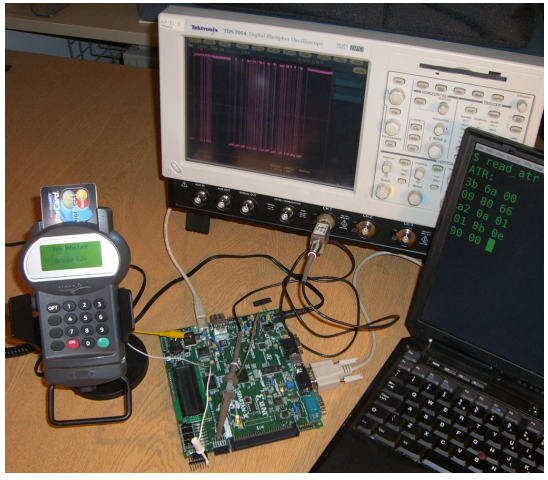
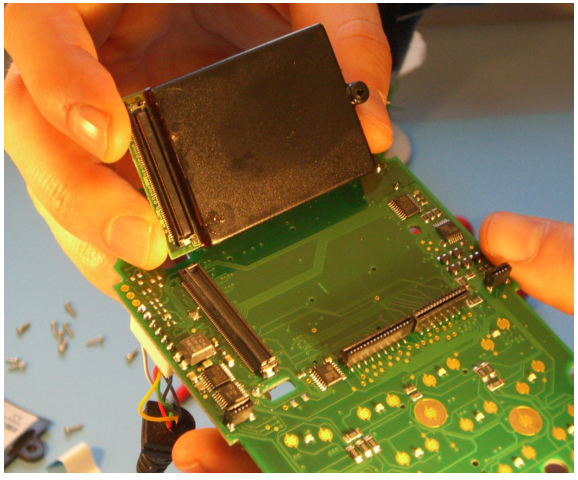
Banking Security Architecture





Steven J. Murdoch

http://www.cl.cam.ac.uk/users/sjm217/

work with Saar Drimer, Ross Anderson, Mike Bond

UNIVERSITY OF CAMBRIDGE
Computer Laboratory

www.torproject.org

Chip & PIN has now been running in the UK for about 5 years

- Chip & PIN, based on the EMV (EuroPay, MasterCard, Visa) standard, is deployed throughout most of Europe
- In process of roll-out elsewhere
- Customer inserts contact-smartcard at point of sale, and enters their PIN
- UK was an early adopter: rollout in 2003–2005; mandatory in 2006
- Chip & PIN changed many things, although not quite what people expected

Chip and PIN

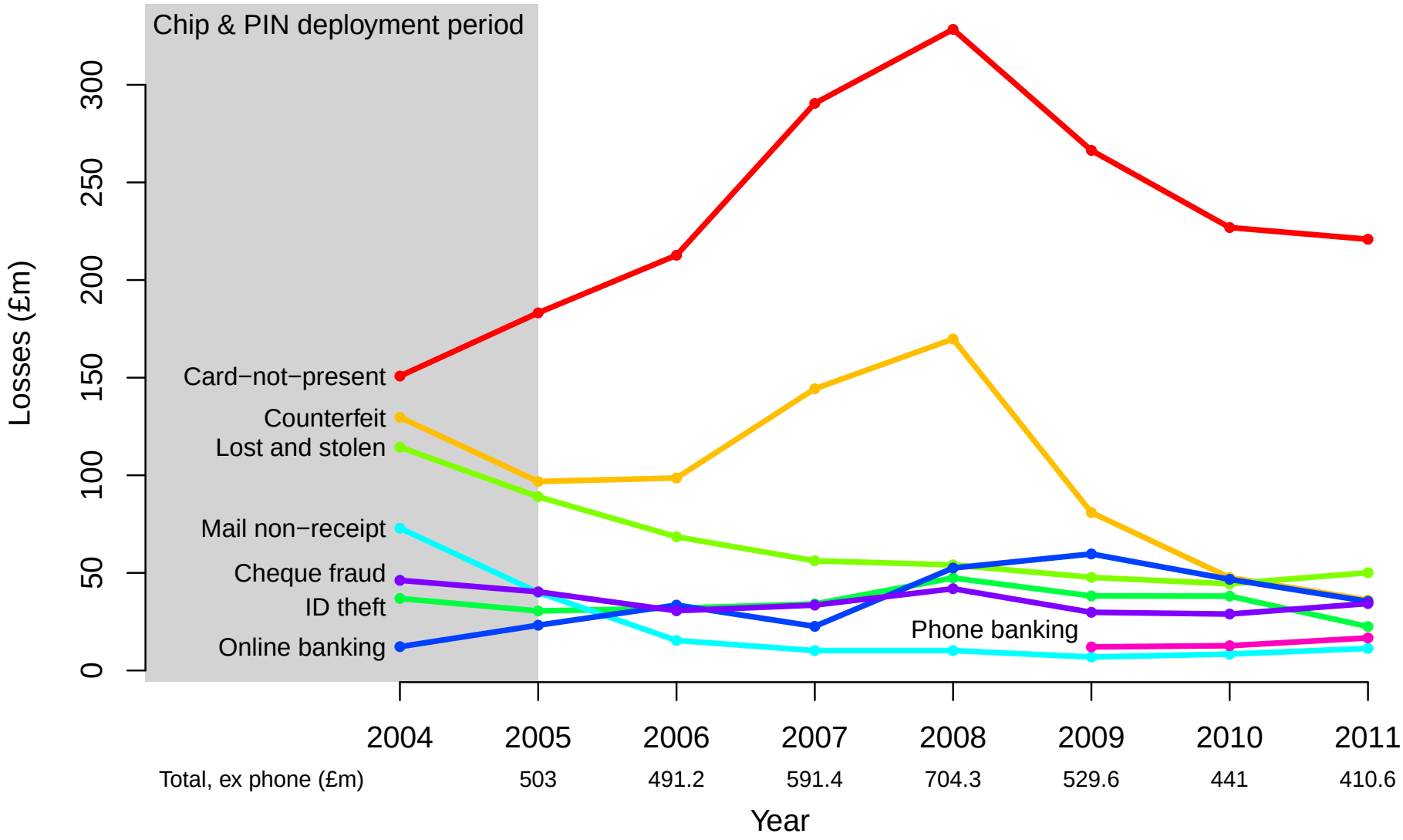
EMVCo

Card payments in the UK are different from the US (and elsewhere)

	Before Chip & PIN	**After Chip & PIN**
Cards	magstrip	magstrip and chip
Card verification	magstrip	chip if possible
ATM	PIN used	PIN used
Point-of-sale	signature used	PIN used

- No difference between credit and debit cards
- No ID check at point-of-sale (signature rarely checked either)
- Introducing Chip & PIN really made two changes:
  - Chip used for authenticating card (ATM and PoS)
  - PIN used for authenticating customer (only new for PoS)
- The effects of the two changes are often conflated

UK fraud figures 2004–2011



Source: Financial Fraud Action UK

Counterfeit fraud mainly exploited backwards compatibility features

- Upgrading to Chip & PIN was too complex and expensive to complete in one step
- Instead, chip cards continued to have a magstrip
  - Used in terminals without functioning chip readers (e.g. abroad)
  - Act as a backup if the chip failed
- Chip also contained a full copy of the magstrip
  - Simplifies issuer upgrade
  - Chip transactions can be processed by systems designed to process magstrip
- Criminals changed their tactics to exploit these features, and so counterfeit fraud did not fall as hoped
- Fraud against UK cardholders moved outside of the UK

Criminals could now get cash

Criminals collected:

- card details by a “double-swipe”, or tapping the terminal/phone line
- PIN by setting up a camera, tapping the terminal, or just watching

Cloned magstrip card then used in an ATM (typically abroad)

In some ways, Chip & PIN made the situation worse

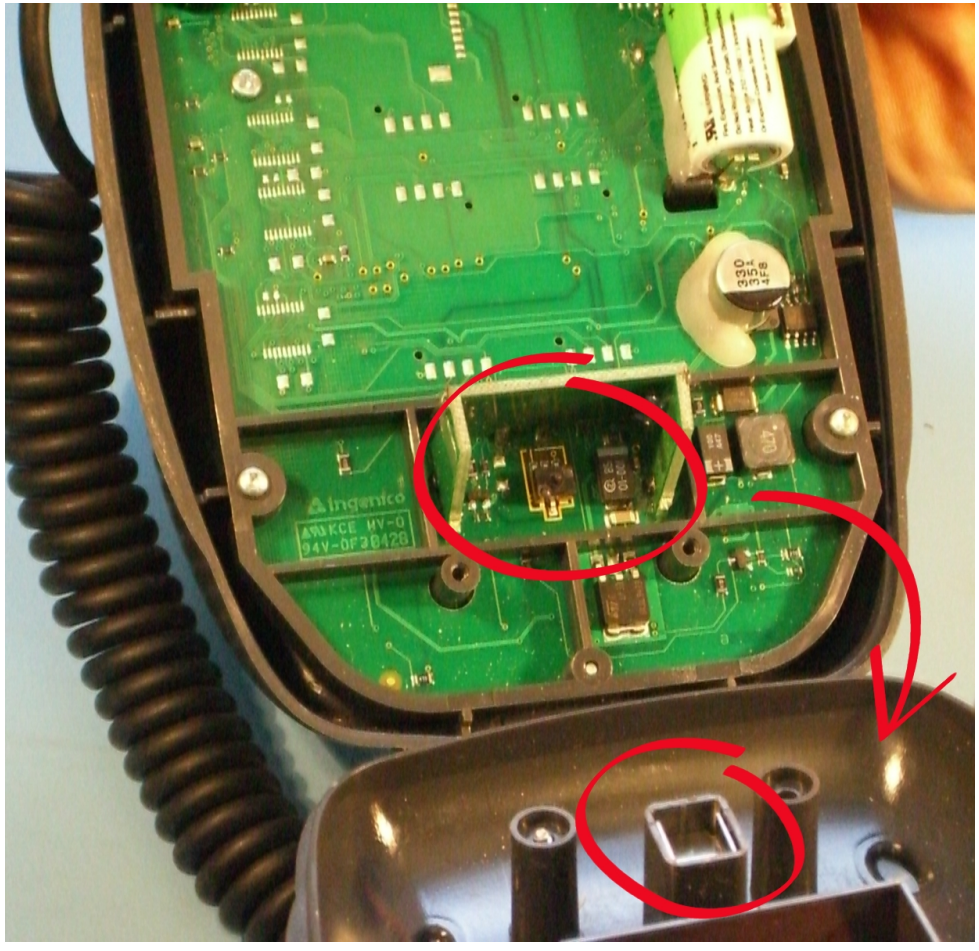
- PINs are used much more often (not just ATM)
- PoS terminals are harder to secure than an ATM

Tonight (ITV, 2007-05-04)

Terminal tamper proofing is supposed to protect the PIN in transit

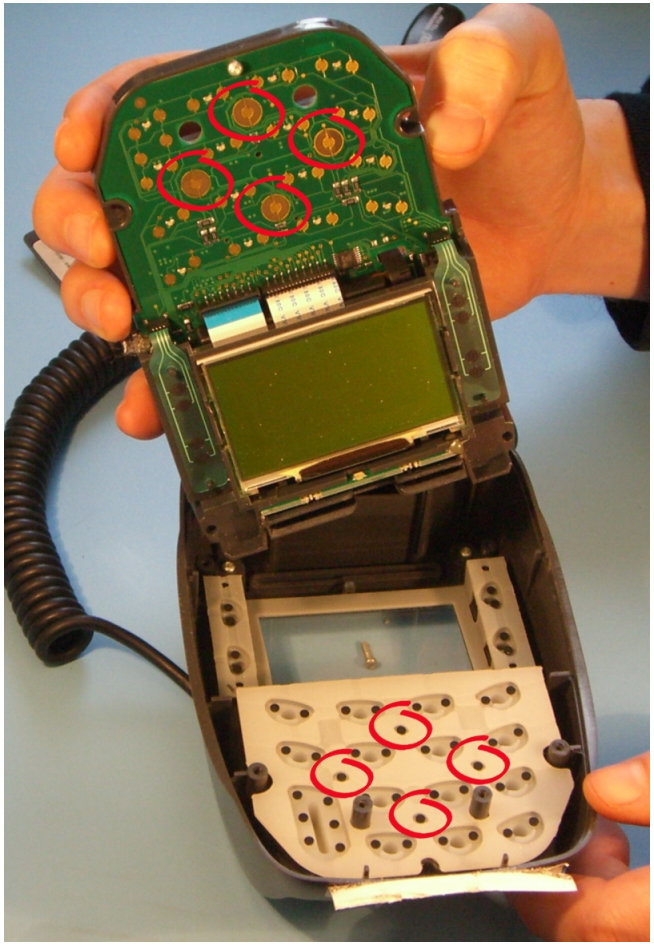
- In PoS transaction, PIN is sent from PIN entry device (PED) to card for verification
- Various standard bodies require that PEDs be tamper proofed: Visa, EMV, PCI (Payment Card Industry), APACS (UK bank industry body)
- Evaluations are performed to well-established standards (Common Criteria)
- Visa requirement states that defeating tamper-detection would take more than 10 hours or cost over **USD $25,000 per PED**

