USB ARMORY RELOADED

Andrea Barisani – Head of Hardware Security

F-Secure

$ whoami

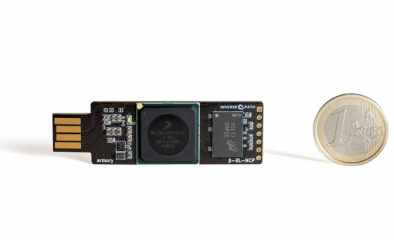
Andrea "lcars" Barisani

I am a 

Founder of INVERSE PATH now part of 

Breaking things since I got my first 

Securing  and much more since 2005.

Maker of the USB armory 

Speaker and trainer at BlackHat, CanSecWest, DEFCON, Hack In The Box, PacSec conferences among many others.

https://andrea.bio | @andreabarisani

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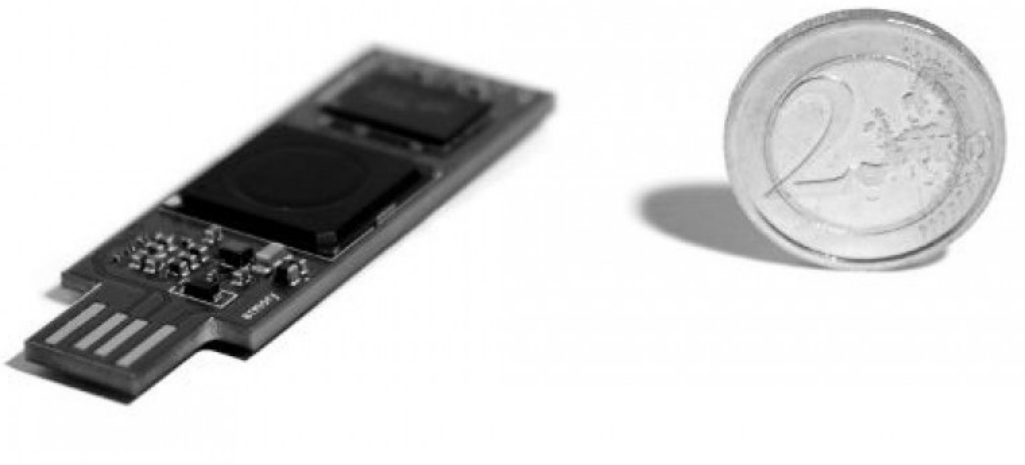
Inverse Path Announce Armory SoC Project

posted on OCTOBER 3, 2014 by L33TDAWG



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The USB armory runs Linux and is a personal server designed for security applications:

Password manager
Encrypted storage
Authentication token
Cryptocurrency wallet
Secure messaging
Hardware Security Module

Customers range from individual security researchers, security companies to large enterprises and government entities.

USB armory Mk I

F-Secure

One of the smallest SBC in the world, met with outstanding demand from security researchers, businesses, OEMs, integrators and security companies.

The good stuff…

It wasn't easy to fill the support gap left by NXP, but we did it until we hit the actual hardware and this resulted in several OSS contributions.

Form factor, priority on security and transparency, the incredible projects and use cases we never dreamed of.

Great research platform for all things (e.g. TrustZone).

MacGyver Armory

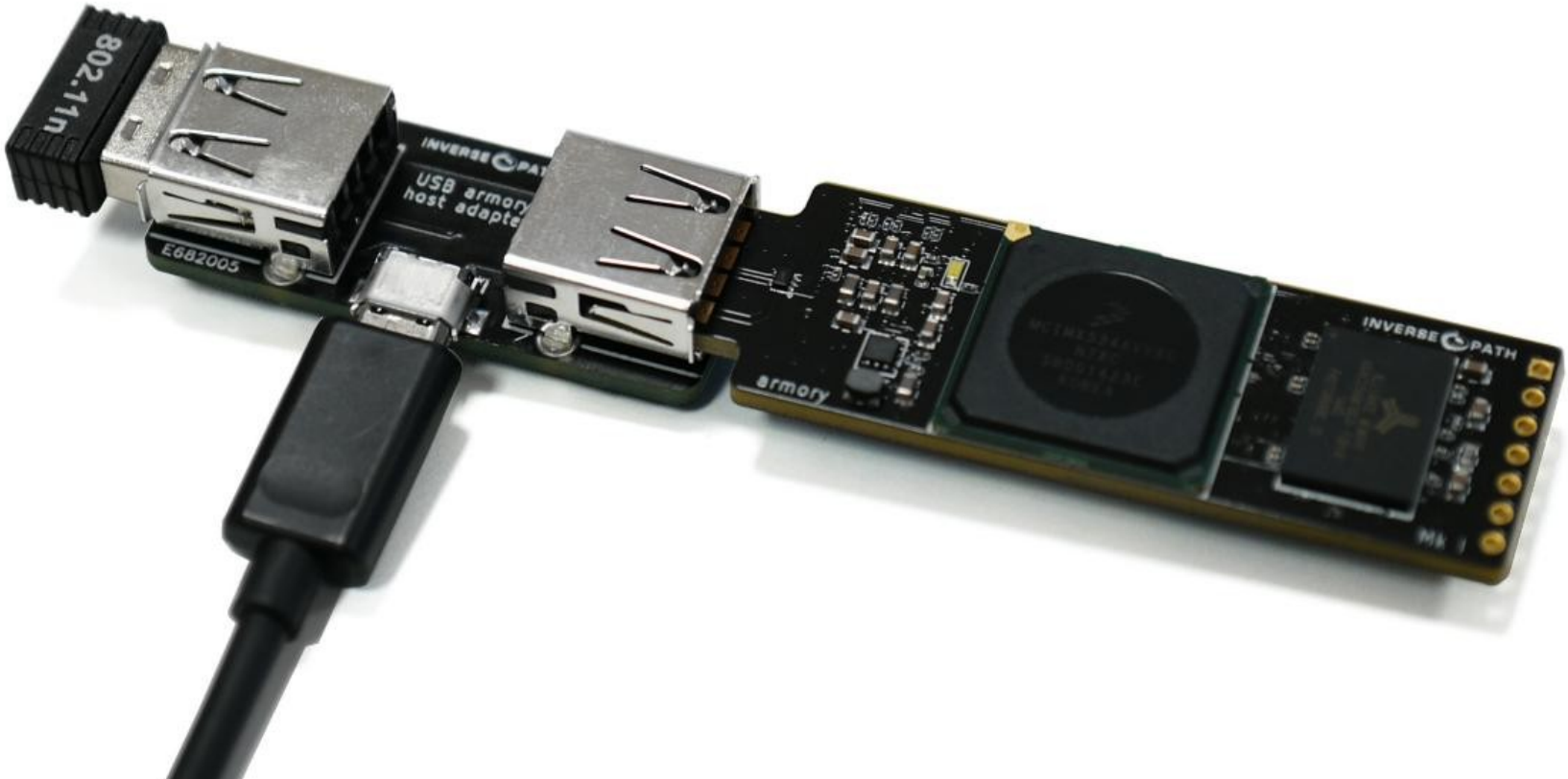
20th Century

DNA storage, conductor, sealing material, adhesive, stress relieve, nomnom
76mm x 19mm

21th Century

Open source hardware and software, ARM Cortex-A8 800MHz, 512MB RAM, microSD, USB 2.0 OTG, Ethernet/storage/UART/HID/etc device emulation, 65mm x 19mm

USB armory Mk I



USB armory Mk I

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Errata...

The microSD hinge is “challenging”.

The PCB plug, in retrospect, was a bad call.

Designing enclosure as an afterthought is a nightmare.

We learned the hard way that NXP long term support does not entail security.

Lack of built-in storage restricts provisioning scalability.

Not ideal for general consumer applications.

HABv4 bypass

In 2017 Quarkslab discovered critical security vulnerabilities that affect HABv4 on the entire NXP i.MX series.

The issue was reported for the i.MX6, Inverse Path immediately investigated applicability to the i.MX53.

An X.509 parsing error (ERR010873 | CVE-2017-7932) and an SDP protection bypass (ERR01872 | CVE-2017-7936) allow arbitrary code execution on SoC in Closed configuration.

The findings prevent the secure operation of unattended setups while attended setups remain protected in case of device loss (but not tampering).

