20 ways past secure boot

Job de Haas
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Who am I …

Job de Haas

- Principal Security Analyst at Riscure
- Testing security on: Set-top-boxes, mobile phones, smart cards, payment terminals, ADSL routers, VoIP modems, smart meters, airbag controllers, USB tokens, …
- Before: Pentesting network security (since 1991)

Riscure

- Services: Security Test Lab
- Product: Side Channel Tools
- Full range testing: detailed hardware to white-box crypto and obfuscation

Overview

- Introduction on secure boot
- Hardware related threats
- Demo
- Logical threats

Secure boot?

- Not talking about UEFI
- Not talking about Microsoft lockdown
- Does not mean it does not apply

Lockdown

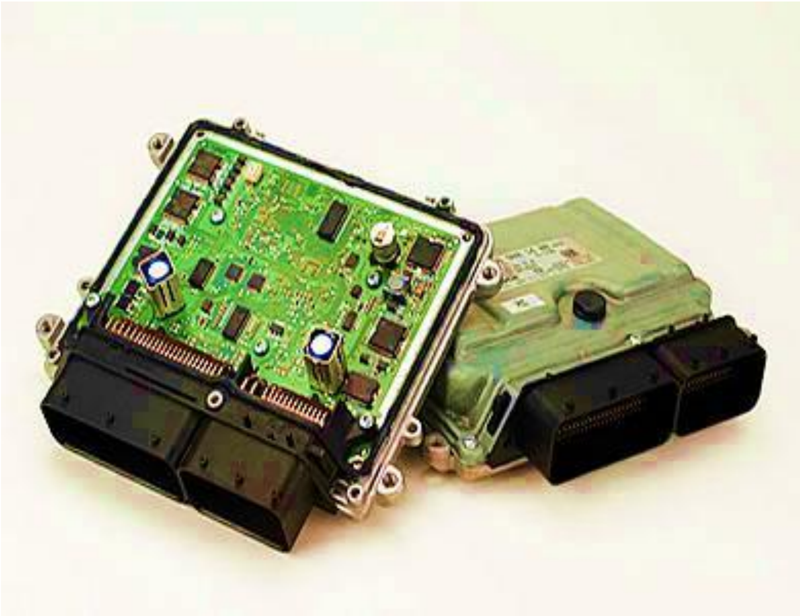
The coming war on general-purpose computing

By Cory Doctorow - Share this article

This article is based on a keynote speech to the Chaos Computer Congress in Berlin, Dec. 2011.

http://www.muktware.com/news/2823/ubuntu-red-hat-take-stand-microsoft-secure-boot-lockdown

Secure boot everywhere



Targets have in common

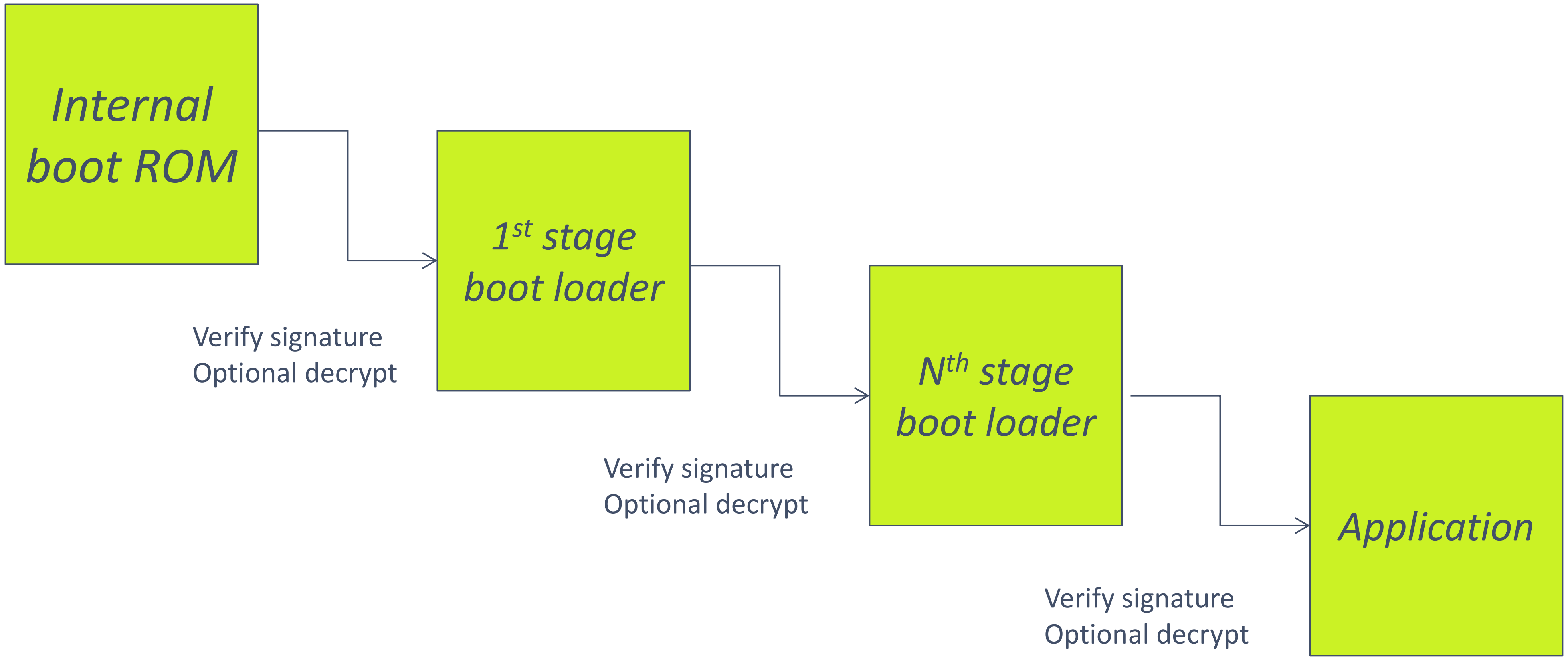
- Want to protect against persistent attacks
- Often nearby
- More often than not: the user

- But also: Loss of device. Stolen identity. Your cash.

Double edged sword:

