ISPD'18

March 28, 2018

Standard CAD Tool-Based Method for Simulation of Laser-Induced Faults in Large-Scale Circuits

Raphael Viera - raphael@ieee.org

Philippe Maurine, Jean-Max Dutertre and Rodrigo Bastos

LIRMM

MINES Saint-Étienne
Une école de l'IMT

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Outline

1 Motivation

2 Classical model of laser fault injection and its limits

3 Proposed model

4 Simulation methodology

5 Simulation results

6 Conclusions

Outline

Fault Attacks on Secure Devices

Why attack?

Fault Attacks on Secure Devices

Why attack?

Theft of service

Fault Attacks on Secure Devices

Why attack?

Theft of service

ID theft

Fault Attacks on Secure Devices

Why attack?

Theft of service

ID theft

Denial of service

Cloning, etc.

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Means to **attack** are being constantly improved

Fault Attacks on Secure Devices

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Means to **attack** are being constantly improved

Means to **defend** are being constantly improved

Fault Attacks on Secure Devices

Why attack?

Theft of service

ID theft

Denial of service

Cloning, etc.

Means to **attack** are being constantly improved

Means to **defend** are being constantly improved

Growing demand for secure chips:

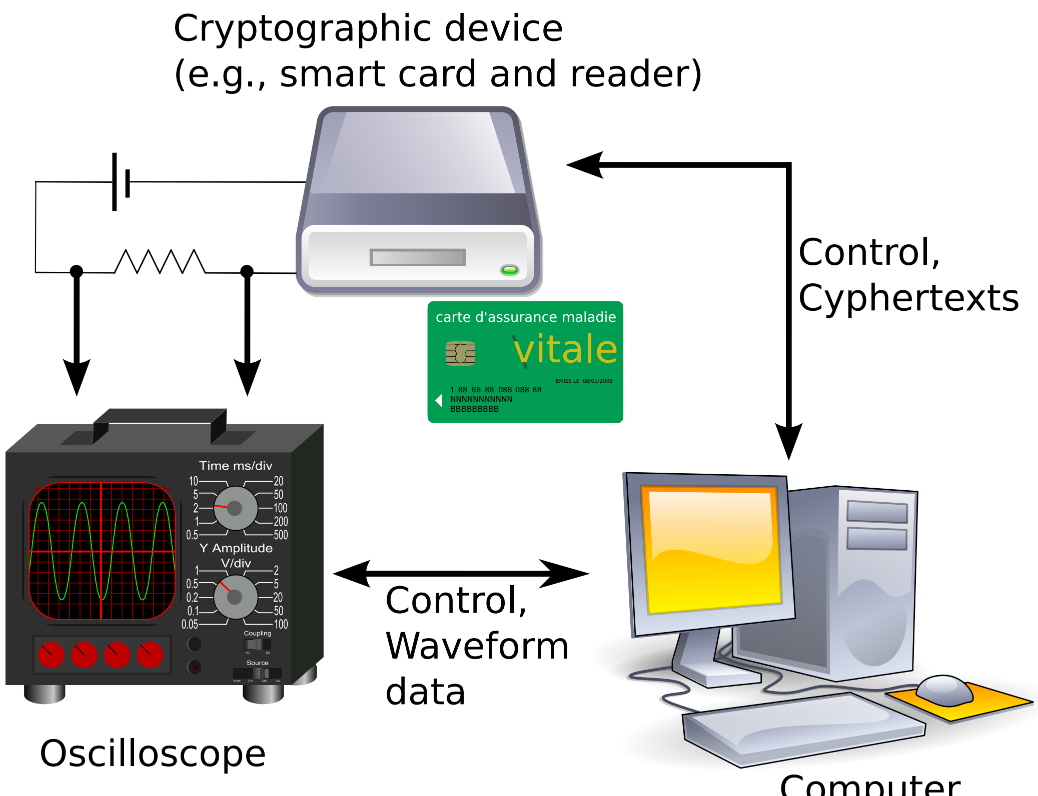
Banking industry, service providers, military applications, etc.

Categories and Methods

Categories and Methods

Non-invasive

- Side-channel
- Power / Clock Glitches
- Software



Picture by Mark Pellegrini [LGPL (http://www.gnu.org/licenses/lgpl.html), GFDL (http://www.gnu.org/copyleft/fdl.html)]

Categories and Methods

Semi-invasive

Laser Fault injection

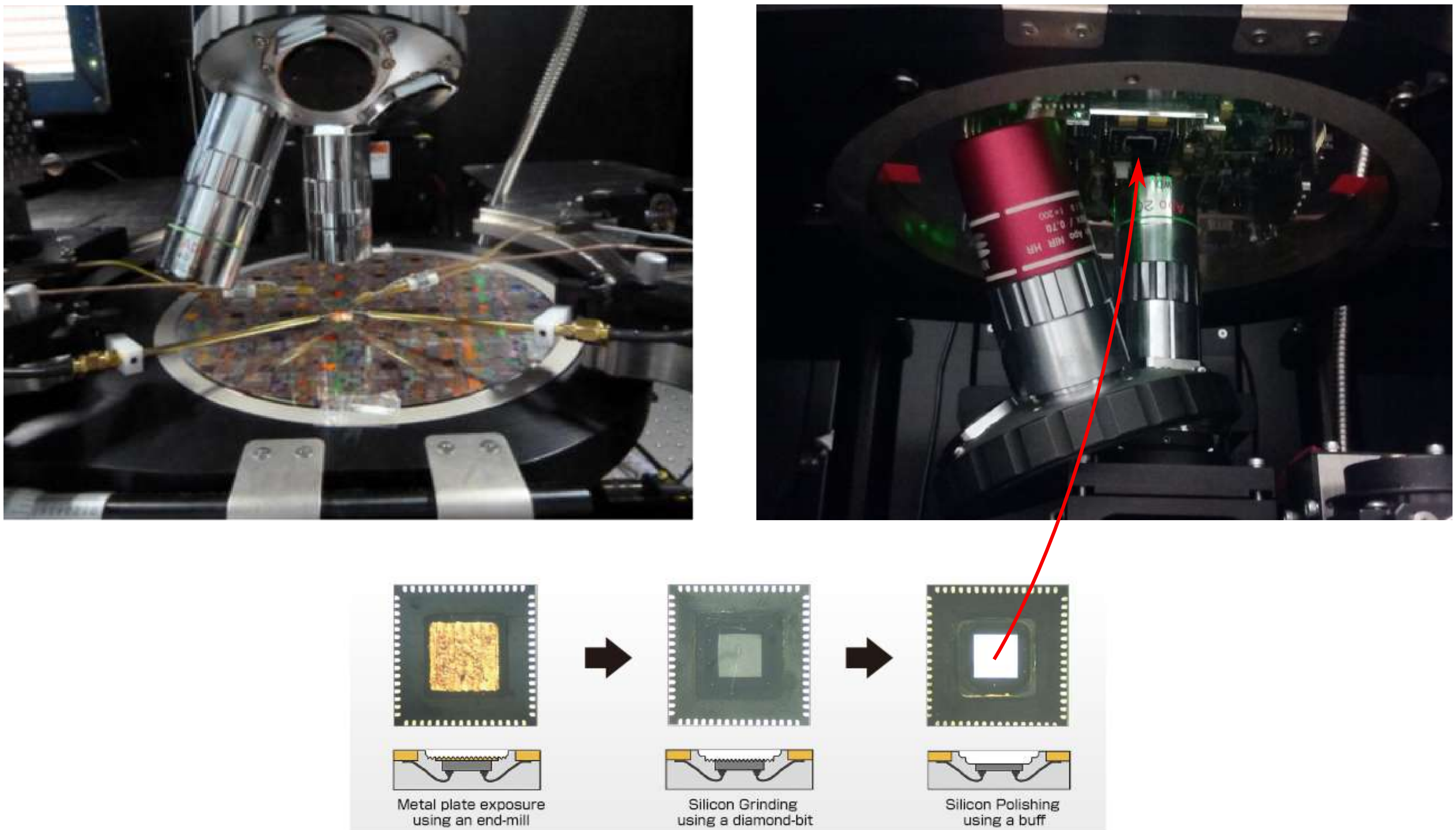
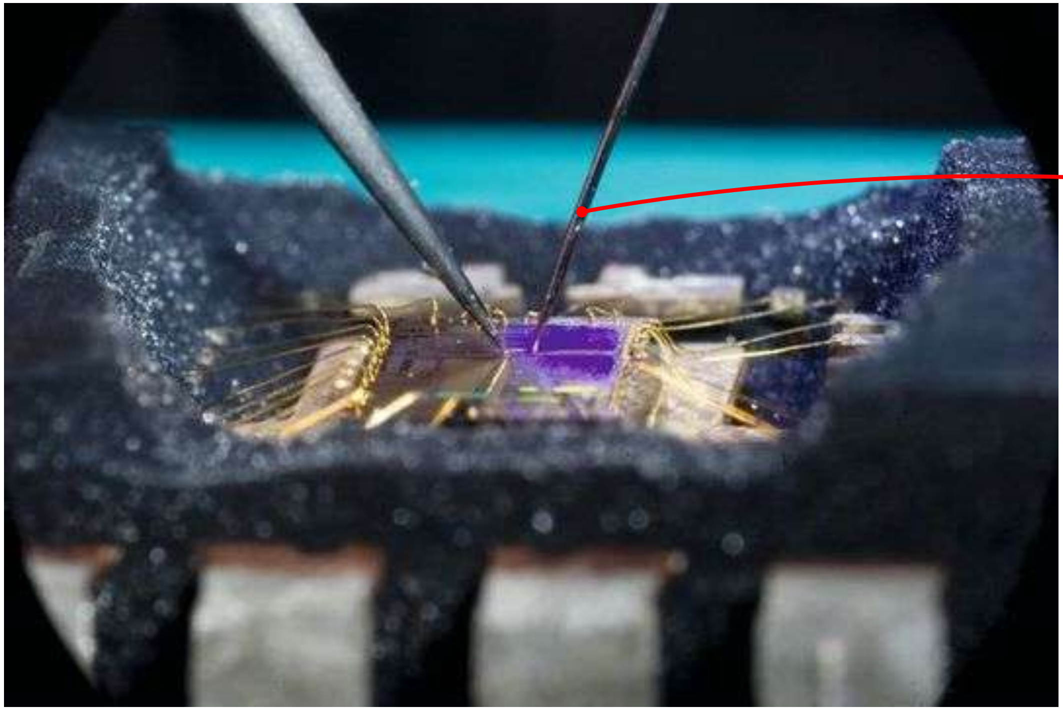


Photo: http://www.nscnet.co.jp/e/pdt/ba102.html

Categories and Methods

Invasive

Microprobing



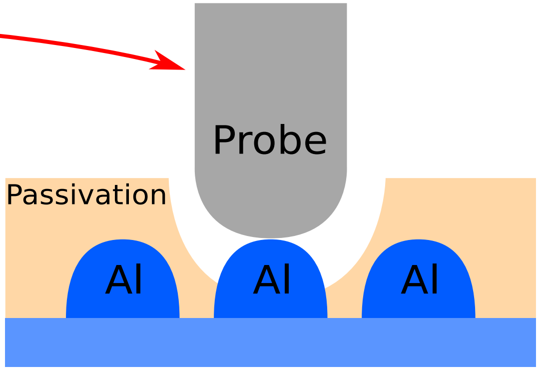
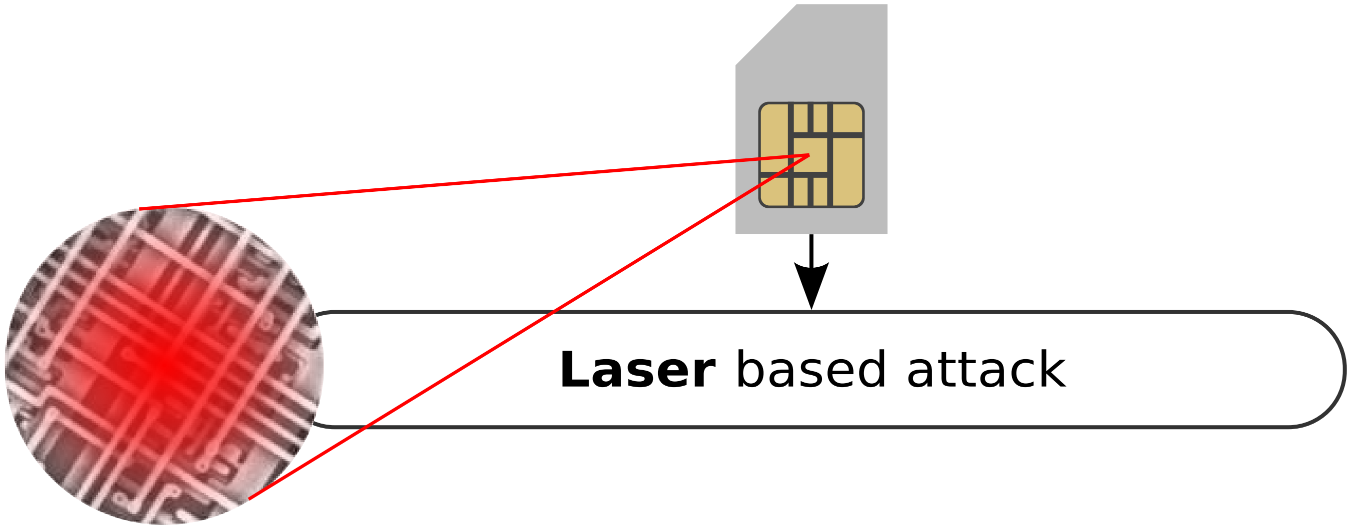
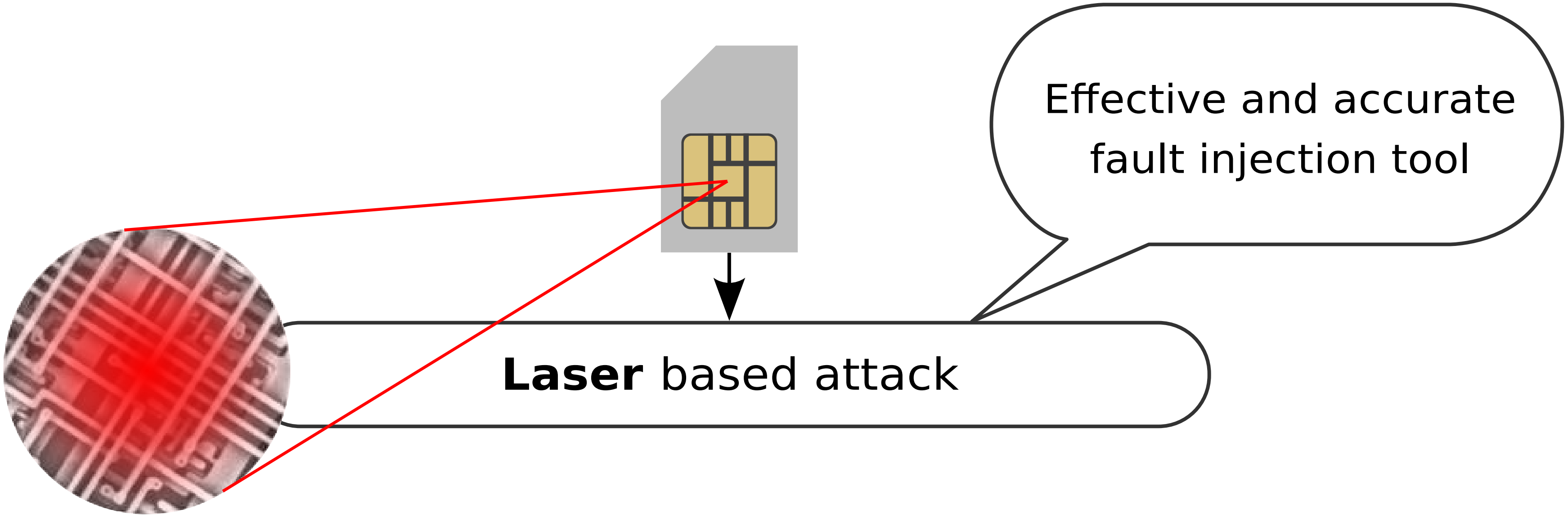
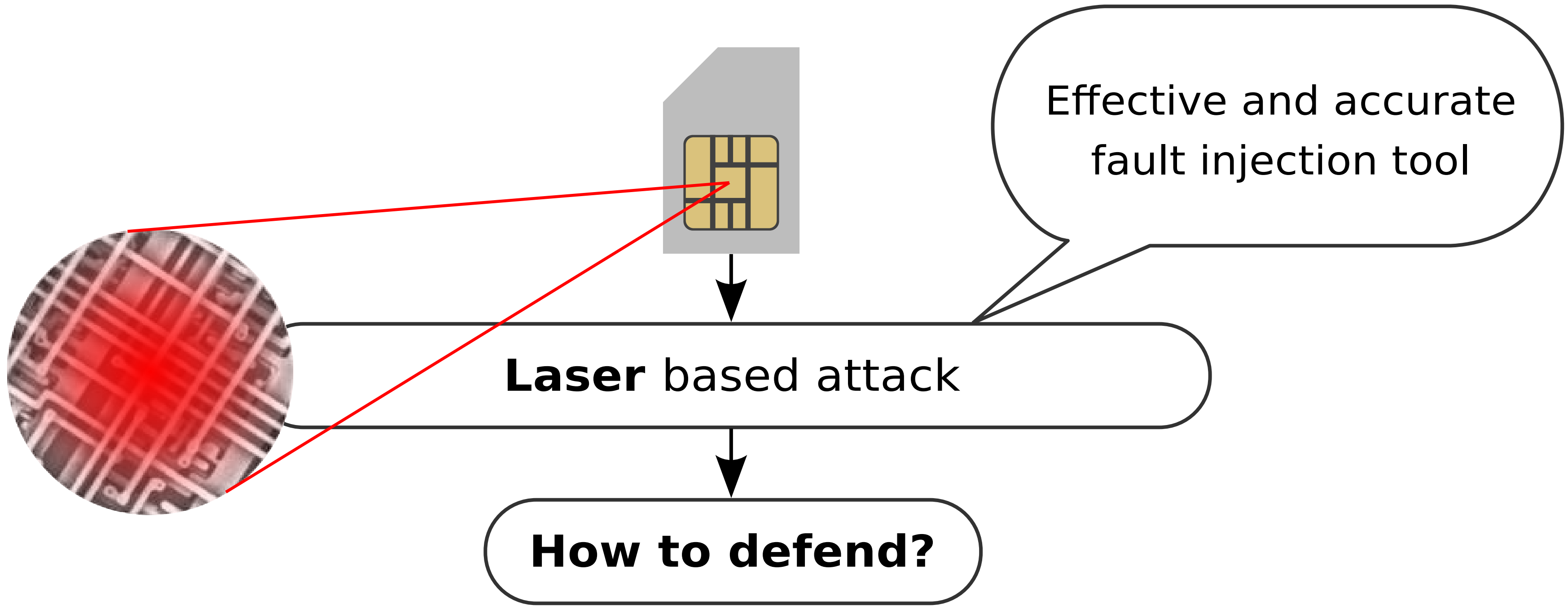


Photo: https://www.maschinewerkzeug.de/business-karriere/uebersicht/artikel/1130365

This work focuses on...


Laser based attack


Effective and accurate
fault injection tool
Laser based attack


Effective and accurate
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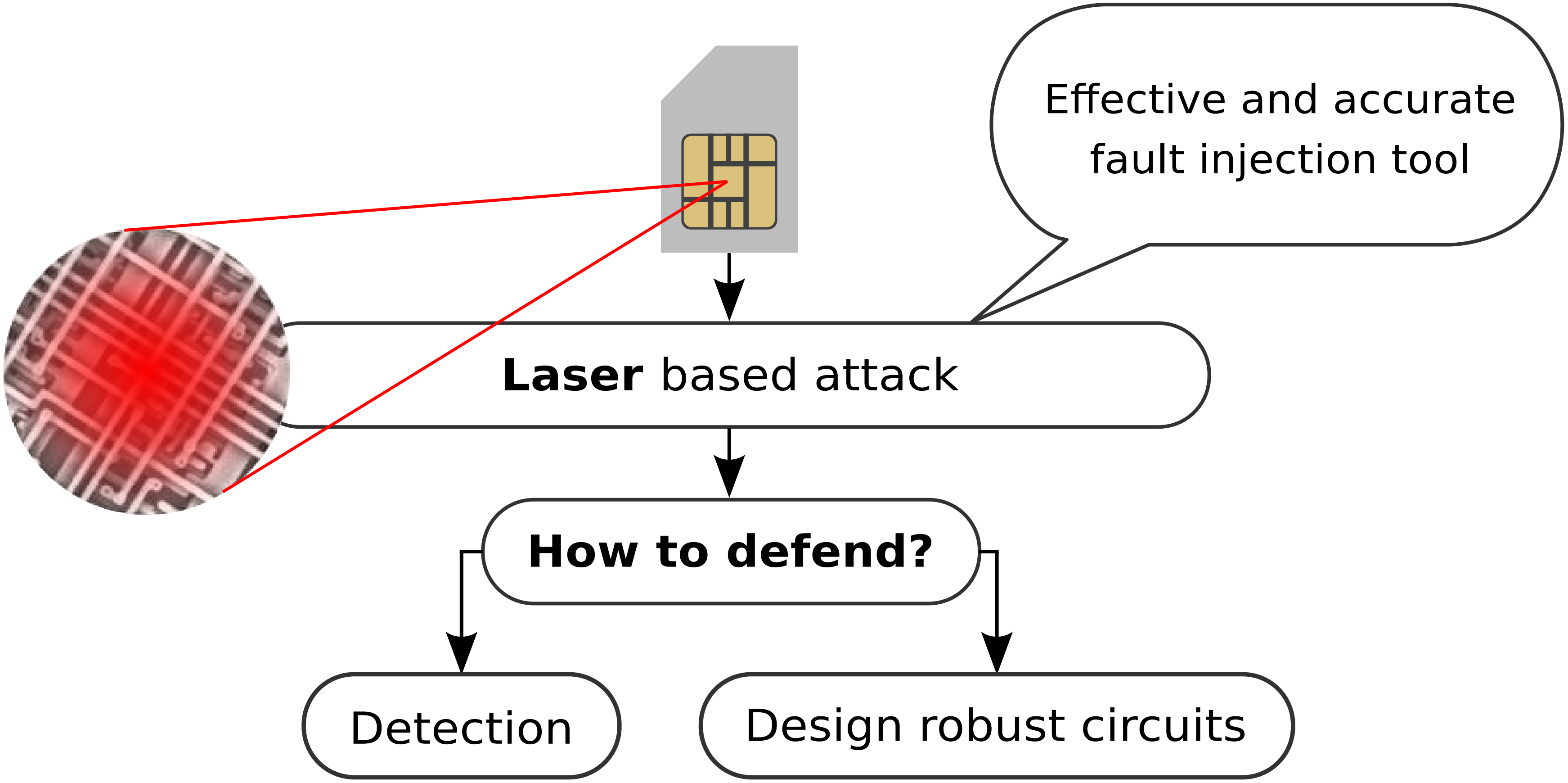
Laser based attack
How to defend?


Effective and accurate
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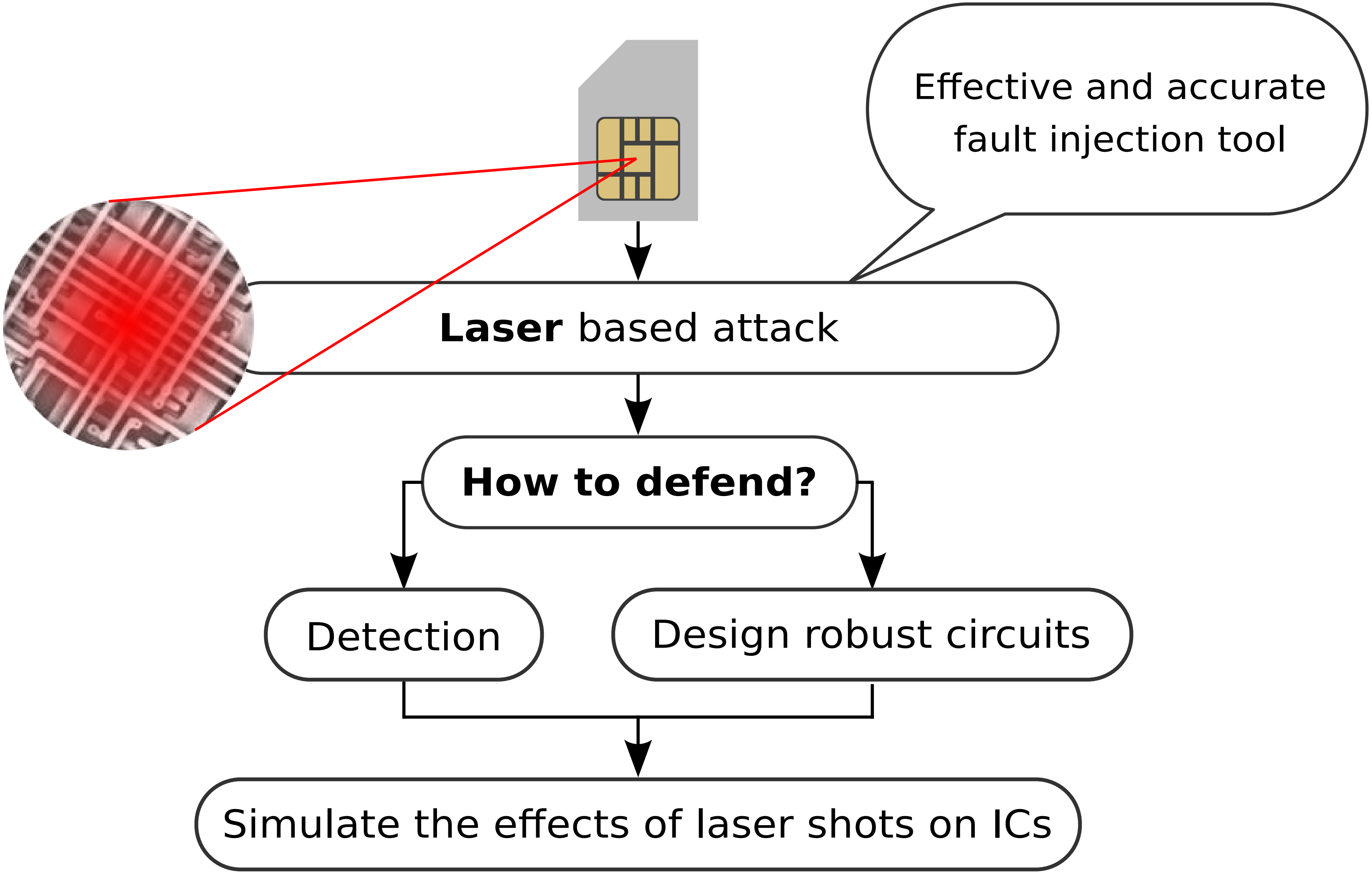
Laser based attack
How to defend?
Detection
Design robust circuits


Effective and accurate fault injection tool
Laser based attack
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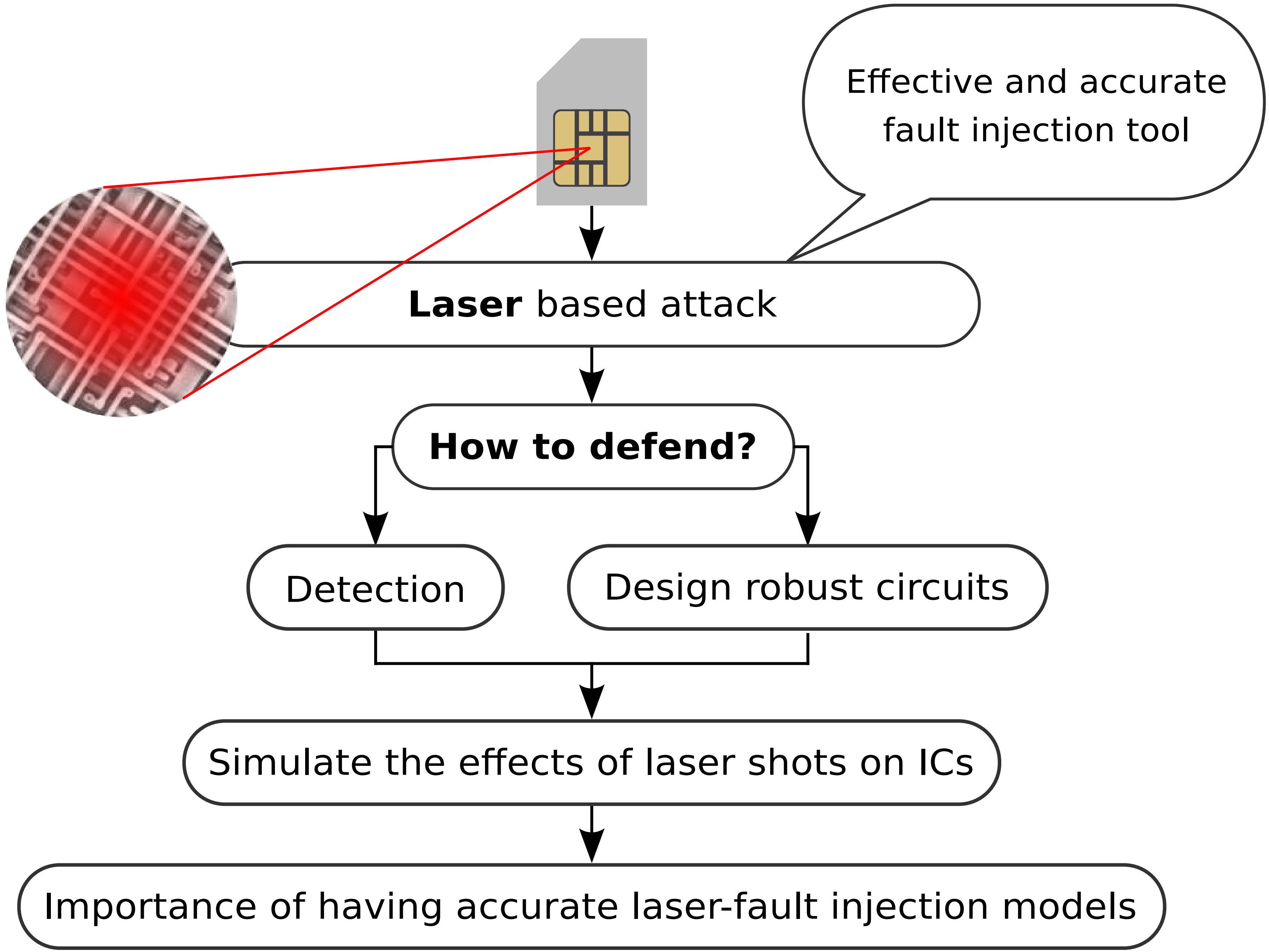
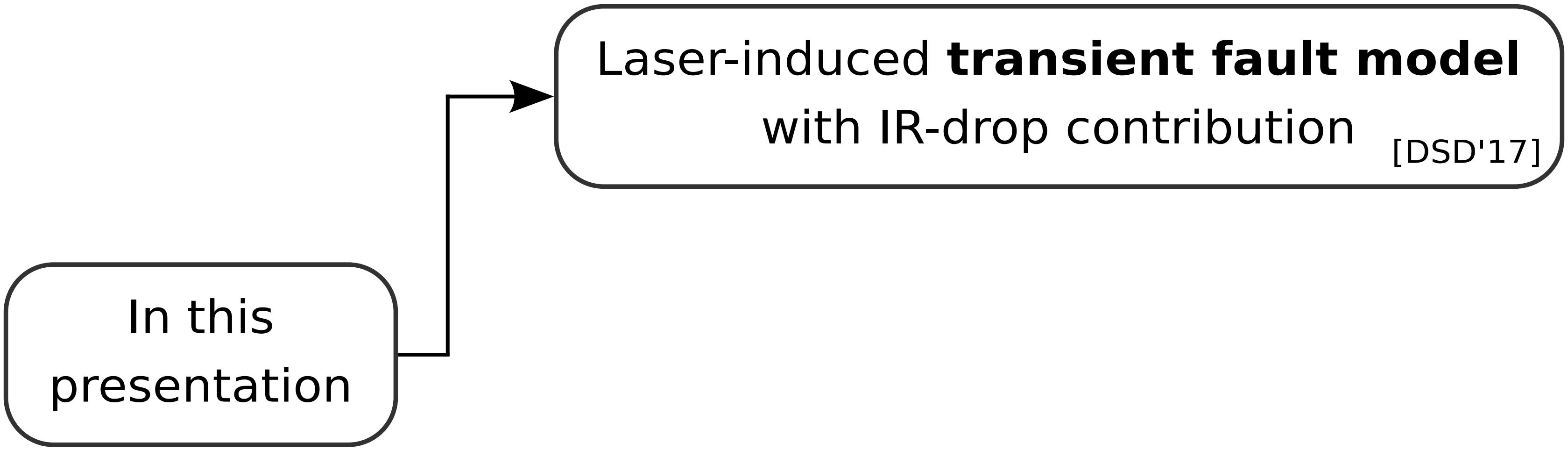
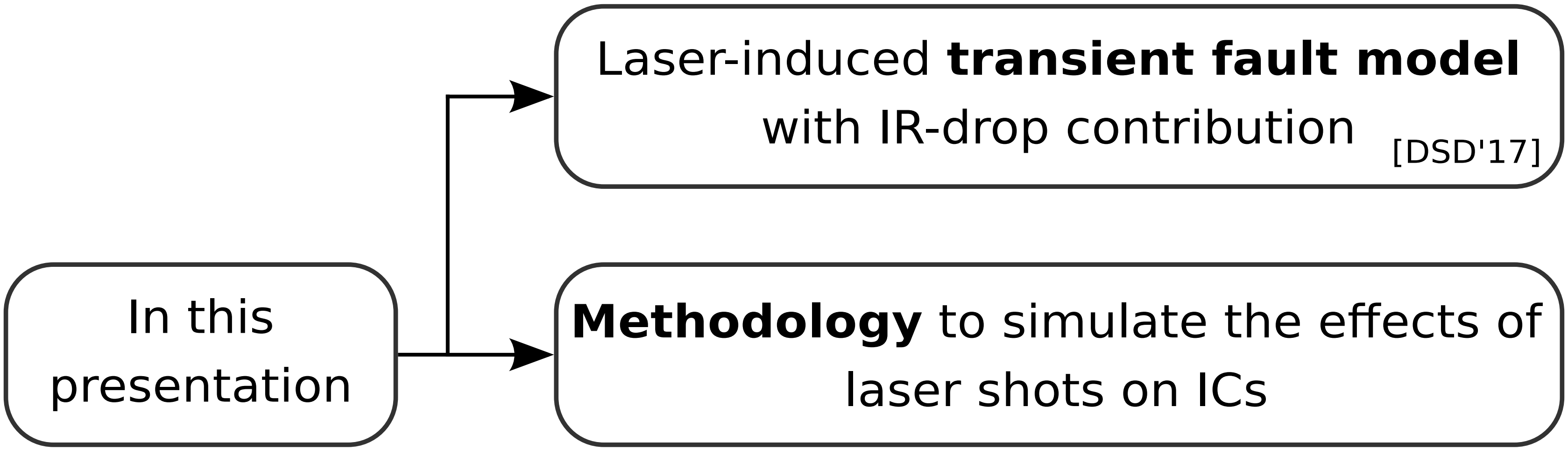
Detection
Design robust circuits
Simulate the effects of laser shots on ICs


Effective and accurate fault injection tool
Laser based attack
How to defend?
Detection
Design robust circuits
Simulate the effects of laser shots on ICs
Importance of having accurate laser-fault injection models


In this presentation
Laser-induced **transient fault model** with IR-drop contribution
[DSD'17]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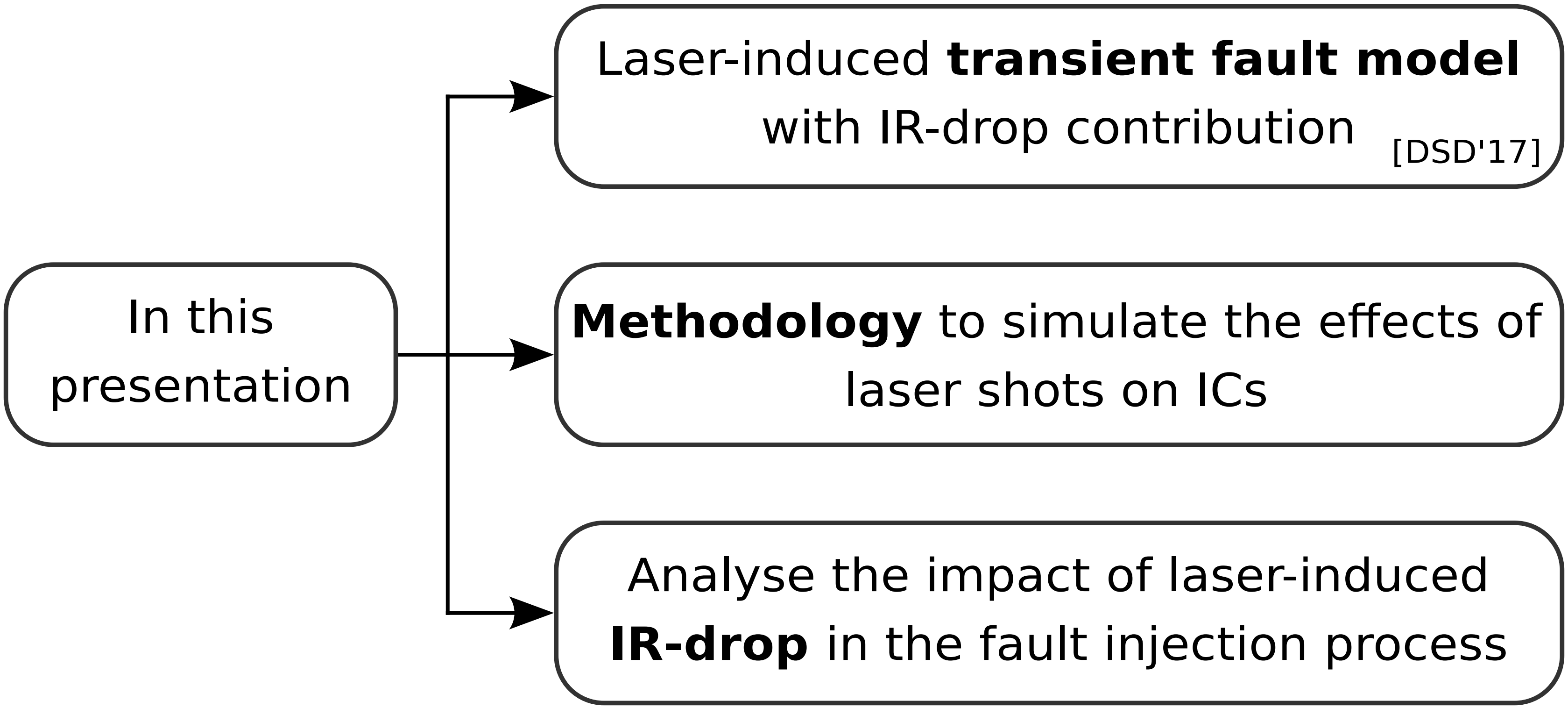
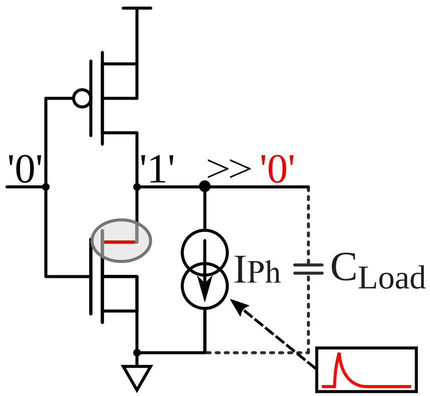
Methodology to simulate the effects of laser shots on ICs

