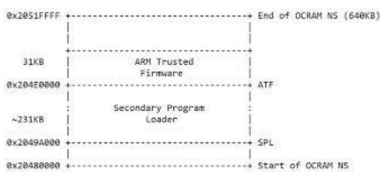
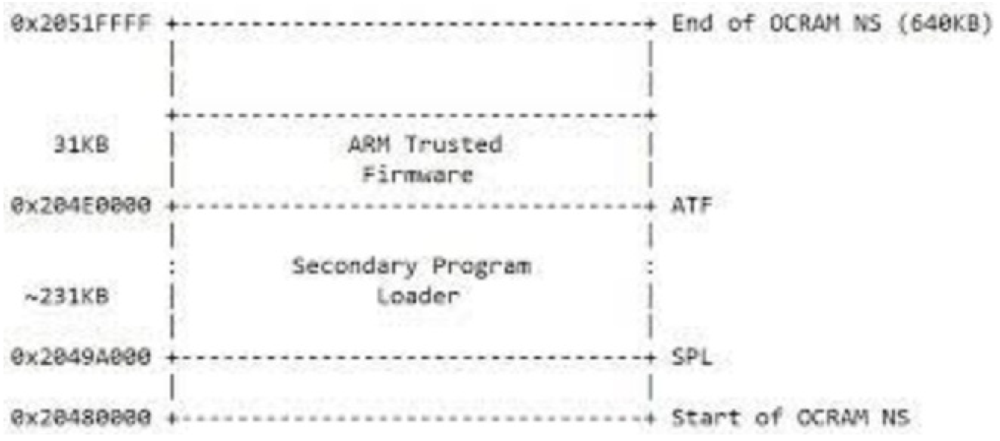


NXP AN14093 Fast Boot Falcon Mode Kernel User Guide

NXP AN14093 Fast Boot Falcon Mode Kernel User Guide



Contents

Introduction

This document guides how to reduce the boot time for the:

- i.MX 8M family (i.MX 8M Mini LPDDR4 EVK, i.MX 8M Nano LPDDR4 EVK, and i.MX 8M Plus LPDDR4 EVK)
- i.MX 9 family (i.MX 93 LPDDR4 EVK) The objectives of this document are as follows:
- Bootloader optimizations
- Linux kernel and user space optimizations
- Comparison between default and improved boot time on all platforms

Software environment

An Ubuntu 20.04 PC is assumed. Linux board support package (BSP) release 6.1.22_2.0.0 is used in the optimization process.

The following prebuild images are used:

- **i.MX 8M Mini:** *imx-image-full-imx8mmevk.wic*
- **i.MX 8M Nano:** *imx-image-full-imx8mnevk.wic*
- **i.MX 8M Plus:** *imx-image-full-imx8mpevk.wic*
- **i.MX 93:** *imx-image-full-imx93evk.wic*

Write the prebuild image on the SD card using the below command:
$ sudo dd if=.wic of=/dev/sd bs=1M status=progress conv=fsync

Note: Check your card reader partition and replace sd with your corresponding partition.

Hardware setup and equipment

- Development **kit NXP i.MX 8MM EVK LPDDR4**
- Development **kit NXP i.MX 8MN EVK LPDDR4**
- Development **kit NXP i.MX 8MP EVK LPDDR4**
- Development **kit NXP i.MX 93 EVK for 11×11 mm LPDDR4**
- microSD card: SanDisk Ultra 32 GB micro secure digital high capacity (SDHC) I Class 10 was used for the current experiment
- micro-USB (i.MX 8M) or Type-C (i.MX 93) cable for debug port

General description

This section describes an overview of the typical modifications required to achieve shorter boot times.

Reduce the bootloader time

You can opt for either of the following two ways to reduce the bootloader time.

- **Remove the boot delay —** Saves about two seconds compared to default configuration while requiring minimal changes. It leads to U-Boot skipping the wait for the keypress stage during boot.
- **Implement the Falcon mode —** Saves about four seconds compared to the default configuration. It enables the second program loader (SPL), a part of U-Boot to load the kernel directly, skipping the full U-Boot.

Reduce the Linux kernel boot time

- **Reduce console messages —** Saves about three seconds. Add quiet to the kernel command line.
- **Slim down the kernel by removing drivers and filesystems —** By default, the kernel image contains a lot of drivers and filesystems (ex: UBIFS) to enable most of the functionalities supported for the board. The list of included drivers and filesystems can be trimmed according to your use case.

Reduce the user-space boot time

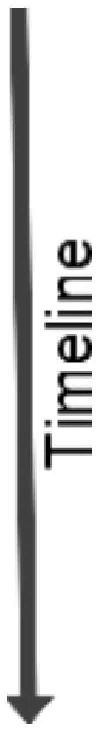
- **Change the running order in the initialization Systemd scripts —** Saves about 600 ms. Launch the desired process as soon as possible, considering its dependencies

Measurements

The scope of the measurements is between the board POR (Power-On Reset) and the start of the INIT process.

The setup used for the following measurements is described in the Boot Time Measurements Methodology document.

Table 1. Measured intervals

Time point	Interval between pulses	Location of the pulse	Boot stages	
BootROM	nRST -> before ddr_init()	board/freescale/<board>/spl.c/board_init_ f()	SPL	
DDR initialization	before ddr_init() -> after ddr_init()	board/freescale/<board>/spl.c/board_init_ f()		
SPL initialization + Load U-Boot image	after ddr_init() -> before image_entry()	common/spl/spl.c/jump_to_image_no_ args()		
U-Boot initializations (init_sequence_f)	before image_entry() -> start init_ sequence_ r	common/board_r.c/board_init_r()	U-BOOT	
U-Boot initializations (init_sequence_r)	start init_sequence_r -> u-boot main_ loop	common/main.c		
Boot sequence	u-boot main_loop -> before load_image	include/configs/<board>.h		
Kernel image load	before load_image -> after load_image	include/configs/<board>.h		
Kernel boot until INIT process	after load_image -> /sbin/init	get the timestamp during Kernel boot	Kernel	

Prerequisites

In this section, the software needed to compile the U-Boot and the Linux kernel in a standalone environment is described.

- **Install the required dependencies**

A series of dependencies, including an ARM64 cross-compiler, are required for this guide.

```
$ sudo apt install flex bison libssl-dev gcc-aarch64-linux-gnu u-boot-tools libncurses5-dev libncursesw5-dev uuid-dev gnutls-dev
```

Next, download the required sources. Place them all in the same directory.

