

Mercury+ AA1 SoC Module

Reference Design for Mercury+ PE3 Base Board User Manual

Purpose

The purpose of this document is to present to the user the overall view of the Mercury+ AA1 SoC module reference design and to provide the user with a step-by-step guide to the complete Intel® SoC design flow used for the Mercury+ AA1 SoC module.

Summary

This document first gives an overview of the Mercury+ AA1 SoC module reference design and then guides through the complete Intel SoC design flow for the Mercury+ AA1 SoC module in the getting started section. In addition, the internals and the boot options of the Mercury+ AA1 SoC module reference design are described.

Product Information	Code	Name
Module	ME-AA1	Mercury+ AA1 SoC Module
Baseboard	ME-PE3	Mercury+ PE3 Base Board

Document Information	Reference	Version	Date
Reference / Version / Date	D-0000-490-003	2023.1_v1.0.0	18.04.2024

Approval Information	Name	Position	Date
Written by	ARUD	FPGA/SoC Embedded Software Engineer	14.04.2024
Verified by	ABUE	FPGA/SoC Senior Embedded Software Engineer	18.04.2024
Approved by	IJOS	Manager, BU SP	18.04.2024

License

Copyright 2024 by Enclustra GmbH, Switzerland.

Permission is hereby granted, free of charge, to any person obtaining a copy of this hardware, software, firmware, and associated documentation files (the "Product"), to deal in the Product without restriction, including without limitation the rights to use, copy, modify, merge, publish, distribute, sublicense, and/or sell copies of the Product, and to permit persons to whom the Product is furnished to do so, subject to the following conditions:

The above copyright notice and this permission notice shall be included in all copies or substantial portions of the Product.

THE PRODUCT IS PROVIDED "AS IS", WITHOUT WARRANTY OF ANY KIND, EXPRESS OR IMPLIED, INCLUDING BUT NOT LIMITED TO THE WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE AND NONINFRINGEMENT. IN NO EVENT SHALL THE AUTHORS OR COPYRIGHT HOLDERS BE LIABLE FOR ANY CLAIM, DAMAGES OR OTHER LIABILITY, WHETHER IN AN ACTION OF CONTRACT, TORT OR OTHERWISE, ARISING FROM, OUT OF OR IN CONNECTION WITH THE PRODUCT OR THE USE OR OTHER DEALINGS IN THE PRODUCT.

Table of Contents

Table of Contents	3
1 Overview	5
1.1 Introduction	5
1.2 Path Variables	5
1.3 Prerequisites	7
2 Reference Design Description	8
2.1 Hard Processor System (HPS)	8
2.1.1 Clocks	8
2.1.2 HPS DDR4 SDRAM	9
2.1.3 SD Card/eMMC	9
2.1.4 I2C	9
2.1.5 Quad SPI Flash Controller	9
2.1.6 UART	9
2.1.7 Ethernet	10
2.1.8 USB	10
2.1.9 HPS GPIOs	10
2.2 FPGA Fabric	11
2.2.1 GPIOs	11
3 Getting Started	12
3.1 Essential Information	12
3.2 Setting up the Hardware	12
3.3 Generating the FPGA Bitstream	14
3.4 Programming the FPGA	15
3.5 Generating the Bootloader	16
3.6 Compiling the HelloWorld Application	17
3.6.1 Installing the ARM GNU Toolchain	17
3.6.2 Building the HelloWorld Application	17
4 Boot Configurations	19
4.1 Preparing the Boot Binaries	19
4.2 SD Card Boot	20
4.2.1 Generating the Image Files	20
4.2.2 Programming the SD Card	20
4.2.3 Preparing the Hardware	20
4.2.4 Booting from the SD Card	21
4.3 QSPI Flash Boot	22
4.3.1 Preparing the QSPI Binaries	22
4.3.2 Preparing the Hardware	22
4.3.3 Programming the QSPI Flash	22
4.3.4 Booting from the QSPI Flash	23
4.4 eMMC Boot	23
4.4.1 Generating the Image Files	23
4.4.2 Preparing the Hardware	23
4.4.3 Programming the eMMC	24
4.4.4 Booting from the eMMC	24
5 Troubleshooting	25
5.1 Enclustra Build Environment Issues	25
5.2 JTAG Issues	25
5.2.1 Detecting the JTAG Cable Fails	25

5.3	UART Connection Issues	25
5.3.1	Recognizing USB UART Fails	25
5.3.2	No Output in the Serial Console	25
5.4	Toolchain Issues	25
5.4.1	A Command is not Found	25
5.5	SD Boot Issues	26
5.6	QSPI Boot Issues	26
5.7	eMMC Boot Issues	26
List of Figures		27
List of Tables		27
References		28

1 Overview

1.1 Introduction

The Mercury+ AA1 SoC module reference design demonstrates a system using the Mercury+ AA1 SoC module in combination with the Mercury+ PE3 base board. It presents the basic configuration of the device and contains a guided getting started tutorial.

A troubleshooting section is included at the end of the document to help the user solve potential issues related to board connectivity and system functionality.

This reference design includes a basic HelloWorld software example. In addition, Enclustra provides Application Notes [6] for selected applications.

An introduction to the Intel tools is provided by the documents below:

- Arria 10 SoC Boot User Guide [16]
- Intel® Quartus® Prime Pro and Standard Software User Guides [8]
- Rocketboards Bootloader Guide [10]

More information on the Mercury+ AA1 SoC module and the Mercury+ PE3 base board can be found in the Mercury+ AA1 SoC Module User Manual [2] and the Mercury+ PE3 Base Board User Manual [3].

The following directory structure applies to the AA1 Reference Design:

Directory	Description
doc	Reference Design documentation
scripts	Scripts directory required for project creation and settings
src	Design pinout, timing constraints and VHDL source code directory
sw	HelloWorld application source files

Table 1: Directory Structure

1.2 Path Variables

The following variables are used to substitute the full path to directories relevant for the reference design build process. Paths not already present in the reference design directory will be created during the build process.

Variable	Full Path	Description
<base_dir>	<base_dir>	Reference design root directory as described in Section 1.1
<quartus_install_dir>	<quartus_install_dir>	Path to the Quartus 23.1 installation directory
<quartus_dir>	<base_dir>/Quartus/<module_name>/<boot_mode>	Quartus project directory
<quartus_outdir>	<base_dir>/Quartus/<module_name>/<boot_mode>/output_files	Quartus output directory
<ebe_dir>	<base_dir>/sw/bsp-altera	Enclustra Build Environment repository [13]
<u-boot_dir>	<base_dir>/sw/bsp-altera/sources/altera-uboot	U-boot source directory
<app_dir>	<base_dir>/sw/HelloWorld	HelloWorld source directory
<hwlib_dir>	<base_dir>/sw/intel-socfpga-hwlib	Intel SoC FPGA HWLIB repository [9]
<hps_handoff_dir>	<base_dir>/Quartus/<module_name>/<boot_mode>/hps_isw_handoff	HPS handoff file directory

Table 2: Path Variables

1.3 Prerequisites

- IT infrastructure
 - Computer with a microSD card slot (optional¹)
 - Supported Linux OS² [7]
- Software
 - Intel® Quartus® Prime Software Suite 23.1 Standard Edition³
 - ARM GNU Toolchain [11]
- Hardware
 - Enclustra Mercury+ AA1 SoC module
 - Enclustra Mercury+ PE3 base board
- Accessories
 - 12 V DC power supply
 - Micro-USB cable
 - microSD card (optional¹)
 - USB-Blaster/USB-Blaster II download cable (optional⁴)

NOTICE



Damage to the device due to USB-Blaster cable incompatibilities

Refer to the Mercury+ AA1 SoC module User Manual [2] to find detailed information about a suitable download cable.

