



## OVP Guide to Using Processor Models

### Model specific information for OpenHwGroup\_CV32E40P

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Author	Imperas Software Limited
Version	99999999
Filename	OVP_Model_Specific_Informationopenhwgroup_riscv_CV32E40P.pdf
Created	9 November 2020
Status	OVP Standard Release

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## Model Release Status

This model is released as part of OVP releases and is included in OVPworld packages. Please visit [OVPworld.org](http://OVPworld.org).

# Contents

<b>1</b>	<b>Overview</b>	<b>1</b>
1.1	Description	1
1.2	Licensing	1
1.3	Extensions	1
1.3.1	Available (But Not Enabled) Extensions	2
1.4	General Features	2
1.5	CLIC	3
1.5.1	CLIC Common Parameters	4
1.5.2	CLIC Internal-Implementation Parameters	4
1.5.3	CLIC External-Implementation Net Port Interface	4
1.6	Interrupts	5
1.7	Debug Mode	6
1.7.1	Debug State Entry	6
1.7.2	Debug State Exit	7
1.7.3	Debug Registers	7
1.7.4	Debug Mode Execution	7
1.7.5	Debug Single Step	7
1.7.6	Debug Ports	8
1.8	Trigger Module	8
1.8.1	Trigger Module Restrictions	8
1.8.2	Trigger Module Parameters	8
1.9	Debug Mask	9
1.10	Integration Support	9
1.10.1	CSR Register External Implementation	9
1.11	Limitations	9
1.12	Verification	10
1.13	References	10
<b>2</b>	<b>Configuration</b>	<b>11</b>
2.1	Location	11
2.2	GDB Path	11
2.3	Semi-Host Library	11
2.4	Processor Endian-ness	11
2.5	QuantumLeap Support	11
2.6	Processor ELF code	11
<b>3</b>	<b>All Variants in this model</b>	<b>12</b>

<b>4</b>	<b>Bus Master Ports</b>	<b>13</b>
<b>5</b>	<b>Bus Slave Ports</b>	<b>14</b>
<b>6</b>	<b>Net Ports</b>	<b>15</b>
<b>7</b>	<b>FIFO Ports</b>	<b>17</b>
<b>8</b>	<b>Formal Parameters</b>	<b>18</b>
8.1	Extension Parameters . . . . .	19
8.2	Parameters with enumerated types . . . . .	20
8.2.1	Parameter user_version . . . . .	20
8.2.2	Parameter priv_version . . . . .	20
8.2.3	Parameter debug_version . . . . .	20
8.2.4	Parameter debug_mode . . . . .	20
8.2.5	Parameter debug_eret_mode . . . . .	20
<b>9</b>	<b>Execution Modes</b>	<b>22</b>
<b>10</b>	<b>Exceptions</b>	<b>23</b>
<b>11</b>	<b>Hierarchy of the model</b>	<b>25</b>
11.1	Level 1: Hart . . . . .	25
<b>12</b>	<b>Model Commands</b>	<b>26</b>
12.1	Level 1: Hart . . . . .	26
12.1.1	isync . . . . .	26
12.1.2	itrace . . . . .	26
<b>13</b>	<b>Registers</b>	<b>27</b>
13.1	Level 1: Hart . . . . .	27
13.1.1	Core . . . . .	27
13.1.2	Machine_Control_and_Status . . . . .	28
13.1.3	Integration_support . . . . .	31

# Chapter 1

## Overview

This document provides the details of an OVP Fast Processor Model variant.

OVP Fast Processor Models are written in C and provide a C API for use in C based platforms. The models also provide a native interface for use in SystemC TLM2 platforms.

The models are written using the OVP VMI API that provides a Virtual Machine Interface that defines the behavior of the processor. The VMI API makes a clear line between model and simulator allowing very good optimization and world class high speed performance. Most models are provided as a binary shared object and also as source. This allows the download and use of the model binary or the use of the source to explore and modify the model.

The models are run through an extensive QA and regression testing process and most model families are validated using technology provided by the processor IP owners. There is a companion document (OVP Guide to Using Processor Models) which explains the general concepts of OVP Fast Processor Models and their use. It is downloadable from the OVPworld website documentation pages.

### 1.1 Description

RISC-V CV32E40P 32-bit processor model

### 1.2 Licensing

This Model is released under the Open Source Apache 2.0

### 1.3 Extensions

The model has the following architectural extensions enabled, and the following bits in the misa CSR Extensions field will be set upon reset:

misa bit 2: extension C (compressed instructions)

misa bit 8: RV32I/64I/128I base ISA

misa bit 12: extension M (integer multiply/divide instructions)

misa bit 23: extension X (non-standard extensions present)

To specify features that can be dynamically enabled or disabled by writes to the misa register in addition to those listed above, use parameter “add\_Extensions\_mask”. This is a string parameter containing the feature letters to add; for example, value “DV” indicates that double-precision floating point and the Vector Extension can be enabled or disabled by writes to the misa register.

Legacy parameter “misa\_Extensions\_mask” can also be used. This Uns32-valued parameter specifies all writable bits in the misa Extensions field, replacing any value defined in the base variant.

Note that any features that are indicated as present in the misa mask but absent in the misa will be ignored. See the next section.

