riscure

Fault Injection Attacks on Secure Boot

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April 13, 2017

Agenda

Practicalities

Fault injection

Bypasses

Mitigations

Secure boot

__Disclaimer:__ we are not talking about UEFI Secure Boot!

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Albert & Niek

- Security Analysts
- Security testing of different products and technologies

Riscure

- Services (Security Test Lab)
  - Hardware / Software / Crypto
  - Embedded systems / Smart cards
- Tools
  - Side channel analysis (passive)
  - Fault injection (active)

This talk shows a bit of both...

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A fault injection definition...

”Introducing faults in a target to alter its intended behavior.”

```
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if( key_is_correct ) <-- Glitch here!
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  open_door();
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How can we introduce these faults?

Fault injection techniques[1]

clock voltage e-magnetic laser

Source: http://www.limited-entropy.com/fault-injection-techniques/

[1] The Sorcerers Apprentice Guide to Fault Attacks. – Bar-El et al., 2004

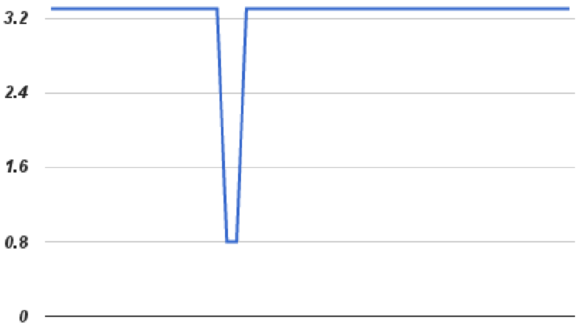
Fault injection techniques[1]

clock

voltage

e-magnetic

laser



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Type of faults

Faults that affect hardware

- Registers
- Buses

Faults that affect hardware that does software[2] [3] [4]

- Instruction corruption

