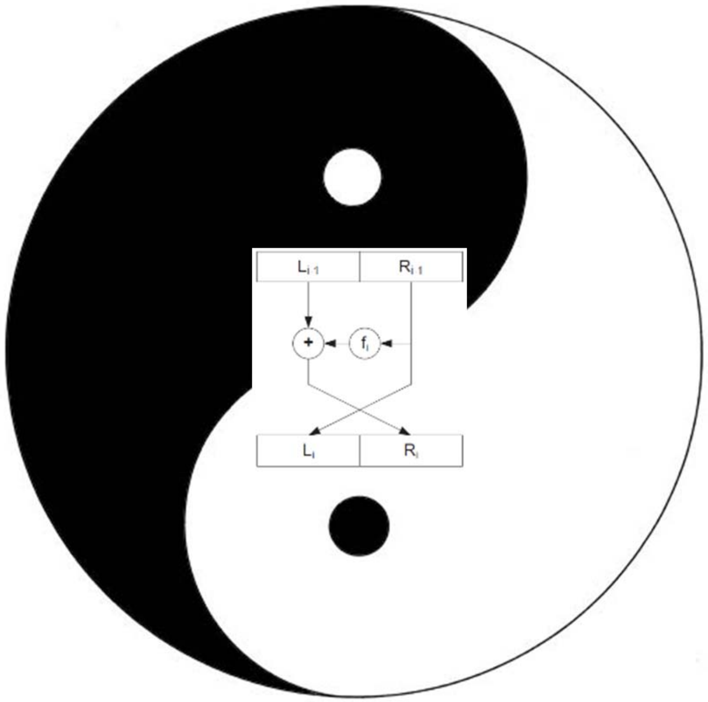
The Yin and Yang Sides of Embedded Security



Indocrypt 2011

December 12, Chennai

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Ruhr University Bochum

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Agenda

- Some thoughts about embedded security
- Yin 1: Car crashes and ECC
- Yin 2: Bar codes and SP ciphers
- Yang 1: Routers and AES
- Yang 2: Subways and 3DES
- Auxiliary stuff

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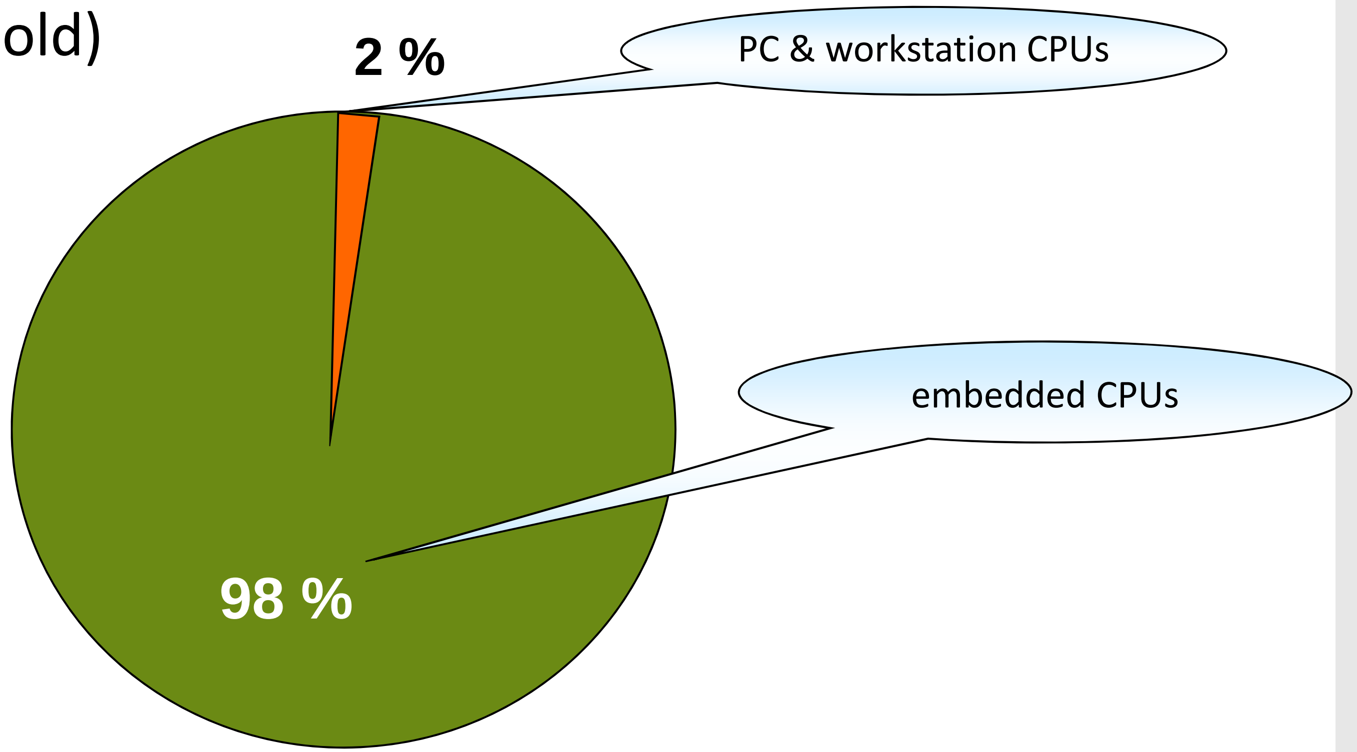
Who cares about embedded systems?

RUB

CPU market (units sold)



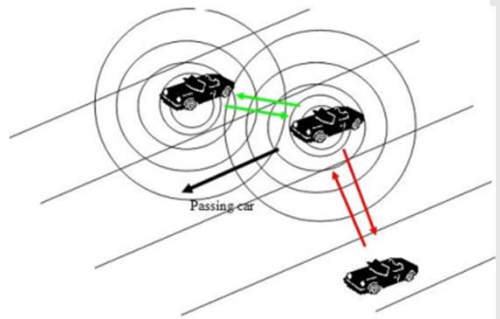
Q: But security ?

Embedded Security – Examples

Embedded DRM applications (iTunes, Kindle, …)

Telemedicine

Privacy & security of car2car communication



Electronic IDs and e-health cards

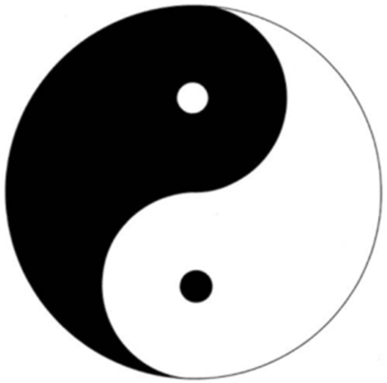
Research in embedded security

Western view

1. Efficienct implementation
2. Secure implementation

Alternative view

1. Yin – constructive



2. Yang – desctructive

The concept of yin yang is used to describe how polar opposites or seemingly contrary forces are interconnected and interdependent in the natural world, and how they give rise to each other in turn.

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Making Cars Talk

- USA [NHTSA, 2010]
  33,000+ car fatalities in 2009
  2m injuries
- EU [KOM 2010 – 389]
  35,000+ car fatalities
  1.5m injuries
- 90% driver errors

Video courtesy of Ken Labertaux, Toyota Research

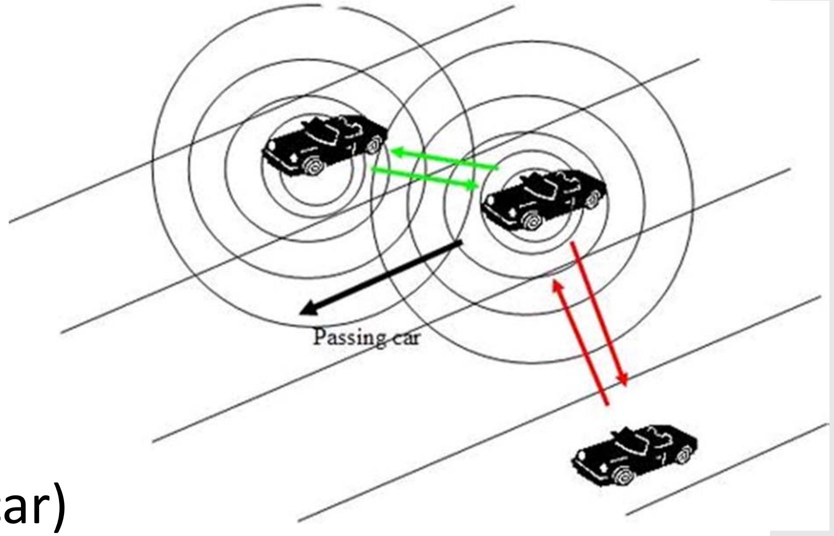
→ Mechanical saftey (safety belt, air bag, ABS): great success but limits have been reached

→ *Electronic driver assistance* will be key tool

VANET – Vehicular Ad-Hoc Networks

Broadcast position & direction information:

1. greatly improve safety
2. improve traffic management



Network characteristics

- small messages (≈ 100 Bytes)
- medium frequency (≈ 10 messages/sec per car)
- very ad-hoc (short lived, high dynamics)
- high number of incoming messages (> 1000msg/sec per car)
- IEEE P1609/DSRC standard

But messages must be authenticated!
(safety-critical & legislative requirements)

