Card-Only Attacks on MiFare Classic

or How to Steal Your Oyster Card and Break into Buildings Worldwide

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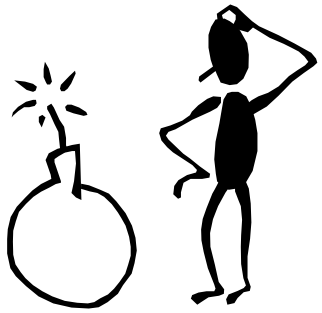
Outline

1. Security in the Smart Card world:
   - Traditional model vs. disruptive RFID technology
   - Open vs. Close source models
2. MiFare Crypto 1 cipher:
   waste of silicon x more than 1 billion copies sold.
3. Barriers to breach:
   - The need for hacking and reverse engineering
   - Hardware set-up
4. Early attacks
5. Card-only attacks [NEW]
   - My own
   - Dutch researchers from Nijmegen
   - Combined
6. Inside Oyster Cards + other countries…
7. Who is to blame?

**About Our Job



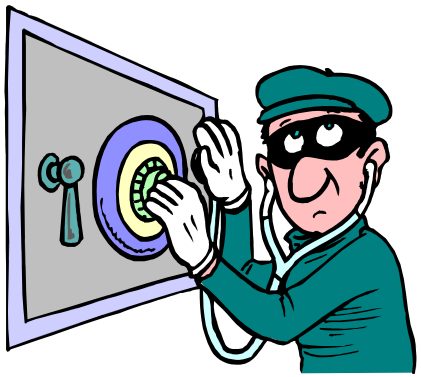
**Key Question:

Is actively researching serious security vulnerabilities socially desirable?

- Of Course Yes!

…will tell you every professional hacker

and every academic code-breaker…



**Bruce Schneier [14 May 2008]:

Problem: A hacker who discovers one [attack] can sell it on the black market, blackmail the vendor with disclosure, or simply publish it without regard to the consequences.

Q: […] is it ethical to research new vulnerabilities?

A: Unequivocally, yes. [according to Schneier]

Because:

- Vulnerability research is vital because it trains our next generation of computer security experts.

http://www.schneier.com/blog/archives/2008/05/the_ethics_of_v.html

** Traditional Military Doctrine

- Each country has 3 frontiers:
  - land
  - sea
  - air, space

as a consequence they have 3 armies.

Now, we have a new frontier, the digital frontier.
Shouldn't we have a fourth army?

- It would be totally useless and waste of money?
  - Arguably less than the 3 above (better technical education for young people).

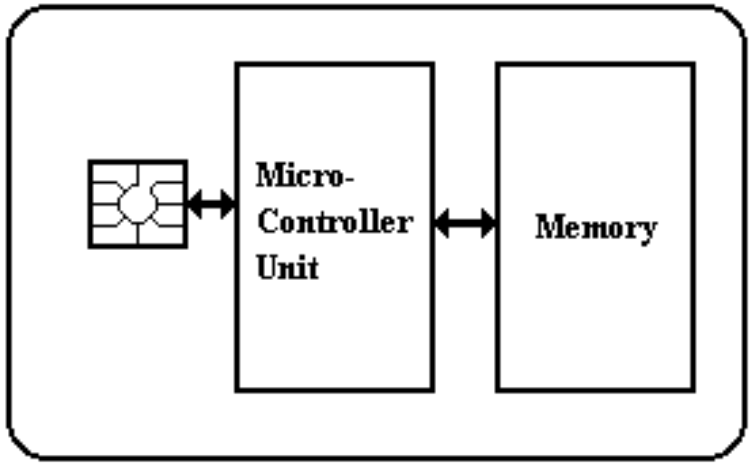
Smart Cards

Key Remark

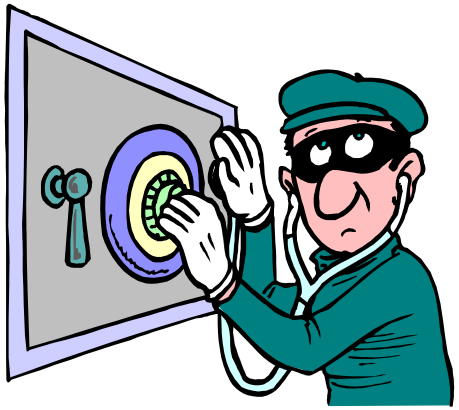
Software CANNOT be protected by software.

Smart Cards

- Microcontroller = CPU+memory
- as powerful as a PC 12-15 years ago (32 bit, 1G HD)
- much more secure:
  - security features enforced by hardware, cannot be circumvented by software
  - effective business model:
    - the card Issuer can manage his security independently of other hardware that is NOT trusted
    - the user can control how the card is used



Smart Cards - Security



Cryptography helps:

- Secure your data
  - encrypted memory
  - secure messaging
- Secure your identity:
  - very strong forms of authentication where the secret keys never ever leave the chip

Secure execution of cryptographic functions

<= tamper resistance

- Protect against side-channel attacks

*UCL Smart Cards Lab

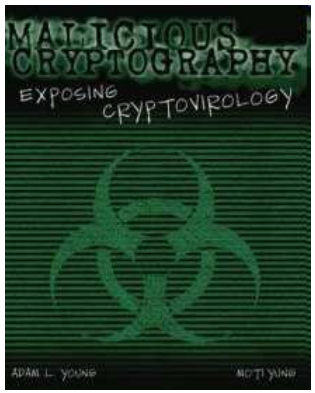
- COMPGA12 Applied Cryptography:
- We run a Smart Cards Lab for students.

****Cryptography: Disruptive Technology for Crime

Example:

- Extortion: encrypt data, ask for $$$.

- Impossible without public key cryptography…
  - which is VERY difficult to make…



as difficult as going to the moon, >30 years of research, 100s of researchers…

Why Smart Cards Are Good

Or are they?

The classical model for smart card security [Schneier and Schostack 1999] is about

- splitting the security perimeter:
  - One entity cannot breach other people's security
- hardware barriers that cannot be breached by software,
- physical control of the card by the user,
- and trusting the entities involved in developing components of a secure system
  - Schneier and Schostack already pointed out that companies/people involved in this business can compromise it's security.
    - Mistrust w.r.t. an industry dominated (at that time) by the French?
    - Not quite.

slight problem..

Problems:

This model totally breaks apart with RFID smart cards:

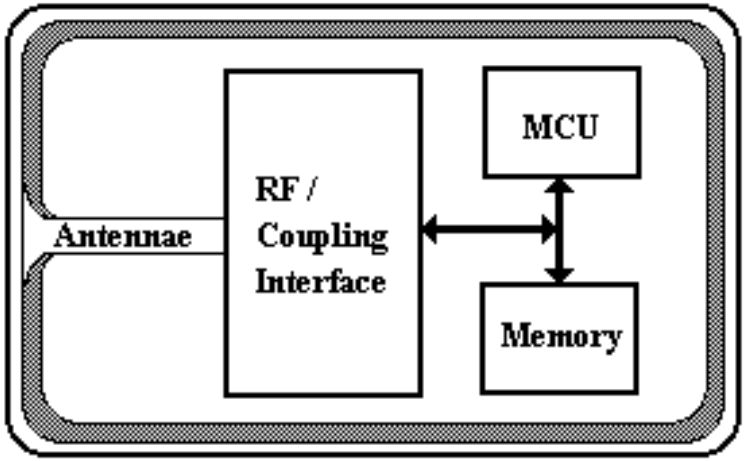
- RFID => no user control.

The secrecy of the product spec is:

- not an extra security layer, but a source of unexpected and critical security vulnerabilities
  - that by the fact of being hidden gives an utterly false sense of security

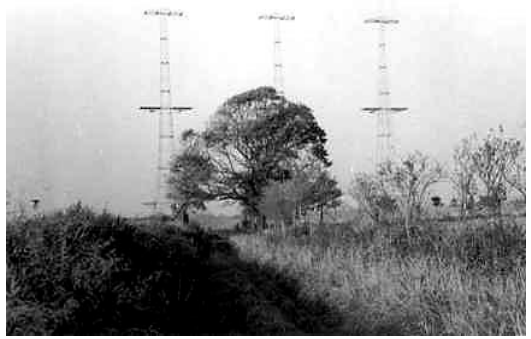
Contact-less Smart Card

- with RF transceiver
- 0.1 s transaction
  - much less energy
  - even less computing power



Contact-less Authentication - History

IFF: Identify Friend or Foe (1942)



Challenge-

-Response

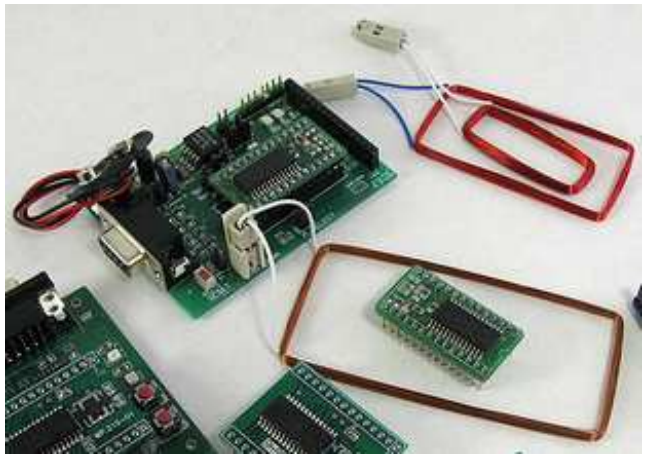
problem: relay attacks

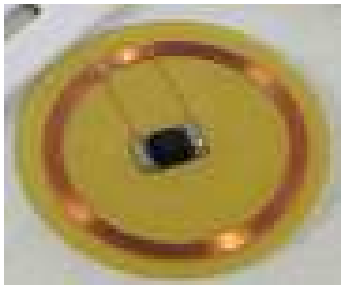
Form Factors

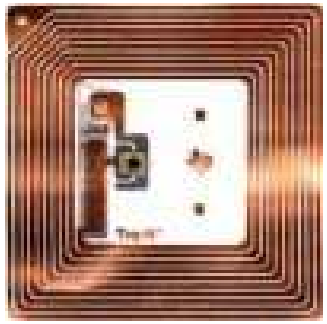
key fob

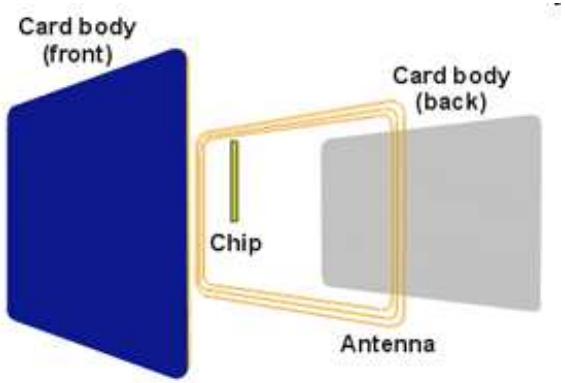
Antenna

large loop antenna









Source: Gemplus - All About Smart Cards

Transport Card Standards

Main Standards:

- Calypso [France, Belgium]
- MiFare [UK, Holland, Poland]
- Sony Felica [Japan,India,HongKong,etc..]

MiFare Classic Crypto-1

Stream cipher used in about 200 million RFID chips worldwide.

- Ticketing (e.g. London's Underground).
- Access to high-security buildings
- Etc.

Claimed VERY Secure..

YES, very safe,
can be used for cashless payment (!!!)

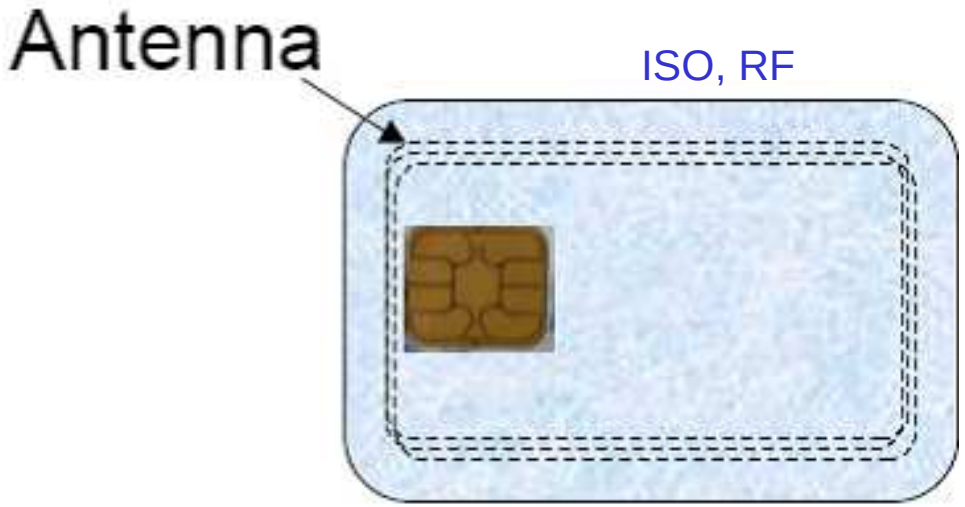
example of third party claims (from ACR 120 manual):

5.3 We would like to use MIFARE® for cashless payment. How safe is it?

Security is always a property of the overall system, not of the components. It requires careful design.
A properly designed system will require **ALL** barriers to be hacked in order to be broken.
For good design start specifying feasible attacks. Then create barriers to block them.
MIFARE® was specifically designed for cashless payment applications. The MIFARE® concept provides following barriers:

- Anticollision/-selection
- Atomic value transaction
- Ciphered communication
- Storage of values and data protected by mutual authentication
- Weak field keys that allow decrement only
- Stored keys in the reader that are not readable
- Keys in the card that are not readable
- A brute force attack by trying different keys is limited by the transaction time (several msec) of the card and would last virtually forever.
- Etc.

Double/Triple Interface Cards



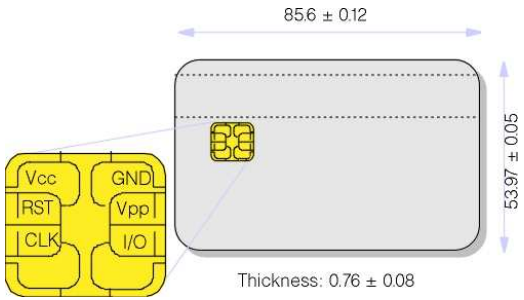
E.g. corporate badge

- Functionalities:
  - Enter doors,
  - PC log-in,
  - PGP decrypt and sign
- Adopted worldwide, e.g. U.S. Army

ISO, USB, RF

Open Source or Close Source?

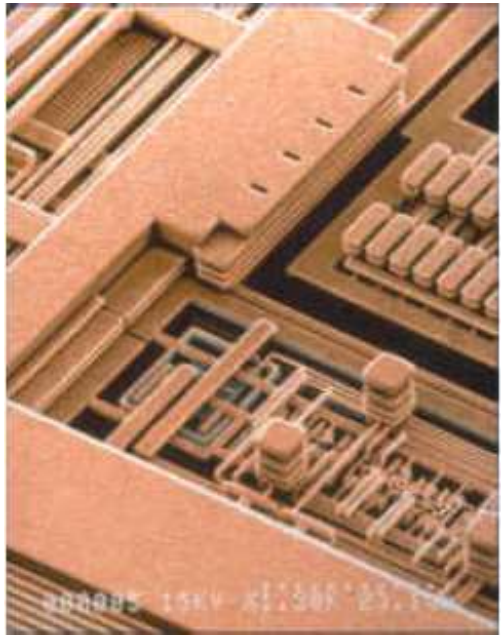
The eternal tension in the industry:
competition ⇔ cooperation.



1. huge set of standards:
   - public bodies: ISO/IEC, ETSI, etc.
   - 10s of intra-industry standard bodies such as GlobalPlatform, TCG

2. many industrial/commercial/ trade/security secrets

What's Inside?



Open Source vs. Closed Source Crypto

Secrecy:

Very frequently
an obvious
business decision.

- Creates entry barriers for competitors.
- But also defends against hackers.