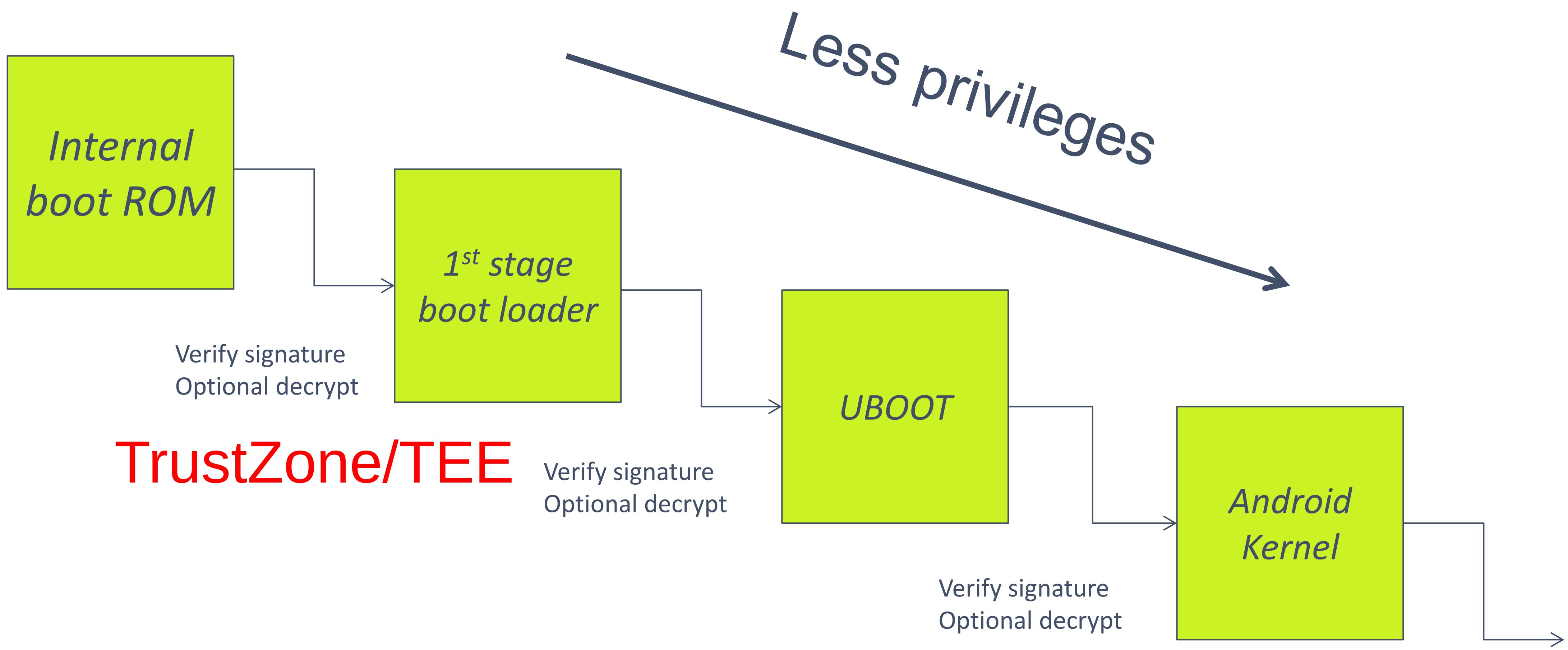
- Protects users against evil agencies and common thieves
- Protects corporations against their users
- Can deny users control of their hardware

Secure boot theory



- Root key internal
- Chain of trust

Secure boot example

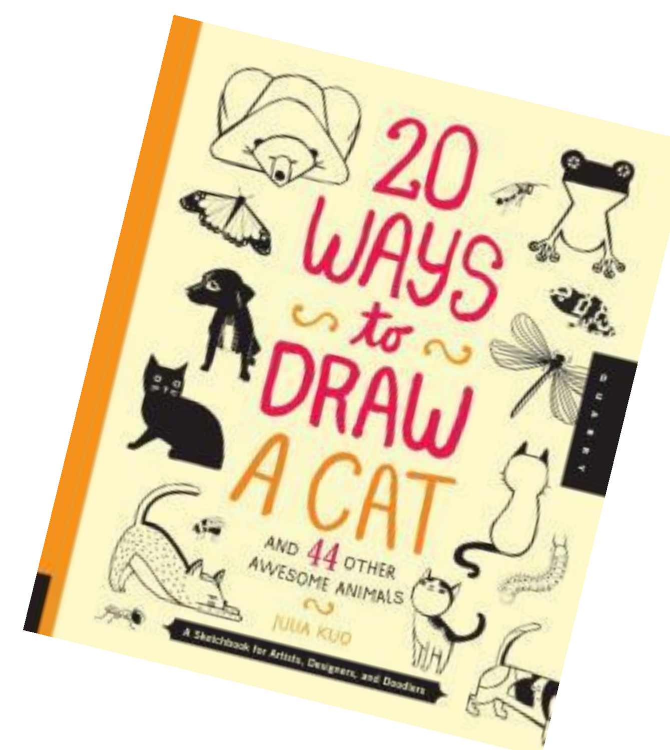


- Secure boot failure:
  - Arbitrary code execution
  - Possible persistent attacks
  - Stepping stone for further attacks

Userland Exploit

20 ways to …

- Did not try to classify and cross-classify all weaknesses
- Many different ways to count them
- Tried to find sufficiently different ones…



Hardware related threats

20. debug access to boot stage (JTAG)

- JTAG can allow full low level control of execution
- Can be very difficult to do without in production
- Physical complexity of connecting is overestimated

Source: http://www.riffbox.org

Mitigation:

- Secure designs can disable or lock JTAG
- Solution is chip dependent

19. Debug/service functionality

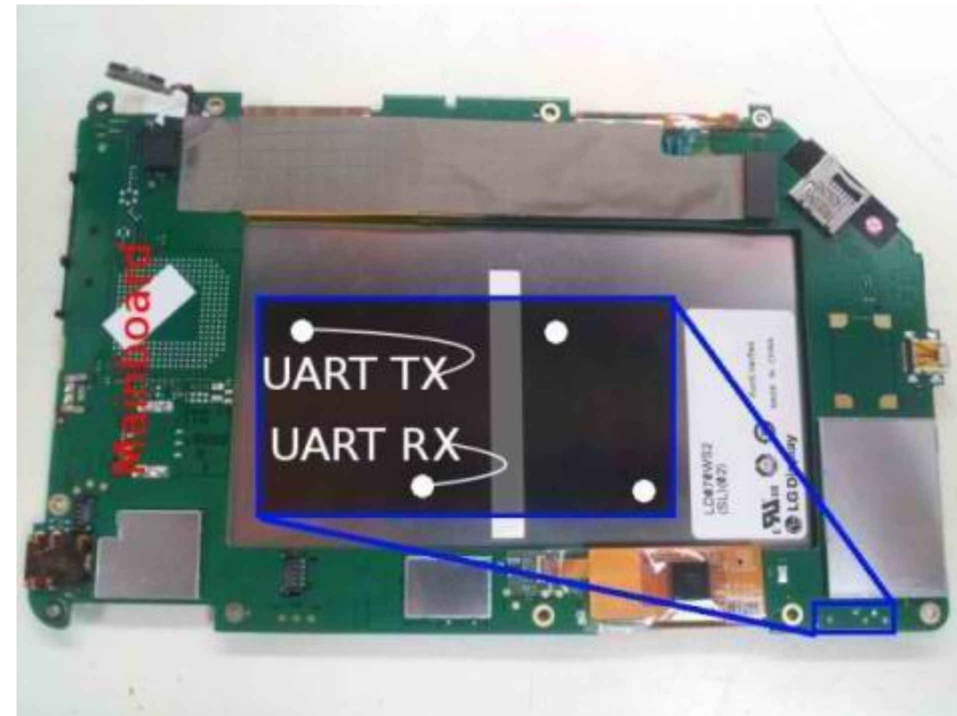
- UART is almost as persistent as JTAG
- Many devices leave some form of access for debug/service purposes
- What is the point of using u-boot to check the signature of the kernel, while commands are present like:

  ⇒ help mw
  mw - memory write (fill)
  Usage: mw [.b, .w, .l] address value [count]

- Example: Nook boot lock exploit (2012) http://www.xda-developers.com/android/patch-this-barnes-and-noble-nook-tablet-hardware-protection-compromised/

Nook boot UART exploit

- Post by **hkvc:**



Source: http://www.xda-developers.com

```
UBOOTPROMT> md.l 80e84808
----- This should show 1a00000a
…
UBOOTPROMPT> mw.l 80e84808 e1a00000
------------- This modify with NOP

UBOOTPROMPT> md.l 80e84808
------ should show e1a00000
…
UBOOTPROMPT> mmcinit 0; fatload mmc 0:1 0x81000000 flashing_boot.img; booti 0x81000000

Now it should boot with out giving a signature error.
```

Mitigation:

- Every chain in the boot process matters
- At least use some device unique authentication

18. Overriding boot source medium

- Boot source is selectable. Can a user override it (straps)?
- Does a system have different rules based on source?
- Also very effective as stepping stone (no brick)

- Automotive ECU’s have a ‘boot pin’
- JIG’s sold to reflash/remap firmware

Mitigation:

- Disable undesired functionality
- There should not be any unauthenticated exception for booting

Source: http://www.briskoda.net

17. TOCTOU race conditions

- Integrity check is performed on content in external storage
- Then the code is read or directly executed from the external storage
- Typical case: boot from external NOR flash
- Attack: After the integrity check alter stored code
- Nokia BB5 unlock by Dejan Kaljevic (2007):
- http://forum.gsmhosting.com/vbb/f299/bb5-sp-unlocking-theory-443418/

Mitigation:

- Protect the memory interface for code execution
- Load code in (D)RAM

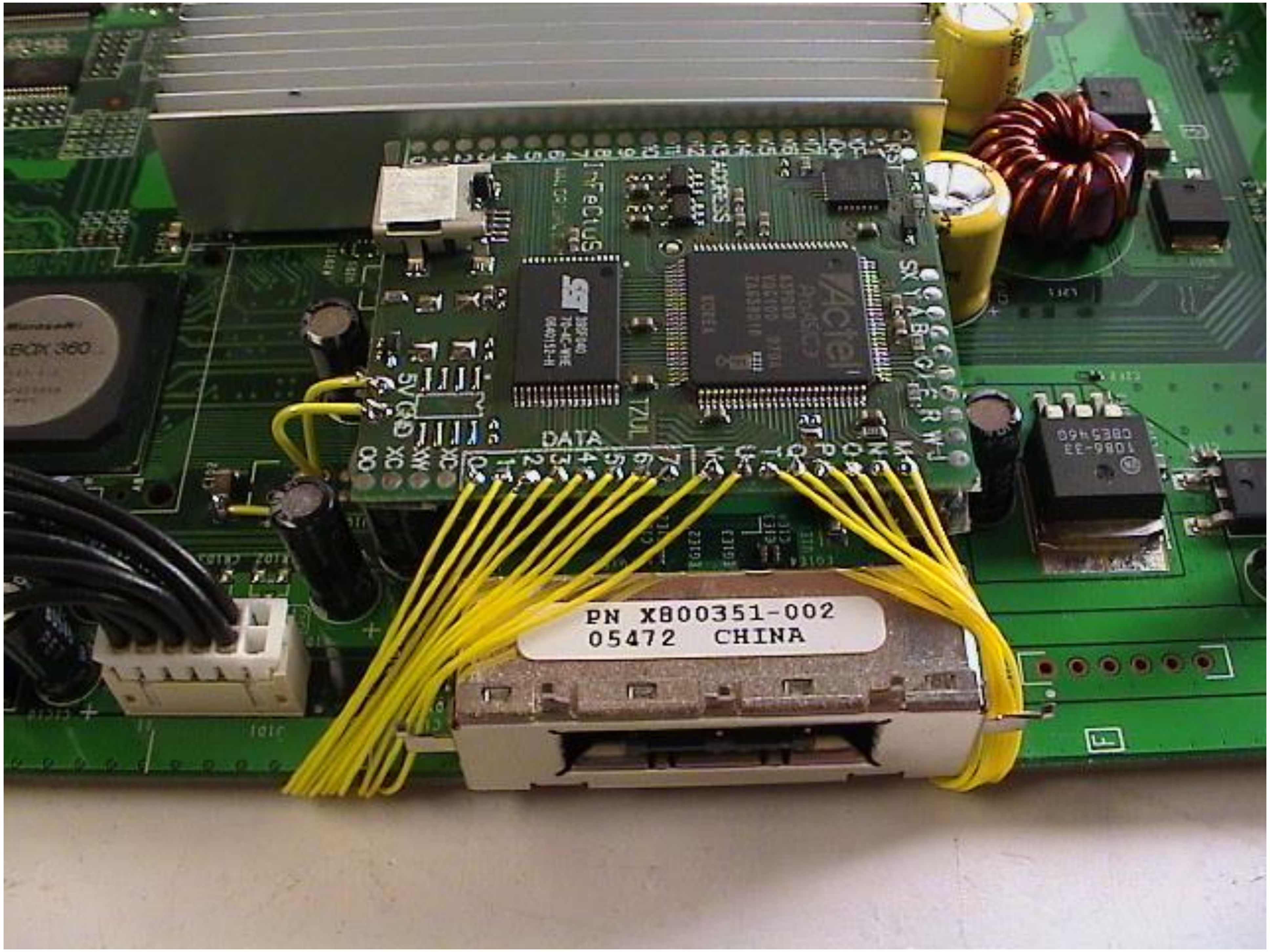
16. Timing attacks

- May allow guessing much faster than brute-force
- Typical on compare (HMAC)
- Hash calculated with symmetric key is stored with firmware. Boot calculates same and compares (20 bytes)
- memcmp has different timing if byte is correct or wrong
- Example: Xbox 360
- http://beta.ivc.no/wiki/index.php/Xbox_360_Timing_Attack

Mitigation:

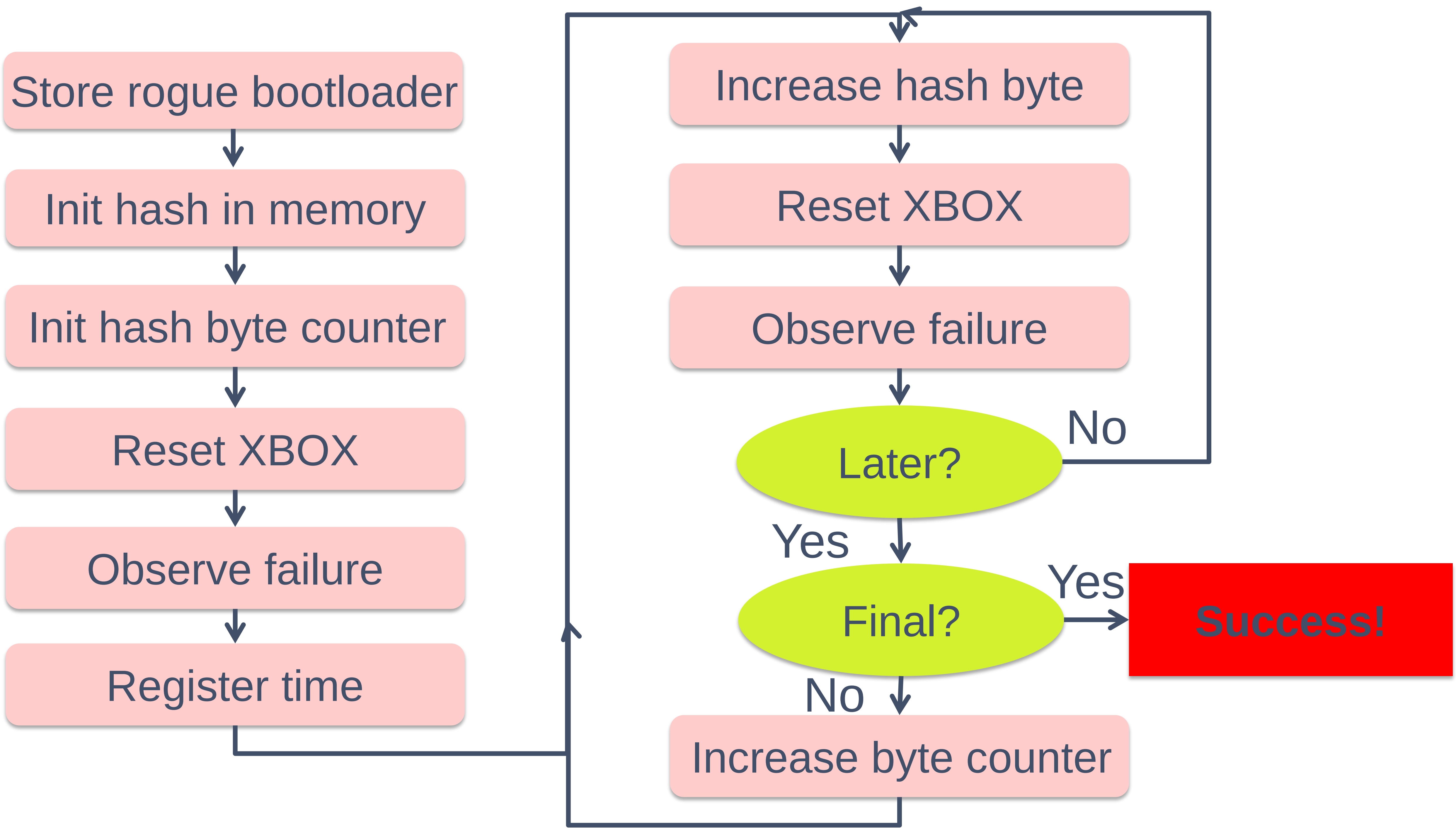
- Side channel leakage review
- http://www.riscure.com/benzine/documents/Paper_Side_Channel_Patterns.pdf

