PolarFire® SoC Linux Boot Time

Introduction

Microchip's PolarFire SoC FPGAs include the industry's RISC-V based Microprocessor Subsystem (MSS) and FPGA fabric that inherits all the features of the PolarFire family. The PolarFire SoC MSS includes 5x 64-bit RISC-V processor cores, AXI Switch, DDR Controller, Fabric Interface Controllers (FIC), and a rich set of peripherals. It also offers an unparalleled combination of low power consumption, thermal efficiency, and defense-grade security for smart, connected systems. It is the first SoC FPGA with a deterministic L2 memory subsystem enabling real-time applications. Built on the award-winning, mid-range, low-power PolarFire FPGA architecture, PolarFire SoC devices deliver up to 50% lower power than alternative FPGAs, span from 25k to 460k logic elements, and feature 12.7G transceivers.

Microchip's PolarFire SoC Icicle kit features an MPFS250T PolarFire SoC device and on board memories such as LPDDR4, SPI, and eMMC flash for running Linux. For more information, see UG0882: PolarFire SoC FPGA ICICLE Kit User Guide.

Linux boot time is the time length measured from the loading of Zeroth Stage Boot Loader (ZSBL) to the Linux user log-in prompt from the time the PolarFire SoC device is powered on. The PolarFire SoC boot sequence is simple and does not affect the overall performance by avoiding complex boot loader and kernel configurations. This white paper describes the unoptimized and optimized Linux boot time for Yocto and Buildroot platforms measured on PolarFire SoC Icicle kit. The following table lists the system configuration used for measuring the Linux boot time for Yocto and Buildroot.

Table 1. System Configuration

System Configuration	Description
Product and Architecture	Icicle kit, RISC-V
Platform	Linux (Yocto and Buildroot)
CPU Core Frequency	600 MHz
External Memory Access	eMMC/SD, LPDDR4
LPDDR4 Frequency	800 MHz
Compiler	GCC
Toolchain	riscv64-oe-linux-gcc(v9.3.0)
Utility	Grabserial

Note: For information about building Linux using Yocto on Icicle kit, see PolarFire SoC Yocto BSP.

Note: For information about building Linux using Buildroot on Icicle kit, see PolarFire SoC Buildroot SDK.

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1. Linux Boot Flow

Microchip provides Hart Software Services (HSS) software code, which is stored in eNVM of the PolarFire SoC device during device programming. HSS is the ZSBL that runs on the E51 monitor core. When the device is powered up, HSS performs the following:

- Programs eMMC with Linux Image via USB
- Loads U-Boot from eMMC to LPDDR4

U-Boot is an open-source bootloader for embedded systems and runs in Supervisor Mode (S mode).
U-Boot loads the Linux OS from eMMC to LPDDR4 and switches control to Linux.

The following steps are required for bringing up Linux on Icicle kit:

1. Programming the PolarFire SoC device with the reference design. This step also programs the device eNVM with HSS.
2. Setting the jumper configuration on the Icicle kit.
3. Programming the eMMC flash or SD card with the Linux image.

For more information, see PolarFire SoC GitHub.

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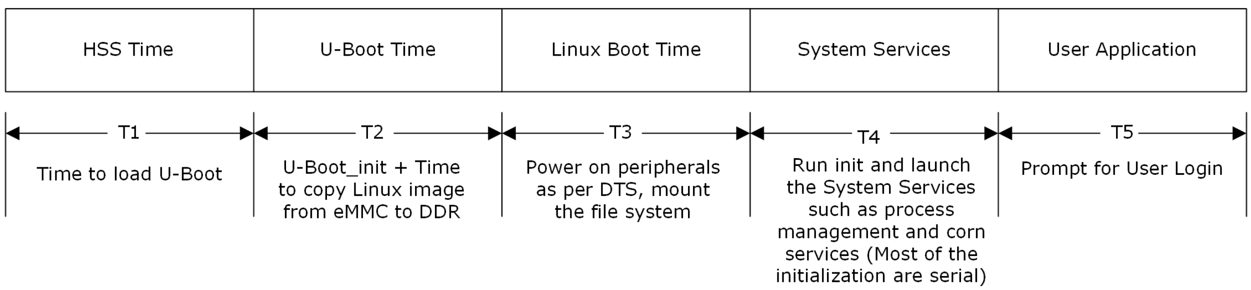
2. Boot Time Optimization

Boot time optimization is an area of interest for most of the real-time systems and is an important component of system performance as users must wait for the boot to complete before they can use the device. Boot time optimization reduces the boot time of a system at various levels of booting.

This white paper provides a reference for measuring boot time benchmarking on the PolarFire SoC Icicle kit. It mainly focuses on HSS boot time, U-Boot time, Linux boot time, and System Services.

The following figure shows the Linux boot time parameters on PolarFire SoC Icicle kit.

Figure 2-1. Linux Boot Time Parameters



Kernel optimizations are considered at T1, T2, T3, and T4, as shown in the preceding figure.

The following table lists the software and hardware requirements for boot time optimization.

Table 2-1. Boot Time Optimization Requirements

Software	Version
Yocto	2020.12
Buildroot	2020.12
Kernel	5.6.16
HSS	2020.12
U-Boot	2020.12
Hardware	**Version**
PolarFire SoC Icicle Kit	(MPFS250T_ES-FCVG484E)

The area of optimizations are:

HSS Time: The time taken from the system start-up (searching the source for the payload and unpack) to the destination, that is, loading U-Boot from SD Card/eMMC to DDR. In this optimization, the search time for the source is reduced to one sec (which in general takes five seconds). Microchip banner is removed to reduce the overall booting time of the cores associated with the payload.