### 1.3.1 Available (But Not Enabled) Extensions

The following extensions are supported by the model, but not enabled by default in this variant:

misa bit 0: extension A (atomic instructions) (NOT ENABLED)

misa bit 1: extension B (bit manipulation extension) (NOT ENABLED)

misa bit 3: extension D (double-precision floating point) (NOT ENABLED)

misa bit 4: RV32E base ISA (NOT ENABLED)

misa bit 5: extension F (single-precision floating point) (NOT ENABLED)

misa bit 7: extension H (hypervisor) (NOT ENABLED)

misa bit 10: extension K (cryptographic) (NOT ENABLED)

misa bit 13: extension N (user-level interrupts) (NOT ENABLED)

misa bit 18: extension S (Supervisor mode) (NOT ENABLED)

misa bit 20: extension U (User mode) (NOT ENABLED)

misa bit 21: extension V (vector extension) (NOT ENABLED)

To add features from this list to the base variant, use parameter “add\_Extensions”. This is a string parameter containing the feature letters to add; for example, value “DV” indicates that double-precision floating point and the Vector Extension should be enabled, if they are absent.

Legacy parameter “misa\_Extensions” can also be used. This Uns32-valued parameter specifies the reset value for the misa CSR Extensions field, replacing any value defined in the base variant.

## 1.4 General Features

On this variant, the Machine trap-vector base-address register (mtvec) is writable. It can instead be configured as read-only using parameter “mtvec\_is\_ro”.

Values written to “mtvec” are masked using the value 0xfffff01. A different mask of writable bits may be specified using parameter “mtvec\_mask” if required. In addition, when Vectored interrupt mode is enabled, parameter “tvec\_align” may be used to specify additional hardware-enforced base address alignment. In this variant, “tvec\_align” defaults to 0, implying no alignment constraint.

The initial value of “mtvec” is 0x1. A different value may be specified using parameter “mtvec” if required.

On reset, the model will restart at address 0x0. A different reset address may be specified using parameter “reset\_address” if required.

On an NMI, the model will restart at address 0x0. A different NMI address may be specified using parameter “nmi\_address” if required.

WFI will halt the processor until an interrupt occurs. It can instead be configured as a NOP using parameter “wfi\_is\_nop”. WFI timeout wait is implemented with a time limit of 0 (i.e. WFI causes an Illegal Instruction trap in Supervisor mode when mstatus.TW=1).

The “cycle” CSR is implemented in this variant. Set parameter “cycle\_undefined” to True to instead specify that “cycle” is unimplemented and reads of it should trap to Machine mode.

The “time” CSR is not implemented in this variant and reads of it will require emulation in Machine mode. Set parameter “time\_undefined” to False to instead specify that “time” is implemented.

The “instret” CSR is implemented in this variant. Set parameter “instret\_undefined” to True to instead specify that “instret” is unimplemented and reads of it should trap to Machine mode.

Unaligned memory accesses are supported by this variant. Set parameter “unaligned” to “F” to disable such accesses.

A PMP unit is not implemented by this variant. Set parameter “PMP\_registers” to indicate that the unit should be implemented with that number of PMP entries.

## 1.5 CLIC

The model can be configured to implement a Core Local Interrupt Controller (CLIC) using parameter “CLICLEVELS”; when non-zero, the CLIC is present with the specified number of interrupt levels (2-256), as described in the RISC-V Core-Local Interrupt Controller specification (see references). When “CLICLEVELS” is non-zero, further parameters are made available to configure other aspects of the CLIC, as described below.

The model can be configured either to use an internal CLIC model (if parameter “externalCLIC” is False) or to present a net interface to allow the CLIC to be implemented externally in a platform component (if parameter “externalCLIC” is True). When the CLIC is implemented internally, net ports for standard interrupts and additional local interrupts are available. When the CLIC is implemented externally, a net port interface allowing the highest-priority pending interrupt to be delivered is instead present. This is described below.

### 1.5.1 CLIC Common Parameters

This section describes parameters applicable whether the CLIC is implemented internally or externally. These are:

“CLICANDBASIC”: this Boolean parameter indicates whether both CLIC and basic interrupt controller are present (if True) or whether only the CLIC is present (if False).

“CLICXNXTI”: this Boolean parameter indicates whether xnxti CSRs are implemented (if True) or unimplemented (if False).

“CLICXCSW”: this Boolean parameter indicates whether xscratchsw and xscratchswl CSRs registers are implemented (if True) or unimplemented (if False).

“mclicbase”: this parameter specifies the CLIC base address in physical memory.

“tvt\_undefined”: this Boolean parameter indicates whether xtvt CSRs registers are implemented (if True) or unimplemented (if False). If the registers are unimplemented then the model will use basic mode vectored interrupt semantics based on the xtvec CSRs instead of Selective Hardware Vectoring semantics described in the specification.

“intthresh\_undefined”: this Boolean parameter indicates whether xintthresh CSRs registers are implemented (if True) or unimplemented (if False).

“mclicbase\_undefined”: this Boolean parameter indicates whether the mclicbase CSR register is implemented (if True) or unimplemented (if False).

### 1.5.2 CLIC Internal-Implementation Parameters

This section describes parameters applicable only when the CLIC is implemented internally. These are:

“CLICCFGMBITS”: this Uns32 parameter indicates the number of bits implemented in cliccfg.nmbits, and also indirectly defines CLICPRIVMODES. For cores which implement only Machine mode, or which implement Machine and User modes but not the N extension, the parameter is absent (“CLICCFGMBITS” must be zero in these cases).

“CLICCFGLBITS”: this Uns32 parameter indicates the number of bits implemented in cliccfg.nlbits.

