

Aquila is a RISC-V RV32IM compliant processor core that is designed as a reusable AXI4 IP for the Xilinx Vivado EDA tool. Currently, Aquila only supports M mode of RISC-V. Before synthesis of the hardware and compilation of the software, you must install Xilinx Vivado (2018.2 was used) and 32-bit RISC-V GNU toolchain (gcc 8.2.0 was used) on your system. A typical directory structure for Aquila HW-SW development under Linux system is as follows:

```
aquila --- aquila_soc (the Aquila Vivado project)
      |
      +-- sw --- uartboot (the boot code ROM generator)
            |
            +-- elibc (super-mini C standard library)
            |
            +-- test (test memory allocation, timer ISR, and
                    floating-point operations thru printf().
                    The program depends on elibc library.)
```

## 1 Introduction to the Aquila Platform

The Vivado project “aquila\_soc” contains the minimal architecture of an Aquila platform. The block diagram of the project is shown in Fig. 1. The red dash box in Fig. 1 contains two IPs, bdm and aquila, of the Aquila processor subsystem. The block “bdm” is a boot/debug IP that loads a boot rom code into the DDRx main memory, and triggers the the Aquila core to execute the boot code. By default, the boot code is loaded to the address starting at 0xB0000000 and it will set the stack area to 0xBFFE0000 ~ 0xBFFF0000. The initial stack area can be changed through the linker script. Upon reset of Aquila, the boot code will be waiting for a user program to be transferred through the UART device, Xilinx axi\_uartlite, at a baud rate of 115200. A user can use the “send file” menu item of TeraTerm to transfer a RISCV binary for execution. When the user program is received, the boot code will load it into the addresses starting at 0x80000000, and execute the program.

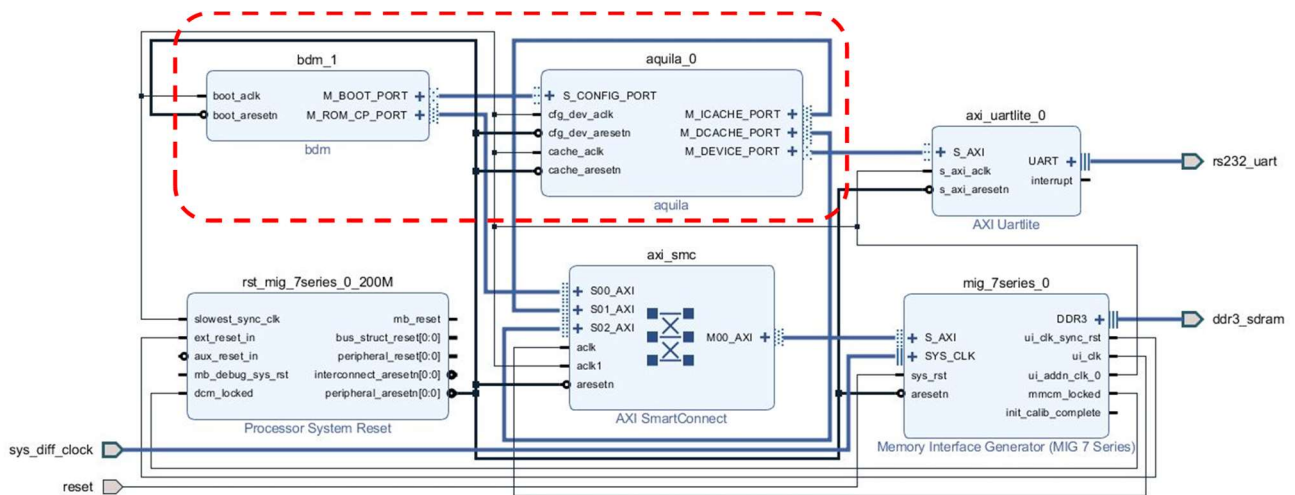


Fig. 1. The Vivado block diagram of a minimal Aquila SoC.

The Aquila processor core has three master ports for I-Cache, D-Cache, and I/O Devices, respectively. In Fig. 1, the device port is connected directly to the axi\_uartlite device. More devices can be connected to the Aquila core via an AXI Interconnect. Do not forget to edit the device addresses in Vivado block design tab as shown in Fig. 2. However, there is an address decoder in the Aquila IP, in `aquila_top.v`, that presumes the following system address map:

0x0000_0000 - 0xBFFF_FFFF: DDRx DRAM memory (cached)
0xC000_0000 - 0xCFFF_FFFF: device memory (un-cached)
0xF000_0000 - 0xF000_0010: CLINT I/O registers (un-cached)

Therefore, you must assign an address between 0xC0000000 and 0xCFFFFFFF to your I/O devices so that the I/O requests from the Aquila core will be redirected properly to the device port.

