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## Acronyms in This Document

A list of acronyms used in this document.

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>AHB-L</td>
<td>Advanced High-performance Bus – Lite</td>
</tr>
<tr>
<td>CPU</td>
<td>Central Processing Unit</td>
</tr>
<tr>
<td>CSR</td>
<td>Control and Status Register</td>
</tr>
<tr>
<td>DMIPS</td>
<td>Dhrystone MIPS (Million Instructions per Second)</td>
</tr>
<tr>
<td>FPGA</td>
<td>Field Programmable Gate Array</td>
</tr>
<tr>
<td>GDB</td>
<td>Gnu Debugger</td>
</tr>
<tr>
<td>HDL</td>
<td>Hardware Description Language</td>
</tr>
<tr>
<td>IP</td>
<td>Intellectual Property</td>
</tr>
<tr>
<td>IRQ</td>
<td>Interrupt Request</td>
</tr>
<tr>
<td>ISA</td>
<td>Instruction Set Architecture</td>
</tr>
<tr>
<td>JTAG</td>
<td>Joint Test Action Group</td>
</tr>
<tr>
<td>LUT</td>
<td>Lookup Table</td>
</tr>
<tr>
<td>MC</td>
<td>Micro-Controller (RISC-V for Micro-Controller applications)</td>
</tr>
<tr>
<td>OpenOCD</td>
<td>Open On-Chip Debugger</td>
</tr>
<tr>
<td>PIC</td>
<td>Programmable Interrupt Controller</td>
</tr>
<tr>
<td>RISC-V</td>
<td>Reduced instruction set computer-V (five)</td>
</tr>
<tr>
<td>RV32IMC</td>
<td>RISC-V Integer, M and Compressed Instruction Sets</td>
</tr>
<tr>
<td>WFI</td>
<td>Wait For Interrupt</td>
</tr>
</tbody>
</table>
1. Introduction

The Lattice Semiconductor RISC-V MC CPU soft IP contains a 32-bit RISC-V processor core and optional submodules – Timer and Programmable Interrupt Controller (PIC). The CPU core is with instruction and data caches. The CPU core supports RV32IMC instruction set, external interrupts, and debug feature that is JTAG – IEEE 1149.1 compliant. The Timer submodule is a 64-bit real time counter, which compares a real-time register with another register to assert the timer interrupt. The PIC submodule aggregates up to eight external interrupt inputs into one external interrupt. The submodule registers are accessed by the processor core using a 32-bit Advanced High-performance Bus – Lite (AHB-L) interface.

The design is implemented using Verilog HDL, and it can be configured and generated using the Lattice Propel™ Builder software. It supports Lattice Avant™, MachXO5™-NX, Certus™-NX, CertusPro™-NX, CrossLink™-NX, MachXO3D™, MachXO3™, and MachXO2™ FPGA devices.

1.1. Quick Facts

Table 1.1 presents a summary of the RISC-V MC CPU IP Core.

<table>
<thead>
<tr>
<th>IP Requirements</th>
<th>Supported FPGA Family</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resource Utilization</td>
<td>Targeted Devices</td>
</tr>
<tr>
<td></td>
<td>LAV-AT, LFMXOS, LFD2NX, LFCPNX, LIFCL, LAMXO3D, LCMXO3L, LCMXO3LF, LCMXO2</td>
</tr>
<tr>
<td>Supported User Interfaces</td>
<td>AHB – Lite Interface</td>
</tr>
<tr>
<td>Resources</td>
<td>See Table A.1, Table A.2, Table A.3.</td>
</tr>
<tr>
<td>Design Tool Support</td>
<td>Lattice Implementation</td>
</tr>
<tr>
<td></td>
<td>Lattice Propel Builder 2023.1, Lattice Radiant 2023.1</td>
</tr>
<tr>
<td>Simulation</td>
<td>For a list of supported simulators, see the Lattice Radiant™ and Lattice Diamond™ software user guide.</td>
</tr>
</tbody>
</table>

1.2. Features

The RISC-V MC soft IP has the following features:
- RV32IMC instruction set
- Five stages of pipelines
- Support the AHB-L bus standard for instruction/data port
- Optional caches, including a 4 KB two-way instruction cache and a 4 KB two-way data cache (for Lattice Avant, MachXOS-NX, Certus-NX, CertusPro-NX, and CrossLink-NX only)
- Optional debug using Gnu Debugger (GDB) and Open On-Chip Debugger (OpenOCD)
- Optional PIC module
- Optional Timer module
- Interrupt and exception handling under Machine Mode
- > 0.7 DMIPS/MHz performance
- > 100 MHz on CrossLink-NX devices (tested on the Hello World template provided by Propel)

1.3. Conventions

The nomenclature used in this document is based on Verilog HDL.
2. Functional Descriptions

2.1. Overview
The RISC-V MC CPU IP processes data and instructions while monitoring external interrupts. As shown in Figure 2.1, the CPU IP has a 32-bit processor core and optional submodules. It uses one AHB-L interface (Read-Only) for instruction fetch and another AHB-L interface (Read/Write Access) for data access. See Table 2.5 and Table 2.6 for the AHB-L Instruction Fetch and Data Accessing ports definition. The CPU core, PIC, Timer and AHB-L multiplexor run in the system clock domain. The Core Debug runs in both system clock domain and JTAG clock domain.

