DIFFERENTIAL FAULT INTENSITY ANALYSIS
on PRESENT and LED Block Ciphers

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Outline

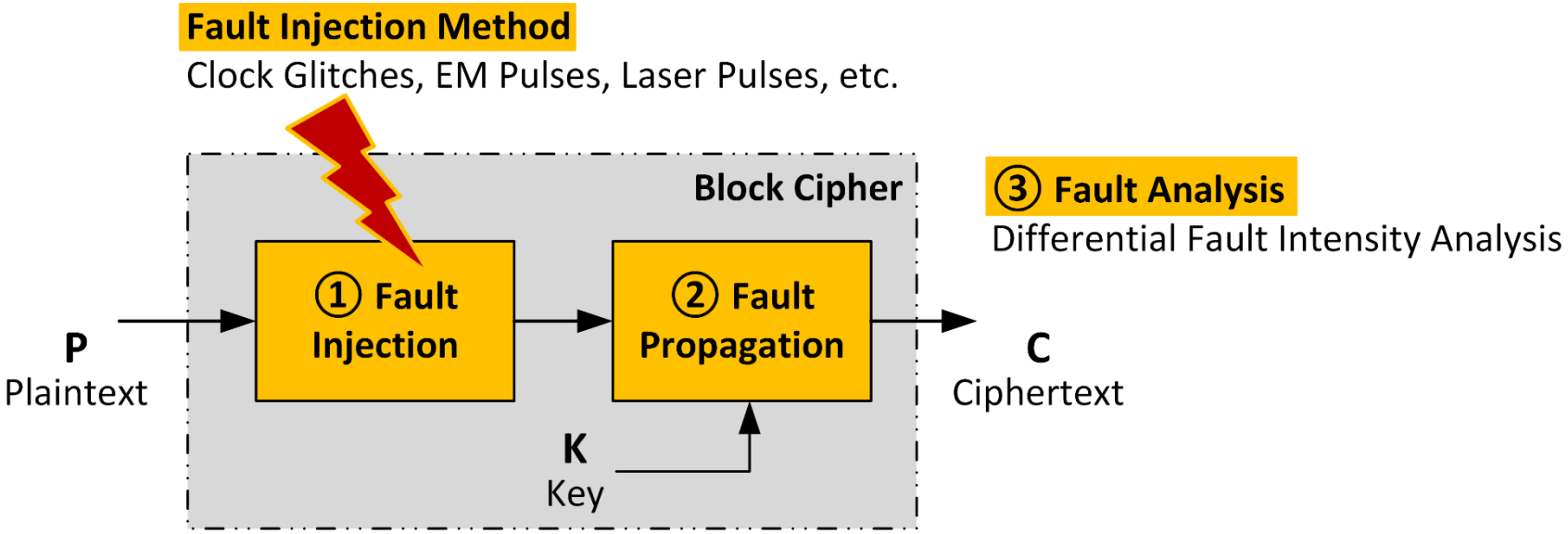
1. Fault Attack Requirements
2. Biased Faults
3. Exploiting Biased Faults:
   - Differential Fault Intensity Analysis (DFIA)
   - Results for PRESENT
4. Fault Injection Resolution and DFIA
5. Related Work
6. Conclusion

In a nutshell

- The basis of Differential Fault Intensity Analysis (DFIA) is biased (non-uniform) fault behavior.
- DFIA provides a feasible (cheap, general) biased fault model.
- DFIA works even we do not have high-capability fault injection equipment.

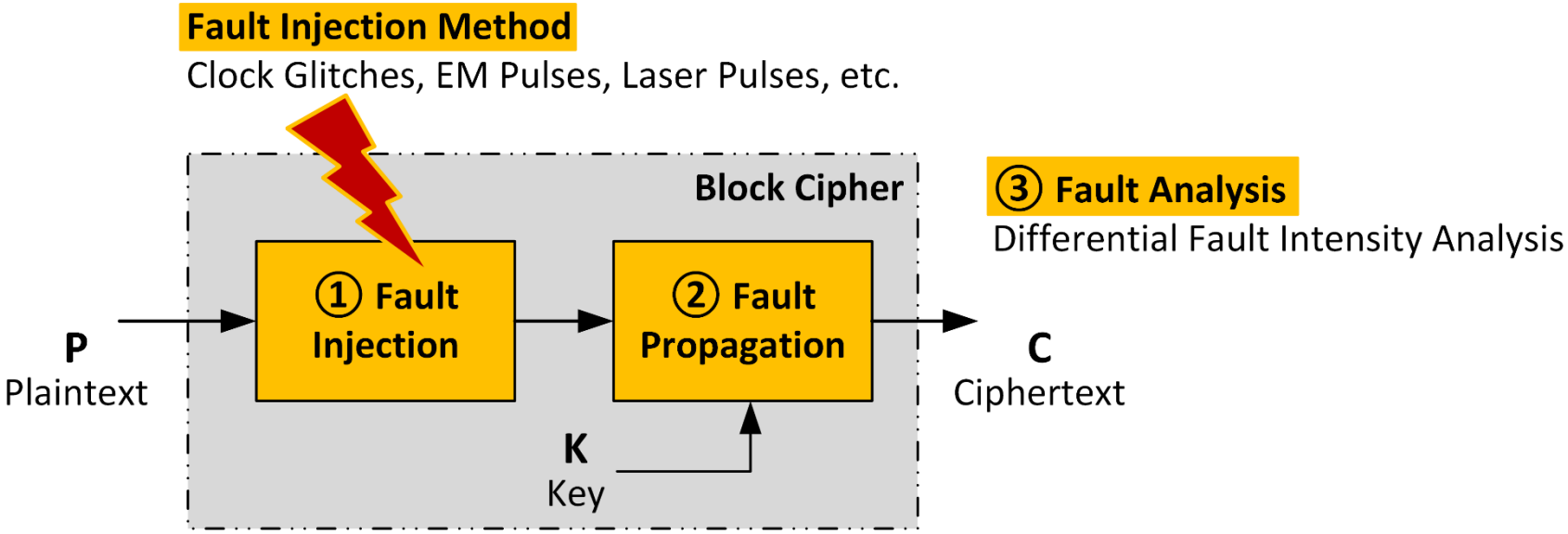
Fault Attack Requirements

- Fault Attacks:
  1. Injecting faults in cipher's state
  2. Observing the effects of the fault
  3. Analyzing the effects to retrieve the key



Fault Attack Requirements

- Fault analysis relies on fault model.
  - Fault model: Assumptions/Restrictions on the injected faults
- Attacker needs a feasible fault model.



