

Owning and Cloning NFC Payment Cards

# Crash and Pay

# About me

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- Security Jerk.
- Failed “Musician”
- Does stuff with computers.

# Stuff I'm assuming you know / you can ignore for this talk

- Low level NFC/RFIDs stuff (initialization etc)
- What a credit card is.
- How to do a contactless transaction
- How tradition magstripe cloning is performed.
- Basics of crypto
- The inanity of writing parsers in C.

# Handy Definitions!

<b>ATC</b>	Application Transaction Counter	Monotonic counter of transactions performed
<b>UN</b>	Unpredictable Number	Random number used in transaction
<b>CVV/ CVC</b>	Card Verification Value (VISA)/ Card Verification Code (Mastercard)	Used to prevent alteration of data on the card.
<b>dCVV/ CVC<sub>3</sub></b>	CVV <sub>3</sub> (Mastercard)/ dynamic CVV(Visa)	Used to prevent alteration of card data and prevent cloning of cards.
<b>TTQ</b>	Terminal Transaction Qualifiers (Visa)	Indicates what kind of card verification the terminal supports
<b>PAN</b>	Personal Account Number	Account Number assigned to the user
<b>PSE</b>	Payment Systems Environment	Tells terminal that the card is a banking card
<b>AID</b>	Application Identifier	Tells terminal what brands the card supports (Mastercard, Visa etc)
<b>PDOL</b>	Processing Data Options List	List of tags we need the terminal to send the card (amount, UN etc).
<b>AFL</b>	Application File Locator	Indicate what records the terminal needs to read.
<b>AIP</b>	Application Interchange Profile	Field to tell the terminal what authentications the card supports

# Overview of an NFC Payment (First bit)

Contactless Card



Terminal



1. Select(PSE)

2. Payment Directory

3. Select (AID)

4. FCI (AID, PDOL list etc)

```
Apdu: File Control Information (FCI) Template  
(47 bytes):  
04 0e 32 50 41 59 2e 53 59 53 2e 44 44 46 30 31 a5 1d bf 0c 1d 61 18 4f 07 d0  
00 00 00 04 10 10 07 01 01 50 0a 4d 41 53 54 45 52 43 41 52 44
```

```
Apdu: File Control Information (FCI) Template  
(59 bytes):  
04 07 d0 00 00 00 04 10 10 a5 2d 50 0a 4d 41 53 54 45 52 43 41 52 44 07 01 01  
5f 2d 02 65 6e 9f 11 01 01 9f 12 0a 32 3f 20 44 65 67 72 65 65 73 bf 0c 05 9  
f 4d 02 00 0a
```

```
0x77: Response Message Template Format 2  
(18 bytes):  
82 02 58 80 94 0c 08 01 01 00 10 01 01 01 18 01 02 00
```

# How to clone a VISA card

The proceeding information is for education use only.  
This is not a license to clone other peoples cards.  
Don't blame me if someone does this to you, buy a roll of tin foil and wrap your card in it.



# Verification Modes Supported By VISA

- Dynamic CVV - dCVV
  - Legacy magstripe equivalent mode
  - Terrible, broken on release
- Cryptogram Version Number 17 - CVN17
  - Updated to magstripe equivalent mode
  - Lot better than dCVV
- Quick Visa Smart Debit/Credit - qVSDC
  - Reduced EMV mode
  - Defined in standard for speed
- Visa Smart Debit/Credit - VSDC
  - Full EMV mode (i.e CDA)
  - Slower – requires card to be in field for complete transaction

# How does the card/terminal know what mode to use?

## ■ 9F66 - TTQ – Terminal Transaction Qualifier

**Table 1 – Summary of Possible Card / Reader Interactions**

<b>Contactless Card Capability</b> <b>Reader Configuration</b>	<b>MSD and qVSDC</b>	<b>MSD, qVSDC, and VSDC</b>
<b>MSD and qVSDC</b>	qVSDC	qVSDC
<b>qVSDC only</b>	qVSDC	qVSDC
<b>qVSDC and VSDC</b>	qVSDC	VSDC
<b>MSD, qVSDC, and VSDC</b>	qVSDC	VSDC
<b>MSD and VSDC</b>	MSD	VSDC
<b>MSD</b>	MSD	MSD

