CycPUF: Cyclic Physical Unclonable Function

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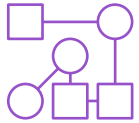
Agenda

Introduction

Problem statement and preliminaries



CycPUF

Cyclic delay-based PUFs and their behavior

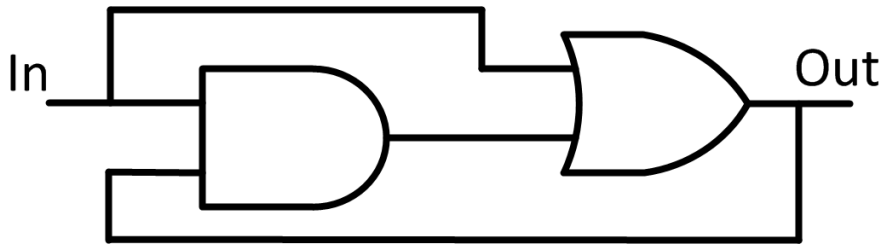
Experiments

Attack resiliency, FGPA emulation and functional metrics

Cyclic Combinational Circuits

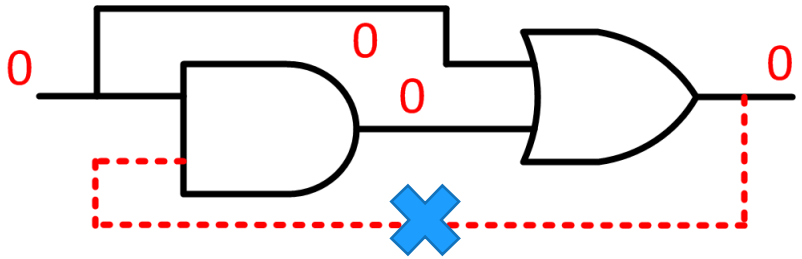
Combinational circuits with loops or feedback paths

