IMXLUG

i.MX Linux User's Guide

Rev. LF5.15.71_2.2.0 — **User guide**
16 December 2022

Document information

Information	Content
Keywords	i.MX, Linux, LF5.15.71_2.2.0
Abstract	This document describes how to build and install the i.MX Linux OS BSP, where BSP stands for Board Support Package, on the i.MX platform. It also covers special i.MX features and how to use them.

1 Overview

This document describes how to build and install the i.MX Linux OS BSP, where BSP stands for Board Support Package, on the i.MX platform. It also covers special i.MX features and how to use them.

The document also provides the steps to run the i.MX platform, including board DIP switch settings, and instructions on configuring and using the U-Boot bootloader.

The later chapters describe how to use some i.MX special features when running the Linux OS kernel.

Features covered in this guide may be specific to particular boards or SoCs. For the capabilities of a particular board or SoC, see the *i.MX Linux Release Notes* (IMXLXRN).

1.1 Audience

This document is intended for software, hardware, and system engineers who are planning to use the product, and for anyone who wants to know more about the product.

1.2 Conventions

This document uses the following conventions:

- `Courier New` font: This font is used to identify commands, explicit command parameters, code examples, expressions, data types, and directives.

1.3 Supported hardware SoCs and boards

These are the systems covered in this guide:

- i.MX 6Quad SABRE-SD board and platform
- i.MX 6DualLite SABRE-SD platform
- i.MX 6SoloX SABRE-SD platform
- i.MX 7Dual SABRE-SD platform
- i.MX 6QuadPlus SABRE-SD platform
- i.MX 6UltraLite EVK platform
- i.MX 6ULL EVK platform
- i.MX 6ULZ EVK platform
- i.MX 7ULP EVK platform
- i.MX 8QuadMax MEK board
- i.MX 8QuadXPlus MEK platform
- i.MX 8DualXLite EVK Platform
- i.MX 8M Quad EVK platform
- i.MX 8M Mini EVK Board
- i.MX 8M Nano EVK Board
- i.MX 8M Plus EVK board
- i.MX 8DualX MEK Board
- i.MX 8ULP EVK Board
- i.MX 93 EVK board

Some abbreviations are used in places in this document.

- SABRE-SD refers to the i.MX 6Quad SABRE-SD, i.MX 6DualLite SABRE-SD, i.MX 6QuadPlus SABRE-SD, and i.MX 7Dual SABRE-SD boards.
- SoloX or SX refers to the i.MX 6SoloX SABRE-SD boards.
- 6UL refers to the i.MX 6UltraLite board.
- 6ULL refers to the i.MX 6ULL board.
- 6ULZ refers to the i.MX 6ULZ board.
- 7ULP refers to the i.MX 7Ultra Low Power platform.
- 8QXP refers to the 8QuadXPlus platform.
- 8QM refers to the 8QuadMax platform.
- 8MQ refers to the 8M Quad platform.
- 8MM refers to the 8M Mini platform.
- 8MN refers to the 8M Nano platform.
- 8MP refers to the 8M Plus platform.
- 8DXL refers to the 8DualXLite platform.
- 8DX refers to the 8DualX platform.
- 8ULP refers to the i.MX 8Ultra Low Power platform.
- i.MX 93 refers to the i.MX 93 EVK board.

1.4 References

i.MX has multiple families supported in software. The following are the listed families and SoCs per family. The i.MX Linux Release Notes describes which SoC is supported in the current release. Some previously released SoCs might be buildable in the current release but not validated if they are at the previous validated level.

- i.MX 6 Family: 6QuadPlus, 6Quad, 6DualLite, 6SoloX, 6SLL, 6UltraLite, 6ULL, 6ULZ
- i.MX 7 Family: 7Dual, 7ULP
- i.MX 8 Family: 8QuadMax, 8ULP
- i.MX 8M Family: 8M Plus, 8M Quad, 8M Mini, 8M Nano
- i.MX 8X Family: 8QuadXPlus, 8DualXLite, 8DualX
- i.MX 9 Family: i.MX 93

This release includes the following references and additional information.

- *i.MX Linux Release Notes* (IMXLXRN) - Provides the release information.
- *i.MX Linux User's Guide* (IMXLUG) - Provides the information on installing U-Boot and Linux OS and using i.MX-specific features.
- *i.MX Yocto Project User's Guide* (IMXLXYOCTOUG) - Describes the board support package for NXP development systems using Yocto Project to set up host, install tool chain, and build source code to create images.
- *i.MX Machine Learning User's Guide* (IMXMLUG) - Provides the machine learning information.
- *i.MX Linux Reference Manual* (IMXLXRM) - Provides the information on Linux drivers for i.MX.
- *i.MX Graphics User's Guide* (IMXGRAPHICUG) - Describes the graphics features.
- *i.MX Porting Guide* (IMXXBSPPG) - Provides the instructions on porting the BSP to a new board.
- *i.MX VPU Application Programming Interface Linux Reference Manual* (IMXVPUAPI) - Provides the reference information on the VPU API on i.MX 6 VPU.
- *Harpoon User's Guide* (IMXHPUG) - Presents the Harpoon release for i.MX 8M device family.

- *i.MX Digital Cockpit Hardware Partitioning Enablement for i.MX 8QuadMax* (IMXDCHPE) - Provides the i.MX Digital Cockpit hardware solution for i.MX 8QuadMax.
- *i.MX DSP User's Guide* (IMXDSPUG) - Provides the information on the DSP for i.MX 8.
- *i.MX 8M Plus Camera and Display Guide* (IMX8MPCDUG) - Provides the information on the ISP Independent Sensor Interface API for the i.MX 8M Plus.

The quick start guides contain basic information on the board and setting it up. They are on the NXP website.

- SABRE Platform Quick Start Guide (IMX6QSDPQSG)
- SABRE Board Quick Start Guide (IMX6QSDBQSG)
- i.MX 6UltraLite EVK Quick Start Guide (IMX6ULTRALITEQSG)
- i.MX 6ULL EVK Quick Start Guide (IMX6ULLQSG)
- SABRE Automotive Infotainment Quick Start Guide (IMX6SABREINFOQSG)
- i.MX 7Dual SABRE-SD Quick Start Guide (SABRESDBIMX7DUALQSG)
- i.MX 8M Quad Evaluation Kit Quick Start Guide (IMX8MQUADEVKQSG)
- i.MX 8M Mini Evaluation Kit Quick Start Guide (8MMINIEVKQSG)
- i.MX 8M Nano Evaluation Kit Quick Start Guide (8MNANOEVKQSG)
- i.MX 8QuadXPlus Multisensory Enablement Kit Quick Start Guide (IMX8QUADXPLUSQSG)
- i.MX 8QuadMax Multisensory Enablement Kit Quick Start Guide (IMX8QUADMAXQSG)
- i.MX 8M Plus Evaluation Kit Quick Start Guide (IMX8MPLUSQSG)

Documentation is available online at nxp.com.

- i.MX 6 information is at nxp.com/iMX6series
- i.MX SABRE information is at nxp.com/imxSABRE
- i.MX 6UltraLite information is at nxp.com/iMX6UL
- i.MX 6ULL information is at nxp.com/iMX6ULL
- i.MX 7Dual information is at nxp.com/iMX7D
- i.MX 7ULP information is at nxp.com/imx7ulp
- i.MX 8 information is at nxp.com/imx8
- i.MX 6ULZ information is at nxp.com/imx6ulz

2 Introduction

The i.MX Linux BSP is a collection of binary files, source code, and support files that can be used to create a U-Boot bootloader, a Linux kernel image, and a root file system for i.MX development systems. The Yocto Project is the framework of choice to build the images described in this document, although other methods can be used.

All the information on how to set up the Linux OS host, how to run and configure a Yocto Project, generate an image, and generate a rootfs, are covered in the *i.MX Yocto Project User's Guide* (IMXLXYOCTOUG).

When Linux OS is running, this guide provides information on how to use some special features that i.MX SoCs provide. The release notes provide the features that are supported on a particular board.

3 Basic Terminal Setup

The i.MX boards can communicate with a host server (Windows OS or Linux OS) using a serial cable. Common serial communication programs such as HyperTerminal, Tera Term, or PuTTY can be used. The example below describes the serial terminal setup using HyperTerminal on a host running Windows OS.

The i.MX 6Quad/QuadPlus/DualLite SABRE-AI boards connect to the host server using a serial cable.

The other i.MX boards connect the host driver using the micro-B USB connector.

1. Connect the target and the PC running Windows OS using a cable mentioned above.
2. Open HyperTerminal on the PC running Windows OS and select the settings as shown in the following figure.

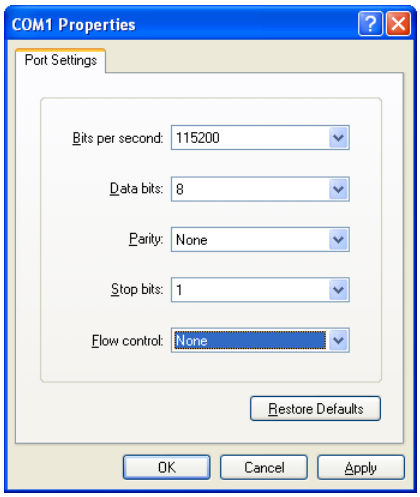


Figure 1. Teraterm settings for terminal setup

The i.MX 8 board connects the host driver using the micro USB connector. The USB to serial driver can be found under www.ftdichip.com/Drivers/VCP.htm. The FT4232 USB to serial converter provides four serial ports. The i.MX 8 board uses the first port for the Arm Cortex-A cores console and the second port for SCU's console. Users need to select the first port (COM) in the terminal setup. The i.MX 8DXL board uses the third and fourth ports respectively for Arm Cortex-A cores console and SCU console.

4 Booting Linux OS

Before booting the Linux OS kernel on an i.MX board, copy the images (U-Boot, Linux kernel, device tree, and rootfs) to a boot device and set the boot switches to boot that device. There are various ways to boot the Linux OS for different boards, boot devices, and results desired. This section describes how to prepare a boot device, where files need to be in the memory map, how to set switches for booting, and how to boot Linux OS from U-Boot.

4.1 Software overview

This section describes the software needed for the board to be able to boot and run Linux OS.

To boot a Linux image on i.MX 6 and i.MX 7, the following elements are needed:

- Bootloader (U-Boot)
- Linux kernel image (zImage)
- A device tree file (`.dtb`) for the board being used
- A root file system (`rootfs`) for the particular Linux image
- Arm Cortex-M4 image for i.MX 7ULP

To boot a Linux image on i.MX 8QuadMax, i.MX 8QuadXPlus, and i.MX 8DXL, multiple elements are needed:

- Bootloader (`imx-boot` built by `imx-mkimage`, which is a tool that combines firmware and U-Boot to create a bootloader for i.MX 8), which includes U-Boot, Arm Trusted Firmware, DCD file, System controller firmware, and the SECO firmware since i.MX 8QuadMax/i.MX 8QuadXPlus B0 and i.MX 8DXL A1.
- (Optional) Arm Cortex-M4 image
- Linux kernel image (Image built by `linux-imx`)
- A device tree file (`.dtb`) for the board being used
- A root file system (`rootfs`) for the particular Linux image

On i.MX 8M Quad, i.MX 8M Mini, i.MX 8M Nano, and i.MX 8M Plus, multiple elements are needed:

- `imx-boot` (built by `imx-mkimage`), which includes SPL, U-Boot, Arm Trusted Firmware, DDR firmware
- HDMI firmware (only supported by i.MX 8M Quad)
- Linux kernel image
- A device tree file (`.dtb`) for the board being used.
- A root file system (`rootfs`) for the particular Linux image

On i.MX 8ULP, four elements are needed:

- `imx-boot` (built by `imx-mkimage`), which includes SPL, U-Boot, Arm Trusted Firmware, OP-TEE, uPower Firmware, Sentinel Firmware, and Arm Cortex-M33 image
- Linux kernel image
- A device tree file (`.dtb`) for the board being used
- A root file system (`rootfs`) for the particular Linux image

On i.MX 93, multiple elements are needed:

- `imx-boot` (built by `imx-mkimage`), which includes SPL, U-Boot, Arm Trusted Firmware, OP-TEE, Sentinel Firmware, DDR PHY Firmware
- Linux kernel image
- (Optional) Arm Cortex-M33 image
- A device tree file (`.dtb`) for the board being used
- A root file system (`rootfs`) for the particular Linux image

The system can be configured for a specific graphical backend. For i.MX 8, the graphical backend is XWayland. For i.MX 7ULP, the default backend is XWayland.

4.1.1 Bootloader

U-Boot is the tool recommended as the bootloader for i.MX 6 and i.MX 7. i.MX 8 and i.MX 9 require a bootloader that includes U-Boot as well as other components described below. U-Boot must be loaded onto a device to be able to boot from it. U-Boot images are board-specific and can be configured to support booting from different sources.

The pre-built or Yocto project default bootloader names start with the name of the bootloader followed by the name of the platform and board and followed by the name of the device that this image is configured to boot from: `u-boot-[platform][board]_[machine_configuration].bin`. If no boot device is specified, it boots from SD/MMC.

The manufacturing tool can be used to load U-Boot onto all devices with i.MX 6 and i.MX 7. U-Boot can be loaded directly onto an SD card using the Linux `dd` command. U-Boot can be used to load a U-Boot image onto some other devices.

On i.MX 8, the U-Boot cannot boot the device by itself. The i.MX 8 pre-built images or Yocto Project default bootloader is `imx-boot` for the SD card, which is created by the `imx-mkimage`. The `imx-boot` binary includes the U-Boot, Arm trusted firmware, DCD file (8QuadMax/8QuadXPlus/8DXL), system controller firmware (8QuadMax/8QuadXPlus/8DXL), SPL (8M SoC), DDR firmware (8M), HDMI firmware (8M Quad), and SECO firmware (8QuadMax/8QuadXPlus/8DXL).

On i.MX 8M SoC, the second program loader (SPL) is enabled in U-Boot. SPL is implemented as the first-level bootloader running on TCML (For i.MX 8M Nano and i.MX 8M Plus, the first-level bootloader runs in OCRAM). It is used to initialize DDR and load U-Boot, U-Boot DTB, Arm trusted firmware, and TEE OS (optional) from the boot device into the memory. After SPL completes loading the images, it jumps to the Arm trusted firmware BL31 directly. The BL31 starts the optional BL32 (TEE OS) and BL33 (U-Boot) for continue booting kernel.

In `imx-boot`, the SPL is packed with DDR Firmware together, so that ROM can load them into Arm Cortex-M4 TCML or OCRAM (only for i.MX 8M Nano and i.MX 8M Plus). The U-Boot, U-Boot DTB, Arm Trusted firmware, and TEE OS (optional) are packed into a FIT image, which is finally built into `imx-boot`.

4.1.2 Linux kernel image and device tree

This i.MX BSP contains a pre-built kernel image based on the 5.15.71 version of the Linux kernel and the device tree files associated with each platform.

The same kernel image is used for all the i.MX 6 and i.MX 7 with name zImage. Device trees are tree data structures, which describe the hardware configuration allowing a common kernel to be booted with different pin settings for different boards or configurations. Device tree files use the `.dtb` extension. The configuration for a device tree can be found in the Linux source code under `arch/arm/boot/dts` in the `*.dts` files.

The i.MX Linux delivery package contains pre-built device tree files for the i.MX boards in various configurations. Filenames for the prebuilt images are named `Image-[platform]-[board]-[configuration].dtb`. For example, the device tree file of the i.MX 8QuadMax MEK board is `Image-imx8qm-mek.dtb`.

For i.MX 6 and i.MX 7, the `*ldo.dtb` device trees are used for LDO-enabled feature support. By default, the LDO bypass is enabled. If your board has the CPU set to 1.2 GHz, you should use the `*ldo.dtb` device tree instead of the default, because LDO bypass mode is not supported on the CPU at 1.2 GHz. The device tree `*hdcp.dtb` is used to enable the HDCP feature because of a pin conflict, which requires this to be configured at build time.

On i.MX 8, i.MX 8M, i.MX 8ULP, and i.MX93, the kernel is 64 bit and device trees are located in the `arch/arm64/boot/dts/freescale` folder and use the dts extension.

The kernel is built using linux-imx software provided in the release package and the filename starting with `Image`.

4.1.3 Root file system

The root file system package (or rootfs) provides busybox, common libraries, and other fundamental elements.

The i.MX BSP package contains several root file systems. They are named with the following convention: `[image name]-[backend]-[platform][board].[ext4|wic]`. The ext4 extension indicates a standard file system. It can be mounted as NFS, or its contents can be stored on a boot media such as an SD/MMC card.

The graphical backend to be used is also defined by the rootfs.

4.2 Universal update utility

The Universal Update Utility (UUU) runs on a Windows or Linux OS host and is used to download images to different devices on an i.MX board.

4.2.1 Downloading UUU

Download UUU version 1.4.243 or later from https://github.com/NXPmicro/mfgtools/releases.

4.2.2 Using UUU

To use the UUU for i.MX 6, i.MX 7, i.MX 8, and i.MX 9, follow the instructions below:

1. Connect a USB cable from a computer to the USB OTG/TYPE C (or Micro-B, depending on board) port on the board for download link.
2. Connect a USB cable from the OTG-to-UART port to the computer for console output.
3. Open a Terminal emulator program. See Section "Section 3" in this document.
4. Set the boot pin to serial download mode mode. See Section "Section 4.5.11" in this document.

To use the UUU for i.MX 8ULP EVK, follow the instructions below:

- To burn single-boot image and rootfs to eMMC, run the following command:

```
uuu -b emmc_all imx-boot-imx8ulpevk-sd.bin-
flash_singleboot_m33 <rootfs.wic.zst>
```

- To burn single-boot image to FlexSPI2 NOR flash, run the following command:

```
uuu -b qspi imx-boot-imx8ulpevk-fspi.bin-
flash_singleboot_m33_flexspi
```

- To burn dual-boot image and rootfs to eMMC and FlexSPI0 NOR flash, perform the following steps:
  1. Prepare `imx-boot-imx8ulpevk-sd.bin-flash_singleboot_m33`, `imx-boot-imx8ulpevk-sd.bin-flash_dualboot`, `imx-boot-imx8ulpevk-sd.bin-flash_dualboot_m33`, and `<rootfs.wic>`.
  2. Update the UUU script file `uuu_8ulp_dual.auto` with the file path and name of the images above.

3. Run `uuu mfgtools/scripts/samples/uuu_8ulp_dual.auto`.

For detailed usage of UUU, see github.com/NXPmicro/mfgtools/wiki.

For example, the following command writes `rootfs.wic` into eMMC.

```
uuu -b emmc_all <bootloader> <rootfs.wic>
```

The following command decompresses `zst` file and writes into eMMC:

```
uuu -b emmc_all <bootloader> <rootfs.wic.zst/*>
```

The following command executes downloading and bootloader (SPL and U-Boot) by USB:

```
uuu -b spl <bootloader>
```

The following command burns into eMMC (If only one board is supported in such a release package and the board supports eMMC chip):

```
uuu <release package>.zip
```

Note:

For i.MX 8QuadXPlus B0, UUU flashes the eMMC image to boot partition with 32 KB offset. It may not be compatible with all eMMC devices. It is recommended to enable eMMC fastboot mode and use the UUU kernel version script to flash the eMMC image to boot partition with 0 offset.

4.3 Preparing an SD/MMC card to boot

This section describes the steps to prepare an SD/MMC card to boot up an i.MX board using a Linux host machine. These instructions apply to SD and MMC cards although for brevity, and usually only the SD card is listed.

For a Linux image to be able to run, four separate pieces are needed:

- Linux OS kernel image (zImage/Image)
- Device tree file (`*.dtb`)
- Bootloader image
- Root file system (for example, EXT4)

The Yocto Project build creates an SD card image that can be flashed directly. This is the simplest way to load everything needed onto the card with one command.

A `.wic` image contains all four images properly configured for an SD card. The release contains a pre-built `.wic` image that is built specifically for the one board configuration. It runs the Wayland graphical backend. It does not run on other boards unless U-Boot, the device tree, and rootfs are changed.

When more flexibility is desired, the individual components can be loaded separately, and those instructions are included here as well. An SD card can be loaded with the individual components one-by-one or the `.wic` image can be loaded and the individual parts can be overwritten with the specific components.

The rootfs on the default `.wic` image is limited to a bit less than 4 GB, but re-partitioning and re-loading the rootfs can increase that to the size of the card. The rootfs can also be changed to specify the graphical backend that is used.

The device tree file (`.dtb`) contains board and configuration-specific changes to the kernel. Change the device tree file to change the kernel for a different i.MX board or configuration.

By default, the release uses the following layout for the images on the SD card. The kernel image and DTB move to use the FAT partition without a fixed raw address on the SD card. The users have to change the U-Boot boot environment if the fixed raw address is required.

Table 1. Image layout

Start address (sectors)	Size (sectors)	Format	Description
0x400 bytes (2)	0x9FFC00 bytes (20478)	RAW	i.MX 6 and i.MX 7 U-Boot and reserved area
0x8400 (66)	0x9F7C00 (20414)	RAW	i.MX 8M Quad and i.MX 8M Mini imx-boot reserved area
0x8000 (64)	0x9F800 (20416)	RAW	i.MX 8QuadMax/8QuadXPlus/ 8M Nano/8M Plus/8DXL/ 8DualX/8ULP, i.MX 93
0xa00000 bytes (20480)	500 MB (1024000)	FAT	Kernel Image and DTBs
0x25800000 bytes (1228800)	Remaining space	Ext3/Ext4	Rootfs

4.3.1 Preparing the card

An SD/MMC card reader, such as a USB card reader, is required. It is used to transfer the bootloader and kernel images to initialize the partition table and copy the root file system. To simplify the instructions, it is assumed that a 4 GB SD/MMC card is used.

Any Linux distribution can be used for the following procedure.

The Linux kernel running on the Linux host assigns a device node to the SD/MMC card reader. The kernel might decide the device node name or udev rules might be used. In the following instructions, it is assumed that udev is not used.

To identify the device node assigned to the SD/MMC card, carry out the following command:

```
$ cat /proc/partitions
major minor  #blocks  name
   8     0   78125000 sda
   8     1   75095811 sda1
   8     2          1 sda2
   8     5    3028221 sda5
   8    32  488386584 sdc
   8    33  488386552 sdc1
   8    16    3921920 sdb
   8    18    3905535 sdb1
```

In this example, the device node assigned is /dev/sdb (a block is 1024 Bytes).

Note: *Make sure that the device node is correct for the SD/MMC card. Otherwise, it may damage your operating system or data on your computer.*

4.3.2 Copying the full SD card image

The SD card image (with the extension `.wic`) contains U-Boot, the Linux image and device trees, and the rootfs for a 4 GB SD card. The image can be installed on the SD card with one command if flexibility is not required.

Carry out the following command to copy the SD card image to the SD/MMC card. Change `sdx` below to match the one used by the SD card.

```
$ sudo dd if=<image name>.wic of=/dev/sdx bs=1M && sync
```

The entire contents of the SD card are replaced. If the SD card is larger than 4 GB, the additional space is not accessible.

4.3.3 Partitioning the SD/MMC card

The full SD card image already contains partitions. This section describes how to set up the partitions manually. This needs to be done to individually load the bootloader, kernel, and rootfs.

There are various ways to partition an SD card. Essentially, the bootloader image needs to be at the beginning of the card, followed by the Linux image and the device tree file. These can either be in separate partitions or not. The root file system needs to be in a partition that starts after the Linux section. Make sure that each section has enough space. The example below creates two partitions.

On most Linux host operating systems, the SD card is mounted automatically upon insertion. Therefore, before running fdisk, make sure that the SD card is unmounted if it was previously mounted (through `sudo umount /dev/sdx`).

Start by running fdisk with root permissions. Use the instructions above to determine the card ID. We are using `sdx` here as an example.

```
$ sudo fdisk /dev/sdx
```

Type the following parameters (each followed by <ENTER>):

```
p         [lists the current partitions]
d         [to delete existing partitions.  Repeat this until no
 unnecessary partitions
           are reported by the 'p' command to start fresh.]
n         [create a new partition]
p         [create a primary partition - use for both
 partitions]
1         [the first partition]
20480     [starting at offset sector]
1024000   [ending position of the first partition to be used
 for the boot images]
p         [to check the partitions]
n
p
2
1228800   [starting at offset sector, which leaves enough space
 for the kernel,
```

```
                the bootloader and its configuration data]
<enter>   [using the default value will create a partition that
 extends to
                the last sector of the media]
p         [to check the partitions]
w         [this writes the partition table to the media and
 fdisk exits]
```

4.3.4 Copying a bootloader image

This section describes how to load only the bootloader image when the full SD card image is not used. Execute the following command to copy the U-Boot image to the SD/MMC card.

```
$ sudo dd if=<U-Boot image> of=/dev/sdx bs=1k seek=<offset>
 conv=fsync
```

Where offset is:

- 1 - for i.MX 6 or i.MX 7
- 33 - for i.MX 8QuadMax A0, i.MX 8QuadXPlus A0, and i.MX 8M Quad, and i.MX 8M Mini
- 32 - for i.MX 8QuadXPlus B0, i.MX 8QuadMax B0, i.MX 8DualX, i.MX 8DXL, i.MX 8M Nano, i.MX 8M Plus, i.MX 8ULP, and i.MX 9

The first 16 KB of the SD/MMC card, which includes the partition table, is reserved.

4.3.5 Copying the kernel image and DTB file

This section describes how to load the kernel image and DTB when the full SD card image is not used. The pre-built SD card image uses the VFAT partition for storing kernel image and DTB, which requires a VFAT partition that is mounted as a Linux drive and the files are copied into it. This is the preferred method.

Another method that can be used is for users to put the kernel image and DTB to the fixed raw address of the SD card by using the `dd` command. The later method needs to modify the U-Boot default environment variables for loading the kernel image and DTB.

Default: VFAT partition

1. Format partition 1 on the card as VFAT with this command:

   ```
   $ sudo mkfs.vfat /dev/sdx1
   ```

2. Mount the formatted partition with this command:

   ```
   $ mkdir mountpoint
   $ sudo mount /dev/sdx1 mountpoint
   ```

3. Copy the zImage and `*.dtb` files to the `mountpoint` by using `cp`. The device tree names should match the one used by the variable specified by U-Boot. Unmount the partition with this command:

   ```
   $ sudo umount mountpoint
   ```

Alternative: Pre-defined raw address

The following command can be used to copy the kernel image to the SD/MMC card:

For i.MX 6 and i.MX7, use this command:

```
$ sudo dd if=zImage_imx_v7_defconfig of=/dev/sdx bs=512
 seek=2048 conv=fsync
```

For i.MX 8, use this command:

```
sudo dd if=Image-imx8qmsabreauto.bin of=/dev/sdx bs=512
 seek=2048 conv=fsync
```

Each of them copies the kernel to the media at offset 1 MB (bs x seek = 512 x 2048 = 1 MB). The file `zImage_imx_v7_defconfig` refers to the `zImage` file created when using the `imx_v7_defconfig` configuration file, which supports both i.MX 6 and i.MX 7 SoCs.

The i.MX DTB image can be copied by using the copy command and copying the file to the 2nd partition or the following commands copy an i.MX DTB image to the SD/MMC card by using `dd` command.

Choose a command for your board:

```
$ sudo dd if=zImage-imx6qp-sabreauto.dtb of=/dev/sdx bs=512
 seek=20480 conv=fsync
$ sudo dd if=zImage-imx6qp-sabresd.dtb of=/dev/sdx bs=512
 seek=20480 conv=fsync
$ sudo dd if=zImage-imx6q-sabreauto.dtb of=/dev/sdx bs=512
 seek=20480 conv=fsync
$ sudo dd if=zImage-imx6q-sabresd.dtb of=/dev/sdx bs=512
 seek=20480 conv=fsync
$ sudo dd if=zImage-imx6sl-evk.dtb of=/dev/sdx bs=512
 seek=20480 conv=fsync
$ sudo dd if=zImage-imx7d-sdb.dtb of=/dev/sdx bs=512 seek=20480
 conv=fsync
```

For i.MX 6 and i.MX 7, the following command can be used to copy the kernel image to the boards, such as the i.MX 6UltraLite EVK board and i.MX 6ULL EVK board:

```
$ sudo dd if=zImage-imx6ul-14x14-evk.dtb of=/dev/sdx bs=512
 seek=20480 conv=fsync
$ sudo dd if=zImage-imx6ull-14x14-evk.dtb of=/dev/sdx bs=512
 seek=20480 conv=fsync
```

For i.MX 6 and i.MX 7, this copies the board-specific `.dtb` file to the media at offset 10 MB (bs x seek = 512 x 20480 = 10 MB).

4.3.6 Copying the root file system (rootfs)

This section describes how to load the rootfs image when the full SD card image is not used.

Copy the target file system to a partition that only contains the rootfs. This example uses partition 2 for the rootfs. First format the partition. The file system format `ext3` or `ext4` is a good option for the removable media due to the built-in journaling. Replace `sdx` with the partition in use in your configuration.

```
$ sudo mkfs.ext3 /dev/sdx2
Or
```

```
$ sudo mkfs.ext4 /dev/sdx2
```

Copy the target file system to the partition:

```
$ mkdir /home/user/mountpoint
$ sudo mount /dev/sdx2 /home/user/mountpoint
```

Extract a rootfs package to a directory: for example, extract `imx-image-multimedia-imx7ulpevk.tar.zst` to `/home/user/rootfs`:

```
$ cd /home/user/rootfs
$ tar -jxvf imx-image-multimedia-imx7ulpevk.tar.zst
```

The rootfs directory needs to be created manually.

Assume that the root file system files are located in `/home/user/rootfs` as in the previous step:

```
$ cd /home/user/rootfs
$ sudo cp -a * /home/user/mountpoint
$ sudo umount /home/user/mountpoint
$ sync
```

The file system content is now on the media.

Note: *Copying the file system takes several minutes depending on the size of your rootfs.*

4.4 Downloading images

Images can be downloaded to a device using a U-Boot image that is already loaded on the boot device or by using the Manufacturing Tool UUU. Use a terminal program to communicate with the i.MX boards.

4.4.1 Downloading images using U-Boot

The following sections describe how to download images using the U-Boot bootloader.

The commands described below are generally useful when using U-Boot. Additional commands and information can be found by typing `help` at the U-Boot prompt.

The U-Boot `print` command can be used to check environment variable values.

The `setenv` command can be used to set environment variable values.

4.4.1.1 Flashing an Arm Cortex-M4 image on QuadSPI

i.MX 6SoloX SABRE-SD, i.MX 7ULP EVK, and i.MX 7Dual SABRE-SD boards have the Arm Cortex-M4 processor and QuadSPI memory that can be used to flash an image to it.

Note:

To enable the full features for i.MX 7ULP, burn the Arm Cortex-M4 image to QuadSPI. It is recommended to use the MFGTool script `uuu LF5.15.71_2.2.0_images_MX7ULPEVK.zip\uuu_sd_m4.auto` to burn both BSP and Arm Cortex-M4 images.

i.MX U-Boot provides a reference script on i.MX 7Dual SABRESD and i.MX 6SoloX SABRE-SD to flash the Arm Cortex-M4 image from the SD card. To execute the script, perform the following steps:

1. Copy the Arm Cortex-M4 image to the first VFAT partition of the boot SD card. Name the file to `m4_qspi.bin`.
2. Boot from the SD card.
3. Flash the Arm Cortex-M4 image from the SD card to the NOR flash on QuadSPI2 PortB CS0 on the i.MX 6SoloX SABRE-SD board or QuadSPI1 PortA CS0 offset 1 MB on the i.MX 7Dual SABRE-SD board.

```
U-Boot > run update_m4_from_sd
```

Alternatively, users can flash the Arm Cortex-M4 image from TFTP by performing the following steps:

1. Boot from the SD card.
2. TFTP the Arm Cortex-M4 image.

```
U-Boot > tftp ${loadaddr} m4_qspi.bin
```

3. Select the NOR flash on QuadSPI2 PortB CS0 on the i.MX 6SoloX SABRE-SD board.

```
U-Boot > sf probe 1:0
```

Select the NOR flash on QuadSPI1 PortA CS0 on the i.MX 7Dual SABRE-SD board and i.MX 7ULP EVK board.

```
U-Boot > sf probe 0:0
```

4. Flash the Arm Cortex-M4 image to the selected NOR flash. The erase size is `${filesize}`, around 64 Kbytes. This example assumes that it is 128 Kbytes.

```
U-Boot > sf erase 0x0 0x20000
U-Boot > sf write ${loadaddr} 0x0 ${filesize}
```

i.MX 7Dual SABRE-SD needs to program the Arm Cortex-M4 images to 1 MB offset, because the first 1 MB is used by the U-Boot image in QuadSPI.

```
U-Boot > sf erase 0x100000 0x20000
U-Boot > sf write ${loadaddr} 0x100000 ${filesize}
```

Note:

On i.MX 7Dual SABRE-SD, the Arm Cortex-M4 image on QuadSPI is supported only when the U-Boot image is built by the target `mx7dsabresd_qspi1_defconfig` booted by U-Boot from QuadSPI.

The default U-Boot for the i.MX 7Dual SABRESD board uses the Cortex-M4 image from the SD card and runs it on OCRAM.

On i.MX 7ULP EVK, the Arm Cortex-M4 image needs to be programmed. Otherwise, it will not boot.

4.4.1.2 Downloading an image to MMC/SD

This section describes how to download U-Boot to an MMC/SD card that is not the one used to boot from.

Insert an MMC/SD card into the SD card slot. This is slot SD3 on i.MX 6 SABRE, SD2 on i.MX 6UltraLite EVK and i.MX 6ULL EVK, SD1 on i.MX 7Dual SABRE-SD and i.MX 7ULP EVK (MicroSD), and SD1 on i.MX 8QuadMax MEK, 8QuadXPlus MEK, and i.MX 8M Quad EVK.

Note:

To enable the full features for i.MX 7ULP, burn the Arm Cortex-M4 image to QuadSPI. It is recommended to use the MfgTool script `uuu LF5.15.71_2.2.0_images_MX7ULPEVK.zip\uuu_sd_m4.auto` *to burn both BSP and Arm Cortex-M4 images.*

For i.MX 7ULP, to burn the Arm Cortext-M4 image to QuadSPI, perform the following steps:

1. Copy the Arm Cortext-M4 image to the SD card `vfat` partition, insert the SD card, and then boot to the U-Boot console.
2. Probe the Quad SPI in U-Boot, and erase an enough big size QuardSPI flash space for this Arm Cortext-M4 image.

```
U-Boot > sf probe
U-Boot > sf erase 0x0 0x30000;
```

3. Read the Arm Cortext-M4 image (in the first `vfat` partition on the SD card) to memory address, the Arm Cortext-M4 image name is `sdk20-app.img` here.

```
U-Boot > fatload mmc 0:1 0x62000000 sdk20-app.img;
```

4. Write the Arm Cortext-M4 image to the QuardSPI.

```
U-Boot > sf write 0x62000000 0x0 0x30000
```

To flash the original U-Boot, see Section Section 4.3.

The U-Boot bootloader is able to download images from a TFTP server into RAM and to write from RAM to an SD card. For this operation, the Ethernet interface is used and U-Boot environment variables are initialized for network communications.

The boot media contains U-Boot, which is executed upon power-on. Press any key before the value of the U-Boot environment variable, `bootdelay`, decreases and before it times out. The default setting is 3 seconds to display the U-Boot prompt.