“CLICSELHVEC”: this Boolean parameter indicates whether Selective Hardware Vectoring is supported (if True) or unsupported (if False).

### 1.5.3 CLIC External-Implementation Net Port Interface

When the CLIC is externally implemented, net ports are present allowing the external CLIC model to supply the highest-priority pending interrupt and to be notified when interrupts are handled. These are:

“irq\_id\_i”: this input should be written with the id of the highest-priority pending interrupt.

“irq\_lev\_i”: this input should be written with the highest-priority interrupt level.



“irq\_sec\_i”: this 2-bit input should be written with the highest-priority interrupt security state (00:User, 01:Supervisor, 11:Machine).

“irq\_shv\_i”: this input port should be written to indicate whether the highest-priority interrupt should be direct (0) or vectored (1). If the “vtv\_undefined” parameter is False, vectored interrupts will use selective hardware vectoring, as described in the CLIC specification. If “vtv\_undefined” is True, vectored interrupts will behave like basic mode vectored interrupts.

“irq\_id\_i”: this input should be written with the id of the highest-priority pending interrupt.

“irq\_i”: this input should be written with 1 to indicate that the external CLIC is presenting an interrupt, or 0 if no interrupt is being presented.

“irq\_ack\_o”: this output is written by the model on entry to the interrupt handler (i.e. when the interrupt is taken). It will be written as an instantaneous pulse (i.e. written to 1, then immediately 0).

“irq\_id\_o”: this output is written by the model with the id of the interrupt currently being handled. It is valid during the instantaneous irq\_ack\_o pulse.

“sec\_lvl\_o”: this output signal indicates the current secure status of the processor, as a 2-bit value (00=User, 01:Supervisor, 11=Machine).

## 1.6 Interrupts

The “reset” port is an active-high reset input. The processor is halted when “reset” goes high and resumes execution from the reset address specified using the “reset\_address” parameter when the signal goes low. The “mcause” register is cleared to zero.

The “nmi” port is an active-high NMI input. The processor resumes execution from the address specified using the “nmi\_address” parameter when the NMI signal goes high. The “mcause” register is cleared to zero.

All other interrupt ports are active high. For each implemented privileged execution level, there are by default input ports for software interrupt, timer interrupt and external interrupt; for example, for Machine mode, these are called “MSWInterrupt”, “MTimerInterrupt” and “MExternalInterrupt”, respectively. When the N extension is implemented, ports are also present for User mode. Parameter “unimp\_int\_mask” allows the default behavior to be changed to exclude certain interrupt ports. The parameter value is a mask in the same format as the “mip” CSR; any interrupt corresponding to a non-zero bit in this mask will be removed from the processor and read as zero in “mip”, “mie” and “mideleg” CSRs (and Supervisor and User mode equivalents if implemented).

Parameter “external\_int\_id” can be used to enable extra interrupt ID input ports on each hart. If the parameter is True then when an external interrupt is applied the value on the ID port is sampled and used to fill the Exception Code field in the “mcause” CSR (or the equivalent CSR for other execution levels). For Machine mode, the extra interrupt ID port is called “MExternalInterruptID”.

The “deferint” port is an active-high artifact input that, when written to 1, prevents any pending-and-enabled interrupt being taken (normally, such an interrupt would be taken on the next instruction after it becomes pending-and-enabled). The purpose of this signal is to enable alignment with hardware models in step-and-compare usage.

## 1.7 Debug Mode

The model can be configured to implement Debug mode using parameter “debug\_mode”. This implements features described in Chapter 4 of the RISC-V External Debug Support specification with version specified by parameter “debug\_version” (see References). Some aspects of this mode are not defined in the specification because they are implementation-specific; the model provides infrastructure to allow implementation of a Debug Module using a custom harness. Features added are described below.

Parameter “debug\_mode” can be used to specify three different behaviors, as follows:

1. If set to value “vector”, then operations that would cause entry to Debug mode result in the processor jumping to the address specified by the “debug\_address” parameter. It will execute at this address, in Debug mode, until a “dret” instruction causes return to non-Debug mode. Any exception generated during this execution will cause a jump to the address specified by the “dexc\_address” parameter.
2. If set to value “interrupt”, then operations that would cause entry to Debug mode result in the processor simulation call (e.g. `opProcessorSimulate`) returning, with a stop reason of `OP_SR_INTERRUPT`. In this usage scenario, the Debug Module is implemented in the simulation harness.
3. If set to value “halt”, then operations that would cause entry to Debug mode result in the processor halting. Depending on the simulation environment, this might cause a return from the simulation call with a stop reason of `OP_SR_HALT`, or debug mode might be implemented by another platform component which then restarts the debugged processor again.

### 1.7.1 Debug State Entry

The specification does not define how Debug mode is implemented. In this model, Debug mode is enabled by a Boolean pseudo-register, “DM”. When “DM” is True, the processor is in Debug mode. When “DM” is False, mode is defined by “mstatus” in the usual way.

Entry to Debug mode can be performed in any of these ways:

1. By writing True to register “DM” (e.g. using `opProcessorRegWrite`) followed by simulation of at least one cycle (e.g. using `opProcessorSimulate`), `dcsr` cause will be reported as trigger;
2. By writing a 1 then 0 to net “haltreq” (using `opNetWrite`) followed by simulation of at least one cycle (e.g. using `opProcessorSimulate`);
3. By writing a 1 to net “resethaltreq” (using `opNetWrite`) while the “reset” signal undergoes a negedge transition, followed by simulation of at least one cycle (e.g. using `opProcessorSimulate`);
4. By executing an “ebreak” instruction when Debug mode entry for the current processor mode is enabled by `dcsr.ebreakm`, `dcsr.ebreaks` or `dcsr.ebreaku`.