The DRAM memory area is further divided into code section, data section, heap section, and stack section through the linker script of a program. A typical setup of these sections for a Xilinx KC705 development board (with 1GB of DDR3 DRAM) are as follows:

0x8000_0000 - 0x8000_8FFF: program code section
0x8000_8000 - 0x8100_7FFF: data section
0x9000_0000 - 0xAFFF_FFFF: heap section
0xBFFE_0000 - 0xBFFF_0000: stack section

These section areas can be modified through the linker script. Note that the stack section is physically initialized in the boot code. Therefore, if you intend to change the stack section in the linker script of the application program, you must change that in the linker script `uartboot.ld` as well. Therefore, a re-synthesis of the Aquila SoC is necessary to reflect the new stack area.

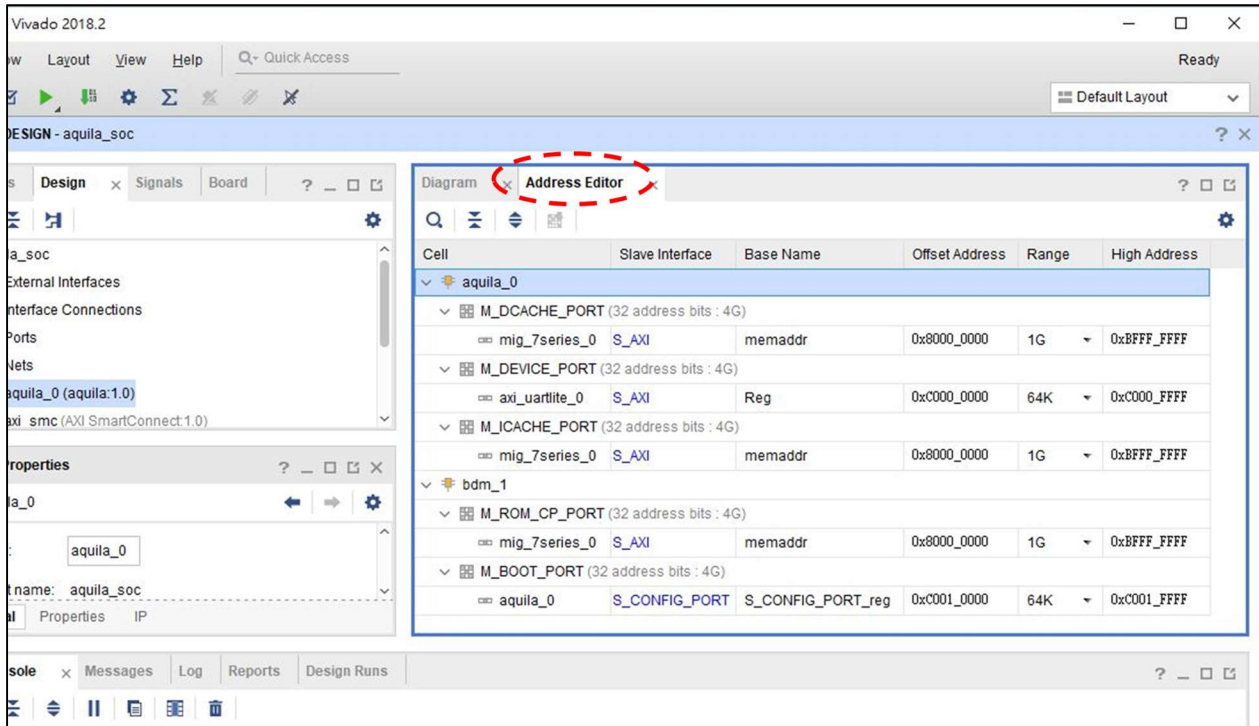


Fig. 2. Device address editor in Vivado.

Once you have generated and configured the bitstream for the target FPGA (KC705), you will see a welcome message showing on the terminal emulator (such as Tera Term) on the host PC (see Fig. 3). The parameters for the UART terminal are 115200, 8-N-1.

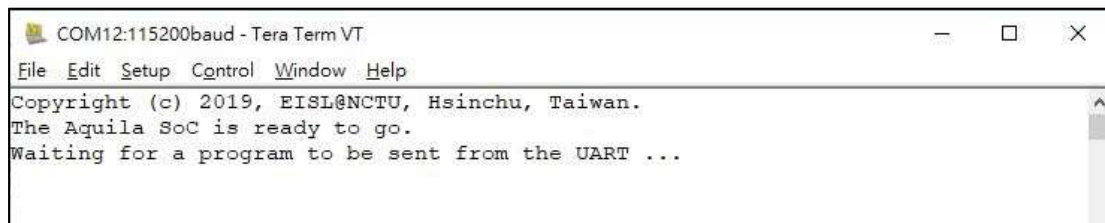


Fig. 3. The boot message from the Aquila SoC.