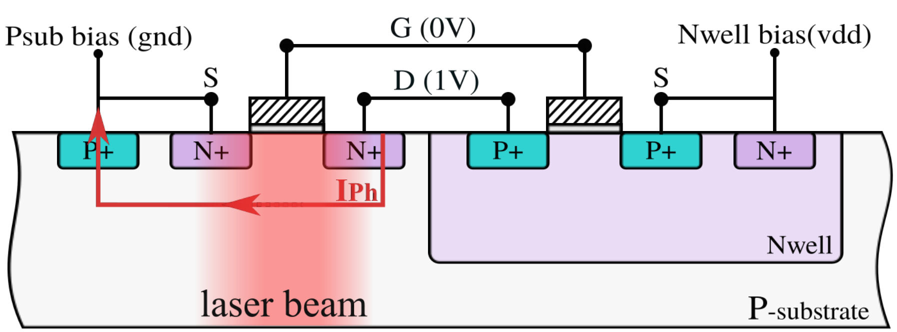

In this presentation
Laser-induced **transient fault model** with IR-drop contribution
[DSD'17]
Methodology to simulate the effects of laser shots on ICs
Analyse the impact of laser-induced **IR-drop** in the fault injection process

Outline

Outline

Classical model for simulating laser-induced transient currents on ICs





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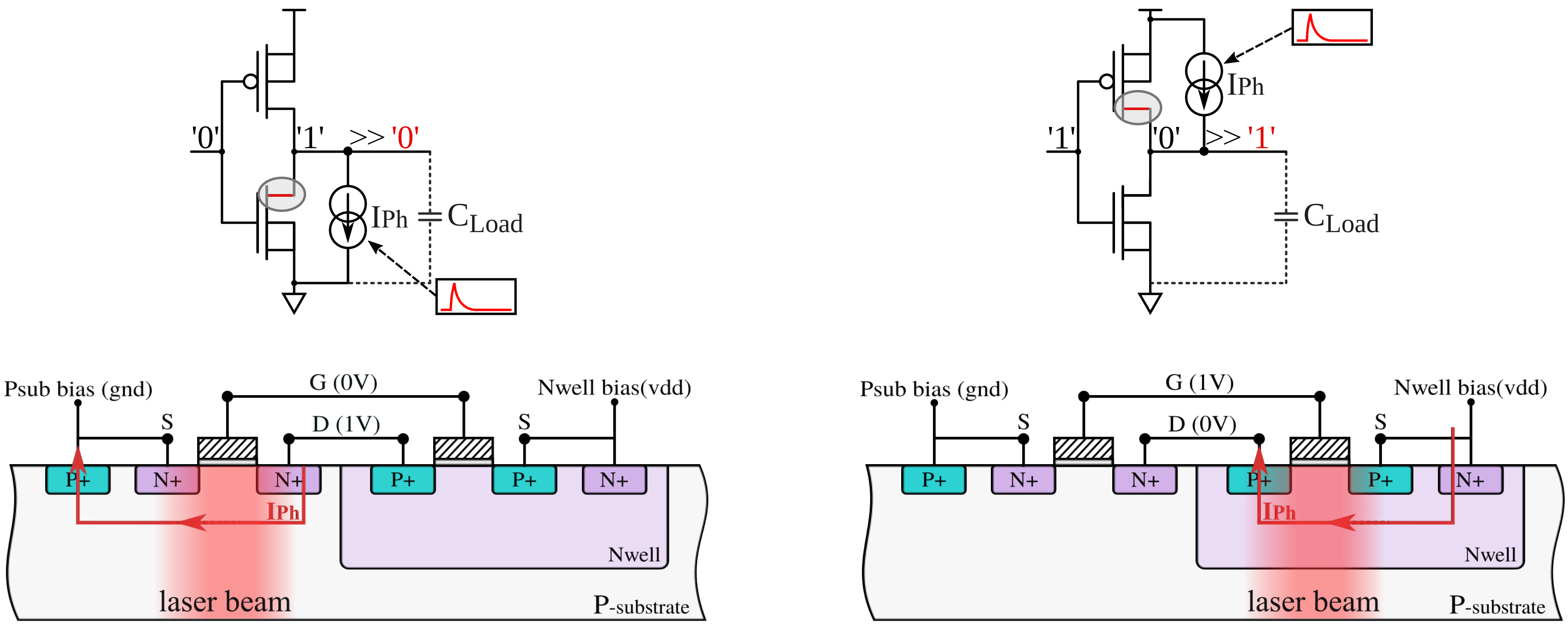
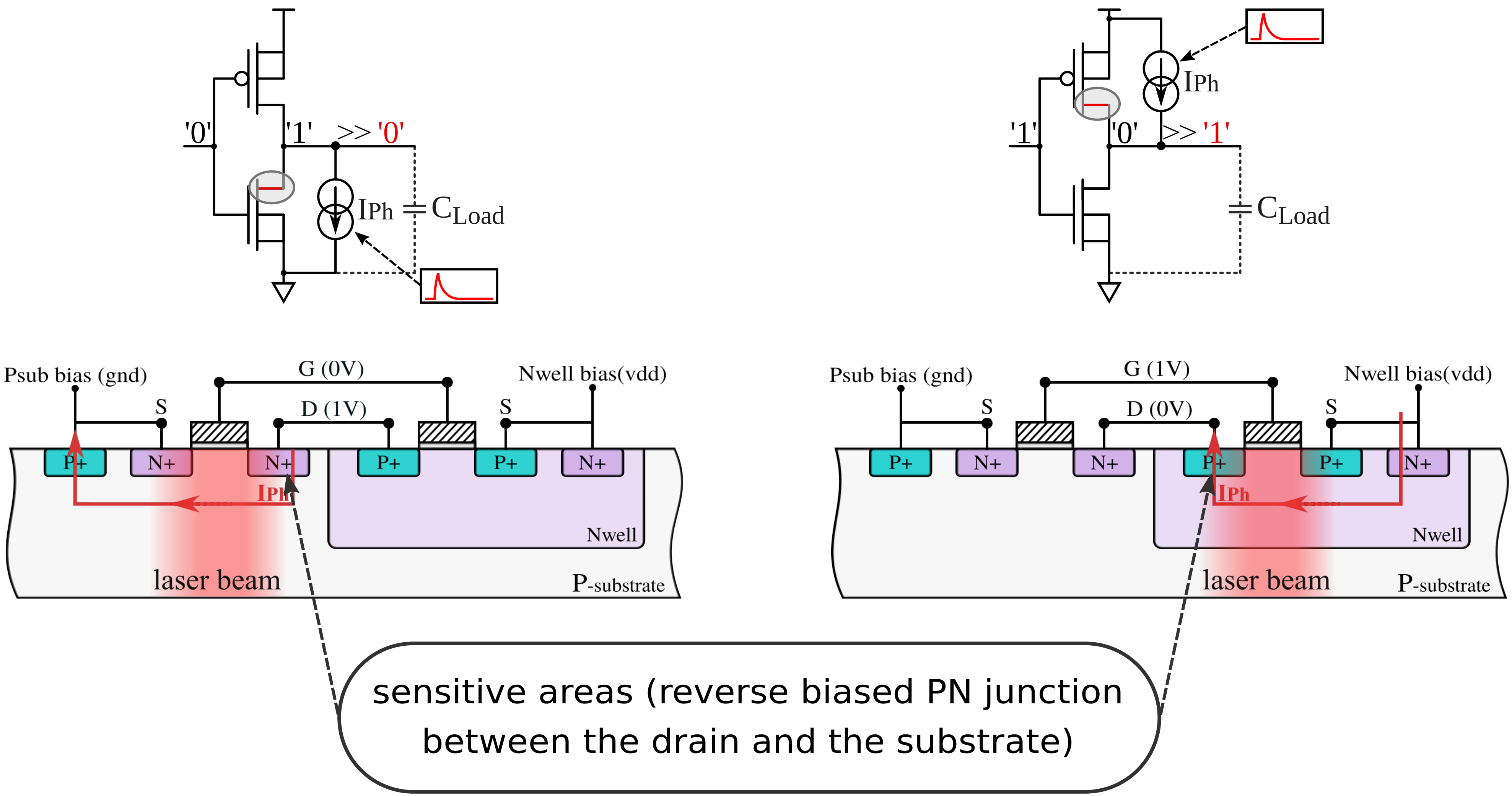
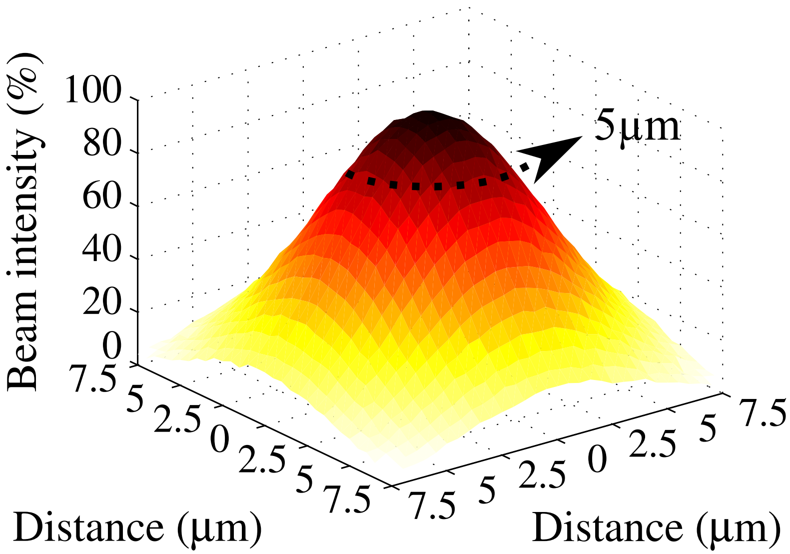


Classical model for simulating laser-induced transient currents on ICs



Spatial distribution of the laser-induced photocurrent



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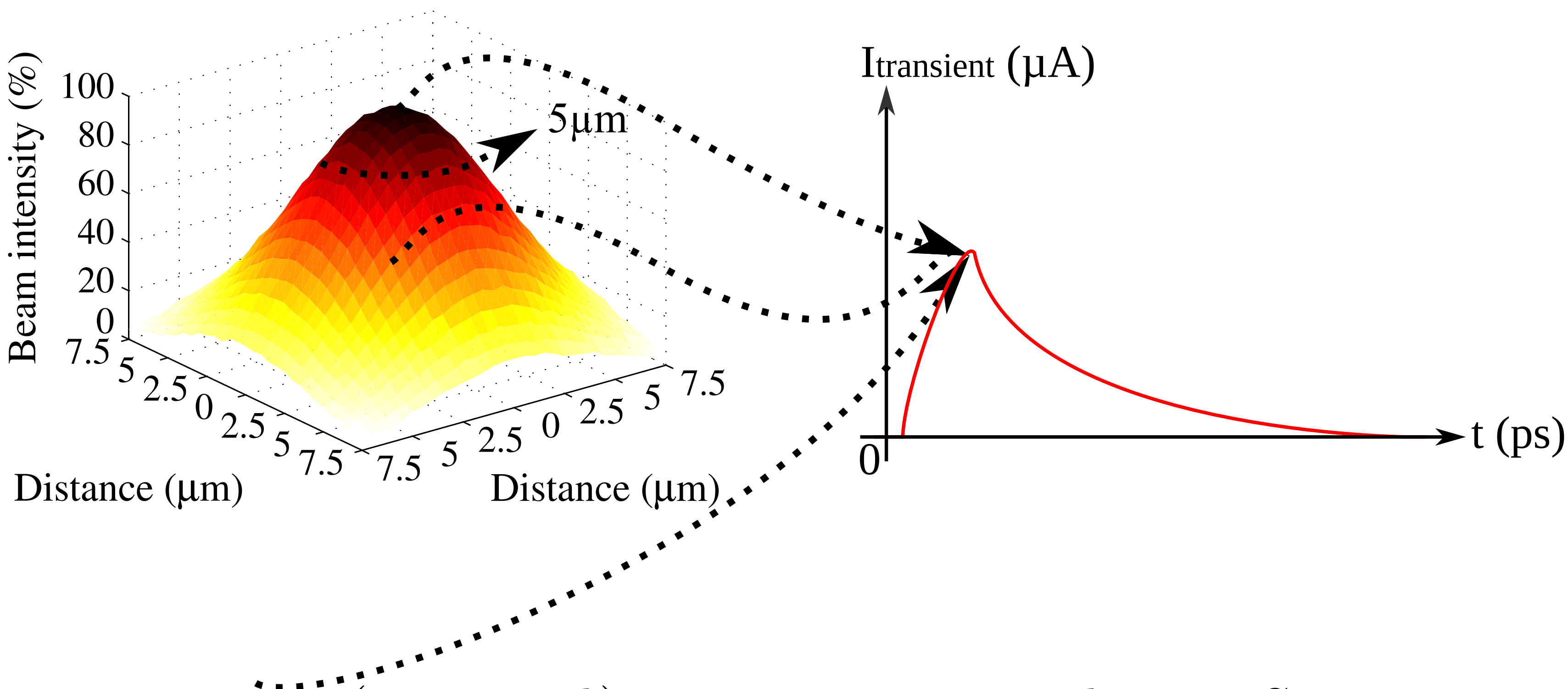
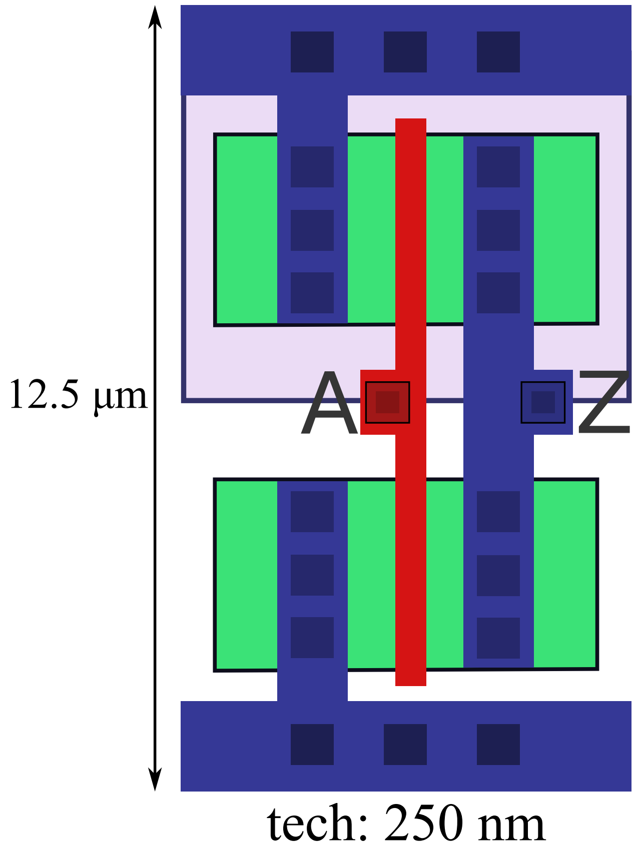


$$I_{ph_{\text{peak}}} = (a \times V + b) \times \alpha_{gauss(x,y)} \times Pulse_w \times S$$

A. Sarafianos et al., “Building the electrical model of the pulsed photoelectric laser stimulation of an nmos transistor in 90nm technology”

Standard cell(s) illuminated by a 5µm laser spot diameter



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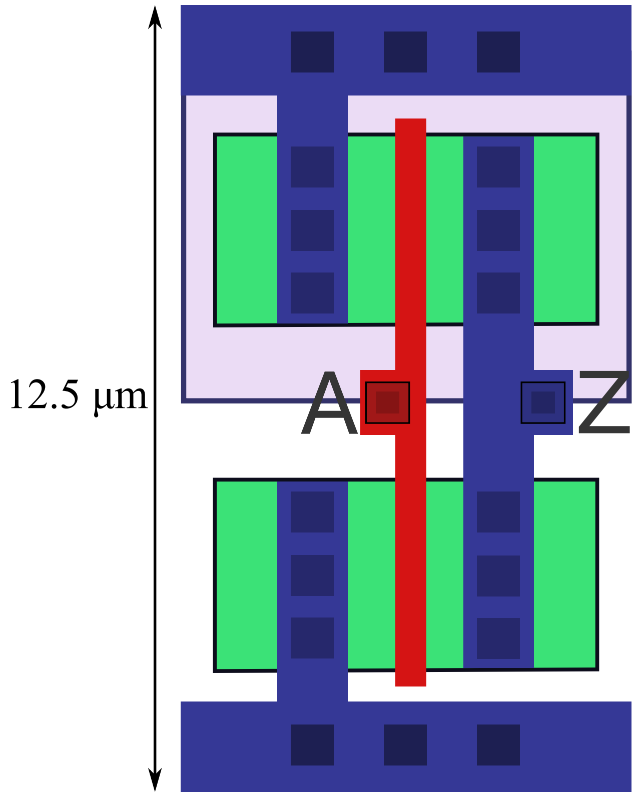
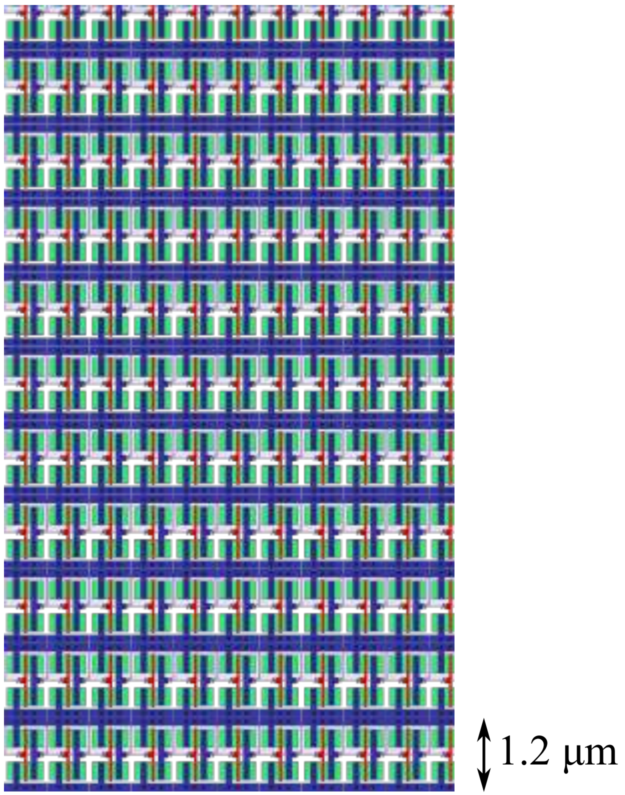
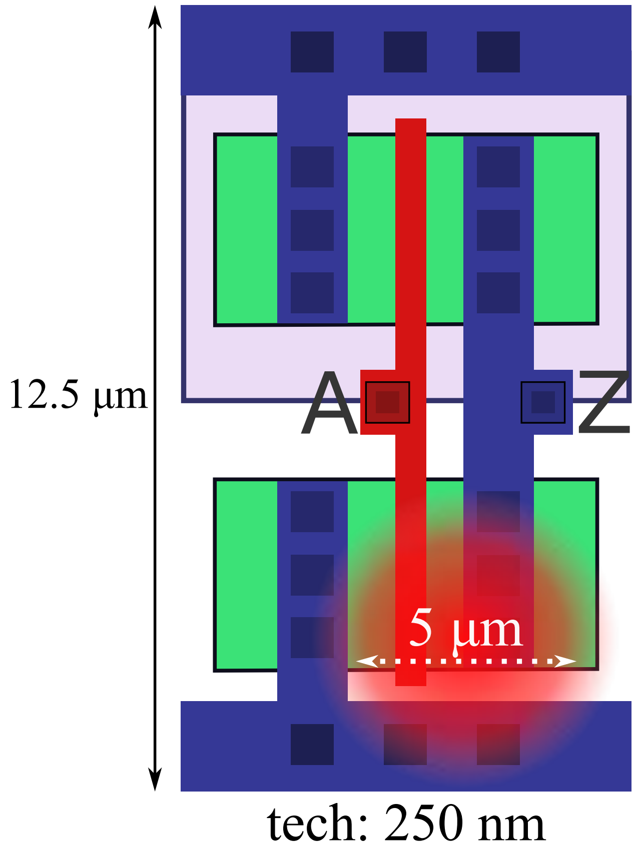


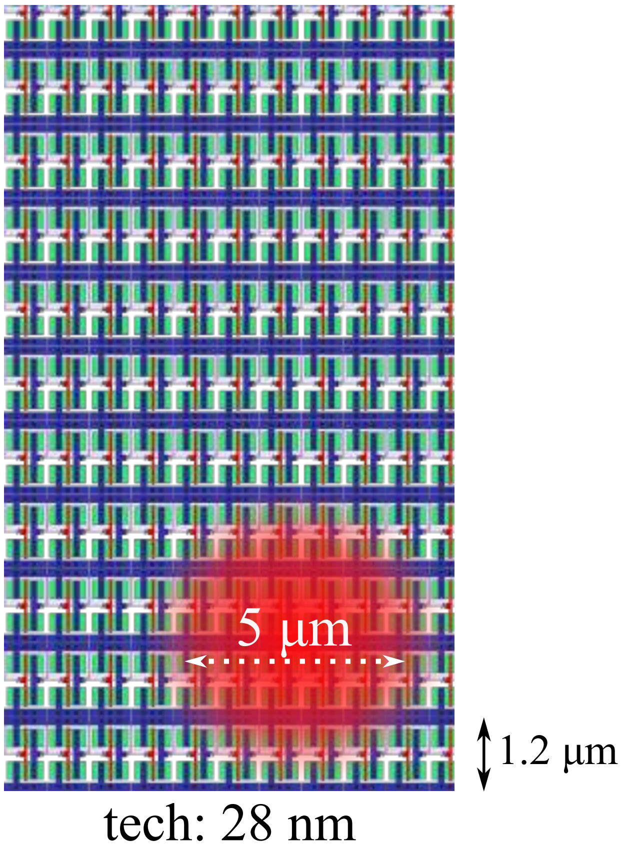
tech: 250 nm



tech: 28 nm

Standard cell(s) illuminated by a 5µm laser spot diameter





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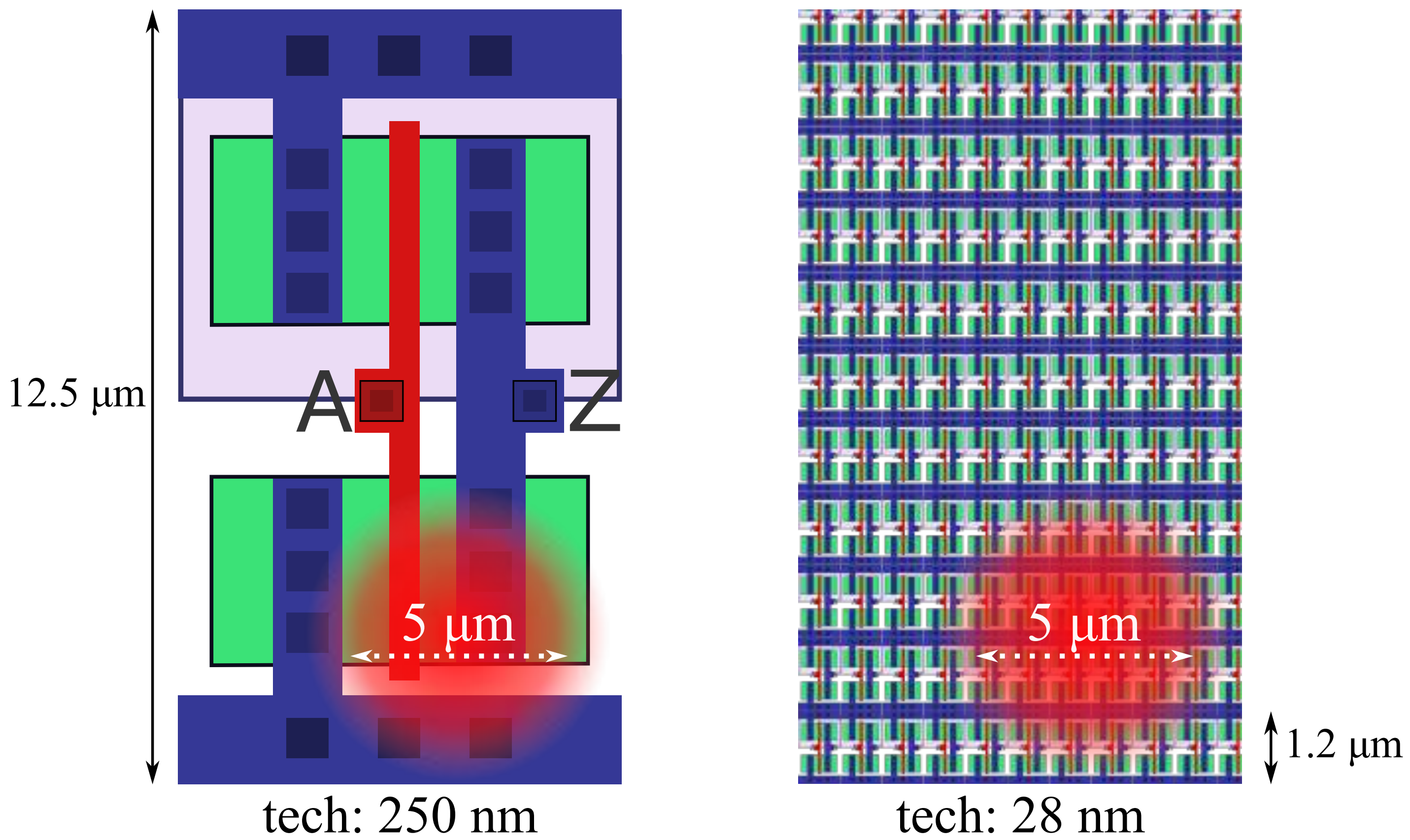
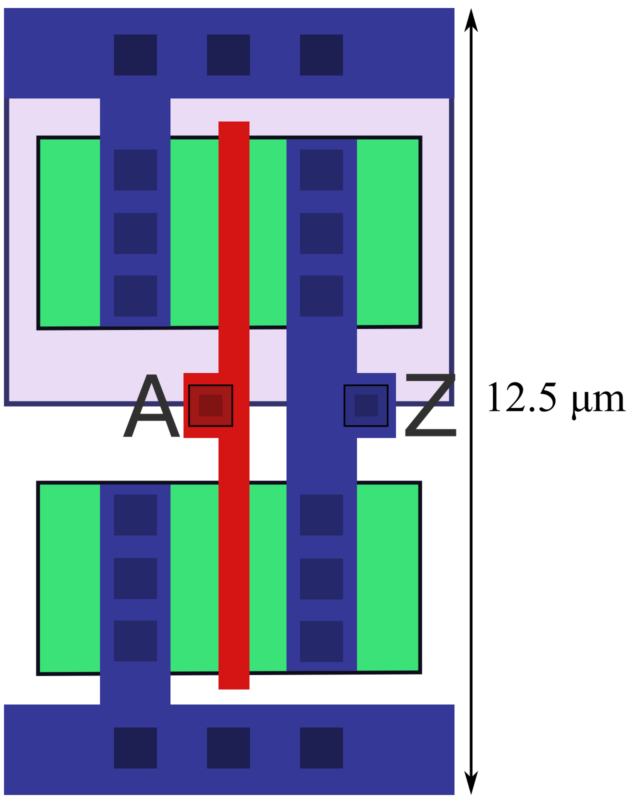
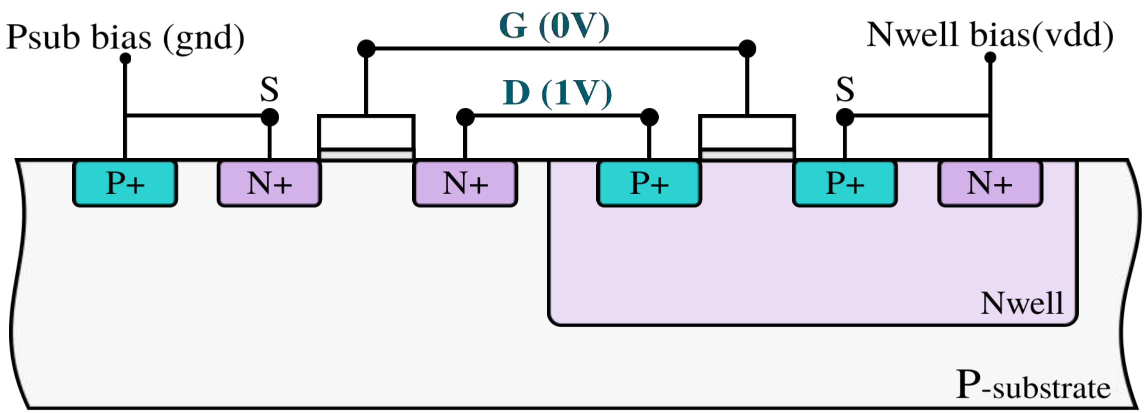


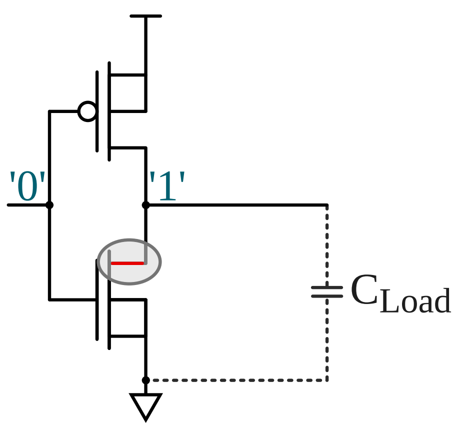
How does the standard cell height influence
in the fault injection process?

Case 1:
Only NMOS transistors are illuminated by the laser beam



tech: 250 nm





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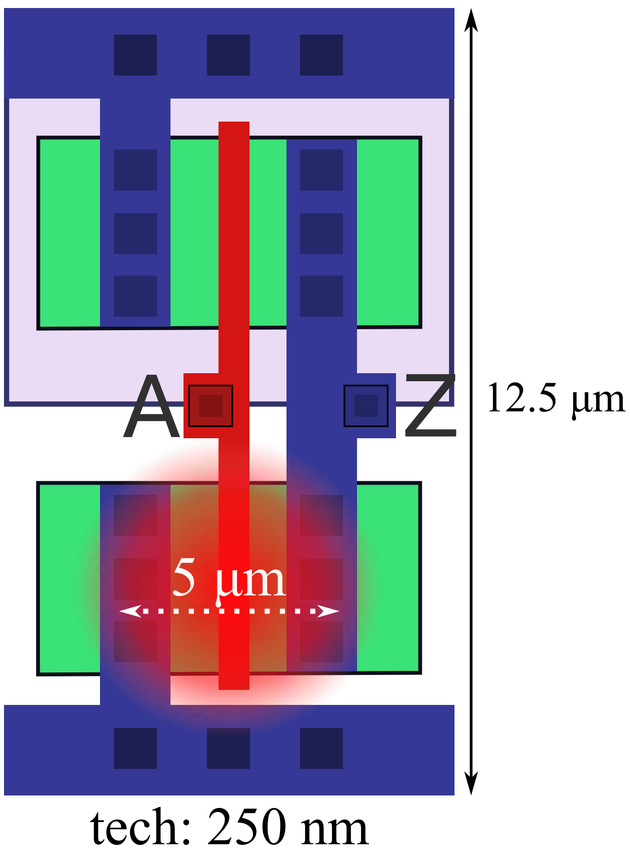

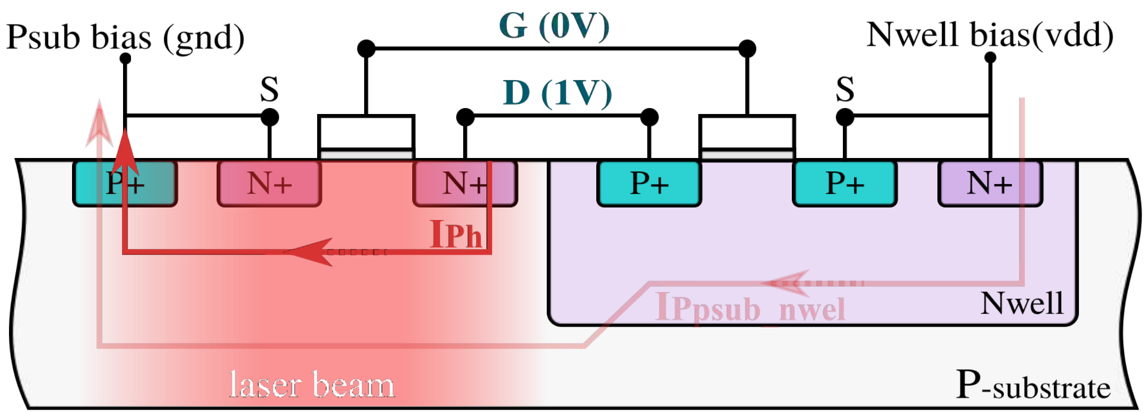

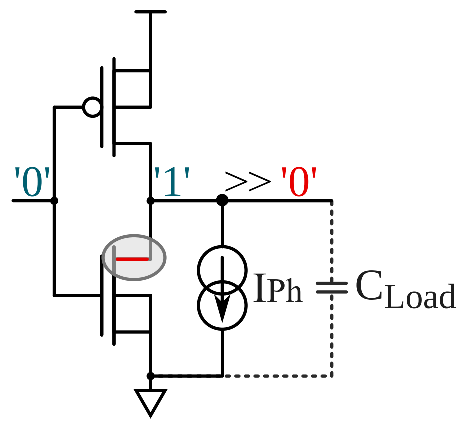

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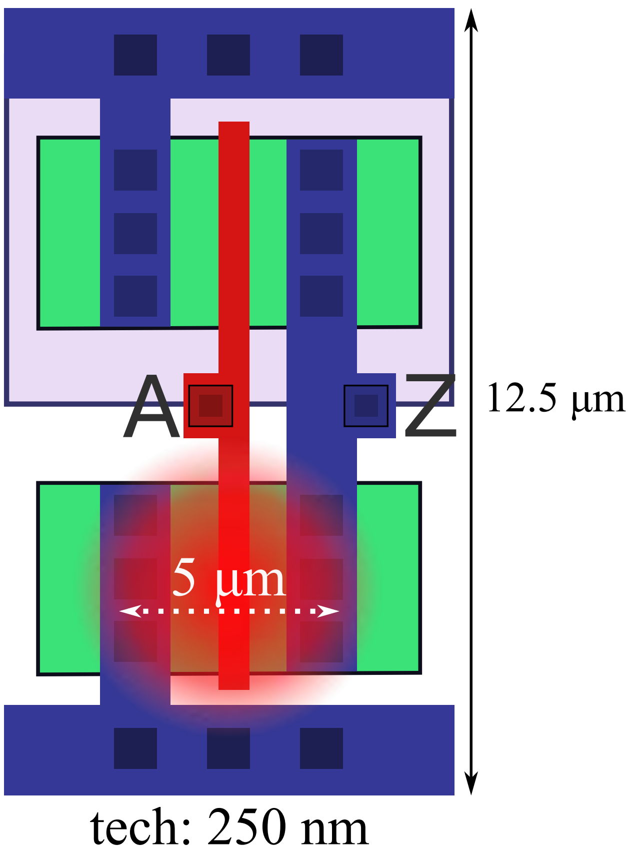
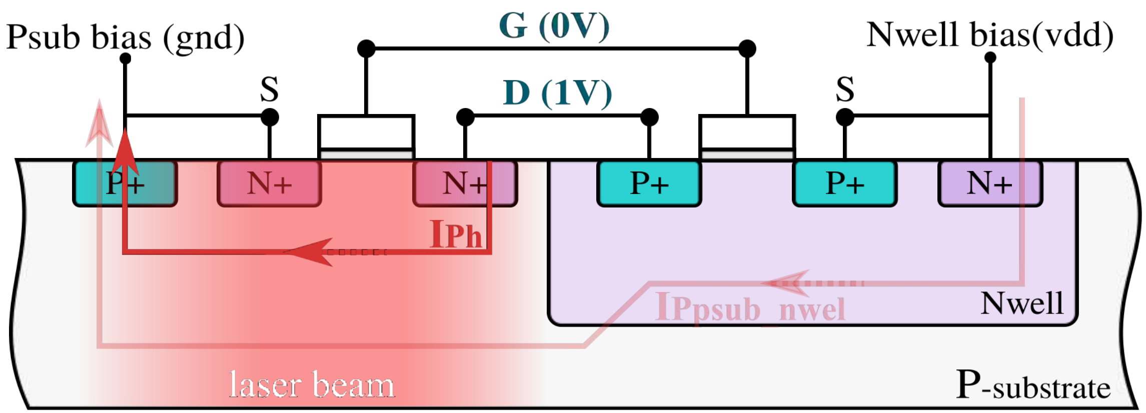
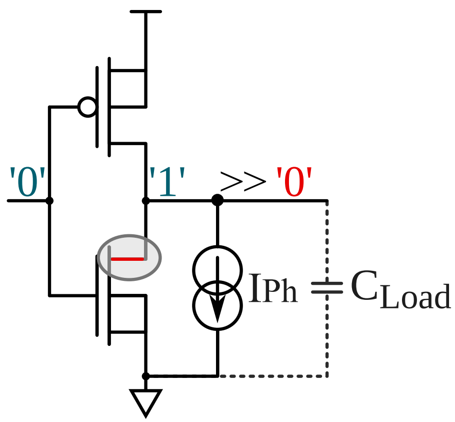


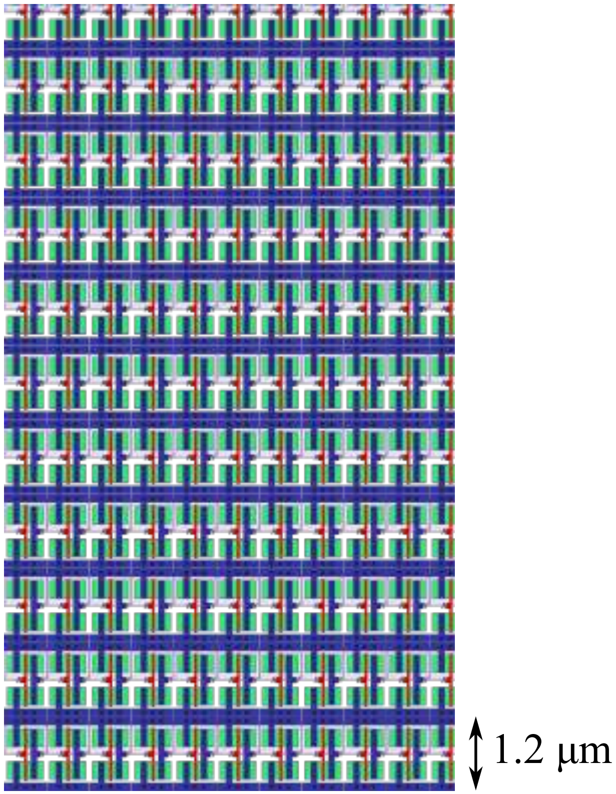




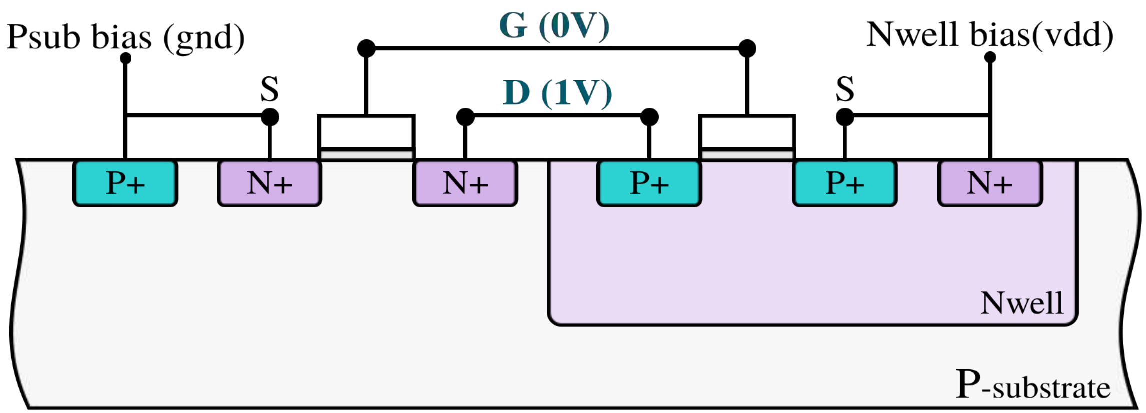
Weak laser-induced currents in the Nwell-Psub junction (classical model is OK)

