Laser Fault Injection on RO-based PUFs Implemented on FPGA

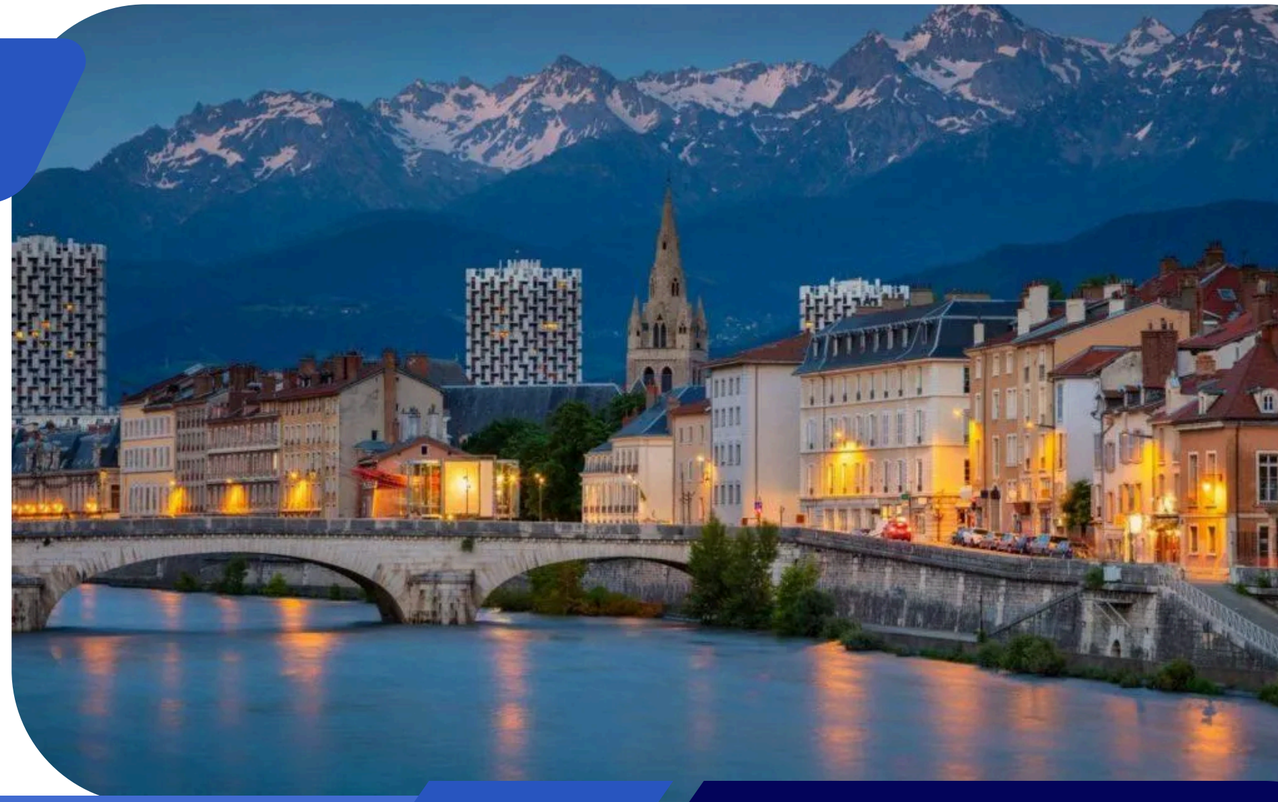
Presented by

Aghiles DOUADI

Co-advised by TIMA and LCIS Laboratories

Université Grenoble Alpes & Grenoble INP & CNRS

- Giorgio DI NATALE
- Vincent BEROULLE
- Elena-Ioana VATAJELU
- Paolo MAISTRI



Grenoble, October 1, 2025

ANR Project Framework

Funding for this work was provided by the French Agence Nationale de la Recherche (POP project, ANR-21-CE39-0004).

➤ **TIMA** : Techniques de l'Informatique et de la Microélectronique pour l'Architecture des systèmes intégrés

➤ **LCIS** : Laboratoire de Conception et d'Intégration des Systèmes

➤ **MSE** : Centre de Microélectronique de Provence

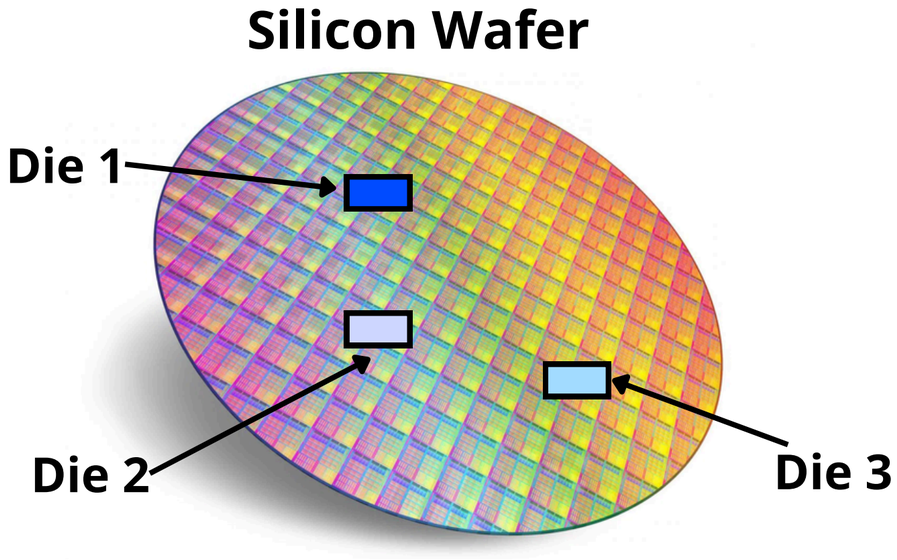
➤ **LabHC** : Laboratoire Hubert Curien

https://anr.fr/Projet-ANR-21-CE39-0004

Presentation Outline

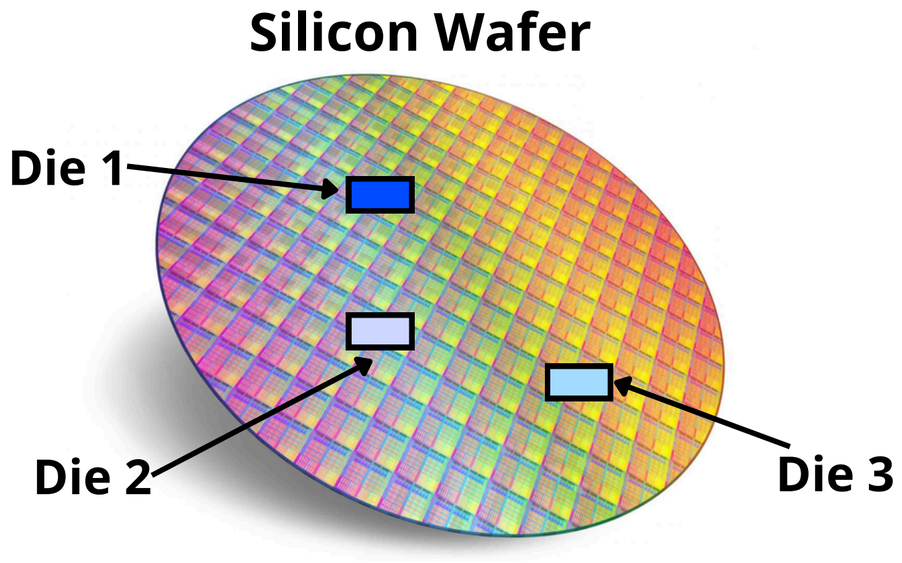
1. Context and Motivation
2. RO Implementation
3. Laser Attacks on ROs and RO-PUFs
4. Conclusion

Physical Unclonable Function



- **Wafer-to-Wafer** variations
- **Die-to-Die** variations
- **Within-Die** variations