Key tool for authentication: digital signatures with elliptic curves …

Elliptic Curve Primitive

- Given an elliptic curve *E* and a point *P*

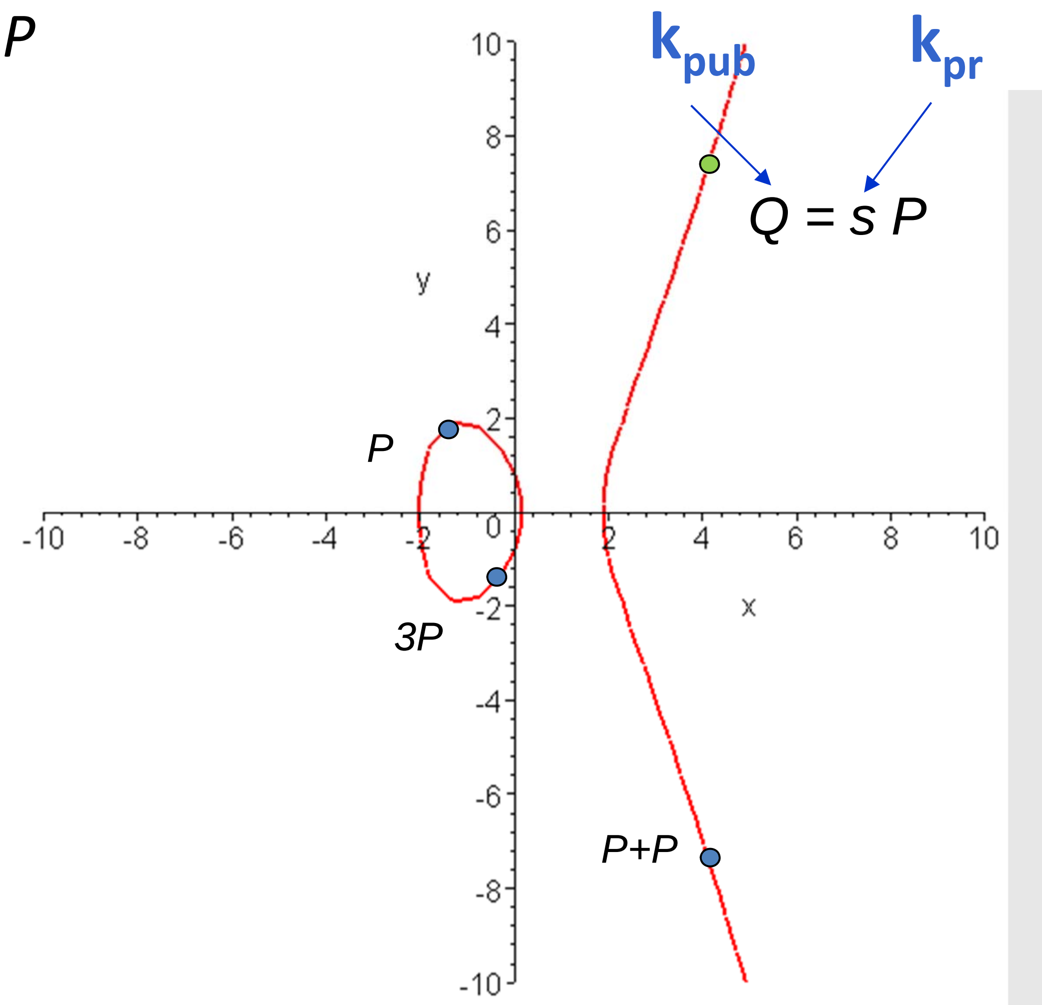
$$E:\ y^2=x^3+ax+b \bmod p$$

- Public key *Q* is multiple of base point *P*

$$Q = \underbrace{P + P}_{\text{group operation}} + \ldots + P = s\,P$$

- EC discrete logarithm problem:

$$s = dlog_P(Q)$$



Point Addition R = P + T

Jacobian Coordinates over GF(p)

- Input $P = (X_1,Y_1,Z_1)$; $T = (X_2,Y_2,Z_2)$
- Output $R = (X_3,Y_3,Z_3)$

$A = X_1Z_2^2 \bmod p$

$B = X_2Z_1^2 \bmod p$

$C = Y_1Z_2^3 \bmod p$

$D = Y_2Z_1^3 \bmod p$

$E = B - A \bmod p$

$F = D - C \bmod p$

$\boldsymbol{X_3} = -E^3-2AE^2+F^2$

$\boldsymbol{Y_3} = -CE^3+F(AE^2-X_3)$

$\boldsymbol{Z_3} = Z_1Z_2E$

1 Point Add = 14 MUL_{256bit} = 3584 MUL_{16bit}

Can we generate 1000+ signatures/sec with commodity hardware? (think Tara Tiny < Rs. 300,000)

Real-Time Signature Engine for VANETs

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Requirements

- 256bit ECC Engine (long-term security)
- 1000 sign./sec → 1,000,000,000 Mul_{16} /sec

New VANET Signature Engine

- Idea: use DSP blocks (fast mult-and-add units) on commercial FPGAs
- 1 Mul_{256} requires 63 cycles@500MHz
- **Low-cost FPGA: > 1.500 signatures/sec**
- (high-end FPGA: 30.000 signature/sec)
- performance and cost-performance record for **commercial hardware**

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Lightweight Cryptography

- “We need security with less than 2000 gates”
  Sanjay Sarma, AUTO-ID Labs, CHES 2002

- $3 trillions annually due to product piracy* (> US budget)

*Source: www.bascap.com

⇒ Authentication & identification: can both be fixed with cryptography

Strong Identification (symmetric crypto)

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r

$e_k\ (r) = y$

1. random challenge r
2. encrypted response y
3. verification

   $e_k\ (r) = y'$

   $y == y'$

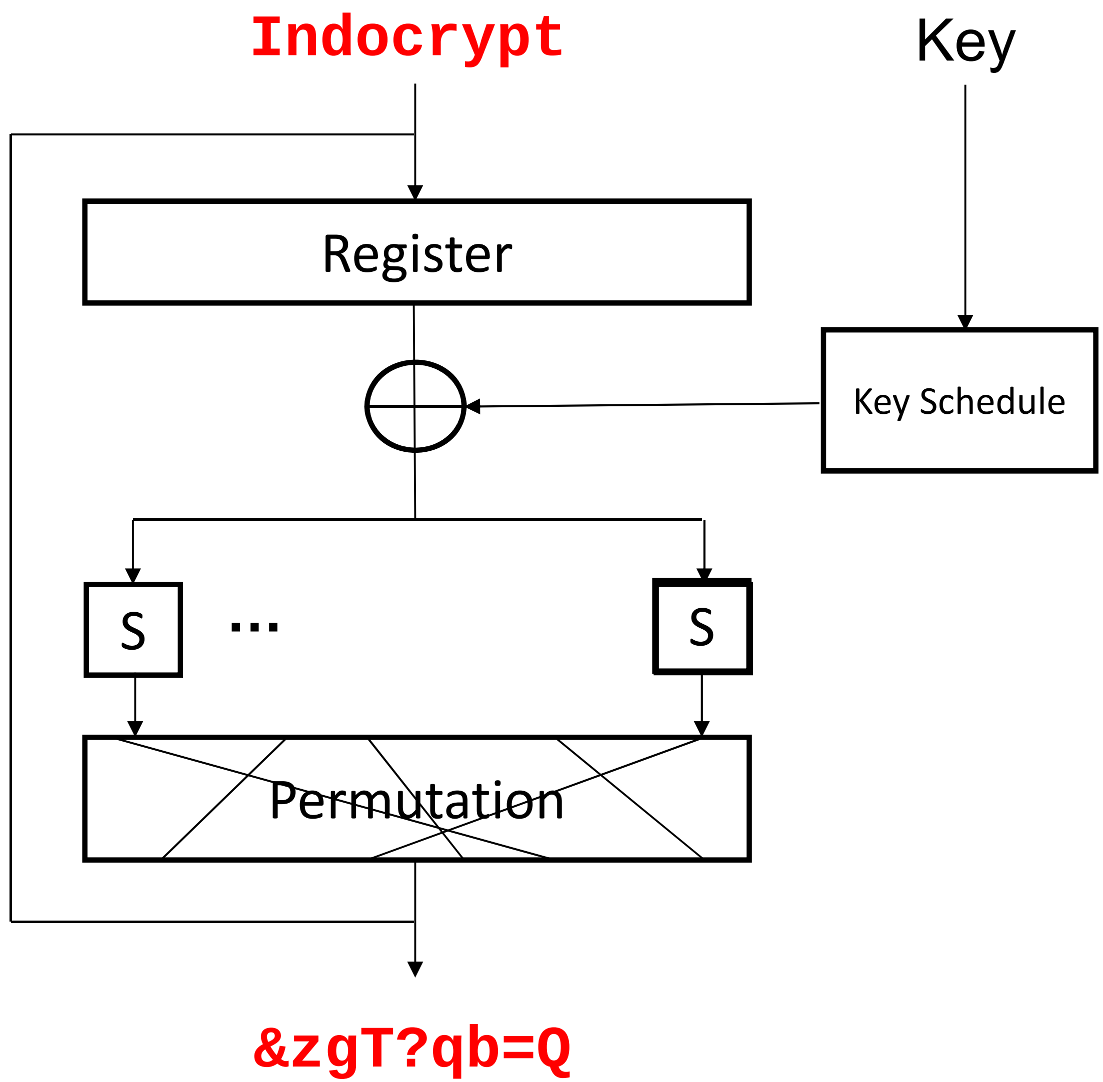
Challenge: Encryption function e() at extremely low cost

