



Injecting Chaos: Fault Attack Setup and Analysis Via ChipWhisperer

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Contents

- 1 Introduction To Fault Attacks
- 2 Setting Up a Fault Injection Lab with ChipWhisperer
- 3 Real-world Replication of the State-of-the-Art
- 4 Flipping Bits to Break BipBip
- 5 Fault Analysis of PQC: Injection Attack on Kyber
- 6 Future Work

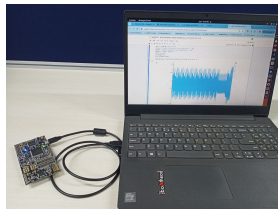
Introduction To Fault Attacks

- **Fault Injection Attacks (FIA)** are hardware-based attacks that introduce faults into a system to alter its behavior.
- Attackers induce transient errors to bypass security checks, alter data or extract sensitive data.
- Common techniques:
 - Voltage Glitching
 - Clock Glitching
 - Electromagnetic (EM) Pulses
 - Laser Fault Injection
- Often used to target cryptographic algorithms (e.g., AES, RSA).

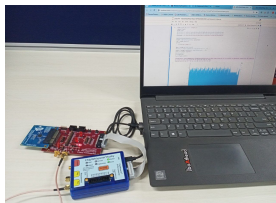
Setting Up a Fault Injection Lab with ChipWhisperer

- **ChipWhisperer** is an open-source toolchain for side-channel and fault injection research.
- Designed for teaching research and evaluating hardware security.
- Includes:
 - CWNano, CWLite or CWHusky hardware for capturing traces.
 - Target board (e.g., XMEGA, STM32, SAM4S).
 - Software suite for glitching, capturing, and analysis.
- Supports fault injection via:
 - Clock Glitching
 - Voltage Faults
 - Electromagnetic Pulse Injection (with add-ons like ChipShouter)

Hardware Setup



CWN Lite with ARM
32-bit Target



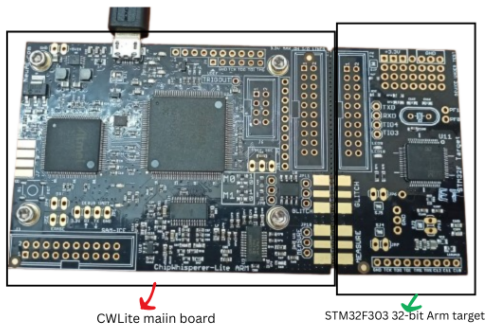
CWHusky with
SAM4S Target



PhyWhisperer setup

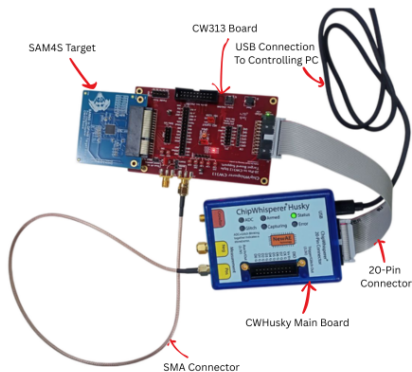
CWLite with ARM 32-bit Target

- 10-bit 105MS/s ADC for capturing power traces
- Clock and voltage fault generation via FPGA-based pulse generation
- Sample Buffer Size: 24,573 samples
- Capable of doing both Voltage glitching and clock glitching

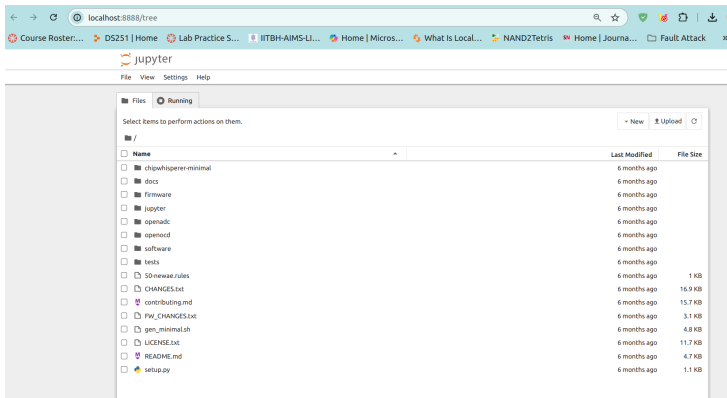


CWhusky with SAM4S Target

- 12-bit 200MS/s ADC for capturing power traces
- Sample Buffer Size: 131124 samples
- Capable of doing both Voltage glitching and clock glitching



