Introduction of Security and Anti-Hacking Solutions with i.MX Applications Processors

JNK-CON-T0982

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Introduction

i.MX-based products

- Rich, mobile, end-user, connected platforms
- Increasingly valuable assets: end-user data, licensed content, access credentials, intellectual property
- Increasingly threatened: malware, hacking, misuse

i.MX Trust Architecture

- Protects assets of multiple stakeholders
- Guards against sophisticated attacks
- Assures software measures

Agenda

- Introduction
- Why a Trust Architecture?
- Trust Architecture Features
- Trusted Architecture Deployment
- High Assurance Boot
  - Code Signing Tool
  - Manufacturing Tool
- Summary

Why a Trust Architecture

Background

- i.MX product characteristics
  - Client / end-user (not server or fabric)
  - Mobile (physically vulnerable)
  - Connected (“internet of things”, remote threats)
  - Rich & open SW (large attack surface)

- Security trends
  - Percentage of breaches involving end-user devices <u>doubled</u> year-on-year (Verizon/US Secret Service)
  - Cybercriminals shifting focus from PC to mobile users (Cisco)
  - Major trojans continue to migrate to mobile devices (Security Week)

Assets & Stakeholders

Asset	Stakeholder	Attack
Content - Media - Applications	Content owner	Piracy
Service access - Network - Enterprise	Service provider	Fraud
Intellectual property - Owned - Licensed	Manufacturer	Espionage
Personal data - Identification - Connections	End user	Privacy breach

Threats

- Malware
  - Rootkits, trojans, viruses, worms, keyloggers, bots,...
  - Risk enhanced by rich & open OS
  - Countermeasures: trusted execution, high assurance boot
- Hacking
  - Reverse engineering, brute force
  - Countermeasures: secure storage, secure debug, encryption
- Physical attack
  - Bus snooping, glitching,
  - Countermeasures: secure storage, tamper detection

i.MX Trust Architecture Features & Deployment

i.MX Trust Architecture Features

Trusted Execution

- Isolates execution of critical SW from possible malware
- TrustZone Secure & Normal Worlds (processor modes)
- Hardware firewalls between CPU & DMA masters and memory & peripherals

High Assurance Boot

- Authenticated boot: prevents unauthorized SW execution
- Encrypted boot: protects SW confidentiality
- Digital signature checks embedded in on-chip boot ROM
- Run every time processor is reset

HW Cryptographic Accelerators

- i.MX family dependent
- Symmetric: AES-128, AES-256, 3DES, ARC4
- Message Digest & HMAC: SHA-1, SHA-256, MD-5

i.MX Trust Architecture Features (continued)

Secure Storage

- Protects data confidentiality and integrity
- Off-chip: cryptographic protection including device binding
- On-chip: self-clearing Secure RAM
- HW-only keys: no SW access

HW Random Number Generation

- Ensures strong keys and protects against protocol replay
- On-chip entropy generation
- Cryptographically secure deterministic RNG

Secure Clock

- Provides reliable time source
- On-chip, separately-powered real-time clock
- Protection from SW tampering

i.MX Trust Architecture Features (continued)

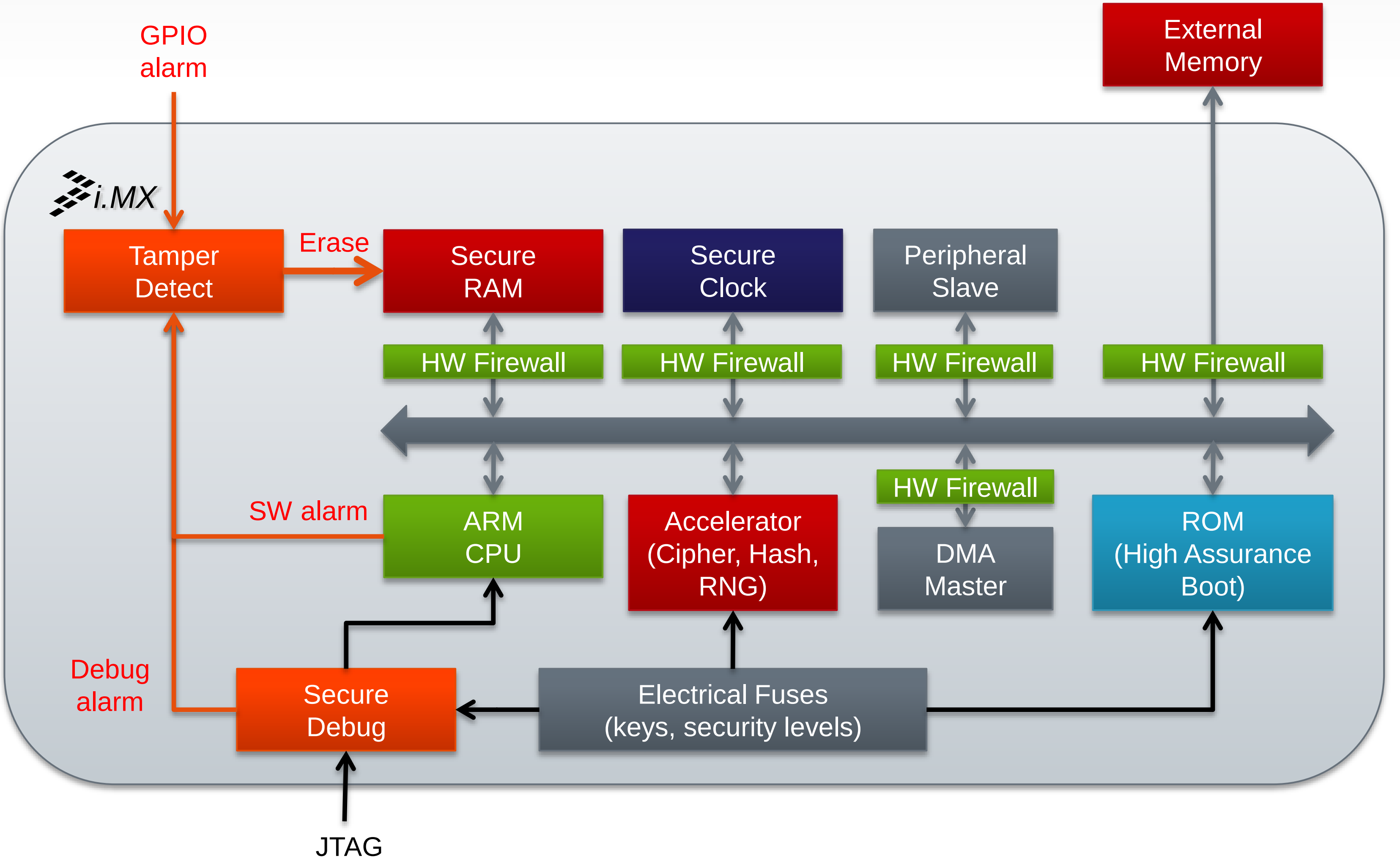
Secure Debug:

- Protects against HW debug (JTAG) exploitation for:
  - Security circumvention
  - Reverse engineering
- Three security levels + complete JTAG disable

Tamper Detection

- Protects against run-time tampering
- Monitoring of various alarm sources
  - Debug activation
  - External alarm (e.g. cover seal)
  - SW integrity checks
  - SW alarm flags
- HW and SW tamper response
- Support varies by i.MX family

i.MX Trust Architecture – Overview



i.MX Trust Architecture Deployment

Feature	i.MX 258	i.MX 27L	i.MX 28x	i.MX 35x	i.MX 508	i.MX 51x	i.MX 53x	i.MX 6x
Trusted Execution						✓	✓	✓
High Assurance Boot	V3		V4	V3	V4	V3	V4	V4
Secure Storage	✓		✓	✓	✓	✓	✓	✓
Hardware RNG	✓	✓		✓	✓	✓	✓	✓
Secure Clock	✓				✓	✓	✓	✓
Secure Debug	✓	✓		✓	✓	✓	✓	✓
Tamper Detection	✓	✓*		✓*		✓*	✓*	✓

* External Digital Tamper only monitored when main power is supplied.