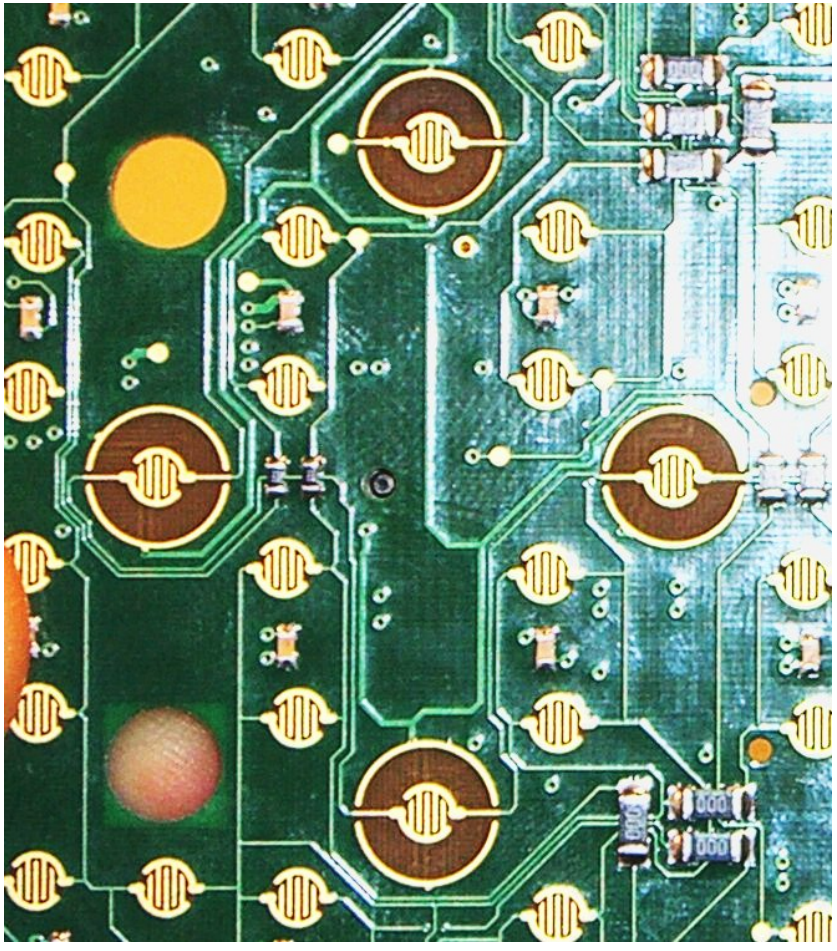
Protection measures: tamper switches



Ingenico i3300

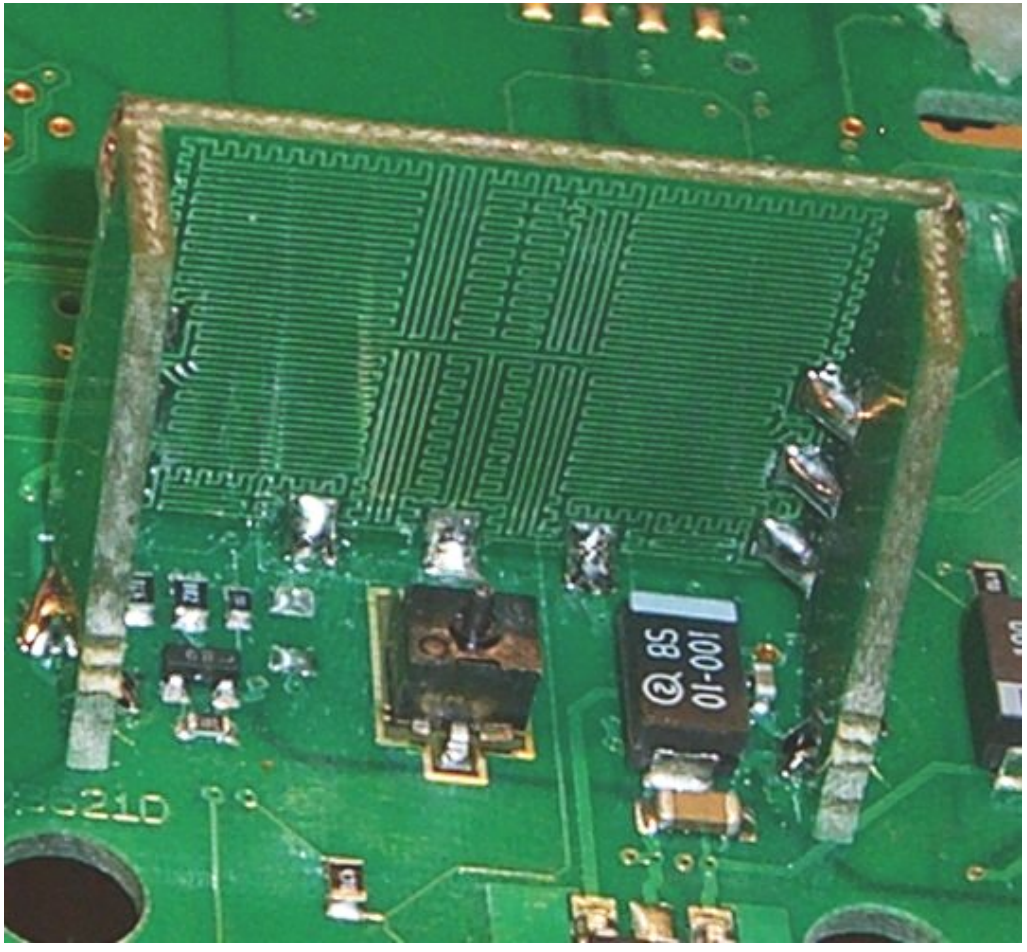
Protection measures: tamper switches

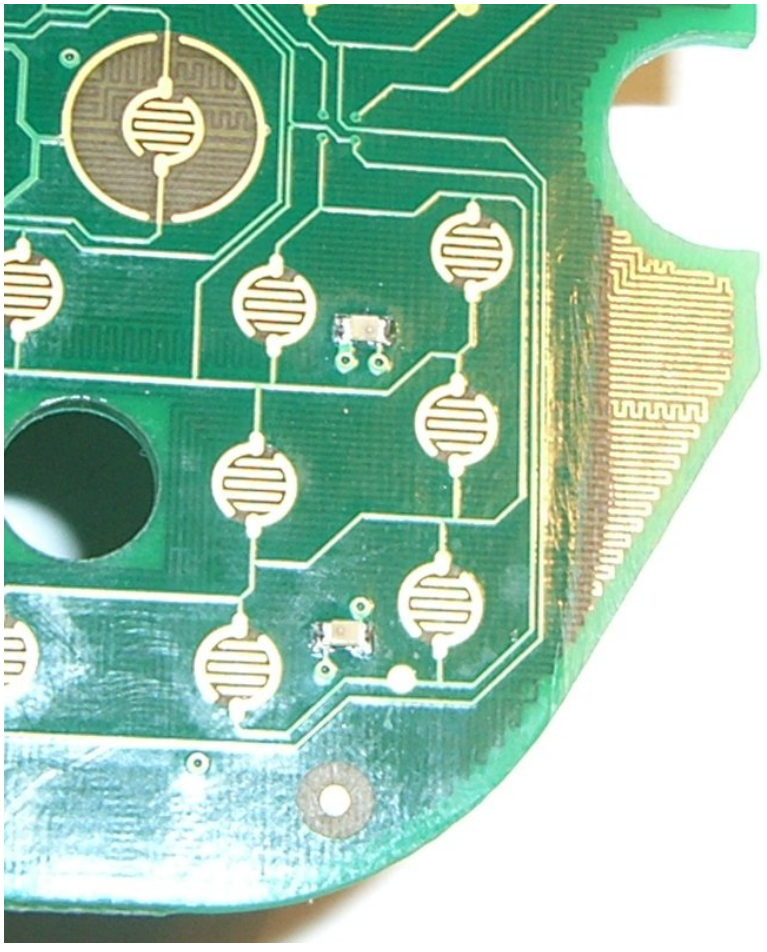




Ingenico i3300

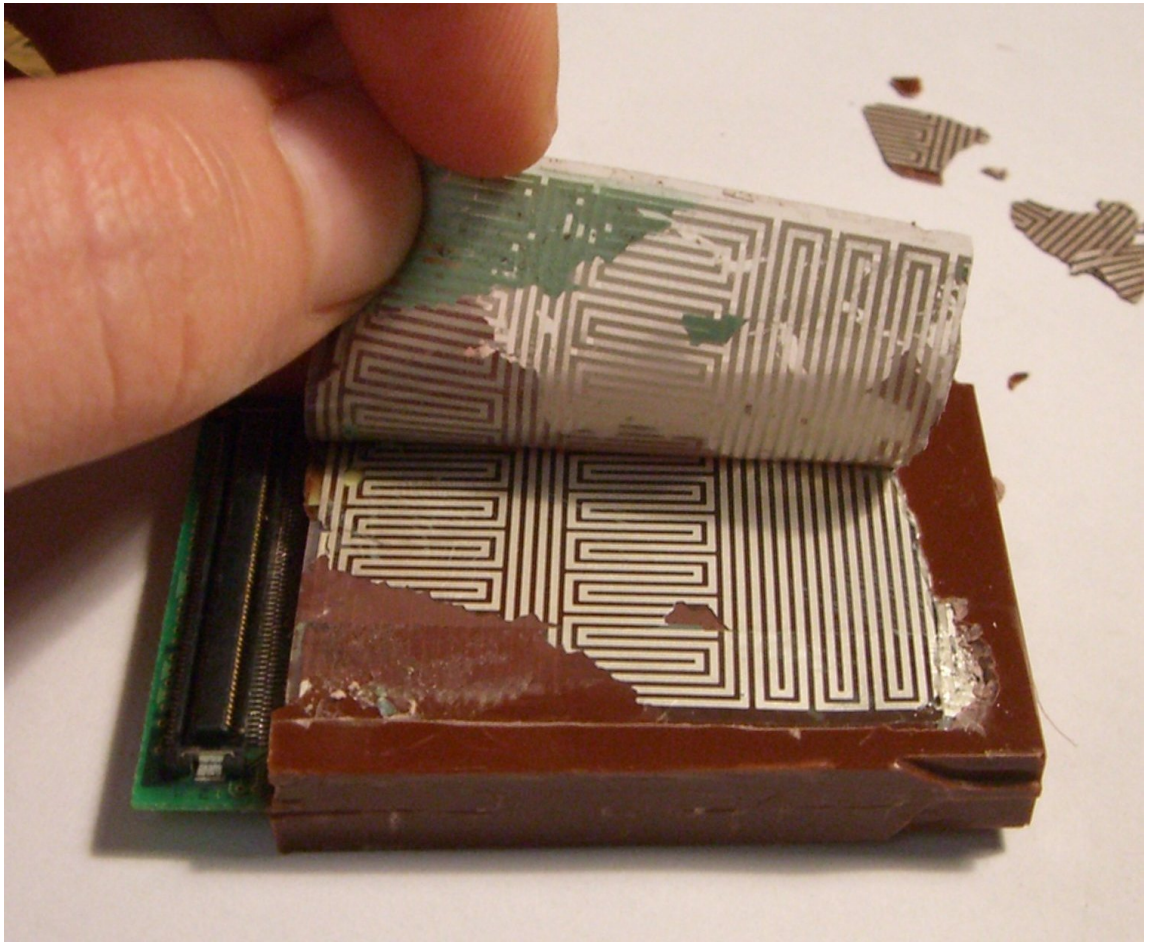
Protection measures: tamper meshes





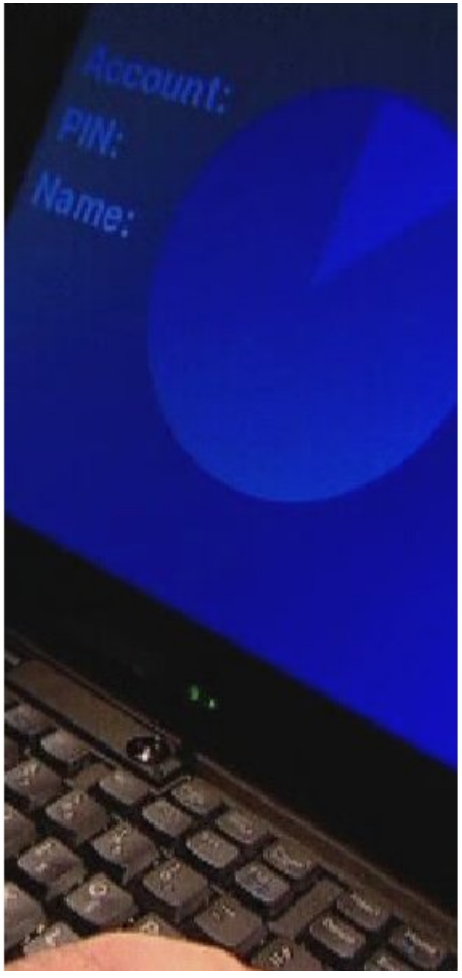
Ingenico i3300

Protection measures: tamper meshes



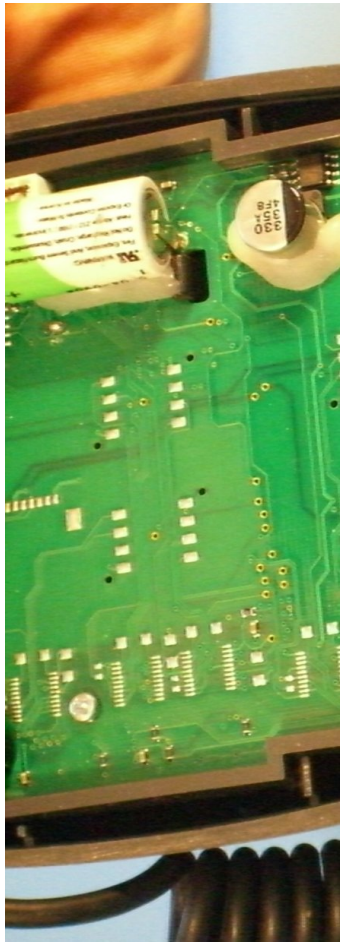
Ingenico i3300

BBC Newsnight filmed our demonstration for national TV



BBC Newsnight, BBC2, 26 February 2008

Holes in the tamper mesh allow the communication line to be tapped



An easily accessible compartment can hide a recording device

This type of fraud is still a serious problem in the UK

Initially (2005), PEDs were tampered on a small scale and installed by someone impersonating a service engineer