Physical Unclonable Function



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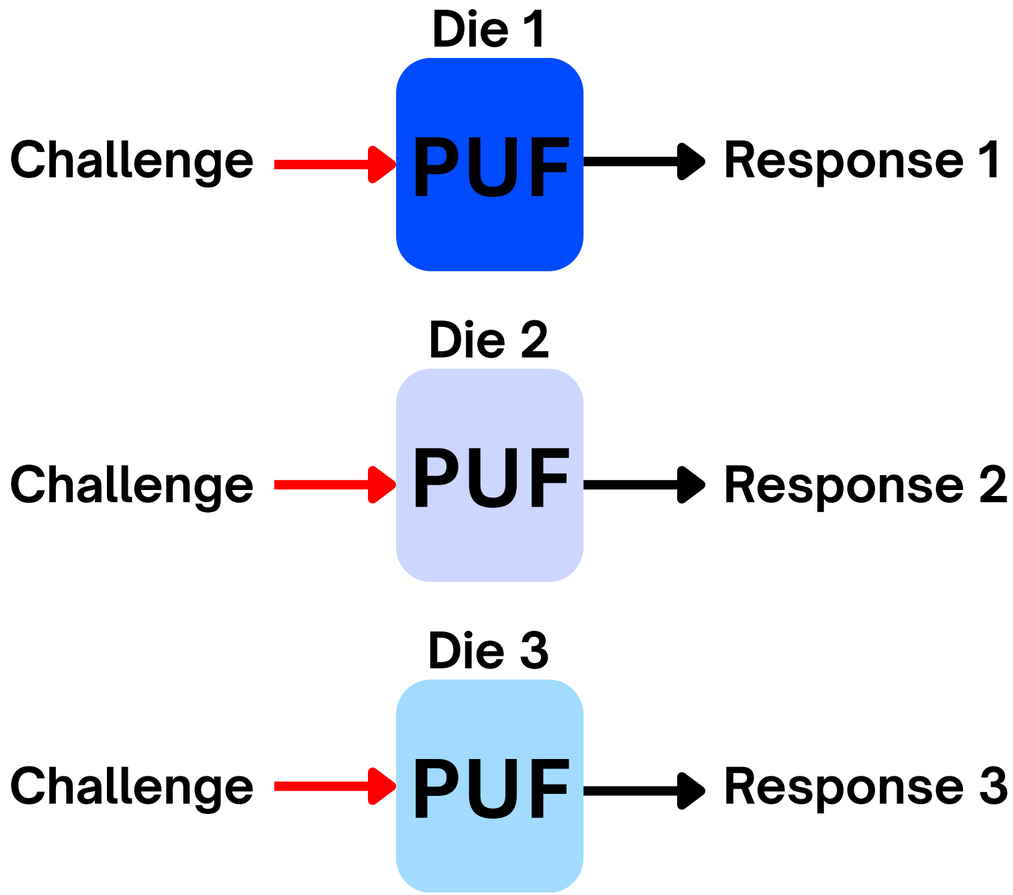
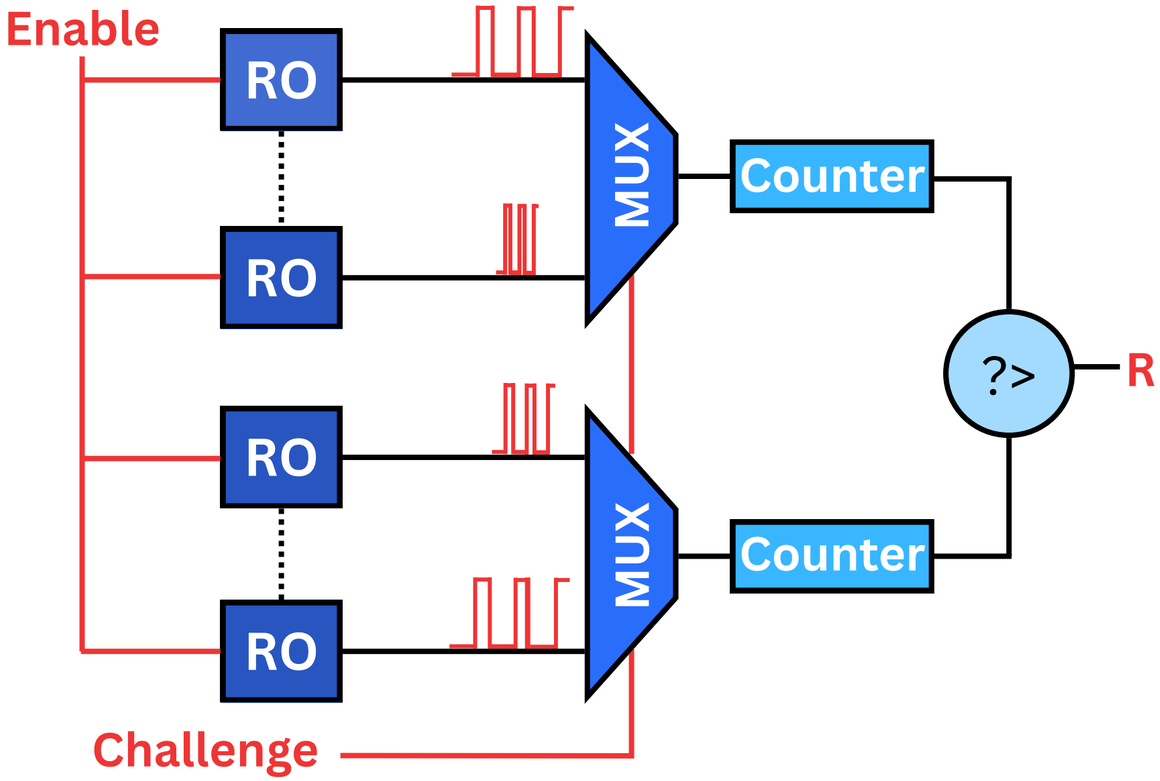
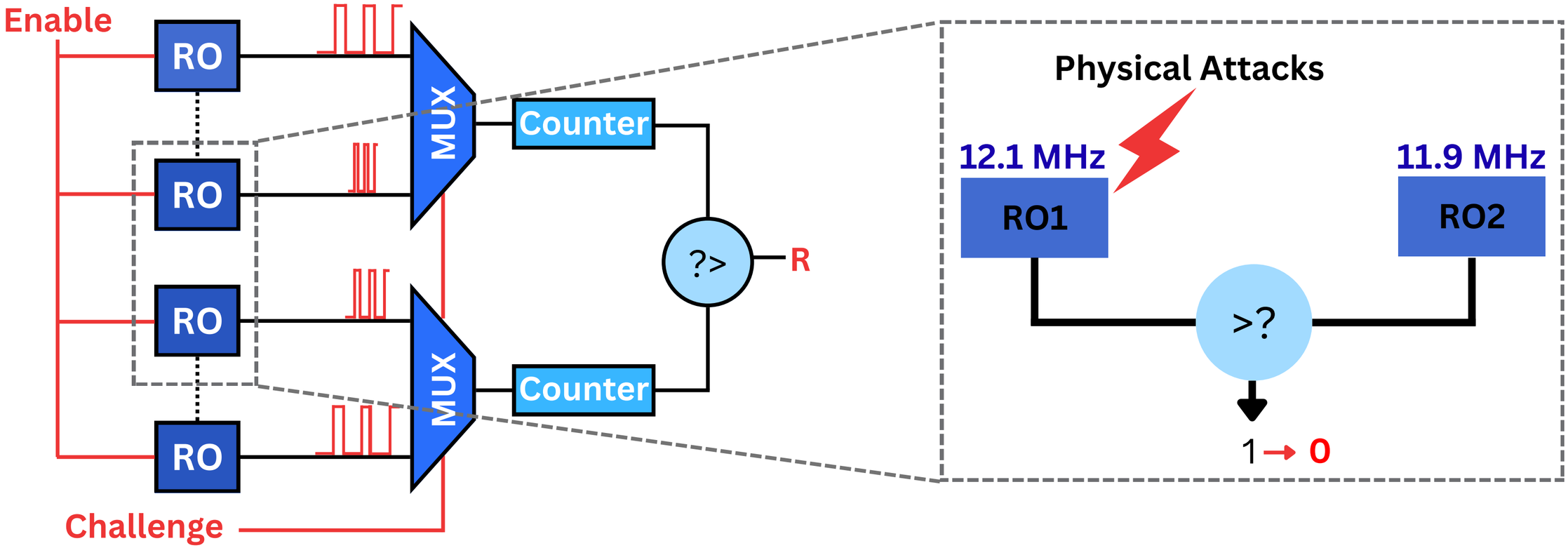


