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Breaking Mifare DESFire MF3ICD40: Power Analysis and Templates in the Real World

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EMSEC EmbeddedSecurity

Acknowledgements

- **Timo Kasper**
- **Christof Paar**

Outline of this talk

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1. **Contactless Smartcards**
2. **Mifare DESFire** MF3ICD40
3. **DPA** on Mifare DESFire MF3ICD40
4. **Template Attacks** on Mifare DESFire MF3ICD40
5. **Lessons Learned**

A brief introduction

Contactless Smartcards

Contactless Smartcards: Overview

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- **Contactless Smartcard** = RFID + Cryptography
  - **Secret key** on device
  - Cloning ≈ extract secret key
- Some applications
  - (Micro-)Payment
  - Passport
  - Public transport
  - Access control

Sources:
Wikipedia, cutviews.com

Contactless Smartcards: History

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- First generation (around 2000):
  Mifare Classic, Legic Prime, TI DST, Hitag, ...
  - Proprietary cipher
  - Short key (max. 48 bit)
  - **Analytical attacks**
- **Today:**
  Mifare Plus, Legic Advant, Infineon SLE, SmartMX, Mifare DESFire (EV1), ...
  - Analytically secure
  - **Side-channel attacks**

Example

Mifare DESFire MF3ICD40

Mifare DESFire MF3ICD40 in a nutshell

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- Introduced around 2002 by **Philips** (now **NXP**)
- **3DES** w/ 112-bit key for authentication and data encryption
- 4 kB non-volatile memory
  - 28 applications w/ max. 16 files each
  - 14 keys per application + 1 master key
  - Access rights on file level
- Based on asynchronous 8051 w/ 3DES engine
- “Glue logic”

Mifare DESFire MF3ICD40: Authentication protocol

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Reader (PCD) | **DESFire MF3ICD40 (PICC)**

AUTH →

Generate 64-bit nonce n_c

$B_0 = 3DES_{k_c}(n_c)$

← **B0**

Choose B_1, B_2

B_1, B_2 →

$C_2 = 3DES_{k_c}(B_2)$

$C_1 = 3DES_{k_c}(B_1)$

…

Mifare DESFire MF3ICD40: IC photograph

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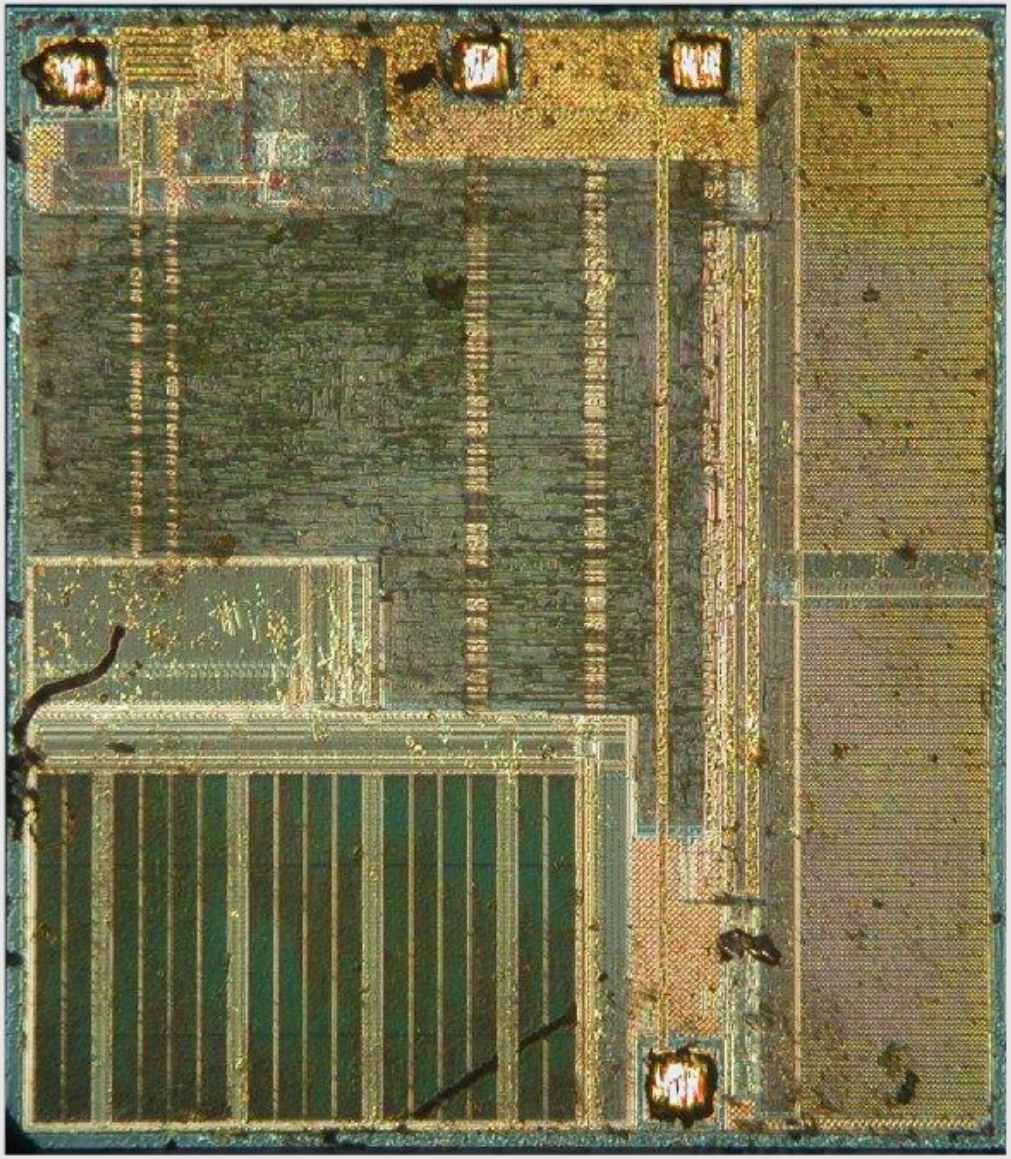