NXP did not release any P/N updates for the i.MX53.

https://github.com/inversepath/usbarmory/blob/master/software/secure_boot/Security_Advisory-Ref_QBVR2017-0001.txt

HABv4 bypass


```
Timeline
========

2017-05-18: Quarkslab presents findings at the 2017 Qualcomm Mobile Security
            Summit [9], materials are not disclosed to the public at this time.
2017-05-30: Quarkslab communicates embargo period until 2017-07-18.
2017-05-30: Inverse Path proposes preliminary advisory release on 2017-06-05.
2017-06-05: Inverse Path releases preliminary advisory.
2017-06-06: added assigned CVE numbers.
2017-07-19: Quarkslab public release of findings [4].
2017-07-19: Inverse Path release of full advisory and i.MX53 PoC [6].
2017-07-27: added link to i.MX Community post that lists affected P/Ns.
```

F-Secure prioritized announcing the existence of the issue before the full advisory release, additionally developed and released a full PoC.

The `usbarmory_csftool` is the only Open Source implementation for HABv4 signing as well as the first and only exploitation tool ;-)

“Break your own product, and break it hard”
https://labsblog.f-secure.com/2017/07/19/break-your-own-product-and-break-it-hard/

HABv4 bypass

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```
$ usbarmory_csftool -h
Usage: usbarmory_csftool [OPTIONS]
  -A | --csf_key <private key path>  CSF private key in PEM format
  -a | --csf_crt <public  key path>  CSF public  key in PEM format
  -B | --img_key <private key path>  IMG private key in PEM format
  -b | --img_crt <public  key path>  IMG public  key in PEM format
  -I | --table   <SRK table path>    Input SRK table (see usbarmory_srktool -O)
  -x | --index   <SRK key index>     Index for SRK key (1-4)
  -i | --image   <filename>          Image file w/ IVT header (e.g. u-boot.imx)
  -o | --output  <filename>          Write CSF to file
  -s | --serial                      Serial download mode
  -S | --dcd     <address>           Serial download DCD OCRAM address
     |                                (depends on mfg tool, default: 0x00910000)
     |
  -d | --debug                       Show additional debugging information
  -T | --hab_poc                     Apply HAB bypass PoC (CVE-2017-7932)
     |
  -h | --help                        Show this help
```

Publishing PoC code encourages further investigation and testing of issues among vendors or other affected parties; it promotes security research; and it empowers other skilled parties to further verify the scope and impact of vulnerabilities.