**Table 3 – Terminal Transaction Qualifiers (Tag '9F66')**

<b>Byte</b>	<b>Bit</b>	<b>Definition</b>
1	8	'1' – Contactless magnetic stripe (MSD) supported '0' – Contactless magnetic stripe (MSD) not supported
	7	'1' – Contactless VSDC supported '0' – Contactless VSDC not supported
	6	'1' – Contactless qVSDC supported '0' – Contactless qVSDC not supported
	5	'1' – Contact VSDC supported '0' – Contact VSDC not supported
	4	'1' – Reader is Offline Only '0' – Reader is Online Capable
	3	'1' – Online PIN supported '0' – Online PIN not supported
	2	'1' – Signature supported '0' – Signature not supported
	1	RFU – b'x'
2	8	'1' – Online cryptogram required '0' – Online cryptogram not required
	7	'1' – CVM required '0' – CVM not required
	6-1	RFU – b'xxxxxx'
3	8-1	RFU – b'xxxxxxxx'
4	8-1	RFU – b'xxxxxxxx'



# VISA Authentication flow dCVV mode

Contactless Card



Terminal



5. Get Processing Options(PDOL)

9f66: Terminal Transaction Qualifiers (TTQ)  
9f02: Amount, Authorised (Numeric)  
9f37: Unpredictable Number  
5f2a: Transaction Currency Code

6. AIP, AFL

```
57: Track 2 Equivalent Data (19 bytes): 48 62 70 00 57 22 49 45 d1 51 02 21  
00 00 00 37 70 90 0f  
5f20: Cardholder Name (2 bytes): /  
9f1f: Track 1 Discretionary Data (17 bytes): 00000000709000000
```

7. Read Records

Track Datas

Generate track 1 and  
Track 2 datas

# So lets clone a VISA card in dCVV

- We have to use dCVV mode.
- All other modes appear to use long random numbers.
- dCVV is a legacy mode
- So limits amount of devices in the field.
- dCVV sucks. No random number, not use of transaction specific data.
- Plus its optional – issuers can set static CVVs if they want here!

# How to prevent cloning (VISA)

- Issuers can disable dCVV Support – my ING debit card doesn't support this.
- Processors must not support dCVV mode
- Terminals must use strong cryptographic secure random number generation.

It has been agreed that a migration from dCVV to Cryptogram Version 17 will take place for MSD readers and that by a migration date to be determined, MSD readers will support Cryptogram 17. An MSD market is not a full data market and Cryptogram 10 is not supported in these markets.

# Cloning a Mastercard!

Hey – I'm an equal opportunity troll!



# What does Mastercard Support?

- Magstripe Mode
  - – generate dynamic CVV code and insert into track data
- MChip Mode
  - EMV – validate records and calculate application cryptogram.

# NFC Payments (MAGSTRIPE modes only)

Contactless Card



Terminal



Generate UN  
(hopefully random...)

7. Compute Cryptographic Checksum

CVCs, ATC

9. Read Records

10. Track Datas

```
77: Response Message Template Format 2 (15 bytes):  
9f61: CVC3 Track 2 (2 bytes): 46 2f  
9f60: CVC3 Track 1 (2 bytes): 7e 3f  
9f36: Application Transaction Counter (2 bytes): 02 44
```

Generate track 1 and  
Track 2 datas



# Great – lets clone a card.



1. Criminal scans victims card and application performs  $10^{\text{length}(\text{UN})}$  transactions



4. App looks up the supplied UN, responds with correct CVC and ATC codes



2. Criminal takes app to a retailer and buy stuff



5. Criminal runs off with loot.



3. Terminal send UN to "card"

# How we determine the required length of the UN?

Length of UN = NumBitsSet(KtrackX) – TtrackX

However CVV/CVC has to be formatted to fit in Track Data.

So we format it as Binary Coded Decimal.