## 2 The Software Samples of the Aquila SoC

In the software directory, `aquila/sw`, there are four subdirectories that contains a UART boot code, a super-mini standard C library and a test application, respectively. To build the software, you can simply run “make” in each directory. For the super-mini C library, there is no Makefile. Any program that depends on this library, such as the test program, should refer to the library in its Makefile. The software project under `aquila/sw/uartboot` generates a boot code with starting address at `0xB0000000` and stack area at `0xBFFE0000 ~ 0xBFFF0000`. The target file `bootrom.mem` shall be copied to the Aquila Vivado project directory, under `aquila/aquila_soc/ip_repo/bdm/hdl`. This is the ROM memory file of a small boot code that will be loaded into DDRx main memory for execution.

Once the boot code is executed, a message will be sent to the UART device (Fig. 3). A terminal emulator running on the host computer can be used to interact with the Aquila SoC. A user can use the “Send file” menu command in Tera Term (see Fig. 4) to transfer a RISC-V binary executable in \*.ebf format to the main memory for execution. Note that you must check the binary transfer mode in the “Send file” option. The \*.ebf format is a binary executable created using ‘objcopy’, then prepended by a 4-byte length header.

A test program is located in the directory `aquila/sw/test`. To build `test.ebf`, simply type “make” under this directory. The test program depends on the ‘elibr’ library for basic I/O, tick count, and memory management support. Fig. 6 shows the execution result of the test program.

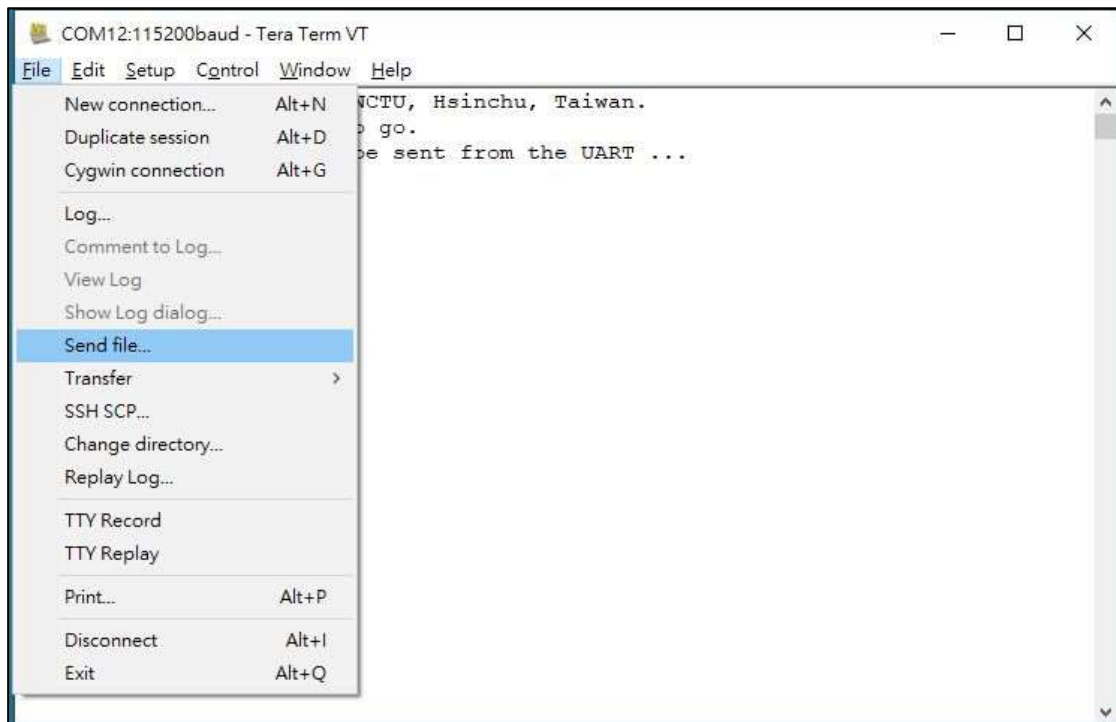


Fig. 4. Use “Send file” in Tera Term to load a binary executable to the DDRx main memory for execution.