Kerckhoffs' principle: [1883]

"The system must remain secure should it fall in enemy hands …"

***Remark

Smart Cards:

They are already in ‘enemy’ hands

- even more for RFID…

Kerckhoffs' principle: [1883]

Most of the time: incorrectly understood.

Utopia. Who can force companies to publish their specs???

No obligation to disclose.

- Security when disclosed.
- Better security when not disclosed.

Yes (1,2,3,4):

1. Military:
   layer the defences.

Yes (2):

2)

Basic economics:

these 3 extra months

(and not more ☹)

are simply worth a

a lot of money.

Yes (3):

3)

Prevent the erosion of profitability / barriers for entry for competitors / "inimitability"

Yes (4):

4)

Avoid Legal Risks

- companies they don't know where their code is coming from, they want to release the code and they can't because it's too risky!
- re-use of code can COMPROMISE own IP rights and create unknown ROYALTY obligations (!!!)
- clone/stolen code is more stable, more reliable, easier to understand!

Kerckhoffs principle is WRONG in the world of secure hardware devices

Dutch researchers got a large grant to develop an OPEN SOURCE replacement for the Oyster card system.

This cannot work.

- Algorithm secrecy [once they are good] MUST be preserved.
- Reason: side channel attacks are VERY hard to prevent.
- In some applications, for example Pay TV the system is broken immediately when the cryptographic algorithms are public.

Custom Crypto

Case Studies

- PayTV: algorithms were updated hundreds of times, systems were cracked as soon as the algorithm was reverse engineered.
- In GSM/3G:
  the encryption algorithms are public
  - broken for all 2G algorithms.
  - The authentication algorithms [protect the operator's $$$] are SECRET and were not hacked/cracked so far.
- In bank cards, all algorithms are public.

Yet it seems there was no hacker attack on them yet
[many other attacks are easier!]

Silicon Hacking

Famous Silicon Hacker

Christopher Tarnovsky

Tarnovsky Testimonial Against NDS

"Sure, I've broken the cards of Kudelski",

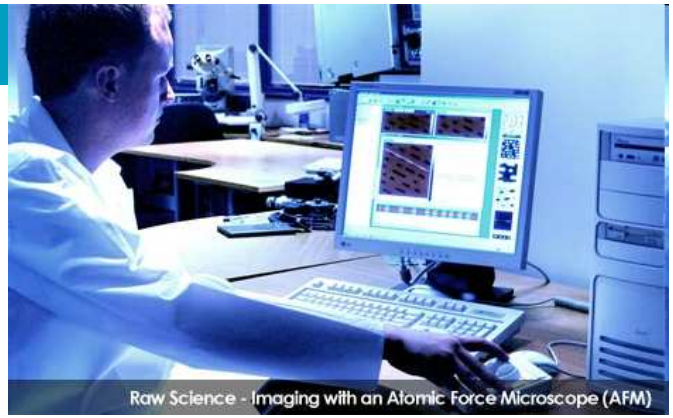
"I was paid by NDS to do it. This is an activity that all companies in the trade do.“

He also said that he was offered 100 000 dollars if he can break Xbox360. He replied that it was not enough.

Tarnovsky Lab

Only a few thousands of dollars worth of equipment

More Expensive:

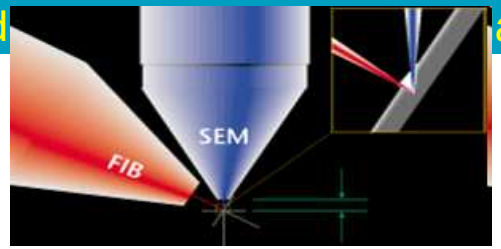


- Atomic Force Microscope

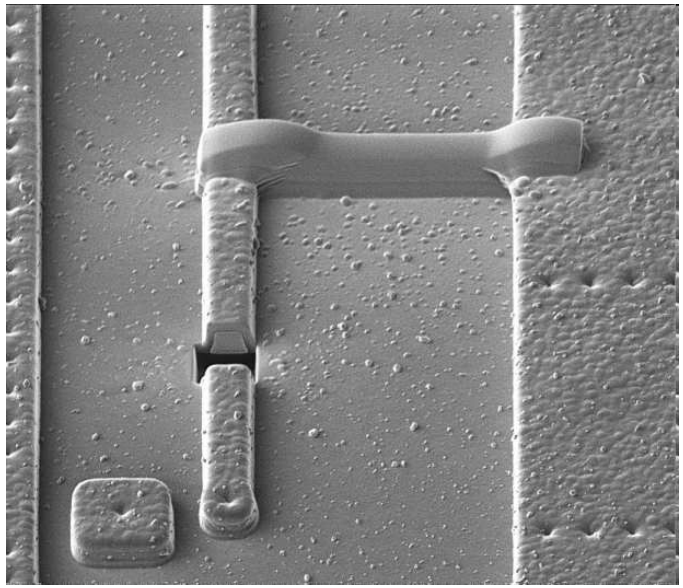
- FIB device

(Focused Ion Beam, 0.5 M€)

Canal+ Technologies Lab



FIB:

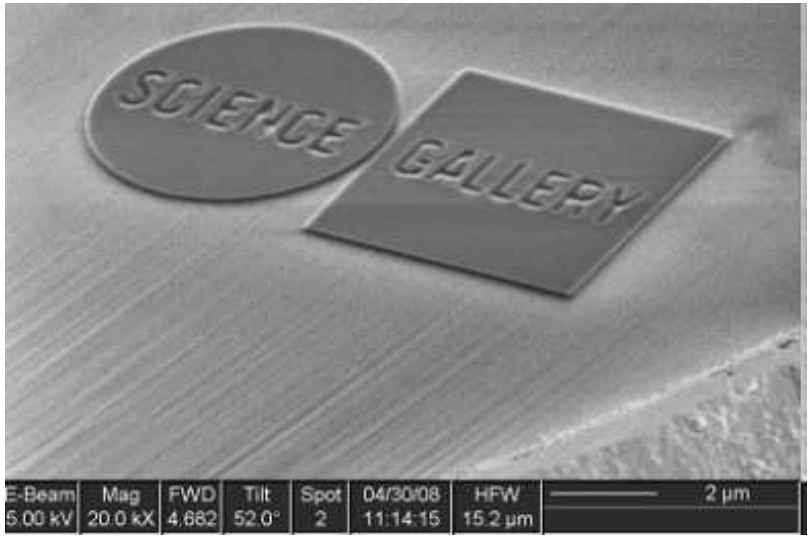


Example resolution: 10 nm

Classical applications: failure analysis of ICC

But also: circuit modification:

- Local material removal:
  - cutting metal lines, milling, gas enhanced etching
- Local rebuilding/rewiring of the device
  - new metal interconnects
  - new insulating layers
- Fine tuning of analog components: decrease/increase R or C…
- Reading (electron image) ←
- Art: writing on the nm scale: →



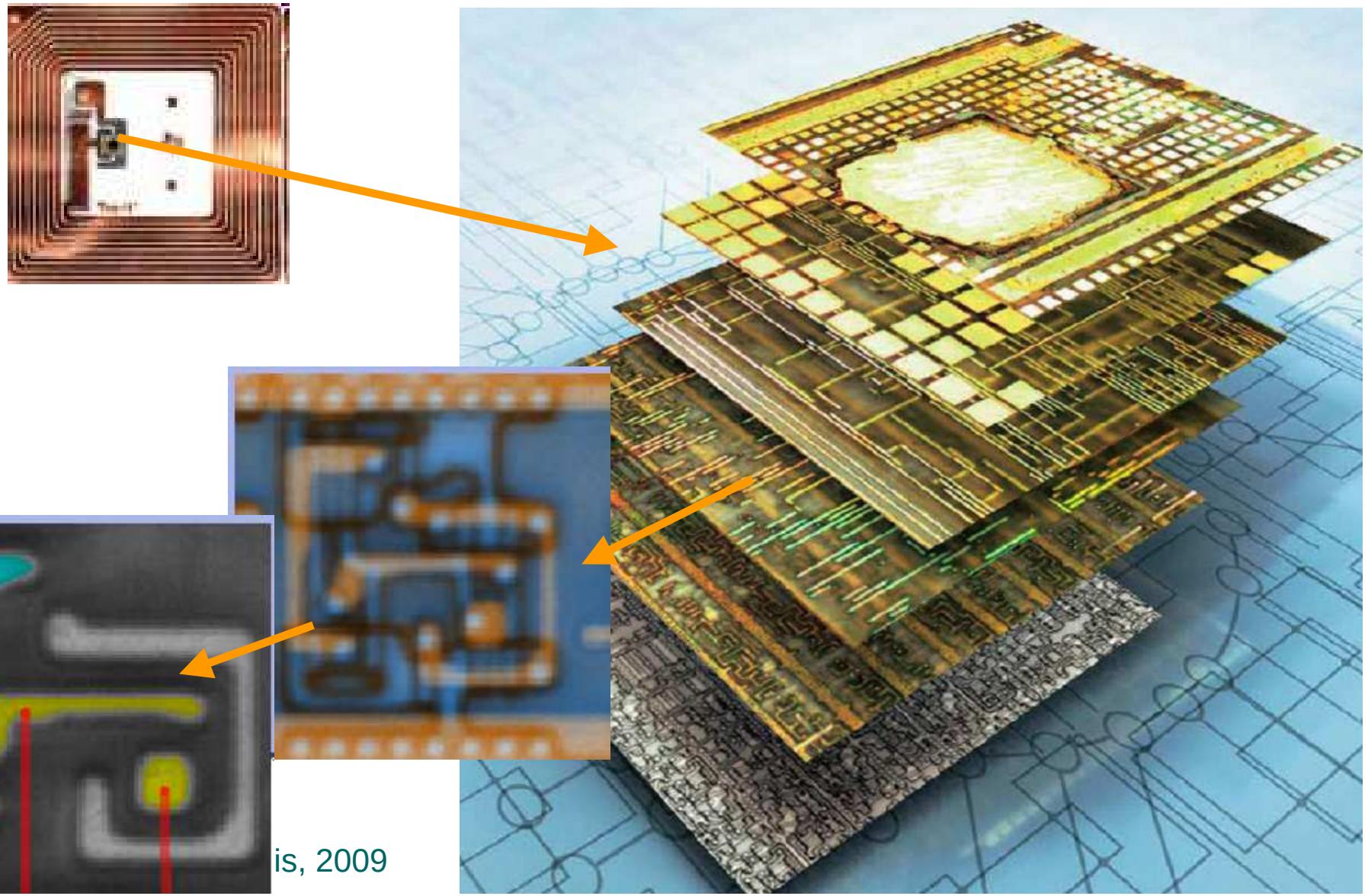
Clear and Present Danger

Reverse engineering is NOT that hard.

No need for a FIB device
(Focused Ion Beam, 0.5 M€).

A few thousand dollars microscope +software.

Reverse-Engineering [Nohl et al.]



is, 2009

Crypto-1 Cipher

Waste of Silicon

MiFare was manufactured by Philips, now NXP, and licensed to Infineon.

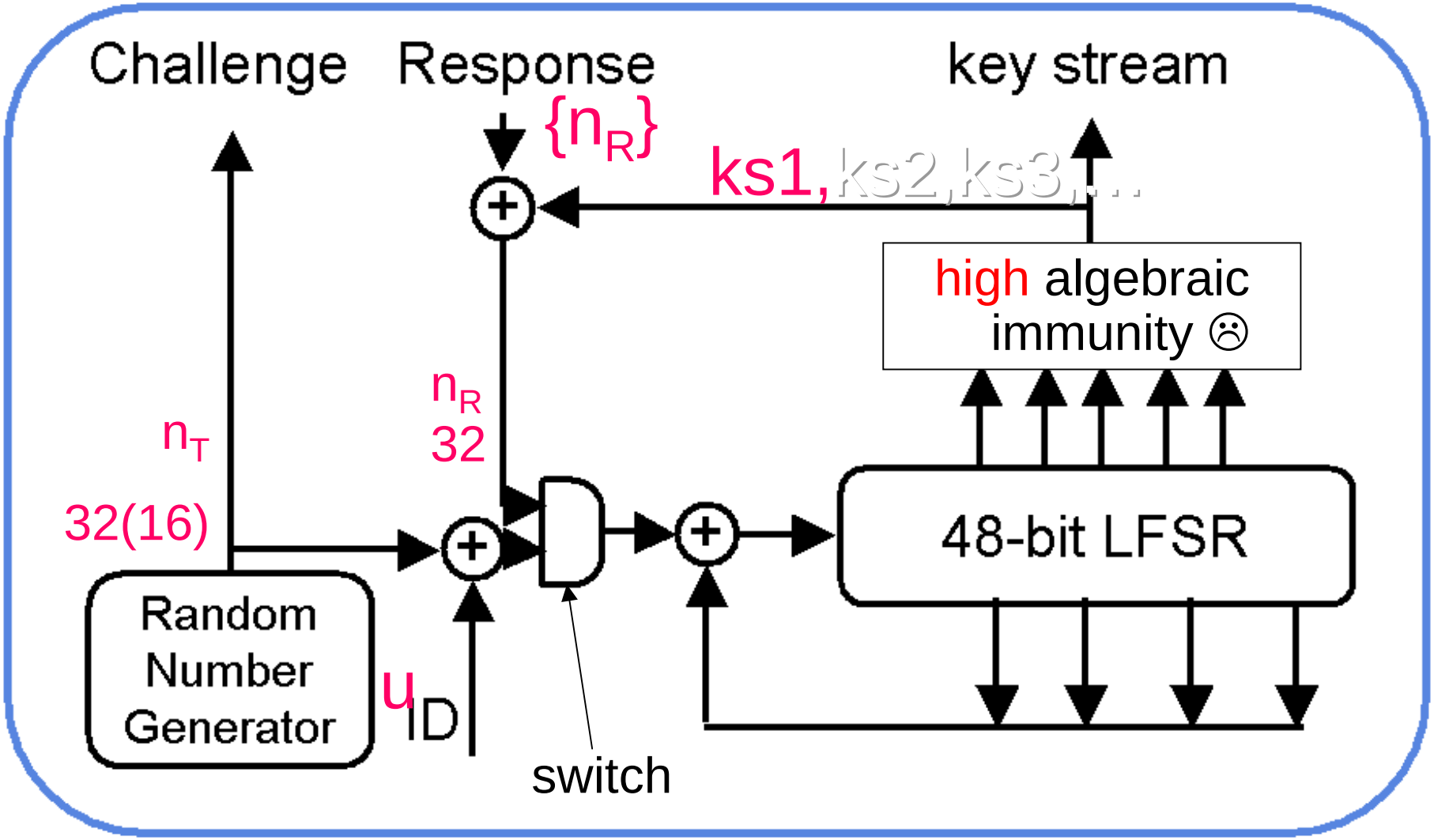
BUT, even a hardware or software designer would NOT notice how weak the cipher is.

Identical Boolean functions are implemented differently.

Camouflage?

