# The Next 10 Years of IT Security: RFID, BMWs and Burglars


**Stanford University**
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# Overview

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- Embedded Systems and Security
- Case Study 1: Securing RFID
- Case Study 2: High Speed Signature Engine
- Case Study 3: Access Control and Physical Attacks
- Related Activities

# What are Embedded Systems?

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Embedded System

- „Processor hidden in a product“, or
- „A computer that doesn‘t look like a computer“

# Characteristics of Embedded Systems

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- Definition: „Device with processor“





- Single purpose
- Interacts with the world
- many, many applications

# Is this really important ?

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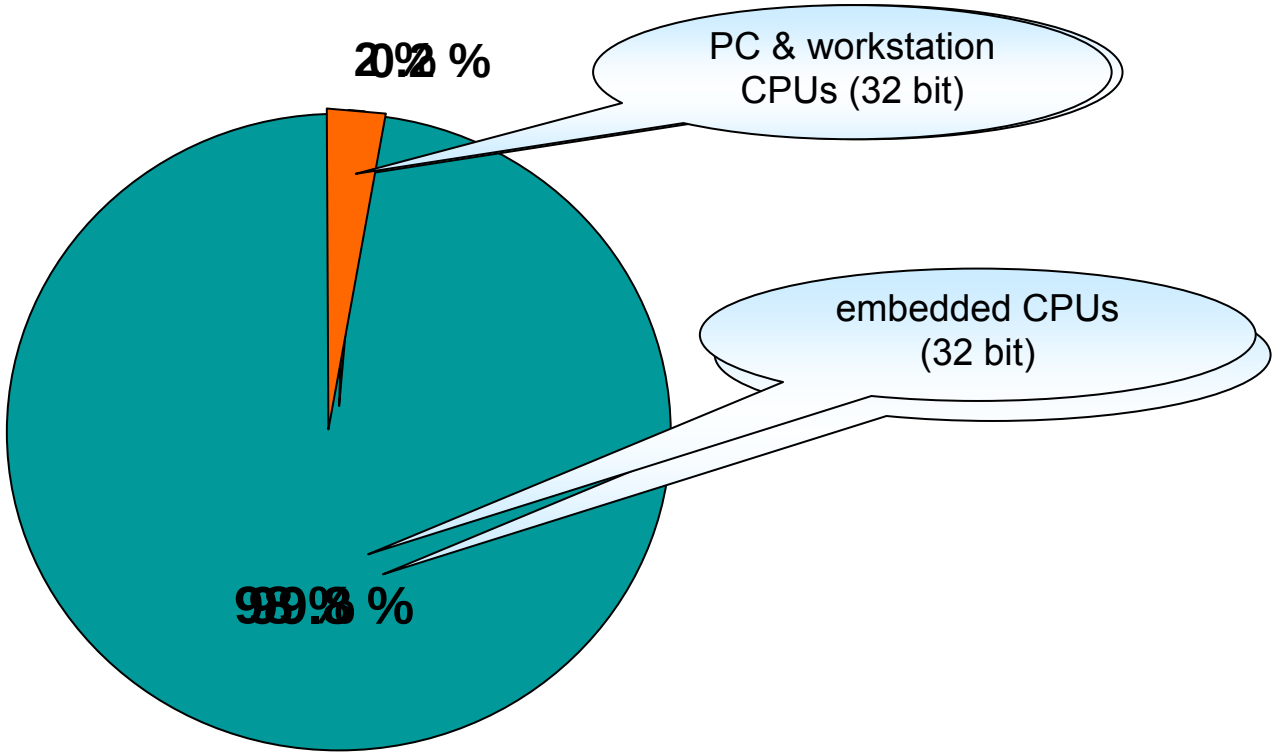
- current CPU market
- by the numbers




- So, how does embedded technology affect the future IT landscape?

# Brave New Pervasive World

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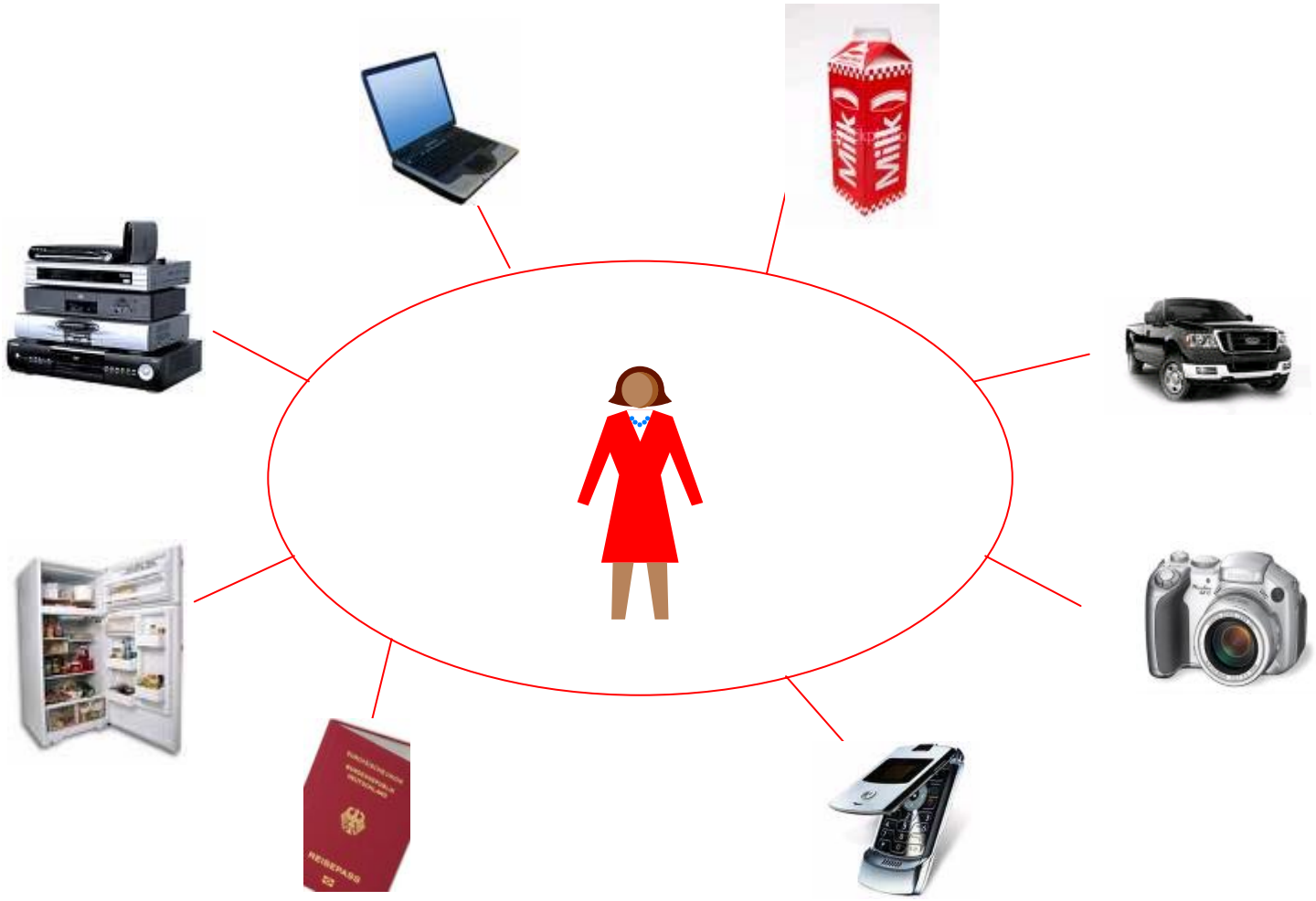

