Differential Fault Intensity Analysis

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Outline

1. **DFIA vs DFA?**
2. **Explaining Biased Faults**
3. **An Attack Based on Fault Bias**
4. **Experiments**
   - **Fault Bias Exists**
   - **DFIA Demonstration**
5. **Related Work and Conclusions**

Differential Fault Analysis (DFA)

Cryptographic Algorithm ➡ **Fault Model** { *Random Byte*, *Random Bit*, *Chosen Bit* } ➡ **DFA**

C, C', C'', .. → K

Implementations and Actual Faults

Cryptographic Algorithm ➡ **Fault Model**
- *Random Byte*
- *Random Bit*
- *Chosen Bit*

➡ **DFA**: C, C’, C’’, .. → K

Implementation / **Fault Injection**

Cryptographic Architecture ➡ **Fault**
- *Fault Bias*
- *1-bit, 2-bit, ..*

Differential Fault Intensity Analysis (DFIA)

Cryptographic Algorithm ➡ **Fault Model**

Random Byte
Random Bit
Chosen Bit

➡ **DFA**
C, C’, C’’, .. → K

Implementation

Fault Injection

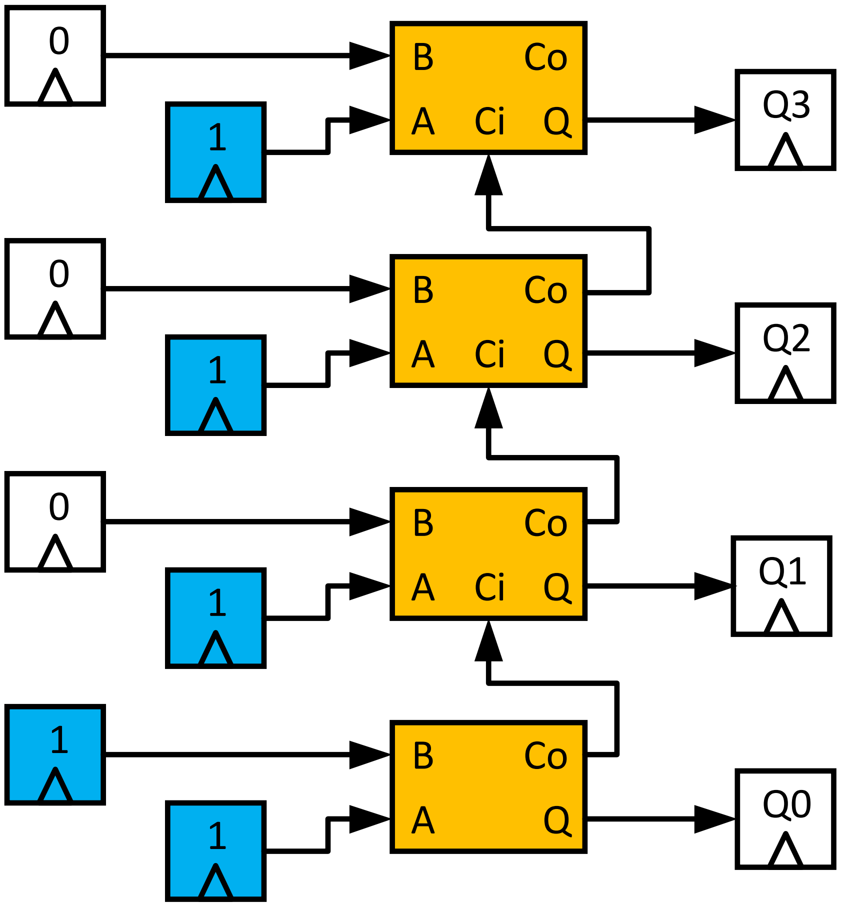
Variable Fault Intensity

Cryptographic Architecture ➡ **Fault**

Fault Bias
1-bit, 2-bit, ..

➡ **DFIA**
C, C_1’, C_2’, .. → K

Where do Biased Faults come from?



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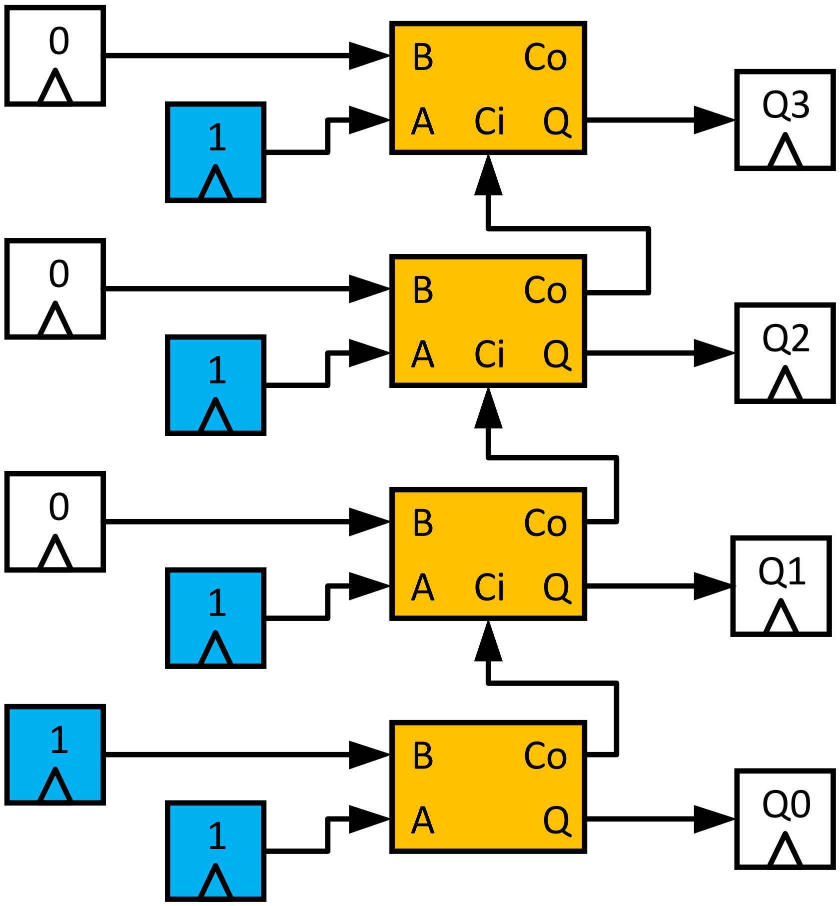

