Reverse-Engineering of Hardware Circuits

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SR2I301

Presentation Outline

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Definition of reverse-engineering

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- When the algorithm to attack is unknown, the system is a “black-box”.
- This means that the only way to attack is to analyze the input/output relationships $\Rightarrow$ hard in general (but for cube attacks [DS09, DS10])
- Therefore, the first step is to recover the algorithm.

Hardware versus Software reverse-engineering

- **Software**: The compiled code can be read-out from memories, and disassembled. Typically A5/1, A5/2, Hitag2 and Keeloq have been retrieved like that.
- **Hardware**: The functionality is buried into an ASIC.

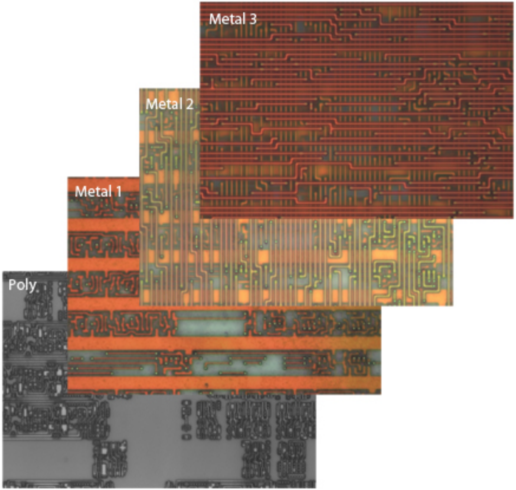
Goal of reverse-engineering

Goals

1. Retrieving an algorithm and then cryptanalyse it:
    - This was the case of CRYPTO1 (MyFare) or DSC (DECT).
    - Indeed, the confidential algorithm is most often weak.
2. Breaking a protection:
    - Understand how memories are encrypted by a secure microcontroller [Mah97].
    - Afterwards, all the code is exposed.
    - It thus becomes easy to identify bugs, that can be exploited at the software-level.
    - Thanks to buffer overflows, take the control of the application.
3. Intellectual property matters:
    - Accessing the design of a competitor, so as to steal it.
    - Checking that the competitor does not infringe my patents.

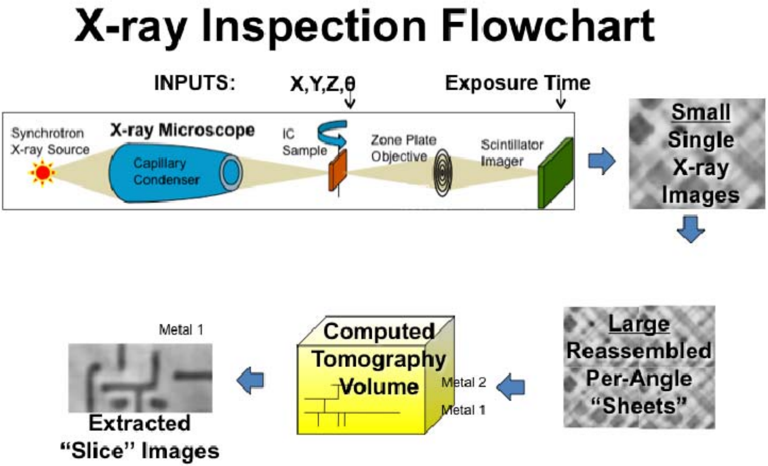
Presentation Outline

Principle of Circuit Reverse-Engineering: Delayering



Principle of Circuit Reverse-Engineering:

Tomography [BBT+11] (see also [Zei13])