Timing attack with Infectus board



source: http://beta.ivancover.com

XBOX 360 timing attack procedure



Brute forcing 16*128 = 2048 values takes **about 2 hrs**

15. Glitch sensitivity

- Glitching is an effective way to subvert execution flow
- Examples of glitch sensitive coding:
  - using infinite loops
  - single comparisons (signature verification)
  - binary layout (return skipping)
  - using external memories
- Seldom a persistent attack; effective as stepping stone
- PS3: http://rdist.root.org/2010/01/27/how-the-ps3-hypervisor-was-hacked/
- XBOX 360: reset glitch attack: http://www.free60.org/Reset_Glitch_Hack

Mitigation:

- Fault injection review:
  http://www.riscure.com/benzine/documents/Paper_Side_Channel_Patterns.pdf

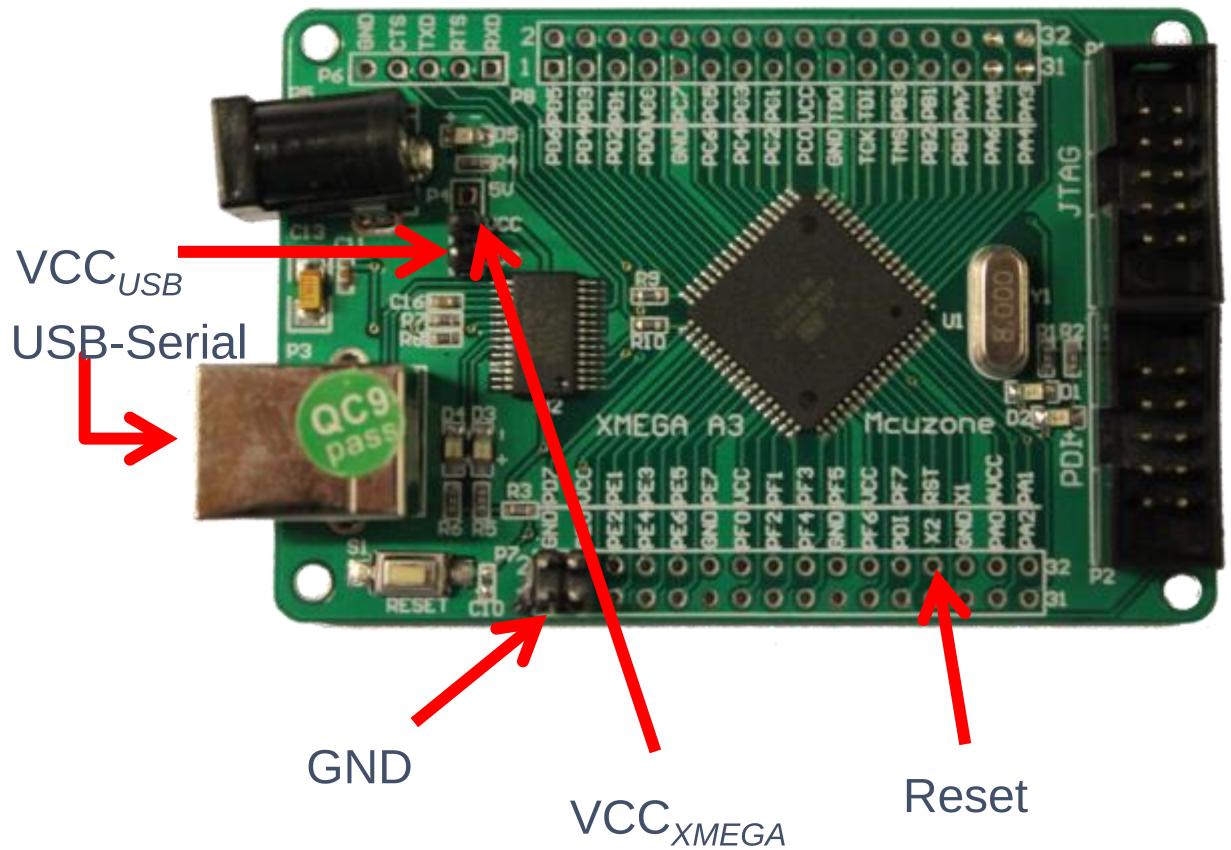
Examples of glitch sensitive code

```
                LDR        R1, =0xD0800
                BL         load_and_check
                MOV        R3, R0
                STR        R3, [R11,#var_C]
                LDR        R3, [R11,#var_C]
                CMP        R3, #0
                BGE        next

forever
                B          forever
; ---------------------------------------------------------------

next
                LDR        R0, =0x43DFE000
                MOV        R1, #0x2000
                BL         load_and_check
                MOV        R3, R0
                STR        R3, [R11,#var_C]
                LDR        R3, [R11,#var_C]
                CMP        R3, #0
                BGE        next2

forever2
                B          forever2
; ---------------------------------------------------------------

next2
                LDR        R0, =0x43DFDC00
                MOV        R1, #0x400
```

```
                BNE        nokey
                MOV        R0, R5
                BL         decrypt
                CMP        R0, #0
                BNE        enter
                MOV        R0, #0xD
                BL         fatal
; ---------------------------------------------------------------
                B          enter
; ---------------------------------------------------------------

nokey
                BL         check_checksum
                CMP        R0, #0
                BNE        enter
                MOV        R0, #0xF
                BL         fatal
; ---------------------------------------------------------------
                B          enter
; ---------------------------------------------------------------

bit10set
                BL         check_checksum
                CMP        R0, #0
                BNE        sig
                MOV        R0, #0xF
                BL         fatal
; ---------------------------------------------------------------

sig
                CMP        R4, #1
                BNE        enter
                MOV        R0, R5
                BL         check_sig
                CMP        R0, #0
                BNE        check_other_sig
                MOV        R0, #0xE
                BL         fatal
; ---------------------------------------------------------------
                B          enter
; ---------------------------------------------------------------
```

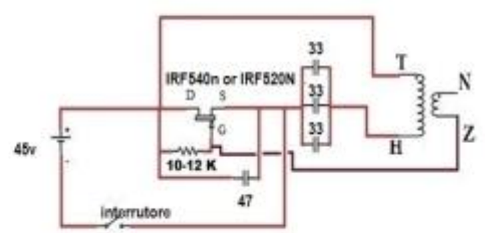
Glitch demo

- XMEGA target
- Fake secure boot implementation:
  - Mimics signature verification
  - Prints message
- Goal:
  Manipulate the target
  to failing the signature check
  and execute main code
- Method:
  - Electromagnetic Fault Injection



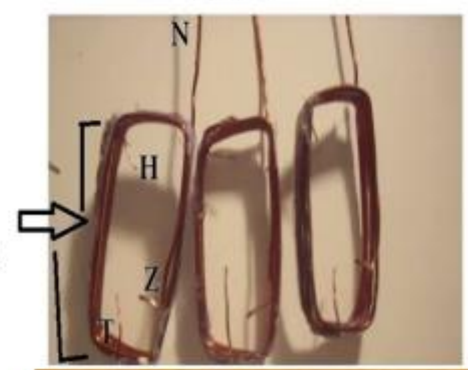
Is it a real attack?