Due to a combination with another terrible weakness half of the silicon is wasted…

Crypto-1 Algo + Auth. Protocol



Background – Crypto 1 Cipher

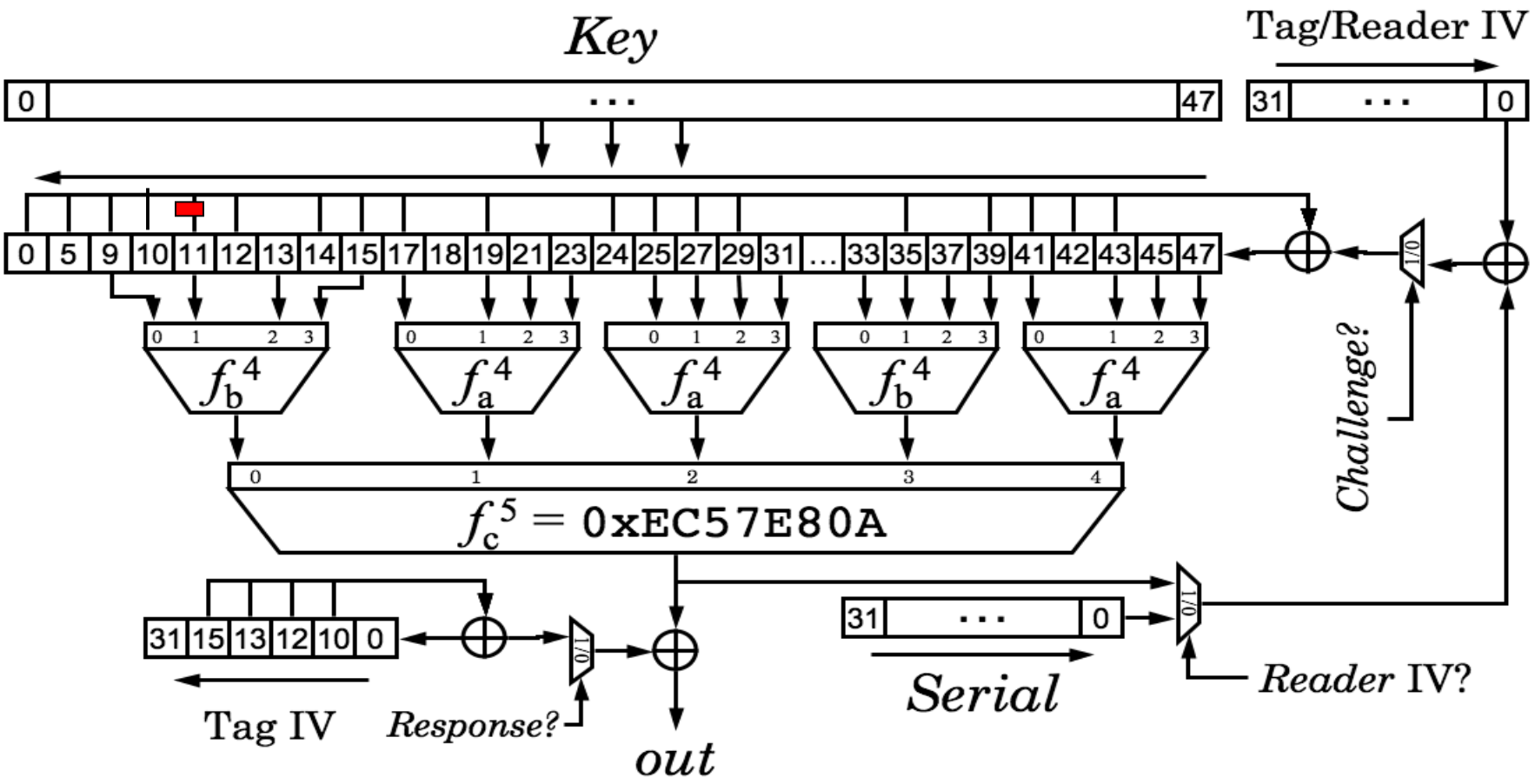
- 48 bit LFSR
- The feedback function *L* is as follows:

Definition 2.1. The feedback function $L : \mathbb{F}_2^{48} \to \mathbb{F}_2$ is defined by $L(x_0 x_1 \ldots x_{47}) := x_0 \oplus x_5 \oplus x_9 \oplus x_{10} \oplus x_{12} \oplus x_{14} \oplus x_{15} \oplus x_{17} \oplus x_{19} \oplus x_{24} \oplus x_{25} \oplus x_{27} \oplus x_{29} \oplus x_{35} \oplus x_{39} \oplus x_{41} \oplus x_{42} \oplus x_{43}$.

- The non-linear filter function *f* is defined as:

$$f(x_0 x_1 \ldots x_{47}) := f_c(f_a(x_9, x_{11}, x_{13}, x_{15}), f_b(x_{17}, x_{19}, x_{21}, x_{23}), f_b(x_{25}, x_{27}, x_{29}, x_{31}), f_a(x_{33}, x_{35}, x_{37}, x_{39}), f_b(x_{41}, x_{43}, x_{45}, x_{47})).$$

Crypto1 Cipher



$f_a^4 = 0x9E98 = (a+b)(c+1)(a+d)+(b+1)c+a$

$f_b^4 = 0xB48E = (a+c)(a+b+d)+(a+b)cd+b$

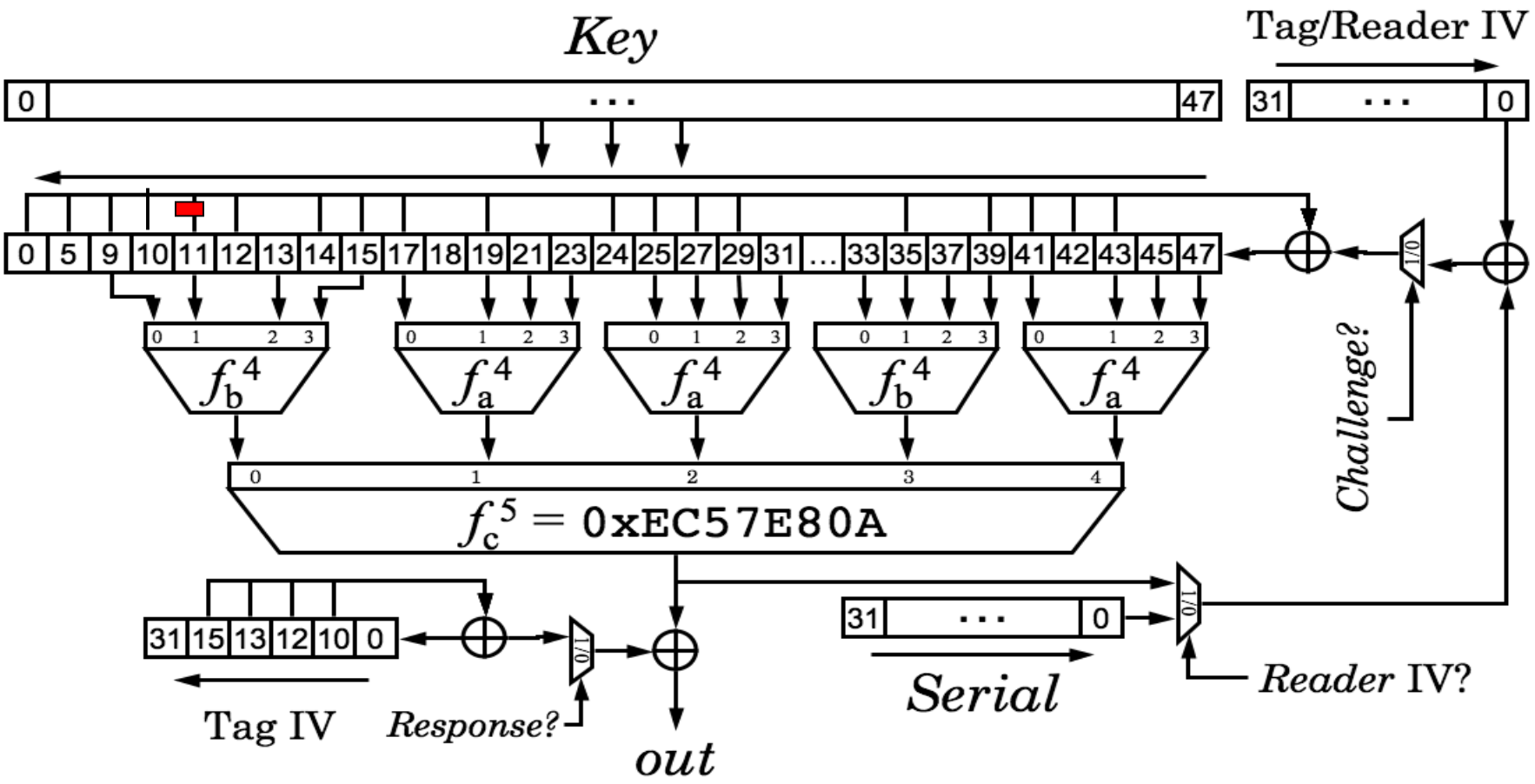
Tag IV ⊕ Serial is loaded first, then Reader IV ⊕ NFSR

Waste of Silicon

Internal bits are computed 2-3 times.

One could save half of the gates!

Crypto1 Cipher



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$f_b^4 = 0xB48E = (a+c)(a+b+d)+(a+b)cd+b$

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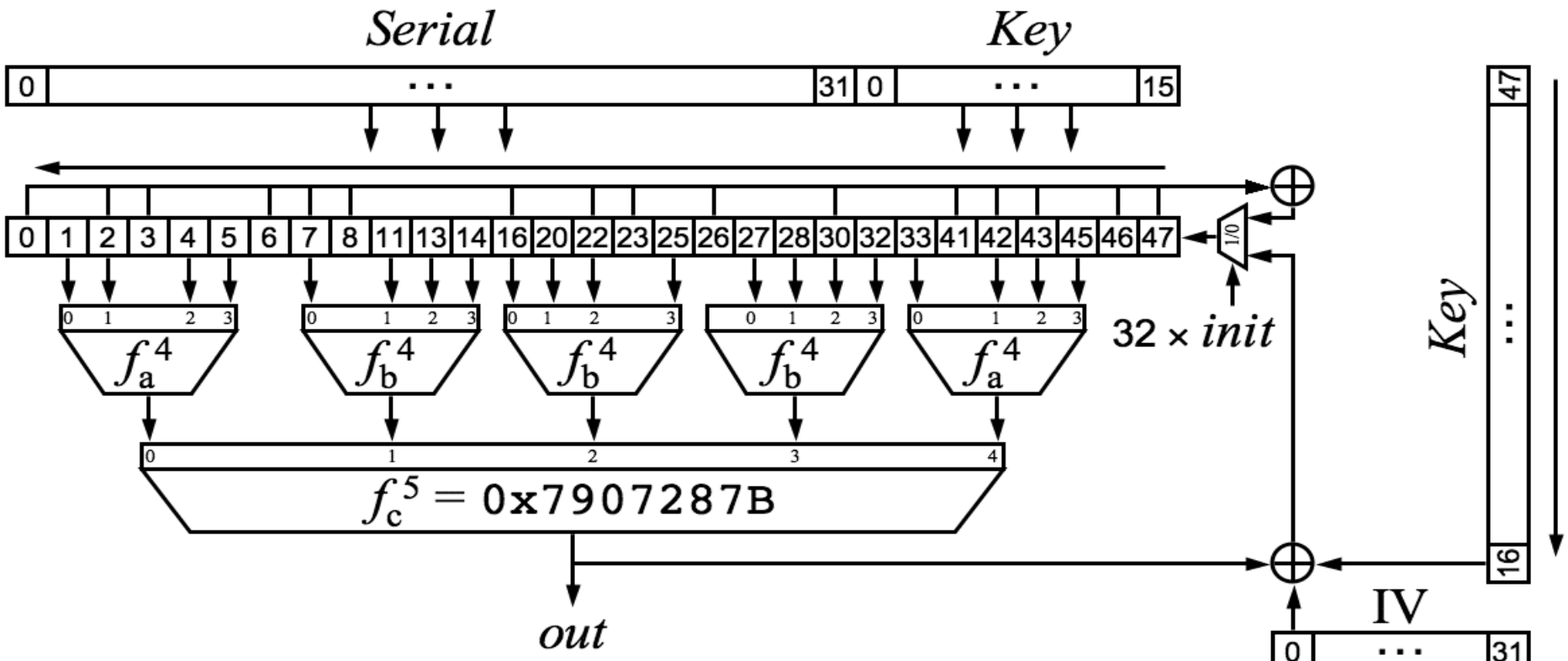
Hitag2 Cipher



inverse(first 32 keystream bits) = authenticator

f_a^4 = 0x2C79 = abc+ac+ad+bc+a+b+d+1

f_b^4 = 0x6671 = abd+acd+bcd+ab+ac+bc+a+b+d+1

Strong or Weak?

High Algebraic Immunity.

- Does NOT help.
- Many “direct” algebraic attacks exist. We can break “any cipher”, if not too complex…

First efficient attack on this cipher was an Algebraic Attack
[Courtois, O’Neil, Nohl, see eprint/2008/166].

Soon became obsolete.

Exhaustive Key Search

- 48 bits, about 4 years on 1 CPU.
  - Hours with FPGA.

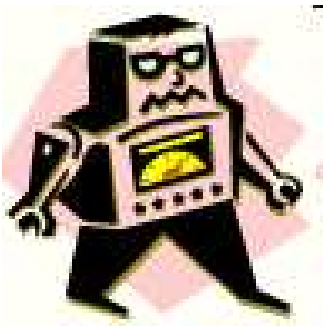
Our First Attack [04/2008]

- 12 seconds on the same CPU.

Better Attack [09/2008]

- 0.05 seconds.
  [de Koning Gans et al, Esorics 2008]

Beyond Crypto-1



…AC can break “any cipher”, if not too complex…

But other attacks are faster…

- However,
  - our attack does NOT require human intervention
  - more generally applicable:
    we can also break Hitag2 in 1 day
    (instead of say 4 years).
    - has fully irregular taps. See: Inversion attacks:

[Ross Anderson: Searching for the Optimum Correlation Attack, FSE'94]

- to appear in ACS’2009, September 2009.

Clone Attacks

Cloning the Card

Remark:

I wouldn't care that much about hackers that get free rides on the Tube.

- What about the Cabinet Office, nuclear facilities, big banks in the City?
  - It seems that most buildings actually use MiFare Classic (70 % market share) or an even less secure LF systems..

Key Sizes and Brute Force Attacks

Key Size = 48 Bits

Single PC – 3 years. FPGA: days…

Claim: 48 bits can still be
a SECURE key size in 2010.

- in authentication only (extra randomness effectively prevents brute force attacks),

So brute for attacks are infeasible

WHAT???? Yes.

Brute Force Infeasible?

Yes, due to the protocol.

Sound engineering principle:

The card never ever answers anything related to the secret data, unless the reader sends a valid cryptogram on 8 bytes…

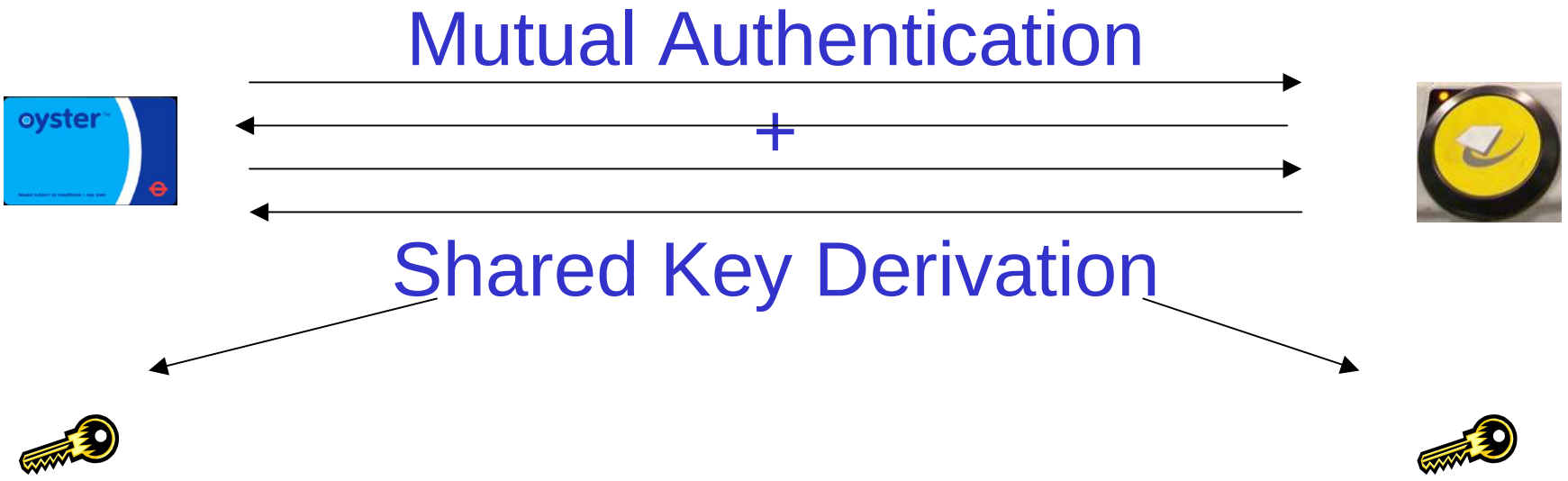
If I know the key, it takes time to confirm this.