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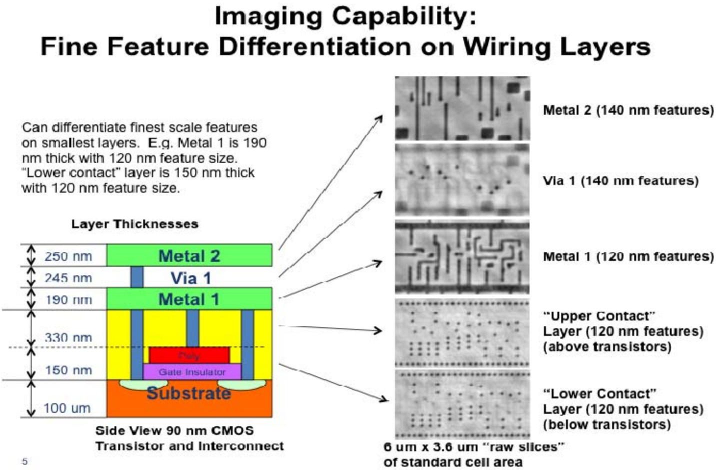
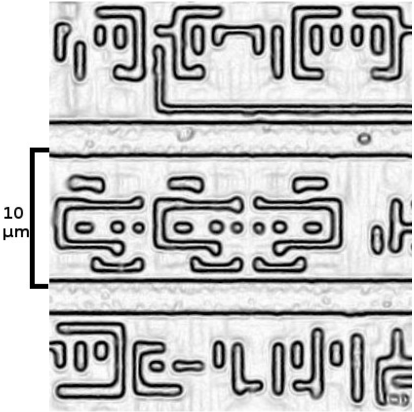
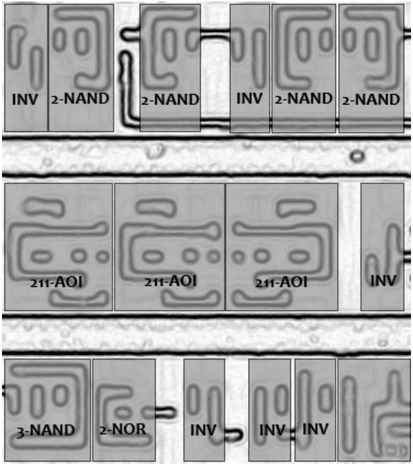
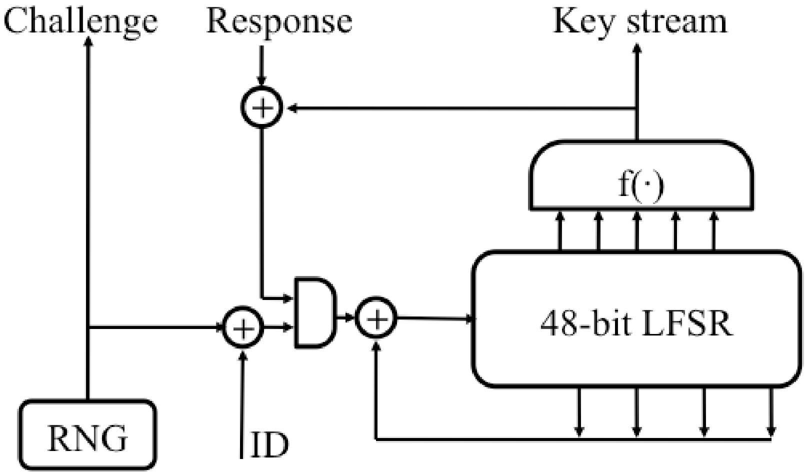


Example of MyFare (NXP) [NSP08]

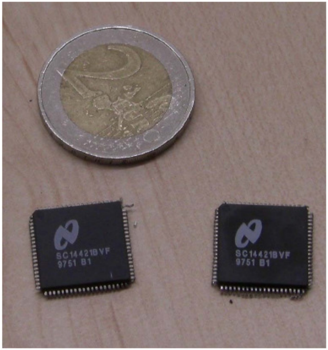


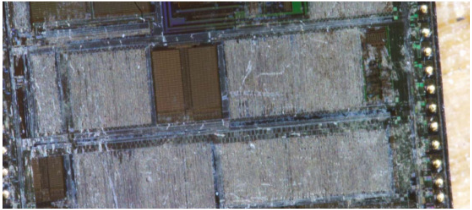


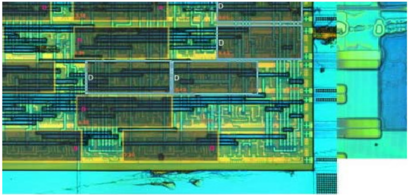
Example of MyFare (NXP) – CRYPTO1 exposed [NSP08]