HW Comparison

Feature	i.MX53	i.MX 6 D/Q & D/L	TI OMAP	NVIDIA Tegra	QCOM QSD	MARVELL ARMADA	Samsung Exynos 5	Intel Atom
Trusted Execution	✓	✓	M-shield	Limited	Limited	✓	✓	✗
Secure Boot	✓	✓ (including encrypted boot)	✓	✓	✓	? (16x)	✗	✗
Secure Storage	✓	✓	✓	?	?	?	✓	✗
HW key protection	✓	✓	✓	?	?	?	✗	✗
Cryptographic Accelerators	Symmetric Hash RNG	Symmetric Hash RNG	Symmetric Asymmetric Hash RNG	?	?	Symmetric Hash	✓?	✗
Secure Real Time Clock	✓	✓	?	?	?	?	✗	✗
HW Firewalls	CSU	CSU	✓	?	?	?	?	✗
Content Protection	✗	HDCP DTCP	OMA HDCP	HDCP?	SecureMSM	?	HDCP?	✗
Secure Debug	✓	✓	✓	?	?	?	?	✗
Tamper Detection	✓	✓	?	?	?	?	?	✗
Security level (bits)	128	128	112?	?	?	?	?	✗

i.MX High Assurance Boot

High Assurance Boot – Purpose

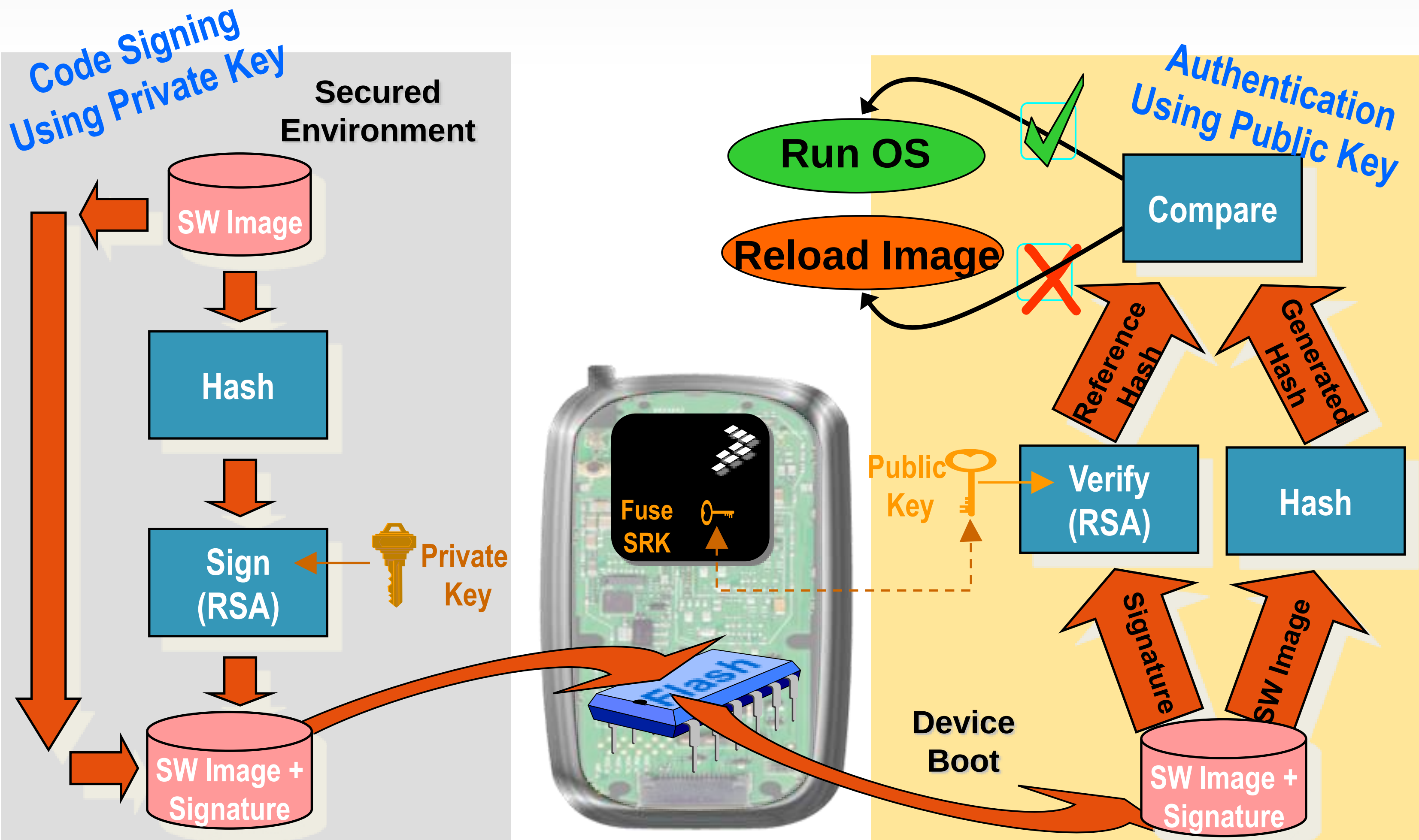
High Assurance Boot ensures the boot sequence:

- Uses authentic SW
- Remains confidential (if required)
- Establishes a “known-good” system state

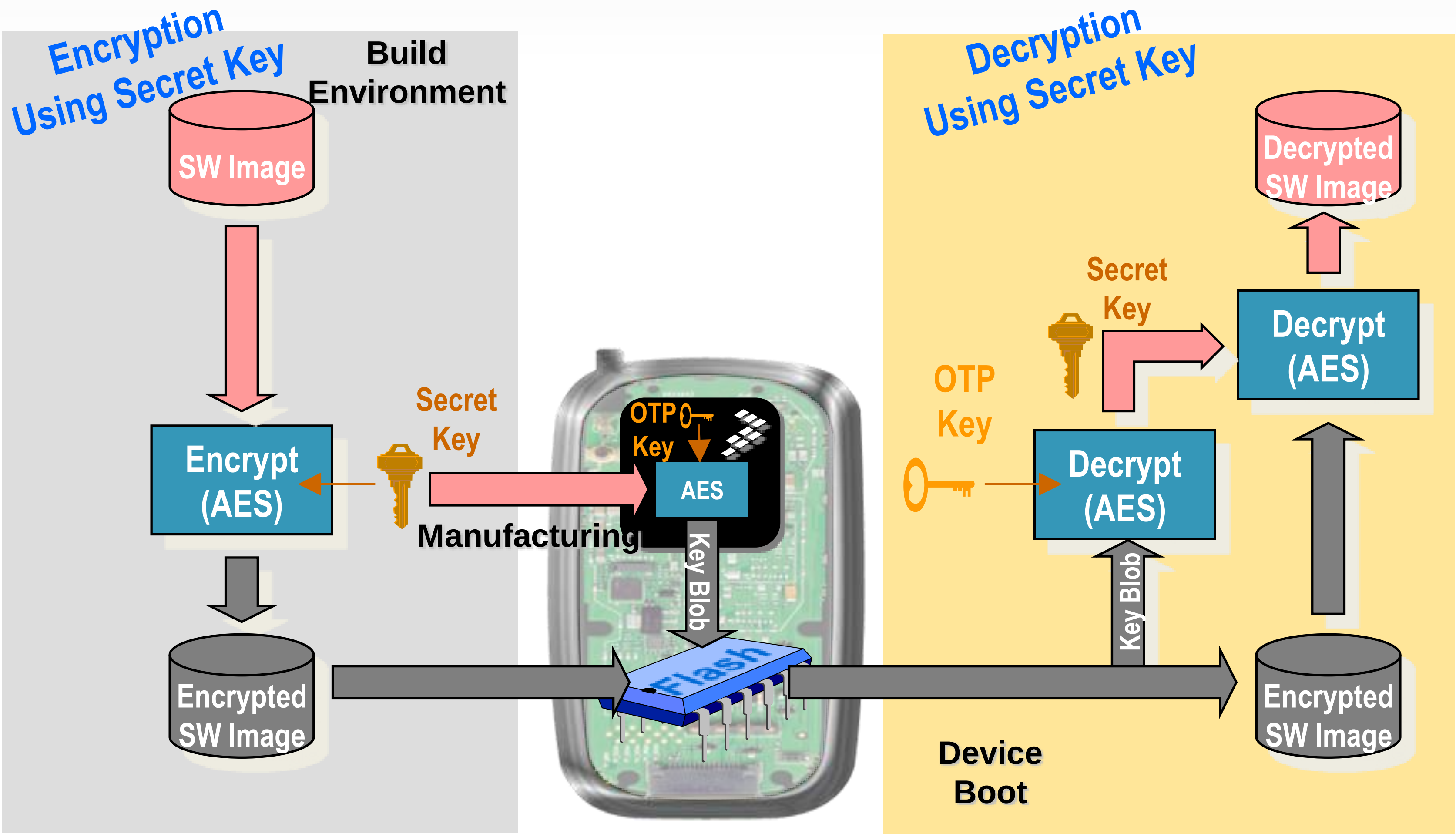
High Assurance Boot protects against:

- Platform re-purposing
- Rootkits and similar unauthorized SW designed to
  - harvest secrets
  - circumvent access controls
- Offline SW reverse engineering (if required)

High Assurance Boot – Operation



High Assurance Boot – Encrypted



i.MX High Assurance Boot – Enablement &Tools

High Assurance Boot – Tools

Freescale Reference Code Signing Tool (CST):

- Offline process of creating digital signatures
- Signing Keys and signatures generated by device manufacturers
- Supports code signing for: i.MX258, i.MX28, i.MX35x, i.MX508, i.MX51x, i.MX53x and i.MX6x

Manufacturing Tool:

