Side Channel Attacks and Countermeasures for Embedded Systems

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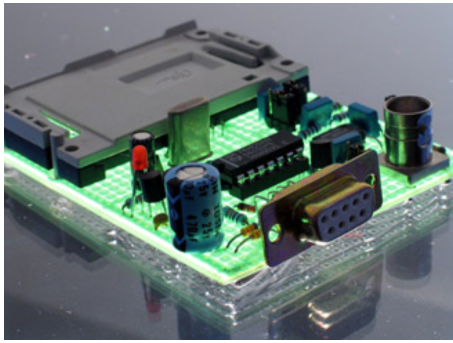
Agenda

- **Advances in Embedded Systems Security**
  - From USB stick to game console
  - Current attacks
  - Cryptographic devices
- Side Channels explained
  - Principles
  - Listening to your hardware
  - Types of analysis
- Attacks and Countermeasures
  - Breaking a key
  - Countermeasures theory
  - Practical implementations

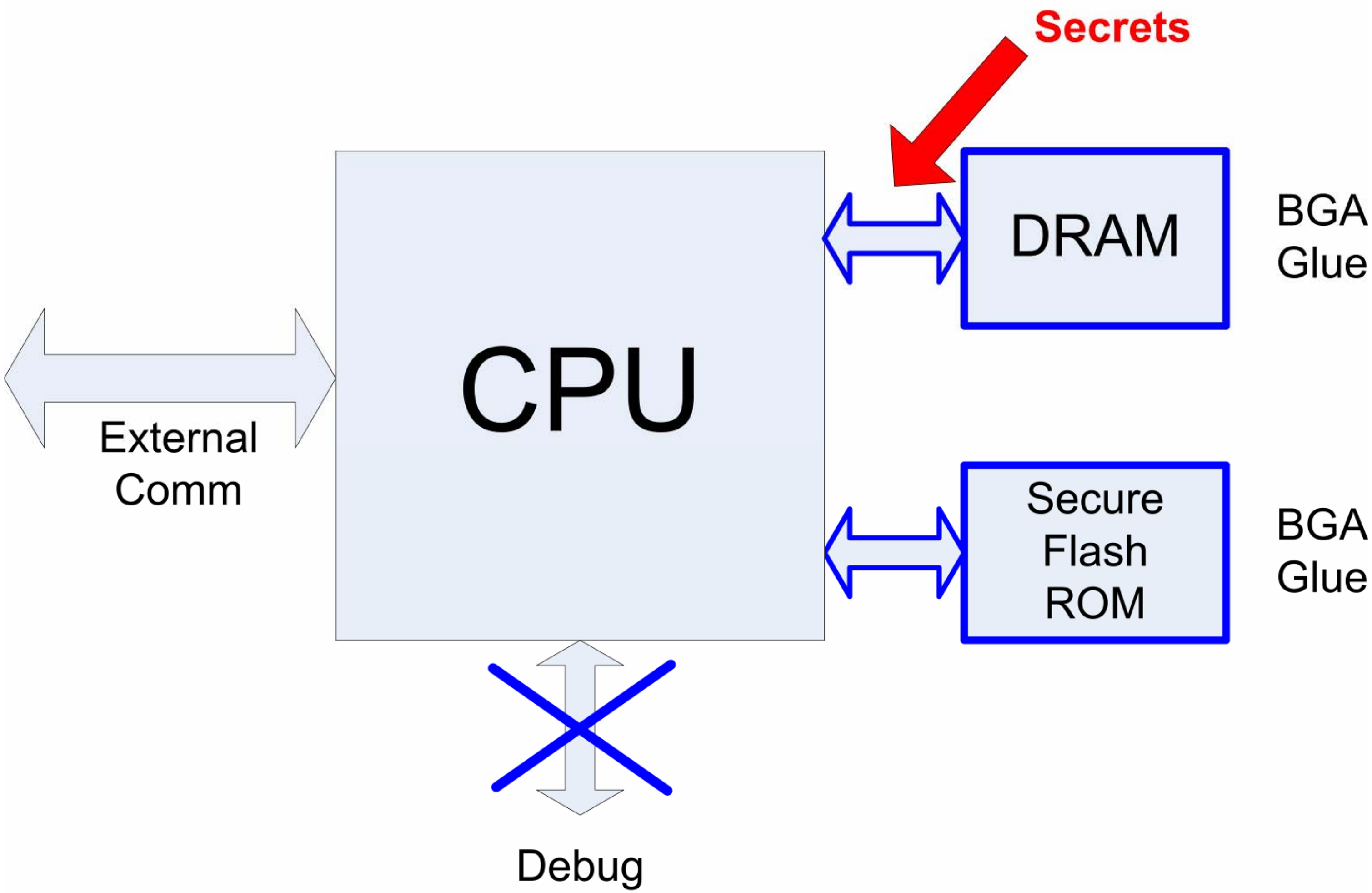


Security in embedded systems

Trends in embedded hardware security

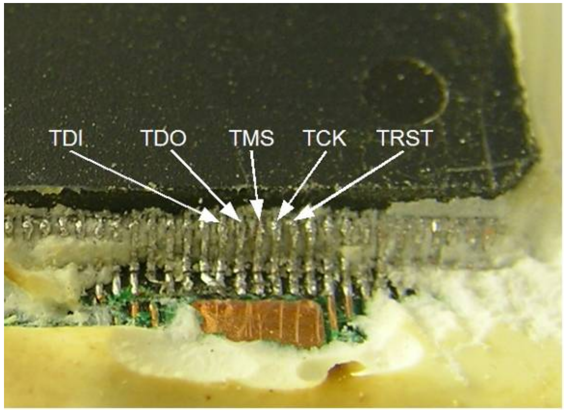
- Preventing **debug** access
  - Fuses, Secure access control
- Protecting **buses and memory** components
  - Flash memories with security, DRAM bus scrambling
- Increase in **code integrity**
  - Boot loader ROM in CPU, Public key signature checking
- Objectives:
  - Prevent running unauthorized code
  - Prevent access to confidential information
  - ➢ **Effective** against most “conventional” attacks

Popular 'hardware' attacks



Attacks on glue and BGA

- Cheap BGA reballing in phone unlocking and repair



- Glue can be removed with chemicals or hot air

(See also Joe Grand's BH presentations on hardware attacks)

Towards cryptographic devices

- **Smart cards** represent the ultimate cryptographic device:
  - Operate in a hostile environment
  - Perform cryptographic operations on data
  - Harnessing both the cryptographic operation and the key
  - Tamper resistant
- General purpose processors are **incorporating** more and more smart card style security
- Why **not use** a smart card?
  - Also adds complexity
  - How to communicate securely with it?
  - Some do (PayTV, TPM etc)

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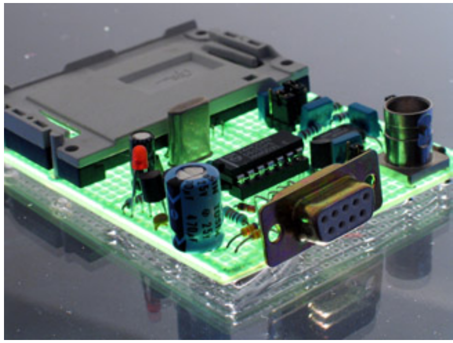
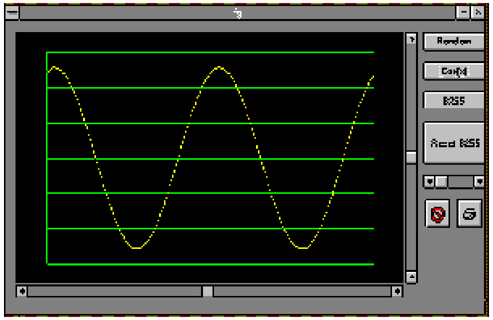