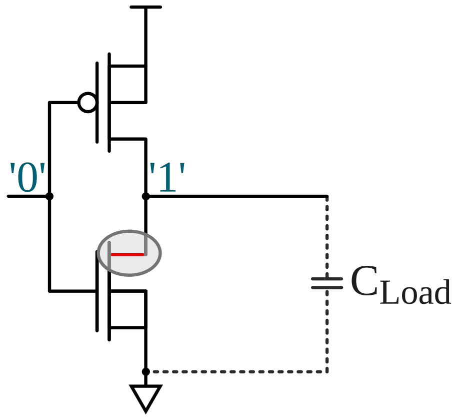
Case 2:

NMOS and PMOS transistors are **always** illuminated by the laser beam



tech: 28 nm





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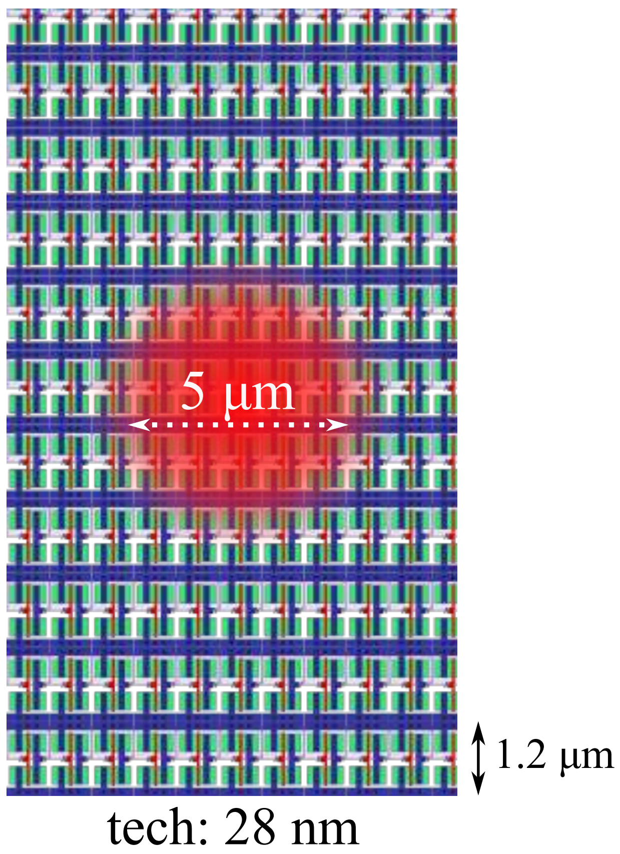

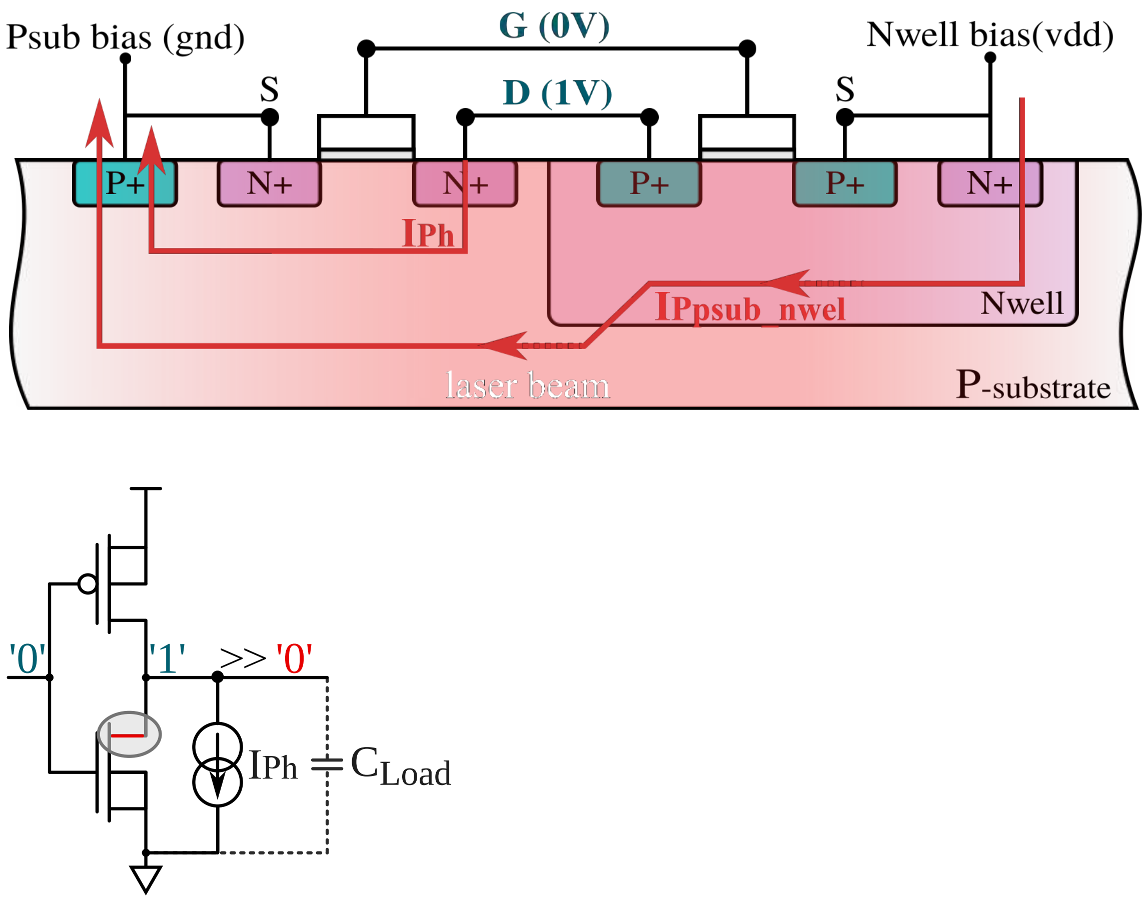

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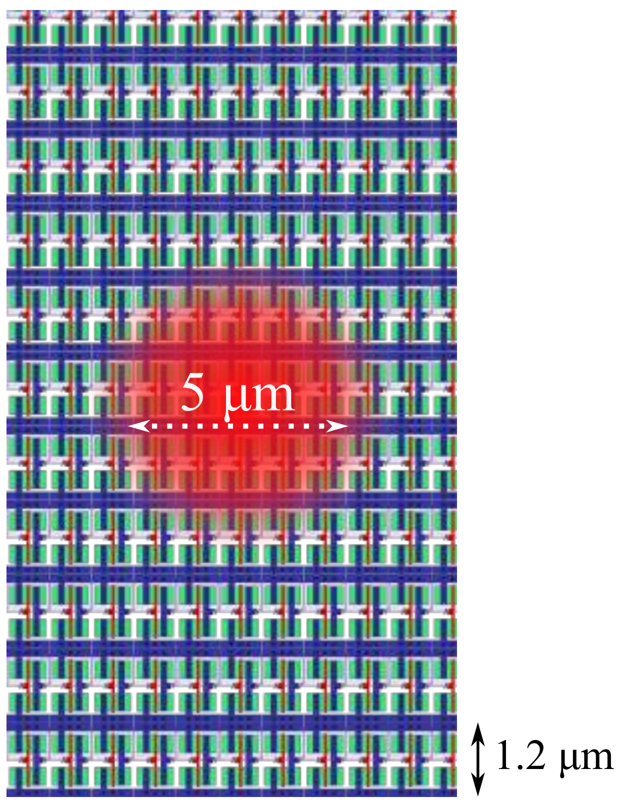

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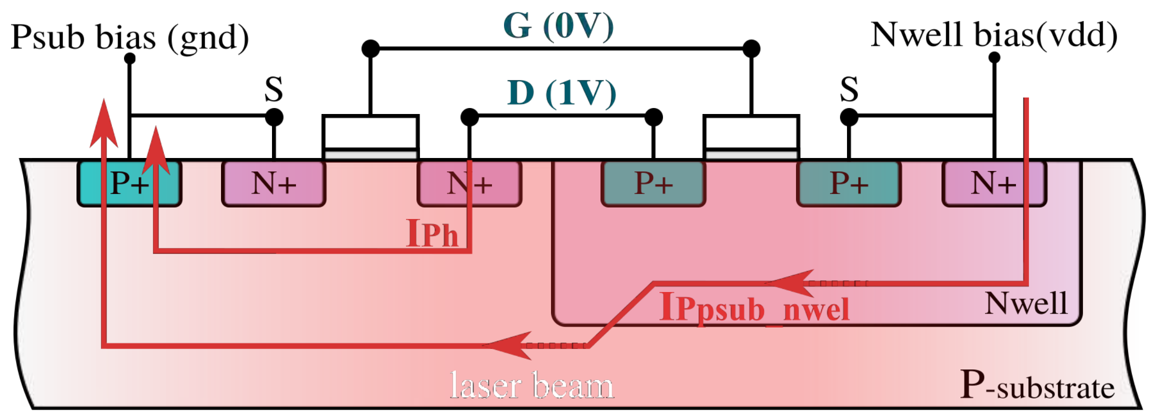
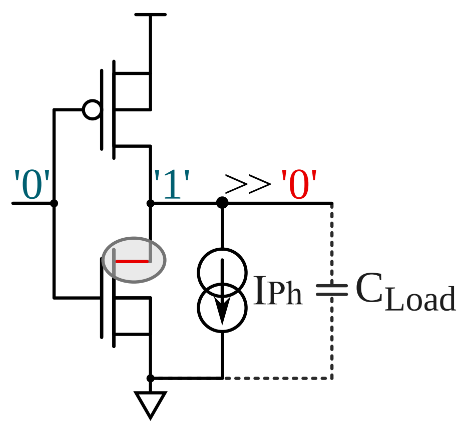




Laser-induced currents
in the Nwell-Psub junction
(classical model is **incomplete**)

Outline

Outline

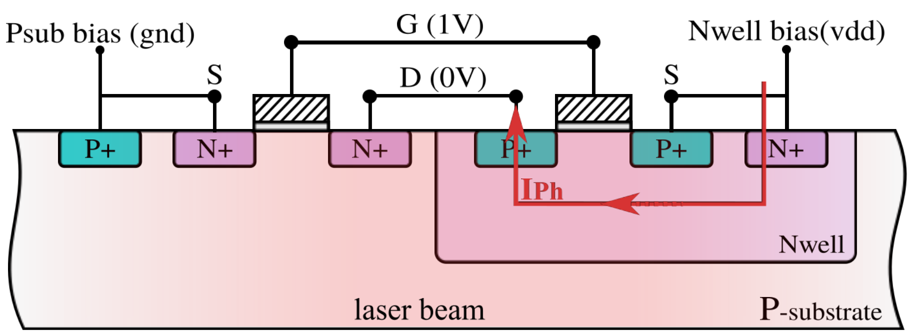
3.1 - Upgraded electrical model

Classical Model

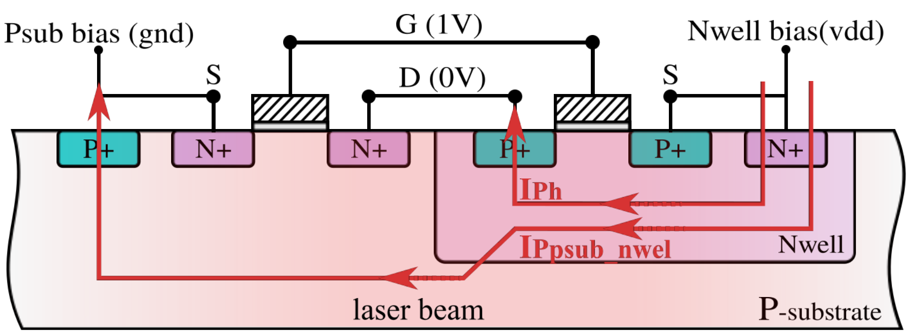
Upgraded Electrical Model

3.1 - Upgraded electrical model

Classical Model



Upgraded Electrical Model



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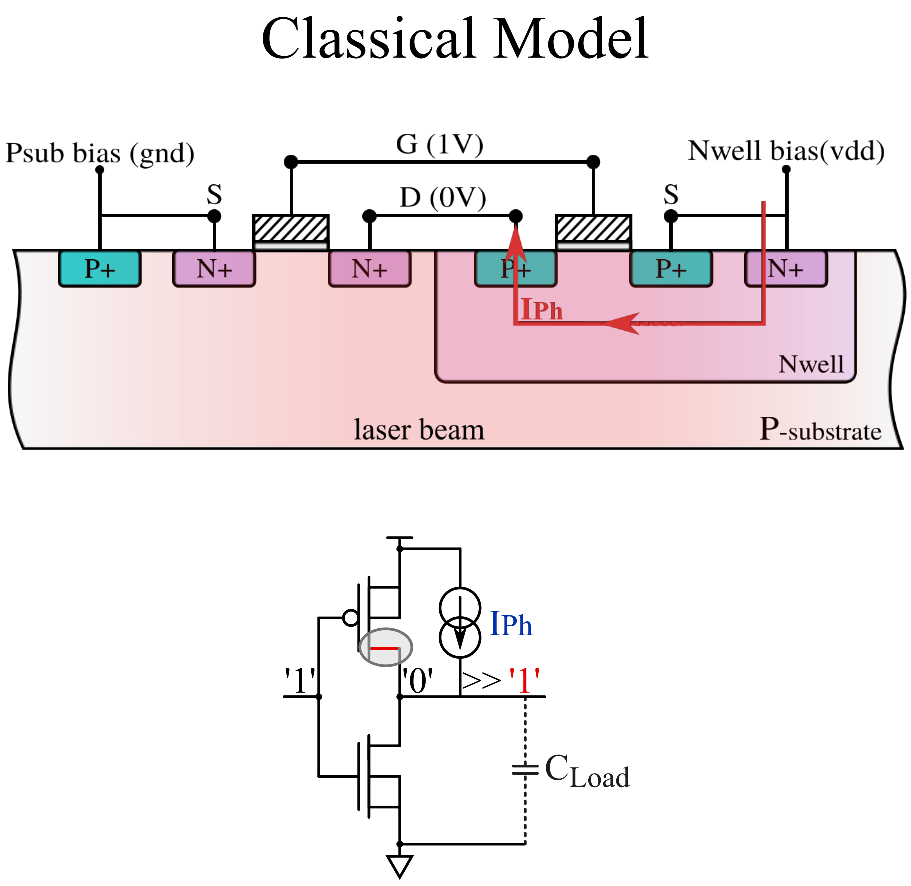
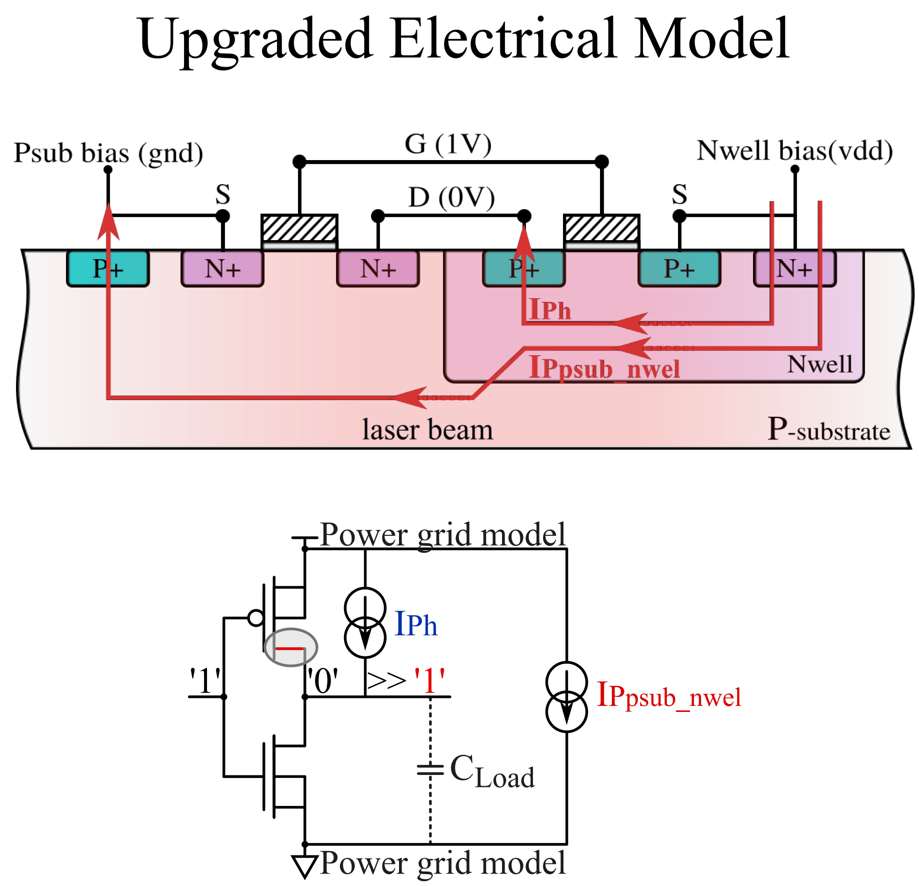


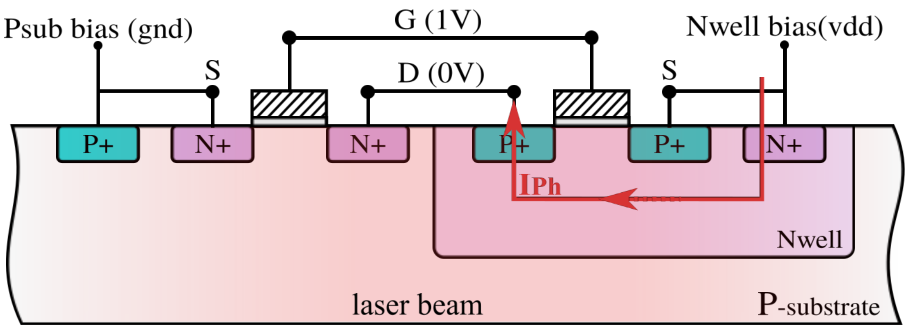


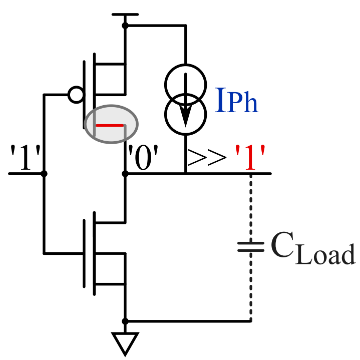
$$I_{ph} = (a \times V + b) \times \alpha_{gauss(x,y)} \times Pulse_w \times S$$

$$IP_{Psub\_nwell} = factor \times I_{ph}$$

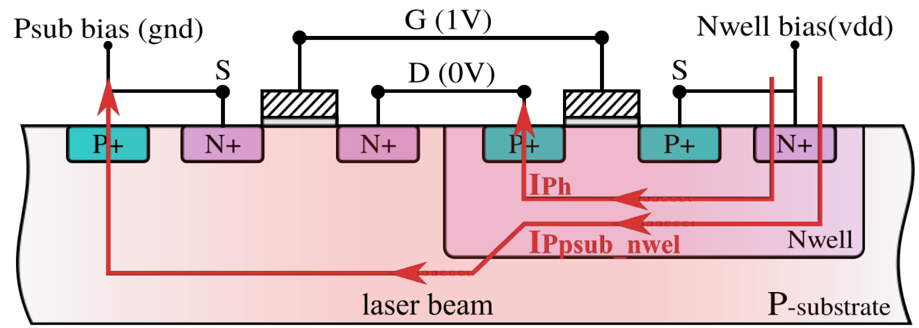
3.1 - Upgraded electrical model

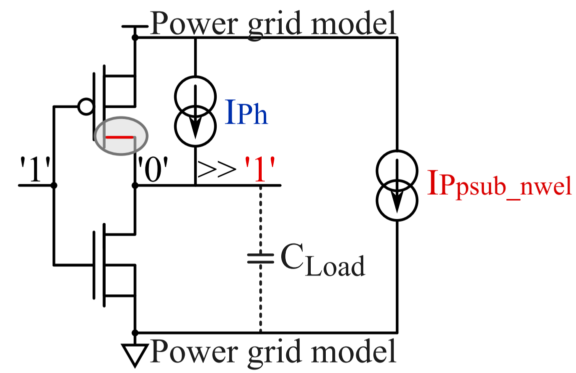
Classical Model





Upgraded Electrical Model





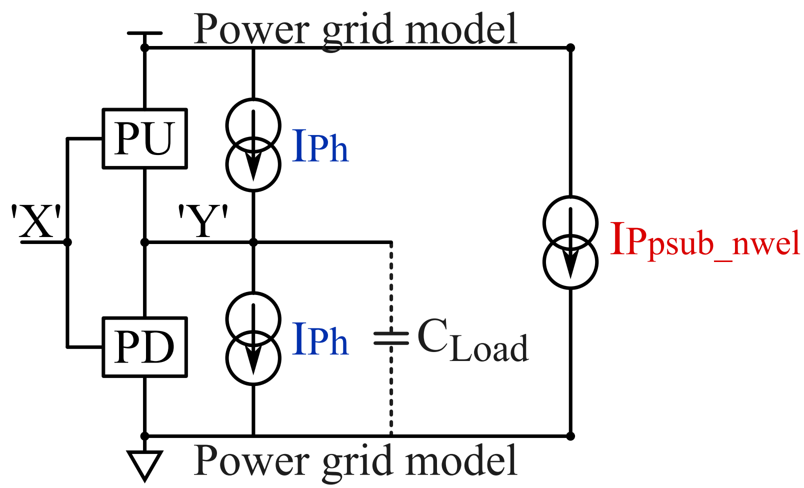
$$I_{ph} = (a \times V + b) \times \alpha_{gauss(x,y)} \times Pulse_w \times S$$

$$IP_{Psub\_nwell} = factor \times I_{ph}$$

(>10)

J.M. Dutertre et al., “Improving the ability of Bulk Built-In Current Sensors to detect Single Event Effects by using triple-well CMOS

Upgraded Electrical Model



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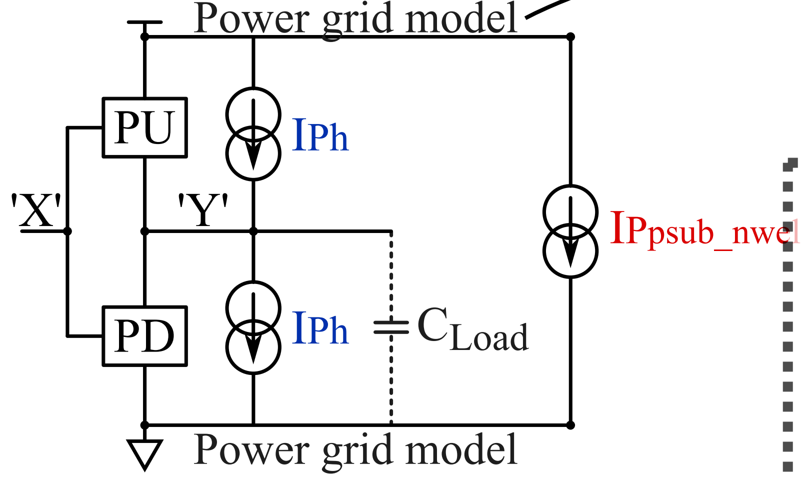
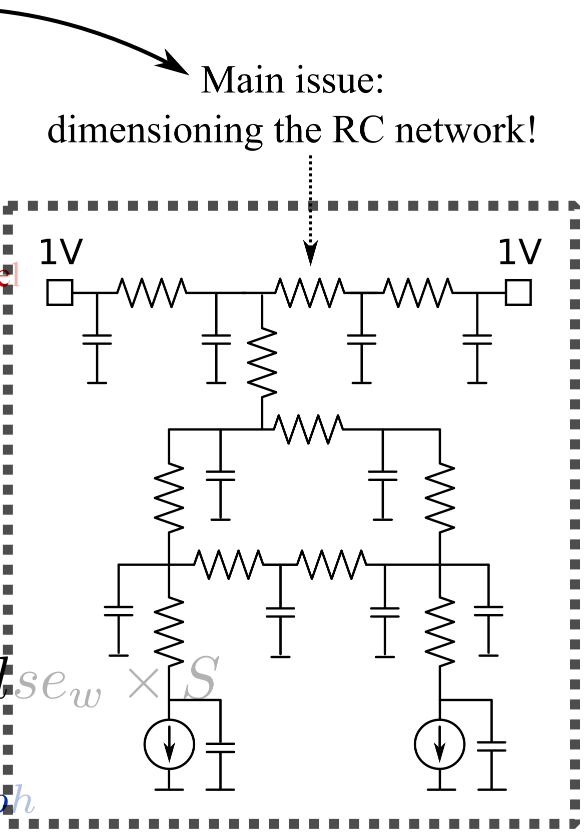
(>10)

Upgraded Electrical Model





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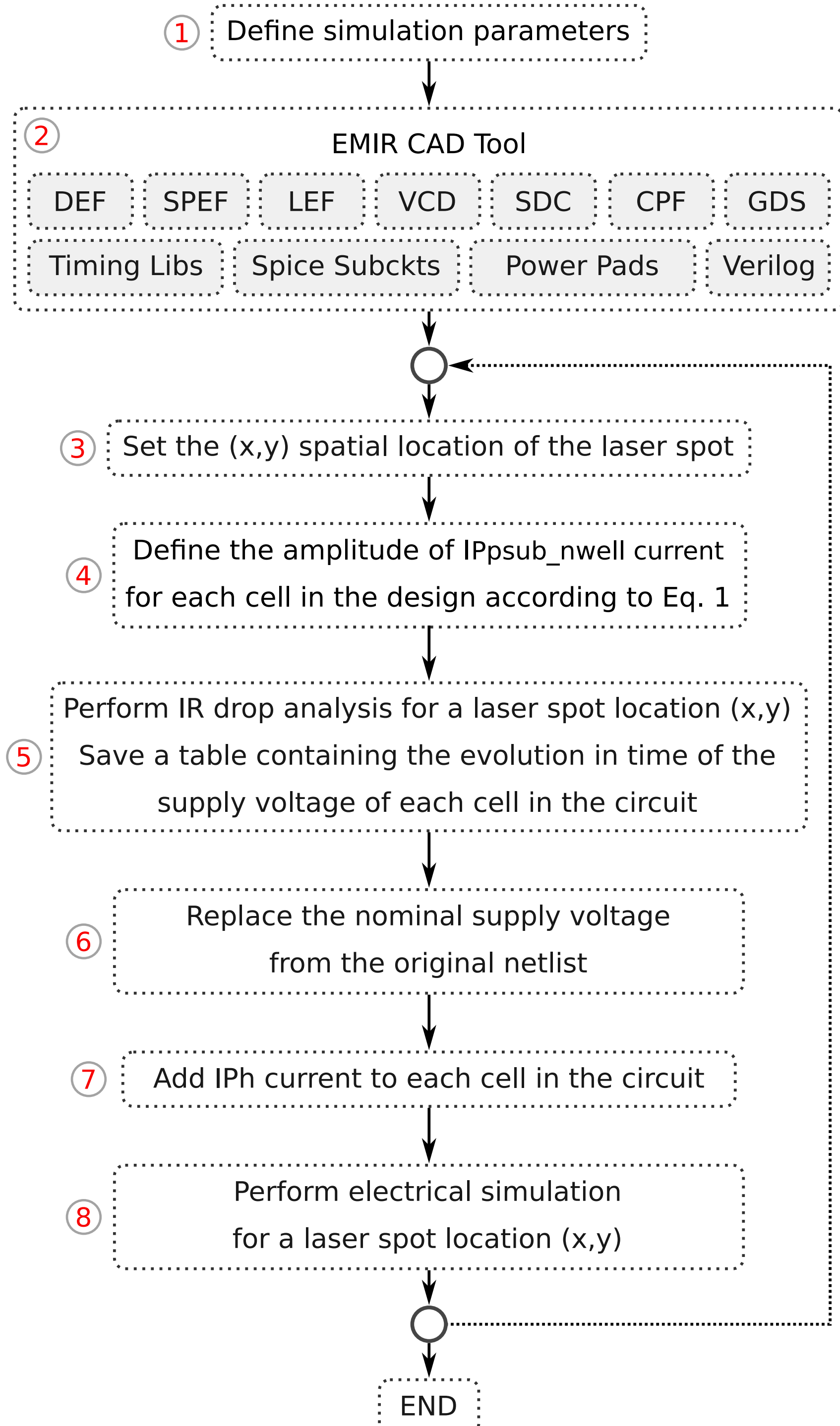
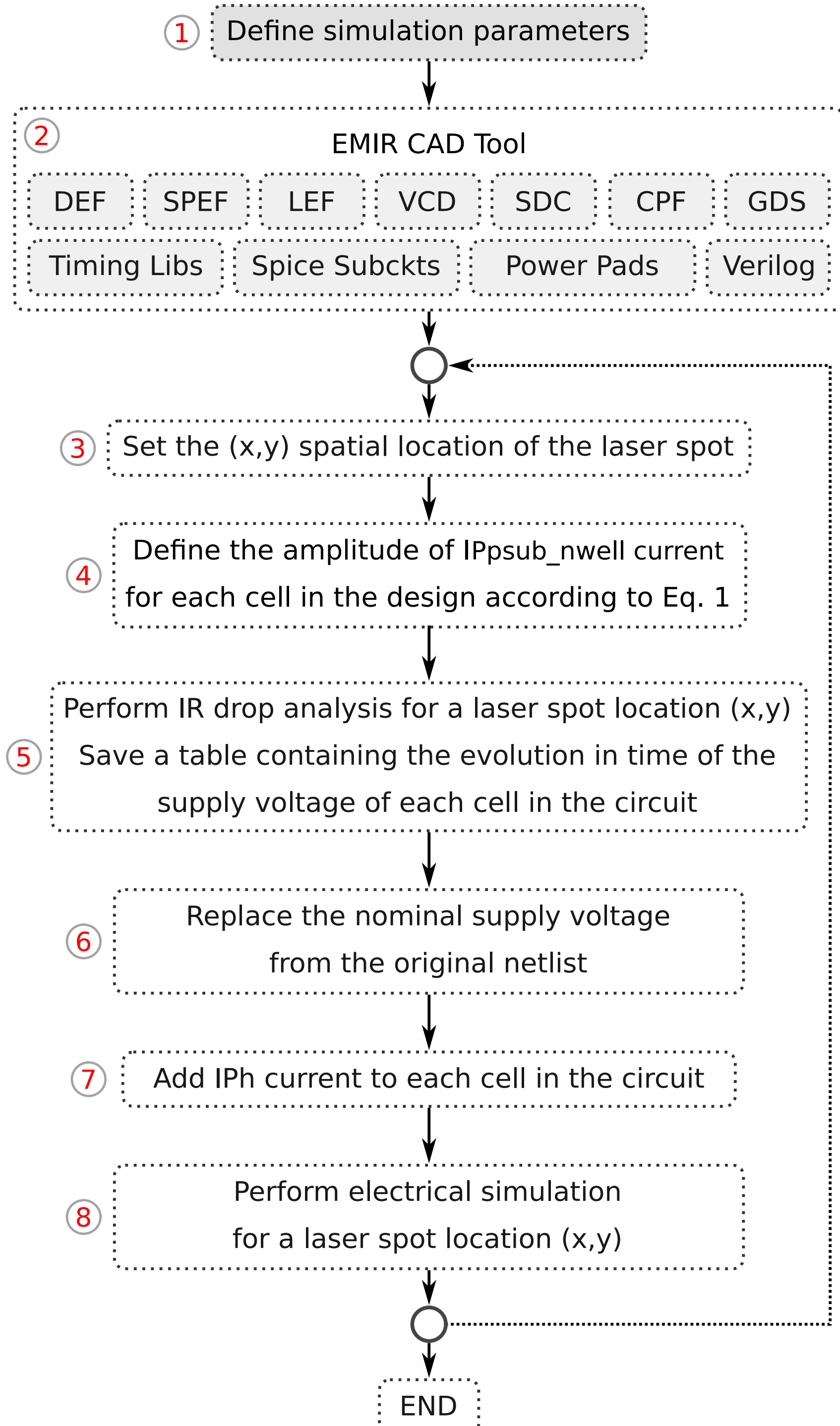
(>10)

Outline

Outline


1
Define simulation parameters
2
EMIR CAD Tool
DEF
SPEF
LEF
VCD
SDC
CPF
GDS
Timing Libs
Spice Subckts
Power Pads
Verilog
3
Set the (x,y) spatial location of the laser spot
4
Define the amplitude of IPpsub_nwell current
for each cell in the design according to Eq. 1
5
Perform IR drop analysis for a laser spot location (x,y)
Save a table containing the evolution in time of the
supply voltage of each cell in the circuit
6
Replace the nominal supply voltage
from the original netlist
7
Add IPh current to each cell in the circuit
8
Perform electrical simulation
for a laser spot location (x,y)
END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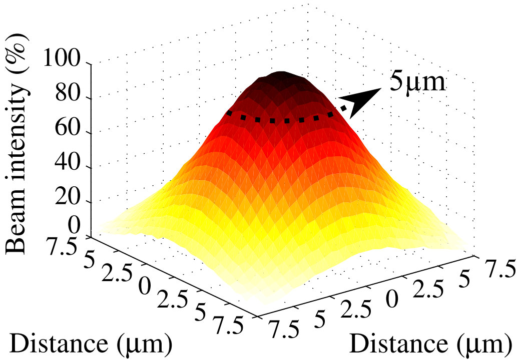
END

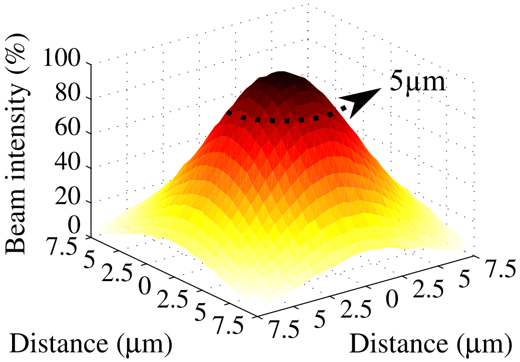
1 Define simulation parameters

Laser beam diameter - Laser shot power

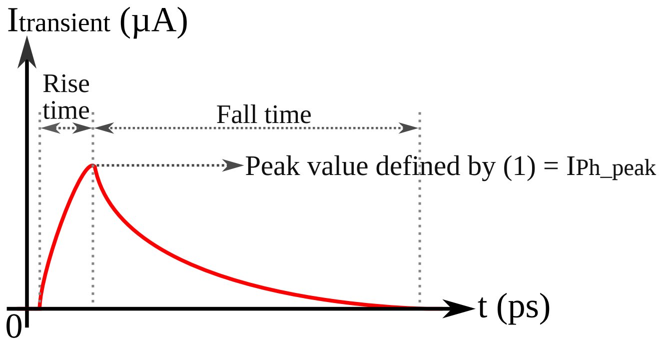


1 Define simulation parameters

Laser beam diameter - Laser shot power

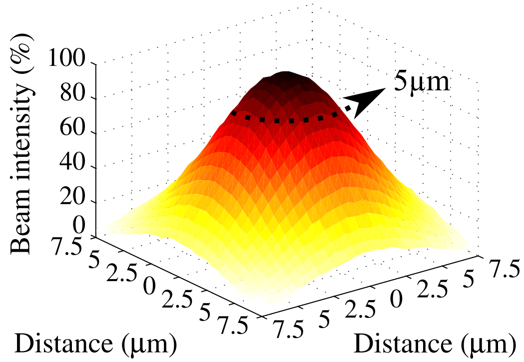


Laser shot duration

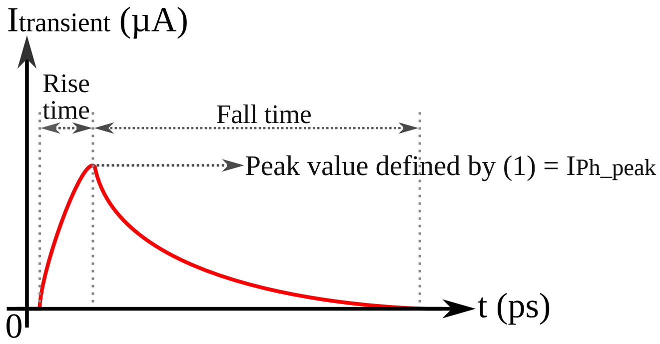


1 Define simulation parameters

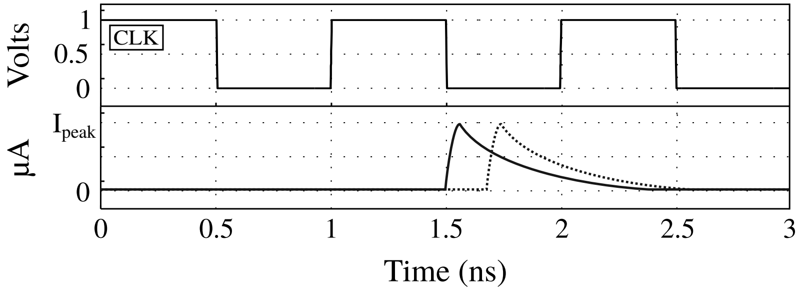
Laser beam diameter - Laser shot power



Laser shot duration

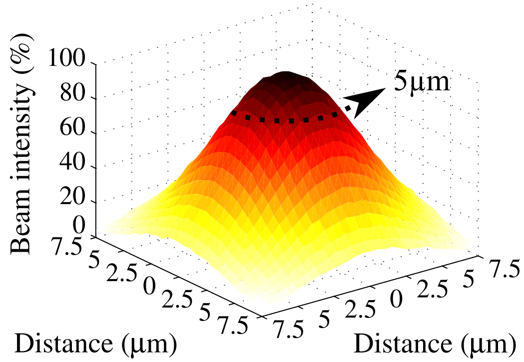


Time at which the laser shot occurs w.r.t. the zero of the simulation

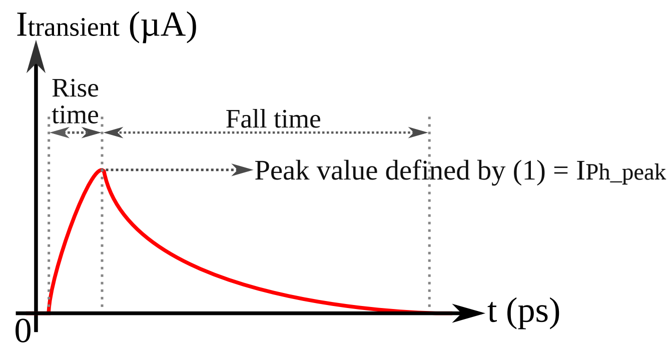


① Define simulation parameters

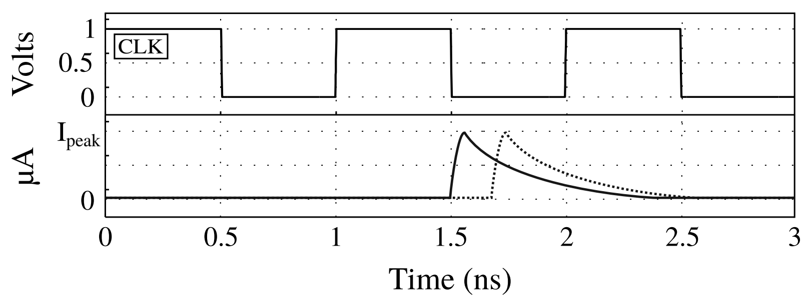
Laser beam diameter - Laser shot power



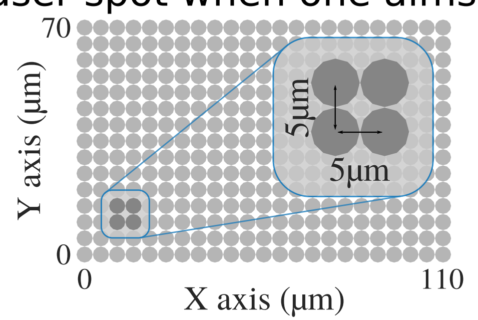
Laser shot duration

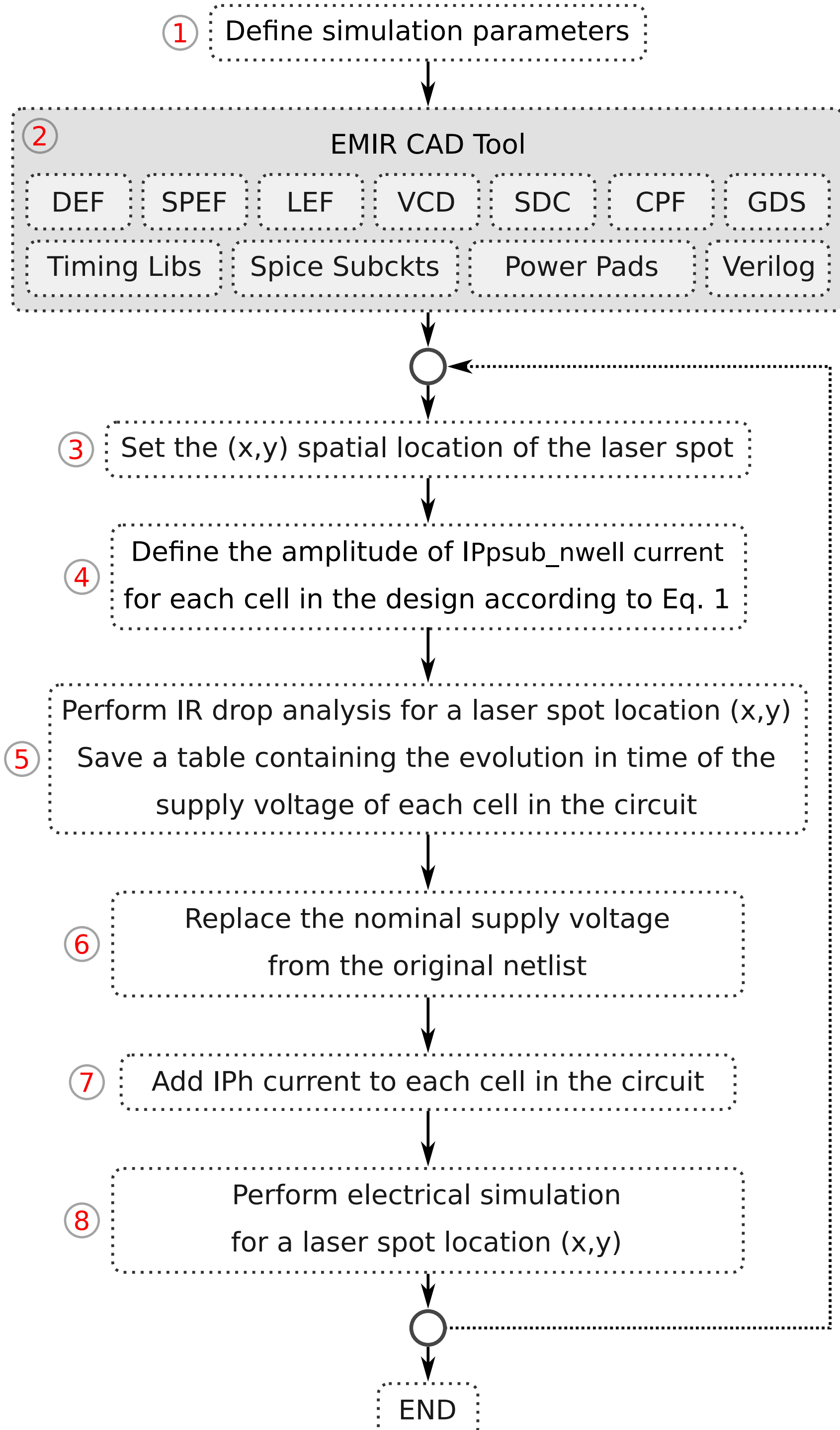


Time at which the laser shot occurs w.r.t. the zero of the simulation



(X, Y) displacement step of the laser spot when one aims to draw a fault sensitivity map