2.2. Modules Description
2.2.1. RISC-V Processor Core
The processor core follows the RV32IMC instruction set. Figure 2.2 shows the processor core block diagram.
2.2.1.1. Interrupt
Whenever an interrupt occurs, it has to remain in its active level until it is cleared by the processor core interrupt service routine.

If an interrupt occurs, before jumping to the interrupt service routine, the processor core stops the prefetch stage and waits for all instructions in the later pipeline stages to complete their execution.

2.2.1.2. Exception
If an exception occurs, the processor core stops the corresponding instruction, flushes all previous instructions, and waits until the terminated instruction reaches the writeback stage before jumping to the exception service routine.

2.2.1.3. Low Power Mode
Processor core enters into low power mode with WFI command, PC halts during low power mode, and processor wakes up if there is external/timer interrupt.

2.2.1.4. Debug
The processor core supports the IEEE-1149.1 JTAG debug logic with two hardware breakpoints.
Users should select soft JTAG on Lattice Avant family devices. This feature is for Lattice Avant only. To debug with soft JTAG, extra pin assignment efforts are required at post-synthesis. TCK must be assigned to a PCLK pin.

2.2.1.5. Instruction and Data Caches
The processor core supports instruction and data caches.
The instruction and data caches are both 4 KB two-way set associative, each cache line contains 32 bytes. The cache strategy for data cache is write through, and the cache eviction policy of both caches is round robin.
The instruction and data caches can be enabled/disabled together by checking/unchecking the “CACHE_ENABLE” option when instantiating CPU in Propel, and the cacheable address range can be configured by setting the “CACHEABLE_ADDR_LOW” and “CACHEABLE_ADDR_HIGH” parameters.

When cache is enabled, it is required to store the instructions into the instruction cache range.

It should be noted that the instruction and data caches should only be enabled for Certus-NX, CertusPro-NX, CrossLink-NX and MachXO5-NX devices, as they have enough resources to support the caches.

### 2.2.1.6 Control and Status Registers

The processor core supports the Control and Status Registers (CSRs) listed in Table 2.1.

#### Table 2.1. RISC-V Processor Core Control and Status Registers

<table>
<thead>
<tr>
<th>CSR No.</th>
<th>CSR Name</th>
<th>Access</th>
<th>Fields</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x300</td>
<td>mstatus</td>
<td>read/write</td>
<td>bit[12:11]: mpp, privilege mode before entering trap, should always be 2'b11 (machine mode) in this CPU core. bit[7]: mpie, mie before entering trap, updated to mie value when entering to trap. bit[3]: mie, global interrupt enable.</td>
</tr>
<tr>
<td>0x304</td>
<td>mie</td>
<td>read/write</td>
<td>bit[11]: meie, machine mode external interrupt enable. bit[7]: mtie, machine mode timer interrupt enable. bit[3]: msie, machine mode software interrupt enable.</td>
</tr>
<tr>
<td>0x305</td>
<td>mtvec</td>
<td>read/write (initialized to 0x20)</td>
<td>bit[31:2]: trap vector base address, 4-byte aligned. bit[0]: trap vector mode, all traps set the program counter to the base address in RISC-V MC CPU core. Bit[1] is not supported. Only 1'0 - direct mode and 1'b1 - vectored mode are available.</td>
</tr>
<tr>
<td>0x340</td>
<td>mscratch</td>
<td>read/write</td>
<td>bit[31:0]: for use by machine mode, it is used to hold a pointer to a machine-mode hart-local context space and swapped with a user register upon entry to a machine mode trap handler.</td>
</tr>
<tr>
<td>0x341</td>
<td>mepc</td>
<td>read/write</td>
<td>bit[31:0]: when trap is taken into machine mode, mepc is used to store the address of the instruction that encountered exception.</td>
</tr>
<tr>
<td>0x342</td>
<td>mcause</td>
<td>read only</td>
<td>bit[31]: 1'b1 - interrupt, 1'b0 - exception bit[3:0]: exception code for interrupt: 3 - machine software interrupt 7 - machine timer interrupt 11 - machine external interrupt for exception: 0 - instruction address misaligned 1 - instruction access fault 2 - illegal instruction 4 - load address misaligned 5 - load access fault</td>
</tr>
<tr>
<td>0x343</td>
<td>mtval</td>
<td>read only</td>
<td>bit[31:0]: When a hardware breakpoint is triggered, or an instruction fetch, load or store address is misaligned or access exception occurs, mtval is written with the fault address. It may also be written with illegal instruction when an illegal instruction occurs.</td>
</tr>
<tr>
<td>0x344</td>
<td>mip</td>
<td>read/write</td>
<td>bit[11]: meip, machine mode external interrupt pending, read only. bit[7]: mtp, machine mode timer interrupt pending, read only. bit[3]: msip, machine mode software interrupt pending, readable and writable.</td>
</tr>
</tbody>
</table>
2.2.2. Submodule (PIC/Timer)

The CPU soft IP contains submodules: PIC and Timer. The PIC and Timer share the same start address in the memory map and a fixed two KB address range is allocated, if either PIC or Timer is enabled.

