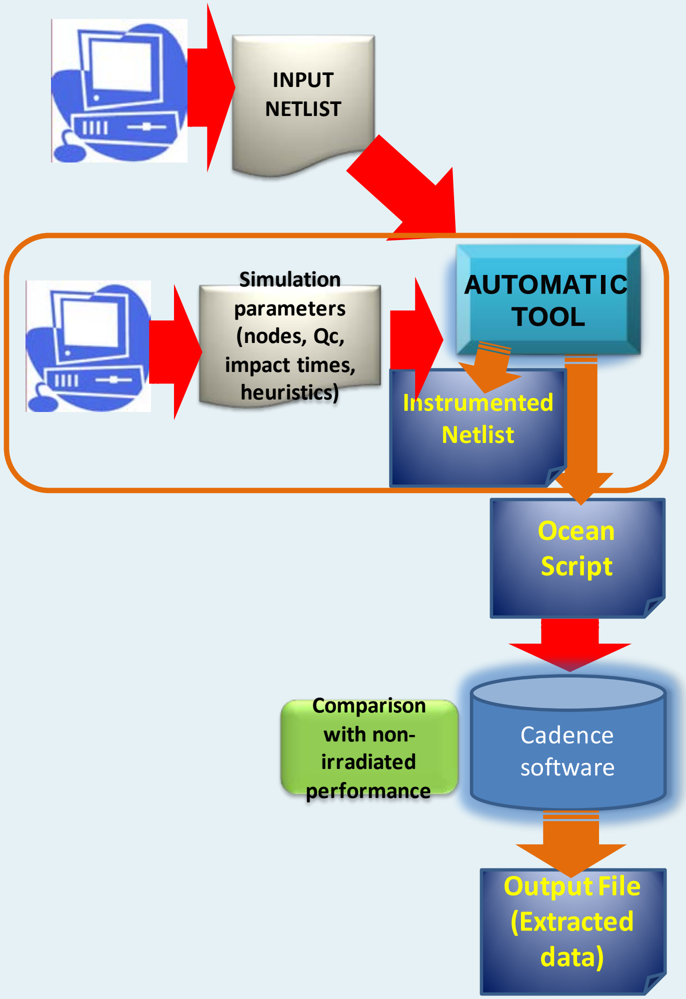
- Starting point: circuit test-bench



Single Event Simulation Analyzer

- From the input netlist, the tool:
  - Step 1: generates an instrumented netlist
  - Step2 : creates a simulation script that automatically:
    - analyzes the SET sensitivity of the analog circuit .
    - Extracts critical information and provides an output file with the results.

Single Event Simulation Analyzer



- Step 1: Netlist instrumentation:
  - Technology information is provided to the designer.
  - SET emulation models are added to generate a new netlist.

Define the technology

Welcome to SET analyzer

>> loadtech ST130nm.txt
Successful

A technology file is loaded (provided to the designer) with the required information for SET models placement, making this process technology independent.

Example: SET Sensitivity for a 130 nm analog cell

Instrumented netlist

Welcome to SET analyzer

>> loadtech ST130nm.txt
Successful

>> source netlistCM130nm
Source netlist netlistCM130nm successfully opened
Successful

A technology file is loaded (provided to the designer) with the required information for SET models placement and particle impacts, making this process technology independent.