The most important and compelling reason to take this approach, however, is this: In scenarios where detailed technical information has already been made public, the lack of a working PoC does not, and should not, constitute any form of “protection.”

The future

The **USB armory Mk II** aims to continue our support for this class of product and to improve the Mk I.

Primary design goals

The microSD hinge replacement with a push/pull slot.

Real USB plugs, plug + socket for integrated host adapter.

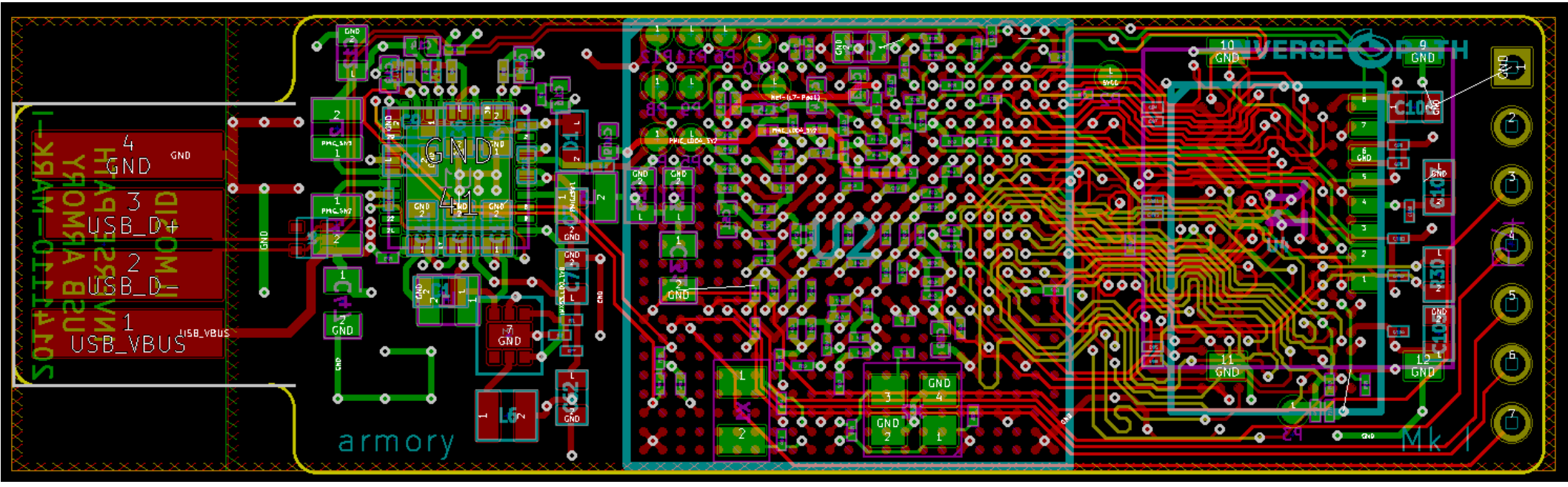
Enclosure design right from the beginning.

Full internal and third party security audit for HABv4 and chain of trust.

Addition of built-in eMMC storage and external crypto authenticator.

Bluetooth communication.

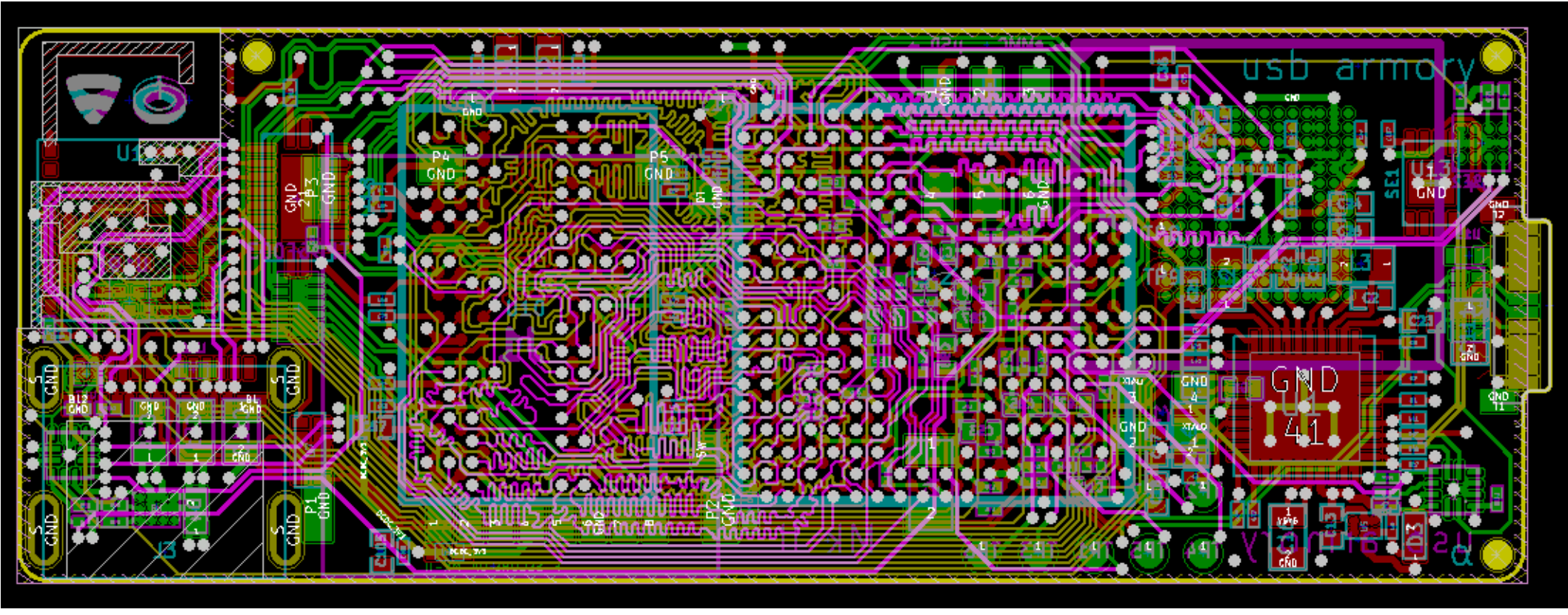
USB armory Mk I



open source hardware

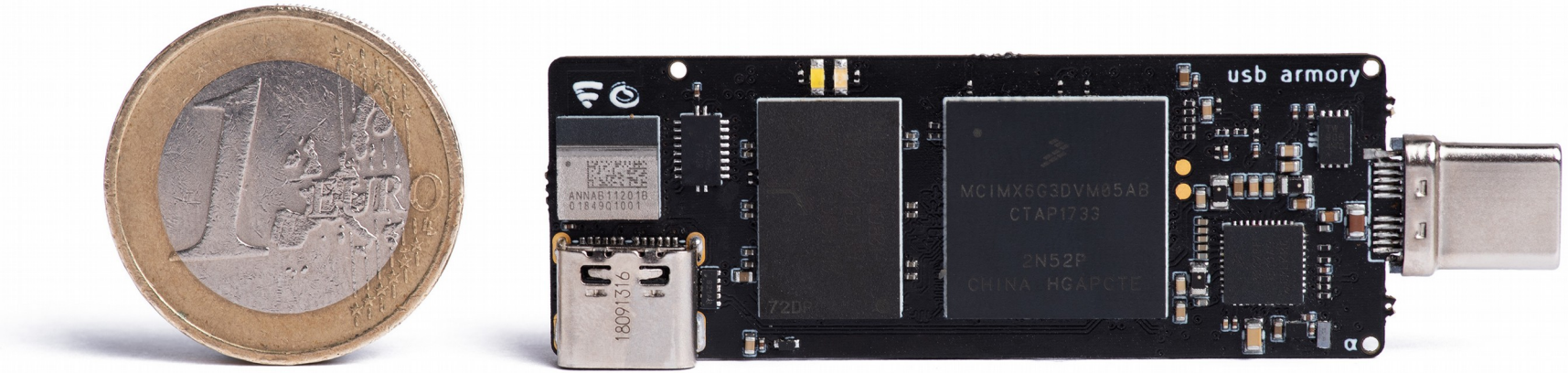
USB armory Mk II

F-Secure



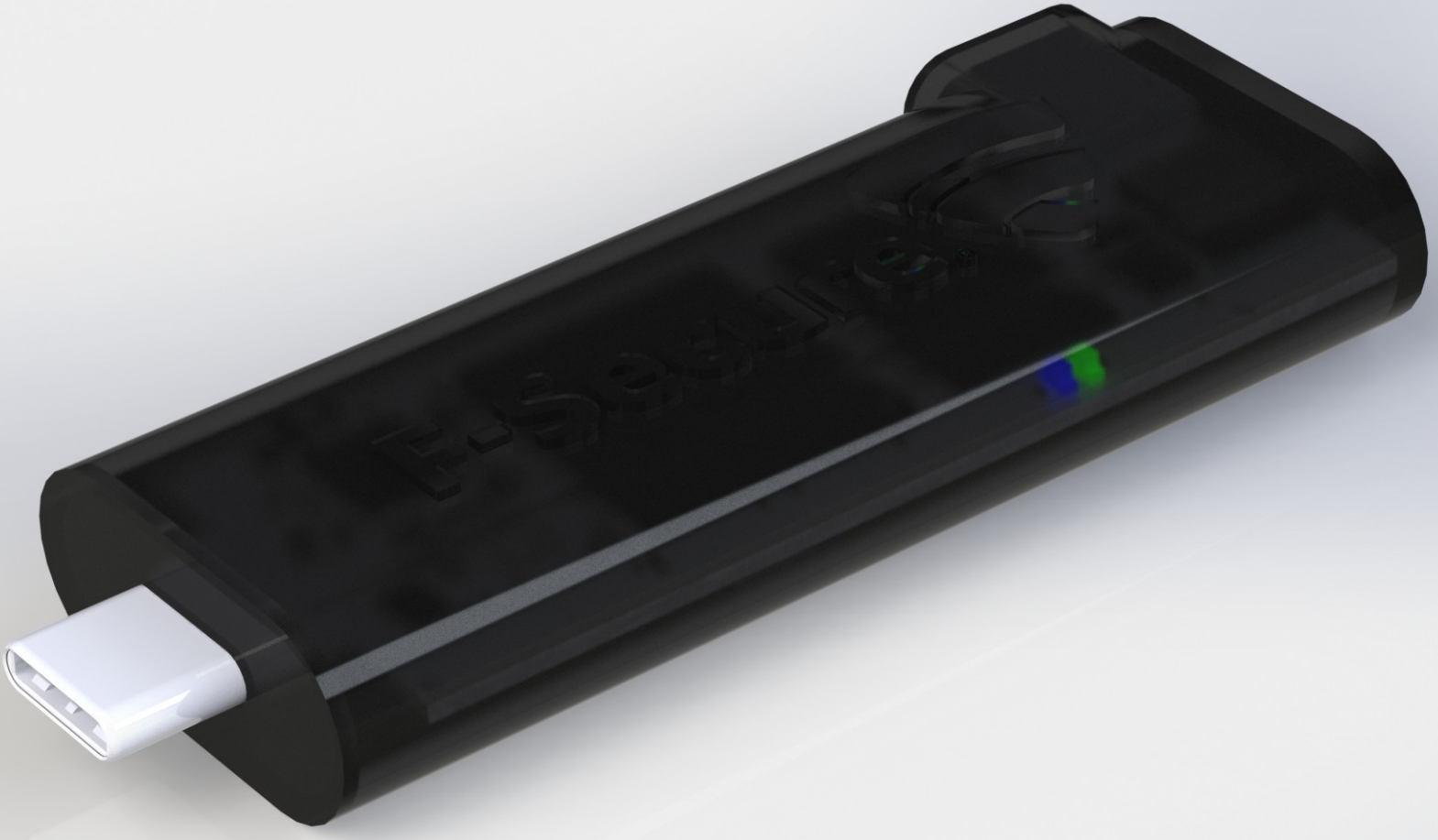
open source hardware

USB armory Mk II



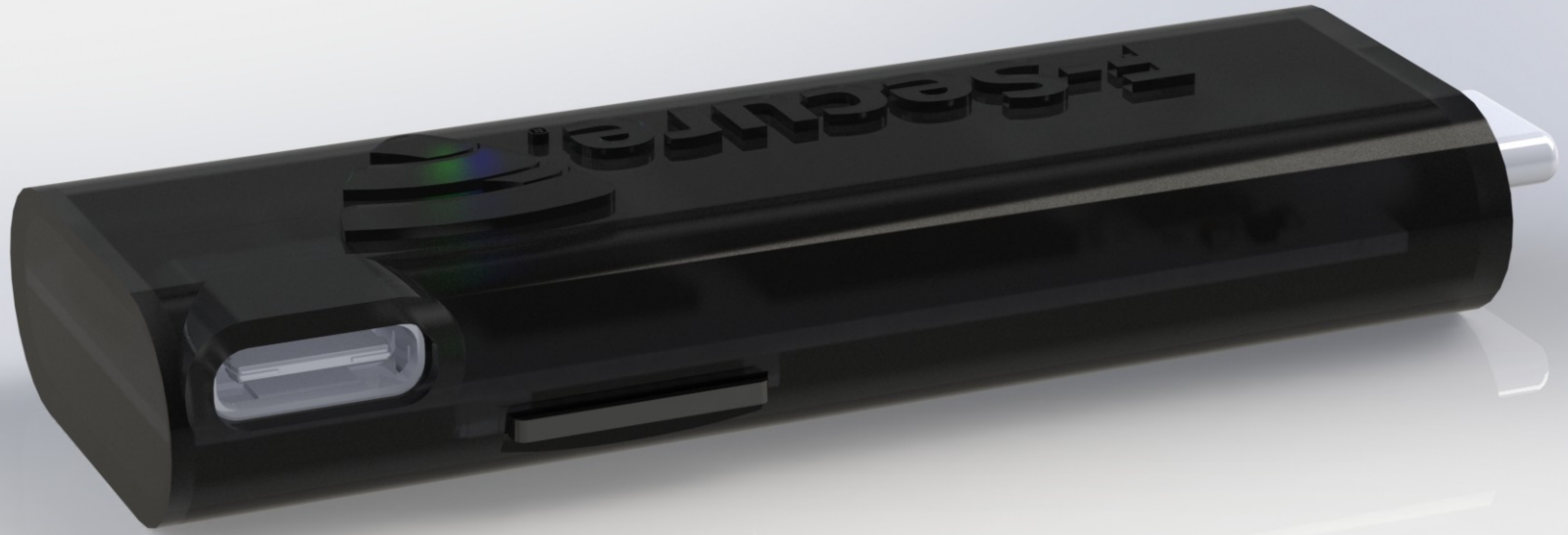
USB armory Mk II

Enclosure design



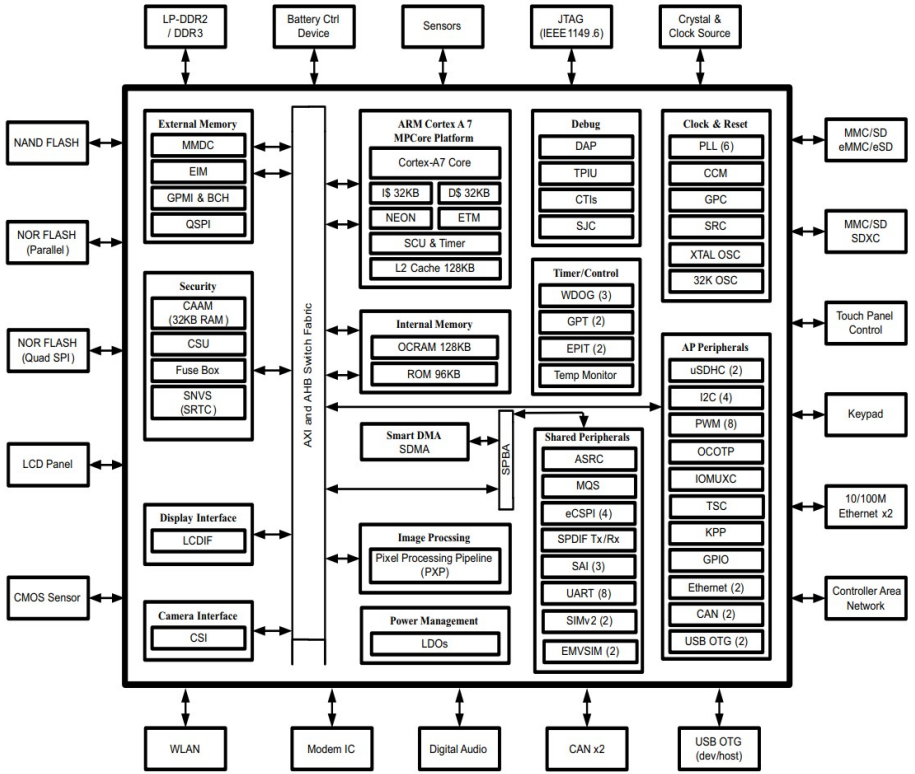
Enclosure design

Enclosure design



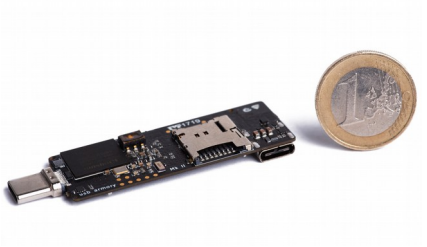
NXP – i.MX6UL /i.MX6ULZ

ARM® Cortex™-A7 528/900 MHz



Hardware security features

- High Assurance Boot (HAB 4.2.6)
- Cryptographic accelerator (CAAM/DCP)
- True Random Number Generator (TRNG)
- Bus Encryption Engine (BEE - OTF AES) (i.MX6UL only)
- Secure Non-Volatile Storage (SNVS)
- ARM® TrustZone®



NXP - Secure Non-Volatile Storage (SNVS)

The SNVS feature relies on the OTPMK, a **unique per-device hardware key**, which cannot be read directly as it can only be used via the SoC internal Cryptographic Accelerator and Assurance Module (CAAM), when secure booted.

The SNVS feature can be summarized as follows:

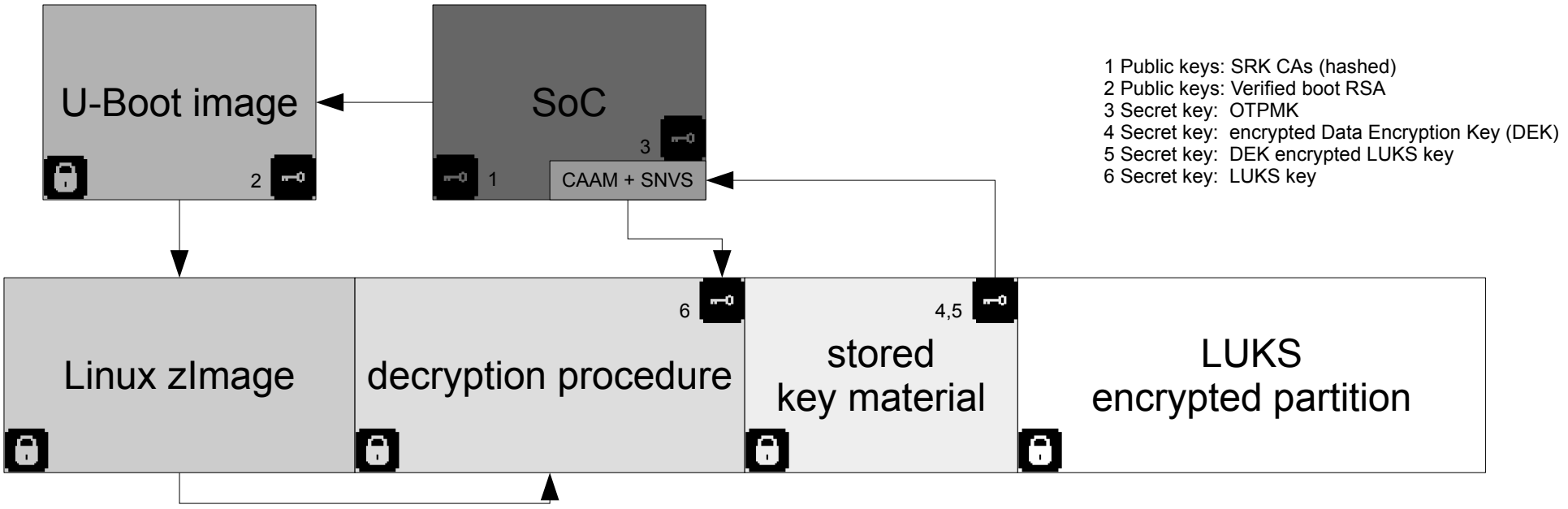
A random 256-bit blob encryption key (BK) is generated.

The **blob encryption key is used to encrypt the desired data** via the CAAM AES-CCM function, providing **confidentiality and integrity protection**.

The blob encryption key is AES-ECB encrypted with a key derived from the OTPMK (BKEK), using a Single-step Key-Derivation Function, resulting in the blob.

The HAB secure boot sequence, or runtime environment, can directly support authenticated decryption of arbitrary data blobs (including the bootloader image).

Full chain of trust example - i.MX6UL



key material

authenticated + encrypted

- SoC authenticates U-Boot
- U-Boot authenticates Linux
- Linux uses SVNS decrypted key material to unlock the encrypted partition

HAB tools

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Hash generation