Side Channel Analysis

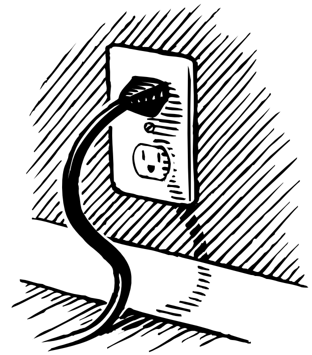
- What?
  - read ‘hidden’ signals
- Why?
  - retrieve secrets
- How?
  - Attack channels
  - Methods
  - Tools

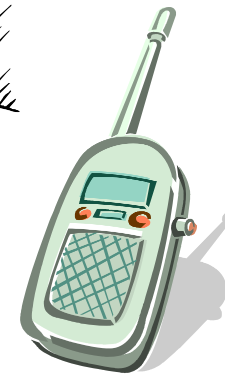


Attack Channels

- Time

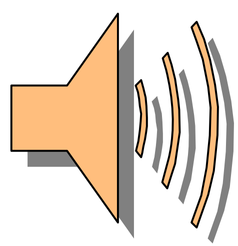
- Power consumption





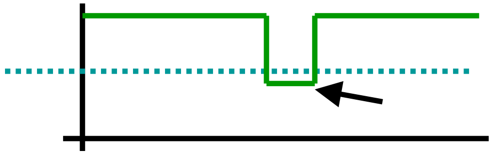
- Electro-Magnetic radiation
- Light emission

- Sound

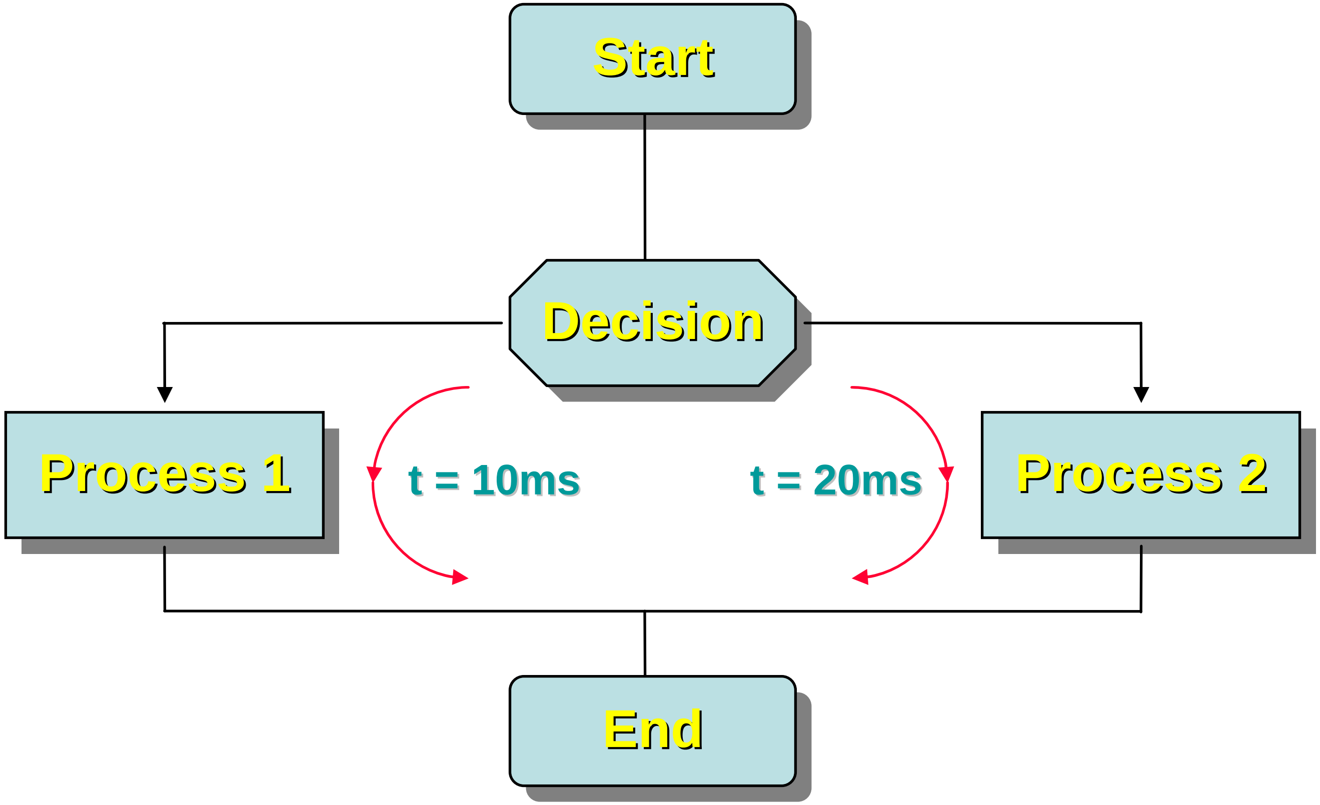


Passive versus active attacks

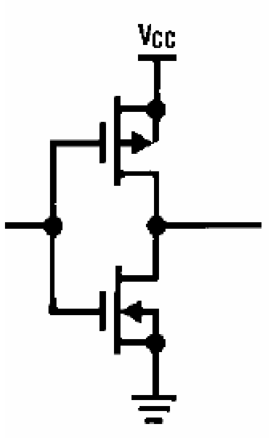
- **Passive** attacks
  - Only observing the target
  - Possibly modifying it to execute a specific behavior to observe
  - **Examples**: time, power or EM measurements
- **Active** attacks
  - Manipulating the target or its environment outside of its normal behavior
  - Uncovering cryptographic keys through ‘fault injection’
  - Changing program flow (eg. circumvent code integrity checks)
  - **Examples**: Voltage or clock glitching, laser pulse attacks