- Platform software provisioning
- One-Time Programmable e-fuse burning

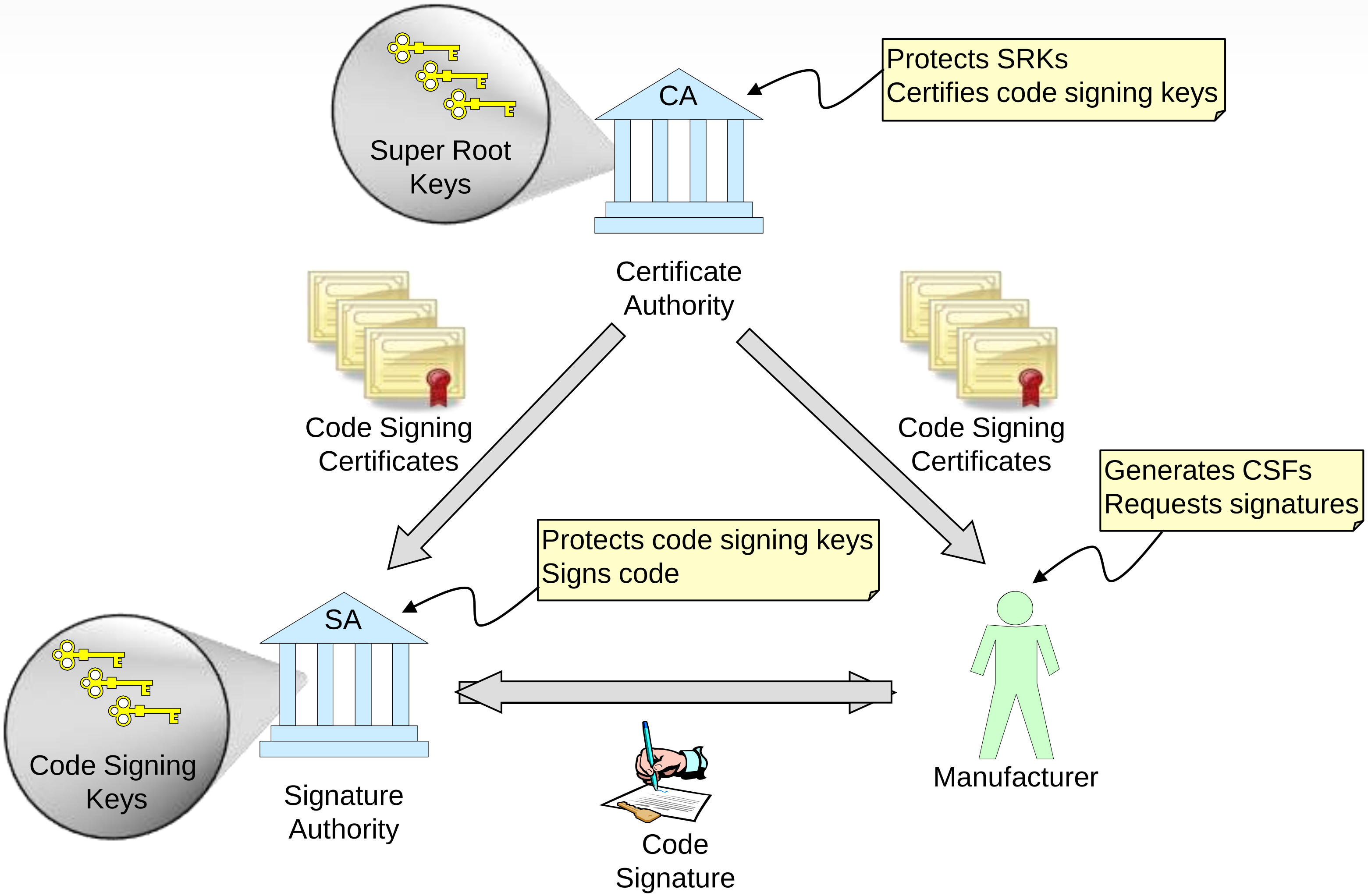
- Both can be downloaded from: http://www.freescale.com/webapp/sps/site/overview.jsp?code=IMX_DESIGN

Planned Updates and New Features

- Code signing for i.MX application notes
  - Ties in device configuration, code signing, fusing together in a single document
  - HAB3 version nearing completion
  - HAB4 version in development
- Documentation and updates to the CST tool describing how to replace parts of the tool with a 3rd party tool or HSM (Hardware Security Module)
  - For customers that require a higher level of private key protection.
- Support for i.MX 6 family encrypted boot.
- Support for MS Windows.
- Secure boot example included in future i.MX6 Linux BSP releases
  - Authentication of u-boot and Linux kernel images