It takes time to reject wrong keys too.

2^{32} queries to the card => months of online time querying the card...

The Protocol

Mutual Authentication + Secure Messaging



Tag Nonce

- The pseudo random number generator uses a 16 bit LFSR to produce a 32 bit nonce.

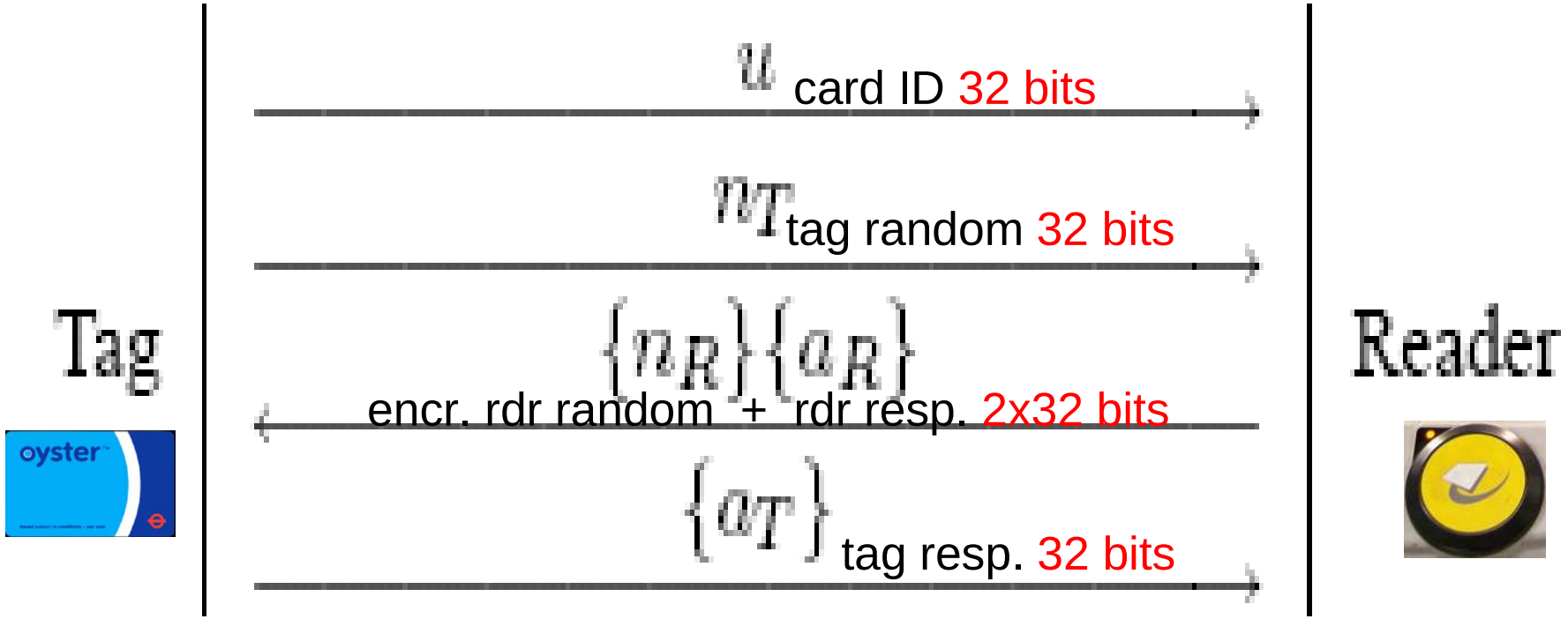
$$L_{16}(x_0 x_1 \dots x_{15}) := x_0 \oplus x_2 \oplus x_3 \oplus x_5$$

- The successor function is defined as follows:

$$\mathrm{suc}(x_0 x_1 \dots x_{31}) := x_1 x_2 \dots x_{31} L_{16}(x_{16} x_{17} \dots x_{31})$$

- The period of the PRG is 65535, it shifts every 9.44μs, and cycles in 618ms.
- For some [clone/compatible/etc] cards it will be
  - 618ms/X, for example x=4,5 etc..

Authentication Protocol



=> starting from now,
all read/write commands data is sent encrypted…

Step by Step

1. First the reader and the card engage in the anti-collision protocol where the reader learns the unique ID of the card and selects the card.
2. The reader issues a command '60 0X' by which it starts the mutual symmetric-key authentication process between the card and the reader, with the key pertaining to the block number 0X.
3. The card answers with a random n_T on 4 bytes,

Step by Step

4. The reader sends a cryptogram on 8 bytes which is $n_R \oplus ks1$ and $suc^2(n_T) \oplus ks2$.
5. The card responds with 4 bytes, $suc^3(n_T) \oplus ks3$.
6. Then all subsequent communications and data are encrypted and the card will now accept read, write and increment commands for block 0X.

Here n_R is the 32-bit nonce chosen by the reader, suc is a certain bijective function, and $(ks1, ks2, ks3)$ are the 96 bits of the keystream produced by the

Generation of LFSR Stream – 1

Definition 2.6. Given a key $k = k_0 k_1 \dots k_{47} \in \mathbb{F}_2^{48}$, a tag nonce $n_T = n_{T,0} n_{T,1} \dots n_{T,31} \in \mathbb{F}_2^{32}$, a uid $u = u_0 u_1 \dots u_{31} \in \mathbb{F}_2^{32}$, and a reader nonce $n_R = n_{R,0} n_{R,1} \dots n_{R,31} \in \mathbb{F}_2^{32}$, the internal state of the cipher at time i is $\alpha_i := a_i a_{i+1} \dots a_{i+47} \in \mathbb{F}_2^{48}$. Here the $a_i \in \mathbb{F}_2$ are given by

$$
\begin{aligned}
a_i &:= k_i && \forall i \in [0, 47] \\
a_{48+i} &:= L(a_i, \dots, a_{47+i}) \oplus n_{T,i} \oplus u_i && \forall i \in [0, 31] \\
a_{80+i} &:= L(a_{32+i}, \dots, a_{79+i}) \oplus n_{R,i} && \forall i \in [0, 31] \\
a_{112+i} &:= L(a_{64+i}, \dots, a_{111+i}) && \forall i \in \mathbb{N}.
\end{aligned}
$$

Generation of LFSR Stream – 2

Furthermore, we define the keystream bit $b_i \in \mathbb{F}_2$ at time i by

$$b_i := f(a_i a_{1+i} \ldots a_{47+i}) \qquad \forall i \in \mathbb{N}.$$

We denote encryptions by $\{-\}$ and define $\{n_{R,i}\}, \{a_{R,i}\} \in \mathbb{F}_2$ by

$$\{n_{R,i}\} := n_{R,i} \oplus b_{32+i} \qquad \forall i \in [0, 31]$$
$$\{a_{R,i}\} := a_{R,i} \oplus b_{64+i} \qquad \forall i \in [0, 31].$$

Attacks with a [Genuine] Reader

Key Recovery:

Brute Force

- About 4 years on 1 CPU. Minutes w. FPGA.

Nijmegen Attack

- 0.05 seconds.
  [de Koning Gans et al, Esorics 2008]

These are mild threats. Why?

Keystream Needed:

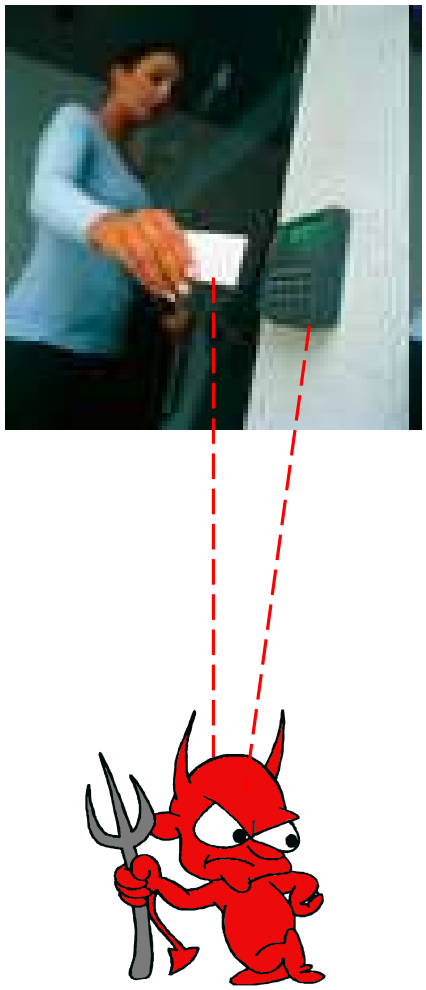
In Theory:

Keystream Data => 0.05 seconds.

In practice:

Very hard to get this data.

Small window of opportunity for the thief.



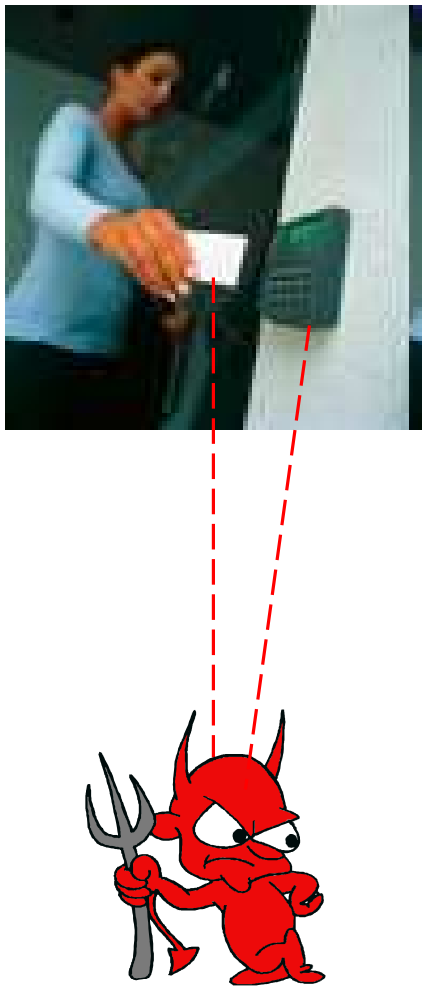
However

Known attacks:

Require to either

- scan legitimate card reader [that must already know the key!]
- eavesdrop and record genuine transactions

- and also later: access to the card (<10 cm).



NOT very practical.

Require to already penetrate inside the building with equipment etc…

Interception - Another Slight Problem…

Regulation of Investigatory Powers Act
RIPA [2000].

[…] “It shall be an offence for a person intentionally and without lawful authority to intercept, at any place in the United Kingdom, any communication in the course of its transmission “ […]

Card-Only Attacks

Card-Only Attacks

<u>The real security question is:</u>

Can I copy it, when I am sitting near the cardholder for a few minutes in the underground (contactless card queries).

Yes!

Card-Only Attacks

The attacker needs to sit next to the victim for a number of seconds / minutes.

- On a train, on a plane…
- Can be when travelling in the following country.

Then the hacker steal your identity:

make a clone of your card,

- and later penetrate the building.
- or sell the working card on the black market

Card-Only Attacks

Danger is 24h/24:

Anybody that is sitting/standing next to you can steal your identity (or at least enter some very nice building…)

Card-Only Attacks
Infeasible -> Possible?

Parity Attacks

Problem 1: The card does encrypt data with redundancy.

One should never do that.

- more costly
- weaker
  - and even weaker with a stream cipher:

    Ciphertext Only attack (weak)=>

    gives (small weight) LINEAR equations on the keystream (very strong)

Compare to GSM

BTW:

For the same reason it is currently easy to eavesdrop to GSM communications.

And sometimes make free calls…

Cf. [Biham-Barkan-Keller: Instant Ciphertext-Only Cryptanalysis of GSM.. Crypto'03 and JoC'08]

Problem 2: A Bug in MiFare Classic

Discovered accidentally.

- sometimes, under certain conditions, the card outputs a mysterious 4 bits…
- given the fact that many RFID readers are not 100 % reliable, it is easy to overlook it

Then one can guess how it works…

- what are these conditions?,
- can I predict when this will happen?

Parity Weakness…

- Parity bit computed over the plaintext and is encrypted using the same bit as the next plaintext bit
- If all 8 parity bits are correct but the answer is wrong, the tag responds with the 4 bit error code 0x5 encrypted.

$$p_j := n_{T,8j} \oplus n_{T,8j+1} \oplus \cdots \oplus n_{T,8j+7} \oplus 1$$
$$p_{j+4} := n_{R,8j} \oplus n_{R,8j+1} \oplus \cdots \oplus n_{R,8j+7} \oplus 1$$
$$p_{j+8} := a_{R,8j} \oplus a_{R,8j+1} \oplus \cdots \oplus a_{R,8j+7} \oplus 1$$
$$\forall j \in [0, 3]$$

and the encryptions $\{p_j\}$ of these by

$$\{p_j\} := p_j \oplus b_{8+8j} \qquad \forall j \in [0, 11].$$

The Bug?

Or maybe a backdoor?

- Stop pretending that everything happens by accident.
- We need to assume the worst scenario and examine the consequences:
  - Smart card companies are in the position to embed backdoors in products and these will NOT be found for many many years…

Secure Product Development

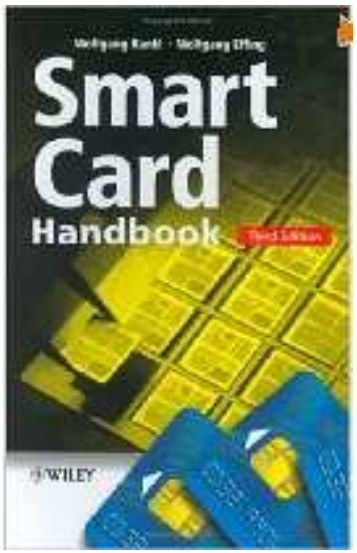
Secure Hardware Dev. Management

[In smart cards] one design criterion differs from the criteria used for standard chips but is nonetheless very important is that absolutely no undocumented mechanisms or functions must be present in the chip ('that's note a bug, that's a feature').

Since they are not documented, they can be unintentionally overlooked during the hardware evaluation and possibly be used later for attacks.

The use of such undocumented features is thus strictly prohibited [...]

[pages 518-519 in the Smart Card handbook by Wolfgang Rankl and Wolfgang Effing, 1088 pages, Wiley, absolute reference in the industry]



Application Development Management

Goals:

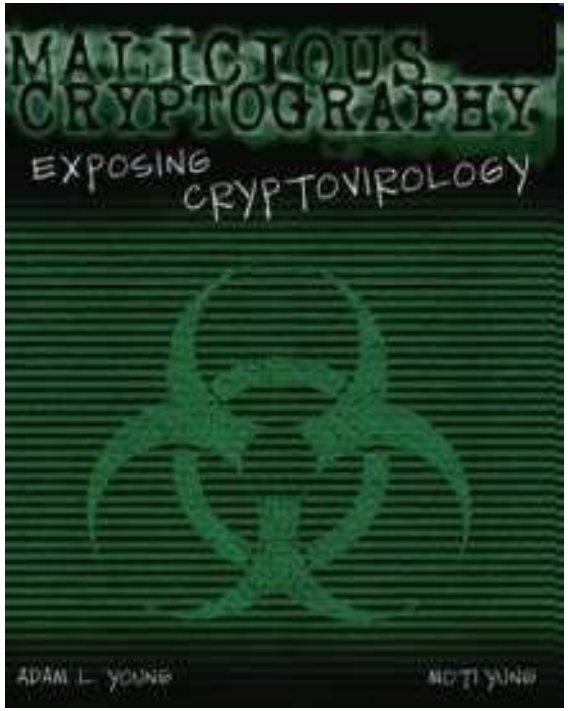
- Avoid backdoors, Trojans, covert channels, bugs etc.
- Kleptography: techniques to leak keys to the attacker,

- form of perfect crime.

There are various forms of leaking keys:

- intentionality impossible to prove
- intentionality provable

ONLY with source code



Application Development Management

Goals:

- Avoid backdoors…

Means:

- Segregation of duties.
- Monitoring.

Application Development Management

Solutions:

- Never one developer works alone on an application.
- One developer knows only some parts of the spec(!).