¹Only required for SD card boot mode.

²This reference design was built and tested with Ubuntu 20.04 and Ubuntu 22.04.

³Check the Mercury+ AA1 SoC Module User Manual [2] for details on device support in Quartus tools.

⁴Only required for loading the bitstream and/or programming the QSPI flash via Quartus.

2 Reference Design Description

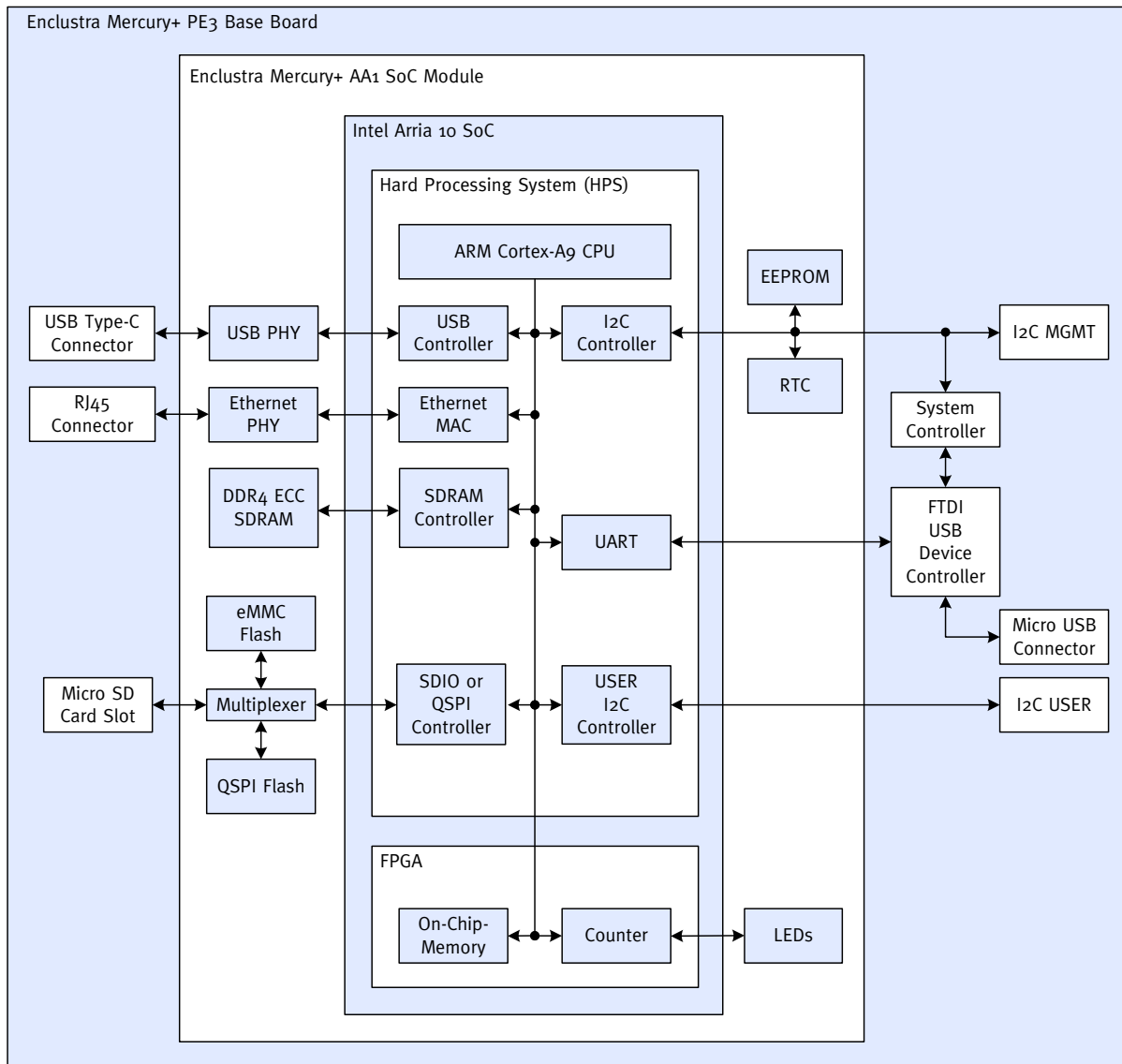


Figure 1: Hardware Block Diagram

2.1 Hard Processor System (HPS)

2.1.1 Clocks

The HPS input clock frequency is configured to 33.33 MHz. The HPS CPU (MPU) clock frequency is configured to its corresponding maximum frequency, as specified in the Intel® Arria 10 Device Datasheet [15]. The maximum MPU clock performance depends on the device speed grade and the VCC_INT voltage. Refer to the Mercury+ AA1 SoC Module User Manual [2] for details.

In addition, a 50 MHz clock and a 100 MHz clock are exported from the HPS to the FPGA. These clocks can be modified within the Platform Designer in the Arria 10 HPS properties.

2.1.2 HPS DDR4 SDRAM

The DDR4 SDRAM memory is attached to the HPS and runs at its corresponding maximum DDR frequency. ECC is enabled by default.

The DDR4 configuration can be modified in the Arria 10 HPS properties in the Platform Designer.

2.1.3 SD Card/eMMC

The SD/MMC controller is mapped to the HPS dedicated pins GP2IO[0:5,8:11] with up to 8 data bits. The controller can be connected in 4-bit mode to an external SD card on the base board or in 8-bit mode to the on-board eMMC flash. This enables SD card and eMMC flash access as well as booting from the SD card or eMMC flash, respectively.

To configure the Mercury+ AA1 SoC module to boot from the SD card, the configuration DIP switches on the Mercury+ PE3 base board must be set according to Section 4.2.3. For details on the eMMC flash boot mode, refer to the Mercury+ AA1 SoC Module User Manual [2].

The HPS pins GP2IO[0:5] are shared between the SD card, the eMMC flash and the QSPI flash. Only one of those storage devices can be used at a given moment. Switching between them at runtime is possible with the FLASH_SEL (FLASH_SEL_BS1) signal on GP2IO[6] and the FLASH_OE# (FLASH_OE#_HPS) signal on GP1IO[5].