- Slot machine EMP jammer



NB: la bobina H-T è avvolta su un lato della bobina Z-N

Bobina



FILO RAME 1,5mm Z - N 8 GIRI per una misura massima di 5cm X 3cm
FILO RAME 0.5mm H - T 80 giri come da immagine
3 CONDENSATORI DA 33pf 50v
1 CONDENSATORE DA 47pf 50V
IRF540N OPPURE USARE IRF 520N
1 INTERRUTTORE TIPO SWITCH
5 BATTERIE 9V
NB: ATTENZIONE: SE NON DOVESSE FUNZIONARE ELIMINARE LA RESISTENZA DA 10K

Slot machine EMP jamming

http://www.youtube.com/watch?v=dew0KD_-ypw

Code section

```
secure_boot = fake_signaturecheck();

if (secure_boot) {
     sprintf(counter_msg, "Secure booting!\n");
     for (i=0;counter_msg[i] != 0; i++) {
          serial_send(counter_msg[i]);
     }
} else {
     sprintf(counter_msg, "Insecure booting!\n");
     for (i=0;counter_msg[i] != 0; i++) {
          serial_send(counter_msg[i]);
     }
     while(1);
}

…
sprintf(counter_msg, "Lets go!\n");
```

Typical FI set up

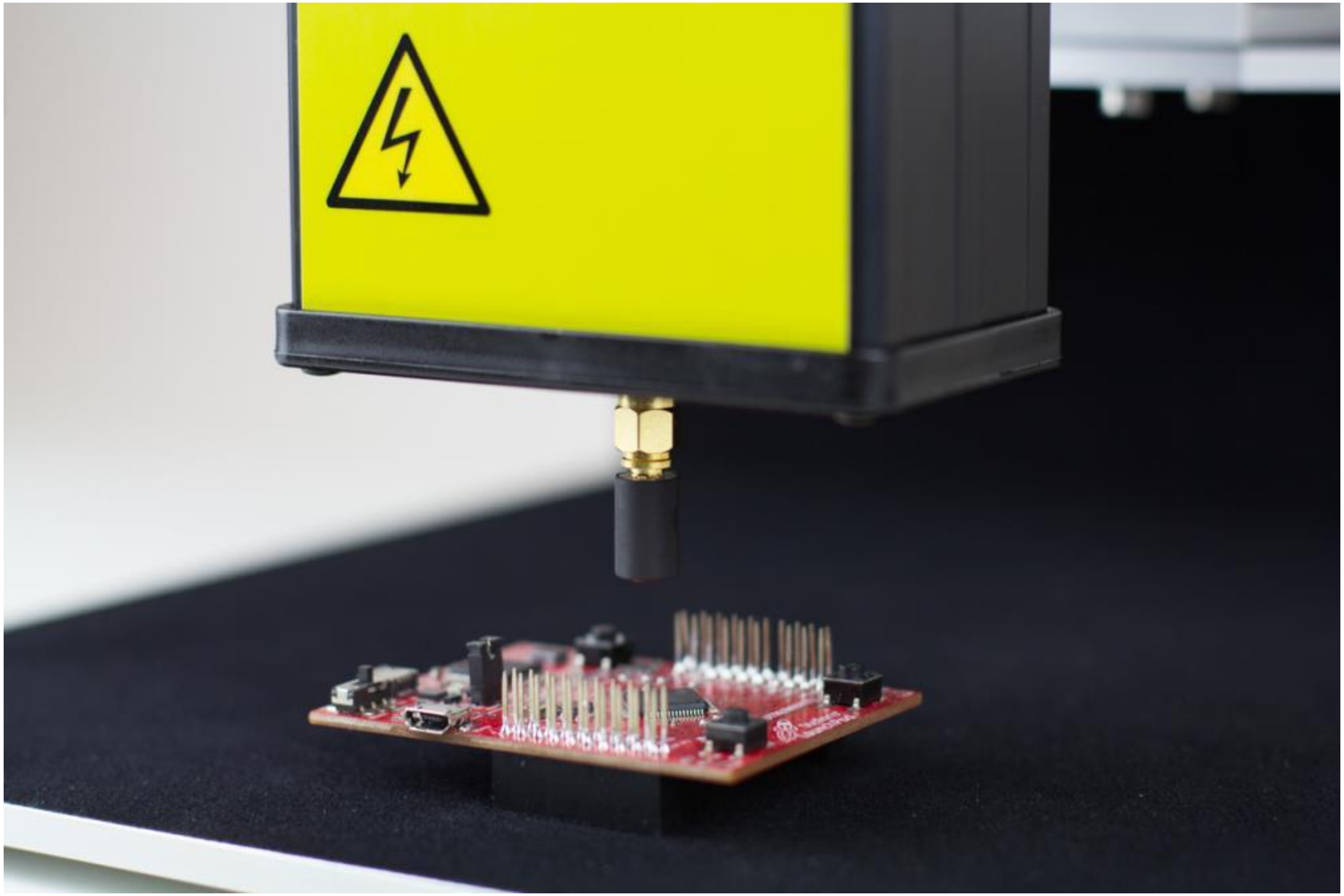
Configure

Data

Reset

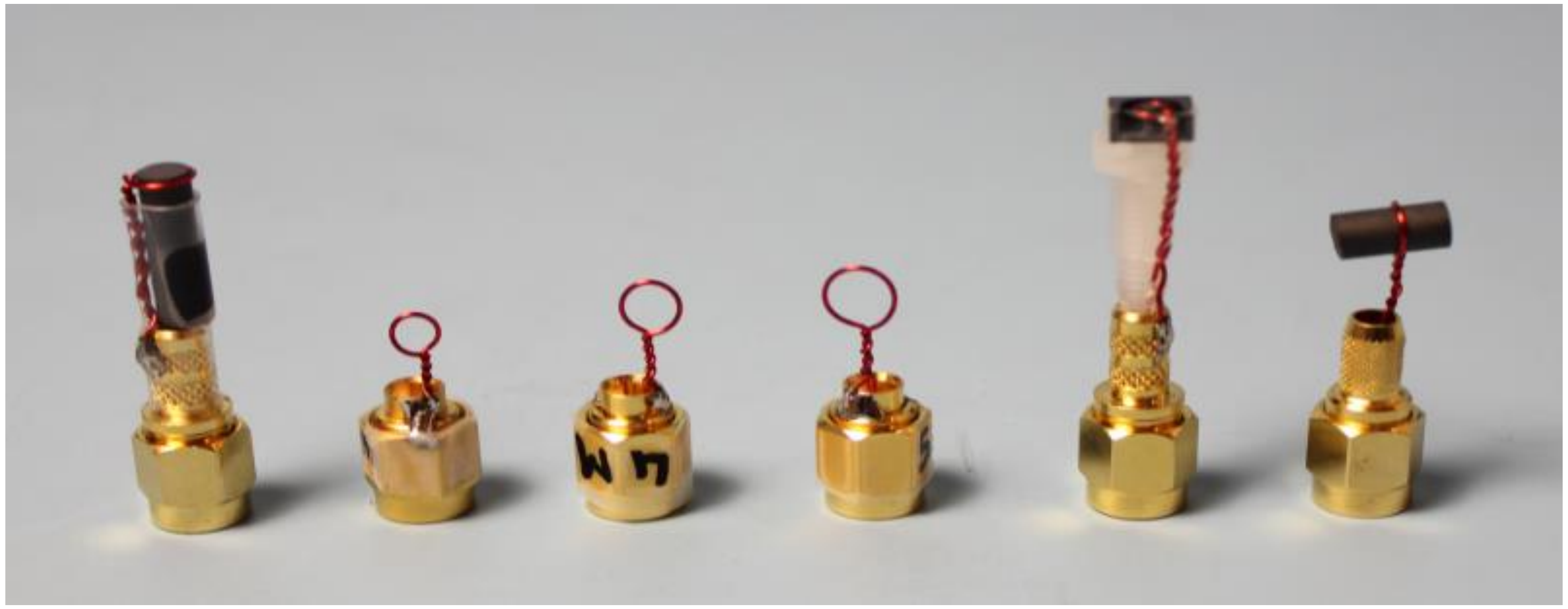
Inject Fault

EM-FI Transient Probe



Research probes

riscure



The EM-Probes from left to right: Probe 1, 2.3, 2.4, 2.5, 3, and 4

Probe Name	Description
Probe 1	Horizontal coil, 4mm diameter, ferrite core
Probe 2.3	Vertical coil, 3mm diameter, no core
Probe 2.4	Vertical coil, 4mm diameter, no core
Probe 2.5	Vertical coil, 5mm diameter, no core
Probe 3	Horizontal coil, 4mm diameter, EP5 ferrite core
Probe 4	Vertical coil, 4mm diameter, ferrite core

DEMO

Logical threats

13. Design mistakes

- Making wrong assumptions or adding risky features

Examples:

- Empty signature is accepted as good
- One flag means: no signing necessary
- Early removal of signature: iPhone 2G,3G (2008)
- http://theiphonewiki.com/wiki/Pwnage

Mitigation:

- Design review / Implementation review

12. Accessibility of boot ROM after boot

- Having access to the binary code of a boot rom allows detailed analysis
- Useful for:
  - Logical attacks
  - Locating glitch points
- Value is difficult to quantify:
  - Also in closed ROMs bugs are found
  - Breakthrough in some cases was clearly delayed
- Examples: original Xbox, iPhone, etc.