```
$ usbarmory_srktool -h
Usage: usbarmory_srktool [OPTIONS]
  -1 | --key1  <public key path>     SRK public key 1 in PEM format
  -2 | --key2  <public key path>     SRK public key 2 in PEM format
  -3 | --key3  <public key path>     SRK public key 3 in PEM format
  -4 | --key4  <public key path>     SRK public key 4 in PEM format
  -o | --hash  <output filename>     Write SRK table hash to file
  -O | --table <output filename>     Write SRK table to file
```

Bootloader signing

```
$ usbarmory_csftool -h
Usage: usbarmory_csftool [OPTIONS]
  -A | --csf_key <private key path>  CSF private key in PEM format
  -a | --csf_crt <public  key path>  CSF public  key in PEM format
  -B | --img_key <private key path>  IMG private key in PEM format
  -b | --img_crt <public  key path>  IMG public  key in PEM format
  -I | --table   <SRK table path>    Input SRK table (see usbarmory_srktool -O)
  -x | --index   <SRK key index>     Index for SRK key (1-4)
  -i | --image   <filename>          Image file w/ IVT header (e.g. u-boot.imx)
  -o | --output  <filename>          Write CSF to file
```

NXP CAAM + SNVS driver (i.MX6UL)

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https://github.com/inversepath/caam-keyblob

```
$ sudo modprobe caam_keyblob

caam_keyblob: Trusted State detected
```

Go userspace implementation:

```
$ caam_tool enc dek.bin dek_blob.bin
caam_tool: encrypting 32 bytes from dek.bin
caam_tool: caam_kb_data &{Text:0x49c000 TextLen:32 Blob:0x4a0000 BlobLen:80 Keymod:0x48c010 KeymodLen:16}
caam_tool: encrypted 80 bytes to dek.bin

$ caam_tool dec dek.bin dek_blob.bin
caam_tool: decrypting 80 bytes from dek_blob.bin
caam_tool: caam_kb_data &{Text:0x478000 TextLen:32 Blob:0x474000 BlobLen:80 Keymod:0x412140 KeymodLen:16}
caam_tool: decrypted 32 bytes to dek.bin
```

NXP DCP + SNVS driver (i.MX6ULZ)

F-Secure

https://github.com/inversepath/mxs-dcp