```
mov r0, r1   11100001101000000000000000000001
mov r0, r3   11100001101000000000000000000011
```

- Instruction skipping

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Is this useful?

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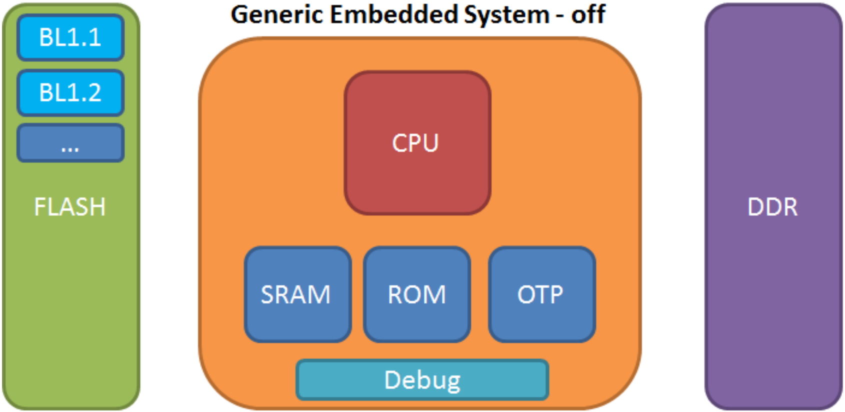
Secure boot



Generic Embedded System - off

BL1.1

BL1.2

...

FLASH

CPU

SRAM

ROM

OTP

Debug

DDR

Remarks

- Integrity and confidentiality of flash contents are not assured!
- A mechanism is required for this assurance: **secure boot!**

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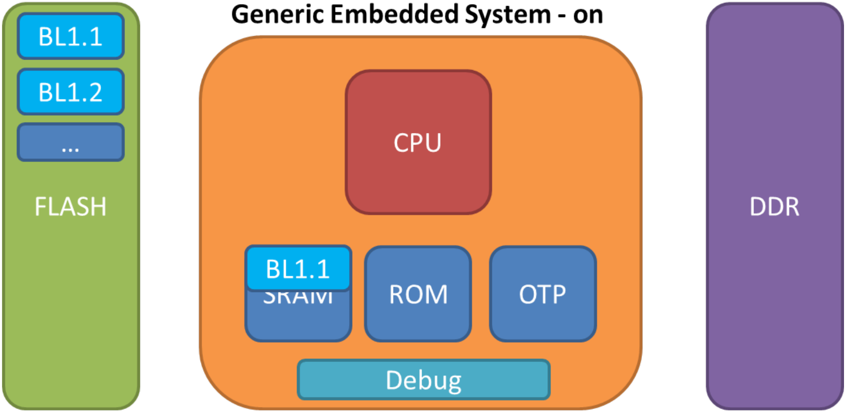

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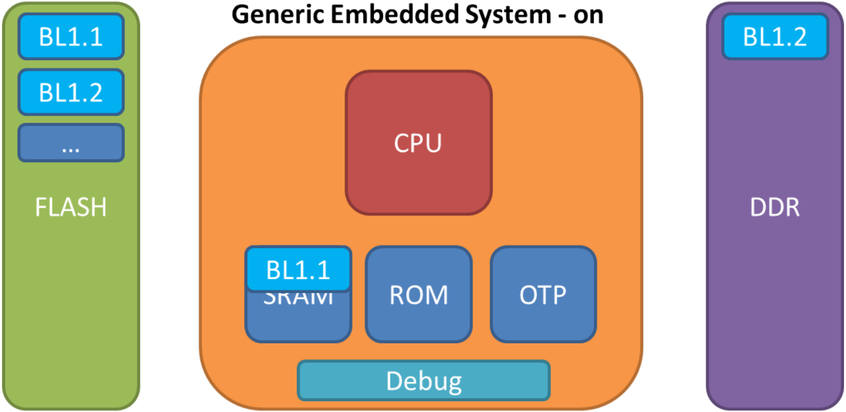

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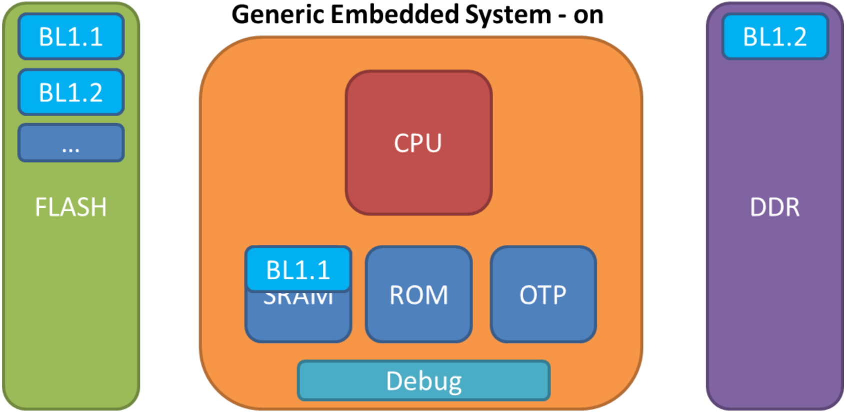

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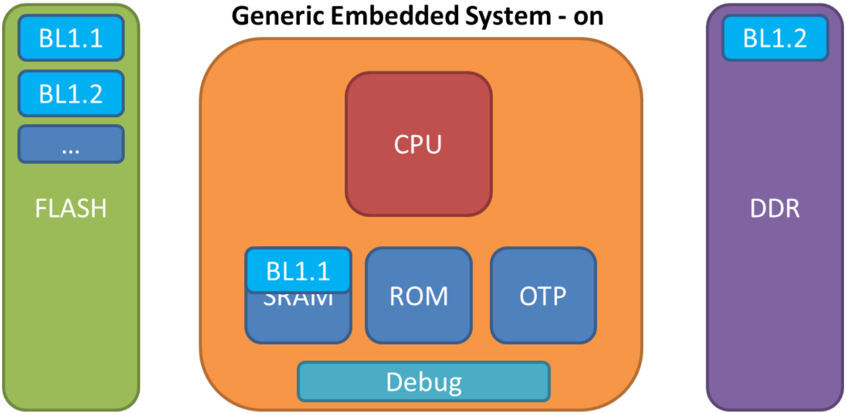

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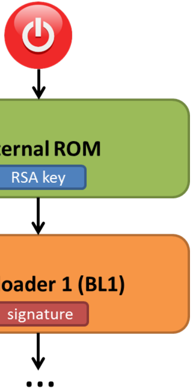
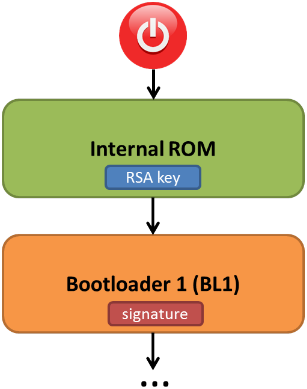


- Assures **integrity** (and **confidentiality**) of flash contents
- The **chain of trust** is similar to PKI[5] found in browsers
- One **root of trust** composed of immutable code and key

[5] Public Key Infrastructure

Secure boot



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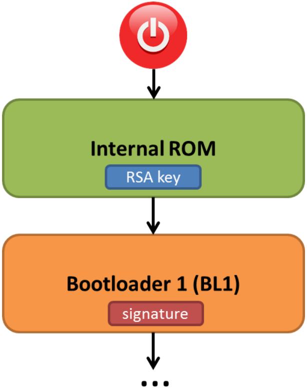