And issuer limits length of UN to suit their systems

Take a UN of 4 bytes:

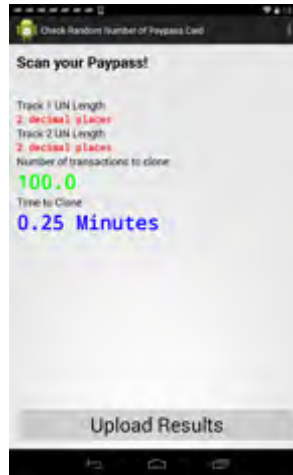
- 4 bytes binary =  $2^{32}$  values = 4,294,967,296
- 4 bytes BCD =  $10^8$  values = 100,000,000
- 2 numbers(1 byte BCD) =  $10^2$  values = **100**



# Solutions!

- Issuers need to program cards to support long UN numbers (my GE cards have this)
- Processors need to monitor ATC codes – if you jump ATCs by a bit you should flag it as fraud.
- Terminal Manufacturers need to use proper cryptographically strong RNGs
- Monitor “Generate Cryptographic Checksum” commands.
- Request 2<sup>nd</sup> factor when ATCs jump – I get this when I’ve tested in Australia
- Wrap yourself in tin foil?

# So I made an app to test your own cards



- <https://github.com/peterfillmore/Check-Paypass-Random-Number>
- Scan your card and find the time it takes to clone!
- Doesn't bork your card – i.e no transactions take place – just a reads the appropriate record.

# Tools



# ACR-122U, PCSCd, PyScard and RFIDiot



- ~AUD\$50 on ebay
- <https://pypi.python.org/pypi/pyscard>
- Adam Laurie's RFIDiot: <https://github.com/AdamLaurie/RFIDiot>
- My fork used in this talk: <https://github.com/peterfillmore/RFIDiot/tree/preplayattack>
- Crappy driver – PCSCd pegs core at 100% - frequent resets needed.
- See Charlie Millers talk Don't Stand So Close To Me: An Analysis of the NFC Attack Surface `: <https://www.youtube.com/watch?v=qRFpjLIhoXo>

# Android phone with HCE support



- I love HCE – Host Card Emulation – added Android 4.4 (KitKat)
- Best tool I've found – takes care of a lot of pain.
- Can't emulate low level stuff (i.e UID, card parameters)
- 1 stop shop to cloning a card!
- Great tool for in field testing – no one questions a phone in your hand.
- <https://github.com/peterfillmore/Check-Paypass-Random-Number>
- Not releasing my cloner tool – that's a can of worms I'm not going to open.

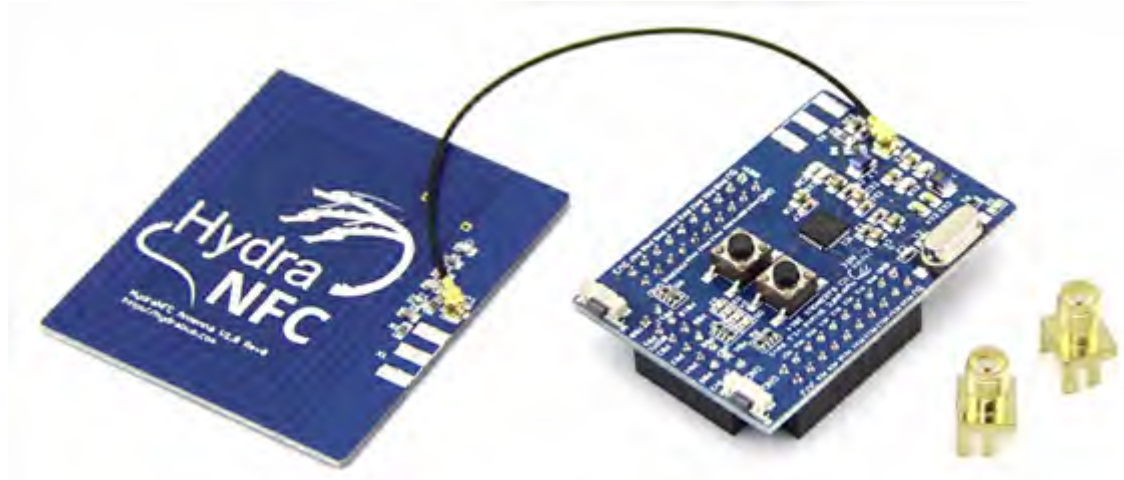
# Proxmark3



- Lots of improvements in the last few months.
- You can control everything!
- EMV support added in my git branch:

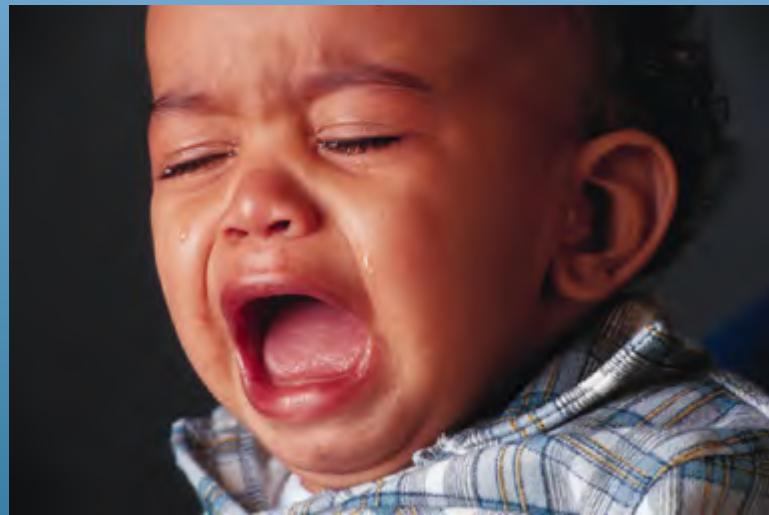
<https://github.com/peterfillmore/proxmark3>

# HydraNFC+HydraBus



- Benjamin Vernoux's Project.
- <http://hydrabus.com/>
- In between a Proxmark3 and an Android phone.
- Hopefully will provide a good fuzzing platform (i.e. hardware control and easy software).

# My Failures





# Failures / how not to do hardware exploitation

- Thought I had a buffer overflow when fuzzing – actually just the watchdog timer resetting 😞
- Lots of pain getting jtag sorted. Make sure you disable watchdog timer!
- Even after getting jtag – can't get it to boot when connected – I think its related to the timers.
- Tried to QEMU it – got it running but stopped at trying to emulate all the hardware.

# JTAG! OpenOCD! Still Failed!



Steps:

1. Look for unpopulated pads
2. Download data sheet
3. Trace pads to chip
4. Patch firmware to enable JTAG and disable watchdog timers
5. OpenOCD and connect to GDB