1
Define simulation parameters
2
EMIR CAD Tool
DEF
SPEF
LEF
VCD
SDC
CPF
GDS
Timing Libs
Spice Subckts
Power Pads
Verilog
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Set the (x,y) spatial location of the laser spot
4
Define the amplitude of IPpsub_nwell current
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5
Perform IR drop analysis for a laser spot location (x,y)
Save a table containing the evolution in time of the
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6
Replace the nominal supply voltage
from the original netlist
7
Add IPh current to each cell in the circuit
8
Perform electrical simulation
for a laser spot location (x,y)
END

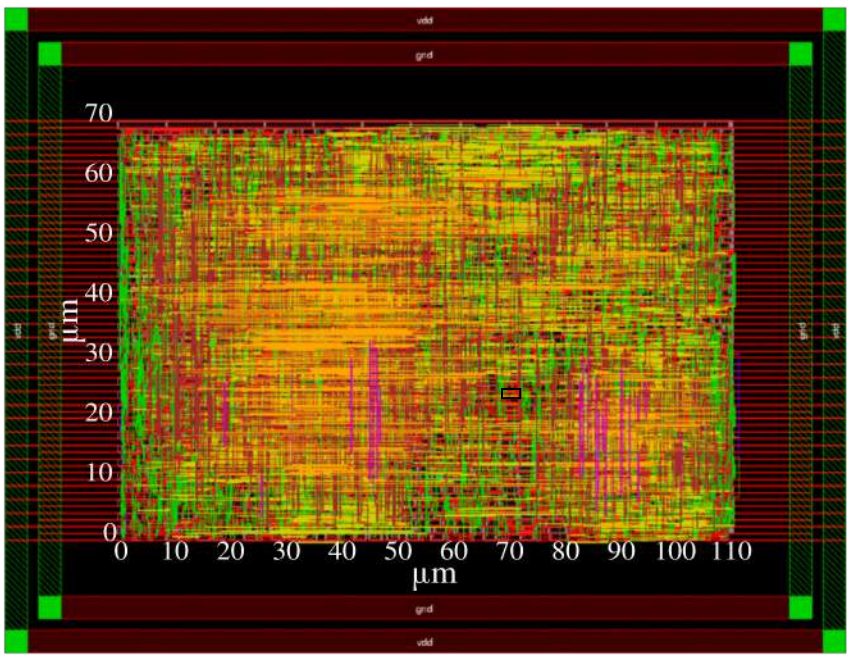
2

Cadence Voltus

EMIR CAD Tool

DEF | SPEF | LEF | VCD | SDC | CPF | GDS

Timing Libs | Spice Subckts | Power Pads | Verilog



ARM 7 - 5.21 k instances

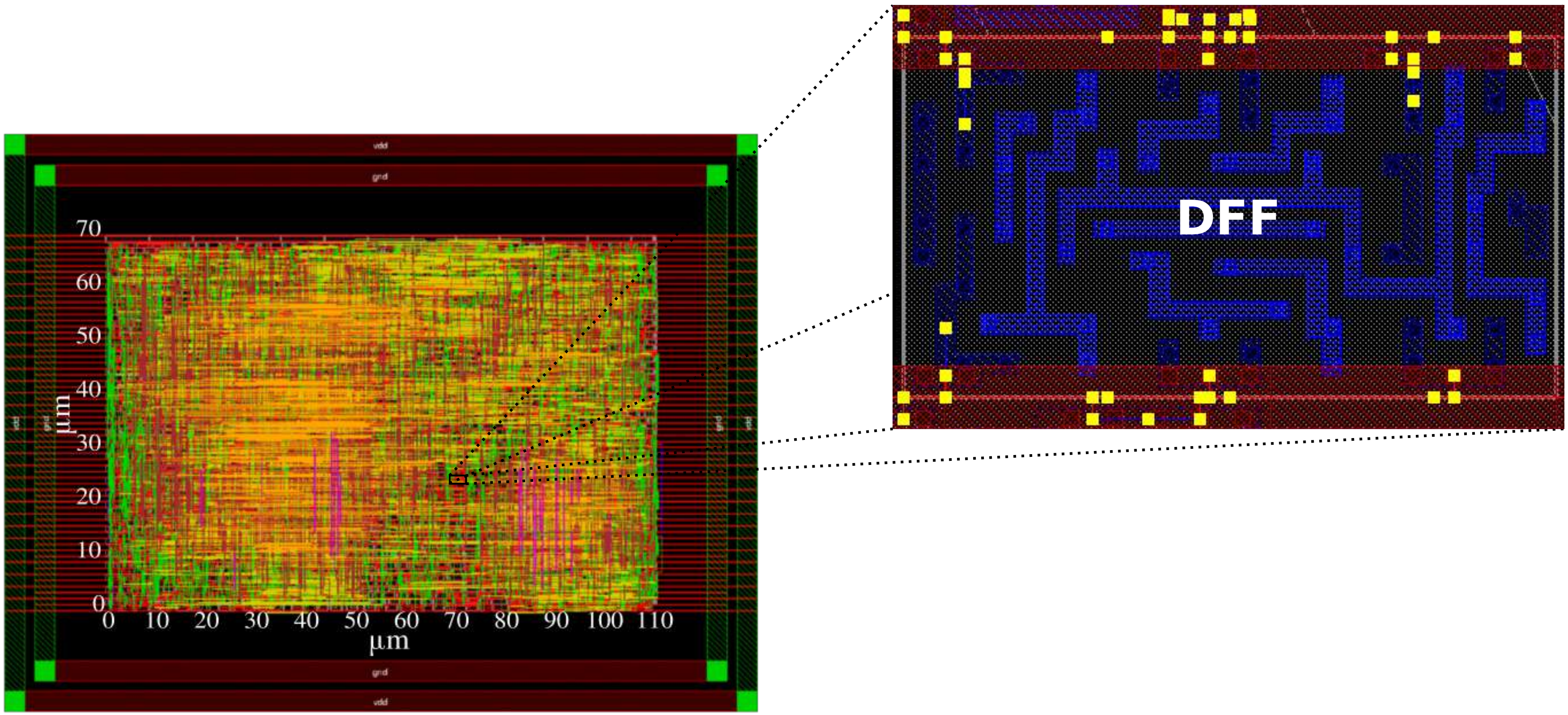
2

Cadence Voltus

EMIR CAD Tool

DEF | SPEF | LEF | VCD | SDC | CPF | GDS

Timing Libs | Spice Subckts | Power Pads | Verilog



ARM 7 - 5.21 k instances

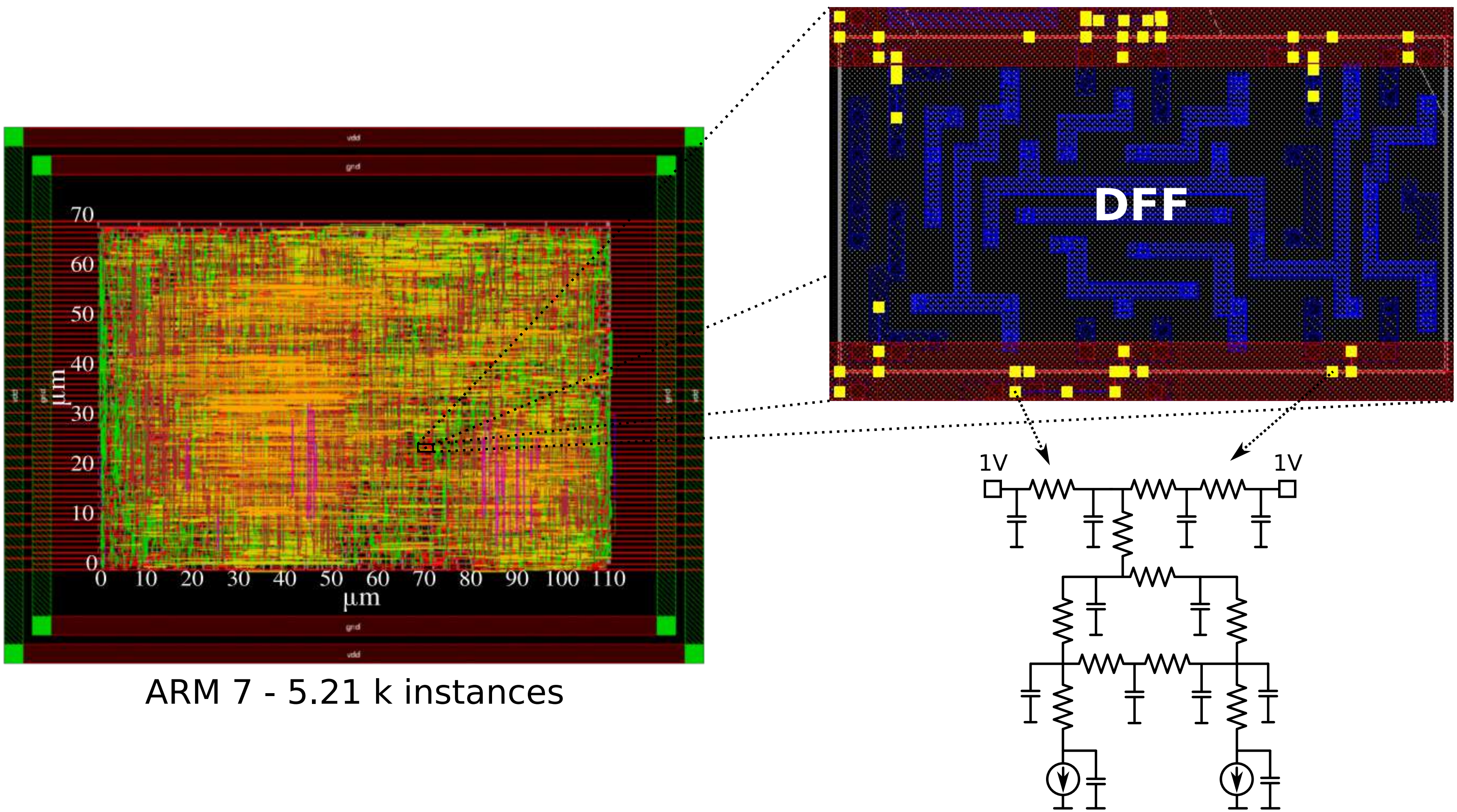
2

EMIR CAD Tool

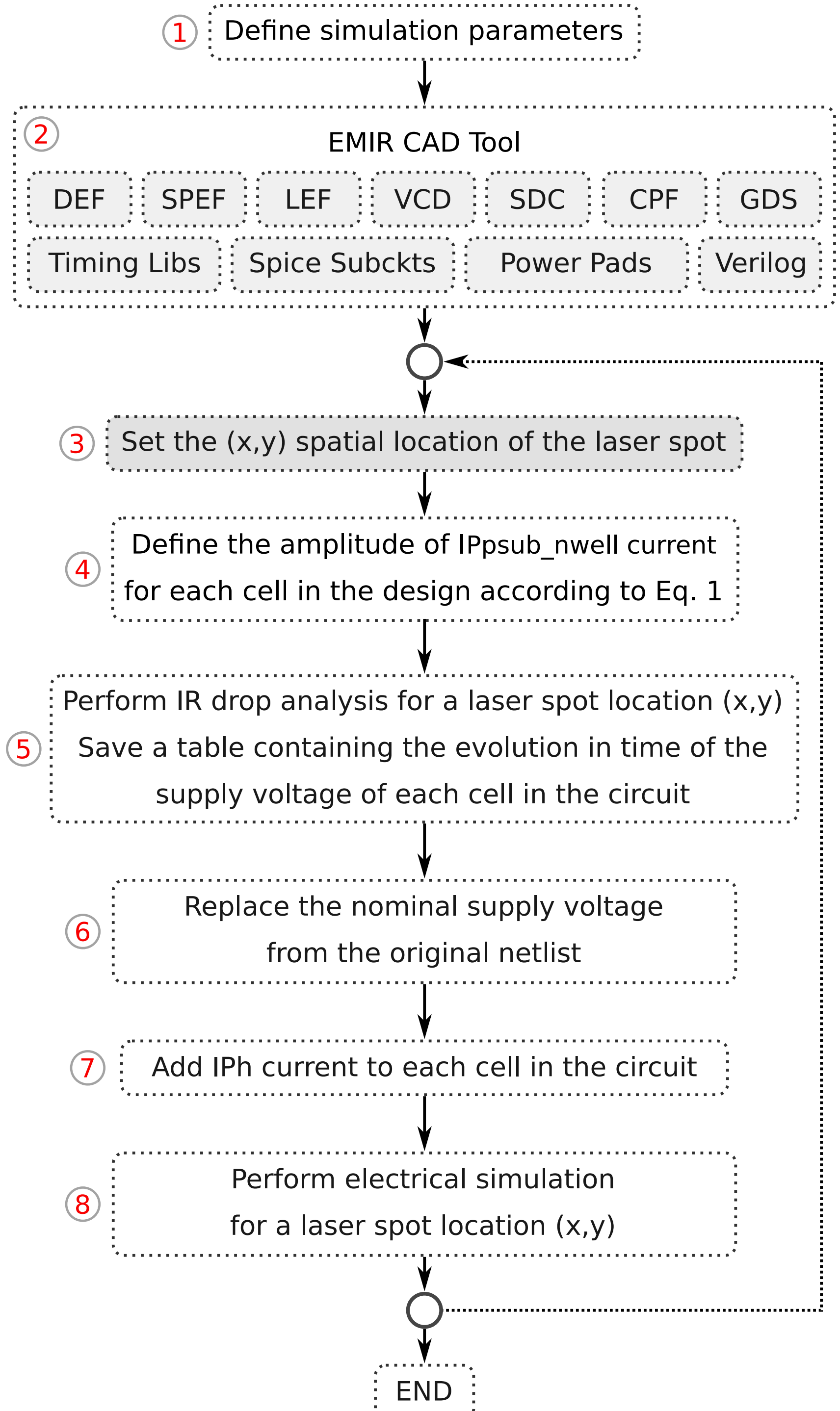
Cadence Voltus

DEF | SPEF | LEF | VCD | SDC | CPF | GDS

Timing Libs | Spice Subckts | Power Pads | Verilog



ARM 7 - 5.21 k instances


1 Define simulation parameters
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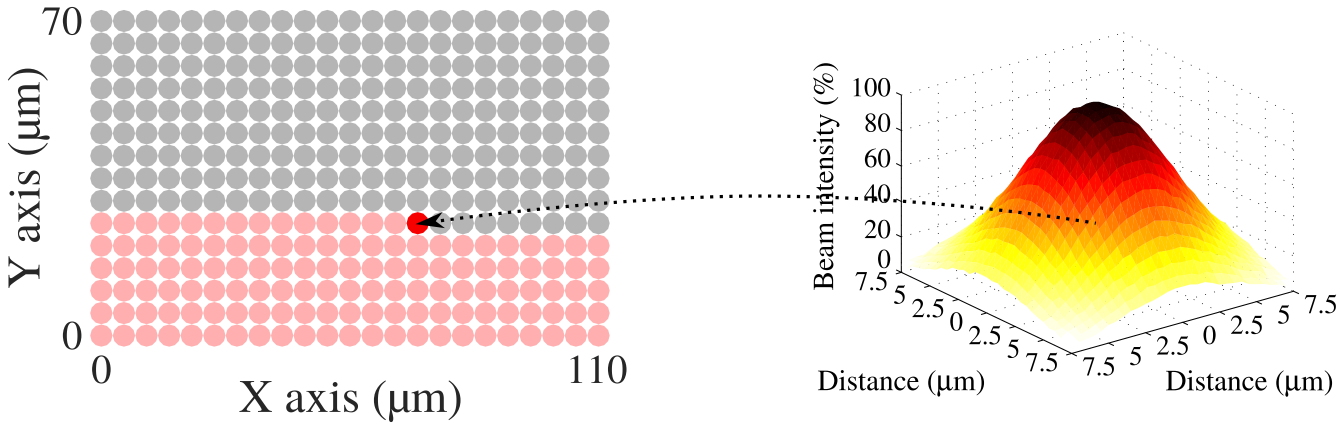
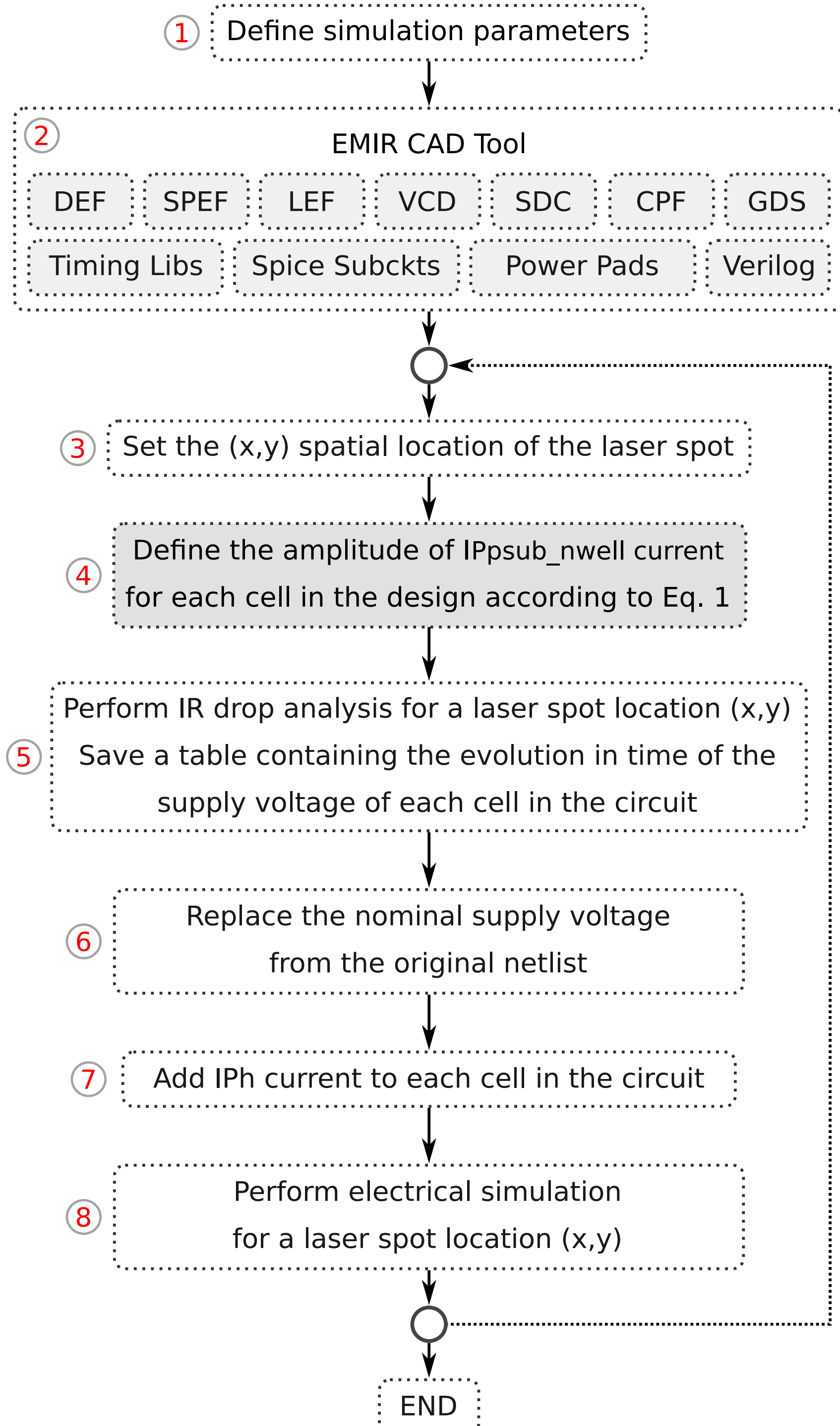
7 Add IPh current to each cell in the circuit
8 Perform electrical simulation
for a laser spot location (x,y)
END

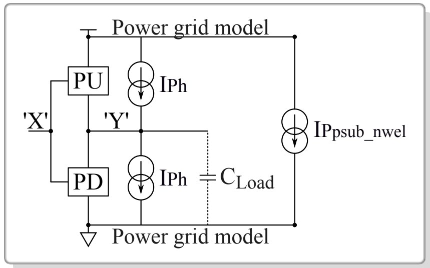
3 Set the (x,y) spatial location of the laser spot



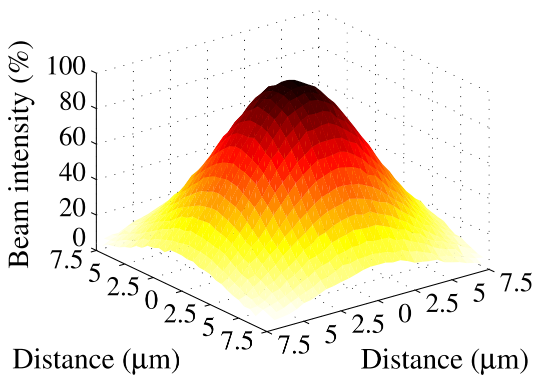
4 - Simulation methodology

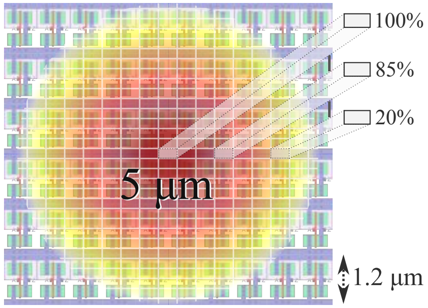


4 Define the amplitude of IPpsub_nwell current for each cell in the design according to Eq. 1

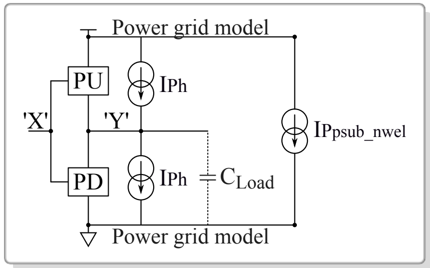


$$I_{ph} = (a \times V + b) \times \alpha_{gauss(x,y)} \times Pulse_w \times S$$

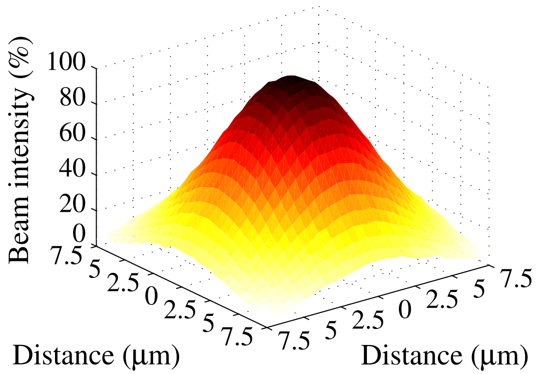


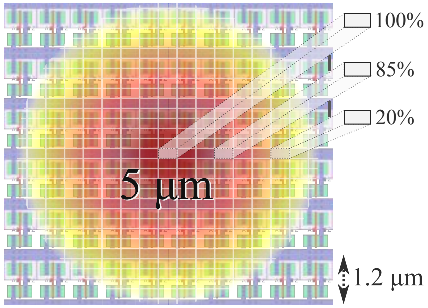


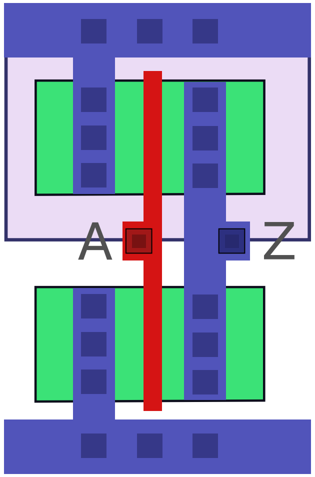
4 Define the amplitude of IPpsub_nwell current for each cell in the design according to Eq. 1



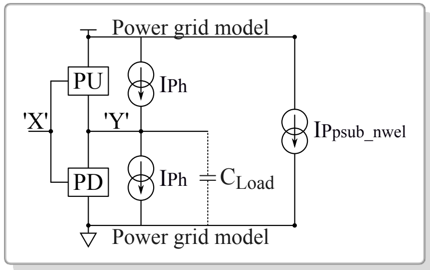
$$I_{ph} = (a \times V + b) \times \alpha_{gauss(x,y)} \times Pulse_w \times S$$



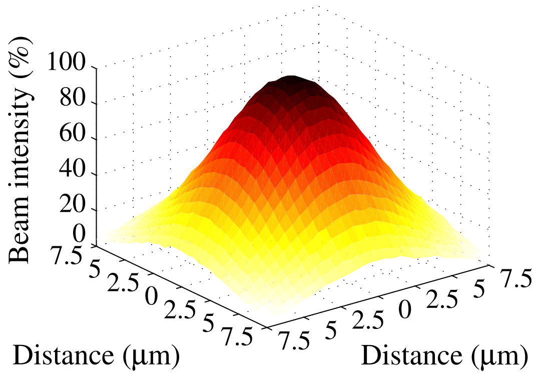


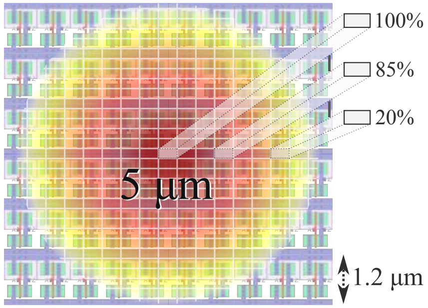


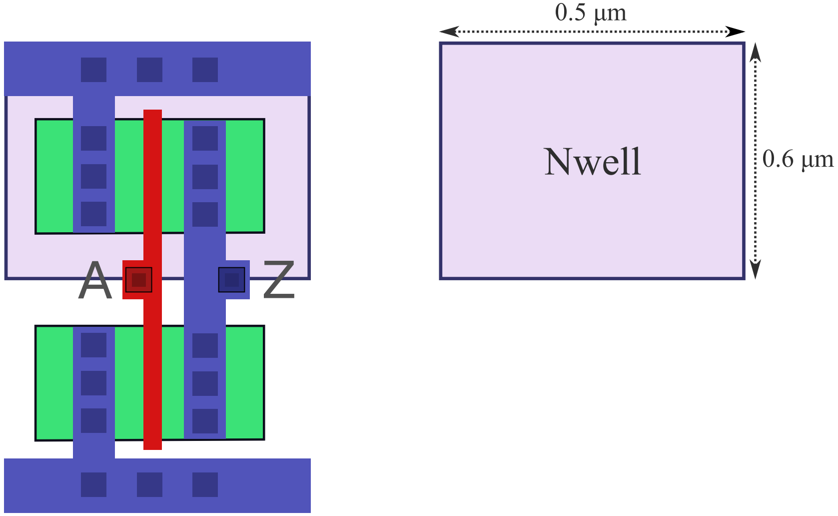
4 Define the amplitude of IPpsub_nwell current for each cell in the design according to Eq. 1



$$I_{ph} = (a \times V + b) \times \alpha_{gauss(x,y)} \times Pulse_w \times S$$

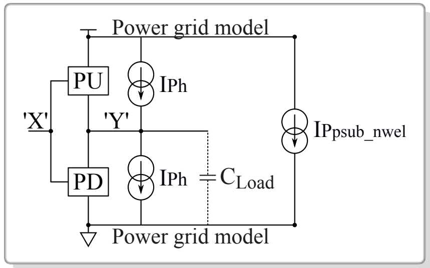




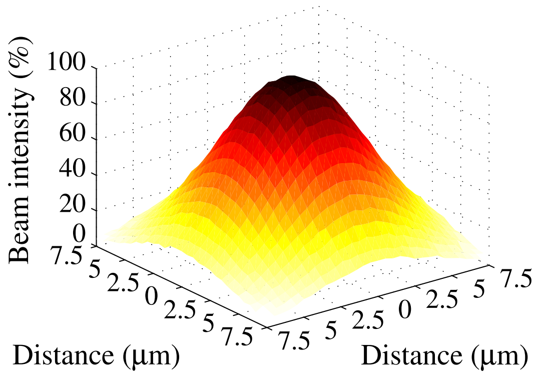


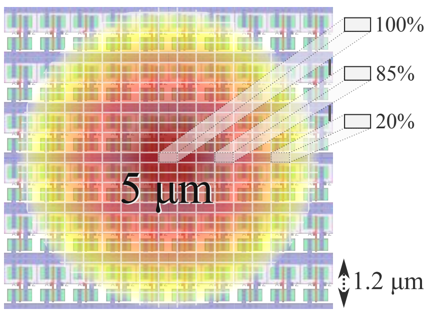
Nwell area: 0.30 µm^2

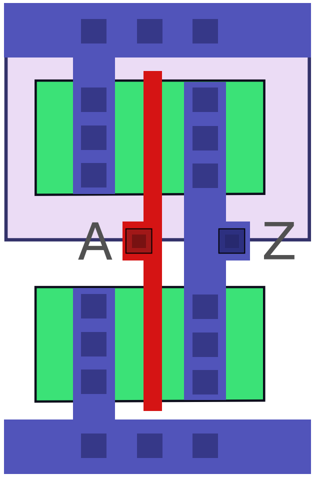
4 Define the amplitude of IPpsub_nwell current for each cell in the design according to Eq. 1

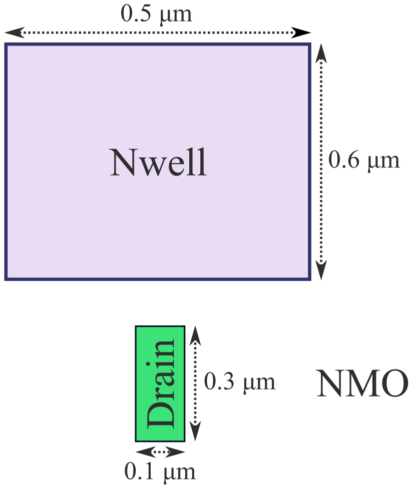


$$I_{ph} = (a \times V + b) \times \alpha_{gauss(x,y)} \times Pulse_w \times S$$





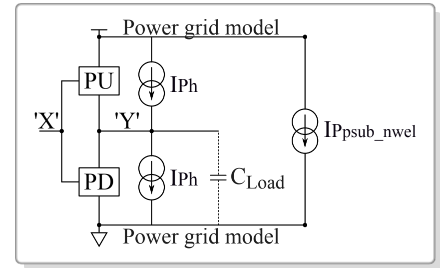




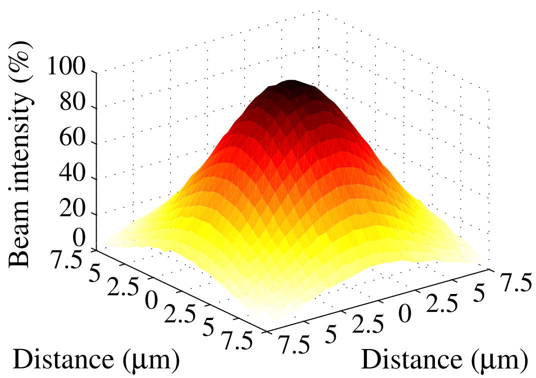
Nwell area: 0.30 µm^2

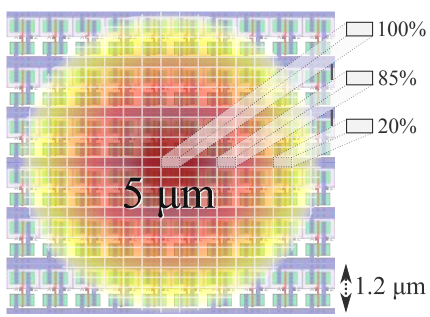
NMOS Drain area: 0.03 µm^2

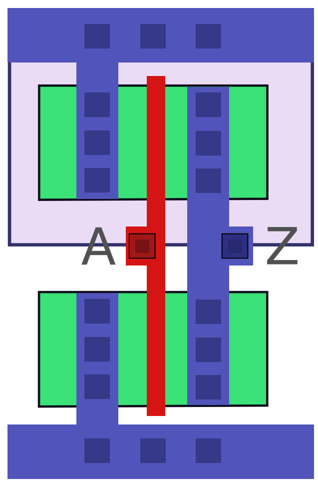
4 Define the amplitude of IPpsub_nwell current for each cell in the design according to Eq. 1

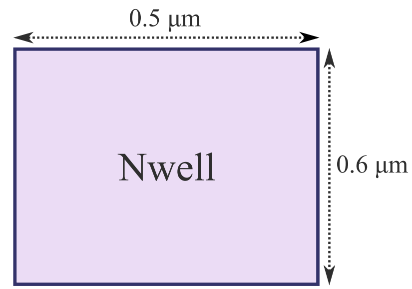


$$I_{ph} = (a \times V + b) \times \alpha_{gauss(x,y)} \times Pulse_w \times S \qquad IP_{Psub\_nwell} = factor \times I_{ph}$$

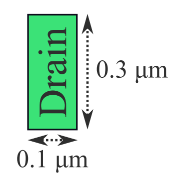








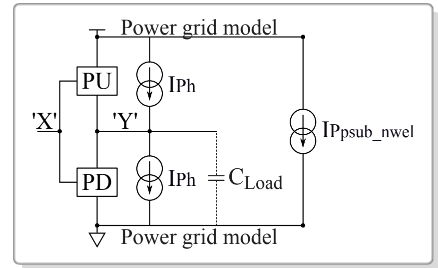
Nwell area: 0.30 µm²



NMOS Drain area: 0.03 µm²

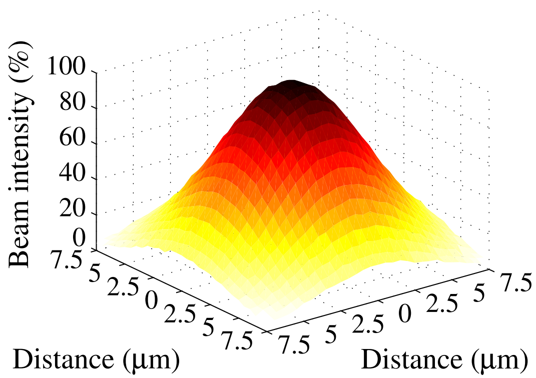
$$factor = \frac{0.30\ \mu m^2}{0.03\ \mu m^2} = 10.00$$

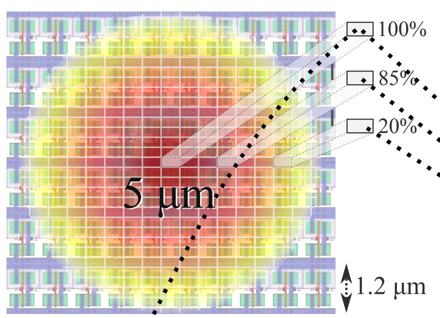
4 Define the amplitude of IPpsub_nwell current for each cell in the design according to Eq. 1

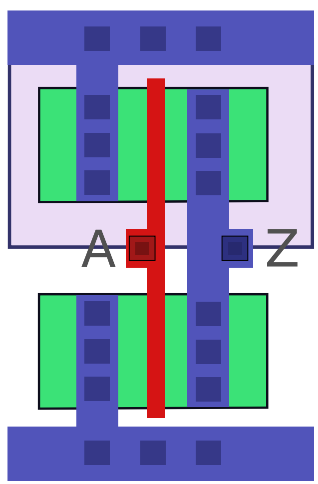


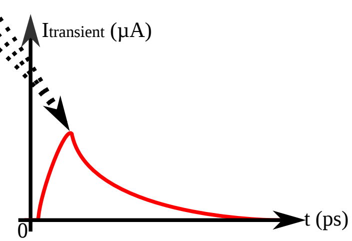
$$I_{ph} = (a \times V + b) \times \alpha_{gauss(x,y)} \times Pulse_w \times S$$

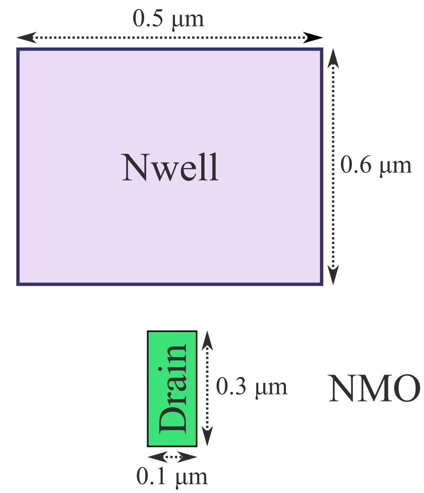
$$IP_{Psub\_nwell} = factor \times I_{ph}$$