- **Download imx-mkimage**

mkimage is a tool, which combines the SPL, U-Boot proper, ATF, and DDR firmware into a single image, resulting in the U-Boot image to be flashed on the SD card.

```
$ git clone https://github.com/nxp-imx/imx-mkimage
$ cd imx-mkimage
$ git checkout lf-6.1.22-2.0.0
```

- **Download ATF**

```
$ git clone https://github.com/nxp-imx/imx-atf
```

$ cd imx-atf
$ git checkout lf-6.1.22-2.0.0

- **Download U-Boot**

*$ git clone **https://github.com/nxp-imx/uboot-imx***
$ cd uboot-imx
$ git checkout lf-6.1.22-2.0.0

- **Download Linux kernel**

*$ git clone **https://github.com/nxp-imx/linux-imx***
$ cd linux-imx
$ git checkout lf-6.1.22-2.0.0

- **Download the double data rate (DDR) firmware**

*$ wget **https://www.nxp.com/lgfiles/NMG/MAD/YOCTO/firmware-imx-8.20.bin***
$ chmod +x firmware-imx-8.20.bin
$ ./firmware-imx-8.20.bin

- **[Only for i.MX 93] Download the EdgeLock Secure Enclave (ELE) firmware**

*$ wget **https://www.nxp.com/lgfiles/NMG/MAD/YOCTO/firmware-sentinel-0.9.bin***
$ chmod +x firmware-sentinel-0.9.bin
$ ./firmware-sentinel-0.9.bin

Build the images

Optionally, to check whether the sources and the prerequisites were downloaded correctly, execute the following steps. Otherwise, skip for now and implement **Section 7 "Bootloader optimizations" and Section 8 "Kernel space optimizations".**

Build the Arm Trusted Firmware

$ CROSS_COMPILE=aarch64-linux-gnu- make PLAT= bl31 Where can have the following values: imx8mn, imx8mm, imx8mp, or imx93.
The generated binary is located in the build//release/ directory.

Build the U-Boot

1. *Copy bl31.bin from ATF (build//release/) to imx-mkimage//*
2. *Copy all lpddr4* files from firmware/ddr/synopsys/ of the firmware-imx package to imxmkimage//.*
3. **[Only for i.MX 93]** *Copy the image of the ELE firmware container mx93a0-ahab-container.img of the firmware-sentinel to imx-mkimage/iMX9/.*
4. Compile the U-Boot.

   $ cd uboot-imx $ make distclean

   $ ARCH=arm CROSS_COMPILE=aarch64-linux-gnu- make

   $ CROSS_COMPILE=aarch64-linux-gnu- make -j

$(nproc –all)

To build U-Boot without Falcon support (default boot mode to check that everything compiles), use the following .

1. *imx8mm_evk_defconfig for **i.MX 8MM***
2. *imx8mn_evk_defconfig for **i.MX 8MN***
3. *imx8mp_evk_defconfig for **i.MX 8MP***
4. *imx93_11x11_evk_defconfig for i.MX 93 For the Falcon mode, the is (use this defconfig file only after Section 7.3 “Falcon mode implementation”).*
5. *imx8mm_evk_falcon_defconfig for **i.MX 8MM***
6. *imx8mn_evk_falcon_defconfig for **i.MX 8MN***
7. *imx8mp_evk_falcon_defconfig for **i.MX 8MP***
8. *imx93_11x11_evk_falcon_defconfig **for i.MX 93***

5. *Copy u-boot*.bin and spl/u-boot-spl*.bin into imx-mkimage//.*
6. *Copy imx8mm-evk.dtb (for i.MX 8M Mini LPDDR4 EVK) or imx8mn-evk.dtb (for i.MX 8M Nano LPDDR4 EVK) or imx8mp-evk.dtb (for i.MX 8M Plus LPDDR4 EVK) or imx93-11×11-evk.dtb for (i.MX 93 11×11 LPDDR4 EVK) from uboot-imx/arch/arm/dts/ to imx-mkimage//.*
7. *Copy mkimage from uboot-imx/tools/ into imx-mkimage//, renaming into mkimage_uboot.*
   ```
   $ cp uboot-imx/tools/mkimage imx-mkimage//mkimage_uboot
   ```
8. **Generate the complete U-Boot image:** flash.bin.
   ```
   $ cd imx-mkimage # for i.MX 8M*
   $ make SOC= flash_evk # for i.MX 93
   $ make SOC=iMX9 flash_singleboot
   ```
   Where can take the following values: iMX8MM, iMX8MN, iMX8MP.

Build the Linux kernel

```
$ cd linux-imx
$ ARCH=arm64 CROSS_COMPILE=aarch64-linux-gnu- make imx_v8_defconfig
$ ARCH=arm64 CROSS_COMPILE=aarch64-linux-gnu- make -j $(nproc –all) all
```

The resulted binary Image is located in arch/arm64/boot directory.

Write the binaries on the SD card

To check that the build is correct, write the resulted binaries on the SD card and boot the board.

- **Write the U-Boot image:**
  ```
  $ sudo dd if=flash.bin of=/dev/sd bs=1k seek= conv=fsync
  ```
  Where is:
- 32 – for i.MX 8M Nano, i.MX 8M Plus and i.MX 93
- 33 – for i.MX 8M Mini
- **Write the Linux Kernel:**
  ```
  $ sudo mount /dev/sd1 /mnt
  $ cp Image /mnt
  $ umount /mnt
  ```

Bootloader optimizations

This chapter includes the following information.

- Section 7.1 “Default boot mode”
- Section 7.2 “Falcon mode”
- Section 7.3 “Falcon mode implementation”
- Section 7.4 “Memory map”
- Section 7.5 “Function calls during the Falcon mode”

Default boot mode

Figure 1 describes the default boot sequence. After power on or reset, i.MX 8M executes the Boot ROM (the primary program loader), stored in its read-only memory (ROM).

Boot ROM configures the system-on-chip (SoC) by performing basic peripheral initializations such as Phase Locked Loops (PLLs), clock configurations, memory initialization (SRAM). Then it finds a boot device from where it loads a bootloader image, which can include the following components: U-Boot SPL, ATF, U-Boot, and so on.