Example of DECT (Alcatel) [NTW10]

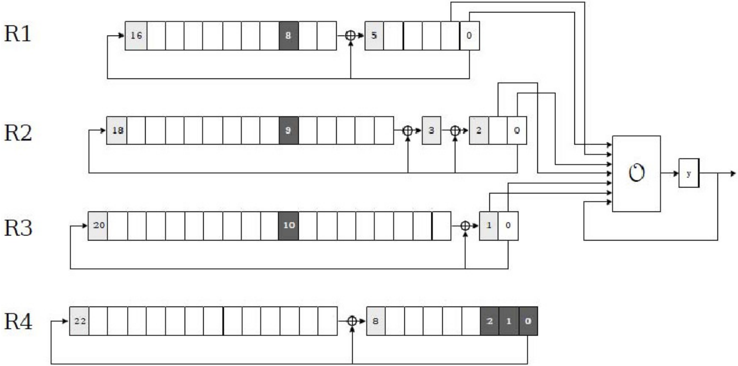






See also: https://deDECTed.org/.

Example of DECT (Alcatel) – DSC exposed [NTW10]

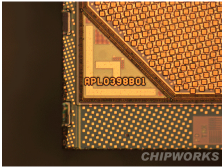


DSC = DECT Standard Cipher.

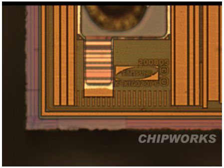
Professional techniques

Example of http://www.chipworks.com/ [TJ09] iPAD tear-down (see also http://www.ltecusa.com/ and many others).

Apple / Microprocessor (with DRAM)

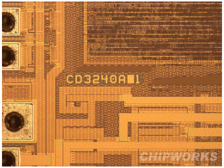


Samsung / 1 Gb mobile DDR SDRAM (x2)

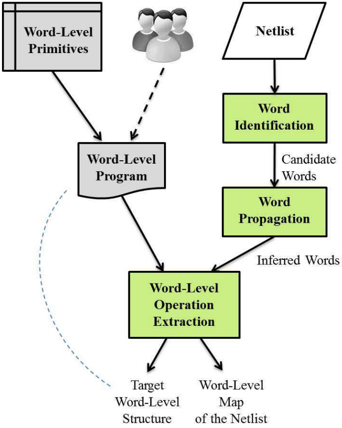


Broadcom / Microcontroller with NVM (used for touch-screen)