Fault Attack Requirements

- Differential Fault Intensity Analysis (DFIA):
  1. How can we obtain biased faults?
     - With low-cost setups
     - With applicability to any fault injection method

     $\Longrightarrow$ A feasible fault model

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- Differential Fault Intensity Analysis (DFIA):
  1. How can we tune the injected faults?
     - With low-cost setups
     - With applicability to any fault injection method

     ⟹ A feasible fault model

  2. How can we exploit the biased faults?
     - Using side-channel analysis approach
     - Similar to Differential Power Analysis (DPA)

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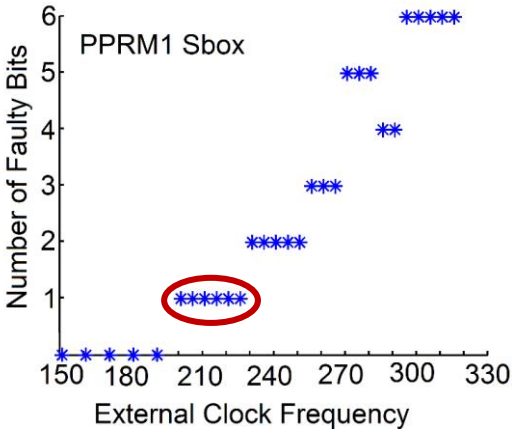
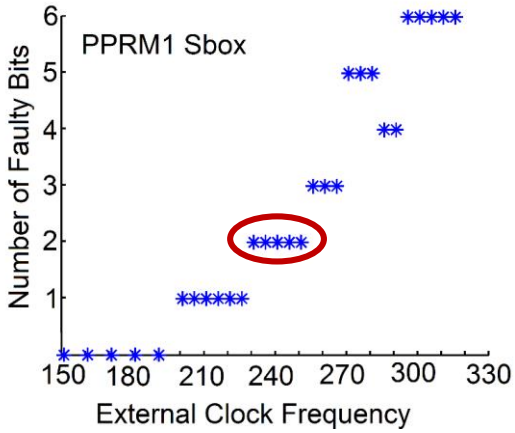
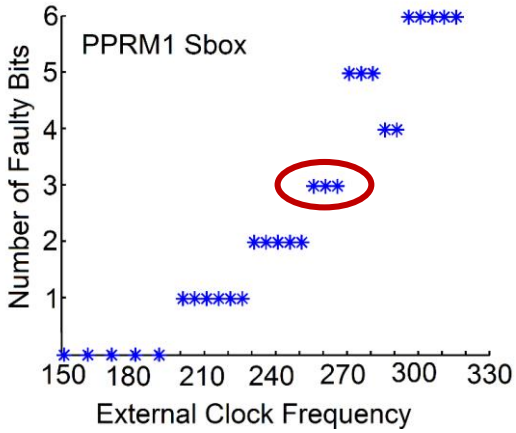
Observation I

- # of Faults vs. External Clock Frequency

Clock-glitching (Ghalaty et al. FDTC'14)







f_1 = 210 MHz

Faults = 1

f_1 = 240 MHz

Faults = 2

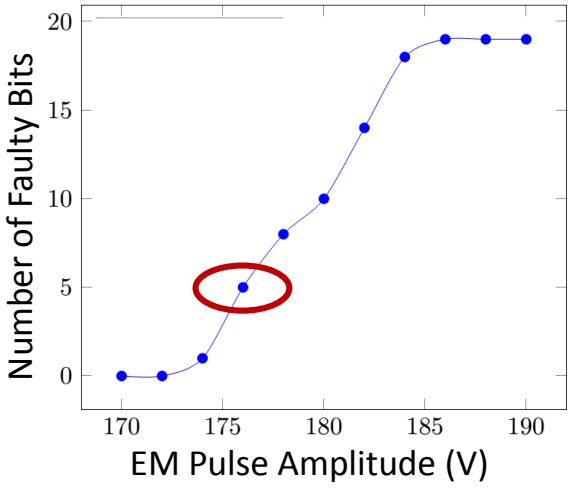
f_1 = 270 MHz

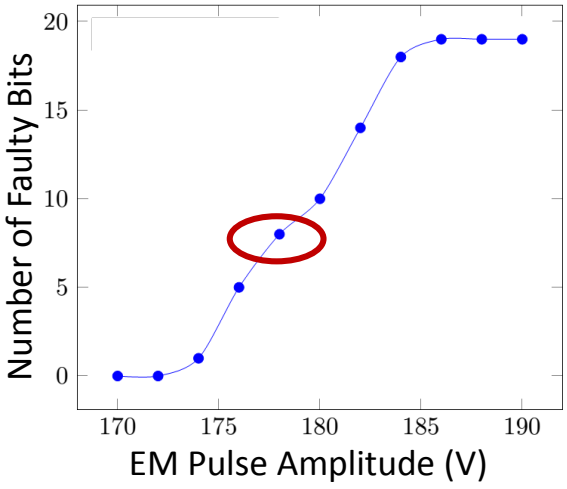
Faults = 3

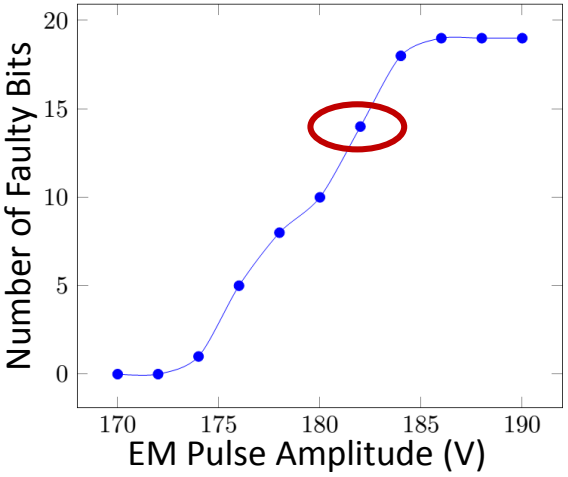
Observation II

- # of Faults vs. EM Pulse Amplitude

Electromagnetic (EM) Pulses (Moro et al. FDTC'13)







V_{pulse} = 176 V

Faults = 5

V_{pulse} = 178 V

Faults = 8

V_{pulse} = 182 V

Faults = 13

Creating Biased Faults

- How can we inject biased faults?
  - By varying the fault intensity
- Fault Intensity:
  - The strength of the applied stress on the attacked device

Fault Injection Method	Fault Intensity
Clock-glitching	Clock frequency
EM Pulses	Pulse voltage

Creating Biased Faults (cont.)