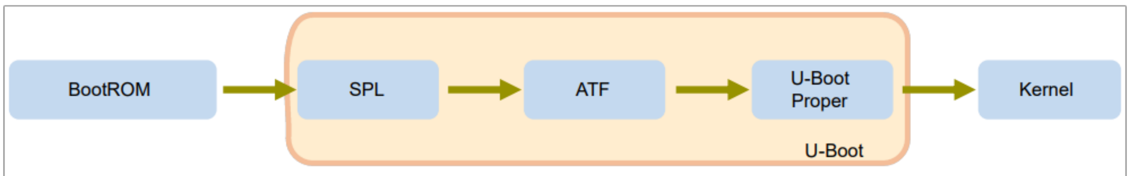


Figure 1. Default boot sequence

A typical U-Boot image does not fit inside the internal SRAM and therefore is split into two parts: **secondary program loader (SPL) and U-Boot proper.**

SPL is the first stage of the bootloader, a smaller preloaded that shares sources as U-Boot, but with a minimal set of code that fits into SRAM. SPL is loaded into SRAM. It configures and initializes some peripherals and, most importantly, dynamic random-access memory (DRAM). Later, it loads the ATF and U-Boot proper into the DRAM. The final step is to jump to ATF, which will, in turn, jump to U-Boot proper.

Arm Trusted Firmware (ATF), included recently in the i.MX8* family, provides a reference trusted code base for the Armv8 architecture. It implements various Arm interface standards, including the Power State Coordination Interface (PSCI). The binary is typically included in the bootloader binary. It is started in the early stages of U-Boot. Without ATF, the kernel cannot set up the services, which must be executed in the Secure World environment.

U-Boot proper is the second stage bootloader. It offers a flexible way to load and start the Linux kernel. Also, it provides a minimal set of tools to interact with the hardware on the board via a command-line interface. It runs from DRAM and initializes the additional hardware devices. For example, network, USB, and DSI/CSI. Then, it loads and prepares the device tree (FDT). The main task handled by the U-Boot is the loading and starting of the kernel image itself.

Linux kernel runs from DRAM and takes over the system completely. The U-Boot has no longer control over the system from this point onward.

Falcon mode

Falcon mode is a feature in U-Boot that enables fast booting by allowing SPL to start the Linux kernel.
It completely skips the U-Boot loading and initialization, with the effect of reducing the time spent in the bootloader.

Figure 2 illustrates the Falcon mode booting sequence.

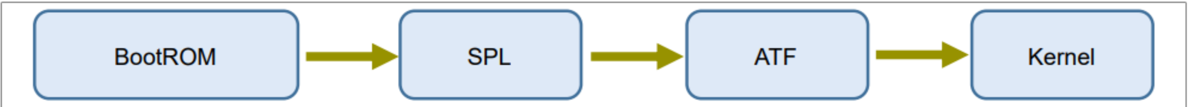


Figure 2. Falcon Mode boot sequence

To implement this mode, perform the following actions:

- Activate some specific configurations for Falcon.
- Prepare the Flattened Device Tree (FDT) in advance.
- Configure ATF to jump to kernel.
- Generate the kernel flattened image tree (FIT) image containing the ATF and the kernel image.

Falcon mode implementation

For ease of implementation, a series of patches has been prepared for enabling the Falcon mode. Download the associated software AN14093SW.zip to get the patches, and perform the following steps.

Apply the U-Boot patch:
$ cd uboot-imx
$ git am 0001-Enable-Fast-Boot-on-i.MX-8M-Family-and-i.MX-93.patch

This patch creates the Falcon configuration files for each platform (i.MX 8M and i.MX 93), which can be found in the uboot-imx/configs/ directory, under the name: _falcon_ defconfig. The configuration files are based on the default ones _defconfig, to which Falcon support is added as follows.

Enabled parameters [=y]

- CONFIG_SPL_SERIAL
- CONFIG_CMD_SPL — Enables spl export command in U-Boot; required for step 15.
- CONFIG_SPL_MMC — Enables SPL to read from MMC using the SPL MMC API.
- CONFIG_MMC_BROKEN_CD **[only for i.MX 93]**
- CONFIG_SPL_FS_FAT — Enables SPL to read from FAT partition.
- CONFIG_SPL_LOAD_FIT
- CONFIG_FIT
- CONFIG_SPL_OS_BOOT — **Activates the Falcon mode.**
- CONFIG_ SPL_MMC_IO_VOLTAGE and CONFIG_SPL_MMC_UHS_SUPPORT — Enable MMC high speed transfer for SPL, used to reduce the loading time for the Kernel image (*not functional for i.MX 8MM since SPL DM is not supported due to OCRAM size limitation).
- CONFIG_LTO [only for i.MX 8MN] — Reduces the binary size by adding link-time optimizations. Required on i.MX 8M Nano to ensure the SPL image with FAT support fits.

  Disabled parameter [=n]

  CONFIG_SPL_BOOTROM_SUPPORT

  Set parameters

  CONFIG_SYS_SPL_ARGS_ADDR

  With:
- 0x43000000 for i.MX 8MN, i.MX 8MM and i.MX 8MP
- 0x83000000 for i.MX 93

CONFIG_SPL_FS_LOAD_PAYLOAD_NAME with u-boot.itb

CONFIG_SPL_FS_LOAD_KERNEL_NAME with Image.itb

CONFIG_SPL_FS_LOAD_ARGS_NAME with:

- imx8mm-evk-falcon.dtb **for i.MX 8MM**
- imx8mn-evk-falcon.dtb **for i.MX 8MN**
- imx8mp-evk-falcon.dtb **for i.MX 8MP**
- imx93-11×11-evk-falcon.dtb **for i.MX 93**

CONFIG_CMD_SPL_WRITE_SIZE **with** 0xC000

CONFIG_FIT_EXTERNAL_OFFSET=0x3000 **[only for i.MX 93]**

In addition, the patch implements the spl_start_uboot() function, located in uboot-imx/board/ freescale//spl.c, where is: imx8mm_evk, imx8mn_evk, imx8mp_evk or imx93_evk. This function checks if SPL should start the kernel or U-Boot. If the ‘c’ key is pressed during boot, the function returns 1, meaning that U-Boot must be started. Otherwise, SPL should start the kernel. To bring it up in the operational state in which Ethernet MAC can interact with PHY, the PHY must be reset from SPL for i.MX 8M Family. This is also added when applying the U-Boot patch. The PHY is reset in the board_init_r() function, located in the uboot-imx/common/spl/spl.c file.