Software Environment



Real-world Replication of the State-of-the-Art

Diagonals in the AES

Diagonal 0 [D_0]

a_{00}	a_{01}	a_{02}	a_{03}
a_{10}	a_{11}	a_{12}	a_{13}
a_{20}	a_{21}	a_{22}	a_{23}
a_{30}	a_{31}	a_{32}	a_{33}

Diagonal 1 [D_1]

a_{00}	a_{01}	a_{02}	a_{03}
a_{10}	a_{11}	a_{12}	a_{13}
a_{20}	a_{21}	a_{22}	a_{23}
a_{30}	a_{31}	a_{32}	a_{33}

Diagonal 2 [D_2]

a_{00}	a_{01}	a_{02}	a_{03}
a_{10}	a_{11}	a_{12}	a_{13}
a_{20}	a_{21}	a_{22}	a_{23}
a_{30}	a_{31}	a_{32}	a_{33}

Diagonal 3 [D_3]

a_{00}	a_{01}	a_{02}	a_{03}
a_{10}	a_{11}	a_{12}	a_{13}
a_{20}	a_{21}	a_{22}	a_{23}
a_{30}	a_{31}	a_{32}	a_{33}

Identifying the location from Power Trace

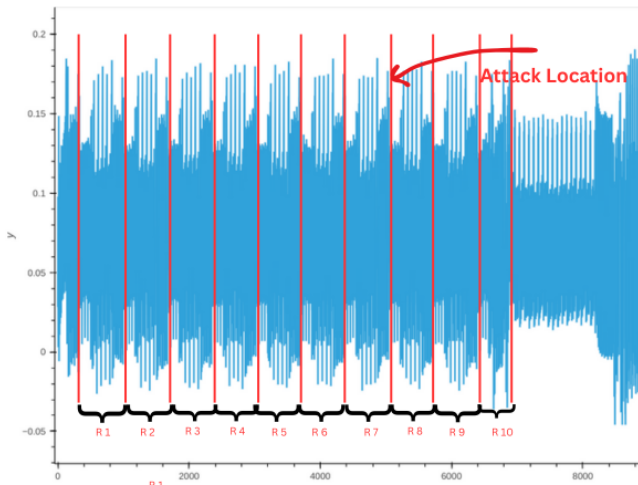


Figure: Power Trace of AES128 on CWLite-ARM

Using Clock Glitching

Target: AES-128 on CWLite-ARM

- 8th round identified at sample range: **5080–5120**
- Clock glitch injected at: **5086 samples**

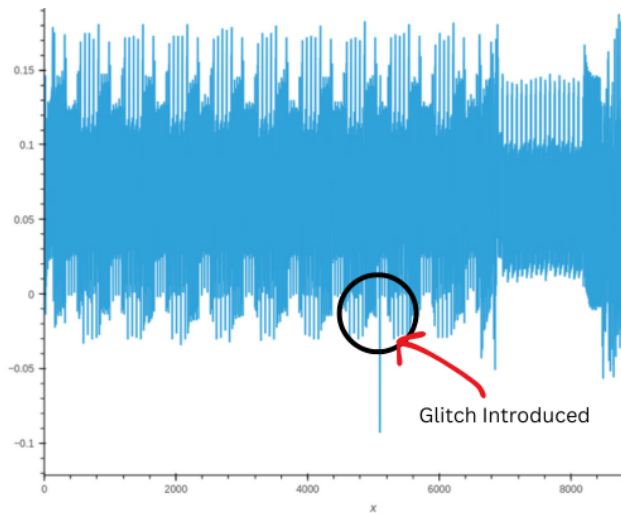
Glitch Configuration:

```
1 scope.glitch.clk_src = "clkgen"  
2 scope.glitch.output = "clock_xor"  
3 scope.glitch.trigger_src = "ext_single"  
4 scope.glitch.repeat = 1  
5 scope.io.hs2 = "glitch"  
6 scope.glitch.offset = 10  
7 scope.glitch.width = 3
```

Result:

- Faulty Ciphertext: 56 9b 6f 66 c9 41 96 f7 9c f1 49 44 29
13 04 e4
- Correct Ciphertext: f5 d3 d5 85 03 b9 69 9d e7 85 89 5a 96
fd ba af