PED was collected later, and card details extracted

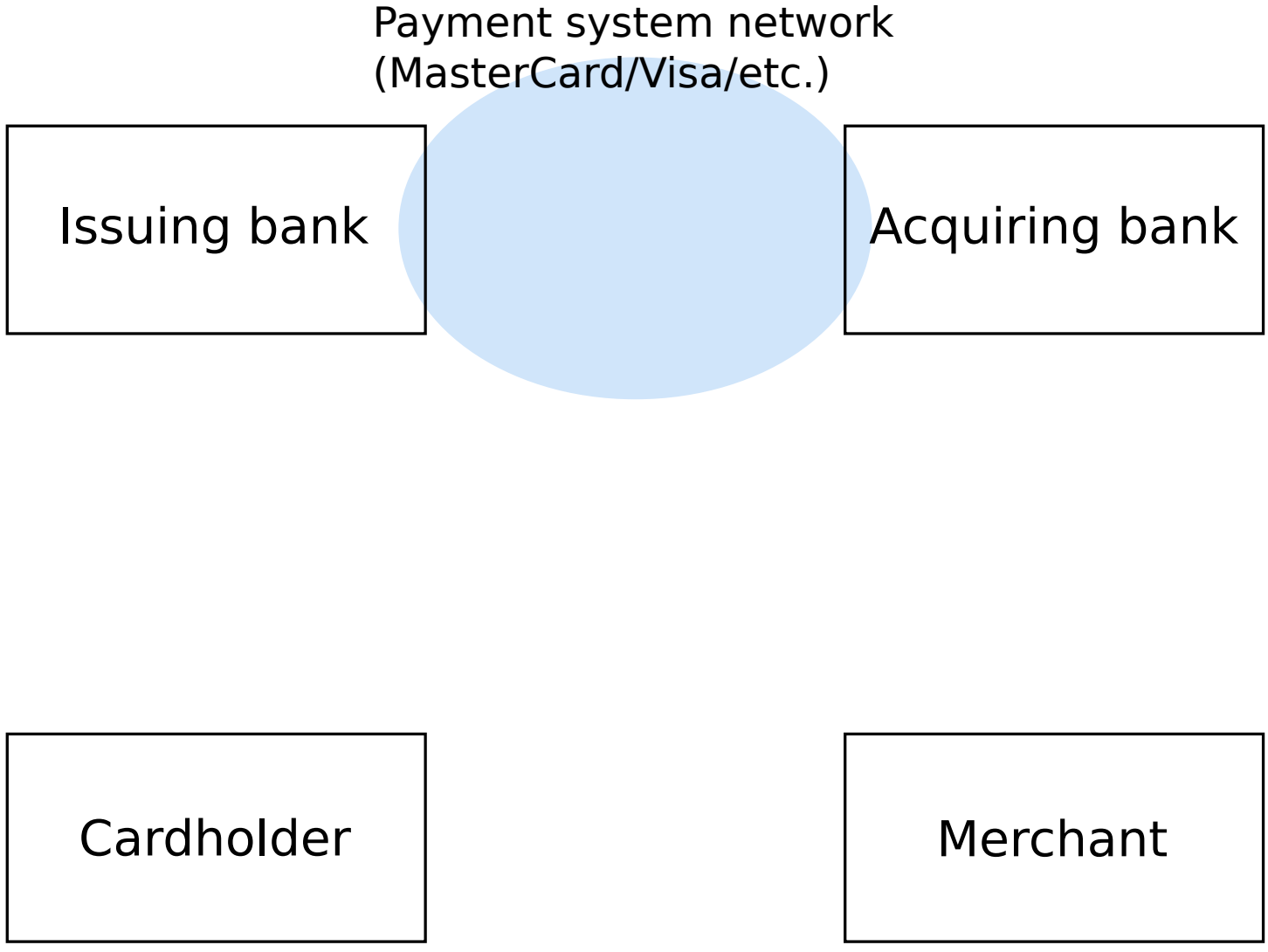
Now PEDs are being tampered with at or near their point of manufacture

A cellphone module is inserted so it can send back lists of card numbers and PINs automatically

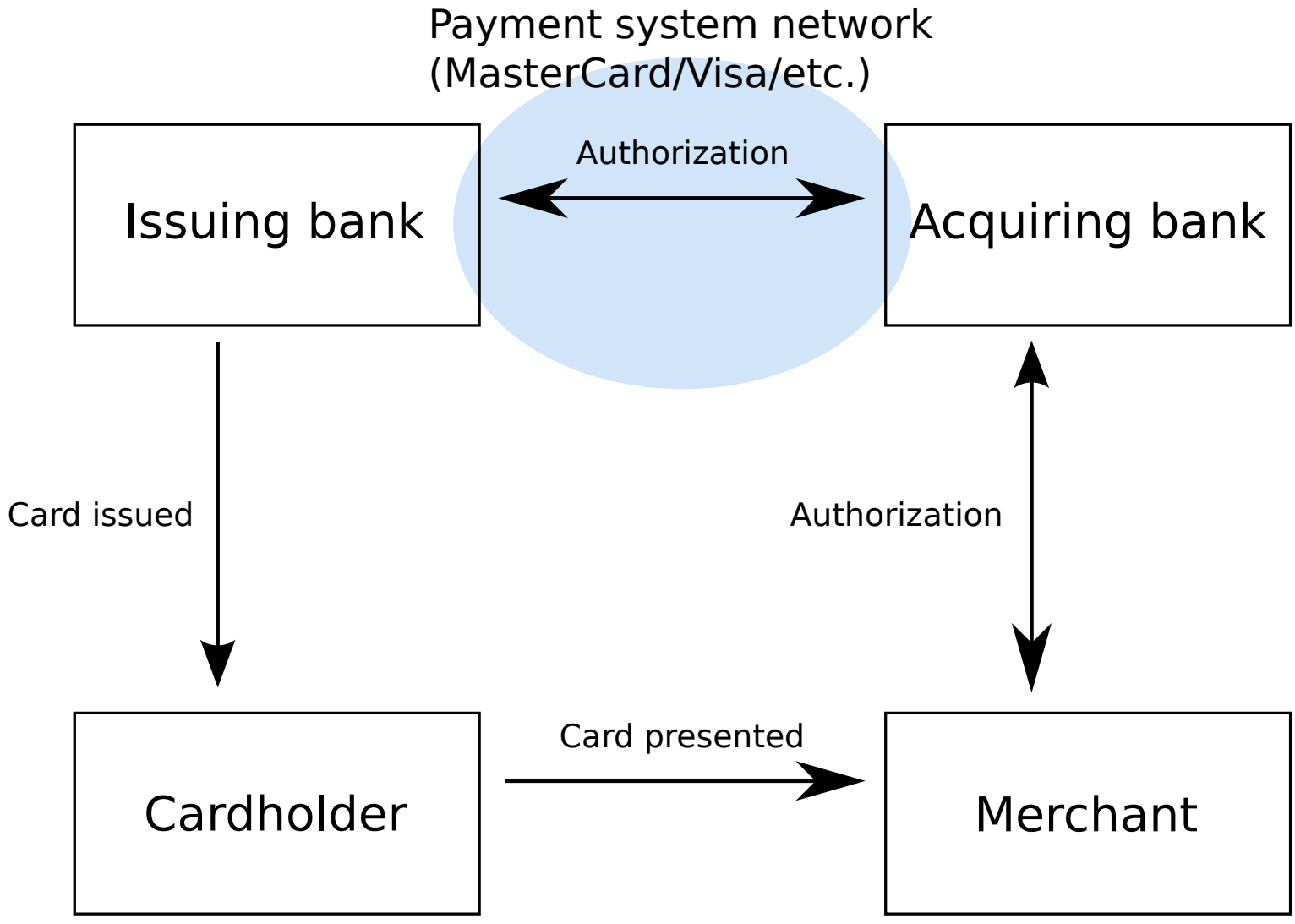
Chip & PIN vulnerabilities

- Fallback vulnerabilities are not strictly-speaking a Chip & PIN vulnerability
- However, vulnerabilities do exist with Chip & PIN
- To understand these, we need some more background information
- To pay, the customer inserts their smart card into a payment terminal
- The chip and terminal exchange information, fulfiling three goals:
  - Card authentication: that the card presented is genuine
  - Cardholder verification: that the customer presenting the card is the authorized cardholder
  - Transaction authorization: that the issuing bank accepts the transaction