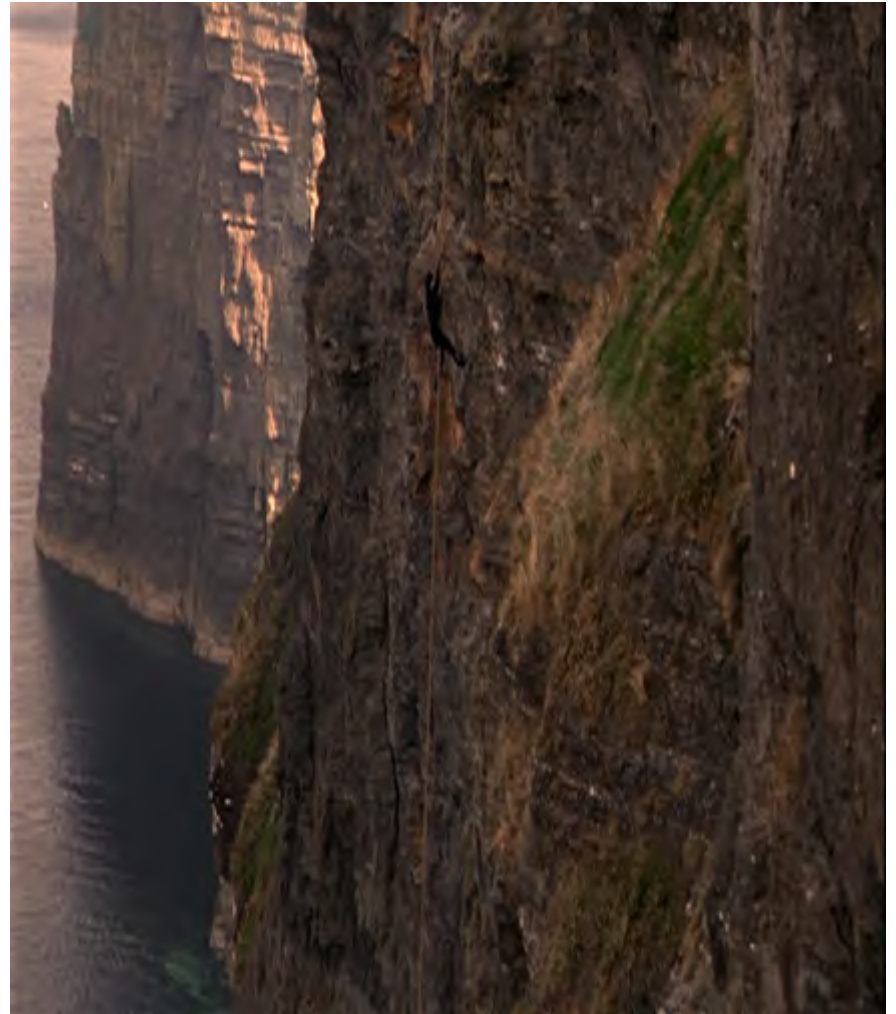
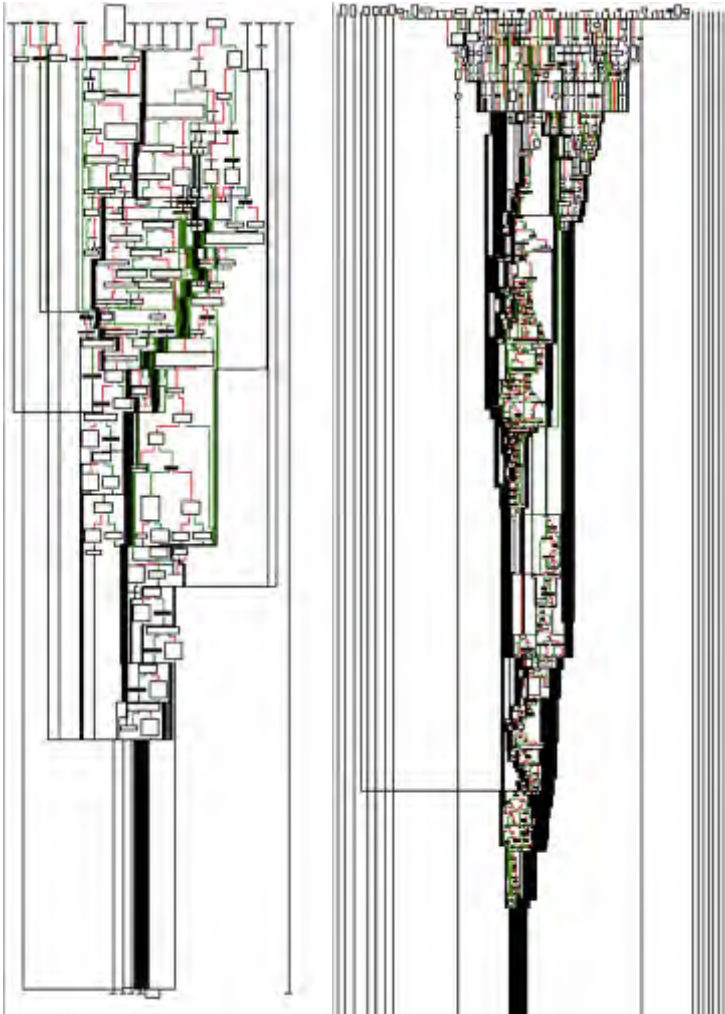


```
seg000:0000306C      setupWatchdogTimers
seg000:0000306C
seg000:0000306E      000      LDR    R2, =0x20305D
seg000:00003070      000      LDR    R3, =WDTG
seg000:00003072      000      STR    R2, [R3]
seg000:00003076      000      MOVS   R3, WDTG0
seg000:00003078      000      MOVS   R2, #0
seg000:0000307A      000      STRB   R2, [R3]
seg000:0000307A      initWDFEED
seg000:0000307A      000      LDR    R2, =WDFEED
seg000:0000307C      000      MOVS   R3, WDFEED
seg000:0000307E      000      NEGS   R3, R3
seg000:00003080      000      STRB   R3, [R2]
seg000:00003082      reloadWatchdog
seg000:00003082      000      MOVS   R3, WDTG0 ; '0'
seg000:00003084      000      STRB   R3, [R2]
seg000:00003086      000      BX     LR
seg000:00003086      ; End of function setupWatchdogTimers
```