Ring-Oscillator PUF and Physical Attack Vulnerabilities



➤ The ROs are **identically designed**

Ring-Oscillator PUF and Physical Attack Vulnerabilities



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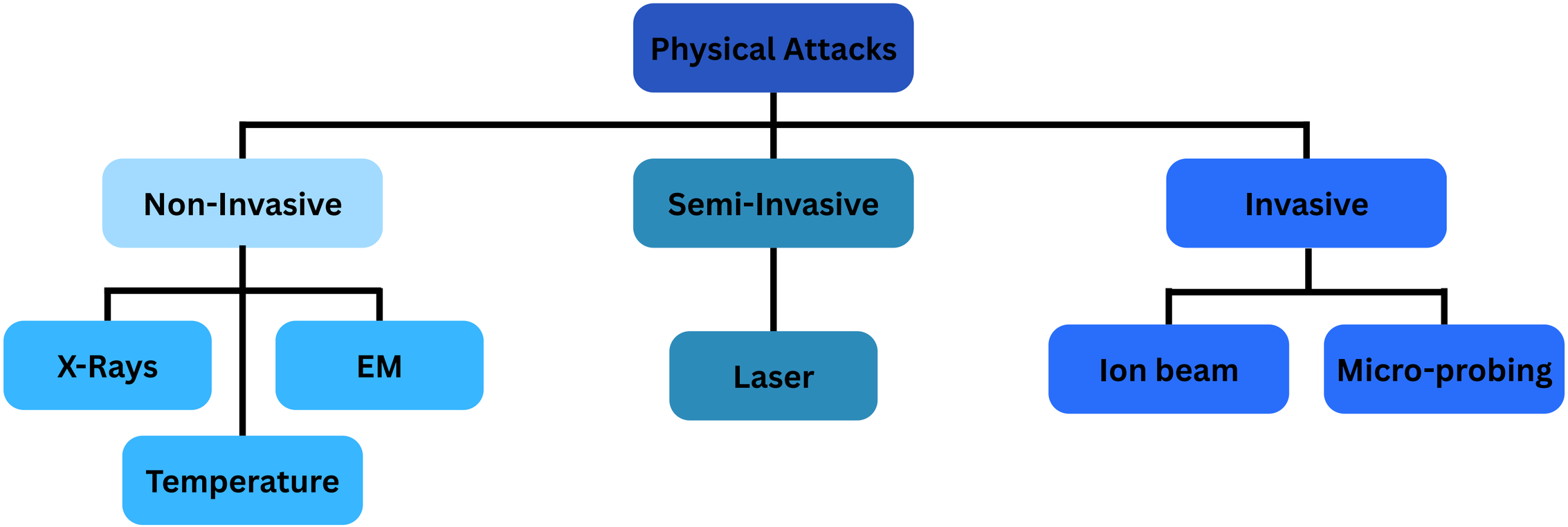
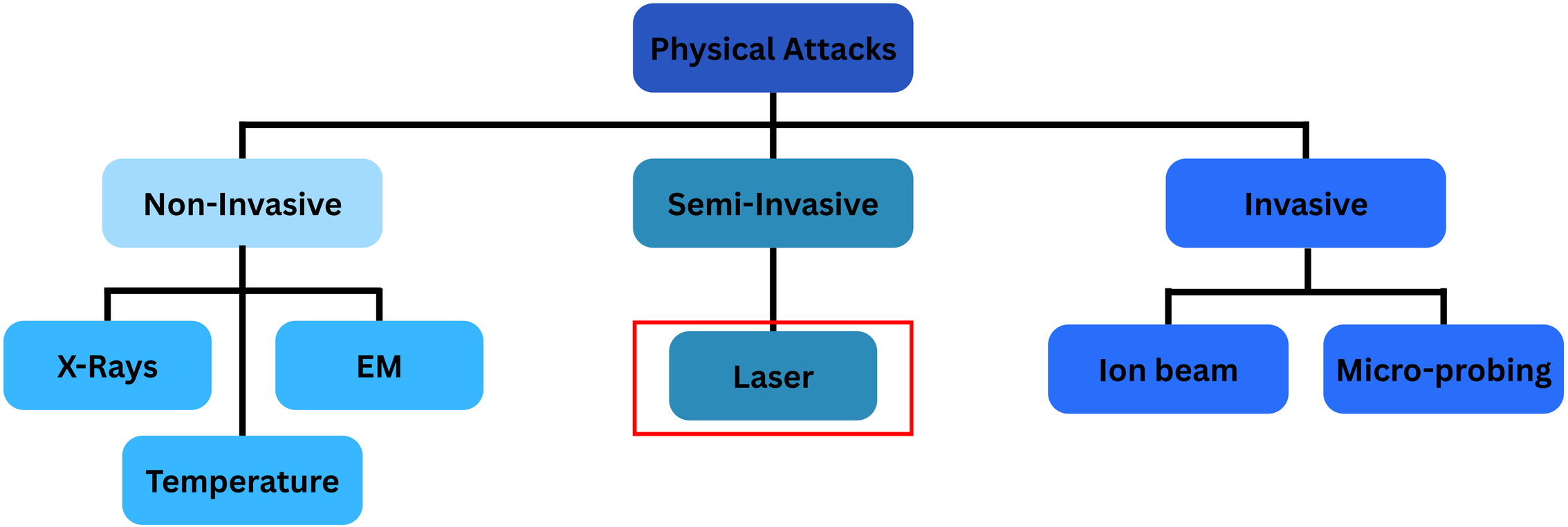
Physical Attacks



Invasive attacks are **more expensive** and harder to carry out, but they are **more effective**.

Physical Attacks



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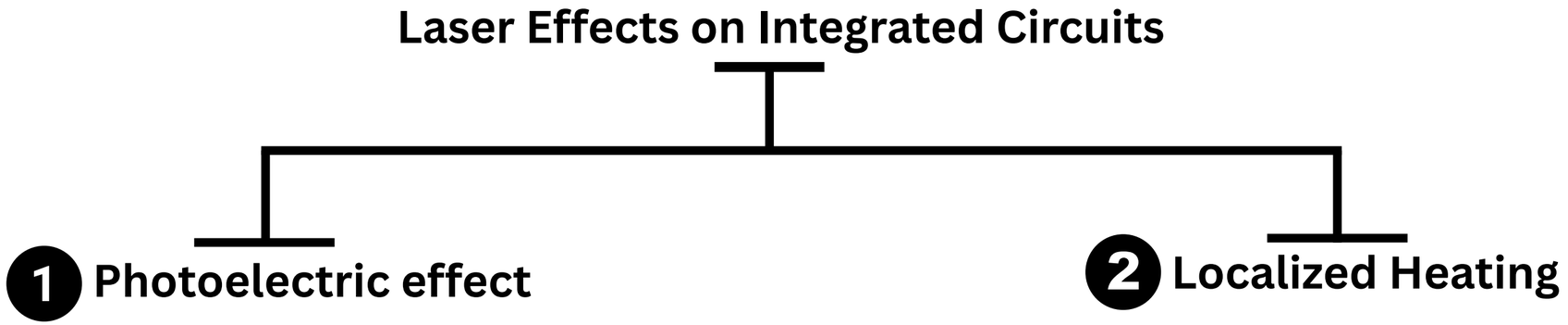
Laser Effects

Laser irradiation on an integrated circuit can induce **two significant effects**.



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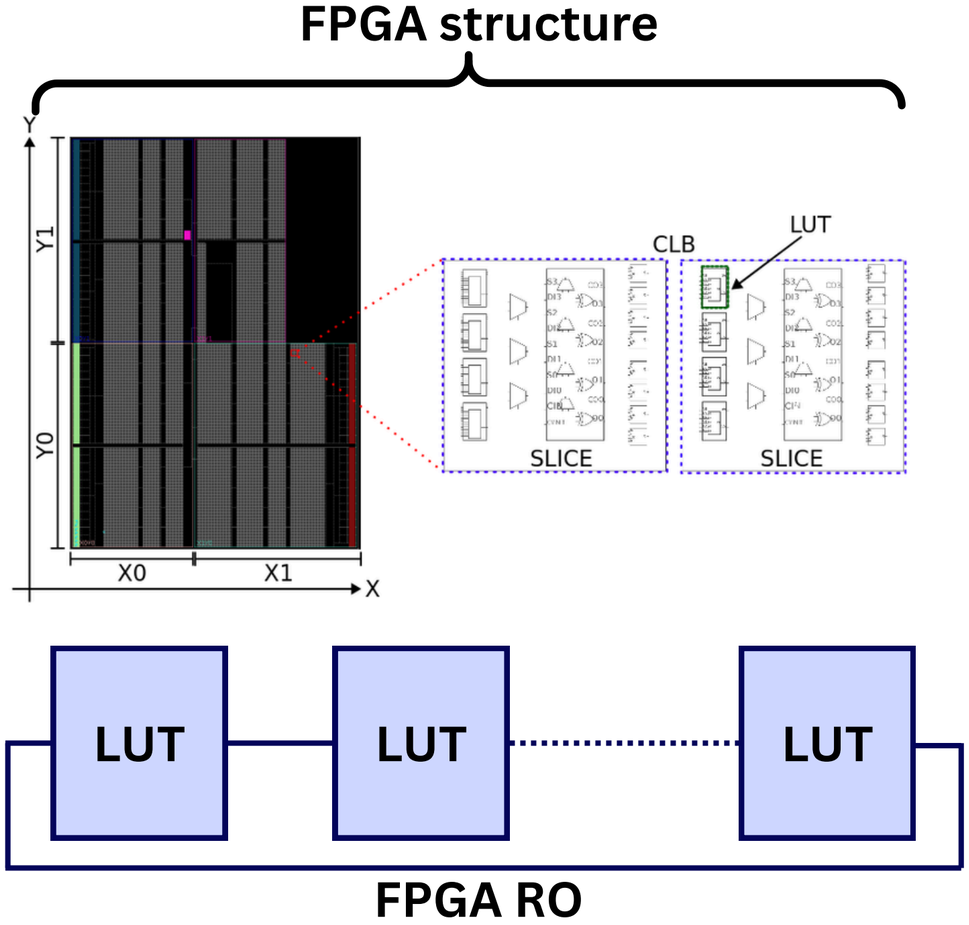
Automation of RO Placement on FPGA

Implementing ROs on an **FPGA** is challenging, **especially for PUFs**, where frequency differences must stem **from variability**, **not design**.



