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Flottes

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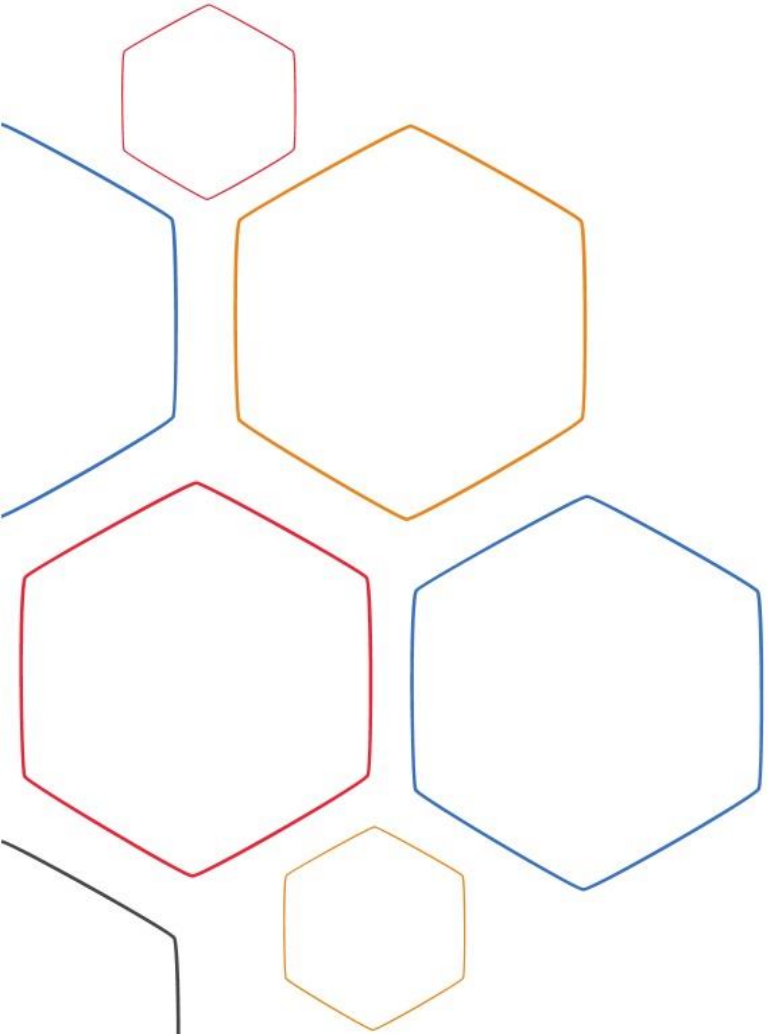
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Logic-Locking schemes and side channel attacks resilience

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Thesis Supervisors : Florent Bruguier, Marie-Lise Flottes, Sophie Dupuis