```
$ sudo modprobe mxs_dcp

mxs_dcp: Trusted State detected
```

Go userspace implementation:

```
$ dcp_tool enc dek.bin dek_blob.bin
dcp_tool: enc dek.bin to dek_blob.bin
dcp_tool: deriving key, diversifier ab
dcp_tool: done

$ dcp_tool dec dek.bin dek_blob.bin
dcp_tool: dec dek_blob.bin to dek.bin
dcp_tool: deriving key, diversifier ab
dcp_tool: done
```

INTERLOCK key derivation with SNVS

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CAAM + SNVS (i.MX6UL)

```
$ cat interlock.conf
{"hsm":"caam-keyblob:luks"}
$ interlock -c interlock.conf -o derive:ab
cCS2IXA1sBMOn0eU665uhg==
```

DCP + SNVS (i.MX6ULZ)

```
$ cat interlock.conf
{"hsm":"mxs-dcp:luks"}
$ interlock -c interlock.conf -o derive:ab
RReS5gTYc41h3G58FQ2igA==
```

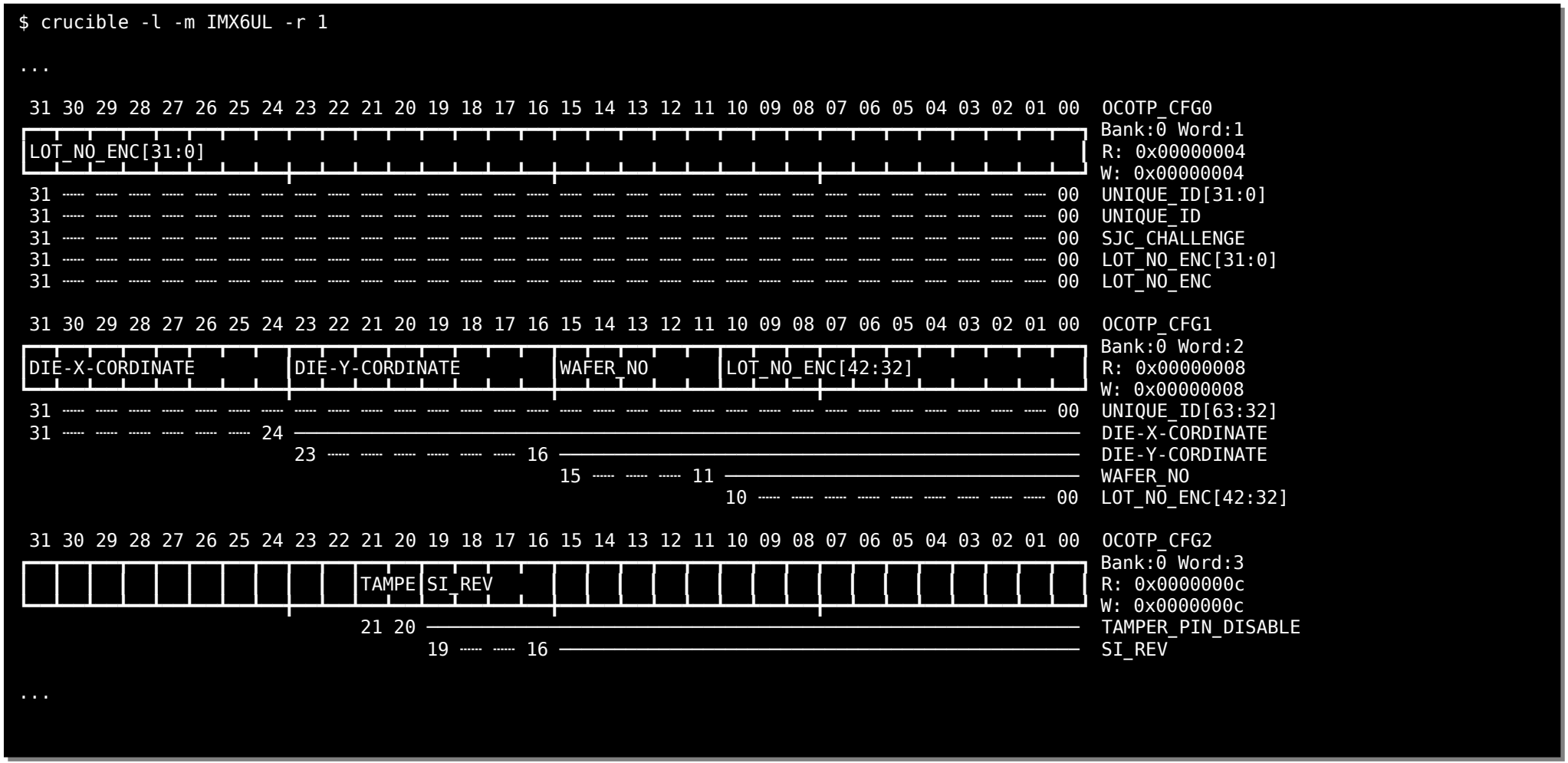
https://github.com/inversepath/interlock

With support for NXP DCP, SCC2, CAAM the INTERLOCK file encryption front-end is the single OSS app with the most complete support for NXP SoC security. (DEMO!)

One-Time-Programmable (OTP) fuses

https://github.com/inversepath/crucible

OTP fuse management with crucible



crucible - i.MX6UL example

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Blow a fuse

```
$ sudo crucible -m IMX6UL -r 1 -b 16 blow MAC1_ADDR 0x001f7b1007e3
IMX6UL ref:1 op:blow addr:0x88 off:0 len:48 val:0xe307107b1f000000
```

Read a fuse

```
$ sudo crucible -m IMX6UL -r 1 -b 16 read MAC1_ADDR
IMX6UL ref:1 op:read addr:0x88 off:0 len:48 val:0x001f7b1007e3
```

Read a fuse (minimal output for batch operations)

```
$ sudo crucible -s -m IMX6UL -r 1 -b 16 read MAC1_ADDR
001f7b1007e3
```

```
registers:
  OCOTP_LOCK:
    bank: 0
    word: 0
    fuses:
      TESTER_LOCK:
        offset: 0
        len: 2
      BOOT_CFG_LOCK:
        offset: 2
        Len: 2
...
  OCOTP_MAC0:
    bank: 4
    word: 2
    fuses:
      MAC1_ADDR:
        offset: 0
        len: 48
  OCOTP_MAC1:
    bank: 4
    word: 3
  OCOTP_MAC:
    bank: 4
    word: 4
```

crucible - i.MX6UL lock down

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It is vital to reduce the low-level SoC attack surface as much as possible and ensure lock down of all relevant fuses.

```
# set device in Closed Configuration (IMX6ULRM Table 8-2, p245)
crucible -m IMX6UL -r 1 -b 2 -e big blow SEC_CONFIG 0b11

# disable NXP reserved mode (IMX6ULRM 8.2.6, p244)
crucible -m IMX6UL -r 1 -b 2 -e big blow DIR_BT_DIS 1

# Disable debugging features (IMX6ULRM Table 5-9, p216)
# * disable Secure JTAG controller
# * disable JTAG debug mode
# * disable HAB ability to enable JTAG
# * disable tracing
crucible -m IMX6UL -r 1 -b 2 -e big blow SJC_DISABLE 1
crucible -m IMX6UL -r 1 -b 2 -e big blow JTAG_SMODE 0b11
crucible -m IMX6UL -r 1 -b 2 -e big blow JTAG_HEO 1
crucible -m IMX6UL -r 1 -b 2 -e big blow KTE 1