→ almost all existing ciphers not optimized for cost …

→ **Q: How cheap can we make cryptography?**

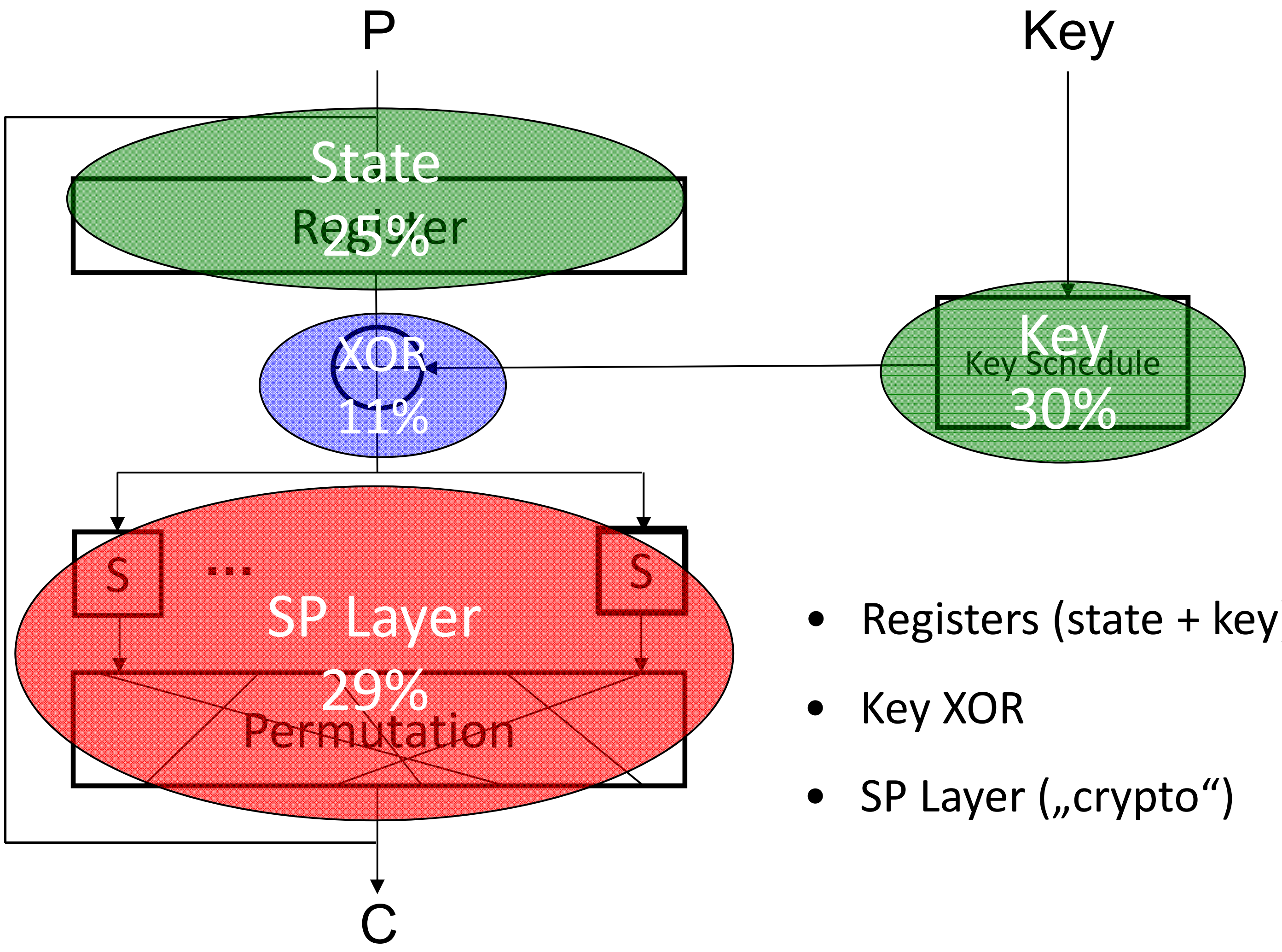
PRESENT – An agressively cost-otimized block cipher for RFID

- pure substitution-permutation network
- 64 bit block, 80/128 bit key
- 4-4 bit Sbox
- 31 round (32 clks)
- secure against DC, LC
- joint work with Lars Knudsen, Matt Robshaw et al.



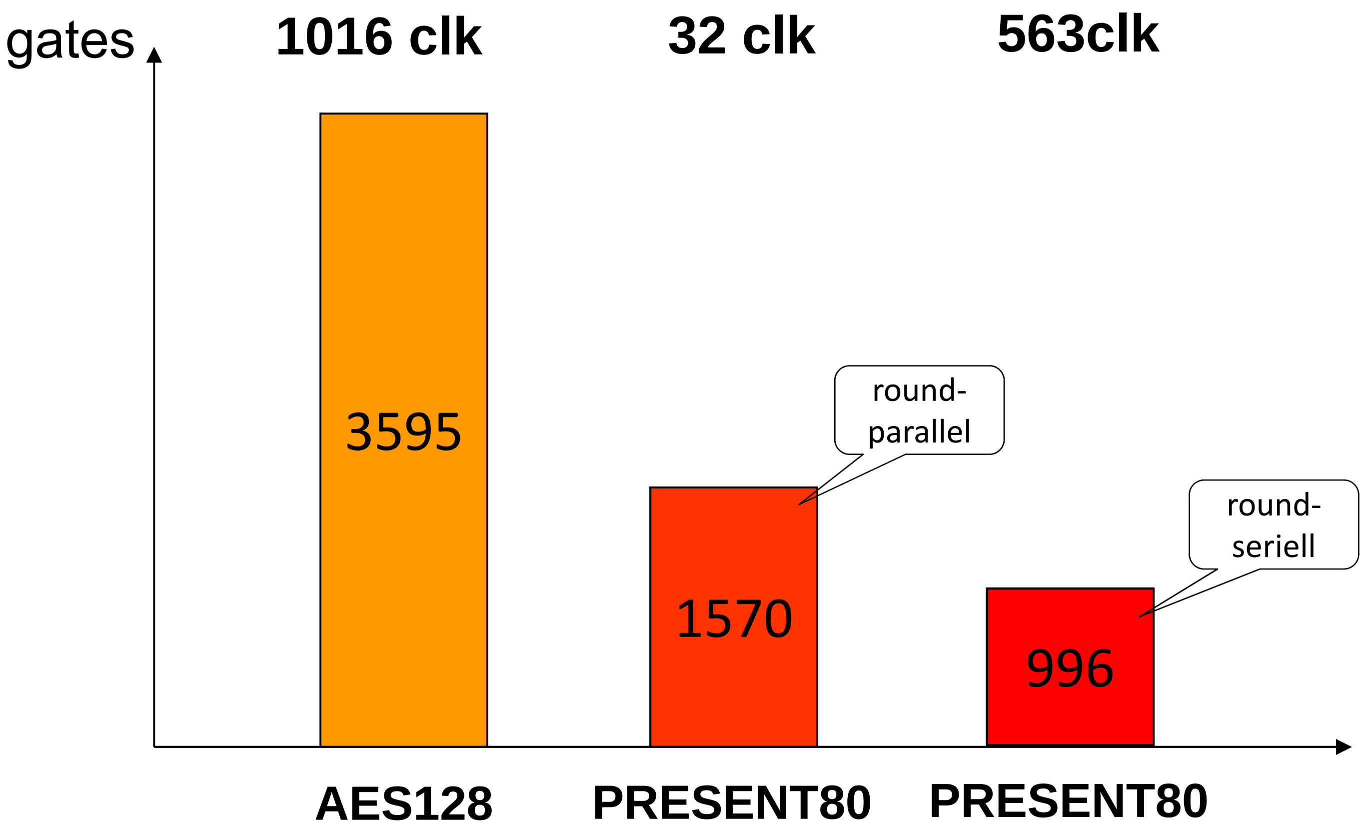
Resource use within PRESENT

Round-parallel implementation (1570ge)



- Registers (state + key) 55%
- Key XOR 11%
- SP Layer („crypto“) 29%

Results – PRESENT



- Smallest secure cipher
- Serial implementation approaches theoretical complexity limit: almost all area is used for the 144 bit state (key + data path)
- ISO standard pending (2012)
- “German Security Award 2010”

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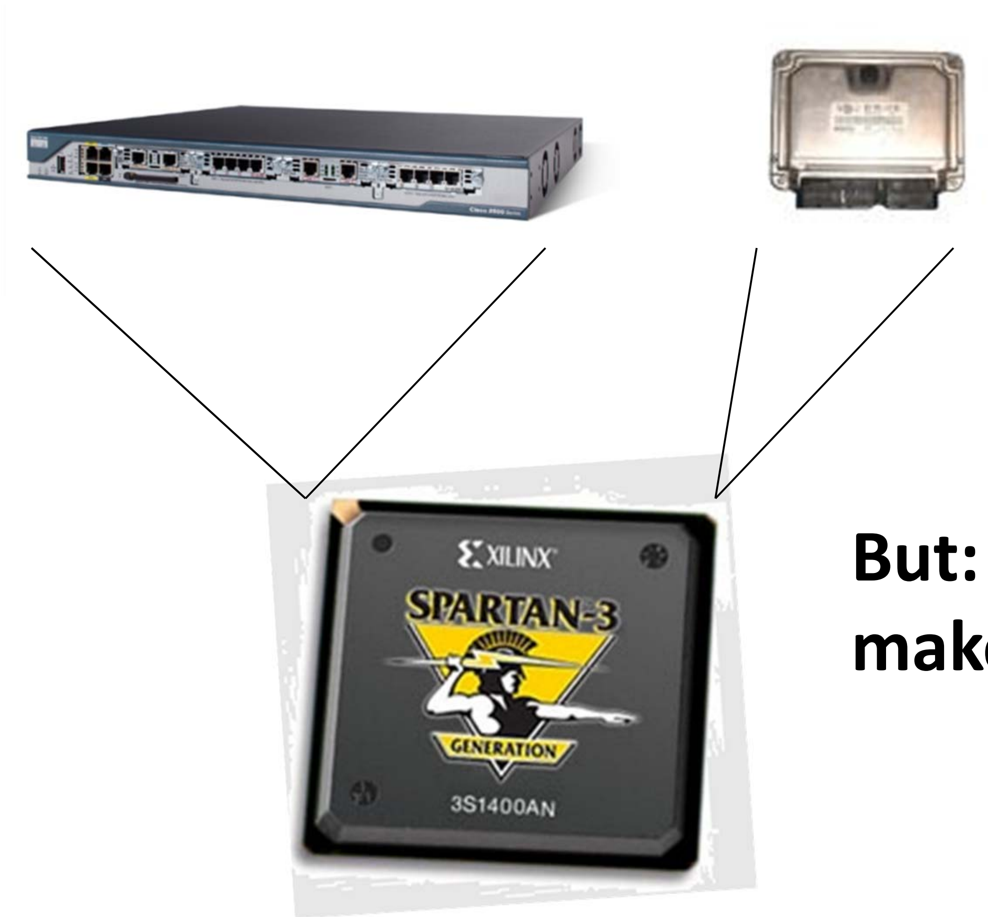
FPGAs = Reconfigurable Hardware