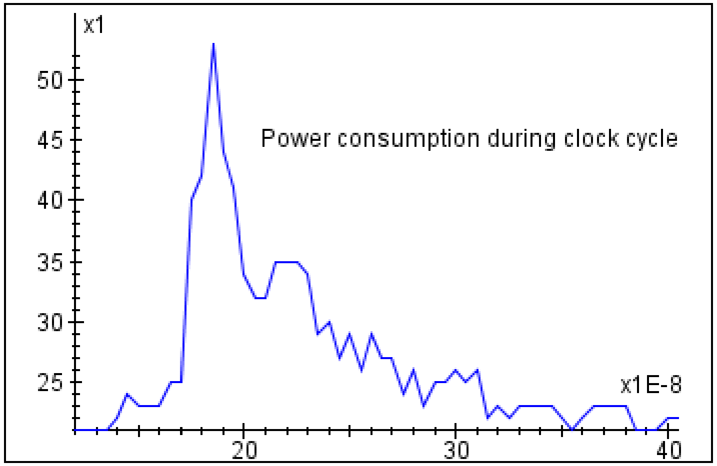


Principle of timing analysis



Principle of power analysis



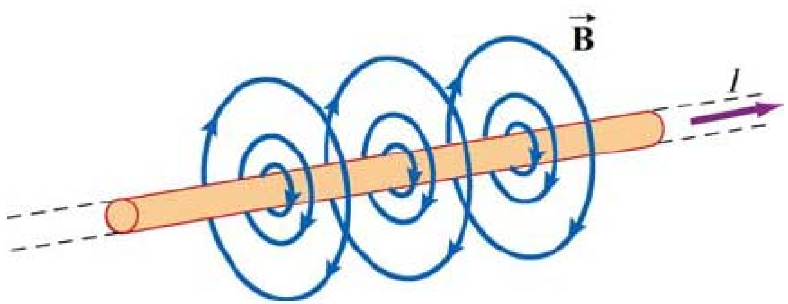


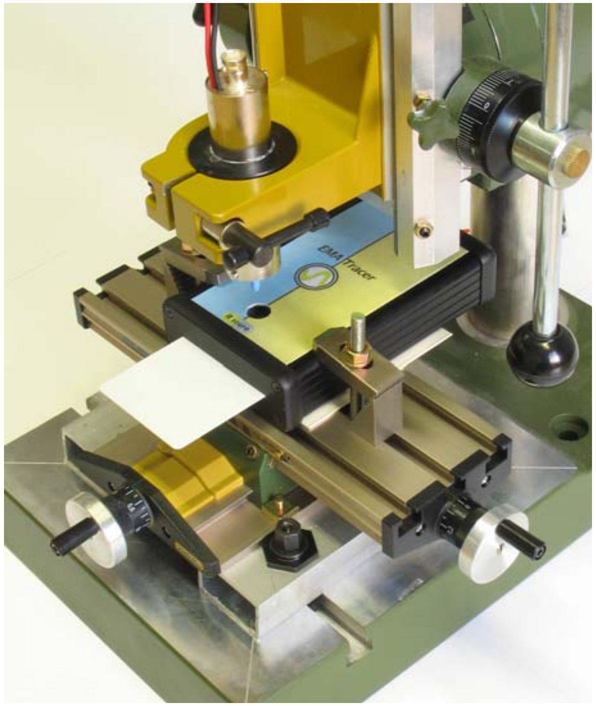
- Semiconductors use current while **switching**
- **Shape** of power consumption profile reveals activity
- **Comparison** of profiles reveals processes and data
- Power is consumed when switching from 1→0 or 0→1

Principle of electromagnetic analysis

Riscure

- Electric and Magnetic field are **related** to current
- Probe is a **coil** for magnetic field
- Generally the **near field** (distance << λ) is most suitable
- Adds **dimension position** compared to the one dimensional power measurement



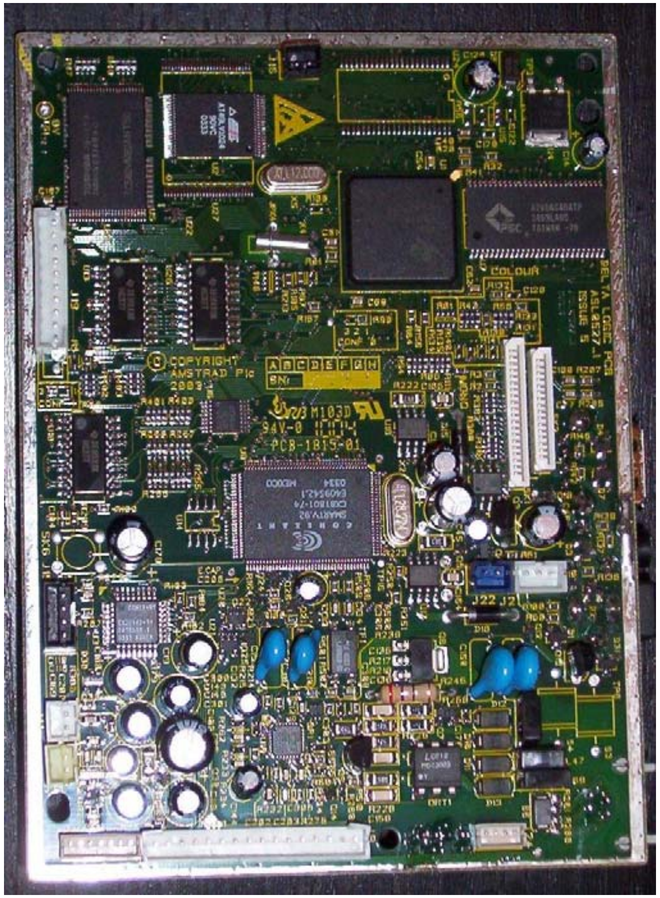


Side channel analysis tools

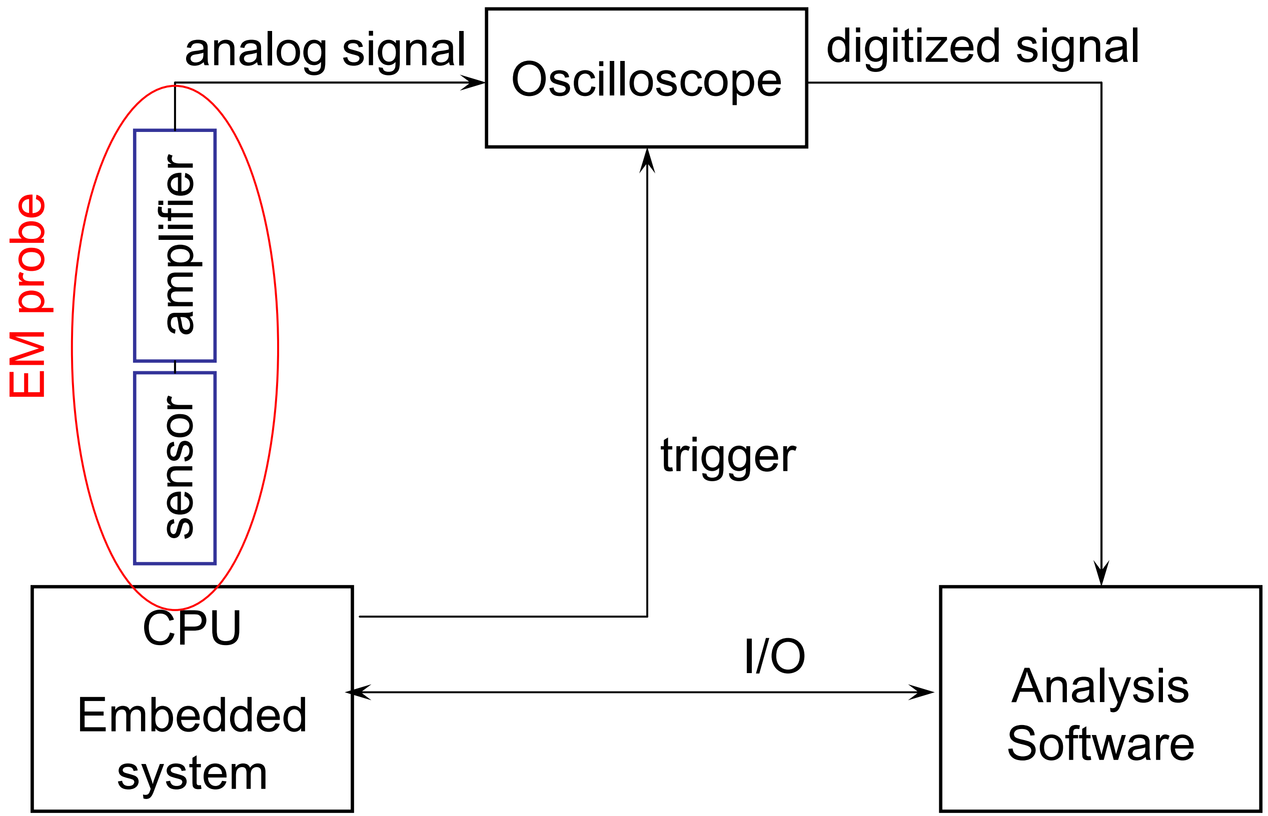
- Probes
  - Power: Intercept power circuitry with small resistor
  - EM: Coil with low noise amplifier
- Digital storage oscilloscope
- High bandwidth amplifier
- Computer with analysis and control software