# To further reduce the attack surface:
#  * disable Serial Download Protocol (SDP) READ_REGISTER command (IMX6ULRM 8.9.3, p310)
#  * disable SDP over UART (IMX6ULRM 8.9, p305)
crucible -m IMX6UL -r 1 -b 2 -e big blow SDP_READ_DISABLE 1
crucible -m IMX6UL -r 1 -b 2 -e big blow UART_SERIAL_DOWNLOAD_DISABLE 1
```

https://github.com/inversepath/usbarmory/wiki/Secure-boot-(Mk-II)

Buildroot

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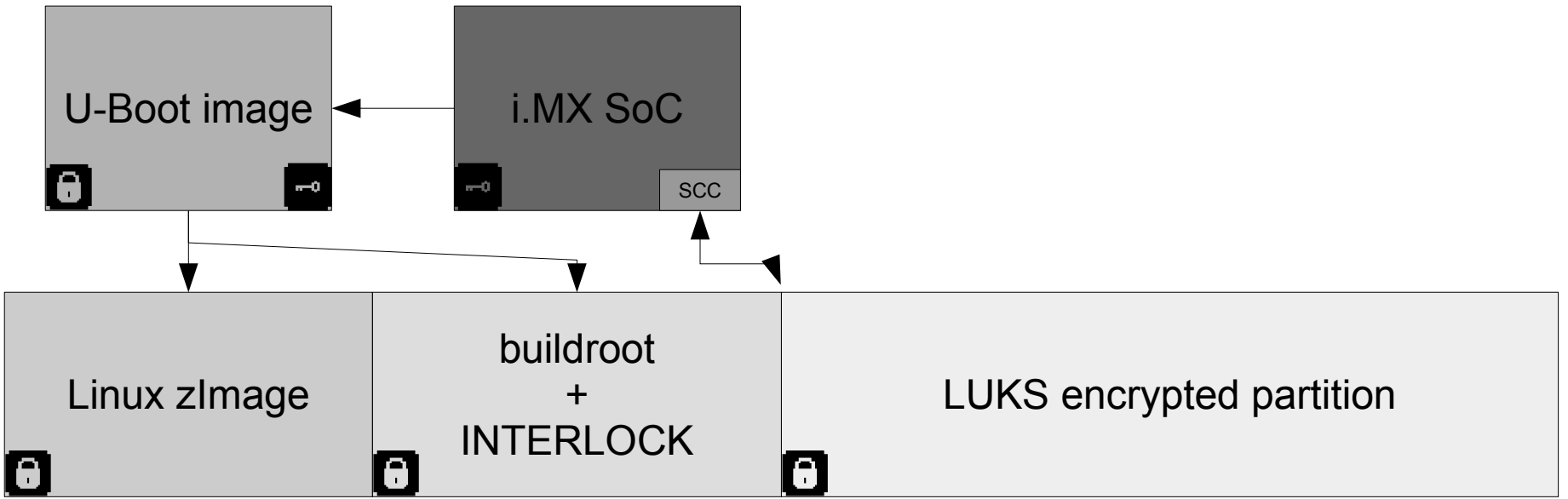
https://github.com/inversepath/usbarmory/tree/master/software/buildroot

Custom buildroot profiles allow compilation of bootloader, kernel, runtime environment and target application with an automatic cross-compilation process.

```
make BR2_EXTERNAL=${USBARMORY_GIT}/software/buildroot interlock_mark_one_defconfig
make BR2_EXTERNAL=${USBARMORY_GIT}/software/buildroot # yes, it's that easy!
```



U-BLOX ANNA-B112

The addition of a Bluetooth module opens up a variety of new use cases.

The trust towards the host can now be limited to the strict amount necessary.

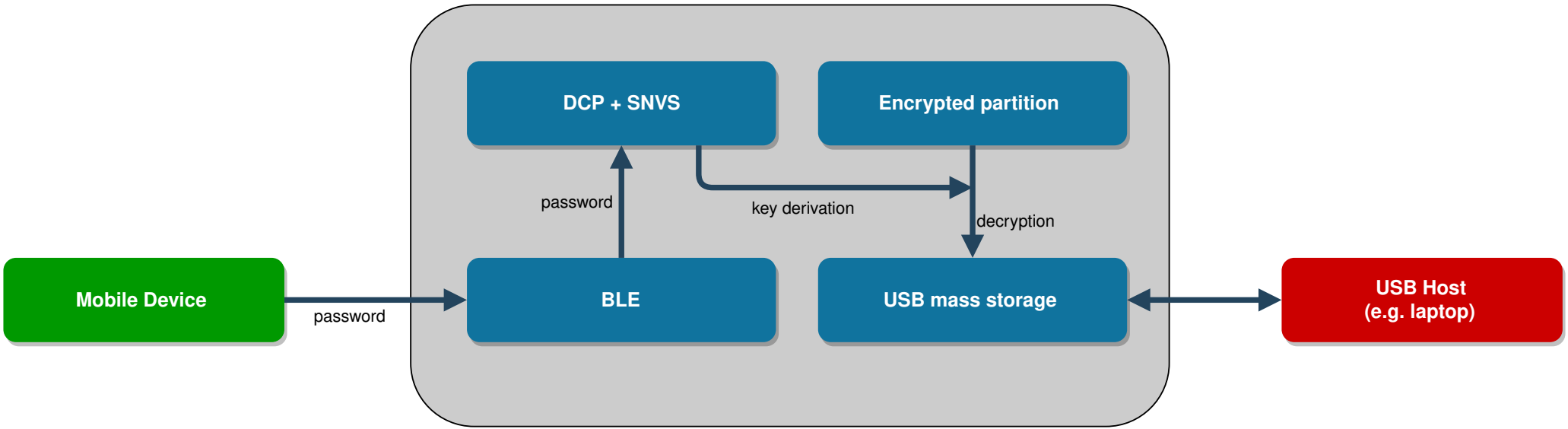
Out-of-band interaction with a mobile app is now possible

The ANNA-B112 module supports an "OpenCPU" option to allow arbitrary firmware, replacing the built-in u-blox one, on its Nordic Semiconductor nRF52832 SoC.

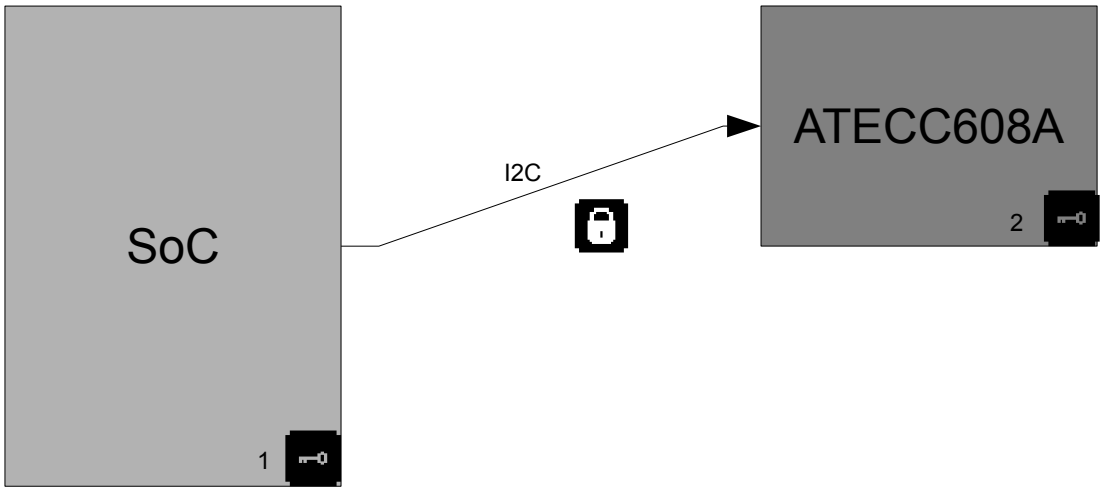
This allows provisioning of the SoC with Nordic SDK, Wirepas mesh, ARM Mbed or arbitrary user firmware. The nRF52832 SoC features an ARM Cortex-M4 CPU with 512 kB of internal Flash and 64 kB of RAM.

DEMO

Full chain of trust example - i.MX6UL



Rollback protection + external keyring



1 Secret keys: ReadKey, WriteKey

2 Slots (16x) for key, certificates or data
High Endurance Monotonic Counters (2x)
OTPs (512-bit)

key material

authenticated + encrypted

The SoC can establish a secure session with the ATECC608A, using safely stored read and write keys, certificates or data.

This allows secure key/certificate access or use, additionally two High Endurance Monotonic Counters can be used for rollback protection.

Provides an additional hardware keyring for (partial) mitigation of further HAB issues.

i.MX6UL - Security audit

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Against Silicon Revision 1.2 and HAB 4.1 or greater, meaning P/Ns “AB” or greater, with patched HABv4.

Completed as an internal + third party security audit for HABv4 as well as our buildroot chain of trust implementation.

Conclusions

No further issues have been identified in the patched boot ROM.

Freescale kernel module issues (invalid error values, NULL pointer exceptions, various operational errors), all resolved in our own caam-keyblob driver implementation.

Several U-Boot issues identified and resolved (CVE-2018-18439, CVE-2018-18440)

armoryctl - hardware control tool

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https://github.com/inversepath/armoryctl