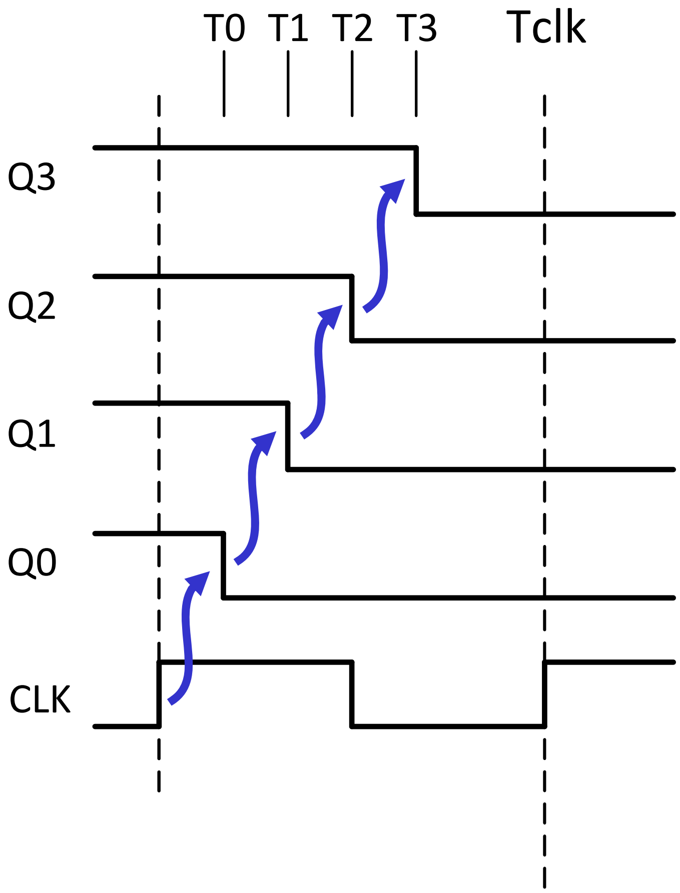

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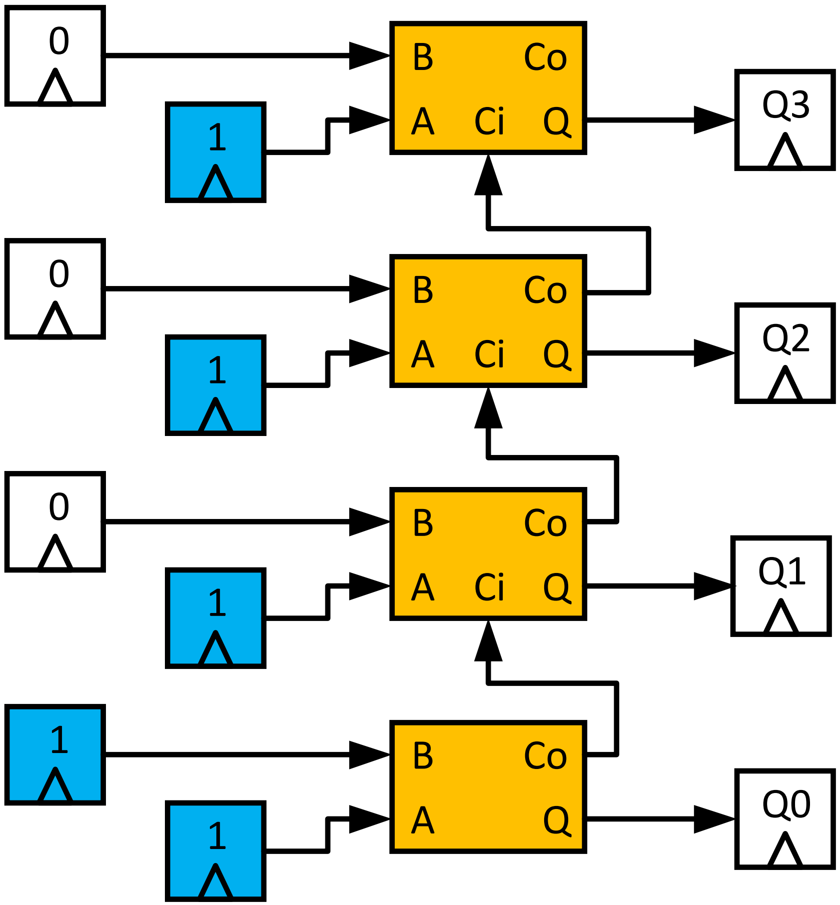
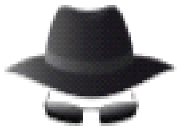
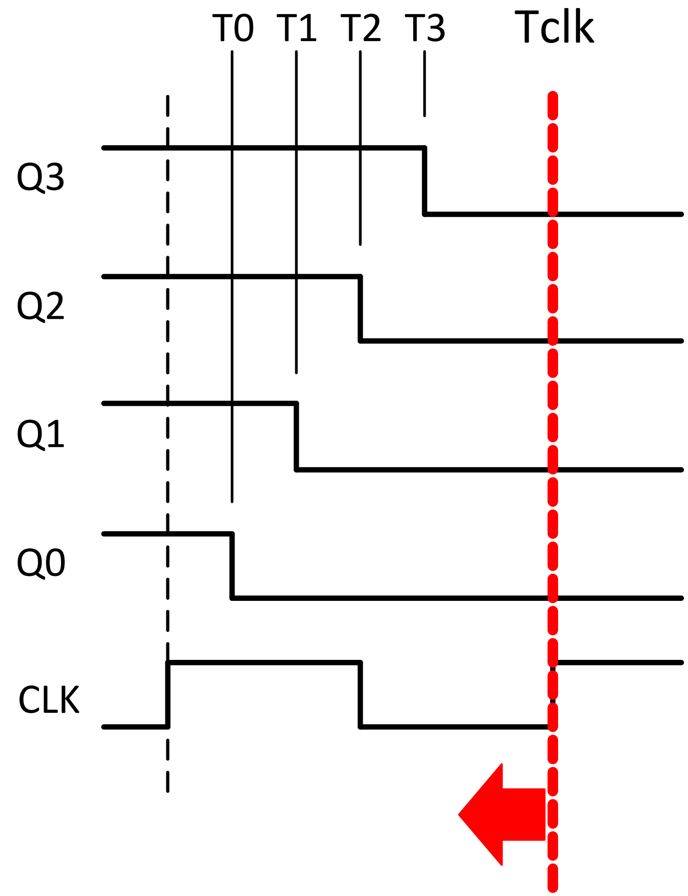