Apply the ATF patch:
$ cd imx-atf
$ git am 0001-Add-support-to-jump-to-Kernel-directly-from-ATF.patch
The patch adds support for jumping directly to the kernel. Since ATF does not support to jump directly to kernel on NXP platforms, the FDT address must be passed as an argument, in bl31_early_platform_setup2() function, located in imx-atf/plat/imx/imx8m// _bl31_setup.c for i.MX8M Family and imx-atf/plat/imx/imx93/imx93_bl31_setup.c for i.MX93.

Apply the mkimage patch:

$ cd imx-mkimage
$ git am 0001-Add-scripts-for-Fast-Boot-implementation-for-i.MX8M-.patch

This patch adds the “os” property to uboot-1 node of the U-Boot FIT image source (u-boot.its) .This property is required when loading U-Boot (the case when spl_start_uboot() returns 1) while Falcon Mode is enabled. Otherwise, the U-Boot fails to boot.
In addition, the patch adds the script, which generates the U-Boot FIT image for i.MX 93 (since in this version does not exist): imx-mkimage/iMX9/mkimage_fit_atf.sh.
The second script added by this patch is the one used to generate the kernel FIT image (ATF + kernel) – needed for the Falcon mode implementation. This script is used for both i.MX 8M Family and i.MX 93.

1. Build the ATF as stated in **Section 5.1.** Copy the modified ATF binary into imx-mkimage//.
2. Build the bootloader image as stated in Section 5.2 – Falcon Mode. Write the resulted U-Boot binary according to Section 6.
3. [Only for i.MX93] Generate the U-Boot FIT image. When building the flash.bin image, the u-boot.itb FIT image is not built automatically for i.MX93, since there is no script that generates it.

   $ cd imx-mkimage/iMX9

   $ DEK_BLOB_LOAD_ADDR=0x80400000 TEE_LOAD_ADDR=0x96000000 ATF_LOAD_ADDR=0x204e0000 ./mkimage_fit_atf.sh imx93-11×11-evk.dtb > u-boot.its

   $ ./mkimage_uboot -E -p 0x3000 -f u-boot.its u-boot.itb
4. Copy the u-boot.itb binary located in imx-mkimage/ on the first (FAT) partition of the SD card.

5. Before building the Linux kernel, you may want to optimize it according to Section 8.2 “Remove the unnecessary drivers and file systems”. Build the Linux kernel according to Section 5.3 “Build the Linux kernel”.
6. Generate the kernel FIT Image. The FIT image contains the ATF and the kernel Image. This is loaded during Falcon mode by SPL. Since SPL does not load the ATF image in the Falcon mode, the ATF must be included into the FIT image.
   To prepare the FIT image (Image.itb), the mkimage_fit_atf_kernel.sh script is used. Copy the kernel Image to the imx-mkimage// directory:
   $ cp linux-imx/arch/arm64/boot/Image imx-mkimage/
   Generate the FIT image:
   - For i.MX8M
     $ cd imx-mkimage/iMX8M
     # for i.MX8MM
     $ ATF_LOAD_ADDR=0x00920000 KERNEL_LOAD_ADDR=0x40200000 ../mkimage_fit_atf_kernel.sh > Image.its
     # for i.MX8MN
     $ ATF_LOAD_ADDR=0x00960000 KERNEL_LOAD_ADDR=0x40200000 ../mkimage_fit_atf_kernel.sh > Image.its
     # for i.MX8MP
     $ ATF_LOAD_ADDR=0x00970000 KERNEL_LOAD_ADDR=0x40200000 ../mkimage_fit_atf_kernel.sh > Image.its
     # To generate the FIT binary run:
     $ ./mkimage_uboot -E -p 0x3000 -f Image.its Image.itb
   - For i.MX93
     $ cd imx-mkimage/iMX9
     $ ATF_LOAD_ADDR=0x204e0000 KERNEL_LOAD_ADDR=0x80200000 ../ mkimage_fit_atf_kernel.sh > Image.its
     # To generate the FIT binary run:
     $ ./mkimage_uboot -E -p 0x3000 -f Image.its Image.itb
7. Copy the resulted Image.itb file to the first (FAT) partition of the SD card.
8. Prepare the Flattened Device Tree and write it on the SD card. When booting in Falcon Mode, a key step is to prepare the device tree. Usually, U-Boot does FDT fixups when booting Linux. It means that to the initial device tree, U-Boot adds the kernel arguments and the memory node, among other modifications. These arguments can be found in one of the configuration files: uboot-imx/configs/_evk.h, under the name bootargs. They specify console parameters and tell the kernel where to find the root file system. Where is: imx8mm, imx8mn, imx8mp or imx93. There are two methods of generating the Flattened Device Tree:
   - **Method 1:** By manually adding the required fixups to the device tree
   - **Method 2:** By letting U-Boot to do the fixups and save the resulted device tree Method 2 is more general and requires less knowledge, but it is also lengthier and with several other steps.
     Method 1: You can try generating the FDT manually, by adding the bootargs and the memory node to the kernel device tree. For example, for i.MX 93 create the imx93-11×11-evk-falcon.dts file in linuximx/arch/arm64/boot/dts/freescale and add the code lines from below. The memory node is copied from the U-Boot’s DTS. The included device tree can be changed according to your use case. In this case, we are using the default kernel device tree.

```
#include "imx93-11×11-evk.dts" / { memory { reg = <0x00 0x80000000 0x00 0x80000000>; device_type = "memory"; }; chosen { bootargs = "console=ttyLP0,115200 earlycon root=/dev/mmcblk1p2 rootwait rw"; }; };
```

Recompile the kernel to generate the associated device tree binary and copy the resulted imx93-11×11-evk-falcon. dtb file to the first partition of the SD card.

If you chose the first method, the next step is to boot the board and the Falcon mode should be functional.

Method 2: FDT can be prepared by using a spl export command in the U-Boot stage. To enter in U-boat, keep the C key pressed. The command is equivalent to running boom until the device tree fixup is done. The device tree in memory is the one needed for the Falcon mode. This image has to be saved to the SD card boot partition.