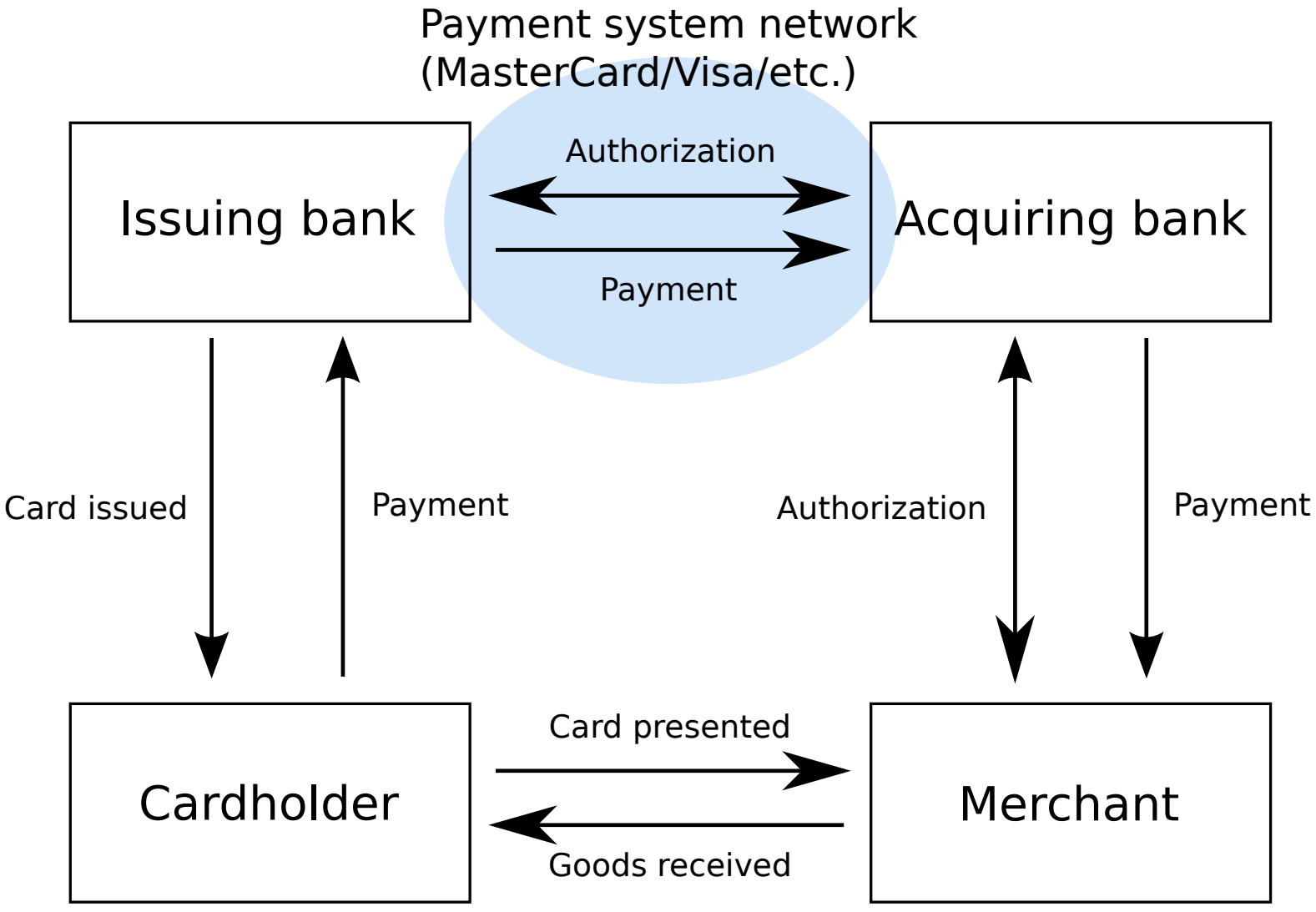
Terminology



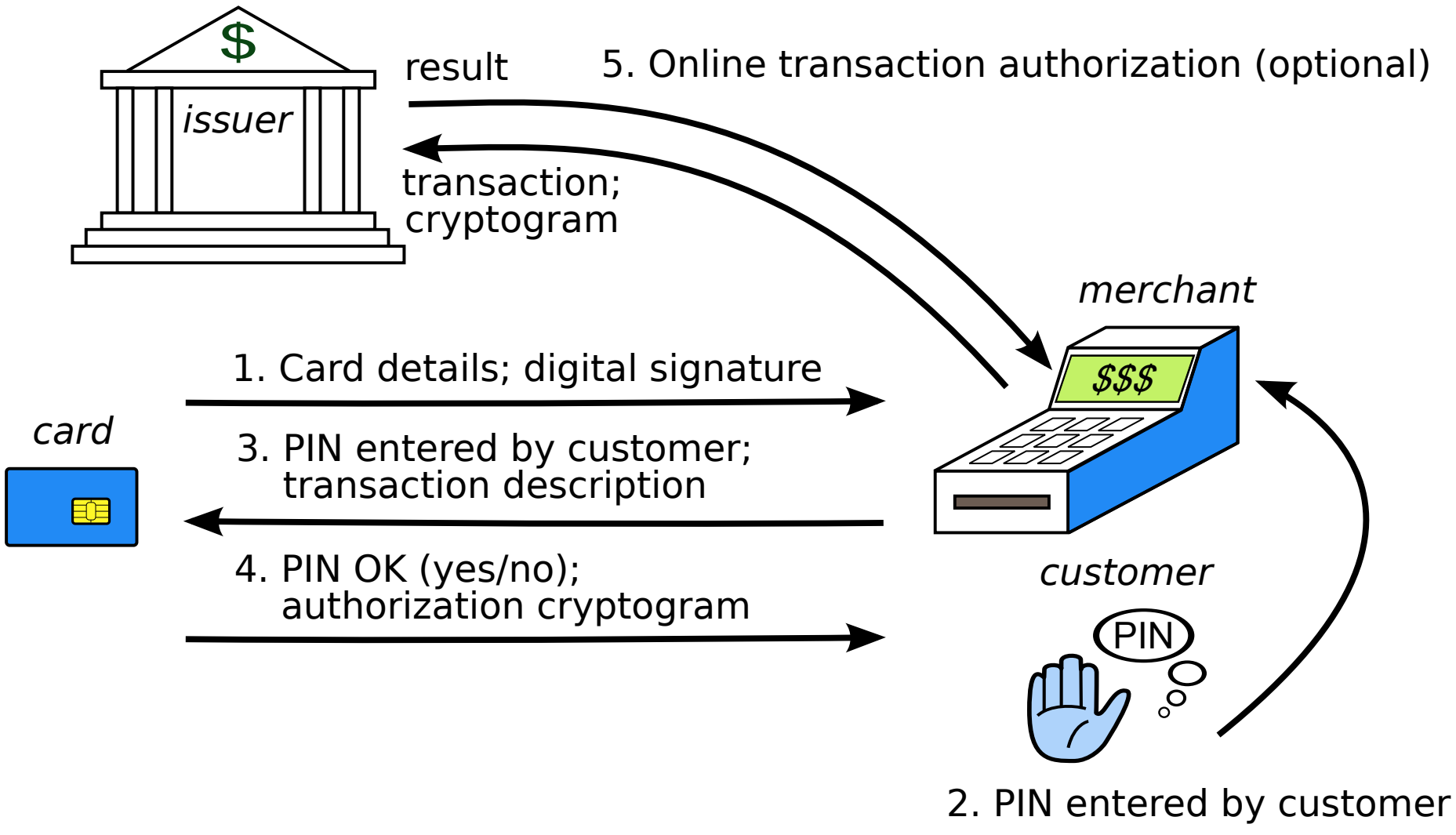
Terminology



Terminology

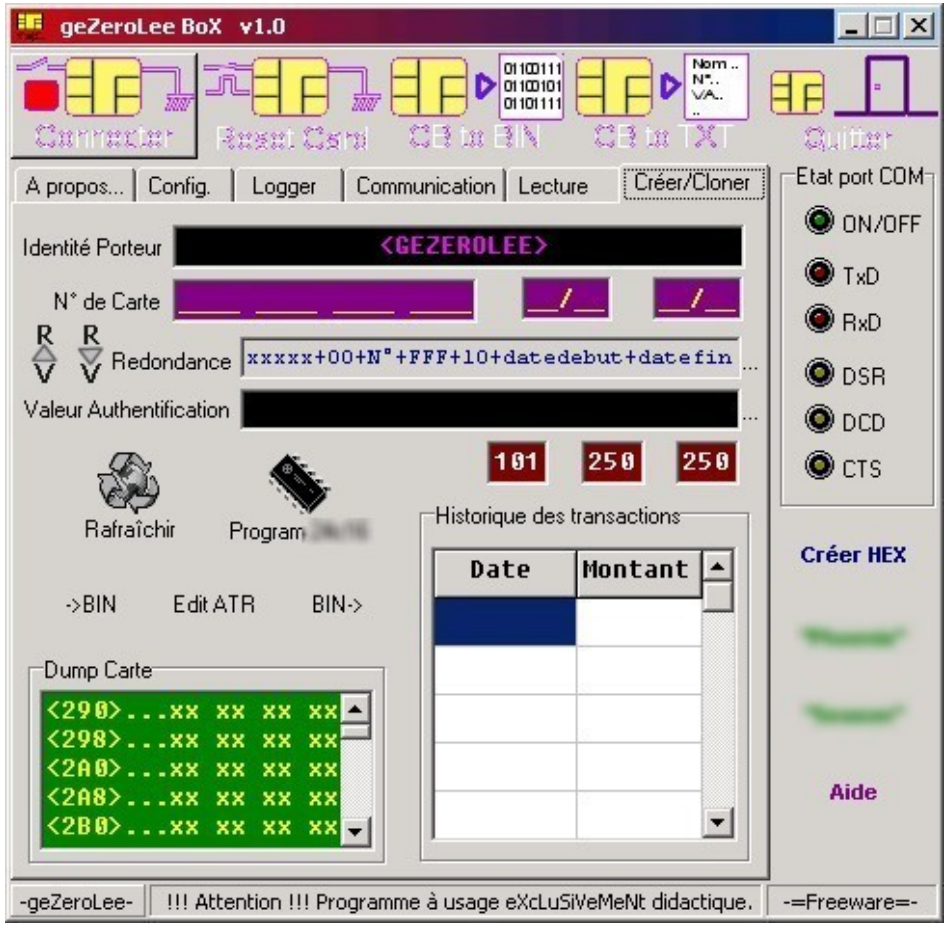


Simplified Chip & PIN transaction



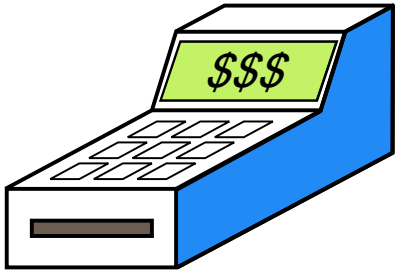
The YES-card attack

- Criminals can copy EMV chip cards
- This fake card will contain the correct digital signature
- Also, it can be programmed to accept any PIN (hence “YES”)
- However, the fake card can be detected by online transaction authorization



The YES-card attack

merchant



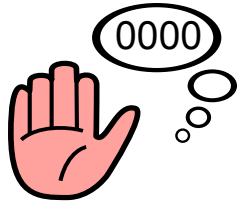
1. Card details; digital signature

fake card

3. **Wrong PIN entered by crook;** transaction description

4. **PIN OK (yes); Wrong cryptogram**

crook



2. Wrong PIN entered by crook

Defending against the YES-card

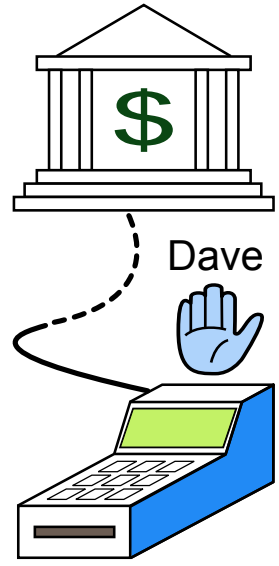
- YES-cards are responsible for a relatively small amount of fraud
- Can be detected by online transaction authorization
- Can also be detected by more advanced chip cards which can produce a dynamic digital signature
  - DDA (dynamic data authentication), as opposed to SDA (static data authentication)
  - Previously DDA cards were prohibitively expensive, but now cost about the same as SDA cards
- PIN verification can be performed online too, rather than allowing the card to do so
  - Need to securely send the PIN back to the issuer
  - UK ATMs use online PIN verification
  - UK point-of-sale terminals use offline PIN verification

Our attack was shown on BBC1's consumer program, which aired February 2007

"We got our highest ratings of the run for the story (6.2 million, making it the most watched factual programme of last week)... it's provoked quite a response from viewers." – Rob Unsworth, Editor, "Watchdog"

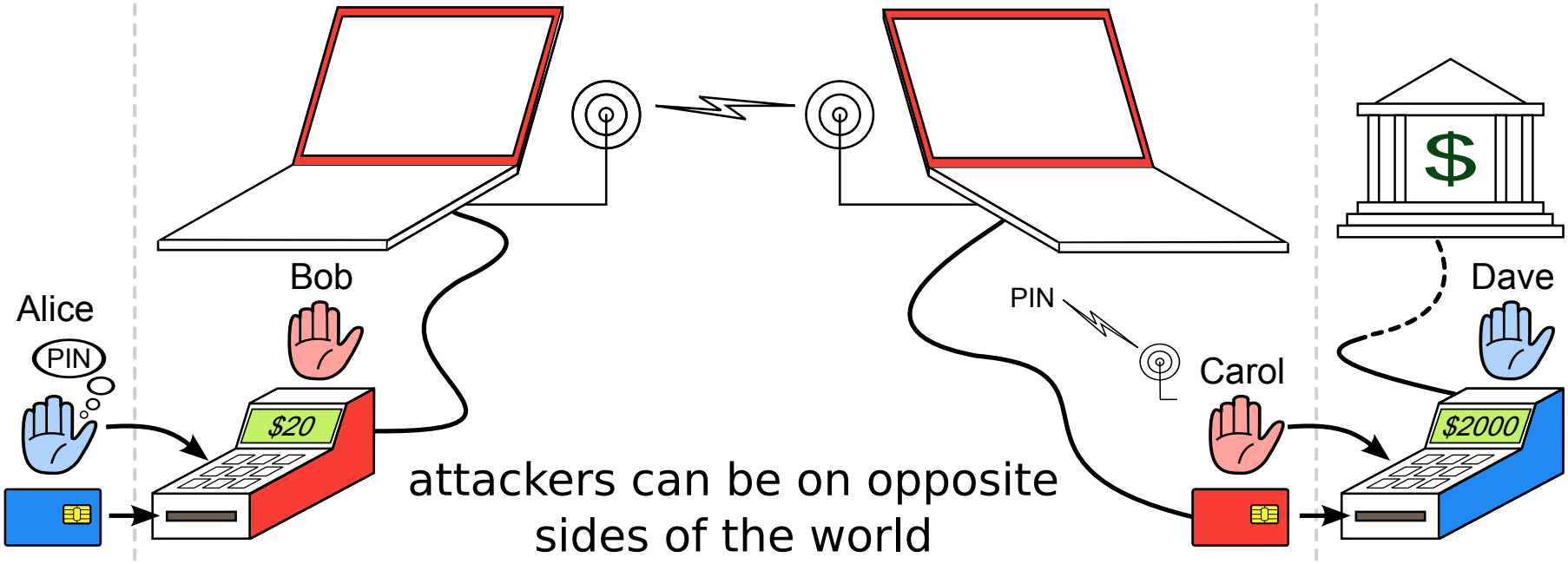
Our demonstration helped many cardholders reach a favourable resolution with banks

The relay attack: Alice thinks she is paying $20, but is actually charged $2 000 for a purchase elsewhere



Honest cardholder Alice and merchant Dave are unwitting participants in the relay attack

The relay attack: Alice thinks she is paying $20, but is actually charged $2 000 for a purchase elsewhere



Alice inserts her card into Bob's *fake* terminal, while Carol inserts a fake card into Dave's *real* terminal. Using wireless communication the $2 000 purchase is debited from Alice's account