1. To clean up the environment variables stored on MMC/SD to their defaults, execute the following command in the U-Boot console:

```
U-Boot > env default -f -a U-Boot > saveenv U-Boot > reset
```

2. Configure the U-Boot environment for network communications. The following is an example. The lines preceded by the "#" character are comments and have no effect.

```
U-Boot > setenv serverip <your TFTPserver ip>
U-Boot > setenv bootfile <your kernel zImage/Image name on
 the TFTP server>
U-Boot > setenv fdtfile <your dtb image name on the TFTP
 server>
```

The user can set a fake MAC address through ethaddr environment if the MAC address is not fused.

```
U-Boot > setenv ethaddr 00:01:02:03:04:05
U-Boot > save
```

3. Copy zImage/Image to the TFTP server. Then download it to RAM:

```
U-Boot > dhcp
```

4. Query the information about the MMC/SD card.

```
U-Boot > mmc devU-Boot > mmcinfo
```

5. Check the usage of the `mmc` command. The `blk#` is equal to `<the offset of read/write>/<block length of the card>`. The `cnt` is equal to `<the size of read/write>/<block length of the card>`.

```
U-Boot > help mmc
mmc - MMC sub system
Usage:
mmc read addr blk# cnt
mmc write addr blk# cnt
mmc erase blk# cnt
mmc rescan
mmc part - lists available partition on current mmc device
mmc dev [dev] [part] - show or set current mmc device
 [partition]
mmc list - lists available devices
```

6. Program the kernel zImage/Image located in RAM at `${loadaddr}` into the SD card. For example, the command to write the image with the size 0x800000 from `${loadaddr}` to the offset of 0x100000 of the microSD card. See the following examples for the definition of the MMC parameters.

```
blk# = (microSD Offset)/(SD block length) = 0x100000/0x200 =
 0x800
```

```
cnt = (image Size)/(SD block length) = 0x800000/0x200 =
 0x4000
```

This example assumes that the kernel image is equal to 0x800000. If the kernel image exceeds 0x800000, increase the image length. After issuing the TFTP command, filesize of the U-Boot environment variable is set with the number of bytes transferred. This can be checked to determine the correct size needed for the calculation. Use the U-Boot command printenv to see the value.

```
U-Boot >  mmc dev 2 0
U-Boot > tftpboot ${loadaddr} ${bootfile}
### Suppose the kernel zImage is less than 8M.
U-Boot > mmc write ${loadaddr} 0x800 0x4000
```

7. Program the dtb file located in RAM at `${fdt_addr}` into the microSD.

```
U-Boot > tftpboot ${fdt_addr} ${fdtfile}
U-Boot > mmc write ${fdt_addr} 0x5000 0x800
```

8. On i.MX 6 SABRE boards, you can boot the system from `rootfs` on SD card, using the HannStar LVDS as display. The kernel MMC module now uses a fixed `mmcblk` index for the uSDHC slot. The SD3 slot uses `mmcblk2` on i.MX 6 SABRE boards, the SD1 slot uses `mmcblk0` on the i.MX 7Dual SABRE-SD board, and the SD2 slot uses `mmcblk1` on the i.MX 6UltraLite board and i.MX 6ULL EVK board. The SD1 slot uses `mmcblk1` on i.MX 8 MEK boards and i.MX 8M boards.
9. Boot the board.

```
U-Boot > setenv bootcmd_mmc 'run bootargs_base mmcargs;mmc
 dev;mmc
```

```
read ${loadaddr} 0x800 0x4000;mmc read ${fdt_addr} 0x5000
 0x800;bootz ${loadaddr} - ${fdt_addr}'
U-Boot > setenv bootcmd 'run bootcmd_mmc'
U-Boot > saveenv
```

4.4.1.3 Using eMMC

There is an eMMC chip on i.MX SABRE boards, i.MX 8 MEK and EVK boards, i.MX 8M EVK boards, and i.MX 8ULP EVK boards. It is accessed through SDHC4 on i.MX 6 SABRE boards, SDHC3 on i.MX 7Dual SABRE-SD board, SDHC1 on i.MX 8 MEK/EVK boards and i.MX 8M EVK boards, and SDHC0 on i.MX 8ULP EVK board. The i.MX 7ULP EVK board also supports to rework eMMC on the MicroSD port. The following steps describe how to use this memory device.

Note:

To enable the full features for i.MX 7ULP, burn the Arm Cortex-M4 image to QuadSPI. It is recommended to use the MfgTool script `uuu LF5.15.71_2.2.0_images_MX7ULPEVK.zip\uuu_sd_m4.auto` *to burn both BSP and Arm Cortex-M4 images.*

1. Execute the following command on the U-Boot console to clean up the environments stored on eMMC:

```
U-Boot > env default -f -a
U-Boot > save
U-Boot > reset
```

2. Configure the boot pin. Power on the board and set the U-Boot environment variables as required. For example,

```
U-Boot > setenv serverip <your tftpserver ip>
U-Boot > setenv bootfile <your kernel zImage/Image name on
 the tftp server>
U-Boot > setenv fdtfile <your dtb image name on the tftp
 server>
### The user can set fake MAC address via ethaddr enviroment
 if the MAC address is not fused
U-Boot > setenv ethaddr 00:01:02:03:04:05
U-Boot > save
```

3. Copy zImage to the TFTP server. Then download it to RAM:

```
U-Boot > dhcp
```

4. Query the information about the eMMC chip.

```
U-Boot > mmc dev
U-Boot > mmcinfo
```

5. Check the usage of the `mmc` command. `blk#` is equal to `<the offset of read/write>/<block length of the card>`. `cnt` is equal to `<the size of read/write>/<block length of the card>`.

```
mmc read addr blk# cnt
mmc write addr blk# cnt
mmc erase blk# cnt
mmc rescan
mmc part - lists available partition on current mmc device
mmc dev [dev] [part] - show or set current mmc device
 [partition]
mmc list - lists available devices
```

6. Program the kernel zImage/Image into eMMC. For example, the command below writes the image with the size 0x800000 from `${loadaddr}` to the offset 0x100000 of the eMMC chip. Here, the following equations are used: 0x800 =0x100000/0x200, 0x4000=0x800000/0x200. The block size of this card is 0x200. This example assumes that the kernel image is less than 0x800000 bytes. If the kernel image exceeds 0x800000, enlarge the image length.

```
### Select mmc dev 2 (USDHC4) on the i.MX 6 SABRESD board:
U-Boot > mmc dev 2 0
### Select mmc dev 1 (USDHC3) on the i.MX 7Dual SABRESD
 board:
U-Boot > mmc dev 1 0
### Select mmc dev 1 (USDHC2) on the i.MX 6UltraLite EVK
 board:
U-Boot > mmc dev 1 0
### Select mmc dev 0 (USDHC1) on the i.MX 7ULP EVK board:
U-Boot > mmc dev 0 0
### Select mmc dev 0 (eMMC0) on the i.MX 8QuadMax MEK, i.MX
 8QuadXPlus MEK, i.MX 8M Quad, 8DualX, and 8DXL boards:
U-Boot > mmc dev 0 0
### select mmc dev 2 (USDHC3) on the i.MX 8M Mini EVK, i.MX
 8M Nano EVK, and i.MX 8M Plus EVK:
U-Boot > mmc dev 2 0
### select mmc dev 0 （USDHC0） on the i.MX 8ULP EVK
U-boot > mmc dev 0
### Suppose kernel zImage is less than 8 MB:
U-Boot > tftpboot ${loadaddr} ${bootfile}
U-Boot > mmc write ${loadaddr} 0x800 0x4000
```

7. Program the dtb file located in RAM at `${fdt_addr}` into the eMMC chip.

```
U-Boot > tftpboot ${fdt_addr} ${fdtfile}
U-Boot > mmc write ${fdt_addr} 0x5000 0x800
```

8. Boot up the system through the rootfs in eMMC, using the HannStar LVDS as display. The kernel MMC module now uses the fixed `mmcblk` indexes for the USDHC slots. The eMMC/SD4 slot on the i.MX 6 SABRE boards is `mmcblk3`. The eMMC5.0 on the i.MX 8QuadMax MEK board, i.MX 8QuadXPlus MEK board, and i.MX 8M Quad EVK board are `mmcblk0`. The eMMC5.0/SD3 slot on the i.MX 7Dual SABRE board is `mmcblk2`. eMMC is not populated on the i.MX 7Dual SABRE board.

```
U-Boot > setenv mmcboot 'run bootargs_base mmcargs; mmc dev
 2;
mmc read ${loadaddr} 0x800 0x4000; mmc read ${fdt_addr}
 0x5000 0x800;bootz ${loadaddr} - ${fdt_addr} '
U-Boot > setenv bootcmd 'run mmcboot'
U-Boot > saveenv
```

9. Boot up the system through the rootfs in eMMC, using the CLAA WVGA panel as display:
   - For i.MX 6 boards:

```
U-Boot > setenv mmcargs 'setenv bootargs ${bootargs}
root=/dev/mmcblk3p2 rootwait rw video=mxcfb0:dev=lcd,CLAA-
WVGA,if=RGB565 ip=dhcp'
```

   - For i.MX 7Dual SABRE boards:

```
U-Boot > setenv mmcargs 'setenv bootargs ${bootargs}
```

```
root=/dev/mmcblk2p2 rootwait rw video=mxcfb0:dev=lcd,CLAA-
WVGA,if=RGB565 ip=dhcp'
```

10. Boot up the system through rootfs in eMMC, using HDMI as display:
    - For i.MX 6 boards:

```
U-Boot > setenv mmcargs 'setenv bootargs
 ${bootargs} root=/dev/mmcblk3p2 rootwait
 rw video=mxcfb0:dev=hdmi,1920x1080M@60,if=RGB24'
```

    - For i.MX 7Dual SABRE boards:

```
U-Boot > setenv mmcargs 'setenv bootargs
 ${bootargs} root=/dev/mmcblk2p2 rootwait
 rw video=mxcfb0:dev=hdmi,1920x1080M@60,if=RGB24'
```

    - For i.MX 8QuadMax/8QuadXPlus/8M Quad/8M Plus, the following display kernel parameters are supported:
      a. Pick a particular video mode for legacy FB emulation since system startup.

```
video=HDMI-A-{n}: {video_mode}
```

      `n` can be **1** to the maximum number of HDMI connectors in the system. video_mode should be the one that the monitor on the connector supports. For example, `video=HDMI-A-1:1920x1080@60`. By default, if there is no parameter in the command line, the system uses the video mode that the monitor recommends.

      b. Enable or disable legacy FB emulation.

```
drm_kms_helper.fbdev_emulation=0 or 1
```

      0 to disable, **1** to enable. By default, if there is no parameter in the command line, the emulation is enabled.

      c. Set legacy FB emulation framebuffer's bits per pixel (bpp) parameter.

```
imxdrm.legacyfb_depth=16 or 24 or 32
```

      By default, if there is no parameter in the command line, bpp is **16**.

To program the rootfs to MMC/SD, see Section 4.4.2 or Section 4.3.

4.4.1.4 Flashing U-Boot on SPI-NOR from U-Boot

Flashing directly to SPI-NOR with TFTPBoot is limited to i.MX 6 SABRE-AI boards. To flash U-Boot on SPI-NOR, perform the following steps:

1. Boot from an SD card.
2. Set Jumper J3 to position: 2-3.
3. Fetch the U-Boot image with built-in SPI-NOR support. This example uses `u-boot.imx`.

```
U-Boot > tftpboot ${loadaddr} u-boot.imx
```

4. Flash the U-Boot image in SPI-NOR.

```
U-Boot > sf probe
U-Boot > sf erase 0 0x80000
```

```
U-Boot > sf write ${loadaddr} 0x400 0x7FC00
```

5. Set boot switches to boot from SPI-NOR on SABRE-AI.
   - S2-1 1
   - S2-2 1
   - S2-3 0
   - S2-4 0
   - S1-[1:10] X
6. Reboot the target board.

4.4.1.4.1 Flashing an Arm Cortex-M4 image on QuadSPI

i.MX 6SoloX SABRE-SD, i.MX 7ULP EVK, and i.MX 7Dual SABRE-SD boards have the Arm Cortex-M4 processor and QuadSPI memory that can be used to flash an image to it.

Note:

To enable the full features for i.MX 7ULP, burn the Arm Cortex-M4 image to QuadSPI. It is recommended to use the MFGTool script `uuu LF5.15.71_2.2.0_images_MX7ULPEVK.zip\uuu_sd_m4.auto` to burn both BSP and Arm Cortex-M4 images.

i.MX U-Boot provides a reference script on i.MX 7Dual SABRESD and i.MX 6SoloX SABRE-SD to flash the Arm Cortex-M4 image from the SD card. To execute the script, perform the following steps:

1. Copy the Arm Cortex-M4 image to the first VFAT partition of the boot SD card. Name the file to `m4_qspi.bin`.
2. Boot from the SD card.
3. Flash the Arm Cortex-M4 image from the SD card to the NOR flash on QuadSPI2 PortB CS0 on the i.MX 6SoloX SABRE-SD board or QuadSPI1 PortA CS0 offset 1 MB on the i.MX 7Dual SABRE-SD board.

```
U-Boot > run update_m4_from_sd
```

Alternatively, users can flash the Arm Cortex-M4 image from TFTP by performing the following steps:

1. Boot from the SD card.
2. TFTP the Arm Cortex-M4 image.

```
U-Boot > tftp ${loadaddr} m4_qspi.bin
```

3. Select the NOR flash on QuadSPI2 PortB CS0 on the i.MX 6SoloX SABRE-SD board.

```
U-Boot > sf probe 1:0
```

Select the NOR flash on QuadSPI1 PortA CS0 on the i.MX 7Dual SABRE-SD board and i.MX 7ULP EVK board.

```
U-Boot > sf probe 0:0
```

4. Flash the Arm Cortex-M4 image to the selected NOR flash. The erase size is `${filesize}`, around 64 Kbytes. This example assumes that it is 128 Kbytes.

```
U-Boot > sf erase 0x0 0x20000
U-Boot > sf write ${loadaddr} 0x0 ${filesize}
```

i.MX 7Dual SABRE-SD needs to program the Arm Cortex-M4 images to 1 MB offset, because the first 1 MB is used by the U-Boot image in QuadSPI.

```
U-Boot > sf erase 0x100000 0x20000
U-Boot > sf write ${loadaddr} 0x100000 ${filesize}
```

Note:

On i.MX 7Dual SABRE-SD, the Arm Cortex-M4 image on QuadSPI is supported only when the U-Boot image is built by the target `mx7dsabresd_qspi1_defconfig` *booted by U-Boot from QuadSPI.*

The default U-Boot for the i.MX 7Dual SABRESD board uses the Cortex-M4 image from the SD card and runs it on OCRAM.

On i.MX 7ULP EVK, the Arm Cortex-M4 image needs to be programmed. Otherwise, it will not boot.

4.4.1.5 Flashing U-Boot on Parallel NOR from U-Boot

Flashing directly to Parallel NOR with TFTPBoot is limited to i.MX 6 SABRE-AI boards. To flash U-Boot on Parallel NOR, perform the following steps:

1. Check the jumper J3, should not between pins 2 and 3.
2. Update the SD U-Boot with EIM NOR version. For details on commands, see Section 4.3.4. Then boot from the SD card.
3. TFTP the U-Boot image.

```
tftpboot ${loadaddr} u-boot.imx
```

4. Flash the U-Boot image.

```
cp.b ${loadaddr} 0x08001000 ${filesize}
```

5. Change boot switches and reboot.

```
S2 all 0 S1-6 1 others 0
```

6. By default, rootfs is mounted on NFS.

4.4.2 Using an i.MX board as the host server to create a rootfs

Linux OS provides multiple methods to program images to the storage device. This section describes how to use the i.MX platform as a Linux host server to create the rootfs on an MMC/SD card or the SATA device. The following example is for an SD card. The device file node name needs to be changed for a SATA device.

1. Boot from NFS or other storage. Determine your SD card device ID. It could be `mmcblk*` or `sd*`. (The index is determined by the USDHC controller index.) Check the partition information with the command:

```
$ cat /proc/partitions
```

2. To create a partition on the MMC/SD card, use the `fdisk` command (requires root privileges) in the Linux console:

```
root@ ~$ sudo fdisk /dev/$SD
```

Replace `$SD` above with the name of your device.

3. If this is a new SD card, you may get the following message:

```
The device contains neither a valid DOS partition table, nor
 Sun, SGI or OSF disk label
Building a new DOS disklabel. Changes will remain in memory
 only,
until you decide to write them. After that the previous
 content
won't be recoverable.
The number of cylinders for this disk is set to 124368.
There is nothing wrong with that, but this is larger than
 1024,
and could in certain setups cause problems with:
1) software that runs at boot time (e.g., old versions of
 LILO)
2) booting and partitioning software from other OSs
   (e.g., DOS FDISK, OS/2 FDISK)
```

   The usual prompt and commands to partition the card are as follows. Text in boldface indicates what the user types.

```
Command (m for help): p
Disk /dev/sdd: 3965 MB, 3965190144 bytes
4 heads, 32 sectors/track, 60504 cylinders, total 7744512
 sectors
Units = sectors of 1 * 512 = 512 bytes
Sector size (logical/physical): 512 bytes / 512 bytes
I/O size (minimum/optimal): 512 bytes / 512 bytes
Disk identifier: 0x00080bff
        Device Boot      Start         End      Blocks   Id
 System
```

4. As described in Section 4.6, the rootfs partition should be located after the kernel image. The first 0x800000 bytes can be reserved for MBR, bootloader, and kernel sections. From the log shown above, the `Units` of the current MMC/SD card is 32768 bytes. The beginning cylinder of the first partition can be set to "0x300000/32768 = 96." The last cylinder can be set according to the rootfs size. Create a new partition by typing the letters in bold:

```
Command (m for help): n
 e extended
 p primary partition (1-4)
Select (default p): p
Partition number (1-4): 1
First cylinder (1-124368, default 1): 96
Last cylinder or +size or +sizeM or +sizeK (96-124368,
 default 124368): Using default value 124368
Command (m for help): w
The partition table has been altered!
Calling ioctl() to re-read $SD partition table
```

5. Check the partitions (see above) to determine the name of the partition. `$PARTITION` is used here to indicate the partition to be formatted. Format the MMC/SD partitions as `ext3` or `ext4` type. For example, to use `ext3`:

```
root@ ~$ mkfs.ext3 /dev/$PARTITION
mke2fs 1.42 (29-Nov-2011)
Filesystem label=
OS type: Linux
Block size=4096 (log=2)
Fragment size=4096 (log=2)
```

```
248992 inodes, 994184 blocks
49709 blocks (5.00%) reserved for the super user
First data block=0
Maximum filesystem blocks=1019215872
31 block groups
32768 blocks per group, 32768 fragments per group
8032 inodes per group
Superblock backups stored on blocks:
        32768, 98304, 163840, 229376, 294912, 819200, 884736
Writing inode tables: done
Creating journal (16384 blocks): done
Writing superblocks and filesystem accounting information:
 done
This filesystem will be automatically checked every 20 mounts
 or
180 days, whichever comes first.  Use tune2fs -c or -i to
 override.
```

6. Copy the rootfs contents to the MMC/SD card. The name may vary from the one used below. Check the directory for the rootfs desired. (Copy the `*.ext2` to NFS rootfs).

```
mkdir /mnt/tmpmnt
mount -t ext3 -o loop /imx-image-multimedia.ext3 /mnt/tmpmnt
cd /mnt
mkdir mmcblk0p1
mount -t ext3 /dev/$PARTITION /mnt/mmcblk0p1
cp -af /mnt/tmpmnt/* /mnt/mmcblk0p1/
umount /mnt/mmcblk0p1
umount /mnt/tmpmnt
```

7. Type `sync` to write the contents to MMC/SD.
8. Type `poweroff` to power down the system. Follow the instructions in Section 4.7 to boot the image from the MMC/SD card.

Note: *By default, v2013.04 and later versions of U-Boot support loading the kernel image and DTB file from the SD/MMC vfat partition by using the fatload command. To use this feature, perform the following steps:*

1. *Format the first partition (for example 50 MB) of the SD/MMC card with vfat filesystem.*
2. *Copy zImage and the DTB file into the VFAT partition after you mount the VFAT partition into your host computer.*
3. *Make sure that the zImage and DTB filename are synchronized with the filename pointed to by the U-Boot environment variables: `fdtfile` and `image`. Use the print command under U-Boot to display these two environment variables. For example:*

```
print fdtfile image
```

4. *U-Boot loads the kernel image and the DTB file from your VFAT partition automatically when you boot from the SD/MMC card.*

The following is an example to format the first partition to a 50 MB vfat filesystem and format the second partition to an ext4 filesystem:

```
~$ fdisk /dev/sdb
Command (m for help): n
Partition type:
   p   primary (0 primary, 0 extended, 4 free)
   e   extended
```

```
Select (default p): p
Partition number (1-4, default 1): 1
First sector (2048-30318591, default 2048): 4096
Last sector, +sectors or +size{K,M,G} (4096-30318591, default
 30318591): +50M
Command (m for help): p
Disk /dev/sdb: 15.5 GB, 15523119104 bytes
64 heads, 32 sectors/track, 14804 cylinders, total 30318592
 sectors
Units = sectors of 1 * 512 = 512 bytes
Sector size (logical/physical): 512 bytes / 512 bytes
I/O size (minimum/optimal): 512 bytes / 512 bytes
Disk identifier: 0x3302445d
   Device Boot      Start         End      Blocks   Id  System
/dev/sdb1            4096      106495       51200   83  Linux
Command (m for help): n
Partition type:
   p   primary (1 primary, 0 extended, 3 free)
   e   extended
Select (default p): p
Partition number (1-4, default 2): 2
First sector (2048-30318591, default 2048): 106496
Last sector, +sectors or +size{K,M,G} (106496-30318591, default
 30318591):
Using default value 30318591
Command (m for help): p
Disk /dev/sdb: 15.5 GB, 15523119104 bytes
64 heads, 32 sectors/track, 14804 cylinders, total 30318592
 sectors
Units = sectors of 1 * 512 = 512 bytes
Sector size (logical/physical): 512 bytes / 512 bytes
I/O size (minimum/optimal): 512 bytes / 512 bytes
Disk identifier: 0x3302445d
   Device Boot      Start         End      Blocks   Id  System
/dev/sdb1            4096      106495       51200   83  Linux
/dev/sdb2          106496    30318591    15106048   83  Linux
Command (m for help): w
The partition table has been altered!
Calling ioctl() to re-read partition table.
Syncing disks.
~$ mkfs.vfat /dev/mmcblk0p1
~$ mkfs.ext4 /dev/mmcblk0p2
```

4.5 How to boot the i.MX boards

When U-Boot is loaded onto one of the devices that support booting, the DIP switches can be used to boot from that device. The boot modes of the i.MX boards are controlled by the boot configuration DIP switches on the board. For help with locating the boot configuration switches, see the quick start guide for the specific board as listed under References above.

The following sections list basic boot setup configurations. The tables below represent the DIP switch settings for the switch blocks on the specified boards. An X means that particular switch setting does not affect this action.

4.5.1 Booting from an SD card in slot SD1

The following table shows the DIP switch settings for booting from the SD card slot labeled SD1 on the i.MX 7Dual SABRE-SD boards.

Table 2. Booting from SD1 on i.MX 7Dual SABRE-SD

Switch	D1	D2	D3	D4	D5	D6	D7	D8
SW2	OFF	OFF	ON	OFF	OFF	OFF	OFF	OFF
SW3	ON	OFF	-	-	-	-	-	-

The following table shows the DIP switch settings for booting from the SD card slot labeled SD1 on the i.MX 7ULP EVK boards.

Table 3. Booting from SD1 on i.MX 7ULP EVK

Switch	D1	D2	D3	D4
SW1	ON	OFF	OFF	ON

The following table shows the bootcfg pin settings for booting from the SD card slot labeled SD1 on the i.MX 8QuadMax MEK boards.

Table 4. Booting from SD1 on i.MX 8QuadMax MEK

Switch	D1	D2	D3	D4	D5	D6	D7	D8
SW2	OFF	OFF	ON	ON	OFF	OFF	-	-

The following table shows the bootcfg pin settings for booting from the SD card slot labeled SD1 on the i.MX 8QuadXPlus MEK boards.

Note: *This is the same setting for the i.MX 8DualX MEK and i.MX 8DXL EVK boards.*

Table 5. Booting from SD1 on i.MX 8QuadXPlus MEK

Switch	D1	D2	D3	D4
SW2	ON	ON	OFF	OFF

4.5.2 Booting from an SD card in slot SD2

The SD card slot that is labeled SD2 indicates that this slot is connected to the uSDHC pin SD2 on the processor. Most boards label this slot as SD2. This slot is referred to as SD2 in this document.

The following table shows the DIP switch settings for booting from the SD card slot labeled SD2 and J500 on the i.MX 6 SABRE-SD boards. The SD2 card slot is located beside the LVDS1 connection on the back of the board.

Table 6. Booting from SD2 (J500) on i.MX 6 SABRE-SD

Switch	D1	D2	D3	D4	D5	D6	D7	D8
SW6	ON	OFF	OFF	OFF	OFF	OFF	ON	OFF

The i.MX 6UltraLite EVK board or i.MX 6ULL EVK board has one TF card slot on the CPU board. This slot uses the USDHC2 controller. The following table shows the DIP switch settings for booting from the TF slot.

Table 7. Booting from TF on i.MX 6UltraLite EVK and i.MX 6ULL EVK

Switch	D1	D2	D3	D4
SW601	OFF	OFF	ON	OFF
SW602	ON	OFF	-	-

The i.MX 8M Quad EVK board has one TF card slot. This slot uses the USDHC2 controller. The following table shows the DIP switch settings for booting from the TF slot.

Table 8. Booting from TF on i.MX 8M Quad EVK

Switch	D1	D2	D3	D4
SW801	ON	ON	OFF	OFF
SW802	ON	OFF	-	-

The i.MX 8M Mini EVK board has one TF card slot. This slot uses the USDHC2 controller. The following table shows the DIP switch settings for booting from the TF slot.

Table 9. Booting from TF on i.MX 8M Mini EVK

Switch	D1	D2	D3	D4	D5	D6	D7	D8
SW1101	OFF	ON	OFF	OFF	OFF	ON	ON	OFF
SW1102	OFF	OFF	ON	ON	OFF	ON	OFF	OFF

The i.MX 8M Nano EVK board has one TF card slot. This slot uses the USDHC2 controller. The following table shows the DIP switch settings for booting from the TF slot.

Table 10. Booting from TF on i.MX 8M Nano EVK

Switch	D1	D2	D3	D4
SW1101	ON	ON	OFF	OFF

The i.MX 8M Plus EVK board has one TF card slot. This slot uses the USDHC2 controller. The following table shows the DIP switch settings for booting from the TF slot.

Table 11. Booting from TF on i.MX 8M Plus EVK

Switch	D1	D2	D3	D4
SW4	OFF	OFF	ON	ON

The following table shows the DIP switch settings for booting from the USDHC2 slot.

Table 12. Booting from USDHC2 on i.MX 93 11x11 EVK

Switch	D1	D2	D3	D4
SW1301	OFF	ON	OFF	OFF

4.5.3 Booting from an SD card in slot SD3

The SD card slot that is labeled SD3 indicates that this slot is connected to the uSDHC pin SD3 on the processor. Most boards label this slot as SD3. This slot is referred to as SD3 in this document.

The following table shows the DIP switch settings to boot from an SD card in slot SD3 on i.MX 6 SABRE-AI boards.

Table 13. Booting from an SD card in slot SD3 on i.MX 6 SABRE-AI

Switch	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
S1	X	X	X	OFF	ON	X	X	X	X	X
S2	X	OFF	ON	OFF	-	-	-	-	-	-
S3	OFF	OFF	ON	OFF	-	-	-	-	-	-

The following table shows the DIP switch settings to boot from an SD card in slot SD3 on i.MX 6SoloX SABRE-AI boards.

Table 14. Booting from an MMC card in Slot SD3 on i.MX 6SoloX SABRE-AI

Switch	D1	D2	D3	D4	D5	D6	D7	D8
S4	OFF	ON	OFF	X	OFF	OFF	ON	OFF
S3	X	OFF	OFF	OFF	ON	ON	OFF	OFF
S1	OFF	OFF	ON	OFF	-	-	-	-

The following table shows the DIP switch settings for booting from SD3, also labeled as J507. The SD3 slot is located between the HDMI and UART ports.

Table 15. Booting from an SD card in slot SD3 on i.MX 6 SABRE-SD

Switch	D1	D2	D3	D4	D5	D6	D7	D8
SW6	OFF	ON	OFF	OFF	OFF	OFF	ON	OFF

4.5.4 Booting from an SD card in slot SD4

The following table describes the dip switch settings for booting from an SD card in slot SD4.

The SD4 slot is on the center of the edge of the SoloX board.

Table 16. Booting from an SD card in slot SD4 on i.MX 6SoloX SABRE-SD

Switch	D1	D2	D3	D4	D5	D6	D7	D8
SW10	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
SW11	OFF	OFF	ON	ON	ON	OFF	OFF	OFF
SW12	OFF	ON	OFF	OFF	OFF	OFF	OFF	OFF

Table 17. Booting from an MMC card in slot SD4 on i.MX 6SoloX SABRE-SD

Switch	D1	D2	D3	D4	D5	D6	D7	D8
SW10	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
SW11	OFF	OFF	ON	ON	ON	OFF	OFF	OFF
SW12	OFF	ON	ON	OFF	OFF	OFF	OFF	OFF

4.5.5 Booting from eMMC

eMMC 4.4 is a chip permanently attached to the board that uses the SD4 pin connections from the i.MX 6 processor. For more information on switch settings, see table "MMC/ eMMC Boot Fusemap" in the IC reference manual.

The following table shows the boot switch settings to boot from eMMC4.4 (SDIN5C2-8G) on i.MX 6 SABRE-SD boards.

Table 18. Booting from eMMC on i.MX 6 SABRE-SD

Switch	D1	D2	D3	D4	D5	D6	D7	D8
SW6	ON	ON	OFF	ON	OFF	ON	ON	OFF

i.MX 7Dual is different from i.MX 6. The eMMC uses the SD3 pin connections from the i.MX 7Dual processor.

Table 19. Booting from eMMC on i.MX 7Dual SABRE-SD

Switch	D1	D2	D3	D4	D5	D6	D7	D8
SW2	OFF	ON	OFF	ON	OFF	OFF	OFF	OFF
SW3	ON	OFF	-	-	-	-	-	-

The following table shows the boot switch settings to boot from eMMC4.4 on the i.MX 7ULP EVK boards.

Table 20. Booting from eMMC on i.MX 7ULP EVK

Switch	D1	D2	D3	D4
SW1	ON	OFF	OFF	OFF

The following table shows the boot switch settings to boot from eMMC5.0 on the i.MX 8QuadMax MEK boards.

Table 21. Booting from eMMC on i.MX 8QuadMax MEK

Switch	D1	D2	D3	D4	D5	D6	D7	D8
SW2	OFF	OFF	OFF	ON	OFF	OFF	-	-

The following table shows the boot switch settings to boot from eMMC5.0 on the i.MX 8QuadXPlus MEK boards.

Note: *This is the same setting for the i.MX 8DualX MEK and i.MX 8DXL EVK boards, except that 8DXL EVK uses SW1.*

Table 22. Booting from eMMC on i.MX 8QuadXPlus MEK

Switch	D1	D2	D3	D4
SW2	OFF	ON	OFF	OFF

The following table shows the boot switch settings to boot from eMMC5.0 on the i.MX 8M Quad EVK boards.

Table 23. Booting from eMMC on i.MX 8M Quad EVK

Switch	D1	D2	D3	D4
SW801	OFF	OFF	ON	OFF

The following table shows the boot switch settings to boot from eMMC5.1 on the i.MX 8M Mini EVK boards.

Table 24. Booting from eMMC on i.MX 8M Mini EVK

Switch	D1	D2	D3	D4	D5	D6	D7	D8
SW1101	OFF	ON	ON	ON	OFF	OFF	ON	OFF
SW1102	OFF	OFF	OFF	OFF	ON	OFF	ON	OFF

The following table shows the boot switch settings to boot from eMMC5.1 on the i.MX 8M Nano EVK boards.

Table 25. Booting from eMMC on i.MX 8M Nano EVK

Switch	D1	D2	D3	D4
SW1101	OFF	ON	OFF	OFF

The following table shows the boot switch settings to boot from eMMC5.1 on the i.MX 8M Plus EVK boards.

Table 26. Booting from eMMC on i.MX 8M Plus EVK

Switch	D1	D2	D3	D4
SW4	OFF	OFF	OFF	ON

The following table lists the boot switch settings to boot from eMMC5.1 on the i.MX 8ULP EVK.

Table 27. Singleboot booting from eMMC on i.MX 8ULP EVK

Switch	D1	D2	D3	D4	D5	D6	D7	D8
SW5	OFF	OFF	OFF	OFF	OFF	OFF	OFF	ON

Table 28. Dualboot booting from eMMC for A35 on i.MX 8ULP EVK

Switch	D1	D2	D3	D4	D5	D6	D7	D8
SW5	OFF	ON	OFF	OFF	OFF	OFF	OFF	ON

Table 29. Booting from eMMC for i.MX 93 11x11 EVK

Switch	D1	D2	D3	D4
SW1301	OFF	OFF	OFF	OFF

4.5.6 Booting from SATA

The following switch settings enable booting from SATA.

SATA booting is supported only by the i.MX 6Quad/6QuadPlus SABRE boards.

Table 30. Booting from SATA on i.MX 6 SABRE-SD

Switch	D1	D2	D3	D4	D5	D6	D7	D8
SW6	OFF	OFF	OFF	OFF	OFF	ON	OFF	OFF

4.5.7 Booting from NAND

The following table shows the DIP switch settings needed to boot from NAND on i.MX 6 SABRE-AI boards.

Table 31. Booting from NAND on i.MX 6 SABRE-AI

Switch	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
S1	OFF	OFF	OFF	ON	OFF	OFF	OFF	OFF	OFF	OFF
S2	OFF	OFF	OFF	ON	-	-	-	-	-	-
S3	OFF	OFF	ON	OFF	-	-	-	-	-	-

The following table shows the DIP switch settings needed to boot from NAND for i.MX 7Dual SABRE-SD boards.

Table 32. Booting from NAND on i.MX 7Dual SABRE-SD

Switch	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
S2	OFF	ON	ON	X	X	X	X	OFF	-	-
S3	ON	OFF	X	X	X	X	X	X	-	-

The following table shows the DIP switch settings needed to boot from NAND for i.MX 8M Mini DDR4 EVK boards.

Table 33. Booting from NAND on i.MX 8M Mini DDR4 EVK

Switch	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
SW1101	OFF	ON	OFF	OFF	OFF	OFF	OFF	ON	-	-
SW1102	OFF	OFF	OFF	ON	ON	ON	ON	OFF	-	-

4.5.8 Booting from SPI-NOR

Enable booting from SPI NOR on i.MX 6 SABRE-AI boards by placing a jumper on J3 between pins 2 and 3.

Table 34. Booting from SPI-NOR on i.MX 6 SABRE-AI

Switch	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
S1	X	X	X	X	X	X	X	X	X	X
S2	ON	ON	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
S3	OFF	OFF	ON	OFF	-	-	-	-	-	-

4.5.9 Booting from EIM (Parallel) NOR

The following table shows the DIP switch settings to boot from NOR.

Table 35. Booting from EIM NOR on i.MX 6 SABRE-AI

Switch	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
S1	X	X	X	OFF	OFF	ON	X	X	X	X
S2	X	OFF	OFF	OFF	-	-	-	-	-	-
S3	OFF	OFF	ON	OFF	-	-	-	-	-	-

Note:

SPI and EIM NOR have pin conflicts on i.MX 6 SABRE-AI boards. Neither can be used for the same configuration. The default U-Boot configuration is set to SPI NOR.

4.5.10 Booting from QuadSPI or FlexSPI

The following tables list the DIP switch settings for booting from QuadSPI.

Table 36. Booting from QuadSPI on i.MX 6SoloX SABRE-SD

Switch	D1	D2	D3	D4	D5	D6	D7	D8
SW10	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
SW11	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
SW12	OFF	OFF	OFF	ON	ON	OFF	OFF	OFF

Table 37. Booting from QuadSPI on i.MX 6SoloX SABRE-AI

Switch	D1	D2	D3	D4	D5	D6	D7	D8
SW4	OFF	OFF	OFF	OFF	ON	OFF	OFF	OFF
SW3	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
SW1	OFF	OFF	ON	OFF	-	-	-	-

Table 38. Booting from QuadSPI on i.MX 7Dual SABRE-SD

Switch	D1	D2	D3	D4	D5	D6	D7	D8
SW2	ON	OFF	OFF	OFF	OFF	OFF	OFF	OFF
SW3	ON	OFF	-	-	-	-	-	-

Table 39. Booting from QuadSPI on i.MX 6UltraLite EVK and i.MX 6ULL EVK

Switch	D1	D2	D3	D4
SW601	OFF	OFF	OFF	OFF
SW602	ON	OFF	-	-

Table 40. Booting from FlexSPI on i.MX 8QuadMax MEK

Switch	D1	D2	D3	D4	D5	D6	D7	D8
SW2	OFF	OFF	OFF	ON	ON	OFF	-	-

Table 41. Booting from FlexSPI on i.MX 8QuadXPlus MEK

Switch	D1	D2	D3	D4
SW2	OFF	ON	ON	OFF

Table 42. Booting from FlexSPI on i.MX 8M Mini LPDDR4 EVK

Switch	D1	D2	D3	D4	D5	D6	D7	D8
SW1101	OFF	ON	OFF	OFF	OFF	OFF	OFF	OFF
SW1102	OFF	ON	OFF	OFF	OFF	OFF	OFF	ON

Table 43. Booting from QuadSPI on i.MX Nano EVK

Switch	D1	D2	D3	D4
SW601	OFF	OFF	OFF	OFF
SW602	ON	OFF	-	-

Table 44. Booting from QuadSPI on i.MX 8M Plus EVK

Switch	D1	D2	D3	D4
SW4	OFF	ON	ON	OFF

Table 45. Singleboot booting from FlexSPI NOR on i.MX 8ULP EVK

Switch	D1	D2	D3	D4	D5	D6	D7	D8
SW5	OFF	OFF	OFF	OFF	OFF	ON	OFF	ON

Table 46. Dualboot booting from FlexSPI for A35 on i.MX 8ULP EVK

Switch	D1	D2	D3	D4	D5	D6	D7	D8
SW5	OFF	ON	OFF	OFF	OFF	ON	OFF	ON

4.5.11 Serial download mode for the Manufacturing Tool

No dedicated boot DIP switches are reserved for serial download mode on i.MX 6 SABRE-SD. There are various ways to enter serial download mode. One way is to set the boot mode to boot from SD slot SD3 (set SW6 DIP switches 2 and 7 to **on**, and the rest are **off**). Do not insert the SD card into slot SD3, and power on the board. After the message "HID Compliant device" is displayed, the board enters serial download mode. Then insert the SD card into SD slot SD3. Another way to do this is to configure an invalid boot switch setting, such as setting all the DIP switches of SW6 to off.

The following table shows the boot switch settings for i.MX 6 SABRE-AI boards, which are used to enter serial download mode for the Manufacturing Tool. If the boot image in the boot media is not validated, the system also enters the serial download mode.