[Prerequisites]

a. Build the kernel legacy u Image file from Image.

Image is a special image file that adds a 64-byte header before the actual kernel Image, where loader information is specified (load address, entry point, OS type, and so on).

This type of image is needed by the spl command, to generate the Flattened Device Tree.

- **For i.MX 8M**

```
$ cd linux-imx/arch/arm64/boot
$ mkimage -A arm -O linux -T kernel -C none -a 0x43FFFFC0
-e 0x44000000 -n "Linux kernel" -d Image uImage
Image Name: Linux kernel
Created: Wed Jul 26 14:12:09 2023
Image Type: ARM Linux Kernel Image (uncompressed)
Data Size: 31072768 Bytes = 30344.50 KiB = 29.63 MiB
Load Address: 43ffffc0
Entry Point: 44000000
```

- **For i.MX 93**

```
$ cd linux-imx/arch/arm64/boot
$ mkimage -A arm -O linux -T kernel -C none -a 0x83FFFFC0
-e 0x84000000 -n "Linux kernel" -d Image uImage
Image Name: Linux kernel
Created: Wed Jul 26 14:14:09 2023
Image Type: ARM Linux Kernel Image (uncompressed)
Data Size: 31072768 Bytes = 30344.50 KiB = 29.63 MiB
Load Address: 83ffffc0
Entry Point: 84000000
```

Where:

- *A [Architecture]: To set architecture.*
- *O [os]: To set the operating system.*
- *T [image type]: To set the image type.*
- *C [compression type]: To set the compression type.*
- *n [image name]: To set image name to image name.*
- *d [image data file]: To use image data from an image data file.*
- *a [load address]: To set the load address with a hex number.*
- *e [entry point]: To set the entry point with a hex number.*

- **b**. Copy the kernel uImage to the EXT2 partition of the SD card.

  ```
  sudo mount /dev/sd2 /mnt
  $ sudo mkdir -p /mnt/home/root/.falcon
  $ sudo cp uImage /mnt/home/root/.falcon
  $ sudo umount /mnt
  ```

  To prepare the FDT using spl export command, perform the following steps.

  1. Boot the board into U-Boot and stop it right before entering in the autoboot sequence. To enter in U-Boot, the ‘c’ key must be pressed during boot. At this point, Falcon Mode fails since there is no prepared FDT for Linux kernel on the SD card.
  2. [Optional] If you need a different FDT from the default one, run the following command first. The file must be on the FAT partition on the SD.

     ```
     u-boot=> setenv fdtfile .dtb
     ```

  3. Load the FDT into RAM.

     ```
     u-boot=> run loadfdt
     43801 bytes read in 15 ms (2.8 MiB/s)
     ```

  4. Load the kernel uImage into RAM.

     ```
     u-boot=> ext2load mmc 1:2 ${loadaddr} /home/root/.falcon/uImage
     31072832 bytes read in 387 ms (76.6 MiB/s)
     ```

  5. If you require the kernel boot-time optimizations as well, run the commands from Section 8.1 “Add quiet”, step 2, before the next step.
  6. Load the kernel boot arguments.

     ```
     u-boot=> spl export fdt ${loadaddr} – ${fdt_addr_r}
     ## Booting kernel from Legacy Image at 80400000 …
     Image Name: Linux kernel
     Created: 2023-07-19 6:57:40 UTC
     Image Type: ARM Linux Kernel Image (uncompressed)
     Data Size: 31072768 Bytes = 29.6 MiB
     Load Address: 83ffffc0
     Entry Point: 84000000
     Verifying Checksum … OK
     ## Flattened Device Tree blob at 83000000
     Booting using the fdt blob at 0x83000000
     Working FDT set to 83000000
     Loading Kernel Image
     Using Device Tree in place at 0000000083000000, end 000000008300db18
     Working FDT set to 83000000
     subcommand failed (err=-1)
     subcommand failed (err=-1)
     Using Device Tree in place at 0000000083000000, end 0000000083010b18
     Working FDT set to 83000000
     Argument image is now in RAM: 0x0000000083000000
     ```

     Note: The difference between the start and the end addresses in bold above is the size of the patched FDT in memory. Copy the resulted FDT from RAM to the FAT partition of the SD card specifying the right copy size as the last parameter. In the example output above, that would be 0x83010b18 – 0x83000000 = 0x10b18.

# for i.MX 93

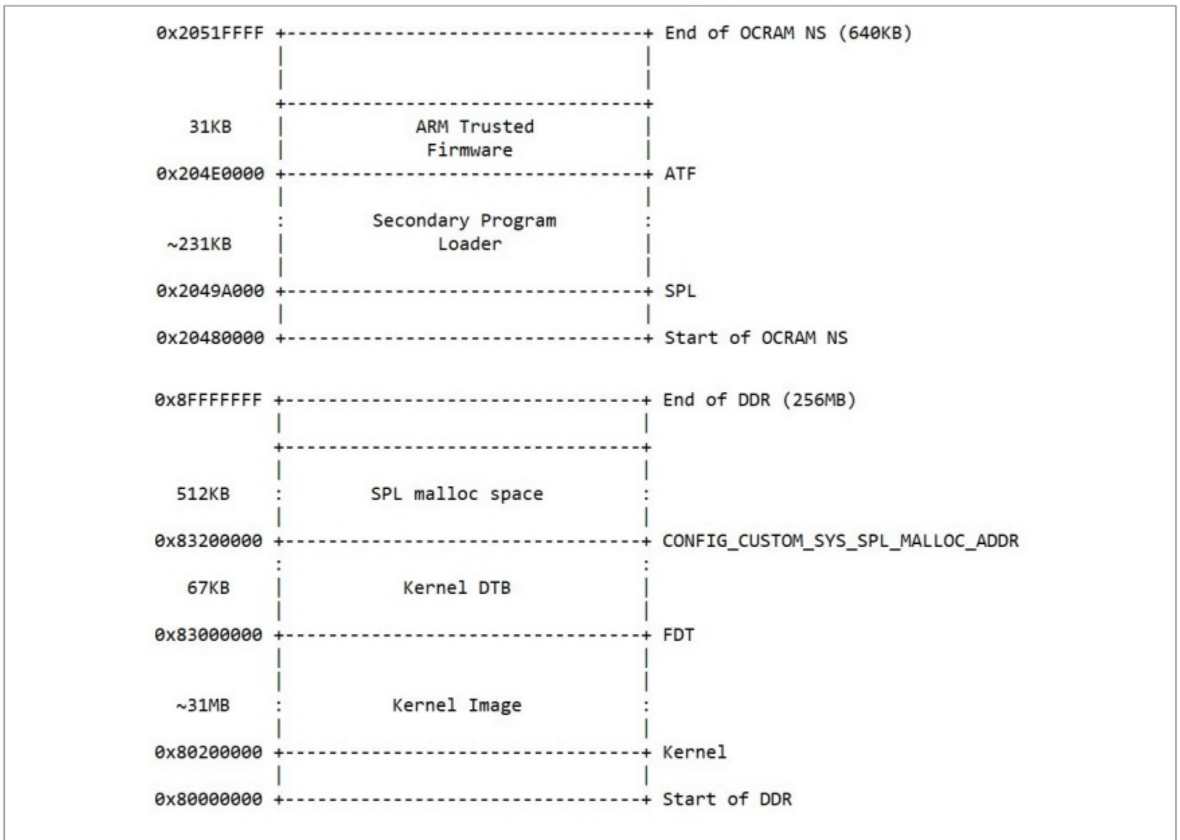
u-boot=> fatwrite mmc ${mmcdev}:${mmcpart} ${fdt_addr_r} imx93-11×11-evk-falcon.dtb 0x10b18