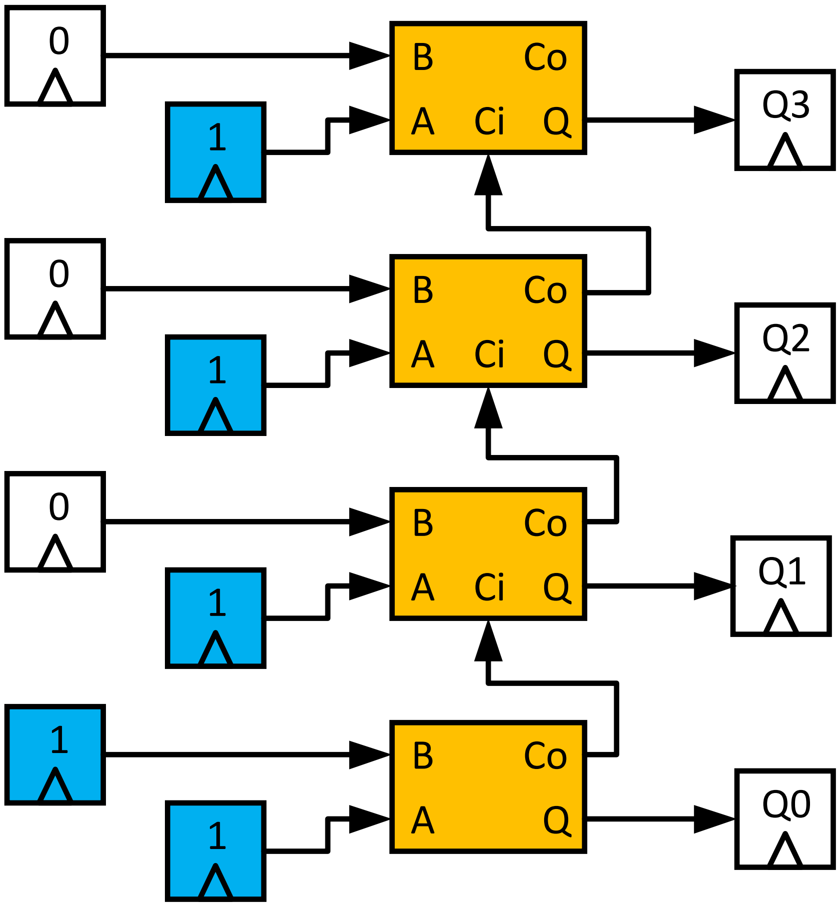


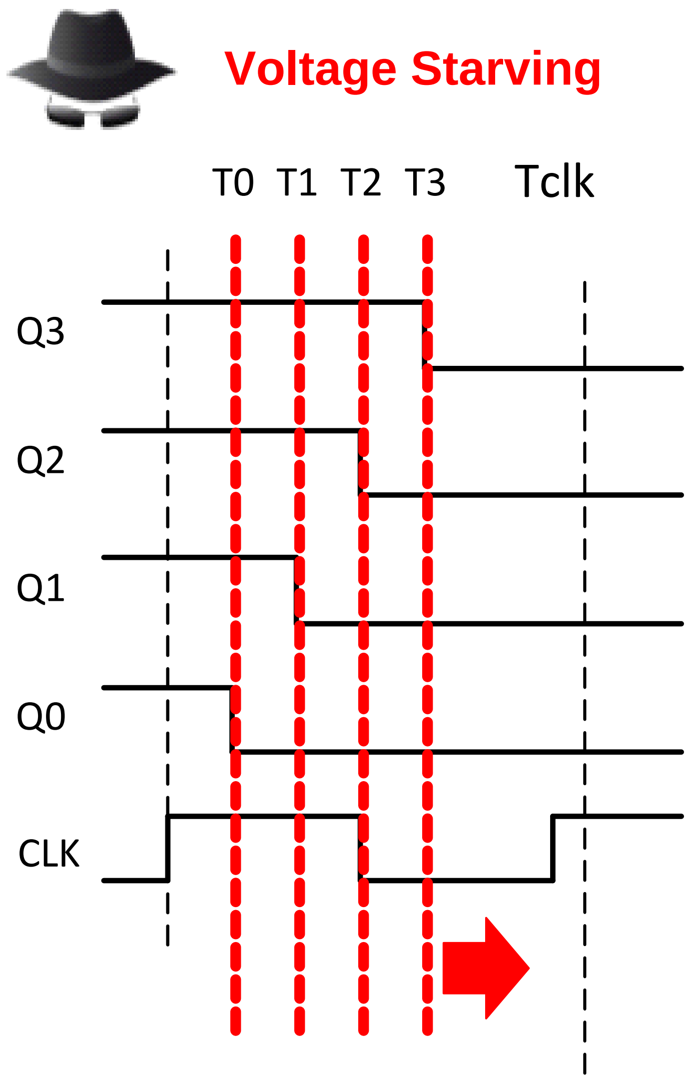
Clock Glitching



$P_{fault}(Q3) > P_{fault}(Q2) > P_{fault}(Q1) > P_{fault}(Q0)$

Where do Biased Faults come from?



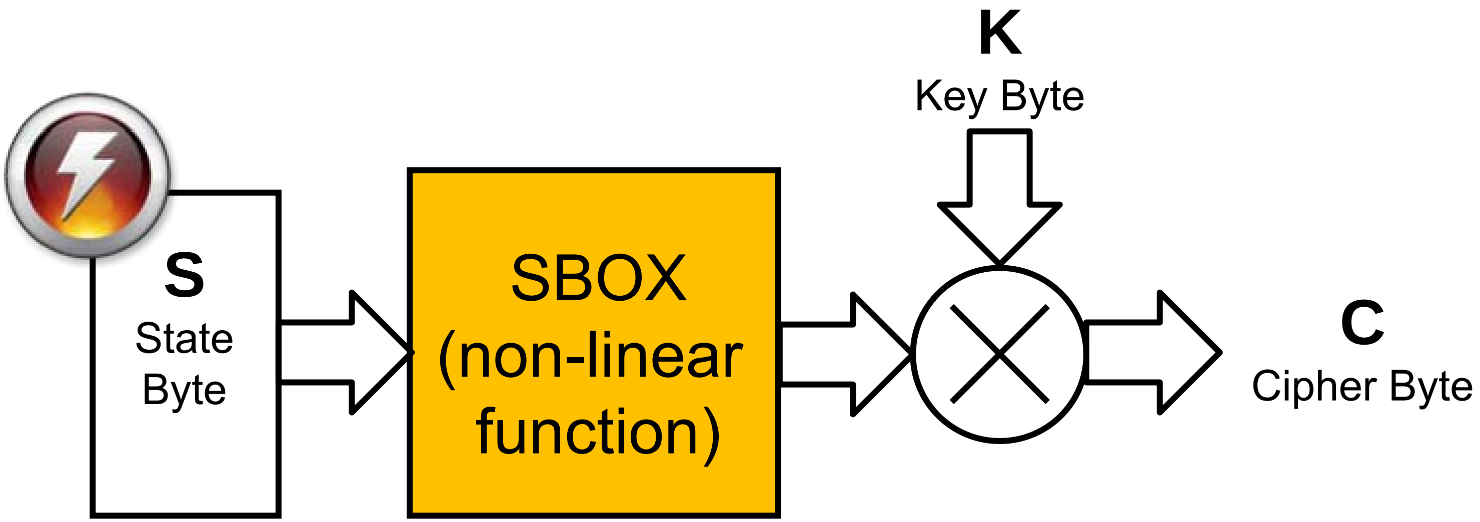


$P_{fault}(Q3) > P_{fault}(Q2) > P_{fault}(Q1) > P_{fault}(Q0)$

Biased Faults

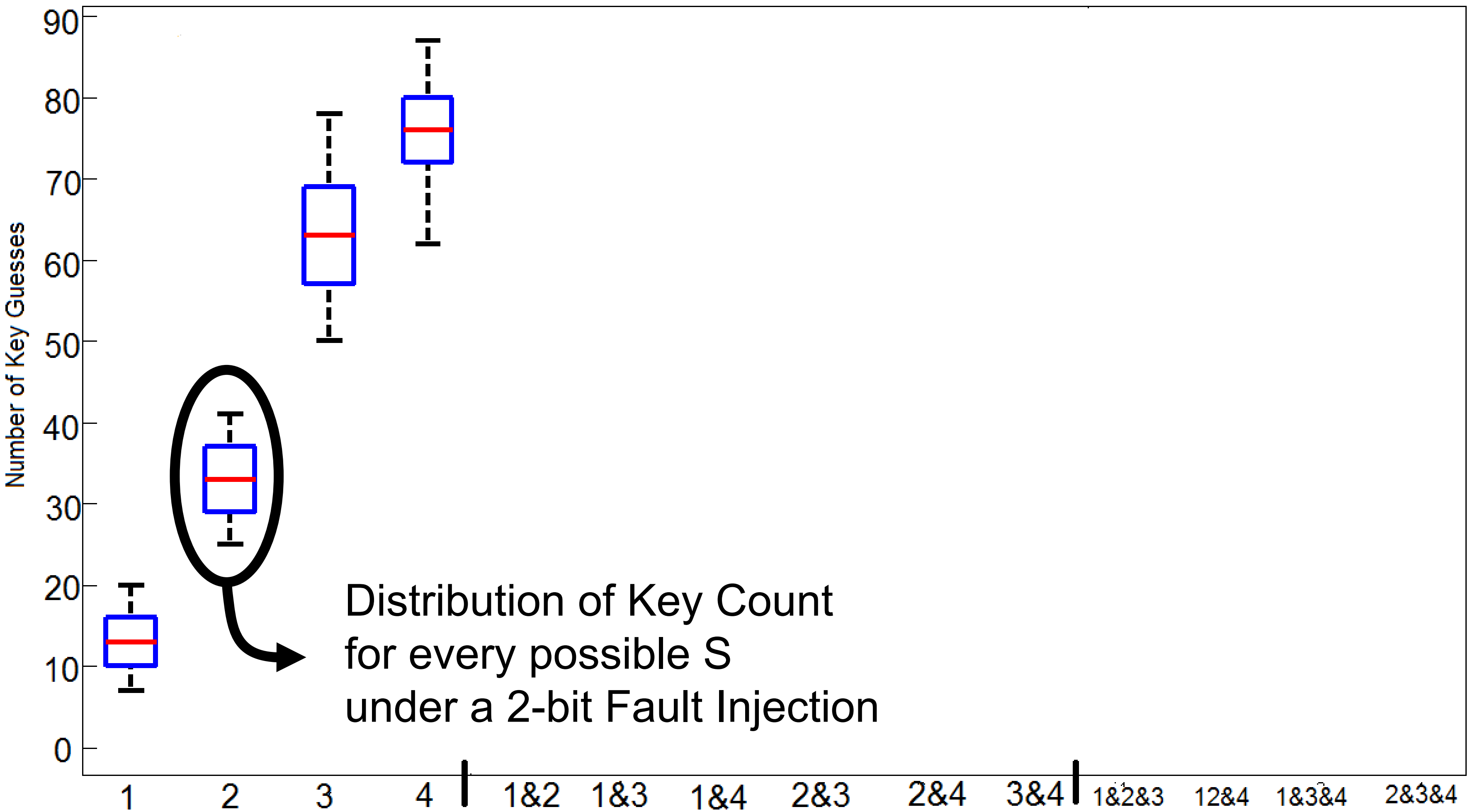
- **Non-uniform propagation time results in non-uniform fault response.**
- **Varying Fault Intensity [Li 2010] will trigger non-uniform faults. We call this Fault Bias.**
- **Fault Bias is the basis of DFIA.**