Mitigation:

- Disable ROM access (when leaving ROM execution)
- Execute-only ROM (less secure, hard to use)

11. Crypto sanitization

- After the boot code uses cryptographic engines they may become available for generic code
- State can be reused, registers may be read
- Attack: create more signatures, decrypt/encrypt more code

Mitigation:

- Clear key and data registers of crypto engines and any other memory used for storing sensitive data
- Better too much than too little

10. Firmware Upgrade / Recovery flaws

- Important feature to mitigate flaws in the field
- Don’t worry about the firmware update, but worry about the mechanism itself
- Updated firmware should follow same rules as installed fw

Examples:

- Many phone and game lock-down mechanisms subverted

Mitigation:

- Limit the functionality!
- Prevent rollback: can negate fixes
- Better to have ‘debug upgrade’ than debug built-in

9. Relying on unverified code

- Typical example: verified (ROM) code copied to RAM and used later
- Runtime flaws can lead to code modification before use

Examples:

- iPhone: http://rdist.root.org/2008/03/17/apple-iphone-bootloader-attack/
- SamyGo.tv:
  RSA disabler application (2010)

Source: http://forum.samygo.tv

Mitigation:

- Using a single instance of critical code is good; do not copy but execute in place (ROM)

8. Service backdoor / password

- Everyone understands this can be bad
- More often: "It is bad, but not for my application"
- And then later the application requirements change
- Strong solutions require significant infrastructure

Examples:

- Many car tuning ECU cables/software
- 'Magic' authentication allows
  firmware mods, changing car keys, mileage

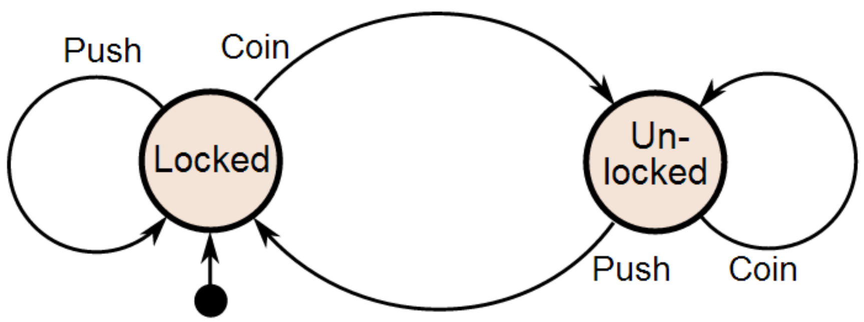
Mitigation:

- Depends on use case
- Make use of connected world to improve possibilities

Typical bootloader screens

7. State errors

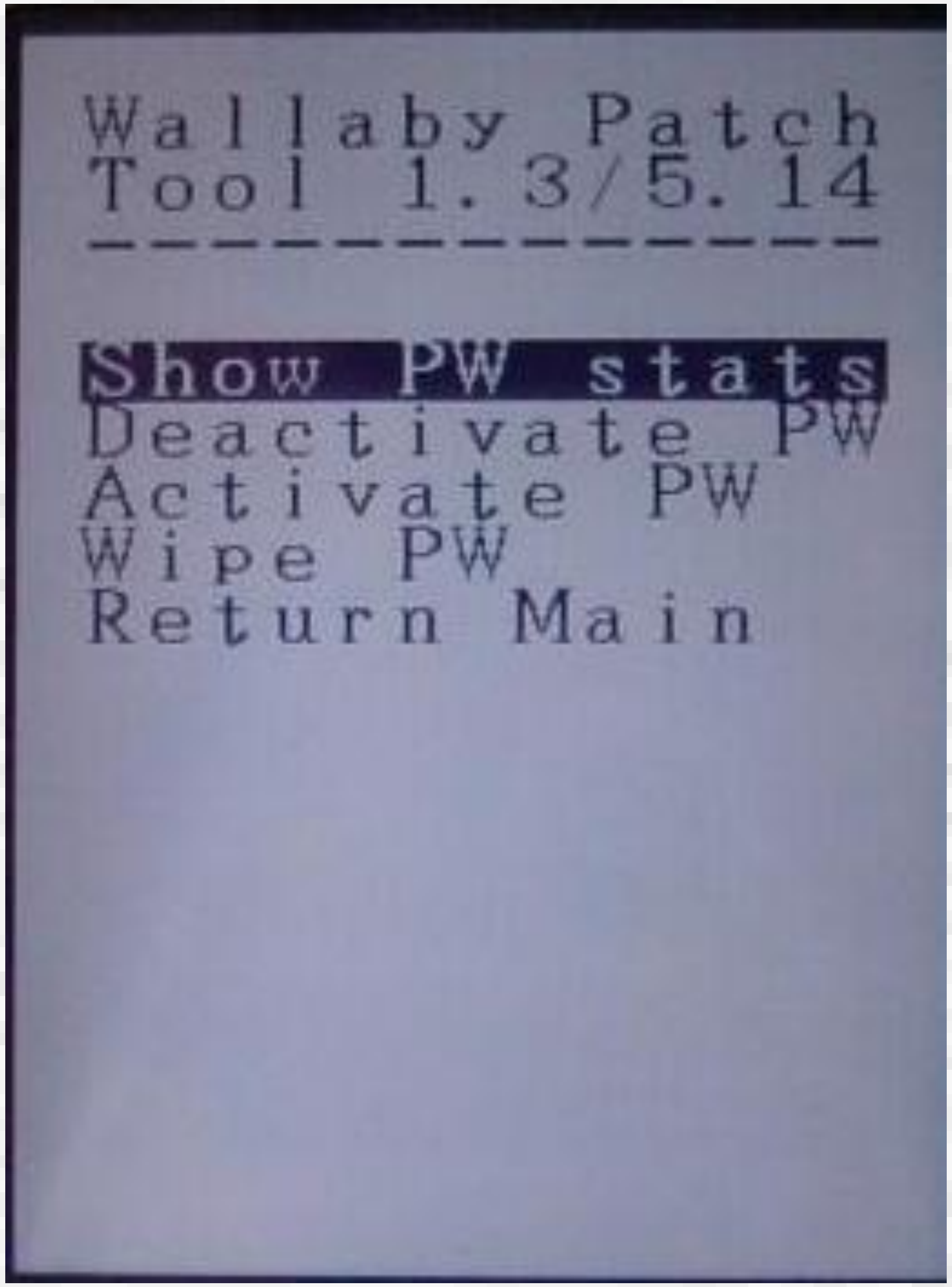
- Where is state stored?
- How can a state sequence be influenced?
- Suspend/resume example:
  State is stored insecurely, which allows a local exploit to subvert the boot process on resume
  → maximum privilege escalation