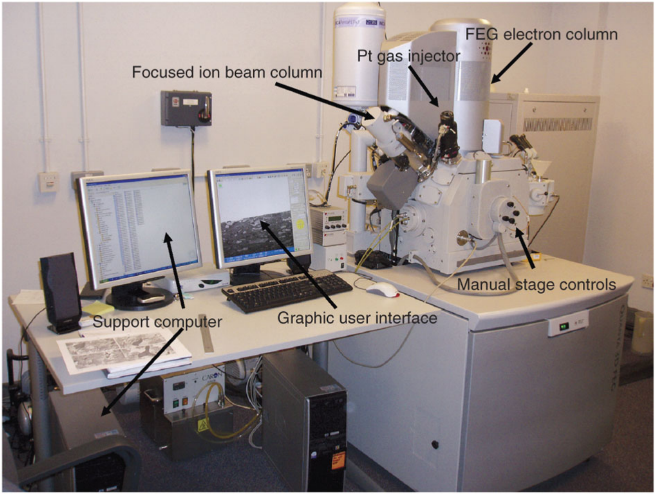
TI / Touchscreen line driver



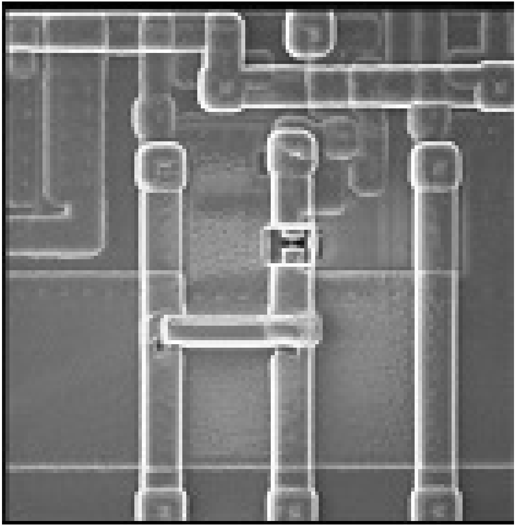
WordRev: Finding word-level structures in a sea of bit-level gates [LGS+13]



Focused Ion Beam (FIB)



Edition of a circuit thanks to a FIB (Focused Ion Beam)



Can be used for instance to unlock memories [Gir07].

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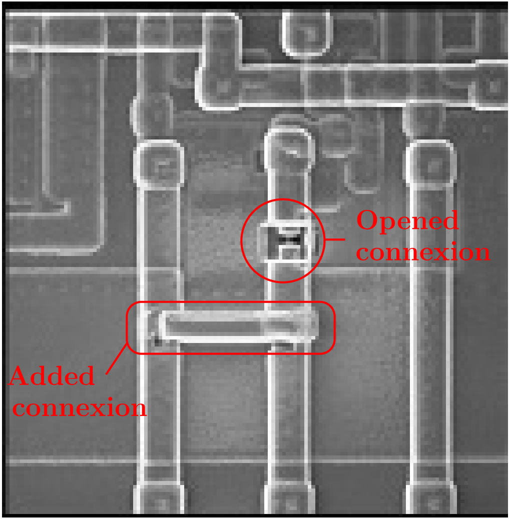

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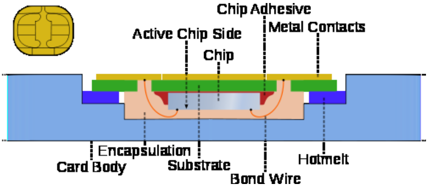
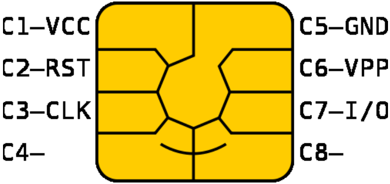
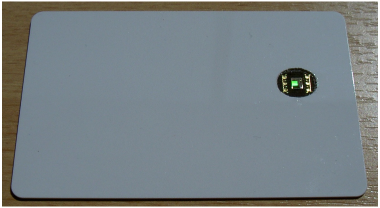
Presentation Outline