```
USB armory Mk II hardware control tool

Usage: armoryctl [options] [command]
  -c string
        ANNA-B112 firmware cache path (default "/home/lcars/.armoryctl")
  -d    debug
  -f    skip hardware check and force execution
  -i int
        ATECC608A I2C bus number
  -l int
        ATECC608A I2C address (default 96)
  -m int
        FUSB303 I2C bus number
  -n int
        FUSB303 I2C address (default 49)
  -o int
        TUSB320 I2C bus number
  -p int
        TUSB320 I2C address (default 97)
  -q int
        PF1510 I2C bus number
  -r int
        PF1510 I2C address (default 8)
  -s int
        ANNA-B112 UART speed (default 115200)
  -u string
        ANNA-B112 UART path (default "/dev/ttymxc0")
  -x string
        OpenOCD lookpath (default "openocd")

LED control:
  led (white|blue) (on|off)

Type-C plug port controller (TUSB320):
  tusb id                    # read controller identifier
  tusb current_mode          # read advertised current

Type-C receptacle port controller (FUSB303):
  fusb id                    # read controller identifier
  fusb current_mode          # read advertised current
  fusb enable                # enable the controller
  fusb disable               # disable the controller

Bluetooth module (ANNA-B112):
  ble info                   # read device information
  ble enable                 # set visible peripheral BLE role
  ble disable                # disable BLE communication
  ble reset                  # reset the module
  ble bootloader_mode        # switch to bootloader mode
  ble normal_mode            # switch to normal operation
  ble rc_lfck (flash|at)     # set LF clock source to internal RC oscillator
  ble update <firmware path> # module firmware update

Secure Element #1 (ATECC608A):
  se1 info                   # read device information
  se1 self_test                     # execute self test procedure

Power Management Integrated Circuit (PF1510):
  pmic info                  # read device information
```

USB armory Mk II – public repositories

Documentation
https://github.com/inversepath/usbarmory/wiki

caam-keyblob (i.MX6UL) - CAAM + SNVS driver
https://github.com/inversepath/caam-keyblob

mxs-dcp (i.MX6ULL) - DCP + SNVS driver
https://github.com/inversepath/mxs-dcp

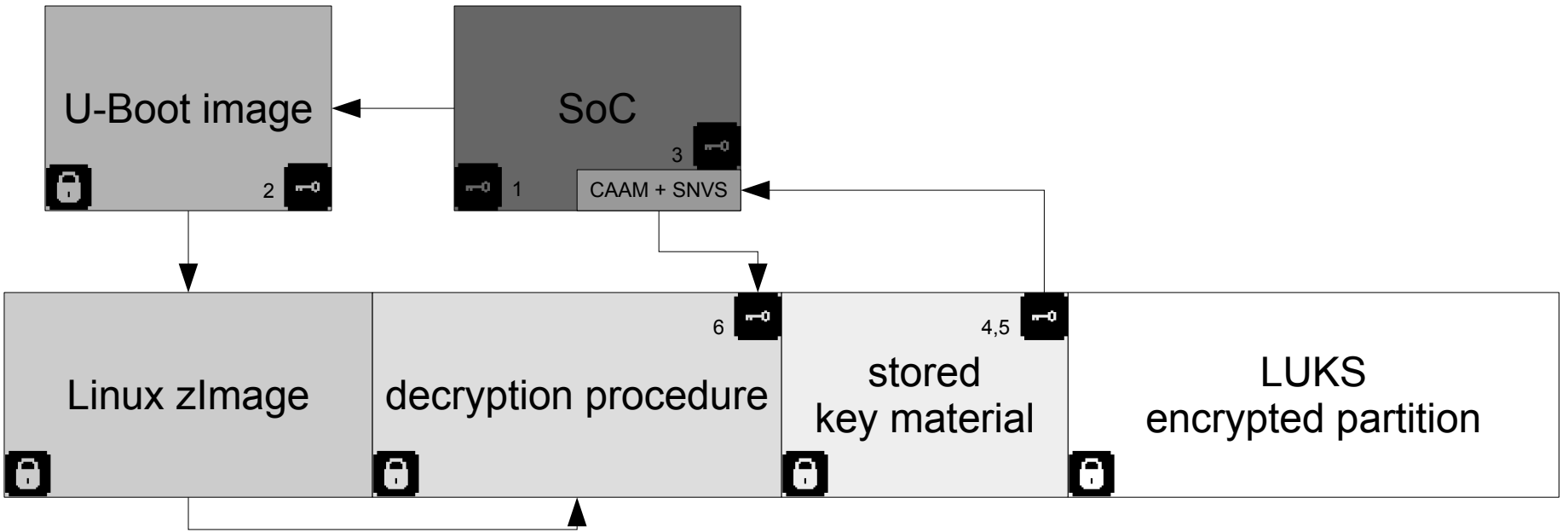
INTERLOCK with CAAM/DCP support
https://github.com/inversepath/interlock

crucible - OTP fusing tool
https://github.com/inversepath/crucible

armoryctl - hardware control tool
https://github.com/inversepath/armoryctl

Buildroot profile for embedded INTERLOCK distribution
https://github.com/inversepath/usbarmory/tree/master/software/buildroot

Reducing the attack surface



When building single purpose firmware images the attack surface, and maintenance burden, of the Linux kernel and runtime is considerable.

We introduce a development project that ultimately aims to reduce it as much as possible.

TamaGo

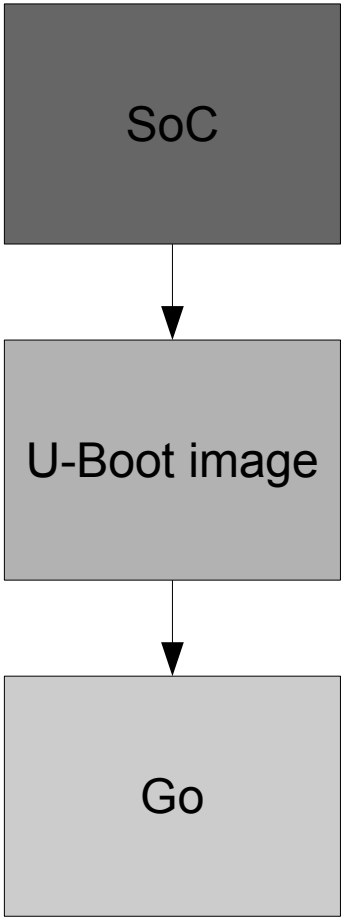
```
vec_start 0x81000000
vec_size 0x40
bootstack start 0x9ff00000
exception stack_start 0x9ff20000
exception stack_size 0x10000
g0.stackguard0 0x9fef0000
g0.stackguard1 0x9fef0000
g0.stack.lo 0x9fef0000
g0.stack.hi 0x9ff00000
mmu_map: 0x80000000 0x20000000
------------------------------------------------------------------------
imx6_rng: self-test...done
imx6_rng: seeding...done
imx6_soc: i.MX6ULL (0x65, 0.1) @ freq:900 MHz - native:true
Hello from tamago/arm! (epoch 3038767125)
launched 6 test goroutines
-- i.mx6 dcp -----------------------------------------------------------
imx6_dcp: derived SNVS key 7d5fec1ee57ab31e4ca75a59c568ffb6
-- file ----------------------------------------------------------------
read /tamago-test/tamago.txt (22 bytes)
-- sleep ---------------------------------------------------------------
sleeping 100ms @ 72238750
   slept 100ms @ 174514000
-- rng -----------------------------------------------------------------
   51682759bfbeee914df905b69d37a3504f94ab2d40dbdd3f5a51e1c7c061a285
-- ecdsa ---------------------------------------------------------------
ECDSA sign and verify with p224 ... done (114.507375ms)
ECDSA sign and verify with p256 ... done (47.94475ms)
-- btc -----------------------------------------------------------------
Script Hex: 76a914128004ff2fcaf13b2b91eb654b1dc2b674f7ec6188ac
Script Disassembly: OP_DUP OP_HASH160 128004ff2fcaf13b2b91eb654b1dc2b674f7ec61 OP_EQUALVERIFY OP_CHECKSIG
Script Class: pubkeyhash
Addresses: [12gpXQVcCL2qhTNQgyLVdCFG2Qs2px98nV]
Required Signatures: 1
Transaction successfully signed
------------------------------------------------------------------------
completed 6 goroutines
Goodbye from tamago/arm (5.7927555s)
exit with code 0 halting
```

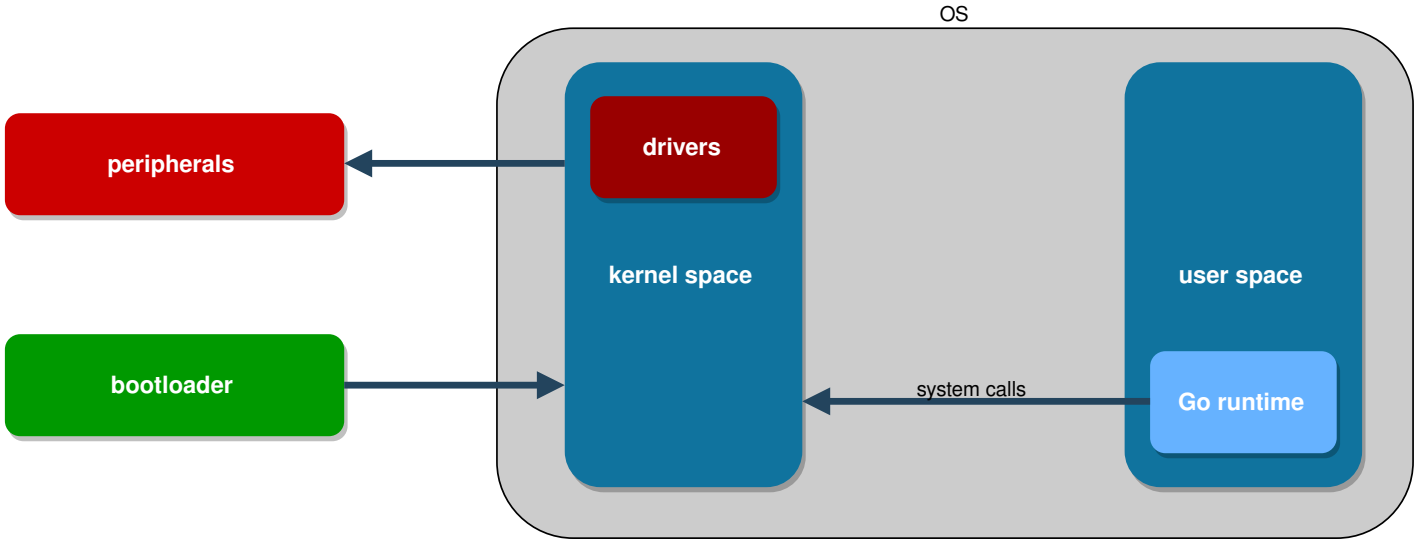
F-Secure

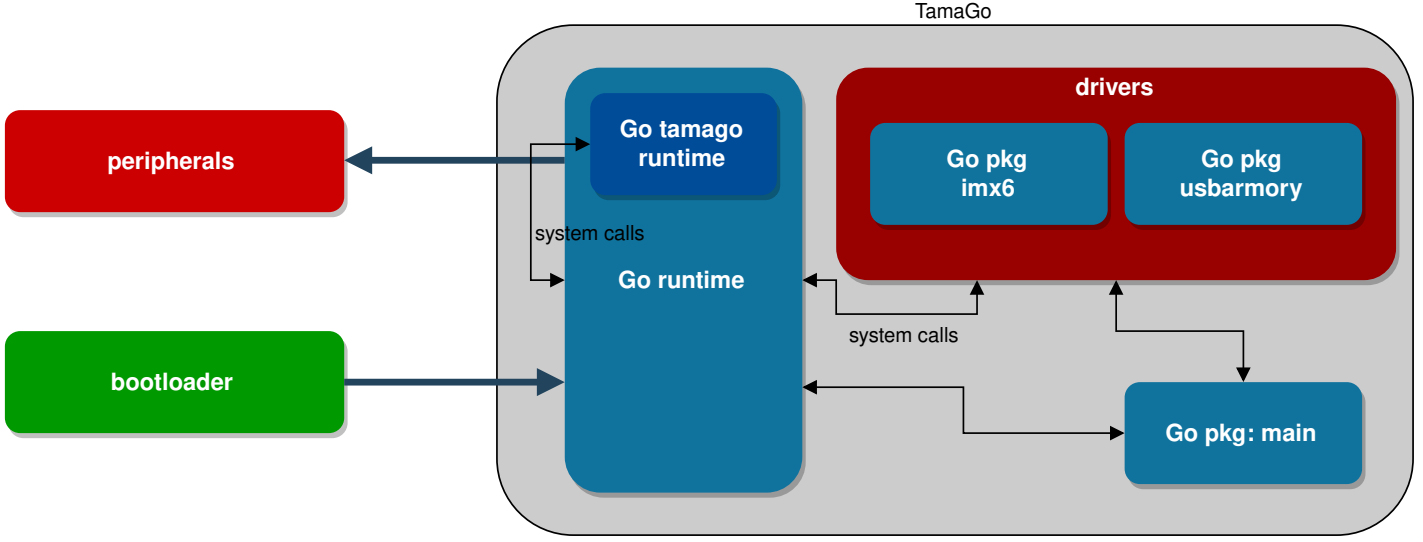
TamaGo