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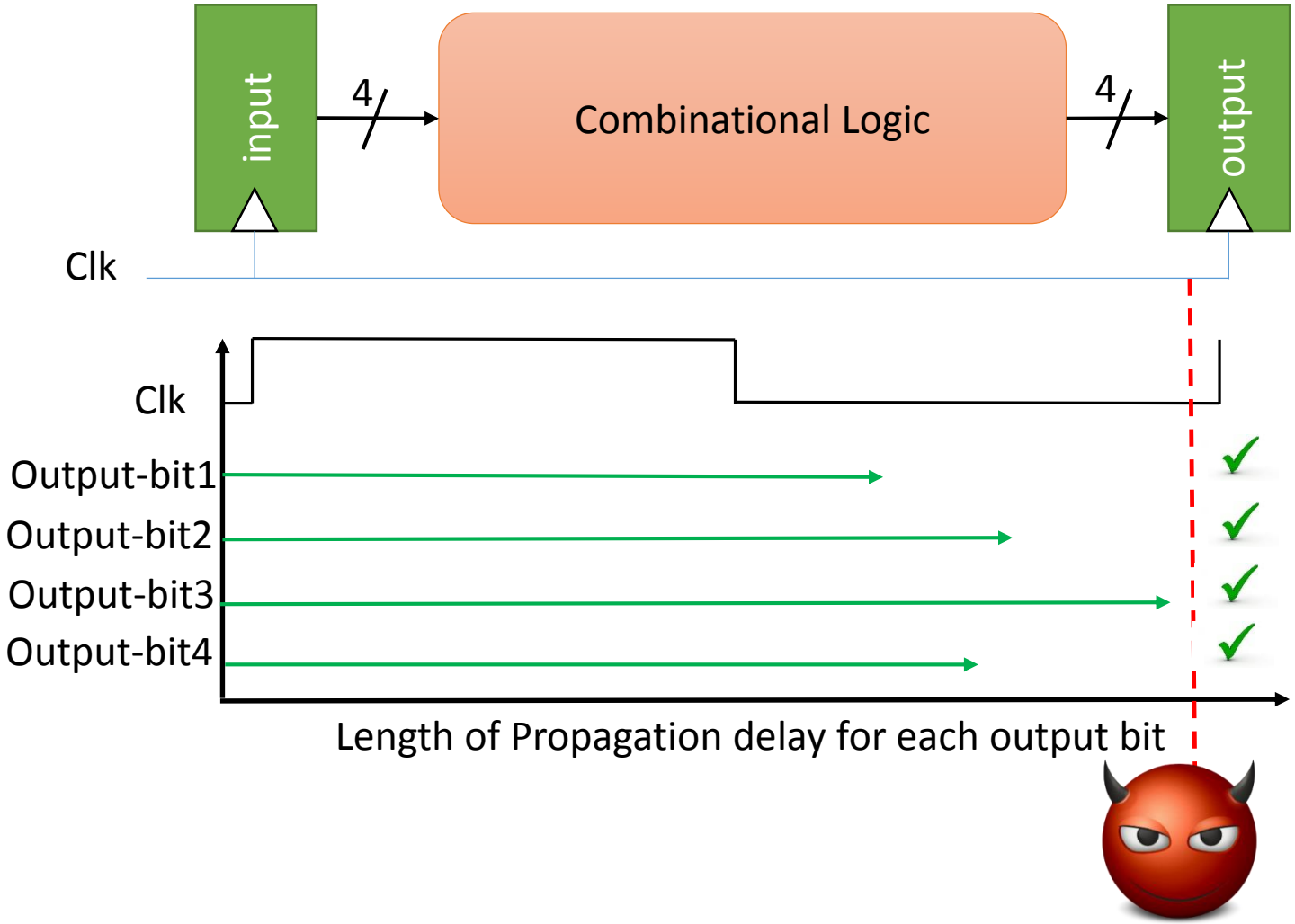
  - By varying the fault intensity
- Fault Intensity:
  - The strength of the applied stress on the attacked device

Fault Injection Method	Fault Intensity
Clock-glitching	Clock frequency
EM Pulses	Pulse voltage

- Biased (Non-uniform) Fault Behavior:
  - Number of Faults ~ Fault Intensity
  - Small change in Fault Intensity → Small change in Faulty Value