Power Trace after the Glitch



AES Fault Analysis: Rounds 8–10

After Fault Injection at Start of 8th Round

No Fault				With Fault				Diff			
96	e9	e9	3c	96	e9	e9	3c	00	00	00	00
71	87	61	89	71	a3	61	89	00	24	00	00
6a	91	04	13	6a	91	04	13	00	00	00	00
e4	c7	90	ff	e4	c7	90	ff	00	00	00	00

After Round 8 (SubBytes, ShiftRows, MixColumns, AddRoundKey)

0c	b7	3b	ad	2b	b7	3b	ad	27	00	00	00
77	b8	a0	c3	4d	b8	a0	c3	3a	00	00	00
31	0a	19	d8	2c	0a	19	d8	1d	00	00	00
43	b0	70	eb	5e	b0	70	eb	1d	00	00	00

AES Fault Analysis: Rounds 8–10

After Round 9

<i>c2</i>	10	<i>a5</i>	54
<i>df</i>	31	<i>da</i>	<i>c0</i>
67	79	42	5 <i>d</i>
9 <i>b</i>	74	40	<i>fa</i>

<i>dc</i>	52	13	6 <i>e</i>
<i>d0</i>	73	1 <i>b</i>	<i>ec</i>
68	<i>bf</i>	35	4 <i>b</i>
8 <i>a</i>	<i>f0</i>	<i>f6</i>	<i>ec</i>

1 <i>e</i>	42	<i>b6</i>	3 <i>a</i>
0 <i>f</i>	42	<i>c1</i>	2 <i>c</i>
0 <i>f</i>	<i>c6</i>	77	16
11	84	<i>b6</i>	16

After Round 10 (Final Output)

Correct Ciphertext

<i>f5</i>	03	<i>e7</i>	96
<i>d3</i>	<i>b9</i>	85	<i>fd</i>
<i>d5</i>	69	89	<i>ba</i>
85	9 <i>d</i>	5 <i>a</i>	<i>af</i>

Faulty Ciphertext

56	<i>c9</i>	9 <i>c</i>	29
9 <i>b</i>	41	<i>f1</i>	13
6 <i>f</i>	96	49	04
66	<i>f7</i>	44	<i>e4</i>

Difference

<i>a3</i>	<i>ca</i>	7 <i>b</i>	<i>bf</i>
48	<i>f8</i>	74	<i>ee</i>
<i>ba</i>	<i>ff</i>	<i>c0</i>	<i>be</i>
<i>e3</i>	6 <i>a</i>	1 <i>e</i>	4 <i>b</i>

After 8th Round

f_1			
f_2			
f_3			
f_4			

After 9th Round

$2f_1$	f_4	f_3	$3f_2$
f_1	f_4	$3f_3$	$2f_2$
f_1	$3f_4$	$2f_3$	f_2
$3f_1$	$2f_4$	f_3	f_2

After 10th Round Shift Row

$2f_1$	f_4	f_3	$3f_2$
f_4	$3f_3$	$2f_2$	f_1
$2f_3$	f_2	f_1	$3f_4$
f_2	$3f_1$	$2f_4$	f_3

If we represent the 10^{th} round key as K_{10} , it can be expressed as:

k_{00}	k_{01}	k_{02}	k_{03}
k_{10}	k_{11}	k_{12}	k_{13}
k_{20}	k_{21}	k_{22}	k_{23}
k_{30}	k_{31}	k_{32}	k_{33}

Using Voltage Glitching

Target: AES-128 on CWLite-ARM

- 8th round identified at sample range: **5080–5120**
- Clock glitch injected at: **5100 samples**