Table 47. Setup for the Manufacturing Tool on i.MX 6 SABRE-AI

Switch	D1	D2	D3	D4
S3	OFF	ON	OFF	OFF

Table 48. Setup for the Manufacturing Tool on i.MX 7Dual SABRE-SD

Switch	D1	D2	D3	D4
S3	OFF	ON	-	-

Table 49. Setup for Manufacturing Tool on i.MX 6UltraLite EVK and i.MX 6ULL EVK

Switch	D1	D2
SW602	OFF	ON

Table 50. Setup for Manufacturing Tool on i.MX 7ULP EVK

Switch	D1	D2	D3	D4
SW1	OFF	ON	-	-

Table 51. Setup for Manufacturing Tool on i.MX 8M Quad EVK

Switch	D1	D2
SW802	OFF	ON

Table 52. Setup for Manufacturing Tool on i.MX 8M Plus EVK

Switch	D1	D2	D3	D4
SW4	OFF	OFF	OFF	ON

Table 53. Setup for Manufacturing Tool on i.MX 8M Mini EVK

Switch	D1	D2	D3	D4	D5	D6	D7	D8
SW1101	ON	OFF	X	X	X	X	X	X
SW1102	X	X	X	X	X	X	X	X

Table 54. Setup for Manufacturing Tool on i.MX 8M Nano EVK

Switch	D1	D2	D3	D4
SW1101	ON	OFF	OFF	OFF

Table 55. Setup for Manufacturing Tool on i.MX 8QuadMax MEK

Switch	D1	D2	D3	D4	D5	D6
SW2	OFF	OFF	ON	OFF	OFF	OFF

Note:

The following settings are same for the i.MX 8DualX MEK and i.MX 8DXL EVK boards (8DXL EVK uses SW1).

Table 56. Setup for Manufacturing Tool on i.MX 8QuadXPlus MEK

Switch	D1	D2	D3	D4
SW2	ON	OFF	OFF	OFF

Table 57. Setup for Manufacturing Tool on i.MX 8ULP EVK

Switch	D1	D2	D3	D4	D5	D6	D7	D8
SW2	OFF	OFF	OFF	OFF	OFF	OFF	ON	OFF

Table 58. Setup for Manufacturing Tool on i.MX 93 11x11 EVK

Switch	D1	D2	D3	D4
SW1301	ON	ON	OFF	OFF

Note:

If the SD card with bootable image is plugged in SD2 (baseboard), ROM will not fall back into the serial download mode.

4.5.12 How to build U-Boot and Kernel in standalone environment

To build U-Boot and Kernel in a standalone environment, perform the following steps.

First, generate an SDK, which includes the tools, toolchain, and small rootfs to compile against to put on the host machine.

- Generate an SDK from the Yocto Project build environment with the following command. To set up the Yocto Project build environment, follow the steps in the *i.MX Yocto Project User's Guide* (IMXLXYOCTOUG). In the following command, set `Target-Machine` to the machine you are building for. The `populate_sdk` generates a script file that sets up a standalone environment without Yocto Project. This SDK should be updated for each release to pick up the latest headers, toolchain, and tools from the current release.

```
DISTRO=fsl-imx-fb MACHINE=Target-Machine bitbake core-image-
minimal -c populate_sdk
```

Note:
If the building process is interrupted, modify `conf/local.conf` to comment out the line: `PACKAGE_CLASSES = "package_deb"`, and then execute the `populate_sdk` command again.

- From the build directory, the `bitbake` was run in, copy the `sh` file in `tmp/deploy/sdk` to the host machine to build on and execute the script to install the SDK. The default location is in `/opt`, but it can be placed anywhere on the host machine.

On the host machine, the following are the steps to build U-Boot and Kernel.

Toolchain Configuration:

- For i.MX 6 and i.MX 7 builds on the host machine, set the environment with the following command before building.

```
source /opt/fsl-imx-fb/5.15-kirkstone/environment-setup-
cortexa9hf-neon-poky-linux-gnueab
```

```
export ARCH=arm
```

- For i.MX 8 and i.MX 9 builds on the host machine, set the environment with the following command before building.

```
source /opt/fsl-imx-xwayland/5.15-kirkstone/environment-setup-
aarch64-poky-linux
                                        export ARCH=arm64
```

U-Boot:

Download source by cloning with:

```
git clone https://github.com/nxp-imx/uboot-imx -b lf_v2021.04
cd uboot-imx
```

- To build an i.MX 6 or i.MX 7 U-Boot in the standalone environment, find the configuration for the target boot. In the following example, i.MX 6ULL is the target.

```
make clean
make mx6ull_14x14_evk_defconfig
make
```

- To build an i.MX 8 U-Boot in the standalone environment, find the configuration for the target boot. In the following example, i.MX 8QuadMax MEK board is the target and it runs on the Arm Cortex-A53 core by default. SPL image (u-boot-spl.bin) is also generated with the default defconfig. It is needed when booting with OP-TEE image.

```
make distclean
make imx8qm_mek_defconfig
make
```

For i.MX 8QuadXPlus MEK and i.MX 8DualX board:

```
make distclean
make imx8qxp_mek_defconfig
make
```

For i.MX 8DXL EVK board:

```
make distclean
make imx8dxl_evk_defconfig
make
```

- For i.MX 8M Quad EVK:

```
make distclean
make imx8mq_evk_defconfig
make
```

- For i.MX 8M LPDDR4 EVK:

```
make distclean
make imx8mm_evk_defconfig
make
```

- For i.MX 8M DDR4 EVK:

```
make distclean
make imx8mm_ddr4_evk_defconfig
make
```

- For i.MX 8M Plus LPDDR4 EVK board:

```
make distclean
make imx8mp_evk_defconfig
make
```

- For i.MX 8ULP EVK board:

```
make distclean
make imx8ulp_evk_defconfig
make
```

- For i.MX 93 11x11 EVK board:

```
make distclean
make imx93_11x11_evk_defconfig
make
```

Kernel:

Download source by cloning with:

```
git clone https://github.com/nxp-imx/linux-imx -b lf-5.15.y
cd linux-imx
```

- To build the kernel in the standalone environment for i.MX 6 and i.MX 7, execute the following commands:

```
make imx_v7_defconfig
make
```

- To build the kernel in the standalone environment for i.MX 8 and i.MX 9, execute the following commands:

```
make imx_v8_defconfig
make
```

Note:

Users need to modify configurations for fused parts. For example, the i.MX 6UltraLite has four parts, G0, G1, G2, and G3.

The fused modules are as follows:

- *G0: TSC, ADC2, FLEXCAN1, FLEXCAN2, FREQ_MON, TEMP_MON, VOLT_MONLCDIF, CSI, ENET2, CAAM, USB_OTG2, SAI23, BEE, UART5678, PWM5678, ECSPI34, I2C34, GPT2, and EPIT2.*
- *G1: TSC, ADC2, FLEXCAN2, FREQ_MON, TEMP_MON, VOLT_MON, LCDIF, CSI, ENET2, and BEE.*
- *G2: FREQ_MON, TEMP_MON, VOLT_MON, and BEE.*
- *G3: No fused module.*

U-Boot configuration changes:

G0:

```
/* #define CONFIG_VIDEO */
#define CONFIG_FEC_ENET_DEV 0
/* #define CONFIG_CMD_BEE */
#define CONFIG_USB_MAX_CONTROLLER_COUNT 1
```

G1:

```
/* #define CONFIG_VIDEO */
#define CONFIG_FEC_ENET_DEV 0
/* #define CONFIG_CMD_BEE */
```

G2:

```
/* #define CONFIG_CMD_BEE */
```

G3: No change.

4.5.13 How to build imx-boot image by using imx-mkimage

For i.MX 8QuadMax, to build `imx-boot` image by using `imx-mkimage`, perform the following steps:

1. Copy `u-boot.bin` from `u-boot/u-boot.bin` to `imx-mkimage/iMX8QM/`.
2. Copy `scfw_tcm.bin` from SCFW porting kit to `imx-mkimage/iMX8QM/`.
3. Copy `bl31.bin` from Arm Trusted Firmware (`imx-atf`) to `imx-mkimage/iMX8QM/`.
4. Copy the SECO firmware container image (`mx8qmb0-ahab-container.img`) to `imx-mkimage/iMX8QM/`.
5. Run `make SOC=iMX8QM flash` to generate `flash.bin`.
6. If using OP-TEE, copy `tee.bin` to `imx-mkimage/iMX8QM/` and copy `u-boot/spl/u-boot-spl.bin` to `imx-mkimage/iMX8QM/`. Run `make SOC=iMX8QM flash_spl` to generate `flash.bin`.

For i.MX 8QuadXPlus, to build `imx-boot` image by using `imx-mkimage`, perform the following steps:

1. Copy `u-boot.bin` from `u-boot/u-boot.bin` to `imx-mkimage/iMX8QX/`.
2. Copy `scfw_tcm.bin` from SCFW porting kit to `imx-mkimage/iMX8QX/`.
3. Copy `bl31.bin` from Arm Trusted Firmware (`imx-atf`) to `imx-mkimage/iMX8QX/`.
4. Copy the SECO firmware container images (`mx8qxpb0-ahab-container.img` and `mx8qxpc0-ahab-container.img`) to `imx-mkimage/iMX8QM/`.
5. Run `make SOC=iMX8QX flash` to generate `flash.bin` for i.MX 8QuadXPlus B0, and run `make SOC=iMX8QX REV=C0 flash` to generate `flash.bin` for i.MX 8QuadXPlus C0.
6. If using OP-TEE, copy `tee.bin` to `imx-mkimage/iMX8QX/` and copy `u-boot/spl/u-boot-spl.bin` to `imx-mkimage/iMX8QX/`. Run `make SOC=iMX8QX flash_spl` to generate `flash.bin`.

For i.MX 8DXL, to build `imx-boot image` by using `imx-mkimage`, perform the following steps:

1. Copy `u-boot.bin` from `u-boot/u-boot.bin` to `imx-mkimage/iMX8DXL/`.
2. Copy `scfw_tcm.bin` from SCFW porting kit to `imx-mkimage/iMX8DXL/`.
3. Copy `bl31.bin` from Arm Trusted Firmware (`imx-atf`) to `imx-mkimage/iMX8DXL/`.
4. Copy the image of SECO firmware container (`mx8dxla1-ahab-container.img` and `mx8dxlb0-ahab-container.img`) to `imx-mkimage/iMX8DXL/`.

5. Run `make SOC=iMX8DXL flash` to generate `flash.bin` for i.MX 8DXL A1, and run `make SOC=iMX8DXL REV=B0 flash` to generate `flash.bin` for i.MX 8DXL B0.
6. If using OP-TEE, copy `tee.bin` to `imx-mkimage/iMX8DXL/` and copy `u-boot/spl/u-boot-spl.bin` to `imx-mkimage/ iMX8DXL/`. Run `make SOC=iMX8DXL flash_spl` to generate `flash.bin`.
7. If skipping loading V2X firmware, add `V2X=NO` to make command, like `make SOC=iMX8DXL V2X=NO flash`.

The following is a matrix table for targets of i.MX 8QuadMax and i.MX 8QuadXPlus.

Table 59. Matrix table for targets of i.MX 8QuadMax, i.MX 8QuadXPlus, and i.MX 8DXL

-	OP-TEE	U-Boot	SPL	Cortex-M4
`flash_spl`	Yes	Yes	Yes	No
`flash`	No	Yes	No	No
`flash_linux_m4`	Yes	Yes	Yes	Yes
`flash_regression_linux_m4`	No	Yes	No	Yes

For i.MX 8ULP EVK, to build `imx-boot` image by using `imx-mkimage`, perform the following steps:

1. Copy `u-boot.bin` from `u-boot/u-boot.bin` and `u-boot-spl.bin` from `u-boot/spl/u-boot-spl.bin` to `imx-mkimage/iMX8ULP/`.
2. Copy `bl31.bin` from Arm Trusted firmware (`imx-atf`) to `imx-mkimage/iMX8ULP/`.
3. Copy the image of Sentinel firmware container `mx8ulpa0-ahab-container.img` to `imx-mkimage/iMX8ULP/`.
4. Copy the image of uPower firmware image `upower.bin` to `imx-mkimage/iMX8ULP/`.
5. Copy the Cortex-M33 image `m33_image.bin` to `imx-mkimage/iMX8ULP/`.
6. If using OP-TEE, copy `tee.bin` to `imx-mkimage/iMX8ULP/`. The `bl31.bin` copied in Step 2 must be built with OP-TEE SPD enabled.
7. Run `make SOC=iMX8ULP flash_singleboot_m33` to generate `flash.bin`.

Note: *For the location where the binaries for Sentinel/SECO/uPower/M33/V2X firmwares are available to download, see the Table "BSP and multimedia standard packages" in the i.MX Linux Release Notes (IMXLXRN).*

The following table list the `imx-mkimage` targets used on i.MX 8ULP.

Table 60. imx-mkimage targets used on i.MX 8ULP

Boot type	Cortex-A35	Cortex-M33	SW5[8:1]

Single Boot	(Default) Boot Cortex-A35 + Cortex-M33 from eMMC:
	`make SOC=iMX8ULP flash_singleboot_m33`
	Boot Cortex-A35 only from eMMC:
	`make SOC=iMX8ULP flash_singleboot`
			1000_xx00 Single Boot-eMMC

Table 60. imx-mkimage targets used on i.MX 8ULP*...continued*

Boot type	Cortex-A35	Cortex-M33	SW5[8:1]

	Boot Cortex-A35 + Cortex-M33 from FlexSPI NOR:
	`make SOC=iMX8ULP flash_singleboot_m33_flexspi`
	Boot Cortex-A35 only from FlexSPI NOR:
	`make SOC=iMX8ULP flash_singleboot_flexspi`
			1010_xx00 Single Boot-NOR

Dual Boot	`make SOC=iMX8ULP flash_ dualboot`	For RAM target: `make SOC=iMX8ULP` flash_dualboot_m33For Flash target: `make SOC=iMX8ULP flash_ dualboot_m33_xip`	1000_0010 A35-eMMC/ M33-NOR
	`make SOC=iMX8ULP flash_ dualboot_flexspi`		1010_0010 A35-Nor/ M33-NOR
Low Power Boot	-		1000_00x1 A35-eMMC/ M33-NOR
	-		1010_00x1 A35-Nor/ M33-NOR

For i.MX 8M EVK, to build `imx-boot` image by using `imx-mkimage`, perform the following steps:

1. Copy and rename mkimage from `u-boot/tools/mkimage` to `imx-mkimage/iMX8M/mkimage_uboot`.
2. Copy `u-boot-spl.bin` from `u-boot/spl/u-boot-spl.bin` to `imx-mkimage/iMX8M/`.
3. Copy `u-boot-nodtb.bin` from `u-boot/u-boot-nodtb.bin` to `imx-mkimage/iMX8M/`.
4. Copy `imx8mq-evk.dtb` (for i.MX 8M Quad EVK), `imx8mm-evk.dtb` (for i.MX 8M Mini LPDDR4 EVK), `imx8mm-ddr4-evk.dtb` (for i.MX 8M Mini DDR4 EVK), or `imx8mp-evk.dtb` (for i.MX 8M Plus LPDDR4 EVK) from `u-boot/arch/arm/dts/` to `imx-mkimage/iMX8M/`.
5. Copy `bl31.bin` from Arm Trusted Firmware (`imx-atf`) to `imx-mkimage/iMX8M/`.
6. Copy `firmware/hdmi/cadence/signed_hdmi_imx8m.bin` from the `firmware-imx` package to `imx-mkimage/iMX8M/`.
7. For i.MX 8M Quad and i.MX 8M Mini LPDDR4 EVK, copy `lpddr4_pmu_train_1d_dmem.bin`, `lpddr4_pmu_train_1d_imem.bin`, `lpddr4_pmu_train_2d_dmem.bin`, and `lpddr4_pmu_train_2d_imem.bin` from `firmware/ddr/synopsys` of the `firmware-imx` package to `imx-mkimage/iMX8M/`.
   For i.MX 8M Mini DDR4 EVK, copy `ddr4_imem_1d.bin`, `ddr4_dmem_1d.bin`, `ddr4_imem_2d.bin`, and `ddr4_dmem_2d.bin` from `firmware/ddr/synopsys` of the `firmware-imx` package to `imx-mkimage/iMX8M`.
   For i.MX 8M Plus LPDDR4 EVK, copy `lpddr4_pmu_train_1d_dmem_201904.bin`, `lpddr4_pmu_train_1d_imem_201904.bin`, `lpddr4_pmu_train_2d_dmem_201904.bin`, and `lpddr4_pmu_train_2d_imem_201904.bin` from `firmware/ddr/synopsys` of the `firmware-imx` package to `imx-mkimage/iMX8M/`.
8. For i.MX 8M Quad EVK, run `make SOC=iMX8M flash_evk` to generate `flash.bin` (imx-boot image) with HDMI FW included.
   For i.MX 8M Mini LPDDR4 EVK, run `make SOC=iMX8MM flash_evk` to generate `flash.bin` (imx-boot image).
   For i.MX 8M Mini DDR4 EVK, run `make SOC=iMX8MM flash_ddr4_evk` to generate `flash.bin` (imx-boot image).

For i.MX 8M Plus LPDDR4 EVK, run `make SOC=iMX8MP flash_evk` to generate `flash.bin` (imx-boot-image).
To boot with eMMC fasboot on i.MX 8M Quad EVK and i.MX 8M Mini LPDDR4 EVK, use `flash_evk_emmc_fastboot target`.

For i.MX 93, to build `imx-boot` image by using `imx-mkimage`, perform the following steps:

1. Copy `u-boot.bin` from `u-boot/u-boot.bin` and `u-boot-spl.bin` from `uboot/ spl/u-boot-spl.bin` to `imx-mkimage/iMX9/`.
2. Copy `bl31.bin` from Arm Trusted firmware (`imx-atf`) to `imx-mkimage/iMX9/`.
3. Copy the image of Sentinel firmware container `mx93a0-ahab-container.img` to `imx-mkimage/iMX9/`.
4. If using OP-TEE, copy `tee.bin` to `imx-mkimage/iMX9/`. The `bl31.bin` copied in Step 2 must be built with OP-TEE SPD enabled.
5. Run `make SOC=iMX9 flash_singleboot` to generate `flash.bin`.

4.6 Flash memory maps

This section describes the software layout in memory on memory devices used on the i.MX boards.

This information is useful for understanding subsequent sections about image downloading and how the images are placed in memory.

The mtdparts directive can be used in the Linux boot command to specify memory mapping. The following example briefly describes how to use memory maps. Memory is allocated in the order of how it is listed. The dash (-) indicates the the rest of the memory.

```
mtdparts=[memory type designator]:[size]([name of partition]),
[size]([name of partition]),-([name of final partition])
```

4.6.1 MMC/SD/SATA memory map

The MMC/SD/SATA memory scheme is different from the NAND and NOR flash, which are deployed in the BSP software. The MMC/SD/SATA must keep the first sector (512 bytes) as the Master Boot Record (MBR) to use MMC/SD as the rootfs.

Upon boot-up, the MBR is executed to look up the partition table to determine which partition to use for booting. The bootloader should be after the MBR. The kernel image and rootfs may be stored at any address after the bootloader. By default, the the U-Boot boot arguments use the first FAT partition for kernel and DTB, and the following ext3 partition for the root file system. Alternatively, users can store the kernel and the DTB in any raw memory area after the bootloader. The boot arguments must be updated to match any changed memory addresses.

The MBR can be generated through the fdisk command when creating partitions in MMC/SD cards on a Linux host server.

4.6.2 NAND flash memory map

The NAND flash memory map is configured from the Linux kernel command line.

For example:

```
mtdparts=gpmi-nand:64m(boot),16m(kernel),16m(dtb),-(rootfs)
```

4.6.3 Parallel NOR flash memory map

The default configuration contains only one parallel NOR partition. The parallel NOR device is generally 4 MB. U-Boot is loaded at the beginning of parallel NOR so that the device can boot from it. The default configuration is that on boot up, U-Boot loads the kernel, DTB, and root file system from the SD/MMC card into DDRAM. The end user can change the default settings according to their needs. More partitions can be added through the kernel command line. The memory type designator for the command below consists of the NOR address and the designator. This information can be found in the i.MX `.dtsi`device tree file in `arch/arm/boot/dts`. The following is an example of what might be added to the Linux boot command line:

```
mtdparts=8000000.nor:1m(uboot),-(rootfs)
```

The address for parallel NOR is 0x8000000 for i.MX 6 SABRE-AI.

4.6.4 SPI-NOR flash memory map

The SPI-NOR flash memory can be configured using the Linux kernel command line.

U-Boot should be loaded at the 1 KB offset of the SPI-NOR memory, so that the device can boot from it. The default configuration is that on boot up, U-Boot loads the kernel, DTB, and root file system from the SD/MMC card into DDRAM. The end user can change the default settings according to their needs. More partitions can be added through the kernel command line. The following is an example of what might be added to the Linux boot command line:

```
mtdparts=spi32766.0:768k(uboot),8k(env),128k(dtb),-(kernel)
```

4.6.5 QuadSPI flash memory map

The QuadSPI flash memory can be configured using the Linux kernel command line.

U-Boot is loaded at the beginning of the QuadSPI memory so that the device can boot from it. The default configuration is that on boot up, U-Boot loads the kernel, DTB, and root file system from the SD/MMC card into DDRAM. The end user can change the default settings according to their requirements. More partitions can be added through the kernel command line. The following is an example of what might be added to the Linux boot command line:

```
mtdparts=21e4000.qspi:1m(uboot),8m(kernel),1m(dtb),-(user)
```

U-Boot has the mapping below to help in accessing the QuadSPI flash in U-Boot for non-parallel mode.

Table 61. U-Boot mapping for QuadSPI

Device on hardware	Device in U-Boot	Memory address in U-Boot	Remark
QuadSPI1 Port A CS0	sf probe 0:0 on i.MX 6SoloX SABRE-AI board, i.MX 7Dual SABRE-SD board, i.MX 6Ultra Lite EVK board, i.MX 8QuadMax MEK, i.MX 8QuadXPlus MEK, and i.MX 8DXL EVK	0x60000000 0x08000000	-
QuadSPI1 Port B CS0	sf probe 1:0 on i.MX 6 SoloX SABRE-AI board	0x68000000	-
QuadSPI2 Port A CS0	sf probe 0:0 on i.MX 6SoloX SABRE-SD board	0x70000000	-
QuadSPI2 Port B CS0	sf probe 1:0 on i.MX 6SoloX SABRE-SD board	0x78000000	-

Table 62. U-Boot mapping for FlexSPI for i.MX 8ULP

Device on hardware	Device in U-Boot	Memory address in U-Boot	Remark
Flexspi0 PortA CS0	sf probe 0:0	0x04000000	-
Flexspi2 PortA CS0	sf probe 2:0	0x60000000	-

4.7 Running Linux OS on the target

This section describes how to run a Linux image on the target using U-Boot.

These instructions assume that you have downloaded the kernel image using the instructions in Section 4.4 or Section 4.3. If you have not set up your Serial Terminal, see Section 3.

The basic procedure for running Linux OS on an i.MX board is as follows. This document uses a specific set of environment variable names to make it easier to describe the settings. Each type of setting is described in its own section as follows.

1. Power on the board.
2. When U-Boot comes up, set the environment variables specific to your machine and configuration. Common settings are described below and settings specific to a device are described in separate sections.
3. Save the environment setup:

```
U-Boot > saveenv
```

4. Run the boot command:

```
U-Boot > run bootcmd
```

The commands `env default -f -a` and `saveenv` can be used to return to the default environment.

Specifying the console

The console for debug and command-line control can be specified on the Linux boot command line. The i.MX 6Quad SABRE-AI board uses `ttymxc2`, so it is not same for all

boards. It is usually specified as follows, but the baud rate and the port can be modified. Therefore, for NFS, it might be `ttymxc3`.

```
U-Boot > setenv consoleinfo 'console=ttymxc2,115200'
```

For the i.MX 7ULP EVK, i.MX 8QuadMax MEK boards, and i.MX 8QuadXPlus MEK board, change to " console=ttyLP0,115200".

Specifying displays

The display information can be specified on the Linux boot command line. It is not dependent on the source of the Linux image. If nothing is specified for the display, the settings in the device tree are used. Add `${displayinfo}` to the environment macro containing `bootargs`. The specific parameters can be found in the *i.MX Linux Release Notes* (IMXLXRN). The following are some examples of these parameters.

- `U-Boot > setenv displayinfo 'video=mxcfb0:dev=hdmi,1920x1080M@60,if=RGB24'` for an HDMI display
- `U-Boot > setenv displayinfo 'video=mxcfb1:dev=ldb video=mxcfb0:dev=hdmi,1920x1080M@60,if=RGB24'` for LVDS and HDMI dual displays
- `U-Boot > setenv displayinfo 'video=mxcfb0:dev=lcd,if=RGB565'` for an LCD
- `U-Boot > setenv displayinfo 'video=mxcepdcfb:E060SCM,bpp=16 max17135:pass=2,vcom=-2030000'` for an EPDC connection
- `U-Boot > setenv displayinfo 'video=mxcfb0:mxcfb0:dev=lcd,if=RGB565 video=mxcfb1:dev=hdmi,1920x1080M@60,if=RGB24'` for LCD and HDMI dual displays

Specifying memory addresses

The addresses in the memory where the kernel and device tree are loaded to do not change based on the device that runs Linux OS. The instructions in this chapter use the environment variables `loadaddr` and `ftd_addr` to indicate these values. The following table shows the addresses used on different i.MX boards.

Table 63. Board-specific default values

Variable	6Quad, 6QuadPlus, and 6Dual Lite SABRE (AI and SD)	6SoloX SD	7Dual SABRE-SD	6UltraLite, 6ULL and 6ULZ EVK	7ULP EVK	8QuadMax, 8Quad XPlus, 8DualX, and 8DXL	8ULP	8M Quad/ 8M Mini EVK	i.MX 93	Description
`loadaddr`	0x12000000	0x80800000	0x80800000	0x80800000	0x60800000	0x80200000	0x80400000	0x40400000	0x80400000	Address in the memory the kernel are loaded to
`fdt_addr`	0x18000000	0x83000000	0x83000000	0x83000000	0x63000000	0x83000000	0x83000000	0x43000000	0x83000000	Address in the memory the device tree code are copied to

In addition, `fdtfile` is used to specify the filename of the device tree file. The commands used to set the U-Boot environment variables are as follows:

```
U-Boot > setenv loadaddr 0x80080000
U-Boot > setenv fdtaddr 0x80f00000
U-Boot > setenv fdtfile fsl-imx7ulp-evk.dtb
```

Specifying the location of the root file system

The rootfs can be located on a device on the board or on NFS. The settings below show some options for specifying these.

- `U-Boot > setenv rootfsinfo 'root=/dev/nfs ip=dhcp nfsroot= ${serverip}:${nfsroot},v3,tcp'`
- `U-Boot > setenv rootfsinfo 'root=/dev/nfs ip=dhcp weim-nor nfsroot=${serverip}:${nfsroot},v3,tcp'`
- `U-Boot > setenv rootfsinfo 'ubi.mtd=4 root=ubi0:rootfs rootfstype=ubifs rootwait rw mtdparts=gpmi-nand:64m(boot),16m(kernel),16m(dtb),-(rootfs)'`
- `U-Boot > setenv rootfsinfo 'root=/dev/mmcblk0p2 rootwait rw'`

Special settings

i.XM 6Solo, and 6UltraLite can specify `uart_from_osc` on the command line to specify that the OSC clock rather than PLL3 should be used. This allows the system to enter low power mode.

```
U-Boot > setenv special 'uart_from_osc'
```

Creating the boot command line

For clarification, this document groups the bootargs into one macro as follows:

```
U-Boot > setenv bootargsset 'setenv bootargs ${consoleinfo}
 ${rootfsinfo} ${displayinfo} ${special}'
```

The executed boot command is then as follows. Arguments vary by device.

```
U-Boot > setenv bootcmd 'run bootargsset; {settings-for-
device}; bootz ${loadaddr} - ${fdt_addr}'
```

4.7.1 Running the image from NAND

NAND can be found on i.MX 6 SABRE-AI boards.

Power on the board, and then enter the commands provided. The following settings may be used to boot the Linux system from NAND.

Assume that the kernel image starts from the address 0x1400000 byte (the block starting address is 0x800). The kernel image size is less than 0x400000 byte. The rootfs is located in `/dev/mtd2`.

```
U-Boot > setenv bootcmd 'run  bootargsset; nand read
 ${loadaddr} 0x1000000 0x800000; nand read ${fdt_addr}
 0x2000000 0x100000; bootz ${loadaddr} - ${fdt_addr}'
```

4.7.2 Running Linux OS from Parallel NOR

Parallel NOR is available on i.MX 6 SABRE-AI boards. The following procedure can be used to boot the system from Parallel NOR.

1. Assume that the kernel image starts at address 0xc0000 bytes.
2. At the U-Boot prompt, set up these variables:

```
U-Boot > setenv bootcmd 'run bootargsset; cp.b 0x80c0000
 ${loadaddr} 0x800000;cp.b 0x80a0000 ${fdt_addr}
 0x20000;bootz ${loadaddr} - ${fdt_addr} '
```

4.7.3 Running the Linux OS image from QuadSPI

QuadSPI is available on i.MX 6SoloX SABRE-SD boards, i.MX 7Dual SABRE-SD boards, i.MX 6UltraLite EVK boards, i.MX 6ULL EVK boards, and i.MX 8QuadMax MEK, and i.MX 8QuadXPlus MEK. The following procedure may be used to boot the Linux system from QuadSPI NOR.

1. Assume that the kernel image starts from the address 0xA00000 byte and the DTB file starts from address 0x800000.
2. At the U-Boot prompt, set the following environment variables:

```
U-Boot > setenv bootcmd 'run bootargsset; sf probe; sf read
 ${loadaddr} 0xA00000 0x2000; sf read ${fdt_addr} 0x800000
 0x800; bootz ${loadaddr} - ${fdt_addr} '
```

4.7.4 Running the Arm Cortex-M4/7/33 image

On the i.MX 6SoloX boards, there are two ways to boot Arm Cortex-M4 images in U-Boot:

- Arm Cortex-M4 processor Normal Up (supported on i.MX 6SoloX SABRE-AI and SABRE-SD boards). Performed by running the U-Boot command. Requires:
  1. U-Boot normal SD image if Arm Cortex-A9 processor boots from the SD card. U-Boot normal QSPI image if Arm Cortex-A9 processor boots from the QSPI NOR flash.
  2. Kernel DTB: imx6sx-sdb-m4.dtb for i.MX 6SoloX SABRE-SD board. imx6sx-sabreauto-m4.dtb for i.MX 6SoloX SABRE-AI board.
  3. Have the Arm Cortex-M4 image burned. (NOR flash of QuadSPI2 PortB CS0 for i.MX 6SoloX SABRE-SD board. NOR flash of QuadSPI1 PortB CS0 for i.MX 6SoloX SABRE-AI board.)
- Arm Cortex-M4 processor Fast Up (only supported on i.MX 6SoloX SABRE-SD boards). Initiated by U-Boot at a very early boot phase to meet the requirement of Arm Cortex-M4 processor booting in 50 ms. No U-Boot command is involved. Requires:
  1. U-Boot Arm Cortex-M4 fast up image and Arm Cortex-A9 processor must boot from the QSPI2 NOR flash.
  2. Kernel DTB: `imx6sx-sdb-m4.dtb`.
  3. Have the Arm Cortex-M4 image burned (NOR flash of QuadSPI2 PortB CS0).

To facilitate the Arm Cortex-M4 processor Normal Up, a script has been added to the default U-Boot. The following steps may help users who need to run the Cortex-M4 processor Normal Up script.

1. Power on the board.

2. On the i.MX 6SoloX SABRE-SD board, assumed that the Arm Cortex-M4 image is at address 0x78000000 (NOR flash of QuadSPI2 PortB CS0). On the i.MX 6SoloX SABRE-AI board, assumed that the Arm Cortex-M4 image is at address 0x68000000 (NOR flash of QuadSPI1 PortB CS0).

At the U-Boot prompt:

```
U-Boot > run m4boot
```

Or users can perform the commands without depending on the script:

```
U-Boot > sf probe 1:0
```

For the i.MX 6SoloX SABRE-SD board:

```
U-Boot >  bootaux 0x78000000
```

For the i.MX 6SoloX SABRE-AI board:

```
U-Boot >  bootaux 0x68000000
```

Note:

For how to add the MCC demo to the kernel and limit RAM available to kernel to use it, see Chapter 53 "i.MX 6 SoloX MultiCore Communication (MCC)" of the i.MX Linux Reference Manual (IMXLXRM).

As well as supporting running the Arm Cortex-M4 image from QuadSPI, the default i.MX 7Dual SABRE-SD board supports loading the Arm Cortex-M4 image from the SD card and running it on OCRAM.

Prepare the Arm Cortex-M4 image to the FAT partition of the SD card. Name the file to `m4_qspi.bin` when using `m4boot` script.

After the board is powered on, the following information is displayed at the U-Boot prompt:

```
U-Boot > run m4boot
```

Or perform the commands without depending on the script:

```
u-boot=> fatload mmc 0:0 ${loadaddr} m4_qspi.bin
u-boot=> cp.b ${loadaddr} 0x7e0000 ${filesize}
u-boot=> bootaux 0x7e0000
```

Note:

If your demo has no resource table, such as NXP `hello_world.bin`, clear the resource table area. Otherwise, Linux OS may shows the garbage value.

- *For i.MX 8M Mini/Nano/Quad LPDDR4 EVK: run `#mw 0xb80ff000 0 4` to clear the garbage resource table area.*
- *For i.MX 8M Plus LPDDR4 EVK: run `#mw 0x550ff000 0 4` to clear the garbage resource table area.*

On the i.MX 8M boards, perform the commands to boot the Arm Cortex-M Core core:

```
u-boot=> fatload mmc 1:1 ${loadaddr} m4.bin
```

```
u-boot=> cp.b ${loadaddr} 0x7e0000 ${filesize}
u-boot=> bootaux 0x7e0000
```

There are two methods to start the remote core: U-Boot `bootaux` and Linux `remoteproc`.

Whether to use `bootaux` or `remoteproc` to start the remote core, use `remoteproc` to stop or start the Cortex-M core for debug purposes only. It is not recommended to stop the Cortex-M core from Linux OS in a production system.

If you choose to use `remoteproc` to start the remote core directly, execute `run prepare_mcore` in U-Boot before starting the Linux OS.

On the i.MX 8QuadMax and i.MX 8QuadXPlus boards, there are two ways to boot the Arm Cortex-M4 cores:

- Booting from ROM
  Users need to use imx-mkimage to pack the Arm Cortex-M4 images into imx-boot image. It is necessary to specify the core ID and its TCML address in the build command. The following is an example:

```
flash_linux_m4: $(MKIMG) mx8qmb0-ahab-container.img
 scfw_tcm.bin u-boot-spl.bin m4_image.bin m4_1_image.bin u-
boot-atf-container.img
  ./$(MKIMG) -soc QM -rev B0 -dcd skip -append mx8qmb0-ahab-
container.img -c -flags 0x00200000 -scfw scfw_tcm.bin -ap u-
boot-spl.bin a53 0x00100000 -p3 -m4 m4_image.bin 0 0x34FE0000
 -p4 -m4 m4_1_image.bin 1 0x38FE0000 -out flash.bin
  cp flash.bin boot-spl-container.img
  @flashbin_size=`wc -c flash.bin | awk '{print $$1}'`; \
                  pad_cnt=$$(((flashbin_size + 0x400 - 1) /
 0x400)); \
                  echo "append u-boot-atf-container.img at $
$pad_cnt KB"; \
                  dd if=u-boot-atf-container.img of=flash.bin
 bs=1K seek=$$pad_cnt;
```

Note:
When booting with the packed Cortex-M4 image (`flash_linux_m4`), use kernel DTB with RPMSG enabled, like `fsl-imx8qm-mek-rpmsg.dtb` for i.MX 8QuadMax MEK or `fsl-imx8qxp-mek-rpmsg.dtb` for i.MX 8QuadXPlus MEK.

- Booting from U-Boot (not support multiple partitions enabled)
  U-Boot supports loading the Arm Cortex-M4 image from the FAT partitions of the SD card with default name `m4_0.bin` and `m4_1.bin`. After the board is booted into the U-Boot console, use the following command to boot Arm Cortex-M4 core 0:

```
U-Boot > run m4boot_0
Or the command to boot M4 core 1:
U-Boot > run m4boot_1
Or perform the commands for core 0 without depending on the
 script:
U-Boot > fatload mmc 1:1 0x80280000 m4_0.bin
U-Boot > dcache flush; bootaux 0x80280000 0
```

On the i.MX 93 11x11 EVK, use `bootaux`:

```
=> fatload mmc 1:1 ${loadaddr}
 imx93_m33_TCM_rpmsg_lite_str_echo_rtos.bin
15948 bytes read in 4 ms (3.8 MiB/s)
```

```
=> cp.b ${loadaddr} 0x201e0000 ${filesize}
=> bootaux 0x201e0000 0
## Starting auxiliary core stack = 0x20020000, pc =
 0x0FFE05D5...
```

Pass `clk_ignore_unused` in bootargs when using `bootaux` to kick Arm Cortex-M33.