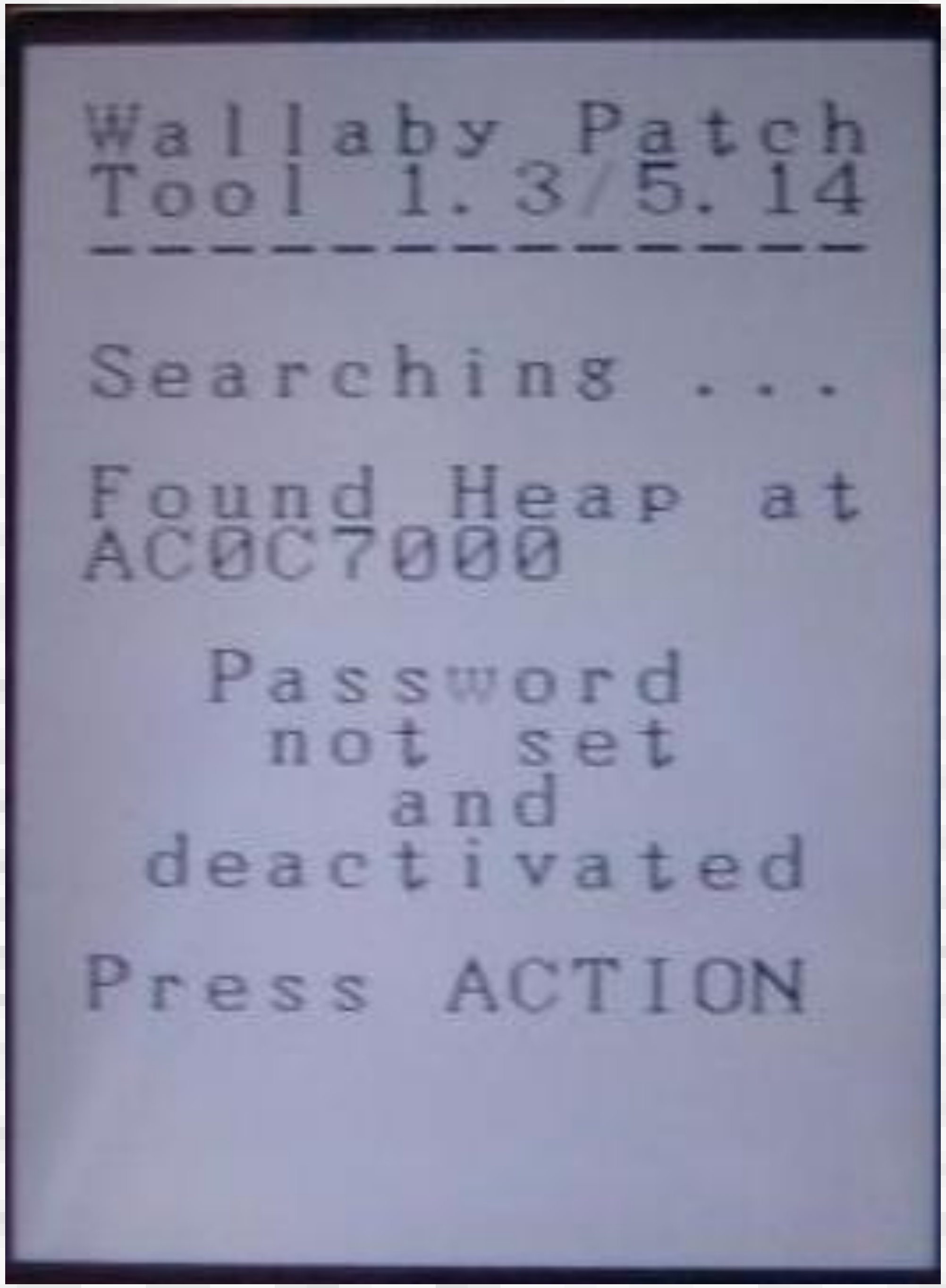


Mitigation:

- Analyze all state variables in the boot sequence (exception handling, suspend/resume, storage, integrity)
- Consider both logical and fault injection threats

Custom boot loader menu





6. Driver weaknesses

- Boot code has several functions:
  - Boot from different media including file system (USB, SD, MMC, UART, NOR, NAND, SPI)
  - Ensure fall back and restore mechanisms
  - Perform parsing of firmware image formats
- Input parsing problems can lead to overflows, integer sign problems, etc. etc.
- Example: iPhone exploits
- http://theiphonewiki.com/wiki/Usb_control_msg(0xA1,_1)_Exploit
- http://theiphonewiki.com/wiki/Limera1n_Exploit
- http://theiphonewiki.com/wiki/SHA-1_Image_Segment_Overflow

Mitigation:

- Code review, fuzzing,
- Limiting functionality to bare minimum, code reuse

5. ROM patching functionality

- Desired for maximum in-field updatability
- Hook based techniques
- Can act as a boomerang
- Used in smart cards both for security fixes as exploitation

Source: http://www.innoozest.com

Mitigation:

- Don't use it?
- If you need it, think again how to limit attacker possibilities

4. Decryption ≠ Authentication

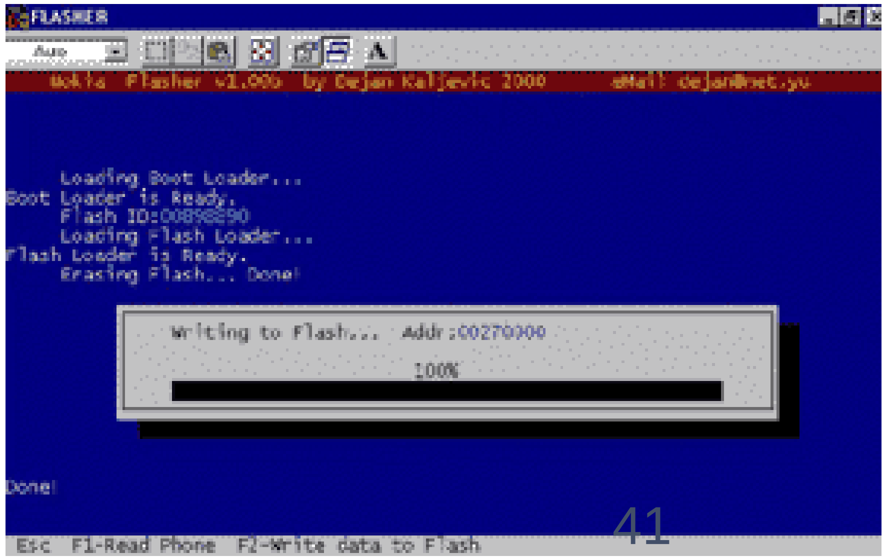
- Some schemes add encryption of boot code
- Some misinterpret this for authentication / integrity
- ECB, CBC mode all allow small changes

Example:

- Nokia DCT4 2nd stage loader u_2nd.fia could be patched to load unencrypted 3rd stage
- http://www.dejankaljevic.org/download/dct4_rd.zip 2002/2005

Mitigation:

- Always verify authenticity
- First verify, then decrypt



3. Inappropriate signing area

- If anything is left unsigned, what can it be used for?