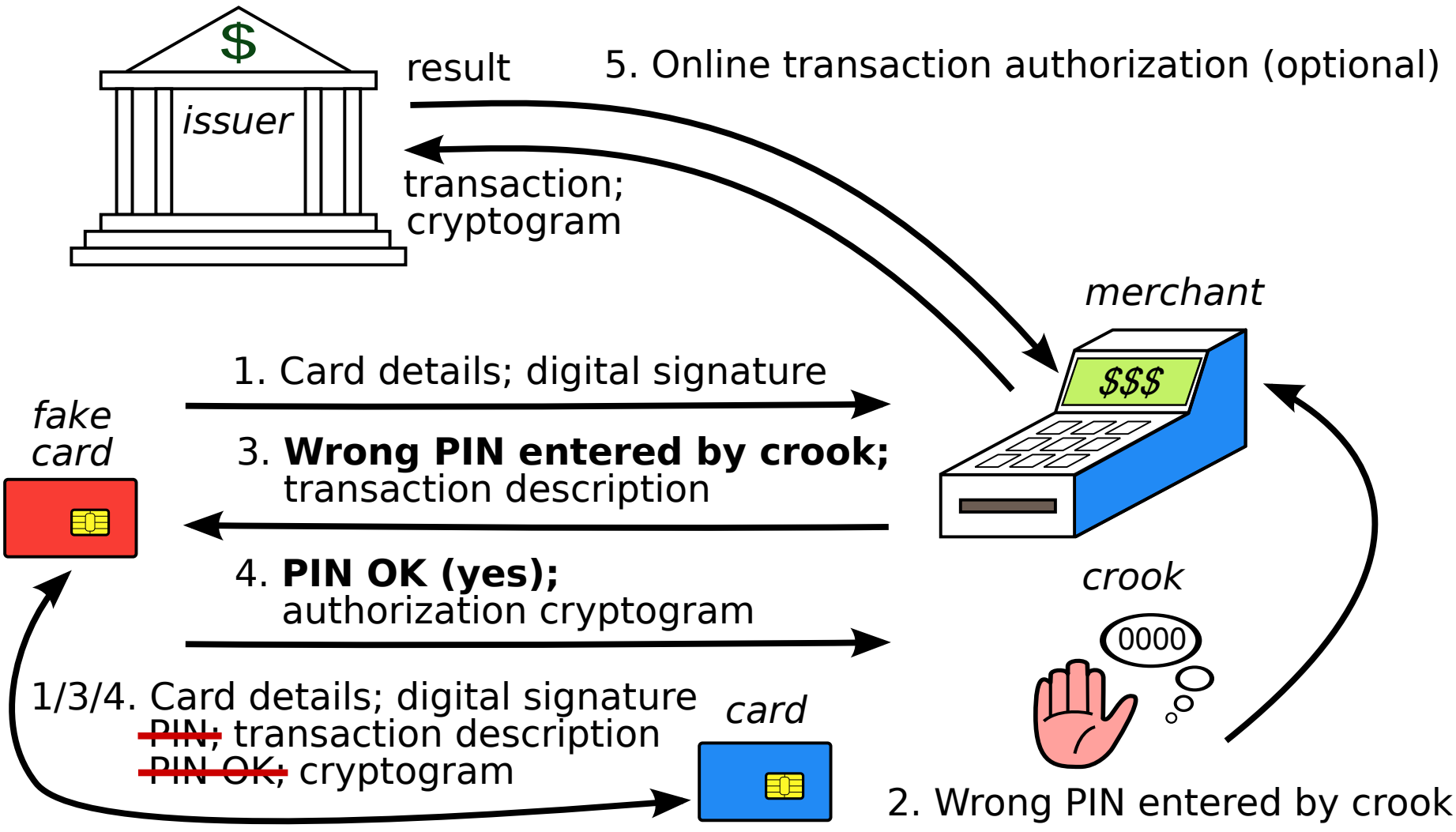
The no-PIN attack

- The no-PIN attack allows criminals to use a stolen card without knowing its PIN
- It requires inserting a device between the genuine card and payment terminal
- This attack works even for online transactions, and DDA cards

BBC Newsnight filmed our demonstration for national TV

BBC Newsnight, BBC2, 11 February 2010

The no-PIN attack



Why does this attack work?

- Complexity
  - 4 000 pages of specification!
  - Data needs to be combined from several different sources and specifications (EMV, MasterCard, ISO, APACS)
  - Despite quantity, no specification actually describes the necessary checks
- Bad design of ags
  - Card produces a ag (card verification results CVR) which says whether PIN verification succeeded
  - But this ag is in an issuer-specific format and so cannot be parsed by the terminal
  - Flag produced by terminal (TVR) is set either if PIN verification succeeded or terminal skipped check
  - Other ags may exist (country-specific, covered by APACS and ISO), but evidently are not checked in practice
- Implementation problems
  - Since issuers dont check ags, terminals mis-report state

Current and proposed defences

- Skimming
  - iCVV: Slightly modifying copy of magnetic strip stored on chip
  - Disabling fallback: Preventing magnetic strip cards from being used in EMV-enabled terminals
  - Better control of terminals: Prevent skimmers from being installed
- YES-card
  - Dynamic Data Authentication (DDA): Place a public/private keypair on every card
  - Online authorization: Require that all transactions occur online
- No-PIN attack
  - Defences currently still being worked on
  - Extra consistency checks at issuer may be able to spot the attack
  - Combined DDA/Application Cryptogram Generation (CDA): Move public key authentication stage to the end

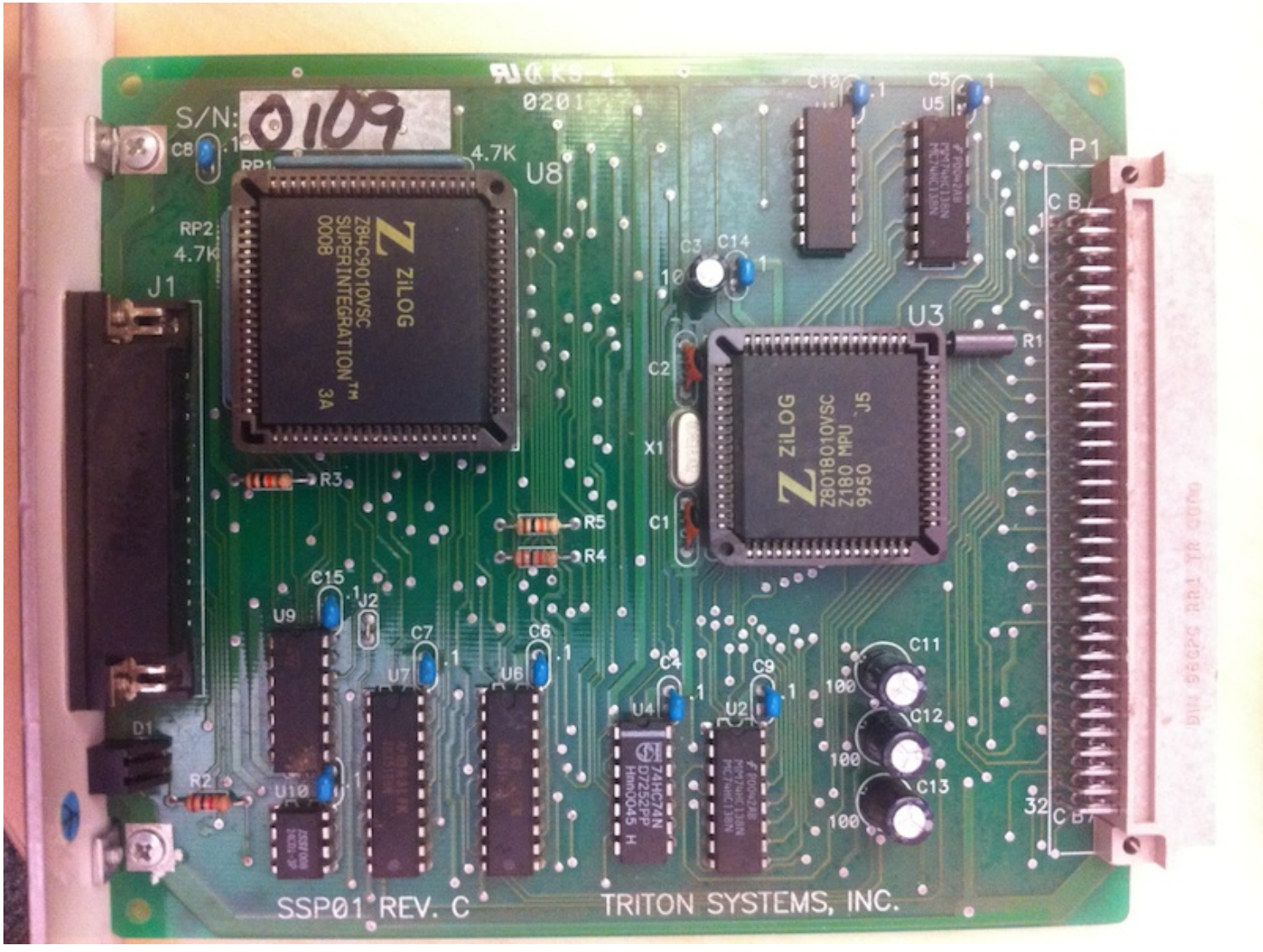
Random numbers?

Date	Time	UN
2011-06-29	10:37:24	`F1246E04`
2011-06-29	10:37:59	`F1241354`
2011-06-29	10:38:34	`F1244328`
2011-06-29	10:39:08	`F1247348`

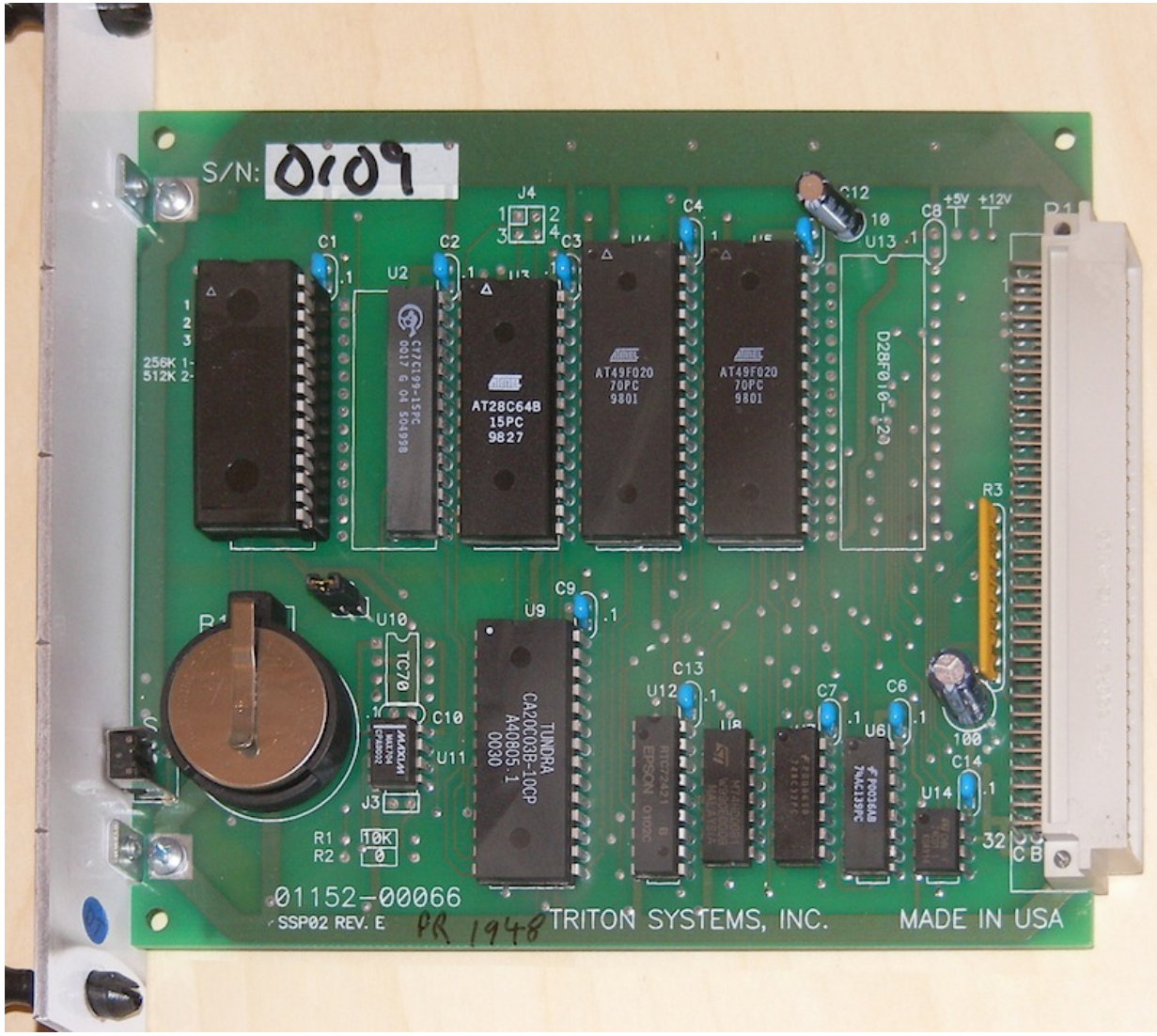
Reverse engineering

NCR ATM

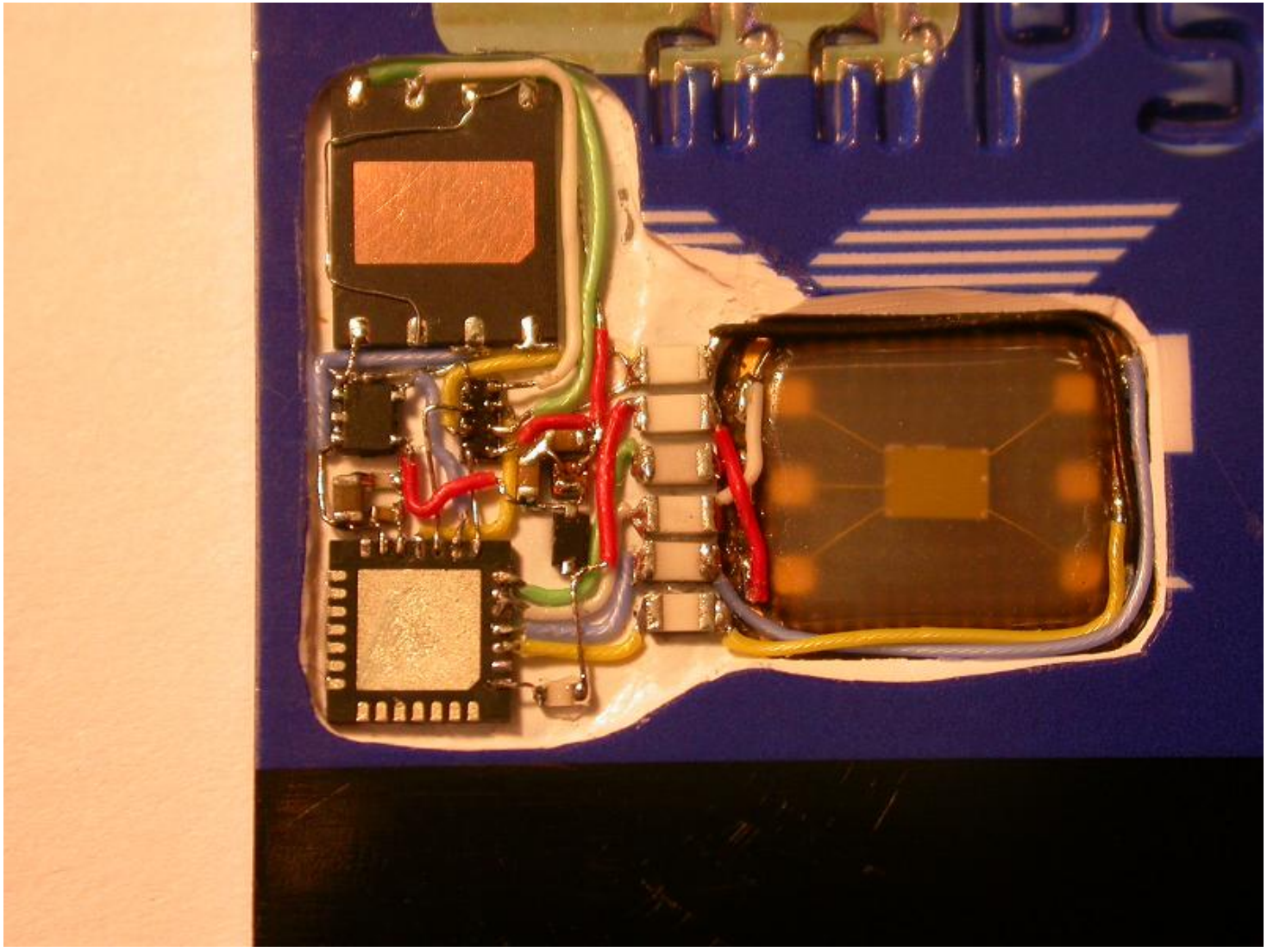
Triton ATM (CPU board)