In all cases, the processor will save required state in “dpc” and “dcsr” and then perform actions described above, depending in the value of the “debug\_mode” parameter.

### 1.7.2 Debug State Exit

Exit from Debug mode can be performed in any of these ways:

1. By writing False to register “DM” (e.g. using `opProcessorRegWrite`) followed by simulation of at least one cycle (e.g. using `opProcessorSimulate`);
2. By executing an “dret” instruction when Debug mode.

In both cases, the processor will perform the steps described in section 4.6 (Resume) of the Debug specification.

### 1.7.3 Debug Registers

When Debug mode is enabled, registers “dcsr”, “dpc”, “dscratch0” and “dscratch1” are implemented as described in the specification. These may be manipulated externally by a Debug Module using `opProcessorRegRead` or `opProcessorRegWrite`; for example, the Debug Module could write “dcsr” to enable “ebreak” instruction behavior as described above, or read and write “dpc” to emulate stepping over an “ebreak” instruction prior to resumption from Debug mode.

### 1.7.4 Debug Mode Execution

The specification allows execution of code fragments in Debug mode. A Debug Module implementation can cause execution in Debug mode by the following steps:

1. Write the address of a Program Buffer to the program counter using `opProcessorPCSet`;
2. If “debug\_mode” is set to “halt”, write 0 to pseudo-register “DMStall” (to leave halted state);
3. If entry to Debug mode was handled by exiting the simulation callback, call `opProcessorSimulate` or `opRootModuleSimulate` to resume simulation.

Debug mode will be re-entered in these cases:

1. By execution of an “ebreak” instruction; or:
2. By execution of an instruction that causes an exception.

In both cases, the processor will either jump to the debug exception address, or return control immediately to the harness, with `stopReason` of `OP_SR_INTERRUPT`, or perform a halt, depending on the value of the “debug\_mode” parameter.

### 1.7.5 Debug Single Step

When in Debug mode, the processor or harness can cause a single instruction to be executed on return from that mode by setting `dcsr.step`. After one non-Debug-mode instruction has been executed, control will be returned to the harness. The processor will remain in single-step mode until `dcsr.step` is cleared.

### 1.7.6 Debug Ports

Port “DM” is an output signal that indicates whether the processor is in Debug mode

Port “haltreq” is a rising-edge-triggered signal that triggers entry to Debug mode (see above).

Port “resethaltreq” is a level-sensitive signal that triggers entry to Debug mode after reset (see above).

## 1.8 Trigger Module

This model is configured with a trigger module, implementing a subset of the behavior described in Chapter 5 of the RISC-V External Debug Support specification with version specified by parameter “debug\_version” (see References).

### 1.8.1 Trigger Module Restrictions

The model currently supports tdata1 of type 0, type 2 (mcontrol), type 3 (icount), type 4 (itrigger), type 5 (etrigger) and type 6 (mcontrol6). icount triggers are implemented for a single instruction only, with count hard-wired to 1 and automatic zeroing of mode bits when the trigger fires.

### 1.8.2 Trigger Module Parameters

Parameter “trigger\_num” is used to specify the number of implemented triggers. In this variant, “trigger\_num” is 1.

Parameter “tinfo” is used to specify the value of the read-only “tinfo” register, which indicates the trigger types supported. In this variant, “tinfo” is 0x04.

Parameter “tinfo\_undefined” is used to specify whether the “tinfo” register is undefined, in which case reads of it trap to Machine mode. In this variant, “tinfo\_undefined” is 0.

Parameter “tcontrol\_undefined” is used to specify whether the “tcontrol” register is undefined, in which case accesses to it trap to Machine mode. In this variant, “tcontrol\_undefined” is 1.

Parameter “mcontext\_undefined” is used to specify whether the “mcontext” register is undefined, in which case accesses to it trap to Machine mode. In this variant, “mcontext\_undefined” is 0.

Parameter “scontext\_undefined” is used to specify whether the “scontext” register is undefined, in which case accesses to it trap to Machine mode. In this variant, “scontext\_undefined” is 0.

Parameter “amo\_trigger” is used to specify whether load/store triggers are activated for AMO instructions. In this variant, “amo\_trigger” is 0.

Parameter “no\_hit” is used to specify whether the “hit” bit in tdata1 is unimplemented. In this variant, “no\_hit” is 1.

Parameter “mcontext\_bits” is used to specify the number of writable bits in the “mcontext” register. In this variant, “mcontext\_bits” is 0.

Parameter “mvalue\_bits” is used to specify the number of writable bits in the “mvalue” field in “extra32”/“extra64” registers; if zero, the “mselect” field is tied to zero. In this variant, “mvalue\_bits” is 0.

Parameter “mcontrol\_maskmax” is used to specify the value of field “maskmax” in the “mcontrol” register. In this variant, “mcontrol\_maskmax” is 0.

## 1.9 Debug Mask

It is possible to enable model debug messages in various categories. This can be done statically using the “override\_debugMask” parameter, or dynamically using the “debugflags” command. Enabled messages are specified using a bitmask value, as follows:

Value 0x002: enable debugging of PMP and virtual memory state;

Value 0x004: enable debugging of interrupt state.