Examples:

- iPhone 3GS, Samsung Galaxy S4
- http://theiphonewiki.com/wiki/0x24000_Segment_Overflow
- http://blog.azimuthsecurity.com/2013/05/exploiting-samsung-galaxy-s4-secure-boot.html

Mitigation:

- Do not use headers, pointers, addresses without/before checking authenticity

2. Key management

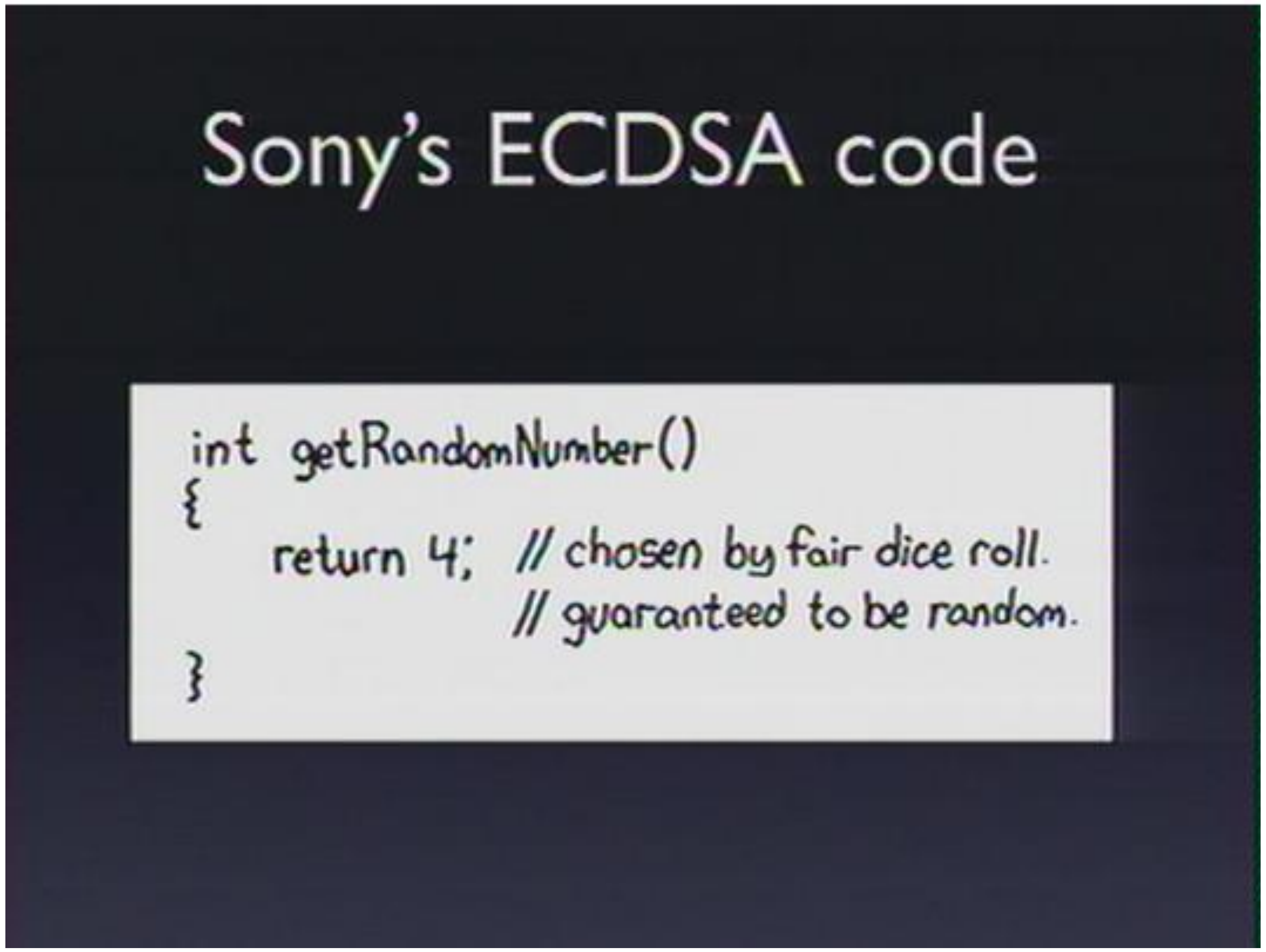
- Disclosing signing keys
- Also:
  Signing development boot loaders with production keys
- Last year: we identified issue with a device in the field
- Vendor currently working on mitigation

Mitigation:

- Starting from the first key you create, implement proper key management: storage, access, lifetime, revocation
- Provide for test keys and test devices to limit exposure

1. Weak signing keys/methods

PS3 Epic Fail



Source: http://events.ccc.de/congress/2010
Console Hacking 2010

1. Weak signing keys/methods

- Know and understand the weaknesses of the algorithms and protocols used

Examples:

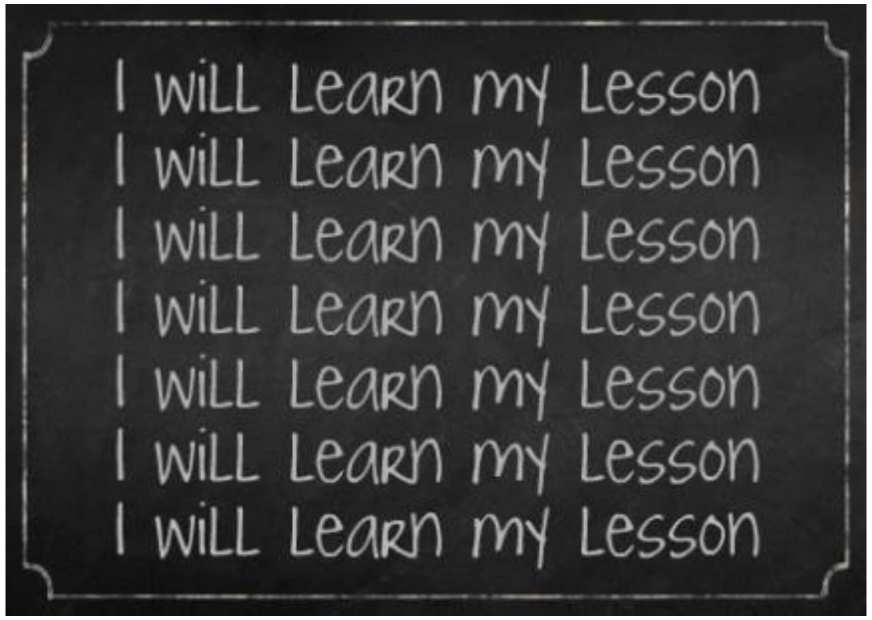
- RSA small exponent signature verification
- PS3 ECDSA signatures with same ‘random’
- http://events.ccc.de/congress/2010/Fahrplan/events/4087.en.html

Mitigation:

- Cryptographic review

Parting thoughts

- The purpose and function determine what is a sufficiently strong implementation
- High security applications need to consider many aspects including side channel and fault injection attacks
- But: proper design principles go a long way
- Learn your lessons from the past
- And pay attention to detail…



Source: http://www.jeffalytics.com

Challenge your security

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