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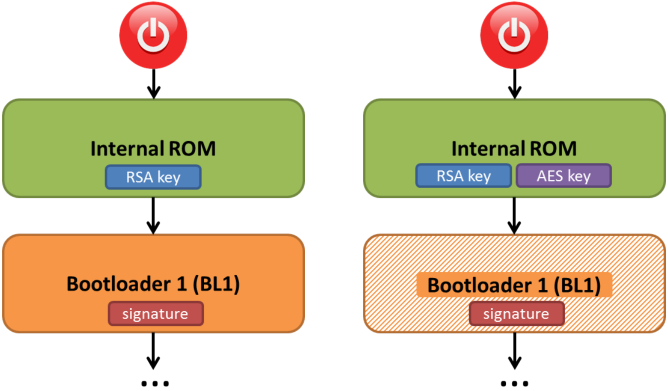

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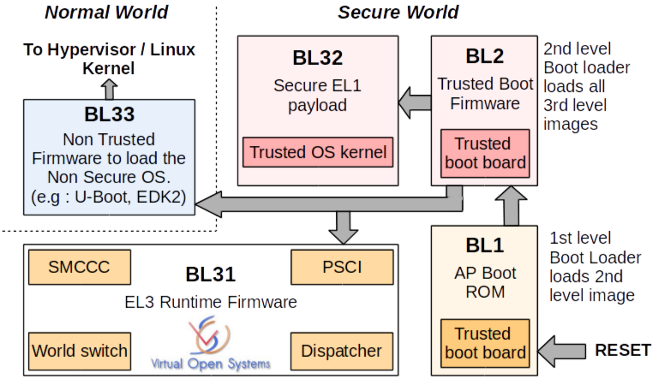

Normal World

Secure World

To Hypervisor / Linux Kernel

BL33

Non Trusted Firmware to load the Non Secure OS. (e.g : U-Boot, EDK2)

BL32

Secure EL1 payload

Trusted OS kernel

BL2

Trusted Boot Firmware

Trusted boot board

2nd level Boot loader loads all 3rd level images

BL31

EL3 Runtime Firmware

SMCCC

PSCI

World switch

Dispatcher

BL1

AP Boot ROM

Trusted boot board

1st level Boot Loader loads 2nd level image

RESET

Key

EL3 Execution

Secure EL1 Execution

Normal EL2/EL1 Execution

Glossary

EDK2 – EFI Development Kit 2
EL – Exception Level
PSCI – Power State Control Interface
BL – Boot Loader
SMC – Secure Monitor Call

Source: http://community.arm.com/docs/DOC-9306

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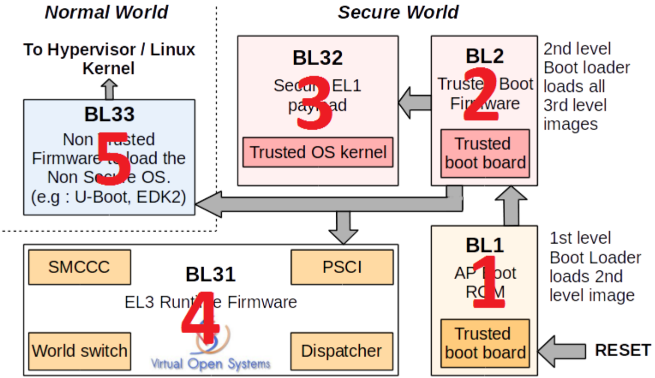

Key

- EL3 Execution
- Secure EL1 Execution
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Why use a hardware attack?

”Logical issues exist in secure boot implementations!!?”

Bootloader vulnerabilities

- S5L8920 (iPhone)[6]
- Amlogic S905[7]

However

- A small code base results in a small logical attack surface
- Implementations without vulnerabililties likely exist

Other attack(s) must be used when not logically flawed!