Note: The name of the saved FDT must match the name set in the CONFIG_SPL_FS_LOAD_ARGS_NAME variable in Step 1 from Section 7.3 “Falcon mode implementation”. Otherwise, the SPL does not load the device tree in the DRAM and the board fails to boot.

9. After reboot, by default, the board will boot in Falcon Mode.

Memory map

Figure 3 is the memory map during Falcon Mode for i.MX93.
BootROM loads SPL and the SPL runs from the on-chip RAM (OCRAM – the internal processor memory). SPL initializes the dynamic RAM (DDR), loads the ATF into OCRAM, then loads the kernel device tree and the kernel image into DDR. SPL has a reserved memory space in DDR, for malloc. This area must not be overwritten while in SPL



```
0x2051FFFF +--------------------------------+ End of OCRAM NS (640KB)
           |                                |
           |                                |
           +--------------------------------+
   31KB    |          ARM Trusted           |
           |           Firmware             |
0x204E0000 +--------------------------------+ ATF
           |                                |
           :       Secondary Program        :
  ~231KB   |            Loader              |
           |                                |
0x2049A000 +--------------------------------+ SPL
           |                                |
0x20480000 +--------------------------------+ Start of OCRAM NS

0x8FFFFFFF +--------------------------------+ End of DDR (256MB)
           |                                |
           +--------------------------------+
           |                                |
  512KB    :        SPL malloc space        :
           |                                |
0x83200000 +--------------------------------+ CONFIG_CUSTOM_SYS_SPL_MALLOC_ADDR
           :                                :
   67KB    |          Kernel DTB            |
           |                                |
0x83000000 +--------------------------------+ FDT
           |                                |
           |                                |
  ~31MB    :         Kernel Image           :
           |                                |
0x80200000 +--------------------------------+ Kernel
           |                                |
0x80000000 +--------------------------------+ Start of DDR
```

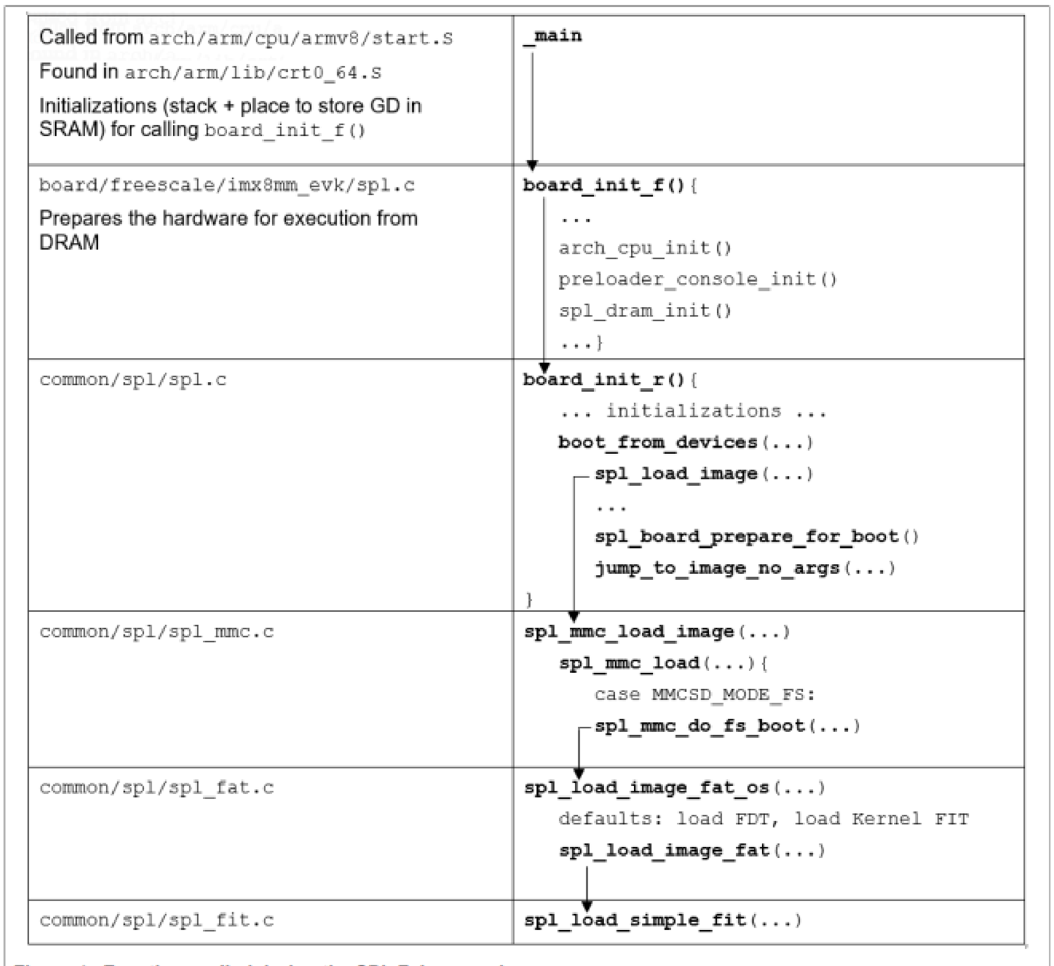
Figure 3. Memory map during Falcon Mode for i.MX93

Table 2 lists the addresses for the i.MX 8M family.