2.1.4 I2C

The I2C controller I2C0 is mapped to the FPGA-HPS shared pins GP1IO[6:7]. It is connected to the I2C_MGMT-Bus on the Mercury+ PE3 Base Board.

The I2C controller I2C1 is connected through the FPGA fabric to the I2C_USER-Bus on the Mercury+ PE3 Base Board.

The available I2C devices are listed in the Mercury+ AA1 SoC Module User Manual [2] and the Mercury+ PE3 Base Board User Manual [3].

2.1.5 Quad SPI Flash Controller

The quad SPI flash controller is mapped to the HPS dedicated pins GP2IO[0:5] in single slave select mode (1SS).

To configure the Mercury+ AA1 SoC module to boot from the QSPI flash the hardware configuration on the Mercury+ PE3 base board must be done according to Section 4.3.4. Refer to the Mercury+ AA1 SoC Module User Manual [2] for details about flash programming and usage.

The HPS pins GP2IO [0:5] are shared between the SD card, the eMMC flash and the QSPI flash. Only one of those storage devices can be used at a given moment. Switching between them at runtime is possible with the FLASH_SEL (FLASH_SEL_BS1) signal on GP2IO[6] and the FLASH_OE# (FLASH_OE#_HPS) signal on GP1IO[5].

2.1.6 UART

The UART1 controller is mapped to the HPS dedicated pins GP2IO[12:13]. It is connected to the FTDI USB device controller via the system controller on the Mercury+ PE3 base board. The UART is configured as shown in Table 3.

Parameter	Value
Baud rate	115'200
Data	8 bit
Parity	None
Stop	1 bit
Flow control	None

Table 3: UART Configuration

2.1.7 Ethernet

The Ethernet MAC EMAC0 is mapped to the FPGA-HPS shared pins GP0IO[12:23]. It is connected to a Microchip (Micrel) KSZ9031 Ethernet PHY on the Mercury+ AA1 SoC module using RGMII. The PHY can be configured via the MDIO interface on PHY address 3.

2.1.8 USB

The USB controller USB0 is mapped to the FPGA-HPS shared pins GP0IO [0:11]. It is connected to a USB3320C USB 2.0 PHY. This interface can be configured for USB host or device mode.

2.1.9 HPS GPIOs

The unused pins from the HPS are available as GPIOs. For details on the I/O assignment, refer to the Mercury+ AA1 SoC module User Manual [2], Section "HPS dedicated and FPGA/HPS shared I/O Pins". For details on the combination of the I/O assignment with the Mercury+ PE3 base board, refer to the Mercury+ PE3 Base Board User Manual [3].

2.2 FPGA Fabric

2.2.1 GPIOs

The FPGA firmware contains a 24-bit counter freely running at 50 MHz. The MSB of this counter is used to blink LED2# with a frequency of approximately 3 Hz.

FPGA Pin	Signal	Function
T8	LED2#	Blinking LED counter MSB

Table 4: FPGA Firmware I/O Configuration

3 Getting Started

This section describes the steps required to configure the Mercury+ AA1 SoC module and Mercury+ PE3 base board in order to run a simple HelloWorld application example:

1. Mount the module and configure the Mercury+ PE3 base board.
2. Generate the FPGA bitstream.
3. Prepare the software workspace.
4. Run a software application.

Read the Mercury+ AA1 SoC module User Manual [2] and the Mercury+ PE3 Base Board User Manual [3] carefully before proceeding.

3.1 Essential Information

Pre-generated binaries may be used instead of building them manually as described in the following sections. The binaries for any supported AA1 variant and boot mode are released on the AA1 Reference Design Github release page [5].

Tip

Workarounds and fixes for potential issues can be found in Section 5.

NOTICE



Damage to the device due to overheating

Depending on the user application, the Mercury+ AA1 SoC module may consume more power than can be dissipated without additional cooling measures.

- Ensure that the SoC is always adequately cooled by installing a heat sink and/or providing air flow.

3.2 Setting up the Hardware

NOTICE



Damage to the device when mounting or removing the module

Mounting or removing the module while the base board is powered can lead to damage to the module or the base board.

- Ensure that the base board is not powered before mounting or removing the module.

The assembly drawing of the Mercury+ PE3 base board is shown in Figure 2. The relevant interfaces are marked in red in the figure as well as in the instructions below.

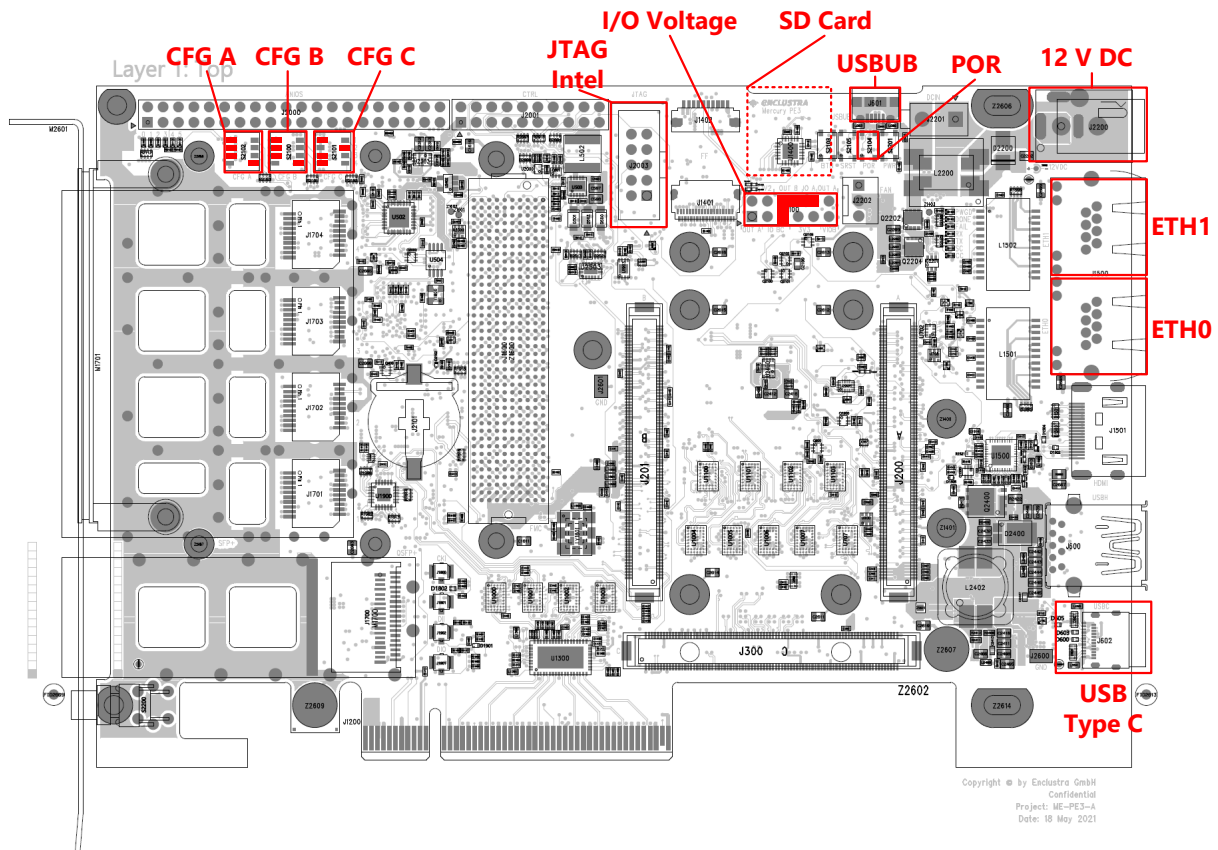


Figure 2: Mercury+ PE3 Base Board Assembly Drawing (Top View)