For i.MX 93, users can directly start/stop Cortex-M33 using `remoteproc` as follows:

```
[  138.693391] remoteproc remoteproc0: stopped remote processor
 imx-rproc
root@imx93evk:~# echo
 imx93_m33_TCM_rpmsg_lite_str_echo_rtos_imxcm33.elf > /sys/
devices/platform/imx93-cm33/remoteproc/remoteproc0/firmware
root@imx93evk:~# echo start > /sys/devices/platform/imx93-cm33/
remoteproc/remoteproc0/state
[  162.361023] remoteproc remoteproc0: powering up imx-rproc
[  162.368617] remoteproc remoteproc0: Booting fw image
 imx93_m33_TCM_rpmsg_lite_str_echo_rtos_imxcm33.elf, size
 175644
[  162.916805]  remoteproc0#vdev0buffer: assigned reserved
 memory node vdevbuffer@a4020000
[  162.926429] virtio_rpmsg_bus virtio0: rpmsg host is online
[  162.935336]  remoteproc0#vdev0buffer: registered virtio0
 (type 7)
[  162.941986]  remoteproc0#vdev1buffer: assigned reserved
 memory node vdevbuffer@a4020000
[  162.951071] virtio_rpmsg_bus virtio1: rpmsg host is online
[  162.956649] virtio_rpmsg_bus virtio1: creating channel
 rpmsg-virtual-tty-channel addr 0x1e
[  162.962559]  remoteproc0#vdev1buffer: registered virtio1
 (type 7)
[  162.971179] remoteproc remoteproc0: remote processor imx-
rproc is now up
root@imx93evk:~#
root@imx93evk:~# echo stop > /sys/devices/platform/imx93-cm33/
remoteproc/remoteproc0/state
[  172.114287] remoteproc remoteproc0: stopped remote processor
 imx-rproc
```

4.7.5 Linux OS login

The default login user name for the i.MX Linux OS is `root` with no password.

4.7.6 Running Linux OS from MMC/SD

This scenario assumes that the board is configured to boot U-Boot, that the Linux kernel image is named zImage and is stored on the SD card in an MS-DOS FAT partition, and one or more device tree files are also stored in this partition. The rootfs is also stored on the SD/MMC card in another partition.

When U-Boot boots up, it detects the slot where it is booting from and automatically sets `mmcdev` and `mmcroot` to use the rootfs on that SD card. In this scenario, the same SD card can be used to boot from any SD card slot on an i.MX 6/7 board, without changing any U-Boot settings. From the U-Boot command line, type `boot` to run Linux OS.

The following instructions can be used if the default settings are not desired.

Set `mmcautodetect` to "no" to turn off the automatic setting of the SD card slot in `mmcdev` and `mmcroot`. The U-Boot `mmcdev` is based on the soldered SD/MMC connections, so it varies depending on the board. The U-Boot `mmc dev 0` is the lowest numbered SD slot present, 1 is the next, and so on. The Linux kernel, though, indexes all the uSDHC controllers whether they are present or not. The following table shows this mapping.

Table 64. Linux uSDHC relationships

uSDHC	mmcroot
uSDHC 1	mmcblk0*
uSDHC 2	mmcblk1*
uSDHC 3	mmcblk2*
uSDHC 4	mmcblk3*

In the default configuration of the SD card and the example here, U-Boot is at the 1024 byte offset, 32 KB offset for the i.MX 8QuadXPlus B0 and i.MX 8QuadMax B0, or 33 KB offset for the i.MX 8QuadXPlus A0, i.MX 8QuadMax A0, i.MX 8M EVK boards before the first partition, partition 1 is the partition with the Linux kernel and device trees, and partition 2 is the rootfs.

Setting up the environment variables

For convenience, this document uses a standard set of variables to describe the information in the Linux command line. The values used here may be different for different machines or configurations. By default, U-Boot supports setting `mmcdev` and `mmcroot` automatically based on the uSDHC slot that we boot from. This assumes zImage, the device tree file (DTB), and the rootfs are on the same SD/MMC card. To set these environment variables manually, set `mmcautodetect` to `no` to disable the feature.

The following is one way to set up the items needed to boot Linux OS.

```
U-Boot > setenv mmcpart 1
U-Boot > setenv loadfdt 'fatload mmc ${mmcdev}:${mmcpart}
 ${fdt_addr} ${fdtfile}'
U-Boot > setenv loadkernel 'fatload mmc ${mmcdev}:${mmcpart}
 ${loadaddr} zImage'
U-Boot > setenv bootcmd 'mmc dev ${mmcdev}; run loadkernel; run
 mmcargs; run loadfdt; bootz ${loadaddr} - ${fdt_addr};'
```

The descriptions of the variables used above are as follows:

- `mmcpart` - This is the partition on the MMC/SD card containing the kernel image.
- `mmcroot` - The location of the root file system on the MMC SD card along with directives for the boot command for the rootfs.

Note: *The U-Boot environment on the pre-built SD card does not match this. It is more complex so that it can automatically deal with more variations. The example above is designed to be easier to understand and use manually.*

Reading the kernel image from eMMC

eMMC has user area, boot partition 1, and boot partition 2. To switch between the eMMC partitions, the user needs to use the command `mmc dev [dev id] [partition id]`. For example,

```
mmc dev 2 0 ---> user area
```

```
mmc dev 2 1 ---> boot partition 1
mmc dev 2 2 ---> boot partition 2
```

4.7.7 Running the Linux image from NFS

To boot from NFS, set the following environment variables at the U-Boot prompt:

```
U-Boot > setenv serverip <your server IP>
U-Boot > setenv image <your kernel zImage name on the TFTP
 server>
U-Boot > setenv fdtfile <your dtb image name on the TFTP
 server>
U-Boot > setenv rootfsinfo 'setenv bootargs ${bootargs} root=/
dev/nfs ip=dhcp \
               nfsroot=${serverip}:/data/rootfs_home/
rootfs_mx6,v3,tcp'
U-Boot > setenv bootcmd_net 'run rootfsinfo; dhcp ${image};
 dhcp ${fdt_addr} \
               ${fdtfile}; booti ${loadaddr} - ${fdt_addr}'
U-Boot > setenv bootcmd 'run bootcmd_net'
```

Note: *If the MAC address has not been burned into the fuses, set the MAC address to use the network in U-Boot.*

```
# eth0:
setenv ethaddr xx:xx:xx:xx:xx:xx
# eth1:
setenv eth1addr xx:xx:xx:xx:xx:xx
```

4.8 Arm SystemReady-IR

4.8.1 Arm SystemReady-IR ACS compliance test

To run the SystemReady-IR ACS on the i.MX 8M Mini EVK board, refer to the Arm SystemReady-IR ACS from: https://github.com/ARM-software/arm-systemready

1. Clone the ACS Git.
2. Flash the pre-build release image or image built from source code on to the U-Disk, SD, or eMMC. If the target storage is also boot storage, flash the boot image (`flash.bin`) thereafter the ACS image. For example, on the U-Disk:

   ```
   sudo dd if=ir_acs_live_image.img of=/dev/sde bs=64M;sync
   ```
3. Boot the board. The ACS test will automatically run up.
4. There will be manual step for the power-off test from ACS. Just re-power on the board when run into that test case.
   The test result will be stored on the storage.
5. Use the SCT_Parser to analyze the ACS result. The SCT_Parser can be obtained from: https://github.com/vstehle/SCT_Parser
6. Copy the `acs_results\sct_results\Overall\Summary.ekl` file from the RESULT partition in U-disk to the SCT_Parser folder. Run `python3 parser.py --config EBBR.yaml Summary.ekl EBBR.seq` to get the final report.

4.8.2 Capsule update

Use the following command to do the capsule update:

- For SD:

```
U-Boot > env set dfu_alt_info "mmc 1=1 raw 0x42 0x2000"
```

- For eMMC:

```
U-Boot > env set dfu_alt_info "mmc 2=1 raw 0x42 0x2000 mmcpart
 1"
U-Boot > efidebug boot add 0 Boot0000 mmc 1:1
 capsule1.bin;efidebug boot next 0
U-Boot > setenv serverip 10.192.242.218;dhcp $loadaddr
 capsule1.bin;fatwrite mmc 1:1 ${loadaddr} /EFI/UpdateCapsule/
capsule1.bin 0x${filesize}
U-Boot > setenv -e -nv -bs -rt -v OsIndications =0x04
U-Boot > efidebug capsule disk-update
reset
```

Do not interrupt U-Boot. Let the board run into grub. Before grub runs, it should update the bootloader automatically and remove `capsule1.bin`. And reboot the board again. The board will boot up with the updated U-Boot.

4.8.3 Linux distro installation

Fedora34:

1. Download the Fedora34 IOT version.
2. Burned into the SD card.
3. Boot from eMMC.
4. Install distro from the SD card to eMMC.

OpenSUSE:

1. Download the OpenSUSE Tumbleweed version.
2. Burn ISO into the USB disk.
3. Boot from eMMC.
4. Install from ISO to eMMC.

5 Enabling Solo Emulation

Solo emulation can be enabled on the i.MX 6DualLite SABRE-SD and i.MX 6DualLite SABRE-AI boards. This is achieved by using a specific U-Boot configuration in the bootloader build process.

When this Solo emulation is enabled on the i.MX 6DualLite SABRE platforms, the capabilities of the i.MX 6DualLite change to the following:

- For solo emulation, use 6DualLite DTB and add `maxcpus=1` to bootcmd of U-Boot.
- 32-bit data bus on DDR RAM.
- 1 GB of RAM for i.MX 6DualLite SABRE-AI.
- 512 MB of RAM for i.MX 6DualLite SABRE-SD.

To build U-Boot for an i.MX 6Solo on an i.MX 6DualLite SABRE-SD card, use the following command:

```
MACHINE=imx6solosabresd bitbake u-boot-imx
```

To build U-Boot for an i.MX 6Solo on an i.MX 6DualLite SABRE-AI card, use the following command:

```
MACHINE=imx6solosabreauto bitbake u-boot-imx
```

6 Power Management

The i.MX power management uses the standard Linux interface. Check the standard Linux power documentation for information on the standard commands. The *i.MX Linux Reference Manual* (IMXLXRM) contains information on the power modes that are available and other i.MX-specific information in the power management section.

There are three main power management techniques on i.MX boards: suspend and resume commands, CPU frequency scaling, and bus frequency scaling. They are described in the following sections.

6.1 Suspend and resume

The power state can be changed by setting the standard Linux state, `/sys/power/state`. The command used to set the power state into suspend mode, available from the command line, is `echo mem > /sys/power/state`. The value `mem` can be replaced by any of the valid power states, as described by the *i.MX Linux Reference Manual* (IMXLXRM).

Use one of the following methods to wake up the system from suspend mode.

- The debug UART can be set as a wake-up source with:

  ```
  echo enabled > /sys/class/tty/ttymxc0/power/wakeup
  ```

  Note:
  It is `ttylp0` for i.MX 8QuadXPlus and i.MX 8QuadMax, and `ttyLP0` for i.MX 8DXL. To identify the current debug UART and configure it as a wake-up source:

  ```
  echo enabled > /sys/class/tty/$(tty | cut -d'/' -f 3)/power/
  wakeup
  ```

- RTC can be used to enter and exit from suspend mode by using the command:

  ```
  /unit_test/SRTC/rtcwakeup.out -d rtc0 -m mem -s 10
  ```

  This command indicates to sleep for 10 secs. This command automatically sets the power state to `mem` mode.

6.2 CPU frequency scaling

Scaling governors are used in the Linux kernel to set the CPU frequency. CPU frequencies can be scaled automatically depending on the system load either in response to ACPI events or manually by userspace programs. For more information about governors, read governors.txt from www.kernel.org/doc/Documentation/cpu-freq/governors.txt.

The following are some of the more frequently used commands:

These commands return information about the system and the current settings.

- The kernel is pre-configured to support only certain frequencies. The list of frequencies currently supported can be obtained from:

```
cat /sys/devices/system/cpu/cpu0/cpufreq/
scaling_available_frequencies
```

- To get the available scaling governors:

```
cat /sys/devices/system/cpu/*/cpufreq/
scaling_available_governors
```

- To check the current CPU frequency:

```
cat /sys/devices/system/cpu/*/cpufreq/cpuinfo_cur_freq
```

  The frequency is displayed depending on the governor set.
- To check the maximum frequency:

```
cat /sys/devices/system/cpu/*/cpufreq/cpuinfo_max_freq
```

- To check the minimum frequency:

```
cat /sys/devices/system/cpu/*/cpufreq/cpuinfo_min_freq
```

These commands set a constant CPU frequency:

- Use the maximum frequency:

```
echo performance > /sys/devices/system/cpu/cpu0/cpufreq/
scaling_governor
```

- Use the current frequency to be the constant frequency:

```
echo userspace > /sys/devices/system/cpu/cpu0/cpufreq/
scaling_governor
```

- The following two commands set the scaling governor to a specified frequency, if that frequency is supported. If the frequency is not supported, the closest supported frequency is used:

```
echo userspace > /sys/devices/system/cpu/cpu0/cpufreq/
scaling_governor
echo <frequency> > /sys/devices/system/cpu/cpu0/cpufreq/
scaling_setspeed
```

6.3 Bus frequency scaling

This release does not support the bus frequency scaling feature on i.MX 7ULP EVK.

This release does not support the bus frequency scaling feature on i.MX 8QuadXPlus and i.MX 8QuadMax.

The system automatically adjusts the bus frequency (DDR, AHB, etc.) for optimal performance based on the devices that are active.

The bus frequency driver is enabled by default. The following DDR frequencies are supported:

- Normal DDR frequency – Default frequency in U-Boot

- Audio DDR frequency – 50 MHz on i.MX 6Quad, i.MX 6DualLite, and i.MX 6SoloX, and 100 MHz on i.MX 7Dual.
- Low power idle DDR frequency – 24 MHz

On the i.MX 8M board:

- For LPDDR4, the Audio DDR frequency is 25 MHz, the low power idle DDR frequency is 25 MHz.
- For DDR4, the audio DDR frequency is 166 MHz, the low power idle DDR frequency is 166 MHz.

To enter a low power idle DDR frequency, ensure that all devices that require high DDR frequency are disabled. Most drivers do active clock management, but certain commands can be used to avoid waiting for timeouts to occur:

`echo 1 > /sys/class/graphics/fb0/blank` -> to blank the display (may need to blank fb1, fb2, and so on, if more than one display is active).

`ifconfig eth0 down` -> disables the Ethernet module. On i.MX 6SoloX, i.MX 7Dual, i.MX 6UltraLite, and i.MX 6UltraLiteLite should also disable Ethernet 1 (eth1).

i.MX 8M Plus needs some additional steps to enable USB runtime PM:

```
echo auto > /sys/bus/platform/
devices/32f10100.usb/38100000.dwc3/power/control
echo auto > /sys/bus/platform/
devices/32f10108.usb/38200000.dwc3/power/control
echo auto > /sys/bus/platform/
devices/32f10108.usb/38200000.dwc3/xhci-hcd.1.auto/power/
control
```

Execute the following command for i.MX 8ULP to enable system level voltage and frequency scaling:

```
ifconfig eth0 down
systemctl stop weston
echo 1 > /sys/devices/platform/imx8ulp-lpm/enable
```

On most systems, the chip enters low power IDLE mode after the above two commands are executed.

To manipulate bus frequency, use the following commands to achieve the results desired:

`cat /sys/bus/platform/drivers/imx_busfreq/soc\:busfreq/enable` -> displays the status of bus frequency.

`echo 0 > /sys/bus/platform/drivers/imx_busfreq/soc\:busfreq/enable` -> disables bus frequency.

`echo 1 > /sys/bus/platform/drivers/imx_busfreq/soc\:busfreq/enable` -> enables bus frequency.

The *i.MX Linux Reference Manual* (IMXLXRM) has more information on the bus frequency in the chapter about DVFS.

7 Multimedia

i.MX provides audio optimized software codecs, parsers, hardware acceleration units, and associated plugins. The i.MX provides GStreamer plugins to access the i.MX

multimedia libraries and hardware acceleration units. This chapter provides various multimedia use cases with GStreamer command line examples.

7.1 i.MX multimedia packages

Due to license limitations, i.MX multimedia packages can be found in two locations:

- Standard packages: provided on the NXP mirror.
- Limited access packages: provided on nxp.com with controlled access.

For details, see the *i.MX Release Notes* (IMXLXRN).

7.2 Building limited access packages

Place the limited access package in the `downloads` directory and read the `readme` file in each package.

For example, README-microsoft in the package `imxcodec-microsoft-$version.tar.gz`.

7.3 Multimedia use cases

GStreamer is the default multimedia framework on Linux OS. The following sections provide examples of GStreamer commands to perform the specific functions indicated. The following table shows how this document refers to common functions and what the actual command is.

Table 65. Command mapping

Variable	$GSTL	$PLAYBIN	$GPLAY	$GSTINSPECT
GStreamer 1.x	gst-launch-1.0	playbin	gplay-1.0	gst-inspect-1.0

One option is to set these as environment variables as shown in the following examples. Use the full path to the command on your system.

```
export GSTL=gst-launch-1.0
export PLAYBIN=playbin
export GPLAY=gplay-1.0
export GSTINSPECT=gst-inspect-1.0
```

In this document, variables are often used to describe the command parameters that have multiple options. These variables are of the format `$description` where the type of values that can be used are described. The possible options can be found in the Section about Multimedia in the *i.MX Linux Release Notes* (IMXLXRN) for i.MX-specific options, or at "gstreamer.freedesktop.org/ for the community options.

The GStreamer command line pipes the input through various plugins. Each plugin section of the command line is marked by an exclamation mark (!). Each plugin can have arguments of its own that appear on the command line after the plugin name and before the next exclamation mark (!). Use `$GSTINSPECT $plugin` to get information on a plugin and what arguments it can use.

Square brackets ([ ]) indicate optional parts of the command line.

7.3.1 Playback use cases

Playback use cases include the following:

- Audio-only playback
- Video-only playback
- Audio/Video file playback
- Other methods for playback

7.3.1.1 Audio-only playback

An audio-only playback command uses this format:

```
$GSTL filesrc location=$clip_name [typefind=true] !
 [$id3parse] ! queue ! $audio_parser_plugins
     ! $audio_decoder_plugin ! $audio_sink_plugin
```

If the file to be played contains an ID3 header, use the ID3 parser. If the file does not have an ID3 header, this has no effect.

This example plays an MP3 file in the audio jack output.

```
$GSTL filesrc location=test.mp3 ! id3demux ! queue !
 mpegaudioparse ! beepdec ! pulsesink
```

7.3.1.2 Video-only playback

```
$GSTL filesrc location=test.video typefind=true
     ! $capsfilter ! $demuxer_plugin ! queue max-size-time=0
     ! $video_decoder_plugin ! $video_sink_plugin
```

This is an example of an MP4 container with H.264 encoding format video file playback:

```
$GSTL filesrc location=test.mp4 typefind=true
     ! video/quicktime ! aiurdemux ! queue max-size-time=0
     ! v4l2h264dec ! autovideosink
```

7.3.1.3 Audio/Video file playback

This is an example of a command to play a video file with audio:

```
$GSTL filesrc location=test_file typefind=true ! $capsfilter
     ! $demuxer_plugin name=demux demux.
     ! queue max-size-buffers=0 max-size-time=0 !
 $video_decoder_plugin
     ! $video_sink_plugin demux.
     ! queue max-size-buffers=0 max-size-time=0 !
 $audio_decoder_plugin
     ! $audio_sink_plugin
```

This is an example of an AVI file:

```
$GSTL filesrc location=test.avi typefind=true ! video/x-msvideo
     ! aiurdemux name=demux demux.
     ! queue max-size-buffers=0 max-size-time=0 !
 $video_decoder_plugin
```

```
      ! autovideosink demux.
      ! queue max-size-buffers=0 max-size-time=0 ! beepdec
      ! alsasink
```

For the platforms without VPU hardware, `$video_decoder_plugin` could be a software decoder plugin like `avdec_h264`.

7.3.1.4 Multichannel audio playback

For the multichannel audio playback settings to be used when PulseAudio is enabled, see Section 7.4.

7.3.1.5 Other methods for playback

Use the `$PLAYBIN` plugin or the i.MX `$GPLAY` command line player for media file playback.

```
$GSTL $PLAYBIN uri=file:///mnt/sdcard/test.avi
$GPLAY /mnt/sdcard/test.avi
```

7.3.1.6 Video playback to multiple displays

Video playback to multiple displays can be supported by a video sink plugin. The video sink for multidisplay mode does not work on i.MX 8 family SoCs.

This use case requires that the system boots in multiple-display mode (dual/triple/four, the number of displays supported is determined by the SOC and the BSP). For how to configure the system to boot in this mode, see the *i.MX Porting Guide* (IMXBSPPG).

7.3.1.6.1 Playing different videos on different displays

The command line to play two videos on different displays might look like this:

```
$GSTL $PLAYBIN uri=file:///$file1 $PLAYBIN uri=file:///$file2
 video-sink="overlaysink
    display-master=false display-slave=true"
```

7.3.1.6.2 Routing the same video to different displays

A video can be displayed on multiple displays with a command as follows:

```
$GSTL $PLAYBIN uri=file:///$filename video-sink="overlaysink
 display-slave=true"
```

7.3.1.6.3 Multiple videos overlay

The `overlaysink` plugin provides support for compositing multiple videos together and rendering them to the same display. The result might look like the following image.

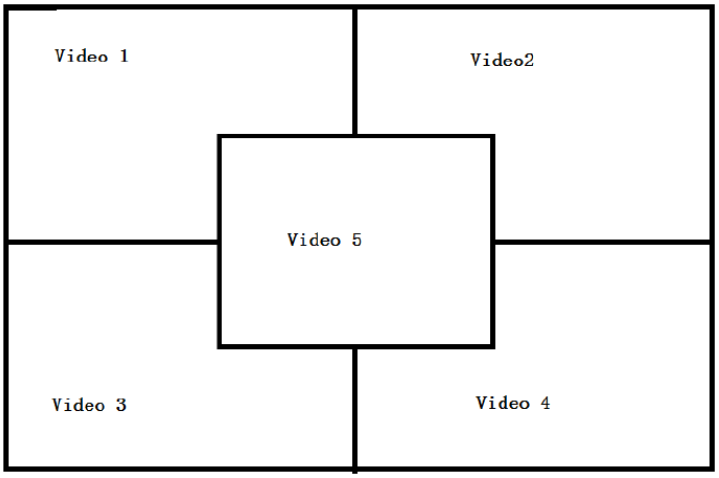


Figure 2. Multiple video overlay

```
gst-launch-1.0 playbin uri=file://$FILE1
    video-sink="overlaysink overlay-width=512 overlay-
height=384"
    playbin uri=file://$FILE2 flags=0x41
    video-sink="overlaysink overlay-left=512 overlay-width=512
 overlay-height=384"
    playbin uri=file://$FILE3 flags=0x41
    video-sink="overlaysink overlay-top=384 overlay-width=512
 overlay-height=384"
    playbin uri=file://$FILE4 flags=0x41
    video-sink="overlaysink overlay-left=512 overlay-top=384
 overlay-width=512
    overlay-height=384"
    playbin uri=file://$FILE5 flags=0x41
    video-sink="overlaysink overlay-left=352 overlay-top=264
 overlay-width=320
    overlay-height=240 zorder=1"
```

7.3.2 Audio encoding

Here are some examples for MP3 encoding.

```
$GSTL filesrc location=test.wav ! wavparse ! lamemp3enc
     ! filesink location=output.mp3
```

7.3.3 Video encoding

The following commands provide some suggestions on how to use the plugins accelerated by VPU hardware to encode some media files (though they only work on a SoC with a VPU).

VPU video encoding only works on SoC with VPU encoder support.

For i.MX 6, use the following command:

```
$GSTL filesrc location=test.yuv
    ! videoparse format=2 witdh=$WIDTH height=$HEIGHT
 framerate=30/1
```

```
    ! vpuenc_xxx ! $MUXER ! filesink location=$output
```

For i.MX 8M Mini/8M Plus, use the following command:

```
$GSTL filesrc location=test.yuv
! rawvideoparse format=2 witdh=$WIDTH height=$HEIGHT
 framerate=30/1 colorimetry=bt709
! v4l2xxxenc ! $MUXER ! filesink location=$output
```

- The target encoder codec type can be:
  - MPEG4, H.263, H.264, and MJPEG for i.MX 6
  - H.264, VP8 for i.MX 8M Mini
  - H.264, HEVC for i.MX 8M Plus
- The `vpuenc_xxx` can be:
  - `vpuenc_mpeg4`, `vpuenc_h263`, `vpuenc_h264`, and `vpuenc_jpeg` for i.MX 6
- The `v4l2xxxenc` can be:
  - `v4l2h264enc` and `v4l2vp8enc` for i.MX 8M Mini
  - `v4l2h264enc` and `v4l2h265enc` for i.MX 8M Plus
- VPU encoder is `v4l2h264enc` on i.MX 8QuadMax and 8QuadXPlus.
- The `$MUXER` can be set to `qtmux`, `matroskamux`, `mp4mux`, `avimux`, or `flvmux`.
- Different muxers support different encoded codec types. Use `$GSTINSPECT` and `$MUXER` to see the capabilities of the muxer to be used.

The following table lists the encoding bitrate modes for i.MX 8M Mini/8M Plus.

Table 66. Encoding bitrate modes

V4L2_CID_MPEG_VIDEO_FRAME_RC_ENABLE	Video bitrate mode	Encoded file

1	`V4L2_MPEG_VIDEO_BITRATE_MODE_CBR`	Bitrate takes effect limited by `MIN_QP` and `MAX_QP`.
		`V4L2_CID_MPEG_VIDEO_BITRATE`
		`V4L2_CID_MPEG_VIDEO_H264_MIN_QP`
		`V4L2_CID_MPEG_VIDEO_H264_MAX_QP`

1	`V4L2_MPEG_VIDEO_BITRATE_MODE_VBR`	Same as the above case but with bigger bitrate variance.

0	`V4L2_MPEG_VIDEO_BITRATE_MODE_CBR`/
	`V4L2_MPEG_VIDEO_BITRATE_MODE_VBR`
		Qp takes effect.
		`V4L2_CID_MPEG_VIDEO_H264_I_FRAME_QP`
		`V4L2_CID_MPEG_VIDEO_H264_P_FRAME_QP`
		`V4L2_CID_MPEG_VIDEO_H264_B_FRAME_QP`

Use `extra-controls` property after `v4l2xxxenc` to specify the value for different codec controls. `v4l2-ctl --device device_path --list-ctrls` shows all video device's controls and their values.

For example:

```
gst-launch-1.0 filesrc location=test.yuv !
 rawvideoparse format=2 width=$WIDTH height=
$HEIGHT colorimetry=bt709 ! v4l2h264enc extra-
controls="encode,frame_level_rate_control_enable=1,h264_mb_level_rate_con
 filesink location=output.h264
```

7.3.4 Transcoding

Transcoding is converting a file from one video encoding to another.

VPU video encoding only works on SoC with VPU encoder support.

For i.MX 6 family with VPU, use the following command:

```
$GSTL filesrc location=$filename typefind=true ! $capsfilter !
 aiurdemux
! vpudec ! imxvideoconvert_ipu ! $CAPS1 ! vpuenc_xxx !
 matroskamux ! filesink location=720p.mkv
```

capsfilter is the container's mime type. CAPS1 is the target video resolution, and the vpuenc_xxx can be vpuenc_mpeg4, vpuenc_h263, vpuenc_h264, and vpuenc_jpeg.

For example:

```
gst-launch-1.0 filesrc location=$FILE.mp4 typefind=true !
 video/quicktime ! aiurdemux !
vpudec ! imxvideoconvert_ipu ! video/x-
raw,format=NV12,width=1280,height=720 ! vpuenc_h264 !
 [h264parse] ! matroskamux ! filesink location=$FILE.mkv
```

For i.MX 8QuadMax/8QuadXPlus, use the following command:

```
gst-launch-1.0 filesrc location=$FILE.mp4 typefind=true !
 video/quicktime ! aiurdemux ! v4l2h264dec ! queue !
 imxvideoconvert_g2d ! queue ! videoconvert ! queue !
 v4l2h264enc ! [h264parse] ! matroskamux ! filesink location=
$FILE.mkv
```

For i.MX 8M Mini/8M Plus, use the following command:

```
gst-launch-1.0 filesrc location=$FILE.mp4 typefind=true !
 video/quicktime ! aiurdemux ! v4l2h264dec ! queue !
 v4l2h264enc ! [h264parse] ! matroskamux ! filesink location=
$FILE.mkv
```

Note:

- *For some mux, such as matroskamux, add h264parse/h265parse before mux.*
- *For i.MX 6, h264parse is not required, because the VPU can output AVC and byte-stream formats. For i.MX 8, h264parse/h265parse should be added before some mux, because the VPU supports only the byte-stream output.*

7.3.5 Audio recording

Audio recording from EARC or S/PDIF on i.MX 8M Plus.

Since Multimedia version 4.7.0, PCM and compressed format eARC recording pipeline are unified into the following commandline:

```
gst-launch-1.0 -v alsasrc provide-clock=false device=hw:1,0 !
 spdifdemux ! decodebin ! playsink audio-sink="alsasink
 device=sysdefault:CARD=wm8960audio buffer-time=40000
 sync=false"
```

Note: *The `imxaudioxcvr` card number is **1**.*

For backward compatibility, the following legacy pipelines are still supported:

For PCM format:

```
gst-launch-1.0 -v alsasrc device=sysdefault:CARD=imxaudioxcvr
  ! audio/x-raw,format=S16LE,channels=2,rate=48000 ! playsink
 audio-sink="alsasink device=sysdefault:CARD=wm8960audio
 buffer-time=40000"
```

For compressed format:

```
gst-launch-1.0 alsasrc device=sysdefault:CARD=imxaudioxcvr !
 audio/x-raw,format=S16LE,channels=2,rate=48000 ! queue
 max-size-buffers=0 max-size-bytes=0 max-size-time=0 !
 spdifdemux ! decodebin ! playsink audio-sink="alsasink
 device=sysdefault:CARD=wm8960audio buffer-time=40000
 sync=false"
```

Note:

Run the following command to work in EARC mode:

```
amixer -c imxaudioxcvr cset numid=1,iface=MIXER,name='XCVR
 Mode' 'eARC'
```

The following examples show how to make an MP3 or WMA audio recording.

- MP3 recording

```
$GSTL pulsesrc num-buffers=$NUMBER blocksize=$SIZE !
 lamemp3enc
! filesink location=output.mp3
```

Note:

The recording duration is calculated as `$NUMBER * $SIZE * 8 / (samplerate * channel * bit width)`.

Therefore, to record 10 seconds of a stereo channel sample with a 44.1K sample rate and a 16 bit width, use the following command:

```
$GSTL pulsesrc num-buffers=430 blocksize=4096 ! 'audio/x-raw,
 rate=44100, channels=2' ! lamemp3enc
! filesink location=output.mp3
```

7.3.6 Video recording

Video recording is done using the camera input, so this activity only applies to platforms with a camera. Different cameras need to be set with different capture modes for special resolutions. See Chapter 14 "supporting cameras with CSI" and Chapter 15 "supporting cameras with MIPI-CSI" in the *i.MX BSP Porting Guide* (IMXBSPPG).

VPU video encoding only works on SoC with VPU encoder support. imxv4l2src is only supported on i.MX 6 and i.MX 7. i. MX 8 supports opensource plugin v4l2src as camera source.

Use the `$GSTINSPECT` command to obtain more information about the codec property.

An example of recording might look like this:

```
$GSTL $V4L2SRC device=$DEVICE num-buffers=300 ! $INPUT_CAPS !
 queue ! $video_encoder_plugin ! [h264parse] ! $MUXER !
 filesink location=output.$EXTENSION
```

- `$V4L2SRC` can be `imxv4l2src`, or `v4l2src` according to the SoC.
- `$DEVICE` could be set to `/dev/video`, `/dev/video0`, or `/dev/video1` according to the system video input device.
- `$INPUT_CAPS` should be set to `video/x-raw,format=(string)NV12,width=1920,height=1080,framerate=(fraction)30/1`.
- `$MUXER` can be set to `qtmux`, `matroskamux`, `mp4mux`, `avimux`, or `flvmux`.
- `$EXTENSION` is filename extension according to the muxer type.

Refer to Section Section 7.3.3 to choose the correct `$video_encoder_plugin`.

7.3.7 Audio/Video recording

This is an example of a command used to record audio and video together:

```
$GSTL -e $V4L2SRC device=$DEVICE ! $INPUT_CAPS ! queue !
 $video_encoder_plugin ! [h264parse] ! queue ! mux. pulsesrc !
 'audio/x-raw, rate=44100, channels=2' ! lamemp3enc ! queue !
 mux. $MUXER name=mux ! filesink location= output.$EXTENSION
```

- `$V4L2SRC` can be `imxv4l2src` or `v4l2src` according to SoC.
- `$INPUT_CAPS` should be set to `video/x-raw, format=(string)NV12, width=1920, height=1080, framerate=(fraction)30/1`.
- `$MUXER` can be set to `qtmux`, `matroskamux`, `mp4mux`, `avimux`, or `flvmux`.

Refer to Section Section 7.3.3 to choose the correct `$video_encoder_plugin`.

Common parameters are as follows:

- `-e` indicates to send EOS when the user presses **Ctrl+C** to avoid output corruption.
- `$EXTENSION` is the filename extension according to the multiplexer type.

7.3.8 Camera preview

This example displays what the camera sees. It is only available on platforms with a camera.

```
$GSTL v4l2src ! 'video/x-raw, format=(string)$FORMAT,
     width=$WIDTH, height=$HEIGHT, framerate=(fraction)30/1'
```

```
     ! v4l2sink
```

Camera preview example:

```
$GSTL v4l2src device=/dev/video1 ! 'video/x-raw,

 format=(string)UYVY,width=640,height=480,framerate=(fraction)30/1'
     ! autovideosink
```

Parameter comments:

- Get the camera support format and resolution using gst-inspect-1.0 v4l2src.
- Set caps filter according to the camera's supported capabilities if the user needs other format or resolution.
- Ensure that the right caps filter has been set, which also needs to be supported by v4l2sink.

7.3.9 Recording the TV-in source

The TV-in source plugin gets video frames from the TV decoder. It is based on the V4l2 capture interface. A command line example is as follows:

```
gst-launch-1.0 v4l2src ! autovideosink
```

Note:

The TV decoder is ADV7180. It supports NTSC and PAL TV mode. The output video frame is interlaced, so the sink plugin needs to enable deinterlace. The default value of v4l2sink deinterface is True.

7.3.10 Web camera

The following command line is an example of how to record and transfer web camera input.

```
$GSTL v4l2src device=/dev/video1 ! $video_encoder_plugin !
 rtph264pay ! udpsink host=$HOST_IP
```

HOST_IP is the IP/multicast group to send the packets to.

This command line is an example of how to receive and display web camera input.

```
$GSTL udpsrc ! buffer-size=204800 (example number) application/
x-rtp ! rtph264depay ! $video_decoder_plugin !  autovideosink
```

7.3.11 HTTP streaming

The HTTP streaming includes the following:

- Manual pipeline

```
$GSTL souphttpsrc location= http://SERVER/test.avi ! typefind
     ! aiurdemux name=demux demux. ! queue max-size-buffers=0
 max-size-time=0
     ! $video_decoder_plugin ! $video_sink_plugin demux. !
 queue max-size-buffers=0 max-size-time=0
```

```
     ! beepdec ! $audio_sink_plugin
```

- PLAYBIN

```
$GSTL $PLAYBIN uri=http://SERVER/test.avi
```

- GPLAY

```
$GPLAY http://SERVER/test.avi
```

7.3.12 HTTP live streaming

The HLS streaming includes the following:

- PLAYBIN

```
$GSTL $PLAYBIN uri=http://SERVER/test.m3u8
```

- GPLAY

```
$GPLAY http://SERVER/test.m3u8
```

7.3.13 MPEG-DASH streaming

The MPEG-DASH streaming includes the following:

- PLAYBIN

```
$GSTL $PLAYBIN uri=http://SERVER/test.mpd
```

- GPLAY

```
$GPLAY http://SERVER/test.mpd
```

Note: *Supports TS, MP4, and WebM container format segment currently.*

7.3.14 Real Time Streaming Protocol (RTSP) playback

Use the following command to see the GStreamer RTP depacketize plugins:

```
$GSTINSPECT | grep depay
```

RTSP streams can be played with a manual pipeline or by using playbin. The format of the commands is as follows.

- Manual pipeline

```
$GSTL rtspsrc location=$RTSP_URI name=source
     ! queue ! $video_rtp_depacketize_plugin ! $vpu_dec !
 $video_sink_plugin source.
     ! queue ! $audio_rtp_depacketize_plugin !
 $audio_parse_plugin ! beepdec ! $audio_sink_plugin
```

- PLAYBIN

```
$GSTL $PLAYBIN uri=$RTSP_URI
```

Two properties of `rtspsrc` that are useful for RTSP streaming are:

- **Latency**: This is the extra added latency of the pipeline, with the default value of 200 ms. If you need low-latency RTSP streaming playback, set this property to a smaller value.
- **Buffer-mode**: This property is used to control the buffering algorithm in use. It includes four modes:
  - None: Outgoing timestamps are calculated directly from the RTP timestamps, not good for real-time applications.
  - Slave: Calculates the skew between the sender and receiver and produces smoothed adjusted outgoing timestamps, good for low latency communications.
  - Buffer: Buffer packets between low and high watermarks, good for streaming communication.
  - Auto: Chooses the three modes above depending on the stream. This is the default setting.

To pause or resume the RTSP streaming playback, use a buffer-mode of slave or none for `rtspsrc`, as in `buffer-mode=buffer`. After resuming, the timestamp is forced to start from 0, and this causes buffers to be dropped after resuming.