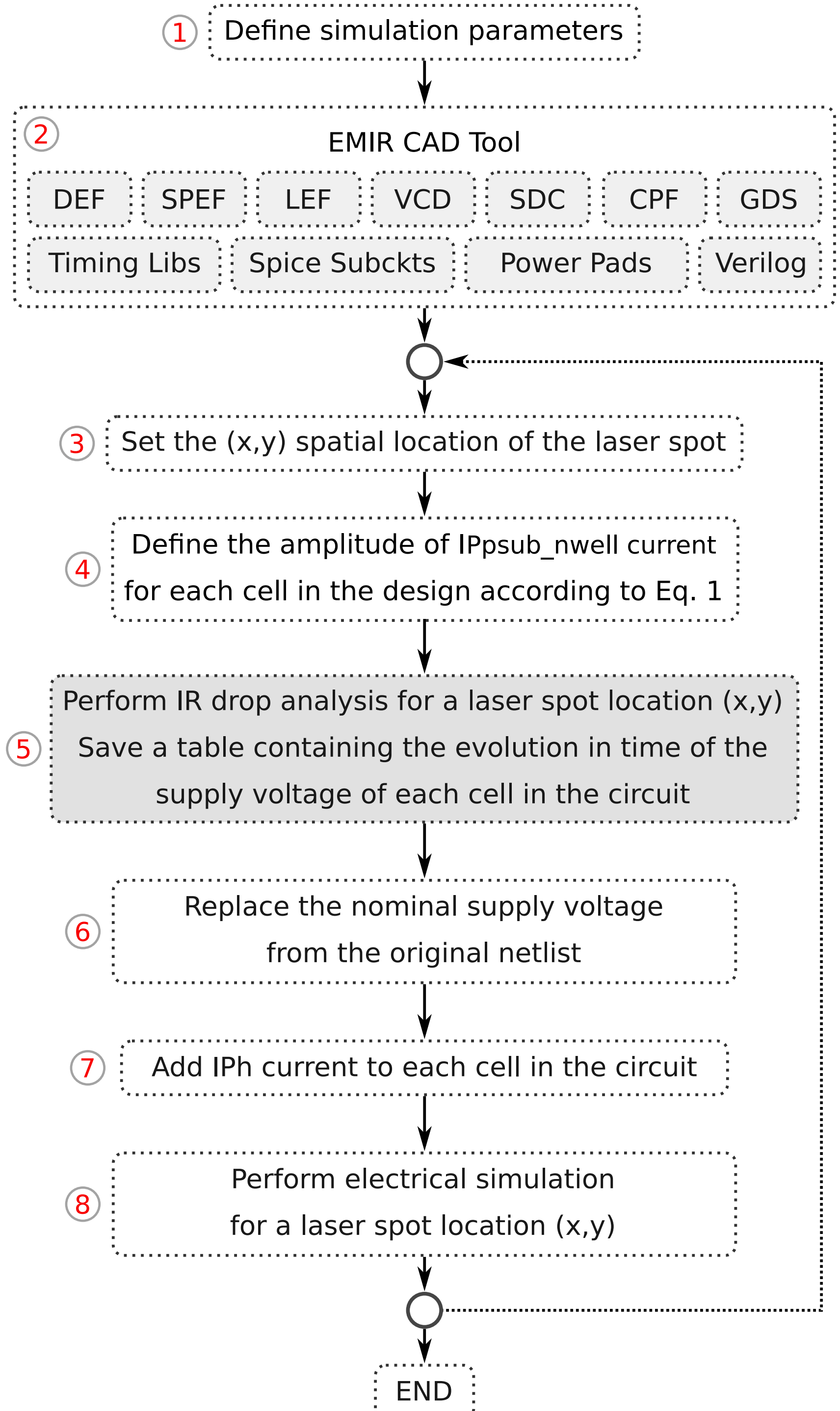


Nwell area: 0.30 µm^2

NMOS Drain area: 0.03 µm^2

$$factor = \frac{0.30\ \mu m^2}{0.03\ \mu m^2} = 10.00$$

create_current_region -current {1.500ns 0.000mA 1.505ns 0.820mA 1.510ns 1.000mA 1.515ns 0.950mA ... 1.800ns 0.000mA} -layer M2 -intrinsic_cap C -loading_cap C -region "1.50 1.50 1.75 1.75"


1
Define simulation parameters
2
EMIR CAD Tool
DEF
SPEF
LEF
VCD
SDC
CPF
GDS
Timing Libs
Spice Subckts
Power Pads
Verilog
3
Set the (x,y) spatial location of the laser spot
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5
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Save a table containing the evolution in time of the
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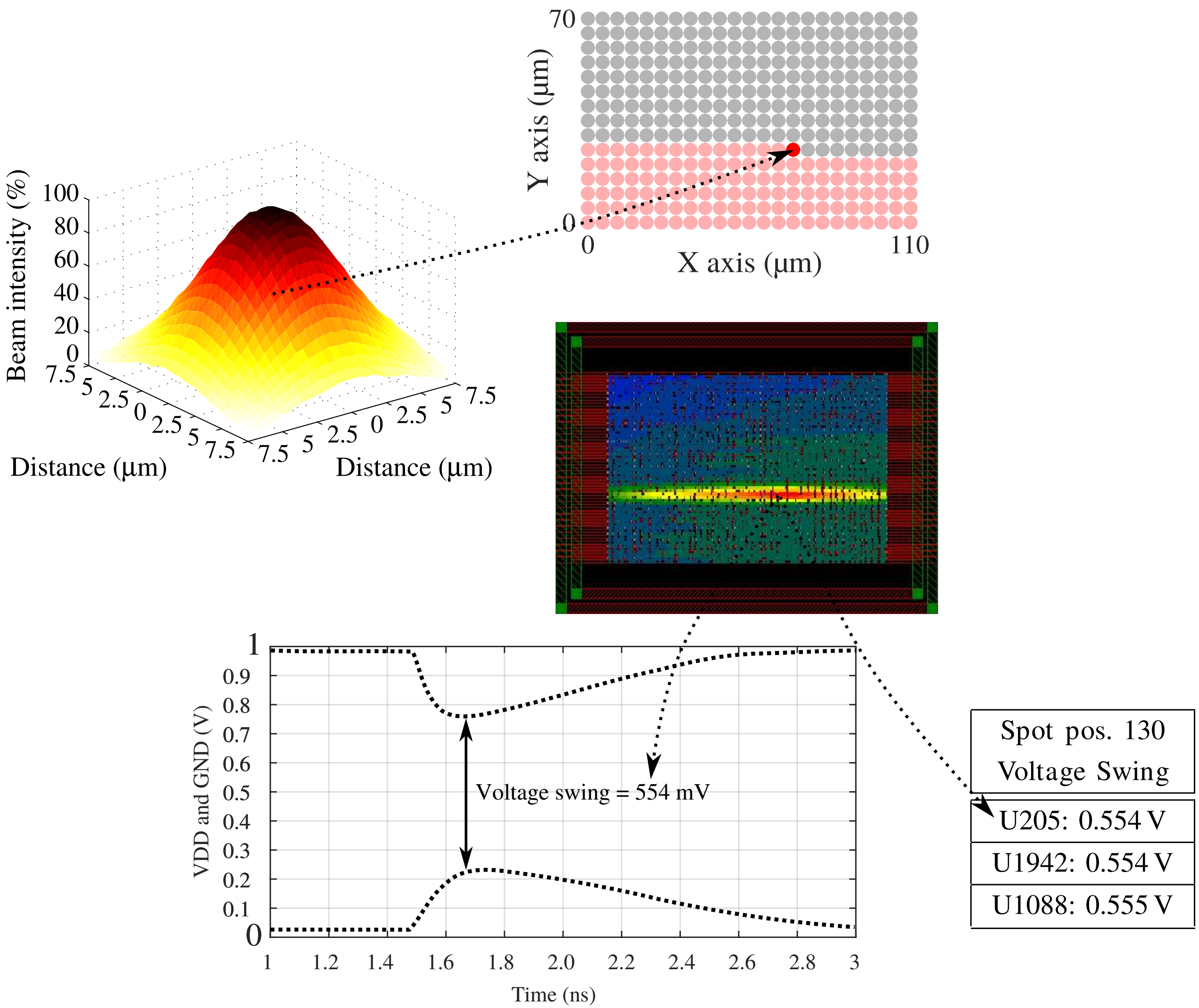
6
Replace the nominal supply voltage
from the original netlist
7
Add IPh current to each cell in the circuit
8
Perform electrical simulation
for a laser spot location (x,y)
END

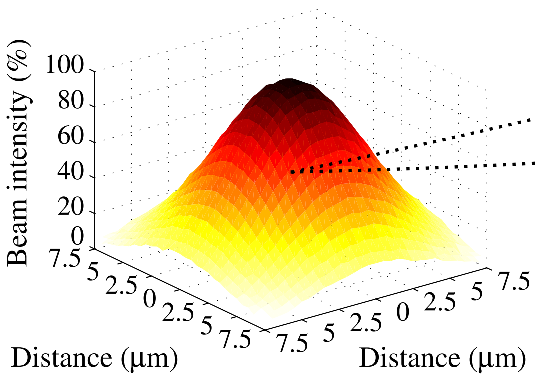
5

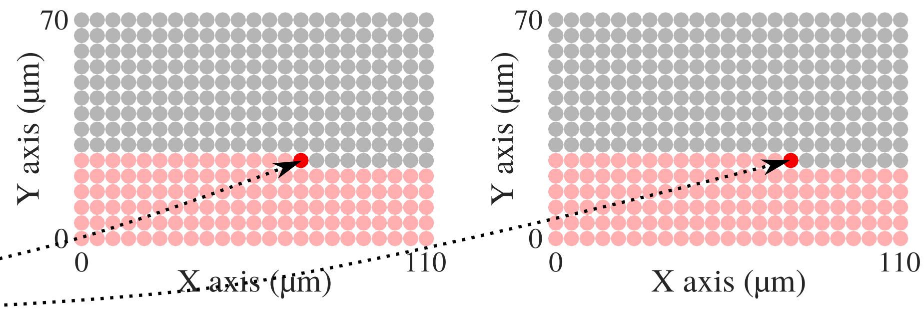
Perform IR drop analysis for a laser spot location (x,y)

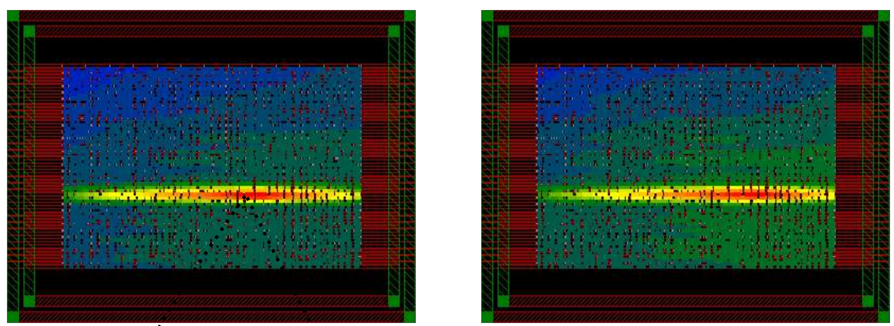
Save a table containing the evolution in time of the supply voltage of each cell in the circuit

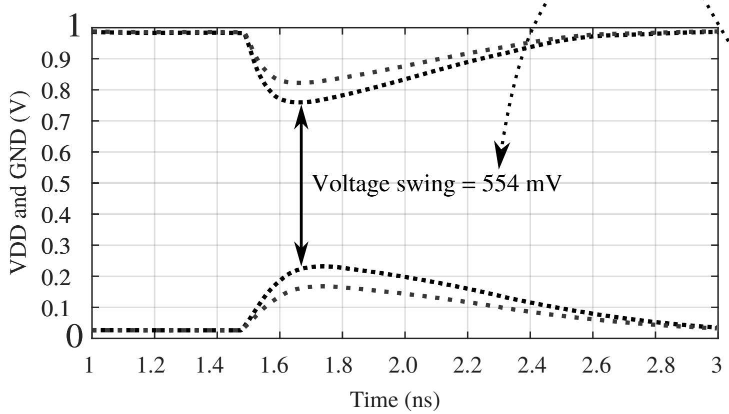


5 Perform IR drop analysis for a laser spot location (x,y)
Save a table containing the evolution in time of the supply voltage of each cell in the circuit



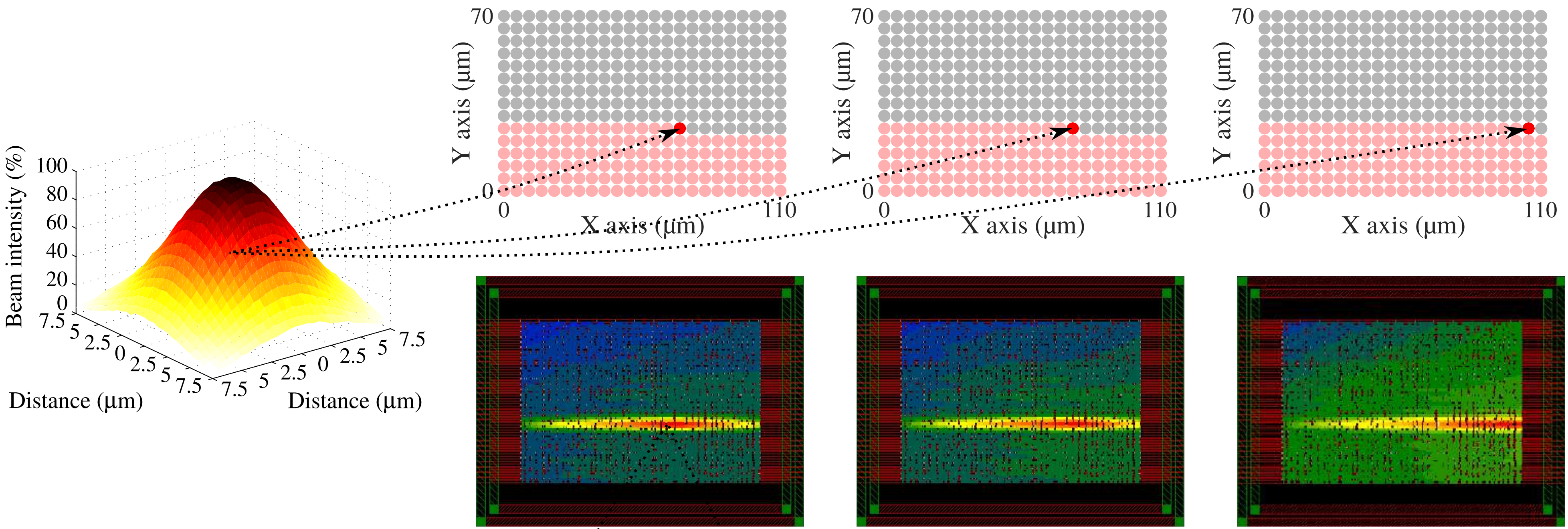


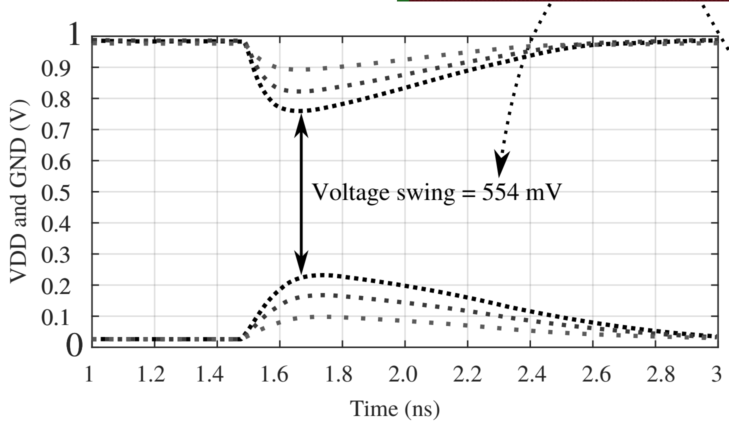




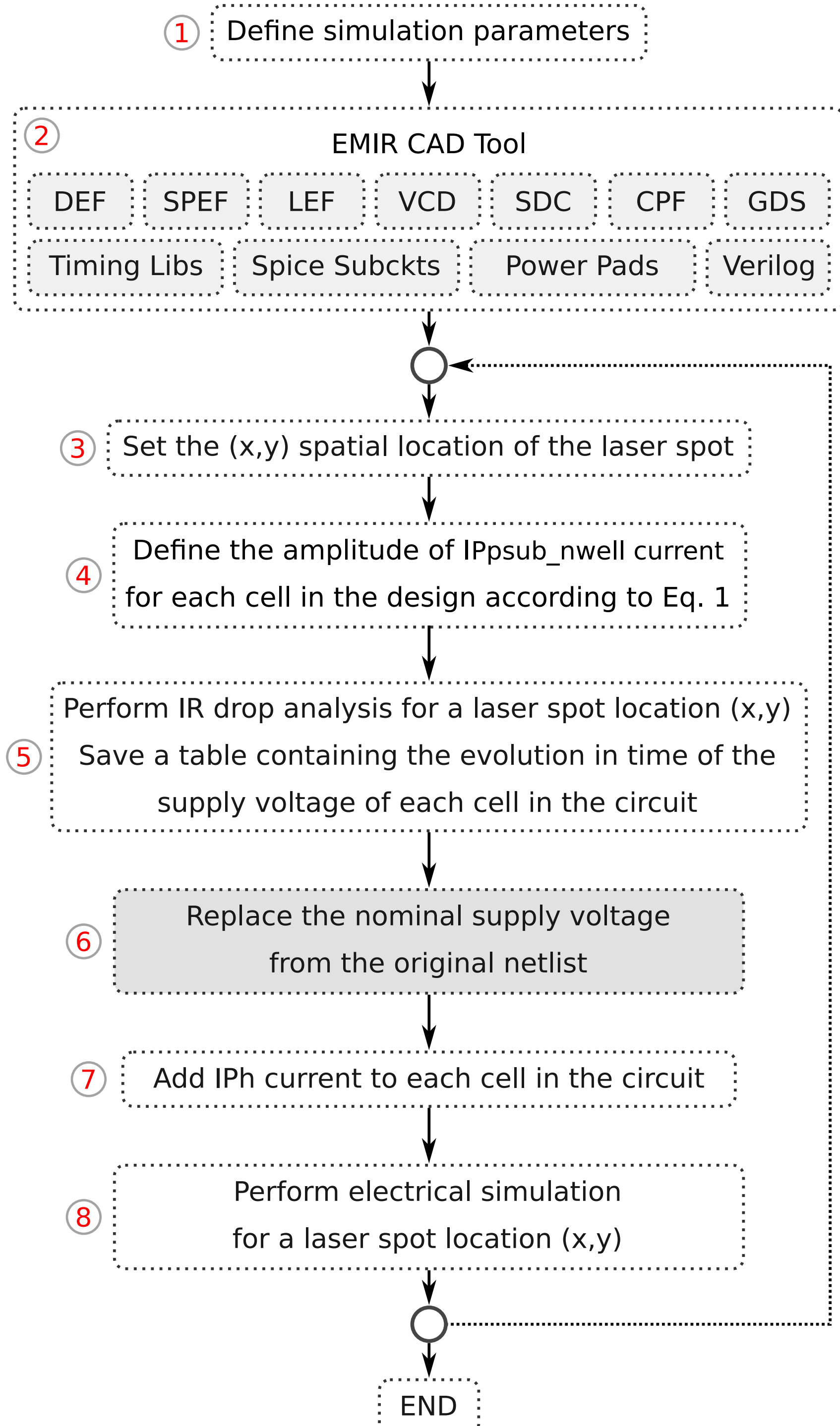
Spot pos. 130 Voltage Swing	Spot pos. 132 Voltage Swing
U205: 0.554 V	U205: 0.670 V
U1942: 0.554 V	U1942: 0.677 V
U1088: 0.555 V	U1088: 0.669 V

5 Perform IR drop analysis for a laser spot location (x,y)
Save a table containing the evolution in time of the supply voltage of each cell in the circuit





Spot pos. 130 Voltage Swing	Spot pos. 132 Voltage Swing	Spot pos. 139 Voltage Swing
U205: 0.554 V	U205: 0.670 V	U205: 0.815 V
U1942: 0.554 V	U1942: 0.677 V	U1942: 0.818 V
U1088: 0.555 V	U1088: 0.669 V	U1088: 0.814 V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Define simulation parameters
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EMIR CAD Tool
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Save a table containing the evolution in time of the
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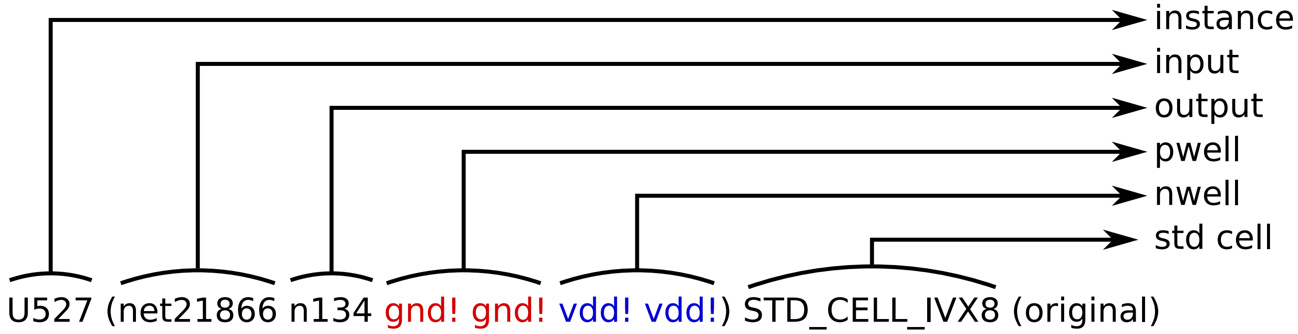
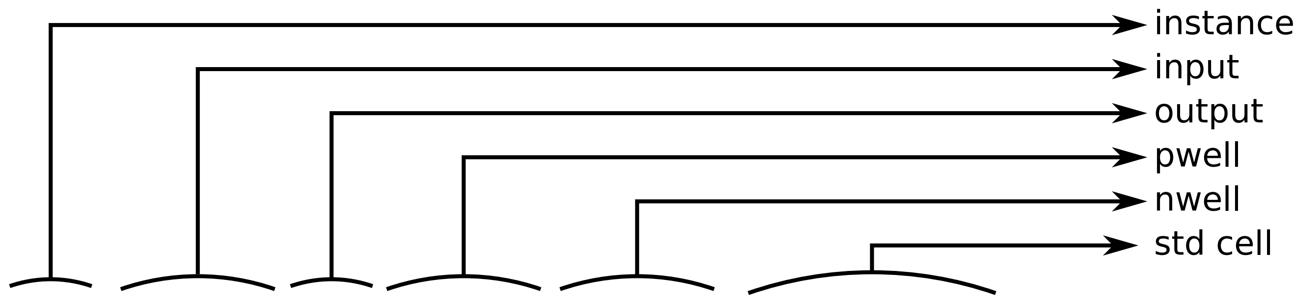
6
Replace the nominal supply voltage
from the original netlist
7
Add IPh current to each cell in the circuit
8
Perform electrical simulation
for a laser spot location (x,y)
END

6 Replace the nominal supply voltage from the original netlist

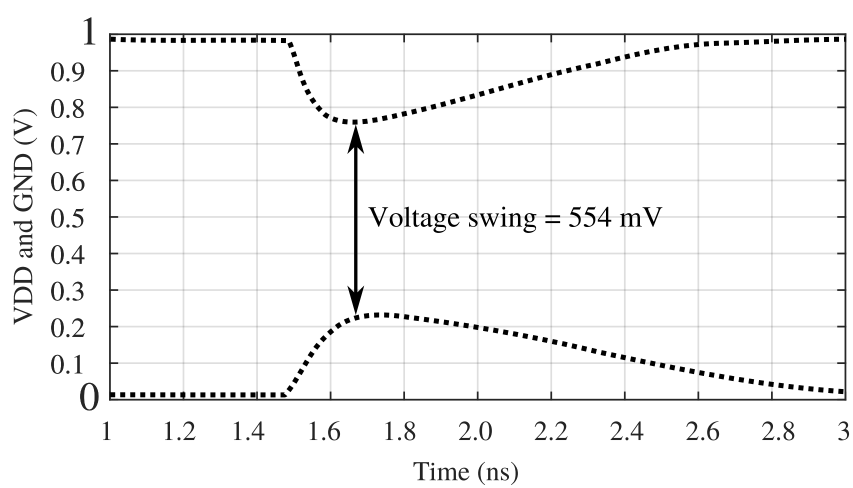


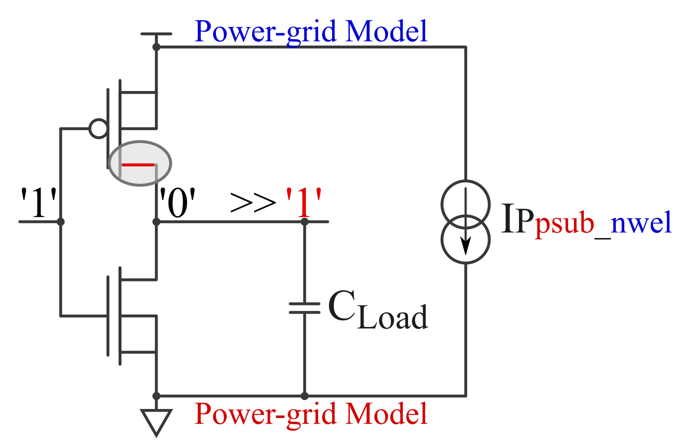
(6) Replace the nominal supply voltage from the original netlist



U527 (net21866 n134 gnd! gnd! vdd! vdd!) STD_CELL_IVX8 (original)

U527 (net21866 n134 GND_U527 GND_U527 VDD_U527 VDD_U527) STD_CELL_IVX8





4 - Simulation methodology

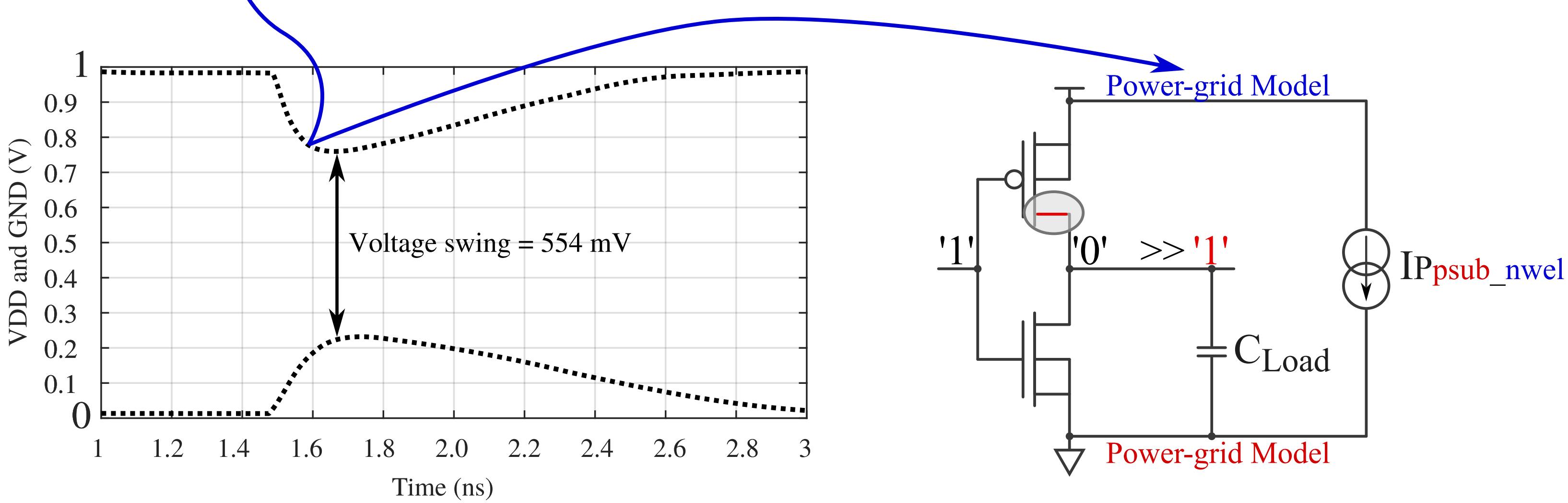
6 Replace the nominal supply voltage from the original netlist

instance
input
output
pwell
nwell
std cell

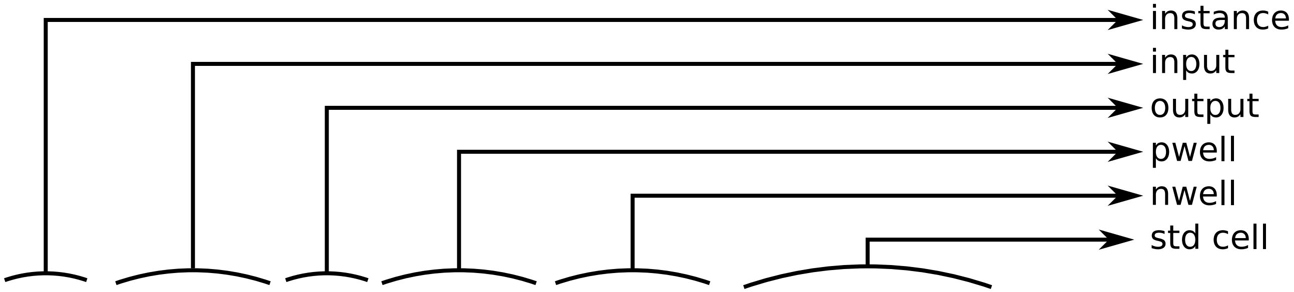
U527 (net21866 n134 gnd! gnd! vdd! vdd!) STD_CELL_IVX8 (original)

U527 (net21866 n134 GND_U527 GND_U527 VDD_U527 VDD_U527) STD_CELL_IVX8

VU527_VDD (vdd! VDD_U527) vsource type=pwl val0=0 wave=[1.5n 1 ... 1.65 0.78 ... tn vn]



6 Replace the nominal supply voltage from the original netlist

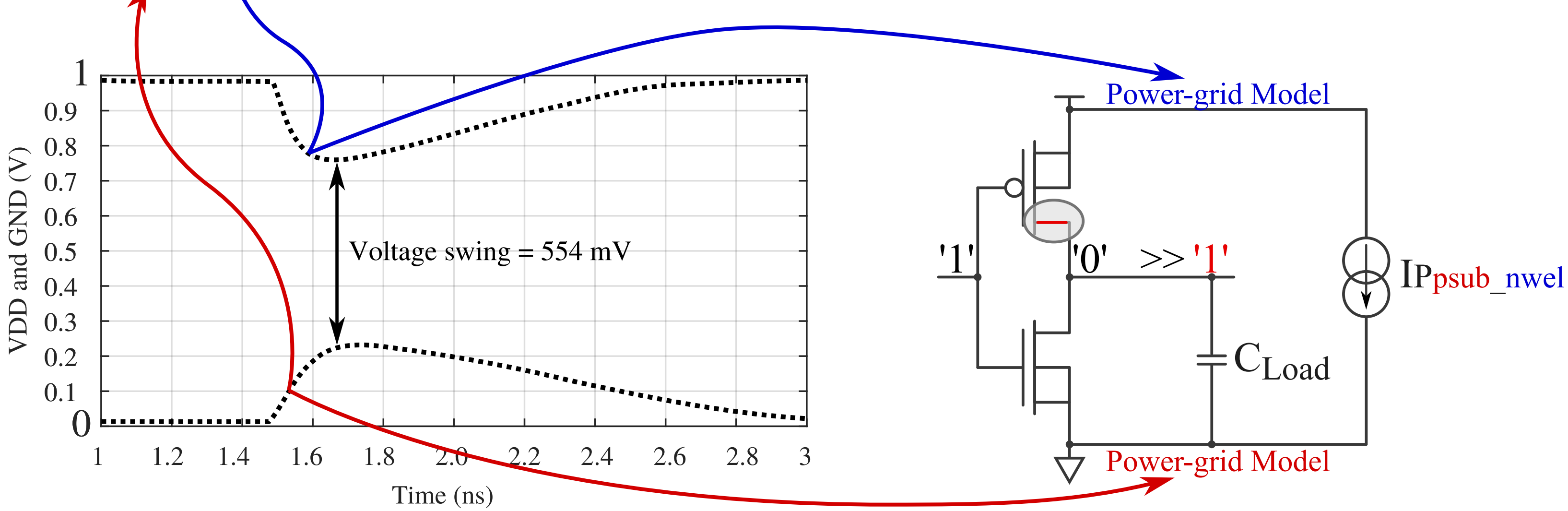


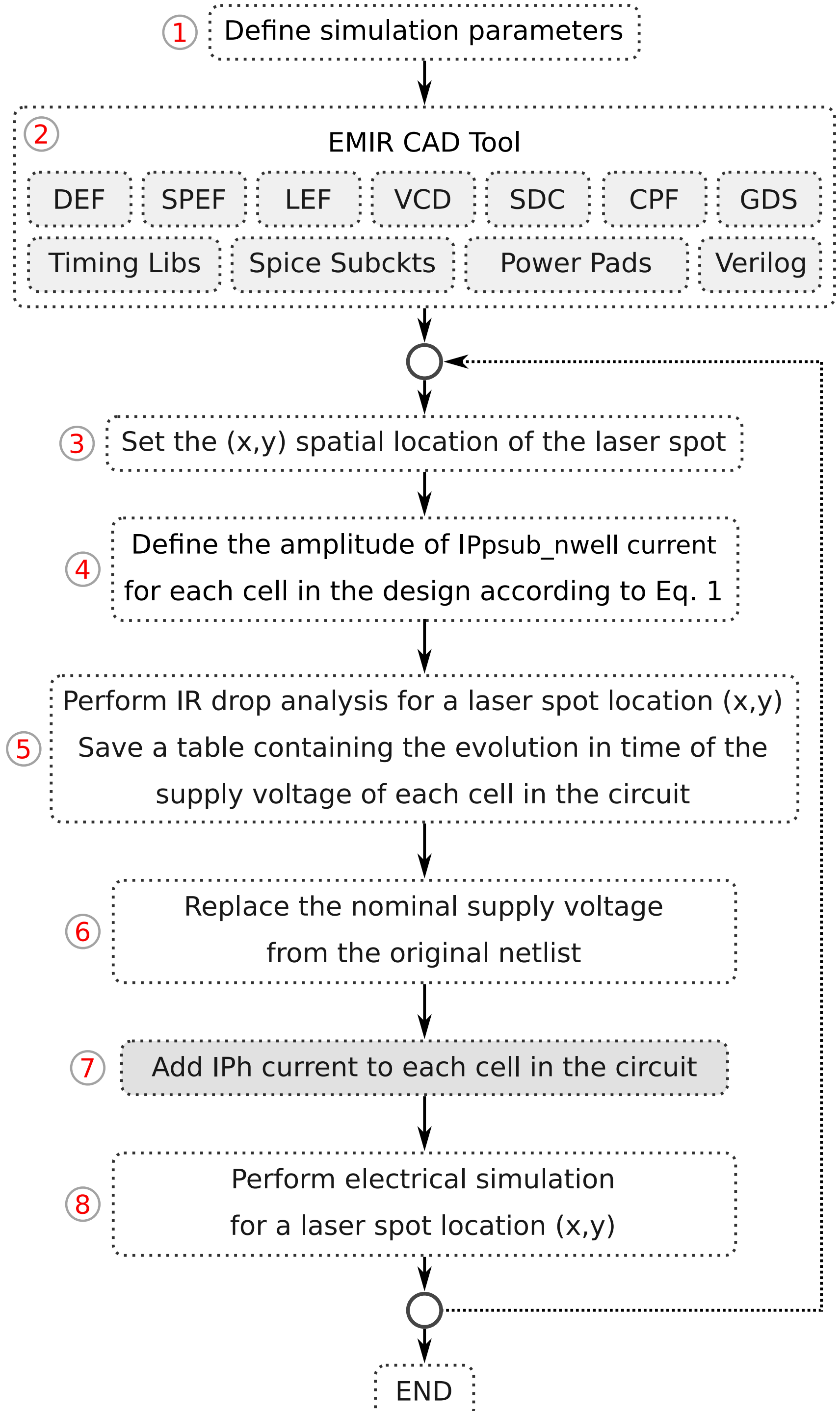
U527 (net21866 n134 gnd! gnd! vdd! vdd!) STD_CELL_IVX8 (original)

U527 (net21866 n134 GND_U527 GND_U527 VDD_U527 VDD_U527) STD_CELL_IVX8

VU527_VDD (vdd! VDD_U527) vsource type=pwl val0=0 wave=[1.5n 1 ... 1.65 0.78 ... tn vn]

VU527_GND (GND_U527 gnd!) vsource type=pwl val0=0 wave=[1.5n 0 ... 1.68 0.23 ... tn vn]




1
Define simulation parameters
2
EMIR CAD Tool
DEF
SPEF
LEF
VCD
SDC
CPF
GDS
Timing Libs
Spice Subckts
Power Pads
Verilog
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Set the (x,y) spatial location of the laser spot
4
Define the amplitude of IPpsub_nwell current
for each cell in the design according to Eq. 1
5
Perform IR drop analysis for a laser spot location (x,y)
Save a table containing the evolution in time of the
supply voltage of each cell in the circuit
6
Replace the nominal supply voltage
from the original netlist
7
Add IPh current to each cell in the circuit
8
Perform electrical simulation
for a laser spot location (x,y)
END

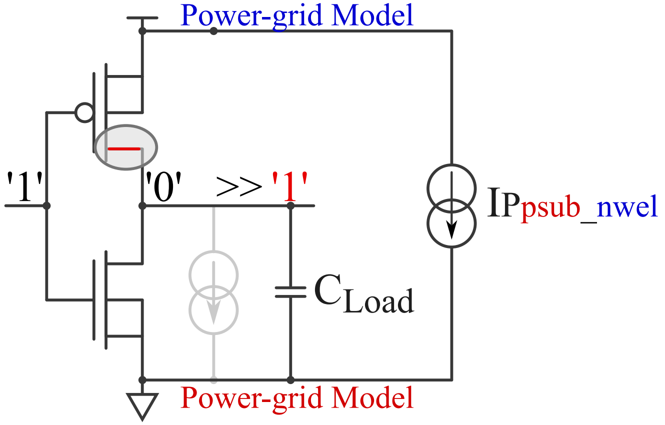
7 Add IPh current to each cell in the circuit

U527 (net21866 n134 gnd! gnd! vdd! vdd!) STD_CELL_IVX8

U527 (net21866 n134 GND_U527 GND_U527 VDD_U527 VDD_U527) STD_CELL_IVX8

VU527_VDD (vdd! VDD_U527) vsource type=pwl val0=0 wave=[1.5n 1 ... 1.65 0.78 ... tn vn]

VU527_GND (GND_U527 gnd!) vsource type=pwl val0=0 wave=[1.5n 0 ... 1.68 0.23 ... tn vn]



7 Add IPh current to each cell in the circuit

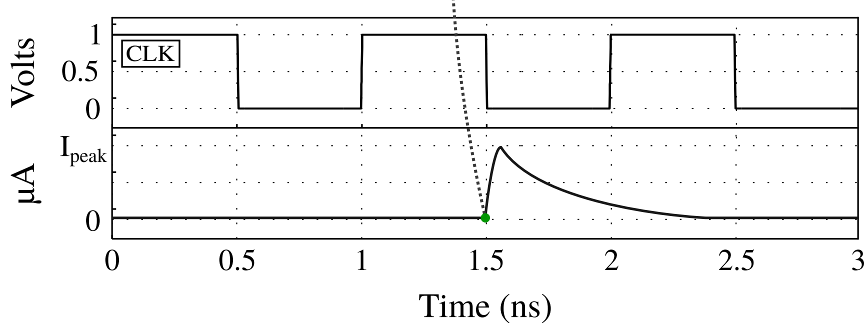
U527 (net21866 n134 gnd! gnd! vdd! vdd!) STD_CELL_IVX8

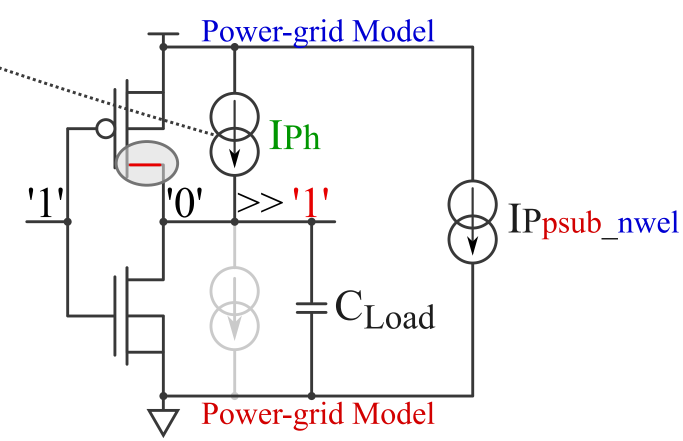
U527 (net21866 n134 GND_U527 GND_U527 VDD_U527 VDD_U527) STD_CELL_IVX8