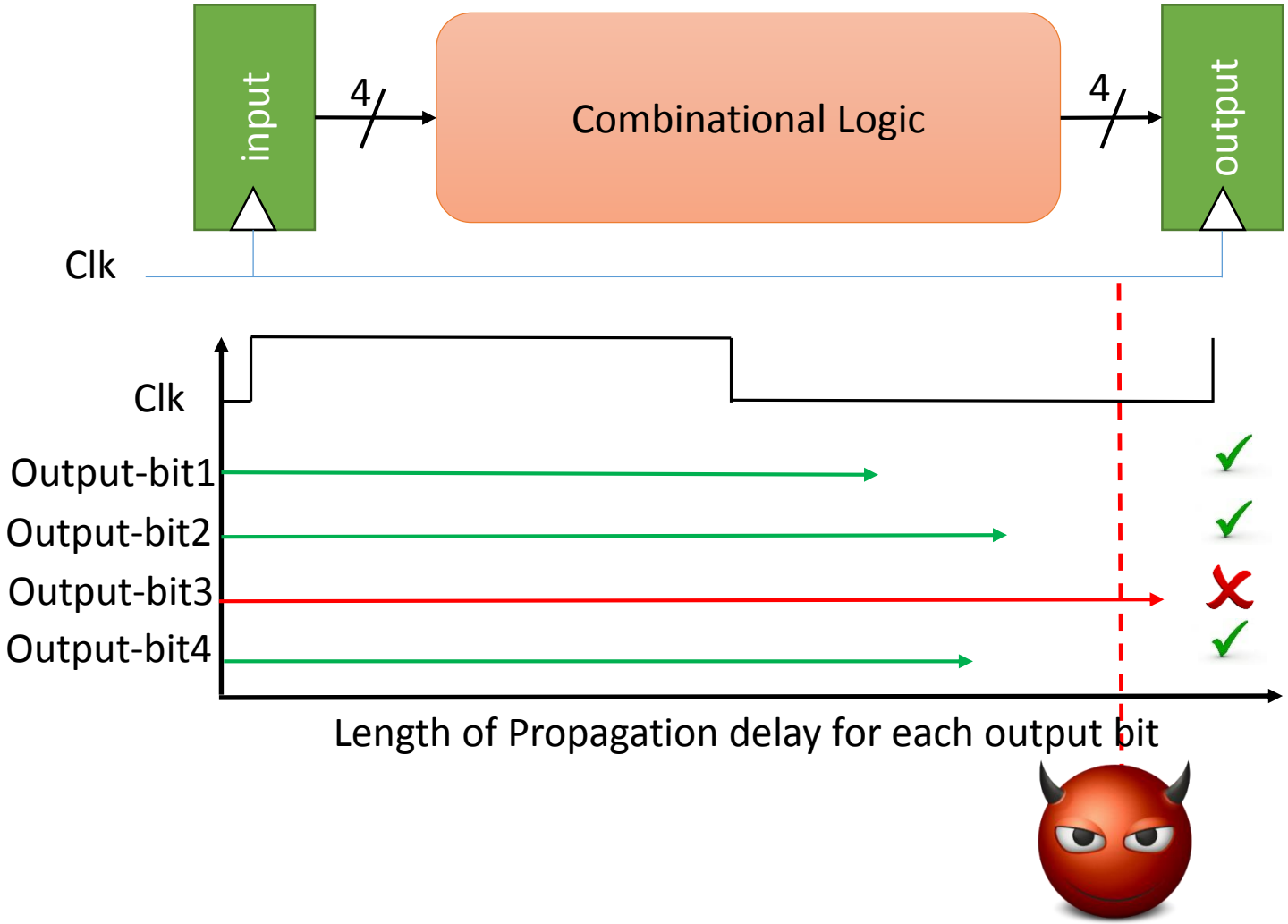
A Fault Mechanism

- Setup Time Violation:



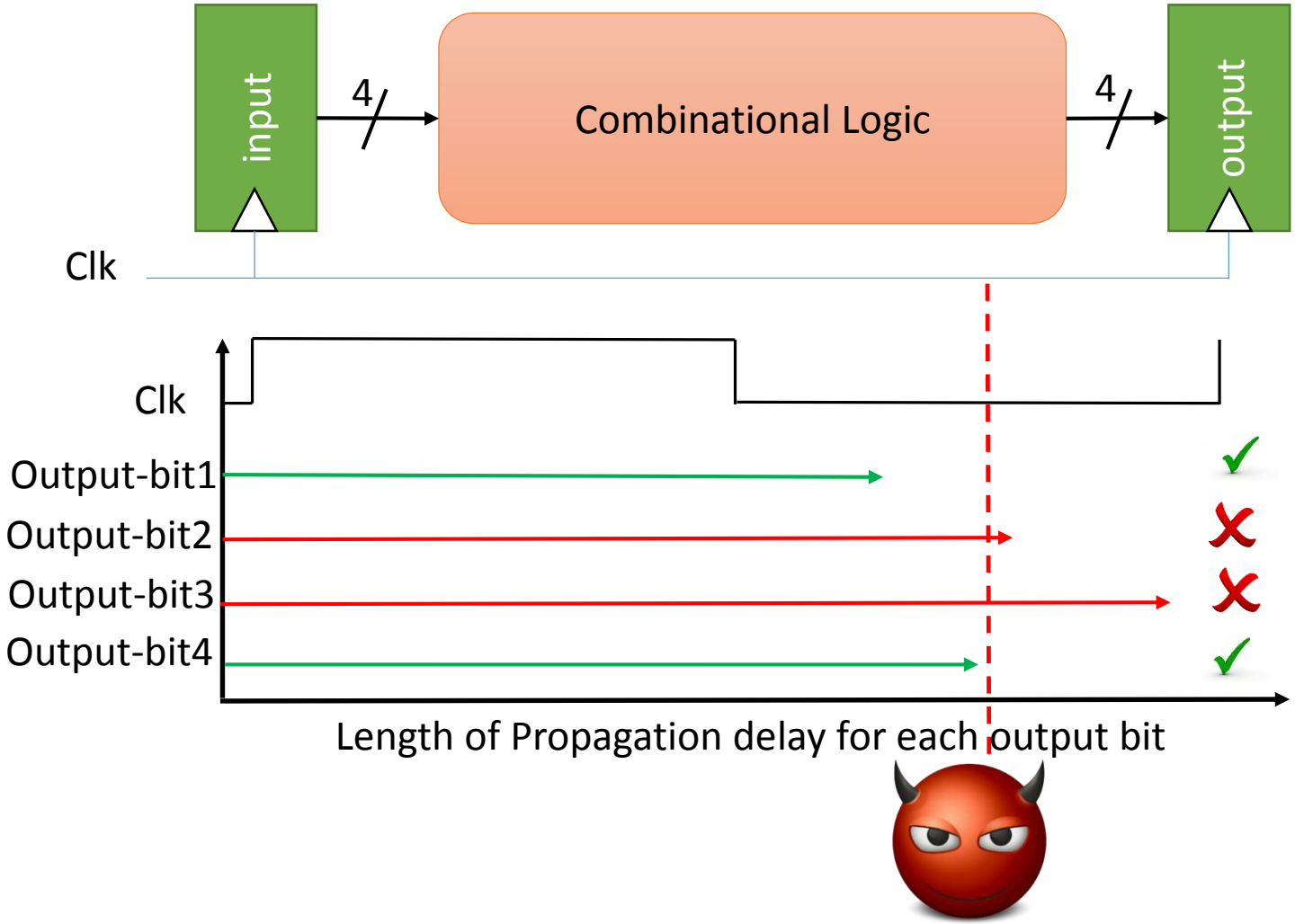
A Fault Mechanism (cont.)