Triton ATM (DES board)



Surveying the problem



Characteristic C

SRC2 EXP6		SRC2 EXP6B	
0	77028437	0	5D01BBCF
1	0D0AF8F9	1	760273FE
2	5C0E743C	2	730E5CE7
3	4500CE1A	3	380CA5E2
4	5F087130	4	580E9D1F
5	3E0CB21D	5	6805D0F5
6	6A05BAC3	6	530B6EF3
7	74057B71	7	4B0FE750
8	76031924	8	7B0F3323
9	390E8399	9	630166E1

Other ATMs

Counters		Weak RNGs	
ATM4	eb661db4	ATM1	690d4df2
ATM4	2cb6339b	ATM1	69053549
ATM4	36a2963b	ATM1	660341c7
ATM4	3d19ca14	ATM1	5e0fc8f2
ATM5	F1246E04	ATM2	6f0c2d04
ATM5	F1241354	ATM2	580fc7d6
ATM5	F1244328	ATM2	4906e840
ATM5	F1247348	ATM2	46099187
		ATM3	650155D7
		ATM3	7C0AF071
		ATM3	7B021D0E
		ATM3	1107CF7D

POS terminal

Stronger RNGs	
POS1	013A8CE2
POS1	01FB2C16
POS1	2A26982F
POS1	39EB1E19
POS1	293FBA89
POS1	49868033

Cashing out

- Pre-play card: load with cryptograms for expected UNs
- Malware attack: tamper with ATM or POS terminal to produce predictable UNs
- Tamper with ATMs or POS in supply chain
- Collusive merchant, modifies software
- Tamper with communications

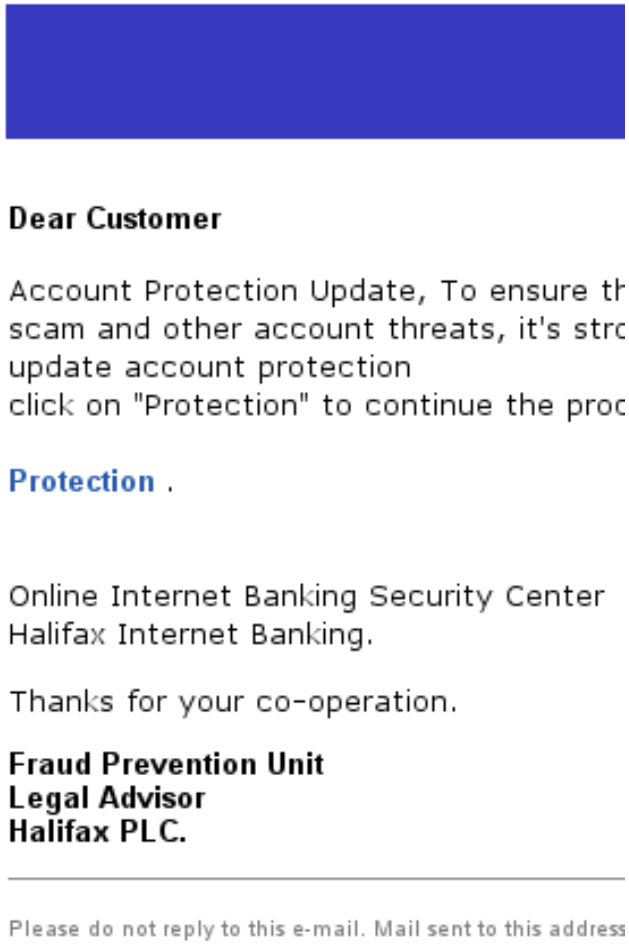
Mitigating the attack

- Detection:
  - Suspicious jumps in transaction counter
  - Lack of issuer authentication
- Prevention:
  - Relying party (issuer) generates the UN
  - Audit trail shows where UNs came from
- Industry response so far has been mixed
  - Details disclosed in early 2012
  - Some surprised by the problem
  - Others less so
  - Some knew of this problem but did not admit it

More information: “Chip and Skim: cloning EMV cards with the pre-play attack”, arXiv:1209.2531

Online banking fraud is a significant and growing problem in the UK

- 174% increase in users between 2001 and 2007
- 185% increase in fraud in 2007–2008 (£ 21.4m in first 6 months of 2008)
- Simple fraud techniques dominate in the UK:
  - Phishing emails
  - Keyboard loggers
- Still work, and still used by fraudsters, due to the comparatively poor security



Dear Customer

Account Protection Update, To ensure th
scam and other account threats, it's strc
update account protection
click on "Protection" to continue the proc

Protection .

Online Internet Banking Security Center
Halifax Internet Banking.

Thanks for your co-operation.

Fraud Prevention Unit
Legal Advisor
Halifax PLC.

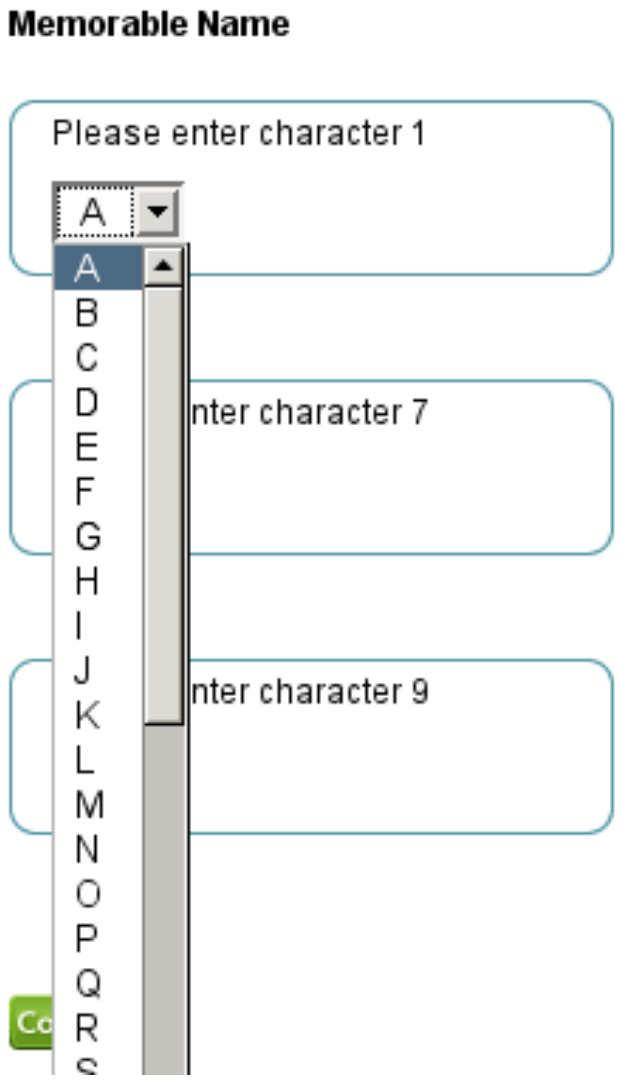
Please do not reply to this e-mail. Mail sent to this address

A variety of solutions have been proposed to resist phishing

- On-screen keyboards
- Picture passwords
- Device fingerprinting
- One-time-passwords/iTAN

All of these defences have been broken by fraudsters

- Malware
- Man in the Middle (MITM)
- Combination: Man in the Browser



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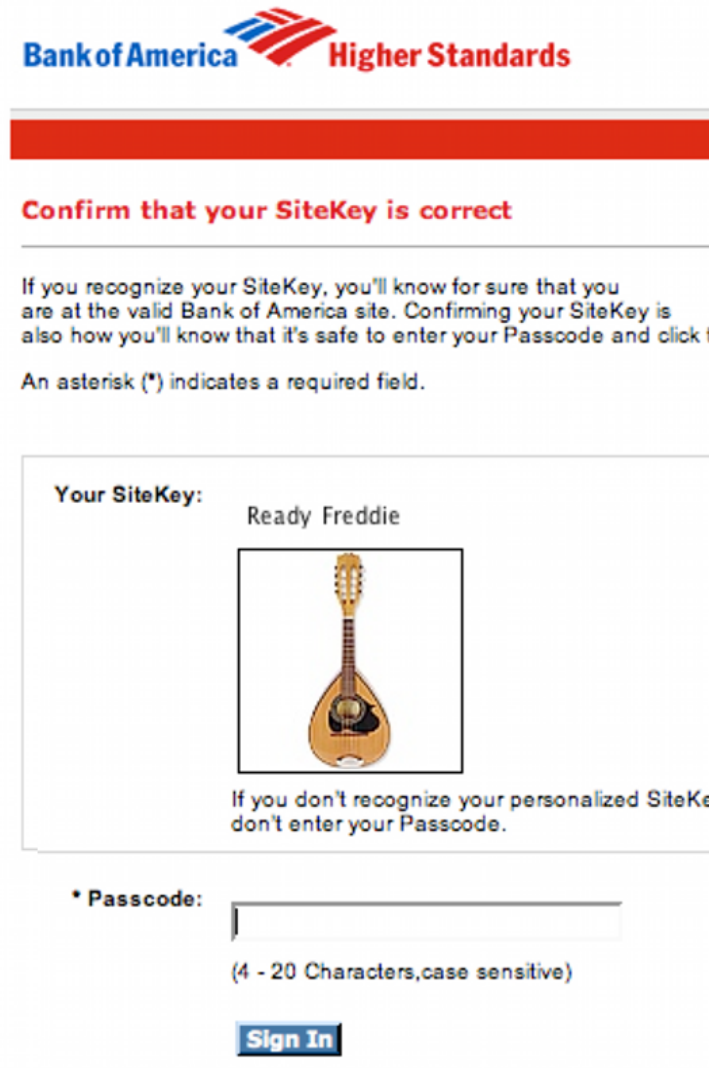

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HTTP Header Information

Which headers does your browser send? When communicating with the webs
contain information about which type of images are supported, which kind of d
cookies etc.