Code Signing for High Assurance Boot

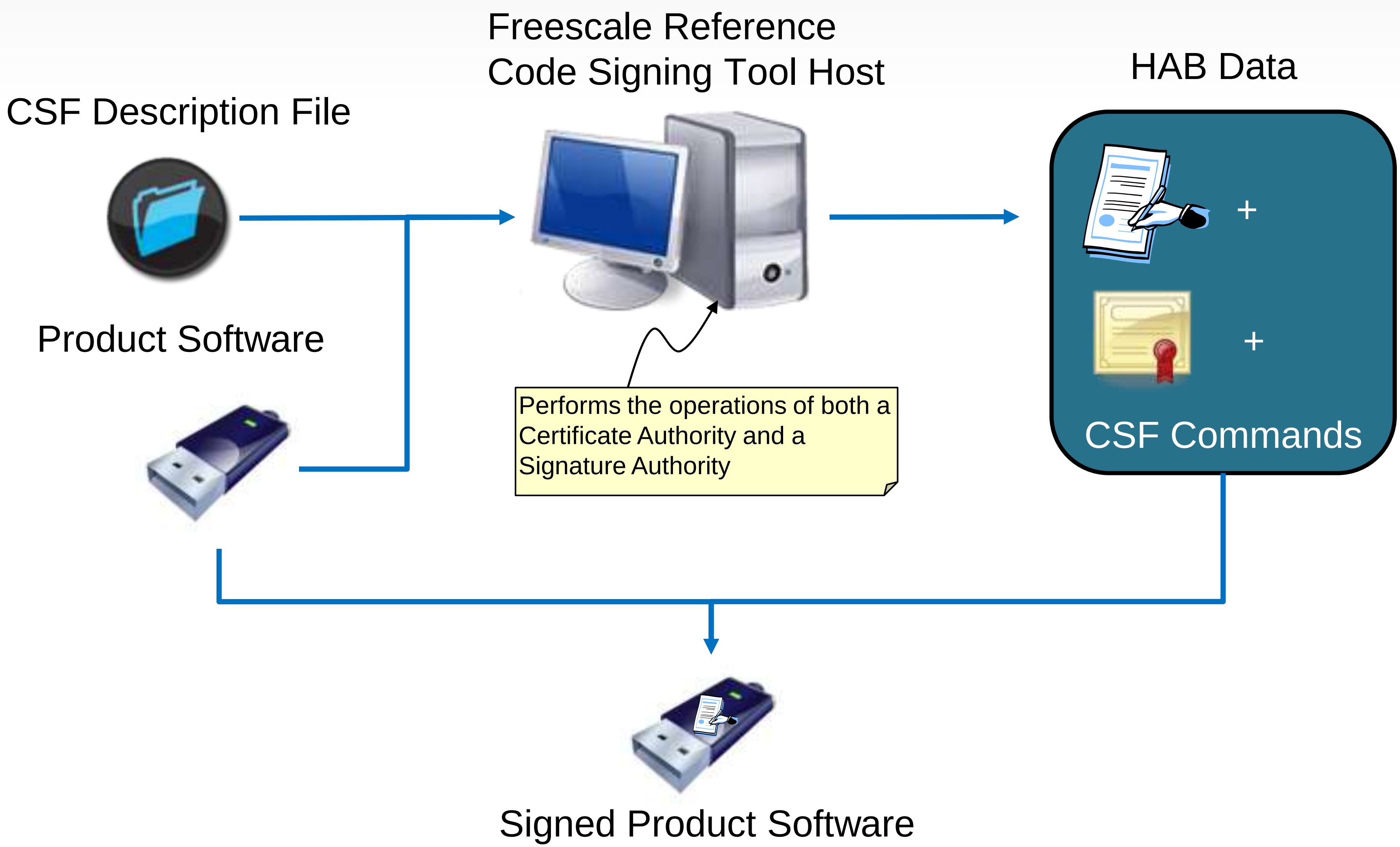
Generic Code-signing Participants



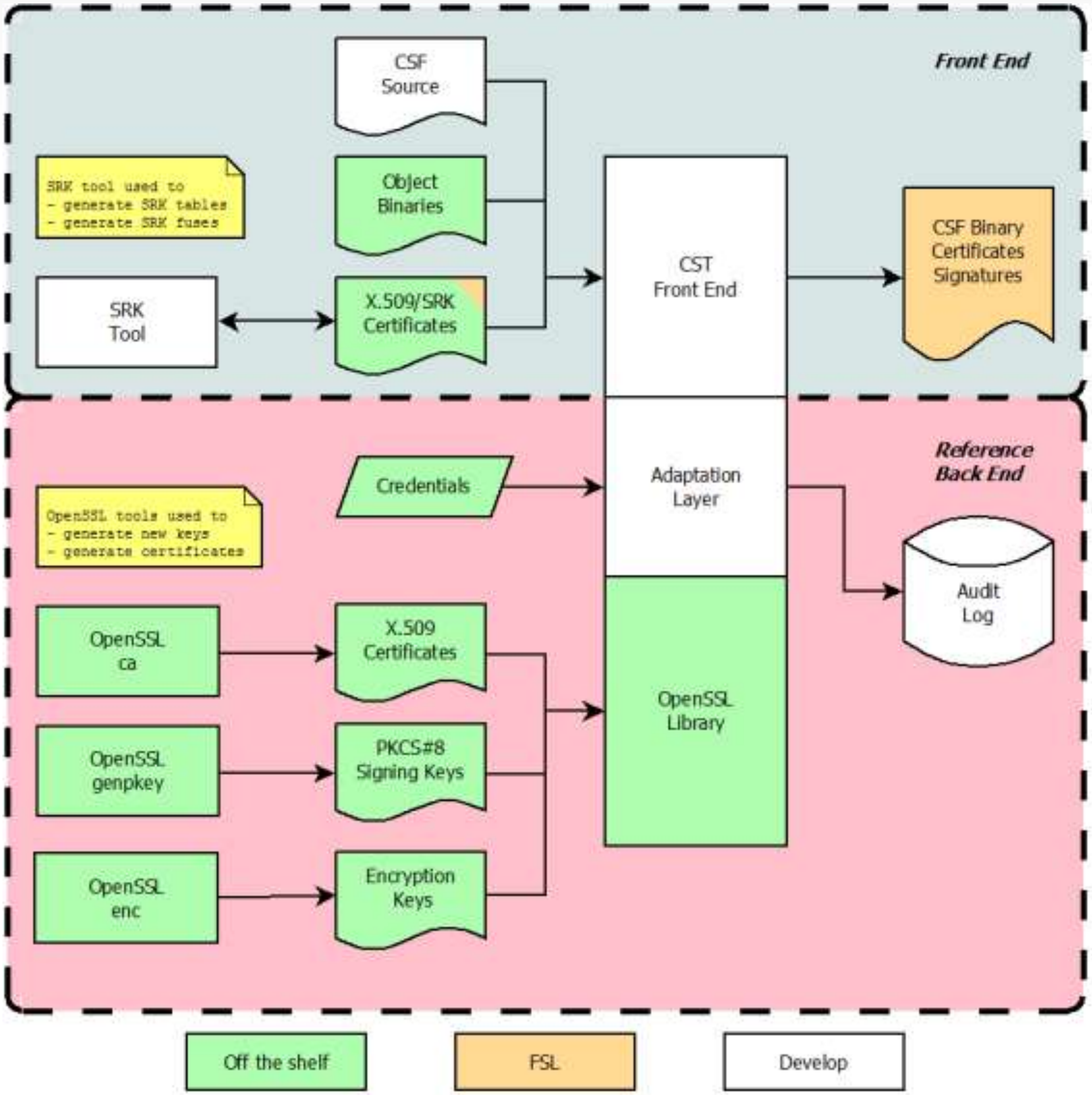
Reference CST Features

- Reference CST supports:
  - CA functionality: key and certificate generation
  - SA functionality: signature generation
  - Freescale specific functions: HAB Command Sequence File (CSF) generation
- Fully self contained application that runs on a Linux PC
  - Cryptographic algorithm support provided by OpenSSL but can be replaced.
- Private keys are password protected in an industry standard format (PKCS#8)

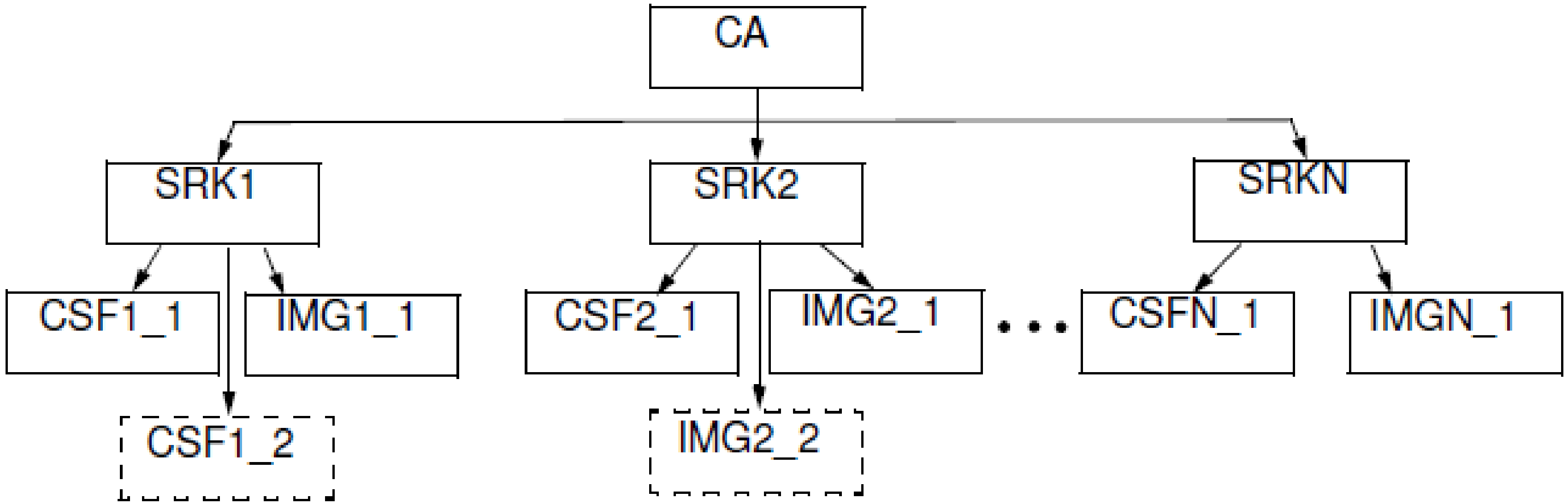
Freescale Reference Code Signing Tool



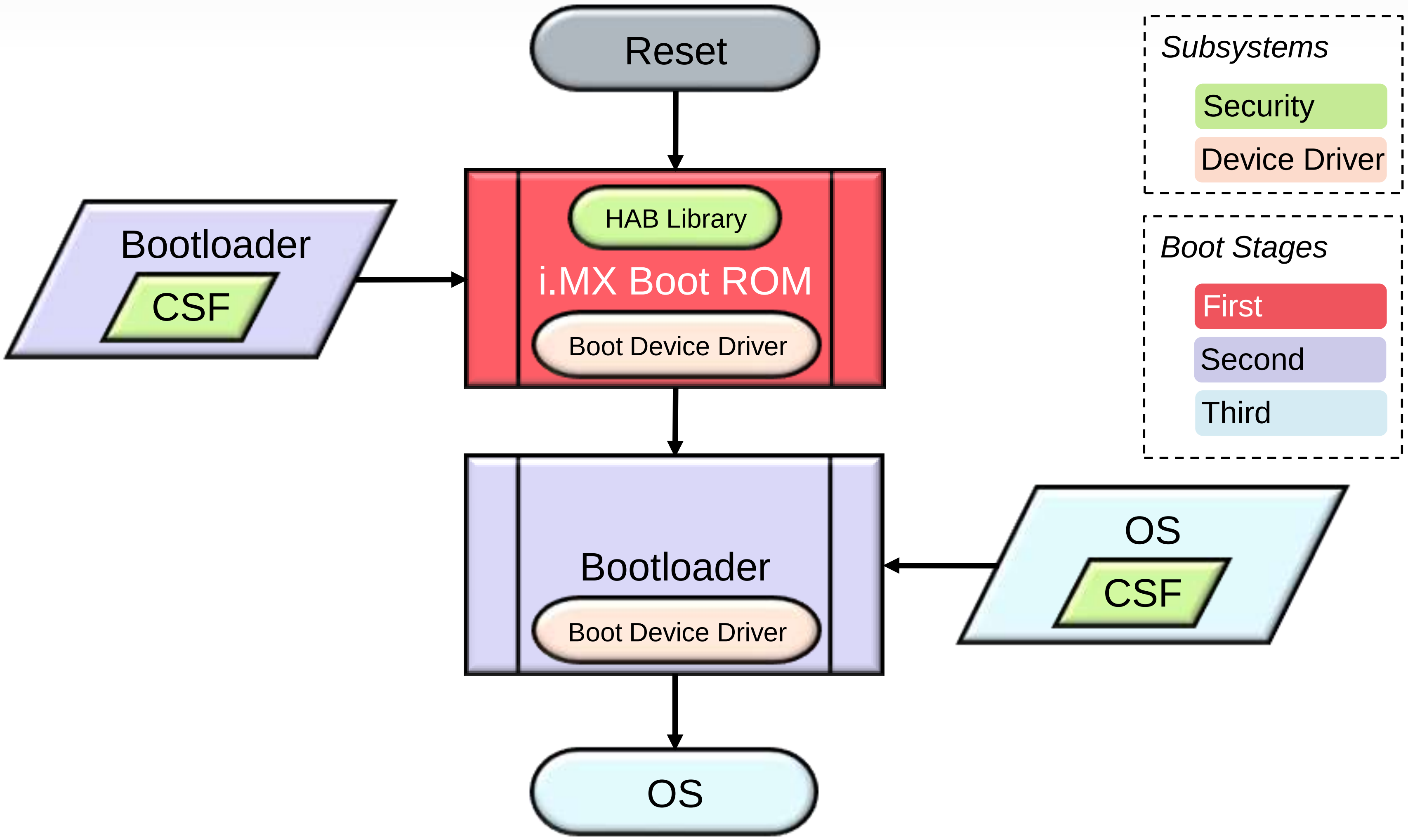
Code signing tools - reference



HAB PKI tree – CA Functionality

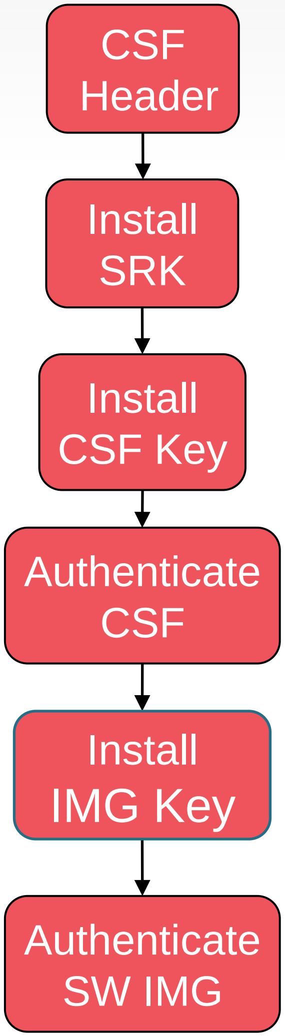


Simple Secure Boot Chain on i.MX



CSF Commands

- Defines the actions that HAB will perform
  - Install a public key
  - Verify a digital signature over a block of data
  - And others
- CSF commands are executed sequentially
- As long as the required areas are covered by a signature a CSF is valid
  - CSF author is responsible for ensuring all vital area are covered by a signature