LIRMM



19/06/2023



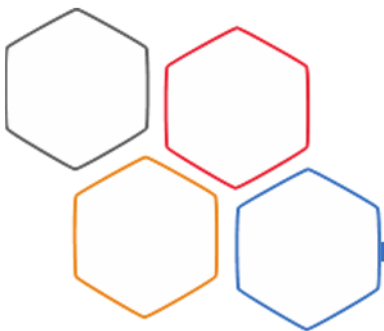
UNIVERSITÉ DE MONTPELLIER



→ Logic Locking

→ SCA on Logic Locking

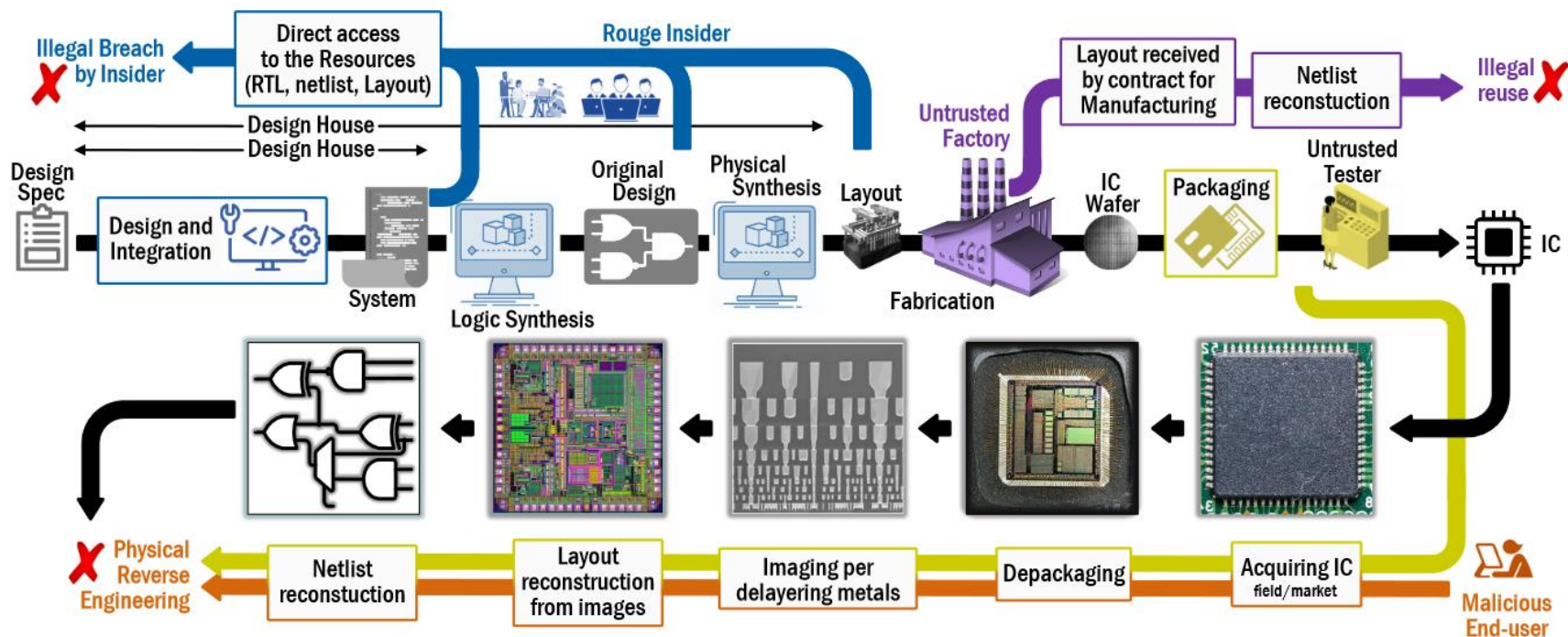
→ Perspectives



- Globalization of the IC production flow

- Threats

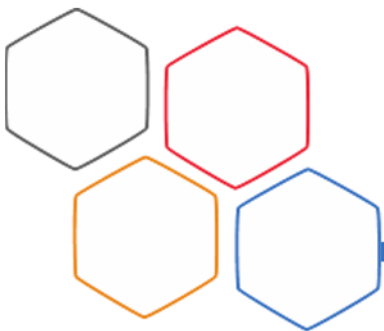
- IP piracy
- Counterfeiting
- Overproduction
- Reverse engineering
- Hardware Trojans



Threat models at different stages of IC production flow [1]

=> Development of solutions for the IP protection

[1] H. M. Kamali, K. Z. Azar, F. Farahmandi, et M. Tehranipoor, « Advances in Logic Locking: Past, Present, and Prospects », p. 39.



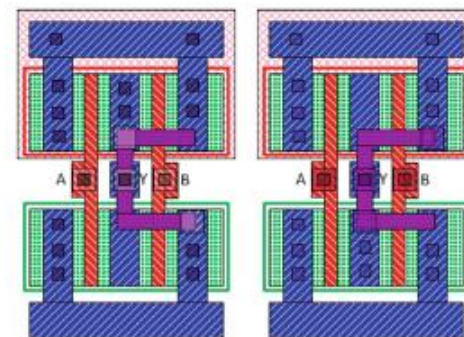
Logic Locking

DFTTr Solutions

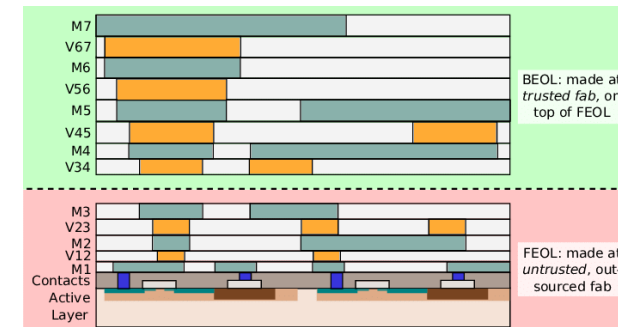
DFTTr (Design For Trust) e.g

- Camouflaging [2]
- Split-manufacturing
- **Logic Locking**

Threat level	Camouflaging	Split manufacturing	Logic Locking
Design team	No	No	Yes
Untrusted Foundry	No	Yes	Yes
End-user	Yes	No	Yes

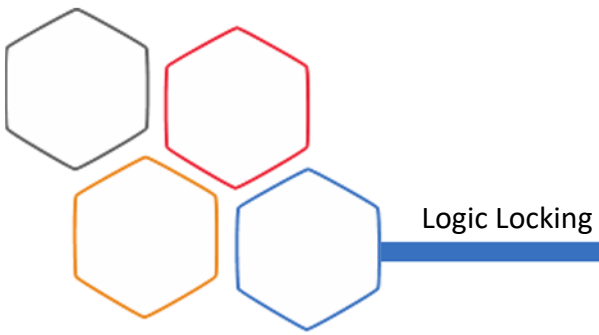


Camouflaging (NAND, NOR) [2]



Split-manufacturing

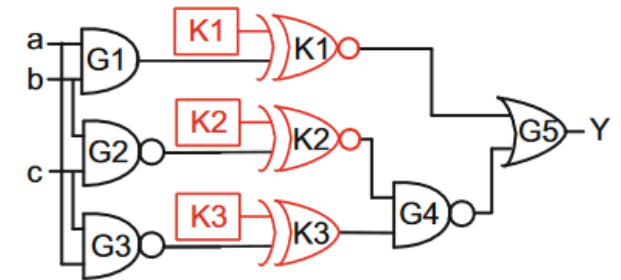
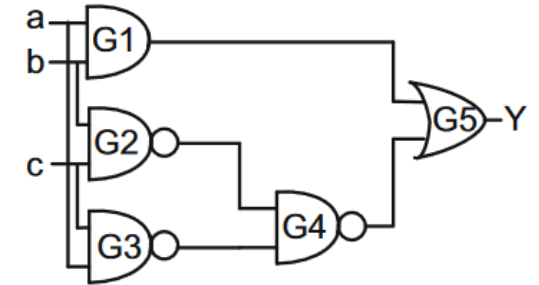
[2] M. Yasin, J. Rajendran, et O. Sinanoglu, Trustworthy Hardware Design: Combinational Logic Locking Techniques. Cham: Springer International Publishing, 2020. doi: [10.1007/978-3-030-15334-2](https://doi.org/10.1007/978-3-030-15334-2).