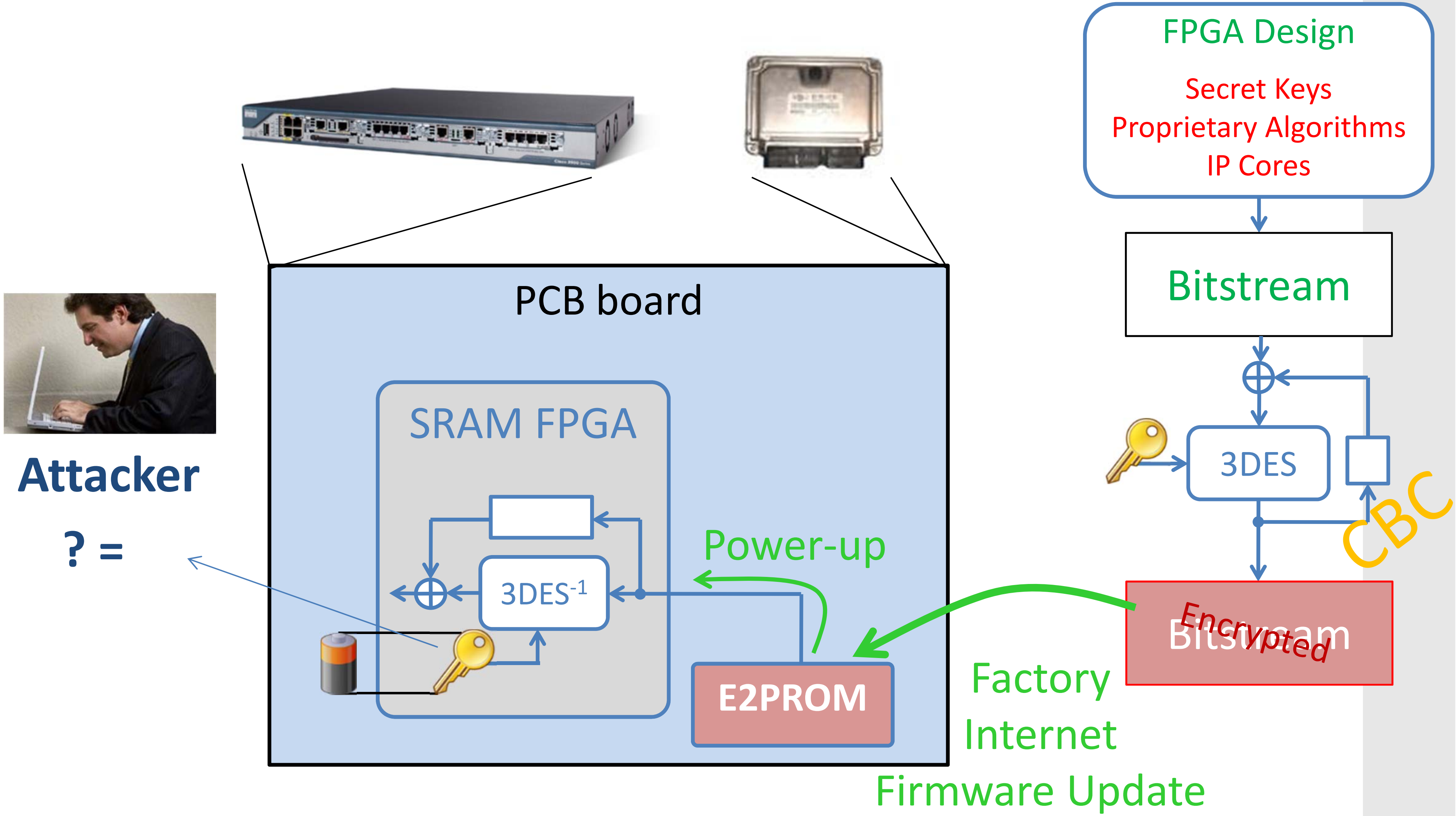


Widely used in

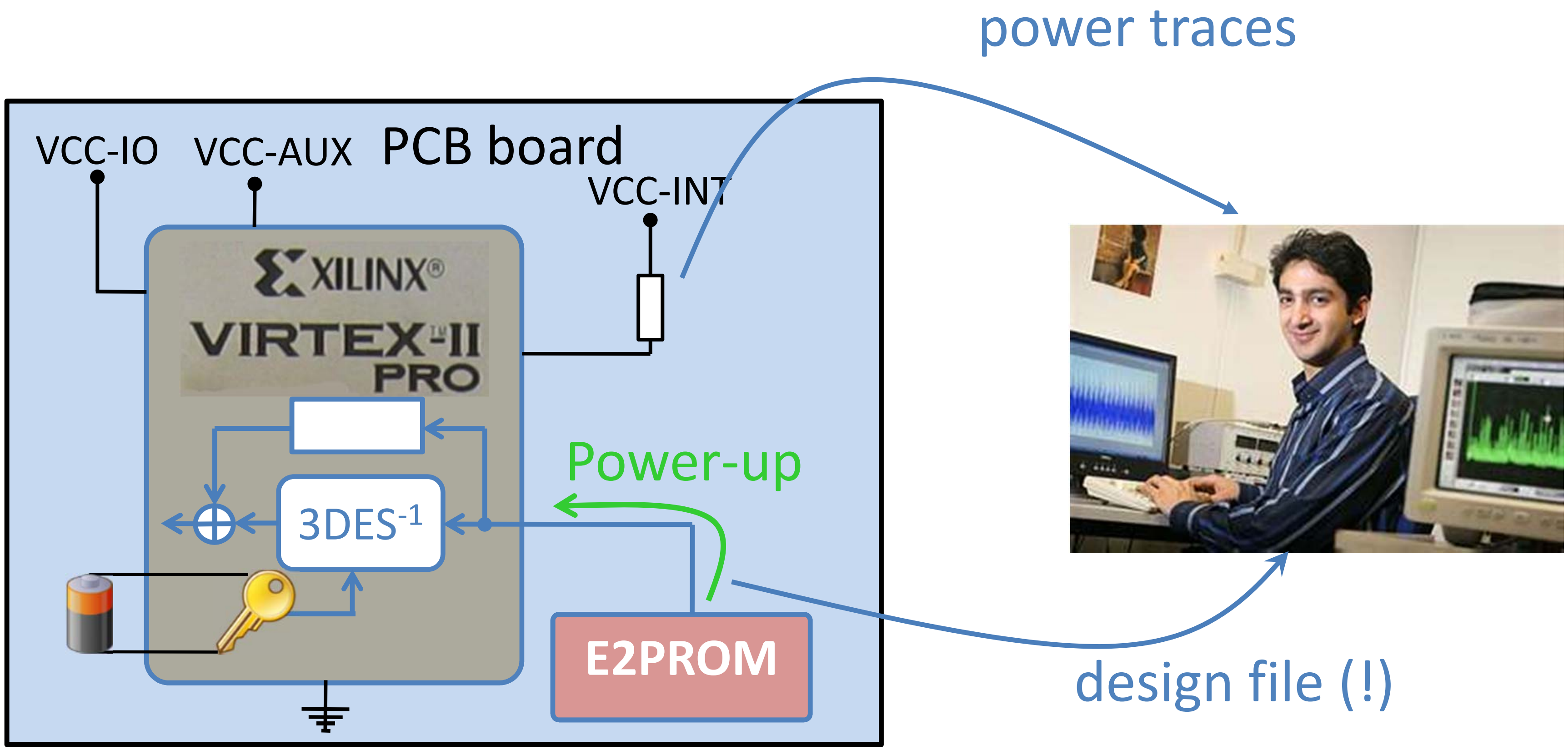
- routers
- consumer products
- automotive, machinery
- military

But: Copying the configuration files makes hardware counterfeiting easy!

Solution: Bitstream encryption



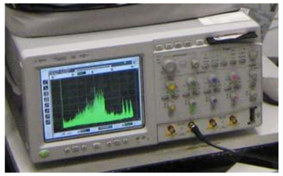
Let’s try side-channel analysis



Side-Channel Attacks (1-slide version)