Application Development Management

Solutions:

- Security audits
  - auditor from the customer: large bank, etc.
- Common Criteria evaluations:
  - The source code is inspected by an independent company: government agency [GCHQ, BSI, DCSSI] or an evaluation lab [such as CEA-LETI] mandated and paid by the customer [to avoid conflicts of interests].

***Common Criteria Certificates

- CESG at GCHQ
  - Communications-Electronics Security Group at Government Communications Headquarters

=> Common Criteria Scheme

EAL = Evaluation Assurance Level

- EAL1: Functionally Tested
  - no need disclose the design/sources to government agencies…
- EAL2: Structurally Tested
  - 6 months, 150 K$
- EAL3: Methodically Tested and Checked
- EAL4: Methodically Designed, Tested, and Reviewed
  - EAL4+: augmented requirements [better crypto!]
  - 24 months, 150 K$ - 2.5 M$ per product
    - Ms. Windows 2000 was certified for an undisclosed amount

commercial

- EAL5: Semi-formally Designed and Tested
- EAL6: Semi-formally Verified Design and Tested
- EAL7: Formally Verified Design and Tested

military

Card-Only Attacks
Infeasible -> Possible?

The “Bug”

Under certain (parity) conditions when we try to spoof the card with an invalid cryptogram, the card replies with 4 bits.

These 4 bits are the encrypted NACK command at a certain later moment in the keystream generation process.

The “Bug”

Parity-based:

Fact 4.2.2 *The card answers with a 4-bit encrypted NACK if and only if the parity bits for the plaintext after decryption are correct.*

For very long time I made my live much harder, designed several attacks where also 8 the parity bits over the ciphertext were correct. Much harder (Exercise: with 16 parity bits one can still break it under 1000 queries, never published…).

Simplification:

Idea: modify the parity bits only.

Remark: most of the time we can safely ignore how these parity equations work, and use only the fact that:

Fact 4.2.3 *Whatever is the spoofed cryptogram C, there is exactly one choice for the 8 parity bits P_C so the card will reply with a 4-bit encrypted NACK.*

The “Bug” was known…

I was the first to circulate a paper that describes this vulnerability in March 2009.

But then I discovered that MANY people knew about it for a long time… including journalists.

What? It was already broken, can it be broken again?

At the time of release I ignored the latest Nijmegen paper [Oakland IEEE Security and Privacy, 18 May 2009].

Special Cards

Weaker Cards

I've recently examined the card used in Kiev, Ukraine underground.

This card will ALWAYS answer the spoof attempt.
Way easier to clone then…

These are unlicensed clones of MiFare Classic.

They are probably illegal in Ukraine
(but nobody expected that there will ever be a method to distinguish them?)

Investigation of Kiev Cards

Well, they are Fudan Microelectronics FM11RF08 from Shanghai, China.

How do I know this?

The same:

- The same ATR (misleading) "3B8F8001804F0CA000003060300010000000006A"
- sak: 08 00 00
- ATQA: 04 00
- Same normal functionality.

Differences: [visible only to experts or can be discovered 'by accident']

- They answer a spoof attempt with probability 1.
- At the end of the block 0 we always find "bcdefghi". Typical with Fudan.
- Original NXP reply to 7-bit frames 0x26.

Counterfeit MiFare Classic

There are other clones.

Come from India, China and Russia (!).

List: see

http://www.proxmark.org/forum/topic/169/mifare-classic-clones/

Experimental Setup

Cheap Stuff…

Only high-level APDU access.

GET CARD SERIAL NUMBER

CLA	INS	P1	P2	Le
FF	CA	00	00	00

LOAD KEY IN RAM REGISTERS

CLA	INS	P1	Kt	Le	Key
FF	82	20	00	06	FFFFFFFFFFFF

MIFARE CLASSIC AUTHENTICATE

CLA	INS	P1	P2	Nb	Kt
FF	88	00	3A	60	00

MIFARE CLASSIC READ

CLA	INS	P1	P2	Le
FF	B0	00	3A	10

MIFARE CLASSIC WRITE

CLA	INS	P1	P2	Lc	Data
FF	D6	00	3A	10	

Example: rfidiot library does send these commands…

Low Level Access

==

Commands sent over the air.

These boards + software work
and are widely available:

C++ + nfclib + ACR122

Example:

> 26
< 0400
> 9320
< CA1C46D141
> 9370CA1C46D141 (CRC)
< 08 (CRC)
> 6000(CRC)
< 24D2783A
> CF80E99F1AA2A1F1
> …

UID

Open PCD

TI TRF7960 EVM

Proxmark 3

Getting the data, difficulties…

Precise timing, switch the magnetic field off and on
=> fix the card nonce.

Very hard to achieve in practice.

**Getting the data, difficulties…

Hard to do: fix the card nonce through timing.

- With OpenPCD and librfid I can achieve Min-entropy of 6 bits and I can do <2 transactions per second.
- With TI TRF7960 EVM we modified the firmware and obtain 33 transactions per second with random nonces.
  - Nijmegen claim 1500 / s
- And 1.6 chosen TC per second.
  - Nijmegen claim 30 / s

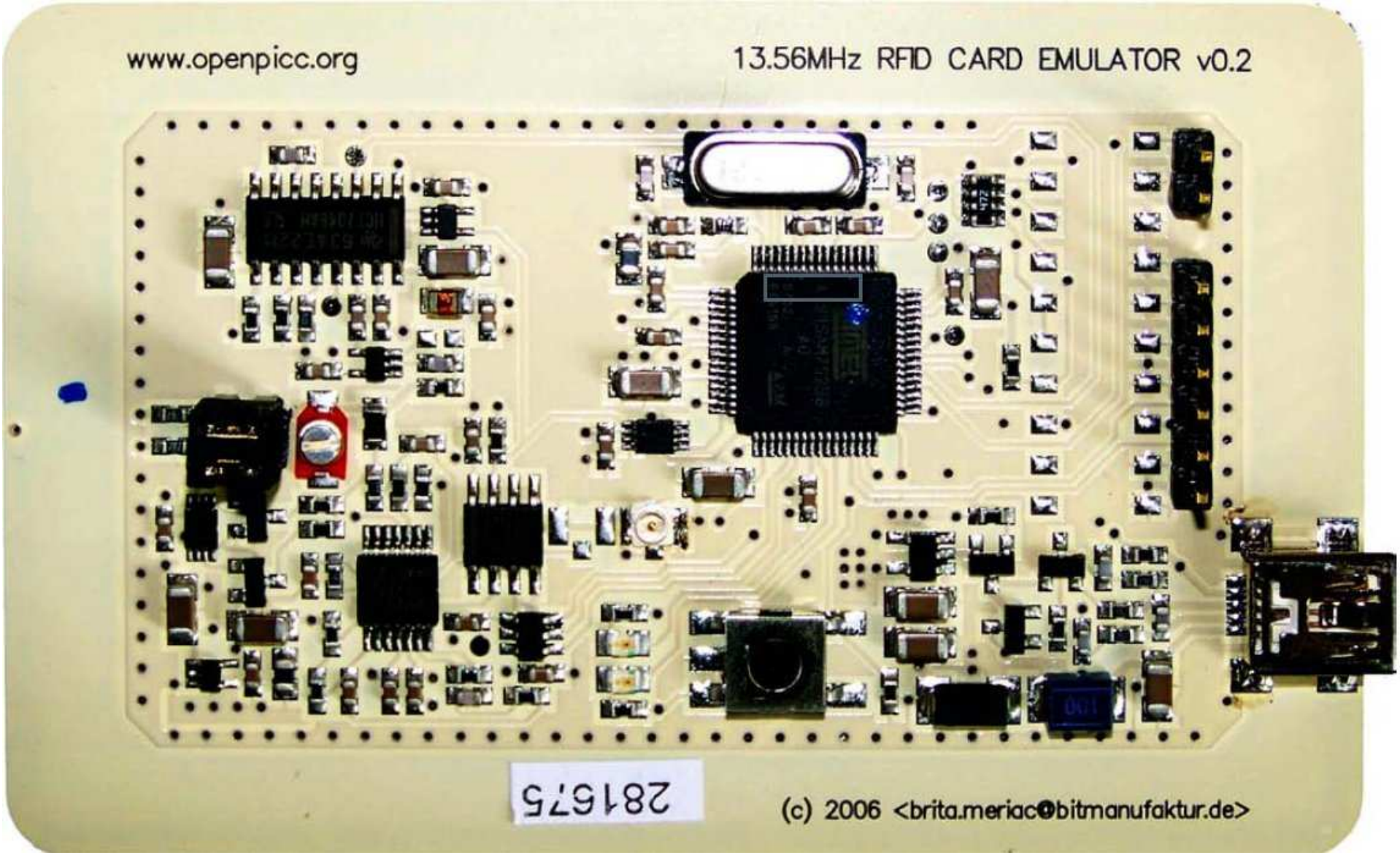
Actually the attack CAN ONLY BE FAST if the firmware has more memory, or better control of the TC. Current dilemma.

Transmission errors can ruin the attack.

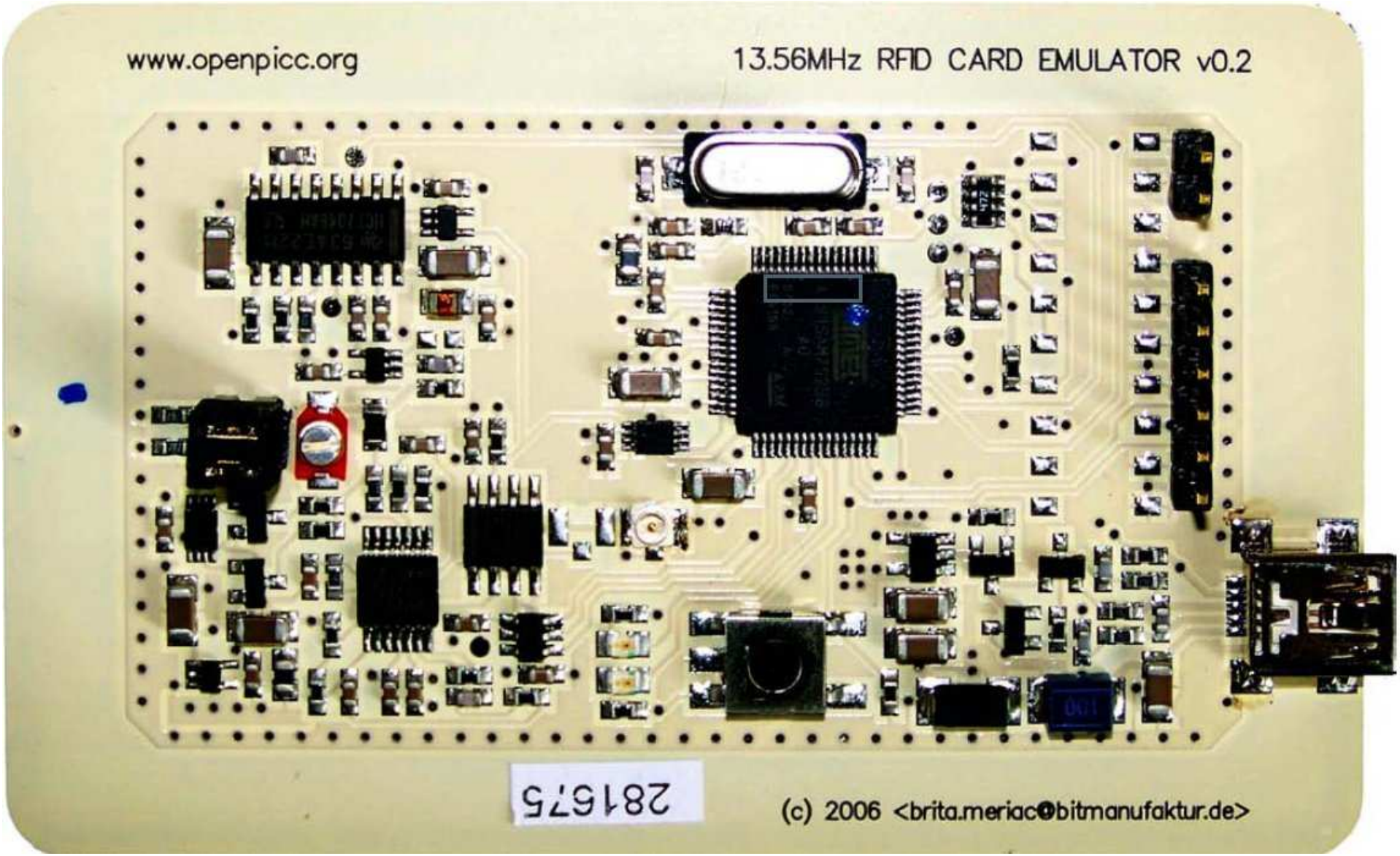
There is no parity bits in the “backdoor” property… They are sometimes received incorrectly… (<0.1%).

Card Simulation

Open PICC


www.openpicc.org
13.56MHz RFID CARD EMULATOR v0.2
281675
(c) 2006 <brita.meriac@bitmanufaktur.de>

Best Sniffer?