Logic Locking

The Logic Locking is a DFT technique which consists in locking the correct behaviour of the circuit with a secret key. $L(i, ks) = F(i), \forall i \in I$

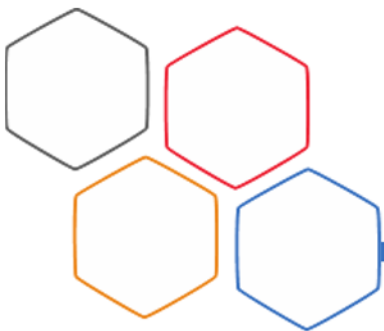
- F : Boolean function
- L : Locked boolean function
- Ks: Secret key



Evaluation Metrics :

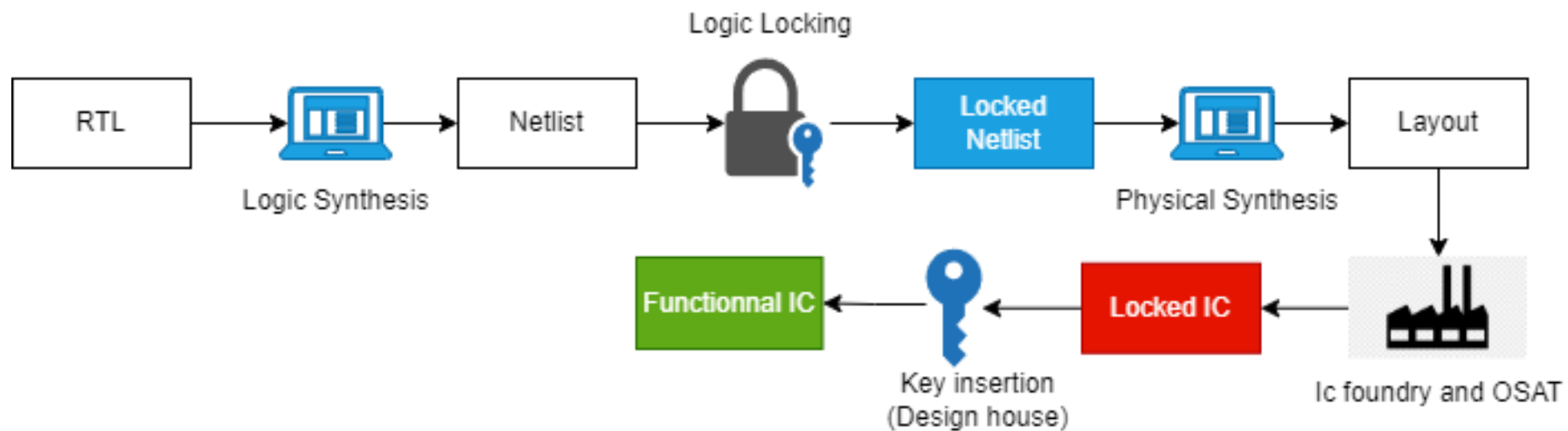
- Output Corruptibility :

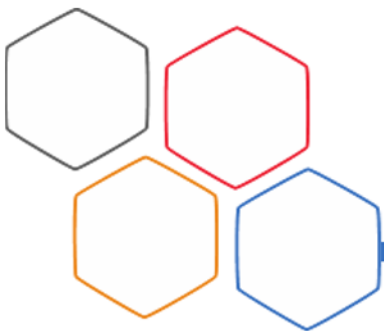
$$OC = \frac{1}{P \times Q \times M} \sum_{i=1}^P \sum_{j=1}^Q HD(O_F(I_i), O_L(I_i, K_j)) \times 100\%$$



Logic Locking

Design flow with Logic Locking





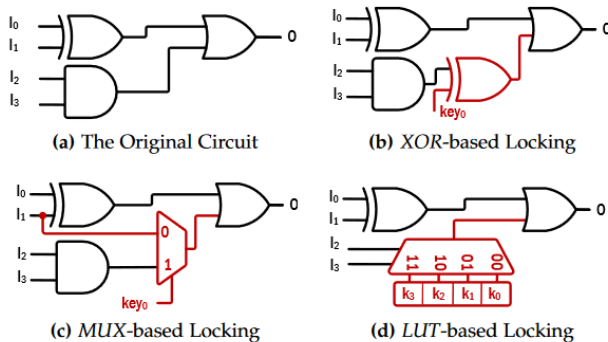
First Logic Locking Techniques (2008-2015)

- Insertion algorithms

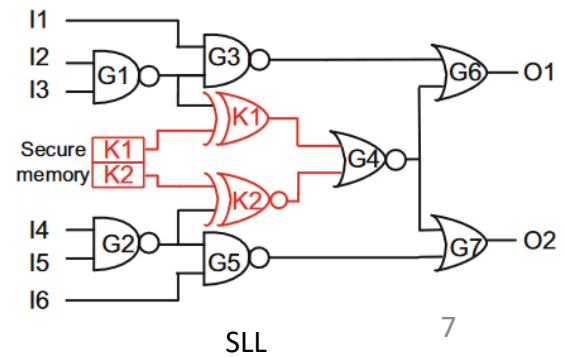
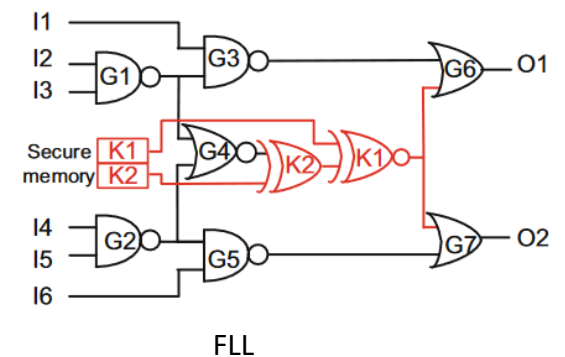
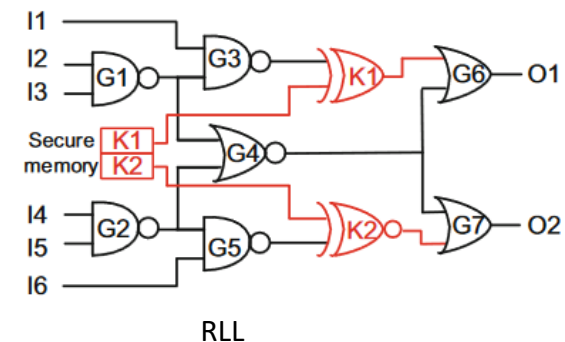
- RLL (Random Logic Locking) introduced by EPIC
- FLL (Fault Logic Locking) to maximize output corruption
- SLL (Strong Logic Locking) a response to the first LL attack