1. Make sure no power is connected to the power connector of the Mercury+ PE3 base board (label **12 V DC**).
2. Set the I/O voltage jumpers on the Mercury+ PE3 base board according to label **I/O Voltage** (the jumpers are marked with red rectangles):
 - VSEL A = 1.8 V (position 8-10)
 - VSEL BC = 1.8 V (position 5-6)
3. Set the configuration DIP switches on the Mercury+ PE3 base board as follows (labels **CFG A**, **CFG B** and **CFG C**):
 - CFG A: [1: OFF, 2: OFF, 3: OFF, 4: ON]
 - CFG B: [1: OFF, 2: OFF, 3: OFF, 4: ON]
 - CFG C: [1: OFF, 2: ON, 3: OFF, 4: OFF]
4. Mount the Mercury+ AA1 SoC module to the Mercury+ PE3 base board.
5. Connect the Micro-USB cable between the computer and the Mercury+ PE3 base board using the Micro-USB port (label **USBUB**).
6. Two new serial ports should be detected by the Linux OS⁵, where <X> denotes the lowest number of those:
 - /dev/ttyUSB<X>
 - /dev/ttyUSB<X+1>
7. Open the serial port with the highest number of the two detected ports and configure it using the parameters specified in Section 2.1.6. Any suitable utility for establishing a serial connection can be used. Below, the `screen` command is used executed in a Linux terminal:
`screen /dev/ttyUSB<X+1> 115200`
 The output of the HelloWorld application will be printed in this terminal after following Section 4.

⁵For issues related to serial port detection, refer to Section 5.3.

8. Optional: Connect a compatible JTAG adapter (see Section 1.3) to the Intel JTAG connector (label **JTAG Intel**).
9. **NOTICE: Damage to the device when applying power. Ensure that the mounting holes on the base board are aligned with the mounting holes of the Mercury+ AA1 SoC module.**
Connect a 12 V DC power supply plug to the power connector of the Mercury+ PE3 base board (label **12 V DC**).

3.3 Generating the FPGA Bitstream

Follow the steps described in this section to generate the reference design bitstream manually.

Tip

Pre-generated bitstreams for all supported AA1 variants are available on the AA1 reference design Github release page [5]. These can be used directly instead of generating the bitstream manually. If using those files directly, the bitstream does not need to be generated manually and this section can be skipped.

1. Configure the `<base_dir>/scripts/settings.tcl` file⁶:
 - (a) Set the `module_name` variable to the desired module variant.
 - (b) Set the `boot_mode` variable to the desired boot mode.
 - (c) Save the file after editing.
2. Start Quartus Prime 23.1, for example, `<quartus_install_dir>/quartus/bin/quartus &`
3. Create the Mercury+ AA1 SoC module reference design project:
 - (a) Select **View > Utility Windows > Tcl Console** to open the Tcl console.
 - (b) Click inside the Tcl console:
 - i. Type `cd {<base_dir>}`
Note the curly brackets around the path.
 - ii. Type `source ./scripts/create_project.tcl`
 - iii. Wait for completion.
4. Open the Mercury+ AA1 SoC module reference design project:
 - (a) Select **File > Open Project...**
 - (b) Navigate to `<base_dir>/Quartus/<module_name>/<boot_mode>`
 - (c) Select the **Mercury_AA1_PE3.qpf** project file.
 - (d) Click **Open**.
5. Compile the design and generate the programming files:
 - (a) Go to **Tasks**.
 - (b) Double-click **Compile Design**.
 - (c) Wait for completion.
 - (d) Check for errors and critical warnings in the **Messages** window.

The build output is located in `<base_dir>/Quartus/<module_name>/<boot_mode>/output_files` and is described in Table 5:

File	Description
Mercury_AA1_PE3.sof	Bitstream

Table 5: Quartus Programming Files

⁶Valid values for the variables are listed at the beginning of the file.

3.4 Programming the FPGA

Follow the steps described in this section to program the FPGA bitstream using the Quartus Programmer from Quartus 23.1 (see Figure 3).

1. Connect a compatible JTAG adapter (see Section 1.3) to the JTAG connector (see label **JTAG Intel** in Figure 2).
2. Select **Tools > Programmer**.
3. Select **Hardware Setup**.
4. Under **Currently selected hardware**, select **USB-Blaster/USB-Blaster II** from the drop-down list.
5. Close the **Hardware Setup** window.
6. In the **Programmer** window, click **Auto Detect**.
7. If prompted, select the device according to the product variant:
 - ME-AA1-270-3E4-D11E-NFX3: 10AS027E4 or 10AS027E4F29
 - ME-AA1-270-2I2-D11E-NFX3: 10AS027E2 or 10AS027E2F29
 - ME-AA1-480-2I3-D12E-NFX3: 10AS048E3 or 10AS048E3F29and click **OK**.
8. If the correct programming file is not automatically selected by the tool, do the following:
 - (a) Click on the device just added.
 - (b) Select **Change File....**
 - (c) Navigate to <base_dir>/Quartus/<module_name>/<boot_mode>/output_files
 - (d) Select the bitstream file (Mercury_AA1_PE3.sof).
 - (e) Click **Open**.
9. Enable the **Program/Configure** checkbox for the device.
10. Click **Start**.
11. After the FPGA is successfully configured, the **DONE** LED lights up.