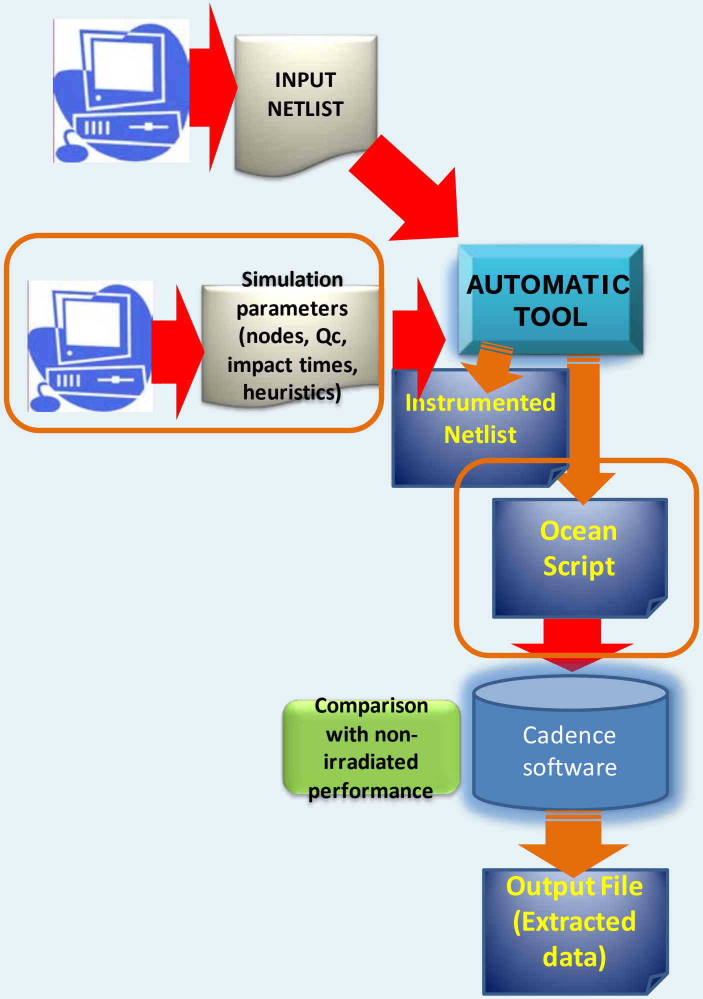
A Spectre netlist is loaded as an input for the tool, which creates an instrumented version adding the SET emulation models

Example: SET Sensitivity for a 130 nm analog cell

Script generation

- Step 2: Automatic script generation

  - Configuration parameters should be defined by the user.
  - Example: *Impact nodes.*



Impact nodes selection

```
>> listAlltargets
Possible targets:
SET_I0_M13
SET_I0_M12
SET_I0_M11
SET_I0_M10
SET_I0_M9
SET_I0_M8
SET_I0_M7
SET_I0_M6
SET_I0_M5
SET_I0_M4
SET_I0_M3
SET_I0_M2
SET_I0_M1
SET_I0_M0
Successful
```

The tool provides a list of the possible targets which have to be properly configured for SET emulation

Example: SET Sensitivity for a 130 nm analog cell

Impact nodes selection

```
>> listAlltargets
Possible targets:
SET_I0_M13
SET_I0_M12
SET_I0_M11
SET_I0_M10
SET_I0_M9
SET_I0_M8
SET_I0_M7
SET_I0_M6
SET_I0_M5
SET_I0_M4
SET_I0_M3
SET_I0_M2
SET_I0_M1
SET_I0_M0
Successful
>> Addtarget SET_I0_M5
Successful
>> Addtarget SET_I0_M7
Successful
>> Addtarget SET_I0_M10
Successful
```

The tool provides a list of the possible targets which have to be properly configured for SET emulation

We can add all the targets for a massive campaign or only a group of them to perform a more selective analysis at a sub-block level

Example: SET Sensitivity for a 130 nm analog cell

Script generation

Step 2: Automatic script generation

- Configuration parameters should be defined:
  - Impact nodes.
  - ***SET model parameters***:
    - *Charge injected*
    - *Impact times*

SET model parameters

```
>> listtargets
Possible impacts in:
Source          Q         T
SET_I0_M7       (0.5p)    (10n 20n)
SET_I0_M5       (0.5p)    (10n 20n)
SET_I0_M10      (0.5p)    (10n 20n)
Successful
```

Critical charge to be injected to emulate a particle impact (defined in the SEE models).

Example: SET Sensitivity for a 130 nm analog cell

SET model parameters

```
>> listtargets
Possible impacts in:
Source          Q          T
SET_I0_M7       (0.5p)     (10n 20n)
SET_I0_M5       (0.5p)     (10n 20n)
SET_I0_M10      (0.5p)     (10n 20n)
Successful
```

Critical charge to be injected to emulate a particle impact (defined in the SEE models).

Impact times.
A generated SET can be more or less critical depending on the impact time selected.

Example: SET Sensitivity for a 130 nm analog cell

SET model parameters

>> listtargets

Possible impacts in:

Source	Q	T
SET_I0_M7	(0.5p)	(10n 20n)
SET_I0_M5	(0.5p)	(10n 20n)
SET_I0_M10	(0.5p)	(10n 20n)

Successful

>> setT SET_I0_M7 (13n 26n 31n)

Successful

>> setQ SET_I0_M10 (0.25p)

Successful

Charge to be injected to emulate a particle impact (defined in the SET models).

Impact times.
A generated SET can be more or less critical depending on the impact time selected.