Test equipment

- CPU: Ti OMAP 5912 150Mhz

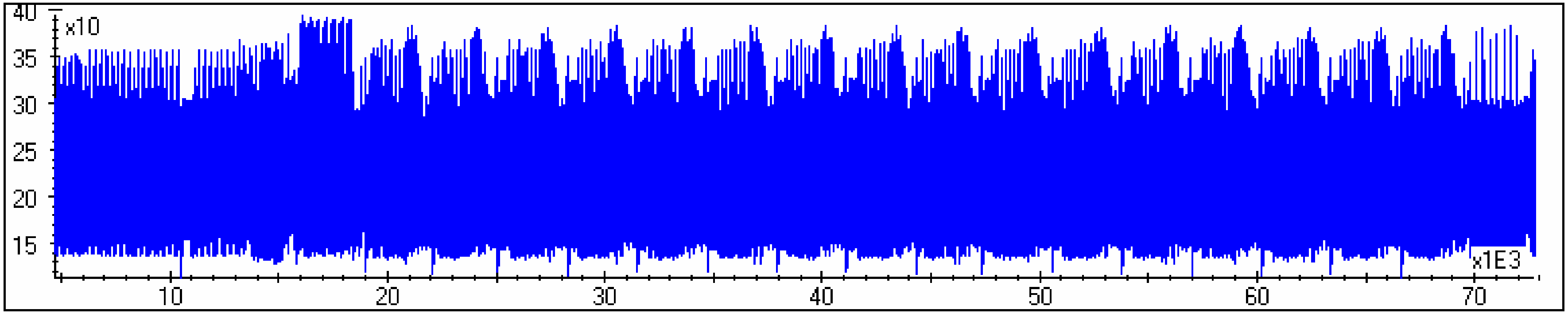


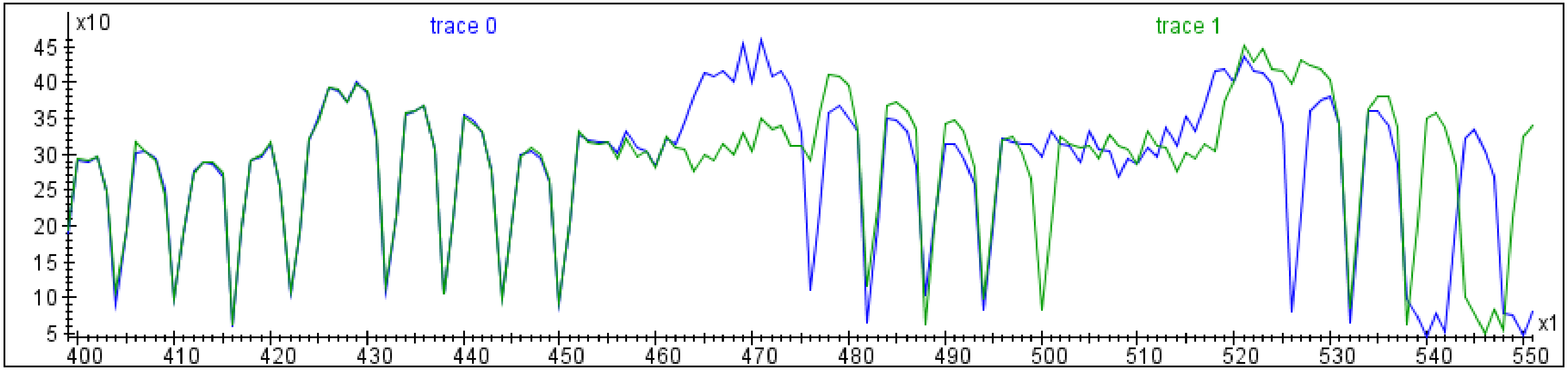
Listening to your hardware - demo



Simple Power/EM Analysis

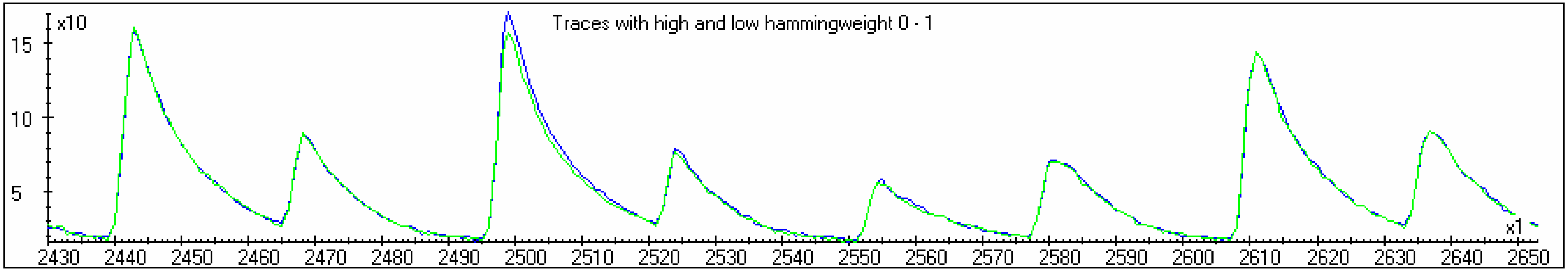
- Recover information by inspection of **single or averaged** traces
- Can also be useful for **reverse engineering** algorithms and implementations