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Why (not) fault injection on secure boot?

Cons

- Invasive
- Physical access
- Expensive

Pros

- No logical vulnerability required
- Typical targets not properly protected

*Especially **relevant** when **assets** are **not available** after boot!*

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Typical assets

Secure code

- Boot code (ROM[8])

Secrets

- Keys (for boot code decryption)

Secure hardware

- Cryptographic engines

[8] Read Only Memory

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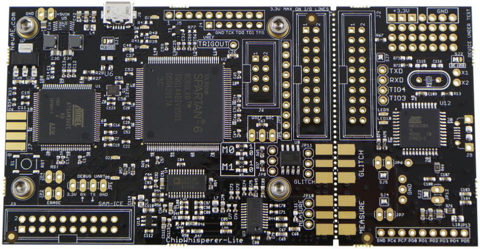
Open source tooling

ChipWhisperer



By NewAE Technology Inc. [9] [10]

[9] https://wiki.newae.com/CW1173_ChipWhisperer-Lite

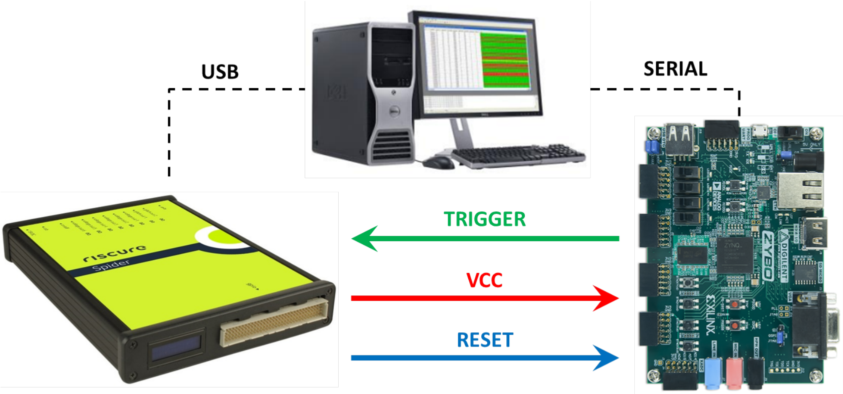
[10] https://www.youtube.com/watch?v=TeCQatNcF20

Commercial tooling

By Riscure[11]

[11] https://www.riscure.com/security-tools/hardware/spider

Fault injection setup



USB

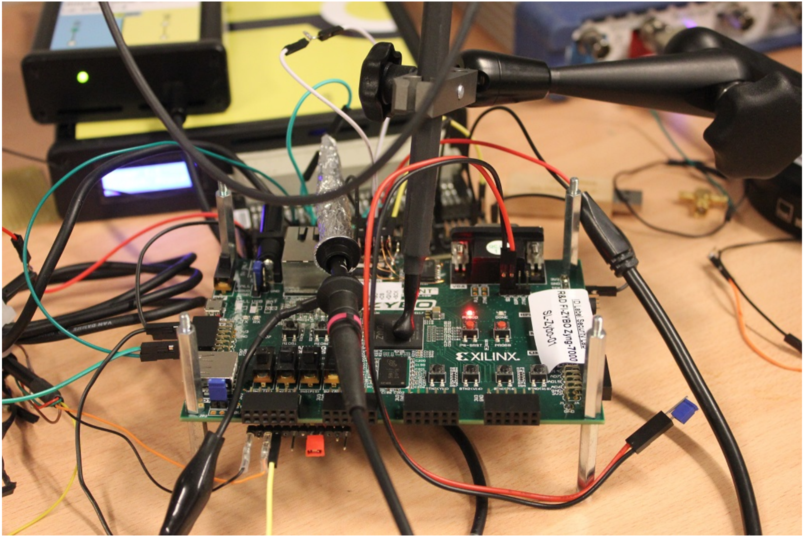
SERIAL

TRIGGER

VCC

RESET

In real life...


ID Labs Security Lab
R&D FI-ZYBO Zynq-7000
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XILINX
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That was the introduction ...

... let’s bypass secure boot!

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Hash comparison

- Applicable to all secure boot implementations
- Bypass of authentication