HTTP Header	Value
HTTP_ACCEPT	text/html,application/xhtml+xml,applicatio
HTTP_ACCEPT_CHARSET	ISO-8859-1,utf-8;q=0.7,*;q=0.7
HTTP_ACCEPT_ENCODING	gzip,deflate
HTTP_ACCEPT_LANGUAGE	en-us,en;q=0.5
HTTP_CONNECTION	keep-alive
HTTP_HOST	browserspy.dk
HTTP_KEEP_ALIVE	300
HTTP_REFERER	http://browserspy.dk/geolocation.php
HTTP_USER_AGENT	Mozilla/5.0 (Macintosh; U; Intel Mac OS X
QUERY_STRING	
REMOTE_ADDR	128.232.9.64
REMOTE_PORT	50625
REQUEST_METHOD	GET
REQUEST_URI	/headers.php
REQUEST_TIME	1261872241

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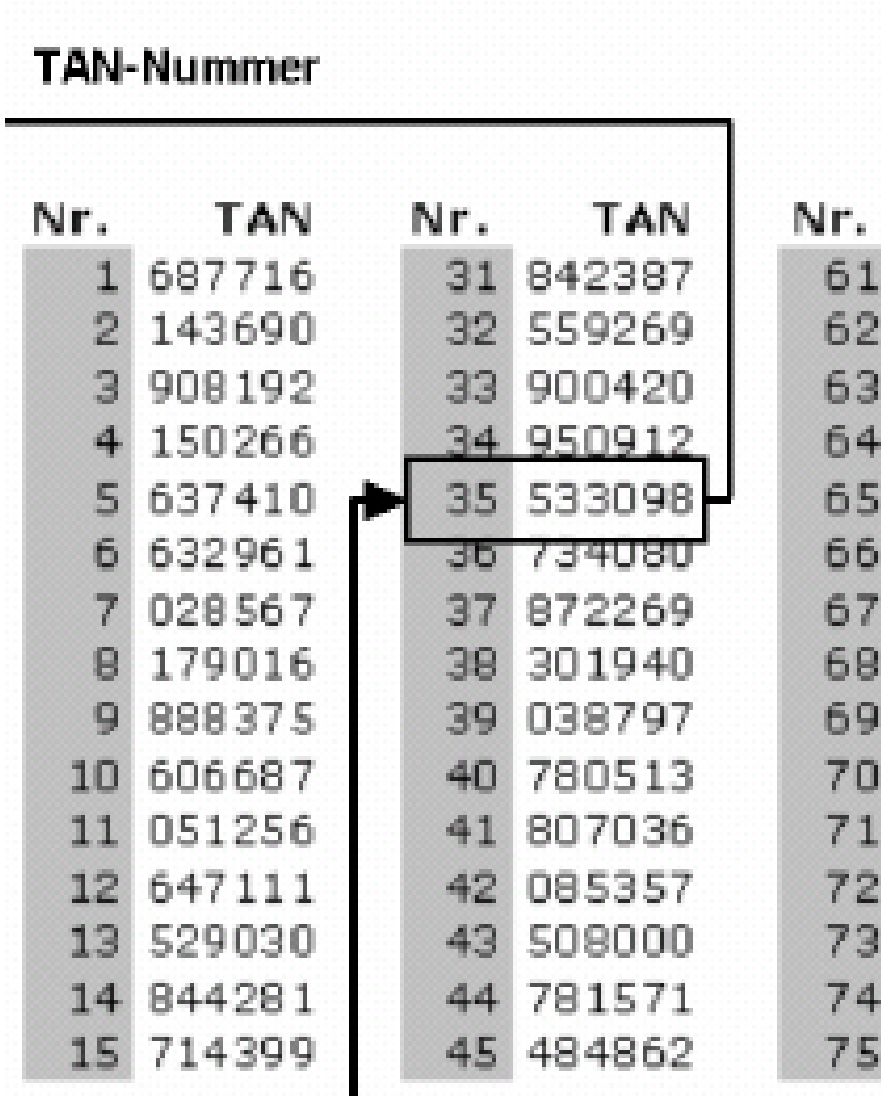

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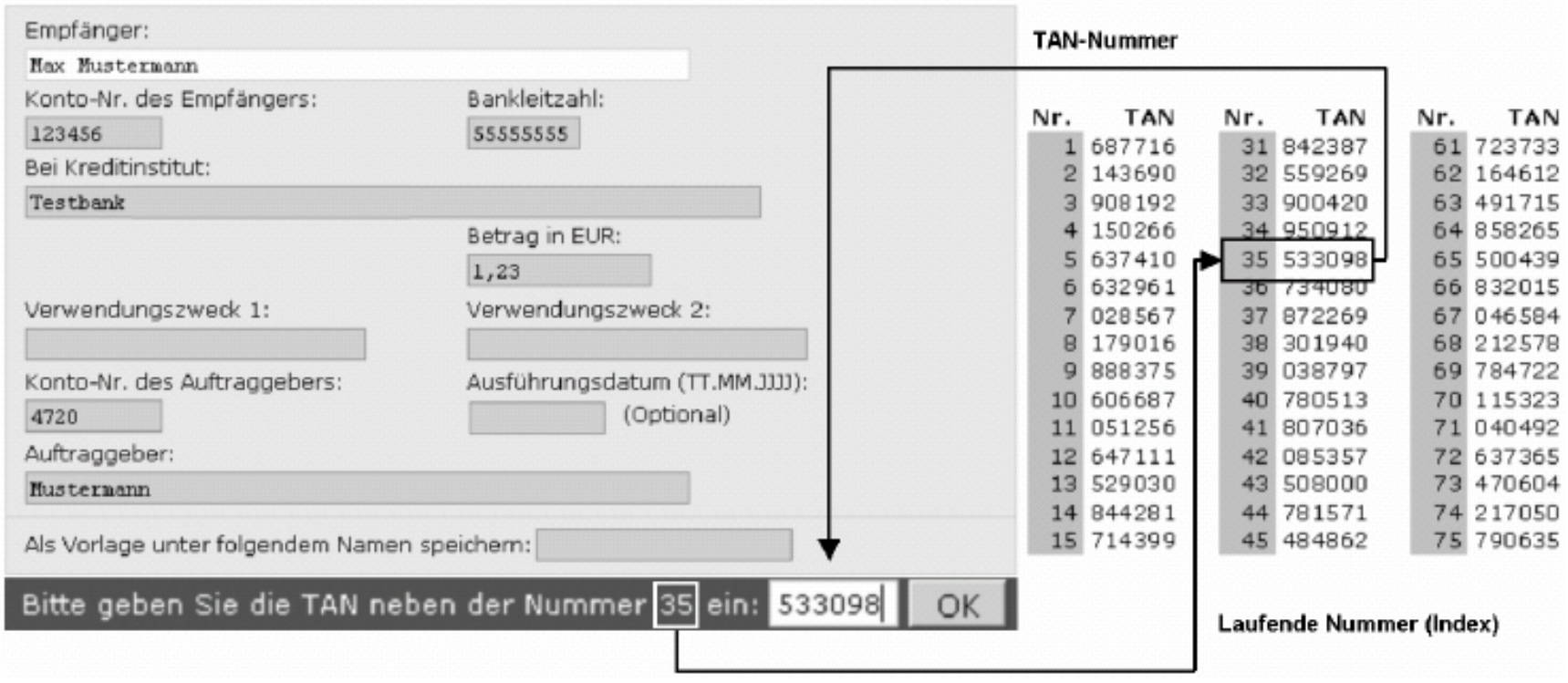
iTAN



Picture: Volksbank Dill eG

Customer must provide the requested one time password

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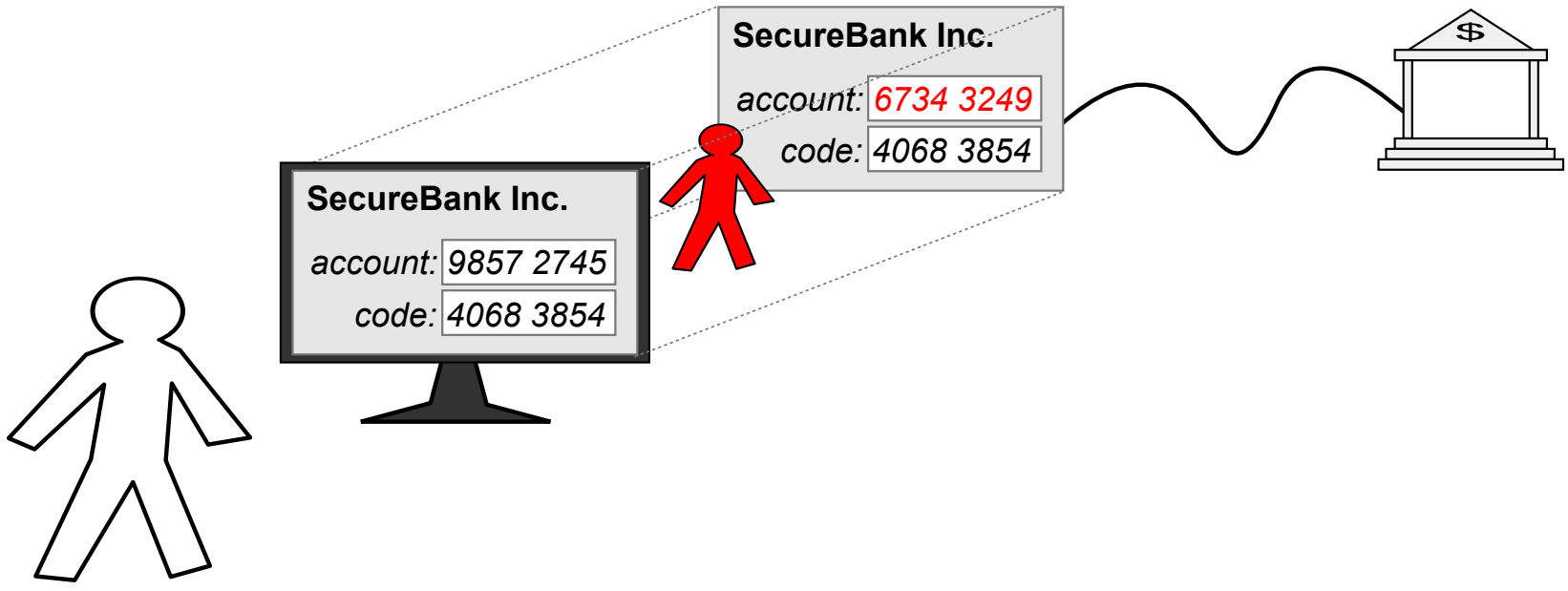
Man in the browser



Malware embeds itself into the browser

Changes destination/amount of transaction in real-time

Any one-time password is valid, and mutual authentication succeeds

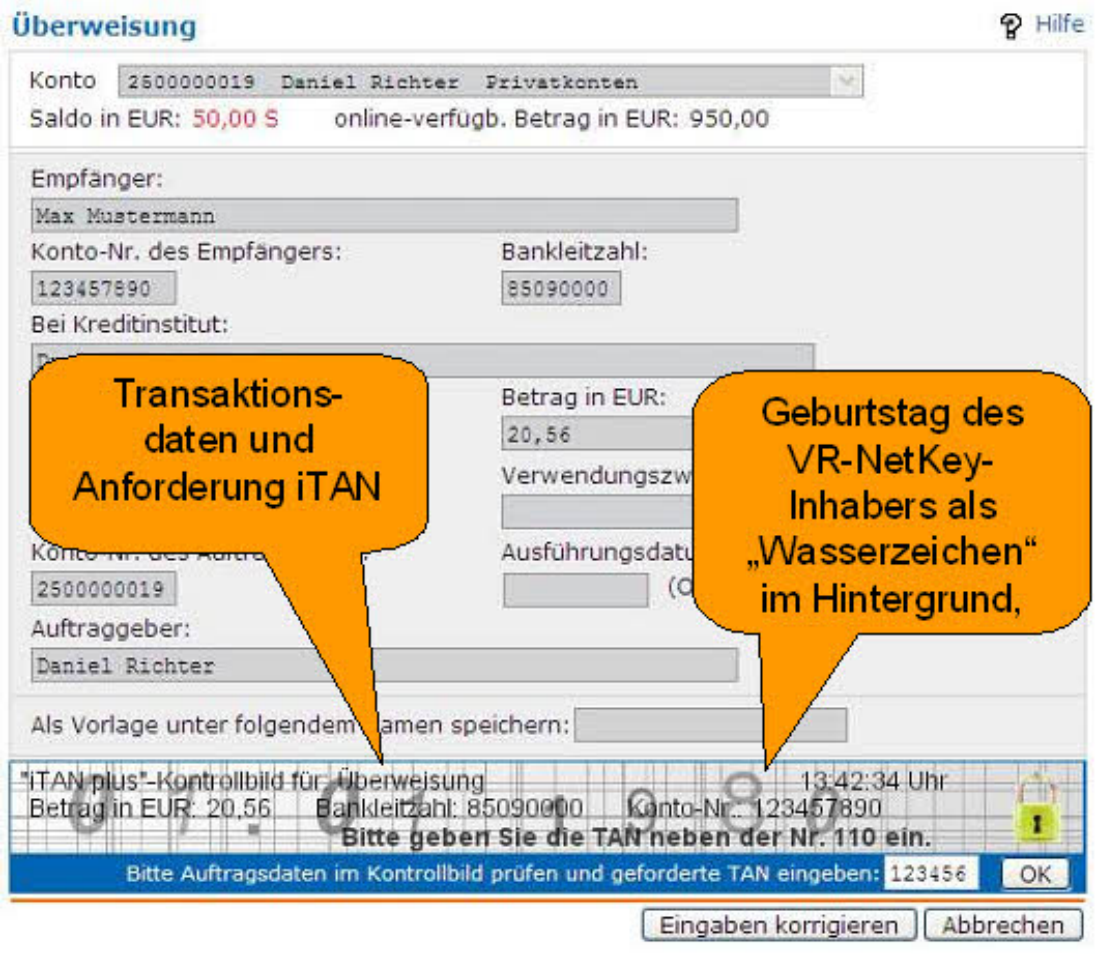
Patches up online statement so customer doesn't know

Somehow the response must be bound to the transaction to be authorised

Embed challenge in a CAPTCHA style image, along with transaction

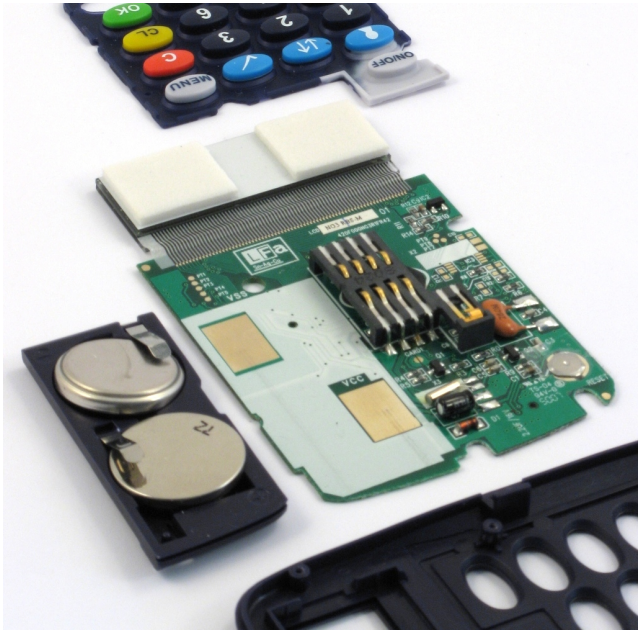
Involving a human can defeat this

May move the fraud to easier banks



Picture: Volksbank Dill eG

Some UK banks have rolled out disconnected smart card readers



CAP (chip authentication programme) protocol specification secret, but based on EMV (Europay, Mastercard, Visa) open standard for credit/debit cards

