When the Decoder Has to Look Twice: Clock-Glitching a PUF Error Correction

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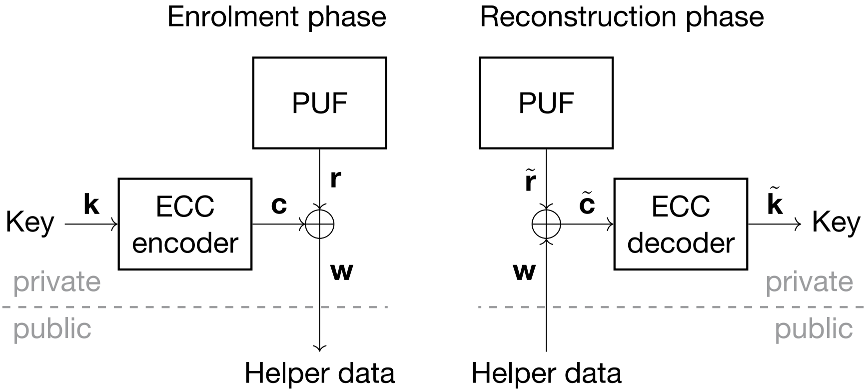
Overview: Fuzzy Commitment Scheme



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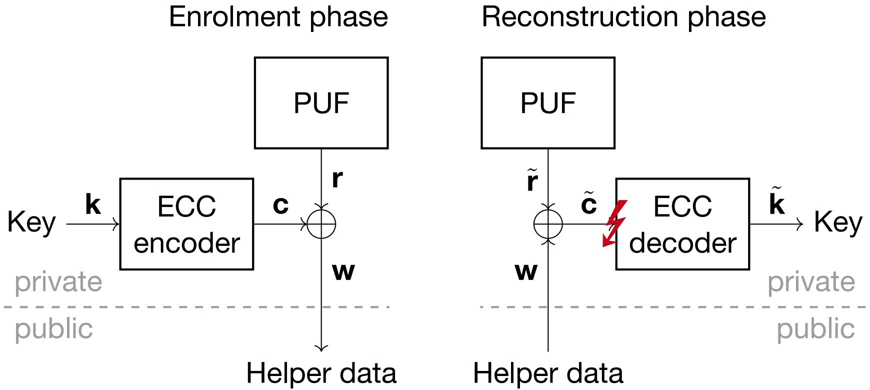

Context: Vulnerabilities of PUF Key Storage Schemes

- Physical attacks on PUF primitives: SCA, FIA
- Helper data manipulation attacks on secure sketches, e.g.
  Becker, “Robust Fuzzy Extractors and Helper Data Manipulation Attacks Revisited: Theory versus Practice”, 2019.
- Side-channel attacks on the error correction codes (ECCs) of PUF systems, e.g.
  Merli, Stumpf, and Sigl, *Protecting PUF Error Correction by Codeword Masking*, 2013.

This work: First fault injection analysis targeting ECC implementations for PUF key storage.

Outline

1. Attack
2. Experiment
3. Masking
4. PUF Noise
5. Realistic Attacker
6. Conclusion

Attack: Scenario

- Physical access to the device under attack
- Possibility to repeatedly trigger key reconstruction phases
- Pass/fail reconstruction phase result
- Serial transfer of the codeword to the ECC decoder

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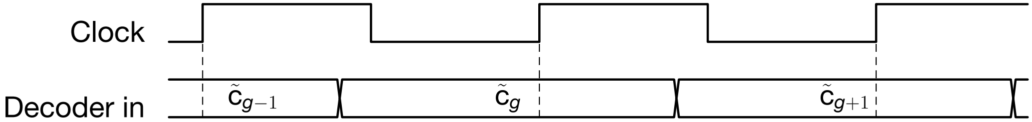
Initially: Powerful attacker

- Noise-free PUF response
- Read/write access to helper data
- Profiling and attack one the same device

Later: More realistic attacker

Attack: Fault Model



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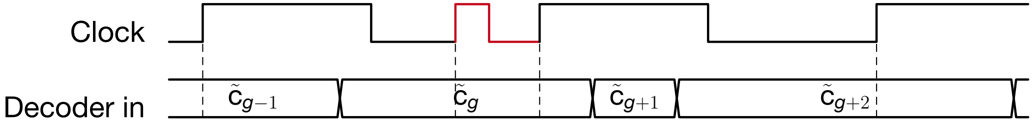

Clock glitch at bit position g:

- Bit $\tilde{c}_{g+1}$ is replaced by bit $\tilde{c}_g$

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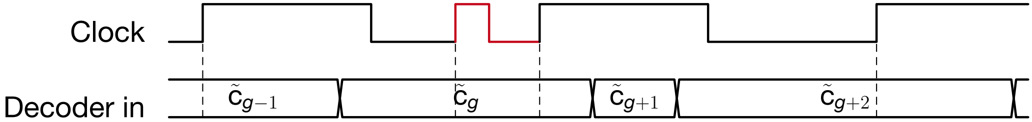

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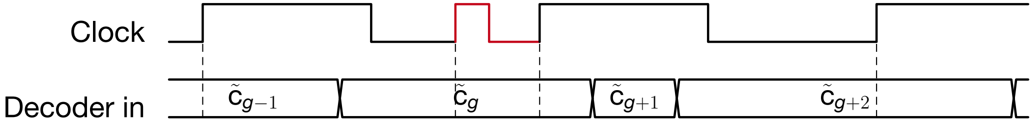

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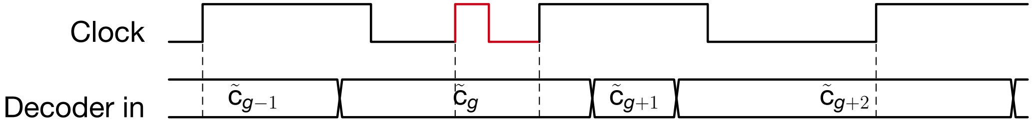

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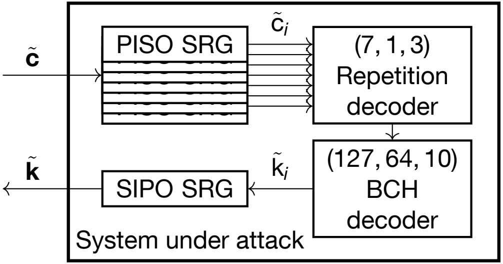
- $n-1$ fault injections $\Rightarrow$ $n-1$ codeword bit differences recoverable

Experiment: Set-up



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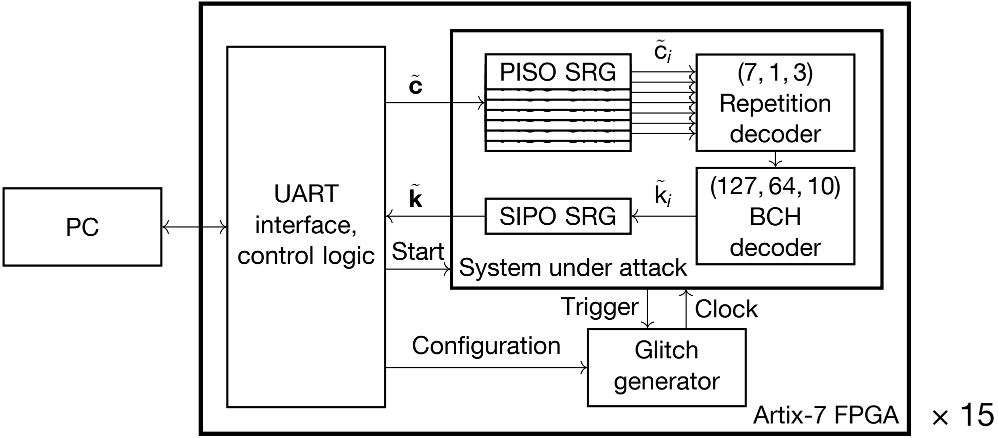

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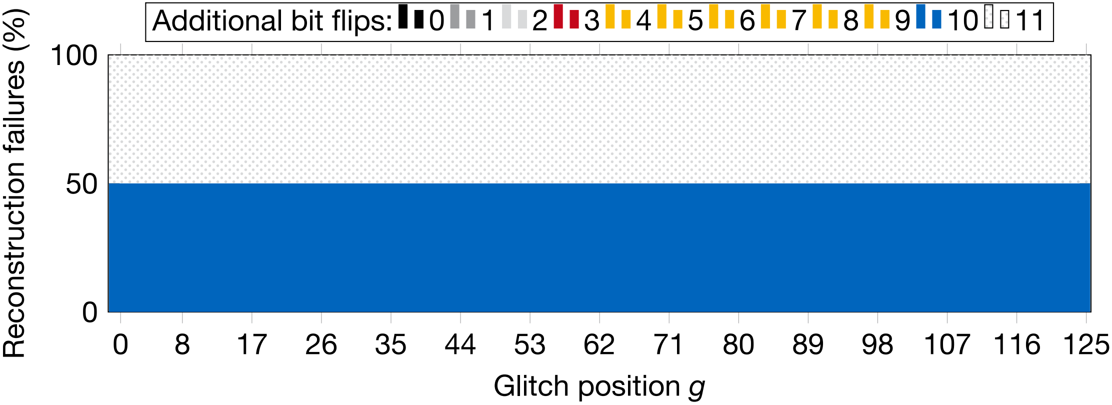
Attack