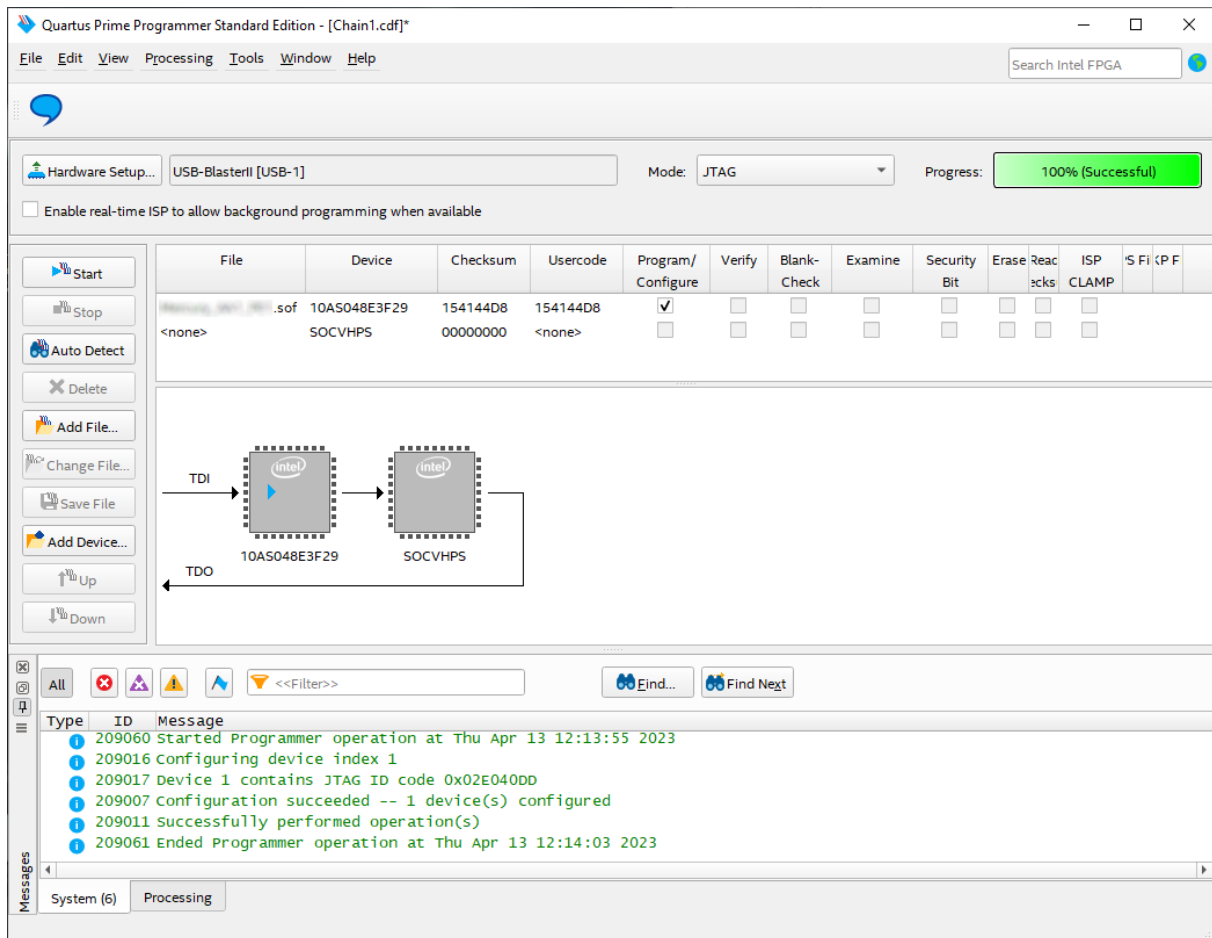


Figure 3: Quartus Programmer Program Bitstream

3.5 Generating the Bootloader

The bootloader (SPL) is used in the boot image creation process described further in Sections 4.2.1 and 4.3.1. The SPL is built alongside U-Boot and requires handoff files from the Quartus design. These handoff files contain HPS settings, memory parameters and address mappings.

Tip

Pre-generated bootloader binaries for the respective boot mode are available on the reference design github release page [5]. However, the bootloader needs to be re-generated whenever the HPS settings are changed.

Open a Linux terminal and execute the following commands to generate the SPL binary:

1. `git clone https://github.com/enclustra-bsp/bsp-altera \`
`--branch intel-v1.9 \`
`<base_dir>/sw/bsp-altera`
2. `cd <base_dir>/sw/bsp-altera`
3. `./build.sh \`
`-d Mercury_AA1/Mercury_PE3/<boot_mode>7 \`
`-o <module_name> \`
`-x U-Boot \`
`-B handoff <hps_handoff_dir>8`

⁷In EBE, the boot mode can be "MMC", "EMMC" or "QSPI".

⁸Use the absolute path to the HPS handoff directory.

The build output is located in `<base_dir>/sw/bsp-altera/sources/altera-uboot` and is described in Table 6:

File	Description
<code>spl/u-boot-splx4.sfp</code>	Bootable image with four SPL binaries in the format required by BootROM
<code>u-boot.img</code>	U-Boot image

Table 6: SPL Output Binaries

For more details regarding the SPL build process refer to [14].

3.6 Compiling the HelloWorld Application

The ARM GNU Toolchain [11] is used to compile the HelloWorld application example. The steps described in the following sections target a Linux Ubuntu OS and have been verified with Ubuntu 20.04 and Ubuntu 22.04.

3.6.1 Installing the ARM GNU Toolchain

The easiest way to install the ARM GNU Toolchain [11] is to use the provided package manager of the Linux OS. Execute these commands in a Linux terminal to install the toolchain:

1. `sudo apt-get update`
2. `sudo apt-get upgrade`
3. `sudo apt-get install gcc-arm-none-eabi`

Alternatively, the ARM GNU Toolchain can be installed manually. Download the appropriate package (AArch32 bare-metal target (arm-none-eabi)) from the ARM GNU Toolchain download page [12]. Extract the archive to the desired location. Add the `bin` folder to the **PATH** variable to make the toolchain available. In addition, install the following packages:

1. `sudo apt-get install build-essential`
2. `sudo apt-get install git`
3. `sudo apt-get install u-boot-tools`
4. `sudo apt-get install mtools`

3.6.2 Building the HelloWorld Application

Before running the commands below, ensure that the ARM GNU Toolchain was successfully installed, as described in Section 3.6.1.

Open a Linux terminal and execute the following commands to build the HelloWorld application:

1. `git clone https://github.com/altera-opensource/intel-socfpga-hwlib \`
`--branch rel_master_23.12.02_pr \`
`<hwlib_dir>`
2. `export INTEL_HWLIB_DIR=<absolute-path-to-<hwlib_dir>>`
3. `cd <base_dir>/sw/HelloWorld`
4. `make`

The build output is located in `<base_dir>/sw/HelloWorld` and described in Table 7:

File	Description
hello.axf	Arm Executable Format file
hello.axf.objdump	Disassembly information of the HelloWorld binary
hello.axf.map	Memory map of the HelloWorld binary
hello.bin	Binary copy of hello.axf generated with <code>arm-none-eabi-objcopy</code>
hello.img	HelloWorld image file generated with <code>mkimage</code>

Table 7: HelloWorld Output Files

4 Boot Configurations

A boot image can be created containing the previously generated binaries to enable booting from various boot modes. The boot image contains the bootloader, the bitstream for programming the FPGA logic and the software bare-metal application. This section describes how to generate a boot image for the Mercury+ AA1 SoC module for each supported boot mode.