Definition of impact times and charge

Example: SET Sensitivity for a 130 nm analog cell

SET model parameters

```
>> listtargets
Possible impacts in:
Source          Q           T
SET_I0_M7       (0.5p)      (10n 20n)
SET_I0_M5       (0.5p)      (10n 20n)
SET_I0_M10      (0.5p)      (10n 20n)
Successful
>> setT SET_I0_M7 (13n 26n 31n )
Successful
>> setQ SET_I0_M10 (0.25p)
Successful
>> listtargets
Possible impacts in:
Source          Q           T
SET_I0_M7       (0.5p)      (13n 26n 31n )
SET_I0_M5       (0.5p)      (10n 20n)
SET_I0_M10      (0.25p)     (10n 20n)
Successful
```

Charge to be injected to emulate a particle impact (defined in the SET models).

Impact times.
A generated SET can be more or less critical depending on the impact time selected.

Example: SET Sensitivity for a 130 nm analog cell

Script generation

Step 2: Automatic script generation

- Configuration parameters should be defined:
  - Impact nodes.
  - SEE model parameters:
    - Critical charge
    - Impact times
  - ***Outputs selected.***

Outputs selection

```
>> listallnodes
Possible output nodes:
/net19    /vcn      /vcp      /vdd
/net10    /Vout     /net11    /vss
/0        /I0/net12           /I0/net16
/I0/net32           /I0/net33
/I0/net24           /I0/net45
/I0/Vout0/I0/net42
Successful
```

A list of available nodes to be selected for analysis is provided, including internal nodes of different sub-blocks.

Example: SET Sensitivity for a 130 nm analog cell

Outputs selection

```
>> listallnodes
Possible output nodes:
/net19    /vcn      /vcp      /vdd
/net10    /Vout     /net11    /vss
/0        /I0/net12           /I0/net16
/I0/net32           /I0/net33
/I0/net24           /I0/net45
/I0/Vout0/I0/net42
Successful
>> addOutput /Vout
Successful
>> addOutput /I0/net32
Successful
```

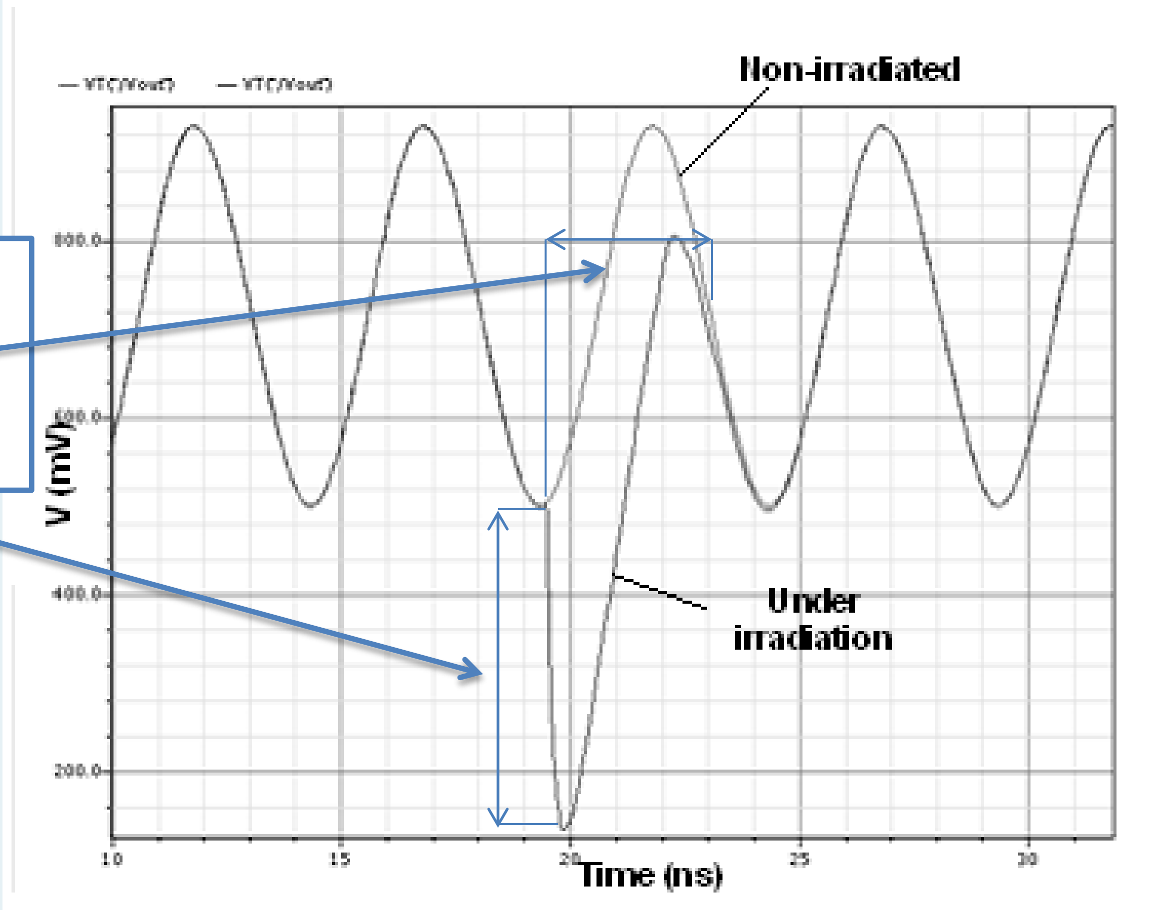
A list of available nodes to be selected for analysis is provided, including internal nodes of different sub-blocks.