Preparation of a smartcard front- and rear-side



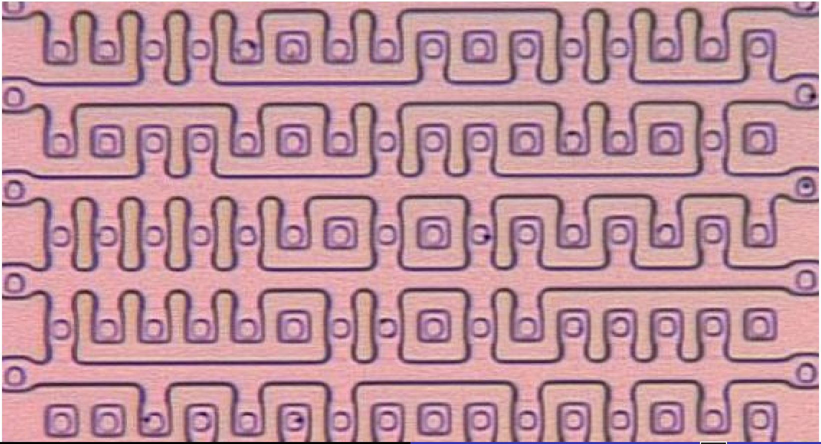




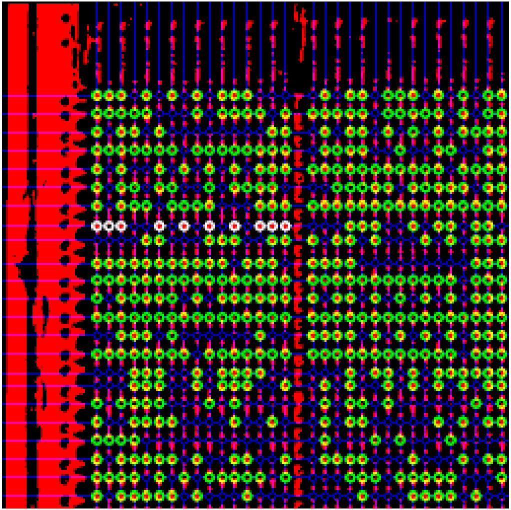
This chemical preparation enables probing and fault injection attacks.

Reading ROMs [KK99]

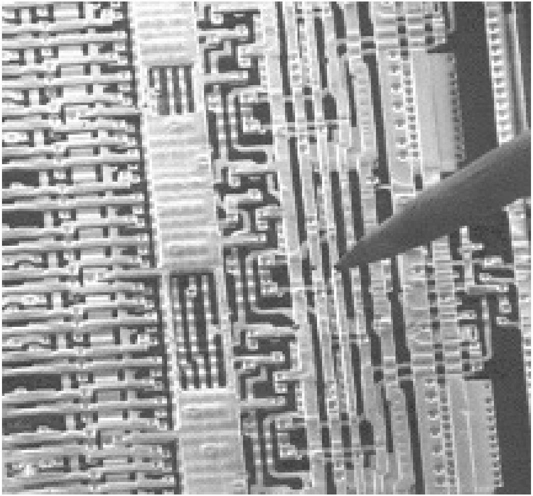
The image shows 16 × 10 bits in an ST16xyz. Every bit is represented by either a present or missing diffusion layer connection.



Semi-automatic extraction of ROM data (`rompar`)



Needles can be used to actively / passively probe signals



- Can be used for instance to read keys as they circulate into the circuit.
- This technique gives the attacker a considerable power.
- However, probing stations allow to simultaneously read only a couple of bits [HPS99]... and only those that are on top of the circuit.

Faults Injection Reverse-Engineering

FIRE on DES / AES

- Already illustrated by Biham & Shamir (reconstructing unknown ciphers [BS97]) on Feistel schemes.
- Works on DES, because the attacker sees *inputs and outputs* differentials (improvement in [LBGRT13]).
- With secret encodings, it still works on DES, because the sbox is non-injective [Cla07].
- FIRE on SPNs (such as AES) is an emerging topic [PMG11].

Presentation Outline

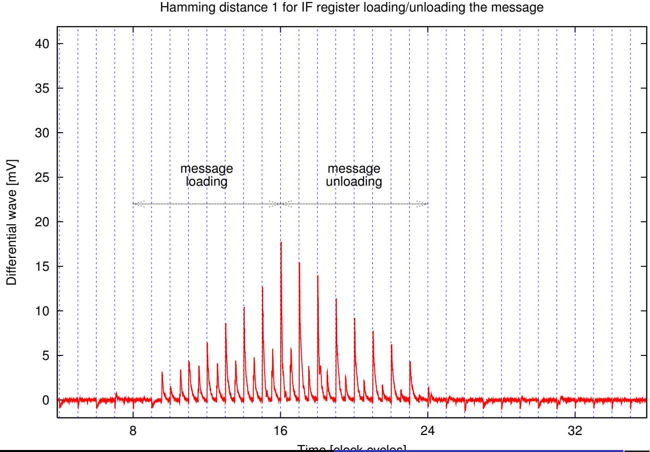
Principle of temporal localization

Use **specific inputs** and **monitor the differences** via one side-channel. For instance, imagine that the key is known.