2.2.2.1. PIC

The PIC aggregates up to eight external interrupt inputs (IRQs) into one interrupt output to processor core. The interrupt status register can be used to read the values of IRQs. Individual IRQs can be configured by programming the corresponding PIC_STATUS, PIC_ENABLE, PIC_SET, and PIC_POL registers. All registers can be accessed through an AHB-L interface, as shown in Figure 2.3.

![PIC Block Diagram](image)

Table 2.2 provides the description of PIC registers.

Table 2.2. PIC Registers

<table>
<thead>
<tr>
<th>Offset</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x000</td>
<td>PIC_STATUS</td>
<td>Interrupt Status Register (read-write) (parameterizable width, min=2, max=8) Indicate the pending interrupt at corresponding interrupt request port(irq[i] at top level).</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Field</th>
<th>Name</th>
<th>Access</th>
<th>Width</th>
<th>Reset</th>
</tr>
</thead>
<tbody>
<tr>
<td>[N-1]</td>
<td>PIC_STATUS [N-1]</td>
<td>RW</td>
<td>1</td>
<td>0x0</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>[1]</td>
<td>PIC_STATUS [1]</td>
<td>RW</td>
<td>1</td>
<td>0x0</td>
</tr>
<tr>
<td>[0]</td>
<td>PIC_STATUS [0]</td>
<td>RW</td>
<td>1</td>
<td>0x0</td>
</tr>
</tbody>
</table>

 PIC_STATUS[i]:
Read
• 0 – no interrupt at irq[i]
• 1 – interrupt pending at irq[i]
Write
• 0 – no effect
• 1 – clear interrupt status for irq[i]
### PIC_ENABLE

**Description:** Interrupt Enable Register (read-write) (parameterizable width, min=2, max=8) Indicate whether the processor responds to the interrupt from corresponding interrupt request port (irq[i]) or not.

<table>
<thead>
<tr>
<th>Field</th>
<th>Name</th>
<th>Access</th>
<th>Width</th>
<th>Reset</th>
</tr>
</thead>
<tbody>
<tr>
<td>[N-1]</td>
<td>PIC_ENABLE[N-1]</td>
<td>RW</td>
<td>1</td>
<td>0x0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>[1]</td>
<td>PIC_ENABLE[1]</td>
<td>RW</td>
<td>1</td>
<td>0x0</td>
</tr>
<tr>
<td>[0]</td>
<td>PIC_ENABLE[0]</td>
<td>RW</td>
<td>1</td>
<td>0x0</td>
</tr>
</tbody>
</table>

**PIC_ENABLE[i]:**
- **Read**
  - 0 – irq[i] disabled
  - 1 – irq[i] enabled
- **Write**
  - 0 – disable irq[i]
  - 1 – enable irq[i]

### PIC_SET

**Description:** Interrupt Set Register (write-only) (parameterizable width, min=2, max=8) Set the interrupt status for corresponding interrupt request port (irq[i]).

<table>
<thead>
<tr>
<th>Field</th>
<th>Name</th>
<th>Access</th>
<th>Width</th>
<th>Reset</th>
</tr>
</thead>
<tbody>
<tr>
<td>[N-1]</td>
<td>PIC_SET [N-1]</td>
<td>W</td>
<td>1</td>
<td>0x0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>[1]</td>
<td>PIC_SET [1]</td>
<td>W</td>
<td>1</td>
<td>0x0</td>
</tr>
<tr>
<td>[0]</td>
<td>PIC_SET [0]</td>
<td>W</td>
<td>1</td>
<td>0x0</td>
</tr>
</tbody>
</table>

**PIC_SET[i]:**
- **Read**
  - Invalid operation gets 0.
- **Write**
  - 0 – no effect
  - 1 – set interrupt status for irq[i] (set PIC_STATUS[i])

### PIC_POL

**Description:** Interrupt Polarity Register (read-write) (parameterizable width, min=2, max=8) Indicates the polarity of corresponding interrupt request (irq[i]) port.