# Failures continued (IDA Pro)

- Threw the firmware update binary into IDA pro
- No identified signatures ☹️
- Tried installing
- Thumb and ARM code mixed is fun!
- Worked out lots of basic system functions.
- But still a bit of a mystery as to many key functions

# Here's some IDA graphs





# Qemu To the Rescue?

- Semi-success.
- Had to customise the platform.
- Injected code to provide Bootloader functions
- Makes reversing a lot easier!

```
UqRegister group: general
r0      0x6e7  1767
r1      0xe0010004  -536805372
r2      0x0      0
r3      0x4000cca  1073745098
r4      0x40007bd8  1073773520
r5      0x0      0
r6      0x0      0
r7      0x0      0
r8      0x0      0
r9      0x0      0
r10     0x400073f0  1073771504
r11     0x0      0
r12     0x7      7

0x3d6e ldr    r3, [pc, #28] ; (0x3d8c)
0x3d70 str    r2, [r3, #0]
0x3d72 movs   r3, #224 ; 0xe0
0x3d74 lsls   r3, r3, #24
0x3d76 movs   r2, #3
0x3d78 strb   r2, [r3, #0]
0x3d7a ldr    r2, [pc, #20] ; (0x3d90)
0x3d7c movs   r3, #86 ; 0x56
0x3d7e negs   r3, r3
0x3d80 strb   r3, [r2, #0]
0x3d82 movs   r3, #85 ; 0x55
0x3d84 strb   r3, [r2, #0]
0x3d86 bx     lr

remote Thread 1 In: Line: ?? PC: 0x3d6c
(gdb) layout mem
warning: Invalid layout specified.
Usage: layout prev | next | <layout_name>
(gdb)
```

# EMV Prevents Cloning right?

- Yes (however...)
- As long as you do everything right.
- And everyone in the payment flow supports it.
- And the reader is not compromised
- And your card doesn't support MSD mode(VISA)
  - Or your card implements a long UN (Mastercard)
- And the issuer is checking ATCs for large jumps (Mastercard)
- And your issuer programmed the card right.
- And the NSA/FSB/PETA haven't copied your master crypto keys (gemalto I'm looking at you)

# Conclusions

- Yes – you can clone Contactless Payment Cards
- Or more correctly Contactless Payment Transactions
- Requires legacy modes to be supported by hardware and processors
- Requires issuers to set low random number lengths(Mastercard).
- Requires old hardware and systems that don't support EMV messaging (Visa)
- Above all depends on proper random numbers being generated by terminals!

# Conclusions 2

- Able to be performed in practice.
- Fraud detection doesn't seem to occur
- Contactless interfaces don't get the love they need in testing.
- EMV relies on complex processing – is highly susceptible to security issues creeping in.
- EMV testing does not perform security testing on kernel code.
- Somebody please let me sniff an Apple Pay transaction!



# Check my github for stuff

- Check your Paypass Random Number
- <https://github.com/peterfillmore/Check-Paypass-Random-Number>
- Forked proxmark to do EMV stuff
- <https://github.com/peterfillmore/proxmark3>
- RFIDIot with additions used in this talk
- <https://github.com/peterfillmore/RFIDIot/tree/preplayattack>
- Slides:
- XXXTBAXXX

# References – aka who have I plagerized off

- “Don’t Stand So Close To Me, An analysis of the NFC attack surface” – Charlie Miller 2012
- “PinPadPwn” – Nils & Rafael Dominguez Vega Pin Pads, 2012
- “Credit Card Fraud - The Contactless Generation” Kristian Paget, 2012
- “Mission Mpossible” –Nils and Jon Butler 2013
- “Cloning Credit Cards: A combined pre-play and downgrade attack on EMV Contactless” - Michael Roland 2013
- Standards - <http://www.emvco.com>
- Utilities - <http://www.emvlab.org/tlvutils/>
- <http://www.cl.cam.ac.uk/research/security/>

# Thanks

- Pwpiwi@proxmark3 – Putting up with my complaining and fixing the Proxmark3 code
- Peter Maydell@linaro – Not insulting me for asking a stupid question on the qemu mailing list.
- Dodgy Chinese Document share sites – for allowing me to skip signing NDAs
- Benjamin Vernoux@hydrabus – buy it!