```
if( memcmp( p, hash, hashlen ) != 0 )
    return( MBEDTLS_ERR_RSA_VERIFY_FAILED );

p += hashlen;

if( p != end )
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Source: `https://tls.mbed.org/`

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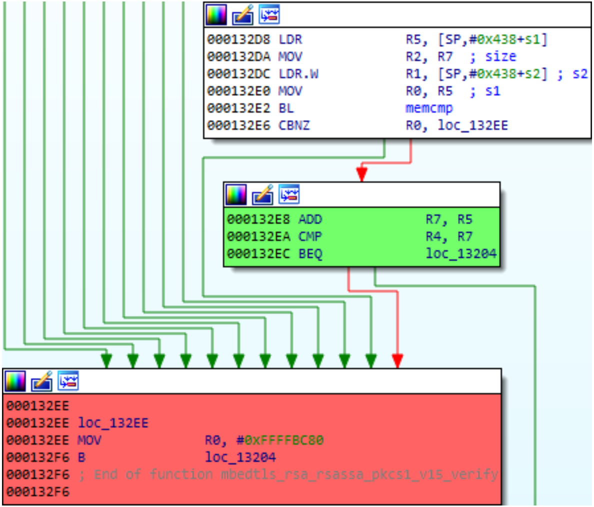

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000132E2 BL              memcmp
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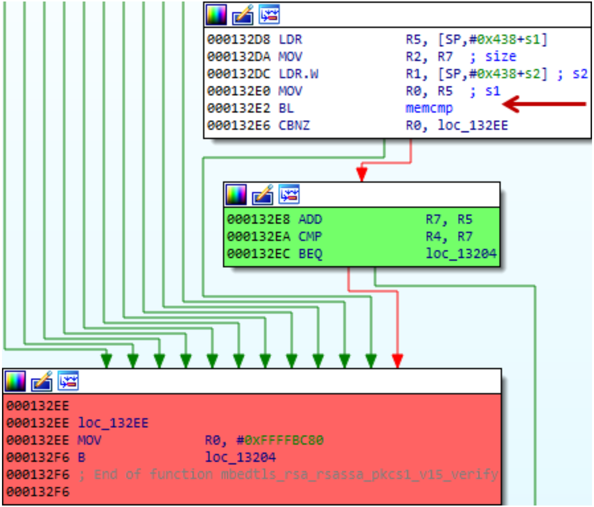
000132EC BEQ             loc_13204
```