# Security Concerns in Embedded Applications

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- Pervasive nature and **safety-critical** applications increase risk potential: *Hard disk crash vs. car crash*
- Often **wireless channels** $\Rightarrow$ vulnerable
- **Contents protection** in many applications: iPod, navigation systems, XBox,, …
- **Secure SW download**: engine control, cell phones, washing machine,…
- **Component protection**: original spare parts, product privacy protection, …
- **Privacy issues:** biometrics (face recognition), geolocation, medical sensors, monitoring of home activities, etc.
- **Legislative requirements**: passports, road toll, data event recorders in machines, …

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# Lightweight Cryptography

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

- $3 trillions annually due to product piracy* (> US budget '07)


*Source: www.bascap.com

⇒ Authentication & identification problem: can both be fixed with cryptography

⇒ Q: How cheap can we make symmetric ciphers?

# Strong Identification (w/ symmetric crypto)




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 symmetric ciphers optimized with SW in mind

# PRESENT – An agressively hardware optimized block cipher for RFID

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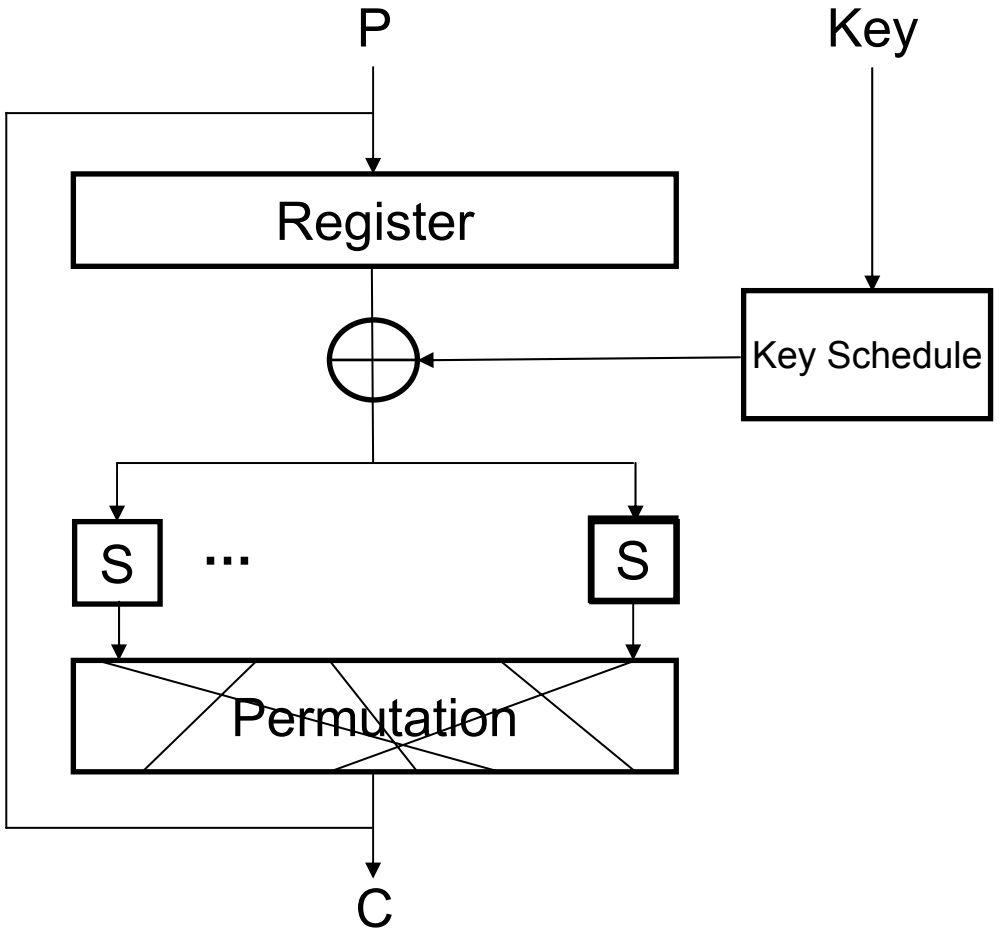
- pure substitution-permutation network
- 64 bit block, 80/128 bit key
- 4-4 bit Sbox
- 31 round (32 clks)
- „provable secure“ against DC, LC
- joint work with Lars Knudsen, Matt Robshaw et al.
- no patents etc.