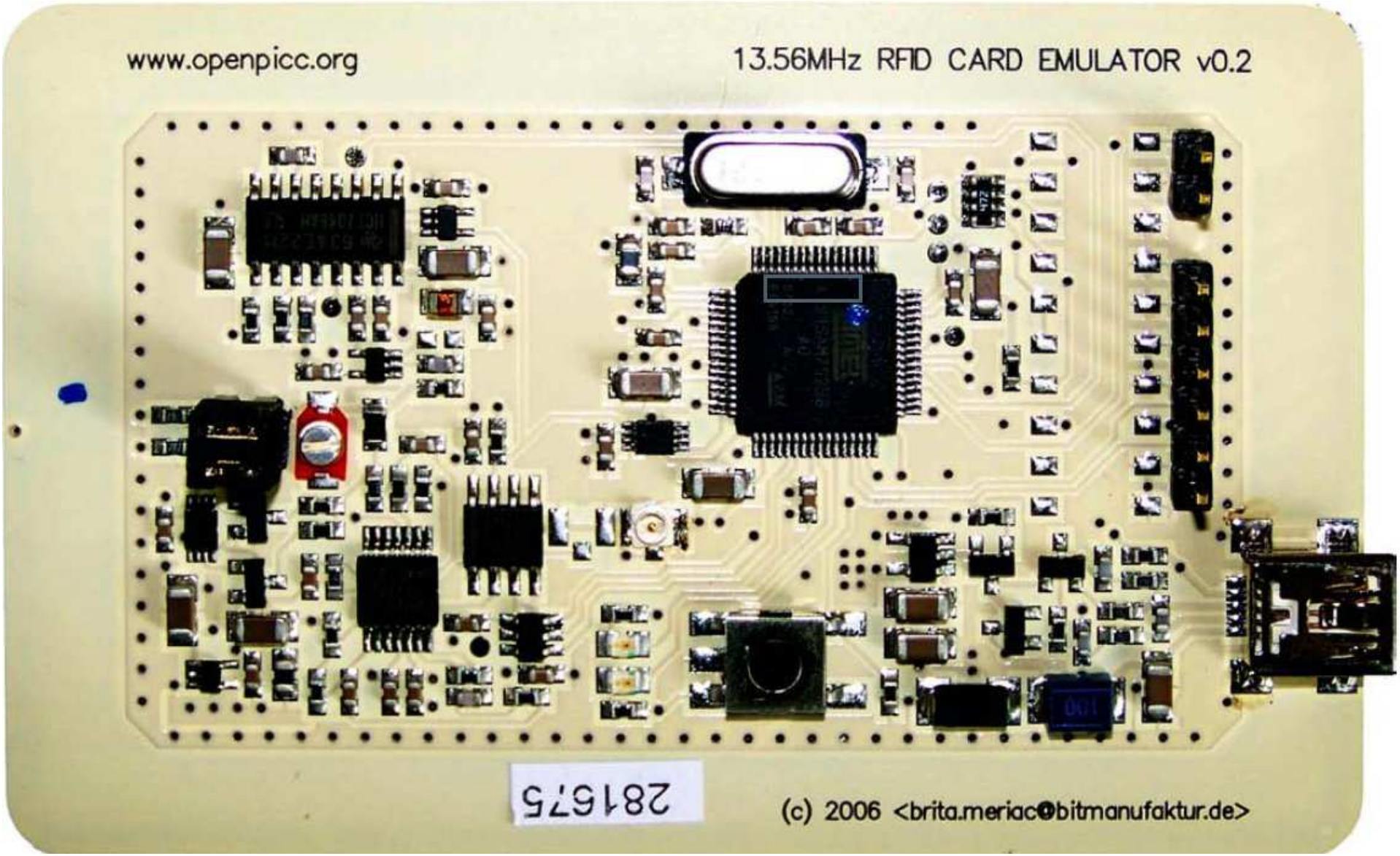
Well…

there are professional sniffers…

ProxiSPY

ISO14443 Contactless Communication Analyzer / Logger

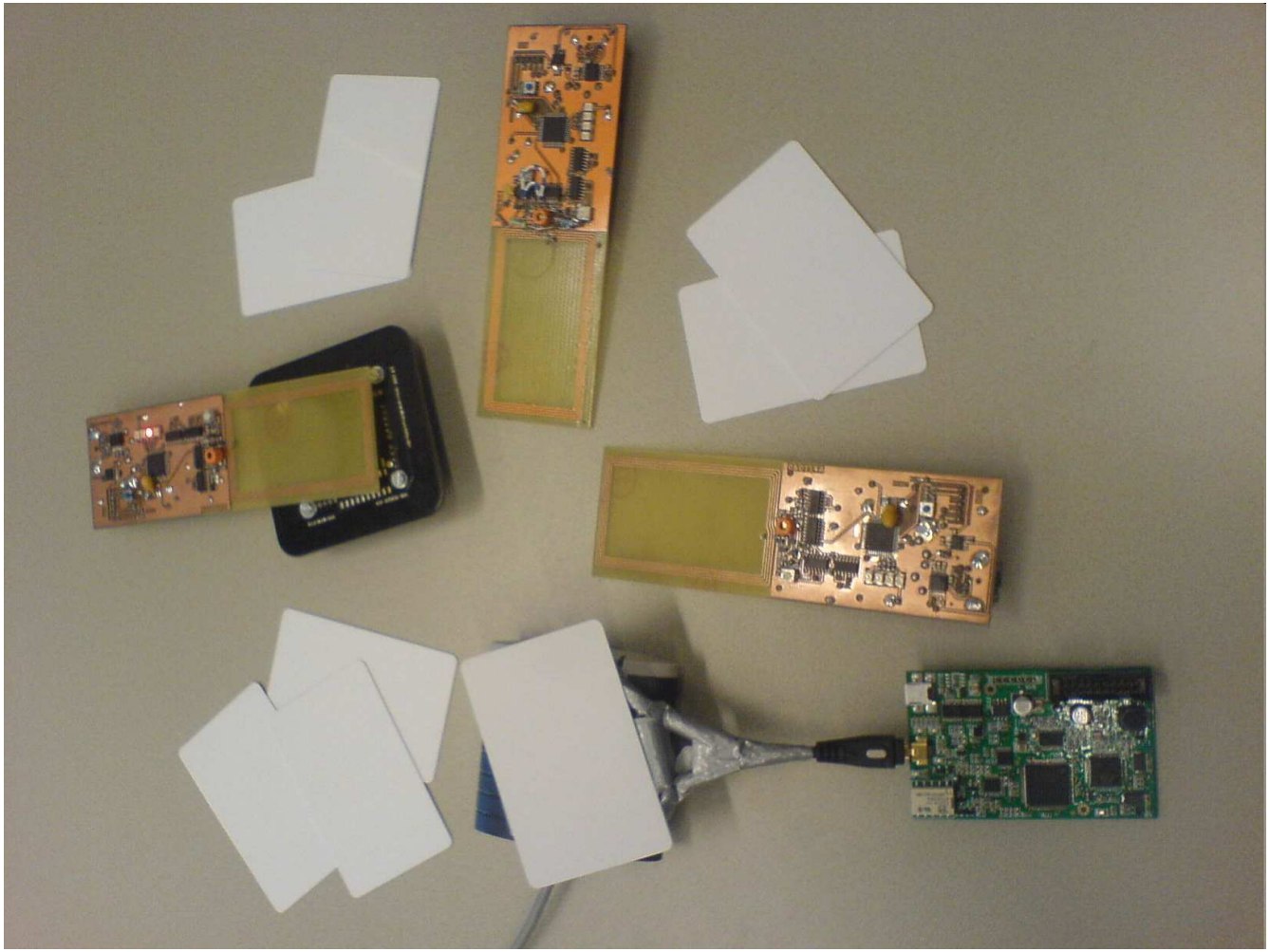
Card Simulator (80 %)



Proxmark 3 does all…

Or This?

Dutch Demo



Recent Results

New Paper by Nijmegen Group

In IEEE Privacy and Security Oakland,
18 May 2009.

$\Rightarrow$ 3[+1] Attacks that exploit the same vulnerability.

How To Compare Attacks

- How Many queries to the card?
  - I don't count SELECT UID command as a query..
  - ("queries" =def "authentication attempts")
- Do we need to reset the card between queries and obtain reliable timing?
  - MAKES queries still like 50 times slower (!)
- Is there a (VERY costly) precomputation?

4 New Attacks by Nijmegen

1. One is brute force.
   - Few seconds access to the card.
     Costly, 2^{48} (FPGA implementation).
     - Nijmegen claim the speed of 1500 MiFare transactions per second => fast data acquisition.
2. Another requires 28500 queries to the card.
   - Takes 15 minutes (constant nonce required).
     (My latest attack requires 300.)

4 New Attacks by Nijmegen

3. Is a very simple pre-computation attack. As expensive as brute force but done only once to pre-compute 384 Gb of data.
    - Then they can clone the card with 4000 queries.
      Takes 2 minutes? Or 2 seconds?
      2 minutes including computation time as it seems.

4. Uses the fact that if you know one key, one other key be recovered instantly.
    - Another bug, VERY SERIOUS
        - Works for many many cards…

Attack 3

Fix the first 4 bytes of the 8-byte cryptogram.

$\{n_R\}$

Pre-compute all states that gives 8 parity conditions + 4 ‘backdoor’ bits fixed to 0000.

Uses random card nonces… Much easier.

Our Attack vs. Nijmegen

Nijmegen attack 3.

- very expensive pre-computation, 400 Gb of data
- then 4000 queries/card
- instant running time.

My latest attack [very different]:

- no pre-computation
- then 300 queries/card, more than 10 times less.
- instant running time too.

=> The strongest attack ever found on MiFare Classic.

My Attack

Cf. eprint.iacr.org/2009/137. Basic Facts:

It is a multiple differential attack.

I exhibit a differential that

- holds simultaneously for 256 differentials this works with probability of about 1/17.
- for 8 differentials the probability is about 0.75 (!!).

Both are differences on 51 bits of the state of the cipher.

A VERY STRONG property(!).

Key Discovery

Fact 5.1.1 *The probability that the 3 bits of the keystream generated during the decryption of the last 3 bits of the 4th byte c_3 do NOT depend on these bits of c_3 is very high, about* 0.75.

cf. eprint.iacr.org/2009/137:

Explanation: This probability is surprisingly high, as shown by our computer simulations. (even when the full 8 bits of c_3 are variable, this probability is still very high, about 1/17). All this is due to the very bad properties of the Boolean functions used in

Consequence

Fact 5.2.1 *If we fix the card nonce* n_T *and a 29-bit prefix of* C*, with probability about 0.75 over* C *the 9 bits of the keystream generated in this process are constant simultaneously for 8 different encryptions. of* C *that share the same 29-bit prefix and vary the last 3 bits of* c_3.

The Differences

Fact: All newly generated bits can be written as a fixed (known) linear function of (unknown) previous state bits AND the new 3-8 keystream bits that, though may be independent on the ciphertext (with proba 0.75 … 1/17) but remain unknown.

The new bits are linear in BOTH types of variables.

⇒ Just take the difference of any bit for two different decryptions. The unknown keystream bit will cancel.

⇒ The difference is a linear function of the previous state bits. So what?

⇒ The difference of previous state bits is always 0: we consider 8..256 encryptions with the same prefix of 29..24 bits in the ciphertext to be decrypted.

Therefore:

Fact 5.3.1 *If we assume that the Crypto-1 keystream generated during the decryption of the 4th byte c_3 is constant and does NOT depend on this byte, then the difference of the state of the cipher at any moment during the computation of ks2 and ks3 is a fixed multivariate linear function that depends on the differences in c_3 and nothing else.*

The Differences

Can be represented by a linear function 3->51 bits.

It can be computed given the linear feedback of the LSFR.

Real-life examples:

```
00000001 8DC1B21F6E10
00000002 1B83643EDC20
00000004 3706C87DB840
```

Remark:

This property is strong (7-255 differences on 51 bits)

It is SO STRONG that the key can be found by hand… Just a lot of information about the internal state…

Similar to differential cryptanalysis of DES…

An exceptional property, but once found, the security collapses totally.

Remark: Connects very well with algebraic cryptanalysis: properties of a cipher, can be exploited automatically with constraint satisfaction techniques [SAT solvers etc.]. Here it is easy that it could be done by hand. But the attack + technique applies to any stream cipher with "bad' Boolean functions. It will just break it.

Origin of this

Hard to believe, due to the spectacular nature of weakness of Boolean functions used in the cipher:

- With probability 10/16 the output of the combined Boolean function on 20 bits does not depend on the last 4 bits.
- In addition, with probability 3/4 the sub-function that deals with the last (and the latest) 4 bits, does not change if we flip the last bit, and with probability 1/2, it does not change when we flip the second last bit,
- and with probability 1/2, it is always 1 whatever is the change to the last 2 bits.

Running the Attack

1. Fix the card nonce through precise timing. Get one reply. P = 1/256.

We need on average 128 queries.

1. Now vary the last 3 bits (29..31) of the Encrypted Reader Cryptogram (ERC) == $\{n_R\}$ == first 4 bytes of the spoof cryptogram sent.
2. Also vary the 5 parity bits that can change, check all cases (exactly one replies).

We do on average $2^5/2$ trials times 2^3 cases.

Running the Attack

4. Repeat the whole* for about 1/0.75 times on average.

*Until the event happens
[otherwise the key found is not correct, or we get a contradiction].

TW. Next time the Step 1 (get one reply) is cheaper:
just change 3rd+4th byte of ERC=={n_R},
replies with P=1/64,
32 attempts on average.

Analysis

How many queries total?

128 +
(1/0.75-1)*32+
(1/0.75-1)*8*16
=

300 (on average)

Data -> Key Recovery

We use 8 replies x 4 bits, plus the information that comes from Parity (only at the end)

5. Now with probability about 0.75, we can simultaneously predict the differences of the states for all the 8 encryptions (cf. Fact 5.2.1 and Fact 5.3.1).

Data -> Key Recovery

One half:

6. Now we use the fact that the combined Boolean function of Crypto-1 reuses most state bits after 2 steps. Thus exactly (and only) 21 state bits determine the two keystream bits bits $(ks3)_0$ and $(ks3)_2$. We will examine all the 2^{21} cases and for each ciphertext where the card have answered we can divide the size of our space by 4. With 8 answers we will determine about 2^5 possible values for the 21 bits.

Data -> Key Recovery

Other half:

7. In the same way, we will determine 2^5 possibilities for the other 21 bits of the state that determines bits $(ks3)_1$ and $(ks3)_3$.

Data -> Key Recovery

Combine + check parity:

8. Then we have a list of 2^{10} states on 42 bits, which we need to extend to 2^{16} possible states on 48 bits.

9. Then by simple roll-back we get about 2^{16} possible initial keys, and checking all the $8 \cdot 8$ parity bits involved in the attack allows to know which key is correct with near certainty.

   Or if we find a contradiction at any stage, this means that the keystream does depend on c_3, contrary to the assumption in Fact 5.2.1.

Data Complexity

300 queries on average.

Computation:

- No precomputation.
- Running time:
  about $C*2^{21}$, instant on a PC.

- More than 10x better than any other attack…

My Attack in Practice

For now it takes 5-10 minutes per sector.

Should take 10 seconds with Proxmark3

Problems:

- communication errors
- hard in fact to fix the nonce…

Diversified Keys
=>
Nested Attacks

Nested Attacks

Nijmegen Paper

3. Is a Time/Data/Memory Tradeoff. As expensive as brute force but done only once to pre-compute 384 Gb of data.
   - Then they can clone the card with 4000 queries.Here the nonce does NOT need to be fixed. Takes 2 minutes? Should be 2 seconds? Is there a mistake in the paper?

4. Uses the fact that if you know one key, one other key be recovered instantly.
   - Another bug, out of scope for now. Easy!

Nested Authentication Attack – 1

- Assume the attacker knows 1 sector key
- The first nonce n_T^0 is sent in clear text. After successful authentication, the next nonce, n_T is sent encrypted as $\{n_T\}$.
  - Attacker computes $\mathrm{suc}^i(n_T^0)$ for i close to δ, where δ is the estimated distance between the two nonces.
  - Attacker can further reduce narrow the possibilities using 3 bits of information from parity bits
    - Because parity bits are computed over the ciphertext.
      - This gives 3 linear equations on the keystream.
  - In practice the card nonce can be known with certitude.

*****in their paper:

- For j = {0,1,2}, we have,

$$n_{T,8j} \oplus n_{T,8j+1} \oplus \cdots \oplus n_{T,8j+7} \oplus n_{T,8j+8} = \{p_j\} \oplus \{n_{T,8j+8}\} \oplus 1$$

- Where $\{n_{T,i}\} := n_{T,i} \oplus b_i$
- Since the attacker observes $\{p_j\}$ and $\{n_{T,8j+8}\}$, it gives him 3 bits of information about n_T
- Also, lets define the distance between 2 nonces formally as:

$$d(n_T, n'_T) := \min_{i \in \mathbb{N}} \mathrm{suc}^i(n_T) = n'_T.$$

Nested Authentication Attack – 3

- So using the distance estimation and the information from parity bit, the attacker can accurately guess the nonce and recover 32 bits of keystream.
- An attack, using the fact that only odd-numbered places of LFSR are used in the filter function, can be used to recover 2^{16} possible keys.
  - Direct inversion attack.

Nested Authentication Attack – 4

Use a very similar “inversion” method as in Malaga paper.

- This attack works in 0.05 s with about 64 bits of keystream.
- But here we have only 32 bits of key stream. A bit more difficult.

$\Rightarrow$ Gives 2^{16} possible keys.

$\Rightarrow$ Done twice, and intersection with 1-2 keys.

Combined Attacks (ours + Nijmegen)

Best Attack in Practice

Use my attack for one sector.

Then use Nested Authentication attack [Nijmegen Oakland paper] for other sectors.

- 10 minutes with my current equipment.
- Should take 10 SECOND TOTAL with Proxmark3. (all keys, all sectors).
  - Proxmark3 can then directly be used to act as a clone.

So How Secure is the Oyster Card?

V3.co.uk

Tech Daily

News | Analysis | Comment | Reviews

Oyster cracker vows to clone cards

Cloning kit could sell for just £200, says researcher

Robert Blincoe, vnunet.com, 28 Jul 2008

*Facts

- There never was a scientific or press report explaining the FULL scale of the problem.
- Auto-censorship:
  - For 6 months we had the spec of the cipher, we never published it, Dutch researchers did it and they had to meet Philips/NXP lawyers in court…
  - For 6 months we knew about the most serious vulnerability (bug) and did not disclose it.
  - We have since discovered further VERY embarassing facts about specific implementations, and we keep information secret. Is there a criminal business case?
    - Denied by NXP, denied by Dutch researchers..
      - In fact I could make any person in this room a millionaire with £40 investment, by giving them <10 lines of code.