Mifare DESFire MF3ICD40: IC photograph

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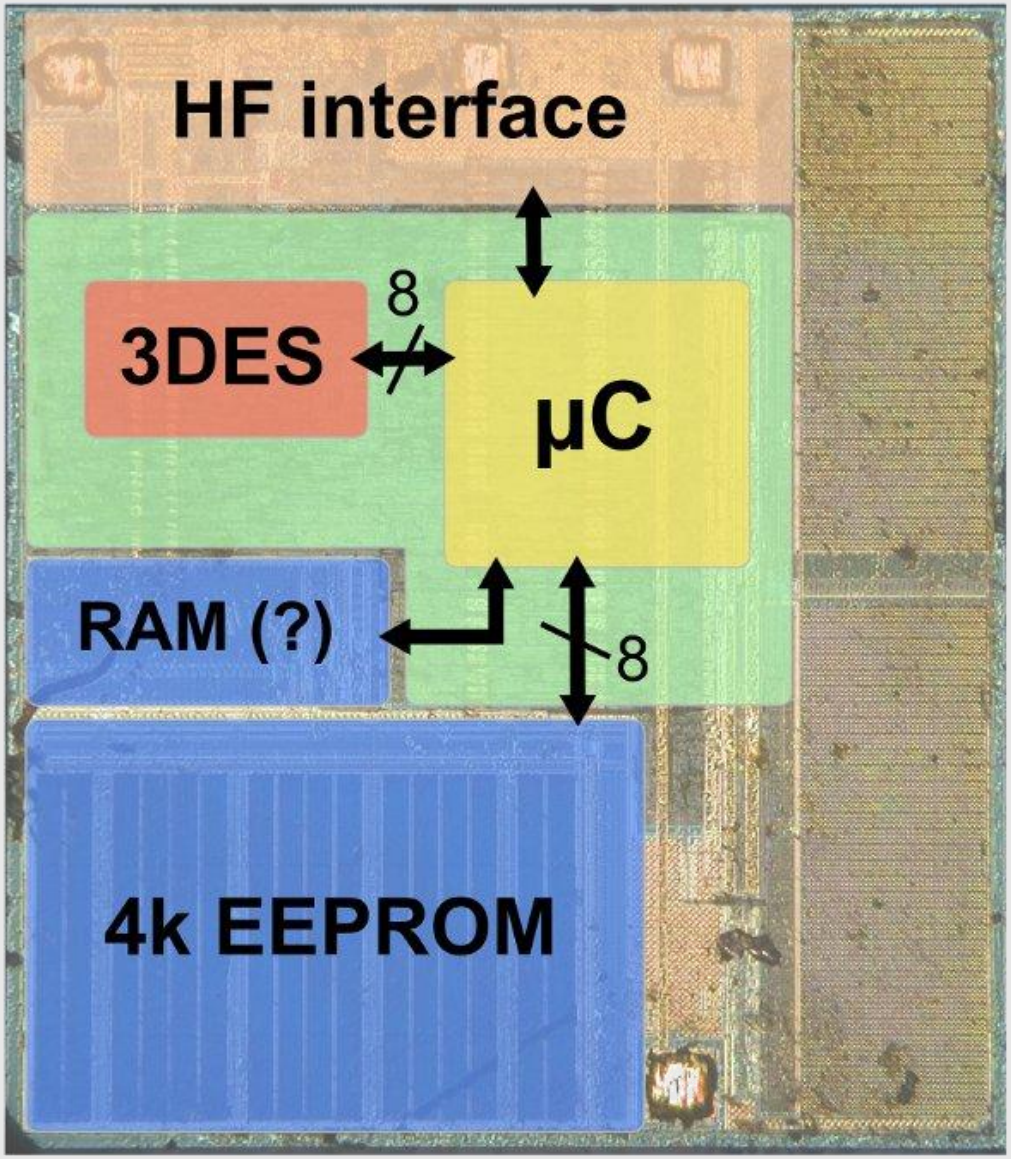