# Resource use within lightweight ciphers

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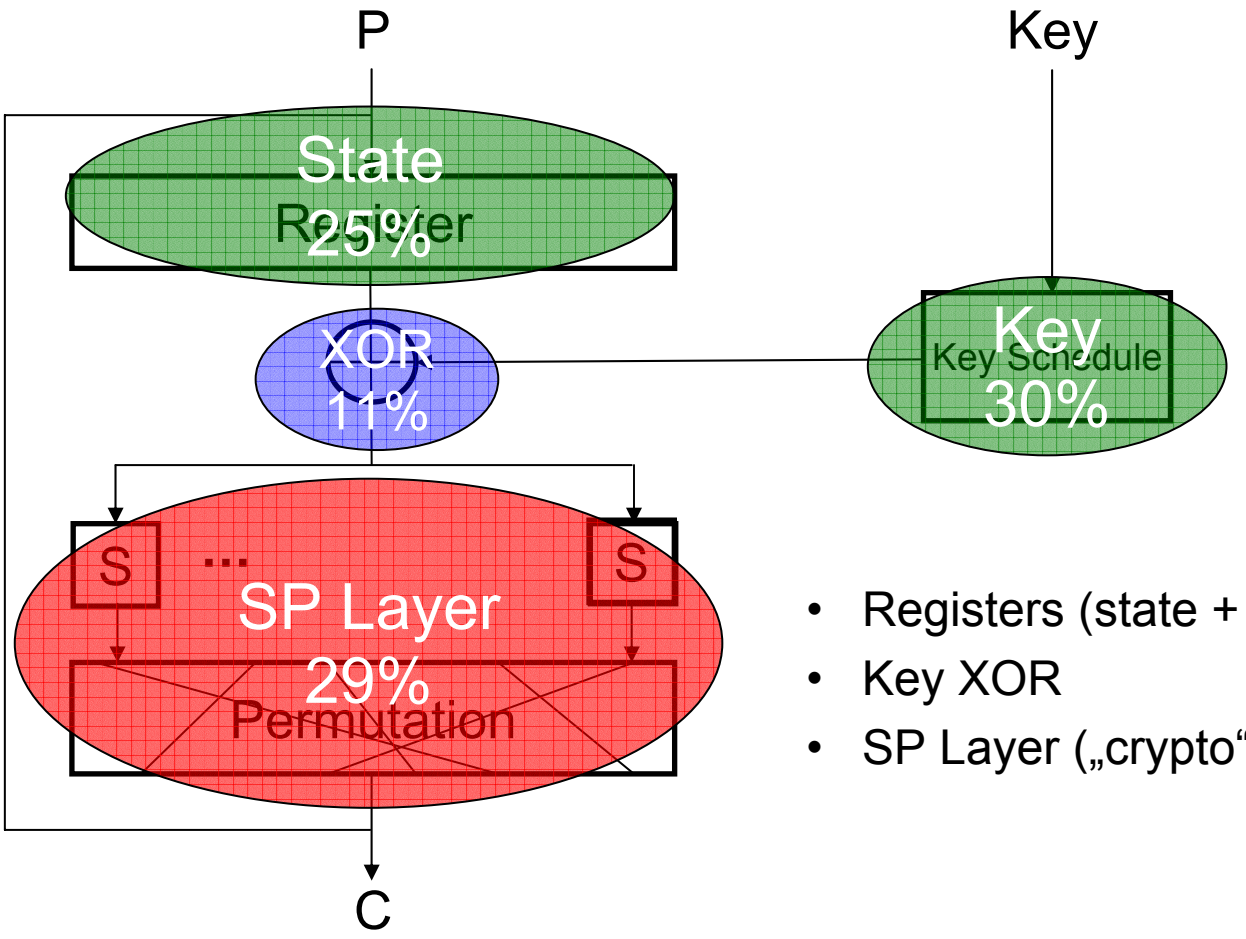
Round-parallel implementation of PRESENT (1570ge)




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

# Results – PRESENT

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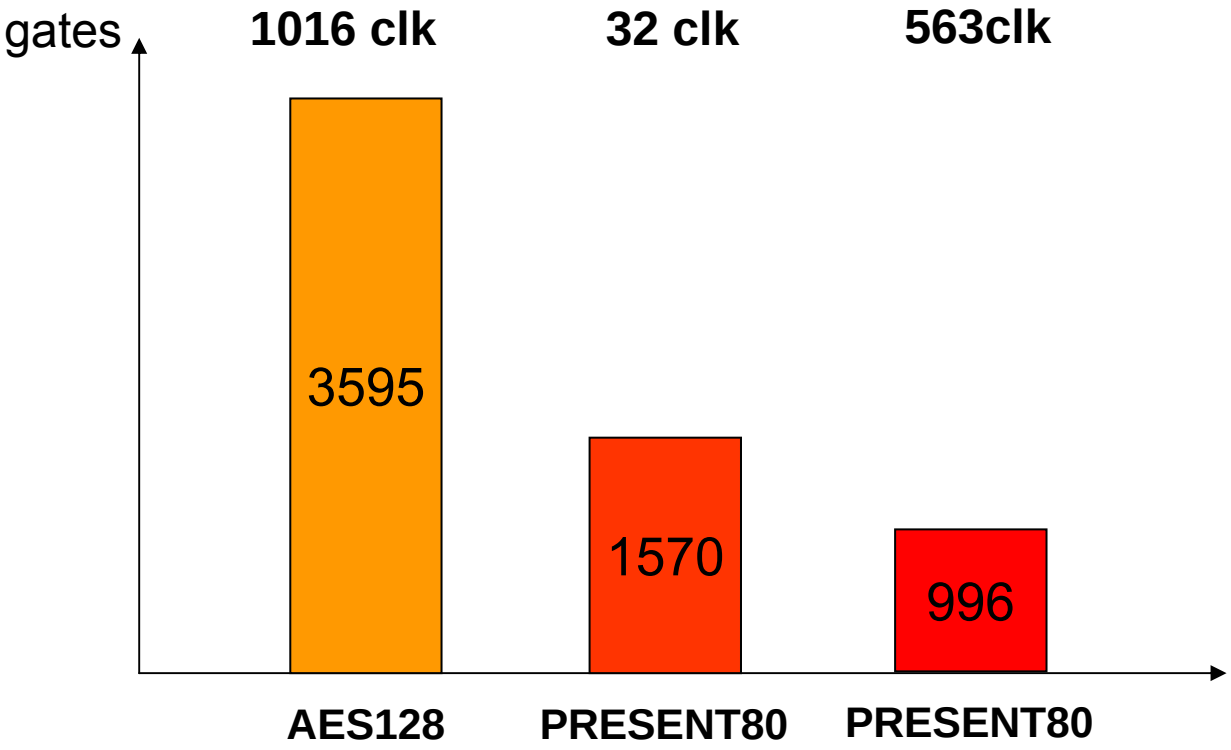


- TA product 1-2 orders of magnitude better than smallest AES architecture
- Serial implementation approaches theoretical complexity limit: almost all area is used for the 144 bit state (key + data path)
- smaller than all stream ciphers
- details: CHES ’07 paper

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# Case Study:
# High Speed Signature Engine

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- USA: 42,000+ car fatalities per year (IIHS, 2002)
- 3.2m injuries (2000)
- est.: 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

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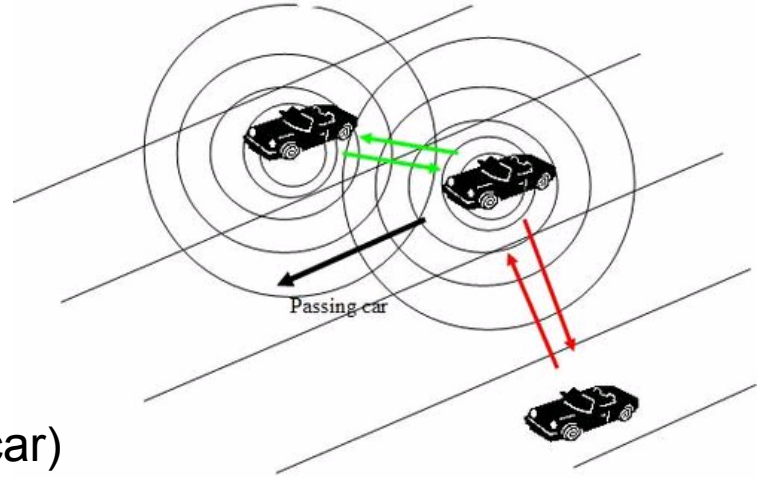
Broadcast position & direction information:

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)

# Elliptic Curve Primitive

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- Given a Point *P* on an elliptic curve E over GF(p):

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

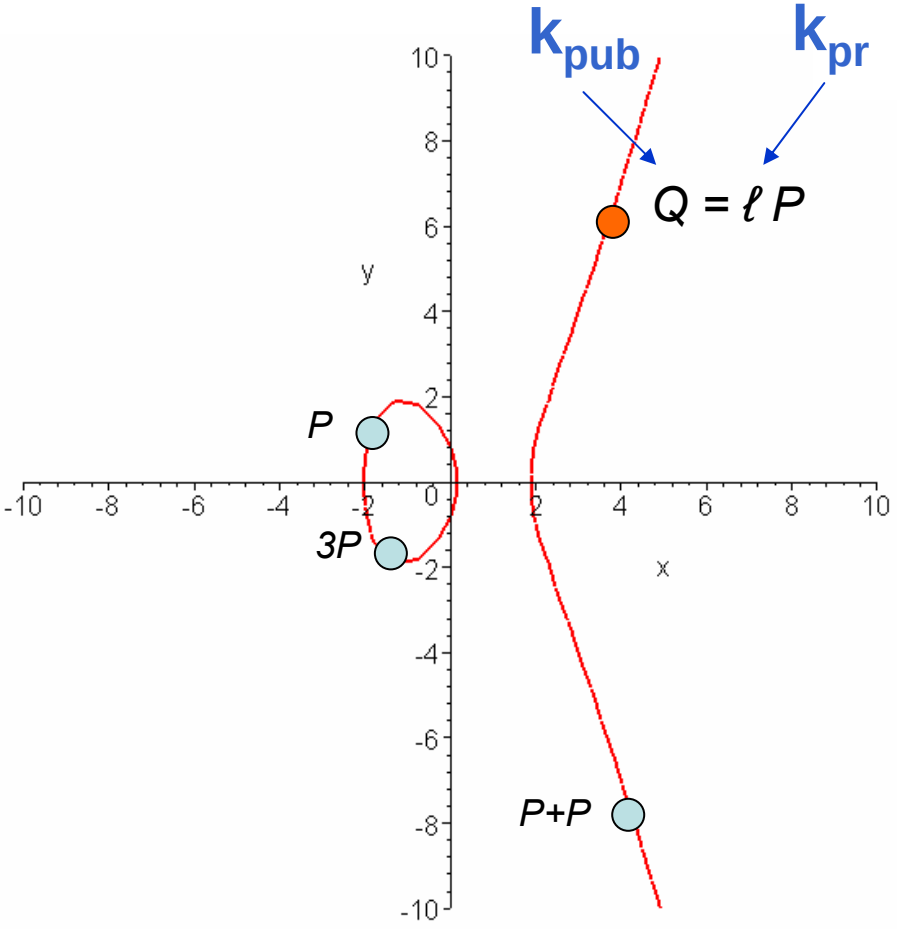
- Public key *Q* is multiple of base point P

group operation

$$Q = P+P+ \ldots +P = \ell P$$

- EC discrete logarithm problem:

$$\ell = dlog_P(Q)$$



# Point Addition on EC

## Jacobian Coordinates over GF(p)

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- **Point Addition** R = P + S
- Input $P = (X_1, Y_1, Z_1)$ ; $S = (X_2, Y_2, Z_2)$
- Output $R = (X_3, Y_3, Z_3)$

$A = X_1 Z_2^2 \bmod p$

$B = X_2 Z_1^2 \bmod p$

$C = Y_1 Z_2^3 \bmod p$

$D = Y_2 Z_1^3 \bmod p$

$E = B - A \bmod p$

$F = D - C \bmod p$

$\boldsymbol{X_3} = -E^3 - 2AE^2 + F^2$ $\quad \boldsymbol{Y_3} = -CE^3 + F(AE^2 - X_3)$ $\quad \boldsymbol{Z_3} = Z_1 Z_2 E$

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

# Real-Time Signature Engine for VANETs

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

- *New VANET Signature Engine*
- 1 $Mul_{256}$ requires 63 cycles@500MHz
- **1 ECC VANET engine: > 1500 signatures/sec**
- performance and cost-performance record for **commercial hardware**
- patent pending

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# Case Study Access Control

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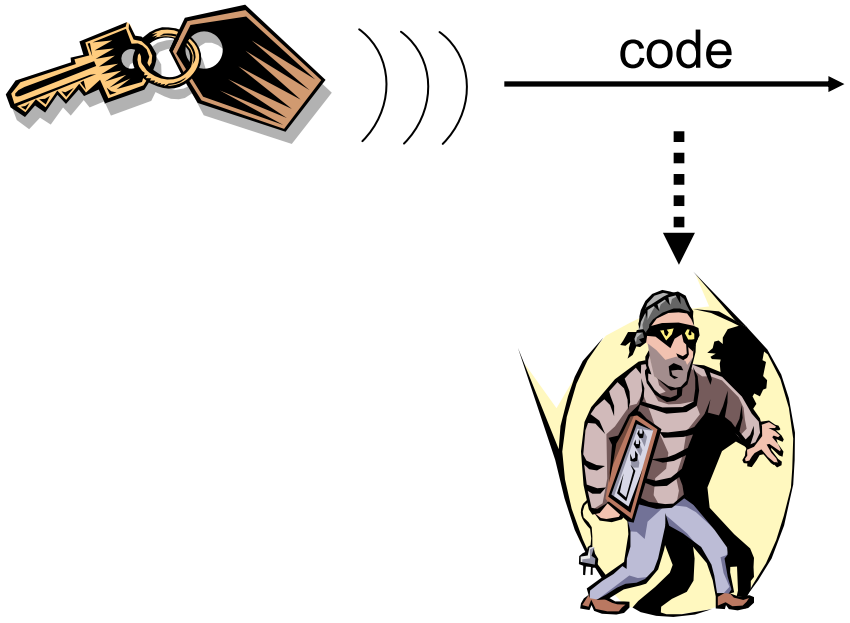
- Simple access controls: fixed code (“password”)




- eavesdropper duplicates key (cloning)
- but the industry learned…

# Case Study Access Control

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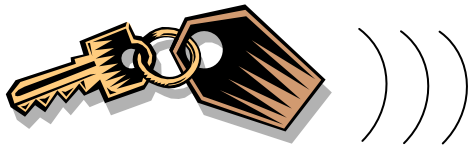
- advanced theft control: rolling code



$code = e_k(n_i)$

- rolling code (or hopping code)
- $code = e_k(n)$
- $code = e_k(n+1)$
- $code = e_k(n+2)$
- ….