Application-Level Problems

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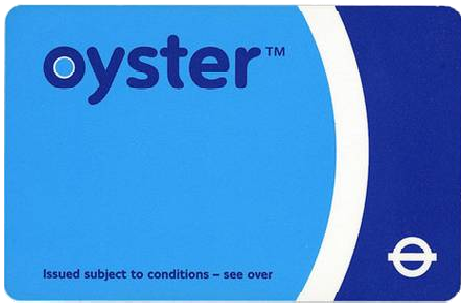
News › UK news › Transport

London tube hit by second Oyster card failure in weeks

Alexandra Topping
The Guardian, Saturday 26 July 2008
Article history



No Criminal Business Case?

Fake Dublin Bus ticket scam uncovered

Cormac Murphy of the Herald writes:

> Fraudsters have been using forged bus and Luas tickets to evade public transport fares, it emerged today.
>
> Dublin Bus launched a full-scale probe when the scam was uncovered, leading to the arrest of a number of suspects.
>
> A man has already been fined €300 in court for using a fake pass, while other cases are pending.
>
> The con centred on the 'Combi' 30-day pass worth €98 which was advertised for sale at a price of €50 on the Gumtree website earlier this year.
>
> The pass is valid on all Dublin Bus vehicles and Luas trams.
>
> The forgeries look almost exactly like the real ones, though they are not recognised by validating machines on buses.
>
> The fraud was exposed when an employee of the bus company was going through 'standard fares' — or fines — issued to passengers.
>
> Mark Kelly, an area manager with the semi-state's revenue protection unit, came across a fine issued to a woman for not having her Dublin Bus identification card with her.
>
> He told the Herald he thought it odd that she would pay €98 for a Combi ticket and then not even carry her free ID.
>
> Mr Kelly kept the ticket with him and within 24 hours had it checked out. It proved to be a forgery.
>
> Dublin Bus officers then discovered an ad on Gumtree for a 30-day bus and Luas pass at a cut-price €50.

Student ran transport scam

By Daniella Miletic
April 20, 2005

A university student faked dozens of transport concession card applications for foreign students at $80 a time, a court was told yesterday.

Samuel Tang, 23, of Forest Hill, conducted the scam between early 2002 and March last year, using a fake school stamp. He pleaded guilty yesterday to 54 counts of dishonestly obtaining student concession cards from the Public Transport Corporation.

His friend Elizabeth Hancock told the County Court that Tang, a computer studies student at Monash University, wanted to help Chinese students on student visas. Holders of such visas are ineligible for travel concession cards.

County Court judge Julie Nicholson heard that students would hand over two passport photos and $80. Tang received $4320 over the two years.

The court heard that a friend Tang visited in 2001 in China advised him to buy a rubber stamp with a school's name on it. Tang's lawyer, Geoff Martin, said that on his return to Melbourne, Tang bought a stamp reading "Bayswater Secondary College". He then gained clients through word of mouth.

Police were alerted after an application that Tang had stamped was questioned at Flinders Street station and the person submitting the application fled.

Travel Card Fraud Detected

An Garda Sić½ochić½na, primarily through the Garda Bureau of Fraud Investigation, and in conjunction with Dublin Bus, Bus Eireann, Iarnrod Eireann & the Department of Social & Family Affairs, have been engaged in an investigation for a number of weeks.

The fraud involved false Travel Passes which are issued by the Department of Social & Family Affairs to persons with special needs. Passes entitle the bearer and an accompanying person free travel throughout the country on all public transport facilities.

The Garda investigation involved the interviewing of a significant number of people, culminating in the arrest of a male, aged 33 yrs. from the Dublin area. He has been charged with offences relating to this matter and is due before the Courts at 10.30a.m. on 10/02/06 at Dublin District Court No. 46.

While the source of these fake cards and the distribution network has now been dismantled, there are a number of fake cards still in circulation. The Garda investigation is continuing with a view to bringing those with fake cards in their possession before the Courts.

The introduction of a new Travel Pass Card System is currently being examined by the Department of Social & Family Affairs. This will significantly aid detection in the event of fake cards being used. It is a serious criminal offence to have in your possession or use these cards unlawfully.

6 Jailed In Metro Farecard Scheme

Probe Searches For 'Mr. Big'

By Lena H. Sun
Washington Post Staff Writer
Saturday, July 19, 2008; B01

Metro Transit Police have arrested six people in an elaborate fare card scam that has so far netted the agency $16,000 worth of stolen Farecards, officials said yesterday. The investigation is ongoing, and officials do not know how much the counterfeit operation has cost the agency.

"This was a sophisticated operation to defraud a public agency," Metro General Manager John B. Catoe Jr. said at a news conference. "We think there is a Mr. Big, and that's who we would like to find."

The thieves traded in counterfeit paper Farecards in Metro Farecard machines to receive legitimate ones, or used the counterfeit ones to add value to electronic SmarTrip cards, officials said.

The thieves also sold some of the legitimate cards on the street at half-price, officials said. Metro is investigating whether the cards were also sold online. Because many transit agencies have similar fare collection systems -- a magnetic strip that is electronically read by a Farecard machine -- Metro has also alerted the American Public Transportation Association, a major industry group, so other agencies can be on the alert.

A NOVELTY IN FRAUD.

SYSTEMATIC FORGERIES TO OBTAIN PASSES FROM TRANSPORTATION COMPANIES.

Capt. Hooker and Detectives McMahon and Irving, of the Nineteenth Sub-precinct, brought to the Yorkville Police Court yesterday Charles Leyster, alias William H. Gill, alias McCurdy, and Peter R. Hallis, who jointly with Leyster used the aliases mentioned. Their offense consists of an organized conspiracy to obtain free passes on different railroads and steam-ship lines, and selling them again for whatever they could obtain for them. The companies so far known to have been swindled are the New-York and Harlem Railroad Company, the New-York and New-Haven, the New-York Central, the Erie Railway Company, the Providence and Rhode Island Railroad Company, the Baltimore and Ohio Railroad Company, the Old Dominion Steam-ship Company, and the C. H. Mallory Steam-ship Company. The conspirators did their own printing, and procured rubber stamps with which to make their bogus orders for free passes appear more official like. From the 1st to the 20th of January they obtained five free passes, worth at an average about $18 50, from Superintendent Bissell, of the New-York and Harlem; Superintendent Toucey, of the New-York Central, and Superintendent Moody, of the New-York and New-Haven. The tick-

Polish Magazine Front Page

Report on pp.28-29

BEZPIECZEŃSTWO

Klonowanie reaktywacja

Karty zbliżeniowe wykorzystywane w systemach kontroli dostępu w firmach czy rozliczania transakcji były reklamowane przez producentów jako bezpieczne. Niektóre z nich można jednak szybko i prosto skopiować – udowadniają naukowcy z Polski i Wlk. Brytanii.

Najnowszy atak na karty Mifare spełnia warunek maksymalnie niekorzystnego scenariusza, gdzie napastnik zdalnie kopiuje dane z karty bez znajomości sygnałów wysyłanych przez czytnik.

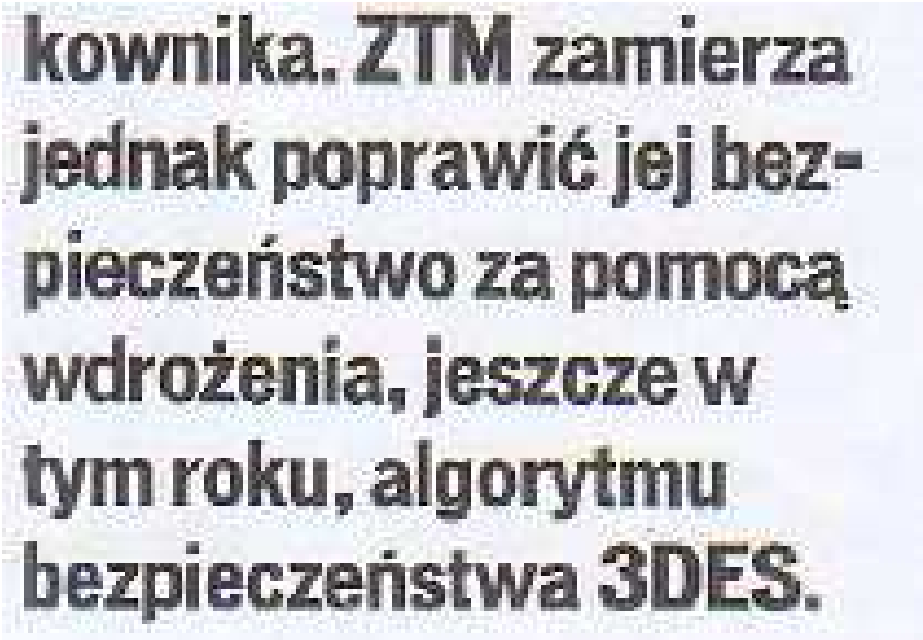
10 sekund

potrzeba, aby skopiować każdą kartę standardu Mifare Classic 1K.

Opis tego ataku przedstawiono na konferencji Eurocrypt 2009 w Kolonii i zostanie ponownie pokazany – uwzględniając nowe zdobycze kryptologii – na Międzynarodowej Konferencji Bezpieczeństwa oraz Kryptografii SECRYPT 2009 w Mediolanie

Warsaw Card Will be Repaired

- in 2010… a MAC will be added to authenticate entries written on the card

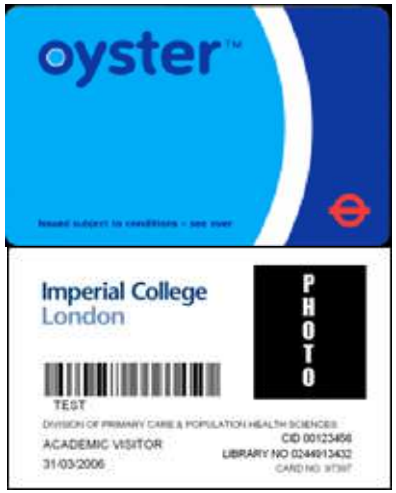

kownika. ZTM zamierza
jednak poprawić jej bez-
pieczeństwo za pomocą
wdrożenia, jeszcze w
tym roku, algorytmu
bezpieczeństwa 3DES.

Security (1A)

Unique ID in sector 0.

Cannot be changed, not even by the manufacturer.

- Can also be used to detect counterfeit (illegal) Chips from Russia, India and China.
  - Fudan clones already sold in 2004!

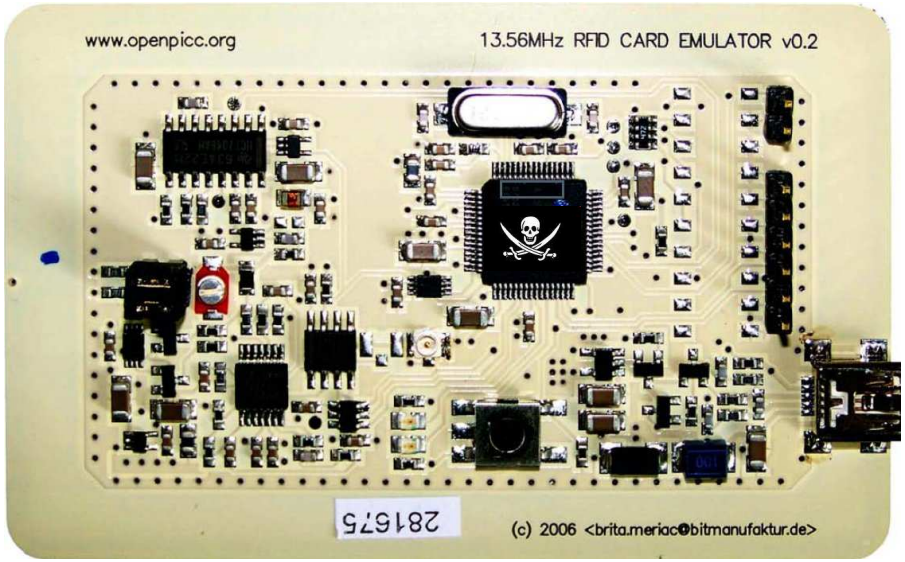


The only security in many building systems…

- renders purchase of MiFare Classic as opposed to Ultralight totally useless!

Attack:

card simulation

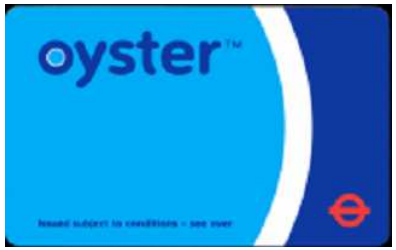


Security (1B)

London Oyster:

Another ID in sector 4.

=> Cannot be changed anymore either.
WORM mechanism through access conditions.



Bytes 1-5 contains the ID printed on the card.

- Reverse order
- Convert to decimal

- Bytes 6-16 used to prove authenticity (proprietary MAC).

=>Cannot emit new Oyster cards myself.

Security (2)

Making cards [slightly…] harder to attack

Diversify all keys for each sector.

- Done for every Oyster card
- Not done in many other countries, examples:
  - In Kiev, Ukraine, the first block uses the default Infineon key A0A1A2A3A4A5 , then keys repeat, for example for blocks 12 and 16 the key is the same..

Security (2)

More examples:

– In Warsaw, Poland, the first block uses the default Philips key FFFFFFFFFFFF, then keys are NOT random, for example many start with 898989, some end with 898989…

⇒ In Poland everything is explained by history. Let me decrypt this one for you:

⇒ Remark: 1989 is the year when Poland broke free from communism!

Security (2)

Making cards [slightly…] harder to attack

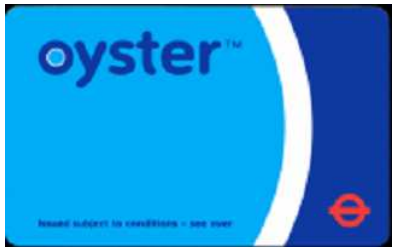
Diversify all keys for each sector.

Caveat:

Because of this Philips recommends to leave one sector encrypted with a default key…

BAD BAD LUCK:

- this makes it clonable in 2 seconds [Nijmegen Nested Attack].
  - not for Oyster though [all keys diversified]



Data Inside The Oyster Card

Data Inside a Card

Keys are diversified, different key for each sector of 4 blocks.

Example of what is found inside:

Block 000: Data: CA1234BD518804004755745461502307
Block 001: Data: 964142434445464748494A4B4C4D0101 .ABCDEFGHIJKLM.
Block 002: Data: 00000000000000000000000000000000
Block 003: Data: 0000000000007F07889900000000000.

sometimes block 2 is FFFFFF……. no apparent reason

Where is My Money?

Block 004: Data: 019CD4161F9B00000140A82D09805522
Block 005: Data: C04080**3408**20200084035400000B26E82
Block 006: Data: 604180**140A**2020002604540100D2F49F
Block 007: Data: 00000000000067878999000000000000

Note: different access conditions than any other sector, due block 4.

How to decode it?

- byte 2 is the counter, the highest is the valid block
- credit £ =

$$\frac{(\text{byte5} * 256 + \text{byte4})}{200.0}$$

- Example: 0x**0A14 =** 2580;
  2580/200.0 = **£12,90**
- Ambiguity: both counters =, the bigger £££ is valid.
  - Unless you fail to touch-out, then the smaller will apply


London Evening Standard
standard.co.uk

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News

HEADLINES: ictory..... Brown dismis

190,000 complain to TfL about overcharging on Oyster cards

Evening Standard
28.04.08

Nearly 190,000 people have complained about being overcharged on their Oyster cards in the past 18 months, figures show today.

Travel History

Blocks 8-63

Block 008: Data: 00003C0000F00000C00300000F000015
Block 009: Data: 00003C0000F0000A000000000F0000A0
Block 010: Data: B8A81A5A100104FC08FCFFFFFF07474A
Block 011: Data: 00000000000007F07889900000000000
…
etc
...