- The tool will only consider for analysis the nodes selected by the designer
- Only the information of this nodes will be saved during simulations

Example: SET Sensitivity for a 130 nm analog cell

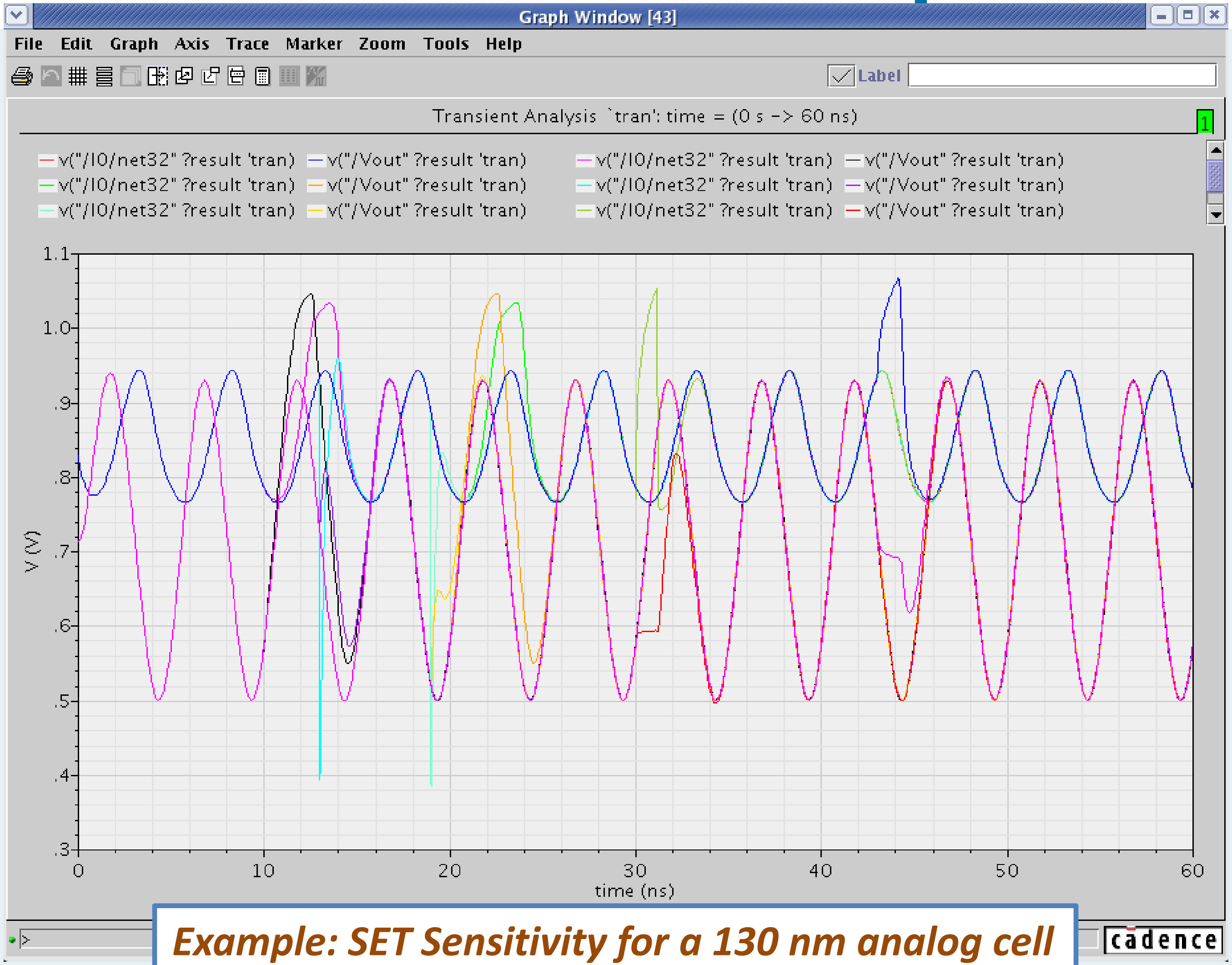
Outputs comparison

Two main transient parameters have been considered:
- Recovery time
- Voltage deviation



Example: SET Sensitivity for a 130 nm analog cell

Transient simulations are performed

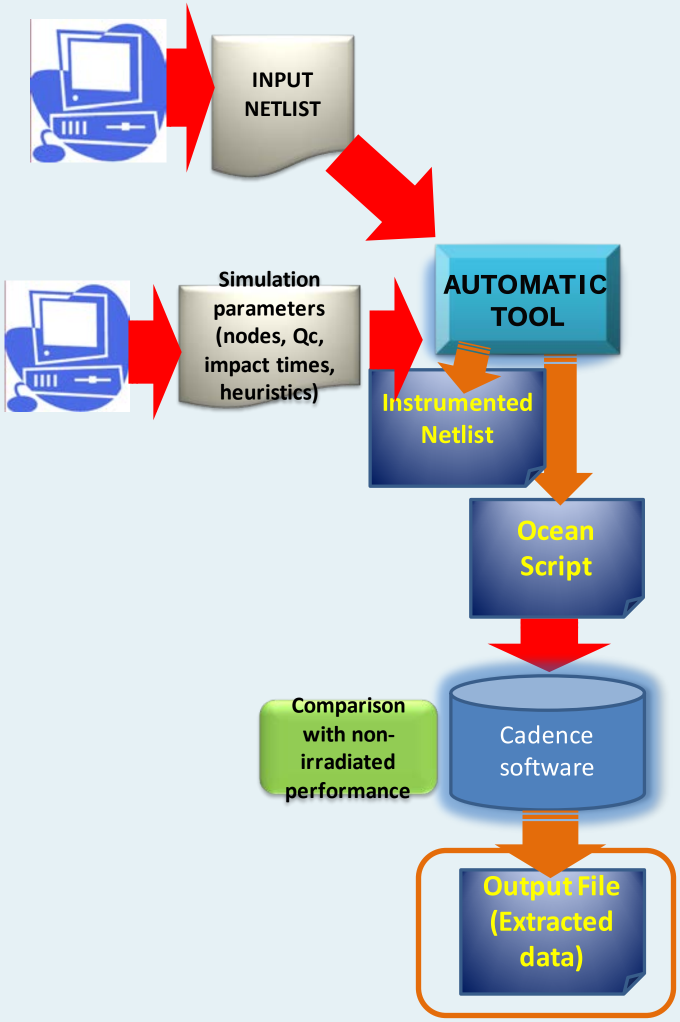


Example: SET Sensitivity for a 130 nm analog cell

Analysis of the results

➢Output file

- Results are automatically extracted, analyzed and saved into an output file.
- The process is transparent to the user.



Database is automatically generated

Output	Impact	Qc	Timp	Trec	Vmax
/I0/net32	I0_M5	5,00E-13	1,00E-08	5.100.000	0.109233
/Vout	I0_M5	5,00E-13	1,00E-08	6.400.000	0.225535
/I0/net32	I0_M5	5,00E-13	2,00E-08	5.100.000	0.109186
/Vout	I0_M5	5,00E-13	2,00E-08	6.400.000	0.225493
/I0/net32	I0_M7	5,00E-13	1.3e-08	2.300.000	0.426629
/Vout	I0_M7	5,00E-13	1.3e-08	3.600.000	0.183520
/I0/net32	I0_M7	5,00E-13	2.6e-08	2.300.000	0.370461
/Vout	I0_M7	5,00E-13	2.6e-08	3.000.000	0.147083
/I0/net32	I0_M10	2,50E-13	1,00E-08	2.800.000	0.205726
/Vout	I0_M10	2,50E-13	1,00E-08	3.900.000	0.186725
/I0/net32	I0_M10	2,50E-13	2.0e-08	3.300.000	0.143872
/Vout	I0_M10	2,50E-13	2.0e-08	4.600.000	0.231184