Example CSF File

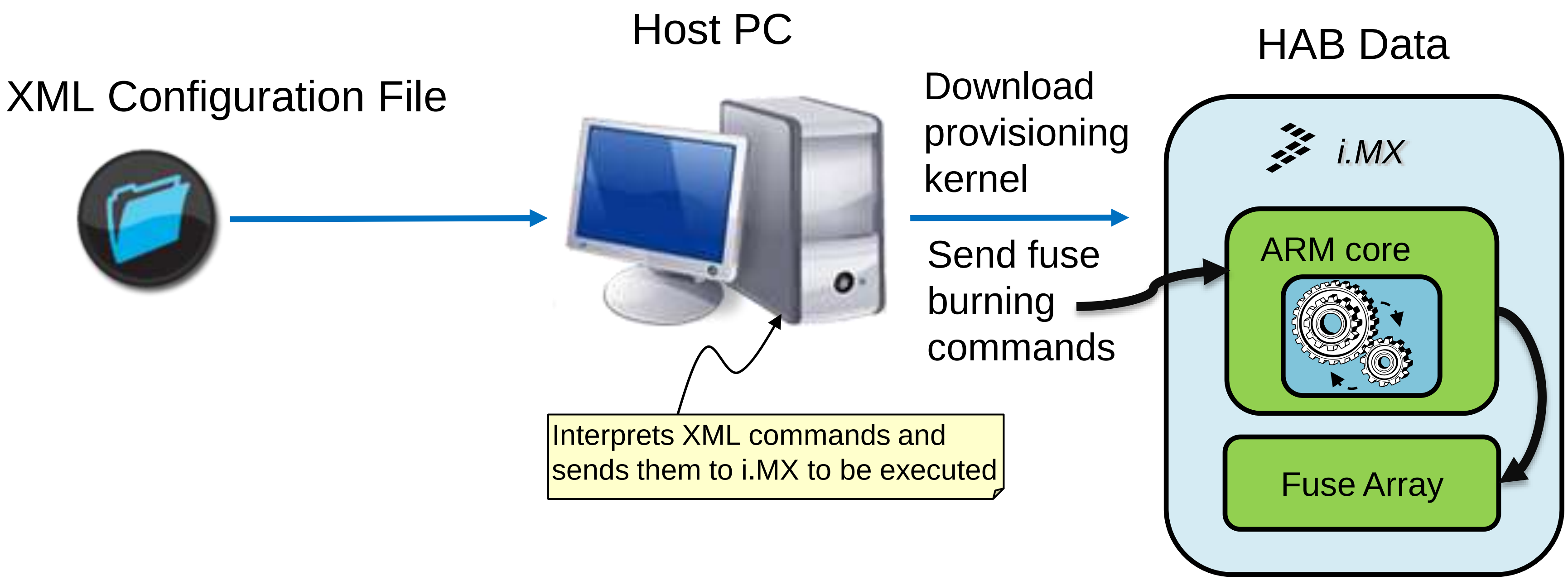
```
[Header]
    Version = 4.0
    Security Configuration = Open
    Hash Algorithm = sha256
    Engine Configuration = 0
    Certificate Format = X509
    Signature Format = CMS
[Install SRK]
    File = "../crts/SRK_1_2_3_4_table.bin"
    Source index = 0
[Install CSFK]
    File = "../crts/CSF1_1_sha256_2048_65537_v3_usr_crt.pem"
[Authenticate CSF]
[Install Key]
    Verification index = 0
    Target index = 2
    File = "../crts/IMG1_1_sha256_2048_65537_v3_usr_crt.pem"
# Sign padded u-boot starting at the IVT through to the end with
# length = 0x2F000 (padded u-boot length) - 0x400 (IVT offset) = 0x2EC00
# This covers the essential parts: IVT, boot data and DCD.
# Blocks have the following definition:
# Image block start address on i.MX, Offset from start of image file,
# Length of block in bytes, image data file
[Authenticate Data]
    Verification index = 2
    Blocks = 0x77800400 0x400 0x2EC00 "u-boot-pad.bin"
```

Manufacturing Tool

Manufacturing Tool Features

- Features in the context of secure boot include:
  - Image provisioning to boot device, e.g. NAND Flash, SD/MMC etc.
  - Uses Serial Download Protocol of i.MX boot ROM
  - Support for fuse burning. Examples include:
    - Security configuration
    - Root key hash
    - Root key revocation
    - Secure JTAG response field
    - and various fuse field lock bits

Manufacturing Tool (cont.)



i.MX 6SLX security

Anti hacking

Motivation for Isolation and Sharing

- The i.MX6 SLX is an AMP (asymmetric multi-processing) architecture that allows mutually exclusive software environments to execute on the Cortex-A9 and Cortex-M4 CPUs

- The i.MX6 SLX bus topology is designed for maximum flexibility to allow direct access to memory/peripherals by all masters (CPUs and peripheral bus masters)

- To protect the software environments from unintended or malicious interaction, it must be possible to “assign” memory/peripherals to a subset of the masters and protect these resources from unassigned masters

- To minimize die size and power, many SoC resources are shared. It must be possible to safely share resources that are accessible by multiple masters

Using Domains for Isolation and Sharing

- i.MX6 SLX provides a framework for isolation and sharing by allowing the system to be partitioned into a programmable set of domains

- For slave peripherals, read/write access permissions will be programmable for each domain

- Semaphore hardware is supported for slave peripherals shared between multiple domains to enable cooperative software to safely access shared peripherals. Optional enforcement of semaphores is provided by hardware. Access to shared peripherals without first obtaining the semaphore is rejected by hardware.

- Memory address spaces will support programmable set of regions with domain read/write access permissions defined for each region

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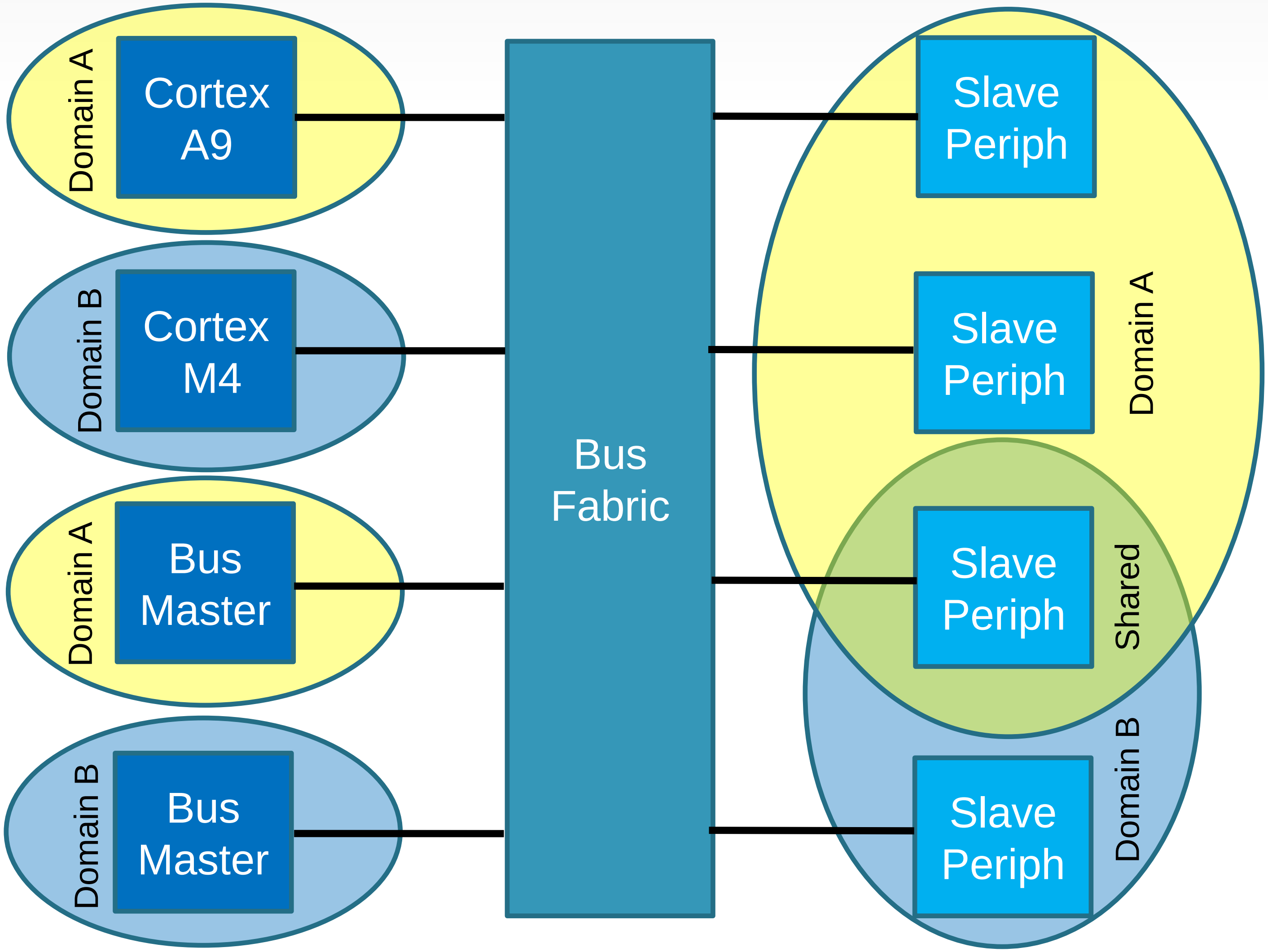
Peripheral Partitioning Using Domains