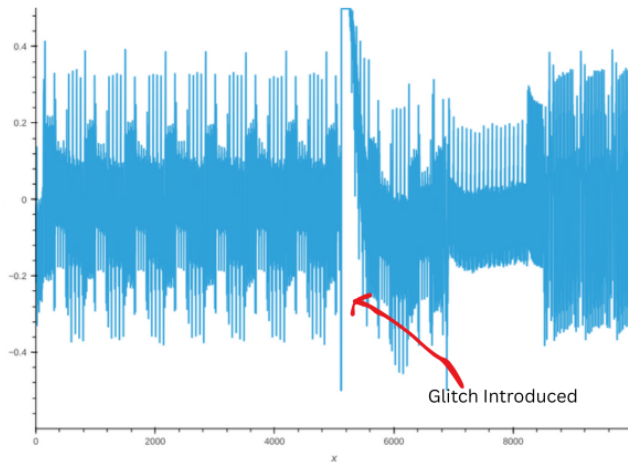
Glitch Configuration:

```
1 scope.glitch.clk_src = "clkgen"
2 scope.glitch.output = "glitch_only"
3 scope.glitch.trigger_src = "ext_single"
4 scope.io.glitch_lp = True
5 scope.io.glitch_hp = True
6 scope.glitch.offset = -37.890625
7 scope.glitch.width = 37.109375
```

Result:

- Faulty Ciphertext: 5d 37 58 b2 4b b2 0b 7c 9e 67 58 55 39
b0 2d ab
- Correct Ciphertext: f5 d3 d5 85 03 b9 69 9d e7 85 89 5a 96
fd ba af

Power Trace after the Glitch



AES Fault Analysis: Rounds 8–10

After Fault Injection at Start of 8th Round

Without Fault	With Fault	Difference
96 e9 e9 3c	96 e9 e9 52	00 00 00 6e
71 87 61 89	52 87 61 89	23 00 00 00
6a 91 04 13	6a 91 04 13	00 00 00 00
e4 c7 90 ff	e4 c7 90 ff	00 00 00 00

After Completion of 8th RoundSubByte,ShiftRow,MixColumn,AddRoundkey(8)

Without Fault	With Fault	Difference
0c b7 3b ad	0c b7 3b 9e	00 00 00 33
77 b8 a0 c3	77 b8 a0 75	00 00 00 b6
31 0a 19 d8	31 0a 19 90	00 00 00 48
43 b0 70 eb	43 b0 70 6e	00 00 00 85

AES Fault Analysis: Rounds 8–10

After The Completion of 9th

Round(SubByte,ShiftRow,MixColumn,AddRoundkey(9))

Without Fault

c2	10	a5	54
df	31	da	c0
67	79	42	5d
9b	74	40	fa

With Fault

b4	11	6b	73
a9	32	a7	5e
fd	7b	f1	c3
77	75	f3	43

Difference

76	01	ce	27
76	03	7d	9e
9a	02	b3	9e
ec	01	b3	b9

After The Completion of 10th Round(SubByte,ShiftRow,AddRoundkey(10)) :

Without Fault

f5	03	e7	96
d3	b9	85	fd
d5	69	89	ba
85	9d	5a	af

With Fault

5d	4b	9e	39
37	b2	67	b0
58	0b	58	2d
b2	7c	55	ab

Difference

a8	48	79	af
e4	0b	e2	4d
8d	62	d1	97
37	e1	0f	04

After 8th Round

		f_1
		f_2
		f_3
		f_4

After 9th Round

f_4	f_3	$3f_2$	$2f_1$
f_4	$3f_3$	$2f_2$	f_1
$3f_4$	$2f_3$	f_2	f_1
$2f_4$	f_3	f_2	$3f_1$

After 10th Round Shift Row

f_4	f_3	$3f_2$	$2f_1$
$3f_3$	$2f_2$	f_1	f_4
f_2	f_1	$3f_4$	$2f_3$
$3f_1$	$2f_4$	f_3	f_2

If we represent the 10^{th} round key as K_{10} , it can be expressed as:

k_{00}	k_{01}	k_{02}	k_{03}
k_{10}	k_{11}	k_{12}	k_{13}
k_{20}	k_{21}	k_{22}	k_{23}
k_{30}	k_{31}	k_{32}	k_{33}

Flipping Bits to Break BipBip

Key Points about BipBip Cipher

- **Tweakable block cipher** tailored for fast decryption in ASICs.
- Uses an unconventional **24-bit block size**, a **256-bit master key**, and a **40-bit tweak**.
- Optimized for latency-sensitive applications (e.g., embedded systems, IoT).
- **Decryption-oriented design** — emphasizes ciphertext-to-plaintext transformation.
- **Decryption Structure Overview:**

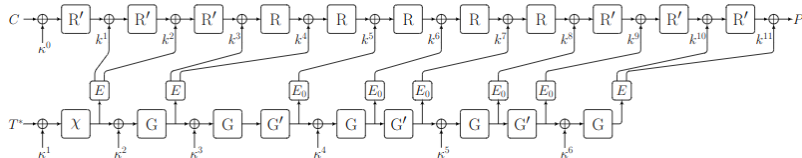


Figure: High Level Decryption Structure of BipBip

Dilip et al. 's Attack Model



Figure: Proposed fault injection attack

- A single bit fault at the start of 9th round s-box operation is required.
- Need such 4 Faulty values where single bit is flipped in the input of 9th round s-box.