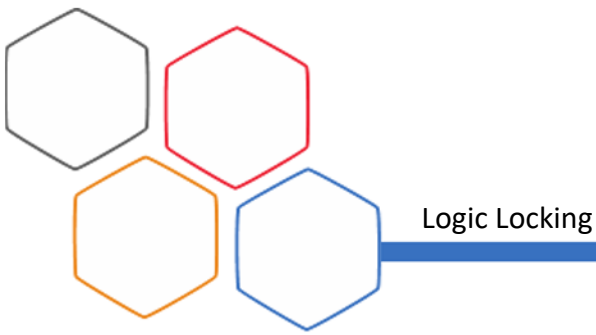
- Key « Gates »

- XOR/XNOR
- MUX's
- LUT's



Different entities insertion

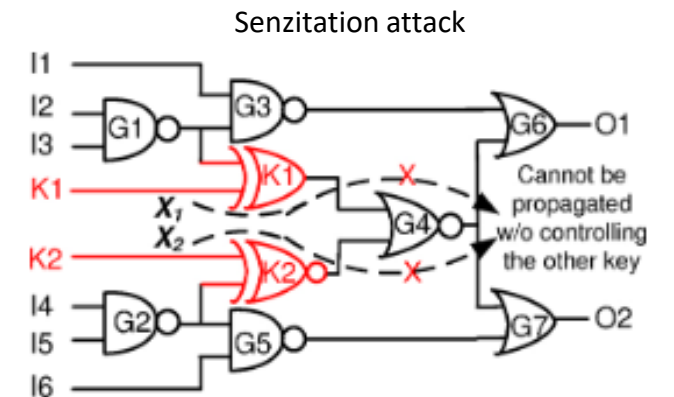
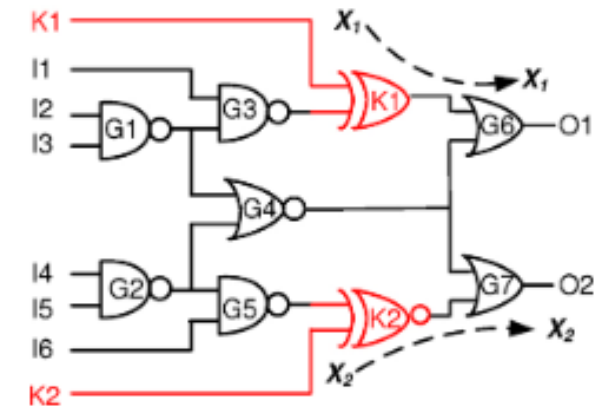




Attack and Threat Model

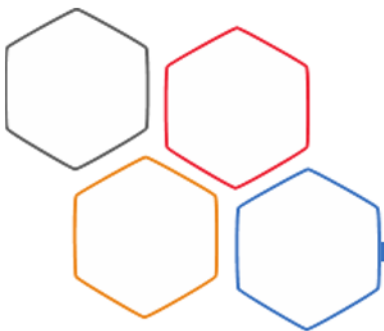
Attack on LL scheme → Retrieve the locking key

- The threat model
 - Functional IC and Locked netlist → Oracle Guided Attacks
- The first attack (Oracle Guided attack)
 - Sensitization attack [3]: Observe key bits on primary outputs
- The first counter-measure
 - Strong Logic Locking

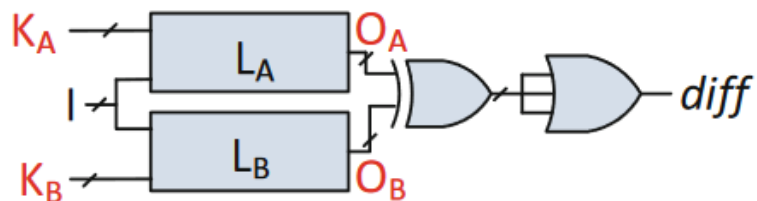


SLL

[3] J. Rajendran, Y. Pino, O. Sinanoglu and R. Karri, "Security analysis of logic obfuscation," *DAC Design Automation Conference 2012*, San Francisco, CA, USA, 2012, pp. 83-89, doi: 10.1145/2228360.2228377

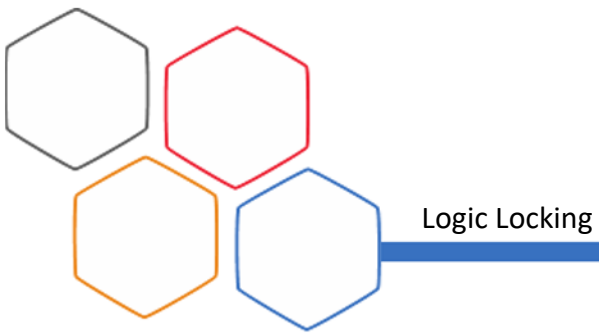


- Subramanyan et al [5]
- The attack flow (iterative process)
 - Construct Mitter circuit
 - Find Distinguishing Input Patterns
 - Refine key resarch Space



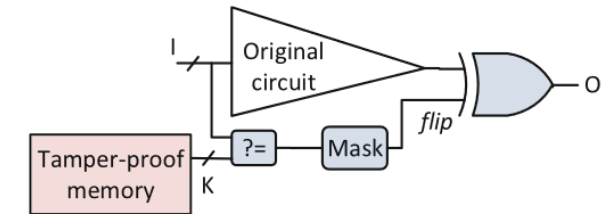
abc	Y	k0	k1	k2	k3	k4	k5	k6	k7	Incorrect keys identified
000	0	1	1	1	1	0	0	0	1	
001	0	0	1	1	1	0	1	0	1	
010	0	1	1	1	1	1	1	0	1	Iter 3 : other keys
011	1	1	1	1	1	0	1	1	1	
100	0	1	1	1	1	1	1	0	1	
101	1	1	1	1	1	1	1	1	0	
110	1	1	1	0	1	1	1	1	1	Iter 1 : k2
111	1	1	0	1	1	1	1	1	1	Iter 2 : k1

[5] P. Subramanyan, S. Ray and S. Malik, "Evaluating the security of logic encryption algorithms," 2015 IEEE International Symposium on Hardware Oriented Security and Trust (HOST), Washington, DC, USA, 2015, pp. 137-143, doi: 10.1109/HST.2015.7140252.