Tip

Pre-generated images may be used for booting instead of rebuilding the image. The binaries for any supported AA1 variant and boot mode are released on the AA1 Reference Design Github release page [5].

4.1 Preparing the Boot Binaries

Follow these steps to prepare the boot binaries:

1. Build the SPL as described in Section 3.5.
2. Build the HelloWorld application as described in Section 3.6.
3. In a Linux terminal, run the following command to convert the bitstream to a suitable format for the boot image:

```
<quartus_install_dir>/quartus/bin/quartus_cpf --hps -c -o \
bitstream_compression=on \
<base_dir>/Quartus/<module_name>/<boot_mode>/output_files/Mercury_AA1_PE3.sof \
<base_dir>/Quartus/<module_name>/<boot_mode>/output_files/bitstream.rbf
```

The following files will be created:

- bitstream.periph.rbf: IO ring configuration file
- bitstream.core.rbf: FPGA fabric configuration file

4. Package the bitstream into a FIT image file:

- (a) Copy the `bitstream.its` file to the `<quartus_outdir>` :

```
cp <u-boot_dir>/board/enclustra/mercury_aa1/bitstream.its \
<quartus_outdir>/bitstream.its
```

- (b) Create the FIT image file:

```
mkimage -E -f <quartus_outdir>/bitstream.its \
<quartus_outdir>/bitstream.itb
```

5. Package the HelloWorld application into a FIT image file. In a Linux terminal, run the following commands:

- (a)

```
cp <u-boot_dir>/board/altera/arria10-socdk/fit_uboot.its \
<app_dir>/fit_uboot.its
```

- (b)

```
cp <u-boot_dir>/u-boot.dtb <app_dir>/u-boot.dtb
```

- (c) Modify the `<app_dir>/fit_uboot.its` file:

- i. Replace `'data = /incbin/(".*u-boot-nodtb.bin");'` with `'data = /incbin/("hello.bin");'`
- ii. Replace `'data = /incbin/(".*u-boot.dtb");'` with `'data = /incbin/("u-boot.dtb");'`
- iii. Change the load address from `'load = <0x01000040>;'` to `'load = <0x00100040>;'`
- iv. Change the entry address from `'entry = <0x01000040>;'` to `'entry = <0x00100040>;'`

- (d) Create the FIT image file:

```
mkimage -E -f <app_dir>/fit_uboot.its <app_dir>/fit_uboot.itb
```

4.2 SD Card Boot

4.2.1 Generating the Image Files

1. Create a 200 MB SD card image with the necessary partitions. In a Linux terminal, run the following commands:
 - (a) `mkdir -p <app_dir>/bootimage`
 - (b) `dd if=/dev/zero of=<app_dir>/bootimage/sdmmc.img bs=64K count=3216`
 - (c) `printf "type=c, size=190MiB \n type=A2, size=10MiB" | sfdisk \
<app_dir>/bootimage/sdmmc.img`
2. Prepare the 190 MB FAT file system:
 - (a) `dd if=/dev/zero of=<app_dir>/bootimage/fat.img bs=64K count=3040`
 - (b) `mkfs.vfat -F 32 <app_dir>/bootimage/fat.img`
3. Copy the required files to the FAT file system:
 - (a) `mcopy -i <app_dir>/bootimage/fat.img <app_dir>/fit_uboot.itb ::u-boot.img`
 - (b) `mcopy -i <app_dir>/bootimage/fat.img <quartus_outdir>/bitstream.itb ::bitstream.itb`
4. Merge the FAT file system with the SD card image:
`dd if=<app_dir>/bootimage/fat.img of=<app_dir>/bootimage/sdmmc.img seek=16 bs=64K`
5. Write the SPL to the Intel A2 boot partition:
`dd if=<u-boot_dir>/spl/u-boot-splx4.sfp of=<app_dir>/bootimage/sdmmc.img seek=3056 bs=64K`

4.2.2 Programming the SD Card

1. Insert a microSD card into the SD card slot of the computer.
2. In a Linux terminal, check the device node of the inserted microSD card:
`dmesg | tail`
An example for the console output is given in Figure 4, where the device node is named `sdd`.
3. **NOTICE: Data loss due to overwriting. Use the `lsblk` command to identify the correct device node.**
Write the SD card image created in Section 4.2.1 to the SD card, replacing `sd<X>` by the identified device node:
`dd if=<app_dir>/bootimage/sdmmc.img of=/dev/sd<X> bs=4M && sync`

```
> dmesg | tail
[3788615.008233] usb-storage 2-3:1.0: USB Mass Storage device detected
[3788615.008945] scsi host6: usb-storage 2-3:1.0
[3788616.023366] scsi 6:0:0:0: Direct-Access    TS-RDF5A Transcend        0004 PQ: 0 ANSI: 6
[3788616.024030] sd 6:0:0:0: Attached scsi generic sg3 type 0
[3788616.274611] sd 6:0:0:0: [sdd] 15360000 512-byte logical blocks: (7.86 GB/7.32 GiB)
[3788616.275598] sd 6:0:0:0: [sdd] Write Protect is off
[3788616.275608] sd 6:0:0:0: [sdd] Mode Sense: 21 00 00 00
[3788616.276486] sd 6:0:0:0: [sdd] Write cache: disabled, read cache: enabled, doesn't support DPO or FUA
[3788616.282967] sdd: sdd1 sdd2
[3788616.286775] sd 6:0:0:0: [sdd] Attached SCSI removable disk
```

Figure 4: Example of an SD Card Device Node

4.2.3 Preparing the Hardware

1. Detach the power supply of the Mercury+ PE3 base board (see label **12 V DC** in Figure 2).
2. Enable the SD card boot mode (default) by setting the configuration DIP switches on the Mercury+ PE3 base board as follows (see label **CFG A** in Figure 2):
 - CFG A = [1: OFF, 2: OFF, 3: OFF, 4: ON]

4.2.4 Booting from the SD Card

1. Insert the SD card into the SD card slot of the Mercury+ PE3 base board (see label **SD Card** in Figure [2](#)).
2. Connect the power supply to the Mercury+ PE3 base board (see label **12 V DC** in Figure [2](#)).

4.3 QSPI Flash Boot

4.3.1 Preparing the QSPI Binaries

Before programming the QSPI binaries, the procedure described in Sections 3.3, 3.5 and 4.1 must be successfully completed with the `boot_mode` variable set to `qspi`. The files needed for programming the QSPI flash are listed in Table 8.