Example: Linux Secure Boot for i.MX6

Code Signing for i.MX6

- Covers the secure boot example that will be included in a future Linux BSP release.
- Following slides cover
  - Generating signing keys with the FSL reference CST
    - Including SRK table generation
    - SRK fuse blowing
  - Signing U-boot
  - Signing the kernel image to extend the secure boot chain

Generating Code Signing Keys and Certs

```
ra7944@kimball [View: ra7944_fsl_cst] - /vobs/cst/release/keys
[1]> ./hab4_pki_tree.sh

    +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
    This script is a part of the Code signing tools for Freescale's
    High Assurance Boot.  It generates a basic PKI tree.  The PKI
    tree consists of one or more Super Root Keys (SRK), with each
    SRK having two subordinate keys:
        + a Command Sequence File (CSF) key
        + Image key.
    Additional keys can be added to the PKI tree but a separate
    script is available for this.  This this script assumes openssl
    is installed on your system and is included in your search
    path.  Finally, the private keys generated are password
    protectedwith the password provided by the file key_pass.txt.
    The format of the file is the password repeated twice:
        my_password
        my_password
    All private keys in the PKI tree are in PKCS #8 format will be
    protected by the same password.

    +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
Do you want to use an existing CA key (y/n)?: n
Enter key length in bits for PKI tree: 2048
Enter PKI tree duration (years): 10
How many Super Root Keys should be generated? 4

+++++++++++++++++++++++++++++++++++++
+ Generating CA key and certificate +
+++++++++++++++++++++++++++++++++++++

Generating a 2048 bit RSA private key
.........................+++
..............................+++
writing new private key to 'temp_ca.pem'
-----

++++++++++++++++++++++++++++++++++++++++
+ Generating SRK key and certificate 1 +
++++++++++++++++++++++++++++++++++++++++

Generating RSA private key, 2048 bit long modulus
.........+++
.............................+++
e is 65537 (0x10001)
Using configuration from ../ca/openssl.cnf
Check that the request matches the signature
```

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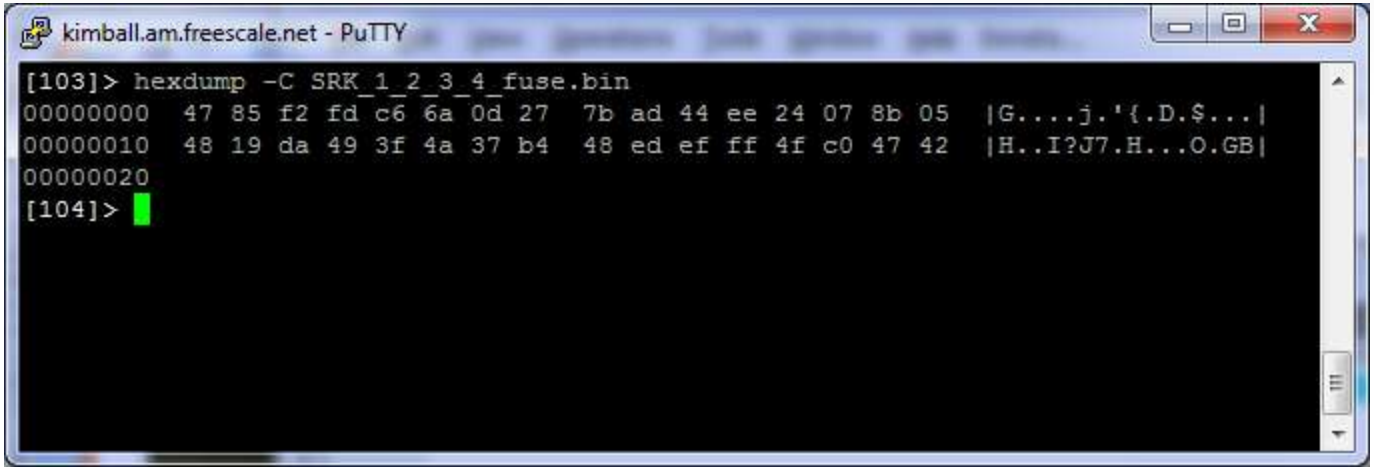
Generating SRK Table

```
ra7944@kimball [View: ra7944_fsl_cst] - /vobs/cst/release/crts
[112]> ../linux/srktool -h 4 -t SRK_1_2_3_4_table.bin -e SRK_1_2_3_4_fuse.bin -d sha25
6 -c ./SRK1_sha256_2048_65537_v3_ca_crt.pem,./SRK2_sha256_2048_65537_v3_ca_crt.pem,./S
RK3_sha256_2048_65537_v3_ca_crt.pem,./SRK4_sha256_2048_65537_v3_ca_crt.pem -f 1
[113]> ls -al SRK_1_2_3_4*
-rw-rw-r--   1 ra7944 devsrc   32 Nov 13 22:44 SRK_1_2_3_4_fuse.bin
-rw-rw-r--   1 ra7944 devsrc 1088 Nov 13 22:44 SRK_1_2_3_4_table.bin
[114]>
```

- Two files are generated:
  - SRK table: contains the SRK table contents which are included in the HAB data.
  - SRK fuse file: contains SHA256 result to be burned to fuses

Burning SRK fuses with Mfg tool for MX6



- Note the –C option to hexdump is ***essential!***
  - Otherwise the bytes will be in the wrong order
- Convert these bytes to little endian words:

```
0xfdf28547 0x270d6ac6 0xee44ad7b 0x058b0724
0x49da1948 0xb4374a3f 0xffefed48 0x4247c04f
```

Example Mfg tool XML script to blow SRK fuses

```
<LIST name="MX6Q Sabre-lite-SPI_NOR" desc="Choose SPI-NOR as media">
    <!--
        boot dip settings for SPI-NOR boot:
        SW26: dip 1, 4, 5, 6 are on. Others are off
        SW28: dip 5 is on. Others are off
    -->
    <CMD type="find" body="Recovery" timeout="180"/>
    <CMD type="boot" body="Recovery" file ="u-boot-mx6q-sabrelite.bin" >Loading uboot.</CMD>
    <CMD type="load" file="uImage" address="0x10800000"
             loadSection="OTH" setSection="OTH" HasFlashHeader="FALSE" >Doing Kernel.</CMD>
    <CMD type="load" file="initramfs.cpio.gz.uboot" address="0x10C00000"
             loadSection="OTH" setSection="OTH" HasFlashHeader="FALSE" >Doing Initramfs.</CMD>
    <CMD type="jump" > Jumping to OS image. </CMD>
    <CMD type="find" body="Updater" timeout="180"/>

    <!-- ***** Caution - running this xml script with the fuse burning commands uncommented
         ***** in the Mfg tool permanently burns fuses.  Once completed this operation cannot
         ***** be undone!
    -->
    <CMD type="push" body="$ echo 0xfdf28547 > /sys/fsl_otp/HW_OCOTP_SRK0">Burn Word 0 of SRK hash field in OTP </CMD>
    <CMD type="push" body="$ echo 0x270d6ac6 > /sys/fsl_otp/HW_OCOTP_SRK1">Burn Word 1 of SRK hash field in OTP </CMD>
    <CMD type="push" body="$ echo 0xee44ad7b > /sys/fsl_otp/HW_OCOTP_SRK2">Burn Word 2 of SRK hash field in OTP </CMD>
    <CMD type="push" body="$ echo 0x058b0724 > /sys/fsl_otp/HW_OCOTP_SRK3">Burn Word 3 of SRK hash field in OTP </CMD>
    <CMD type="push" body="$ echo 0x49da1948 > /sys/fsl_otp/HW_OCOTP_SRK4">Burn Word 4 of SRK hash field in OTP </CMD>
    <CMD type="push" body="$ echo 0xb4374a3f > /sys/fsl_otp/HW_OCOTP_SRK5">Burn Word 5 of SRK hash field in OTP </CMD>
    <CMD type="push" body="$ echo 0xffefed48 > /sys/fsl_otp/HW_OCOTP_SRK6">Burn Word 6 of SRK hash field in OTP </CMD>
    <CMD type="push" body="$ echo 0x4247c04f > /sys/fsl_otp/HW_OCOTP_SRK7">Burn Word 7 of SRK hash field in OTP </CMD>

    <CMD type="push" body="$ cat /sys/fsl_otp/HW_OCOTP_SRK0"/>
    <CMD type="push" body="$ cat /sys/fsl_otp/HW_OCOTP_SRK1"/>
    <CMD type="push" body="$ cat /sys/fsl_otp/HW_OCOTP_SRK2"/>
    <CMD type="push" body="$ cat /sys/fsl_otp/HW_OCOTP_SRK3"/>
    <CMD type="push" body="$ cat /sys/fsl_otp/HW_OCOTP_SRK4"/>
    <CMD type="push" body="$ cat /sys/fsl_otp/HW_OCOTP_SRK5"/>
    <CMD type="push" body="$ cat /sys/fsl_otp/HW_OCOTP_SRK6"/>
    <CMD type="push" body="$ cat /sys/fsl_otp/HW_OCOTP_SRK7"/>
</LIST>
</UCL>
```