The New LL Era

The point function LL (e.g. SAR-Lock)

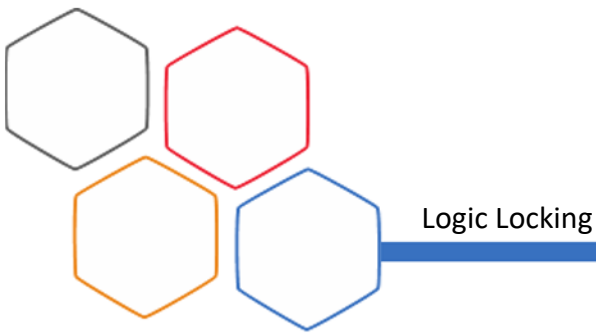


- Weak output corruption →

- Strong SAT resilience 😊
- Black box usage 😞
- Removal attack : Remove protection structure 😞

I	O	k0	k1	k2	k3	k4	k5	k6	k7
000	0	1	0	0	0	0	0	0	0
001	0	0	1	0	0	0	0	0	0
010	0	0	0	1	0	0	0	0	0
011	1	1	1	1	0	1	1	1	1
100	0	0	0	0	0	1	0	0	0
101	1	1	1	1	1	1	0	1	1
110	1	1	1	1	1	1	1	1	1
111	1	1	1	1	1	1	1	1	0

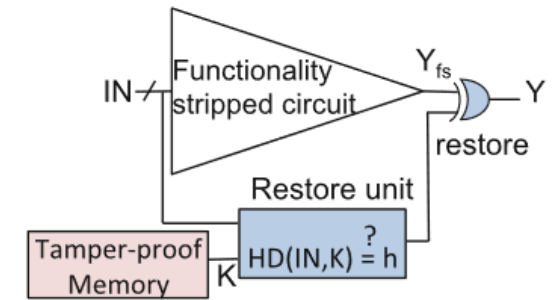
SAR-LOCK (K=110)



The New LL Era

The Corrupt And Correct (CAC) LL (e.g. SFLL-hd)

- Functionality Stripped Circuit
- Introduction of h parameter
 - More output corruption 😊
 - Less but still strong SAT-resilience 😊
 - Good compromise between SAT and black-box resilience 😊
 - Removal attack can not be applicable 😊
- Emergence of new types of attacks 😞
 - ML-based attacks
 - Scheme specified attacks



IN	Yfs	k0	k1	k2	k3	k4	k5	k6	k7	Y
000	0	0	1	1	0	1	0	0	0	0
001	0	1	0	0	1	0	1	0	0	0
010	1	0	1	1	0	1	1	0	1	0
011	1	1	0	0	1	1	1	1	0	1
100	1	0	1	1	1	1	0	0	1	0
101	1	1	0	1	1	0	1	1	0	1
110	1	1	1	0	1	0	1	1	0	1
111	0	0	0	0	1	0	1	1	0	1

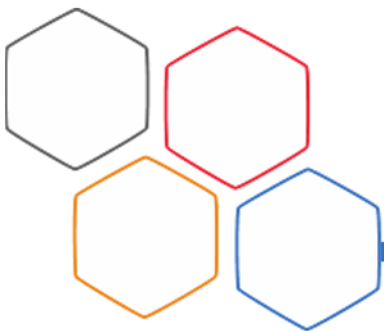
SFLL-HD (K=110, h=1)



→ Logic Locking

→ **SCA on Logic Locking**

→ Perspectives



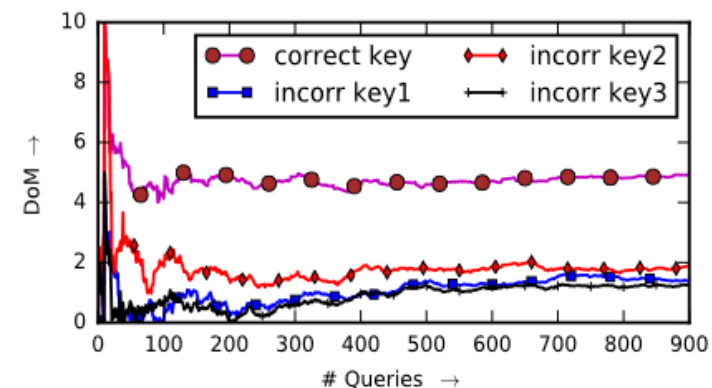
SCA on Logic Locking

What about Side Channel Attacks on pre-SAT LL schemes?

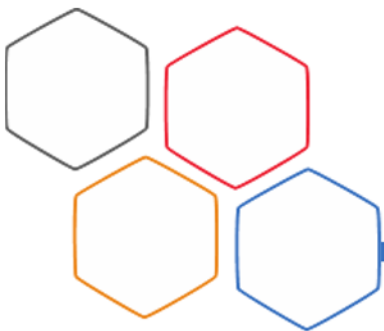
DPA attacks were realised against (RLL, FLL, and SLL) by [6] :

- Threat Model
 - Functionnal IC
 - Locked Netlist
- Iterative attack framework
 - Division of the netlist into logic cones
 - The decision function infered according to the PO's
 - The DoM on every subkey
- Simulated attack results
 - 60% of key-bits was resolved for circuits locked with 32 bits
 - 45% for circuits locked with 64 bits
 - Key aliasing induces ghost keys (High DoM for wrong keys)
 - Simulated power traces
 - Limitation on processing time

Name of cone	# key bits	List of key bits	Resolved?	# of key bits resolved
PO0	1	0	N	0
PO1	1	1	N	0
PO2	6	2,3,4,5,8,9	N	0
PO3	7	10,11,12,16,17,18,19	Y	7
PO5	8	6,7,13,14,15,29,30,31	Y	15
PO4	9	20,21,22,23,24,25,26,27,28	Y	24



[6] A. Sengupta, B. Mazumdar, M. Yasin, et O. Sinanoglu, « Logic Locking With Provable Security Against Power Analysis Attacks », *IEEE Trans. Comput.-Aided Des. Integr. Circuits Syst.*, vol. 39, n° 4, p. 766-778, avr. 2020, doi: [10.1109/TCAD.2019.2897699](https://doi.org/10.1109/TCAD.2019.2897699).