```
000132EE
000132EE loc_132EE
000132EE MOV             R0, #0xFFFFBC80
000132F6 B               loc_13204
000132F6 ; End of function mbedtls_rsa_rsassa_pkcs1_v15_verify
000132F6
```

Multiple locations bypass the check with a single fault!

Hash comparison



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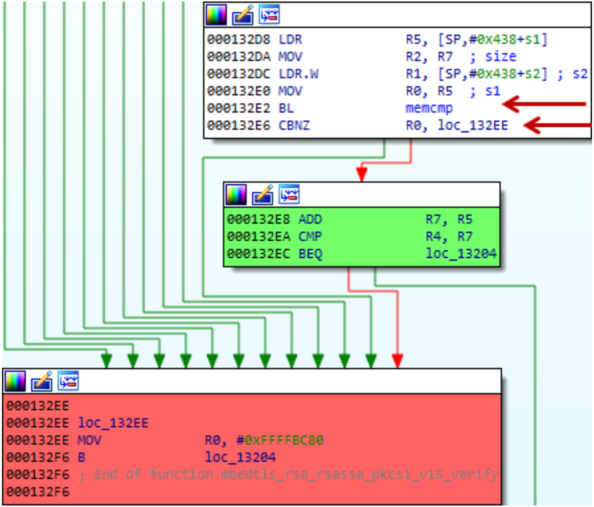

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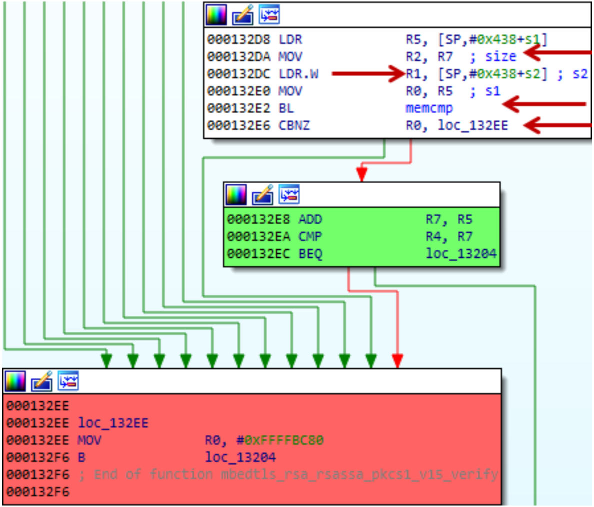

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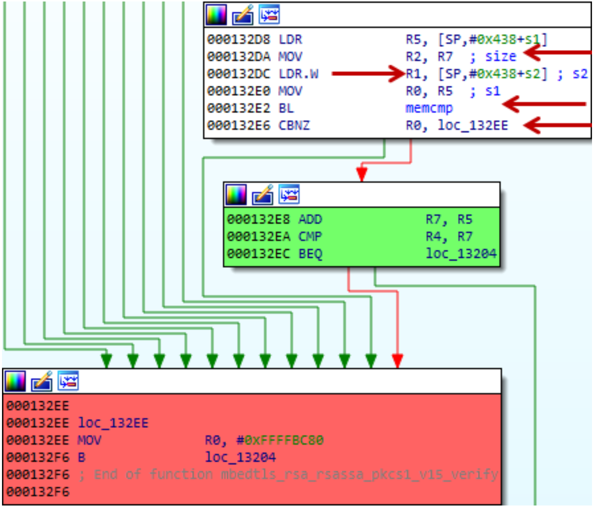

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Multiple locations bypass the check with a single fault!

Signature check call

```
/* glitch here */
if(mbedtls_pk_verify(..., hash, signature, ...)) {
  /* do not boot up the image */
  no_boot();
} else {
  /* boot up the image */
  boot();
}
```

Remarks

- Bypasses can happen on all levels
- Inside functions, inside the calling functions, etc.

Signature check call

```
/* glitch here */
if(mbedtls_pk_verify(..., hash, signature, ...)) {
  /* do not boot up the image */
  no_boot();
} else {
  /* boot up the image */
  boot();
}
```

Remarks

- Bypasses can happen on all levels
- Inside functions, inside the calling functions, etc.

Signature check call

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- Bypasses can happen on all levels
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Infinite loop

- What to do when the signature verification fails?
- Enter an infinite loop!