- Setup Time Violation:



A Fault Mechanism (cont.)

- Setup Time Violation:



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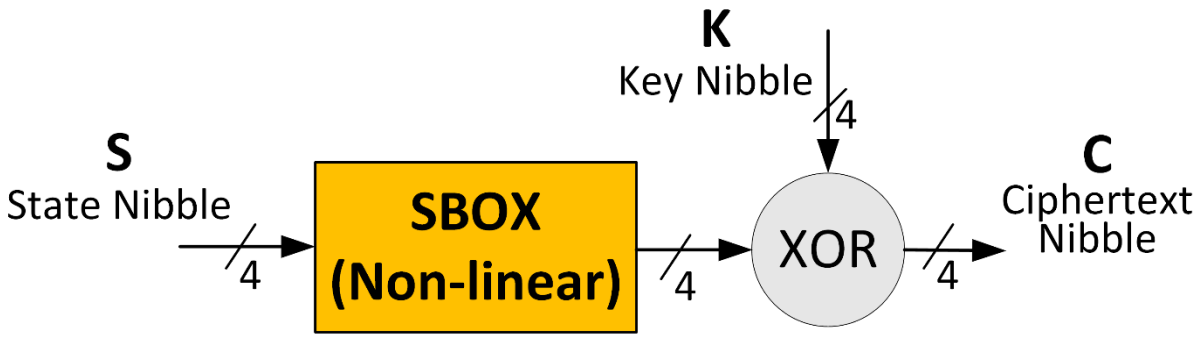
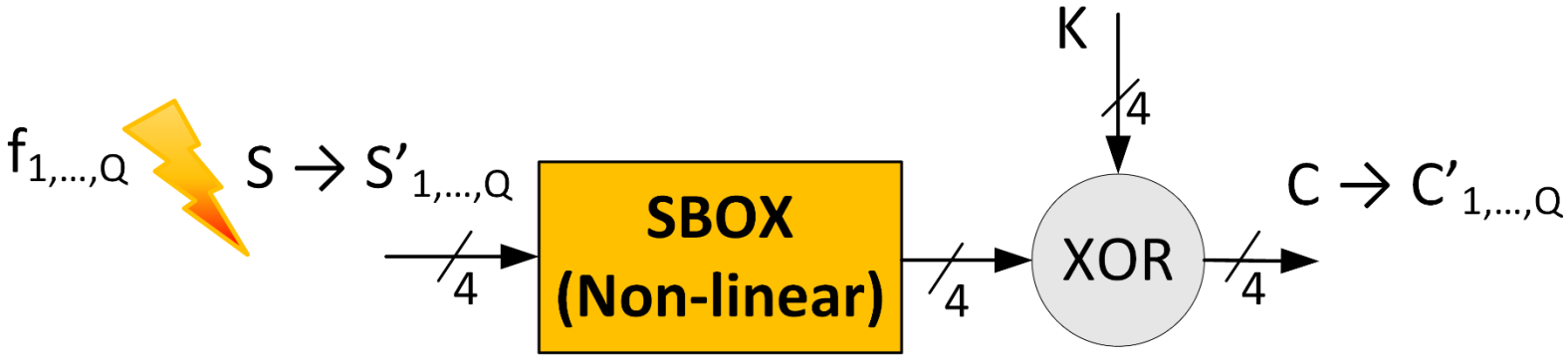
Differential Fault Intensity Analysis

- Differential Fault Intensity Analysis (DFIA):
  - Combines fault injection and DPA principles
  - Induces biased faults by varying the fault intensity
  - Applies a hypothesis test with biased faults
  - Uses biased faults as the source of leakage



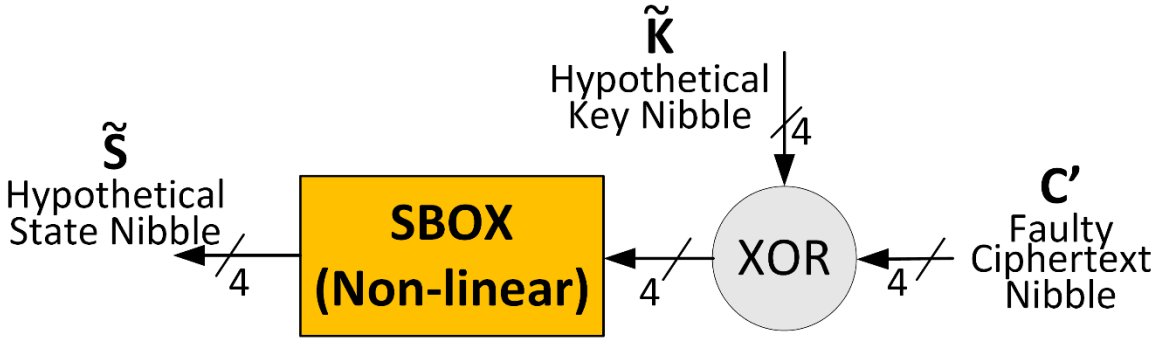
DFIA – Biased Fault Injection

- Step 1: Biased Fault Injection
  - Apply Q different fault intensities ($f_{1,\ldots,Q}$)
  - Induce biased faults ($S'_{1,\ldots,Q}$)
  - Collect faulty ciphertexts ($C'_{1,\ldots,Q}$)