U-Boot Time: The time taken for the U-Boot initialization and copying the Linux image from the eMMC/SD Card to the DDR. U-Boot initializes the hardware minimally, which also locates, loads, and executes the kernel image. In this optimization, disabled features which have a significant impact, such as hardware probing features, device initialization, Trivial File Transfer Protocol (TFTP), and Dynamic Host Configuration Protocol (DHCP) reduces the boot time.

Linux Boot Time: The time taken to power-up peripherals, mounting the file systems, executing and launching the system services. Linux boot time includes kernel execution and system services boot time. In this optimization, removing console messages by adding `quiet` to the cmd line, eliminating printk to CONFIG_PRINTK, sizing down the device tree by removing the unsupported features and unnecessary hardware interfaces reduce the boot time.

Reducing the kernel size helps the kernel load faster. Obtaining a smaller kernel by eliminating the Kernel options such as CONFIG_IKCONFIG, CONFIG_HOTPLUG, CONFIG_KALLSYMS, CONFIG_DEBUG_KERNEL,

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CONFIG_IKCONFIG, CONFIG_DNOTIFY, CONFIG_INOTIFY, and CONFIG_AUTOFS4_FS (automounter), which are not necessary for Linux boot up, speeds up kernel loading, therefore, reducing the kernel initial time when the kernel is loaded.

2.1 Boot Time Parameters

In the PolarFire SoC devices, Linux boot time includes the following parameters.

Table 2-2. Boot Time Parameters

Parameters	Description
HSS Time	Time to load U-Boot from eMMC to DDR
U-Boot Time	U-Boot_init + Time to copy Linux image from eMMC to DDR (till initiating kernel execution)
Linux Boot-Time	Time from start Kernel to shell prompt (Kernel + Userspace)

2.2 Boot Time Measurement

To measure boot time, follow these steps:

1. Download and install Grabserial.
2. Install Python (`sudo apt-get install python3.6`).
3. Execute Grabserial by entering the following cmd during Linux/HSS boots up.

```
sudo grabserial -v -d "/dev/ttyUSB0" -b 115200 -w 8 -p N -s 1 -e 90 -t -m
"Starting kernel.*"
```

```
Opening serial port /dev/ttyUSB0
```

Where,

- -d = serial device
- -t = print timestamps
- -m = match string before starting to log
- -e = number of seconds to capture for (useful when redirecting to a file: ensure that the file is closed cleanly and all output is recorded)
- -o [filename] = output to filename.

Grabserial utility use jiffies (the time between two successive clock ticks) and also adds time stamp to all serial console outputs, which is convenient to analyze the boot time. For more information, see Grabserial.

2.3 Build Procedure Without Optimization

Build the image with default options as described in PolarFire SoC GitHub and execute Grabserial during kernel/HSS boots up. Unoptimized boot time values for Yocto and Buildroot are listed in Table 3-1 and Table 3-2, respectively.

2.4 Build Procedure With Optimization

To optimize the boot time,

1. Follow the step described in PolarFire SoC GitHub for bringing up Linux on Icicle kit.
2. Build HSS by removing the search time of the booting source and by removing the Microchip banner.
3. Build the kernel. Update the file system with the newly built kernel image, kernel modules, and device tree files.

4. Set the log level to 0. This reduces the boot time by eliminating UART print to bottle the neck.
5. Reduce the console message by adding `quiet` to the cmd line.

Optimized boot time values for Yocto and Buildroot are listed in Table 3-1 and Table 3-2, respectively.

3. Boot Time Results

The unoptimized boot time results can be optimized using the following:

- Size Optimization
  - Reducing the size of binaries
  - Removing features that are not required to reduce component size
- Speed Optimization
  - Removing unnecessary kernel options
  - Optimizing for the target processor
  - Using a faster medium for loading bootloader and kernel
  - Reducing the number of tasks leading to the boot
  - Removing features that are not required for the boot process

The following table lists the unoptimized and optimized boot time results for Yocto.

Table 3-1. Yocto Boot Time Results

	Unoptimized	Optimized
HSS	13.18 Secs	8.3 Secs
U-Boot	3.87 Secs	3.87 Secs
Kernel	2.8 Secs	2.2 Secs
User Space	10.9 Secs	10.6 Secs
Total Boot Time	30.75 Secs	24.97 Secs

The following table lists the unoptimized and optimized boot time results for Buildroot.

Table 3-2. Buildroot Boot Time Results

	Unoptimized	Optimized
HSS	13.9 Secs	8.3 Secs
U-Boot	5.2 Secs	4.2 Secs
Kernel	2.2 Secs	1.7 Secs
User Space	6.3 Secs	0.8 Secs
Total Boot Time	27.6 Secs	15 Secs

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4. Summary of Optimized PolarFire SoC Boot Time Results

The following table lists the optimized boot time results for Yocto and Buildroot.

Table 4-1. Optimized Boot Time Results

Platform	PolarFire SoC
Yocto	24.97 Secs
Buildroot	15 Secs

5. Conclusion

In this white paper, the booting process of the Linux system is analyzed at various stages to optimize the boot time. HSS optimization, Kernel decompression, and loading RAM are some of the areas where significant improvement is possible in terms of reducing Linux boot time. Invocation of background processes and system services are other areas of improvement where traditional methods are being used and need to be changed or optimized in order to improve boot time.

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