```
vec_start 0x81000000
vec_size 0x40
bootstack start 0x9ff00000
exception stack_start 0x9ff20000
exception stack_size 0x10000
g0.stackguard0 0x9fef0000
g0.stackguard1 0x9fef0000
g0.stack.lo 0x9fef0000
g0.stack.hi 0x9ff00000
mmu_map: 0x80000000 0x20000000
------------------------------------------------------------------------
imx6_rng: self-test...done
imx6_rng: seeding...done
imx6_soc: i.MX6ULL (0x65, 0.1) @ freq:900 MHz - native:true
Hello from tamago/arm! (epoch 3038767125)
launched 6 test goroutines
-- i.mx6 dcp -----------------------------------------------------------
imx6_dcp: derived SNVS key 7d5fec1ee57ab31e4ca75a59c568ffb6
-- file ----------------------------------------------------------------
read /tamago-test/tamago.txt (22 bytes)
-- sleep ---------------------------------------------------------------
sleeping 100ms @ 72238750
   slept 100ms @ 174514000
-- rng -----------------------------------------------------------------
   51682759bfbeee914df905b69d37a3504f94ab2d40dbdd3f5a51e1c7c061a285
-- ecdsa ---------------------------------------------------------------
ECDSA sign and verify with p224 ... done (114.507375ms)
ECDSA sign and verify with p256 ... done (47.94475ms)
-- btc -----------------------------------------------------------------
Script Hex: 76a914128004ff2fcaf13b2b91eb654b1dc2b674f7ec6188ac
Script Disassembly: OP_DUP OP_HASH160 128004ff2fcaf13b2b91eb654b1dc2b674f7ec61 OP_EQUALVERIFY OP_CHECKSIG
Script Class: pubkeyhash
Addresses: [12gpXQVcCL2qhTNQgyLVdCFG2Qs2px98nV]
Required Signatures: 1
Transaction successfully signed
------------------------------------------------------------------------
completed 6 goroutines
Goodbye from tamago/arm (5.7927555s)
exit with code 0 halting
```

F-Secure




OS
peripherals
bootloader
drivers
kernel space
user space
system calls
Go runtime


TamaGo
peripherals
bootloader
Go tamago runtime
system calls
Go runtime
drivers
Go pkg imx6
Go pkg usbarmory
system calls
Go pkg: main

F-Secure

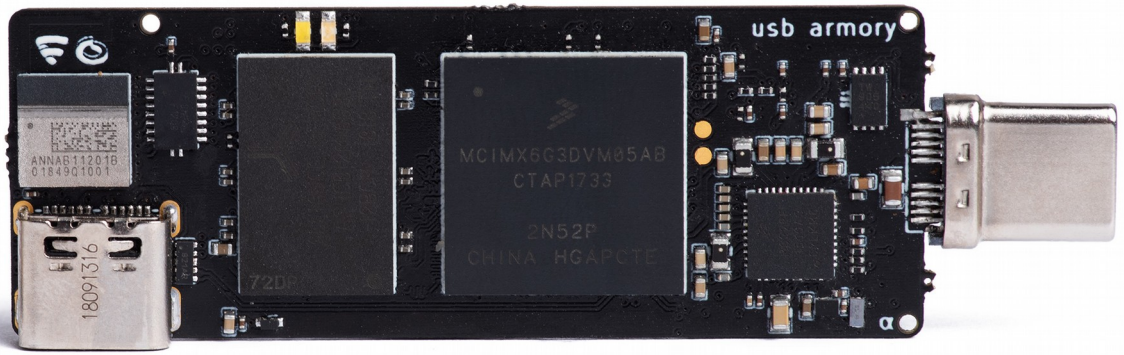
```
// Sample hardware key derivation on USB armory Mk II with TamaGo
//
// +build tamago,arm

package main

import (
	"imx6"
	// required to initialize board
	_ "usbarmory/mark-two"
)

func main() {
	key, err := imx6.DCP.DeriveKey(diversifier, iv)

	// do stuff...
	...
}
```

https://github.com/inversepath/tamago/wiki

F-Secure

Thank you!

Questions?



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https://github.com/inversepath/usbarmory