DFIA – Hypothesis Test

- Step 2: Hypothesis Test with Biased Faults



Given: C' and a KNOWN fault bias f

Find: Most likely key nibble $\tilde{K}$

For all $\tilde{K}$, find $\tilde{S} = SBOX^{-1}(C' \oplus \tilde{K})$

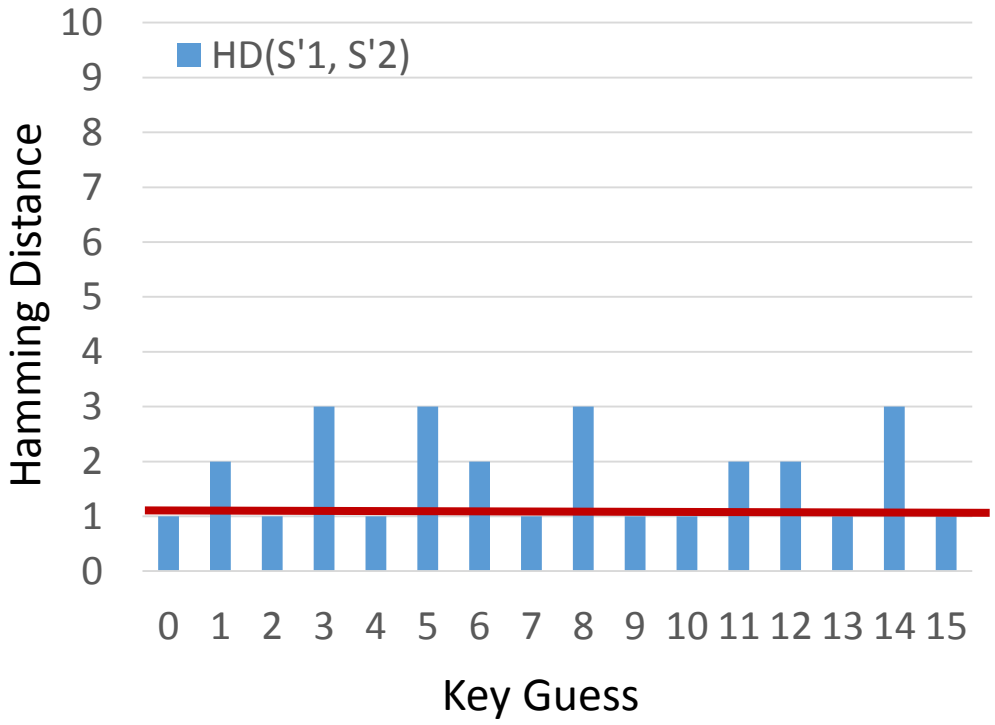
Accumulate $\rho_{\tilde{K}} = \sum HD(\tilde{S})$

Select K = argmin ρ

DFIA – Hypothesis Test Example

- Step 2: Example for PRESENT

$f_{1,\ldots,4}$ → $S'_{1,\ldots,4}$
where $HD(S'_i, S'_{i+1}) = 1$

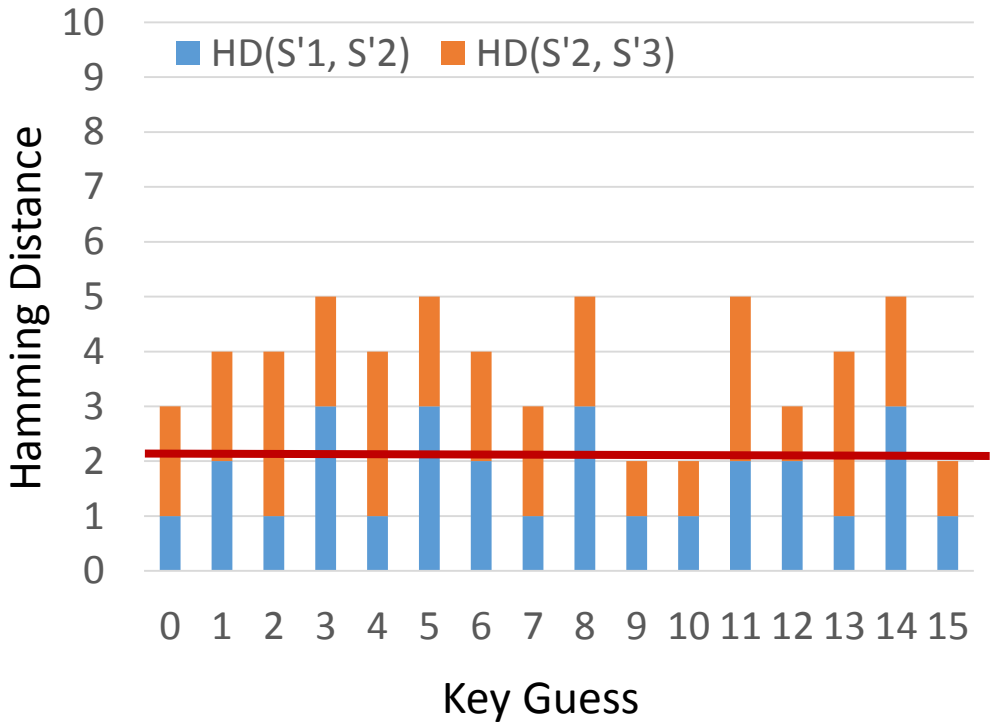


Possible Key Values:
{0,2,4,7,9,10,13,15}

DFIA – Hypothesis Test Example (cont.)

- Step 2: Example for PRESENT

$f_{1,\ldots,4}$ → $S'_{1,\ldots,4}$
where $HD(S'_i, S'_{i+1}) = 1$



Possible Key Values:
{9,10,15}

DFIA – Hypothesis Test Example (cont.)

- Step 2: Example for PRESENT

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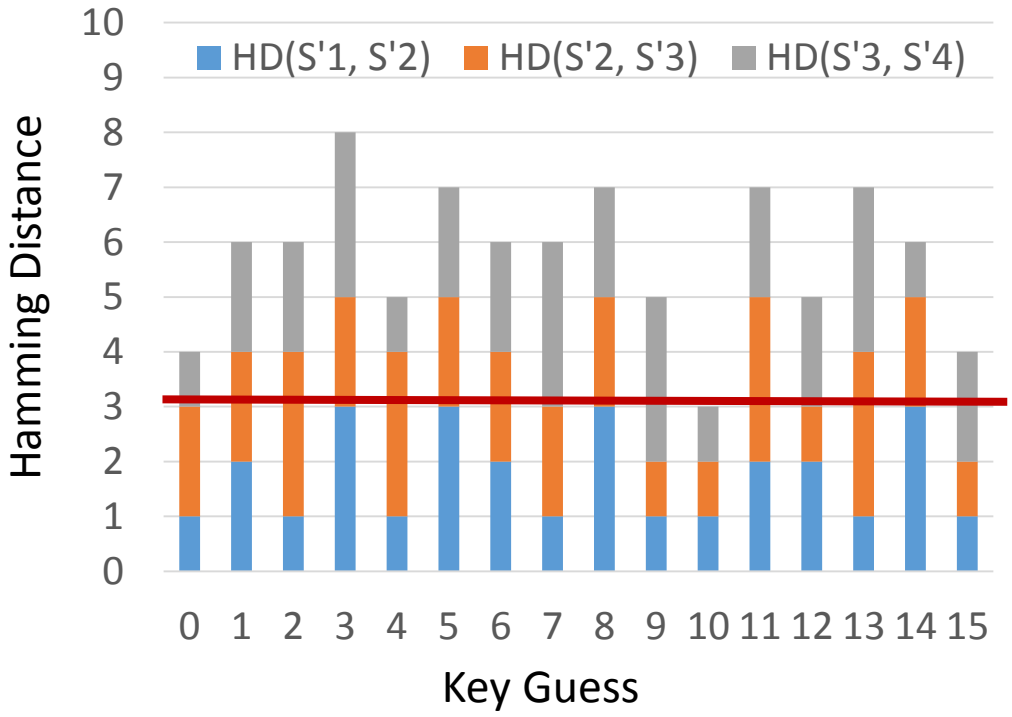