Manual pipeline example:

```
$GSTL rtspsrc location=rtsp://10.192.241.11:8554/test
 name=source
     ! queue ! rtph264depay ! avdec_h264 ! overlaysink source.
     ! queue ! rtpmp4gdepay ! aacparse ! beepdec ! pulsesink
```

Playback does not exit automatically in GStreamer 1.x, if `buffer-mode` is set to `buffer` in the `rtpsrc` plugin.

7.3.15 RTP/UDP MPEGTS streaming

There are some points to keep in mind when doing RTP/UDP MPEGTS Streaming:

- The source file that the UDP/RTP server sends must be in TS format.
- Start the server one second earlier than the time client starts.
- Two properties of `aiurdemux` that are useful for UDP/RTP TS streaming are:
  streaming-latency: This is the extra added latency of the pipeline, and the default value is 400 ms. This value is designed for the situation when the client starts first. If the value is too small, the whole pipeline may not run due to lack of audio or video buffers. In that situation, you should cancel the current command and restart the pipeline. If the value is too large, wait for a long time to see the video after starting the server.
  low_latency_tolerance: This value is a range that total latency can jitter around streaming-latency. This property is disabled by default. When the user sets this value, the maximum latency is (streaming-latency + low_latency_tolerance).

The UDP MPEGTS streaming command line format looks like this:

```
$GSTL udpsrc do-timestamp=false uri=$UDP_URI caps="video/
mpegts"
     ! aiurdemux streaming_latency=400 name=d d. ! queue !
 $vpu_dec
```

```
    !   queue ! $video_render_sink sync=true d. ! queue !
 beepdec ! $audio_sink_plugin sync=true
```

```
$GSTL udpsrc do-timestamp=false uri=udp://10.192.241.255:10000
 caps="video/mpegts"
    ! aiurdemux streaming_latency=400 name=d d. ! queue !
 vpudec
    ! queue ! overlaysink sync=true d. ! queue ! beepdec !
 pulsesink sync=true
```

The format for an RTP MPEGTS streaming command is covered as follows:

```
$GSTL udpsrc do-timestamp=false uri=$RTP_URI caps="application/
x-rtp"
    ! rtpmp2tdepay ! aiurdemux streaming_latency=400 name=d
 d. ! queue ! $vpu_dec
    ! queue ! $video_render_sink sync=true d. ! queue !
 beepdec ! $audio_sink_plugin sync=true
```

```
$GSTL udpsrc do-timestamp=false uri=udp://10.192.241.255:10000
 caps="application/x-rtp"
    ! rtpmp2tdepay ! aiurdemux streaming_latency=400 name=d d.
    ! queue ! vpudec ! queue ! overlaysink sync=true d. !
 queue ! beepdec
    ! pulsesink sync=true
```

7.3.16 RTSP streaming server

The RTSP streaming server use case is based on the open source gst-rtsp-server package. It uses the i.MX aiurdemux plugin to demultiplex the file to audio or video elementary streams and to send them out through RTP. Start the RTSP streaming server on one board, and play it on another board with the RTSP streaming playback commands.

The gst-rtsp-server package is not installed by default in the Yocto Project release. Follow these steps to build and install it.

1. Enable the layer meta-openembedded/meta-multimedia:
   Add the line `BBLAYERS += "${BSPDIR}/sources/meta-openembedded/meta-multimedia"` to the configuration file `$yocto_root/build/conf/bblayers.conf`.
2. Include gst-rtsp-server into the image build:
   Add the line `IMAGE_INSTALL:append = " gstreamer1.0-rtsp-server"` to the configuration file `$yocto_root/build/conf/local.conf`.
3. Run `bitbake` for your image to build with gst-rstp-server.
4. You can find the test-uri binary in the folder:

   ```
   $yocto_root/build/tmp/work/cortexa9hf-vfp-neon-poky-linux-
   gnueabi/gstreamer1.0-rtsp-server/$version/
   build/examples/
   ```

5. Flash the image.
   Copy test-uri into `/usr/bin` in the rootfs on your board and assign execute permission to it.

Some information on running the tool is as follows:

- Command:

```
test-uri $RTSP_URI
```

For example:

```
test-uri file:///home/root/temp/TestSource/mp4/1.mp4
```

- Server address:

```
rtsp://$SERVER_IP:8554/test
```

For example:

```
rtsp://10.192.241.106:8554/test
```

- Client operations supported are Play, Stop, Pause, Resume, and Seek.

7.3.17 Video conversion

There are three video conversion plugins, imxvideoconvert_ipu, imxvideoconvert_g2d, and imxvideoconvert_pxp. All of them can be used to perform video color space conversion, resize, and rotate. imxvideoconvert_ipu can also be used to perform video deinterlacing. They can be used to connect before ximagesink to enable the video rendering on X Windows or used in transcoding to change video size, rotation, or deinterlacing.

Use gst-inspect-1.0 to get each converter's capability and supported input and output formats. Note that imxvideoconvert_g2d can only perform color space converting to RGB space.

Color Space Conversion (CSC)

```
gst-launch-1.0 videotestsrc ! video/x-raw,format=NV12 !
 imxvideoconvert_{xxx} ! video/x-raw,format=RGB16 ! ximagesink
 display=:0
```

Resize

```
gst-launch-1.0 videotestsrc ! video/x-
raw,format=NV12,width=800,height=600 ! imxvideoconvert_{xxx} !
 video/x-raw, width=640, height=480 ! ximagesink display=:0
```

Rotate

```
gst-launch-1.0 videotestsrc ! imxvideoconvert_{xxx}
 rotation=2 ! ximagesink display=:0
```

Video crop with i.MX with G2D

```
gst-launch-1.0 videotestsrc ! videocrop top=10 bottom=10
 right=10 left=10 !imxvideoconvert_g2d videocrop-meta-
enable=true ! queue ! ximagesink display=:0
```

Deinterlacing with i.MX with IPU

```
gst-launch-1.0 playbin uri=file://$FILE video-
sink="imxvideoconvert_ipu deinterlace=3 ! ximagesink display=:0
 sync=false"
```

Transcoding with i.MX with VPU

```
gst-launch-1.0 filesrc location=$FILE.mp4 typefind=true !
 video/quicktime ! aiurdemux ! vpudec ! imxvideoconvert_ipu !
 video/x-raw,format=NV12,width=1280,height=720 ! vpuenc_h263 !
 avimux ! filesink location=$FILE.avi
```

Combination with i.MX with IPU or VPU

It is possible to combine CSC, resize, rotate, and deinterlace at one time. Both of imxvideoconvert_ipu and imxvideoconvert_g2d can be used at the same time in a pipeline. The following is an example:

```
gst-launch-1.0 videotestsrc ! video/x-
raw,format=I420,width=1280,height=800,interlace-
mode=interleaved ! imxvideoconvert_ipu rotation=2
 deinterlace=3 ! video/x-raw,format=NV12,width=800,height=600 !
 vpuenc_h264 ! vpudec ! imxvideoconvert_g2d rotation=3 ! video/
x-raw,format=RGB16,width=640,height=480 ! ximagesink sync=false
 display=:0
```

7.3.18 Video composition

imxcompositor_g2d uses corresponding hardware to accelerate video composition. It can be used to composite multiple videos into one. The video position, size, and rotation can be specified while composition. Video color space conversion is also performed automatically if input and output video are not same. Each video can be set to an alpha and z-order value to get alpha blending and video blending sequence.

Note that imxcompositor_g2d can only output RGB color space format. Use gst-inspect-1.0 to get more detailed information, including the supported input and output video format.

- Composite two videos into one.

```
gst-launch-1.0 imxcompositor_{xxx} name=comp sink_1::xpos=160
 sink_1::ypos=120 ! overlaysink videotestsrc ! comp.sink_0
 videotestsrc ! comp.sink_1
```

- Composite two videos into one with red background color.

```
gst-launch-1.0 imxcompositor_{xxx} background=0x000000FF
 name=comp sink_1::xpos=160 sink_1::ypos=120 ! overlaysink
 videotestsrc ! comp.sink_0 videotestsrc ! comp.sink_1
```

- Composite two videos into one with CSC, resize, and rotate.

```
gst-launch-1.0 imxcompositor_{xxx} name=comp sink_0::width=640
 sink_0::height=480
      sink_1::xpos=160 sink_1::ypos=120 sink_1::width=640
 sink_1::height=480 sink_1::rotate=1 !
      video/x-raw,format=RGB16 ! overlaysink videotestsrc !
      video/x-raw,format=NV12,width=320,height=240 !
 comp.sink_0 videotestsrc !
      video/x-raw,format=I420,width=320,height=240 !
 comp.sink_1
```

- Composite three videos into one with CSC, resize, rotate, alpha, z-order, and keep aspect ratio.

```
gst-launch-1.0 imxcompositor_{xxx} name=comp sink_0::width=640
 sink_0::height=480
      sink_0::alpha=0.5 sink_0::z-order=3 sink_1::alpha=0.8
 sink_1::z-order=2 sink_1::xpos=160
      sink_1::ypos=120 sink_1::width=640 sink_1::height=480
 sink_1::rotate=1 sink_2::xpos=320
      sink_2::ypos=240 sink_2::width=500 sink_2::height=500
 sink_2::alpha=0.6
      sink_2::keep-ratio=true ! video/x-raw,format=RGB16 !
 overlaysink videotestsrc !
      video/x-raw,format=NV12,width=320,height=240 !
 comp.sink_0 videotestsrc !
      video/x-raw,format=I420,width=320,height=240 !
 comp.sink_1 videotestsrc !
      video/x-raw,format=RGB16,width=320,height=240 !
 comp.sink_2
```

7.4 PulseAudio input/output settings

If PulseAudio is installed in the rootfs, the PulseAudio input/output settings may need to be set.

Audio output settings

Use the `pactl` command to list all the available audio sinks:

```
$ pactl list sinks
```

A list of available audio sinks is displayed:

```
Sink #0
        State: SUSPENDED
        Name: alsa_output.platform-soc-audio.1.analog-stereo
        Description: sgtl5000-audio Analog Stereo
   ...
   ...
Sink #1
        State: SUSPENDED
        Name: alsa_output.platform-soc-audio.4.analog-stereo
        Description: imx-hdmi-soc Analog Stereo
   ...
   ...
```

Use the `pacmd` command to set the default audio sink according to the sink number in the list shown above:

```
$ pacmd set-default-sink $sink-number
```

`$sink-number` could be 0 or 1 in the example above.

After setting the default sink, use the command below to verify the audio path:

```
$ gst-launch audiotestsrc ! pulsesink
```

Audio input settings

Use the `pactl` command to list all the available audio sources:

```
$ pactl list sources
```

A list of available audio sources is displayed:

```
Source #0
          State: SUSPENDED
          Name: alsa_output.platform-soc-audio.1.analog-
stereo.monitor
          Description: Monitor of sgtl5000-audio Analog Stereo
   ...
   ...
Source #1
          State: SUSPENDED
          Name: alsa_input.platform-soc-audio.1.analog-stereo
          Description: sgtl5000-audio Analog Stereo ...
   ...
   ...
```

Use the `pacmd` command to set the default audio source according to the source number in the list shown above:

```
$ pacmd set-default-source $source-number
```

`$sink-number` could be 0 or 1 in the example above. If record and playback at the same time is not needed, there is no need to set the monitor mode.

The PulseAudio I/O path setting status can be checked with:

```
$ pactl stat
```

Multichannel output support settings

For those boards that need to output multiple channels, these are the steps needed to enable the multichannel output profile:

1. Use the `pacmd` command to list the available cards:

   ```
   $ pacmd list-cards
   ```

   The available sound cards and the profiles supported are listed.

   ```
   2 card(s) available.
       index: 0
           name: <alsa_card.platform-sound-cs42888.34>
           driver: <module-alsa-card.c>
           owner module: 6
           properties:
                   alsa.card = "0"
                   alsa.card_name = "cs42888-audio"
       ...
       ...
           profiles:
                   input:analog-mono: Analog Mono Input
    (priority 1, available: unknown)
                   input:analog-stereo: Analog Stereo Input
    (priority 60, available: unknown)
   ```

```
    ...
    ...
  active profile: <output:analog-stereo+input:analog-stereo>
    ...
    ...
```

2. Use the `pacmd` command to set the profile for particular features.

```
$ pacmd set-card-profile $CARD $PROFILE
```

`$CARD` is the card name listed by `pacmd list-cards` (for example, `alsa_card.platform-sound-cs42888.34` in the example above), and `$PROFILE` is the profile name. These are also listed by `pamcd list-cards`. (for example, `output:analog-surround-51` in the example above).

3. After setting the card profile, use `$ pactl list sinks` and `$pacmd set-default-sink $sink-number` to set the default sink.

7.5 Installing gstreamer1.0-libav into rootfs

The following steps show how to install `gstreamer1.0-libav` into a rootfs image.

1. Add the following lines into the configuration file `conf/local.conf`.

```
IMAGE_INSTALL:append = " gstreamer1.0-libav"
LICENSE_FLAGS_ACCEPTED = "commercial"
```

2. Build `gstreamer1.0-libav`.

```
$ bitbake gstreamer1.0-libav
```

3. Build the rootfs image.

```
$ bitbake <image_name>
```

8 Audio

8.1 DSP support

DSP support is provided on specific i.MX 8QuadXPlus, i.MX 8QuadMax, and i.MX 8M Plus SoC.

8.1.1 HiFi 4 DSP framework

Supporting HiFi 4 on a custom board is documented in the *i.MX DSP User's Guide* (IMXDSPUG).

8.1.2 Sound Open Firmware

Sound Open Firmware is an open source alternative to HiFi 4 DSP framework. For supporting the HiFi 4 on a custom board, see the SOF project documentation https://thesofproject.github.io available in the public domain.

For details about toolchains, supported platforms, binary packaging, and quick setup of audio scenarios, see SOF User Guide on NXP i.MX 8 platforms.

8.2 HDMI eARC support

eARC is supported on the i.MX 8M Plus EVK board.

The procedure enables audio, which is input through the `imxaudioxcvr` card and played back through the `wm8960audio` card.

Make sure there is a headset plugged into the i.MX 8M Plus EVK audio jack. The procedure is as follows:

1. On i.MX 8M Plus EVK, set `eARC mode`. The default mode is `SPDIF`:

```
amixer -c 0 cset numid=1 2
```

2. On i.MX 8M Plus EVK, use `alsamixer` to set `Headphone` and `Playback` controls to the maximum values for the `wm8960-audio` card.
3. On i.MX 8M Plus EVK, start audio recording on the `imxaudioxcvr` card and playback on the `wm8960audio` card.

```
arecord -Dsysdefault:CARD=imxaudioxcvr -c2 -r48000 -fS32_LE -
twav | aplay -Dsysdefault:CARD=wm8960audio
```

4. Make sure `Digital Audio Out` from the TV is `PCM`. Then, set `eARC mode` to **ON** and check audio on the headset connected to the i.MX 8M Plus EVK jack. The settings on the TV should be as shown in the following figure.

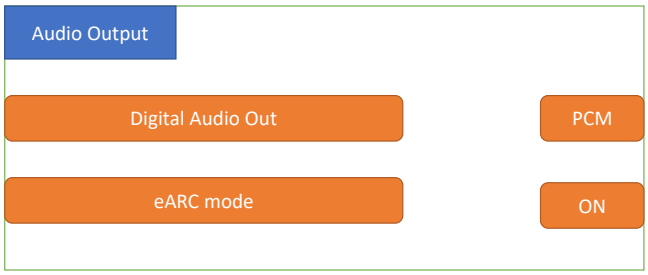


Figure 3. eARC support

Note: *The procedure has been tested on Sony and LG TV.*

The firmware on the eARC RX (i.MX 8M Plus EVK) waits until `HPD=high` is sensed. Therefore, start recording and playback on i.MX 8M Plus before enabling eARC mode on the TV as described in Steps 3 and 4 above. This makes the behavior more predictable on the RX side. In addition, set the subsequent eARC mode to **OFF** then to **ON** on the TV while keeping `arecord … | aplay …` running on i.MX 8M Plus EVK. Check whether you can hear audio in the headset after subsequent eARC mode is set to **ON** on the TV.

Besides, enabling the complete eARC feature, per the HDMI 2.1 specification, is more of a system-level application that integrates different layers and modules of the CEC driver, DRM, HDMI/HDCP controller driver, EDID, and eARC driver modules.

8.3 Low-power voice solution

8.3.1 Introduction

The Cortex-M core on the i.MX 8M Plus, i.MX 8M Mini and i.MX 93 platforms can be used in an AsymmetricMultiprocessing (AMP) architecture for a low-power voice UI solution.

Thevoice activity detection and wake work engine shall use the lowest power core of the i.MX 8M and i.MX 93, so that the Cortex-A cluster and related peripherals can remain in sleep mode for most of the “active listening” time.

Upon successful detection of a wake word, the Cortex-M core shall wake up the Cortex-A domain for better acoustic performance and further voice processing.

There are three components needed for this solution:

- Audio Front End (AFE)
- Linux drivers
- Cortex-M Image

Note: *The Cortex-M image for i.MX 93 is not available yet.*

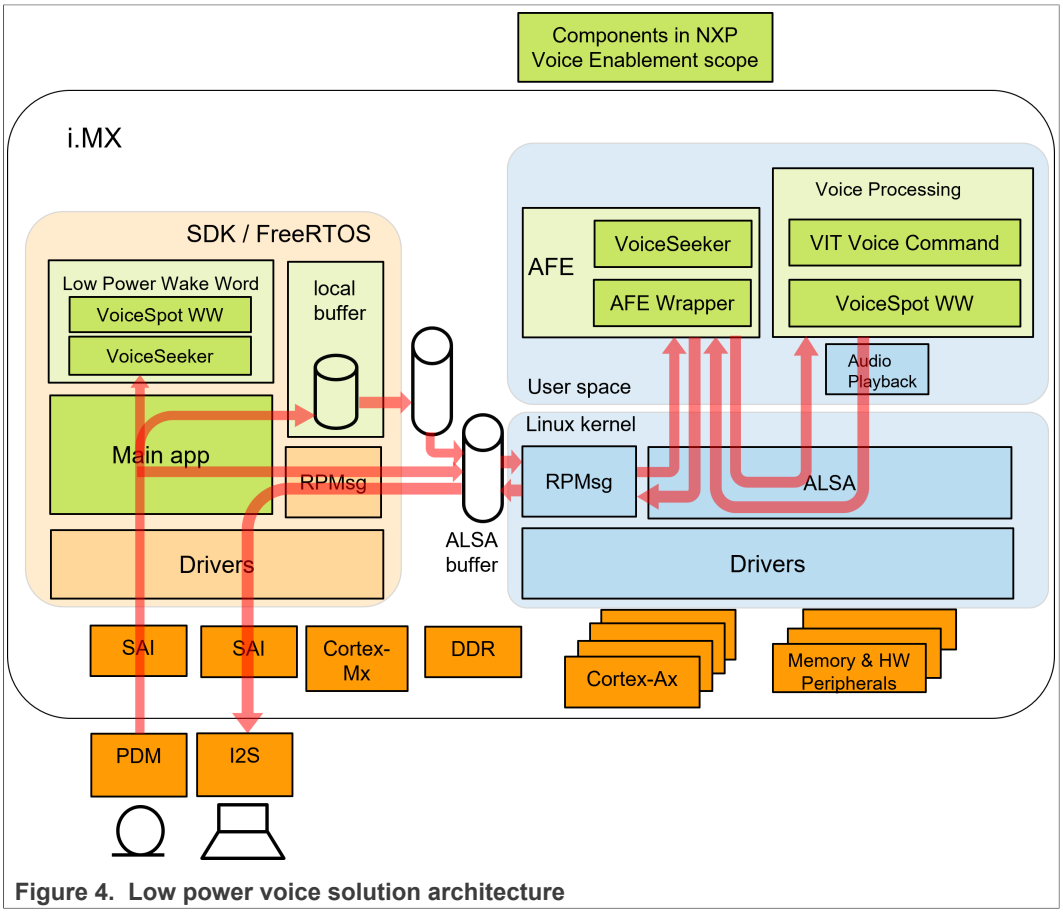


Figure 4. Low power voice solution architecture

8.3.2 Standard voice solution

In addition to the low-power voice solution described in the previous section, a standard voice solution is also available. This solution does not leverage a Cortex-M image and therefore takes the microphone and speaker inputs/outputs directly from the Linux kernel (through drivers and the ALSA library). It also leverages VIT wake word detection engine (in place of VoiceSpot in the low-power voice solution).

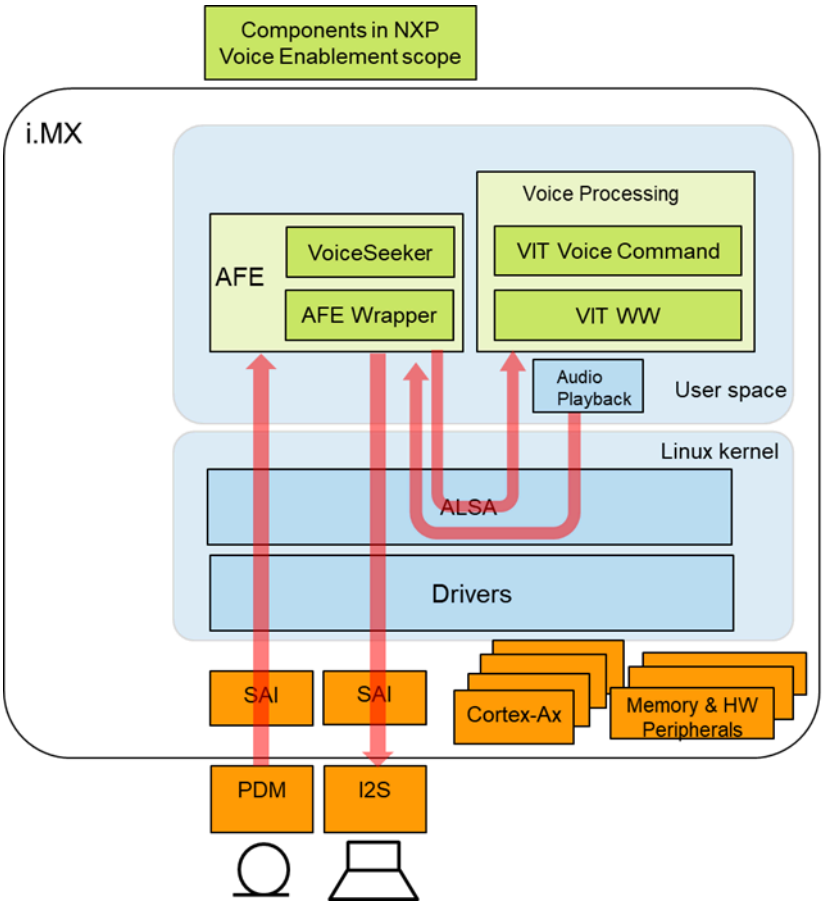


Figure 5. Standardvoice solution architecture

8.3.3 Audio Front End (AFE)

To precisely detect human language, the audio signal from the microphone must be clean, without echo, noise, or other disturbances. To achieve this, a microphone array is typically used, with multiple, (usually) interleaved microphone signals input to the embedded device. Such a compound signal is then fed into a signal processor (commonly known as an Audio Front End), which filters out the noise, echo, and other disturbances. The output from the signal processor is then the desired single channel, clean microphone audio, which is used for further processing (wake-word detection and natural language processing).

To interface audio with the Linux OS, the Advanced Linux Sound Architecture (ALSA) library is used. The following figure shows the audio architecture.

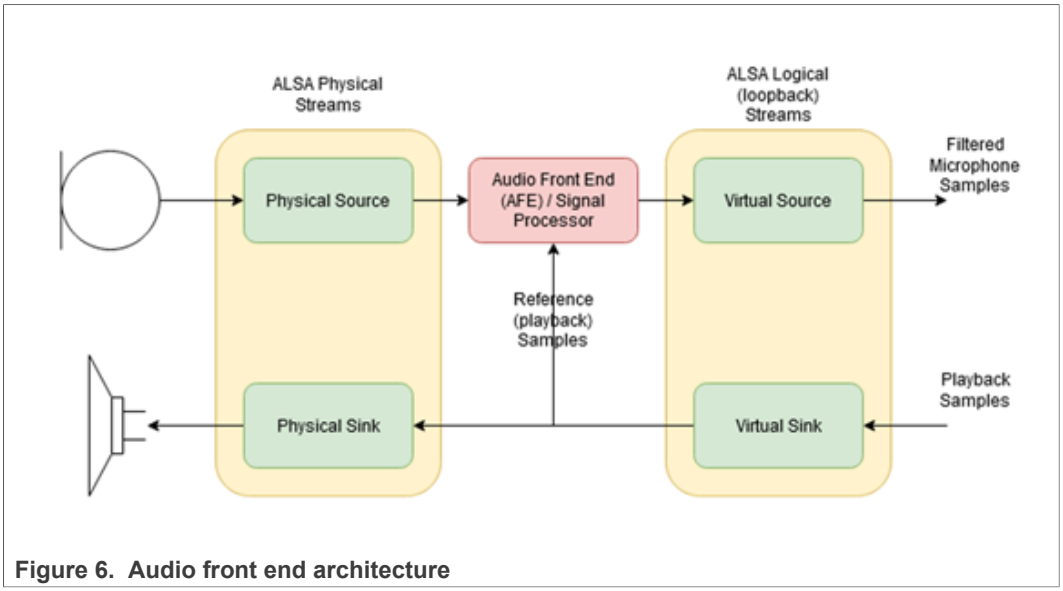


Figure 6. Audio front end architecture

The AFE code is on GitHub: https://github.com/nxp-imx/nxp-afe/, Git tag: `lf-5.15.52-2.1.0`.

The AFE deliveries are in Yocto `rootfs/unit_tests/nxp-afe/` and `/usr/lib/nxp-afe/`.

- `/unit_tests/nxp-afe/afe`: The main application of the AFE
- `/unit_tests/nxp-afe/TODO.md`: User guide document
- `/unit_tests/nxp-afe/asound.conf`: Used for i.MX 8M Mini default dtb
- `/unit_tests/nxp-afe/asound.conf_imx8mp`: Used for i.MX 8M Plus default dtb
- `/unit_tests/nxp-afe/asound.conf_rpmsg_imx8mm`: Used for i.MX 8M Mini RPMsg dtb
- `/unit_tests/nxp-afe/asound.conf_rpmsg_imx8mp`: Used for i.MX 8M Plus RPMsg dtb
- `. /unit_tests/nxp-afe/asound.conf_imx93`: Used for i.MX 93 default dtb
- `/usr/lib/nxp-afe/libdummyimpl.so`: Dummy signal processor
- `/usr/lib/nxp-afe/libdummyimpl.so.2.0`: Dummy signal processor

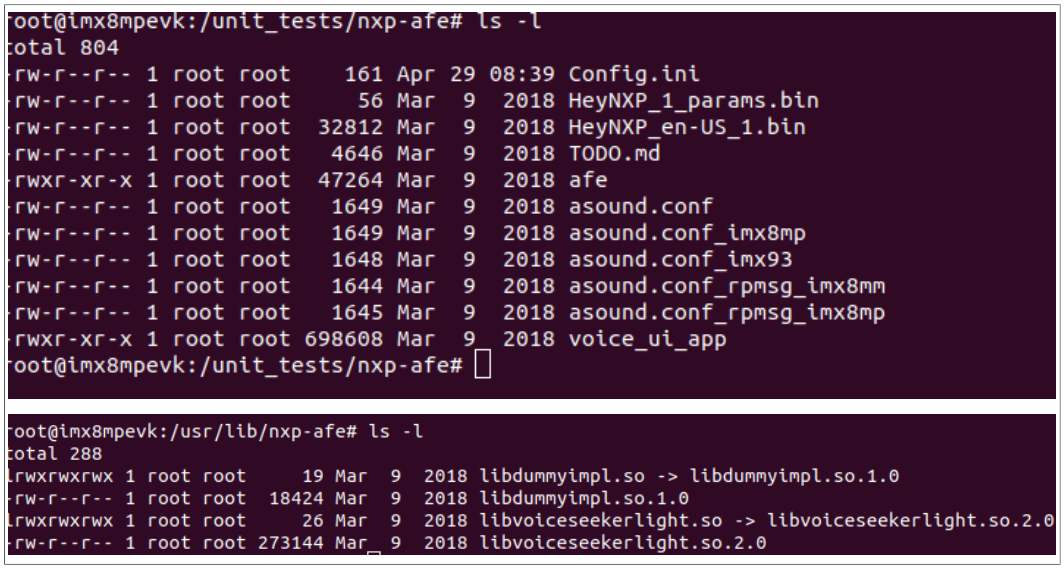
In addition to the AFE, the Yocto BSP integrates VoiceSeeker (a multi-microphone voice control audio front-end signal processing solution), VoiceSpot (a small memory and MIPS profile wake word engine supporting the "Hey NXP" voice trigger word), and VIT for local voice command recognition. These deliveries are available on GitHub: https://github.com/nxp-imx/imx-voiceui. This contains:

- `VoiceSeeker_wrapper` folder contains the code used for generating the shared library used by the AFE wrapper. Check the `TODO.md` in the nxp-afe repository..
- `Voice_UI_Test_app` folder contains the code used for generating the voice UI application called "`voice_ui_app`". This application contains the VoiceSpot wake-word engine and VIT for local voice command recognition. This application uses the output of the AFE for voice detection (wake-word and voice commands).

See the README file in this GitHub repository, which explains how to build the VoiceSeeker library and the Voice UI Test application. Once these are built, the user shall copy the following files to Yocto rootfs:

- Copy `release/Config.ini` to `/unit_tests/nxp-afe/`.

- Copy `release/HeyNXP_1_params.bin` to `/unit_tests/nxp-afe/`.
- Copy `release/HeyNXP_en-US_1.bin` to `/unit_tests/nxp-afe/`.
- Copy `release/libvoiceseekerlight.so.2.0` to `/usr/lib/nxp-afe/libvoiceseekerlight.so.2.0`, symbol link `libvoiceseekerlight.so` to `libvoiceseekerlight.so.2.0`.
- Copy `release/voice_ui_app` to `/unit_tests/nxp-afe/`.



After this, follow the steps in `/unit_tests/nxp-afe/TODO.md` to perform a test. The typical test method is as follows:

- `./voice_ui_app &`
- `./afe libvoiceseekerlight &`
- `aplay test.wav &`
- `arecord -d10 -fS32_LE -r16000 -c1 voiceseeker_afe_on.wav`

The `voice_ui_app` binary enables the following VIT commands:

- MUTE
- NEXT
- SKIP
- PAIR DEVICE
- PAUSE
- STOP
- POWER OFF
- POWER ON
- PLAY MUSIC
- PLAY GAME
- WATCH CARTOON
- WATCH MOVIE

When users say "Hey NXP, power on", the "Hey NXP" wakes up the system, and the "power on" command is detected.

```
trigger = 1, trigger_sample = 0, start_sample = -16012, stop_sample = -1612, score = 345
keyword_start_offset_samples = 16012
ITER = 67
 - Voice Command detected 8 POWER ON
```

There is a configuration file called `Config.ini` through which user can choose the wake-word engine, select the VIT language or implement other settings. It is a part of the standard voice solution.

```
$ cat /unit_tests/nxp-afe/Config.ini
[AFEConfig]
WWDectionDisable = 0
WakeWordEngine = VoiceSpot
DebugEnable = 0
RefSignalDelay = 3211
mic0 = 35.0, 15.15, 0.0
mic1 = 17.5, -15.15, 0.0
mic2 = -17.5, -15.15, 0.0
mic3 = -35.0, 15.15, 0.0
VoiceSpotModel = HeyNXP_en-US_1.bin
VoiceSpotParams = HeyNXP_1_params.bin
VITLanguage = English
```

- `WWDectionDisable`
  Disables/Enables the wake-word and command detection.
  – **0** - By default, enables the wake-word and command detection.
  – **1** - Disables wake-word and command detection. `voice_ui_app` does not work.
- `WakeWordEngine`
  This configuration depends on setting `WWDectionDisable` to **0**. Selects if the `voice_ui_app` uses **VoiceSpot** or **VIT** for wake-word detection.
  – **VoiceSpot** - By default, use **VoiceSpot** to detect the wake-word.
  – **VIT** - Use **VIT** to detect wake-word.
- `DebugEnable`
  – **0** - By default, no debug recordings are made.
  – **1** - Enables recording the AFE input/output streams for debugging and tuning the `RefSignalDelay`.
- `RefSignalDelay`
  Used to calibrate the reference signal delay when using VoiceSeeker's Acoustic Echo Cancellation (AEC). The AEC enabled library is delivered with controlled access through Flexera. Please contact voice@nxp.com for more information.
- `Mic coordinates`
  XYZ coordinates of the microphones in millimeters. The origin of the coordinate axis can be chosen as convenient.
- `VoiceSpotModel/VoiceSpotParams`
  The two parameters depend on setting `WakeWordEngine` to "VoiceSpot". They are used to specify the wake-word model and parameters used by **VoiceSpot**.
- `VITLanguage`
  This configuration depends on setting `WakeWordEngine` to "VIT". Selects the VIT language used to detect the wake-word and commands.
  – English - By default, uses English.
  – Mandarin - If set, available VIT wake-words and commands are listed in Mandarin.

Notes on VIT model:
- VIT Wake-word and commands can be updated with generating new VIT Model thanks to the VIT Model generation online tool.
- To have the new VIT Model considered by the application, the VIT model has be updated in `./vit/i.MX8M_A53/Lib/` or `/vit/i.MX9X_A55/Lib/` and `Voice_ui_app` recompiled.
- Same VIT model is used by the `Voice_ui_app` in low power or standard configuration. In the low power configuration, since VIT is used in voice commands mode only, VIT wake-word information is not considered by the VIT engine.

8.3.4 Linux drivers

Theprimary Linux drivers used by the voice solutions are as follows:

- Loopback sound card: `sound/drivers/aloop.c`
- RPMsg sound card:
  - `sound/soc/fsl/fsl_rpmsg.c`
  - `sound/soc/fsl/imx-pcm-rpmsg.c`
  - `sound/soc/fsl/imx-rpmsg.c`

8.3.5 Cortex-M Image

8.3.5.1 Application name

There are two different Cortex-M applications:

- `low_power_voice`, where Cortex-M runs the VIT LPVAD algorithm. When the Linux OS is suspended, Cortex-M wakes up the Linux OS as soon as voice activity is detected.
- `low_power_wakeword` using VoiceSeeker and VoiceSpot. The Linux OS is resumed only when the “Hey NXP” wake-word is recognized.

Both applications are provided for i.MX 8M Mini and i.MX 8M Plus. This results in the application names below:

- `imx8mm_m4_TCM_low_power_voice.bin`
- `imx8mm_m4_TCM_low_power_wakeword.bin`
- `imx8mp_m7_TCM_low_power_voice.bin`
- `imx8mp_m7_TCM_low_power_wakeword.bin`

8.3.5.2 Board setup

To set up the board, perform the following steps:

1. Ensure the appropriate Cortex-M application is copied to the “boot” partition of your SD Card. The `low_power_voice` and `low_power_wakeword` applications should already exist from the public Yocto builds.
2. Boot the board, stop in U-Boot prompt, and run the commands below:
   a. Chose the appropriate device tree:
      - i.MX 8M Mini:

```
setenv fdtfile imx8mm-evk-rpmsg-wm8524-lpv.dtb
```

- i.MX 8M Plus:

```
setenv fdtfile imx8mp-evk-rpmsg-lpv.dtb
```

b. Load the Cortex-M image from Flash to TCM and boot the core before booting the Linux OS.

```
setenv lpv 'fatload mmc 1:1 0x48000000 <application_name>;
 cp.b 0x48000000 0x7e0000 0x40000; bootaux 0x7e0000;'
setenv bootcmd 'run lpv;'${bootcmd}
```

c. Save the changes above.

```
saveenv
```

3. Reboot the board, and the Cortex-M will be automatically started before the Linux OS. This can be checked on the Cortex-M console.
4. Apply the appropriate ALSA configuration. After the Linux OS has booted, from the console:
   - i.MX 8M Mini:

```
cp /unit_tests/nxp-afe/asound.conf_rpmsg_imx8mm /etc/
asound.conf
```

   - i.MX 8M Plus:

```
cp /unit_tests/nxp-afe/asound.conf_rpmsg_imx8mp /etc/
asound.conf
```

   - Reboot to apply the changes above.
5. Before starting any audio application, e.g., `arecord`, `aplay`, `afe`, load the audio loopback driver. From a Linux OS console:

```
modprobe snd-aloop
```

8.3.5.3 Execution

Once started, users have no direct actions to control the Cortex-M application. It automatically executes appropriate actions according to the Linux state:

- When Linux OS is active: The Cortex-M application is acting as a data pump, getting audio data from the microphones and providing them to ALSA drivers through RPMsg.
- When Linux OS is suspended: Audio data are processed locally on Cortex-M (by either VIT LPVAD or VoiceSeeker/VoiceSpot). The data is also stored in a ring-buffer. Once voice or the wake-word is detected (depending on the application), the Linux OS is automatically resumed, data from the ring buffer is sent to ALSA (so the Linux OS also gets the wakeword), and then the data-pump is re-started.
- Suspending Linux OS: Cortex-M only has the possibility to resume the Linux OS, not to suspend it. Instead, the Linux OS should be suspended by user-space action (the decision to suspend cannot be based only on voice. It should also consider all the other potential user applications running on the Linux OS). For test purposes, this can be forced by the user by entering the following command to the Linux console.

```
echo mem > /sys/power/state
```

8.3.6 Power consumption notes

These applications using the public Yocto release demonstrate the voice UI mechanism described above to suspend the Linux OS and wake up on voice activity or a wakeword, but they still have a much higher power consumption than expected.