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A walkthrough

DPA on Mifare DESFire MF3ICD40

Mifare DESFire MF3ICD40: Preliminaries

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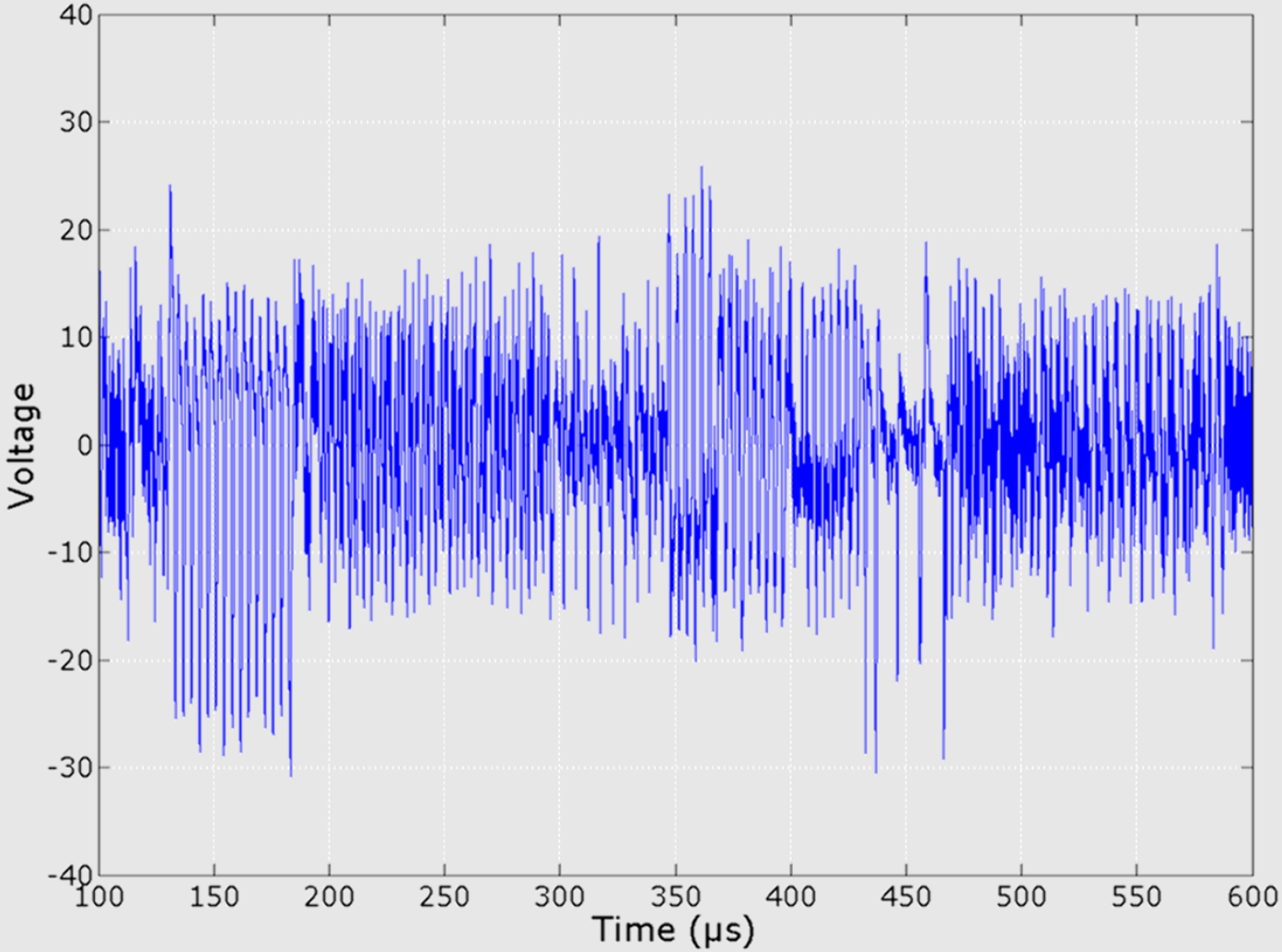
Side-channel leakage of DESFire MF3ICD40 [RFIDSec11]