All other bits in the debug bitmask are reserved and must not be set to non-zero values.

## 1.10 Integration Support

This model implements a number of non-architectural pseudo-registers and other features to facilitate integration.

### 1.10.1 CSR Register External Implementation

If parameter “enable\_CSR\_bus” is True, an artifact 16-bit bus “CSR” is enabled. Slave callbacks installed on this bus can be used to implement modified CSR behavior (use opBusSlaveNew or icmMapExternalMemory, depending on the client API). A CSR with index 0xABC is mapped on the bus at address 0xABC0; as a concrete example, implementing CSR “time” (number 0xC01) externally requires installation of callbacks at address 0xC010 on the CSR bus.

## 1.11 Limitations

Instruction pipelines are not modeled in any way. All instructions are assumed to complete immediately. This means that instruction barrier instructions (e.g. fence.i) are treated as NOPs, with the exception of any Illegal Instruction behavior, which is modeled.

Caches and write buffers are not modeled in any way. All loads, fetches and stores complete immediately and in order, and are fully synchronous. Data barrier instructions (e.g. fence) are treated as NOPs, with the exception of any Illegal Instruction behavior, which is modeled.

Real-world timing effects are not modeled: all instructions are assumed to complete in a single cycle.

Hardware Performance Monitor registers are not implemented and hardwired to zero.

Certain custom features of the CV32E40P are unimplemented. The following Registers are unimplemented: PCCRs, MIEX, MIPX, PCER, PCMR, HWLP PRIVLV. The Custom instructions are unimplemented

## 1.12 Verification

All instructions have been extensively tested by Imperas, using tests generated specifically for this model and also reference tests from <https://github.com/riscv/riscv-tests>.

Also reference tests have been used from various sources including:

<https://github.com/riscv/riscv-tests>

<https://github.com/ucb-bar/riscv-torture>

The Imperas OVPSim RISC-V models are used in the RISC-V Foundation Compliance Framework as a functional Golden Reference:

<https://github.com/riscv/riscv-compliance>

where the simulated model is used to provide the reference signatures for compliance testing. The Imperas OVPSim RISC-V models are used as reference in both open source and commercial instruction stream test generators for hardware design verification, for example:

<http://valtrix.in/sting> from Valtrix

<https://github.com/google/riscv-dv> from Google

The Imperas OVPSim RISC-V models are also used by commercial and open source RISC-V Core RTL developers as a reference to ensure correct functionality of their IP.

## 1.13 References

The Model details are based upon the following specifications:

RISC-V Instruction Set Manual, Volume I: User-Level ISA (User Architecture Version 20190305-Base-Ratification)

RISC-V Instruction Set Manual, Volume II: Privileged Architecture (Privileged Architecture Version 20190405-Priv-MSU-Ratification)

RISC-V External Debug Support (RISC-V External Debug Support Version 0.13.2-DRAFT)

# Chapter 2

## Configuration

### 2.1 Location

This model's VLVN is [openhwgroup.org/processor/riscv/1.0](https://openhwgroup.org/processor/riscv/1.0).

The model source is usually at:

`$IMPERAS_HOME/ImperasLib/source/openhwgroup.org/processor/riscv/1.0`

The model binary is usually at:

`$IMPERAS_HOME/lib/$IMPERAS_ARCH/ImperasLib/openhwgroup.org/processor/riscv/1.0`

### 2.2 GDB Path

The default GDB for this model is: `$IMPERAS_HOME/lib/$IMPERAS_ARCH/gdb/riscv-none-embed-gdb`.

### 2.3 Semi-Host Library

The default semi-host library file is `riscv.org/semihosting/pk/1.0`

### 2.4 Processor Endian-ness

This is a LITTLE endian model.

### 2.5 QuantumLeap Support

This processor is qualified to run in a QuantumLeap enabled simulator.

### 2.6 Processor ELF code

The ELF code supported by this model is: 0xf3.

## Chapter 3

# All Variants in this model

This model has these variants

Variant	Description
CV32E40P	(described in this document)

Table 3.1: All Variants in this model



## Chapter 4

# Bus Master Ports

This model has these bus master ports.

<b>Name</b>	min	max	Connect?	Description
INSTRUCTION	32	34	mandatory	Instruction bus
DATA	32	34	optional	Data bus
CSR	16	16	optional	Artifact bus allowing external implementation of CSR registers

Table 4.1: Bus Master Ports

## Chapter 5

# Bus Slave Ports

This model has no bus slave ports.

## Chapter 6

# Net Ports

This model has these net ports.