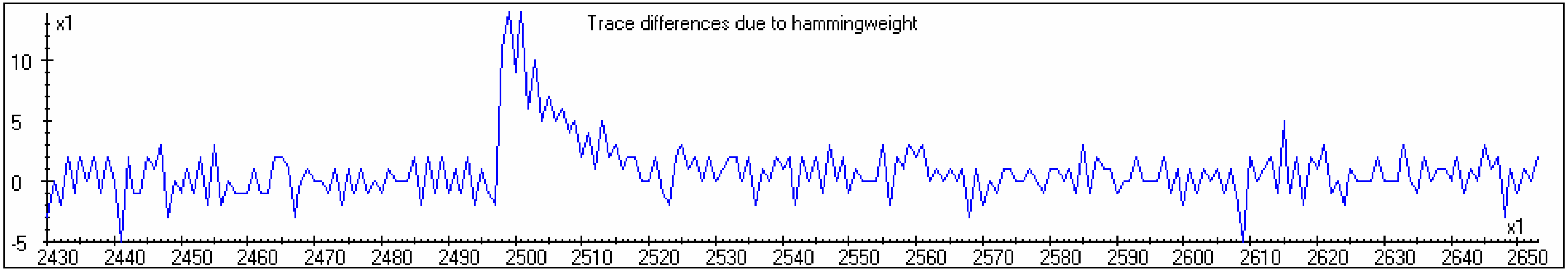




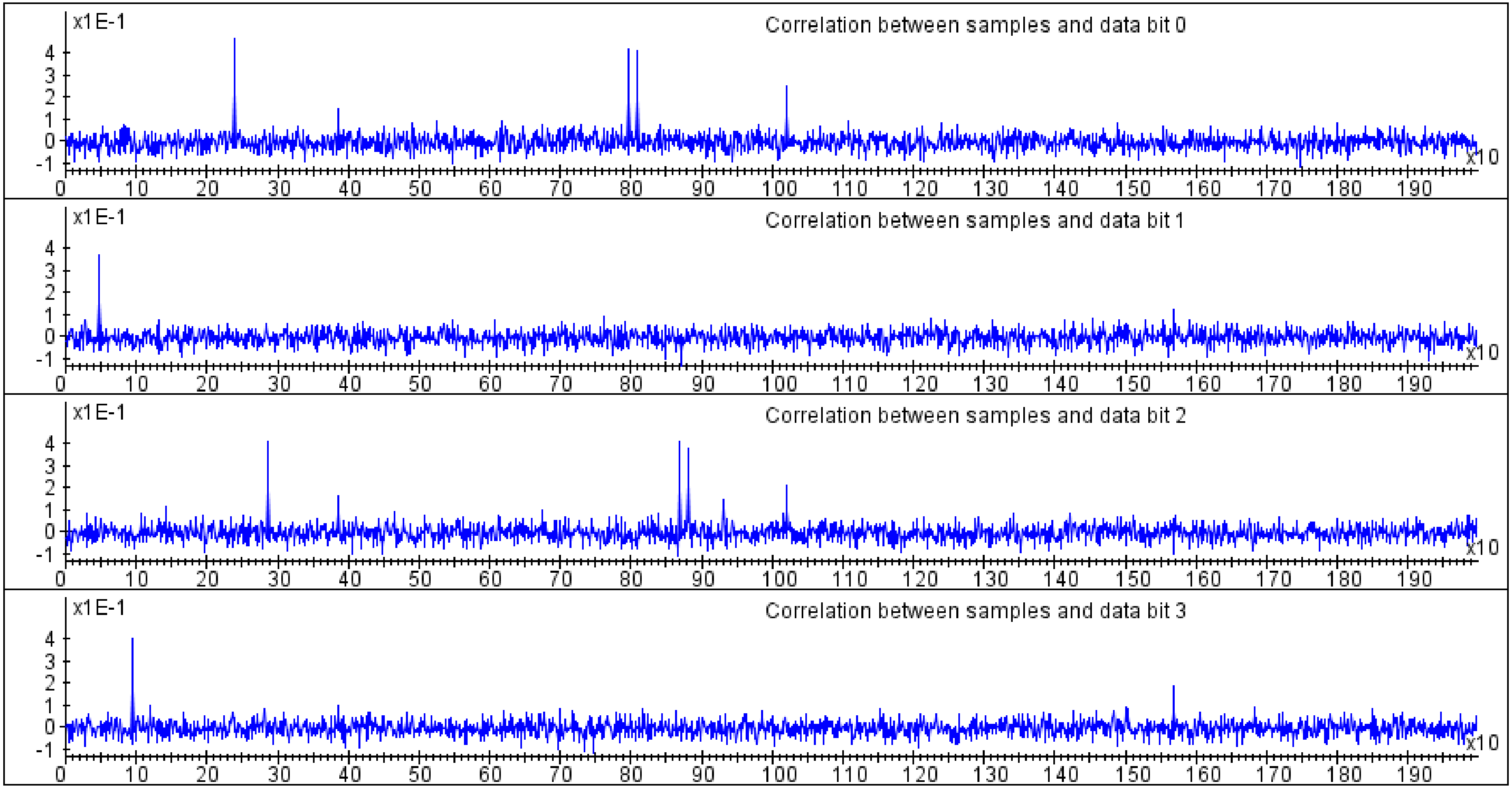
Differential Power/EM Analysis

- Recover information by inspection **difference** between traces with different (random) inputs
- Use **correlation** to retrieve information from noisy signals





Data/signal correlation



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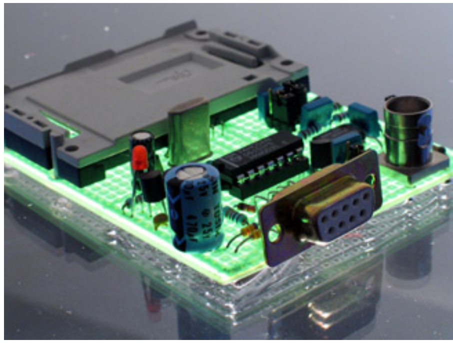
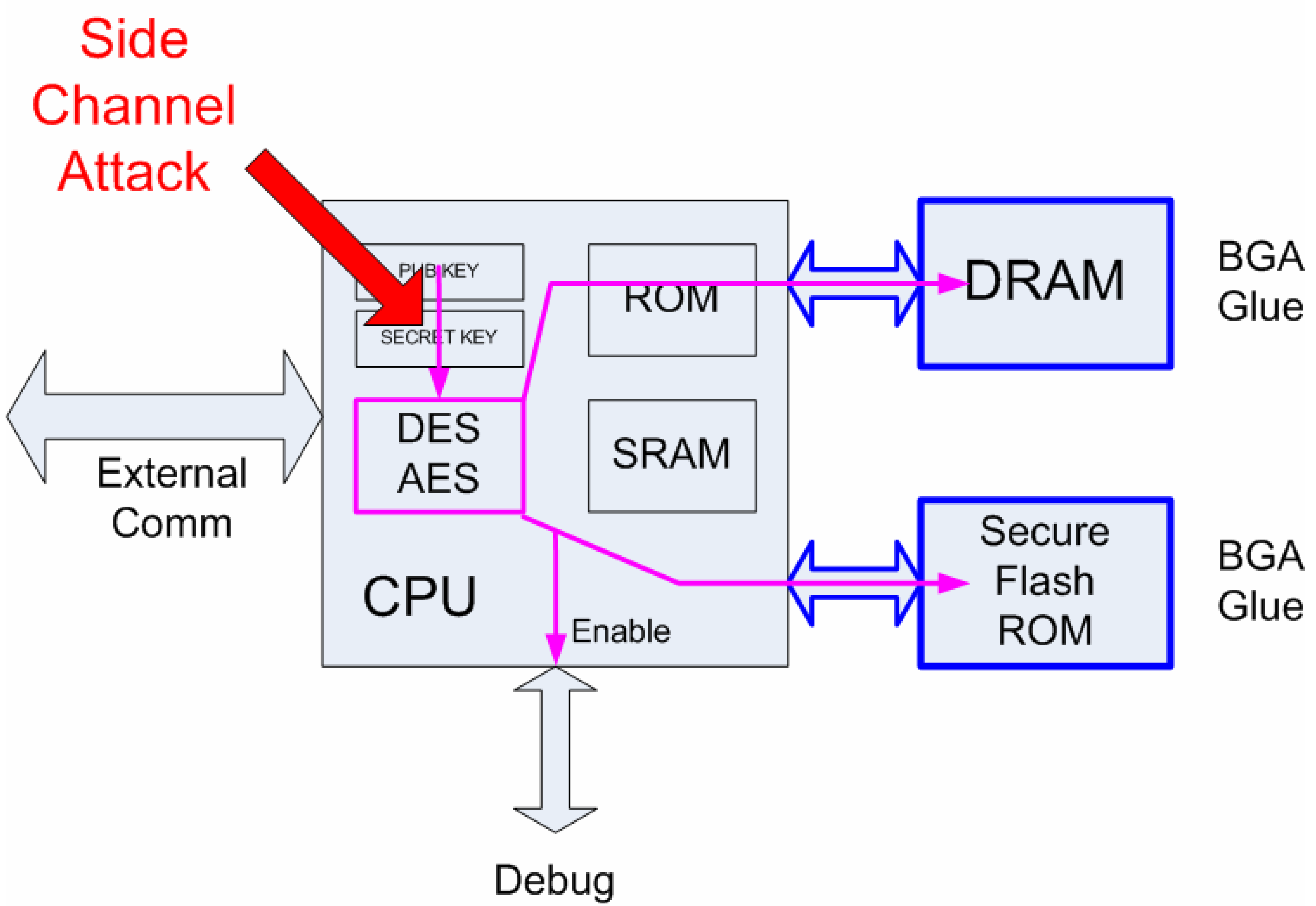