Mifare DESFire MF3ICD40: Preliminaries

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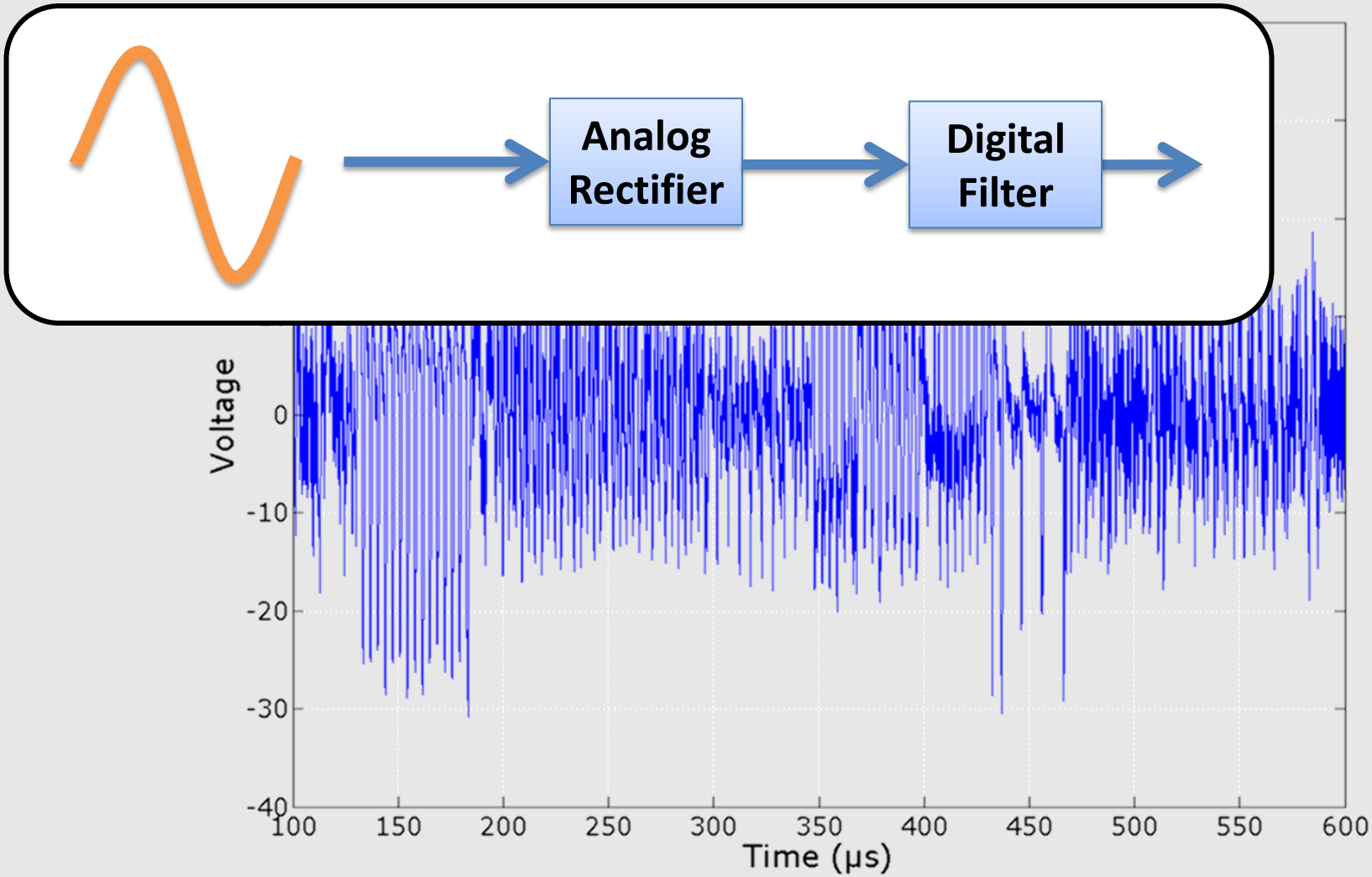