Fuse Burning Hints and Warnings:

- Need to update XML script to match generated SRK fuse file contents
- Experiment with burning on non-essential first
  - Especially important for boards that do no have a CPU socket!
  - General Purpose fuse field is a good place to start. For example:

```
<!-- **** The following is a simple example to burn bit 0 of the GP1 field. The
     **** results can also be verified by the u-boot command:
     **** "md.l 0x021bc600 1"-->
<CMD type="push" body="$ cat /sys/fsl_otp/HW_OCOTP_GP1"/>
<CMD type="push" body="$ cat /sys/fsl_otp/HW_OCOTP_GP2"/>
<CMD type="push" body="$ echo 0x00000001 > /sys/fsl_otp/HW_OCOTP_GP1">Burn bit0 of GP1 at OTP</CMD>
<CMD type="push" body="$ cat /sys/fsl_otp/HW_OCOTP_GP1"/>
<CMD type="push" body="$ cat /sys/fsl_otp/HW_OCOTP_GP2"/>
```

- MX6 does not check SRK hash when sec_config = OPEN
  - A CR has been raised and will be fixed in future HAB versions
- **Do Not blow sec_config field to CLOSED unless absolutely sure!**

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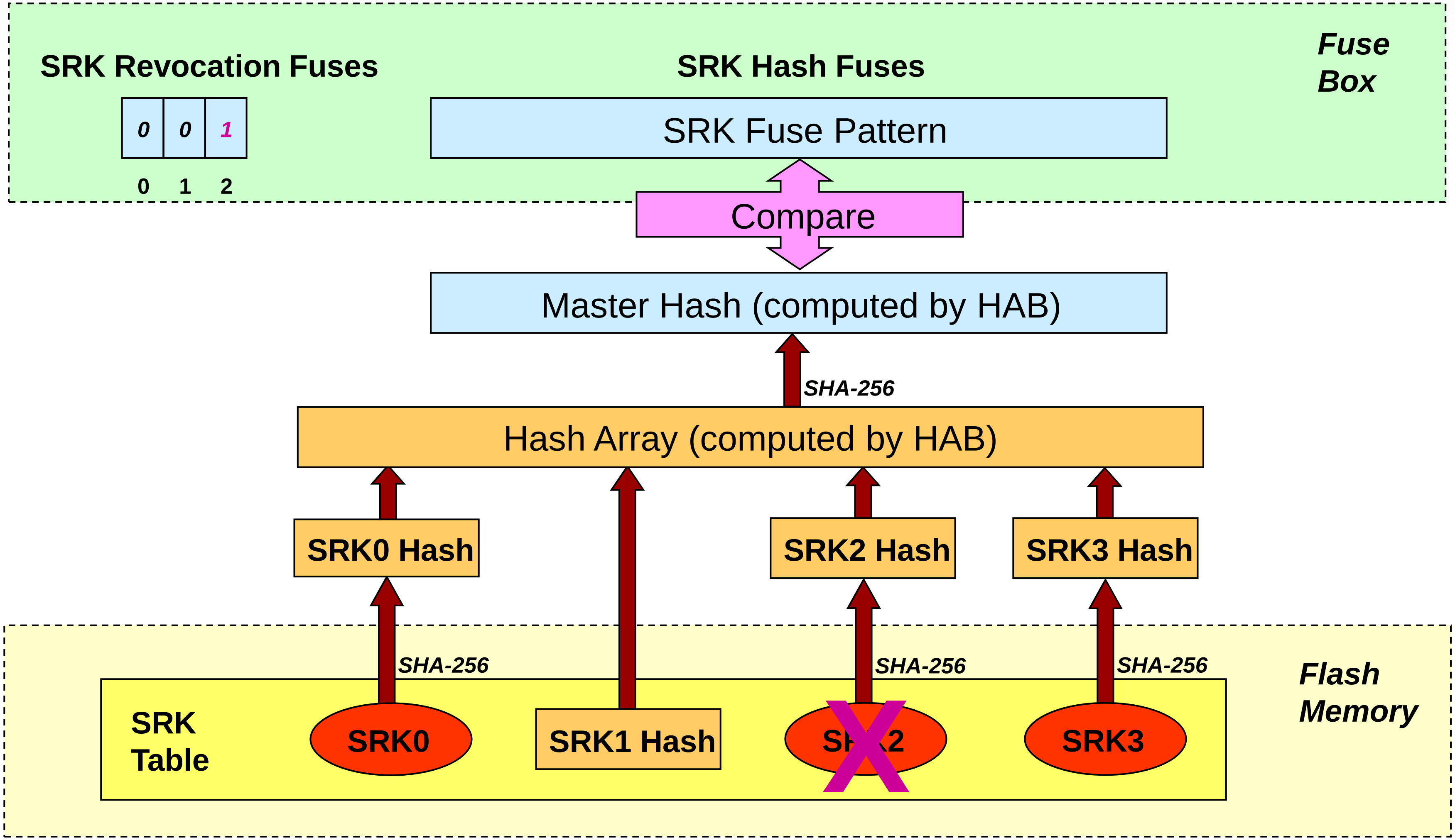
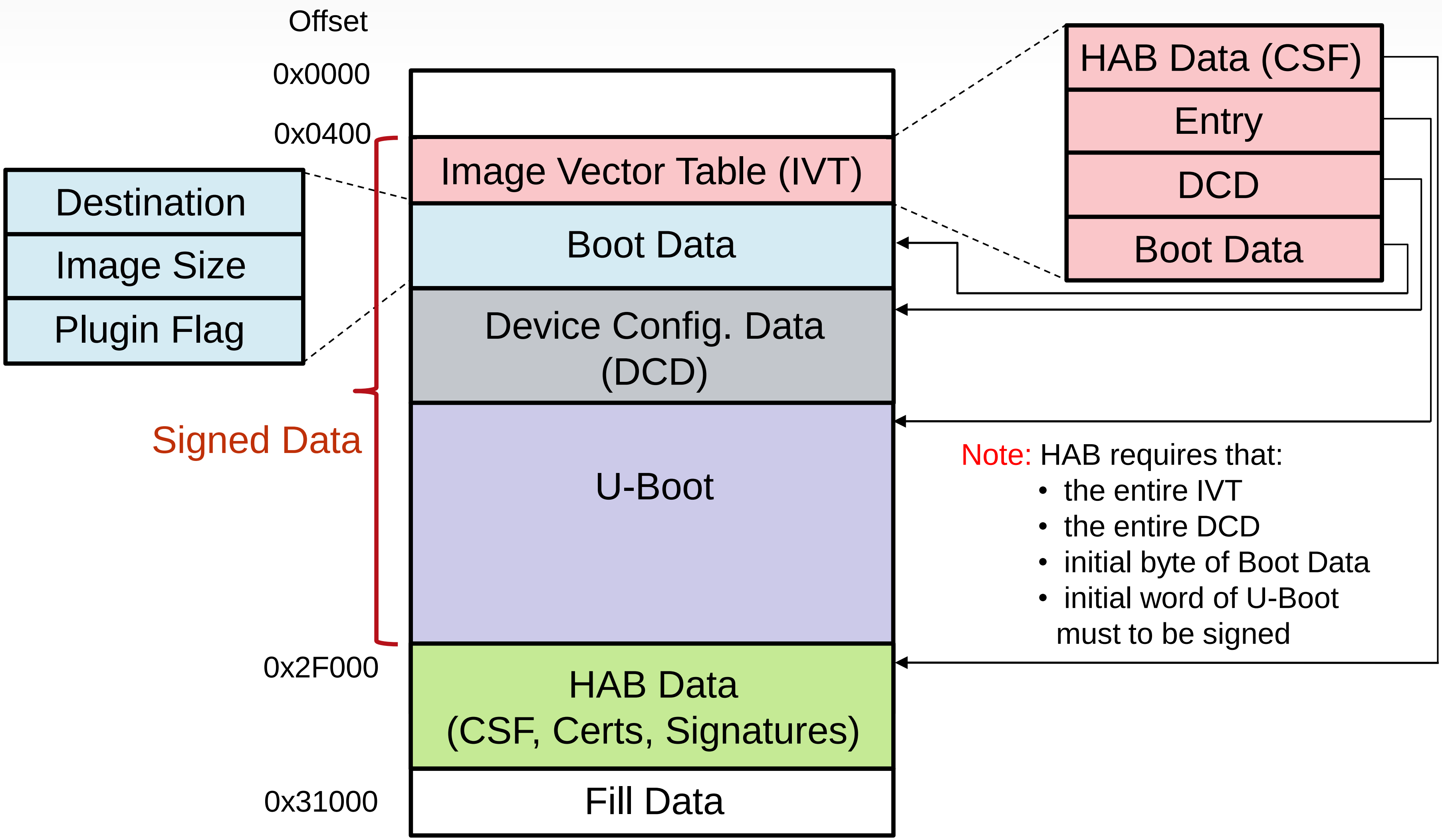
HAB4 SRK Revocation