Analyze cipher

- Find a suited predictable intermediate value in the cipher



Measurements

- Measure the power consumption

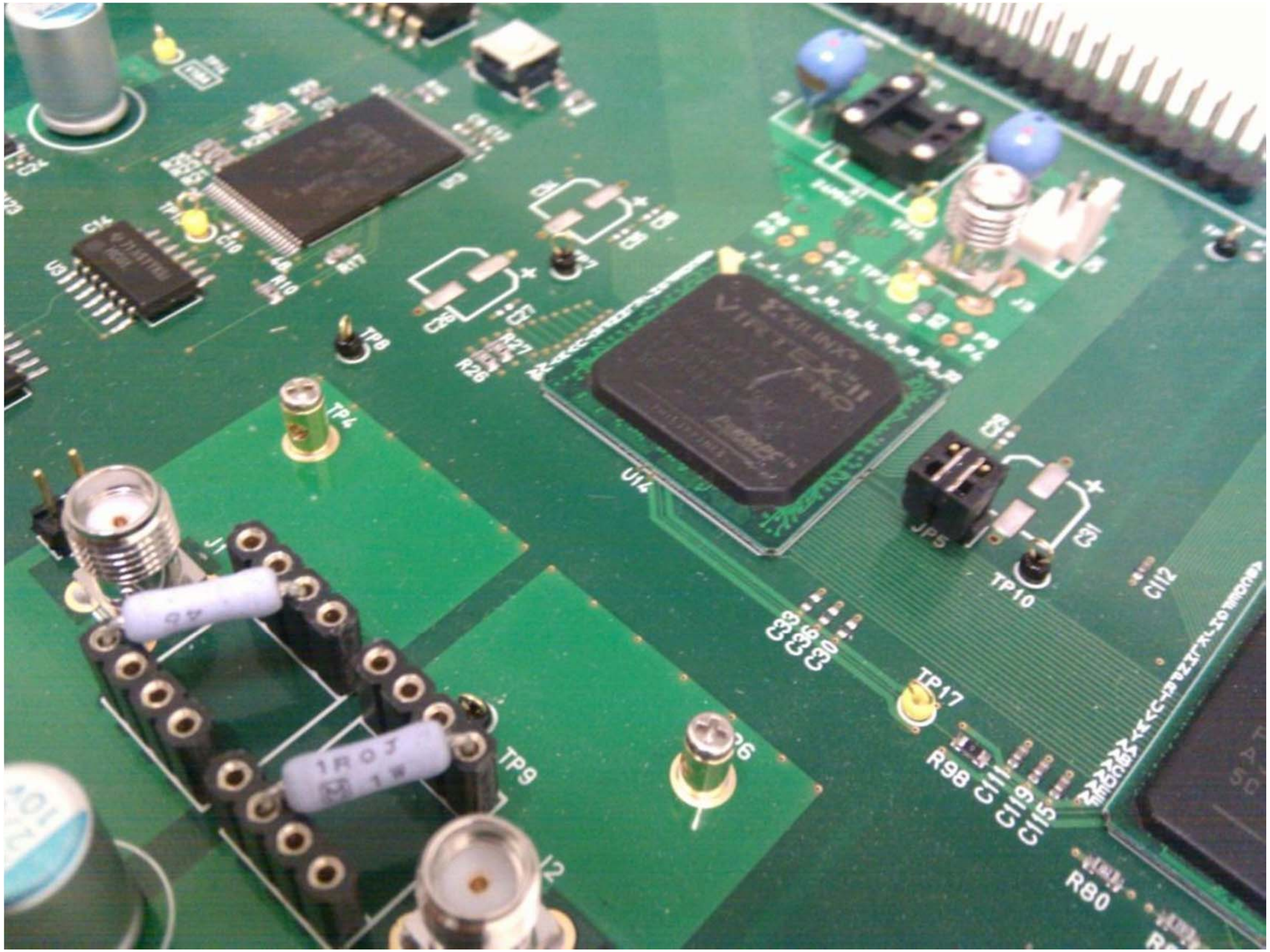
Post Processing

- Post-process acquired data

Key Recovery

- Perform the attack to recover the key

Our measurement set-up



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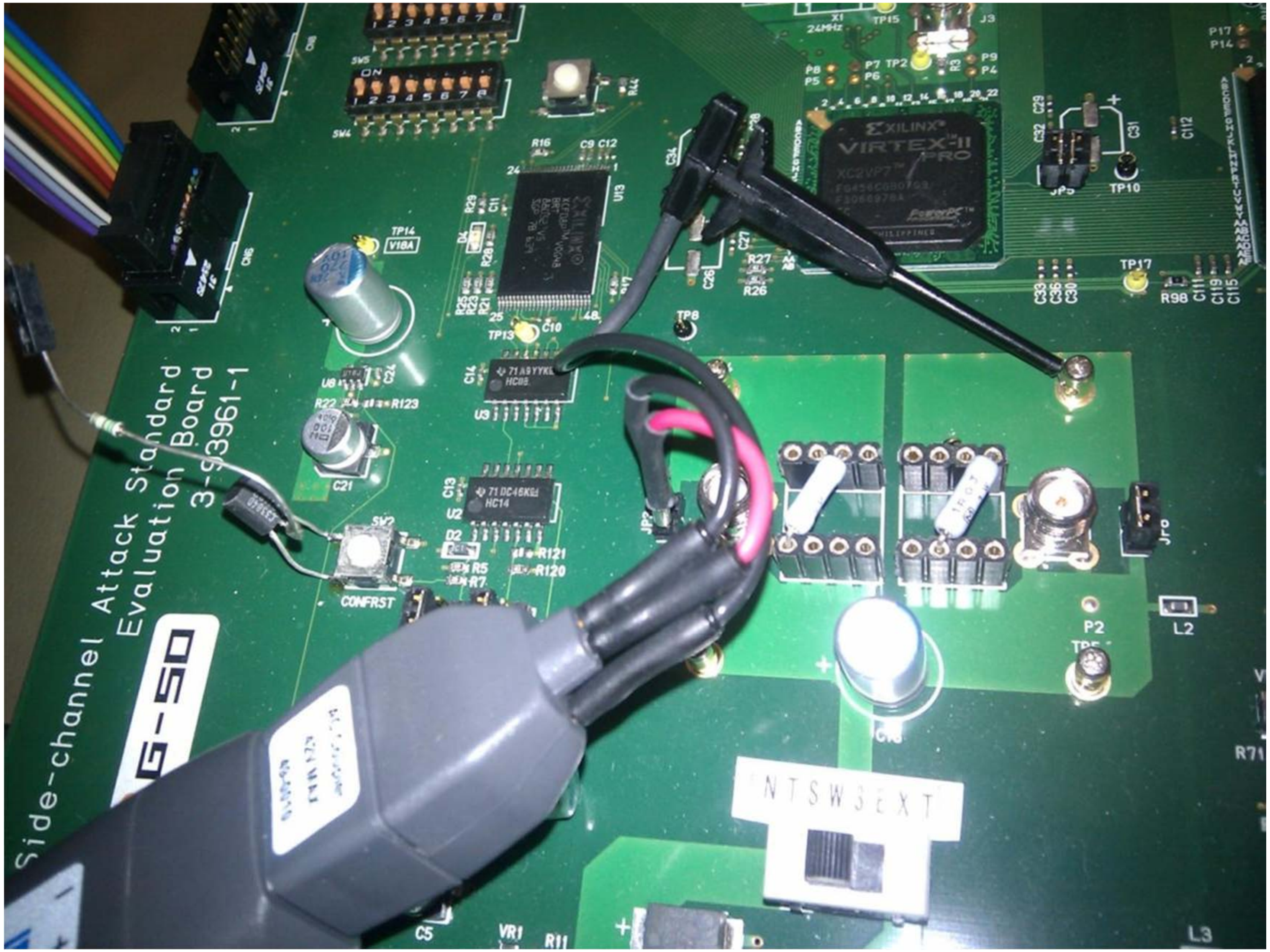
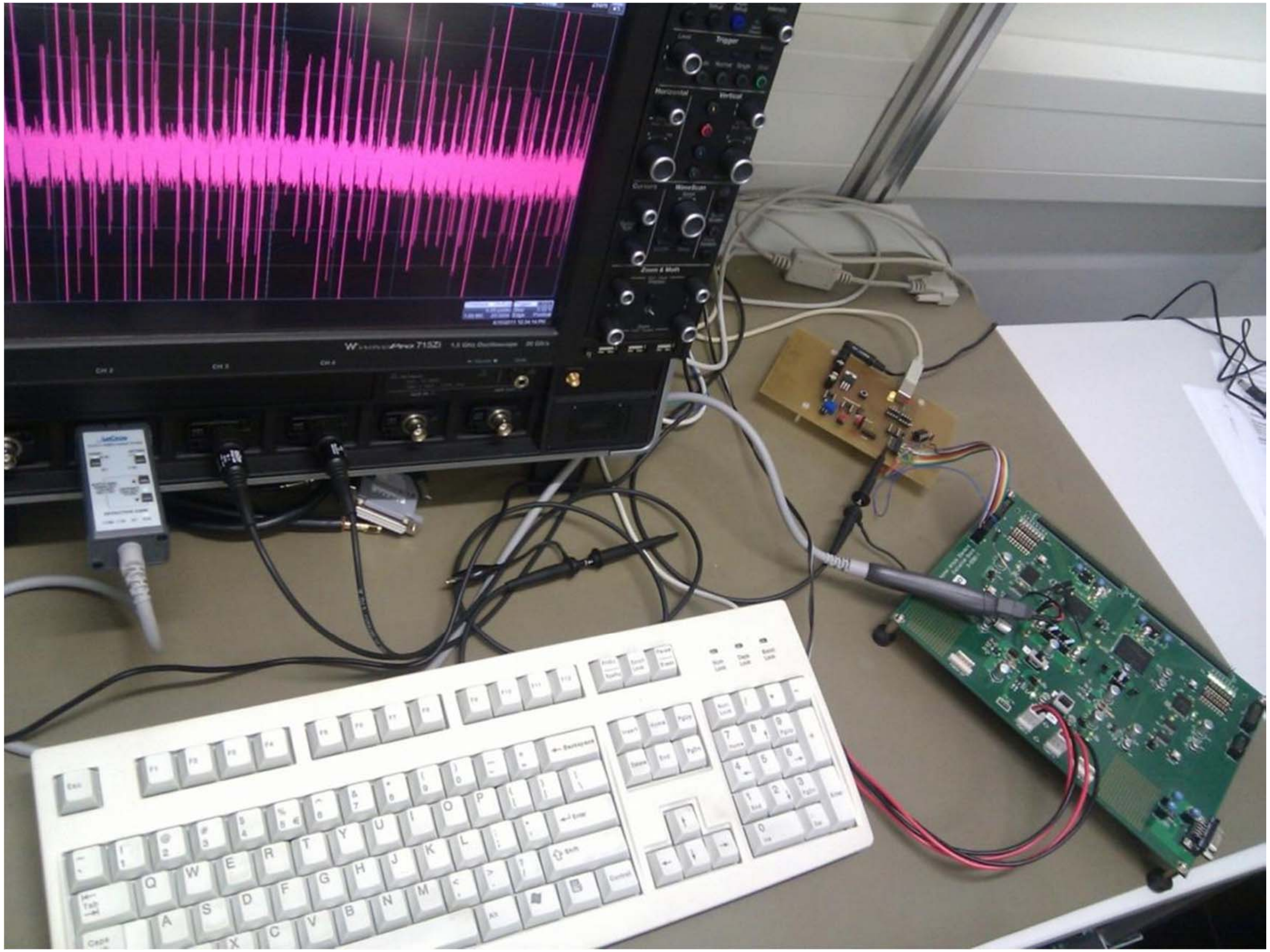
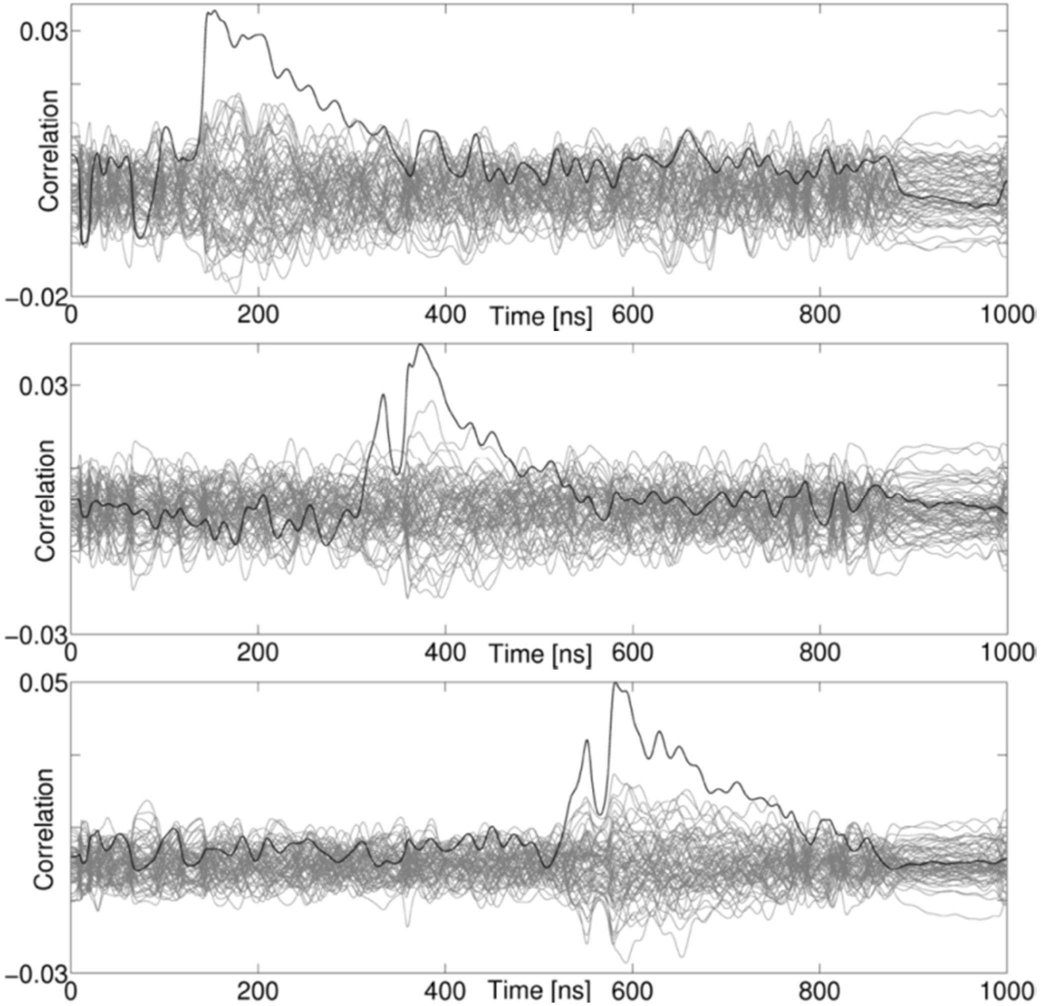