Mifare DESFire MF3ICD40: Profiling

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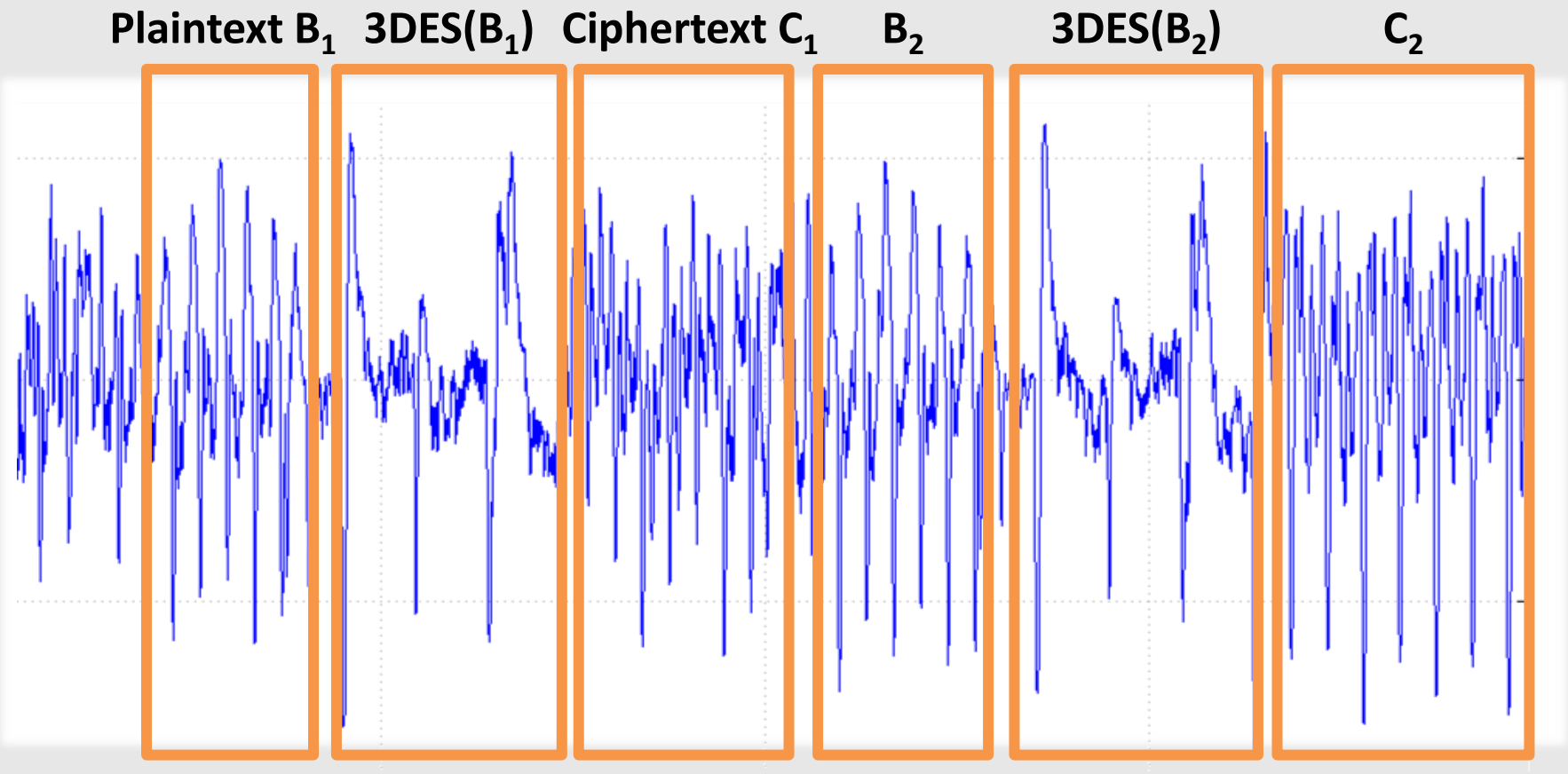
- **Step 1:** Understand device
- Locate plain-/ciphertext bytes using power analysis



DPA on Mifare DESFire MF3ICD40: Side-channel leakages

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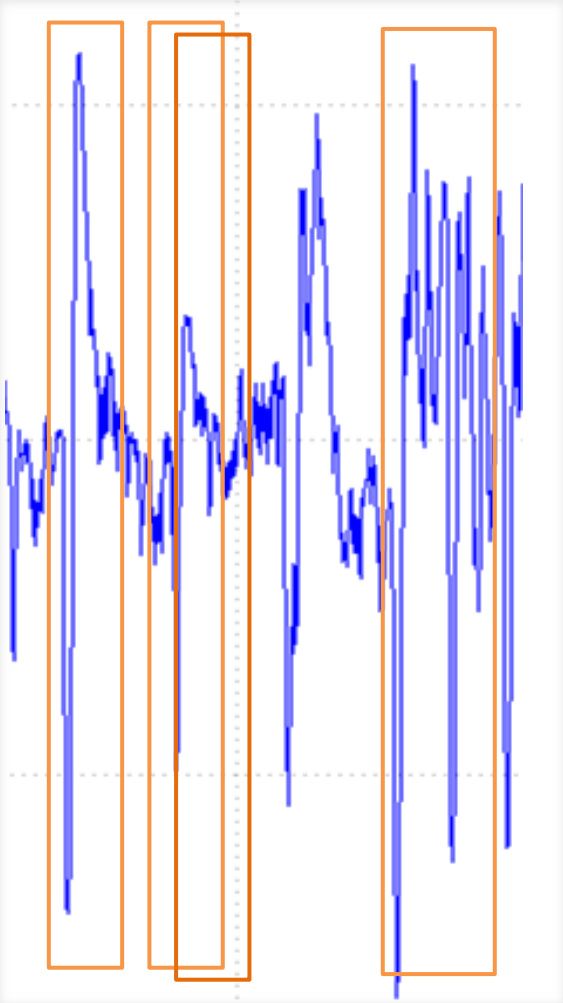
- **Operation:**
  $C = DES_{K1}(DES^{-1}_{K2}(DES_{K1}(B)))$
- Leakage 1: Bitwise **H**amming **D**istance of round 0→1 of $DES_{K1}(B)$, frequency domain
- Leakage 2: **H**amming **W**eight $DES_{K1}(B)$, time domain
- Leakage 3: **HD** round 0→1 of DES^{-1}_{K2}, freq. domain
- Leakage 4: **HW** of ciphertext C