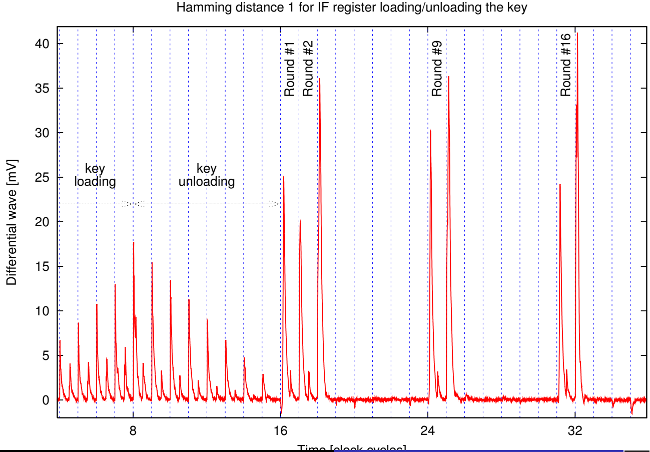
In the next three slides, we suggest to locate:

1. the plaintext loading,
2. the key loading,
3. the key schedule (diversification of the root key for each round).

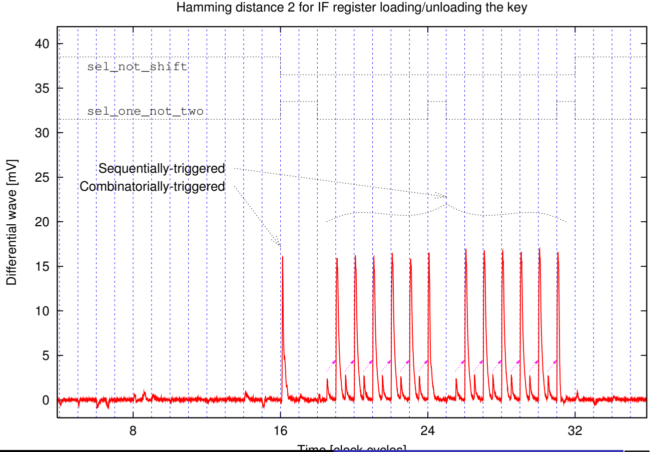
Signature of message loading / unloading in IF (**Reminder**: IF is the InterFace register)