Signal acquisition



... 6 months later

RUB



key of 1st DES

key of 2nd DES

key of 3rd DES

Long story made short: Decryption of “secret” designs is easy!

- Requires *single* power-up (≈ 50,000 traces)
- Complete 3DES key recovered with 2-3 min of computation
- Attack possible even though 3DES is only very small part of chip (< 1%)
- Attack requires some experience, but
  - cheap equipment
  - easy to repeat

Implications

- Reverse engineering of design internals
- Cloning of product
- Alterations of design (chip tuning)
- Trojan hardware (i.e., malicious hardware functions)
- …

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Contactless Payment Cards

- Contactless card ≈ RFID + symmetric crypto
- Many security-sensitive applications
  - payment
  - passport
  - public transport
  - access control

- Security hinges on secrecy of key …

Sources:
Wikipedia, cutviews.com

Brief history of contactless cards

- **First generation** (since 2000 and earlier)
  Mifare Classic, Legic Prime, TI DST, Hitag, ...
  – Proprietary cipher
  – Short key
  – **Classical attacks (mathematical, brute-force) feasible**

- **Today**
  Mifare DESFire (EV1), Mifare Plus, Legic Advant, Infineon SLE, SmartMX, ...
  – 3DES & AES → secure against classical cryptanalysis
  – ?Implementation attacks?

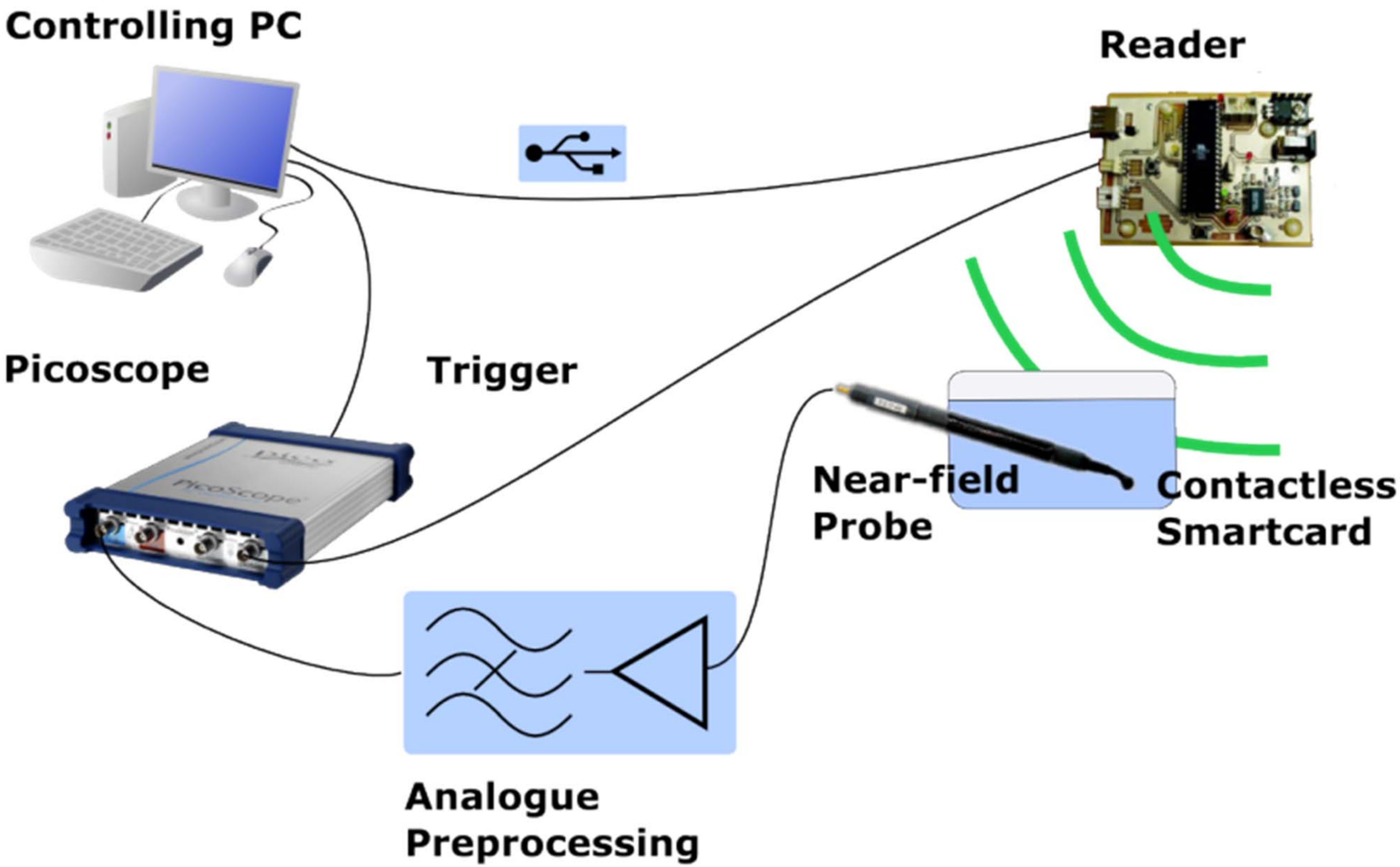
Mifare DESFire Attack

RUB

- **Strong cipher**: 3DES
- **Widely used**: Prague, San Francisco, …
- RFID – **Power traces from EM field**

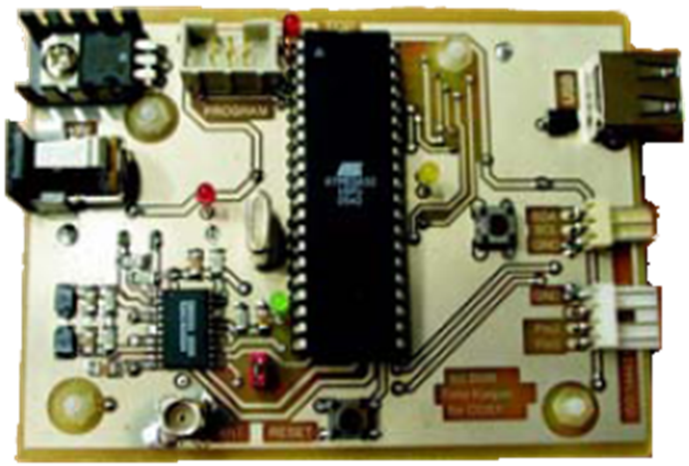
$\Rightarrow$ High **threat for real world (payment) systems**