$e_k()$ is often a block cipher

# Popular Rolling Code Cipher: KeeLoq

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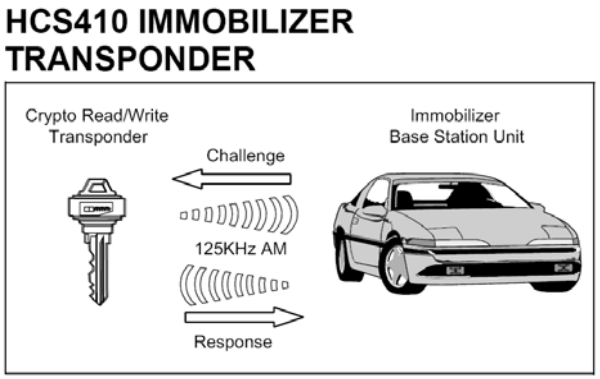
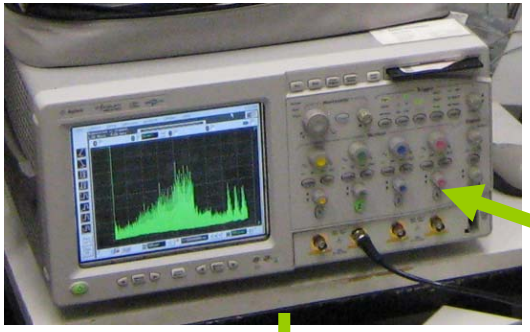


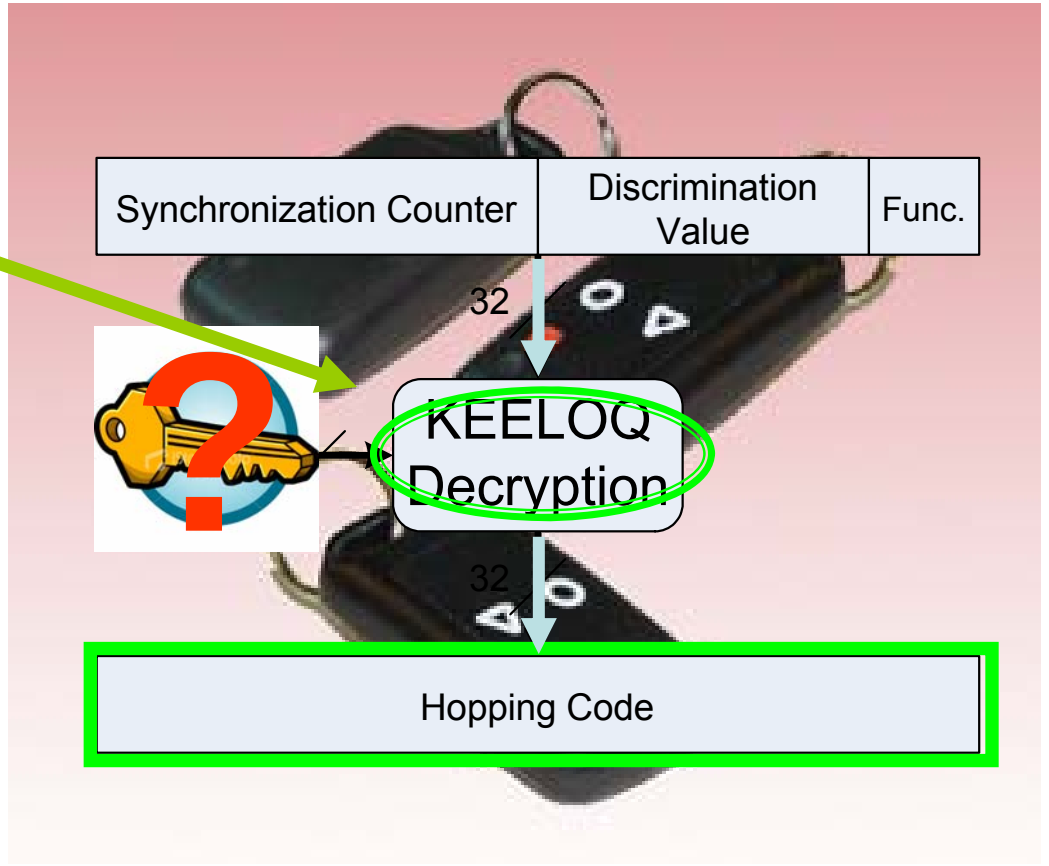

- Garage door access, car access, user authentication, …
- KeeLoq chip embedded in passive or active RFID transponder („car key“)
- Wikipedia (?):
  Chrysler, Daewoo, Fiat, GM, Honda, Toyota, Volvo, Jaguar, ...

- Q: How secure is KeeLoq?
- Best known mathematical attack does not work for rolling code, requires 65,000 encryptions + plaintext + works only for certain (weak) key derivations
- but:

**? What about physical attacks ?**

# Side Channel Analysis






**secret key** of remote control (HCS XXX Chip) !

# Performing the Side-Channel Attack

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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