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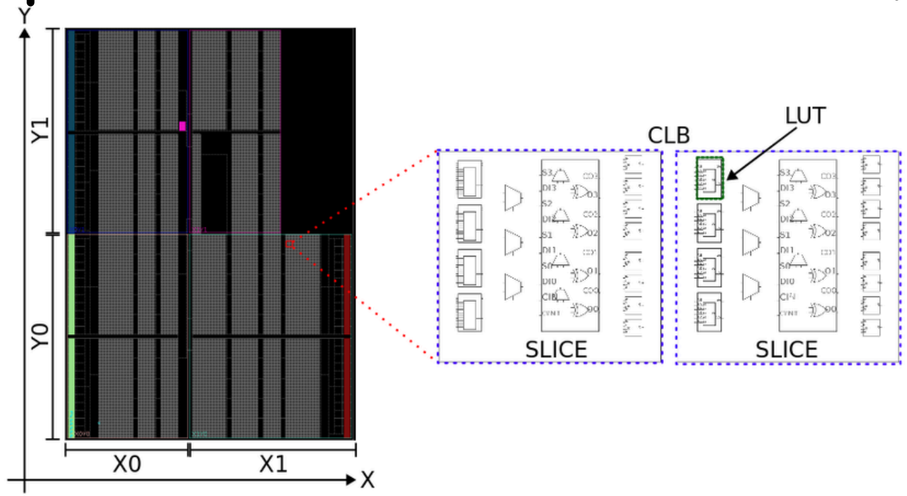
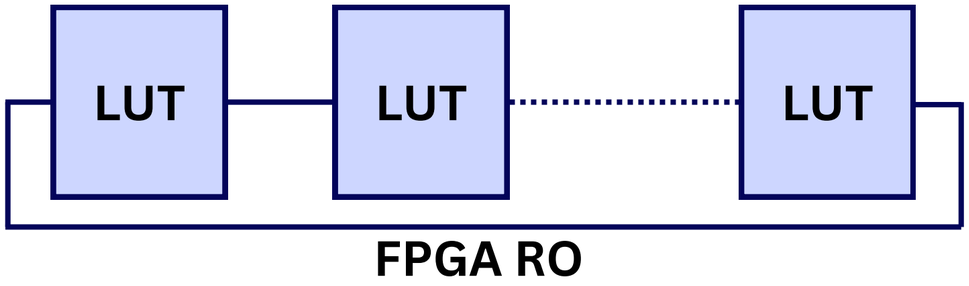
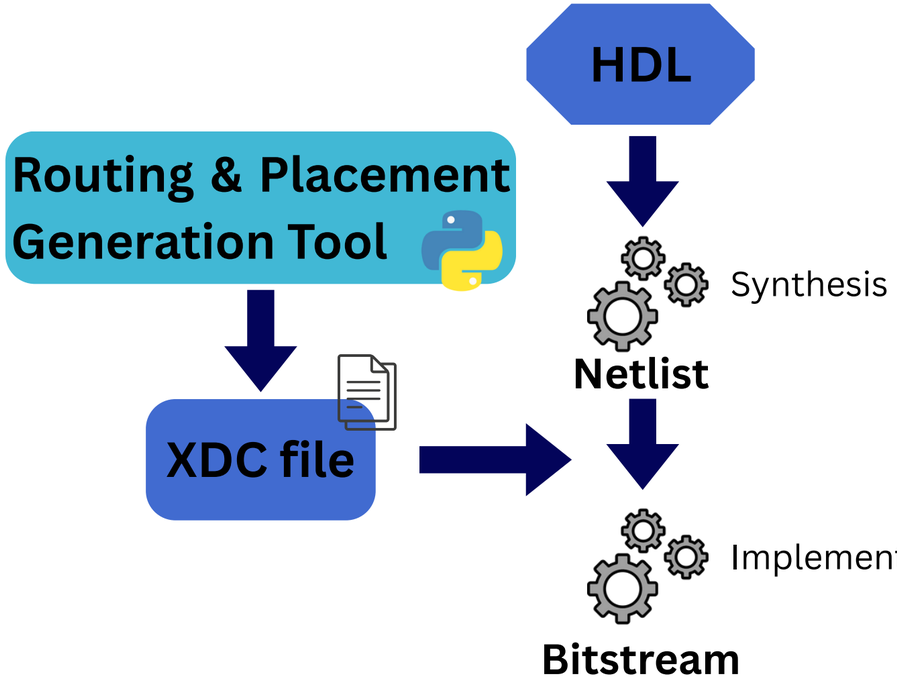
FPGA structure





FPGA RO



ROs with **identical design** and **routing**

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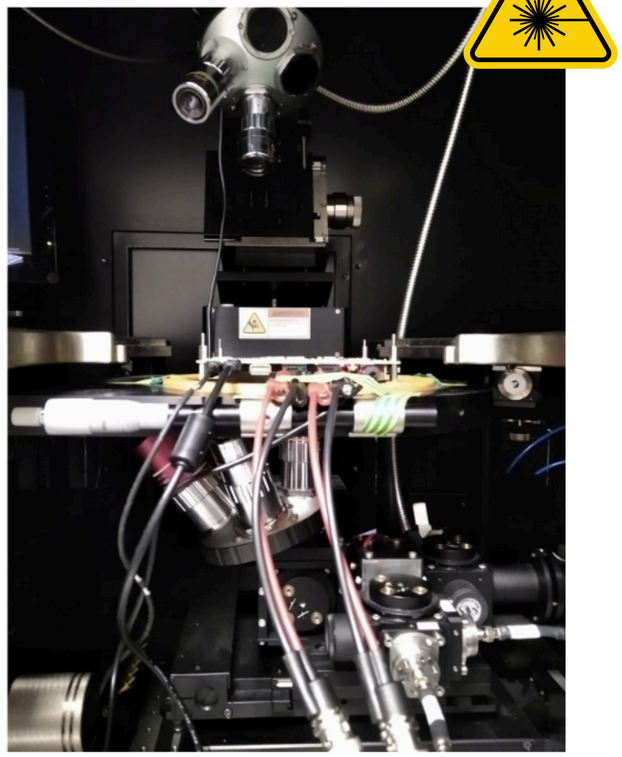
Laser Setup

The laser wavelength is **1064 nm** (photon energy = **1.17 eV**). **Both photocurrent and heating** effects will occur.

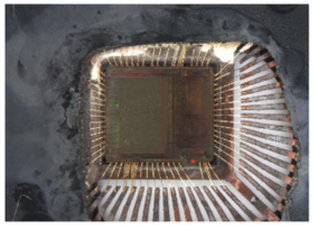
- Laser power ranging from **0.6** to **3 W.**

Microscope objective	Spot size	Transmission coefficient
x 100	1 µm	~26%
x 20	5 µm	~57%
x 5	20 µm	~67%