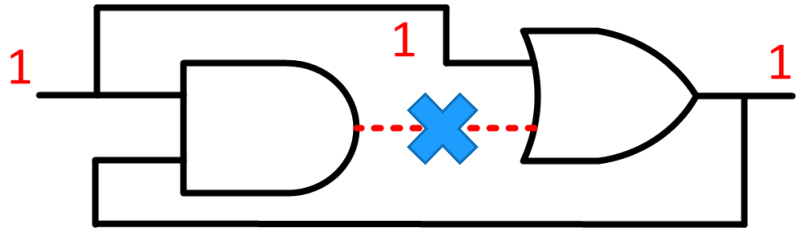
Cyclic Combinational Circuits



Combinational feedback

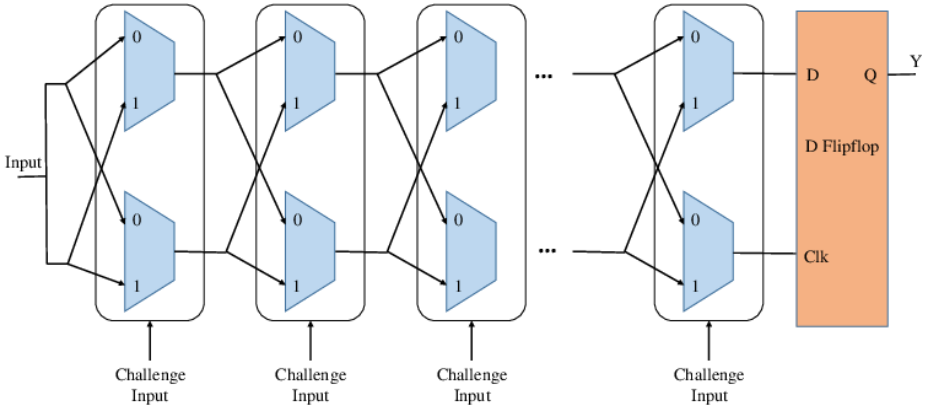
In	Out
0	0
1	1



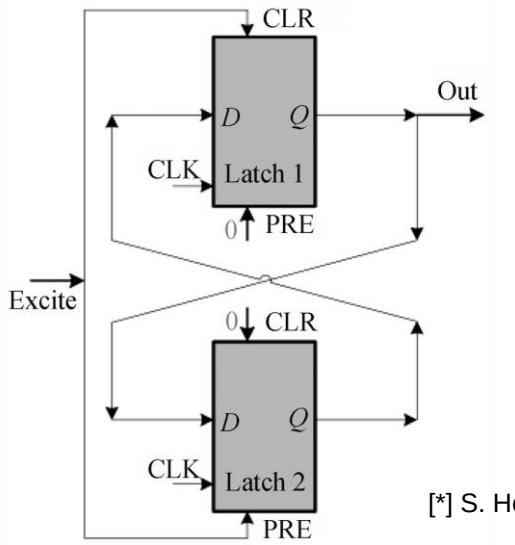


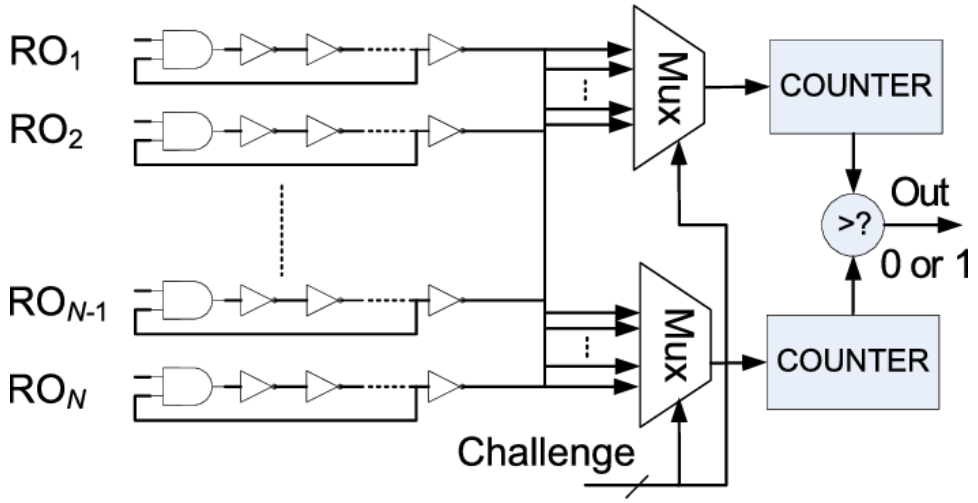
PUF Primer

(a) Arbiter PUF [*]



(b) Butterfly PUF [$]





(c) Ring Oscillator PUF [%]

- Physical Unclonable Function (PUF) produces a unique response (output) to a given challenge (input)
- PUFs have been implemented in cryptography, resource-constrained devices, and privacy protection

[*] S. Hemavathy and V. S. K. Bhaaskaran, "Arbiter PUF—A Review of Design, Composition, and Security Aspects," in IEEE Access, 2023.

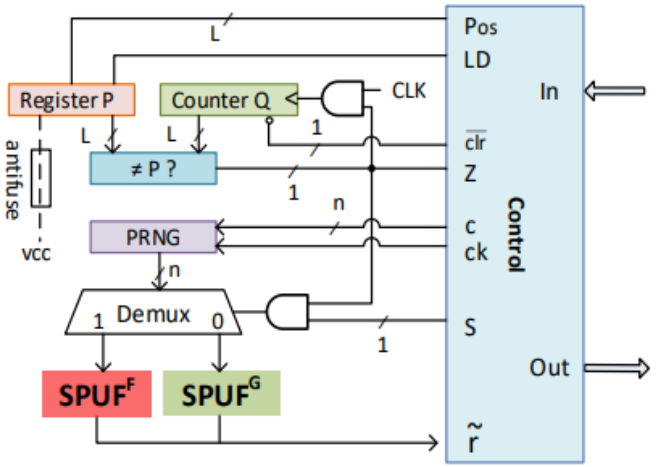
[$] S. S. Kumar, J. Guajardo, R. Maes, G. -J. Schrijen, and P. Tuyls, "The Butterfly PUF Protecting IP on Every FPGA," in HOST, 2008.