Table 2. i.MX 8M family addresses}

Platform	SPL	ATF	Kernel Image	Kernel DTB
i.MX 8M Mini	0x007e1000	0x00920000	0x40200000	0x43000000
i.MX 8M Nano	0x00912000	0x00960000	0x40200000	0x43000000
i.MX 8M Plus	0x00920000	0x00970000	0x40200000	0x43000000

Function calls during the Falcon mode
Figure 4 lists the important functions called during the SPL Falcon mode



Called from `arch/arm/cpu/armv8/start.S` Found in `arch/arm/lib/crt0_64.S` Initializations (stack + place to store GD in SRAM) for calling `board_init_f()`	**`_main`**

`board/freescale/imx8mm_evk/spl.c`
Prepares the hardware for execution from DRAM
	`board_init_f()``{`
	`...`
	`arch_cpu_init()`
	`preloader_console_init()`
	`spl_dram_init()`
	`...}`

`common/spl/spl.c`	**`board_init_r()`**`{`
	`... initializations ...`
	`boot_from_devices``(...)`
	`spl_load_image``(...)`
	`...`
	`spl_board_prepare_for_boot``()`
	`jump_to_image_no_args``(...)`
	`}`

`common/spl/spl_mmc.c`	**`spl_mmc_load_image`**`(...)`
	`spl_mmc_load``(...){`
	`case MMCSD_MODE_FS:`
	`spl_mmc_do_fs_boot``(...)`

`common/spl/spl_fat.c`	**`spl_load_image_fat_os`**`(...)`
	`defaults: load FDT, load Kernel FIT`
	`spl_load_image_fat``(...)`

`common/spl/spl_fit.c`	**`spl_load_simple_fit`**`(...)`

Figure 4. Functions called during the SPL Falcon mode

Kernel space optimizations

This section lists the steps to Section 8.1 “Add quiet” and Section 8.2 “Remove the unnecessary drivers and file systems”.

Add quiet
To reduce the kernel time by about a half, add the quiet argument in the kernel botargos. It suppresses the debug messages during the Linux startup sequence.

Note: The device tree must be regenerated with the new bootargs, using the spl export command.

1. To enter in U-Boot, keep the C key pressed while booting.
2. Edit the mmcargs parameter by adding quiet.

   u-boot=> edit mmcargs

   edit: setenv bootargs ${jh_clk} console=${console} root=${mmcroot} quiet

   u-boot=> saveenv

   Saving Environment to MMC… Writing to MMC(1)… OK
3. Regenerate and save the device tree to the SD card as in **Section 7.3 “Falcon mode implementation”,** step 14.

Remove the unnecessary drivers and file systems
Depending on your use case, you can slim down the kernel by removing unnecessary drivers and file systems.

You can analyze kernel functions during boot with biograph, a kernel feature that allows you to graph what happens in the kernel during initialization.

To create bootgraph, perform the following steps:

1. Add initcall_debug to the kernel botargos.

   a. To enter in U-Boot, keep the C key pressed while booting,

   b. Edit the mmcargs parameter by adding initcall_debug

   ```
   u-boot=> edit mmcargs
   edit: setenv bootargs ${jh_clk} console=${console} root=${mmcroot} quiet
   initcall_debug
   u-boot=> saveenv
   Saving Environment to MMC… Writing to MMC(1)… OK
   ```
2. Regenerate and save the device tree to the SD card as in Section 7.3 “Falcon mode implementation”, step 14.
3. Boot the board and get the kernel log

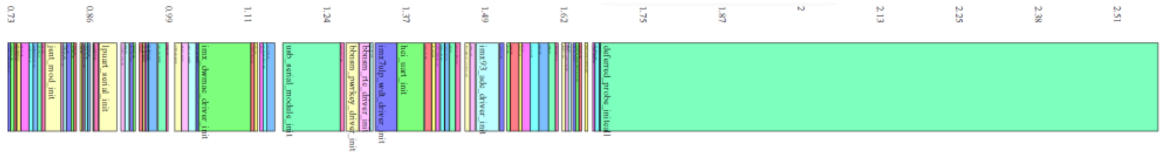
   ```
   root@imx8mn-lpddr4-evk:~# dmesg > boot.log
   ```

   The boot.log file contains data like the following log. The data can be analyzed on how much time each function spend during kernel boot.

   ```
   [2.583922] initcall deferred_probe_initcall+0x0/0xb8 returned 0 after 895357
   [2.583955] calling genpd_power_off_unused+0x0/0x98 @ 1
   [2.583977] initcall genpd_power_off_unused+0x0/0x98 returned 0 after 12 usec
   [2.583984] calling genpd_debug_init+0x0/0x90 @ 1
   [2.584312] initcall genpd_debug_init+0x0/0x90 returned 0 after 321 usecs
   [2.584333] calling ubi_init+0x0/0x23c @ 1
   [2.584627] initcall ubi_init+0x0/0x23c returned 0 after 286 usecs
   ```
4. Copy the resulted boot.log file on the host PC. Go back on the host PC and create the graph using the following commands.

   ```
   $ cd linux-imx/scripts
   $ ./bootgraph.pl boot.log > boot.svg
   ```

   You can obtain something like this and can analyze how the kernel boot time is used.

5. To disable a driver or a feature, update the kernel configuration.

   For example, we disabled the debug from the kernel (that reduce the size of the image) and the UBI file system.

   a. Run the following commands to enter the kernel minicontig.

   ```
   $ cd linux-imx
   $ ARCH=arm64 CROSS_COMPILE=aarch64-linux-gnu- make imx_v8_defconfig
   $ ARCH=arm64 CROSS_COMPILE=aarch64-linux-gnu- make minicontig
   ```

   From the menuconfig, disable CONFIG_UBIFS_FS and CONFIG_DEBUG_KERNEL, similar to Section 7.3 “Falcon mode implementation”. The resulting .config file contains the following lines.

   ```
   # CONFIG_UBIFS_FS is not set
   # CONFIG_DEBUG_KERNEL is not set
   ```

   b. Build the new kernel image.