Some changes are required in both the Cortex-M application and the Yocto image to achieve as low as possible power consumption during the “Linux suspended” state. They are delivered with controlled access through Flexera. For more information, contact your NXP representative.

9 Graphics

There are a number of graphics tools, tests, and example programs that are built and installed in the Linux rootfs. There are some variation on what is included based on the build and packages selected, the board, and the backend specified. This section describes some of them.

The kernel module version of graphics used on the system can be found by running the following command on the board:

```
dmesg | grep Galcore
```

The user-side GPU drivers version of graphics can be displayed using the following command on the board:

```
grep VERSION /usr/lib/libGAL*
```

When reporting problems with graphics, this version number is needed.

9.1 imx-gpu-sdk

This graphics package contains source for several graphics examples for OpenGLES 2.0 and OpenGLES 3.0 APIs for X11, Framebuffer, and XWayland graphical backends. These applications show that the graphics acceleration is working for different APIs. The package includes samples, demo code, and documentation for working with the i.MX family of graphic cores. More details about this SDK are in the *i.MX Graphics User's Guide*. This SDK is only supported for hardware that has OpenGLES hardware acceleration.

9.2 G2D-imx-samples

The G2D Application Programming Interface (API) is designed to make it easy to use and understand the 2D BLT functions. It allows the user to implement customized applications with simple interfaces. It is hardware and platform independent when using 2D graphics.

The G2D API supports the following features and more:

- Simple BLT operation from source to destination
- Alpha blend for source and destination with Porter-Duff rules
- High-performance memory copy from source to destination
- Up-scaling and down-scaling from source to destination
- 90/180/270 degree rotation from source to destination
- Horizontal and vertical flip from source to destination

- Enhanced visual quality with dither for pixel precision-loss
- High performance memory clear for destination
- Pixel-level cropping for source surface
- Global alpha blend for source only
- Asynchronous mode and synchronization
- Contiguous memory allocator
- VG engine

The G2D API document includes the detailed interface description and sample code for reference. The API is designed with C-Style code and can be used in both C and C++ applications.

The G2D is supported on all i.MX. The hardware that supports G2D is described below. For more details, see the Frame Buffer information in the *i.MX Release Notes* (IMXLXRN) to check which hardware is used for G2D.

- For i.MX 6 with GPU, the G2D uses the 2D GPU.
- For i.MX with PXP, the G2D uses the PXP with limited G2D features.

The following is the directory structure for the G2D test applications located under `/opt`.

- g2d_samples
  - g2d_test
    - g2d_overlay_test
    - g2d_multiblit_test

9.3 viv_samples

The directory `viv_samples` is found under `/opt`. It contains binary samples for OpenGL ES 1.1/2.0 and OpenVG 1.1.

The following are the basic sanity tests, which help to make sure that the system is configured correctly.

- cl11: This contains unit tests and FFT samples for OpenCL 1.1 Embedded Profile. OpenCL is implemented on the i.MX 6Quad, i.MX 6QuadPlus, and i.MX 8 boards.
  - – UnitTest
    - clinfo
    - loadstore
    - math
    - threadwalker
    - test_vivante
      - functions_and_kernels
      - illegal_vector_sizes
      - initializers
      - multi_dimensional_arrays
      - reserved_data_types
      - structs_and_enums
      - unions

    - unsupported_extensions
  - fft
- es20: This contains tests for Open GLES 2.0.
  - vv_launcher
    - coverflow.sh
    - vv_launcher
- tiger: A simple OpenVG application with a rotating tiger head. This is to demonstrate OpenVG.
- vdk: Contains sanity tests for OpenGL ES 1.1 and OpenGL ES 2.0.

The tiger and VDK tests show that hardware acceleration is being used. They will not run without it.

9.4 Qt 6

Qt 6 is built into the Linux image in the Yocto Project environment with the command `bitbake imx-image-full`. For more details on Qt enablement, check out the README in the meta-imx repo and the *i.MX Yocto Project User's Guide* (IMXLXYOCTOUG).

10 Security

The i.MX platforms define a series of security acceleration subsystems.

10.1 CAAM kernel driver

10.1.1 Introduction

The Linux kernel contains a Scatterlist Crypto API driver for the NXP CAAM security hardware block. It integrates seamlessly with in-kernel crypto users, such as DM-Crypt, Keyctl, in a way that any disk encryption and key management suites will automatically use the hardware to do the crypto acceleration. CAAM hardware is known in Linux kernel as 'caam', after its internal block name: Cryptographic Accelerator and Assurance Module.

There are several HW interfaces ("backends") that can be used to communicate (for example, submit requests) with the engine, their availability depends on the SoC:

- Register Interface (RI) - available on all SoCs (though access from kernel is restricted on DPAA2 SoCs).
  Its main purpose is debugging (such as single-stepping through descriptor commands), though it is used also for RNG initialization.
- Job Ring Interface (JRI) - legacy interface, available on all SoCs; on most SoCs there are 4 rings.
  Note:
  There are cases when fewer rings are accessible or visible in the kernel, for example, when firmware like Trusted Firmware-A (TF-A) reserves one of the rings.

On top of these backends, there are the "frontends" - drivers that sit between the Linux Crypto API and backend drivers. Their main tasks aim to:

- Register supported crypto algorithms.

- Process crypto requests coming from users (through the Linux Crypto API) and translate them into the proper format understood by the backend being used.
- Forward the CAAM engine responses from the backend being used to the users.

To use a specific implementation, it is possible to ask for it explicitly by using the specific (unique) "driver name" instead of the generic "algorithm name". See official Linux Kernel Crypto API documentation (section Crypto API Cipher References And Priority). Currently, the default priority is 3000 for JRI frontend.

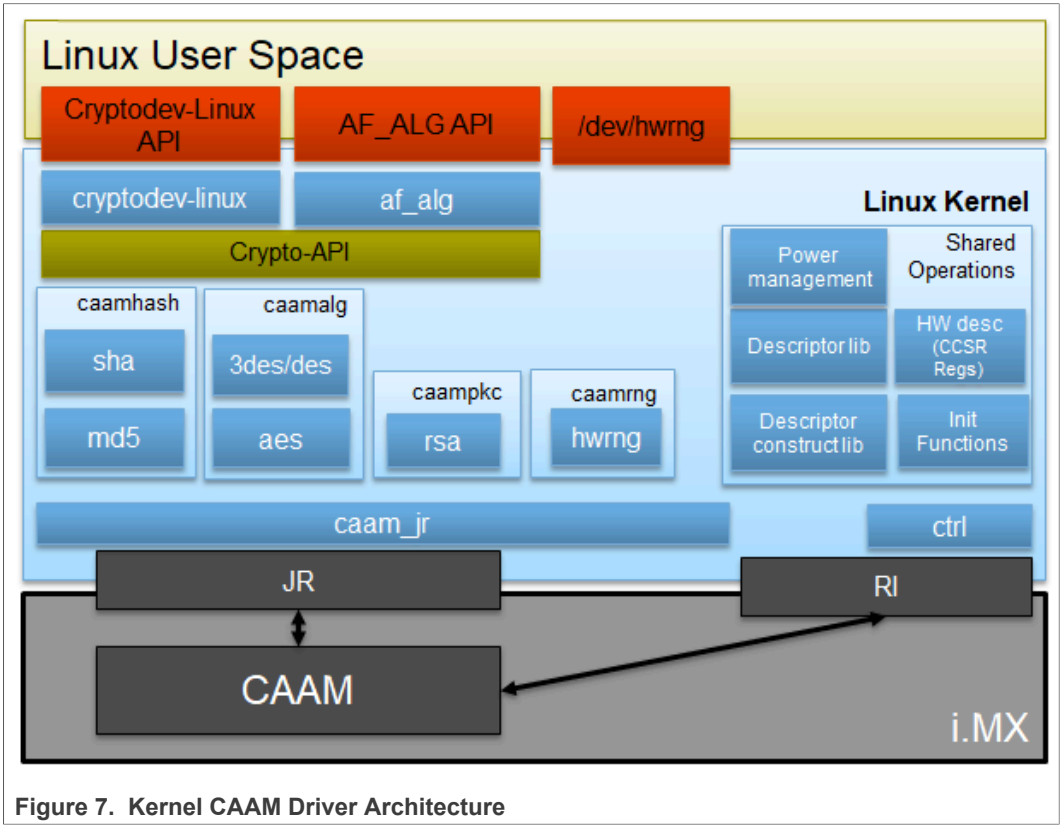


Figure 7. Kernel CAAM Driver Architecture

10.1.2 Source files

The drivers source code is maintained in the Linux kernel source tree, under `drivers/crypto/caam`.The following is a non-exhaustive list of files, mapping to CAAM (some files have been omitted because their existence is justified only by driver logic or design).

Table 67. Source files

Source File	Description	Module name
`ctrl.[c,h]`	Init (global settings, RNG, power management, etc.)	`caam`
`desc.h`	HW description (CCSR registers, etc.)	N/A
`desc_constr.h`	Inline append - descriptor construction library	N/A
`caamalg_desc.[c,h]`	(Shared) Descriptors library (symmetric encryption, AEAD)	`caamalg_desc`
`caamhash_desc.[c,h]`	(Shared) Descriptors library (HASH)	`caamhash_desc`

Table 67. Source files*...continued*

Source File	Description	Module name
`caamrng.c`	RNG (runtime)	N/A
`caamkeyblob_desc.[c,h]`	Descriptors library (black keys and blobs)	`caamkeyblob_desc`
`jr.[c,h]`	JRI backend	`caam_jr`
`caamalg.c`	JRI frontend (symmetric encryption, AEAD)	N/A
`caamhash.c`	JRI frontend (hashing)	N/A
`caampkc.c, pkc_desc.c`	JRI frontend (public key cryptography)	N/A
`caamkeyblob.[c,h]`	JRI frontend (black keys and blobs)	N/A
`caamkeygen.c`	IOCTL calls for key and blob generation/import	N/A

10.1.3 Module loading

CAAM backend drivers can be compiled either built-in or as modules. Frontend drivers are linked to the backend driver. See Section Section 10.1.2 for the list of module names and Section Section 10.1.4 for how kernel configuration looks like and a mapping between menu entries and modules and/or functionalities enabled.

10.1.4 Kernel configuration

The designated driver should be configured in the kernel by default for the target platform. If unsure, check `CONFIG_CRYPTO_DEV_FSL_CAAM`, which is located in the **Cryptographic API** -> **Hardware crypto devices** sub-menu in the kernel configuration.

Table 68. Kernel configuration tree view

Kernel configuration tree view option	Description
---Cryptographic API ---> [*] Hardware crypto devices --->> <*>CAAM/SNVS Security Violation Handler (EXPERIMENTAL) <*>Freescale CAAM-Multicore platform driver backend [ ] Enable debug output in CAAM driver <*> Freescale CAAM Job Ring driver backend --->> (9) Job Ring size [ ] Job Ring interrupt coalescing [*] Register algorithm implementations with the Crypto API [*] Register hash algorithm implementations with Crypto API [*] Register public key cryptography implementations with Crypto API [*] Register caam device for hwrng API [*] Register tagged key cryptography implementations with Crypto API [ ] Test caam rng [*] CAAM Secure Memory / Keystore API (EXPERIMENTAL) (7) Size of each keystore slot in Secure Memory <M> CAAM Secure Memory - Keystore Test/Example (EXPERIMENTAL) <M> Freescale Job Ring UIO support	Enable CAAM device driver: • Basic platform driver: Freescale CAAM-Multicore platform driver backend • Backends/interfaces: Freescale CAAM Job Ring driver backend - JRI • Frontends/crypto algorithms: symmetric encryption, AEAD, "stitched" AEAD; Register algorithm implementations with the Crypto API - via JRI (caamalg driver) • Register hash algorithm implementations with Crypto API - hashing (only via JRI - caamhash driver) • Register public key cryptography implementations with Crypto API - asymmetric/public key (only via JRI - caampkc driver) • Register CAAM device for hwrng API - HW RNG (only via JRI - caamrng driver) • Register algorithms supporting tagged key and generate black keys and encapsulate them into black blobs

Table 69. Device tree binding

Property	Type	Status	Description
compatible	String	Required	`fsl, sec-vX.Y` (preferred) or `fsl, secX.Y`

Sample Device Tree crypto node

```
crypto@30000 {
      compatible = "fsl,sec-v4.0";
      fsl,sec-era = <2>;
      #address-cells = <1>;
```

```
        #size-cells = <1>;
        reg = <0x300000 0x10000>;
        ranges = <0 0x300000 0x10000>;
        interrupt-parent = <&mpic>;
        interrupts = <92 2>;
        clocks = <&clks IMX6QDL_CLK_CAAM_MEM>,
                 <&clks IMX6QDL_CLK_CAAM_ACLK>,
                 <&clks IMX6QDL_CLK_CAAM_IPG>,
                 <&clks IMX6QDL_CLK_EIM_SLOW>;
        clock-names = "mem", "aclk", "ipg", "emi_slow";
};
```

10.1.5 How to test the drivers

Crypto drivers could be validated in two modes: at boot time and at request. To enable crypto testing feature, the kernel needs to be updated as follows.

Table 70. Kernel configuration

Kernel configuration	Description

`--- Cryptographic API  --->`
`[ ] Disable run-time self tests`
`[ ]  Enable extra run-time crypto self tests`
`<M> Testing module`
	Deselect the feature that bypass crypto driver validation. By default, Linux kernel is bypassing crypto driver validation. Disable run-time self tests that normally take place at algorithm registration.
	Enable extra run-time self tests of registered crypto algorithms, including randomized fuzz tests. This is intended for developer use only, as these tests take much longer to run than the normal self tests.
	Enable testing module.

Section from boot log that specify where crypto test are made (If a boot test is passing with success, no information will be reported. For algorithms with no tests available, a line in dmesg will be printed):

```
[    4.647985] alg: No test for
 authenc(hmac(sha224),ecb(cipher_null)) (authenc-hmac-sha224-
ecb-cipher_null-caam)
[    4.661181] alg: No test for
 authenc(hmac(sha256),ecb(cipher_null)) (authenc-hmac-sha256-
ecb-cipher_null-caam)
[    4.671345] alg: No test for
 authenc(hmac(sha384),ecb(cipher_null)) (authenc-hmac-sha384-
ecb-cipher_null-caam)
[    4.681486] alg: No test for
 authenc(hmac(sha512),ecb(cipher_null)) (authenc-hmac-sha512-
ecb-cipher_null-caam)
[    4.691608] alg: No test for authenc(hmac(md5),cbc(aes))
 (authenc-hmac-md5-cbc-aes-caam)
[    4.699802] alg: No test for
 echainiv(authenc(hmac(md5),cbc(aes))) (echainiv-authenc-hmac-
md5-cbc-aes-caam)
[    4.710445] alg: No test for
 echainiv(authenc(hmac(sha1),cbc(aes))) (echainiv-authenc-hmac-
sha1-cbc-aes-caam)
[    4.720488] alg: No test for authenc(hmac(sha224),cbc(aes))
 (authenc-hmac-sha224-cbc-aes-caam)
```

```
[    4.734647] alg: No test for
 echainiv(authenc(hmac(sha224),cbc(aes))) (echainiv-authenc-
hmac-sha224-cbc-aes-caam)
[    4.750504] alg: No test for
 echainiv(authenc(hmac(sha256),cbc(aes))) (echainiv-authenc-
hmac-sha256-cbc-aes-caam)
[    4.762468] alg: No test for authenc(hmac(sha384),cbc(aes))
 (authenc-hmac-sha384-cbc-aes-caam)
[    4.771188] alg: No test for
 echainiv(authenc(hmac(sha384),cbc(aes))) (echainiv-authenc-
hmac-sha384-cbc-aes-caam)
[    4.782380] alg: No test for
 echainiv(authenc(hmac(sha512),cbc(aes))) (echainiv-authenc-
hmac-sha512-cbc-aes-caam)
[    4.792765] alg: No test for
 authenc(hmac(md5),cbc(des3_ede)) (authenc-hmac-md5-cbc-
des3_ede-caam)
[    4.801832] alg: No test for
 echainiv(authenc(hmac(md5),cbc(des3_ede))) (echainiv-authenc-
hmac-md5-cbc-des3_ede-caam)
[    4.812814] alg: No test for
 echainiv(authenc(hmac(sha1),cbc(des3_ede))) (echainiv-authenc-
hmac-sha1-cbc-des3_ede-caam)
[    4.823942] alg: No test for
 echainiv(authenc(hmac(sha224),cbc(des3_ede))) (echainiv-
authenc-hmac-sha224-cbc-des3_ede-caam)
[    4.835465] alg: No test for
 echainiv(authenc(hmac(sha256),cbc(des3_ede))) (echainiv-
authenc-hmac-sha256-cbc-des3_ede-caam)
[    4.846980] alg: No test for
 echainiv(authenc(hmac(sha384),cbc(des3_ede))) (echainiv-
authenc-hmac-sha384-cbc-des3_ede-caam)
[    4.858497] alg: No test for
 echainiv(authenc(hmac(sha512),cbc(des3_ede))) (echainiv-
authenc-hmac-sha512-cbc-des3_ede-caam)
[    4.869764] alg: No test for authenc(hmac(md5),cbc(des))
 (authenc-hmac-md5-cbc-des-caam)
[    4.877977] alg: No test for
 echainiv(authenc(hmac(md5),cbc(des))) (echainiv-authenc-hmac-
md5-cbc-des-caam)
[    4.888078] alg: No test for
 echainiv(authenc(hmac(sha1),cbc(des))) (echainiv-authenc-hmac-
sha1-cbc-des-caam)
[    4.898356] alg: No test for
 echainiv(authenc(hmac(sha224),cbc(des))) (echainiv-authenc-
hmac-sha224-cbc-des-caam)
[    4.908994] alg: No test for
 echainiv(authenc(hmac(sha256),cbc(des))) (echainiv-authenc-
hmac-sha256-cbc-des-caam)
[    4.919653] alg: No test for
 echainiv(authenc(hmac(sha384),cbc(des))) (echainiv-authenc-
hmac-sha384-cbc-des-caam)
[    4.930292] alg: No test for
 echainiv(authenc(hmac(sha512),cbc(des))) (echainiv-authenc-
hmac-sha512-cbc-des-caam)
[    4.940688] alg: No test for
 authenc(hmac(md5),rfc3686(ctr(aes))) (authenc-hmac-md5-
rfc3686-ctr-aes-caam)
```

```
[    4.950372] alg: No test for
 seqiv(authenc(hmac(md5),rfc3686(ctr(aes)))) (seqiv-authenc-
hmac-md5-rfc3686-ctr-aes-caam)
[    4.961281] alg: No test for
 seqiv(authenc(hmac(sha1),rfc3686(ctr(aes)))) (seqiv-authenc-
hmac-sha1-rfc3686-ctr-aes-caam)
[    4.972281] alg: No test for
 authenc(hmac(sha224),rfc3686(ctr(aes))) (authenc-hmac-sha224-
rfc3686-ctr-aes-caam)
[    4.982482] alg: No test for
 seqiv(authenc(hmac(sha224),rfc3686(ctr(aes)))) (seqiv-authenc-
hmac-sha224-rfc3686-ctr-aes-caam)
[    4.993903] alg: No test for
 seqiv(authenc(hmac(sha256),rfc3686(ctr(aes)))) (seqiv-authenc-
hmac-sha256-rfc3686-ctr-aes-caam)
[    5.005331] alg: No test for
 seqiv(authenc(hmac(sha384),rfc3686(ctr(aes)))) (seqiv-authenc-
hmac-sha384-rfc3686-ctr-aes-caam)
[    5.016763] alg: No test for
 seqiv(authenc(hmac(sha512),rfc3686(ctr(aes)))) (seqiv-authenc-
hmac-sha512-rfc3686-ctr-aes-caam)
[    5.028023] caam algorithms registered in /proc/crypto
[    5.157622] caam_jr 31430000.jr2: registering rng-caam
[    5.206167] caam 31400000.caam: caam pkc algorithms
 registered in /proc/crypto
```

10.2 Crypto algorithms support

- Algorithms supported in the Linux kernel scatterlist Crypto API
  The Linux kernel contains various users of the Scatterlist Crypto API, including its IPsec implementation, sometimes referred to as the NETKEY stack. The driver, after registering supported algorithms with the Crypto API, is therefore used to process per packet symmetric crypto requests and forward them to the CAAM hardware. Since CAAM hardware processes requests asynchronously, the driver registers asynchronous algorithm implementations with the crypto API: `ahash`, `skcipher`, and a head with `CRYPTO_ALG_ASYNC` set in `.cra_flags`. Different combinations of hardware and driver software version support different sets of algorithms, so searching for the driver name in `/proc/crypto` on the desired target system will ensure the correct report of what algorithms are supported.
- Authenticated Encryption with Associated Data (AEAD) algorithms
  These algorithms are used in applications where the data to be encrypted overlaps, or partially overlaps, the data to be authenticated, as is the case with IPsec and TLS protocols. These algorithms are implemented in the driver such that the hardware makes a single pass over the input data, and both encryption and authentication data are written out simultaneously. The AEAD algorithms are mainly for use with IPsec ESP (however there is also support for TLS (1.x) record layer encryption (KTLS Support)). CAAM drivers currently supports offloading the following AEAD algorithms:
  - "stitched" AEAD: all combinations of `{ NULL, CBC-AES, CBC-DES, CBC-3DES-EDE, RFC3686-CTR-AES } x HMAC-{MD-5, SHA-1,-224,-256,-384,-512}`
  - "true" AEAD: generic GCM-AES, GCM-AES used in IPsec: `RFC4543-GCM-AES` and `RFC4106-GCM-AES`
- Encryption algorithms
  The CAAM driver currently supports offloading the following encryption algorithms.
- Authentication algorithms

The CAAM driver's ahash support includes keyed (`hmac`) and unkeyed hashing algorithms.

- Asymmetric (public key) algorithms
  Currently, CAAM driver supports RSA-Encrypt and RSA-Decrypt together with pkcs1pad (`rsa-caam`, `sha256`) driver.
- Algorithms supported by CAAM drivers

```
root@imx8mqevk:~# cat /proc/crypto | grep caam driver :
 pkcs1pad(rsa-caam,sha256) driver : rsa-caam driver : cmac-
aes-caam driver : xcbc-aes-caam driver : md5-caam driver :
 hmac-md5-caam driver : sha256-caam driver : hmac-sha256-
caam driver : sha224-caam driver : hmac-sha224-caam driver :
 sha1-caam driver : hmac-sha1-caam driver : seqiv-authenc-
hmac-sha256-rfc3686-ctr-aes-caam driver : authenc-hmac-sha256-
rfc3686-ctr-aes-caam driver : seqiv-authenc-hmac-sha224-
rfc3686-ctr-aes-caam driver : authenc-hmac-sha224-rfc3686-
ctr-aes-caam driver : seqiv-authenc-hmac-sha1-rfc3686-ctr-aes-
caam driver : authenc-hmac-sha1-rfc3686-ctr-aes-caam driver :
 seqiv-authenc-hmac-md5-rfc3686-ctr-aes-caam driver : authenc-
hmac-md5-rfc3686-ctr-aes-caam driver : echainiv-authenc-
hmac-sha256-cbc-des-caam driver : authenc-hmac-sha256-cbc-
des-caam driver : echainiv-authenc-hmac-sha224-cbc-des-caam
 driver : authenc-hmac-sha224-cbc-des-caam driver : echainiv-
authenc-hmac-sha1-cbc-des-caam driver : authenc-hmac-sha1-
cbc-des-caam driver : echainiv-authenc-hmac-md5-cbc-des-caam
 driver : authenc-hmac-md5-cbc-des-caam driver : echainiv-
authenc-hmac-sha256-cbc-des3_ede-caam driver : authenc-
hmac-sha256-cbc-des3_ede-caam driver : echainiv-authenc-
hmac-sha224-cbc-des3_ede-caam driver : authenc-hmac-sha224-
cbc-des3_ede-caam driver : echainiv-authenc-hmac-sha1-cbc-
des3_ede-caam driver : authenc-hmac-sha1-cbc-des3_ede-caam
 driver : echainiv-authenc-hmac-md5-cbc-des3_ede-caam driver :
 authenc-hmac-md5-cbc-des3_ede-caam driver : echainiv-authenc-
hmac-sha256-cbc-aes-caam driver : authenc-hmac-sha256-cbc-
aes-caam driver : echainiv-authenc-hmac-sha224-cbc-aes-caam
 driver : authenc-hmac-sha224-cbc-aes-caam driver : echainiv-
authenc-hmac-sha1-cbc-aes-caam driver : authenc-hmac-sha1-
cbc-aes-caam driver : echainiv-authenc-hmac-md5-cbc-aes-caam
 driver : authenc-hmac-md5-cbc-aes-caam driver : authenc-hmac-
sha256-ecb-cipher_null-caam driver : authenc-hmac-sha224-ecb-
cipher_null-caam driver : authenc-hmac-sha1-ecb-cipher_null-
caam driver : authenc-hmac-md5-ecb-cipher_null-caam driver :
 gcm-aes-caam driver : rfc4543-gcm-aes-caam driver : rfc4106-
gcm-aes-caam driver : ecb-arc4-caam driver : ecb-des3-caam
 driver : tk-ecb-aes-caam driver : ecb-aes-caam driver : ecb-
des-caam driver : rfc3686-ctr-aes-caam driver : ctr-aes-caam
 driver : cbc-des-caam driver : cbc-3des-caam driver : tk-cbc-
aes-caam driver : cbc-aes-caam root@imx8mqevk:~#
```

10.3 CAAM Job Ring backend driver specifications

CAAM Job Ring backend driver (`caam_jr`) implements and uses the job ring interface (JRI) for submitting crypto API service requests from the frontend drivers (`caamalg`, `caamhash`, `caampkc`, `caamrng`, `caamkeyblob`) to CAAM engine.

CAAM drivers have a few options, most notably hardware job ring size and interrupt coalescing. They can be used to fine-tune performance for a particular use case.

The option Freescale CAAM Job Ring driver backend enables the Job Ring backend (`caam_jr`). The sub-option Job Ring Size allows the user to select the size of the hardware job rings. If requests arrive at the driver enqueue entry point in a bursty nature, the bursts' maximum length can be approximated. The user can set the greatest burst length to save performance and memory consumption.

The sub-option Job Ring interrupt coalescing allows the user to select the use of the hardware's interrupt coalescing feature. Note that the driver already performs IRQ coalescing in software, and zero-loss benchmarks have in fact produced better results with this option turned off. If selected, two additional options become effective:

- *Job Ring interrupt coalescing count threshold* (`CRYPTO_DEV_FSL_CAAM_INTC_THLD`) Device Drivers. Selects the value of the descriptor completion threshold, in the range 1-256. A selection of 1 effectively defeats the coalescing feature, and any selection equal or greater than the selected ring size will force timeouts for each interrupt.
- *Job Ring interrupt coalescing timer threshold* (`CRYPTO_DEV_FSL_CAAM_INTC_TIME_THLD`) Selects the value of the completion timeout threshold in multiples of 64 CAAM interface clocks, to which, if no new descriptor completions occur within this window (and at least one completed job is pending), then an interrupt will occur. This is selectable in the range 1-65535.

The options to register to Crypto API, hwrng API respectively, allow the frontend drivers to register their algorithm capabilities with the corresponding APIs. They should be deselected only when the purpose is to perform Crypto API requests in software (on the GPPs) instead of offloading them on CAAM engine.

`caamhash` frontend (hash algorithms) may be individually turned off, since the nature of the application may be such that it prefers software (core) crypto latency due to many small-sized requests.

`caampkc` frontend (public key / asymmetric algorithms) can be turned off too, if needed.

`caamrng` frontend (Random Number Generation) may be turned off in case there is an alternate source of entropy available to the kernel.

`caamkeyblob` frontend (algorithms supporting tagged key) can be turned off if tagged keys or blobs are not used.

10.3.1 Verifying driver operation and correctness

Other than noting the performance advantages due to the crypto offload, one can also ensure the hardware is doing the crypto by looking for driver messages in `dmesg`. The driver emits console messages at initialization time:

```
[    1.830397] caam 30900000.crypto: device ID =
 0x0a16040100000000 (Era 9)
[    1.837113] caam 30900000.crypto: job rings = 2, qi = 0
[    1.849949] caam algorithms registered in /proc/crypto
[    1.855972] caam 30900000.crypto: caam pkc algorithms
 registered in /proc/crypto
[    1.865564] caam_jr 30901000.jr: registering rng-caam
[    1.870766] Device caam-keygen registered
```

If the messages are not present in the logs, either the driver is not configured in the kernel, or no CAAM compatible device tree node is present in the device tree.

10.3.2 Incrementing IRQs in /proc/interrupts

Given a time period when crypto requests are being made, the CAAM hardware will fire completion notification interrupts on the corresponding Job Ring:

```
root@imx8qxpmek:~# cat /proc/interrupts | grep jr
418:       1059          0          0          0     GICv3 485
 Level     31430000.jr2
419:         21          0          0          0     GICv3 486
 Level     31440000.jr3
root@imx8qxpmek:~#
```

If the number of interrupts fired increment, then the hardware is being used to do the crypto. If the numbers do not increment, then check the algorithm being exercised is supported by the driver. If the algorithm is supported, there is a possibility that the driver is in polling mode (NAPI mechanism) and the hardware statistics in debugfs (inbound/outbound bytes encrypted/protected - see below) should be monitored.

10.3.3 Verifying the 'self test' fields say 'passed' in /proc/crypto

An entry such as the one below means the driver has successfully registered support for the algorithm with the kernel crypto API:

```
name         : cbc(des)
driver       : cbc-des-caam
module       : kernel
priority     : 3000
refcnt       : 1
selftest     : passed
internal     : no
type         : givcipher
async        : yes
blocksize    : 8
min keysize  : 8
max keysize  : 8
ivsize       : 8
geniv        : <built-in>
```

Note that although a test vector may not exist for a particular algorithm supported by the driver, the kernel will emit messages saying which algorithms weren't tested, and mark them as 'passed' anyway:

```
[    4.647985] alg: No test for
 authenc(hmac(sha224),ecb(cipher_null)) (authenc-hmac-sha224-
ecb-cipher_null-caam)
[    4.661181] alg: No test for
 authenc(hmac(sha256),ecb(cipher_null)) (authenc-hmac-sha256-
ecb-cipher_null-caam)
[    4.671345] alg: No test for
 authenc(hmac(sha384),ecb(cipher_null)) (authenc-hmac-sha384-
ecb-cipher_null-caam)
[    4.681486] alg: No test for
 authenc(hmac(sha512),ecb(cipher_null)) (authenc-hmac-sha512-
ecb-cipher_null-caam)
```

10.4 OpenSSL offload

The Secure Socket Layer (SSL) protocol is the most widely deployed application protocol to protect data during transmission by encrypting the data using commonly used cipher algorithms such as AES, DES and 3DES. Apart from encryption, it also provides message authentication services using hash/digest algorithms such as SHA1 and MD5. SSL is widely used in application web servers (HTTP) and other applications such as SMTP POP3, IMAP, and Proxy servers, where protection of data in transit is essential for data integrity. There are various versions of SSL protocol such as TLSv1.0, TLSv1.1, TLSv1.2, TLSv1.3, and DTLS (Datagram TLS). This document describes NXP SSL acceleration solution on i.MX platforms using OpenSSL:

- OpenSSL software architecture
- Building OpenSSL with hardware offload support
- Examples of OpenSSL Offloading

10.4.1 OpenSSL software architecture

The SSL protocol is implemented as a library in OpenSSL - the most popular library distribution in Linux and BSD systems. The OpenSSL library has several sub-components such as:

- SSL protocol library
- SSL protocol library Crypto library (Symmetric and Asymmetric cipher support, digest support, etc.)
- Certificate Management

The following figure presents the general interconnect architecture for OpenSSL. Each relevant layer is represented with a clear separation between Linux User Space and Linux Kernel Space.

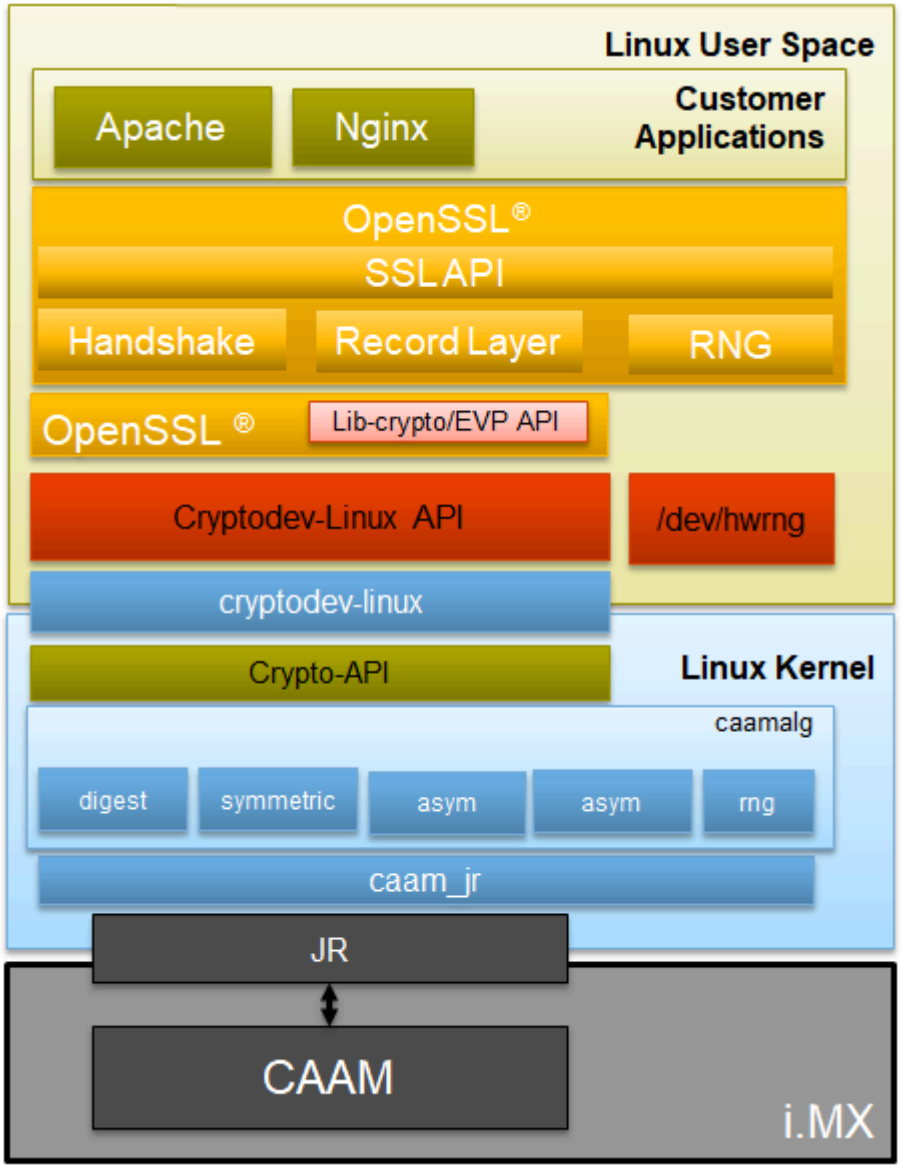


Figure 8. OpenSSL Software stack architecture

10.4.2 OpenSSL's ENGINE interface

OpenSSL Crypto library provides Symmetric and Asymmetric (PKI) cipher support that is used in a wide variety of applications such as OpenSSH, OpenVPN, PGP, IKE, and XML-SEC. The OpenSSL Crypto library provides software support for:

- Cipher algorithms
- Digest algorithms
- Random number generation
- Public Key Infrastructure

Apart from the software support, the OpenSSL can offload these functions to hardware accelerators through the ENGINE interface. The ENGINE interface provides callback hooks that integrate hardware accelerators with the crypto library. The callback hooks

provide the glue logic to interface with the hardware accelerators. Generic offloading of cipher and digests algorithms through Linux kernel is possible with cryptodev engine.

10.4.3 NXP solution for OpenSSL hardware offloading

The following layers can be observed in NXP's solution for OpenSSL hardware offloading:

- `OpenSSL` (user space): implements the SSL protocol
- `cryptodev-engine` (user space): implements the OpenSSL ENGINE interface; talks to `cryptodev-linux` (`/dev/crypto`) through `ioctls`, offloading cryptographic operations in the kernel
- `cryptodev-linux` (kernel space): Linux module that translates ioctl requests from cryptodev-engine into calls to Linux Crypto API
- `AF_ALG` is a netlink-based in the kernel asynchronous interface that adds an AF_ALG address family introduced in 2.6.38.
- Linux Crypto API (kernel space): Linux kernel crypto abstraction layer
- CAAM driver (kernel space): Linux device driver for the CAAM crypto engine

The following are offloaded in hardware in current BSP:

- Symmetric Ciphering operations - AES (CBC, ECB), 3DES (CBC, ECB)
- Digest Operations - SHA (1, 256, 384, 512), MD5
- Public Key Operations - RSA Sign (1k, 2k, 4k) / RSA Verify (1k, 2k, 4k)

10.4.4 Deploying OpenSSL into rootfs

Typically, the imx-image-full includes the OpenSSL and cryptodev modules, but for other Yocto targets, users need to update the conf file from the build directory. Update `conf/local.conf` by adding the following line:

```
CORE_IMAGE_EXTRA_INSTALL+="cryptodev-module openssl-bin"
```

Restart the build procedure:

```
bitbake imx-image-full
```

10.4.5 Running OpenSSL benchmarking tests with cryptodev engine

Probe the cryptodev-module:

```
root@imx8qxpmek:~# modprobe cryptodev
[17044.896494] cryptodev: driver 1.10 loaded.
root@imx8qxpmek:~# openssl engine
(devcrypto) /dev/crypto engine
(dynamic) Dynamic engine loading support
root@imx8qxpmek:~#
```

Note:

Starting from OpenSSL 1.1.1, the cryptodev engine is invoked by OpenSSL by default if the corresponding module has been inserted in the kernel. Thus to perform only SW benchmark test using OpenSSL, remove the cryptodev module by running `rmmod cryptodev`.