# Measuring the Power Consumption

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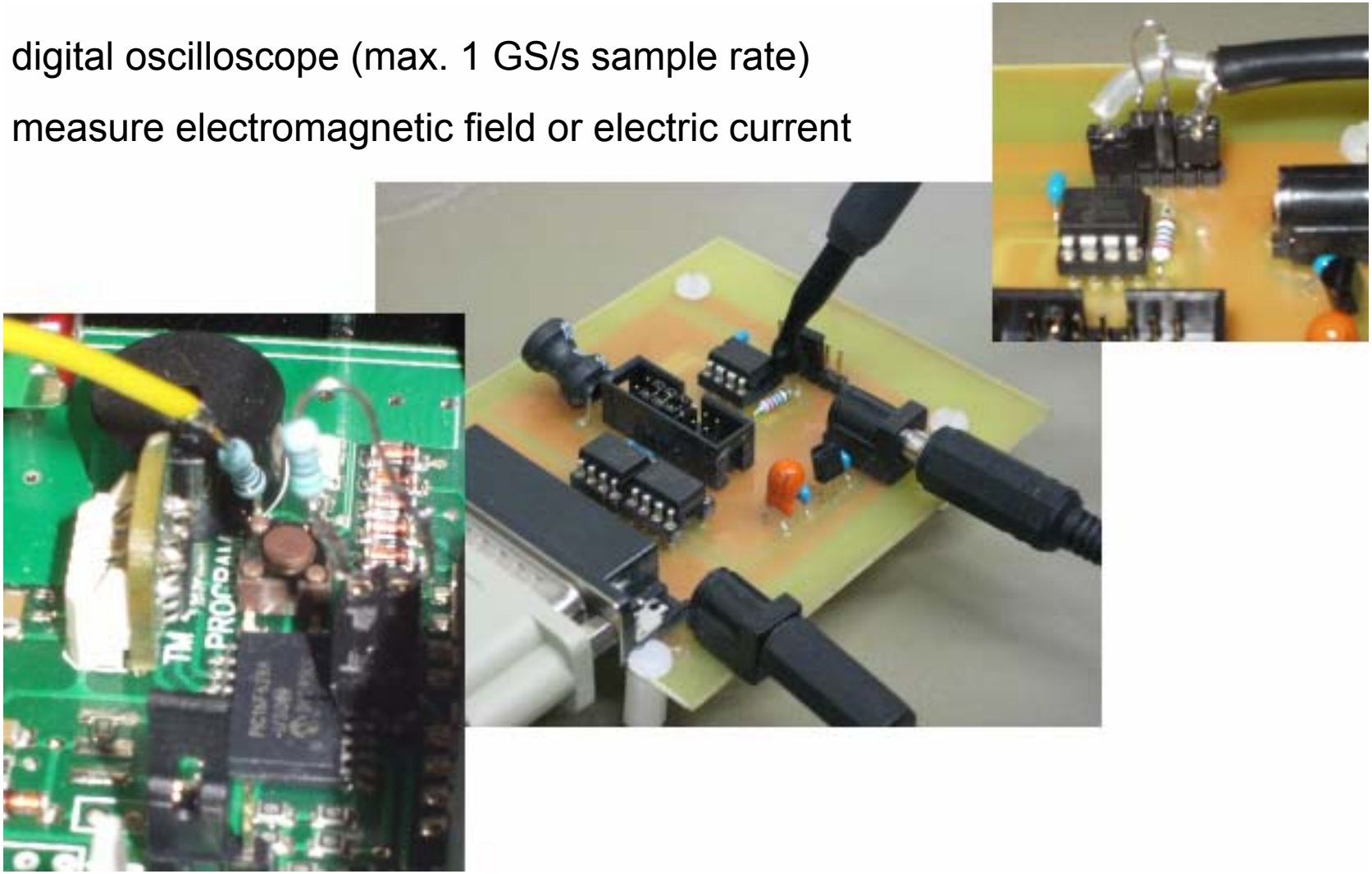
- digital oscilloscope (max. 1 GS/s sample rate)
- measure electromagnetic field or electric current



# Performing the Side-Channel Attack
# KeeLoq - Encryption

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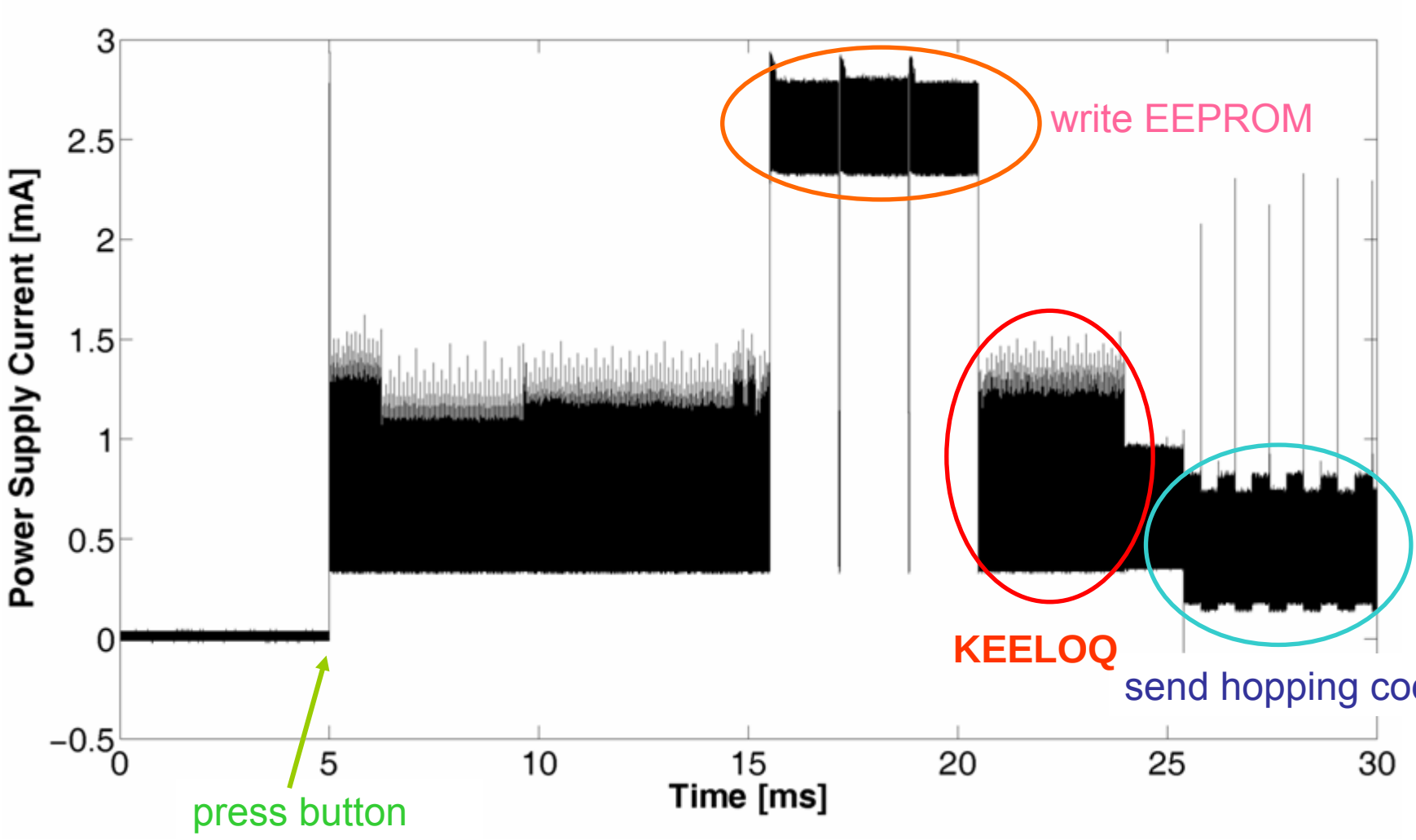

# Performing the Side-Channel Attack

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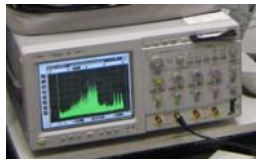


Analyze cipher

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Measurements

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# Performing the Side-Channel Attack
## Key Recovery