Power analysis attacks on SFLL-HD by [6]

- Threat Model

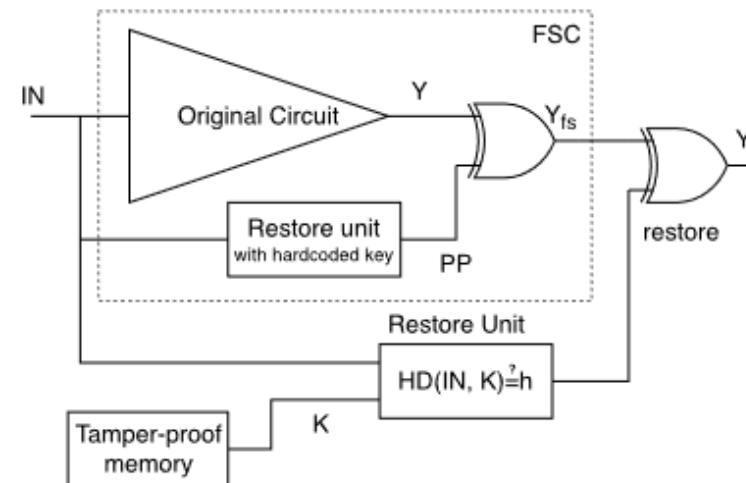
- Functionnal IC
- Locked Netlist

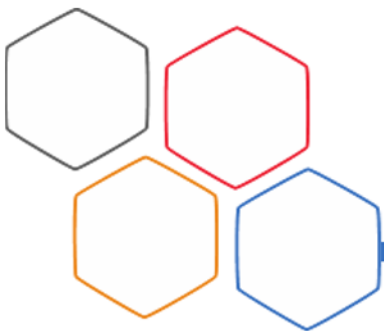
- Attack framework

- The decision function is the primary output bit of the circuit (Y)
- The DoM is calculated

- Attack results : DPA failed

- The PO Y is controlled from all key bits → brute force attack
- The corruption on Y for a few patterns → not significant to distinguish DoM values



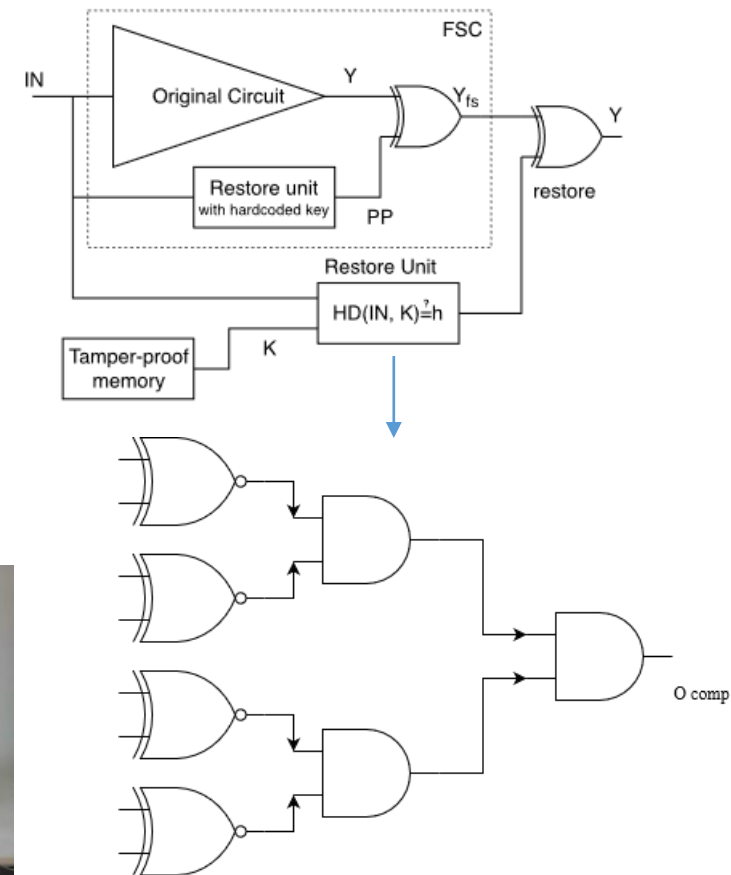
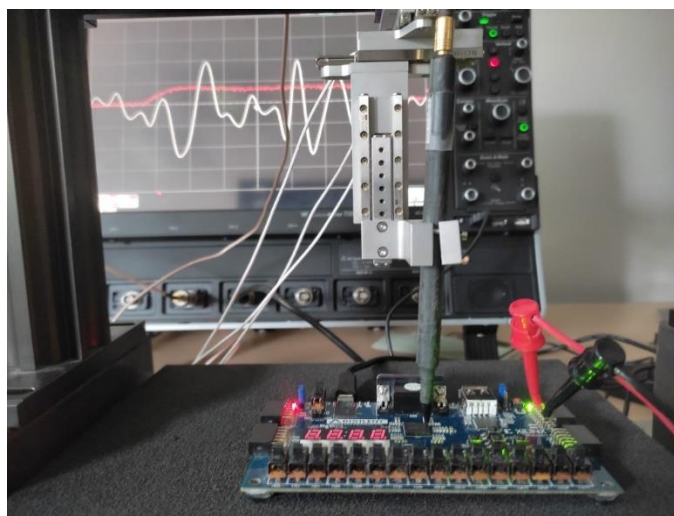
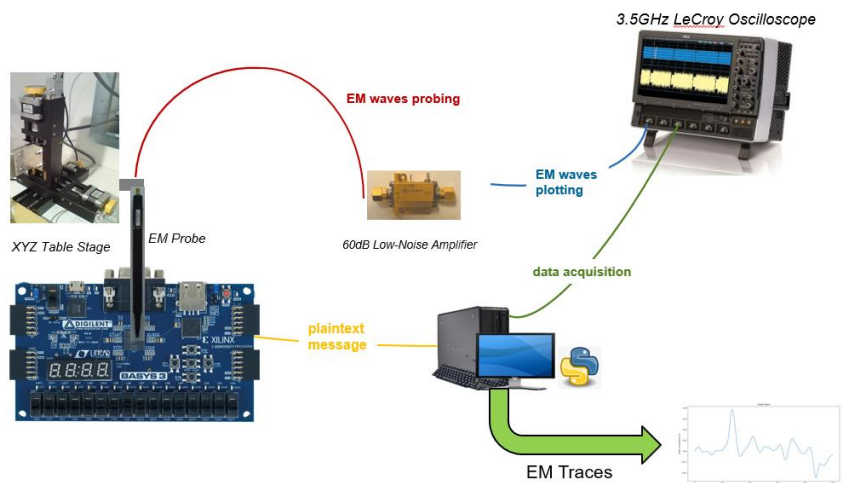