```
/* glitch here */
if(mbedtls_pk_verify(..., hash, signature, ...)) {

  /* do not boot up the image */
  while(1);

} else {

  /* boot up the image */
  boot();
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```

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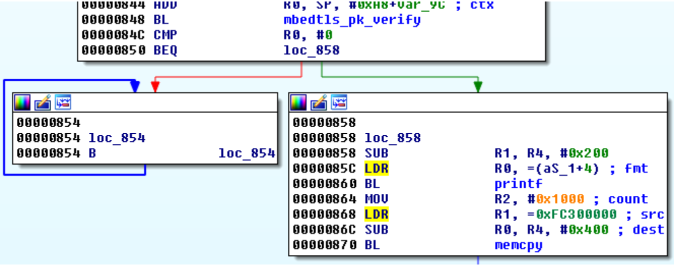

```
00000844 ADD                R0, SP, #0xA8+var_9C ; ctx
00000848 BL                 mbedtls_pk_verify
0000084C CMP                R0, #0
00000850 BEQ                loc_858
```

```
00000854
00000854 loc_854
00000854 B                  loc_854
```

```
00000858
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00000858 SUB                R1, R4, #0x200
0000085C LDR                R0, =(aS_1+4) ; fmt
00000860 BL                 printf
00000864 MOV                R2, #0x1000 ; count
00000868 LDR                R1, =0xFC300000 ; src
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Remarks

- Timing is not an issue!
- Classic smart card attack [12]
- Better to reset or wipe keys

[12] https://en.wikipedia.org/wiki/Unlooper

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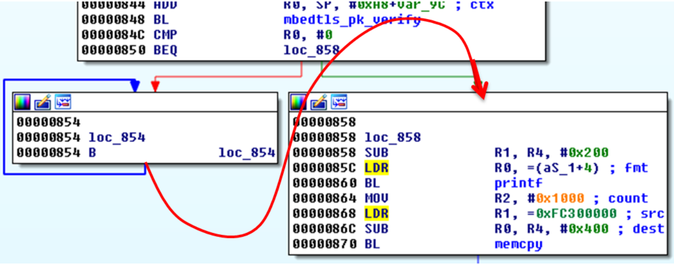

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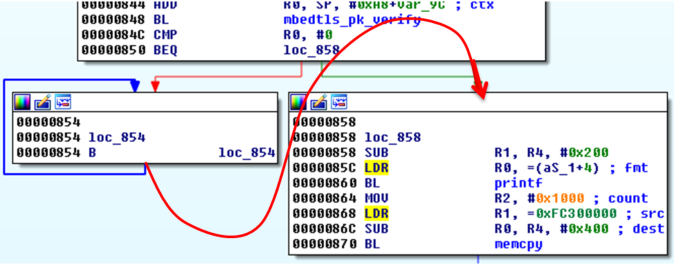

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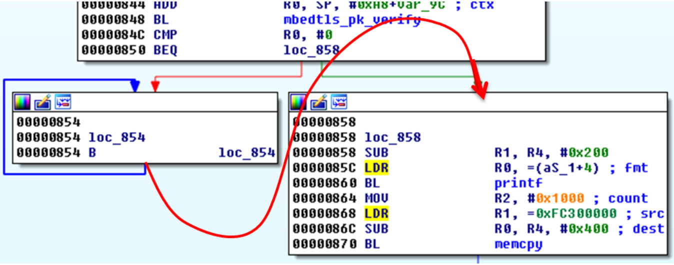

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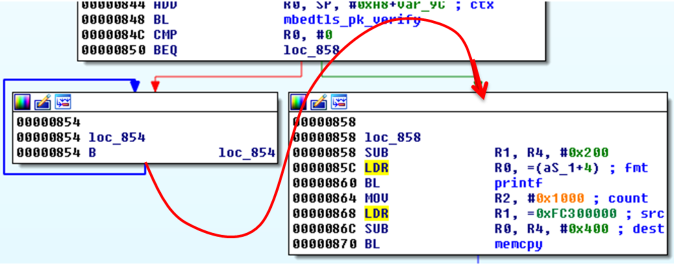

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Hardware countermeasures [13] [14]

- Detect the glitch or fault

Software countermeasures [15]

- Lower the probability of a successful fault
- Do not address the root cause

*You can **lower the probability** but not rule it out!*

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Combined Attacks

Those were the classics and their mitigations ..

... the attack surface is larger![16]

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Combined attack: Copy

- Introducing logical vulnerabilities using fault injection
  - Build your own buffer overflow!
- Easy approach: change *memcpy* the size argument

Before corruption