Secure CPUs

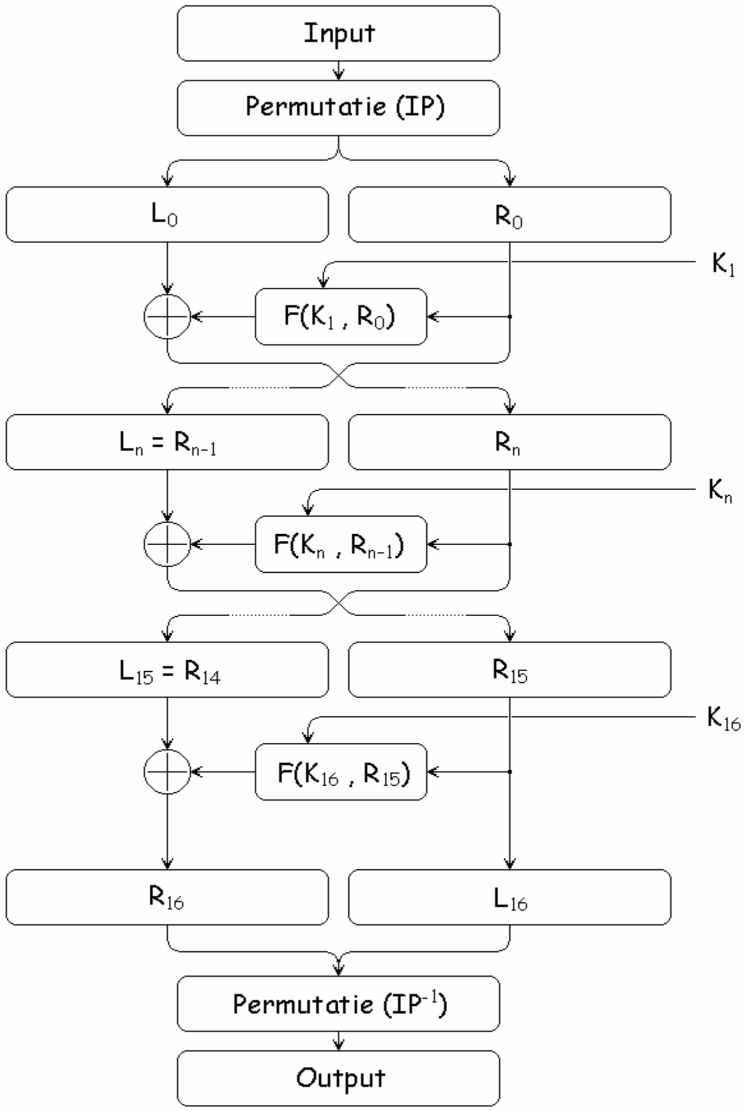


Side
Channel
Attack
PUB KEY
SECRET KEY
ROM
DES
AES
SRAM
CPU
Enable
External
Comm
DRAM
BGA
Glue
Secure
Flash
ROM
BGA
Glue
Debug

Breaking a key - demo

- Example breaking a DES key with a differential attack
- Starting a measurement
- Explaining DES analysis
- Showing results