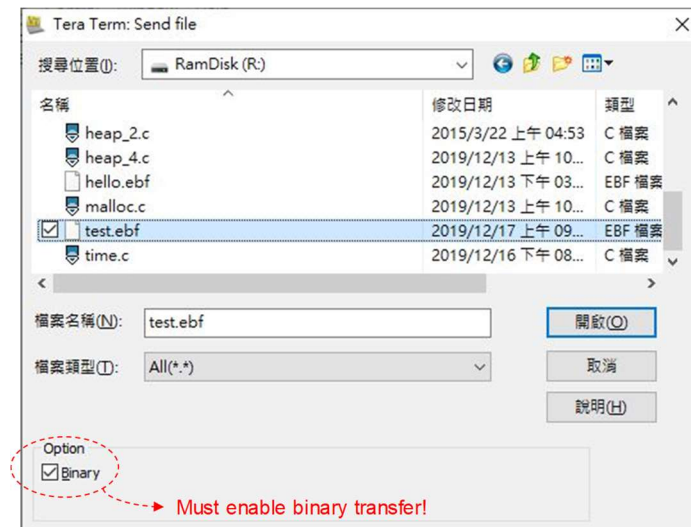
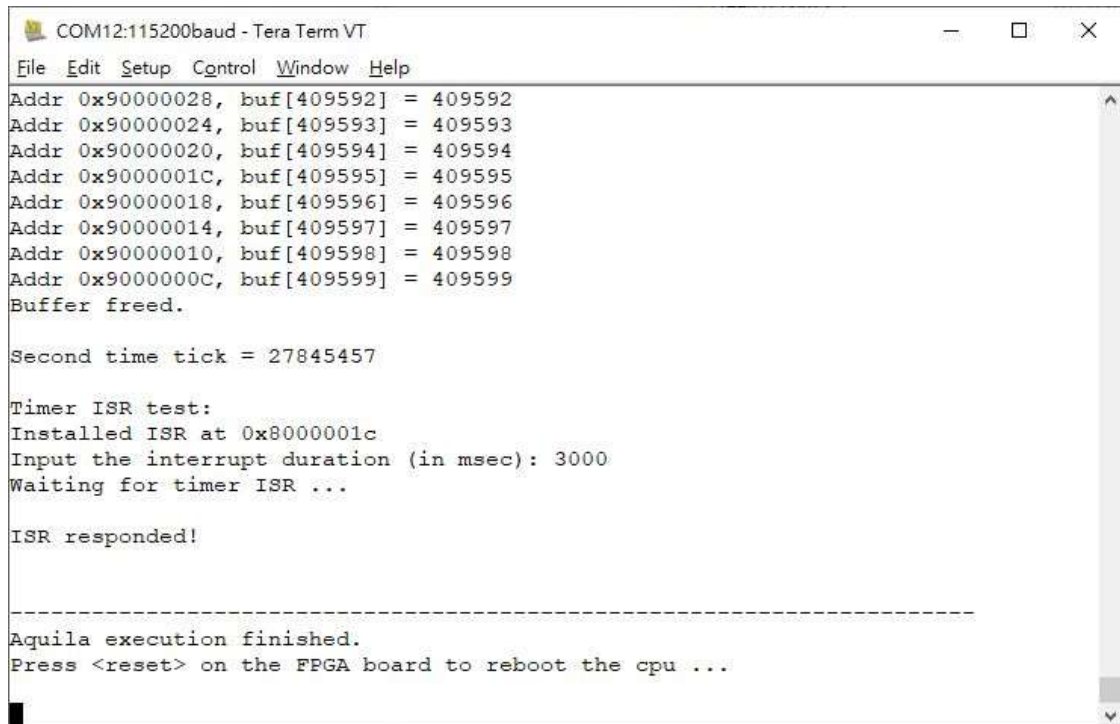


Fig. 5. Selection of the \*.ebf executable using binary transfer mode.



```
COM12:115200baud - Tera Term VT
File Edit Setup Control Window Help
Addr 0x90000028, buf[409592] = 409592
Addr 0x90000024, buf[409593] = 409593
Addr 0x90000020, buf[409594] = 409594
Addr 0x9000001C, buf[409595] = 409595
Addr 0x90000018, buf[409596] = 409596
Addr 0x90000014, buf[409597] = 409597
Addr 0x90000010, buf[409598] = 409598
Addr 0x9000000C, buf[409599] = 409599
Buffer freed.

Second time tick = 27845457

Timer ISR test:
Installed ISR at 0x8000001c
Input the interrupt duration (in msec): 3000
Waiting for timer ISR ...

ISR responded!

-----
Aquila execution finished.
Press <reset> on the FPGA board to reboot the cpu ...
```

Fig. 6. Execution of the test program.