Power Trace of BipBip on CWLite-ARM

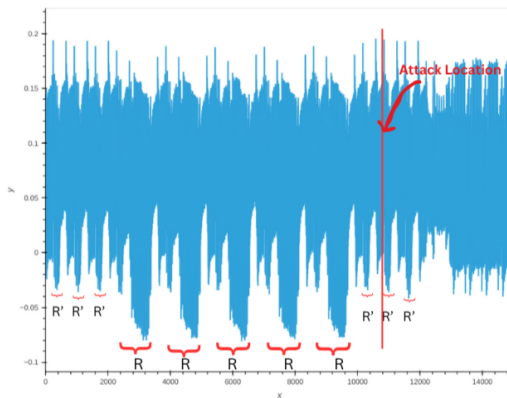


Figure: Power trace BipBip on CWLite-ARM

Glitch Attack Settings on BipBip Implementation

- **Initial Step:** Integrated `sempleserial` for communication between target and scope.
- **Attack Window:** Identified using BipBip power trace on CWLite — approx. between samples 10820 to 10890.
- **CWLite Settings:**
 - `scope.glitch.clk_src = "clkgen"`
 - `scope.glitch.output = "clock_xor"`
 - `scope.glitch.trigger_src = "ext_single"`
 - `scope.glitch.repeat = 1`
 - `scope.io.hs2 = "glitch"`
- **CWHusky Settings:**
 - `scope.glitch.clk_src = "pll"`
- Attack location on CWHusky determined from BipBip's power trace on that platform.

Analysis of the attack

Table: Summary of Clock Glitch Fault Injection Parameters and Results

Location	Width	Offset	Plaintext	Faulty vs Correct state (Input of Round 9)
10841	1.17	1.17	052aa7	Faulty: 0 1 100 100111 111101 101111 Correct: 0 0 100 100111 111101 101111
10842	1.95	1.17	6462d1	Faulty: 00 0 100 100111 111101 101111 Correct: 00 1 100 100111 111101 101111
10855	1.9	1.7	6f2a99	Faulty: 001 0 00 100111 111101 101111 Correct: 001 1 00 100111 111101 101111
10866	1.17	1.17	3c12bc	Faulty: 00110 1 100111 111101 101111 Correct: 00110 0 100111 111101 101111
10878	1.17	1.17	105bfc	Faulty: 001100 1001 0 1 111101 101111 Correct: 001100 1001 1 1 111101 101111
10887	1.9	1.17	1c52e4	Faulty: 001100 10 1 11 111101 101111 Correct: 001100 10 0 11 111101 101111

Fault Analysis of PQC: Injection Attack on Kyber

NIST PQC Standardization Overview

- **Goal:** Identify quantum-resistant public-key cryptographic algorithms for standardization.
- **Initiated:** December 2016 by NIST in response to the threat posed by quantum computers.
- **Process:**
 - Round 1: 69 submissions (Dec 2017)
 - Round 2: 26 candidates (Jan 2019)
 - Round 3: 7 finalists + 8 alternates (July 2020)
 - **Final Selections (July 2022):**
 - **KEM:** Kyber (CRYSTALS-Kyber)
 - **Signatures:** Dilithium, Falcon, SPHINCS+
- **Importance:** Ensures secure communication in a post-quantum world, replacing RSA and ECC.

Detailed Comparison of Kyber Variants

Variant	Security Level (bits)	Public Key (bytes)	Private Key (bytes)	Ciphertext (bytes)
Kyber512	128	800	1,632	768
Kyber768	192	1,184	2,400	1,088
Kyber1024	256	1,568	3,168	1,568

Future Work

Future work includes performing fault injection attacks on other PQC algorithms such as Kyber and Dilithium. Additionally, similar attacks can be extended to other cryptographic ciphers to evaluate their resistance to implementation-level faults.

THANK YOU