File Path	Description
<u-boot_dir>/spl/u-boot-splx4.sfp	Bootloader (SPL)
<app_dir>/fit_uboot.itb	Image file containing the HelloWorld application
<quartus_outdir>/bitstream.itb	Image file containing the bitstream

Table 8: QSPI Programming Files

4.3.2 Preparing the Hardware

1. Disconnect the power supply of the Mercury+ PE3 base board(see label **12 V** in Figure 2).
2. Disconnect all USB cables from the Mercury+ PE3 base board.
3. Set the configuration DIP switch **CFG A** on the Mercury+ PE3 base board as follows (see label **CFG A** in Figure 2):
 - CFG A = [1: ON, 2: OFF, 3: OFF, 4: ON]
4. Connect the Micro-USB cable between the computer and the Mercury+ PE3 base board using the Micro-USB port labeled **USBUB** in Figure 2.
5. Connect a compatible JTAG adapter (see Section 1.3) to the JTAG connector (see label **JTAG Intel** in Figure 2).
6. Reconnect the power supply of the Mercury+ PE3 base board (see label **12 V DC** in Figure 2).

4.3.3 Programming the QSPI Flash

The process of programming large files (such as the FPGA bitstream) to the QSPI flash via JTAG using the `quartus_hps` tool can take up to 30 minutes⁹.

Tip

The pre-generated binaries include an image file containing all individual parts of the QSPI flash at the respective offsets. Instead of programming each file one by one, this QSPI flash image can be used to program the complete flash at once. The image file is provided as part of the release binaries on the AA1 Reference Design Github release page [5].

Execute the following commands in a Linux terminal to program the individual files generated in the previous sections to the respective offsets:

1. Erase the whole QSPI flash chip before programming the binaries:
`<quartus_install_dir>/bin/quartus_hps -c 1 -o E`
2. Program the SPL to QSPI flash address 0 :
`<quartus_install_dir>/bin/quartus_hps -c 1 -o PV -a 0x0 \
<u-boot_dir>/spl/u-boot-splx4.sfp`
3. Program the FIT image containing the HelloWorld application to the QSPI flash address offset 0x100000 :
`<quartus_install_dir>/bin/quartus_hps -c 1 -o PV -a 0x100000 \
<app_dir>/fit_uboot.itb`

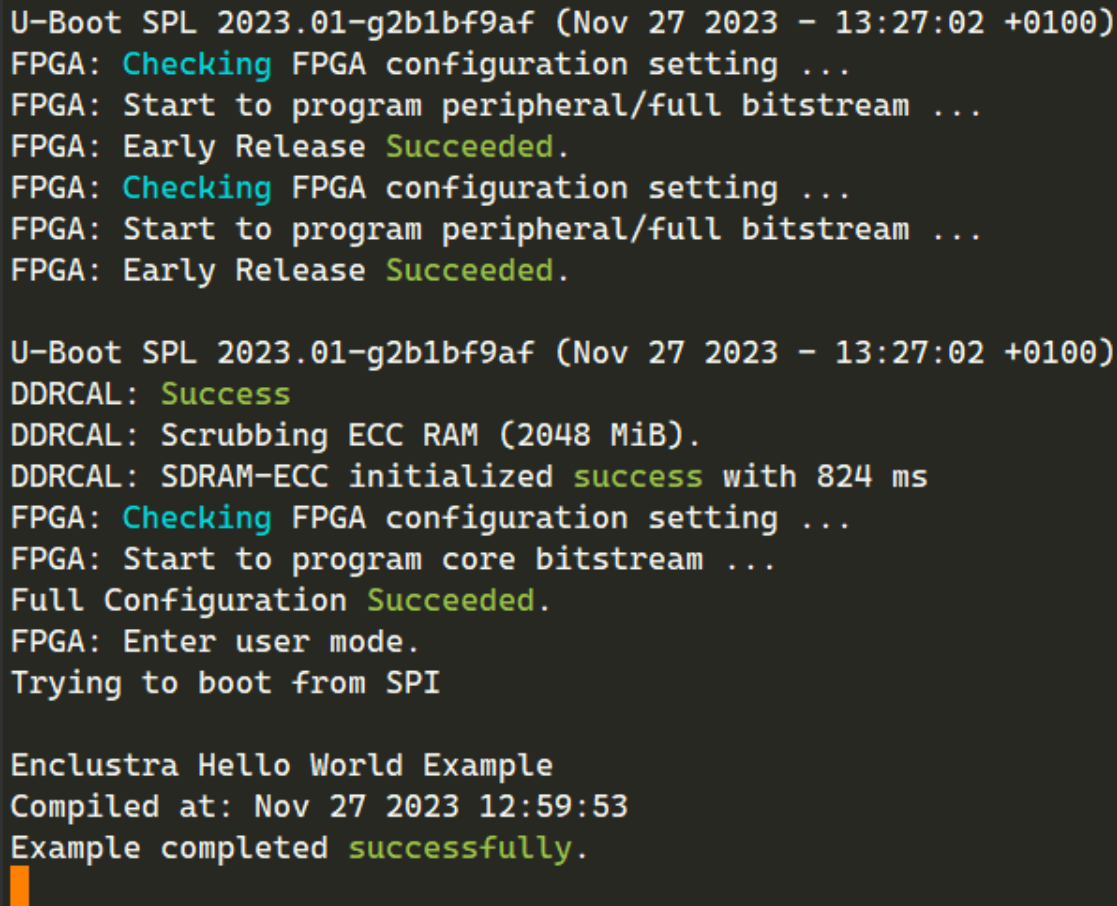
⁹Alternatively, the Enclustra MCT [4] can be used to program the QSPI flash.

4. Program the FIT image containing the bitstream to QSPI flash address offset 0x300000 :
`<quartus_install_dir>/bin/quartus_hps -c 1 -o PV -a 0x300000 \
<quartus_outdir>/bitstream.itb`

4.3.4 Booting from the QSPI Flash

1. Check that the hardware configuration is done according to Section 4.3.2.
2. Press the power-on reset button (see label **POR** in Figure 2) and release it after one second.

The expected output in the serial terminal console is given in Figure 5.



```
U-Boot SPL 2023.01-g2b1bf9af (Nov 27 2023 - 13:27:02 +0100)
FPGA: Checking FPGA configuration setting ...
FPGA: Start to program peripheral/full bitstream ...
FPGA: Early Release Succeeded.
FPGA: Checking FPGA configuration setting ...
FPGA: Start to program peripheral/full bitstream ...
FPGA: Early Release Succeeded.

U-Boot SPL 2023.01-g2b1bf9af (Nov 27 2023 - 13:27:02 +0100)
DDRCAL: Success
DDRCAL: Scrubbing ECC RAM (2048 MiB).
DDRCAL: SDRAM-ECC initialized success with 824 ms
FPGA: Checking FPGA configuration setting ...
FPGA: Start to program core bitstream ...
Full Configuration Succeeded.
FPGA: Enter user mode.
Trying to boot from SPI

Enclustra Hello World Example
Compiled at: Nov 27 2023 12:59:53
Example completed successfully.
```

Figure 5: Example of the Terminal Output in QSPI Boot Mode

4.4 eMMC Boot

4.4.1 Generating the Image Files

Before preparing the eMMC binaries, the procedure described in Sections 3.3, 3.5 and 4.1 must be successfully completed with the `boot_mode` variable set to `emmc`. The steps described in Section 4.2.1 can be used to generate an eMMC image file.