VU527_VDD (vdd! VDD_U527) vsource type=pwl val0=0 wave=[1.5n 1 ... 1.65 0.78 ... tn vn]

VU527_GND (GND_U527 gnd!) vsource type=pwl val0=0 wave=[1.5n 0 ... 1.68 0.23 ... tn vn]

IU527_VDD (VDD_U527 n134) isource dc=0 type=exp val0=0 td1=fstart





7 Add IPh current to each cell in the circuit

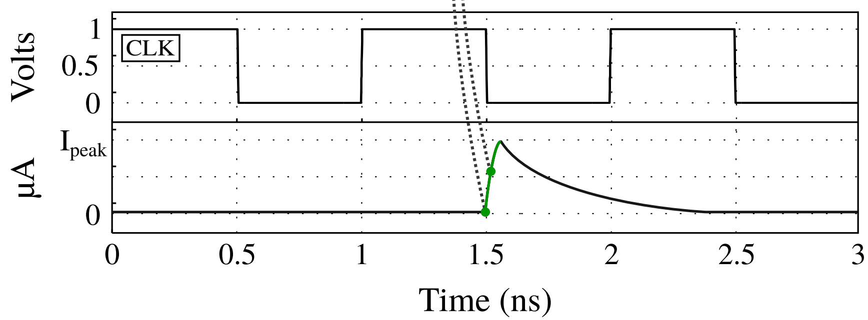
U527 (net21866 n134 gnd! gnd! vdd! vdd!) STD_CELL_IVX8

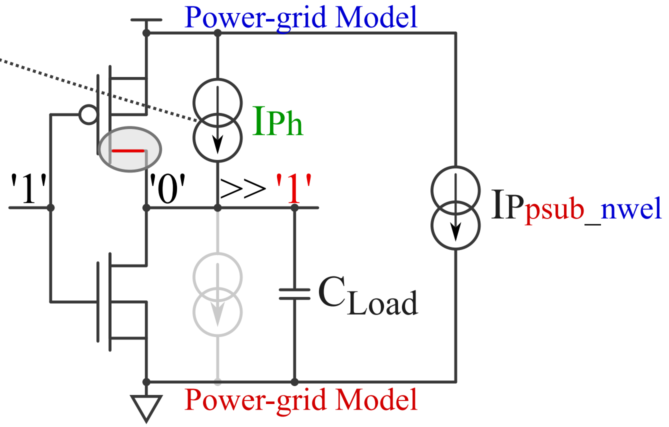
U527 (net21866 n134 GND_U527 GND_U527 VDD_U527 VDD_U527) STD_CELL_IVX8

VU527_VDD (vdd! VDD_U527) vsource type=pwl val0=0 wave=[1.5n 1 ... 1.65 0.78 ... tn vn]

VU527_GND (GND_U527 gnd!) vsource type=pwl val0=0 wave=[1.5n 0 ... 1.68 0.23 ... tn vn]

IU527_VDD (VDD_U527 n134) isource dc=0 type=exp val0=0 td1=fstart
tau1=rise_time





7 Add IPh current to each cell in the circuit

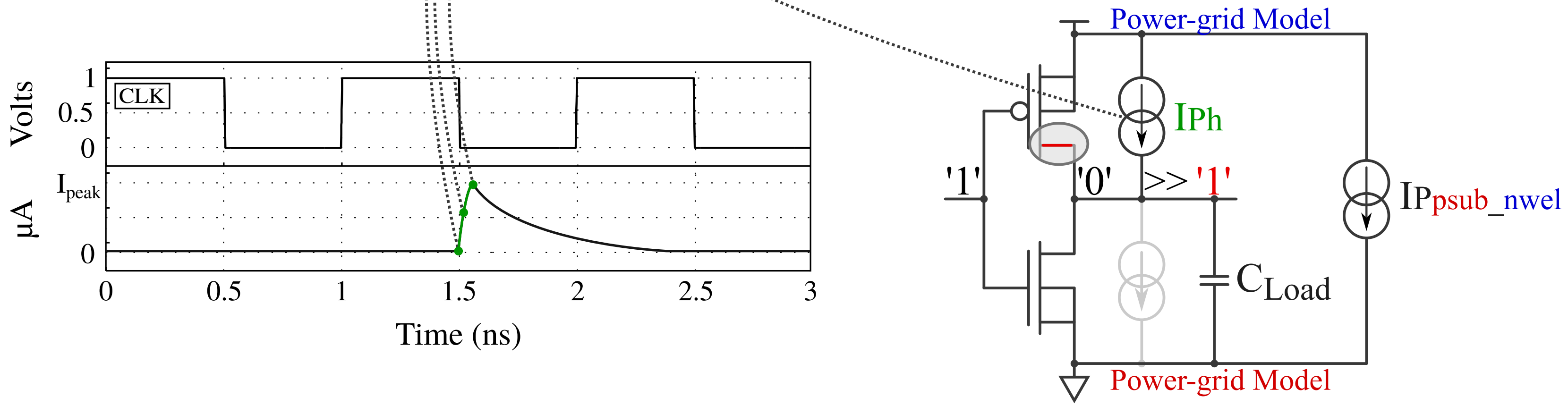
U527 (net21866 n134 gnd! gnd! vdd! vdd!) STD_CELL_IVX8

U527 (net21866 n134 GND_U527 GND_U527 VDD_U527 VDD_U527) STD_CELL_IVX8

VU527_VDD (vdd! VDD_U527) vsource type=pwl val0=0 wave=[1.5n 1 ... 1.65 0.78 ... tn vn]

VU527_GND (GND_U527 gnd!) vsource type=pwl val0=0 wave=[1.5n 0 ... 1.68 0.23 ... tn vn]

IU527_VDD (VDD_U527 n134) isource dc=0 type=exp val0=0 td1=fstart
tau1=rise_time
val1=154.69u



7 Add IPh current to each cell in the circuit

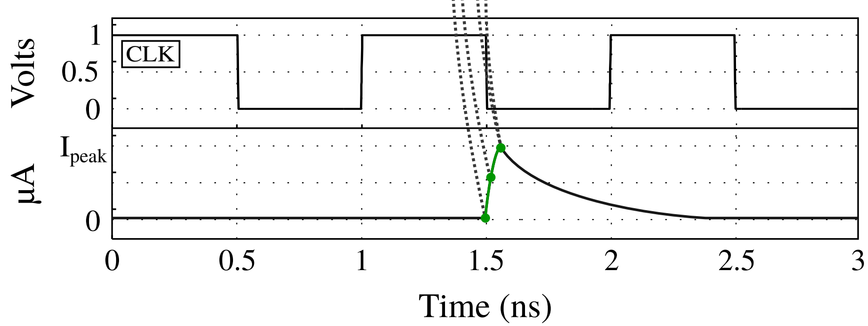
U527 (net21866 n134 gnd! gnd! vdd! vdd!) STD_CELL_IVX8

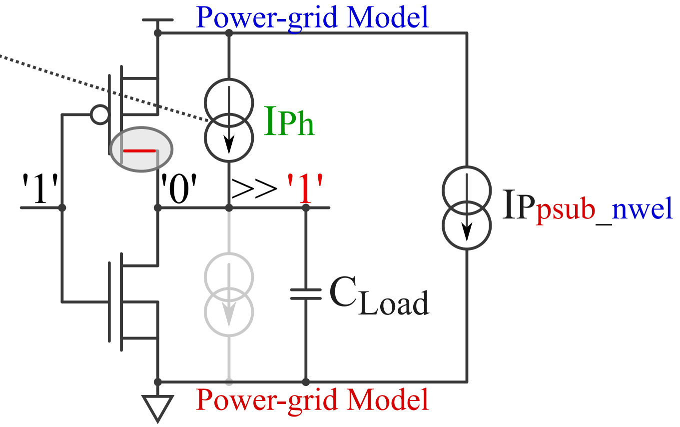
U527 (net21866 n134 GND_U527 GND_U527 VDD_U527 VDD_U527) STD_CELL_IVX8

VU527_VDD (vdd! VDD_U527) vsource type=pwl val0=0 wave=[1.5n 1 ... 1.65 0.78 ... tn vn]

VU527_GND (GND_U527 gnd!) vsource type=pwl val0=0 wave=[1.5n 0 ... 1.68 0.23 ... tn vn]

IU527_VDD (VDD_U527 n134) isource dc=0 type=exp val0=0 td1=fstart
tau1=rise_time
val1=154.69u
td2=fall_start





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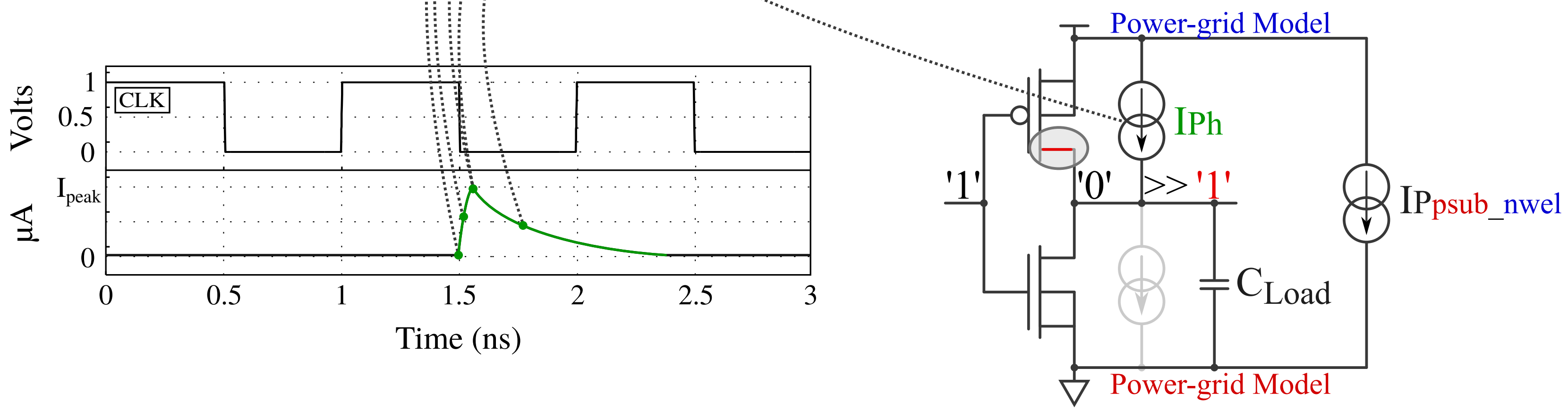
U527 (net21866 n134 gnd! gnd! vdd! vdd!) STD_CELL_IVX8

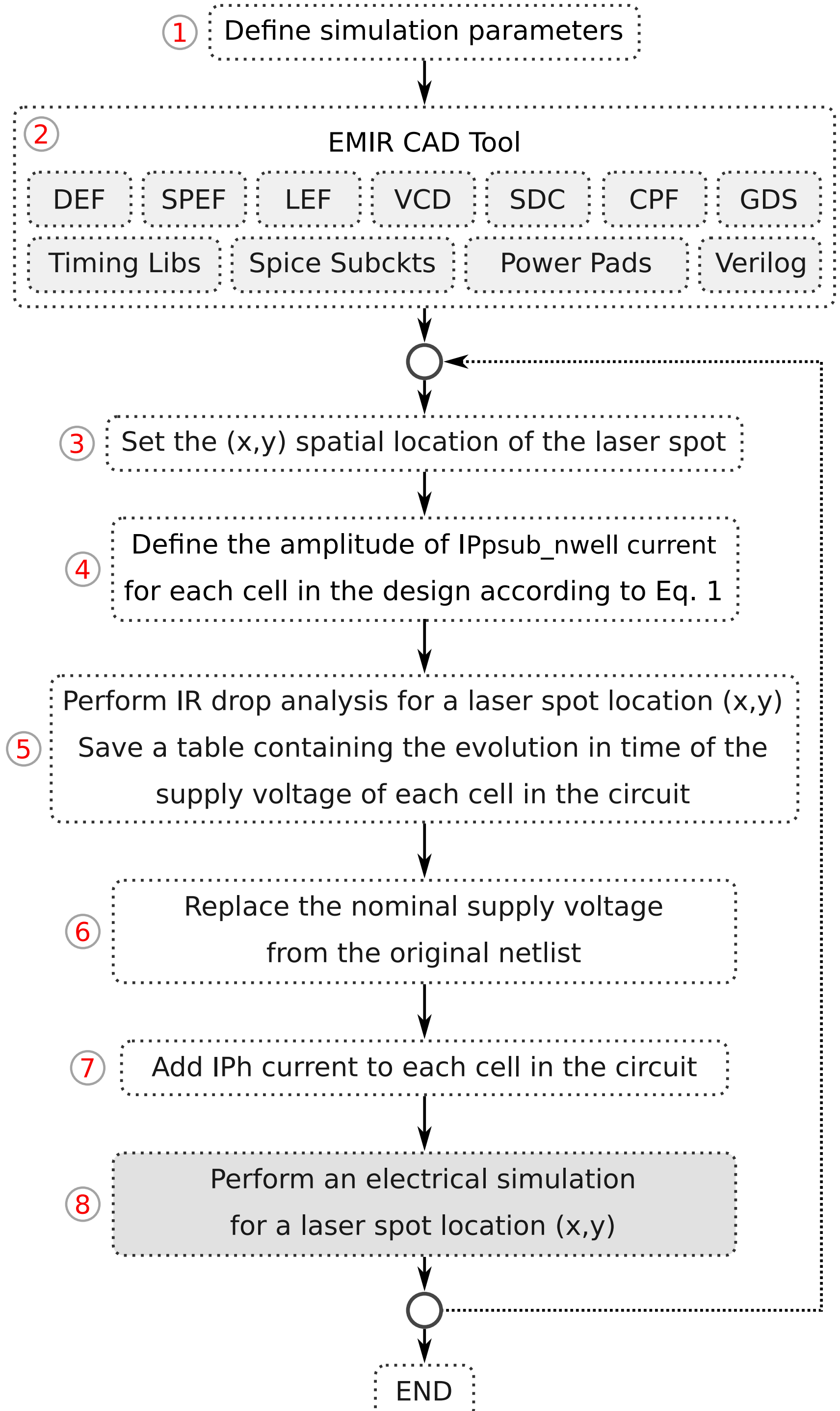
U527 (net21866 n134 GND_U527 GND_U527 VDD_U527 VDD_U527) STD_CELL_IVX8

VU527_VDD (vdd! VDD_U527) vsource type=pwl val0=0 wave=[1.5n 1 ... 1.65 0.78 ... tn vn]

VU527_GND (GND_U527 gnd!) vsource type=pwl val0=0 wave=[1.5n 0 ... 1.68 0.23 ... tn vn]

IU527_VDD (VDD_U527 n134) isource dc=0 type=exp val0=0 td1=fstart
tau1=rise_time
val1=154.69u
td2=fall_start
tau2=fall_time

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Replace the nominal supply voltage
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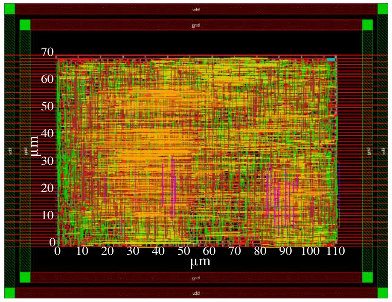
Add IPh current to each cell in the circuit
8
Perform an electrical simulation
for a laser spot location (x,y)
END

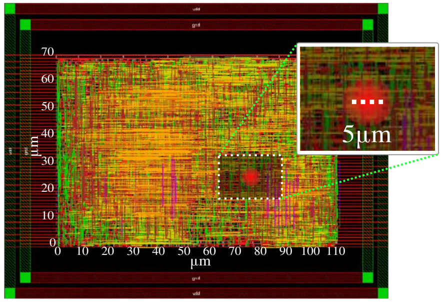
8

Perform an electrical simulation

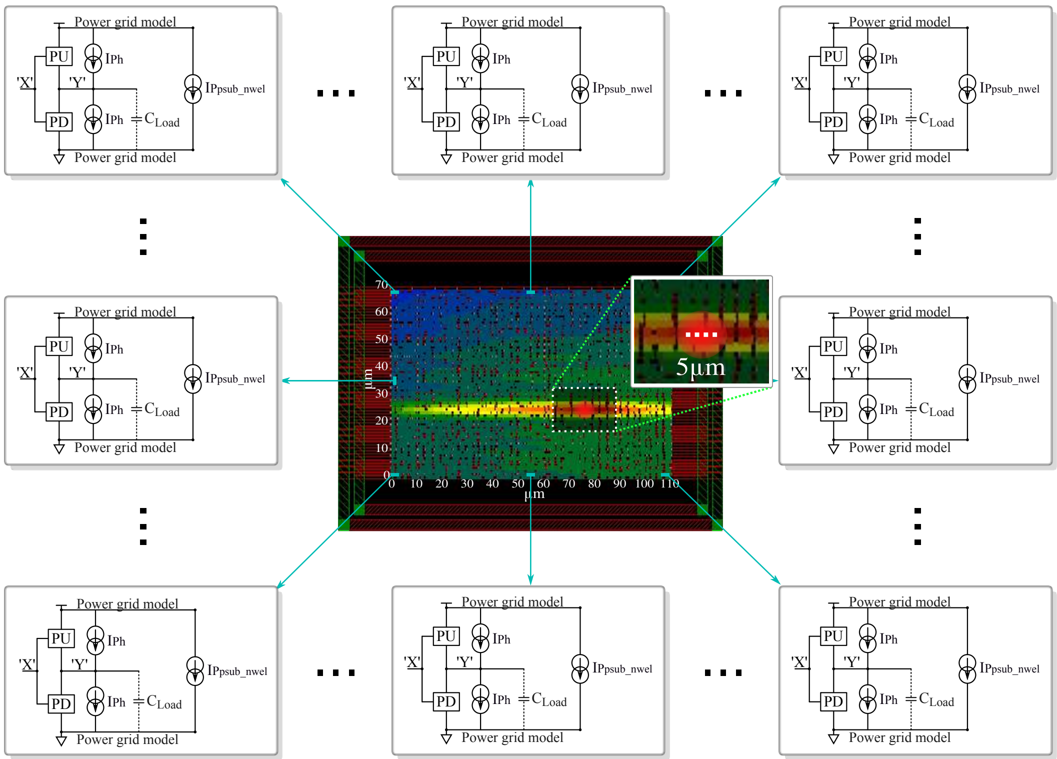
for a laser spot location (x,y)



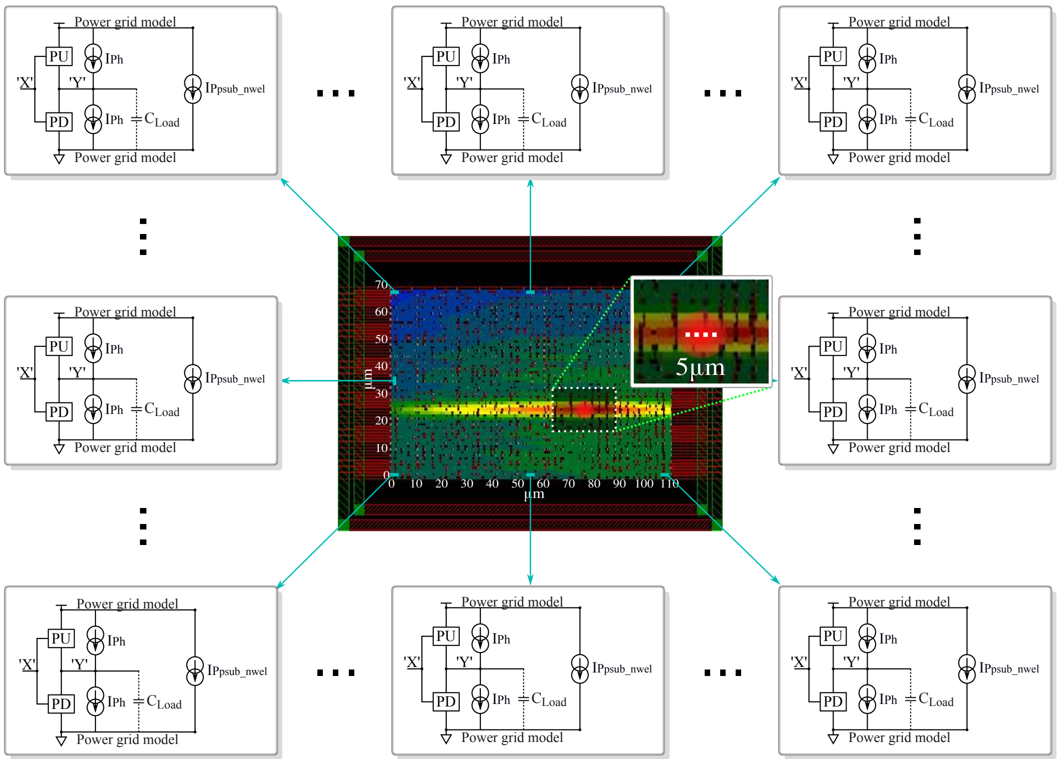
8 Perform an electrical simulation for a laser spot location (x,y)



8 Perform an electrical simulation for a laser spot location (x,y)



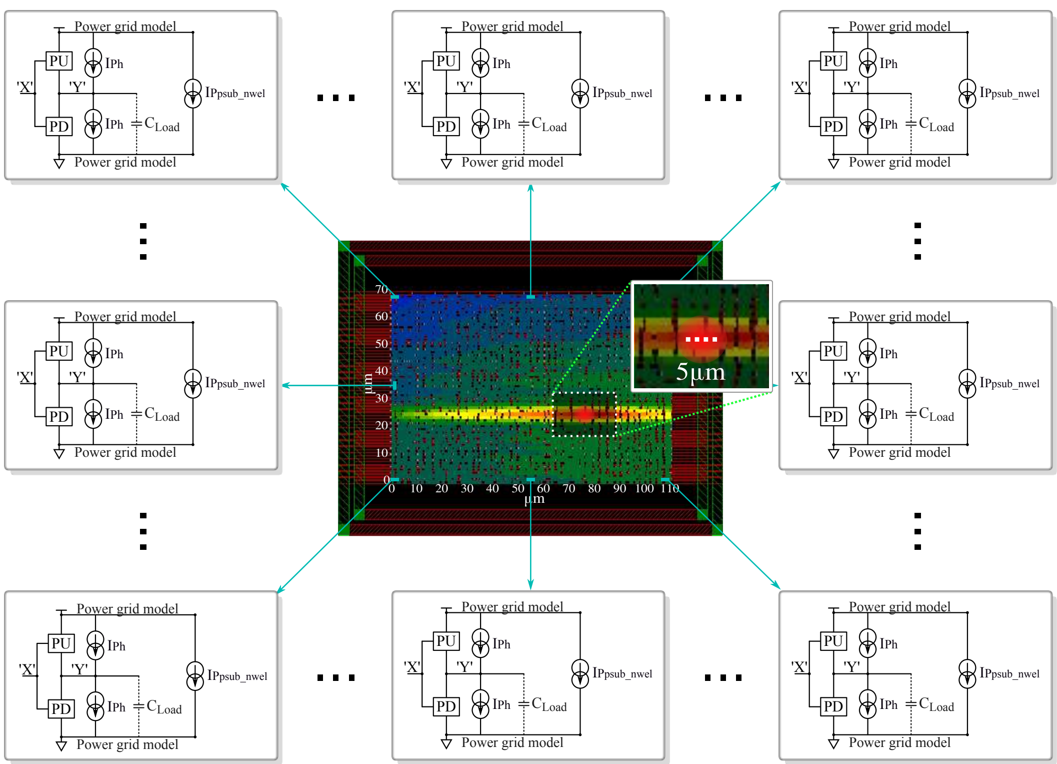
8 Perform an electrical simulation for a laser spot location (x,y)




```
option( ?categ 'turboOpts
 'numThreads  ncpus_active
 'mtOption  "Manual"
 'apsplus  t
 'digitalInstValue  digital_inst_list
 'uniMode  "XPS MS"
)
```

Hybrid simulation

8 Perform an electrical simulation for a laser spot location (x,y)




```
option( ?categ 'turboOpts
 'numThreads  ncpus_active
 'mtOption  "Manual"
 'apsplus  t
 'digitalInstValue  digital_inst_list
 'uniMode  "XPS MS"
)
```

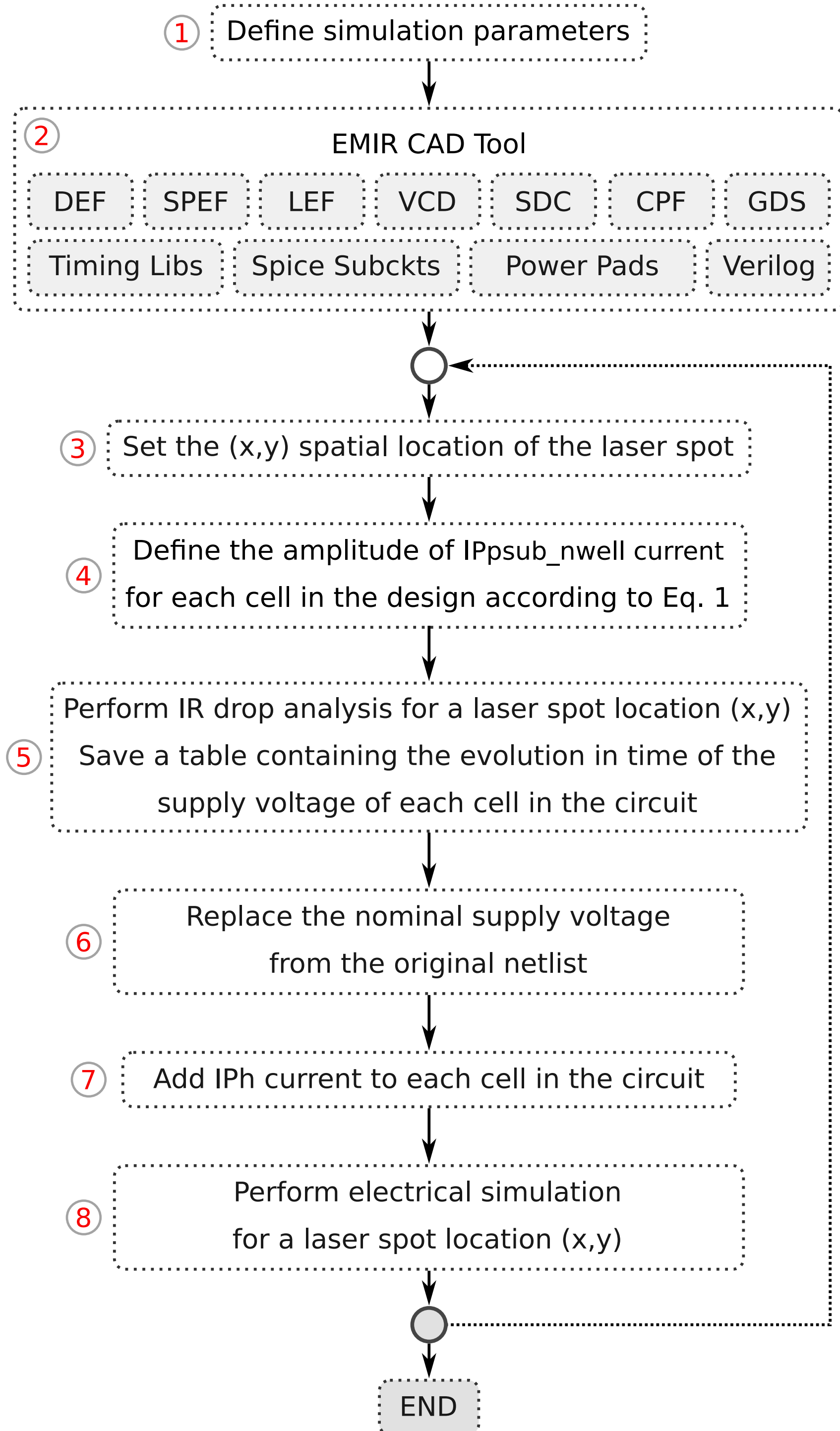
Hybrid simulation

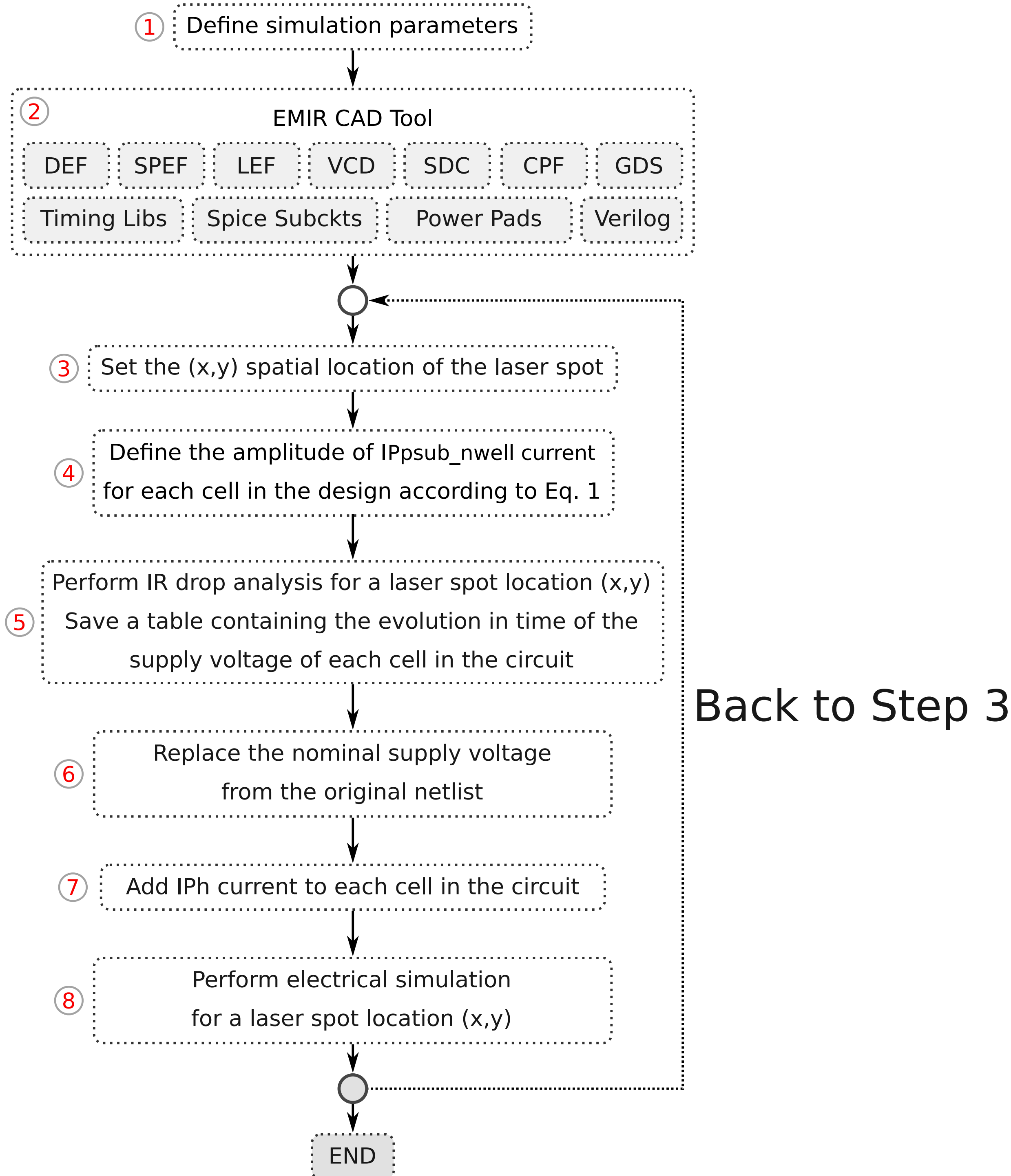
Number of instances simulated with the logic abstraction level for different threshold voltages and different spot locations.

Threshold (IR drop + bounce)	No. of cells (spot loc.130)	No. of cells (spot loc.133)
5%	1676	1646
10%	4744	4866
15%	4878	5033

No. of instances: 5.21k

4 - Simulation methodology




1 Define simulation parameters
2 EMIR CAD Tool
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SDC
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6 Replace the nominal supply voltage
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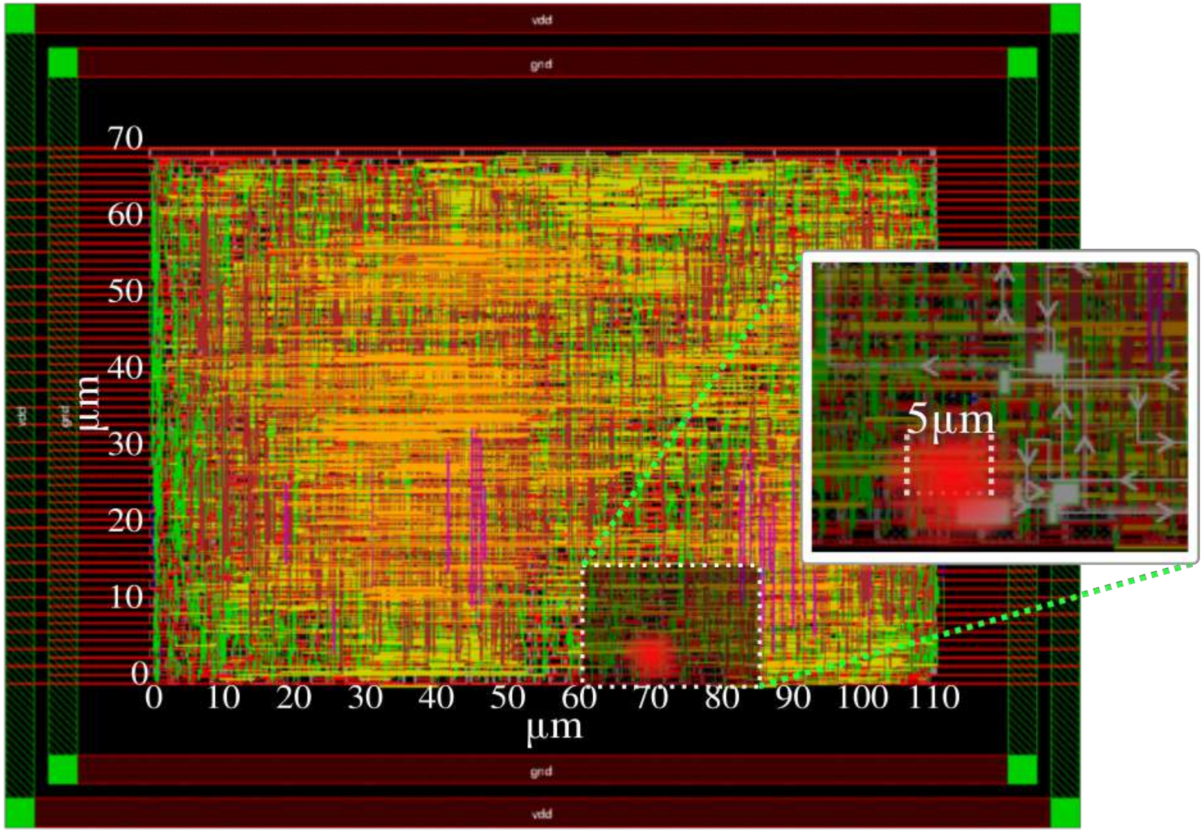
8 Perform electrical simulation
for a laser spot location (x,y)
END
Back to Step 3

Outline

1. Motivation
2. Classical model of laser fault injection and its limits
3. Proposed model
4. Simulation methodology
5. Simulation results
6. Conclusions

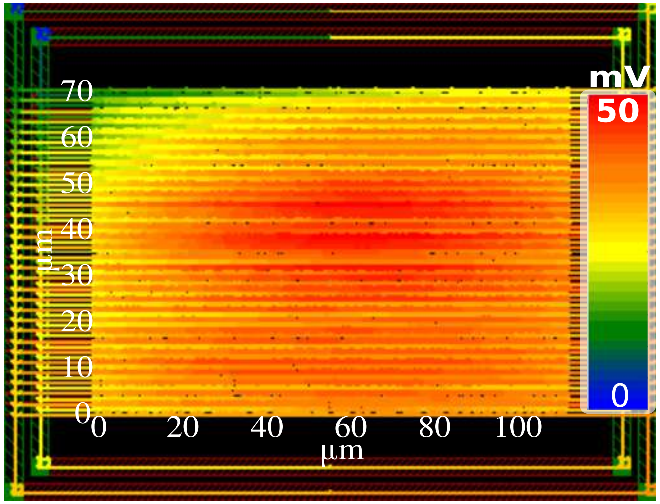
Outline



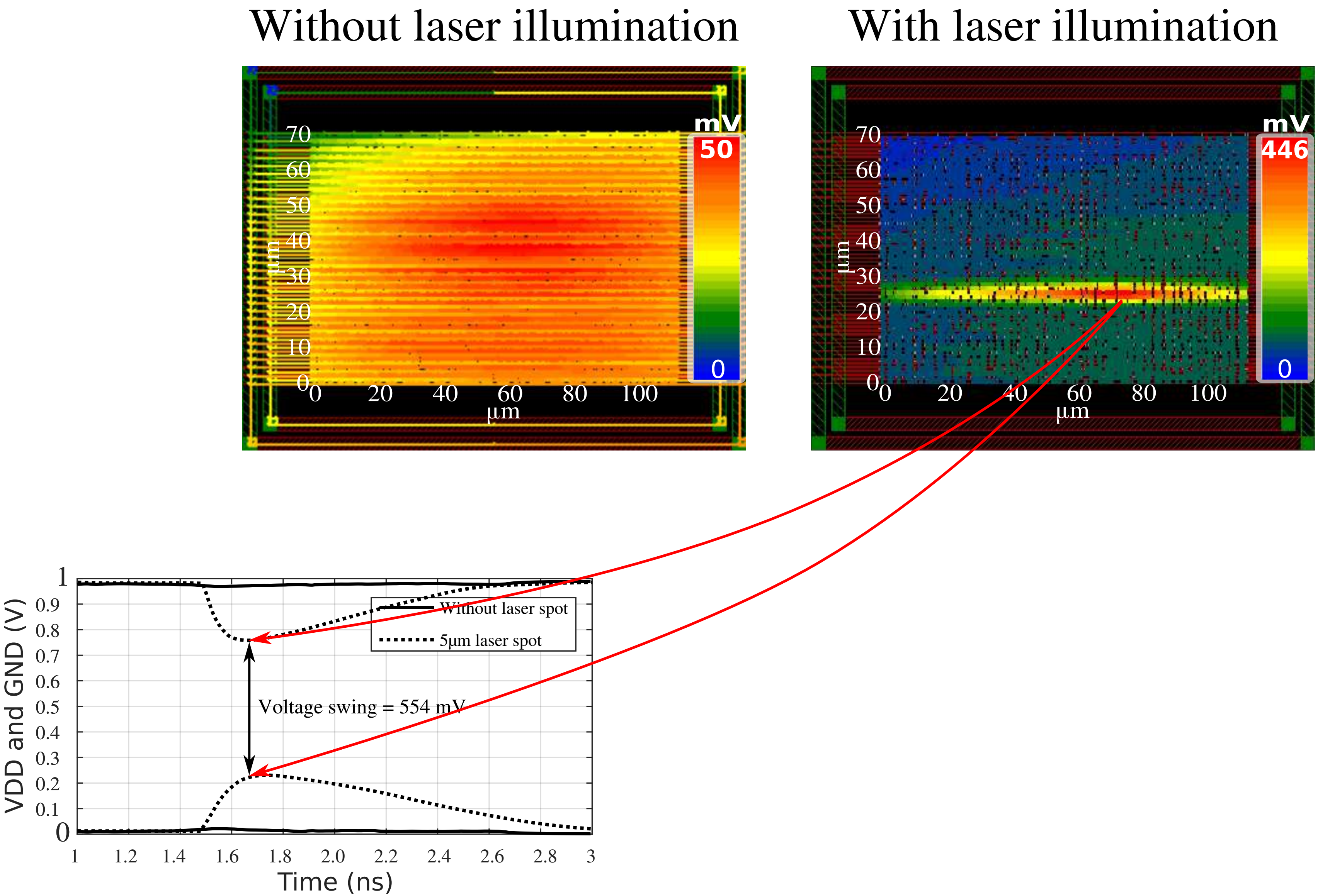
ARM 7 processor
CMOS 28 nm
VDD = 1 V
110 µm x 70 µm
Laser spot diameter = 5 µm