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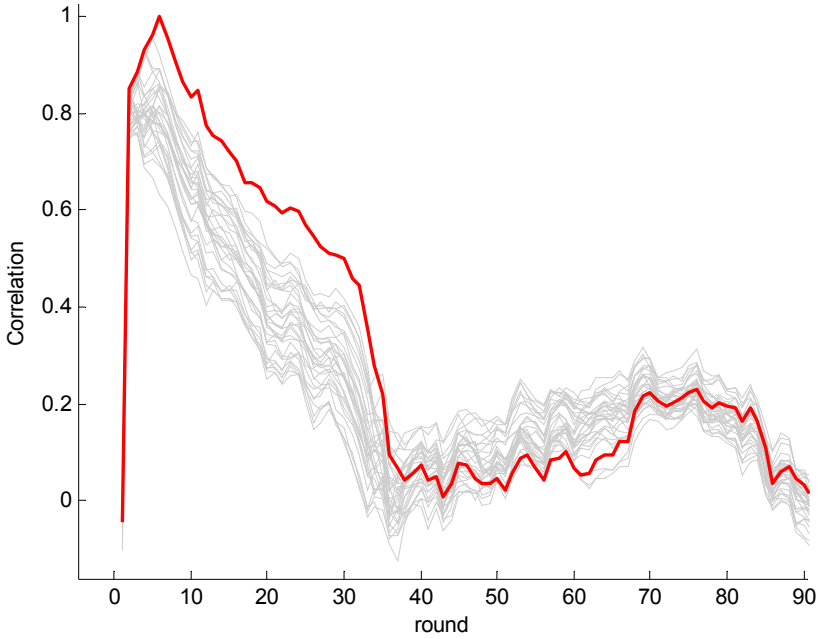
- Correlate power consumption to predicted value y = f(x,k)
- Divide and conquer approach
- Much off-line number crunching




$$r\left(I_i(t), D(X_i, K_h)\right) = \frac{\sum_{i=1}^{M} I_i(t) \cdot D(X_i, K_h)}{\sqrt{\sum_{i=1}^{M}\left(I_i(t) - \overline{I_i(t)}\right)^2 \cdot \sum_{i=1}^{M}\left(D(X_i, K_h) - \overline{D(X_i, K_h)}\right)^2}} - \frac{\frac{1}{M} \cdot \sum_{i=1}^{M} I_i(t) \cdot \sum_{i=1}^{M} D(X_i, K_h)}{\sqrt{\sum_{i=1}^{M}\left(I_i(t) - \overline{I_i(t)}\right)^2 \cdot \sum_{i=1}^{M}\left(D(X_i, K_h) - \overline{D(X_i, K_h)}\right)^2}}$$

# Side Channel Attack on transmitters

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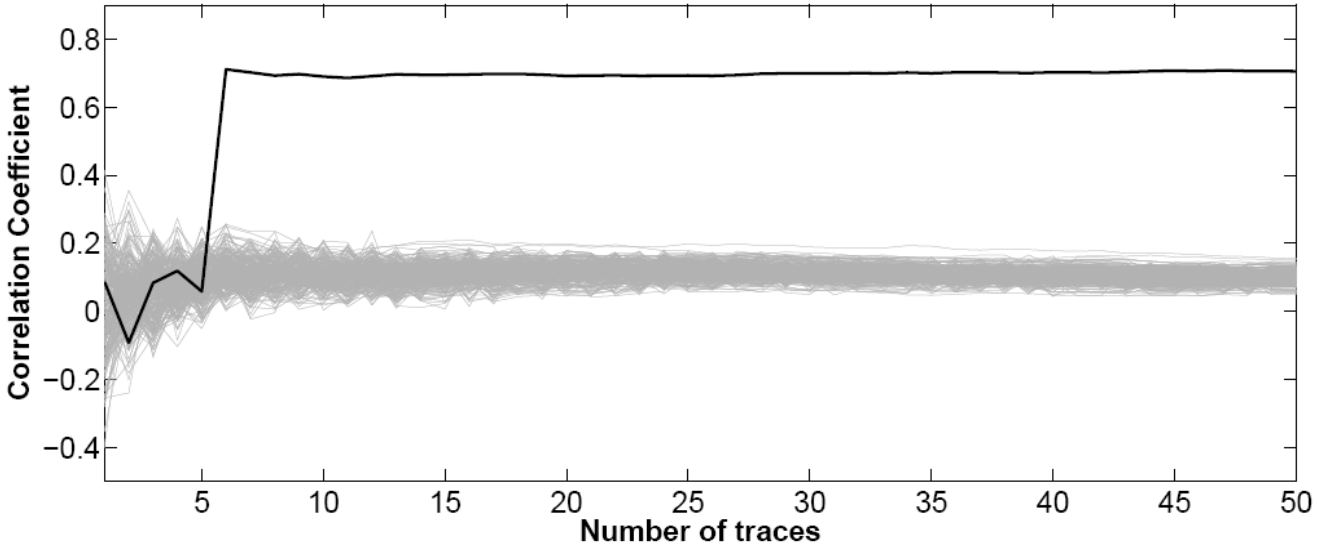
KeeLoq implemented in hardware

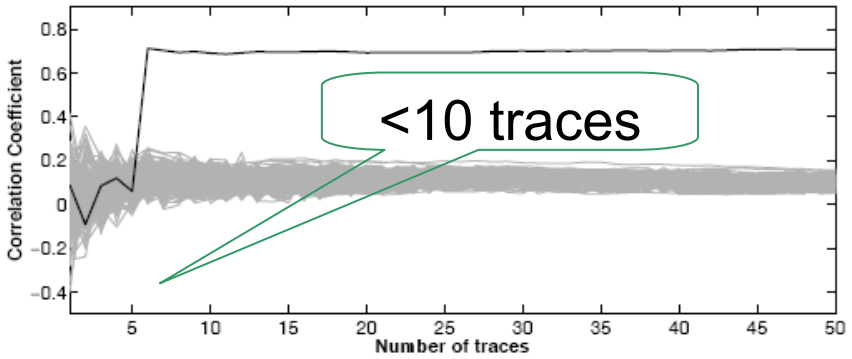
Total attack time (for known device family):
5-30 traces, ≈ minutes



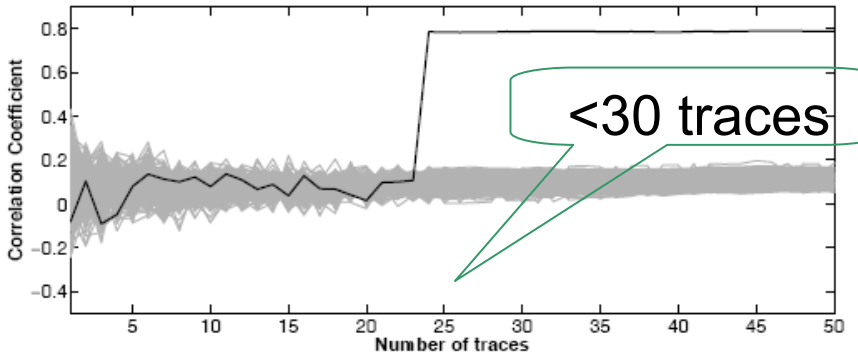

Convergence of correlation coefficient

Rem: low cost equipment suffices (< $1000)