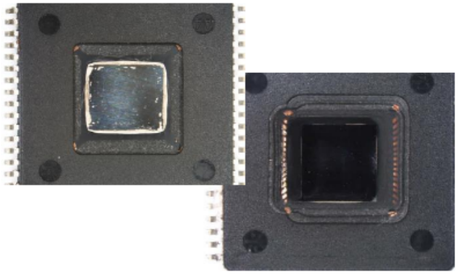
Laser setup



Front side of the chip with the metal layer



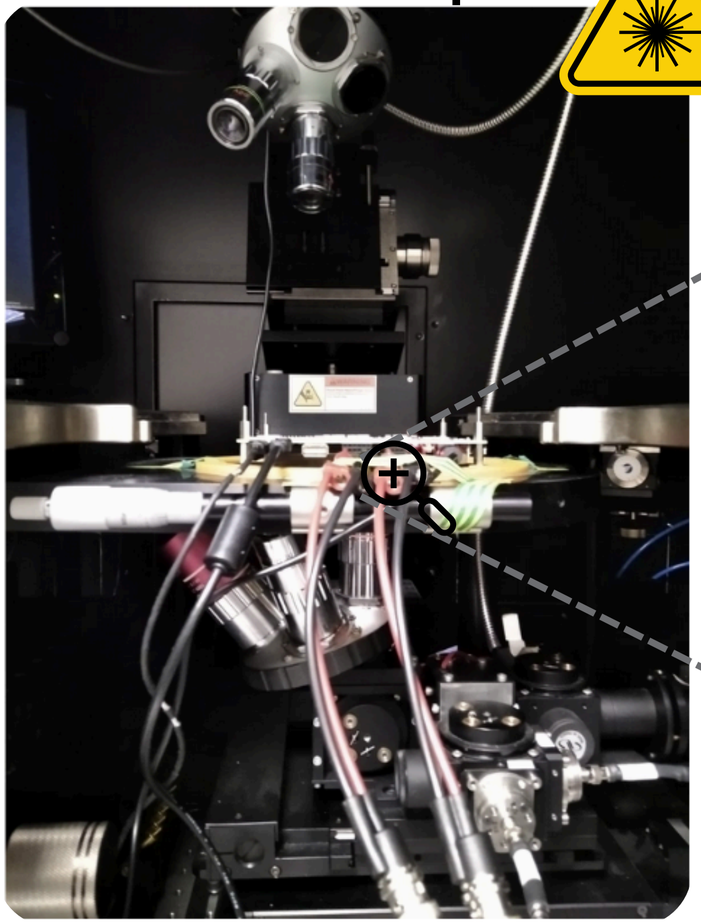
Backside of the chip with thinned silicon



Laser facility provided by the MSE Lab in Gardanne.

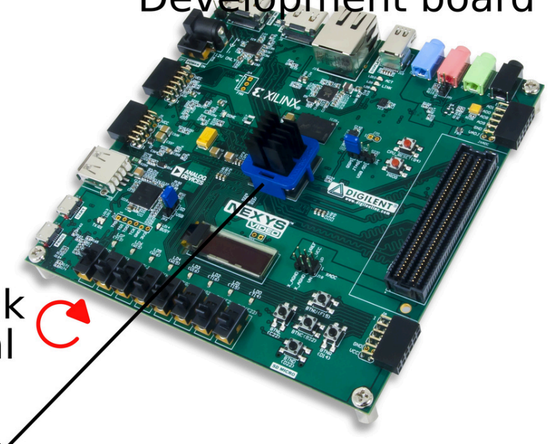
Target’s Specifications

Laser setup



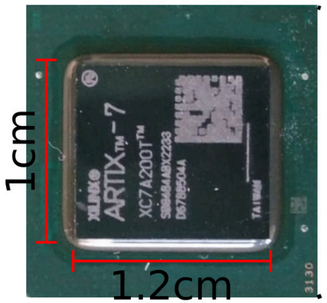
Xilinx Artix-7 Nexys Video board

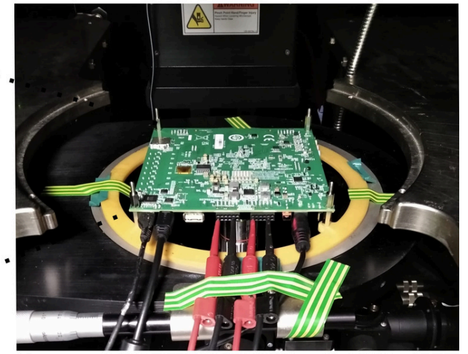
Development board



Heat Sink Removal

FPGA die





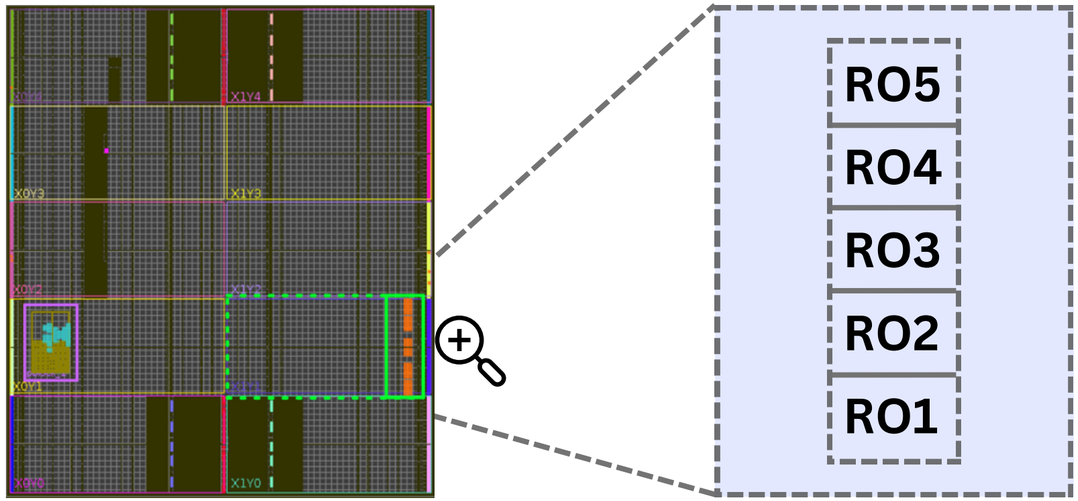
FPGA under test

Effect of the Laser on RO Frequencies

➤ Laser power: **1 W**

➤ Laser spot: **20 µm**

➤ Laser duration: **10 µs**



FPGA floorplan **Targeted zone**

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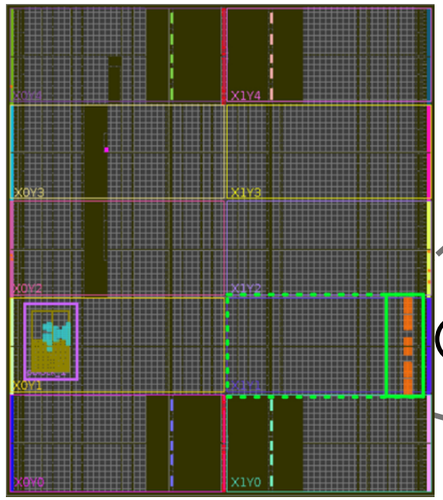
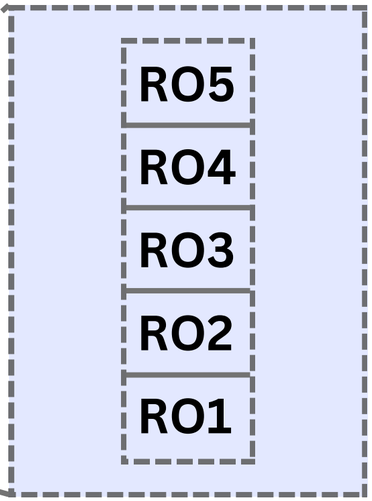
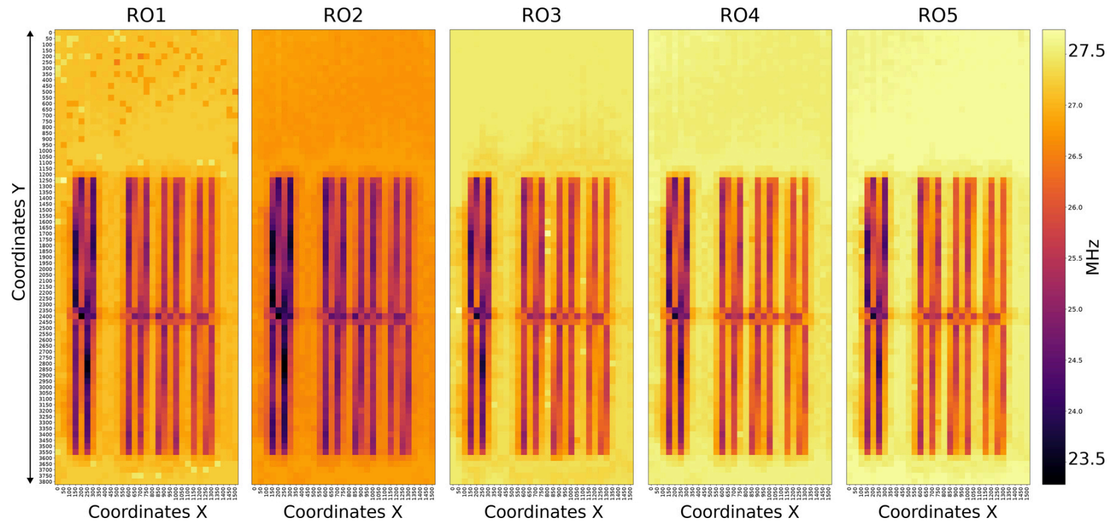