Name	Type	Connect?	Description
reset	input	optional	Reset
nmi	input	optional	NMI
MSWInterrupt	input	optional	Machine software interrupt
MTimerInterrupt	input	optional	Machine timer interrupt
MExternalInterrupt	input	optional	Machine external interrupt
LocalInterrupt0	input	optional	Local Interrupt 0
LocalInterrupt1	input	optional	Local Interrupt 1
LocalInterrupt2	input	optional	Local Interrupt 2
LocalInterrupt3	input	optional	Local Interrupt 3
LocalInterrupt4	input	optional	Local Interrupt 4
LocalInterrupt5	input	optional	Local Interrupt 5
LocalInterrupt6	input	optional	Local Interrupt 6
LocalInterrupt7	input	optional	Local Interrupt 7
LocalInterrupt8	input	optional	Local Interrupt 8
LocalInterrupt9	input	optional	Local Interrupt 9
LocalInterrupt10	input	optional	Local Interrupt 10
LocalInterrupt11	input	optional	Local Interrupt 11
LocalInterrupt12	input	optional	Local Interrupt 12
LocalInterrupt13	input	optional	Local Interrupt 13
LocalInterrupt14	input	optional	Local Interrupt 14
LocalInterrupt15	input	optional	Local Interrupt 15
irq_ack_o	output	optional	interrupt acknowledge (pulse)
irq_id_o	output	optional	acknowledged interrupt id (valid during irq_ack_o pulse)
sec_lvl_o	output	optional	current privilege level
DM	output	optional	Debug state indication
haltreq	input	optional	haltreq (Debug halt request)
resethaltreq	input	optional	resethaltreq (Debug halt request after reset)
deferint	input	optional	Artifact signal causing interrupts to be held off when high

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Table 6.1: Net Ports

## Chapter 7

# FIFO Ports

This model has no FIFO ports.

## Chapter 8

# Formal Parameters

Name	Type	Description
Basic		
variant	Enumeration	Selects variant (either a generic UISA or a specific model)
user_version	Enumeration	Specify required User Architecture version (2.2, 2.3 or 20190305)
priv_version	Enumeration	Specify required Privileged Architecture version (1.10, 1.11, 20190405 or master)
verbose	Boolean	Specify verbose output messages
wfi_is_nop	Boolean	Specify whether WFI should be treated as a NOP (if not, halt while waiting for interrupts)
mtvec_is_ro	Boolean	Specify whether mtvec CSR is read-only
tvec.align	Uns32	Specify hardware-enforced alignment of mtvec/stvec/utvec when Vectored interrupt mode enabled
counteren_mask	Uns32	Specify hardware-enforced mask of writable bits in mcounteren/scounteren registers
noinhibit_mask	Uns32	Specify hardware-enforced mask of always-zero bits in mcountinhibit register
mtvec_mask	Uns64	Specify hardware-enforced mask of writable bits in mtvec register
ecode_mask	Uns64	Specify hardware-enforced mask of writable bits in xcause.ExceptionCode
ecode_nmi	Uns64	Specify xcause.ExceptionCode for NMI
tval_zero	Boolean	Specify whether mtval/stval/utval are hard wired to zero
tval_ii_code	Boolean	Specify whether mtval/stval contain faulting instruction bits on illegal instruction exception
cycle_undefined	Boolean	Specify that the cycle CSR is undefined (reads to it are emulated by a Machine mode trap)
time_undefined	Boolean	Specify that the time CSR is undefined (reads to it are emulated by a Machine mode trap)
instret_undefined	Boolean	Specify that the instret CSR is undefined (reads to it are emulated by a Machine mode trap)
enable_CSR_bus	Boolean	Add artifact CSR bus port, allowing CSR registers to be externally implemented
CSR_remap	String	Comma-separated list of CSR number mappings, each of the form <csr-Name>=<number>
xret_preserves_lr	Boolean	Whether an xRET instruction preserves the value of LR
reset_address	Uns64	Override reset vector address
nmi_address	Uns64	Override NMI vector address
local_int_num	Uns32	Specify number of supplemental local interrupts
unimp_int_mask	Uns64	Specify mask of unimplemented interrupts (e.g. 1<<9 indicates Supervisor external interrupt unimplemented)
force_mideleg	Uns64	Specify mask of interrupts always delegated to lower-priority execution level from Machine execution level
no_ideleg	Uns64	Specify mask of interrupts that cannot be delegated to lower-priority execution levels

no.edeleg	Uns64	Specify mask of exceptions that cannot be delegated to lower-priority execution levels
external_int_id	Boolean	Whether to add nets allowing External Interrupt ID codes to be forced
endian	Endian	Model endian
misa_MXL	Uns32	Override default value of misa.MXL
misa_Extensions	Uns32	Override default value of misa.Extensions
add_Extensions	String	Add extensions specified by letters to misa.Extensions (for example, specify “VD” to add V and D features)
misa_Extensions_mask	Uns32	Override mask of writable bits in misa.Extensions
add_Extensions_mask	String	Add extensions specified by letters to mask of writable bits in misa.Extensions (for example, specify “VD” to add V and D features)
mvendorid	Uns64	Override mvendorid register
marchid	Uns64	Override marchid register
mimpid	Uns64	Override mimpid register
mhartid	Uns64	Override mhartid register (or first mhartid of an incrementing sequence if this is an SMP variant)
mtvec	Uns64	Override mtvec register
Debug		
debug_version	Enumeration	Specify required Debug Architecture version (0.13.2-DRAFT or 0.14.0-DRAFT)
debug_mode	Enumeration	Specify how Debug mode is implemented (none, vector, interrupt or halt)
debug_address	Uns64	Specify address to which to jump to enter debug in vectored mode
dexc_address	Uns64	Specify address to which to jump on debug exception in vectored mode
debug_eret_mode	Enumeration	Specify behavior for MRET, SRET or URET in Debug mode (nop, jump to dexc_address or trap to dexc_address) (nop, jump_to_dexc_address or trap_to_dexc_address)
Memory		
unaligned	Boolean	Specify whether the processor supports unaligned memory accesses
PMP_grain	Uns32	Specify PMP region granularity, G (0 =>4 bytes, 1 =>8 bytes, etc)
PMP_registers	Uns32	Specify the number of implemented PMP address registers
PMP_max_page	Uns32	Specify the maximum size of PMP region to map if non-zero (may improve performance; constrained to a power of two)
Trigger		
tinfo_undefined	Boolean	Specify that the tinfo CSR is undefined
tcontrol_undefined	Boolean	Specify that the tcontrol CSR is undefined
mcontext_undefined	Boolean	Specify that the mcontext CSR is undefined
scontext_undefined	Boolean	Specify that the scontext CSR is undefined
mscontext_undefined	Boolean	Specify that the mscontext CSR is undefined (Debug Version 0.14.0 and later)
amo_trigger	Boolean	Specify whether AMO load/store operations activate triggers
no_hit	Boolean	Specify that tdata1.hit is unimplemented
trigger_num	Uns32	Specify the number of implemented hardware triggers
tinfo	Uns32	Override tinfo register (for all triggers)
mcontext_bits	Uns32	Specify the number of implemented bits in mcontext
mvalue_bits	Uns32	Specify the number of implemented bits in textra.mvalue (if zero, textra.mselect is tied to zero)
mcontrol_maskmax	Uns32	Specify mcontrol.maskmax value
Fast Interrupt		
CLICLEVELS	Uns32	Specify number of interrupt levels implemented by CLIC, or 0 if CLIC absent