<table>
<thead>
<tr>
<th>Field</th>
<th>Name</th>
<th>Access</th>
<th>Width</th>
<th>Reset</th>
</tr>
</thead>
<tbody>
<tr>
<td>[N]</td>
<td>PIC_POL [N]</td>
<td>RW</td>
<td>1</td>
<td>0x0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>[1]</td>
<td>PIC_POL [1]</td>
<td>RW</td>
<td>1</td>
<td>0x0</td>
</tr>
<tr>
<td>[0]</td>
<td>PIC_POL [0]</td>
<td>RW</td>
<td>1</td>
<td>0x0</td>
</tr>
</tbody>
</table>

**PIC_POL[i]:**
- **Read**
  - 0 – irq[i] is active high
  - 1 – irq[i] is active low
- **Write**
  - 0 – Set irq[i] active high
  - 1 – Set irq[i] active low

**Note:** The register definition of PIC follows Lattice Interrupt Interface (LINTR) Standard, refer to [Lattice Memory Mapped Interface (LMMI) and Lattice Interrupt Interface (LINTR) User Guide](FPGA-UG-02039) for more information.
2.2.2.2. Timer

The Timer module provides a 64-bit real-time counter register (mtime) and time compare register (mtimecmp). An output interrupt signal notifies the RISC-V processor core when the value of mtime is greater than or equal to the value of mtimecmp. All registers can be accessed through an AHB-L interface, as shown in Figure 2.4.

Table 2.3 provides the description of Timer registers.

<table>
<thead>
<tr>
<th>Offset</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x400</td>
<td>TIMER_CNT_L</td>
<td>Lower 32 bits of Timer counter register.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Field</td>
<td>Name</td>
</tr>
<tr>
<td>[63:0]</td>
<td>mtime</td>
<td>RW</td>
</tr>
<tr>
<td></td>
<td>mtime</td>
<td>A 64-bit real-time counter register. You must set the register to a non-zero value to start the counting process.</td>
</tr>
<tr>
<td>0x404</td>
<td>TIMER_CNT_H</td>
<td>Higher 32 bits of Timer counter register.</td>
</tr>
<tr>
<td></td>
<td>TIMER_CMP_L</td>
<td>Lower 32 bits for Timer time compare register.</td>
</tr>
<tr>
<td></td>
<td>Field</td>
<td>Name</td>
</tr>
<tr>
<td>[63:0]</td>
<td>mtimecmp</td>
<td>RW</td>
</tr>
<tr>
<td></td>
<td>mtimecmp</td>
<td>This register is used to generate or clear the timer interrupt (mtip). When the value of mtime register is greater than or equal to the value of mtimecmp register, the cpu_mtip_o is asserted. The interrupt remains posted until mtimecmp becomes greater than mtime (typically as a result of writing mtimecmp).</td>
</tr>
</tbody>
</table>
2.3. Signal Description

Table 2.4 to Table 2.7 list the ports of the CPU soft IP in different categories.

2.3.1. Clock and Reset

Table 2.4. Clock and Reset Ports

<table>
<thead>
<tr>
<th>Name</th>
<th>Direction</th>
<th>Width</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>clk_i</td>
<td>In</td>
<td>1</td>
<td>RISC-V soft IP clock</td>
</tr>
<tr>
<td>rst_n_i</td>
<td>In</td>
<td>1</td>
<td>Global reset (active low)</td>
</tr>
<tr>
<td>system_resetn_o</td>
<td>Out</td>
<td>1</td>
<td>Combined Global reset and Debug Reset from JTAG</td>
</tr>
</tbody>
</table>

2.3.2. Instruction and Data Interface

Table 2.5. Instruction Ports

<table>
<thead>
<tr>
<th>Name</th>
<th>Direction</th>
<th>Width</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AHBL_M0_INSTR - HADDR</td>
<td>Out</td>
<td>32</td>
<td>—</td>
</tr>
<tr>
<td>AHBL_M0_INSTR - HWRITE</td>
<td>Out</td>
<td>1</td>
<td>Fixed to 1'b0</td>
</tr>
<tr>
<td>AHBL_M0_INSTR - HSIZE</td>
<td>Out</td>
<td>3</td>
<td>Fixed to 3'b010</td>
</tr>
<tr>
<td>AHBL_M0_INSTR - HPROT</td>
<td>Out</td>
<td>4</td>
<td>Fixed to 4'b1110 when cache is not enabled</td>
</tr>
<tr>
<td>AHBL_M0_INSTR - HTRANS</td>
<td>Out</td>
<td>2</td>
<td>—</td>
</tr>
<tr>
<td>AHBL_M0_INSTR - HBURST</td>
<td>Out</td>
<td>3</td>
<td>—</td>
</tr>
<tr>
<td>AHBL_M0_INSTR - HMASTLOCK</td>
<td>Out</td>
<td>1</td>
<td>Fixed to 1'b0</td>
</tr>
<tr>
<td>AHBL_M0_INSTR - HWDATA</td>
<td>Out</td>
<td>32</td>
<td>—</td>
</tr>
<tr>
<td>AHBL_M0_INSTR - HRDATA</td>
<td>In</td>
<td>32</td>
<td>—</td>
</tr>
<tr>
<td>AHBL_M0_INSTR - HREADY</td>
<td>In</td>
<td>1</td>
<td>—</td>
</tr>
<tr>
<td>AHBL_M0_INSTR - HRESP</td>
<td>In</td>
<td>1</td>
<td>—</td>
</tr>
</tbody>
</table>