10.4.5.1 Running OpenSSL benchmarking tests for symmetric ciphering and digest

In the speed test file, a series of performance tests are made to check the performance of the symmetric and digest operations. The following is described in the OpenSSL test execution:

```
root@imx8qxpmek:~# openssl speed -engine devcrypto -multi 8 -elapsed -evp
 aes-128-cbc
Forked child 1
engine "devcrypto" set.
Forked child 2
engine "devcrypto" set.
...
Got: +F:22:aes-128-
cbc:378616.72:1611328.00:5084501.33:13994666.67:10731793.98:16219060.40 from 6
Got: +H:16:64:256:1024:8192:16384 from 7
Got: +F:22:aes-128-
cbc:120773.33:9344.00:3088298.67:13588480.00:31642965.33:16471967.79 from 7
OpenSSL 1.1.1b  26 Feb 2019
built on: Thu Nov 14 13:22:07 2019 UTC
options:bn(64,64) rc4(char) des(int) aes(partial) idea(int) blowfish(ptr)
compiler: aarch64-poky-linux-gcc  --sysroot=recipe-sysroot -O2 -pipe -g -
feliminate-unused-debug-types -fmacro-prefix-map=
-fdebug-prefix-map= -fdebug-prefix-map=  -fdebug-prefix-map= -
DOPENSSL_USE_NODELETE -DOPENSSL_PIC -DOPENSSL_CPUID_OBJ -DOPENSSL_BN_ASM_MONT
-DSHA1_ASM -DSHA256_ASM -DSHA512_ASM -DKECCAK1600_ASM -DVPAES_ASM -
DECP_NISTZ256_ASM -DPOLY1305_ASM -DNDEBUG
evp              2242.05k     9681.05k    35017.46k   106866.86k   127787.74k
  130077.23k
root@imx8qxpmek:~#
```

Additional ciphers that could be benchmarked: `aes-192-cbc`, `aes-256-cbc`, `aes-128-ecb`, `aes-192-ecb`, `aes-256-ecb`, `aes-128-ctr`, `aes-192-ctr`, `aes-256-ctr`, `des-cbc`, `des-cbc`, `des-ede3-cbc`.

Additional digests that could be benchmarked: `sha1`, `sha224`, `sha256`, `sha384`, `sha512`, `md5`.

10.4.6 Running OpenSSL benchmarking tests with AF_ALG engine

Execute the following commands:

```
Probe the af_alg:
root@imx8mmevk:~# rmmod cryptodev
root@imx8mmevk:~# modprobe af_alg
root@imx8mmevk:~# modprobe algif_hash
root@imx8mmevk:~# modprobe algif_skcipher
root@imx8mmevk:~# modprobe algif_rng
root@imx8mmevk:~# modprobe algif_aead
```

10.4.6.1 Running OpenSSL benchmarking tests for symmetric ciphering and digest

Execute the following command:

```
root@imx8mmevk:~# openssl speed -engine afalg -multi 8 -elapsed -evp aes-128-
cbc
Forked child 0
Forked child 1
engine "afalg" set.
+DT:aes-128-cbc:3:16
engine "afalg" set.
engine "afalg" set.
engine "afalg" set.
...
Got: +H:16:64:256:1024:8192:16384 from 0
```

```
Got: +F:22:aes-128-
cbc:333888.00:1359317.33:4248405.33:5720064.00:6160384.00:6176768.00 from 0
Got: +H:16:64:256:1024:8192:16384 from 1
Got: +F:22:aes-128-
cbc:378336.00:1382826.67:5117269.33:5739178.67:6190421.33:6176768.00 from 1
...
OpenSSL 1.1.1k  25 Mar 2021
built on: Thu Mar 25 13:28:38 2021 UTC
options:bn(64,64) rc4(char) des(int) aes(partial) blowfish(ptr)
compiler: aarch64-poky-linux-gcc  -mcpu=cortex-a53 -march=armv8-a+crc+crypto
 -fstack-protector-strong  -O2 -D_FORTIFY_SOURCE=2 -Wformat -Wformat-security
 -Werror=format-security --sysroot=recipe-sysroot -O2 -pipe -g -feliminate-
unused-debug-types -fmacro-prefix-map=                    -fdebug-prefix-
map=                    -fdebug-prefix-map=                    -fdebug-
prefix-map=  -DOPENSSL_USE_NODELETE -DOPENSSL_PIC -DOPENSSL_CPUID_OBJ -
DOPENSSL_BN_ASM_MONT -DSHA1_ASM -DSHA256_ASM -DSHA512_ASM -DKECCAK1600_ASM -
DVPAES_ASM -DECP_NISTZ256_ASM -DPOLY1305_ASM -DNDEBUG
evp              2682.45k    10842.73k    35957.50k    45915.48k    49722.71k
   50135.04k
```

10.4.7 Running OpenSSL asymmetric tests with PKCS#11 based engine

Prerequisites:

1. For running the PKCS#11 OpenSSL Engine with our PKCS#11 Library, add the following into your global OpenSSL configuration file (often in `/etc/ssl/openssl.cnf`).
   This line must be placed at the top, before any sections are defined:

   ```
   openssl_conf = openssl_init
   ```

   Make sure there are no other `openssl_conf = ...` lines in the file.
   This should be added to the bottom of the file:

   ```
   [openssl_init]
   engines=engine_section
   [engine_section]
   pkcs11 = pkcs11_section
   [pkcs11_section]
   engine_id = pkcs11
   dynamic_path = /usr/lib/engines-3/pkcs11.so
   MODULE_PATH = /usr/lib/libckteec.so.0
   init = 0
   ```

   The `dynamic_path` value is the PKCS#11 engine plug-in, and the `MODULE_PATH` value is the NXP PKCS#11 library. The `engine_id` value is an arbitrary identifier for OpenSSL applications to select the engine by the identifier.
2. Make sure `tee-supplicant` is running.

   ```
   root@imx8mpevk:~# ps -aux | grep tee
   root         661  0.0  0.0  76424  1432 ?        Ssl  May27
    0:00 /usr/bin/tee-supplicant
   ```

   If it is not running, run the following command:

   ```
   root@imx8mpevk:~# tee-supplicant &
   ```

10.4.7.1 Running p11tool to generate key (RSA or EC)

```
root@imx8mpevk:~# mkdir /etc/gnutls
root@imx8mpevk:~# echo load=`find /usr/lib -name
 libckteec.so.0` > /etc/gnutls/pkcs11.conf
root@imx8mpevk:~# p11tool --list-tokens
```

```
root@imx8mpevk:~# p11tool --initialize "<token url>" --
label="<token label>"
Enter Security Officer's PIN:
root@imx8mpevk:~# p11tool --list-tokens
root@imx8mpevk:~# p11tool --initialize-pin "<token url>"
Setting user's PIN...
Enter User's new PIN:
Token <toke label> with URL <token url> requires security
 officer PIN
Enter PIN:<Security Officer's PIN>
```

To generate an RSA key:

```
root@imx8mpevk:~# p11tool --login --generate-rsa --bits=2048 --
label="RSA-key-2048" --outfile="RSA-key-2048.pub" "<token url>"
 --set-pin="<user pin>"
root@imx8mpevk:~# p11tool --login --list-privkeys "<token url>"
 --set-pin="<user pin>"
Object 0:
        URL: token url private
        Type: Private key (RSA-2048)
        Label: RSA-key-2048
        Flags: CKA_PRIVATE; CKA_NEVER_EXTRACTABLE;
 CKA_SENSITIVE;
        ID:
 bc:8e:f3:ca:95:d6:e7:ae:57:89:43:1f:67:a3:e5:d1:05:d8:5d:66
```

Or to generate an EC key:

```
root@imx8mpevk:~# p11tool --login --generate-ecc --
curve=secp256r1 --label="ec-key-256" --outfile="ec-key-256.pub"
 "<token url>" --set-pin="<user pin>"
root@imx8mpevk:~# p11tool --login --list-privkeys "<token url>"
 --set-pin="<user pin>"
Object 0:
        URL: token url private
        Type: Private key (EC/ECDSA-SECP256R1)
        Label: ec-key-256
        Flags: CKA_PRIVATE; CKA_NEVER_EXTRACTABLE;
 CKA_SENSITIVE;
        ID:
 9b:54:b4:c5:88:3f:19:44:cb:b2:40:04:46:fa:a0:48:19:eb:0e:70
```

10.4.7.2 Using OpenSSL from command line

To generate a certificate with its key in the PKCS #11 module, use the following commands. The first command creates a self-signed Certificate for "NXP Semiconductor". The signing is done using the key specified by the URL.

```
root@imx8mpevk:~# openssl req -engine pkcs11 -new -key "<token
 url private>" -keyform engine -out req.pem -text -x509 -subj
 "/CN=NXP Semiconductor"
Engine "pkcs11" set.
Enter PKCS#11 token PIN for token label:<user pin>
```

The second command creates a self-signed certificate for the request. The private key used to sign the certificate is the same private key used to create the request.

```
root@imx8mpevk:~# openssl x509 -engine pkcs11 -signkey "<token
 url private>" -keyform engine -in req.pem -out cert.pem
Engine "pkcs11" set.
Enter PKCS#11 token PIN for token label:<user pin>
root@imx8mpevk:~# ls
cert.pem  req.pem
```

10.4.7.3 Running OpenSSL test for RSA

```
root@imx8mpevk:~# echo "This is plain message 2021-01-18" >
 plain.text
root@imx8mpevk:~# openssl pkeyutl -engine pkcs11 -encrypt -in
 plain.text -out encrypted.enc -inkey cert.pem -certin
root@imx8mpevk:~# openssl pkeyutl -engine pkcs11 -decrypt -in
 encrypted.enc -out plain.dec -inkey "<token url private>" -
keyform engine
Engine "pkcs11" set.
Enter PKCS#11 token PIN for token label:<user pin>
root@imx8mpevk:~# cat plain.text
This is plain message 2021-01-18
root@imx8mpevk:~# cat plain.dec
This is plain message 2021-01-18
```

10.4.7.4 Running OpenSSL test for EC

```
root@imx8mpevk:~# echo "This is plain message 2021-01-18" >
 plain.text
root@imx8mpevk:~# openssl pkeyutl -engine pkcs11 -sign -in
 plain.text -out cert_ecc.sign -inkey "<token url private>" -
keyform engine
Engine "pkcs11" set.
Enter PKCS#11 token PIN for token label:<user pin>
root@imx8mpevk:~# openssl pkeyutl -verify -in plain.text -
sigfile cert_ecc.sign -inkey ecc_cert.pem -certin
Signature Verified Successfully
```

10.5 Disk encryption acceleration

Disk encryption is a technology that protects information by converting it into unreadable code that cannot be deciphered easily by unauthorized people. Disk encryption uses disk encryption software or hardware to encrypt every bit of data that goes on a disk or disk volume. It is used to prevent unauthorized access to data storage. On i.MX Applications Processors, the disk encryption scenarios could be implemented in various ways with different methods of key protection.

This section provides steps to run a transparent storage encryption at block level using DM-Crypt. The figure below presents the software stack that implements disk encryption.

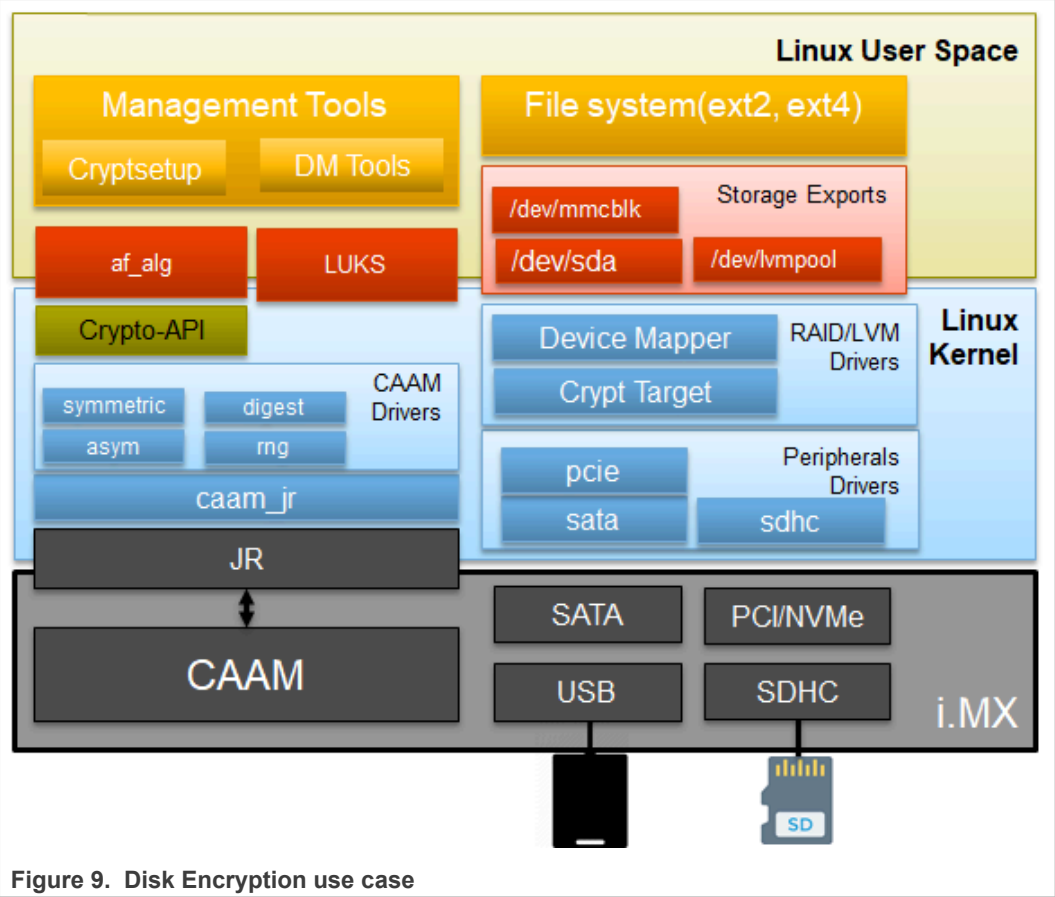


Figure 9. Disk Encryption use case

10.5.1 Enabling disk encryption support in kernel

By default, the kernel configuration file enables the Device Mapper configuration and Crypt Target support as modules. Therefore, to enable disk encryption scenario, after the board is booted up, insert the following modules:

```
root@imx8mqevk:/# modprobe dm-mod
[  266.982638] device-mapper: ioctl: 4.41.0-ioctl (2019-09-16)
 initialised: dm-devel@redhat.com
root@imx8mqevk:/# modprobe dm-crypt
root@imx8mqevk:/# dmsetup targets
crypt            v1.19.0
striped          v1.6.0
linear           v1.4.0
error            v1.5.0
```

If the disk encryption scenario is not enabled, some features in the kernel need to be enabled:

Kernel Configure Tree View Options	Description

`< Device Drivers  --->`
`[*]  Multiple devices driver support (RAID and LVM)  --->`
`<*>  Device mapper support`
`[ ]  Device mapper debugging support`
	DM Crypt support enablement in Linux kernel

Kernel Configure Tree View Options	Description
< > Unstriped target (NEW) <*> Crypt target support <*> Multipath target [*] DM uevents	CONFIG_BLK_DEV_DM=y
< Cryptographic API ---> <*> User-space interface for hash algorithms <*> User-space interface for symmetric key cipher algorithms <*> User-space interface for AEAD cipher algorithms	Enable user space crypto API's to allow simple cryptsetup benchmarks
Cryptographic API --->[*] Hardware crypto devices --->[*] Register tagged key cryptography implementations with Crypto API	Selecting this will register algorithms supporting tagged key, generate black keys and encapsulate them into black blobs.

10.5.2 User space tools for disk encryption

All the required user space tools needed for DM-Crypt are already installed on the board when using Linux i.MX BSP.

If the required user space tools are not installed in the build, add them by editing the `conf/local.conf` file and appending:

```
CORE_IMAGE_EXTRA_INSTALL+="coreutils keyutils lvm2 e2fsprogs-
mke2fs utillinux"
```

- keyutils: provides keyctl, which is required to manage Linux Key retention service.
- lvm2: provides dmsetup utility and libraries to manage device-mapper.
- e2fsprogs-mke2fs: contains necessary tools to create filesystems.
- util-linux: provides blockdev utility needed to read number of sectors from a volume.

10.5.3 DM-Crypt using CAAM backed keys

In Linux Unified Key Setup (LUKS) mode, to generate the disk encryption key (master key), the user supplies a passphrase, which is combined with a salt, and then a hash function is applied for a supplied number of rounds. When the user wants to mount an encrypted volume, the passphrase should be supplied. An alternative could be providing a key file stored in an external drive containing necessary decryption information. Those approaches are not convenient with embedded devices usage.

These blobs are used to import either the plain-key or black-key from a red-blob or black-blob, respectively.

The aim of using DM-Crypt with:

- Trusted keys backed by CAAM
- CAAM's tagged key, used to suppress the mechanism of encrypting the master volume key with a key derived from a user-supplied passphrase

Linux OS provides an in-kernel key management and retention facility called Keyrings. Keyring also enables interfaces to allow accessing keys and performing operations such as add, update, and delete from user-space.

The kernel provides several basic types of keys including ecrypted, trusted, user, and logon.

The CAAM driver has associated a user-space application used to generate:

- A plain key and encapsulated it into Red blob
- A tagged key and encapsulated it into a black blob

10.5.3.1 DM-Crypt with Trusted keys backed by CAAM

DM-Crypt fetches the trusted key which was generated through CAAM, from the kernel keyring, to take advantage of CAAM state.

The key de-capsulated from Red-Blob is different for different CAAM states:

- If System is booted in secure boot with Chain-of-trust established, CAAM state is secure state.
- If system is booted in non-secure (or compromised) state, CAAM state is non-secure state.

Key Value add:

Data that was written in secure state using the trusted key, is not read back from non-trusted or compromised system.

10.5.3.1.1 Usage

The following steps shows how to perform a full disk encryption on i.MX devices.

1. Insert the kernel module.

```
$>: modprobe trusted
```

2. Generate the trusted key:

```
$>: KEYNAME=dm_trust
$>: KEY="$(keyctl add trusted $KEYNAME 'new 32' @s)"
$>: keyctl pipe $KEY >~/$KEYNAME.blob
$>: keyctl list @s
```

Output:

```
$>: keyctl list @s
2 keys in keyring:
 48178143: ----s-rv     0     0 user: invocation_id
143779047: --alswrv     0     0 trusted: dm_trust
```

3. Create a secure volume. It could be a physical partition. In this example, make use of an image file and mount it later.

```
$>: DEV=/dev/loop0
$>: BLOCKS=20
$>: fallocate -l $((BLOCKS*512)) ~/loop0.img
```

```
$>: losetup -P $DEV ~/loop0.img
```

4. Create the mapping table "TABLE". Where:
   - Algo is set in Kernel Crypto API format to use the plain key. Algo/cipher is set to `cbc(aes)-plain`.
   - Key is set as the trusted key of length 32 and the name is exported as `$KEYNAME`.

```
$>: DEV=/dev/loop0
$>: ALGO=capi:cbc(aes)-plain
$>: KEYNAME=dm_trust
$>: BLOCKS=20
$>: TARGET=crypt
$>: TABLE="0 $BLOCKS $TARGET $ALGO :32:trusted:$KEYNAME 0
 $DEV 0 1 allow_discards"
```

5. Use `dmsetup` to create a new device-mapper device named `encrypted` for example, and specify the mapping table "TABLE" created above, as argument.

```
$>: echo $TABLE | dmsetup create encrypted
```

6. Load the device-mapper device named `encrypted` created in the previous step.

```
$>: echo $TABLE | dmsetup load encrypted
```

7. Create a secure volume.

```
$>: dd if=/dev/zero of=/dev/mapper/encrypted || true
```

8. Write to the volume.

```
$>: echo "It works. Congratulations" 1<> /dev/mapper/
encrypted
```

9. Unmount the device.

```
$>: umount /mnt/encrypted/
```

10. Deactivate the device mapper device.

```
$>: dmsetup remove encrypted
```

Restart the board:

```
$>: reboot
```

11. In the next boot, insert the kernel module.

```
$>: modprobe trusted
Step 11: Load the trusted key:
$>: KEYNAME=dm_trust
$>: keyctl add trusted $KEYNAME "load $(cat ~/$KEYNAME.blob)"
 @s
$>: keyctl list @s
```

Output:

```
$>: keyctl list @s
2 keys in keyring:
 48178143: ----s-rv     0     0 user: invocation_id
143779047: --alswrv     0     0 trusted: dm_trust
```

12. Create the mapping table "TABLE". Where:
    - Algo is set in Kernel Crypto API format to use the plain key. Algo/cipher is set to `cbc(aes)-plain`.

- Key is set as the trusted key of length 32 and name is exported as `$KEYNAME`.

```
$>: DEV=/dev/loop0
$>: ALGO=capi:cbc(aes)-plain
$>: KEYNAME=dm_trust
$>: BLOCKS=20
$>: TARGET=crypt
$>: TABLE="0 $BLOCKS $TARGET $ALGO :32:trusted:$KEYNAME 0
 $DEV 0 1 allow_discards"
```

13. Mount the encrypted device.

```
$>: losetup -P $DEV ~/loop0.img
```

14. Specify the mapping table "TABLE" to encrypt the volume using `dmsetup`.

```
$>: echo $TABLE | dmsetup create encrypted
$>: echo $TABLE | dmsetup load encrypted
```

15. Read from the device to verify if the content is same as it was written in the previous boot.

```
$>: hexdump -C /dev/mapper/encrypted
```

10.5.3.2 DM-Crypt with CAAM's tagged key

DM-Crypt can also take advantages of tagged key to protect storage volumes from offline decryption. In addition, the volume could only be opened by the devices that have the same OTPMK burned in the fuses. For more details, see the Security Reference Manual for specific SoC.

The tagged key feature is based on CAAM's black key mechanism. Black key protects user keys against bus snooping while the keys are being written to or read from memory external to the SoC. CAAM supports two different black key encapsulation schemes, which are AES-ECB and AES-CCM.

Regarding AES-ECB encryption, the data is a multiple of 16 bytes long and is intended for quick decryption.

The AES-CCM mode is not as fast as AES-ECB mode, but includes a "MAC tag" (integrity check value) that ensures the integrity of the encapsulated key. A CCM-encrypted black key is always at least 12 bytes longer than the encapsulated key (nonce value + MAC tag).

Black keys are session keys; therefore, they are not power-cycles safe. CAAM's blob mechanism provides a method for protecting user-defined data across system power cycles. It provides both confidentiality and integrity protection. The data to be protected is encrypted so that it can be safely placed into non-volatile storage before the SoC is powered down.

The following diagram illustrates the changes that have been added to support full disk encryption using tagged key. The CAAM driver registers new Cryptographic transformations in the kernel to use ECB and CBC blacken keys, tk(ecb(aes)) and tk(cbc(aes)). The tk prefix refers to Tagged Key.

A Tagged Key is a black key that contains metadata indicating what it is and how to handle it.

```
$ ./caam-keygen
CAAM keygen usage: caam-keygen [options]
```

```
Options:
create <key_name> <key_enc> <key_mode> <key_val>
  <key_name> the name of the file that will contain the black
 key.
  A file with the same name, but with .bb extension, will
 contain the black blob.
  <key_enc> can be ecb or ccm
  <key_mode> can be -s or -t.
     -s generate a black key from random with the size given in
 the next argument
     -t generate a black key from a plaintext given in the next
 argument
  <key_val> the size or the plaintext based on the previous
 argument (<key_mode>)
import <blob_name> <key_name>
  <blob_name> the absolute path of the file that contains the
 blob
  <key_name> the name of the file that will contain the black
 key.
```

By default, the keys and blobs are created in KEYBLOB_LOCATION, which is `/data/caam/`.

Later, CAAM Tagged Key is added into Linux Key Retention service and managed by user-space application such as `keyctl`. Black blobs can be stored on any non-volatile storage.

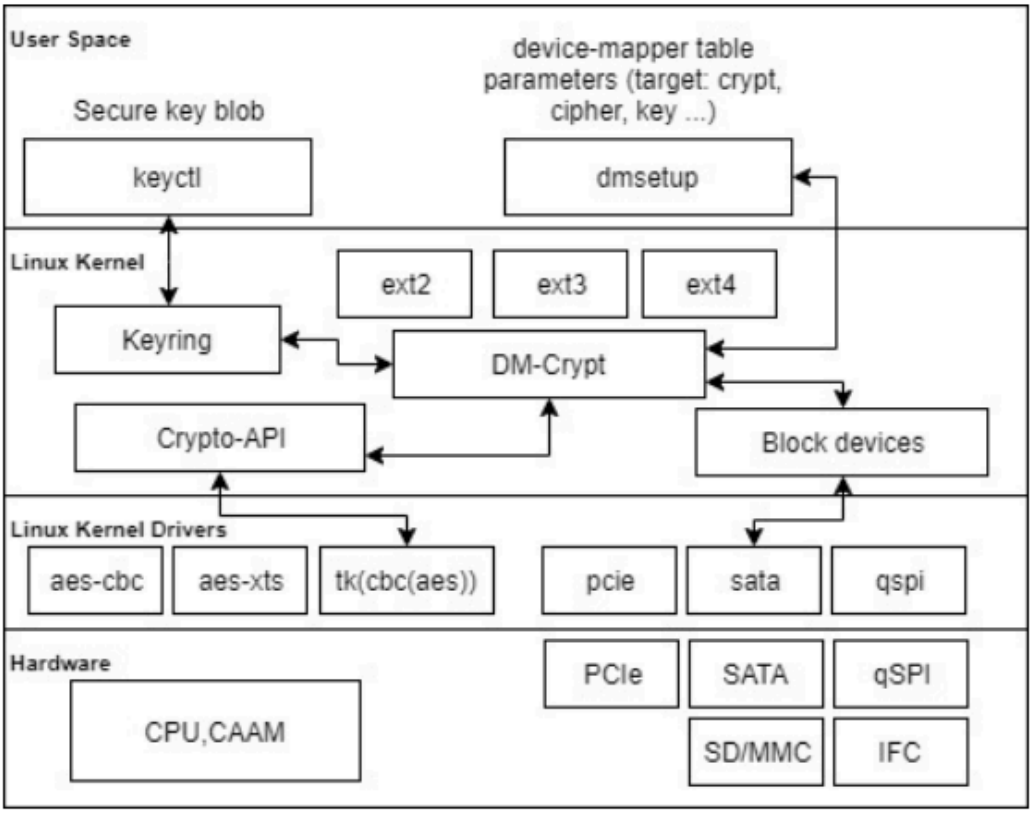


Figure 10. DM-Crypt using CAAM Tagged key - overall architecture

Dmsetup (part of the `libdevmapper` package) is a powerful tool for performing very low-level configuration and is used to manage encrypted volumes.

10.5.4 Usage

The following are the steps to perform a full disk encryption on i.MX devices.

1. After booting the device, make sure that cryptographic transformations using Tagged Key are registered.

```
root@imx8mqevk:~# grep -B1 -A2 tk- /proc/crypto|grep -v
 kernel
name         : tk(ecb(aes))
driver       : tk-ecb-aes-caam
priority     : 3000
--
name         : tk(cbc(aes))
driver       : tk-cbc-aes-caam
priority     : 3000
root@imx8mqevk:~#
```

   And caam-keygen application is available:

```
root@imx8mmevk:~# cd /; find -name "caam-keygen"
./usr/bin/caam-keygen
./dev/caam-keygen
./sys/class/misc/caam-keygen
./sys/devices/virtual/misc/caam-keygen
```

   For now, we only support AES algorithms. Therefore, the size of the key accepted for encryption/decryption is 16, 24, and 32 bytes.

2. Make sure DM-Crypt is enabled.

```
root@imx8mqevk:~# dmsetup targets
crypt            v1.19.0
striped          v1.6.0
linear           v1.4.0
error            v1.5.0
```

   If any of the above is missing, check Kernel configurations or see section Enable disk encryption support in kernel.

3. Then, provide the device with its key, the black key, which could be created either from a defined plain key or randomly.
   Here is an example for black key encrypted with ECB, from a given plaintext of size 16 bytes:

```
root@imx8mqevk:~# ./caam-keygen create fromTextkey ecb -t
 0123456789abcdef
```

   The result is a Tagged Key and a Blob files written to filesystem (the default location is /data/caam). The used key encryption scheme is ECB.

```
root@imx8mqevk:~# ls -la /data/caam/
total 16
drwxr-xr-x 2 root root 4096 Aug 25 15:38 .
drwxr-xr-x 3 root root 4096 Aug 25 15:38 ..
-rw-r--r-- 1 root root   36 Aug 25 15:38 fromTextkey
-rw-r--r-- 1 root root   96 Aug 25 15:38 fromTextkey.bb
```

Next, add the key in key retention service, using `keyctl`:

```
root@imx8mqevk:~# cat /data/caam/fromTextkey  | keyctl padd
 logon logkey: @s
876928653
```

4. Create a secure volume. It could be a physical partition. In this example, make use of an image file and mount it later.

```
root@imx8mqevk:~# dd if=/dev/zero of=encrypted.img bs=1M
 count=32
32+0 records in
32+0 records out
33554432 bytes (34 MB, 32 MiB) copied, 3.20227 s, 10.5 MB/s
root@imx8mqevk:~#
root@imx8mqevk:~# losetup /dev/loop0 encrypted.img
root@imx8mqevk:~#
```

5. Use `dmsetup` to create a new device-mapper device named encrypted for example, and specify the mapping table. The table can be provided on stdin or as argument.

```
root@imx8mqevk:~# dmsetup -v create encrypted --table "0
 $(blockdev --getsz /dev/loop0) crypt capi:tk(cbc(aes))-
plain :36:logon:logkey: 0 /dev/loop0 0 1 sector_size:512"
Name:              encrypted
State:             ACTIVE
Read Ahead:        256
Tables present:    LIVE
Open count:        0
Event number:      0
Major, minor:      253, 0
Number of targets: 1
```

The following is a breakdown of the mapping table:

- `start` means encrypting begins with sector 0.
- `size` is the size of the volume in sectors.
- `blockdev` gets the number of sectors of the device.
- `target` is crypt.
- `cipher` is set in Kernel Crypto API format to use Tagged Key. `cipher` set to `capi:tk(cbc(aes))-plain` and key set to `:36:logon:logkey:` leads to use of the logon key with CAAM Tagged Key transformation.
- `IV` is the Initialization Vector defined to plain, initial vector, which is the 32-bit little-endian version of the sector number, padded with zeros if necessary.
- `key type` is the Keyring key service type, set to Logon Key. 36 is the key size in bytes.
- `key name` is the key description to identify the key to load.
- `IV offset` is the value to add to sector number to compute the IV value.
- `device` is the path to device to be used as backend; it contains the encrypted data.
- `offset` represents encrypted data begins at sector 0 of the device.
- `optional parameters` represent the number of optional parameters.
- sector_size specifies the encryption sector size.

For more detailed options and descriptions, refer to https://gitlab.com/cryptsetup/cryptsetup/-/wikis/DMCrypt.

The created device appears in `/dev/mapper`:

```
root@imx8mqevk:~# dmsetup table --showkey encrypted
```

```
0 65536 crypt capi:tk(cbc(aes))-plain :36:logon:logkey: 0 7:0
 0
```

6. Create a file system on the device.

```
root@imx8mqevk:~# mkfs.ext4 /dev/mapper/encrypted
mke2fs 1.45.3 (14-Jul-2019)
Creating filesystem with 32768 1k blocks and 8192 inodes
Filesystem UUID: 3ba01ad8-ba03-4389-a955-5136b3173c35
Superblock backups stored on blocks:
    8193, 24577
Allocating group tables: done
Writing inode tables: done
Creating journal (4096 blocks): done
Writing superblocks and filesystem accounting information:1
 done
```

7. Set up a mount point.

```
root@imx8mqevk:~# mkdir /mnt/encrypted
```

8. Mount the mapped device.

```
root@imx8mqevk:~# mount -t ext4 /dev/mapper/encrypted /mnt/
encrypted/
[ 9409.936183] EXT4-fs (dm-0): mounted filesystem with
 ordered data mode. Opts: (null)
[ 9409.943892] ext4 filesystem being mounted at /mnt/
encrypted supports timestamps until 2038 (0x7fffffff)
```

9. Write to device.

```
root@imx8mqevk:~# echo "This is an encrypt with black
 key (ECB from text 16 bytes key size) test of full disk
 encryption on i.MX" > /mnt/encrypted/readme.txt
```

10. Unmount the device.

```
root@imx8mqevk:~# umount /mnt/encrypted/
```

11. Deactivate the device mapper device.

```
root@imx8mqevk:~# dmsetup remove encrypted
```

12. Restart the board.

```
root@imx8mqevk:~# reboot
...
root@imx8mqevk:~#
```

13. Import the key from blob and add it to key retention service.

```
root@imx8mqevk:~# ./caam-keygen import /data/caam/
fromTextkey.bb importKey
root@imx8mqevk:~# cat /data/caam/importKey | keyctl padd
 logon logkey2: @s
605536287
root@imx8mqevk:~# ls -la /data/caam/
total 20
drwxr-xr-x 2 root root 4096 Aug 25 15:47 .
drwxr-xr-x 3 root root 4096 Aug 25 15:38 ..
-rw-r--r-- 1 root root   36 Aug 25 15:38 fromTextkey
-rw-r--r-- 1 root root   96 Aug 25 15:38 fromTextkey.bb
-rw-r--r-- 1 root root   36 Aug 25 15:47 importKey
```

```
root@imx8mqevk:~#
```

14. Mount the encrypted device.

```
root@imx8mqevk:~# losetup /dev/loop0 encrypted.img
root@imx8mqevk:~#
```

15. Specify the mapping table to encrypt the volume using `dmsetup`.

```
root@imx8mqevk:~#  dmsetup -v create encrypted --table "0
 $(blockdev --getsz /dev/loop0) crypt capi:tk(cbc(aes))-
plain :36:logon:logkey2: 0 /dev/loop0 0 1 sector_size:512"
Name:              encrypted
State:             ACTIVE
Read Ahead:        256
Tables present:    LIVE
Open count:        0
Event number:      0
Major, minor:      253, 0
Number of targets: 1
```

16. Mount.

```
root@imx8mqevk:~# mount /dev/mapper/encrypted /mnt/encrypted/
[  191.961828] EXT4-fs (dm-0): mounted filesystem with
 ordered data mode. Opts: (null)
[  191.969533] ext4 filesystem being mounted at /mnt/
encrypted supports timestamps until 2038 (0x7fffffff)
root@imx8mqevk:~
```

17. Read from the device.

```
root@imx8mqevk:~# cat /mnt/encrypted/readme.txt
This is an encrypt with black key (ECB from text 16 bytes key
 size) test of full disk encryption on i.MX.
root@imx8mqevk:~#
```

18. Unmount the device and deactivate the device mapper device.

```
root@imx8mqevk:~# umount /mnt/encrypted/; dmsetup remove
 encrypted
```

10.6 crypto_af_alg application support

10.6.1 Prerequisites

The caam-keygen application is needed to import the black key from the black blob. Make sure that the caam-keygen application is already present at `/usr/bin`.

10.6.2 Building the kernel

10.6.2.1 Kernel configuration

- CONFIG_CRYPTO_USER_API
- CONFIG_CRYPTO_USER_API_HASH
- CONFIG_CRYPTO_USER_API_SKCIPHER
- CONFIG_CRYPTO_USER_API_RNG

- CONFIG_CRYPTO_USER_API_AEAD

Get a bootable image that includes the black key support and AF_ALG socket interface for the Linux kernel. Or build the kernel from here: https://github.com/nxp-imx/linux-imx/.

10.6.2.2 Building a toolchain

Build a toolchain to cross compile the sources of the caam-decrypt application. For details, see the *i.MX Yocto Project User's Guide* (IMXLXYOCTOUG).

```
$ wget https://developer.arm.com/-/media/Files/downloads/gnu-
a/8.2-2019.01/gcc-arm-8.2-2019.01-x86_64-aarch64-elf.tar.xz
$ tar xf gcc-arm-8.2-2019.01-x86_64-aarch64-elf.tar.xz
```

10.6.2.3 Cross compiling the user space sources

Set up the environment for cross compilation using the toolchain previously prepared.