Using Biased Faults for Cryptanalysis

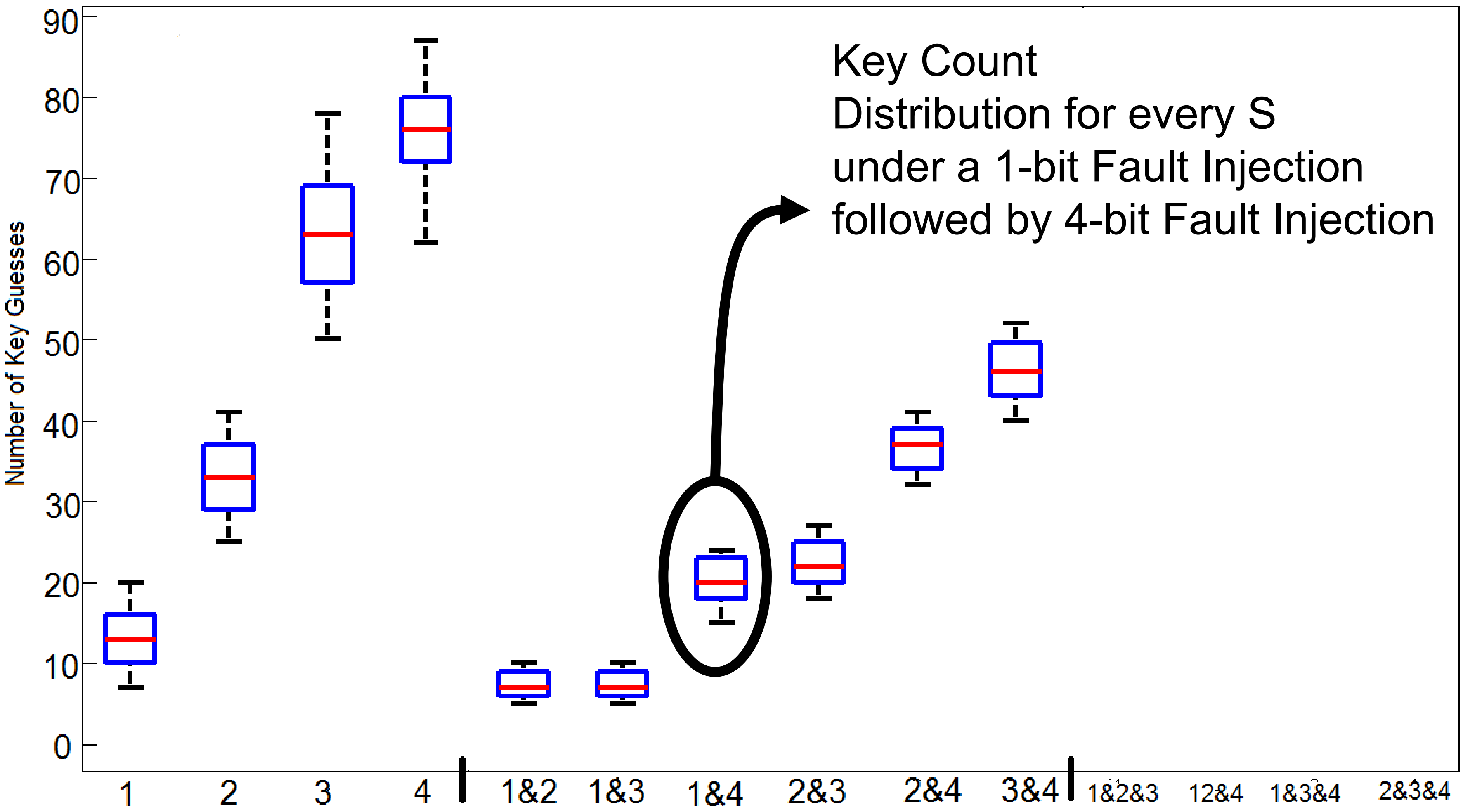


Given: C, C’ for a given fault bias B (1-bit, 2-bit, ...)
Find: number of keys that result in a solution for
C’ = SBOX(S’) xor K, C = SBOX(S) xor K
for all S, S’ where HD(S, S’) <= B