FPGA floorplan



Targeted zone

Laser shot and frequency monitoring



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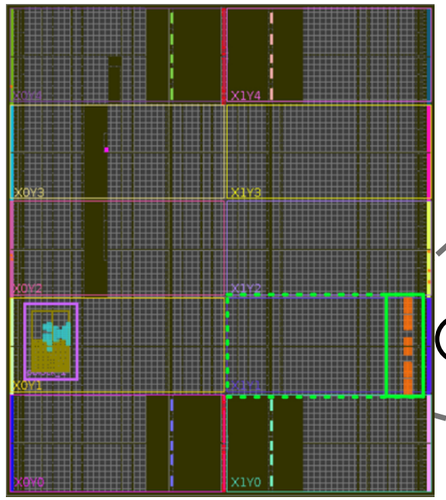

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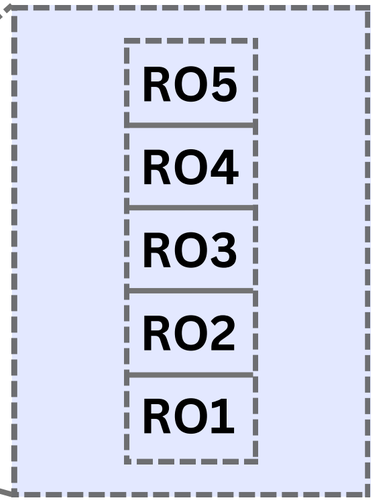
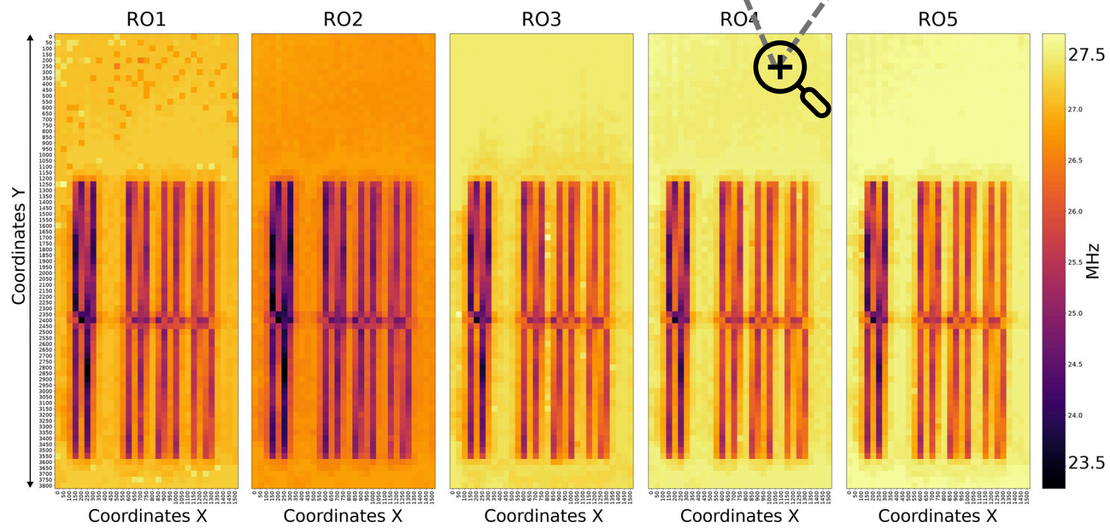


Targeted zone

Laser shot and frequency monitoring

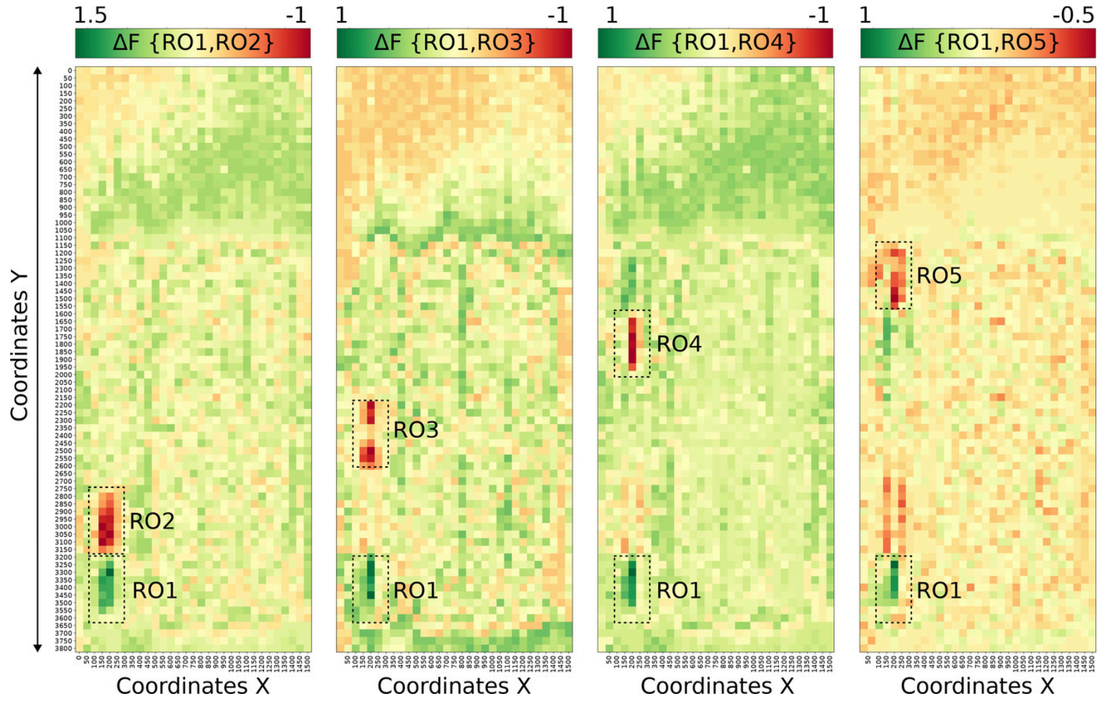
Frequency per laser shot



The frequency decreases of the ROs **follow the same pattern**.

V_{DD} Drop and Thermal Effects

- We subtract the **heatmaps** to isolate the laser-induced **thermal effect**.



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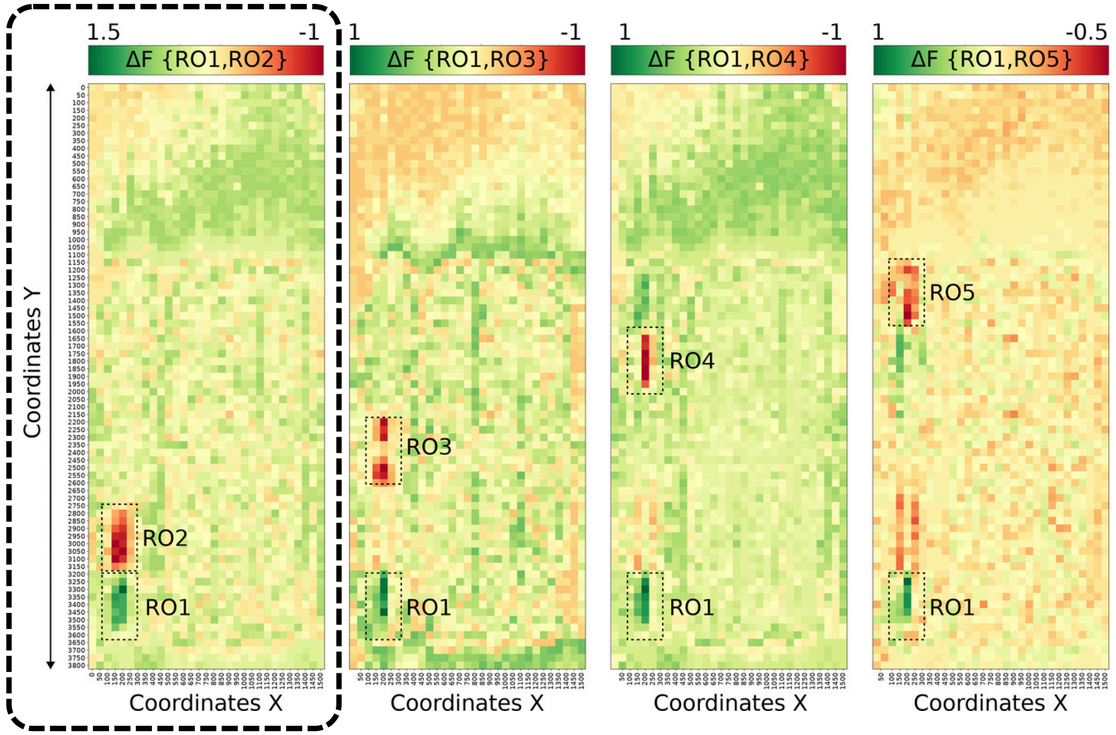