- 15 FPGA boards
- 100 random keys attacked per board
- 250 trials with 127 clock glitches each
- Codeword extracted from average of trials

Glitch Effects: Model Prediction

Experiment: 250 random codewords with a varying number of extra bit flips



Glitch Effects: Observed

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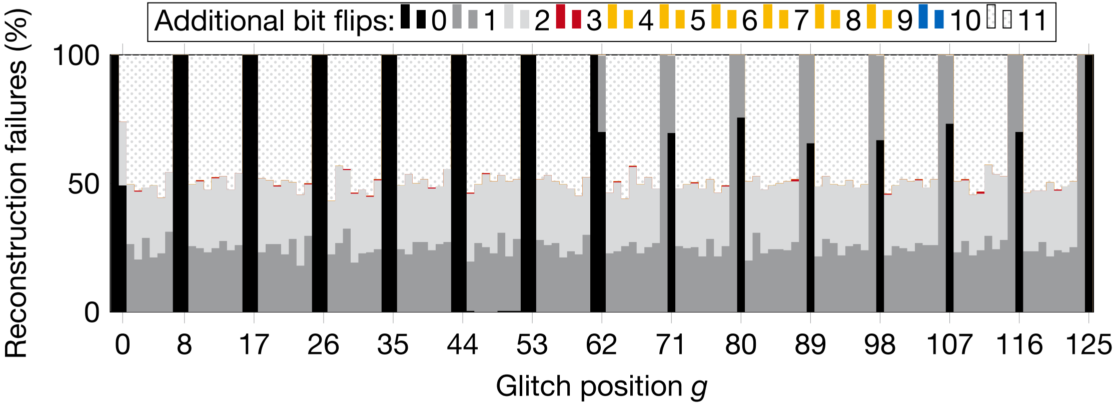

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After 250 trials: 14.8 codeword bit extraction errors on average

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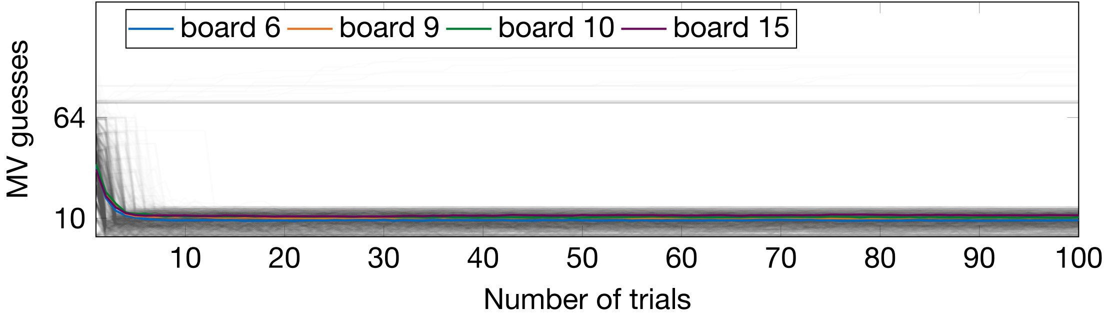

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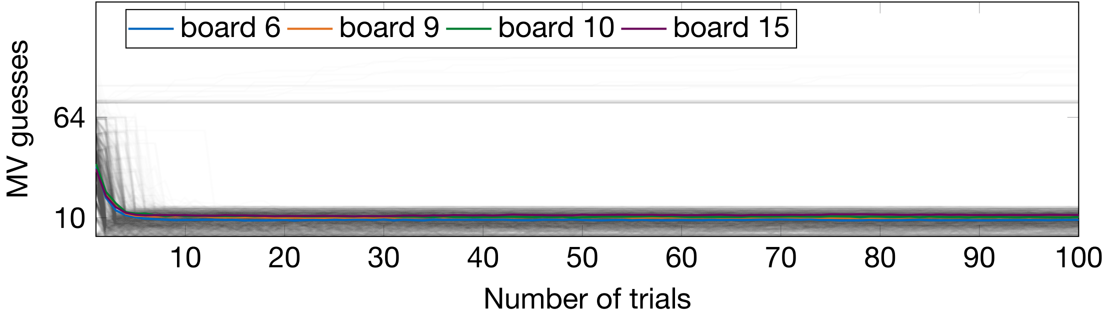
Maximum extraction error probability	8.6 bit