Table 8.1: Parameters that can be set in: Hart

## 8.1 Extension Parameters

Name	Type
------	------

debug	Boolean

Table 8.2: Extension Parameters

## 8.2 Parameters with enumerated types

### 8.2.1 Parameter user\_version

Set to this value	Description
2.2	User Architecture Version 2.2
2.3	Deprecated and equivalent to 20190305
20190305	User Architecture Version 20190305-Base-Ratification

Table 8.3: Values for Parameter user\_version

### 8.2.2 Parameter priv\_version

Set to this value	Description
1.10	Privileged Architecture Version 1.10
1.11	Deprecated and equivalent to 20190405
20190405	Privileged Architecture Version 20190405-Priv-MSU-Ratification
master	Privileged Architecture Master Branch (1.12 draft)

Table 8.4: Values for Parameter priv\_version

### 8.2.3 Parameter debug\_version

Set to this value	Description
0.13.2-DRAFT	RISC-V External Debug Support Version 0.13.2-DRAFT
0.14.0-DRAFT	RISC-V External Debug Support Version 0.14.0-DRAFT

Table 8.5: Values for Parameter debug\_version

### 8.2.4 Parameter debug\_mode

Set to this value	Description
none	Debug mode not implemented
vector	Debug mode implemented by execution at vector
interrupt	Debug mode implemented by interrupt
halt	Debug mode implemented by halt

Table 8.6: Values for Parameter debug\_mode

### 8.2.5 Parameter debug\_eret\_mode

Set to this value	Description
nop	MRET, SRET or URET in Debug mode is a nop
jump_to_dexc_address	MRET, SRET or URET in Debug mode jumps to dexc_address
trap_to_dexc_address	MRET, SRET or URET in Debug mode traps to dexc_address



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Table 8.7: Values for Parameter debug\_eret\_mode

## Chapter 9

# Execution Modes

<b>Mode</b>	Code	Description
Machine	3	Machine mode
Debug	6	Debug mode

Table 9.1: Modes implemented in: Hart

## Chapter 10

# Exceptions

Exception	Code	Description
InstructionAddressMisaligned	0	Fetch from unaligned address
InstructionAccessFault	1	No access permission for fetch
IllegalInstruction	2	Undecoded, unimplemented or disabled instruction
Breakpoint	3	EBREAK instruction executed
LoadAddressMisaligned	4	Load from unaligned address
LoadAccessFault	5	No access permission for load
StoreAMOAddressMisaligned	6	Store/atomic memory operation at unaligned address
StoreAMOAccessFault	7	No access permission for store/atomic memory operation
EnvironmentCallFromMMode	11	ECALL instruction executed in Machine mode
InstructionPageFault	12	Page fault at fetch address
LoadPageFault	13	Page fault at load address
StoreAMOPageFault	15	Page fault at store/atomic memory operation address
MSWInterrupt	67	Machine software interrupt
MTimerInterrupt	71	Machine timer interrupt
MExternalInterrupt	75	Machine external interrupt
LocalInterrupt0	80	Local interrupt 0
LocalInterrupt1	81	Local interrupt 1
LocalInterrupt2	82	Local interrupt 2
LocalInterrupt3	83	Local interrupt 3
LocalInterrupt4	84	Local interrupt 4
LocalInterrupt5	85	Local interrupt 5
LocalInterrupt6	86	Local interrupt 6
LocalInterrupt7	87	Local interrupt 7
LocalInterrupt8	88	Local interrupt 8
LocalInterrupt9	89	Local interrupt 9
LocalInterrupt10	90	Local interrupt 10
LocalInterrupt11	91	Local interrupt 11
LocalInterrupt12	92	Local interrupt 12

LocalInterrupt13	93	Local interrupt 13
LocalInterrupt14	94	Local interrupt 14
LocalInterrupt15	95	Local interrupt 15

Table 10.1: Exceptions implemented in: Hart

# Chapter 11

## Hierarchy of the model

A CPU core may be configured to instance many processors of a Symmetrical Multi Processor (SMP). A CPU core may also have sub elements within a processor, for example hardware threading blocks.