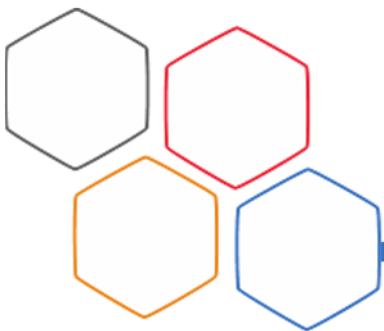
The Threat Model

- Functionnal IC (oracle)
- Locked Netlist

The attack framework

- The attack point will be the restore unit
- Divide and Conquer Methodology can be applied on the key
- The decision function will be the output of the sub-comparator

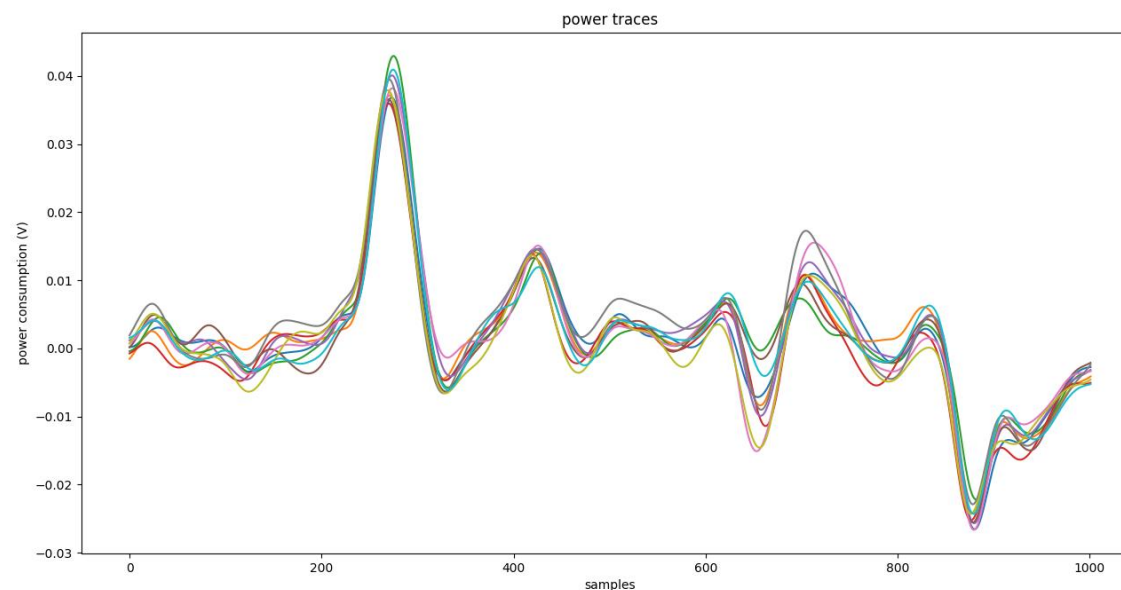


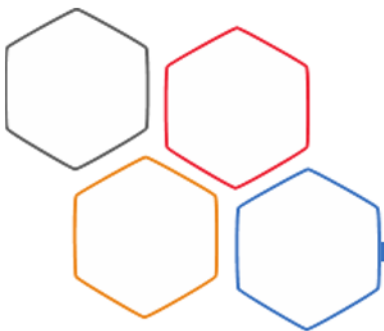


Power Traces Recording on the LIRMM/CNFM SCA platform

- Setup :

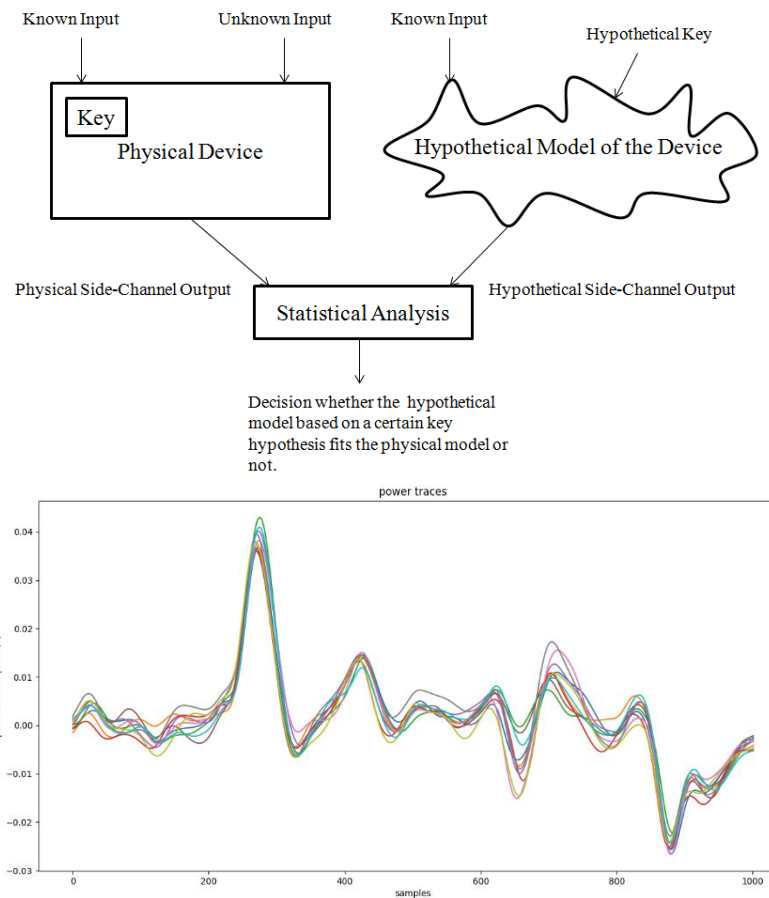
- Circuits : ISCAS circuits locked with SFLL-HD
- 1002 samples
- 2 clock cycles (update of data only on the first)
- Artix-7 FPGA
- Key stored on a register