[%] S. R. Sahoo, S. Kumar, and K. Mahapatra, "A Novel ROPUF for Hardware Security," in VDAT, 2015.

Related Works

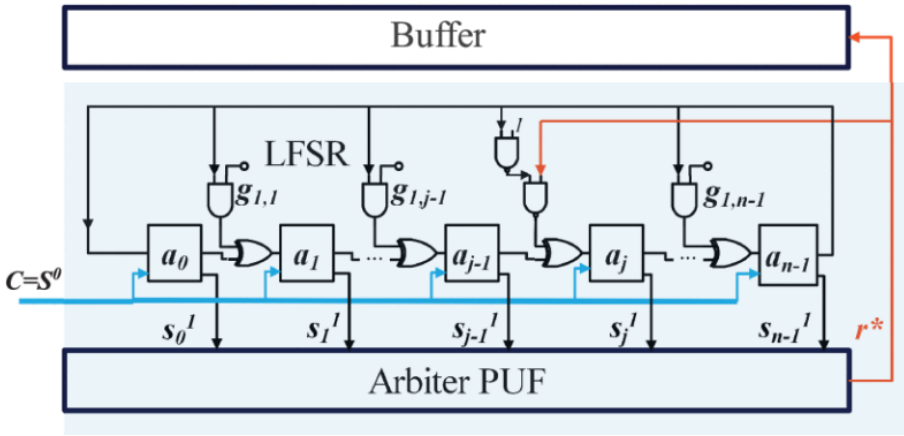
Prior Works and Challenges

- Deception Protocol PUF [*]
  - has been proposed using a Strong PUF, a fake Strong PUF, a PRNG, a *L*-bit counter, a *L*-bit register, a comparator, and a controller



(a) Deception Protocol PUF

- FLAM-PUF [$]
  - Linear-Feedback Shift Registers (LFSR) are used to obfuscate CRPs



(b) FLAM-PUF

- Challenges in PUF
  - ML susceptibility
  - Fault-vulnerability
  - High hardware overhead

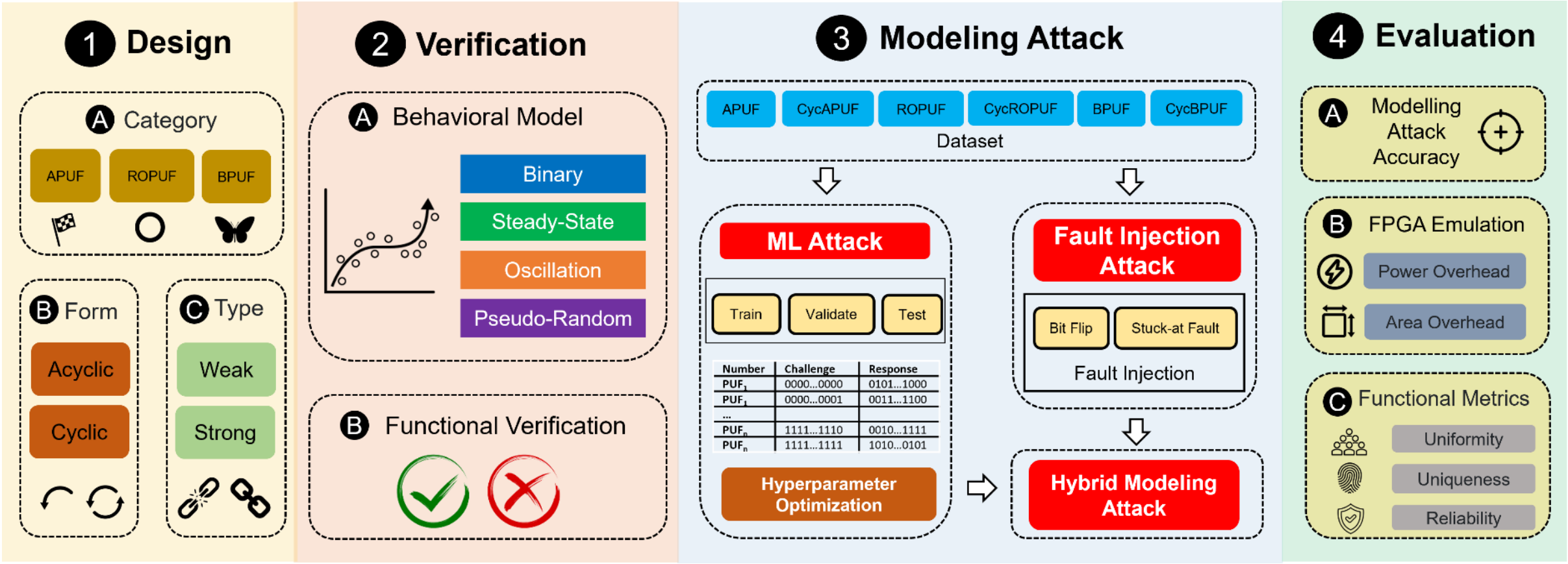
[*] C. Gu, C. -H. Chang, W. Liu, S. Yu, Y. Wang and M. O'Neill, "A Modeling Attack Resistant Deception Technique for Securing Lightweight-PUF-Based Authentication," in IEEE TCAD, 2021.