5.2 - Maximum Voltage Drop

Without laser illumination



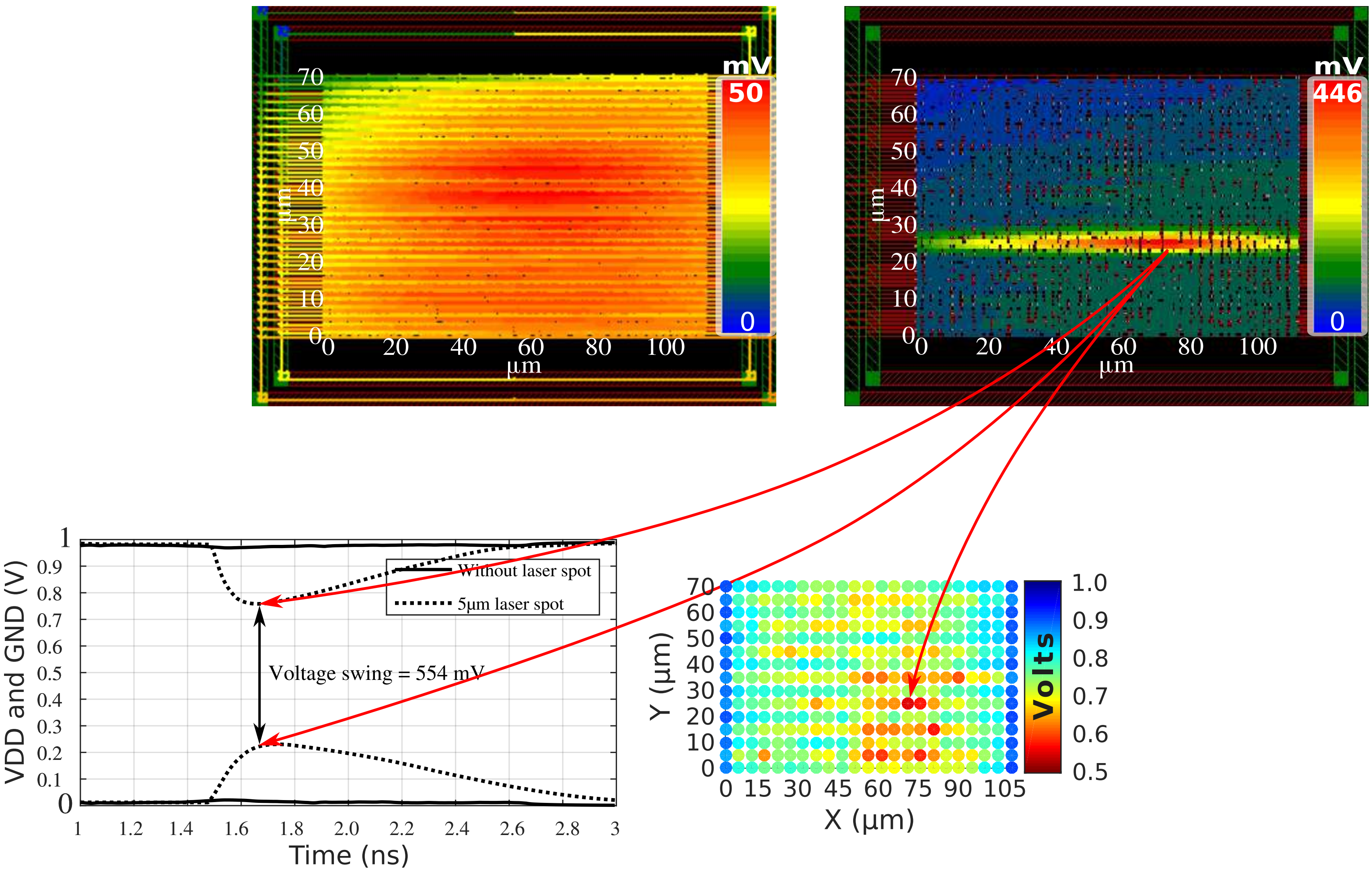
5.2 - Maximum Voltage Drop



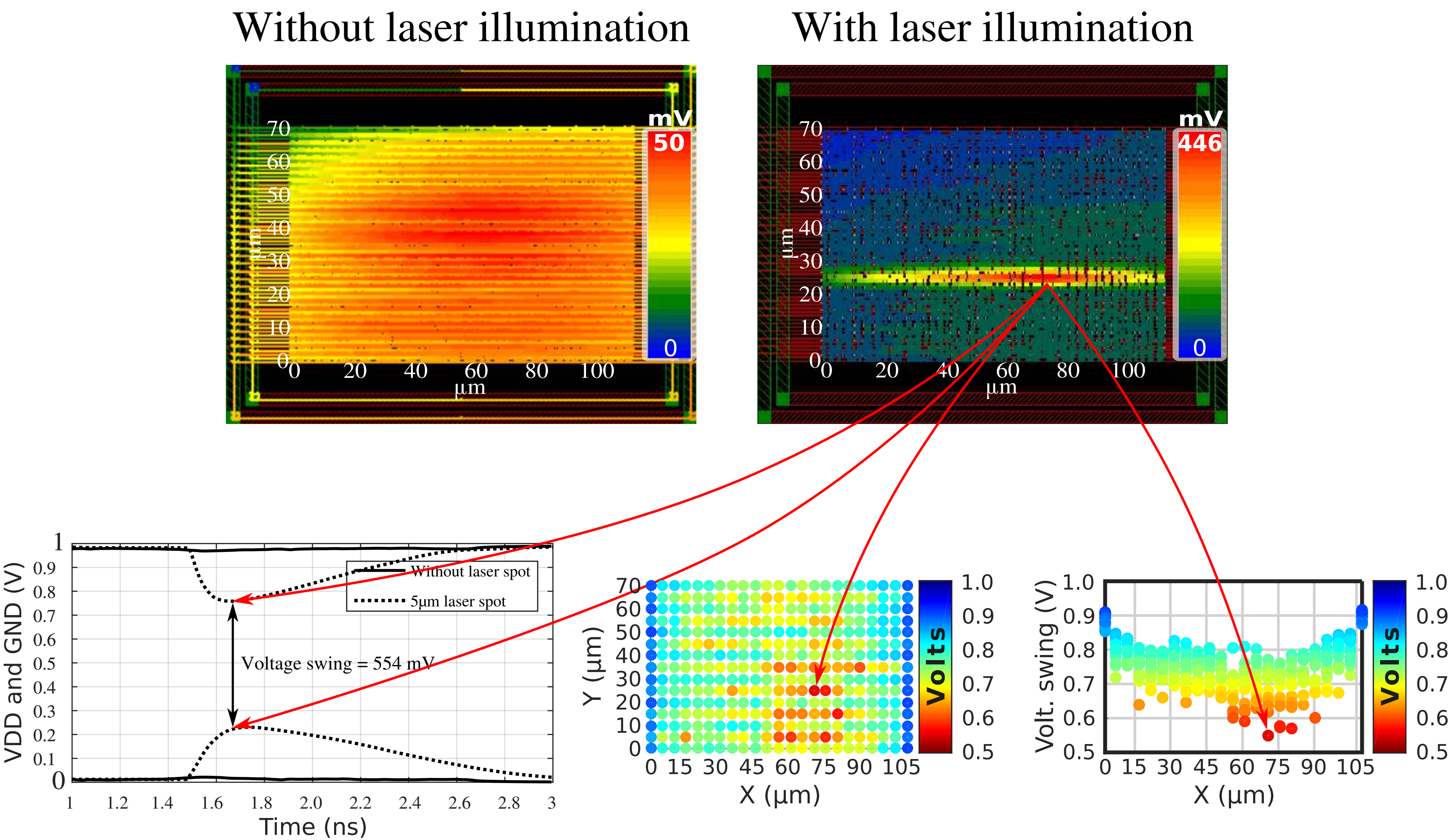
5.2 - Maximum Voltage Drop

Without laser illumination

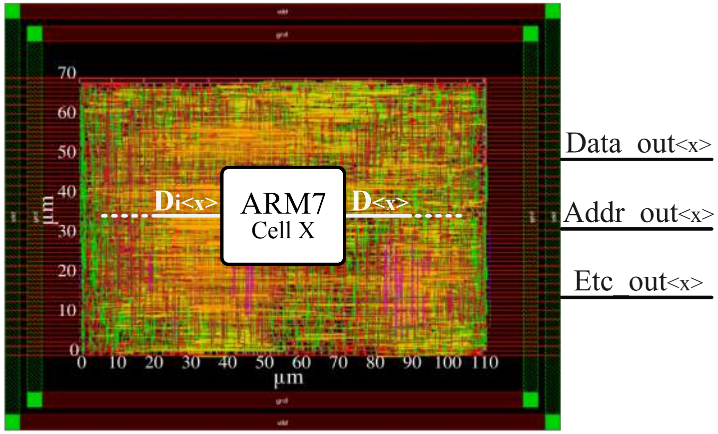
With laser illumination



5.2 - Maximum Voltage Drop



5.3 - Simulated Scenarios and Fault Injection Maps



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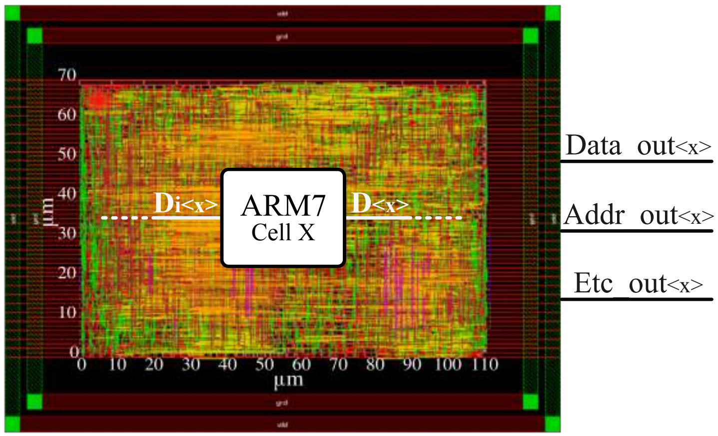
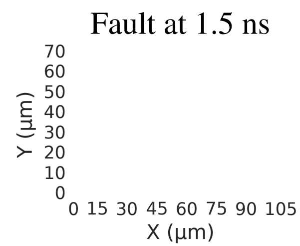
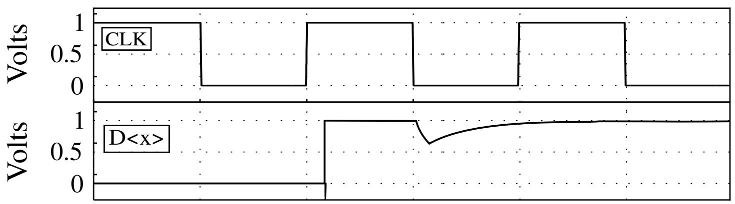




48 faults



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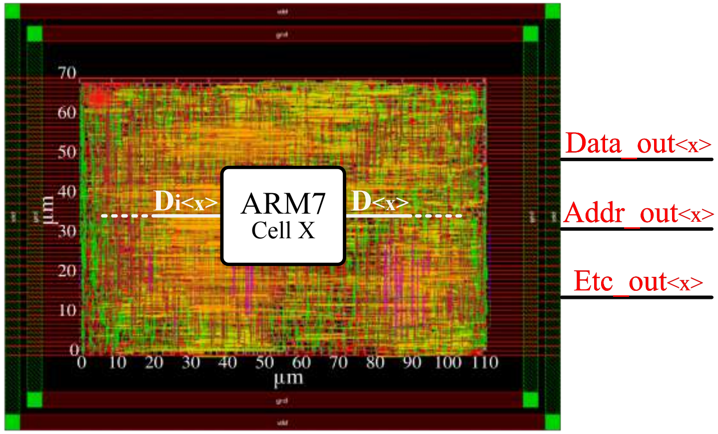

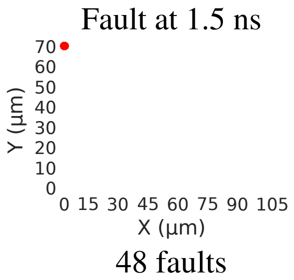

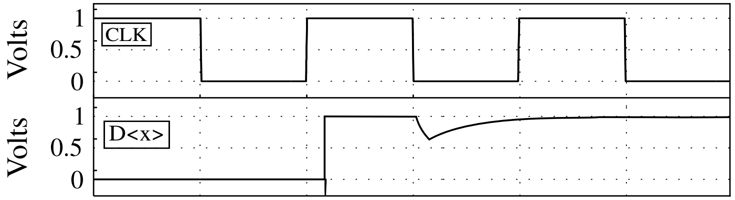

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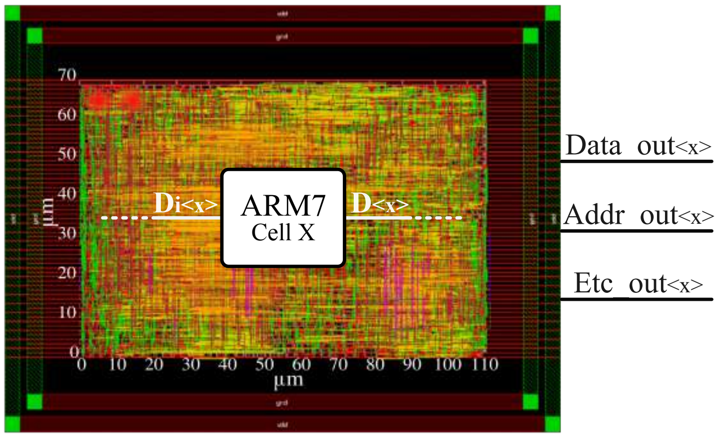

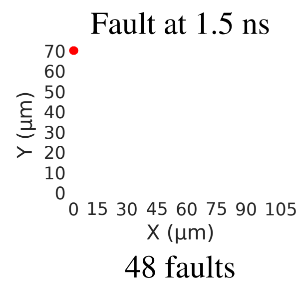

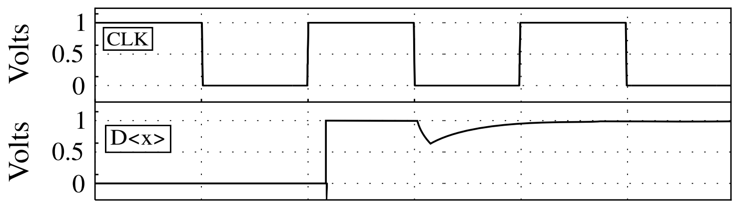

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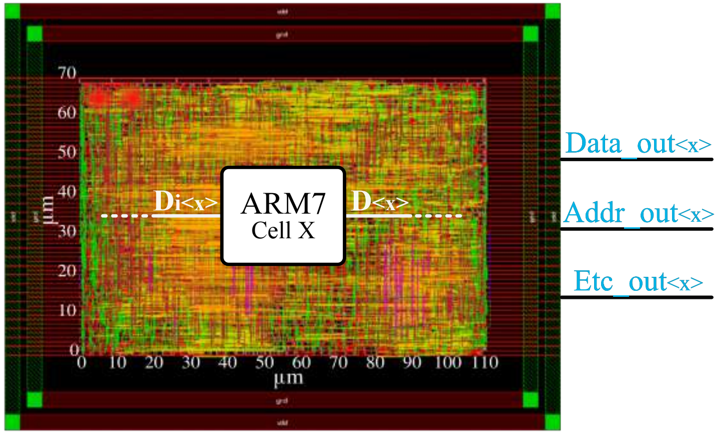

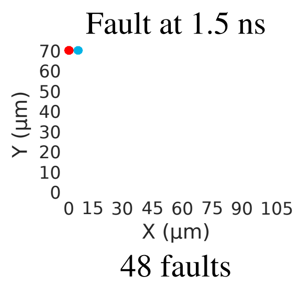

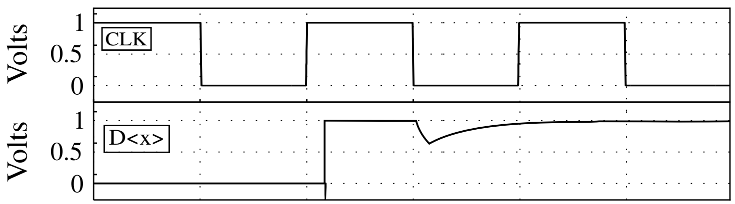

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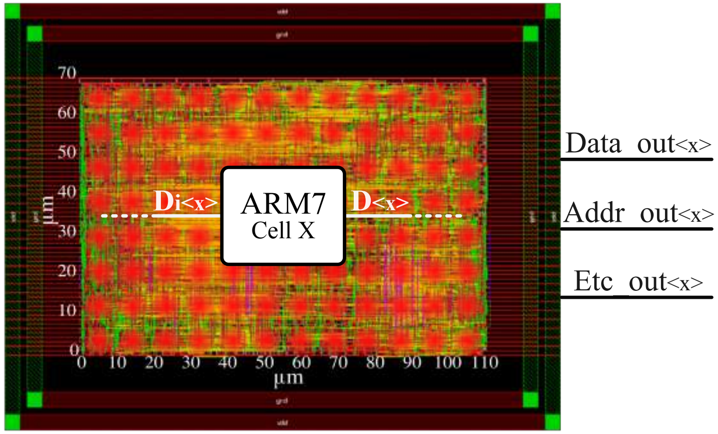

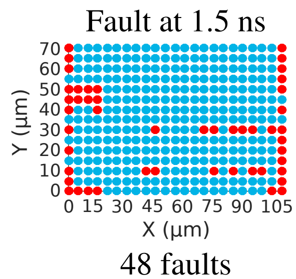

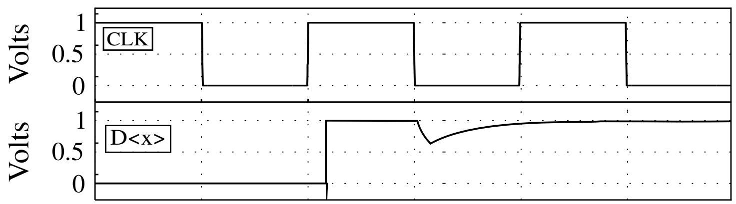

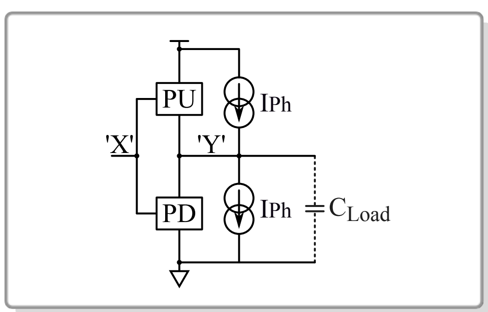

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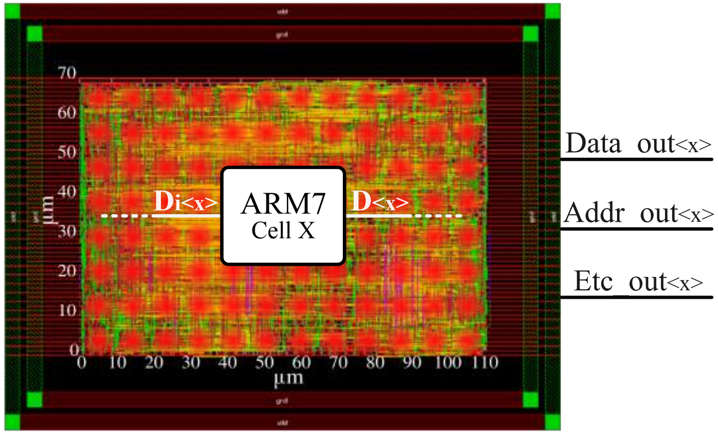

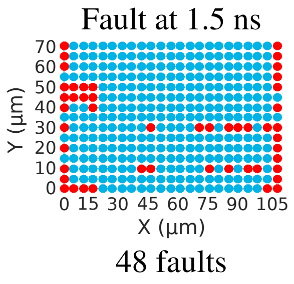

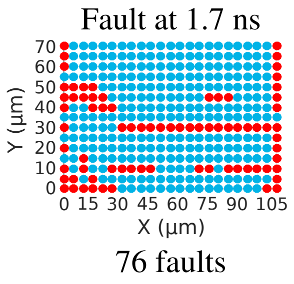

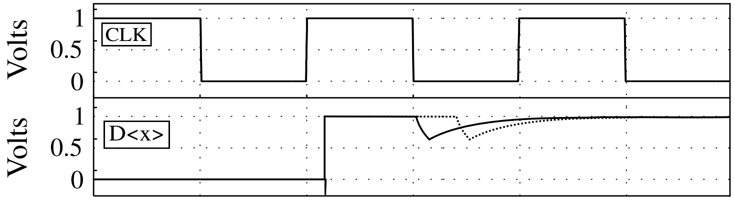

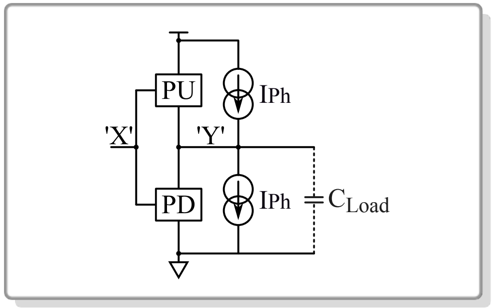

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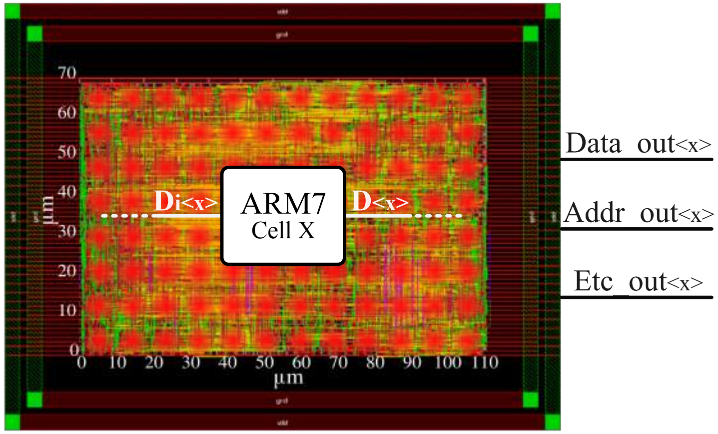
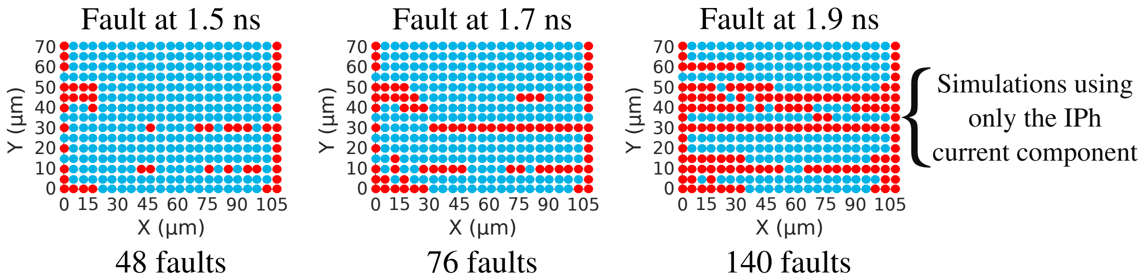
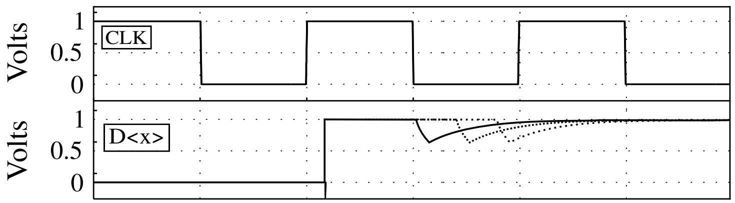
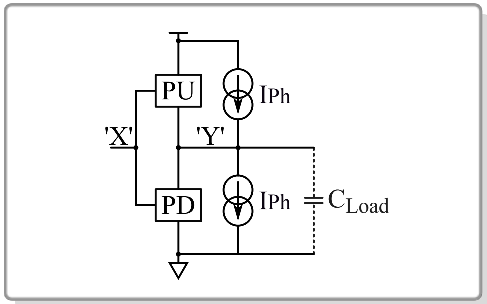
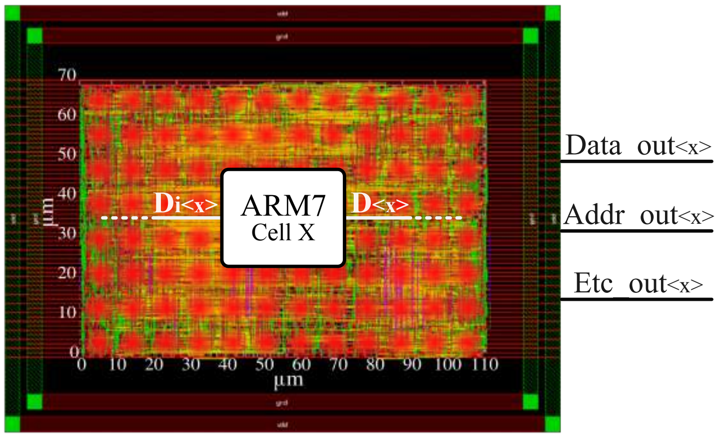


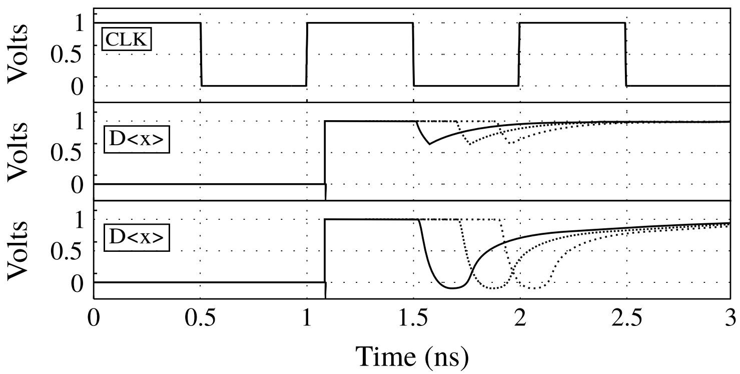


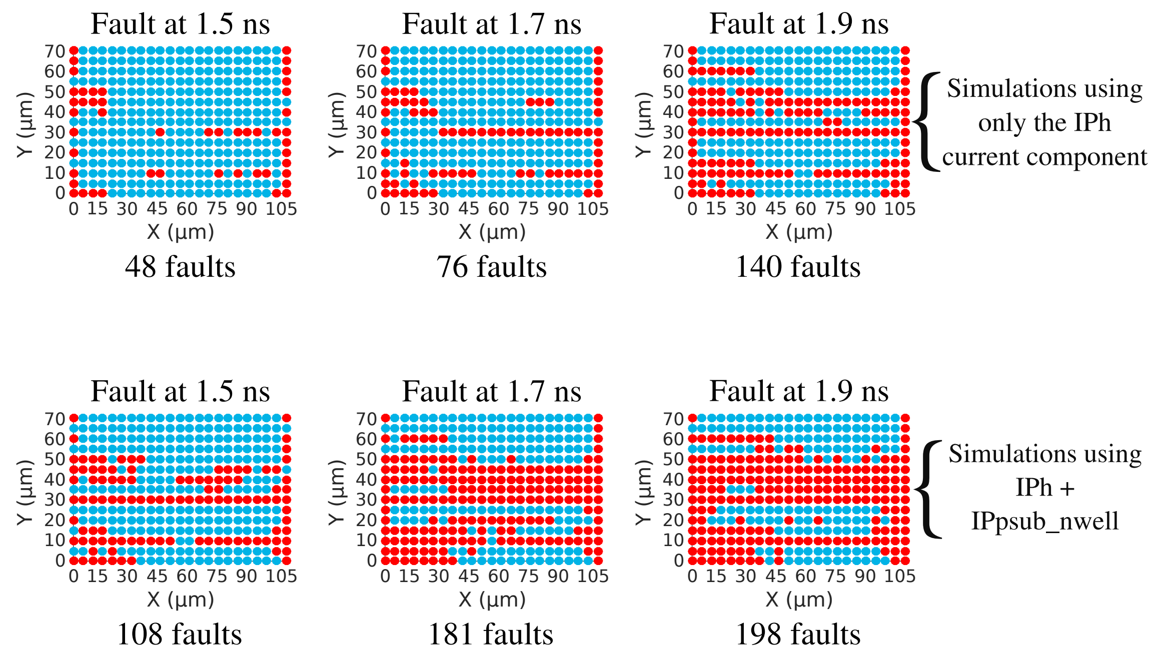


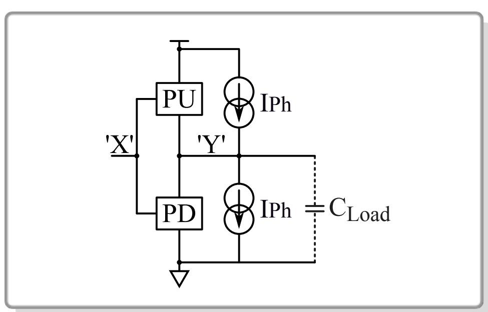


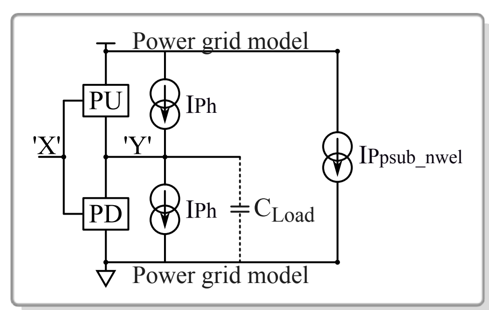
5.3 - Simulated Scenarios and Fault Injection Maps



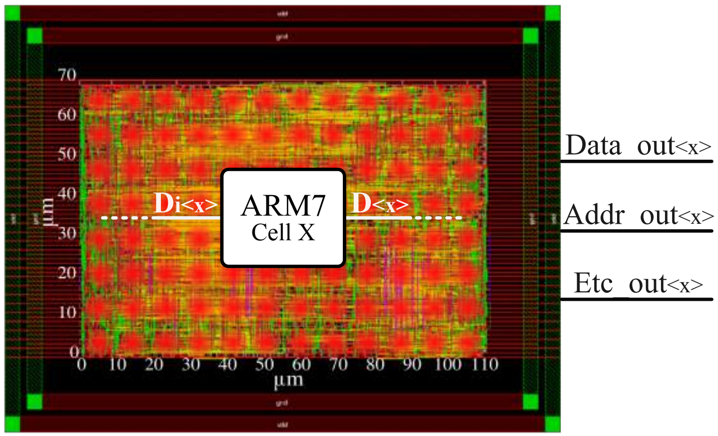


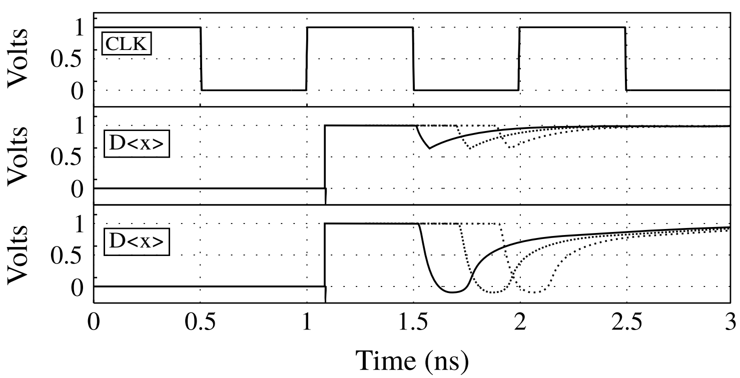


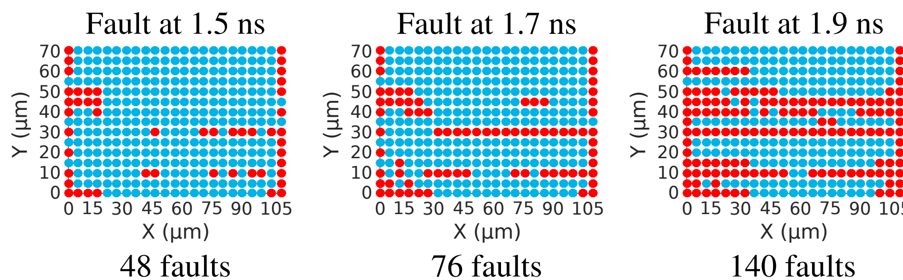




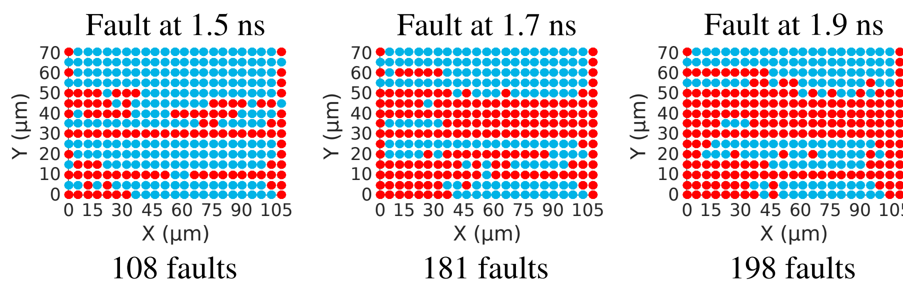
5.3 - Simulated Scenarios and Fault Injection Maps





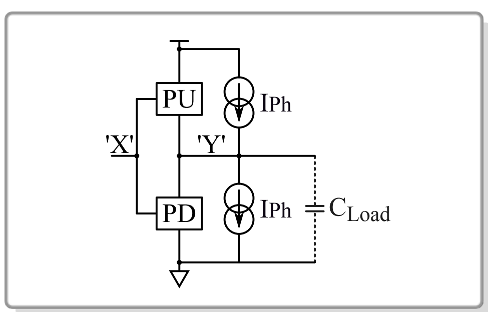


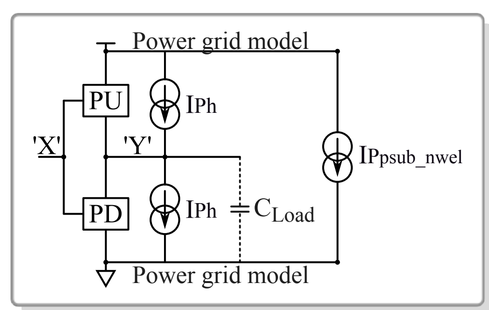
Simulations using only the IPh current component



Simulations using IPh + IPpsub_nwell

108/48 = 2.25 **181/76 = 2.38** **198/140 = 1.41**





Simulation performance regarding one laser shot

(hybrid simulation)

Circuit	No. of instances	Simulation time
ARM 7	5,210	1min 02s

Simulation performance regarding one laser shot

(hybrid simulation)

Circuit	No. of instances	Simulation time
ARM7	5,210	1min 02s
S38584 (ISCAS'89)	20,705	1min 20s

Simulation performance regarding one laser shot

(hybrid simulation)

Circuit	No. of instances	Simulation time
ARM7	5,210	1min 02s
S38584 (ISCAS'89)	20,705	1min 20s
B18 (ITC'99)	52,601	3min 05s

Simulation performance regarding one laser shot

(hybrid simulation)

Circuit	No. of instances	Simulation time
ARM7	5,210	1min 02s
S38584 (ISCAS'89)	20,705	1min 20s
B18 (ITC'99)	52,601	3min 05s
B19 (ITC'99)	105,344	6min 35s

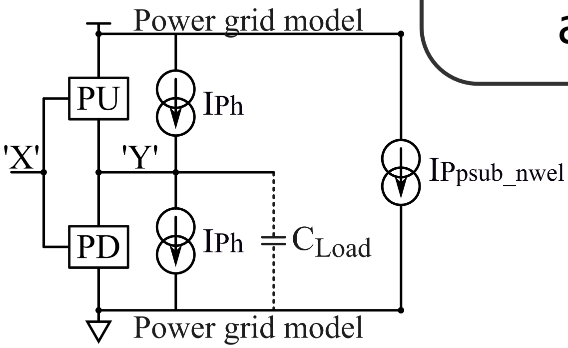
Outline

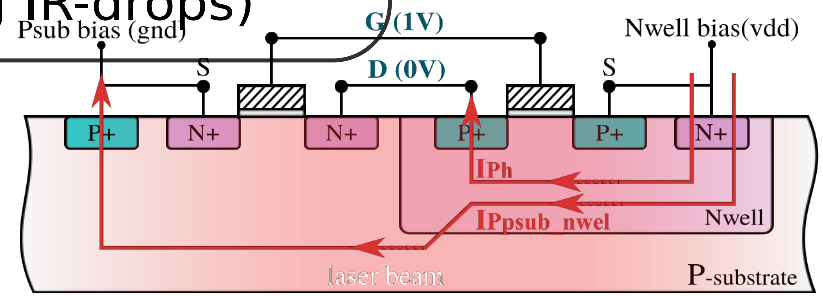
1. Motivation
2. Classical model of laser fault injection and its limits
3. Proposed model
4. Simulation methodology
5. Simulation results
6. Conclusions

Outline

Conclusions

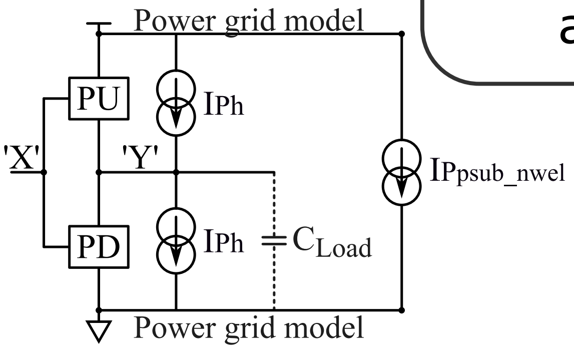
IPpsub_nwell current component is always present (causing IR-drops)

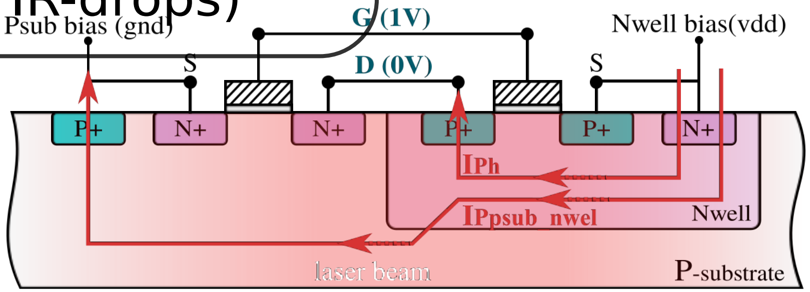




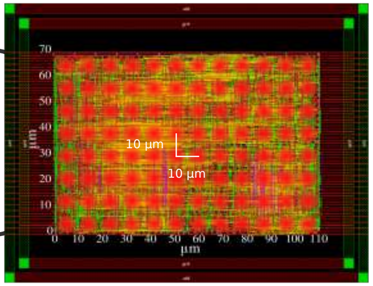
Conclusions

IPpsub_nwell current component is always present (causing IR-drops)

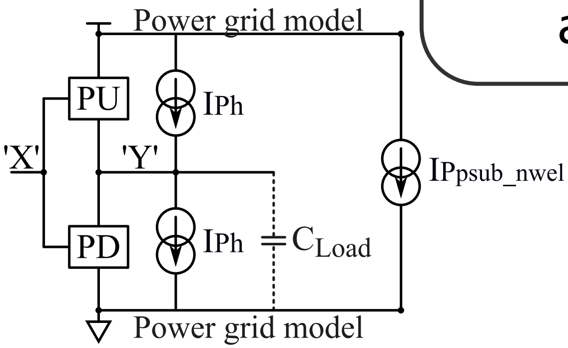




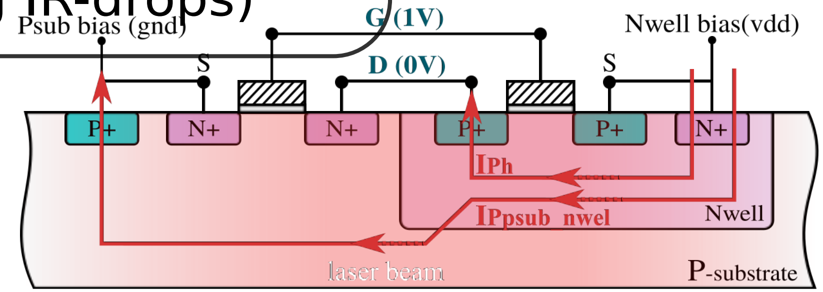
Methodology to simulate the effects of laser shots on ICs based on standard CAD tools