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Example: SET Sensitivity for a 130 nm analog cell

Database is automatically generated

Output	Impact	Qc	Timp	Trec	Vmax
/I0/net32	I0_M5	5,00E-13	1,00E-08	5.100.000	0.109233
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/I0/net32	I0_M10	2,50E-13	1,00E-08	2.800.000	0.205726
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.
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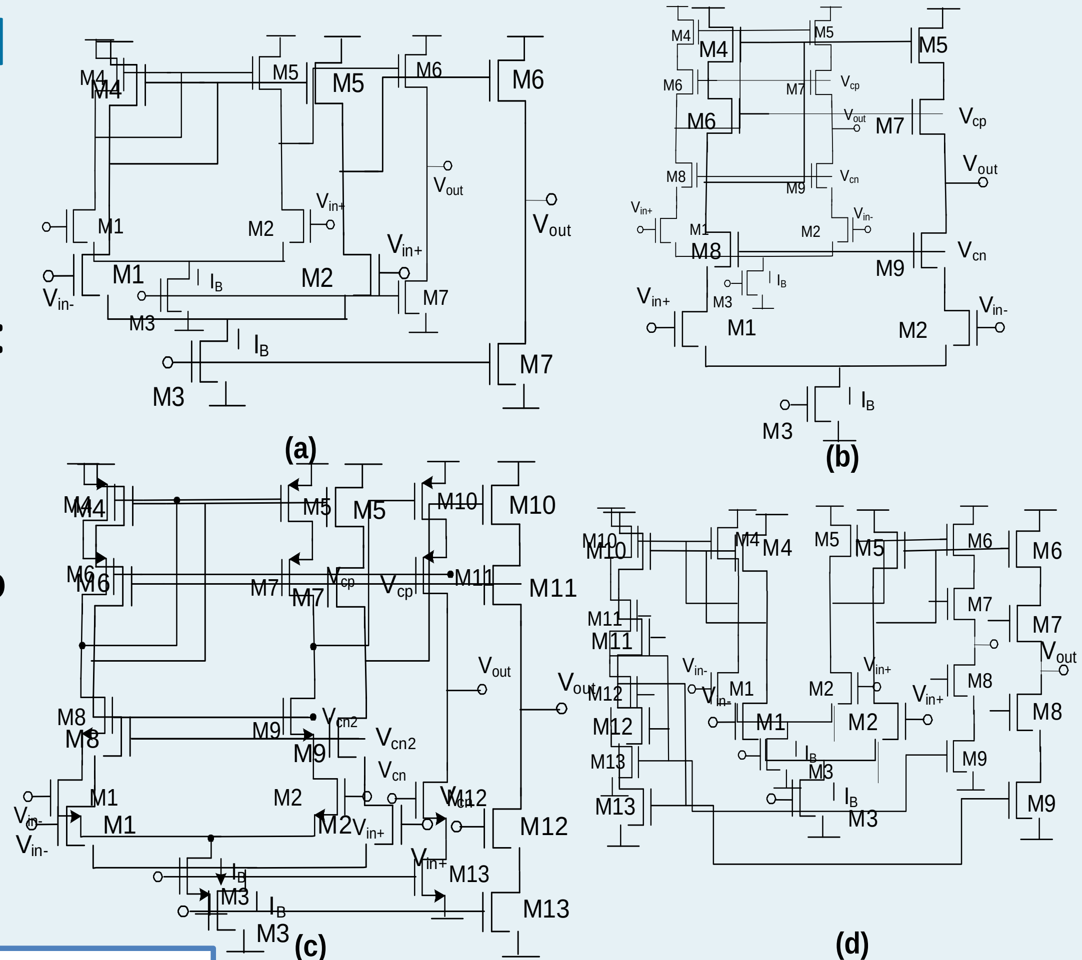
Example: SET Sensitivity for a 130 nm analog cell