DPA on Mifare DESFire MF3ICD40: Steps

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Operation: $C = DES_{K1}(DES^{-1}_{K2}(DES_{K1}(B)))$

Goal: Recover *K1*, *K2* step-by-step

Perform DPAs on

1. **DES 1, round 1**: max. 48/56 bit of *K1* (250k traces)
2. **Full state after DES 1**: remaining bits of *K1* (150k traces)

---

3. **DES 2, round 2**: max. 48/56 bit of *K2* (250k traces)
4. **Ciphertext**: remaining bits of *K2* (< 2000 traces)

DPA on Mifare DESFire MF3ICD40: Management summary

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- **Full key-recovery** with ~ 250k traces (~ 7 hours)
- **Low-cost equipment** ~ 2500 USD

⇒ High **threat potential**

- Opportunities for **optimization**
  - *Three* 3DES operations per trace, currently only *one* used
  - Improved signal processing (analog/digital)
  - Combine with *templates* (next part)

Other attack vectors

Template Attacks on Mifare DESFire MF3ICD40

Template Attacks on Mifare DESFire MF3ICD40: Idea

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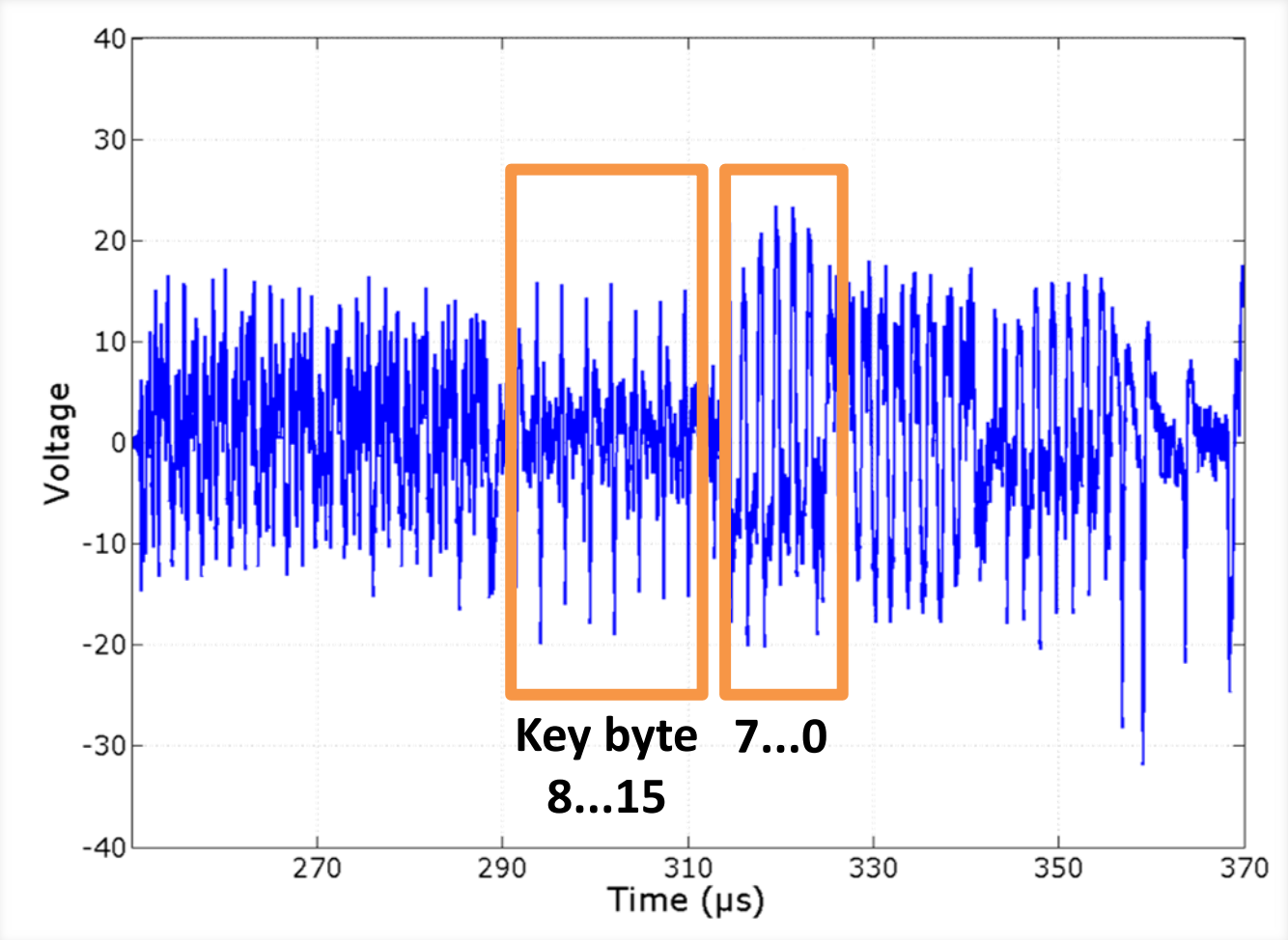
- 3DES I/O via 8-bit bus w/ **strong leakage**
- Including **byte-wise key transfer** ⇒ **template attack**