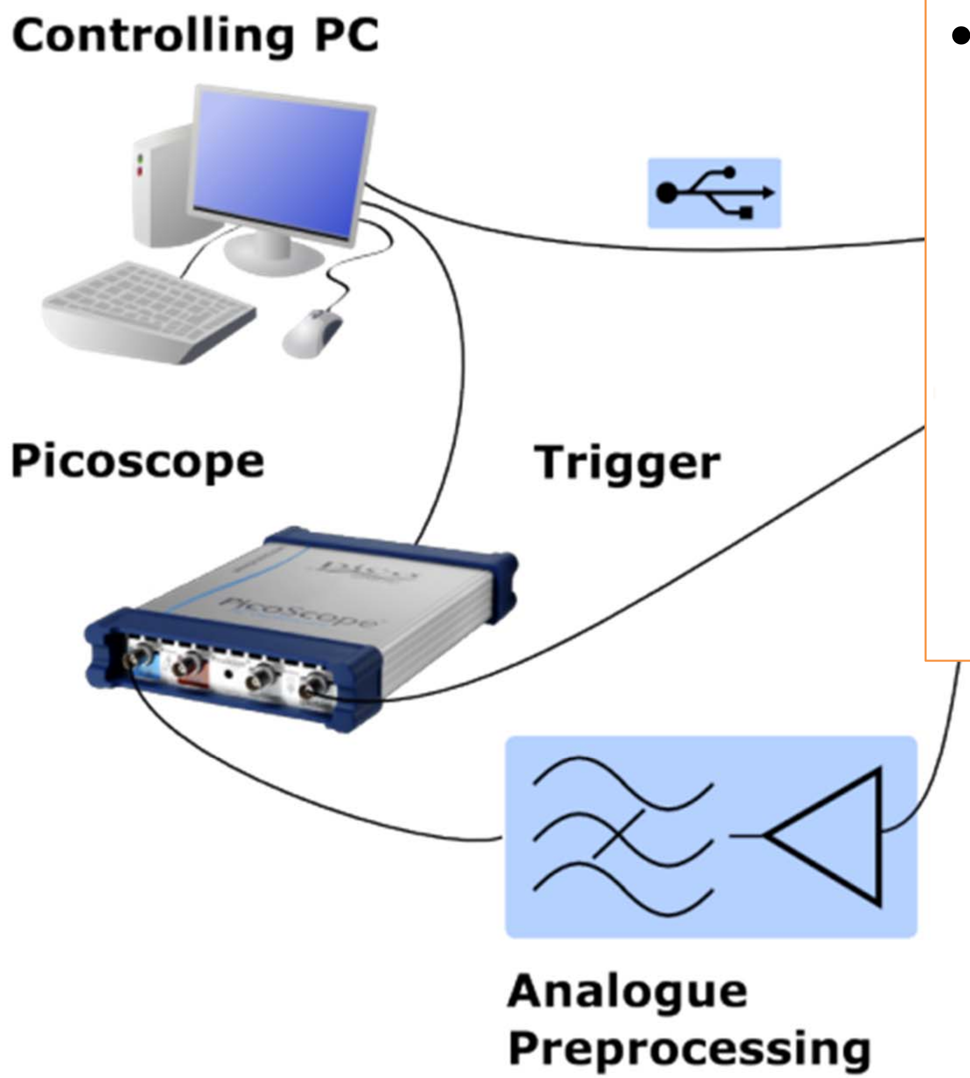
Measurement Setup



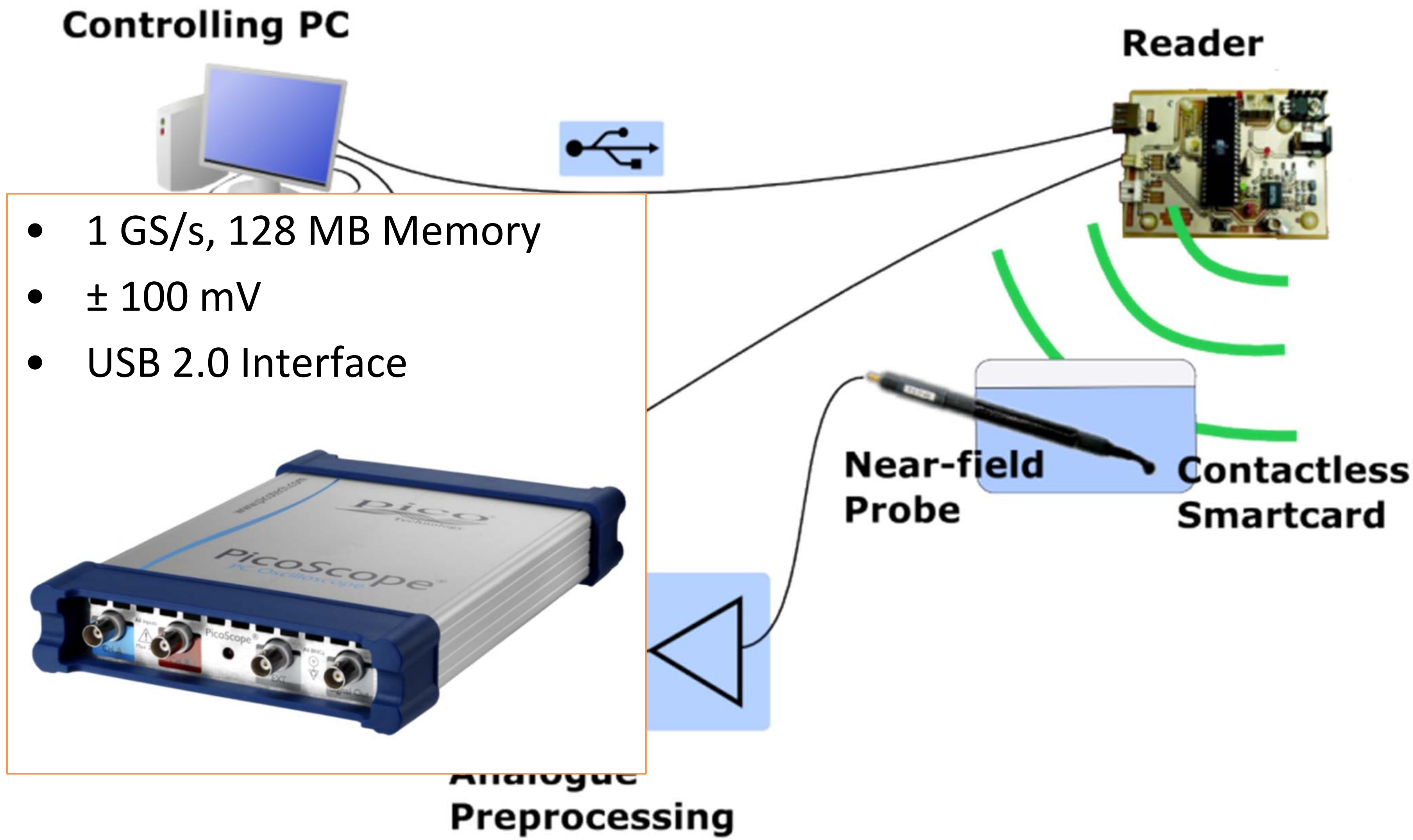
Measurement Setup

- ISO14443-compatible
- Freely Programmable
- Low Cost (< 40 €)