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memcpy(dst, src, 0x1000);
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After corruption

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memcpy(dst, src, 0xCEE5);
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Remark

- Works when dedicated hardware is used (e.g. DMA[17] engines)

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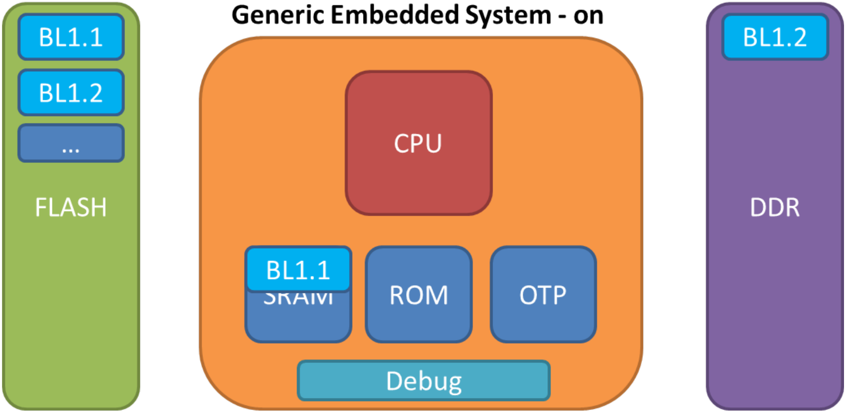

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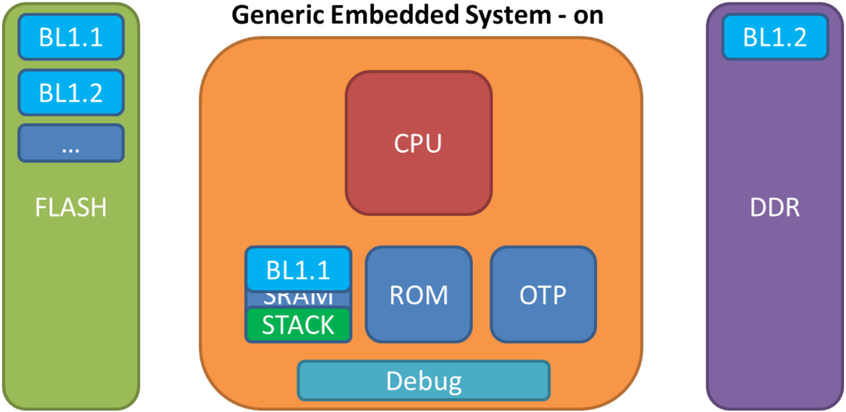

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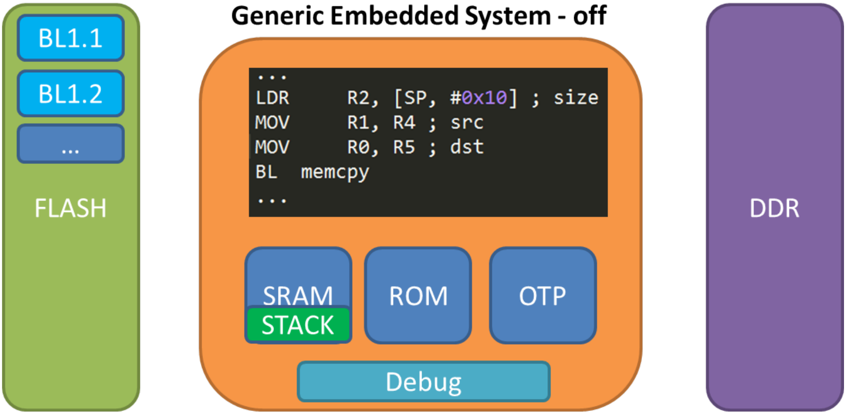

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...
LDR     R2, [SP, #0x10] ; size
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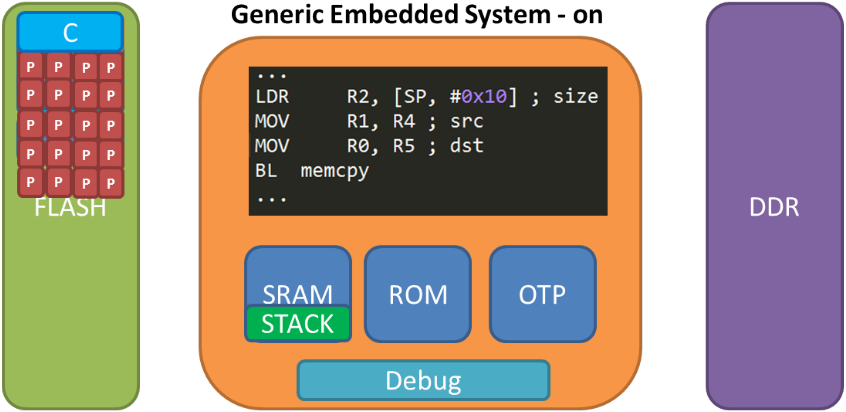

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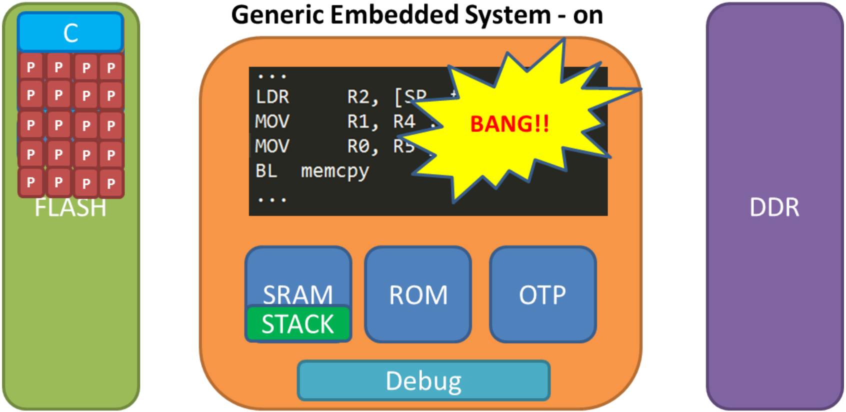

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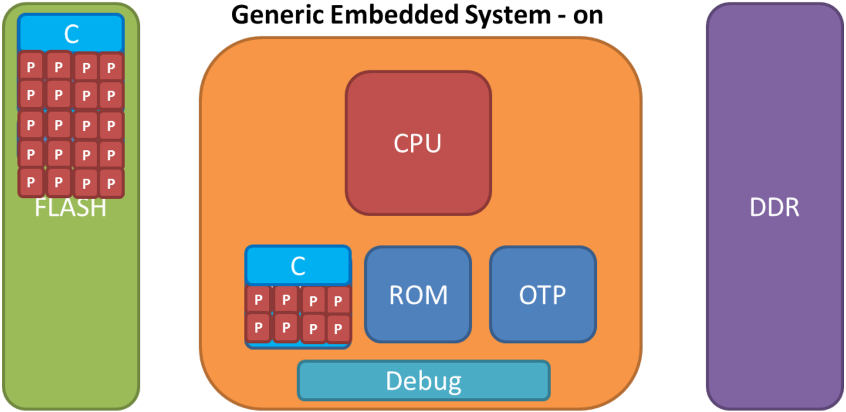

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Combined attack: Wild jungle jump[18]

- Start glitching while/after loading the image but before decryption
- Lots of ’magic’ pointers around, which point close to the code
- Get them from: stack, register, memory
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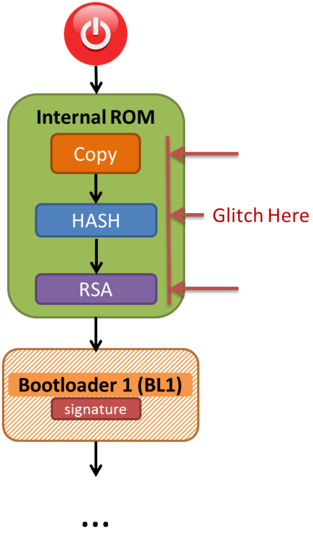

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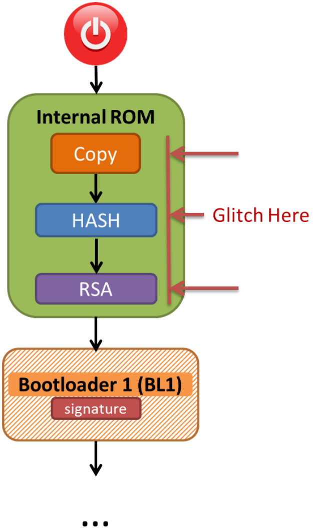

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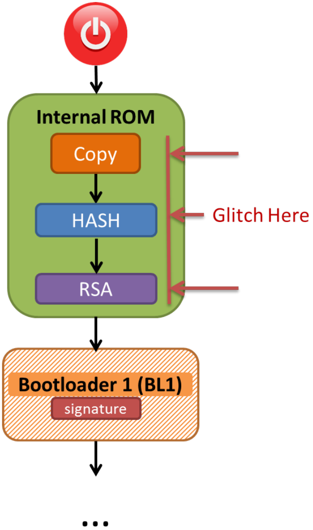

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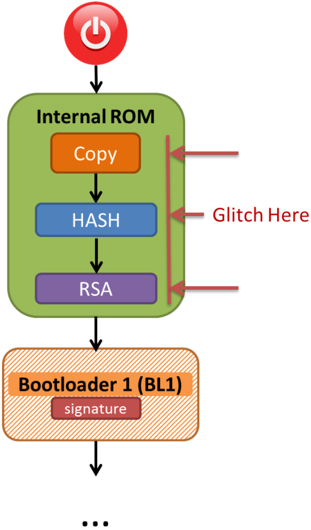

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- Typically little software exploitation mitigation during boot
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Today's standard technology not resistant to fault attacks

Minimize attack surface

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- Minimize code size of boot stages
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Lower the probability

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