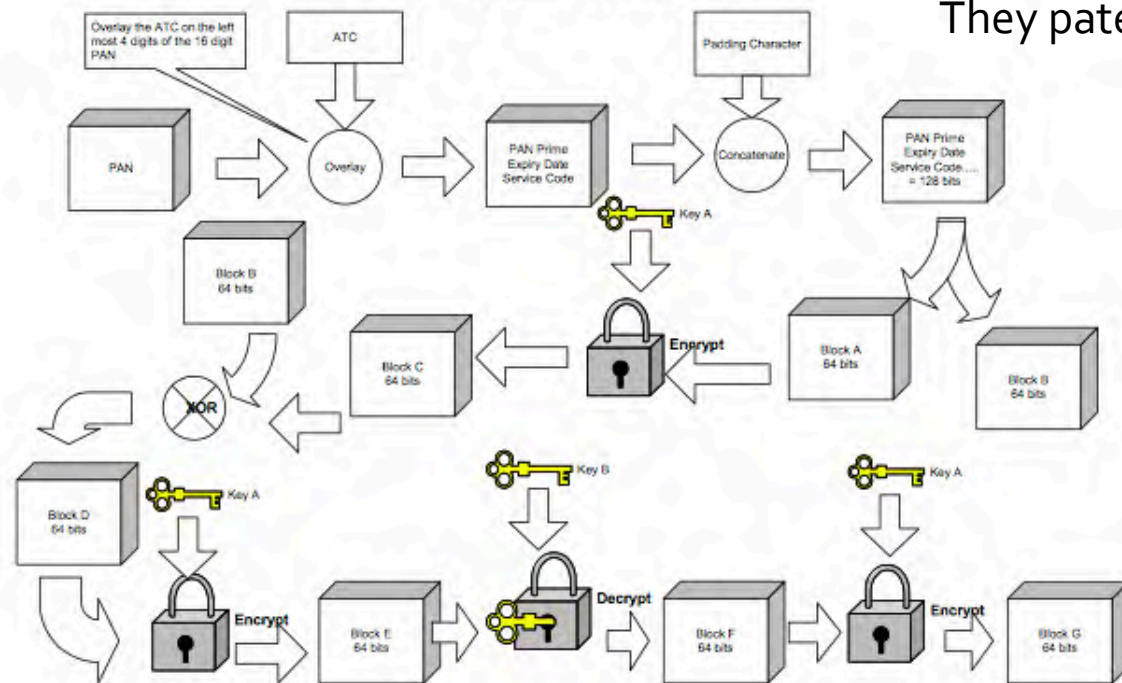


# So lets clone a VISA card in dCVV mode (DEMO)

- Its rather easy – too easy in fact.
- Just have to read the records off the card
- If the card supports dCVV, then it'll copy that into the track data.
- If the card supports only static CVV, then it'll copy it into place.
- If the card doesn't support this method, then it'll return an error code (ING debit – 6984)

# Why dCVV sucks

Figure 5 – Dynamic CVV Algorithm



It has been agreed that a migration from dCVV to Cryptogram Version 17 will take place for MSD readers and that by a migration date to be determined, MSD readers will support Cryptogram 17. An MSD market is not a full data market and Cryptogram 10 is not supported in these markets.