Masking

- Masking is effective against SCA with a similar scenario[1]
- Based on the fault model, masking *could* protect against the attack

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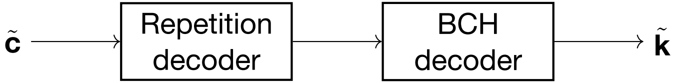

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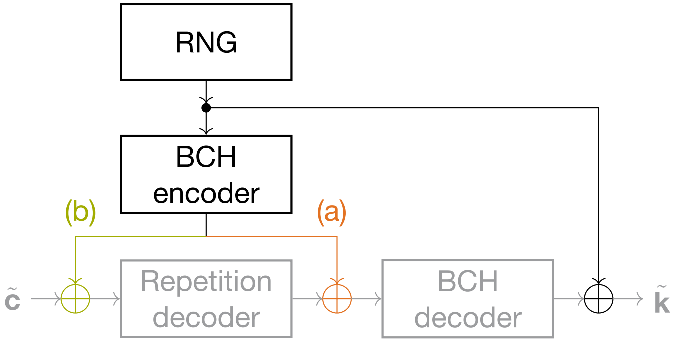

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(a) Mask Applied at BCH Decoder Input

Experiment results

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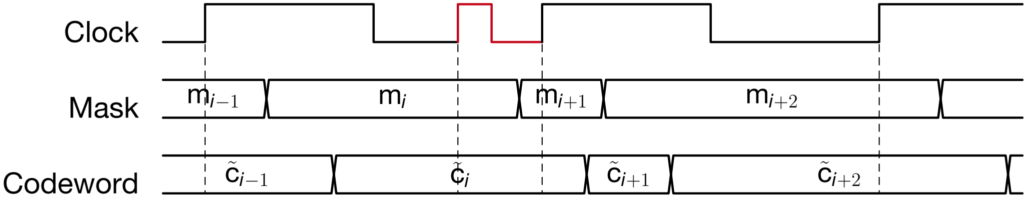
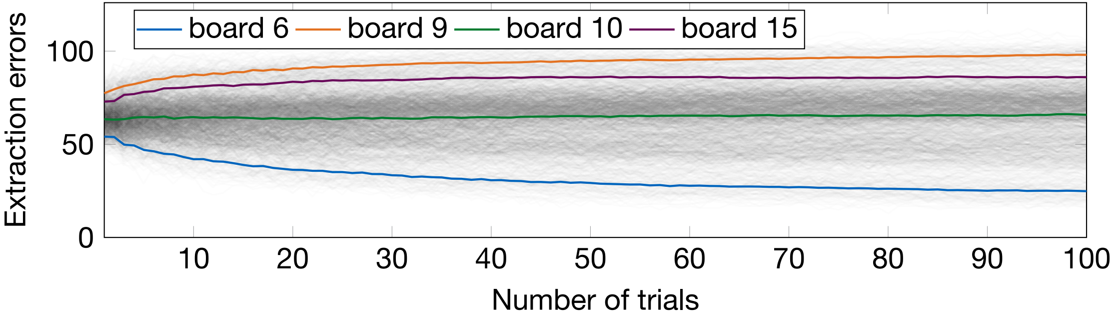
Why?



(b) Mask Applied at Repetition Decoder Input



Some amount of protection, but…

- Best-attackable board: 19 bit left to guess on average
- Mask/codeword propagation delay matching can be impractical

PUF Noise

Model

- Static response offset (e.g. ageing): Can be extracted and compensated
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Results

- Repetition decoder limits noise influence:
  For $\text{BER}_{\text{PUF}} \leq 11\,\%$, fewer than 0.5 bit errors are left on average
- Attack progress is slower, but averaging can combat the remaining errors

⇒ Realistic error rates: Attack performance is nearly the same

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- Profile one device, attack a different device
- No more helper data access/manipulation
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Results

- Attack is significantly slower (approx. factor 10)
- Attack performs well except for 3 boards
- Best-attackable board: 9.6 bit guesses left on average after 250 trials

Summary

Conclusion

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- Masking is difficult to get right and can even make matters worse
- Helper data manipulation detection does not always help

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In the full paper

- Profiling, extraction of static PUF response offsets
- HD manipulation and guessing strategies for more efficient key/codeword recovery
- Error-correcting partially extracted codewords
- Other secure sketches (e.g. syndrome construction)