Template Attacks on Mifare DESFire MF3ICD40: Details

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- 256 possible values per byte (ignoring parity)
- **Training set:** *1,024,000* traces ≙ *4,000* traces per value
- **Test set:** *1,024,000* traces
- Note: Byte 7... 0 ≠ Byte 8 ... 15
- Best results (average bit error rate)
  - 7 ... 0: **1.77 bit errors**
  - 8 ... 15: **0.51 bit errors**
- **Problem:** Leakage card 1 ≠ leakage card 2

Template Attacks on Mifare DESFire MF3ICD40: Management Summary

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- Template attacks **in principle feasible**
- Possible improvements
  - More traces
  - Better classifiers

  } **Reduce error**

  - Calibration

  } **Card 1 → card 2**

- Currently: Limited threat
- **But:** Sometimes **profiling = matching device** (e.g. master key known before)

Conclusions and countermeasures

Lessons Learned

Lessons learned

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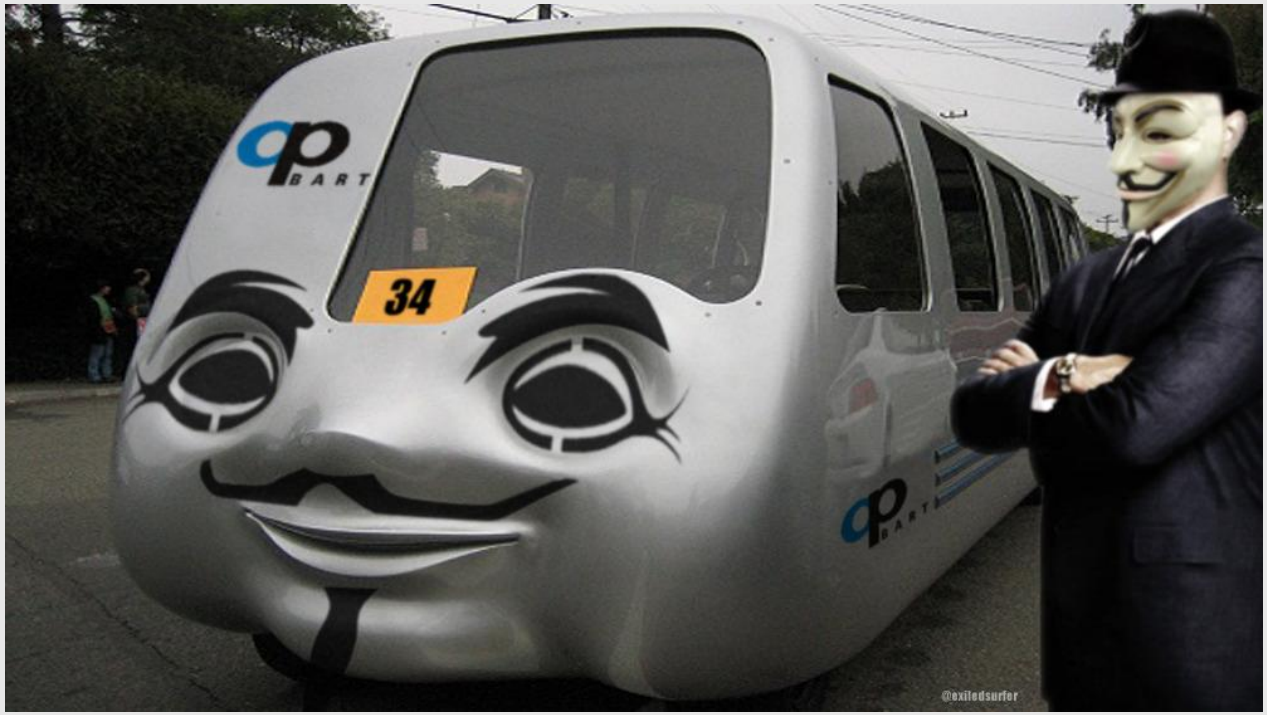
- Power analysis = **Threat in real-world**
  KeeLoq 08, DESFire 11, Xilinx bitstream 11
- One-time engineering effort **high**
- **Then**: Attacks at low cost



Source: @exiledsurfer

What to do?