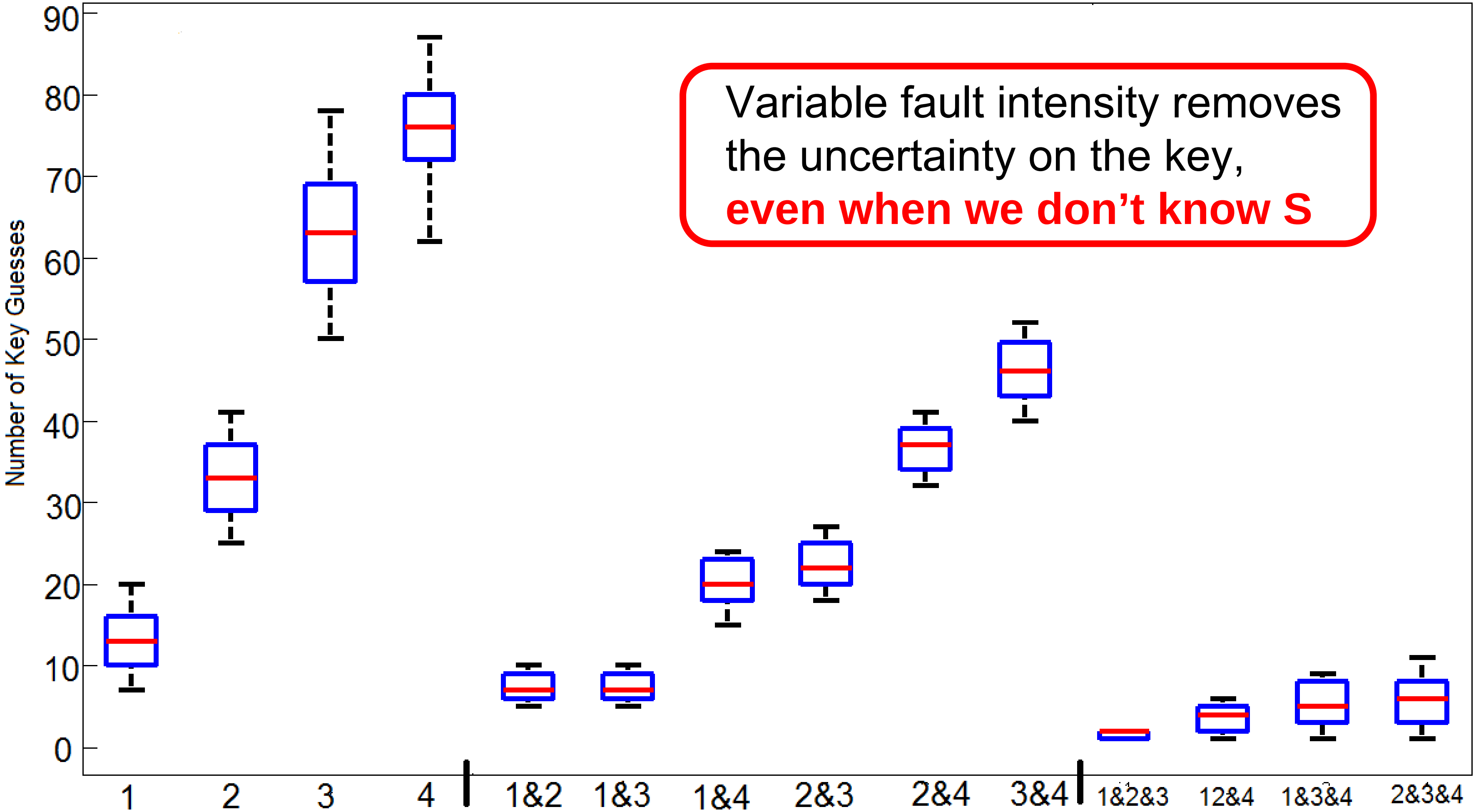
Key uncertainty for **single** biased fault



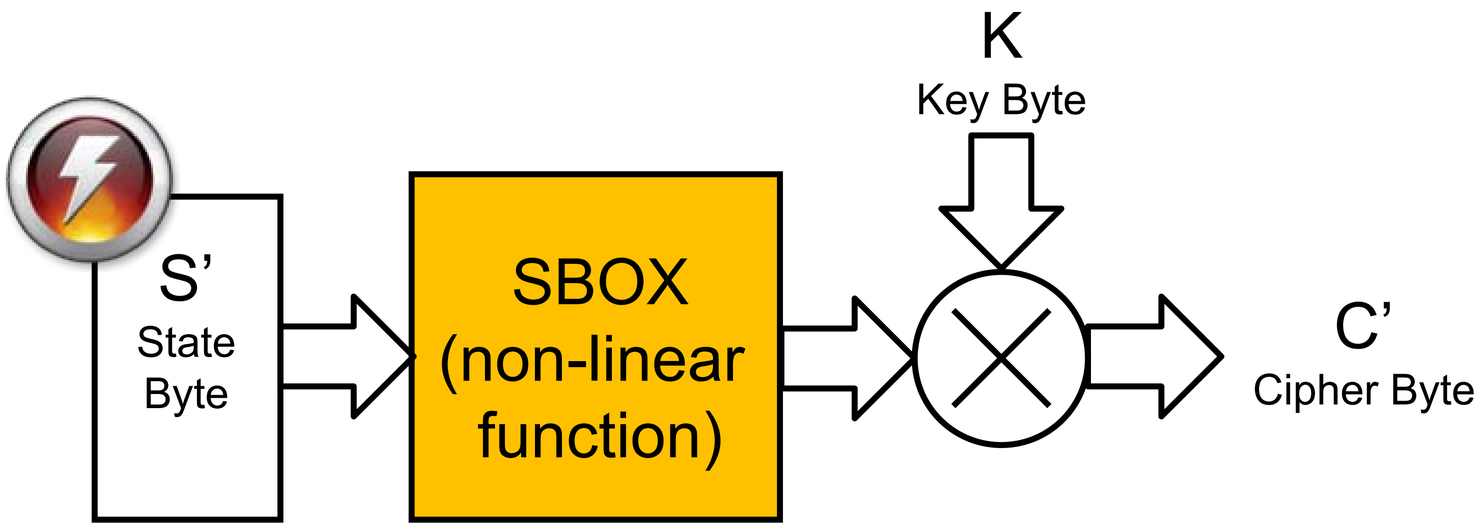
Key uncertainty for **dual** biased fault



Key uncertainty for **triple** biased fault



Hypothesis Test with Biased Faults



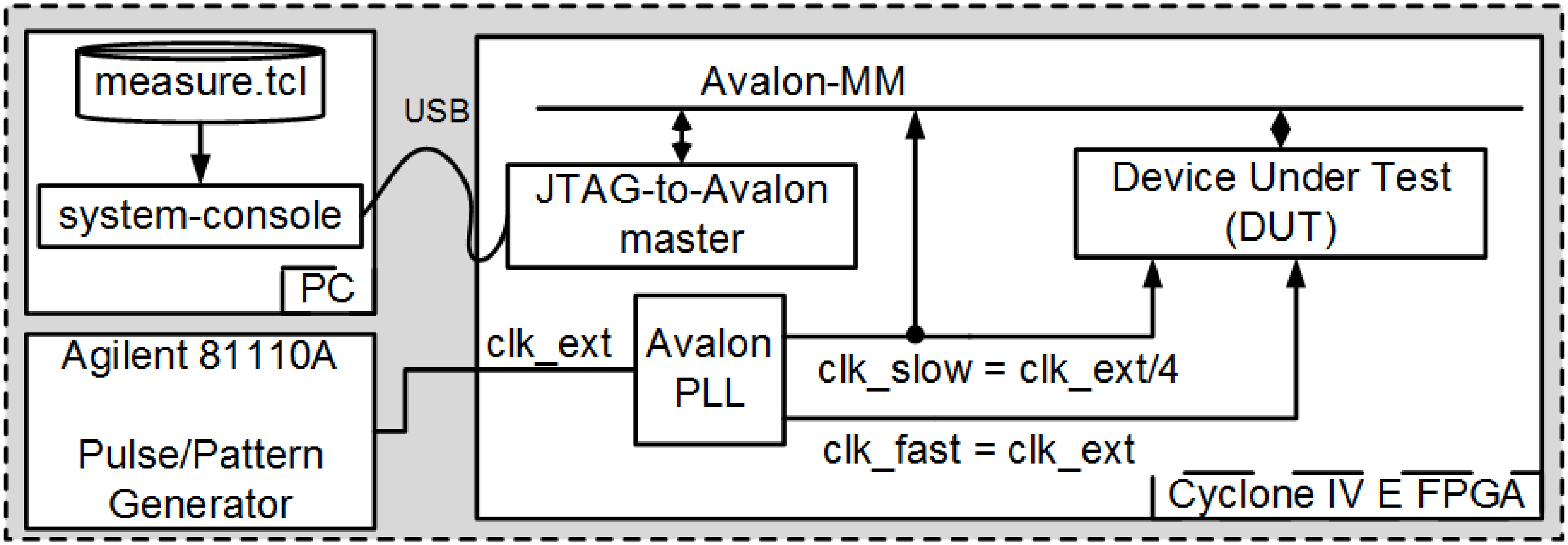
Given: C, C' for a known fault bias B
Find: most likely key byte K