1. In the toolchain folder, set up the environment.

```
$ export CROSS_COMPILE=<path to toolchain>/bin/aarch64-linux-
gnu-
$ export CC=${CROSS_COMPILE}gcc
$ export LD=${CROSS_COMPILE}ld
```

2. Build the caam-decrypt user space application. Go to the source folder and run:

```
$ make clean
$ make
```

10.6.3 Usage

After the device successfully boots with the previously generated image, caam-decrypt can be used to decrypt an encrypted data stored in a file.

```
$ ./caam-decrypt
Application usage: caam-decrypt [options]
Options:
<blob_name> <enc_algo> <input_file> <output_file>
<blob_name> the absolute path of the file that contains the
 black blob
<enc_algo> can be AES-256-CBC
<input_file> the absolute path of the file that contains input
 data
       initialization vector(iv) of 16 bytes prepended
       size of input file must be multiple of 16
<output_file> the absolute path of the file that contains
 output data
```

10.6.4 Use case example

```
$ caam-decrypt myblob AES-256-CBC my_encrypted_file
 output_decrypted
```

where:

- myblob: generated black key blob. The caam-keygen application imports a black key from the black blob. This black key is used by CAAM for decryption.
- AES-256-CBC: currently the only supported symmetric algorithm used for decryption operation. Make sure that the encrypted data must use the same algorithm.
- my_encrypted_file: Encrypted data stored in a file. Initialization vector(iv) of 16 bytes used during encryption must be prepended to encrypted data.

```
AES Encrypted file format
  16 Octets - Initialization Vector (IV) is an input to
 encryption algorithm.
  nn Octets - Encrypted message  (for AES-256-CBC, it must be
 multiple of 16)
```

- output_decrypted: contains decrypted data after successful decryption operation.

10.7 Kernel TLS offload

Linux kernel provides TLS connection offload infrastructure. Once a TCP connection is in ESTABLISHED state, user space can enable the TLS Upper Layer Protocol (ULP) and install the cryptographic connection state. For details regarding the user-facing interface, refer to the TLS documentation in Kernel TLS.

10.7.1 Prerequisites

Check OpenSSL version using the following command. It must be 3.0.0 or higher.

```
openssl version
```

10.7.2 Running Kernel TLS test

On server generate RSA 2048 key, certificate and run openssl s_server:

```
root@imx8mmevk:~# openssl req -new -newkey rsa:2048 -nodes -
keyout rsa.key -out rsa.csr
root@imx8mmevk:~# openssl x509 -req -sha256 -days 365 -in
 rsa.csr -signkey rsa.key -out server.pem
root@imx8mmevk:~# openssl s_server -key rsa.key -cert
 server.pem -accept 443 -ssl_config ktls
Using default temp DH parameters
ACCEPT
```

Run openssl s_client from another terminal:

```
root@imx8mmevk:~# openssl s_client -quiet -connect <server
 ip>:443 -tls1_2 -ssl_config ktls -cipher 'ECDHE-RSA-AES256-
GCM-SHA384'
Connecting to <server ip>
Can't use SSL_get_servername
...
Using Kernel TLS for sending
Using Kernel TLS for receiving
<write some message and enter>
```

Remove -quiet to see full client logs. With TLSv1.2, the Kernel TLS supports these ciphers:

- AES128-GCM-SHA256
- AES256-GCM-SHA384
- ECDHE-RSA-AES128-GCM-SHA256
- ECDHE-RSA-AES256-GCM-SHA384

10.8 IMA/EVM on i.MX SoCs

Integrity Measurement Architecture (IMA): is the Linux integrity subsystem used to detect if files have been accidentally or maliciously altered. It appraises a file's measurement against a "good" value stored as an extended attribute (`security.ima`) and enforces local file integrity checks. The extended attribute (`security.ima`) of a file is the hash value (SHA-1, SHA-256, or SHA-512) of its content. IMA maintains a list of hash values over all executables and other sensitive system files loaded at runtime into the system.

Extended Verification Module (EVM): protects a file’s extended attributes against integrity attacks. The extended security attribute (`security.evm`) stores the HMAC value over other extended attributes associated with the file such as `security.selinux`, `security.SMACK64`, and `security.ima`.

EVM depends on the kernel key retention system and requires an encrypted key named evm-key for the HMAC operation. The key is loaded onto the root user keyring using keyctl utility. EVM is enabled by setting an enable flag in securityfs/evm file.

In normal secure boot process, contents of root file system mounted over persistent storage device are not validated by any mechanism and hence cannot be trusted. Any malicious changes in non-trusted rootfs contents are undetected. IMA EVM is the Linux standard mechanism to verify the integrity of the rootfs. Integrity checks over file attributes and its contents are performed by Linux IMA EVM module before its execution. IMA EVM depends on encrypted key loaded on user’s keyring. Loading keys to root user keyring and enabling EVM is typically done using initramfs image. The initramfs image is validated using secure boot process and becomes the part of chain of trust. Initramfs switches control to main rootfs mounted over storage device, after EVM is successfully enabled on the system.

10.8.1 EVM Key on user keyrings

The EVM security attribute depends on an encrypted key (named `evm-key`) loaded on the user keyring. The encrypted key is derived by the kernel using the master key. The master key can be of the following types:

- User-Key
- Secure-Key
- Trusted-Key

Secure and trusted keys are derived using a hardware security engine for greater security while the security of user-key depends on the user-defined mechanisms irrespective of the hardware. The secure-key is derived using the Layerscape's SEC (aka CAAM). The trusted-key can be used on the platforms supporting TPM.

The encrypted key acts as an HMAC key, which is subsequently used to calculate the HMAC value (`security.evm`) over other security attributes. This key is stored internally by the kernel and user can only see its blob.

10.8.2 Modes of operation in IMA EVM

IMA/EVM is enabled in two modes:

- Fix mode
- Enforce mode

To enable a system with IMA EVM, both modes must be implemented in a sequence as described below:

1. The system needs to be booted in fix mode with `ima_appraise=fix` and `evm=fix` bootargs. After loading the keys on the root keyring, the entire file system is labelled with security attributes. In fix mode, any file with `INTEGRITY_UNKNOWN` is labelled with proper attribute values. This mode must be executed only once while preparing system for field deployment.
2. After the fix mode execution is completed successfully, system needs to be booted IMA EVM in enforce mode. Enforce mode is enabled by setting `ima_appraise=enforce` bootargs. In enforce mode, the files are measured against their “good” values. In case there is a mismatch between calculated security attribute value and stored value, access to that file is denied. While in field the system boot is done in enforce mode only.

10.8.3 Build Steps

Follow instructions mentioned in https://bitbucket.sw.nxp.com/projects/IMX/repos/meta-imx-integrity/browse for building `initramfs`.

1. After building `integrity-image-minimal-<board-name>-<build_no>.rootfs.tar.zst`, extract `tar.zst`.
2. Convert the extracted directory into CPIO file using the following command:

```
find . | cpio -H newc -o > ../<rootfs_name>.cpio
```

3. Gzip the built rootfs above using the following command:

```
gzip ../<rootfs_name>.cpio
```

4. Convert gzipped rootfs into Ramdisk file using the following command:

```
mkimage -A arm -O linux -T ramdisk -d <gzipped_rootfs>
 <Ramdisk_name>
```

5. Flash the kernel image, dtb file, and Ramdisk file on the i.MX board.
6. For fix mode, add the following bootargs to the current bootargs:

```
rootwait rw lsm=integrity rootflags=i_version
 ima_appraise=fix ima_policy=appraise_tcb evm=fix
 initrd=<Ramdisk path>
```

7. For enforce mode, add the following bootargs to the current bootargs:

```
rootwait rw lsm=integrity rootflags=i_version
 ima_appraise_tcb ima_appraise=enforce initrd=<Ramdisk path>"
```

10.8.4 Steps to verify IMA EVM feature

Perform the following checks to ensure that IMA EVM is successfully enabled in enforce mode.

1. Trusted keys and encrypted keys are enabled in kernel image. The Following kernel logs ensures that secure key and encrypted key is successful registered.

```
[    6.893635] Key type trusted registered
[    6.905123] Key type encrypted registered
```

2. IMA EVM is enabled in the kernel image. The following kernel logs ensures IMA EVM is enabled.

```
[    6.909218] ima: No TPM chip found, activating TPM-bypass!
[    6.914738] ima: Allocated hash algorithm: sha1
[    6.962804] evm: HMAC attrs: 0x1
```

3. System is up in enforce mode. The following logs from initramfs and kernel ensures enforce mode is enabled.

```
[    8.248060] EXT4-fs (mmcblk0p2): mounted filesystem with
 ordered data mode. Opts: (null). Quota mode: none.
Loading blobs
[    8.294368] evm: key initialized
```

4. EVM attributes over a file can be checked using `getfattr` utility.

```
root@imx8ulpevk:~# getfattr -d -m . /path/to/file
```

5. Security attribute are appraised successfully upon changing any file contents. The following commands verify the appraise functionality.

```
root@imx8ulpevk:~# vim test_file    // write contents "abc"
root@imx8ulpevk:~# getfattr -d -m .  /path/to/test_file
root@imx8ulpevk:~# vim test_file     // write contents "abcd"
root@imx8ulpevk:~# getfattr -d -m .  /path/to/test_file
```

11 Connectivity

This section describes the connectivity for Bluetooth wireless technology and Wi-Fi, as well as for USB type-C.

11.1 Connectivity for Bluetooth wireless technology and Wi-Fi

Bluetooth and Wi-Fi are supported on i.MX through on-board chip solutions and external hardware. The following table lists the various on-board chips and external solutions.

Table 71. On-board chips and external solutions for Bluetooth and Wi-Fi support

SoC	On-board chip	PCIe M.2 card	uSD card or SDIO M.2 card
8QuadXPlus/8DXL	-	NXP 88W8997 (tested with Murata LBEE5 XV1YM) NXP PCIe 88W9098 (tested with Murata LBEE5ZZ1XL)	-

Table 71. On-board chips and external solutions for Bluetooth and Wi-Fi support*...continued*

SoC	On-board chip	PCIe M.2 card	uSD card or SDIO M.2 card
8QuadMax	-	NXP 88W8997 (tested with Murata LBEE5 XV1YM) NXP PCIe 88W9098 (tested with Murata LBEE5ZZ1XL)	-
8M Quad	-	NXP 88W8997 (tested with Murata LBEE5 XV1YM) NXP PCIe 88W9098 (tested with Murata LBEE5ZZ1XL).	NXP SDIO 88W8997 (tested with Murata LBEE5XV1YM) NXP SDIO IW416 (tested with Murata LBEE5CJ1XK) NXP SDIO 88W8801 (tested with Murata LBWA0ZZ2DS) NXP SDIO 88W9098 (tested with Murata LBEE5ZZ1XL)
8M Nano	NXP 88W8987 (tested with AzureWave AW-CM358SM)	-	-
8M Mini	NXP 88W8987 (tested with AzureWave AW-CM358SM)	-	-
7ULP	-	-	NXP 88W8987 (tested with Murata LBEE5 QD1ZM)
7Dual	-	-	NXP 88W8987 (tested with Murata LBEE5 QD1ZM)
6QuadPlus/Quad/Dual/ Solo	-	-	NXP 88W8987 (tested with Murata LBEE5 QD1ZM)
6SLL/6UltraLite/6ULL/ 6ULZ	-	-	NXP 88W8987 (tested with Murata LBEE5 QD1ZM) NXP SDIO IW416 (tested with Murata LBEE5CJ1XK) NXP SDIO 88W8801 (tested with Murata LBWA0ZZ2DS)

Table 71. On-board chips and external solutions for Bluetooth and Wi-Fi support*...continued*

SoC	On-board chip	PCIe M.2 card	uSD card or SDIO M.2 card
8M Plus	-	NXP 88W8997 (tested with AW-CM276 MAPUR) NXP PCIe 88W9098 (tested with Murata LBEE5ZZ1XL).	NXP SDIO 88W8997 (tested with Murata LBEE5XV1YM) NXP SDIO 88W9098 (tested with Murata LBEE5ZZ1XL)
8ULP	-	-	NXP SDIO IW416 (tested with Murata LBEE5CJ1XK)
i.MX 93	-	-	NXP SDIO IW612 (tested with Murata LBES5PL2EL)

Note: *All Murata LBEE5QD1ZM are tested on i.MX 6/i.MX 7 platforms along with the Murata M.2-to-usd adapter.*

The wireless driver supports wpa_supplicant, which is a WEP/WPA/WPA2/WPA3 encryption authenticated tool.

- Wi-Fi driver: supports NXP 88W8987-based modules with SDIO interface, NXP 88W9098-based modules with PCIe and SDIO interfaces, NXP 88W8997-based modules with PCIe and SDIO interfaces, NXP IW416-based modules with SDIO interface, NXP 88W8801-based modules with SDIO interface, and NXP IW612-based modules with SDIO interface.
- Firmware
  The NXP release package already includes all NXP, Wi-Fi/Bluetooth firmware. It requires to accept NXP license.

To run Wi-Fi, execute the following commands first and follow common commands below:

- For the following steps, execute these commands using connman

```
# For IW612 on i.MX 93:
modprobe sdxxx mod_para=nxp/wifi_mod_para.conf
# For all the other Wi-Fi modules:
modprobe moal mod_para=nxp/wifi_mod_para.conf
$connmanctl
connmanctl> enable wifi
connmanctl> scan wifi
connmanctl> services /* This should list of the network. For
 example wifi_c0e4347f5053_4a62726f_managed_psk*/
connmanctl> agent on
connmanctl> connect wifi_c0e4347f5053_4a62726f_managed_psk /*
 Enter Passphrase */
Agent RequestInput wifi_c0e4347f5053_4a62726f_managed_psk
Passphrase = [ Type=psk, Requirement=mandatory ]
Passphrase?
connmanctl> quit
```

To run NXP Bluetooth with BlueZ stack, execute the following commands (it requires load Wi-Fi first to load Bluetooth firmware):

```
hciattach <device> any 115200 flow
```

```
hciconfig hci0 up
hcitool -i hci0 cmd 0x3f 0x0009 0xc0 0xc6 0x2d 0x00
killall hciattach
hciattach <device> any -s 3000000 3000000 flow
hciconfig hci0 up
```

Run the following commands to connect the Bluetooth device for all chips:

```
$ bluetoothctl
[bluetooth]# default-agent
[bluetooth]# agent on
[bluetooth]# scan on
[bluetooth]# pair xx:xx:xx:xx:xx:xx
[BT dev]# connect xx:xx:xx:xx:xx:xx
[BT dev]# quit
```

Note:

- *Device: /dev/ttymxcN or /dev/ttyLPN.*
- *Different boards have different devices.*

The i.MX 6 boards require board rework to support the Bluetooth/Wi-Fi enablement as well as running with the Bluetooth/Wi-Fi device tree. The following is a list of the hardware modifications required and possibly conflicts caused by these modifications.

- i.MX 6QuadPlus/Quad/Dual/DualLite/Solo: See https://community.nxp.com/docs/DOC-94235. This change HAS a pin conflict with: EPDC/SPI-NOR/GPIO-LED.
- i.MX 6SoloX: Install R328, and disconnect R327. Connect with SD2 slot and BLUETOOTH CABLE CONNECTOR J19. It has no Pin conflict with other modules.
- i.MX 6SLL: Install R127, and double check to ensure R126 and R128 are installed. Connect with SD3 slot and BLUETOOTH CABLE CONNECTOR J4. It has no Pin conflict with other modules.
- i.MX 6UL/ULL/ULZ: Install R1701. It has no Pin conflict with other modules.

Rework is also required to support NXP PCIe 88W9098 on i.MX 8M Plus, and NXP SDIO 88W89997, NXP SDIO IW416, NXP SDIO 88W8801, and SDIO 88W9098 on i.MX 8M Quad.

- To run NXP PCIe 88W9098 on i.MX 8M Plus, perform the hardware rework as follows: Change R452 to 0 ohm.
- To run NXP SDIO 88W89997, NXP SDIO IW416, SDIO 88W8801, and SDIO 88W9098 on i.MX 8M Quad, perform the hardware rework as follows:
  Remove the following 0 Ω 0402 resistors: R1603, R1617, R1618, R1619, R1620, and R1621 (micro SD card J1601)
  Install the following 0 Ω 0402 resistors: R1429, R1430, R1431, R1432, R1433, R1434, R1435, and R1436 (M.2 J1401)

11.2 Connectivity for USB type-C

The following describes the connectivity for USB type-C and power delivery connection on the i.MX 8QuadXPlus MEK board.

- The Linux release includes USB type-C and PD stack, which is enabled by default. The specific power parameters are passed in by DTS. The following fsl-imx8qxp-mek is an example:

```
typec_ptn5110: typec@50 {
```

```
        compatible = "usb,tcpci";
        pinctrl-names = "default";
        pinctrl-0 = <&pinctrl_typec>;
        reg = <0x50>;
        interrupt-parent = <&gpio1>;
        interrupts = <3 IRQ_TYPE_LEVEL_LOW>;
        ss-sel-gpios = <&gpio5 9 GPIO_ACTIVE_LOW>;
        reset-gpios = <&pca9557_a 7 GPIO_ACTIVE_HIGH>;
        src-pdos = <0x380190c8>;
        snk-pdos = <0x380190c8 0x3802d0c8>;
        max-snk-mv = <9000>;
        max-snk-ma = <1000>;
        op-snk-mw = <9000>;
        port-type = "drp";
        sink-disable;
        default-role = "source";
        status = "okay";
};
```

For power capability related configuration, users need to check the PD specification to see how to composite the PDO value. To make it support power source role for more voltages, specify the source PDO. The i.MX 8QuadXPlus board can support 5 V and 12 V power supply.

- The Linux BSP of the Alpha and Beta releases on the i.MX 8QuadXPlus MEK platform only supports power source role for 5 V.
- Users can use /sys/kernel/debug/tcpm/2-0050 to check the power delivery state, which is for debugging purpose information.
- Booting only by type-C port power supply is not supported on the Alpha release.

11.3 NXP Bluetooth/Wi-Fi information

The NXP Bluetooth/Wi-Fi information is as follows:

- SoC version: SDIO 88W8987, PCIe 88W8997, SDIO 88w8997, PCIe 88w9098, SDIO 88W9098, SDIO IW416, SDIO 88W8801, SDIO IW612
- SDIO W8801 Firmware version: 14.92.36.p178
- SDIO-UART IW416 Firmware version: 16.92.21.p55.3
- PCIE-UART W9098 Firmware version: 17.92.1.p136.13
- SDIO-UART W8997 Firmware version: 16.92.21.p55.3
- PCIE-UART W8997 Firmware version: 16.92.21.p55.3
- SDIO-UART W8987 Firmware version: 16.92.21.p69.3
- SDIO-UART W9098 Firmware version: 17.92.1.p136.13
- SDIO-UART IW612 Firmware version: 18.99.1.p75.8
- Wi-Fi/Bluetooth firmware version: for example, 16.92.10.p210
  - 16: Major revision
  - 92: Feature pack
  - 10: Release version
  - p210: Patch number
- For IW612 on i.MX 93, Driver version: MXM5X18312.p7-MGPL
  For all other Wi-Fi modules, Driver version: MXM5x17366.p5-MGPL
  - 5X: Linux 5.x
  - 17366: Release version
  - p5: Patch number

– MGPL: General

Tested using iPerf3 version 3.11.

11.4 Certification

11.4.1 WFA certification

The following table lists the WFA certification.

Table 72. WFA certification

STA	Certification
STA	802.11n
STA	802.11ac
STA	WPS2.0
STA	PMF
STA	WMM-PS
STA	WPA3

For details, see Wi-Fi Alliance Derivative Certification (AN12976).

11.4.2 Bluetooth controller certification

Listing details: https://launchstudio.bluetooth.com/ListingDetails/115533

12 DDR Performance Monitor

12.1 Introduction

There are counters in some i.MX 8 DDR controllers, which are used to monitor DDR signals. Some signals can help users monitor DDR transactions and calculate DDR bandwidth.

12.2 Frequently used events

The following events are frequently used to monitor DDR transactions for different platforms.

- i.MX 8QuadMax/8QuadXPlus/8M Quad/8M Mini/8M Nano: cycles, read-cycles, write-cycles
- i.MX 8M Plus: axid-read, axid-write
- i.MX 8DXL: cycles, read-cycles, write-cycles, axid-read, axid-write

Note:

- *i.MX 8M Plus and 8DXL support AXI ID filtering.*
- *For i.MX 8M Plus, cycles, read-cycles, write-cycles cannot be used since there is a hardware bug that leads to counter overflow.*

12.3 Showing supported events

Run the following commands to show the supported events:

```
# perf list pmu | grep imx8_ddr
imx8_ddr0/activate/ [Kernel PMU event]
imx8_ddr0/axid-read/ [Kernel PMU event]
imx8_ddr0/axid-write/ [Kernel PMU event]
imx8_ddr0/cycles/ [Kernel PMU event]
imx8_ddr0/hp-read-credit-cnt/ [Kernel PMU event]
imx8_ddr0/hp-read/ [Kernel PMU event]
imx8_ddr0/hp-req-nocredit/ [Kernel PMU event]
imx8_ddr0/hp-xact-credit/ [Kernel PMU event]
imx8_ddr0/load-mode/ [Kernel PMU event]
imx8_ddr0/lp-read-credit-cnt/ [Kernel PMU event]
imx8_ddr0/lp-req-nocredit/ [Kernel PMU event]
imx8_ddr0/lp-xact-credit/ [Kernel PMU event]
imx8_ddr0/perf-mwr/ [Kernel PMU event]
imx8_ddr0/precharge/ [Kernel PMU event]
imx8_ddr0/raw-hazard/ [Kernel PMU event]
imx8_ddr0/read-accesses/ [Kernel PMU event]
imx8_ddr0/read-activate/ [Kernel PMU event]
imx8_ddr0/read-command/ [Kernel PMU event]
imx8_ddr0/read-cycles/ [Kernel PMU event]
imx8_ddr0/read-modify-write-command/ [Kernel PMU event]
imx8_ddr0/read-queue-depth/ [Kernel PMU event]
imx8_ddr0/read-write-transition/ [Kernel PMU event]
imx8_ddr0/read/ [Kernel PMU event]
imx8_ddr0/refresh/ [Kernel PMU event]
imx8_ddr0/selfresh/ [Kernel PMU event]
imx8_ddr0/wr-xact-credit/ [Kernel PMU event]
imx8_ddr0/write-accesses/ [Kernel PMU event]
imx8_ddr0/write-command/ [Kernel PMU event]
imx8_ddr0/write-credit-cnt/ [Kernel PMU event]
imx8_ddr0/write-cycles/ [Kernel PMU event]
imx8_ddr0/write-queue-depth/ [Kernel PMU event]
imx8_ddr0/write/ [Kernel PMU event]
```

12.4 Examples for monitoring transactions

This section shows some examples to monitor DDR transactions.

- For i.MX 8QuadMax/8QuadXPlus/8M Quad/8M Mini/8M Nano:

```
# perf stat -a -I 1000 -e imx8_ddr0/cycles/,imx8_ddr0/read-
cycles/,imx8_ddr0/write-cycles/
```

- For i.MX 8M Plus:
  - All masters:

```
# perf stat -a -I 1000 -e imx8_ddr0/axid-
read,axi_mask=0xffff/,imx8_ddr0/axid-write,axi_mask=0xffff/
```

  - GPU 3D:

```
# perf stat -a -I 1000 -e imx8_ddr0/axid-
read,axi_id=0x70/,imx8_ddr0/axid-write,axi_id=0x70/
```

- LCDIF1:

```
# perf stat -a -I 1000 -e imx8_ddr0/axid-
read,axi_id=0x68/,imx8_ddr0/axid-write,axi_id=0x68/
```

- For i.MX 8DXL:
  - All masters:

```
# perf stat -a -I 1000 -e imx8_ddr0/cycles/,imx8_ddr0/read-
cycles/,imx8_ddr0/write-cycles/
# perf stat -a -I 1000 -e imx8_ddr0/axid-
read,axi_mask=0xffff/,imx8_ddr0/axid-write,axi_mask=0xffff/
```

  - USB 2.0:

```
# perf stat -a -I 1000 -e imx8_ddr0/axid-
read,axi_mask=0xb0,axi_id=0x40b/,imx8_ddr0/axid-
write,axi_mask=0xb0,axi_id=0x40b/
```

  - USDHC0:

```
# perf stat -a -I 1000 -e imx8_ddr0/axid-
read,axi_id=0x1b/,imx8_ddr0/axid-write,axi_id=0x1b/
```

12.5 Performance metric

Try to use metric instead of event if event command line is too cumbersome to you. The following is the example on i.MX 8QuadXPlus.

12.5.1 Showing supported metric

Run the following commands to show the supported metric:

```
# perf list metric
List of pre-defined events (to be used in -e):
Metrics:
imx8qxp_bandwidth_usage.lpddr4
    [bandwidth usage for lpddr4 mek board. Unit: imx8_ddr ]
imx8qxp_ddr_read.all
    [bytes all masters read from ddr based on read-cycles
 event. Unit: imx8_ddr ]
imx8qxp_ddr_write.all
    [bytes all masters wirte to ddr based on write-cycles
 event. Unit: imx8_ddr ]
```

12.5.2 Monitoring transactions

Run the following commands to monitor transactions:

```
# perf stat -a -I 1000 -M
 imx8qxp_ddr_read.all,imx8qxp_ddr_write.all
# time counts unit events
1.001115250 28264 imx8_ddr0/read-cycles/ # 441.6 KB
 imx8qxp_ddr_read.all
1.001115250 11622 imx8_ddr0/write-cycles/ # 181.6 KB
 imx8qxp_ddr_write.all
2.002718000 14496 imx8_ddr0/read-cycles/ # 226.5 KB
 imx8qxp_ddr_read.all
```

```
2.002718000 4585 imx8_ddr0/write-cycles/ # 71.6 KB
 imx8qxp_ddr_write.all
```

12.6 DDR Performance usage summary

It is recommended to use metric to monitor DDR transactions, as it is more convenient. You can get DDR bandwidth of all masters or specific master directly without doing extra calculations. Especially on platforms that support AXI ID filtering, get rid of searching masters' ID.

13 One-Time Programmable Controller Driver Using NVMEM Subsystem

13.1 Introduction

The One-Time Programmable Controller driver is realized with the NVMEM Subsystem, which introduces DT representation for consumer devices to get the data they require (MAC addresses, SoC/Revision ID, part numbers, and so on) from the NVMEMs.

13.2 NVMEM provider OCOTP

Use struct nvmem_config to set the configuration of theNVMEM device OCOTP. This structure can define callback to read/write the eFUSE data.

In the read/write function prototype:

- The 1st parameter is the private data of the OCOTP device, and it contains a pointer to the remapped memory.
- The 2nd parameter is from the first data in property reg of a NVMEM consumer, and this offset represents the OCOTP shadow register, to which a eFuse address is mapped.
- The 3rd parameter returns the read data when reading or passes the data to write when writing.
- The 4th parameter, which indicates how many bytes to read/write, is from the second data in property reg of a NVMEM consumer.

```
typedef int (*nvmem_reg_read_t)(void *priv, unsigned int
 offset, void *val, size_t bytes);
typedef int (*nvmem_reg_write_t)(void *priv, unsigned int
 offset, void *val, size_t bytes);
```

13.3 NVMEM consumer

NVMEM consumers are the entities that make use of the NVMEM provider to read from and to NVMEM. In the DTS file, the NVMEM consumer node needs to be written in the NVMEM provider node. The indispensable property is reg. The first data represents the offset of the OCOTP shadow register, to which a eFuse address is mapped. The second data indicates the number of bytes to read or write.

Take the MAC address on i.MX 8M Nano as an example:

The first data in reg is 0x90, 0x400 + 0x90 * 0x4 = 0x640, 0x640 is the first Fuse address of MAC_ADDR. 0x4 represents 4 bytes.

13.4 Examples to read/write the raw NVMEM file in user space

- i.MX 6/i.MX 7/i.MX 8M Mini/8M Nano/8M Plus/8M Quad

```
# hexdump /sys/bus/nvmem/devices/imx-ocotp0/nvmem
```

- i.MX 8ULP

```
# hexdump /sys/bus/nvmem/devices/fsb_s400_fuse1/nvmem
```

14 NXP eIQ Machine Learning

The NXP eIQ machine learning software development environment enables the use of machine learning algorithms on i.MX family SoCs. The eIQ software for i.MX includes inference engines, optimized libraries for hardware acceleration, and an ML security package.

The main eIQ toolkit is integrated in the Yocto BSP, contained in meta-imx/meta-ml layer. The following inference engines are currently supported: TensorFlow Lite, ONNX Runtime, OpenCV, DeepViewRT, and PyTorch. See the *i.MX Machine Learning User's Guide* (IMXMLUG) for details about the eIQ software development environment.

In addition to the toolkit integrated in the Yocto BPS, there is an ML security package delivered separately. See also Security for Machine Learning Package (AN12867).

15 Murata Wi-Fi/Bluetooth Solutions

Table 73. Murata Wi-Fi/Bluetooth solutions with NXP chipsets

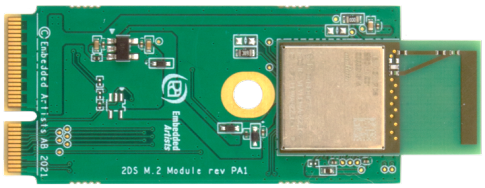
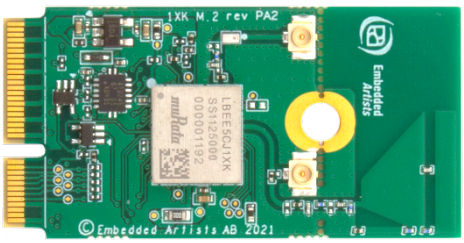
NXP chipset	Murata module (Part number)	Embedded Artists M.2 EVB
88W8801	Type 2DS (LBWA0ZZ2DS)	 EAR00386
IW416	Type 1XK (LBEE5CJ1XK)	 EAR00385

Table 73. Murata Wi-Fi/Bluetooth solutions with NXP chipsets...*continued*

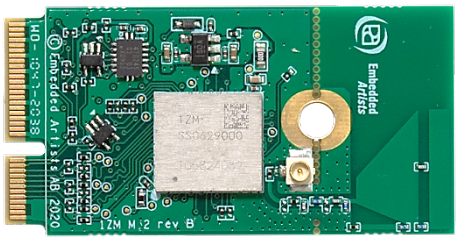
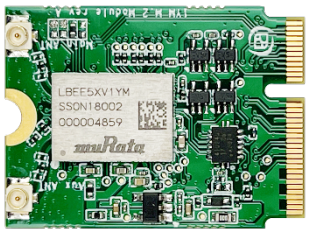
NXP chipset	Murata module (Part number)	Embedded Artists M.2 EVB
88W8987	Type 1ZM (LBEE5QD1ZM)	 EAR00364
88W8997	Type 1YM (LBEE5XV1YM)	 EAR00370
88W9098	Type 1XL (LBEE5ZZ1XL)	 EAR00387

Table 74. Murata Wi-Fi/Bluetooth solutions for NXP and Embedded Artists EVKs

EVK	Murata module	Interconnect	Embedded Artists M.2 Module Part #
NXP i.MX 8QuadMax	Type 1YM (PCIe)	M.2	EAR00370
	Type 1XL (PCIe)	M.2	EAR00387
NXP i.MX 8QuadXPlus	Type 1YM (PCIe)	M.2	EAR00370
	Type 1XL (PCIe)	M.2	EAR00387
NXP i.MX 8M	Type 1XK	uSD-M.2	EAR00385
	Type 1ZM	uSD-M.2	EAR00364
	Type 1YM (SDIO[1])	uSD-M.2	EAR00370
	Type 1XL (SDIO[1])	uSD-M.2	EAR00387
	Type 1YM (PCIe)	M.2	EAR00370
	Type 1XL (PCIe)	M.2	EAR00387
NXP i.MX 8DXL	Type 1YM (PCIe)	M.2	EAR00370
	Type 1XL (PCIe)	M.2	EAR00387

Table 74. Murata Wi-Fi/Bluetooth solutions for NXP and Embedded Artists EVKs...*continued*

EVK	Murata module	Interconnect	Embedded Artists M.2 Module Part #
NXP i.MX 8M Plus	Type 1XK	M.2	EAR00385
	Type 1ZM	M.2	EAR00364
	Type 1YM (SDIO[1])	M.2	EAR00370
	Type 1XL (SDIO[1])	M.2	EAR00387
	Type 1YM (PCIe)	M.2	EAR00370
	Type 1XL (PCIe)	M.2	EAR00387
NXP i.MX 8M Mini LPDDR4	Type 1XK	uSD-M.2	EAR00385
	Type 1ZM	uSD-M.2	EAR00364
	Type 1YM (SDIO[1])	uSD-M.2	EAR00370
	Type 1XL (SDIO[1])	uSD-M.2	EAR00387
	Type 1YM (PCIe)	M.2	EAR00370
	Type 1XL (PCIe)	M.2	EAR00387
NXP i.MX 8M Nano LPDDR4	Type 1XK	uSD-M.2	EAR00385
	Type 1ZM	uSD-M.2	EAR00364
	Type 1YM (SDIO[1])	uSD-M.2	EAR00370
	Type 1XL (SDIO[1])	uSD-M.2	EAR00387
NXP i.MX 7Dual	Type 1XK	uSD-M.2	EAR00385
	Type 1ZM	uSD-M.2	EAR00364
	Type 1YM (SDIO[1])	uSD-M.2	EAR00370
NXP i.MX 7ULP	Type 1XK	uSD-M.2	EAR00385
	Type 1ZM	uSD-M.2	EAR00364
NXP i.MX 6QuadPlus NXP i.MX 6Quad NXP i.MX 6DL	Type 1XK	uSD-M.2	EAR00385
	Type 1YM (SDIO[1])	uSD-M.2	EAR00370
NXP i.MX 6SLL NXP i.MX 6UL NXP i.MX 6ULL/ULZ	Type 1XK	uSD-M.2	EAR00385
	Type 1ZM	uSD-M.2	EAR00364
	Type 1YM (SDIO[1])	uSD-M.2	EAR00370

[1] Default strapping option on Embedded Artists 1YM/1XL M.2 module is WLAN-PCIe. Refer to Embedded Artists datasheet on how to modify strapping on M.2 module for WLAN-SDIO configuration.

16 Note About the Source Code in the Document

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17 Revision History

This table provides the revision history.

Revision history

Revision number	Date	Substantive changes
L4.9.51_imx8qxp-alpha	11/2017	Initial release
L4.9.51_imx8qm-beta1	12/2017	Added i.MX 8QuadMax
L4.9.51_imx8mq-beta	12/2017	Added i.MX 8M Quad
L4.9.51_8qm-beta2/8qxp-beta	02/2018	Added i.MX 8QuadMax Beta2 and i.MX 8Quad XPlus Beta
L4.9.51_imx8mq-ga	03/2018	Added i.MX 8M Quad GA
L4.9.88_2.0.0-ga	05/2018	i.MX 7ULP and i.MX 8M Quad GA release
L4.9.88_2.1.0_8mm-alpha	06/2018	i.MX 8M Mini Alpha release
L4.9.88_2.2.0_8qxp-beta2	07/2018	i.MX 8QuadXPlus Beta2 release
L4.9.123_2.3.0_8mm	09/2018	i.MX 8M Mini GA release
L4.14.62_1.0.0_beta	11/2018	i.MX 4.14 Kernel Upgrade, Yocto Project Sumo upgrade
L4.14.78_1.0.0_ga	01/2019	i.MX6, i.MX7, i.MX8 family GA release
L4.14.98_2.0.0_ga	04/2019	i.MX 4.14 Kernel upgrade and board updates
L4.19.35_1.0.0	07/2019	i.MX 4.19 Beta Kernel and Yocto Project Upgrades
L4.19.35_1.1.0	10/2019	i.MX 4.19 Kernel and Yocto Project Upgrades
LF5.4.3_1.0.0	03/2020	i.MX 5.4 Kernel and Yocto Project Upgrades
L5.4.3_2.0.0	04/2020	i.MX 5.4 Alpha release for i.MX 8M Plus and 8DXL EVK boards

Revision history...*continued*

Revision number	Date	Substantive changes
L5.4.24_2.1.0	06/2020	i.MX 5.4 Beta release for i.MX 8M Plus, Alpha2 for 8DXL, and consolidated GA for released i.MX boards
L5.4.47_2.2.0	09/2020	i.MX 5.4 Beta2 release for i.MX 8M Plus, Beta for 8DXL, and consolidated GA for released i.MX boards
L5.4.70_2.3.0	12/2020	i.MX 5.4 consolidated GA for release i.MX boards including i.MX 8M Plus and i.MX 8DXL
L5.4.70_2.3.0	01/2021	Updated the command lines in Section "Running the Arm Cortex-M4 image"
LF5.10.9_1.0.0	03/2021	Upgraded Yocto Project to Gatesgarth and the kernel upgraded to 5.10.9
LF5.10.35_2.0.0	06/2021	Upgraded Yocto Project to Hardknott and the kernel upgraded to 5.10.35
LF5.10.52_2.1.0	09/2021	Updated for i.MX 8ULP Alpha and the kernel upgraded to 5.10.52
LF5.10.52_2.1.0	10/2021	Added an appendix for Murata Wi-Fi/Bluetooth solutions
LF5.10.72_2.2.0	12/2021	Upgraded the kernel to 5.10.72 and updated the BSP
LF5.15.5_1.0.0	03/2022	Upgraded to the 5.15.5 kernel, Honister Yocto, and Qt6
LF5.15.32_2.0.0	06/2022	Upgraded to the 5.15.32 kernel, U-Boot 2022.04, and Kirkstone Yocto
LF5.15.52_2.1.0	09/2022	Upgraded to the 5.15.52 kernel, and added the i.MX 93.
LF5.15.71_2.2.0	12/2022	Upgraded to the 5.15.71 kernel.

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