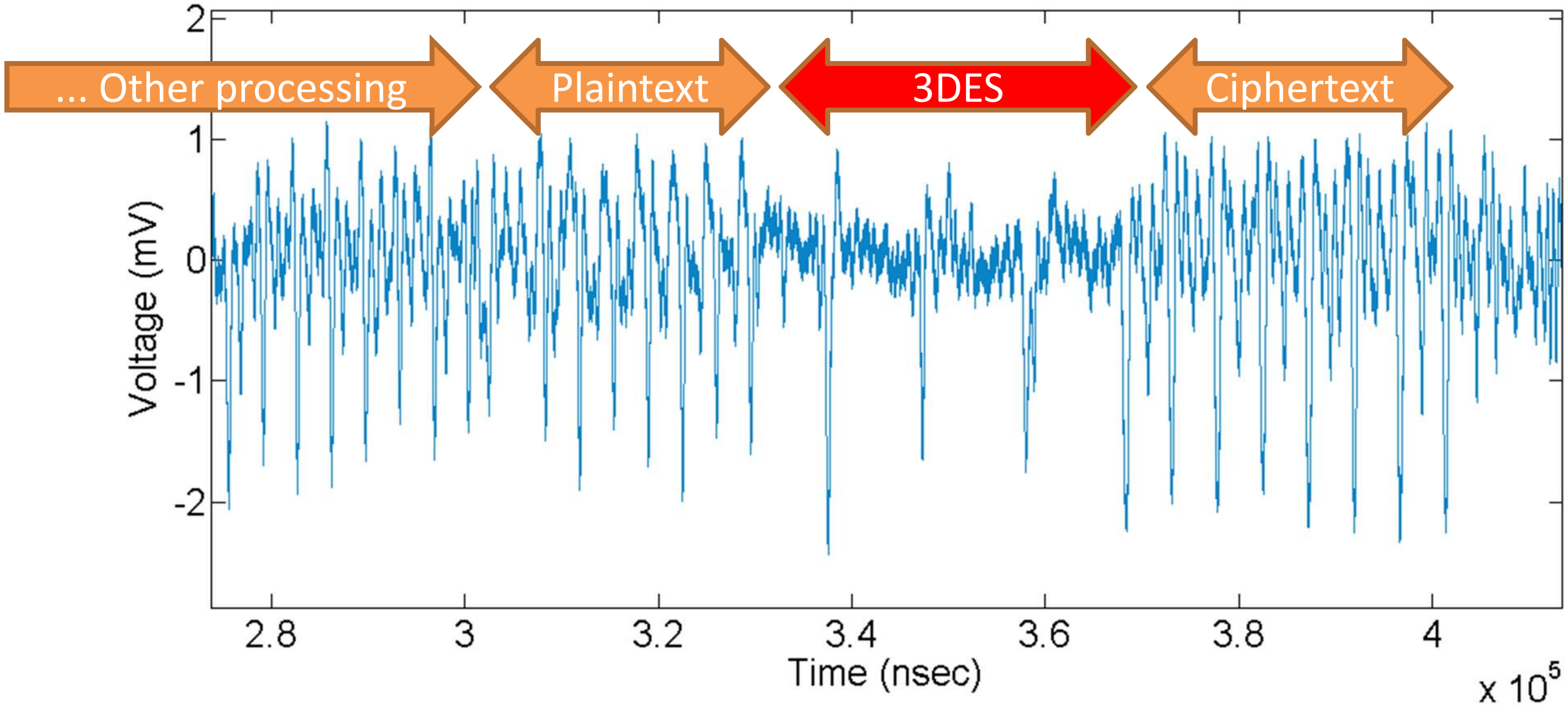


Measurement Setup

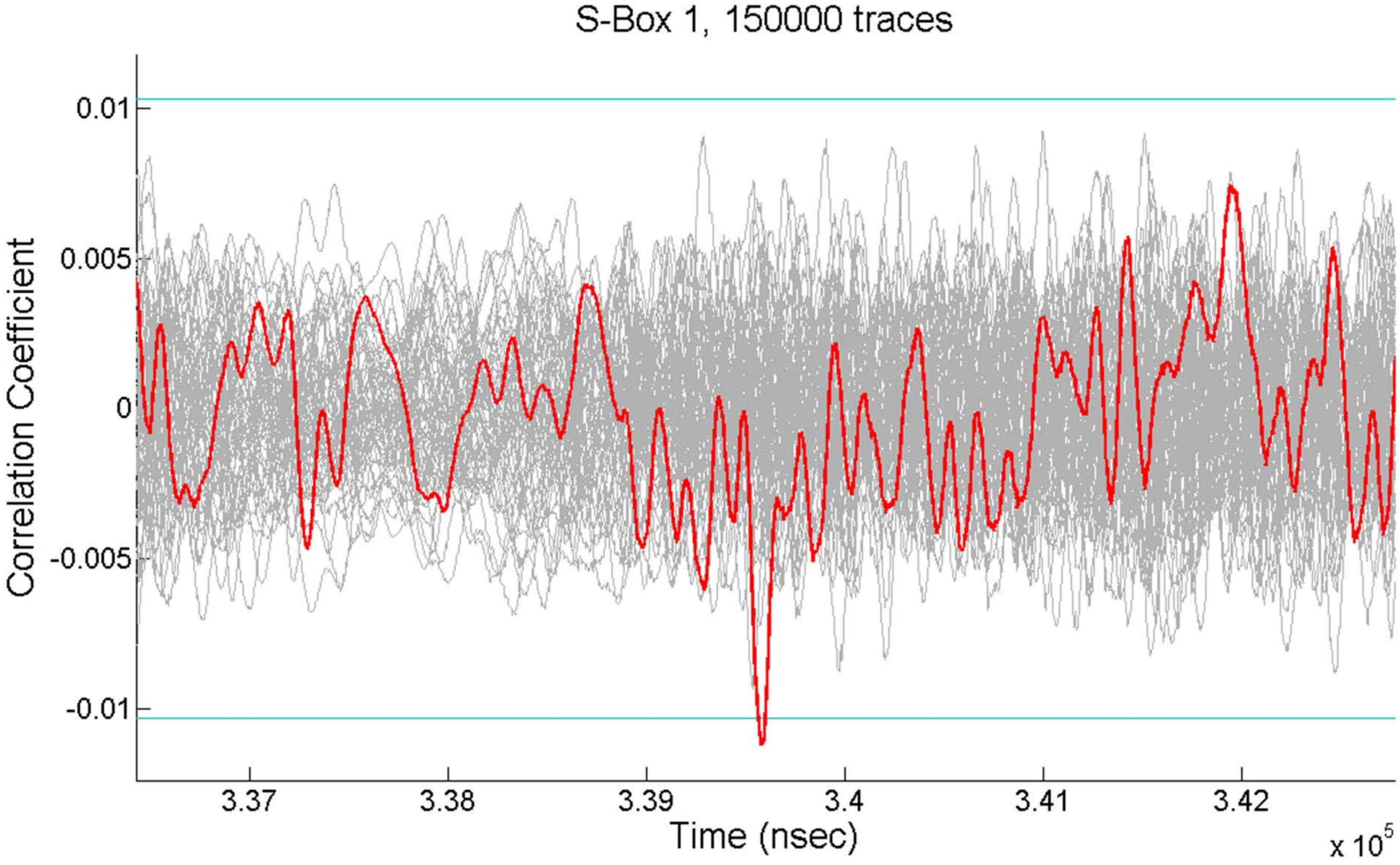


- 1 GS/s, 128 MB Memory
- ± 100 mV
- USB 2.0 Interface

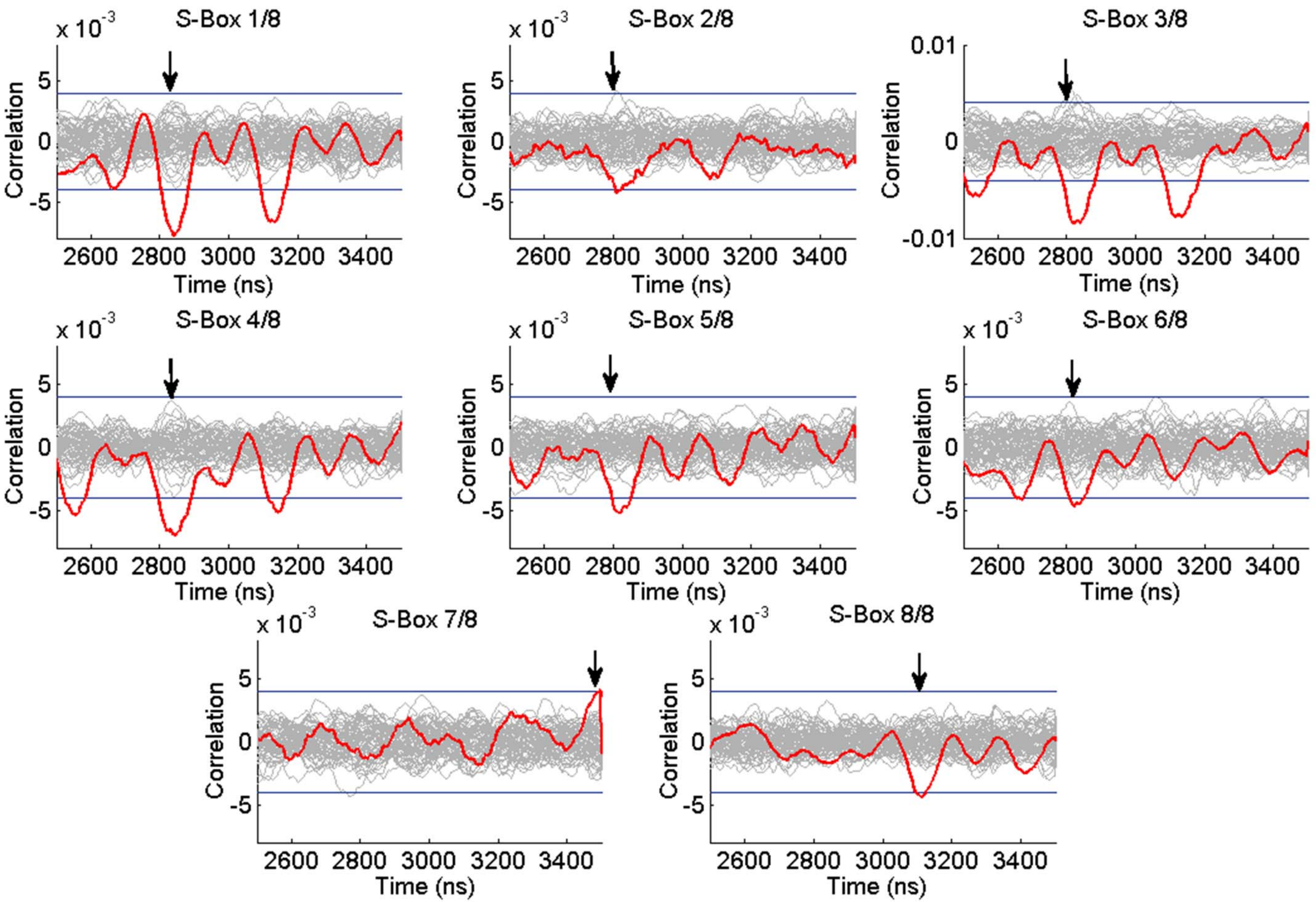
Trace Overview



Example: DPA-extraction of 6 key bits



DES Full Key Recovery



Conclusions: DESFire Attack

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- **Full key-recovery** with appr. 250k traces (≈ hours)
- **Low-cost equipment,** $2500
- Opportunities for optimization

$\Rightarrow$ High **threat for real world (payment) systems**

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Let‘s look again at: Yin Yang and Crypto

The concept of yin yang is used to describe how polar opposites or **seemingly contrary forces** are interconnected and interdependent in the natural world, and how they **give rise to each other** in turn.

This seems very close to the established notion of

$$\text{cryptography} \leftrightarrow \text{cryptanalysis}$$

- Why have we (= crypto community) never talked about yin yang?
- Yin yang might make it easier to explain ethical hacking to the outside world.

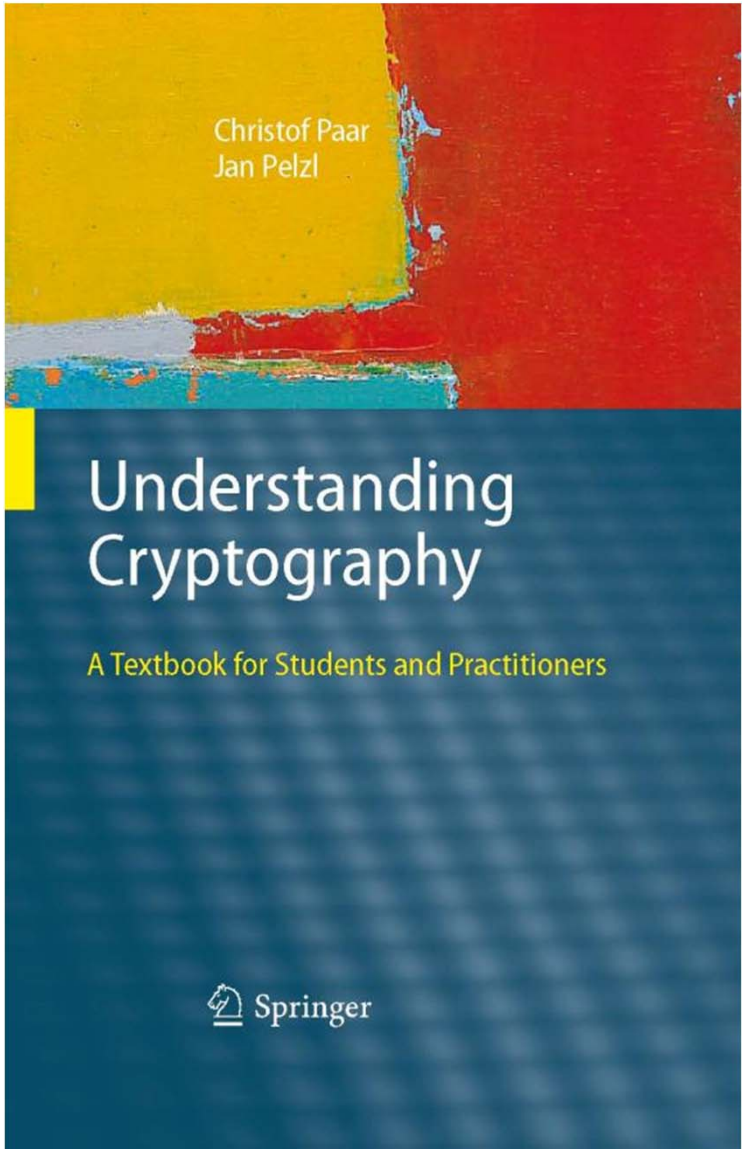
Related Workshops

RFIDsec 2012
June 2012, Nijmwegen, Holland

CHES – Cryptographic Hardware and Embedded Systems
September 2012, Leuven, Belgium

escar – Embedded Security in Cars
November 2012, Germany

… and yet another crypto book



- accessible (hopefully)
- quite comprehensive
- **videos, slides, …**

  www.crypto-textbook.com
- flyers are outside