[$] L. Wu, Y. Hu, K. Zhang, W. Li, X. Xu and W. Chang, "FLAM-PUF: A Response–Feedback-Based Lightweight Anti-Machine-Learning-Attack PUF," in IEEE TCAD, 2022.

CycPUF

Cyclic Physical Unclonable Function

Proposed Solution



CycPUF Framework

CycPUF Behaviour

- By feeding response back into challenge, we create a cyclic PUF that shows *PUF modes*:
  - **Binary**: fixed challenges produce fixed responses like normal
  - **Steady-State:** fixed challenges produce fixed responses; however, it takes time to stabilize
  - **Oscillating**: response vector bounces between two or more different responses, making a discernible pattern
  - **Pseudo-Random**: response vector changes at unpredictable times and has no noticeable pattern

Results

Functional Metrics

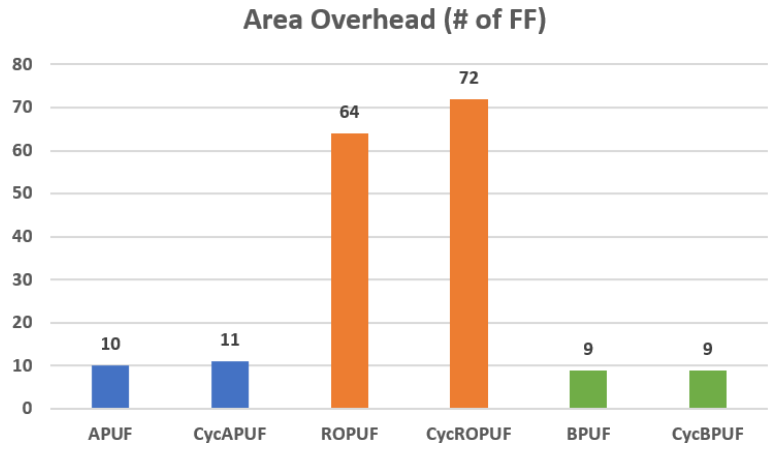
- Avg Bit Value
  - Allows us to apply the acyclic PUF functional metrics to CycPUF