DES



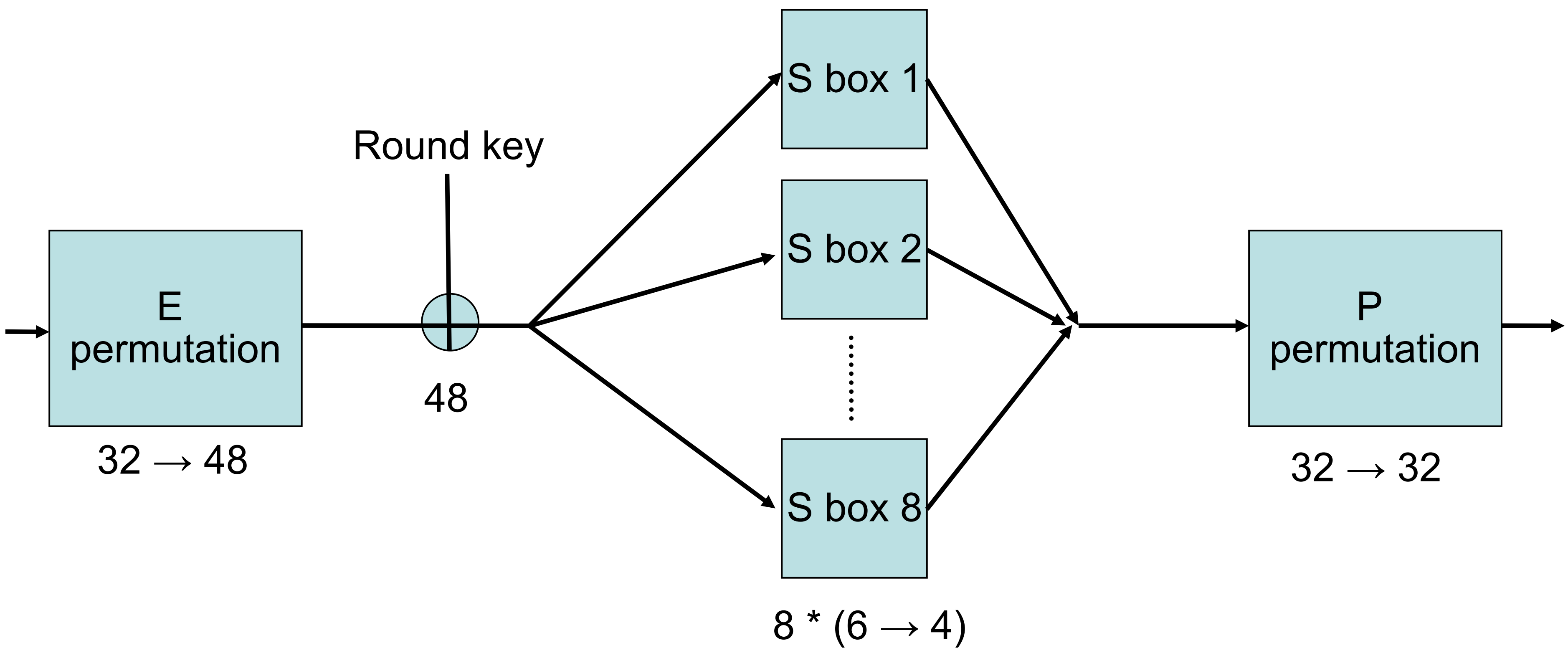
16 rounds

- Input and output are 64 bits
- Key K is 56 bits

  round keys are 48 bits
- Cipher function F mixes

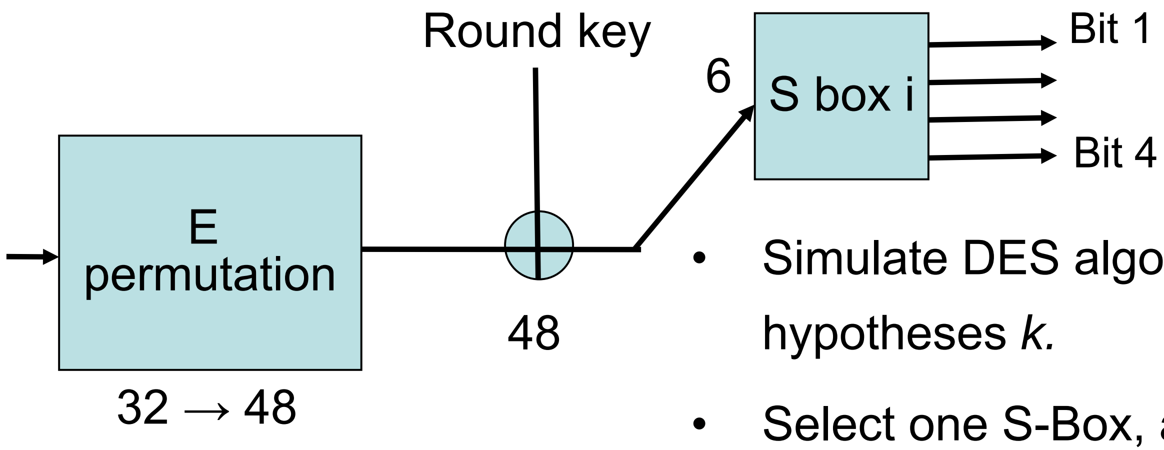
  input and round key

F- function



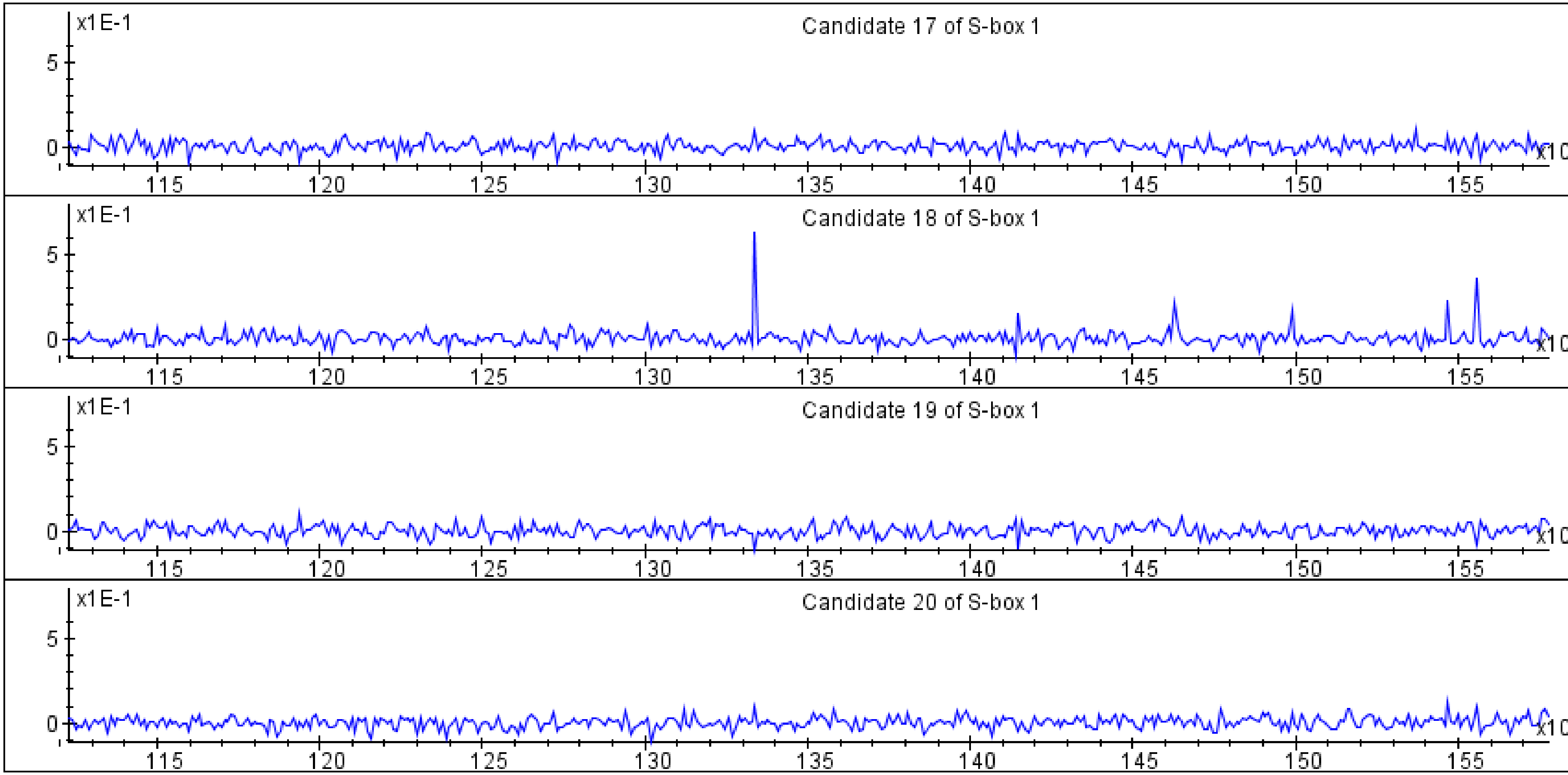
Round key
E
permutation
32 → 48
48
S box 1
S box 2
S box 8
8 * (6 → 4)
P
permutation
32 → 32

DPA on DES



- Simulate DES algorithm based on input bits and hypotheses *k.*
- Select one S-Box, and one output bit *x*. Bit *x* depends on only 6 key bits.
- Calculate differential trace for the 64 different values of *k.*
- Incorrect guess will show noise, correct guess will show peaks.

DPA on DES results

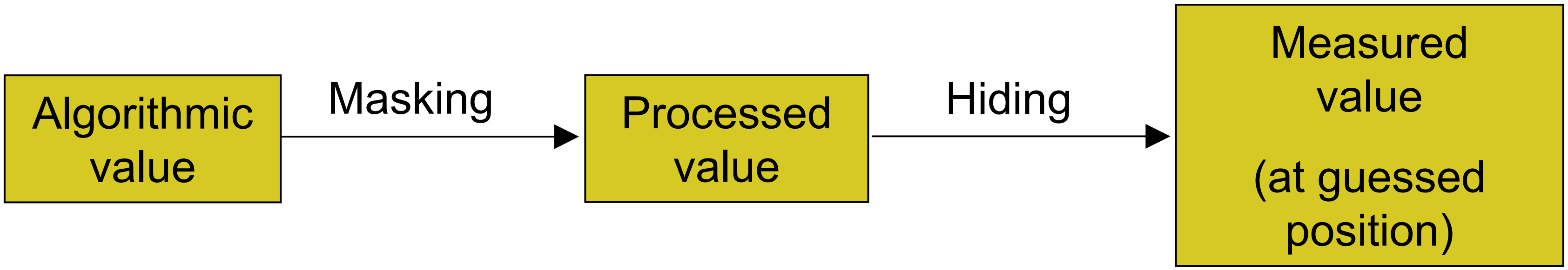


Countermeasures

- **Decrease** leakage
  - Balance processing of values
  - Limit number of operations per key
- **Increase** noise
  - Introduce timing variations in processing
  - Use hardware means

Countermeasures concepts

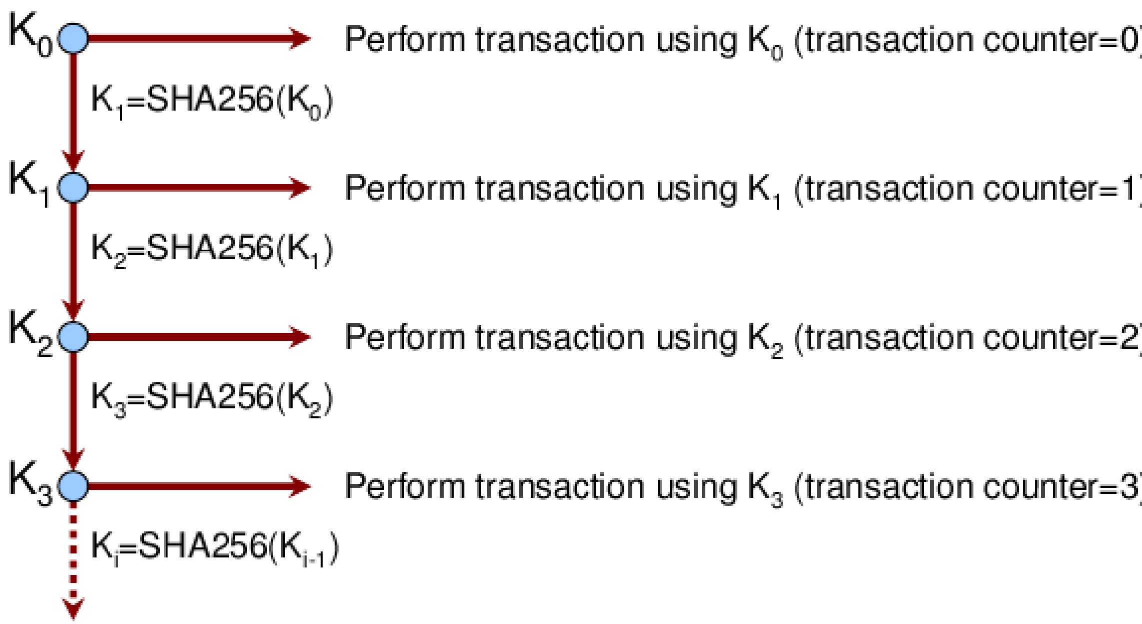
- Passive Side channel attacks:
  - **Hiding**:
    Break relation between processed value and power consumption
  - **Masking / Blinding**:
    Break relation between algorithmic value and processed value



Countermeasure examples

- **Change the crypto protocol** to use key material only for a limited amount of operations. For instance, use short lived session keys based on a hash of an initial key.