$ ARCH=arm64 CROSS_COMPILE=aarch64-linux-gnu- make all

c. Regenerate the kernel FIT image as in Section 7.3 “Falcon mode implementation”, step 13 and copy it to an SD card boot (FAT) partition.

d. [Optional] If you want to use the modified kernel during normal boot, copy the new Image binary to the first SD card boot partition.

User space optimizations

This section lists the steps to Section “Start an application before systemd” and Section “Change the dependencies of a systemd unit”.

Start an application before systemd

If required, a program can be started before systemd.

1. Create a script /home/root/newinit.sh, which starts your program before systemd. Below is a simple example of how to start your program before systemd. Replace the echo line with your desired application.
   ```
   #!/bin/sh
   echo “Early start” > /dev/kmsg
   exec /lib/systemd/systemd
   ```
2. Make the script executable.
   ```
   $ chmod +x newinit.sh
   ```
3. Link /sbin/init to your newinit.sh script.
   ```
   $ ln -sf /home/root/newinit.sh /sbin/init
   ```
   Note: To return to the initial configuration, use the following command.
   ```
   $ ln -sf /lib/systemd/systemd /sbin/init
   ```
4. Reboot the board and check the kernel log. Searching the “Early start” string in dmesg, shows that the newinit.sh script is executed before the init process.

Change the dependencies of a systemd unit

The easiest way to reduce the time spent in user space is to reorder the sequence in which applications are run. To start the service earlier, change the dependencies with which System operates.
On the board, open a /lib/systemd/system/.service file and change the unit dependencies. For example, starting before local-fs-pre.target.

```
[Unit]
…
Before=local-fs-pre.target
Default Dependencies=no
```

If the command system-analyze is called with the blame argument Systemd also provides a utility called systemd-analyze, which prints the services and their starting time.

```
$ systemd-analyze blame
```

To disable a service, you can use the systemctl disable command. To disable some services (especially the ones systemd provides), use the systemctl mask command. However, take care when disabling services since the system can depend on them to operate properly.

Results

Table 3. Initial boot time measurements

	SPL			U-Boot				Kernel	
Board	BootROM	DDRinitialization	SPLinitializations+ Load U-Boot image	U-Boot initializations (init_ sequence_ f)	U-Boot initializations (init_ sequence_ r)	Boot sequence	Kernel image load	ATF + Kernel boot until INIT process	Total time
	(ms)	(ms)	(ms)	(ms)	(ms)	(ms)	(ms)	(ms)	(ms)
i.MX 8MN	161	241	162	363	790	2894	333	3506	8450
i.MX 8MP	162	301	175	373	1726	4181	345	3627	10890
i.MX 8MM	142	265	117	412	812	2970	396	5002	10116
i.MX 93	369	111	117	628	1172	3271	412	3090	9170

Table 4. Optimized boot time measurements

	SPL				Kernel	
Board	BootROM	DDR initialization	SPL initializations	Kernel Image Load[1]	ATF + Kernel Boot until INIT process[2]	Total time
	(ms)	(ms)	(ms)	(ms)	(ms)	(ms)
i.MX 8MN	203	240	86	376	1185	2090
i.MX 8MP	187	301	97	382	1237	2204
i.MX 8MM[3]	139	265	63	1336	2956[3]	4759
i.MX 93	374	111	89	366	1391	2330

1. CONFIG_DEBUG_KERNEL disabled, resulting in a smaller kernel image size => decreases kernel image loading.
2. Kernel log messages are suppressed using quiet.
3. i.MX 8M Mini EVK does not come with an integrated Wi-Fi Module connected to the PCIe port (unlike i.MX 8M Plus). Therefore, the PCIe PHY initialization consumes time waiting for an active link. If a Wi-Fi module is attached to the PCIe interface, the kernel boot time decreases to 1215 ms, so the total boot time is 3018 ms.

Note about the source code in the document

The example code shown in this document has the following copyright and BSD-3-Clause license:

Revision history

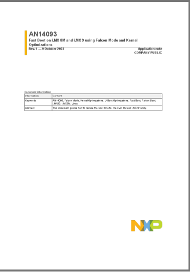
Table 5. Revision history

Revision numb er	Revision Date	Description
1	09 October 2023	Initial release

Legal information

Trademarks

Documents / Resources

 AN14093 Fast Boot on i.MX 8M and i.MX 9 using Falcon Mode and Kernel Optimizations Rev. 1 — 9 October 2023 Application note COMPANY PUBLIC Document information Information / Content Keywords: AN14093, Falcon Mode, Kernel Optimizations, U-Boot Optimizations, Fast Boot, Falcon Boot, i.MX93, i.MX8M, Linux Abstract: This document guides how to reduce the boot time for the i.MX 8M and i.MX 9 family.	NXP AN14093 Fast Boot Falcon Mode Kernel [pdf] User Guide AN14093 Fast Boot Falcon Mode Kernel, AN14093, Fast Boot Falcon Mode Kernel, Boot Falcon Mode Kernel, Falcon Mode Kernel, Mode Kernel

References

- Automotive, IoT & Industrial Solutions | NXP Semiconductors
- Our Terms And Conditions Of Commercial Sale | NXP Semiconductors
- GitHub - nxp-imx/imx-atf: i.MX ARM Trusted firmware
- GitHub - nxp-imx/imx-mkimage: i.MX Mkimage Bootloader Tool
- GitHub - nxp-imx/linux-imx: i.MX Linux kernel
- GitHub - nxp-imx/uboot-imx: i.MX U-Boot
- systemd-analyze(1) - Linux manual page
- i.MX 8M Mini Evaluation Kit | NXP Semiconductors
- i.MX 8M Nano Evaluation Kit | NXP Semiconductors
- i.MX 8M Plus Evaluation Kit | NXP Semiconductors
- i.MX 93 Evaluation Kit | NXP Semiconductors

- Embedded Linux for i.MX Applications Processors | NXP Semiconductors
- nxp.com/lgfiles/NMG/MAD/YOCTO/firmware-imx-8.19.bin
- nxp.com/lgfiles/NMG/MAD/YOCTO/firmware-imx-8.20.bin
- nxp.com/lgfiles/NMG/MAD/YOCTO/firmware-sentinel-0.9.bin
- User Manual