Table 2.6. Data Ports

<table>
<thead>
<tr>
<th>Name</th>
<th>Direction</th>
<th>Width</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AHBL_M1_DATA - HADDR</td>
<td>Out</td>
<td>32</td>
<td>—</td>
</tr>
<tr>
<td>AHBL_M1_DATA - HWRITE</td>
<td>Out</td>
<td>1</td>
<td>—</td>
</tr>
<tr>
<td>AHBL_M1_DATA - HSIZE</td>
<td>Out</td>
<td>3</td>
<td>—</td>
</tr>
<tr>
<td>AHBL_M1_DATA - HPROT</td>
<td>Out</td>
<td>4</td>
<td>Fixed to 4'b1111 when cache is not enabled</td>
</tr>
<tr>
<td>AHBL_M1_DATA - HTRANS</td>
<td>Out</td>
<td>2</td>
<td>—</td>
</tr>
<tr>
<td>AHBL_M1_DATA - HBURST</td>
<td>Out</td>
<td>3</td>
<td>—</td>
</tr>
<tr>
<td>AHBL_M1_DATA - HMASTLOCK</td>
<td>Out</td>
<td>1</td>
<td>—</td>
</tr>
<tr>
<td>AHBL_M1_DATA - HSEL</td>
<td>Out</td>
<td>1</td>
<td>—</td>
</tr>
<tr>
<td>AHBL_M1_DATA - HWDATA</td>
<td>Out</td>
<td>32</td>
<td>—</td>
</tr>
<tr>
<td>AHBL_M1_DATA - HRDATA</td>
<td>In</td>
<td>32</td>
<td>—</td>
</tr>
<tr>
<td>AHBL_M1_DATA - HREADY</td>
<td>In</td>
<td>1</td>
<td>—</td>
</tr>
</tbody>
</table>

Note: Refer to AMBA 3 AHB-Lite Protocol V1.0 for more information.
2.3.3. Interrupt interface

Table 2.7. Interrupt Ports

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Width</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>IRQ_Sx</td>
<td>In</td>
<td>1~8</td>
<td>Peripheral interrupts.</td>
</tr>
<tr>
<td>TIMER_IRQ_M0</td>
<td>Out</td>
<td>1</td>
<td>Timer interrupt output, exists only when &quot;TIMER_ENABLE&quot; is checked.</td>
</tr>
<tr>
<td>TIMER_IRQ_S0</td>
<td>In</td>
<td>1</td>
<td>Timer interrupt input, exists only when &quot;TIMER_ENABLE&quot; is unchecked.</td>
</tr>
</tbody>
</table>

2.4. Attribute Summary

The configurable attributes of the RISC-V MC CPU IP are shown in Table 2.8 and are described in Table 2.9. The attributes can be configured through the Propel Builder software.

Table 2.8. Configurable Attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Selectable Values</th>
<th>Default</th>
<th>Dependency on Other Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>General</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SIMULATION</td>
<td>Checked, Unchecked</td>
<td>UnChecked</td>
<td>—</td>
</tr>
<tr>
<td>CACHE_ENABLE</td>
<td>Checked, Unchecked</td>
<td>Checked</td>
<td>Disabled when SIMULATION</td>
</tr>
<tr>
<td>ICACHE_RANGE_LOW</td>
<td>0 ~ 0xFFFFFFFF</td>
<td>0</td>
<td>Enabled when CACHE_ENABLE</td>
</tr>
<tr>
<td>ICACHE_RANGE_HIGH</td>
<td>0 ~ 0xFFFFFFFF</td>
<td>0xF00000000</td>
<td>Enabled when CACHE_ENABLE</td>
</tr>
<tr>
<td>DCACHE_RANGE_LOW</td>
<td>0 ~ 0xFFFFFFFF</td>
<td>0</td>
<td>Enabled when CACHE_ENABLE</td>
</tr>
<tr>
<td>DCACHE_RANGE_HIGH</td>
<td>0 ~ 0xFFFFFFFF</td>
<td>0xF00000000</td>
<td>Enabled when CACHE_ENABLE</td>
</tr>
<tr>
<td>DEBUG_ENABLE</td>
<td>Checked, Unchecked</td>
<td>Checked</td>
<td>—</td>
</tr>
<tr>
<td>SOFT_JTAG</td>
<td>Checked, Unchecked</td>
<td>Checked when DEBUG_ENABLE and DEVICE == &quot;LAV-AT&quot;</td>
<td>—</td>
</tr>
<tr>
<td>TIMER_ENABLE</td>
<td>Checked, Unchecked</td>
<td>Checked</td>
<td>—</td>
</tr>
<tr>
<td>PIC_ENABLE</td>
<td>Checked, Unchecked</td>
<td>Checked</td>
<td>—</td>
</tr>
<tr>
<td>PICTIMER_START_ADDR</td>
<td>0 ~ 0xFFFFFB00</td>
<td>0xFFFFF0000</td>
<td>Enabled when PIC_ENABLE or TIMER_ENABLE</td>
</tr>
<tr>
<td>IRQ_NUM</td>
<td>2 ~ 8</td>
<td>8</td>
<td>Enabled when PIC_ENABLE</td>
</tr>
<tr>
<td>C_EXT</td>
<td>Checked, Unchecked</td>
<td>Checked</td>
<td>—</td>
</tr>
<tr>
<td>M_EXT</td>
<td>Checked, Unchecked</td>
<td>Unchecked</td>
<td>Enabled when C_EXT (For Certus-NX, CertusPro-NX, CrossLink-NX, MachXO5-NX devices only.)</td>
</tr>
<tr>
<td>JTAG_CHANNEL</td>
<td>14~16</td>
<td>14</td>
<td>Enabled when DEBUG_ENABLE</td>
</tr>
</tbody>
</table>