Example:



Source: Kocher, P. *Design and Validation Strategies for Obtaining Assurance in Countermeasures to Power Analysis and Related Attacks*

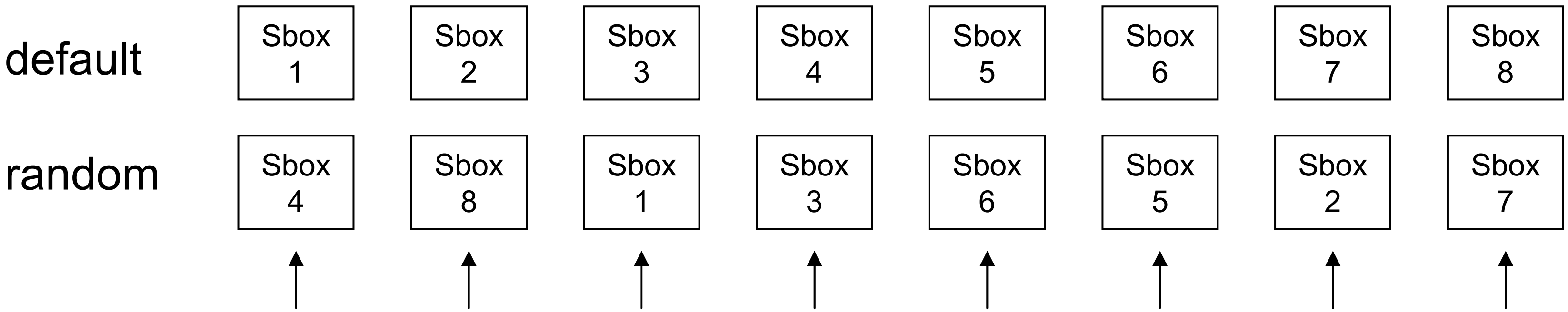
Countermeasure examples

- Remove any execution **time dependence** on data and key. Do not forget cache timing and branch prediction. Also remove **conditional execution** that depends on the key.
- **Randomly insert instructions** with no effect on the algorithm. Use different instructions that are hard to recognize in a trace

default	MOV	XOR	ADD	INC	CMP			
random	MOV	NOP	XOR	ADD	NOP	INC	NOP	CMP
random	MOV	XOR	NOP	ADD	INC	CMP		

Countermeasure examples

- Shuffling: **Changing the order** of independent operations (for instance S-box calculations) per round. This reduces correlation with a factor equal to the number of shuffled operations

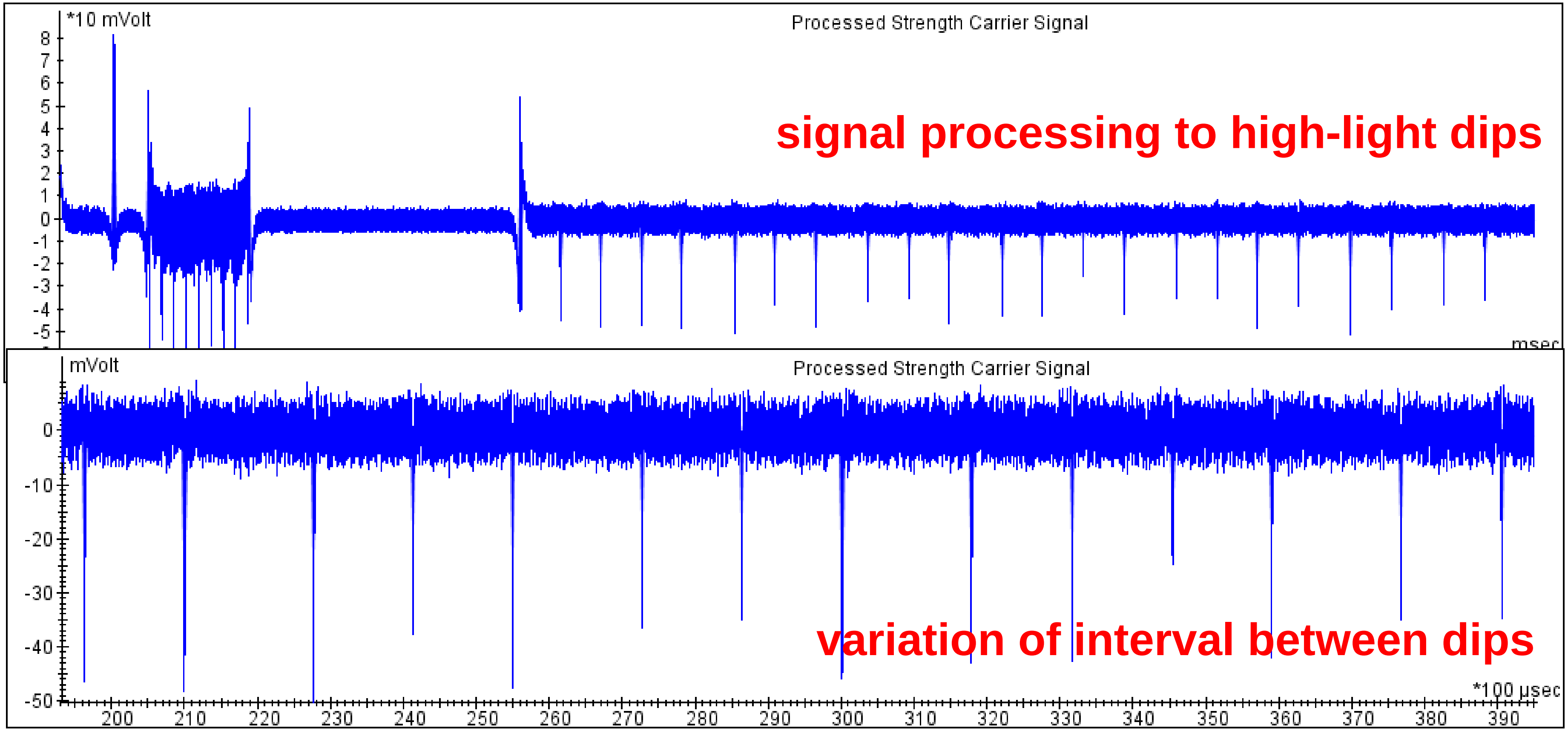


- Implement a **masked** version of the cryptographic algorithm. Examples can be found in research literature for common algorithms (RSA, AES).

Countermeasure demos

- Simple analysis of unprotected trace
- Effect of randomly inserting NOP instructions
- Effect of making RSA square-multiply constant

SPA attack on RSA



1 0 1 0 1 0 0 1 0

key bits revealed

RSA implementations

- Algorithm for $M=c^d$, with d_i is exponent bits ($0 \le i \le t$)
  - $M := 1$
  - For *i* from *t* down to 0 do:
    - $M := M * M$
    - If $d_i = 1$, then $M := M*C$
- Algorithm for $M=c^d$, with d_i group of exponent bits ($0 \le i \le t$)
  - Precompute multipliers C^i
  - $M := 1$
  - For *i* from *t* down to 0 do:
    - For *j* = 1 to groupSize: $M := M * M$
    - $M := M * C^i$

Example: RSA message blinding

- Normal encryption: $M = C^d \bmod n$ under condition:
  - $n = p \cdot q$
  - $e \cdot d = 1 \bmod \mathrm{lcm}(p-1, q-1)$
- Choose a random r, then $C_r = C\, r^e \bmod n$
- Perform RSA: $M_r = C_r{}^d \bmod n = C^d r \bmod n$
- $M = M_r\, r^{-1} \bmod n$

- During the RSA operation itself the operations with exponent d do not depend on C

Test and verification

- The best way to understand side channel leakage is **to measure** your own implementation
- Side channels analysis can be performed on a device to **assess its level of vulnerability** to such attacks
- Such analysis is part of **certification processes** in the payment industry and in Common Criteria evaluations.
- **FIPS 140-3** will require side channel testing for certain levels

Countermeasure licensing

- DPA attacks were first published by **Paul Kocher** et al. from Cryptography Research, Inc. (CRI)
- A large range of countermeasures are **patented** by CRI and other companies
- CRI **licenses** the use of them
- The patents give a good idea of possible countermeasures, check with CRI

Conclusions

- With the increase of security features in embedded devices the importance of **side channel attacks** will also increase
- Most of these devices with advanced security features do **not yet** contain hardware **countermeasures** against side channel attacks
- Side channel attacks present a **serious threat** with wide range of possibilities and a large impact
- Still, software developers can **reduce the risks** of side channel attacks by securing their implementations with software countermeasures

More info

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