Possible Key Values:
{10}

DFIA – Results

- Nibble-serial and Round-serial Implementations:
  - Verilog RTL codes
  - Gate-level netlists for an Altera Cyclone IV FPGA

- Biased Fault Injection:
  - Clock Glitches
  - Gate-level (post-place-and-route) simulation

DFIA – Results (cont.)

- PRESENT (and LED):
  - Step size (resolution): 100ps

	# of Fault Intensity Levels(Q)		# of Glitched Clock Cycles	
	Nibble-Serial	Round-Serial	Nibble-Serial	Round-Serial
PRESENT-80	10	12	10×16=160	12×1=12
PRESENT-128	16	18	16×16=256	18×1=18

DFIA is FEASIBLE on PRESENT (and LED)

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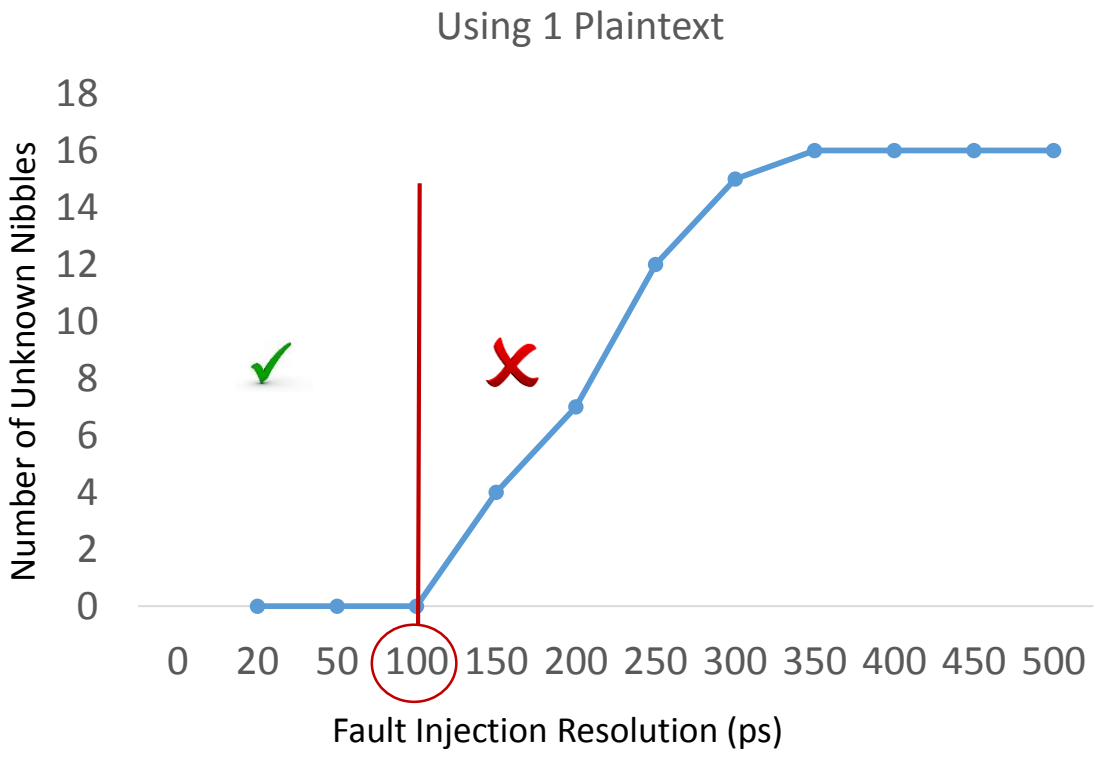
Fault Injection Resolution - Problem