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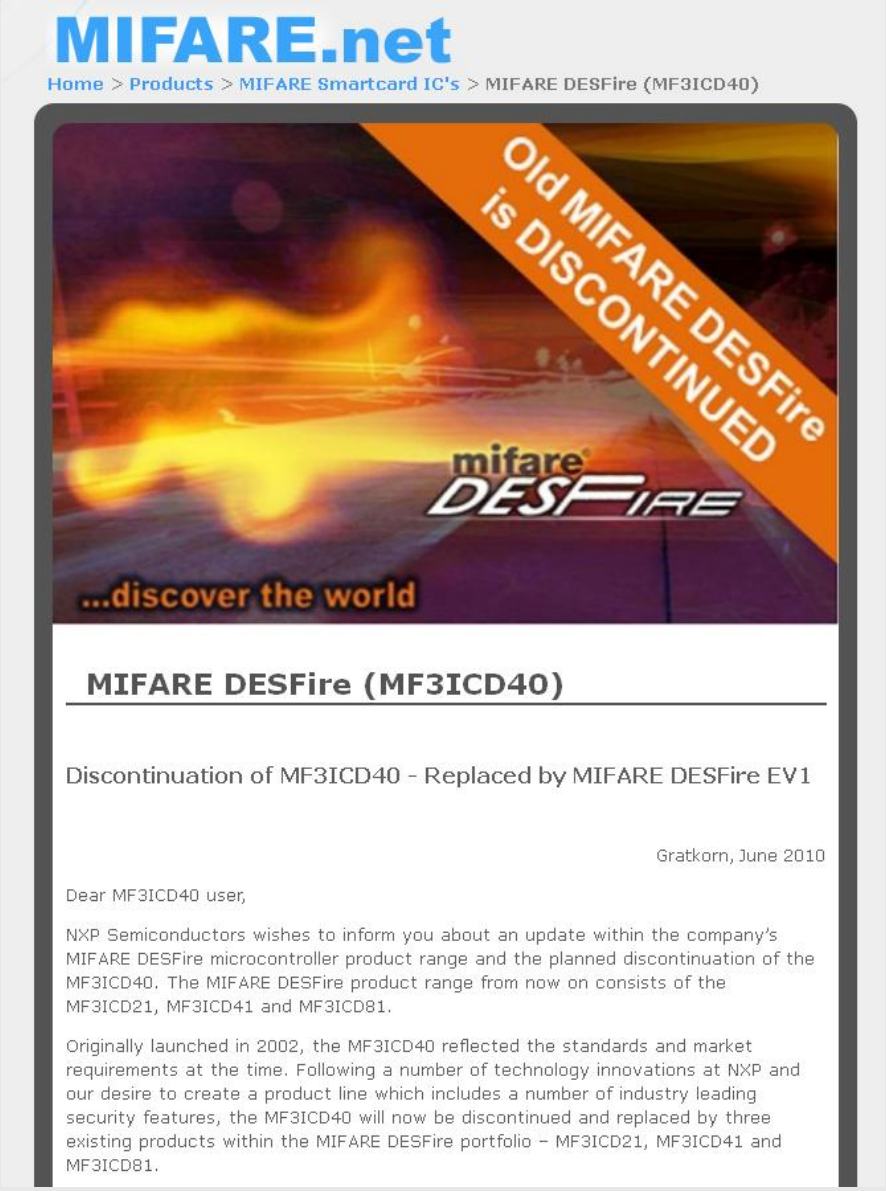
- DESFire MF3ICD40 replaced by **DESFire EV1**
- Use **certified devices**
- Use **countermeasures** on the system level
  - Key diversification
  - Shadow accounts
- Follow ongoing **security research**



MIFARE.net

Home > Products > MIFARE Smartcard IC's > MIFARE DESFire (MF3ICD40)

Old MIFARE DESFire is DISCONTINUED

mifare DESFire

...discover the world

MIFARE DESFire (MF3ICD40)

Discontinuation of MF3ICD40 - Replaced by MIFARE DESFire EV1

Gratkorn, June 2010

Dear MF3ICD40 user,

NXP Semiconductors wishes to inform you about an update within the company's MIFARE DESFire microcontroller product range and the planned discontinuation of the MF3ICD40. The MIFARE DESFire product range from now on consists of the MF3ICD21, MF3ICD41 and MF3ICD81.

Originally launched in 2002, the MF3ICD40 reflected the standards and market requirements at the time. Following a number of technology innovations at NXP and our desire to create a product line which includes a number of industry leading security features, the MF3ICD40 will now be discontinued and replaced by three existing products within the MIFARE DESFire portfolio – MF3ICD21, MF3ICD41 and MF3ICD81.

Source: www.mifare.net

Thanks!
Questions?

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