Here we store the travel history (up to 20 entries)

TFL Public Claims

TFL [let's forget about
a lot of denial before that]
claimed more recently that

- PRIVACY: No personal data is stored in the card.[in Belgium they are…]
- SECURITY: Online database prevents fraud…

Claims - Privacy

- PRIVACY: No personal data is stored in the card.
  - [in Belgium they are… see UCL Belgium Python script]
  - obviously true, for anonymous cards purchased at the counter… [most people], anonymous passes are NOT allowed in Lisbon, Moscow,Helsinki, Warsaw@2010etc…
  - BUT WHY the history stored in the card has >20 entries???
    In Paris [Calypso-based "Navigo" system]:
    - they store 3 entries, judged "the minimum necessary for the purpose of control"
  - BTW: each card has a unique UID + unique number printed on it, that the reader can compute from the card data (block ?). These allows to trace people…

Claims - Security

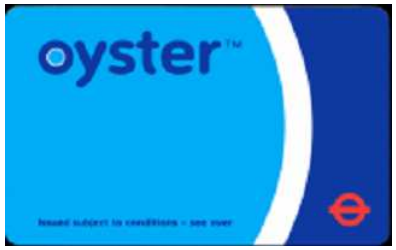
TFL claimed that

- SECURITY: Online database prevents fraud…
  - Well does it???
    - Nijmegen: 24 hours free travel is possible…
- Auxiliary questions to meditate:
  - Is every gate / bus reader connected to the network in real time?
    - Remark: All readers in London are currently being upgraded due to free senior travel scheme
  - Do offline readers store the data?
  - Reset-ability : can we just restore the sectors 5 and 6 from before the travel? And travel again with the same card state?

***Facts

- There never was a scientific or press report explaining the FULL scale of the problem.
- Auto-censorship:
  - For 6 months we had the spec of the cipher, we never published it, Dutch researchers did it and they had to meet Philips/NXP lawyers in court…
  - For 6 months we knew about the most serious vulnerability (bug) and did not disclose it.
  - We have since discovered further VERY embarrassing facts about specific implementations, and we keep information secret. Is there a criminal business case?
    - Denied by NXP, denied by Dutch researchers..
      - In fact I could make any person in this room a millionaire with £40 investment, by giving them <10 lines of code.

MiFare Classic Withdrawn [12/2009]



ITSO: UK transport card system and specs.

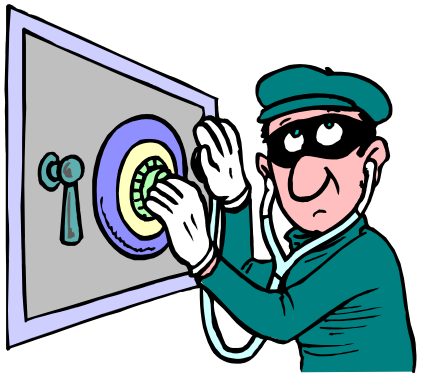
Compatible with both MiFare and Calypso.
And other like DESFire.

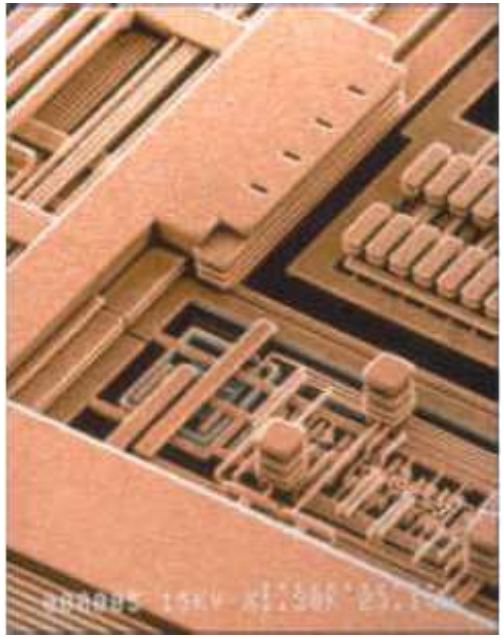
MiFare Cards in ITSO system: 9.1 million [2008].

Fact: MiFare was withdrawn in the UK transport cards within months after our attacks were published.

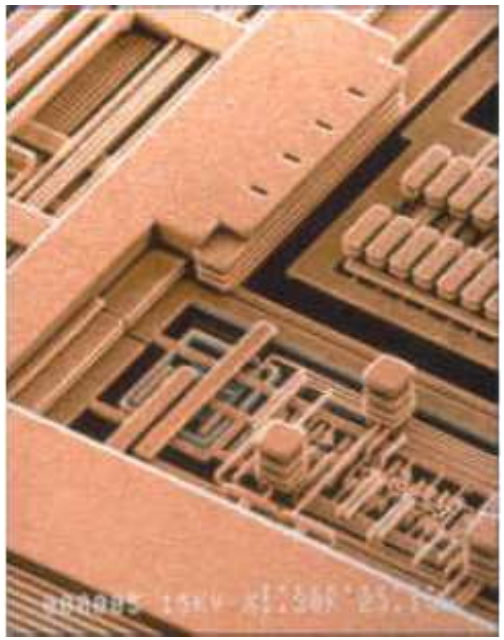
1. ITSO licensed Members shall cease to issue MiFare Classic cards after 31st December 2009.
2. ITSO shall not support any ITSO shell issued on a Mifare Classic card after 31st December 2016.

Conclusion





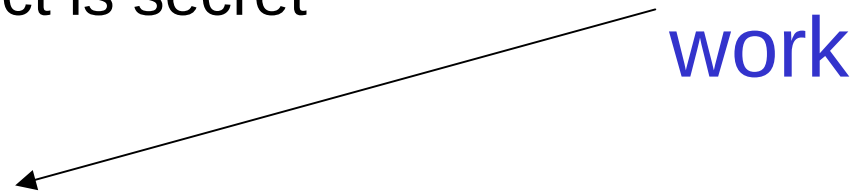
So What's Inside?



Barriers to be Breached

For many smart card products:

- The spec of the product is secret
- The protocol is secret
- The cipher is secret.



- The vulnerabilities (or backdoors..) has to be discovered one by one…
- Then we can recover the key of each card.
- Then we can read the data
- Then we can
  - travel for free/enter the building…
  - publish a paper about cryptanalysis…
  - find a good lawyer to defend against lawsuits…

Why Smart Cards Fail Now

The model … somewhat… breaks apart

with RFID smart cards such as MiFare classic where

- the secrecy of the product is not an extra security layer, but a source of unexpected and critical security vulnerabilities…
  - + false sense of security….

Summary

- We broke >1 billion smart cards covering 70 % of the contactless badge/ticketing market.
- Our attack is more than 10 times better than the Dutch attacks about which there were 10 000 press reports…

- Security of many buildings (banks, military, UK Cabinet Office) is badly compromised.
- Security of many transport [metro,bus] and parking cards worldwide is badly compromised.
- Property and important assets [e;g. government and financial data] are directly under threat.

Post Scriptum 1:
Crime Science Perspective

6 Jailed In Metro Farecard Scheme

Probe Searches For 'Mr. Big'

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**Electronic Subversion

The security perimeter splits that occur in smart cards have a double effect:

- They can prevent one entity from compromising other people's security… hardware barriers can be very effective
- They can also conceal a subversive functionality:
  - A bug, backdoor etc.

Mitigation [Schneier-Shostack'99]: fewer splits, more transparency.
But secrecy is here to stay.
100 % open source == utopia and a fallacy.

The hidden powers of crypto developers are particularly dangerous:

- large scale compromise
- impossibility to prove intentionality: perfect crime
- Impossibility to prove fraud, no forensic traces whatsoever if I update your card wirelessly with a monthly ticket / parking credit:
  perfect fraud.

Post Scriptum 2: Business / Economics

Business is Meant to.. Fail (!)

Should private business develop and sell security products freely?

- Of course yes… Everybody would say.

But remark that, the very nature of a joint-stock (limited liability) business venture is to fail.

(except banks that are covered by the government and do not fail so easily…).

Who is in Charge?

Remark:

Businesses are allowed to fail / default.

Unlike governments and individuals
that typically have to carry on whatever happens.

They Will Fail Us.

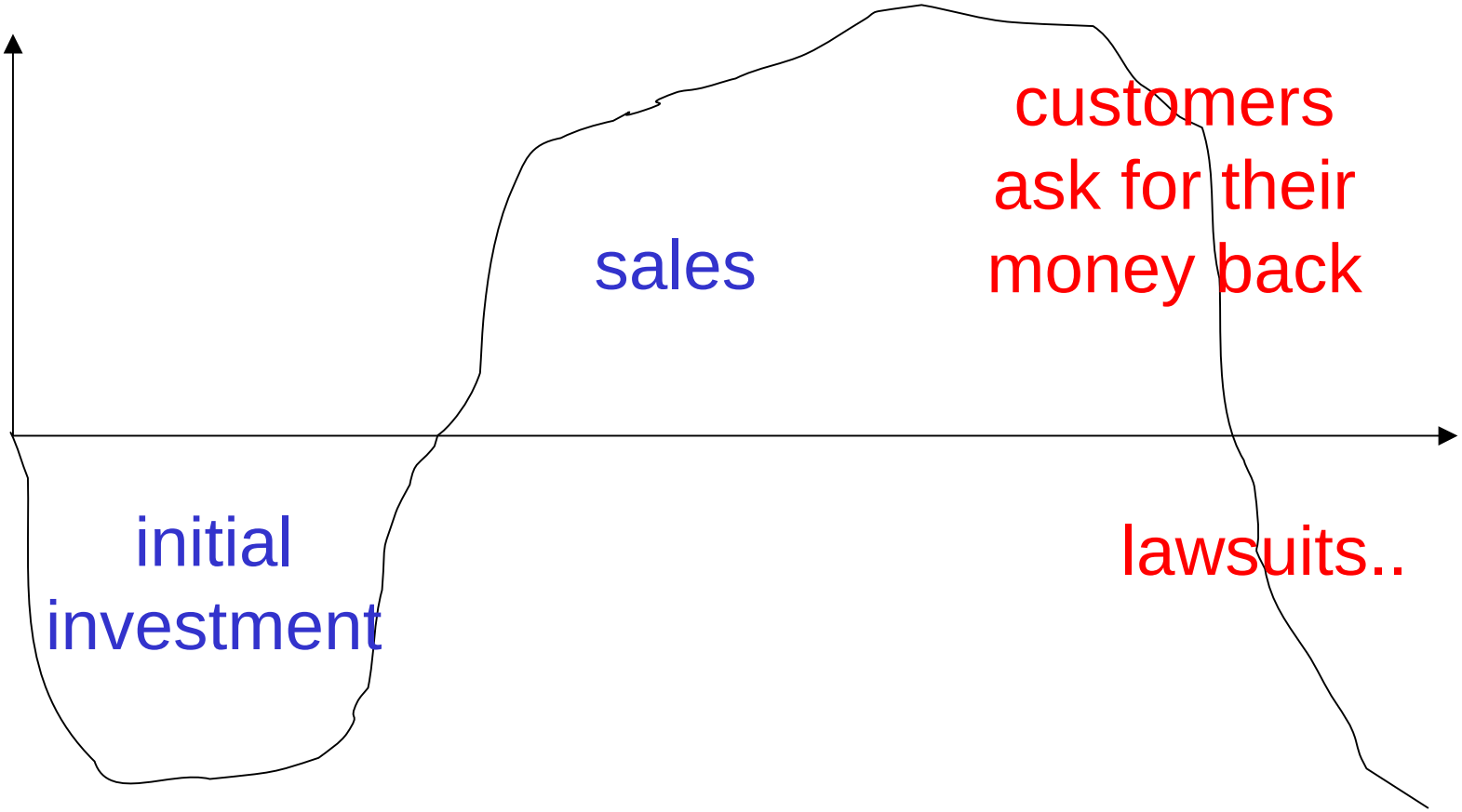
Businesses are likely to fail.

Maybe, again this is
not a BUG,
it is a FEATURE?

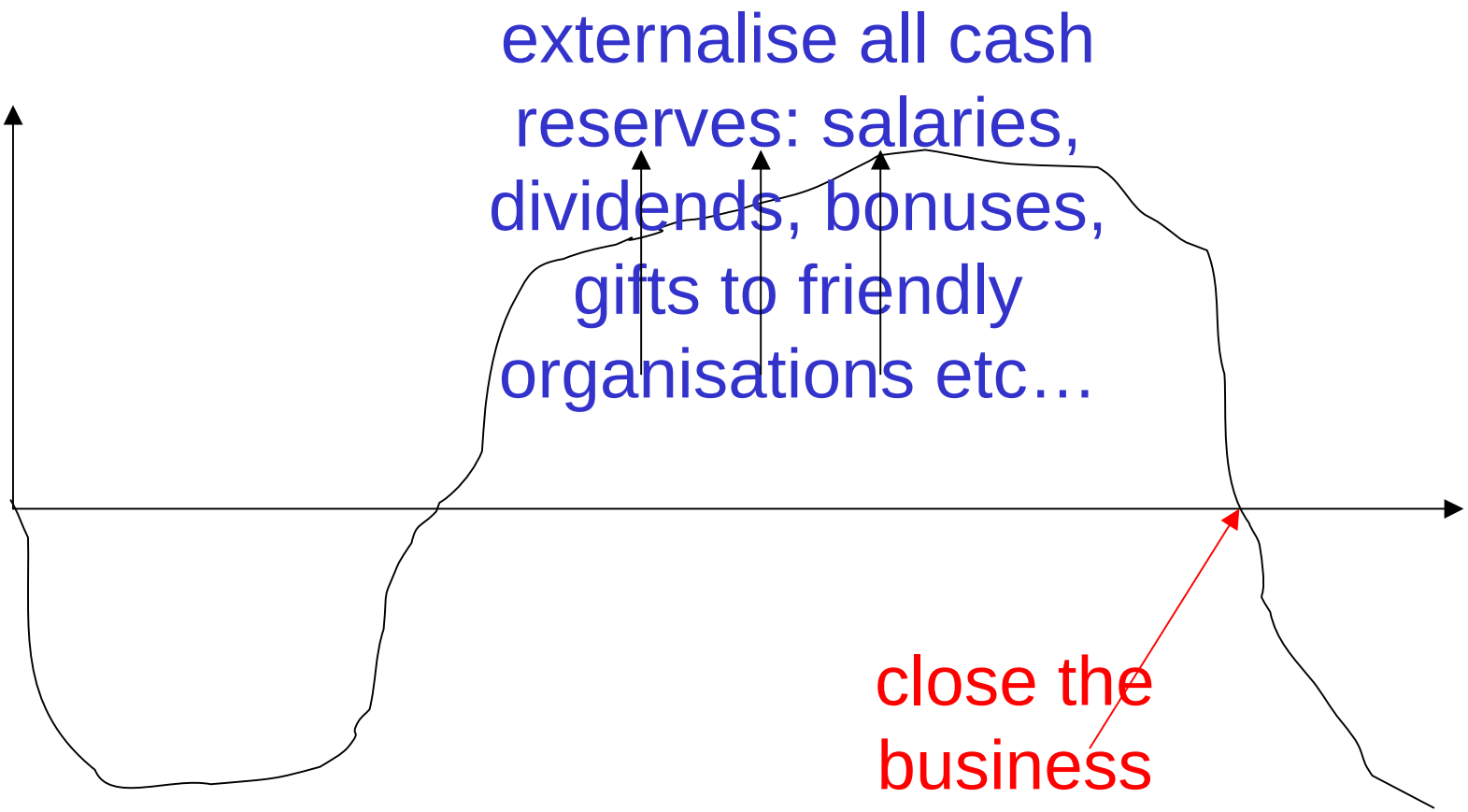
The secret “ring” of excessively highly paid directors and managers refused to comment on that…

Maybe the optimal strategy: it is like making a car run at the maximum speed at any cost, make lots of money, and then crash the business against the wall before the market forces themselves will destroy this unsustainable or fraudulent activity, that must disappear as soon as a more healthy choice is developed by market forces?

Cash Flow for a [Very] Insecure Smart Card Business Venture



Optimal Business Strategy: Drop the Tail!



Question:

Should businesses in the area of security have a DIFFERENT legal status than normal business?

- Extended personal / financial liability?
- Capital reserves?

So that they are less likely to fail us?

Potential problem: technically incompetent or dishonest firms might always prevail and drive people doing “good job” out of business…

**Question 2:

Patents:

disclosure $\leftrightarrow$ monopoly

but the disclosure remains very limited

Wouldn't it make sense to grant a better/extended monopoly to firms that practice

- total disclosure (still dangerous)
- or that pass a strict security evaluation process such as EAL4+ or better?