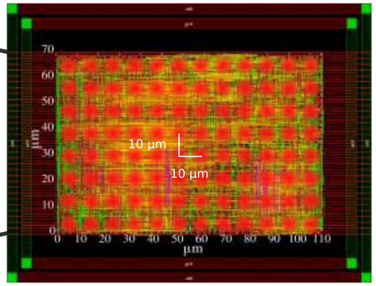
Conclusions



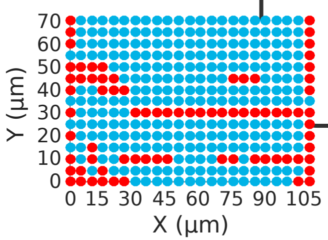
IPpsub_nwell current component is always present (causing IR-drops)



Methodology to simulate the effects of laser shots on ICs based on standard CAD tools

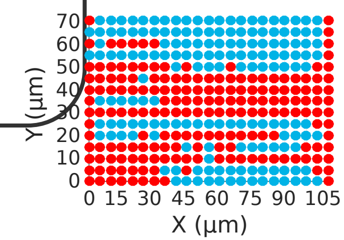


Ignoring the laser-induced IR drop may result in underestimating the risk of fault injection



76 faults

181/76 = 2.38



181 faults

ISPD'18
March 28, 2018

Standard CAD Tool-Based Method for Simulation of Laser-Induced Faults in Large-Scale Circuits

Raphael Viera - raphael@ieee.org
Philippe Maurine, Jean-Max Dutertre and Rodrigo Bastos

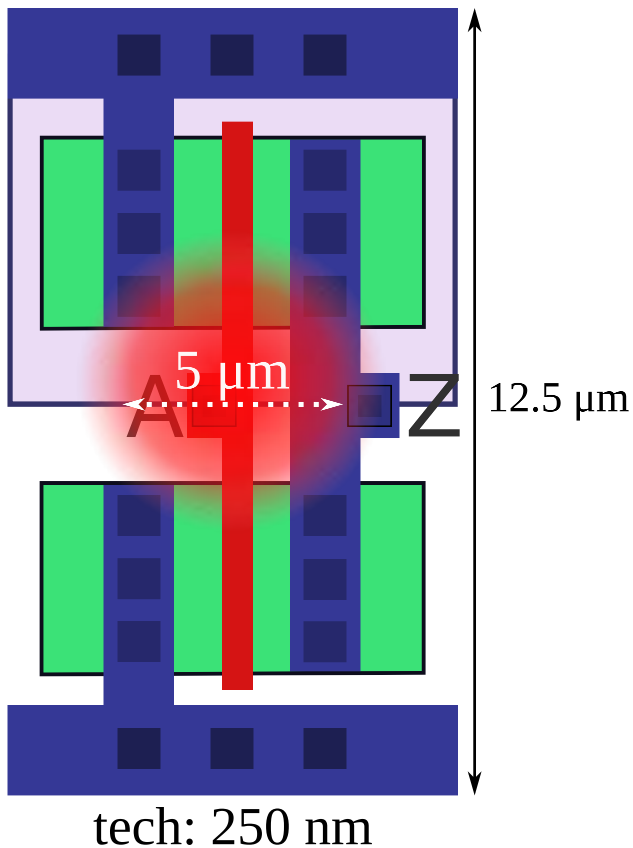
LIRMM

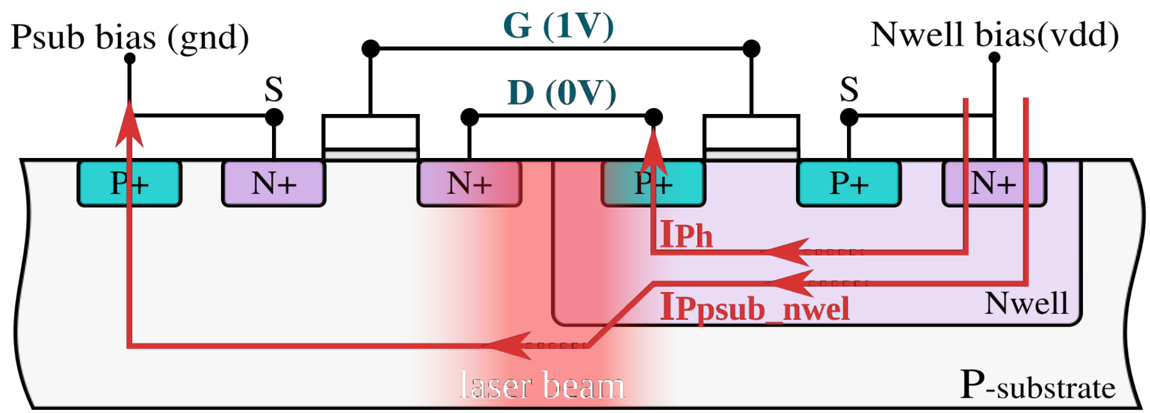
MINES Saint-Étienne
Une école de l'IMT

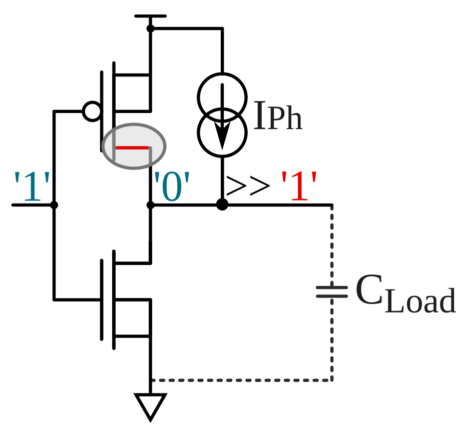
tima

Appendix

Case 4:
Both NMOS and PMOS transistors are illuminated by the laser beam

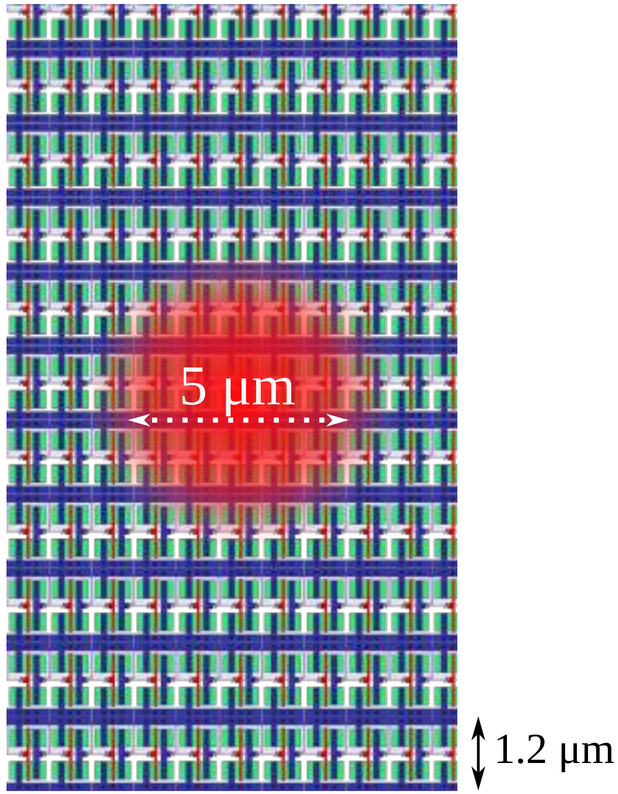




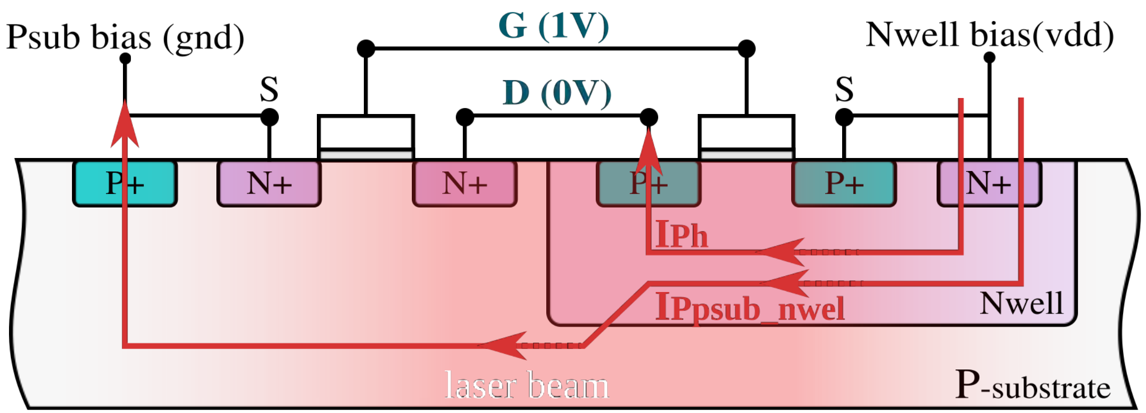


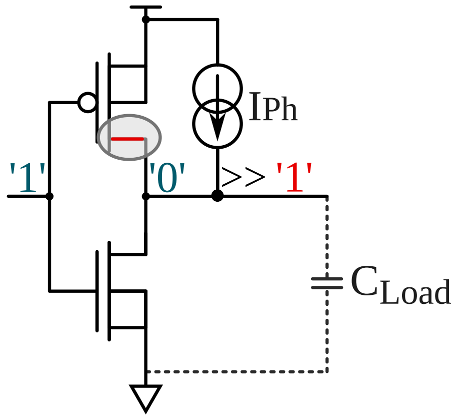
Laser-induced currents
in the Nwell-Psub junction
(classical model is **incomplete**)

Case 6:
NMOS and PMOS transistors are **always** illuminated by the laser beam



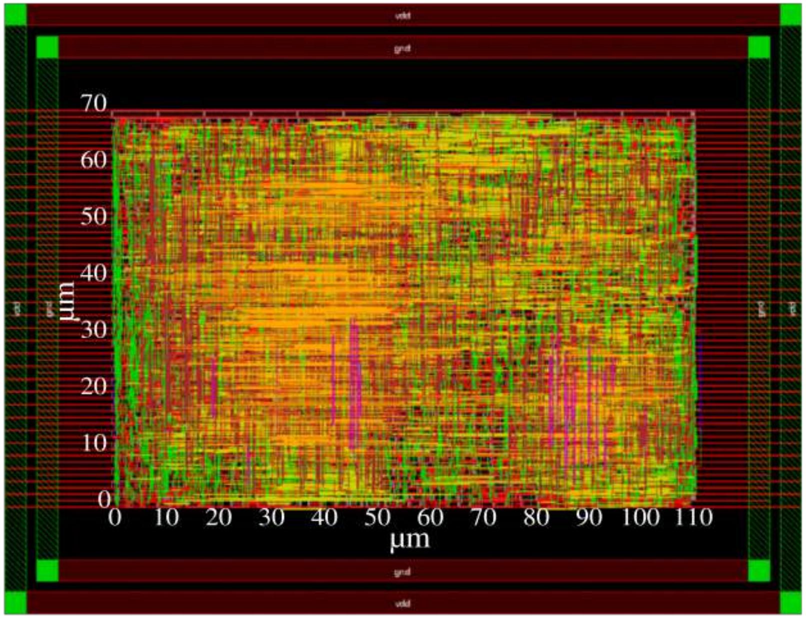
tech: 28 nm





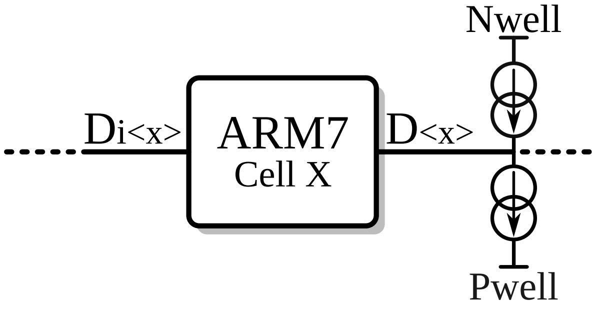
Laser-induced currents
in the Nwell-Psub junction
(classical model is **incomplete**)

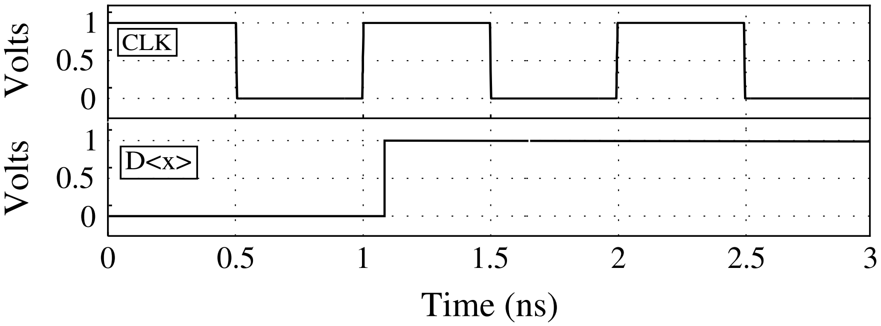
Run a fault free electrical simulation



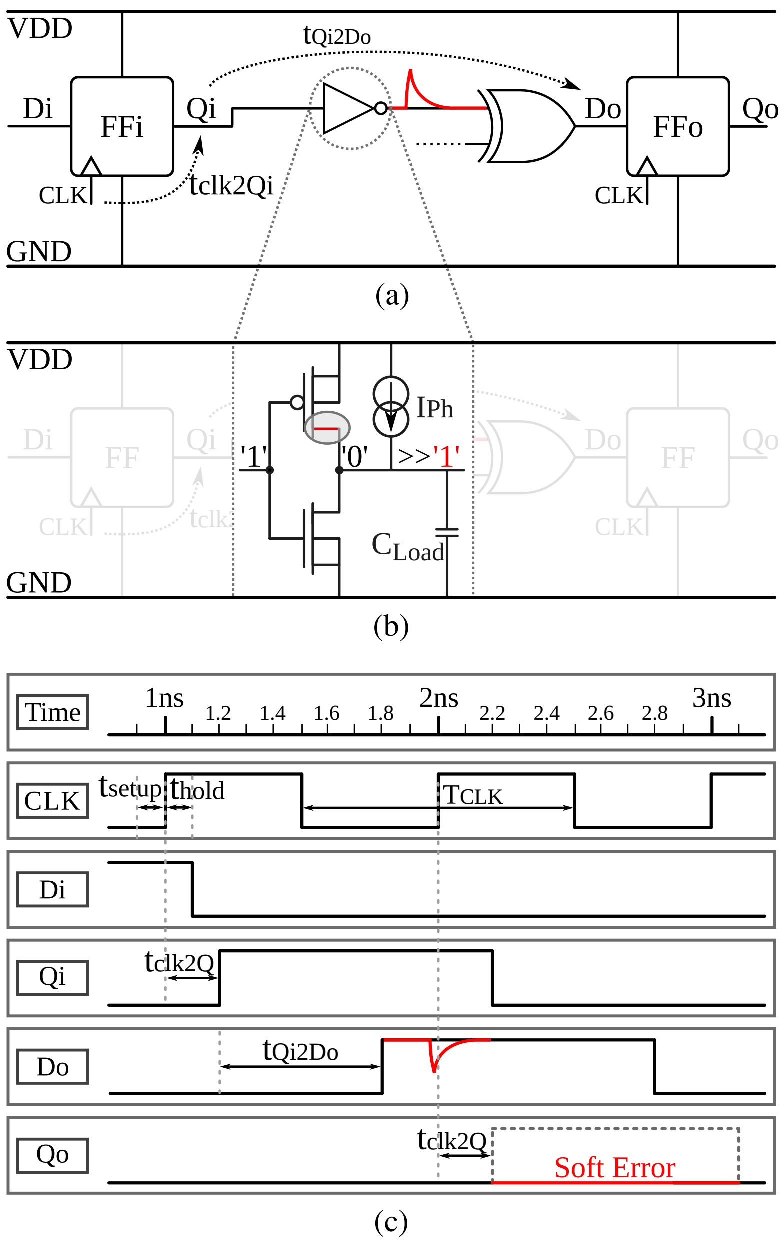
Upgraded model still not in use

Save a golden table with all inputs and outputs of each cell as a function of time

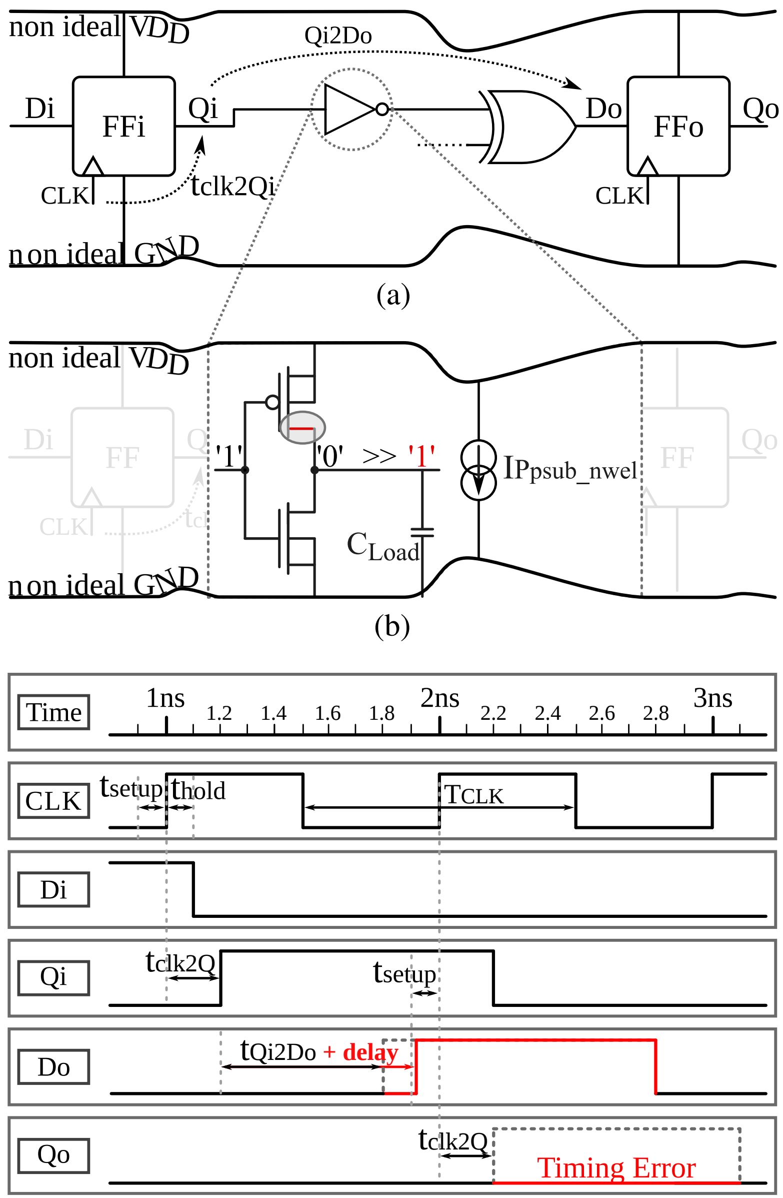




3.2 - Influence of the IPh current component



3.3 - Influence of the IPpsub_nwell current component

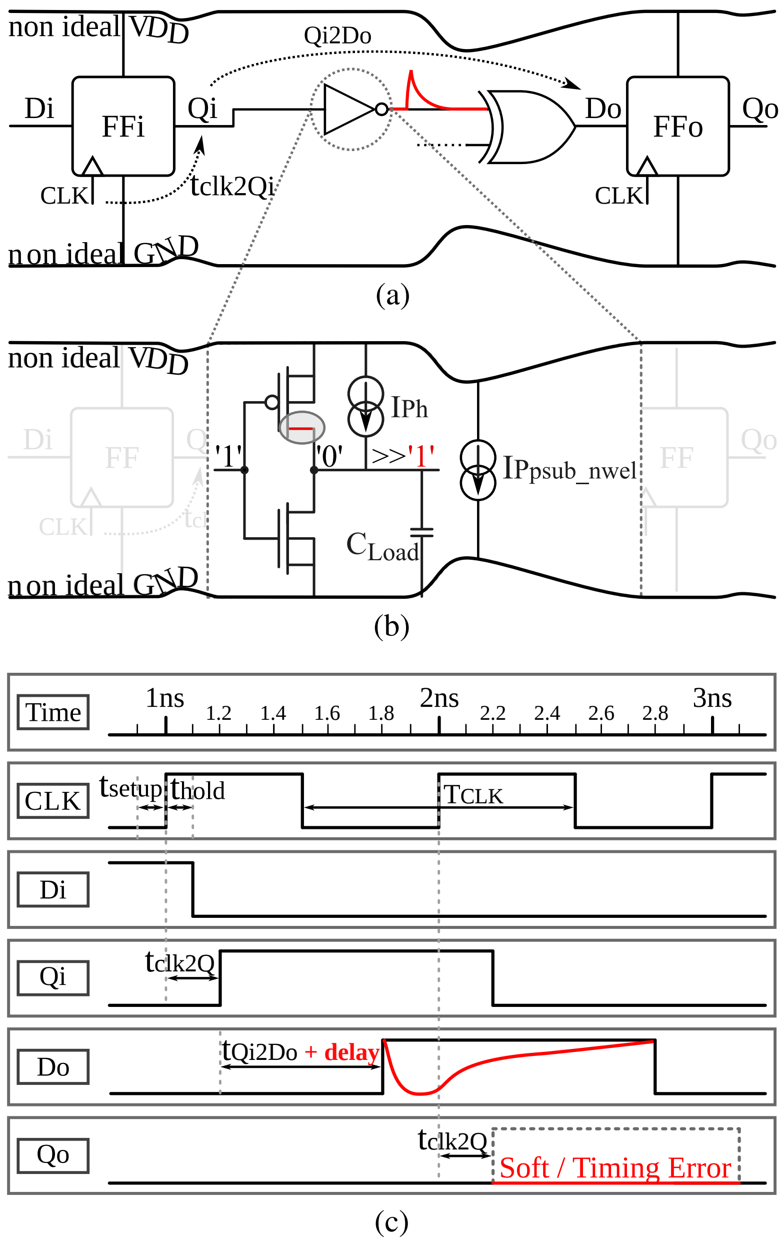


(a)

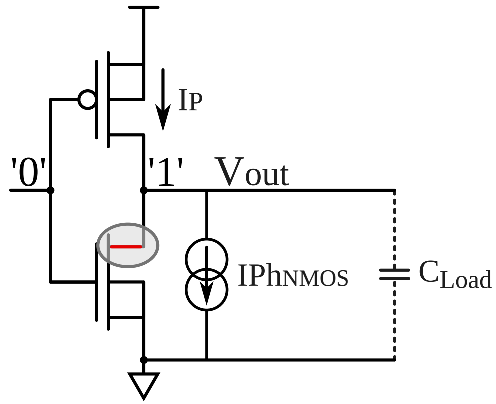
(b)

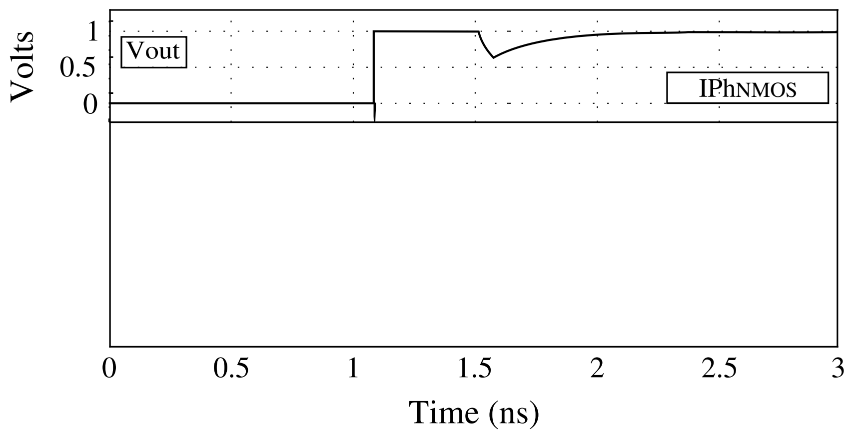
(c)

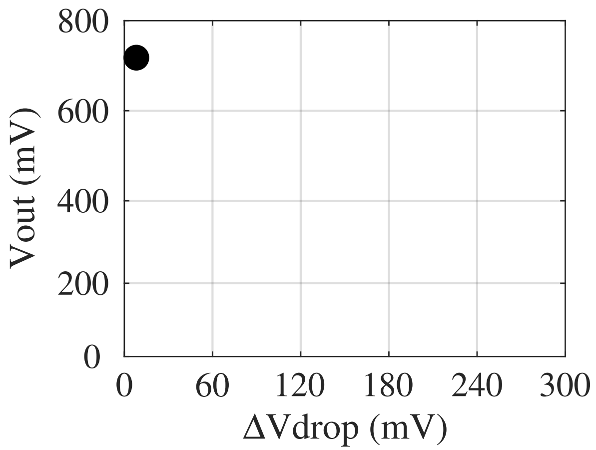
3.4 - Influence of IPh and IPpsub_nwel current components



5.3 - IR drop contribution to the fault injection mechanism

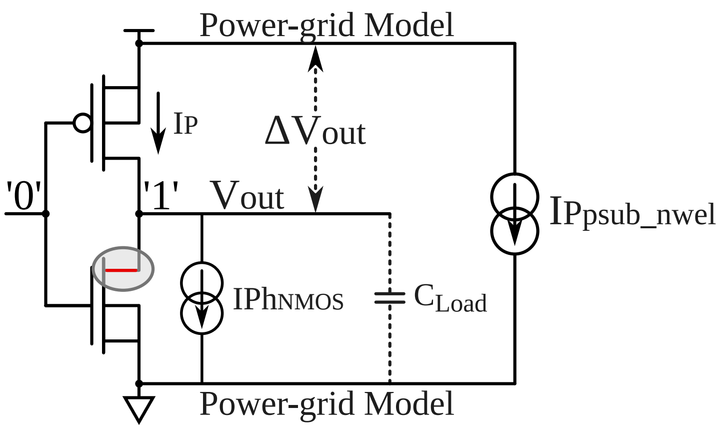


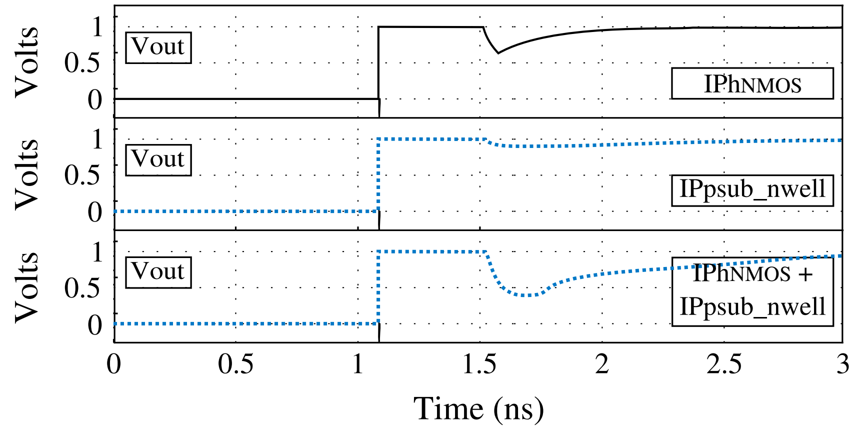


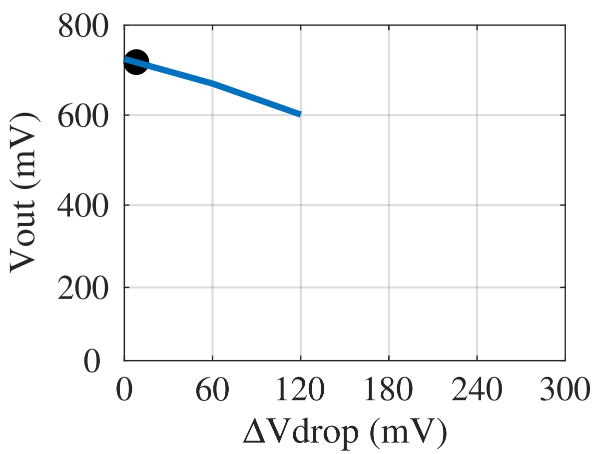


$$\Delta V_{out}(withoutIR) = -\frac{I_{Ph_{NMOS}}}{\frac{\mu \cdot C_{ox} \cdot W}{L}(V_{DD} - V_T)}$$

5.3 - IR drop contribution to the fault injection mechanism



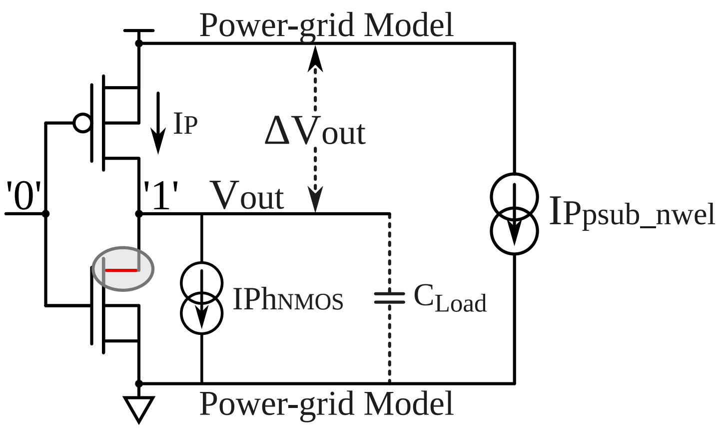


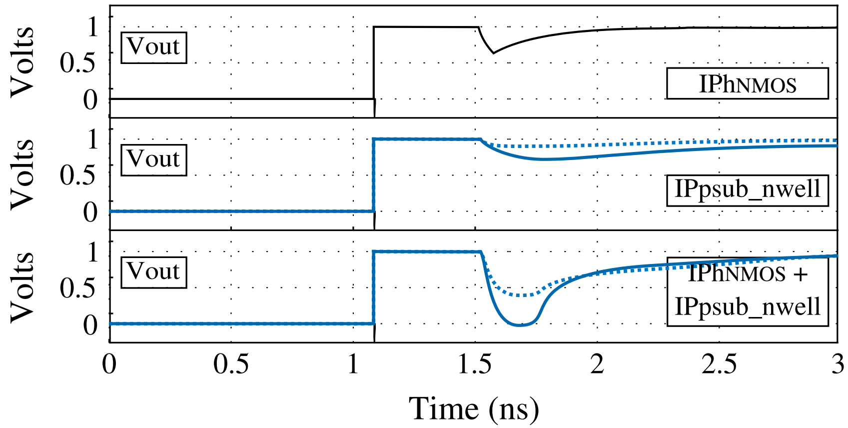


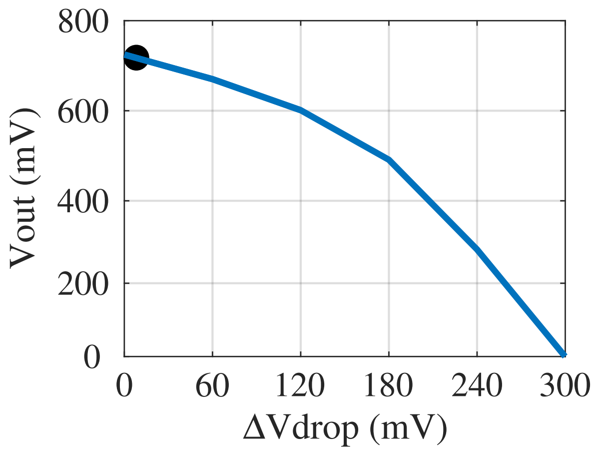
$$\Delta V_{out}(withoutIR) = -\frac{I_{Ph_{NMOS}}}{\frac{\mu \cdot C_{ox} \cdot W}{L}(V_{DD} - V_T)}$$

$$\Delta V_{out}(withIR) = -V_{drop} - \frac{I_{Ph_{NMOS}}}{\frac{\mu \cdot C_{ox} \cdot W}{L}(V_{DD} - V_{drop} - V_T)}$$

5.3 - IR drop contribution to the fault injection mechanism



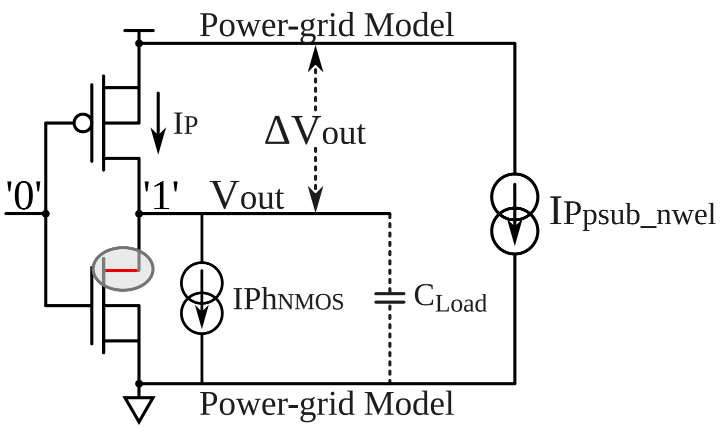


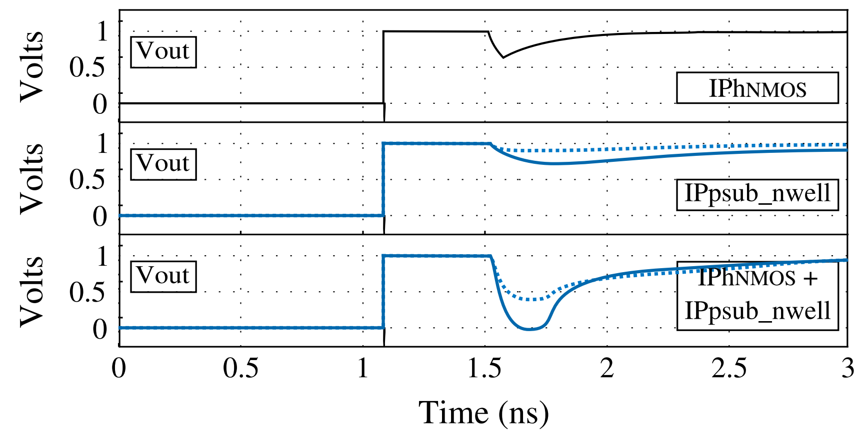


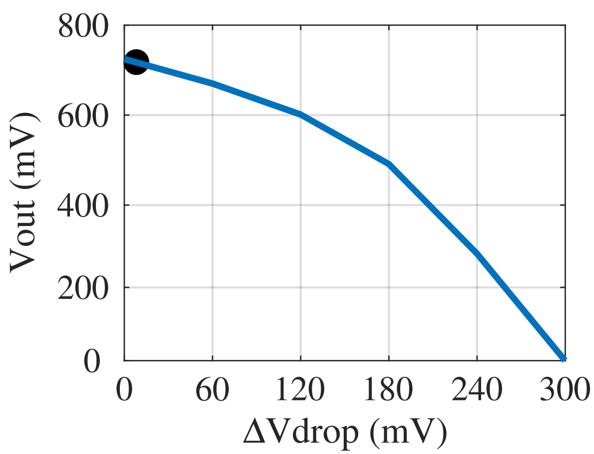
$$\Delta V_{out}(withoutIR) = -\frac{I_{Ph_{NMOS}}}{\frac{\mu \cdot C_{ox} \cdot W}{L}(V_{DD} - V_T)}$$

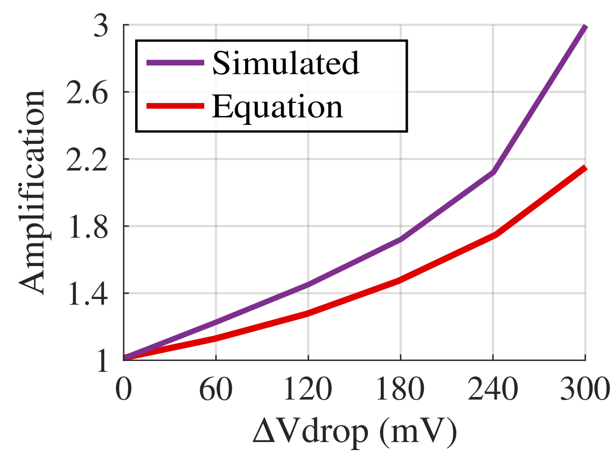
$$\Delta V_{out}(withIR) = -V_{drop} - \frac{I_{Ph_{NMOS}}}{\frac{\mu \cdot C_{ox} \cdot W}{L}(V_{DD} - V_{drop} - V_T)}$$

5.3 - IR drop contribution to the fault injection mechanism







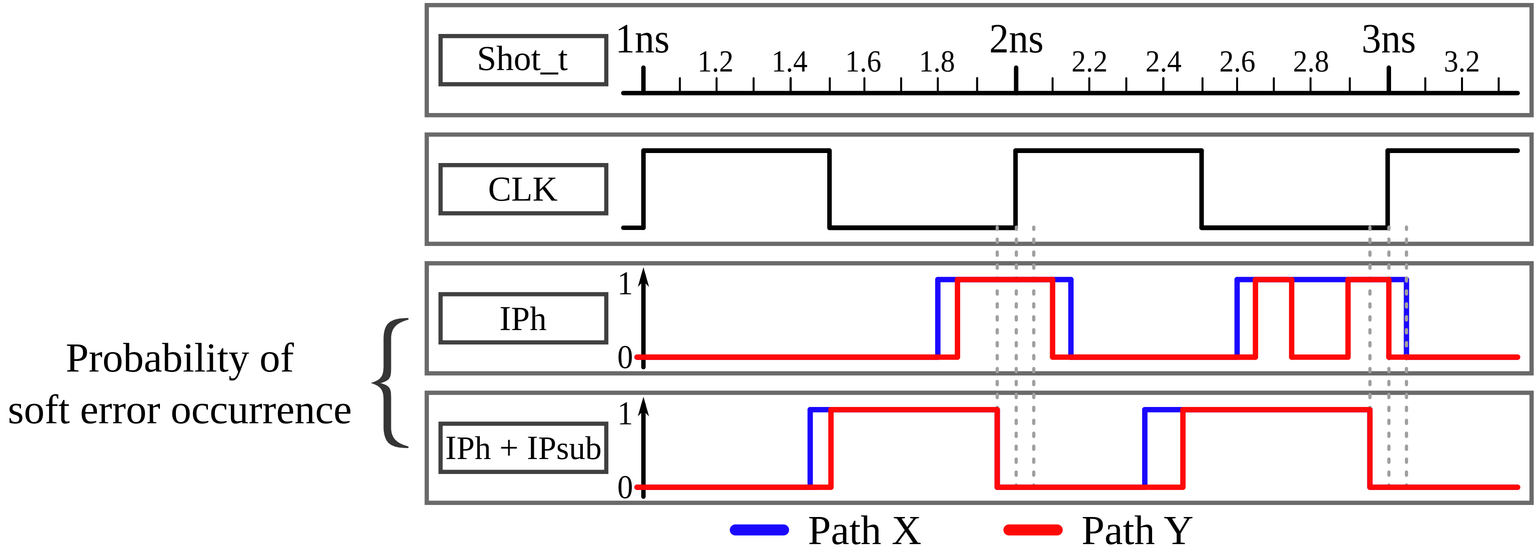


$$\Delta V_{out}(withoutIR) = -\frac{I_{Ph_{NMOS}}}{\frac{\mu \cdot C_{ox} \cdot W}{L}(V_{DD} - V_T)}$$

$$\frac{\Delta V_{out}(withIR)}{\Delta V_{out}(withoutIR)} = \frac{1}{1 - \frac{V_{drop}}{V_{DD} - V_T}}$$

$$\Delta V_{out}(withIR) = -V_{drop} - \frac{I_{Ph_{NMOS}}}{\frac{\mu \cdot C_{ox} \cdot W}{L}(V_{DD} - V_{drop} - V_T)}$$

5.4 - Probability of soft error occurence



Shot_t: Laser shot time

IPh: IPh contribution only

IPh + IPsub: IPh + IPsub_nwell contribution