Table 2.9. Attributes Description

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIMULATION</td>
<td>1: simulation mode 0: synthesis mode</td>
</tr>
<tr>
<td>ICACHE_ENABLE</td>
<td>1: enable instruction cache 0: disable instruction cache</td>
</tr>
<tr>
<td>DCACHE_ENABLE</td>
<td>1: enable data cache 0: disable data cache</td>
</tr>
<tr>
<td>ICACHE_RANGE_LOW</td>
<td>Lower limit of cacheable address range for instruction cache, this address itself is included.</td>
</tr>
<tr>
<td>ICACHE_RANGE_HIGH</td>
<td>Higher limit of cacheable address range for instruction cache, this address itself is included.</td>
</tr>
<tr>
<td>DCACHE_RANGE_LOW</td>
<td>Lower limit of cacheable address range for data cache, this address itself is included.</td>
</tr>
<tr>
<td>Attribute</td>
<td>Description</td>
</tr>
<tr>
<td>----------------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>DCACHE_RANGE_HIGH</td>
<td>Higher limit of cacheable address range for data cache, this address itself is included.</td>
</tr>
</tbody>
</table>
| DEBUG_ENABLE         | 1: debug function enable  
|                      | 0: debug function disable                                                     |
| SOFT_JTAG            | 1: debug with hard JTAG  
|                      | 0: debug with soft JTAG                                                       |
| TIMER_ENABLE         | 1: timer enable  
|                      | 0: timer disable                                                             |
| PIC_ENABLE           | 1: pic enable  
|                      | 0: pic disable                                                               |
| PICTIMER_START_ADDR  | Start address of PIC and Timer                                              |
| IRQ_NUM              | Number of Peripheral Interrupts                                            |
| C_EXT                | 1: support for compressed instruction  
|                      | 0: no support for compressed instruction                                      |
| M_EXT                | 1: support for M standard extension  
|                      | 0: no support for M standard extension                                        |
| JTAG_CHANNEL         | JTAG channel select                                                         |

**Notes:**
- “ICACHE_ENABLE” and “DCACHE_ENABLE” should only be enabled when using CrossLink-NX Devices with sufficient resources. For MachXO2, MachXO3L, MachXO3LF and MachXO3D devices, cache features are not supported as their resources are limited.
- “ICACHE_RANGE_LOW” should not be larger than “ICACHE_RANGE_HIGH”, and address range between “ICACHE_RANGE_LOW” and “ICACHE_RANGE_HIGH” should not be overlapped with peripheral device address ranges. The memory which stores instructions should always be fixed in this range.
- Similarly, “DCACHE_RANGE_LOW” should not be larger than “DCACHE_RANGE_HIGH”, and address range between “DCACHE_RANGE_LOW” and “DCACHE_RANGE_HIGH” should not be overlapped with peripheral devices address ranges.
- “SIMULATION” and “DEBUG_ENABLE” cannot be enabled at the same time.
3. RISC-V MC CPU IP Generation

This section provides information on how to generate the CPU IP Core module using Propel Builder.

To generate the CPU IP Core module:

1. In Propel Builder, create a new design. Select the CPU package.
2. Enter the component name, as shown in Figure 3.1. Click Next.

![Figure 3.1. Entering Component Name](image)

3. Configure the parameters, as shown in Figure 3.2. Click Generate.
4. Verify the information. Click Finish.
5. Confirm or modify the module instance name. Click OK.

![Define Instance](image1)

Figure 3.4. Specifying Instance Name

The CPU IP instance is successfully generated, as shown in Figure 3.5.