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

Accumulate $\rho_{\tilde{K}} = \Sigma(HD(S', S))$

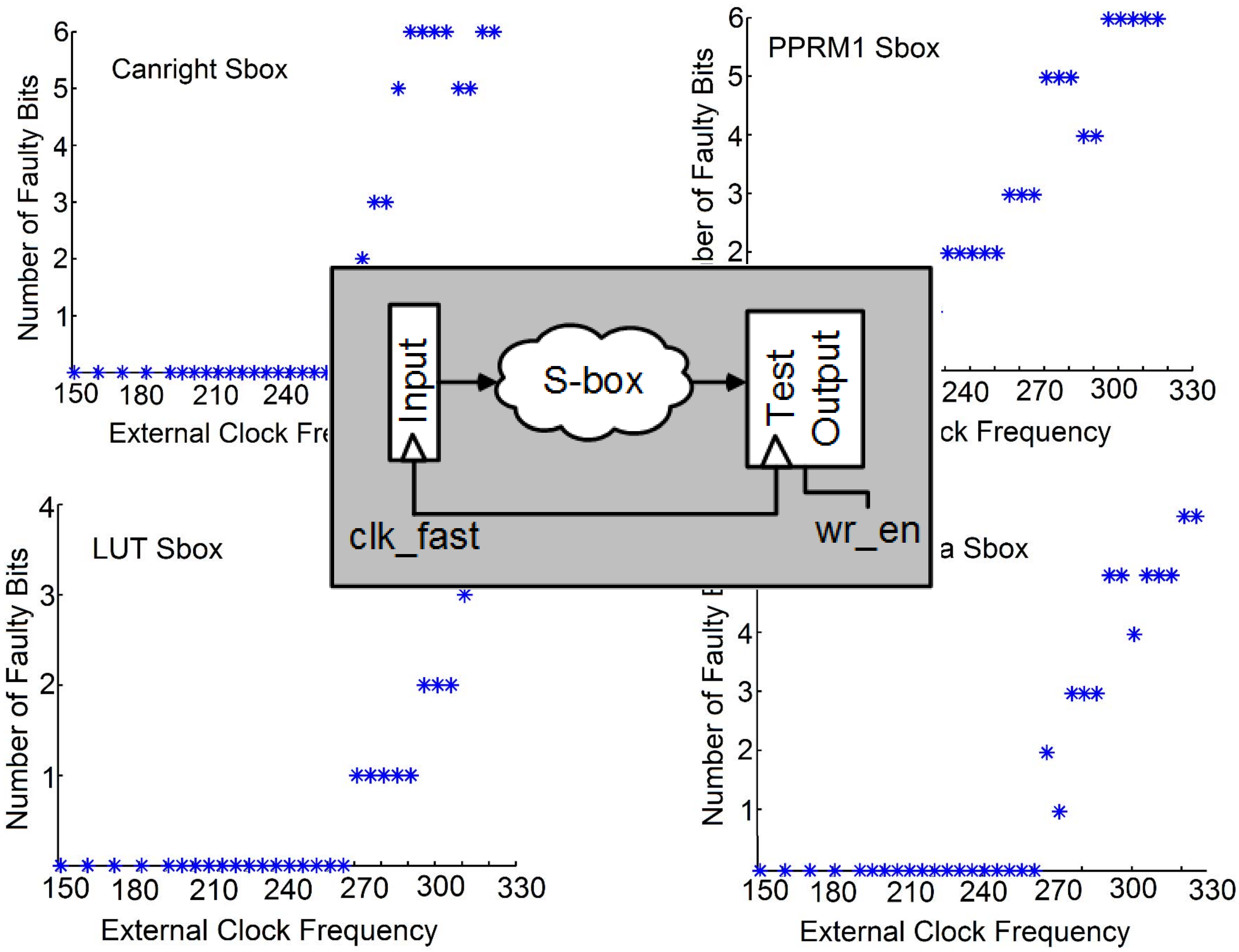
Select K = argmin ρ

Experimental Setup

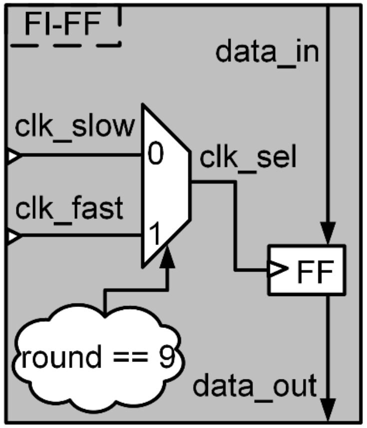


- **FPGA: Altera Cyclone IV (DE2-115)**
- **Agilent 81110A Pulse/Pattern Generator**