Signature of key loading / unloading in IF, plus the CD activity

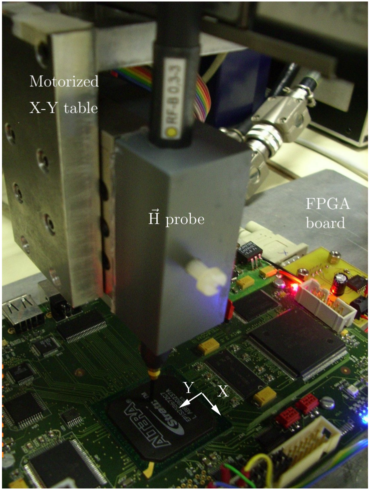


Signature of distance-2 key loading / unloading in IF and of LS^2 in CD



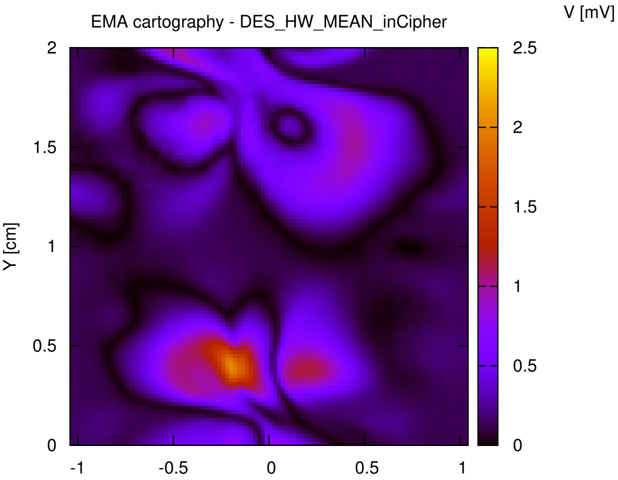
Principle of spacial localization

Using an (X, Y) cartography tool



- Extension: (X, Y, Z, θ) table.
- Helps identify zones that leak a lot; they do not necessarily correspond to the location of the modules! *Id est* they can maybe guide an attack by EMI but not by laser.

Cartography results



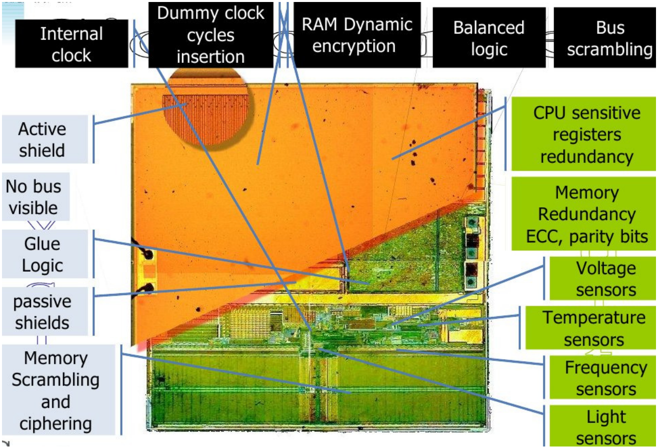
Presentation Outline

Example of the white-box cryptography

White-box cryptography [BCD09, CFD+10]

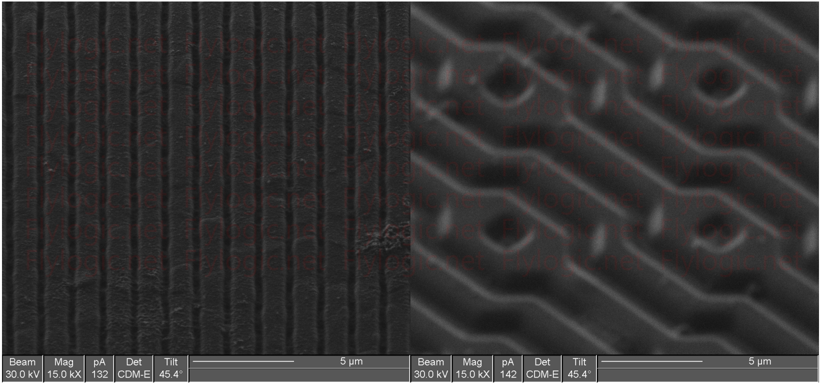
- **Principle**: provide everything (*i.e.* the compiled or the source code of the software) of an algorithm embedding a secret key.
- **Goal**: deny to the attacker the power of retrieving the couple (algorithm + key).

A summary of the countermeasures embedded in a smartcard

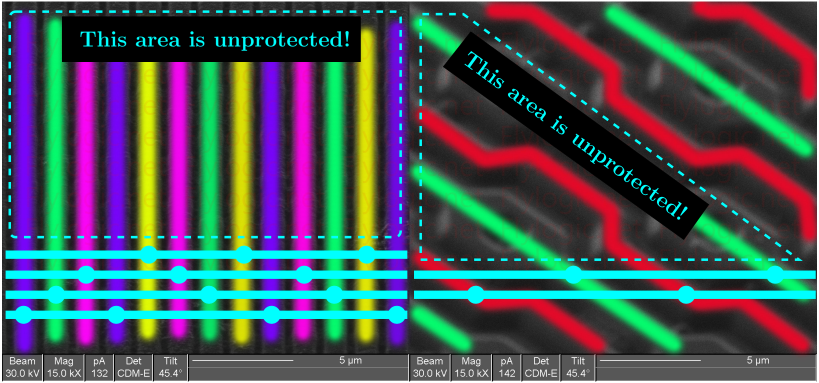


Courtesy of Assia Tria, CEA/LETI.