![Generated Instance](image2)

Figure 3.5. Generated Instance
Appendix A. Resource Utilization

### Table A.1. Resource Utilization in MachXO3D Device (with Cache Disabled)

<table>
<thead>
<tr>
<th>Configuration</th>
<th>LUTs</th>
<th>Registers</th>
<th>EBRs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processor core only</td>
<td>1450</td>
<td>806</td>
<td>4</td>
</tr>
<tr>
<td>Processor core + PIC</td>
<td>1559</td>
<td>845</td>
<td>4</td>
</tr>
<tr>
<td>Processor core + Timer</td>
<td>1844</td>
<td>955</td>
<td>4</td>
</tr>
<tr>
<td>Processor core + Debug</td>
<td>1726</td>
<td>1108</td>
<td>4</td>
</tr>
<tr>
<td>Processor core + C_EXT</td>
<td>1738</td>
<td>860</td>
<td>4</td>
</tr>
<tr>
<td>Processor core + PIC + Timer</td>
<td>1927</td>
<td>989</td>
<td>4</td>
</tr>
<tr>
<td>Processor core + PIC + Timer + Debug</td>
<td>2162</td>
<td>1287</td>
<td>4</td>
</tr>
<tr>
<td>Processor core + PIC + Timer + Debug + C_EXT</td>
<td>2385</td>
<td>1345</td>
<td>4</td>
</tr>
</tbody>
</table>

**Note:** Resource utilization characteristics are generated using Lattice Diamond software.

### Table A.2. Resource Utilization in CrossLink-NX Device (with Cache Disabled)

<table>
<thead>
<tr>
<th>Configuration</th>
<th>LUTs</th>
<th>Registers</th>
<th>EBRs</th>
<th>DSP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processor core only</td>
<td>1620</td>
<td>821</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Processor core + PIC</td>
<td>1789</td>
<td>859</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Processor core + Timer</td>
<td>2103</td>
<td>959</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Processor core + Debug</td>
<td>1979</td>
<td>1194</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Processor core + C_EXT</td>
<td>1911</td>
<td>830</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Processor core + C_EXT + M_EXT</td>
<td>2417</td>
<td>1172</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Processor core + PIC + Timer</td>
<td>2226</td>
<td>994</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Processor core + PIC + Timer + Debug</td>
<td>2494</td>
<td>1375</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Processor core + PIC + Timer + Debug + C_EXT</td>
<td>2790</td>
<td>1450</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

**Note:** Resource utilization characteristics are generated using Lattice Radiant software.

### Table A.3. Resource Utilization in CrossLink-NX Device (with Cache Enabled)

<table>
<thead>
<tr>
<th>Configuration</th>
<th>LUTs</th>
<th>Registers</th>
<th>EBRs</th>
<th>DSP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processor core + only</td>
<td>3372</td>
<td>1423</td>
<td>16</td>
<td>0</td>
</tr>
<tr>
<td>Processor core + PIC</td>
<td>3568</td>
<td>1479</td>
<td>16</td>
<td>0</td>
</tr>
<tr>
<td>Processor core + Timer</td>
<td>3753</td>
<td>1574</td>
<td>16</td>
<td>0</td>
</tr>
<tr>
<td>Processor core + Debug</td>
<td>3687</td>
<td>1810</td>
<td>16</td>
<td>0</td>
</tr>
<tr>
<td>Processor core + C_EXT</td>
<td>3711</td>
<td>1551</td>
<td>16</td>
<td>0</td>
</tr>
<tr>
<td>Processor core + C_EXT + M_EXT</td>
<td>4133</td>
<td>1879</td>
<td>16</td>
<td>6</td>
</tr>
<tr>
<td>Processor core + PIC + Timer</td>
<td>3894</td>
<td>1606</td>
<td>16</td>
<td>0</td>
</tr>
<tr>
<td>Processor core + PIC + Timer + Debug</td>
<td>4309</td>
<td>1980</td>
<td>16</td>
<td>0</td>
</tr>
<tr>
<td>Processor core + PIC + Timer + Debug + C_EXT</td>
<td>4568</td>
<td>2032</td>
<td>16</td>
<td>0</td>
</tr>
</tbody>
</table>

**Note:** Resource utilization characteristics are generated using Lattice Radiant software.
### Table A.4. Resource Utilization in Lattice Avant Device (with Cache Disabled)

<table>
<thead>
<tr>
<th>Configuration</th>
<th>LUTs</th>
<th>Registers</th>
<th>EBRs</th>
<th>DSP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processor core + only</td>
<td>2015</td>
<td>867</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Processor core + PIC</td>
<td>2097</td>
<td>886</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Processor core + Timer</td>
<td>2456</td>
<td>979</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Processor core + Debug</td>
<td>2376</td>
<td>1268</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Processor core + C_EXT</td>
<td>2202</td>
<td>860</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Processor core + C_EXT + M_EXT</td>
<td>2731</td>
<td>1284</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Processor core + PIC + Timer</td>
<td>2535</td>
<td>1017</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Processor core + PIC + Timer + Debug</td>
<td>2869</td>
<td>1444</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Processor core + PIC + Timer + C_EXT</td>
<td>3128</td>
<td>1528</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