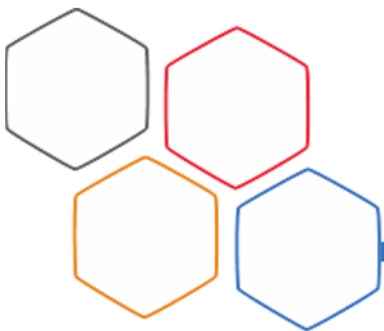


Attack of c432 with SFL- HD ($h=0$)

- Up to 200k traces
- DPA, CPA, MIA and template attacks
- No satisfying results



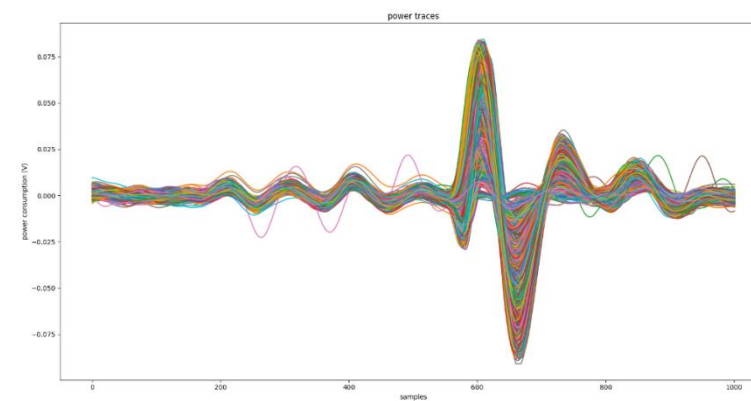
The Post-SAT schemes are really resilient against side channel attacks ?



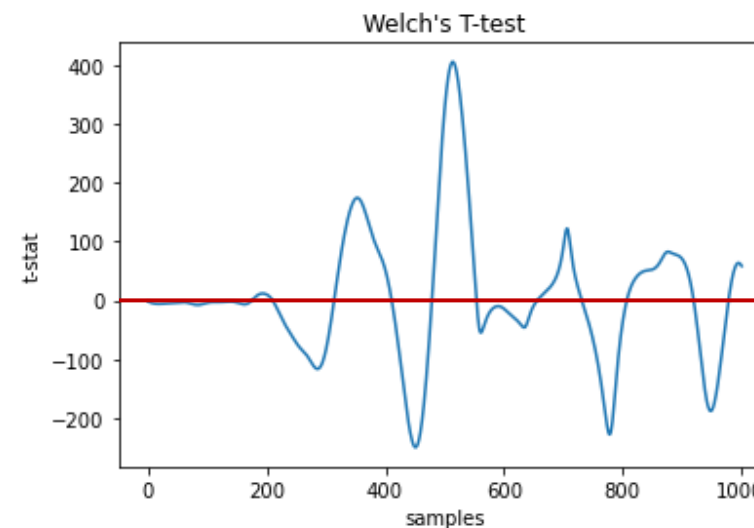
Leackage testing on DES circuit locked

- Leackage testing with Welch's T-test
- 50k traces with fixed correct key
- 50k traces with variable random keys
- The same input vectors were used

$$t = \frac{\overline{X1} - \overline{X2}}{\sqrt{\frac{S1^2}{N1} + \frac{S2^2}{N2}}}$$



Multiple DES power traces



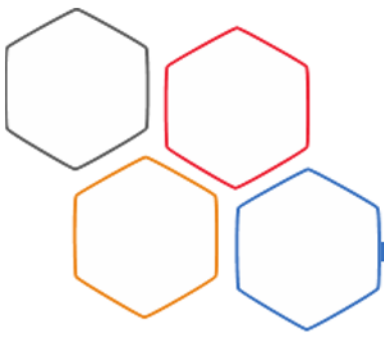
— Leakage limit :]-5,5[



→ Logic Locking

→ SCA on Logic Locking

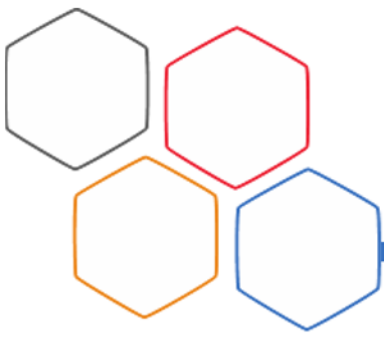
→ Perspectives



Futur Work

Perspectives

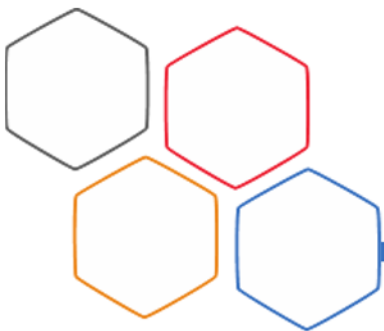
- Analysis of T-test Results
- Identifying the leakage sources
- Conduct the same leakage testing on other circuits with the same scheme
- DPA, CPA, MIA ...



Futur Work

Perspectives

- ➔ Simulation based leakage testing and SCA attacks (Cadence Joules, 28nm ST-FDSOI)
- ➔ Side Channel Attacks against other advanced LL schemes
- ➔ State of the art of other levels LL (RTL, Transistor, Layout)
- ➔ LL schemes with SCA resilience



Thank you all for listening

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