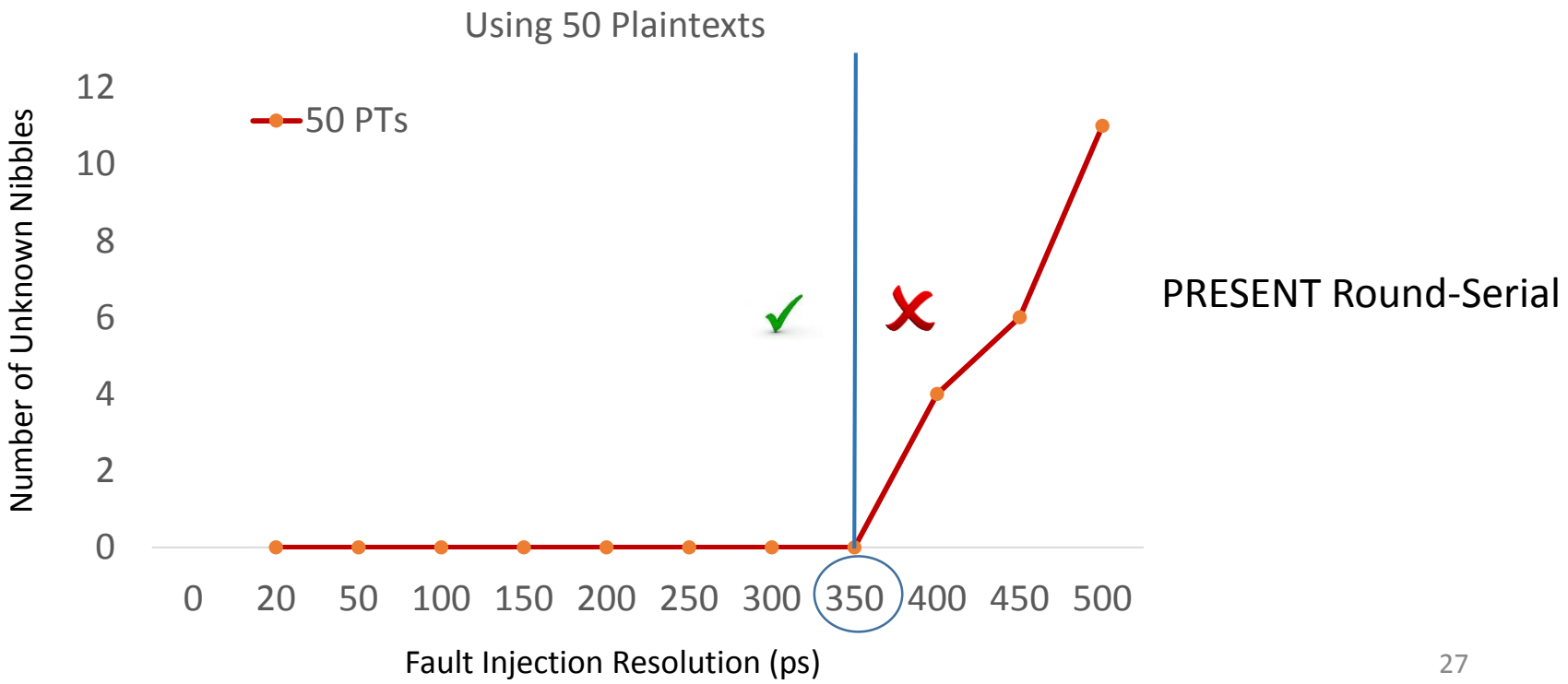
- Does DFIA work with low-resolution fault injection equipment?
  - Resolution: Minimum fault intensity step size
  - Some nibbles of the key cannot be fully retrieved if we use 1 plaintext.



PRESENT Round-Serial

Fault Injection Resolution - Solution

- DFIA still works with low-resolution fault injection equipment:
- Solution:
  - Repeat DFIA steps for different plaintexts $\{P_1, P_2, \ldots, P_m\}$ until finding a unique key



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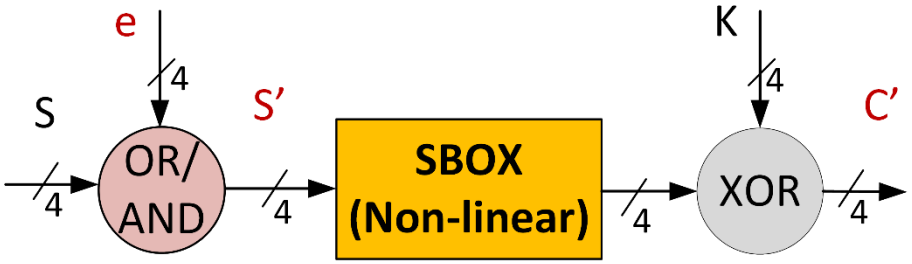
Related Work – Biased Fault Definitions

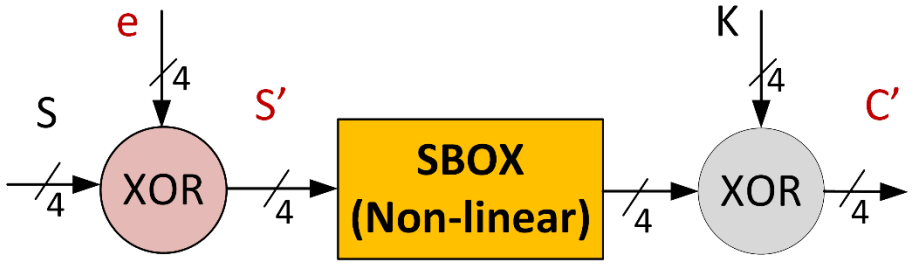
- Biased-Fault-Based Fault Analysis:
  - Non-Uniform Faulty Value Analysis (NUFVA):
    [Fuhr et al. FDTC'13, De Santis et al. LightSec'14, and Li et al. FPS'13]
  - Non-Uniform Error Value Analysis (NUEVA):
    [Lashermes et al. FDTC'12]

NUFVA



e: uniform
S': non-uniform (some values occur more than others)
C': non-uniform (some values occur more than others)

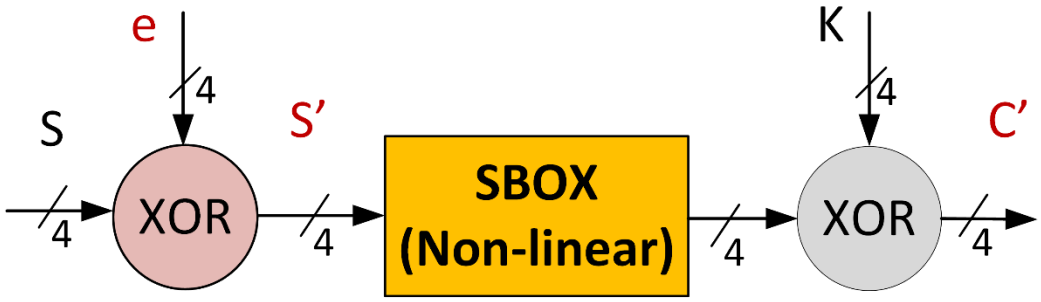
NUEVA



e: non-uniform (some values occur more than others)
S': non-uniform (some values occur more than others)
C': no assumption

Related Work – DFIA vs. NUFVA, NUEVA

- DFIA does not make any assumptions on the biased value of faulty states or ciphertexts.



e: non-uniform (successive values are close to each other)
S': non-uniform (successive values are close to each other)
C': no assumption

- DFIA provides a cheap and general methodology to control the induced faults.

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Conclusion

- DFIA provides
  - a feasible (cheap, general) biased fault model
  - a DPA-like fault analysis methodology
- DFIA is feasible on LED and PRESENT.
- DFIA still works with lower-capability fault injection equipment.

Thank you!