➤ Laser on **RO1** → **RO1–RO2** difference **positive**

➤ Laser on **RO2** → **RO1–RO2** difference **negative**

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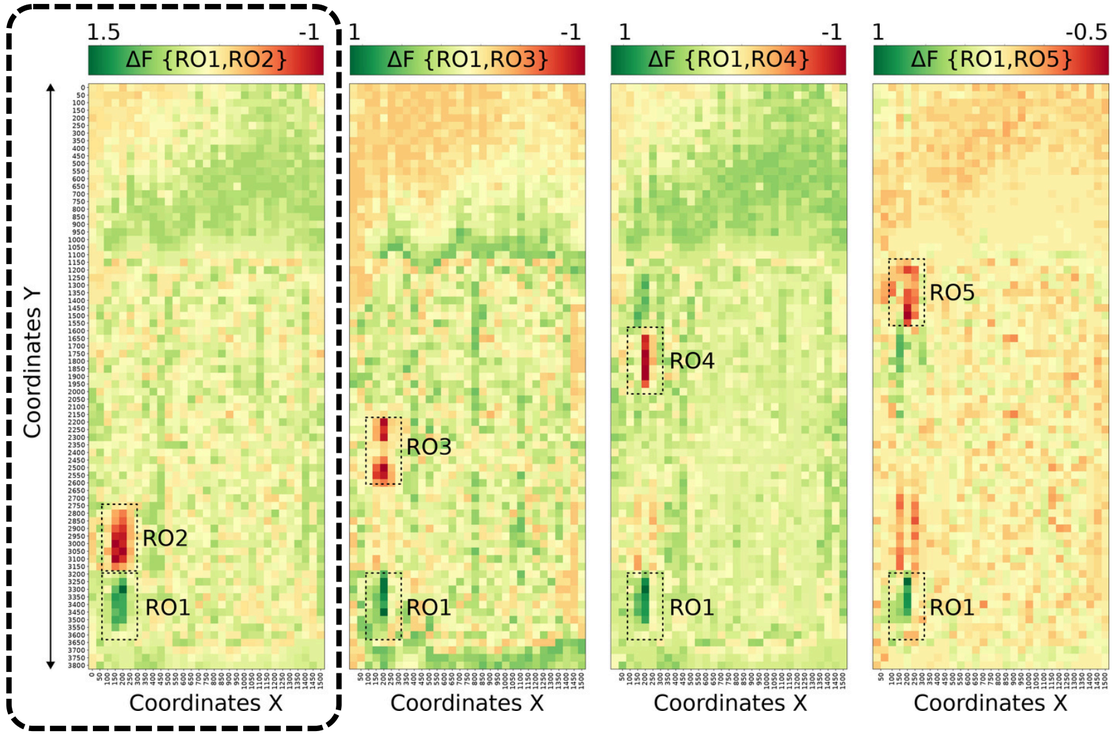

➤ Laser on **RO1** → **RO1–RO2** difference **positive**

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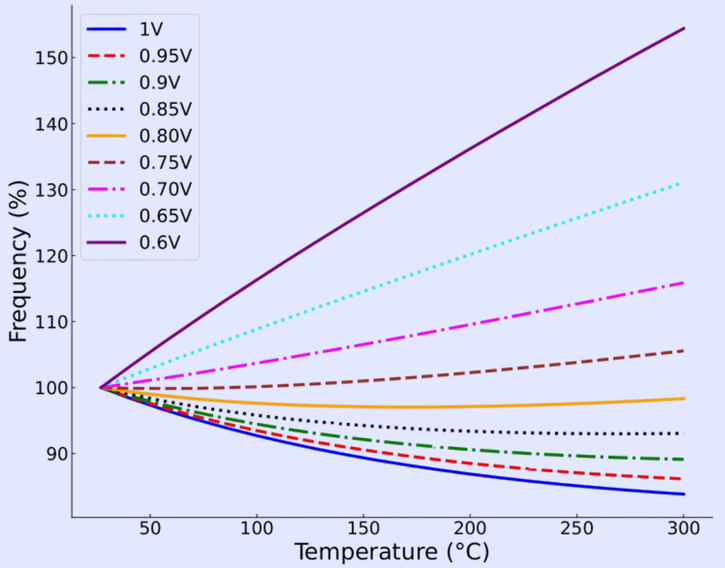
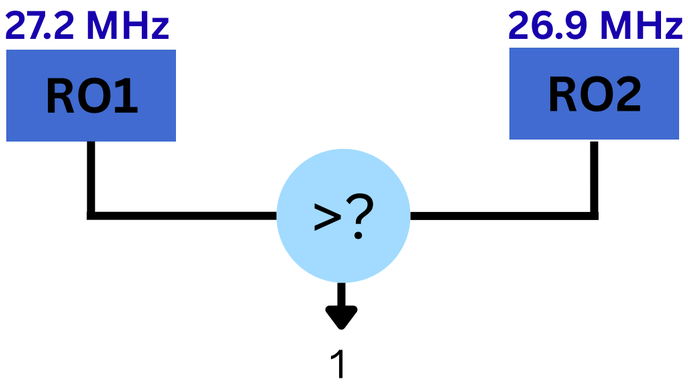
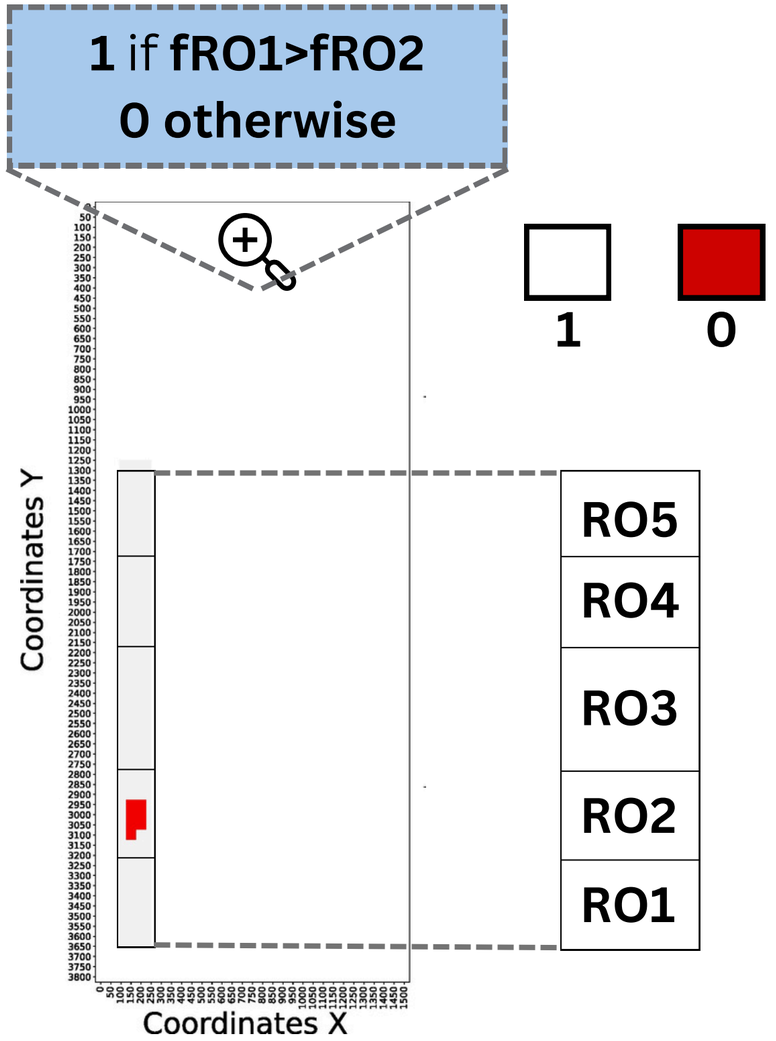
➤ **RO frequency vs V_{DD} & temperature**



Under-supplied RO → frequency rises with temperature.