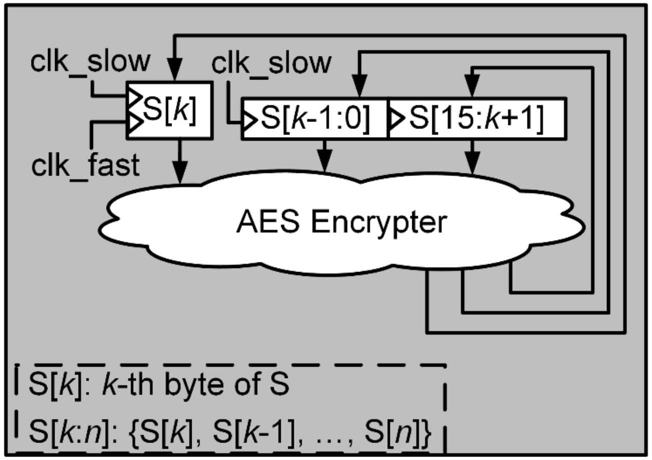
Biased Fault Behavior for Sbox



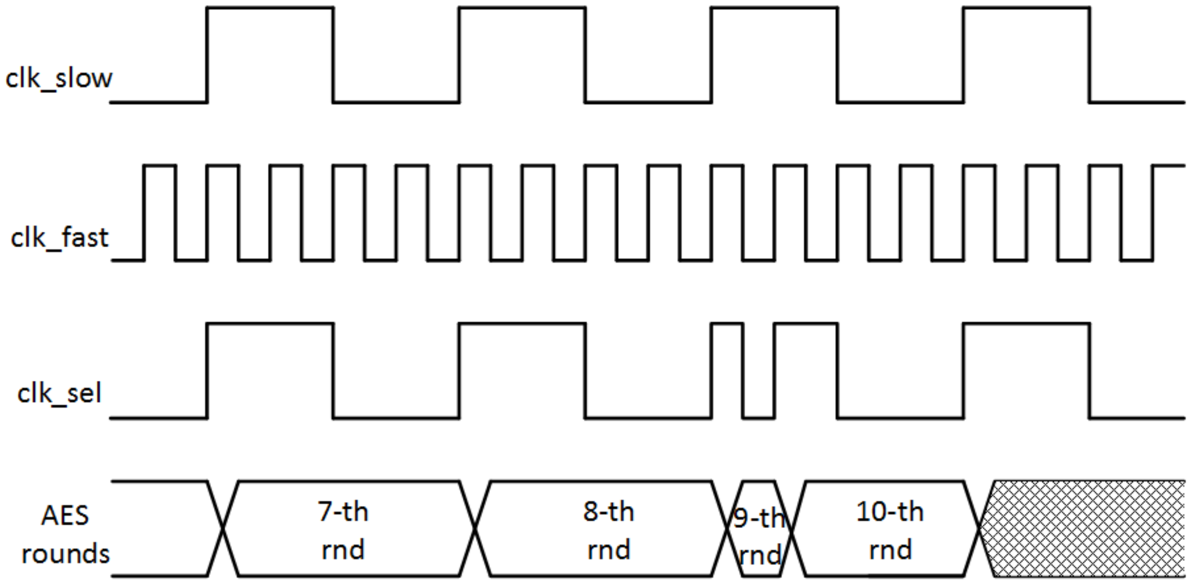
Experimental Setup for AES



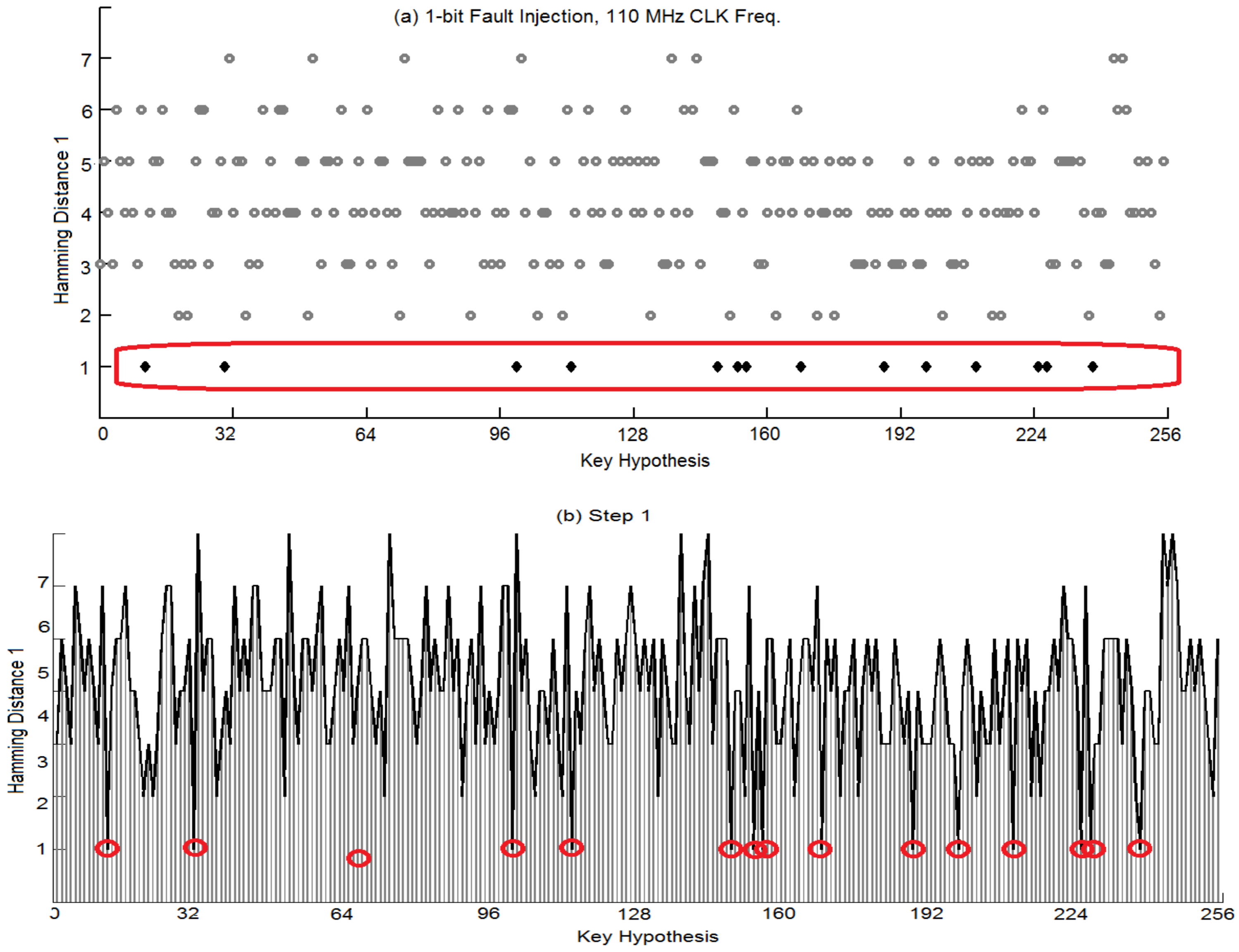
(a)



(b)