# VISA Authentication flow (CVN17 mode)

Contactless Card



Terminal



5. Get Processing Options(PDOL)

6. AIP, AFL, Cryptogram

7. Read Records

Track Datas

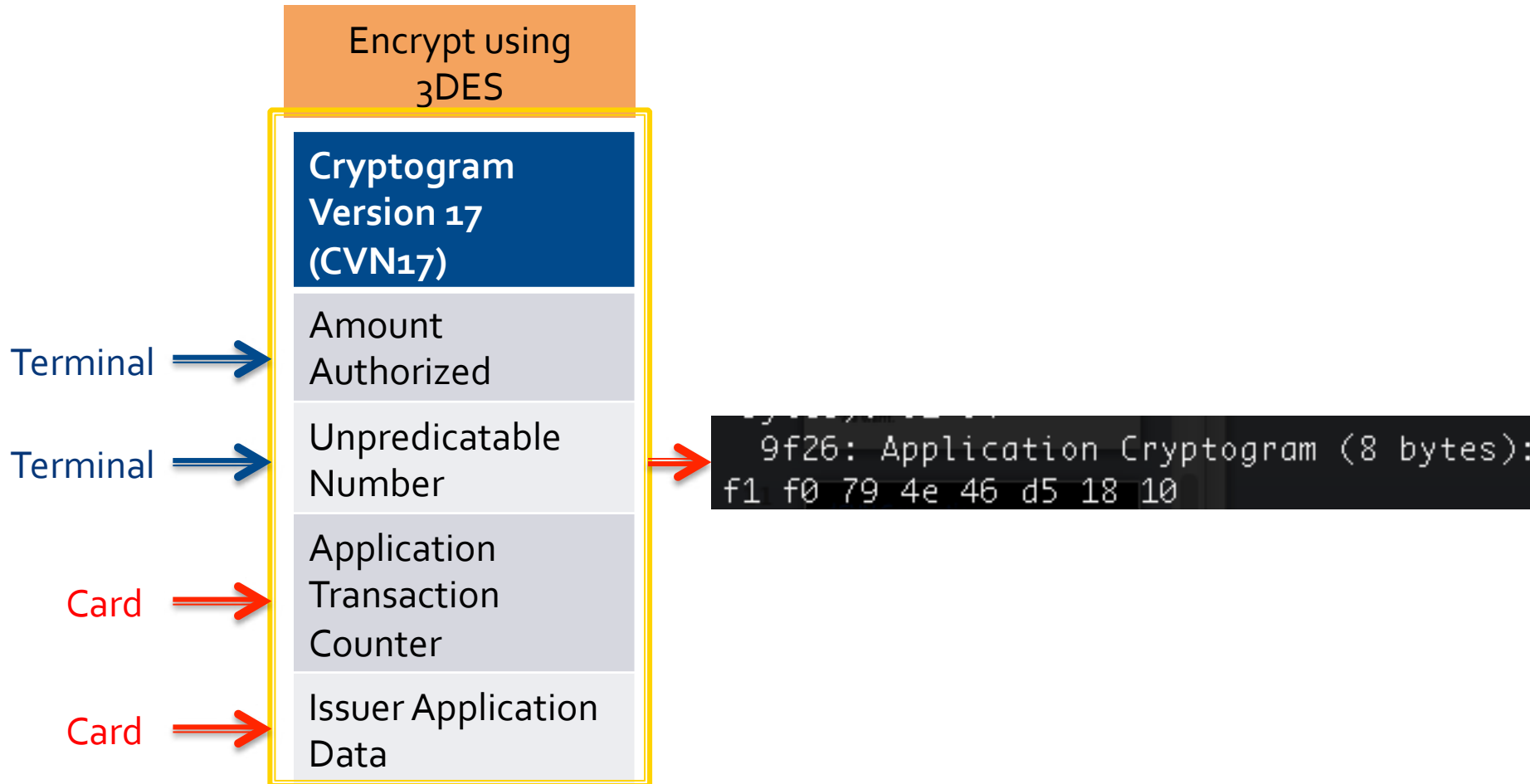
9f66: Terminal Transaction Qualifiers (TTQ)  
9f02: Amount, Authorised (Numeric)  
9f37: Unpredictable Number  
5f2a: Transaction Currency Code

```
9f10: Issuer Application Data (7 bytes): 06 0c 1  
57: Track 2 Equivalent Data (19 bytes): 48 62 70  
9f1f: Track 1 Discretionary Data (17 bytes): 0000  
5f34: Application Primary Account Number (PAN) S  
82: Application Interchange Profile (2 bytes): 00  
9f36: Application Transaction Counter (2 bytes):  
9f26: Application Cryptogram (8 bytes): ed 41 92
```

Generate track 1 and  
Track 2 datas



# CVN17 Generation (how we prevent cloning in VISA cards)



# Tools I used in this research

- Proxmark3 – lots fixed since I started doing this stuff. Can finally emulate ISO14443a tags properly
- My fork with EMV stuff – <http://github.com/peterfillmore/proxmark3>
- RFIDIot + ACR122U – good for learning basics quickly. Beware of the 64 byte limit when trying to emulate tags with proxmark3
- Fork with EMV stuff :
- <https://github.com/peterfillmore/RFIDIot/tree/preplayattack>