U-Boot Image on i.MX6 for SD Boot



Note: HAB requires that:

- the entire IVT
- the entire DCD
- initial byte of Boot Data
- initial word of U-Boot

must to be signed

U-boot CSF Description file

```
[Header]
        Version = 4.0
        Security Configuration = Open        <---- Optional for HAB4
        Hash Algorithm = sha256
        Engine Configuration = 0
        Certificate Format = X509
        Signature Format = CMS
[Install SRK]
        File = "../crts/SRK_1_2_3_4_table.bin"
        Source index = 0
[Install CSFK]
        File = "../crts/CSF1_1_sha256_2048_65537_v3_usr_crt.pem"
[Authenticate CSF]
[Install Key]
        Verification index = 0
        Target index = 2
File = "../crts/IMG1_1_sha256_2048_65537_v3_usr_crt.pem"
# Sign padded u-boot starting at the IVT through to the end with
# length = 0x2F000 (padded u-boot length) - 0x400 (IVT offset) = 0x2EC00
# This covers the essential parts: IVT, boot data and DCD.
# Blocks have the following definition:
# Image block start address on i.MX, Offset from start of image file,
# Length of block in bytes, image data file
[Authenticate Data]
        Verification index = 2
        Blocks = 0x77800400 0x400 0x2EC00 "u-boot-pad.bin"
```

u-Boot Signing Script

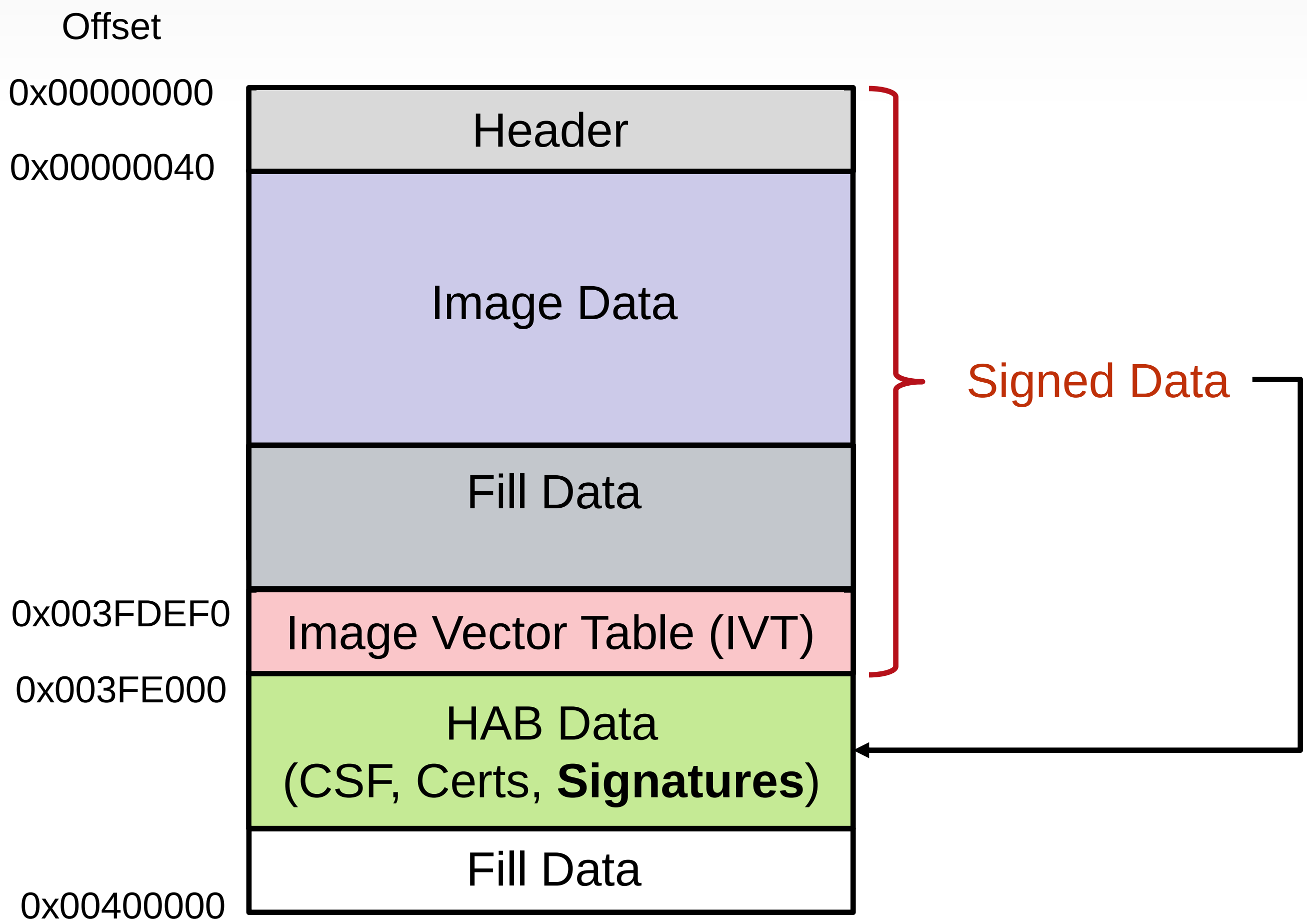
```
#! /bin/bash
echo "extend u-boot to 0x2F000..."
objcopy -I binary -O binary --pad-to 0x2f000 --gap-fill=0xff u-boot.bin u-boot-pad.bin

echo "generate csf data..."
../linux/cst --o u-boot_csf.bin < u-boot.csf

echo "merge image and csf data..."
cat u-boot-pad.bin u-boot_csf.bin > u-boot-signed.bin

echo "extend final image to 0x31000..."
objcopy -I binary -O binary --pad-to 0x31000 --gap-fill=0xff u-boot-signed.bin \
u-boot-signed-pad.bin
echo "u-boot-signed-pad.bin is ready"
```

uImage Memory Map for i.MX6



uImage CSF Description file

```
[Header]
        Version = 4.0
        Security Configuration = Open        <-- Optional for HAB4
        Hash Algorithm = sha256
        Engine Configuration = 0
        Certificate Format = X509
        Signature Format = CMS
[Install SRK]
        File = "../crts/SRK_1_2_3_4_table.bin"
        Source index = 0
[Install CSFK]
        File = "../crts/CSF1_1_sha256_2048_65537_v3_usr_crt.pem"
[Authenticate CSF]
[Install Key]
        Verification index = 0
        Target index = 2
        File = "../crts/IMG1_1_sha256_2048_65537_v3_usr_crt.pem"
# Sign padded uImage start at address 0x10800000
# length = 0x3FE0000
# This covers the essential parts: original uImage and the attached IVT
# Blocks have the following definition:
# Image block start address on i.MX, Offset from start of image file,
# Length of block in bytes, image data file [Authenticate Data]
[Authenticate Data]
        Verification index = 2
        Blocks = 0x10800000 0x0 0x003FE000 "uImage-pad-ivt.bin"
```

uImage IVT Generation (genIVT)

```
#! /usr/bin/perl -w
use strict;
open(my $out, '>:raw', 'ivt.bin') or die "Unable to open: $!";
print $out pack("V", 0x402000D1); # Signature
print $out pack("V", 0x10801000); # Jump Location
print $out pack("V", 0x0); # Reserved
print $out pack("V", 0x0); # DCD pointer
print $out pack("V", 0x0); # Boot Data
print $out pack("V", 0x10BFDFE0); # Self Pointer
print $out pack("V", 0x10BFE000); # CSF Pointer
print $out pack("V", 0x0); # Reserved
close($out);
```

uImage Signing Script

```
#! /bin/bash
echo "extend uImage to 0x3FDFE0..."
objcopy -I binary -O binary --pad-to 0x3fdfe0 --gap-fill=0xff uImage uImage-
pad.bin

echo "generate IVT"
./genIVT
echo "attach IVT..."
cat uImage-pad.bin ivt.bin > uImage-pad-ivt.bin

echo "generate csf data..."
../linux/cst --o uImage_csf.bin < uImage.csf

echo "merge image and csf data..."
cat uImage-pad-ivt.bin uImage_csf.bin > uImage-signed.bin

echo "extend final image to 0x400000..."
objcopy -I binary -O binary --pad-to 0x400000 --gap-fill=0xff uImage-signed.bin \
uImage-signed-pad.bin
```

- Provision uImage-signed-pad.bin to the SD card and boot the board