Active shield 1/2

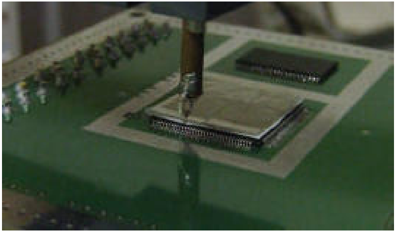


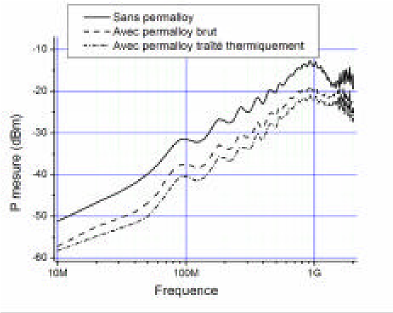
Active shield 2/2



Radiation suppression with a ferromagnetic film

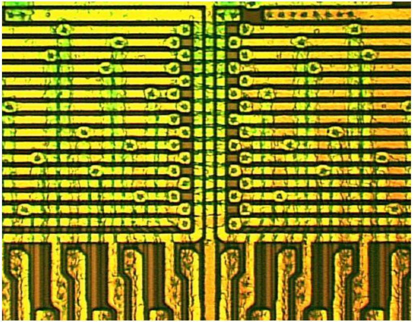
Ferromagnetic material $Ni_{80}Fe_{20}$, *aka* Permalloy.
Experiment with a layer of 20 μm depth [BBD+07].





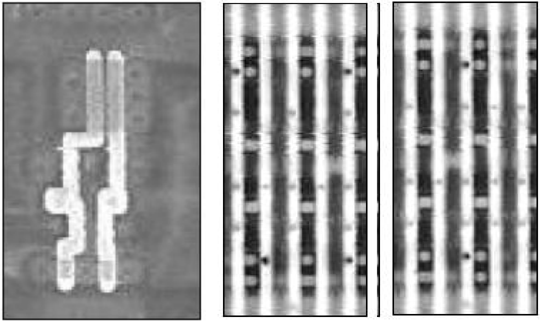
Bus scrambling

- Scrambling can be static or dynamic.
- Static scrambling can also be a feature
  - The mixing comes from a problem of routability of the data/address bus to the memory.
  - Possible because permutations affect equally the `write` and `read` operations.



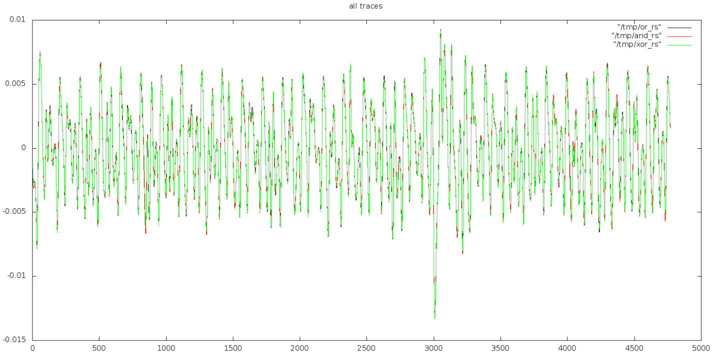
Beware of attacks [FLM10] on scrambled EEPROMs!

Hardware Camo



Hardware-level camouflage of gates. Left: an unprotected gate, whose function is easy to identify. Center, right: *almost* indistinguishable AND/OR camouflaged gates. *[courtesy of SMI / SypherMedia Library]*

Software Camo ARM7 Native Machine Code



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Imaging Integrated Circuits with X-ray Microscopy.
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PhD thesis, Université de Versailles Saint-Quentin-en-Yvelines, 26 octobre 2007.
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