PUF Functional Metrics Results

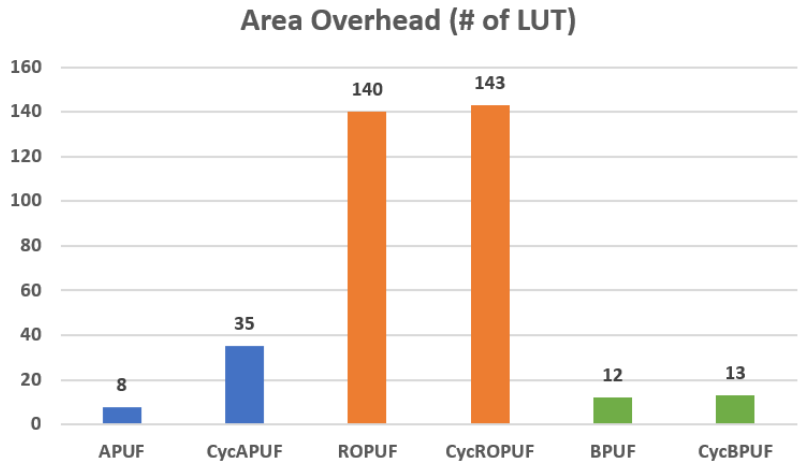
PUF Design	Uniqueness	Uniformity	Reliability
APUF	7.55%	55.42%	99.77%
CycAPUF	47.10%	47.30%	98.34%
ROPUF	44.26%	53.81%	99.05%
CycROPUF	50.68%	52.12%	95.18%
BPUF	11.48%	55.04%	97.45%
CycBPUF	53.05%	46.67%	98.62%

Avg Bit Value = $\frac{1}{m}\sum_{i=1}^{m} r_i[n]$

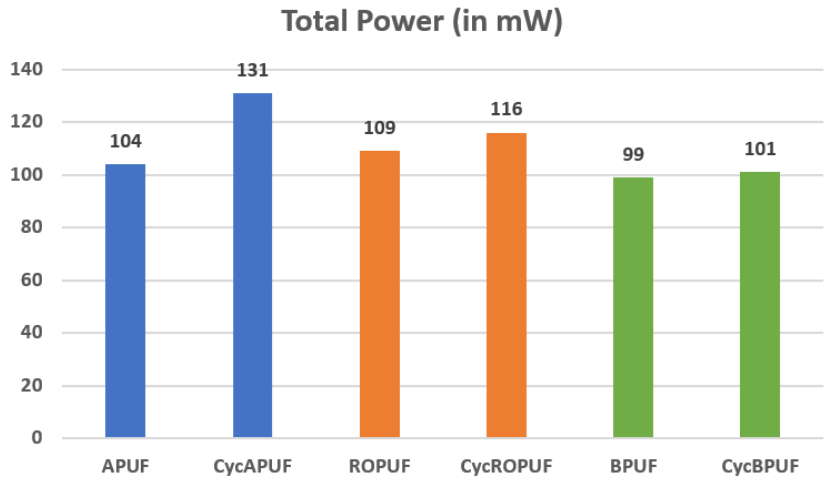
Performance Metrics



(a) Number of FFs



(b) Number of LUTs



(c) Total power consumption

Modeling & Fault-Resiliency

- **DNN-Based ML attack [*]:** fed CRPs into ML model and allowed it to guess CRPs
- **Fault-Injected ML attack [$]:** injected faults to disrupt CycPUF behavior and aid ML model

Modeling Attacks Results

PUF Design	Challenge Size	# of Training CRPs	Model Accuracy
APUF	64	500,000	99.38%
CycAPUF	64	703,340	59.49%
Faulty CycAPUF	64	500,000	76.27%
ROPUF	64	500,000	78.00%
CycROPUF	64	1,048,576	48.74%
Faulty CycROPUF	64	642,603	50.02%
BPUF	64	500,000	83.32%
CycBPUF	64	938,420	54.76%
Faulty CycBPUF	64	582,645	61.44%

[*] P. Santikellur, A. Bhattacharyay, and R. S. Chakraborty, “Deep Learning based Model Building Attacks on Arbiter PUF Compositions,” in Cryptology ePrint Archive, 2019.

[$] S. Tajik, H. Lohrke, F. Ganji, J. -P. Seifert, and C. Boit, "Laser Fault Attack on Physically Unclonable Functions," in FDTC 2015.

Conclusion

Key Takeaways

- Proposed CycPUF & PUF modes
- Close to optimal functional metrics
- High ML resiliency & fault-tolerant

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