Reader prompts for input and displays MAC generated by card

- Customer enters PIN
- Card verifies PIN
- Customer enters transaction details (varies between banks)
- Card calculates MAC over:
  - Counter on card
  - Information entered by customer
  - Result of PIN entry
- Reader displays decimal value from:
  - Some bits from the counter
  - Some bits from the MAC
  - (specified by the card's bit filter)

Usability failures aid fraudsters

CAP reader operates in three modes, which alters the information prompted for and included in the MAC

Identify	No prompt
Respond	8-digit challenge (`NUMBER:`)
Sign	Destination account number (`REF:`) and amount

Banks have inconsistent usage

Barclays	“Identify” for login, “Sign” for transaction
NatWest	“Respond” with first 4 digits random and last 4 being the end of the destination account number

Fraudsters can confuse customers to enter in the wrong thing

Transaction mode not included in MAC

Input to MAC does not include the selected operation mode

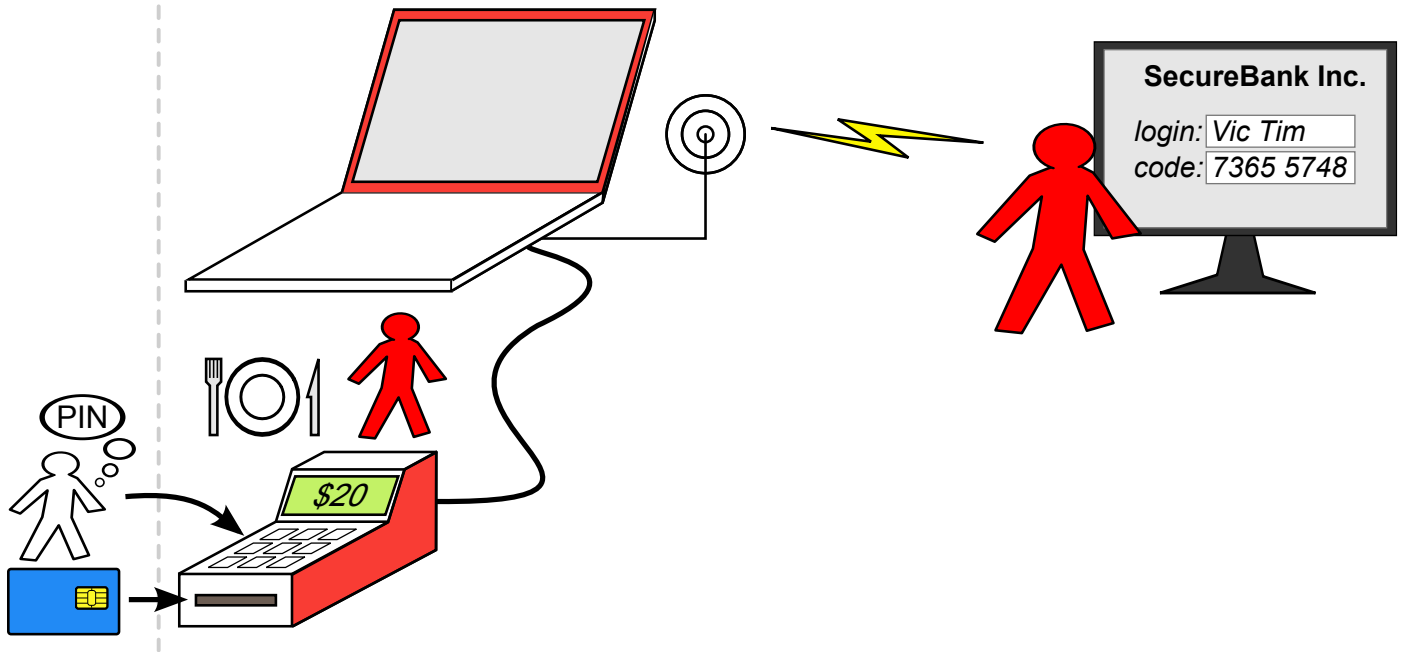
Identify	000000000000	00000000
Respond	000000000000	<challenge>
Sign	<amount>	<account number>

A “Sign” response, with an empty/zero amount, is also a valid “Respond” response

The account number field is overloaded as being nonce in one mode and destination account number in another

This ambiguity can be exploited by fraudsters when fooling customers to enter wrong thing

Nonce is small or absent



No nonce in Barclays variant so response stays valid; only a 4-digit nonce with NatWest (weak – 100 guesses = 63% success rate)

Fake point-of-sale terminal can get response in advance

Even if the nonce was big, a real-time attack still works

BBC Inside Out

We demonstrated this attack on the BBC television programme, Inside Out, earlier this year

CAP readers help muggers

guardian.co.uk

Police think French pair tortured for pin details

Matthew Taylor

The Guardian, Saturday July 5 2008

CAP reader tells someone whether a PIN is correct

Offers assistance to muggers

Affects customers with CAP-enabled cards, even if their bank doesn't use CAP

EMV specification always let this be built, but now devices are distributed for free

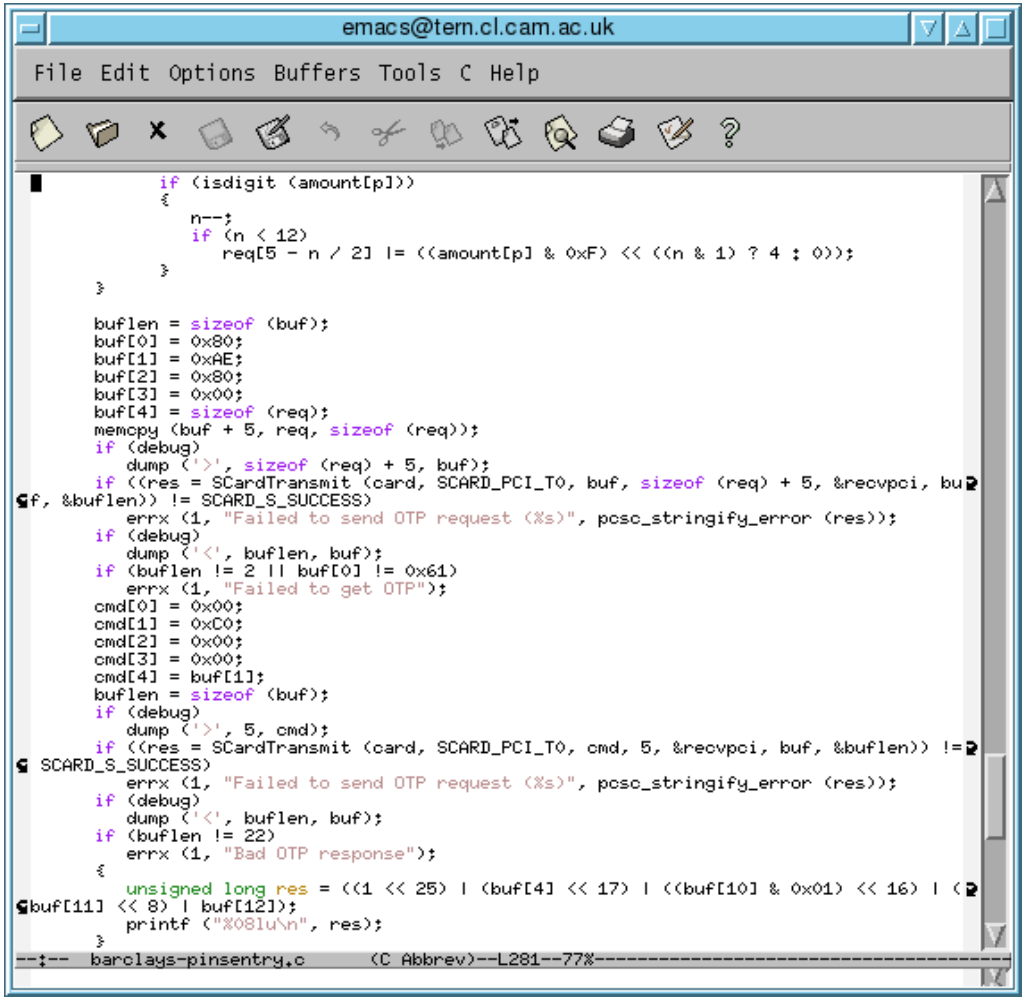
Software implementation of CAP is possible and desirable

CAP readers contain no secrets; possible to do black-box reverse engineering

CAP stops automated transactions: there is demand for a PC implementation

Some available now

If this software becomes popular, malware will attack it



Supply chains can be infiltrated

Telegraph.co.uk

Chip and pin scam 'has netted millions from British shoppers'

A sophisticated "chip and pin" scam run by criminal gangs in China and Pakistan is netting millions of pounds from the bank accounts of British shoppers, America's top cyber security official has revealed.

By Henry Samuel in Paris
Last Updated: 9:25AM BST 15 Oct 2008

Comments 12 | Comment on this article

Photo: PA

Dr Joel Brenner, the US National Counterintelligence Executive, warned that hundreds of chip and pin machines in stores and supermarkets across Europe have been tampered with to allow details of shoppers' credit card accounts to be relayed to overseas fraudsters.

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More on Law and order

Banks are too chipper about pin fraud

Chip and pin scam 'has netted millions from British shoppers'

Credit card fraud at supermarkets increases as financial crisis bites

Gangs hiding bank card readers inside shop chip and pin machines

Credit card crooks 'foil chip and pin security'

Chip & PIN terminals have been found with tapping devices inserted at manufacturer, which send captured details by mobile phone

There is even less control over the supply chain for CAP readers

Criminals could send or sell trojaned readers

What does this mean for customers?

CAP is far better than existing UK systems

- Authentication codes are dynamic
- Authentication codes are bound to transaction (although could be better)

Is this better for customers? Maybe no (at least in the UK)

Consumer protection law is vague: you are protected unless the bank considers you “negligent”

When the UK moved from signature to PIN for card payments, customers found it harder to be refunded for fraud (now 20% are left out of pocket)

The UK is moving from password to PIN for online banking. Might we see the same pattern (it is too soon to tell)?

CAP further increases the customer's liability for online fraud

> The Firm has provided an 'audit trail' of the transactions disputed by you. This shows the location and times of the transactions and evidences that the card used was 'CHIP' read.

Financial Ombudsman Service

CAP further increases the customer's liability for online fraud

> Although you question the Firm's security systems, I consider that the audit trail provided is in a format utilised by several major banks and therefore can be relied upon.

Financial Ombudsman Service

CAP further increases the customer's liability for online fraud

> Although you have requested this information from the Firm yourself (and I consider that it is not obliged to provide it to you) I conclude that this will not make any difference, because this Service has already reviewed this information.

Financial Ombudsman Service

CAP further increases the customer's liability for online fraud

> As we have already advised you, since the advent of CHIP and PIN, this Service is not aware of any incidents where a card with a 'CHIP' has been successfully cloned by fraudsters so that it could be used by them successfully in a cash machine.

Financial Ombudsman Service

CAP further increases the customer's liability for online fraud

> My conclusion therefore is that it is likely that the original card was used to carry out the transactions disputed by you.

Financial Ombudsman Service

Other authentication tokens fix many of the issues in the UK CAP

HHD 1.3 (standard from ZKA, Germany) is stronger than UK CAP, but more typing is required

- Many more modes, selected by initial digits of challenge
- Mode number alters the meaningful prompts
- Up to 7 digit nonce for all modes
- Nonce, and mode number, are included in MAC
- PIN verification is optional

RSA SecurID and Racal Watchword do PIN verification on server, and permit a duress PIN

More improvements require higher unidirectional bandwidth

For usability, customer should not have to type in full challenge

Allows versatility and better security

Flicker TAN

- Very similar to German CAP system (HHD 1.3)
- Rather than typing in transaction, encoded in a flickering image
- Easier to use, because no need to type in information twice
- Exactly as versatile and secure as HHD 1.3
- Customer needs to carry special reader and their card
- Flickering image may be annoying
- Offered by Sparkasse

USB connected readers

- Class-3 smart card reader (with keypad and display)
- For use with HBCI/FinTS online banking
- Requires drivers to be installed, so not usable while travelling
- Also not usable from work (where a lot of people do their online banking)
- Can also be used for digital signatures
- Can have good security, but details depend on protocol
- Offered by Sparkasse

Cronto PhotoTAN

- Transaction description encoded in a custom 2-D barcode
- More versatile than HHD 1.3 (allows for free text)
- Available on mobile phone (Java, Blackberry, Android, Symbian, iPhone, etc. . .)
- Also dedicated hardware, for users without a suitable phone
- Secure and convenient, because most people keep their phone on their person
- Used by Commerzbank
- I did this!

Conclusions

Systems based on EMV are open to a variety of attacks

- While the specification does not forbid implementing resistance measures, it offers little help
- In practice, implementers have slipped up, and customers have been left liable
- EMVs complexity, and large variety of options are particularly problematic
- In particular, not specifying security checks, and making essential data items optional, are a fundamental problem of EMV
- While the specification could be patched to fix the particular vulnerabilities identified, fixing the systemic problems needs a re-write of the protocol and specification
- For online banking, transaction authentication is now essential, which requires a trustworthy display

More: `http://www.cl.cam.ac.uk/research/security/banking/`