Exploiting RO Frequency Shifts for PUF Attacks





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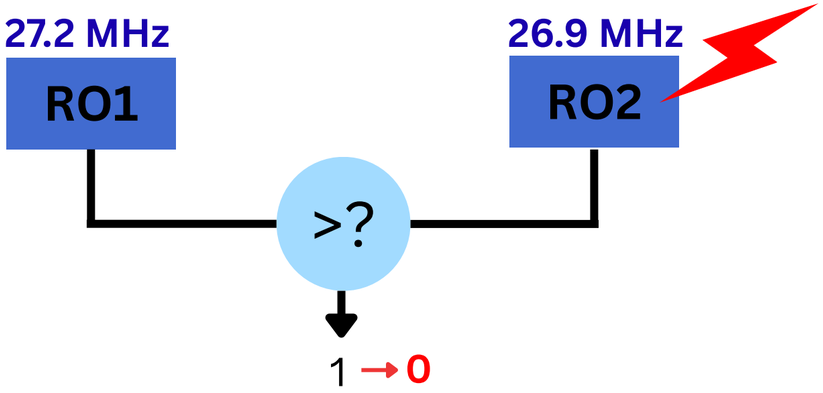

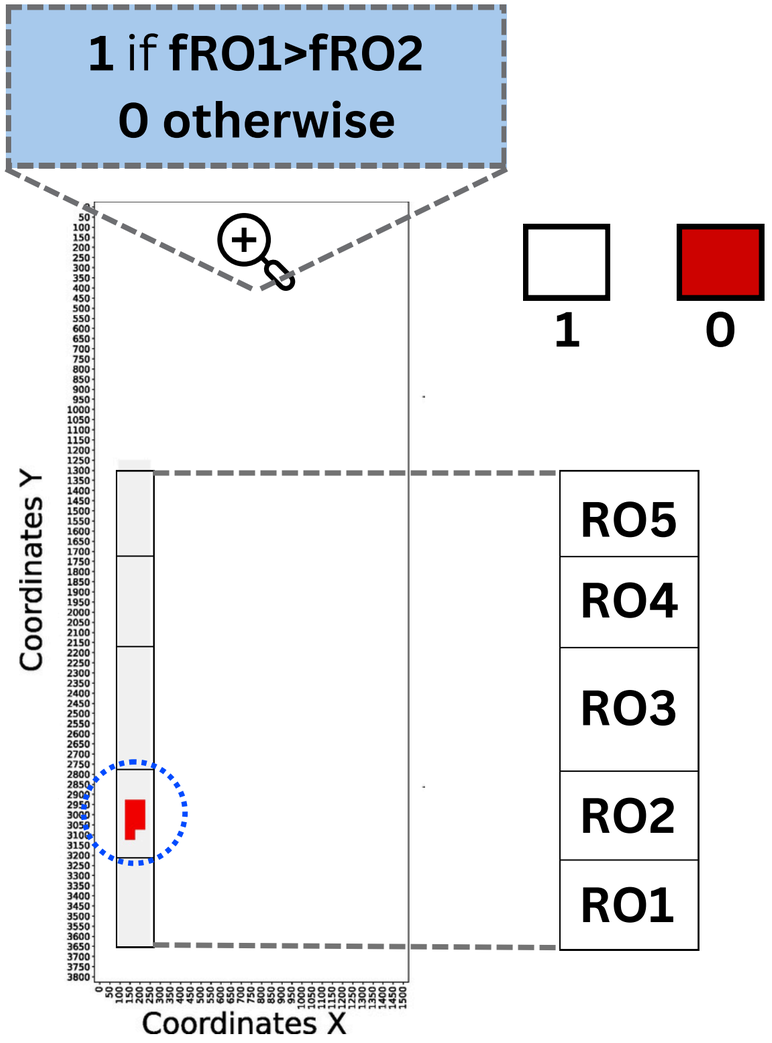

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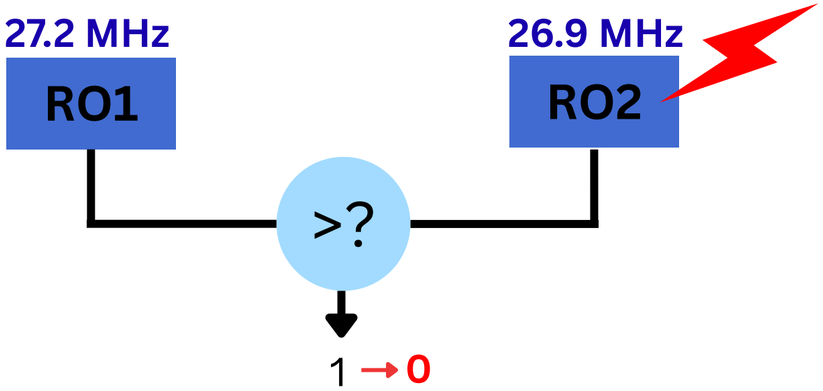

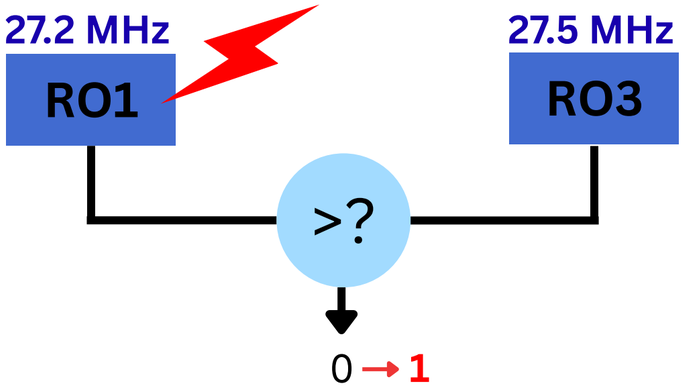

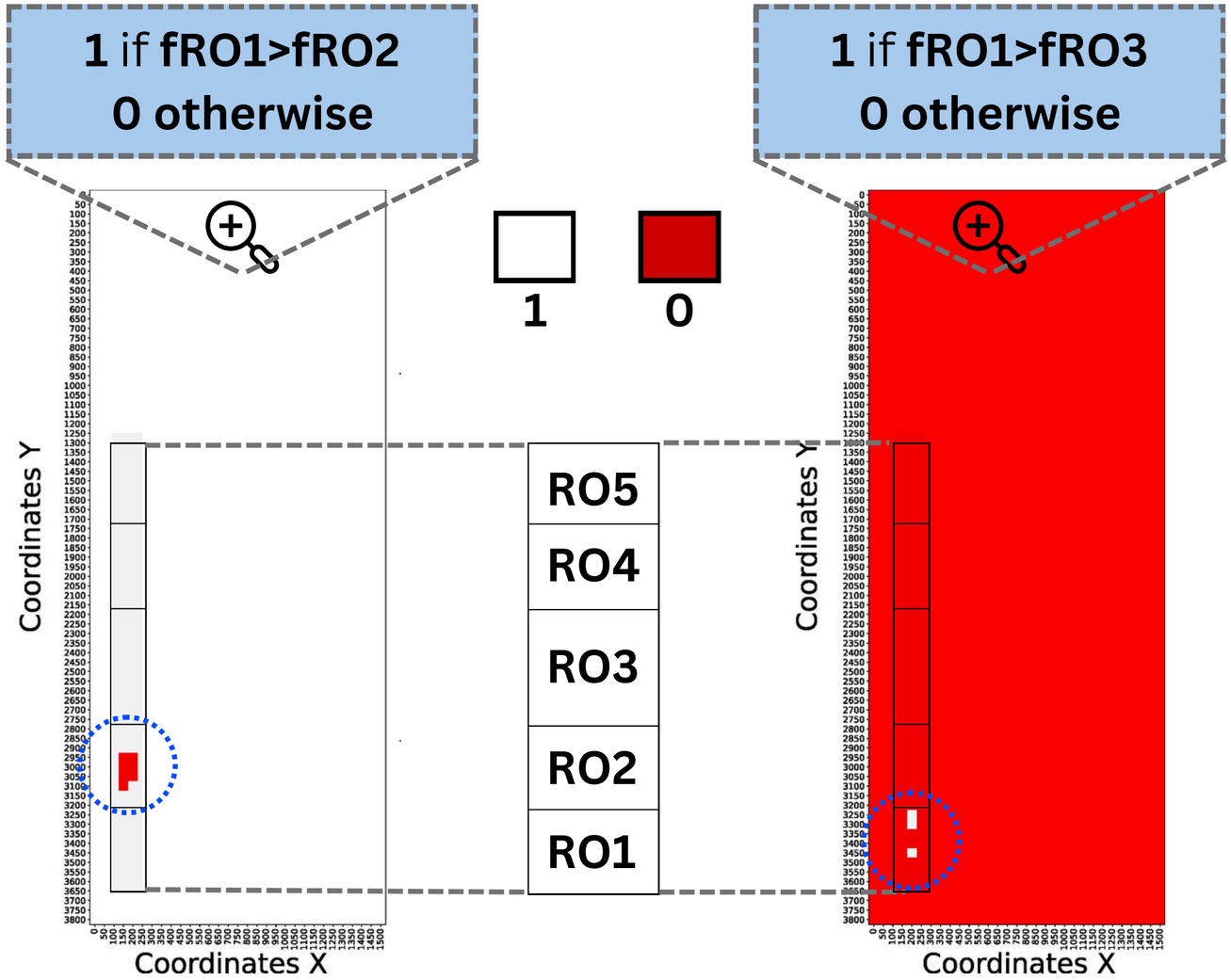

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Conclusion

The laser strongly impacts the frequency of the ROs

- IR drop equally reduces ROs frequencies in the same clock region
- Temperature locally impacts the frequencies of the ROs
- IR drop and temperature may enable PUF response control

Thank You For Your Kind Attention

Q&A