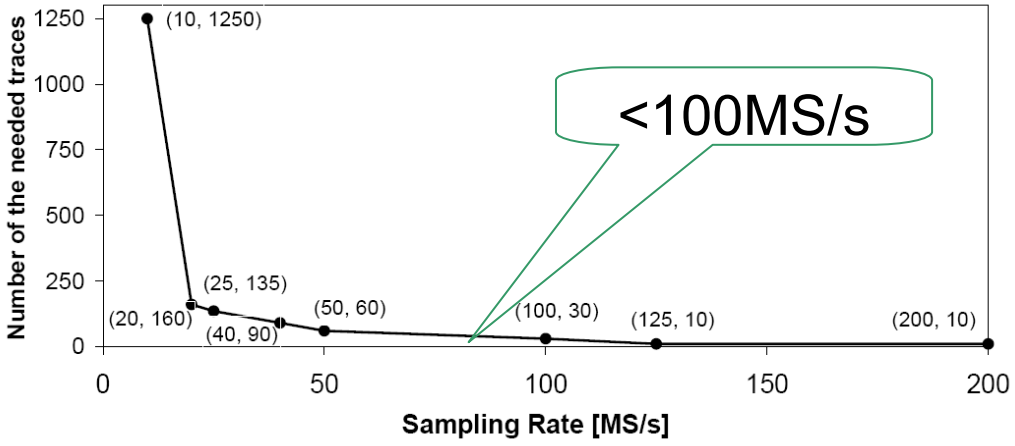
# Comparison of Packages & Sample Rates




(a) DIP




(b) SOIC




No expensive equipment needed !

Rem: SCA on receivers (software) requires several 1000 traces

# So what can we do now?

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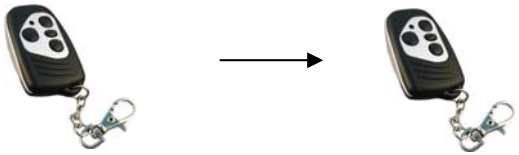
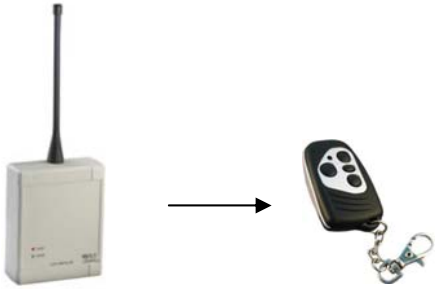
**If we have access to a remote**

Recover device key and clone the device



**If we have access to a receiver**

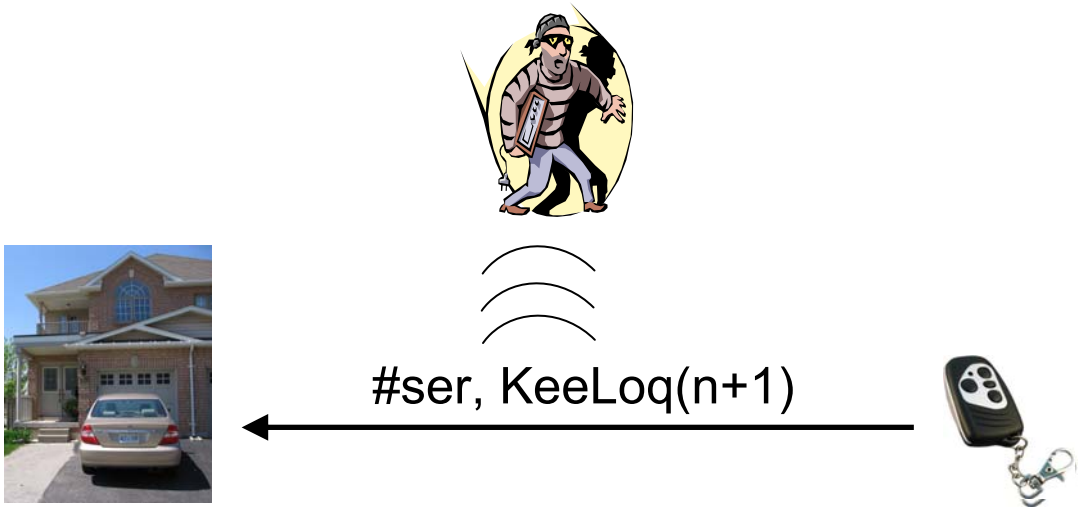
Recover manufacturer key and generate new remotes



# So what can we do now (2) ?

After extracting of manufacturing key:

**Remotely eavesdrop on 1-2 communications & clone key!**




- works for all key derivation schemes
- might require a few hours of computation
  (Rem: not necessary for any system we‘ve analysed.)
- SCA attack is not specific to KeeLoq, e.g., unprotected AES is vulnerable too.

**! Side-channel step (recovery of manufacturer key, difficult)**
**can be outsourced to criminal cryptographers !**

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- Case Study 3: High-Speed Vehicular Communication Engine
- **Related Activities**

# Related Workshops

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**SECSI – Secure Component and Systems Identification**
March 2008, Berlin

**RFIDSec 2008**
July 2008, Budapest

**CHES – Cryptographic Hardware and Embedded Systems**
August 2008, Washington D.C.

**escar – Embedded Security in Cars**
November 2008, Hamburg

# … and a related book

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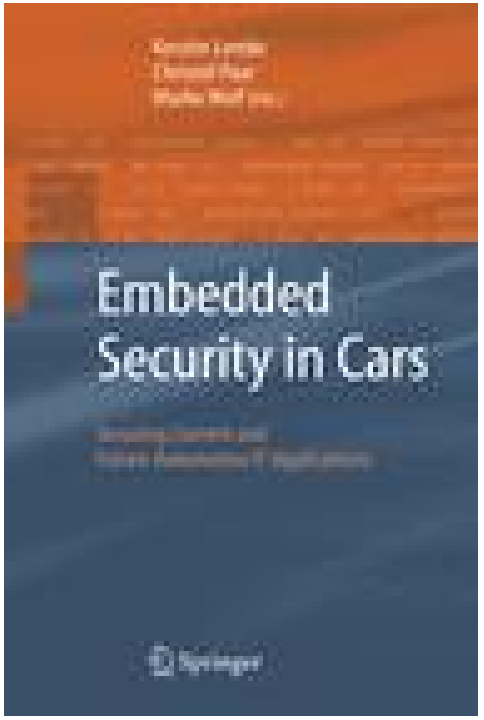
1. Part
   **Embedded technologies in general**
2. Part
   **Security issues in cars**
3. Part
   **Business & security**




Lemke, Paar, Wolf: Embedded Security in Cars, by Springer

# Thank you for your attention!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