4.4.2 Preparing the Hardware

1. Disconnect the power supply of the Mercury+ PE3 base board.
2. Disconnect all USB cables from the Mercury+ PE3 base board.
3. Enable the eMMC boot mode by setting the configuration DIP **CFG A** switch on the Mercury+ PE3 base board as follows (see label **CFG A** in Figure 2):

- Set CFG A = [1: ON, 2: ON, 3: OFF, 4: ON]
4. Connect a USB cable to the Micro-USB port on the Mercury+ PE3 base board (see label **USBUB** in Figure 2).
 5. Connect the power supply to the Mercury+ PE3 base board (see label **12 V DC** in Figure 2).
 6. Reconnect the UART terminal.

4.4.3 Programming the eMMC

Direct programming of the eMMC is not supported by the Intel tools. To program the eMMC, first boot into U-Boot or Linux from another device (SD card or QSPI). A documentation how to program the eMMC with U-Boot or Linux can be found in the Enclustra Build Environment documentation [13].

4.4.4 Booting from the eMMC

1. Check that the hardware configuration is done according to Section 4.4.2.
2. Press the power-on reset button (see label **POR** in Figure 2) and release it after one second.

The expected output in the serial terminal console is the same as in Section 4.2.4.

5 Troubleshooting

5.1 Enclustra Build Environment Issues

- Ensure that the arguments specifying the product model and the binary paths are correct when running the `build.sh` script.
- Run `build.sh clean` or make a fresh clone of the whole repository.
- Verify that all the dependencies given within the EBE documentation [13] are met and all required packages are installed.
- Examine the `<base_dir>/sw/bsp-altera/build.log` file.

If none of the above helps resolving the issue, contact Enclustra Support [1] for assistance.

5.2 JTAG Issues

5.2.1 Detecting the JTAG Cable Fails

1. Make sure that the hardware configuration complies with Section 3.2.
2. Disconnect and reconnect the USB blaster connection and power cycle the Mercury+ PE3 base board.
3. If the problem persists, reboot the computer.

5.3 UART Connection Issues

5.3.1 Recognizing USB UART Fails

- Check that the Micro-USB cable is connected properly.
- Try different `/dev/ttyUSBx`.
- Check that the FTDI VCP drivers are available.
- Unload the FTDI D2XX drivers and reconnect the USB cable.
- Try a different USB cable.

5.3.2 No Output in the Serial Console

1. Check that the baud rate for the UART in the design matches the baud rate set in the serial console.
2. Reconnect to the serial console.

5.4 Toolchain Issues

5.4.1 A Command is not Found

Run the following commands to verify that all the tools are installed correctly:

1. `which arm-none-eabi-gcc`
2. `which make`
3. `which git`
4. `which mkimage`
5. `which mcopy`

The commands should output the path to the respective binary. An example is given in Figure 6.

```
> which arm-none-eabi-gcc && which make && which git && which mkimage && which mcopy  
/usr/bin/arm-none-eabi-gcc  
/usr/bin/make  
/usr/bin/git  
/usr/bin/mkimage  
/usr/bin/mcopy
```

Figure 6: Example of Binary Path Output

5.5 SD Boot Issues

- Make sure that the SD card is formatted according to Section [4.2.1](#).
- Make sure that the hardware configuration complies with Section [4.2.3](#).
- Use the SD card image provided on the AA1 Reference Design Github release page [\[5\]](#).
- Try another SD card.

5.6 QSPI Boot Issues

- Make sure that the QSPI binaries are generated according to Section [4.3.1](#).
- Make sure that the hardware configuration complies with Section [4.3.2](#).
- Use the provided binaries for QSPI boot mode on the AA1 Reference Design Github release page [\[5\]](#).
- Verify that the binaries are written to the correct offset address given in Section [4.3.3](#).
- Use the Enclustra Module Configuration Tool (MCT) [\[4\]](#) to program the QSPI binaries.

5.7 eMMC Boot Issues

- Make sure that the hardware configuration complies with Section [4.4.2](#).
- Use the eMMC image provided on the AA1 Reference Design Github release page [\[5\]](#).
- Make sure that the image is written correctly to the eMMC flash.

List of Figures

1	Hardware Block Diagram	8
2	Mercury+ PE3 Base Board Assembly Drawing (Top View)	13
3	Quartus Programmer Program Bitstream	16
4	Example of an SD Card Device Node	20
5	Example of the Terminal Output in QSPI Boot Mode	23
6	Example of Binary Path Output	26

List of Tables

1	Directory Structure	5
2	Path Variables	6
3	UART Configuration	10
4	FPGA Firmware I/O Configuration	11
5	Quartus Programming Files	14
6	SPL Output Binaries	17
7	HelloWorld Output Files	18
8	QSPI Programming Files	22

References

- [1] Enclustra Support Channel
support@enclustra.com
- [2] Mercury+ AA1 SoC Module User Manual
→ Ask Enclustra for details
- [3] Mercury+ PE3 Base Board User Manual
→ Ask Enclustra for details
- [4] Enclustra Module Configuration Tool (MCT)
<http://www.enclustra.com/en/products/tools/module-configuration-tool/>
- [5] Mercury AA1 PE3 Reference Design Releases
https://github.com/enclustra/Mercury_AA1_PE3_Reference_Design/releases
- [6] Enclustra Application Notes
<https://github.com/enclustra/I2CApNote>
<https://github.com/enclustra/GigabitEthernetAppNote>
- [7] OS Support for Intel® FPGA Complete Design Suite
<https://www.intel.com/content/www/us/en/support/programmable/support-resources/design-software/os-support.html>
- [8] Intel® Quartus® Prime Pro and Standard Software User Guides
<https://www.intel.com/content/www/us/en/support/programmable/support-resources/design-software/user-guides.html>
- [9] Intel SoC FPGA HWLIB repository
<https://github.com/altera-opensource/intel-socfpga-hwlib>
- [10] Rocketboards Bootloader Guide
<https://www.rocketboards.org/foswiki/Documentation/BuildingBootloaderCycloneVAndArria10>
- [11] ARM GNU Toolchain
<https://developer.arm.com/Tools and Software/GNU Toolchain>
- [12] ARM GNU Toolchain download Page
<https://developer.arm.com/downloads/-/arm-gnu-toolchain-downloads>
- [13] Enclustra Build Environment
<https://github.com/enclustra-bsp/bsp-altera>
- [14] Intel SoC FPGA Readme
https://github.com/altera-opensource/u-boot-socfpga/blob/socfpga_v2023.07/doc/README.socfpga
- [15] Intel® Arria® 10 Device Datasheet
<https://www.intel.com/content/www/us/en/docs/programmable/683771/current/device-datasheet.html>
- [16] Arria 10 SoC Boot User Guide
<https://www.intel.com/content/www/us/en/docs/programmable/683735/current/arria-10-soc-boot-user-guide.html>