**Note:** Resource utilization characteristics are generated using Lattice Radiant software.

### Table A.5. Resource Utilization in Lattice Avant Device (with Cache Enabled)

<table>
<thead>
<tr>
<th>Configuration</th>
<th>LUTs</th>
<th>Registers</th>
<th>EBRs</th>
<th>DSP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processor core + only</td>
<td>3340</td>
<td>1364</td>
<td>18</td>
<td>0</td>
</tr>
<tr>
<td>Processor core + PIC</td>
<td>3437</td>
<td>1406</td>
<td>18</td>
<td>0</td>
</tr>
<tr>
<td>Processor core + Timer</td>
<td>3857</td>
<td>1548</td>
<td>18</td>
<td>0</td>
</tr>
<tr>
<td>Processor core + Debug</td>
<td>3708</td>
<td>1806</td>
<td>18</td>
<td>0</td>
</tr>
<tr>
<td>Processor core + C_EXT</td>
<td>3671</td>
<td>1546</td>
<td>18</td>
<td>0</td>
</tr>
<tr>
<td>Processor core + C_EXT + M_EXT</td>
<td>4431</td>
<td>1861</td>
<td>18</td>
<td>6</td>
</tr>
<tr>
<td>Processor core + PIC + Timer</td>
<td>3809</td>
<td>1655</td>
<td>18</td>
<td>0</td>
</tr>
<tr>
<td>Processor core + PIC + Timer + Debug</td>
<td>4381</td>
<td>1995</td>
<td>18</td>
<td>0</td>
</tr>
<tr>
<td>Processor core + PIC + Timer + C_EXT</td>
<td>4559</td>
<td>2168</td>
<td>18</td>
<td>0</td>
</tr>
</tbody>
</table>

**Note:** Resource utilization characteristics are generated using Lattice Radiant software.

### Table A.6. Resource Utilization in CertusPro-NX Device (with Cache Disabled)

<table>
<thead>
<tr>
<th>Configuration</th>
<th>LUTs</th>
<th>Registers</th>
<th>EBRs</th>
<th>DSP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processor core + only</td>
<td>1978</td>
<td>834</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Processor core + PIC</td>
<td>2105</td>
<td>886</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Processor core + Timer</td>
<td>2446</td>
<td>990</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Processor core + Debug</td>
<td>2304</td>
<td>1218</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Processor core + C_EXT</td>
<td>2288</td>
<td>896</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Processor core + C_EXT + M_EXT</td>
<td>2790</td>
<td>1185</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Processor core + PIC + Timer</td>
<td>2578</td>
<td>1032</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Processor core + PIC + Timer + Debug</td>
<td>2871</td>
<td>1390</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Processor core + PIC + Timer + C_EXT</td>
<td>3220</td>
<td>1461</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

**Note:** Resource utilization characteristics are generated using Lattice Radiant software.

### Table A.7. Resource Utilization in CertusPro-NX Device (with Cache Enabled)

<table>
<thead>
<tr>
<th>Configuration</th>
<th>LUTs</th>
<th>Registers</th>
<th>EBRs</th>
<th>DSP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processor core + only</td>
<td>3031</td>
<td>1461</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>Processor core + PIC</td>
<td>3391</td>
<td>1505</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>Processor core + Timer</td>
<td>3812</td>
<td>1607</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>Processor core + Debug</td>
<td>3667</td>
<td>1854</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>Processor core + C_EXT</td>
<td>3691</td>
<td>1613</td>
<td>19</td>
<td>0</td>
</tr>
<tr>
<td>Processor core + C_EXT + M_EXT</td>
<td>4334</td>
<td>2007</td>
<td>19</td>
<td>6</td>
</tr>
<tr>
<td>Processor core + PIC + Timer</td>
<td>3926</td>
<td>1671</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>Processor core + PIC + Timer + Debug</td>
<td>4139</td>
<td>2012</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>Processor core + PIC + Timer + C_EXT</td>
<td>4450</td>
<td>2169</td>
<td>19</td>
<td>0</td>
</tr>
</tbody>
</table>

**Note:** Resource utilization characteristics are generated using Lattice Radiant software.
References

- AMBA 3 AHB-Lite Protocol V1.0
- RISC-V Privileged Specification (20190608)
- RISC-V Instruction Set Manual (20190608)
- Lattice Memory Mapped Interface (LMMI) and Lattice Interrupt Interface (LINTR) User Guide (FPGA-UG-02039)
Technical Support Assistance
Submit a technical support case through www.latticesemi.com/techsupport.
For frequently asked questions, refer to the Lattice Answer Database at www.latticesemi.com/Support/AnswerDatabase
## Revision History

**Revision 1.0, May 2023**

<table>
<thead>
<tr>
<th>Section</th>
<th>Change Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>Production release.</td>
</tr>
</tbody>
</table>