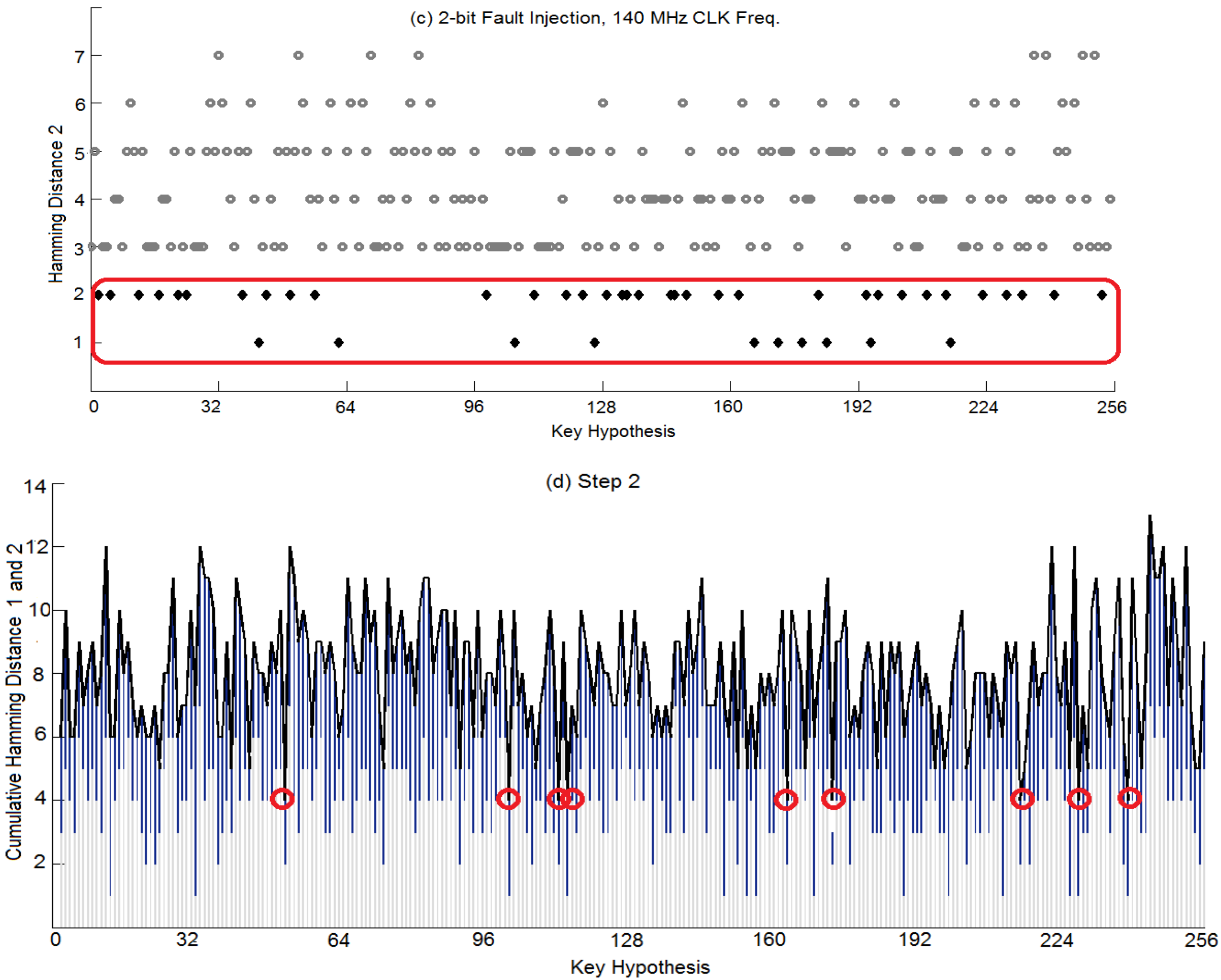


DFIA on AES

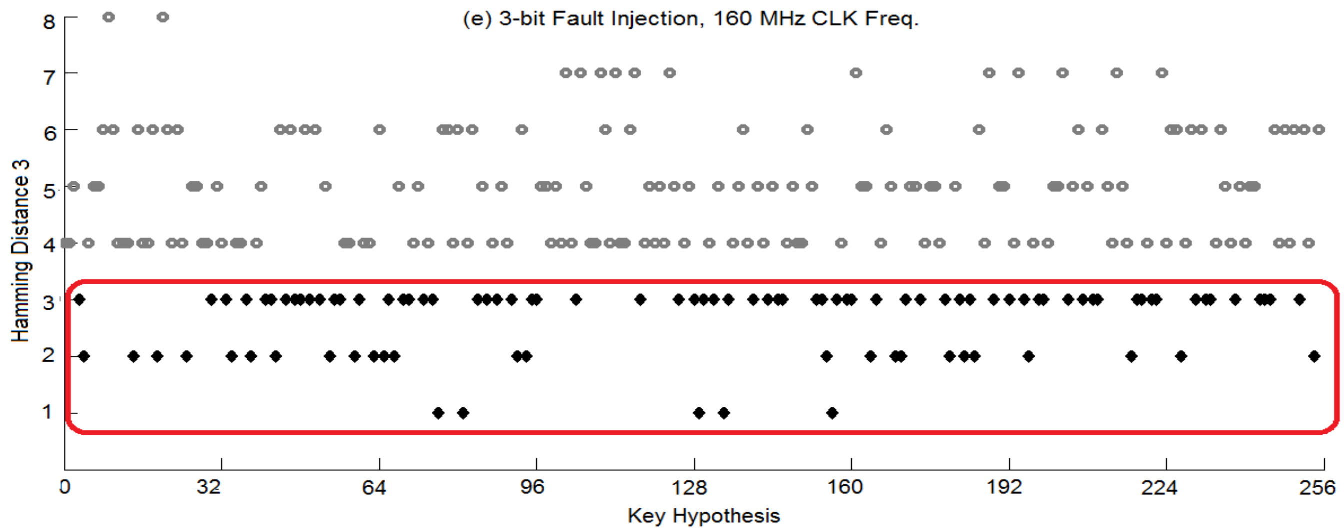


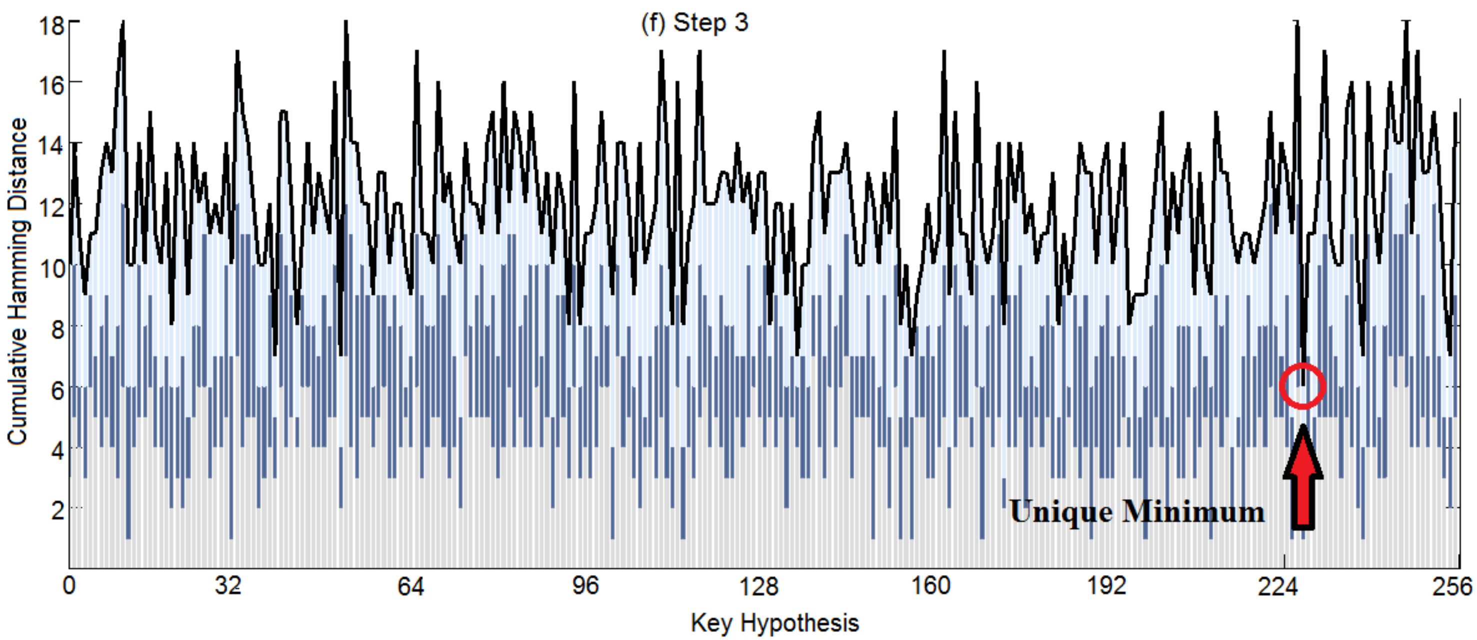
(a) 1-bit Fault Injection, 110 MHz CLK Freq.
Hamming Distance 1
1
2
3
4
5
6
7
0
32
64
96
128
160
192
224
256
Key Hypothesis
(b) Step 1
Hamming Distance 1
1
2
3
4
5
6
7
0
32
64
96
128
160
192
224
256
Key Hypothesis

DFIA Steps on AES



DFIA Steps on AES





DFIA Results on AES

- **AES DFIA when injecting a single-byte fault in round 9**
  - **4.6 fault injections to retrieve 1 key byte (90 exp)**
  - **68 fault injections to retrieve all key bytes (3 exp)**
- **AES DFIA when injecting multiple single-byte faults in round 9**
  - **Fault analysis at 24 clock frequencies between 100MHz and 330 MHz**
  - **7 fault injections to retrieve AES key (1 exp)**

Related Work

- **DFIA is similar to DPA, uses fault bias as a source of side-channel leakage**
- **Unlike FSA [Li], DFIA does not require data dependency on fault sensitivity. It uses fault bias and associated differential effects.**
- **Several recent attacks [Fuhr FDTC 13, deSantis LightSec 14] use bias on the faulty state.**
  - **DFIA does not require bias in the faulty state.**
  - **DFIA is experimentally demonstrated.**

Conclusions

- **DFIA requires slightly more faults than some other round-9 fault attacks**
- **On the other hand, DFIA only uses a loose fault injection requirement, and assumes only the presence of fault bias**

- **Future efforts:**
  - **Apply DFIA to other Algorithms**
  - **Apply DFIA to Software Platforms**
  - **DFIA Countermeasures**