Electromagnetic Fault Injection: How Faults Occur
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To cite this version:

HAL Id: lirmm-02328109
https://hal-lirmm.ccsd.cnrs.fr/lirmm-02328109
Submitted on 31 Mar 2022

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Fault Diagnosis and Tolerance in Cryptography 2019

Electromagnetic Fault Injection: how faults occur?

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Introduction

• Context:

• Objectives:
  - Modelling: impact of an EMFI on IC supply voltage
  - SPICE simulation: impact of an EMFI on IC operation
  - Experimental validation
- Modelling: Impact of an EMFI on IC supply voltage
- Spic Simulation: impact of EMFI on IC operation
- Experimental Validation
EMFI induces parasitic currents mostly in the power and ground networks.

- EM Induction: hypothesis?

- Metal wires from the power/ground networks form many loops!

- Interconnect logic wires don’t form loops.

Modelling: Impact of an EMFI on IC

- EM induction induces currents variation on closed loops.

Probe IC

EMFI induces parasitic currents mostly in the power and ground networks.
Modelling: Impact of an EMFI on IC

- Impact of EMFI on supply voltage.

\[ m_{gnd} = k_{gnd} \sqrt{L_{probe} \times L_{gnd}} \]
\[ m_{vdd} = k_{vdd} \sqrt{L_{probe} \times L_{vdd}} \]
Modelling: Impact of an EMFI on IC

- Impact of EMFI on supply voltage.

\[ m_{\text{vdd}} = m_{\text{gnd}} \]

\[ \text{Swing} = \text{Vdd} - \text{Gnd} \]

\[ m_{\text{vdd}} \neq m_{\text{gnd}} \]

Swing is negative for few ns!
Modelling: Impact of an EMFI on IC supply voltage

Spice Simulation: impact of EMFI on IC operation

Experimental Validation
Modelling: Impact of an EMFI on IC

- Testbench Simulation

\[ Swing = V_{dd} - Gnd \]

\[ Swing_{width} \]

\[ \text{Time (s)} \]

\[ \text{Swing (V)} \]

\[ \text{CLK-REF (V)} \]

\[ \text{CP (V)} \]

\[ \text{IN-REF (V)} \]

\[ \text{Q (V)} \]

\[ \text{CLKQ} \]

\[ \text{20,0ns - 40,0ns} \]
Modelling: Impact of an EMFI on IC

• Logic simulation: Swing amplitude impact on IC operation

Fault criterion $F$:

$$F = \frac{(CK2Q)_{ref}}{(CK2Q)_{inj}}$$

- $F = 1$ Normal Operation
- $0 < F < 1$ Delay
- $F = 0$ Sampling Fault

![Graph showing Normal Operation and Possible Timing Fault with various swing values](image-url)
Modelling: Impact of an EMFI on IC

- Sampling Fault explanation

Normal Operation

NO FAULT

Q = ‘1’
Modelling: Impact of an EMFI on IC

- Sampling Fault explanation

\[ Q = '0' \]
Modelling: Impact of an EMFI on IC

- Sampling Fault explanation

Q = ‘0’
- Modelling: Impact of an EMFI on IC supply voltage
- Spice Simulation: Impact of EMFI on IC operation
- Experimental Validation
EMFI experimental validation

- **Effect of $F_{CLK}$ variations**
  - Target: AES 128bits.
  - EM pulse sweeps, for few periods, with a pulse delay step of 100ps.
  - 50 EMFI shots are performed at each sweep to determine fault probability $P_f$ ($0 < P_f < 1$).
  - As expected Sampling Fault Windows appear with a period equal to that of the IC.
  - Their width are independent of the frequency.
EMFI experimental validation

**Effect of $V_{\text{pulse}}$ variations**

- Determine the evolution of the Sampling Fault Window width in function of $V_{\text{pulse}}$ variations.
- The width of Sampling Fault Windows increases with $V_{\text{pulse}}$. 

![Graph showing the effect of $V_{\text{pulse}}$ variations on Sampling Fault Window width](chart1.png)

![Graph comparing Simulation and Experimental results](chart2.png)
EMFI experimental validation

- **Effect of PW variations**
  - Determine the evolution of the Sampling Fault Window width in function of PW variations.
  - The Pulse Width does not affect much the sampling fault window.
Conclusion

• Conclusion
  ➢ Modelling simulations show that EMFI induces a voltage **bounces or drops** on power networks Vdd and GND. That could induce a **Swing drop**.
  ➢ Sampling Fault occurs when **EM Field** is applied during IC operation around rising CLK edge. In **simulation** and **experimentally**.

• Perspective
  ➢ More accurate **coupling model**.
  ➢ Experimental validation and parallel on **one register** only.
Thank you

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Modelling: Impact of an EMFI on IC

- Logic simulation: Swing amplitude impact on IC operation

Fault criterion $F$:

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![Diagram showing the impact of swing amplitude on fault criteria](image)
Modelling: Impact of an EMFI on IC

- Sampling Fault explanation
Modelling : Impact of an EMFI on IC

- Sampling Fault explanation

**CLK = 0**

V1 is disrupted during the D recovery.

- V1 depends on D when CLK = 0

**CLK = 1**

If CLK edge occurs during V1 alteration: wrong value is sampled and stored in Master loop.

Master

Slave

V1 is disrupted during the D recovery.

- V1 depends on D when CLK = 0

V1 is disrupted during the D recovery.

- V1 depends on D when CLK = 0