Tool performance

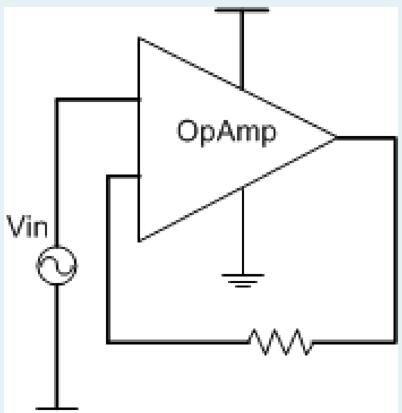
- The analysis of several analog topologies has been performed:
  - 130nm technology
  - Amplifier topologies:
    - a) Two stage Miller OpAmp
    - b) Telescopic OpAmp
    - c) Fully cascoded two stage OpAmp
    - d) Current mirror OpAmp (OTA)



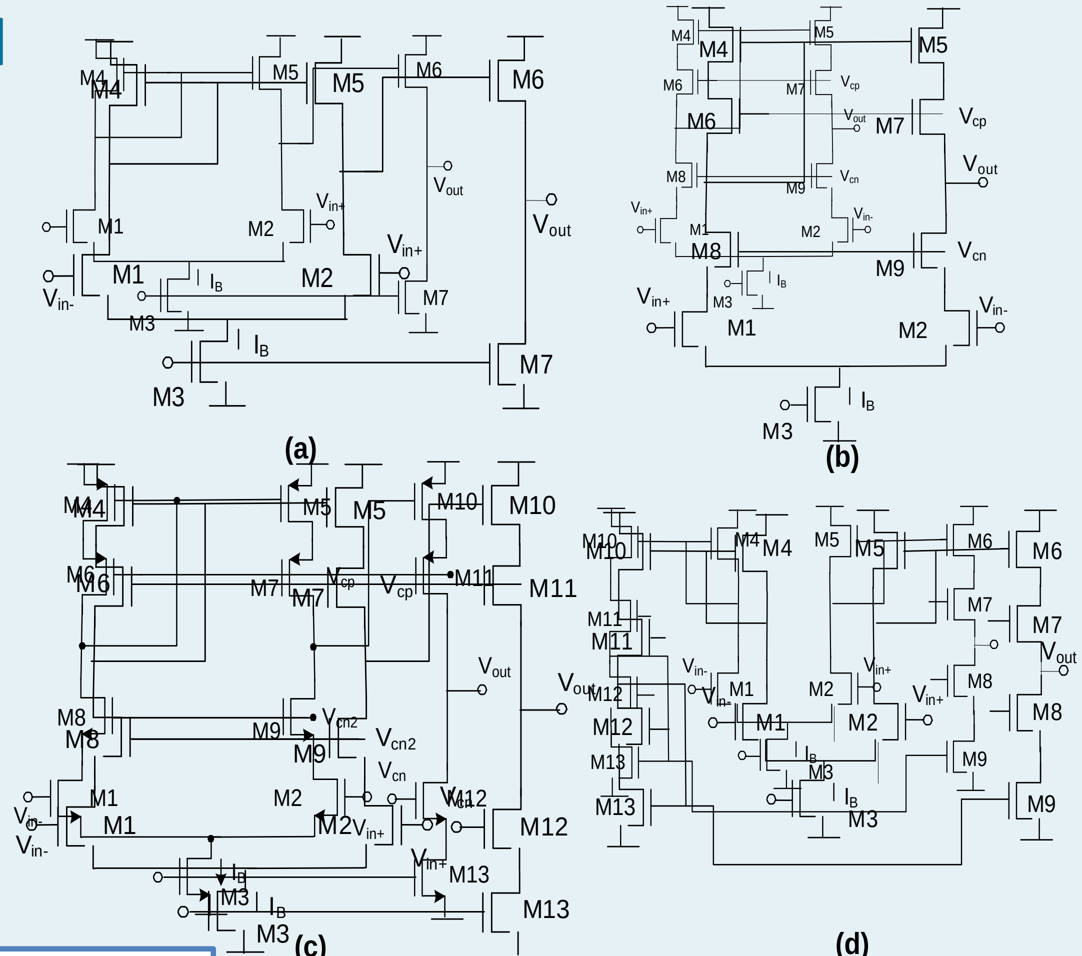
Example: SET Sensitivity for 130 nm analog cells

Tool performance

- The analysis of several analog topologies has been performed:
  - Test-bench:



  - Input signal:
    - *A= 400mV*
    - *Fin= 200MHz (T=5ns)*



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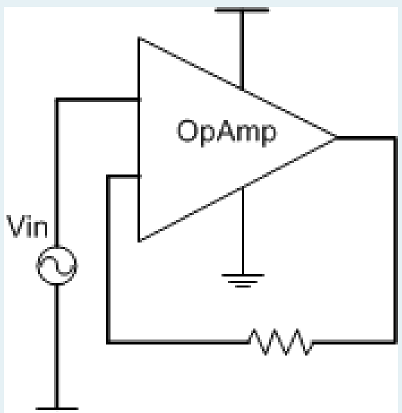

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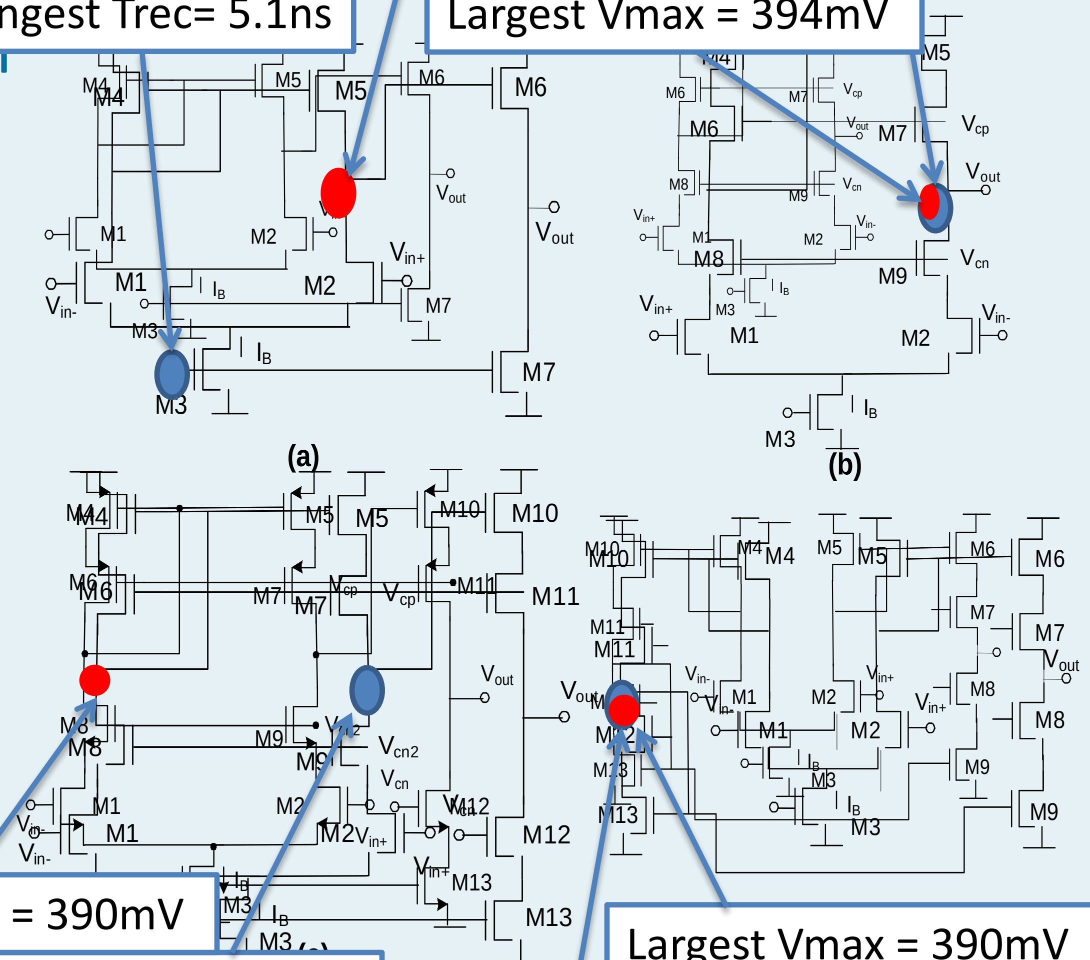

Example: SET Sensitivity for 130 nm c

Conclusions and future work

- A first version of the tool for SET sensitivity analysis in analog schemes has been designed
  - Allows a rapid SET sensitivity analysis of critical nodes at schematic level.
  - Technology independent.
- Tool posibilities and future trends
  - Implementation of alternative SET models.
  - Extension of the fault injection to layout simulation (charge sharing)
  - Unify this tool with FT-Unshades to obtain a mixed signal SET sensitivity analizer.

Thanks for your attention

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