OVP processor models can be written to include SMP blocks and to have many levels of hierarchy. Some OVP CPU models may have a fixed hierarchy, and some may be configured by settings in a configuration register. Please see the register definitions of this model.

This model documentation shows the settings and hierarchy of the default settings for this model variant.

### 11.1 Level 1: Hart

This level in the model hierarchy has 2 commands.

This level in the model hierarchy has 3 register groups:

Group name	Registers
Core	33
Machine_Control_and_Status	179
Integration_support	2

Table 11.1: Register groups

This level in the model hierarchy has no children.

# Chapter 12

## Model Commands

A Processor model can implement one or more **Model Commands** available to be invoked from the simulator command line, from the OP API or from the Imperas Multiprocessor Debugger.

### 12.1 Level 1: Hart

#### 12.1.1 isync

specify instruction address range for synchronous execution

Argument	Type	Description
-addresshi	Uns64	end address of synchronous execution range
-addresslo	Uns64	start address of synchronous execution range

Table 12.1: isync command arguments

#### 12.1.2 itrace

enable or disable instruction tracing

Argument	Type	Description
-after	Uns64	apply after this many instructions
-enable	Boolean	enable instruction tracing
-instructioncount	Boolean	include the instruction number in each trace
-off	Boolean	disable instruction tracing
-on	Boolean	enable instruction tracing
-registerchange	Boolean	show registers changed by this instruction
-registers	Boolean	show registers after each trace

Table 12.2: itrace command arguments

# Chapter 13

## Registers

### 13.1 Level 1: Hart

#### 13.1.1 Core

Registers at level:1, type:Hart group:Core

Name	Bits	Initial-Hex	RW	Description
zero	32	0	r-	
ra	32	0	rw	
sp	32	0	rw	stack pointer
gp	32	0	rw	
tp	32	0	rw	
t0	32	0	rw	
t1	32	0	rw	
t2	32	0	rw	
s0	32	0	rw	
s1	32	0	rw	
a0	32	0	rw	
a1	32	0	rw	
a2	32	0	rw	
a3	32	0	rw	
a4	32	0	rw	
a5	32	0	rw	
a6	32	0	rw	
a7	32	0	rw	
s2	32	0	rw	
s3	32	0	rw	
s4	32	0	rw	
s5	32	0	rw	
s6	32	0	rw	
s7	32	0	rw	
s8	32	0	rw	
s9	32	0	rw	
s10	32	0	rw	
s11	32	0	rw	
t3	32	0	rw	
t4	32	0	rw	
t5	32	0	rw	
t6	32	0	rw	
pc	32	0	rw	program counter

Table 13.1: Registers at level 1, type:Hart group:Core

### 13.1.2 Machine\_Control\_and\_Status

Registers at level:1, type:Hart group:Machine\_Control\_and\_Status

Name	Bits	Initial-Hex	RW	Description
mstatus	32	1800	rw	Machine Status
misa	32	40801104	rw	ISA and Extensions
mie	32	0	rw	Machine Interrupt Enable
mtvec	32	1	rw	Machine Trap-Vector Base-Address
mcounteren	32	0	rw	Machine Counter Enable
mcountinhibit	32	d	rw	Machine Counter Inhibit
mhpmevent3	32	0	rw	Machine Performance Monitor Event Select 3
mhpmevent4	32	0	rw	Machine Performance Monitor Event Select 4
mhpmevent5	32	0	rw	Machine Performance Monitor Event Select 5
mhpmevent6	32	0	rw	Machine Performance Monitor Event Select 6
mhpmevent7	32	0	rw	Machine Performance Monitor Event Select 7
mhpmevent8	32	0	rw	Machine Performance Monitor Event Select 8
mhpmevent9	32	0	rw	Machine Performance Monitor Event Select 9
mhpmevent10	32	0	rw	Machine Performance Monitor Event Select 10
mhpmevent11	32	0	rw	Machine Performance Monitor Event Select 11
mhpmevent12	32	0	rw	Machine Performance Monitor Event Select 12
mhpmevent13	32	0	rw	Machine Performance Monitor Event Select 13
mhpmevent14	32	0	rw	Machine Performance Monitor Event Select 14
mhpmevent15	32	0	rw	Machine Performance Monitor Event Select 15
mhpmevent16	32	0	rw	Machine Performance Monitor Event Select 16
mhpmevent17	32	0	rw	Machine Performance Monitor Event Select 17
mhpmevent18	32	0	rw	Machine Performance Monitor Event Select 18
mhpmevent19	32	0	rw	Machine Performance Monitor Event Select 19
mhpmevent20	32	0	rw	Machine Performance Monitor Event Select 20
mhpmevent21	32	0	rw	Machine Performance Monitor Event Select 21
mhpmevent22	32	0	rw	Machine Performance Monitor Event Select 22
mhpmevent23	32	0	rw	Machine Performance Monitor Event Select 23
mhpmevent24	32	0	rw	Machine Performance Monitor Event Select 24
mhpmevent25	32	0	rw	Machine Performance Monitor Event Select 25
mhpmevent26	32	0	rw	Machine Performance Monitor Event Select 26
mhpmevent27	32	0	rw	Machine Performance Monitor Event Select 27
mhpmevent28	32	0	rw	Machine Performance Monitor Event Select 28
mhpmevent29	32	0	rw	Machine Performance Monitor Event Select 29
mhpmevent30	32	0	rw	Machine Performance Monitor Event Select 30
mhpmevent31	32	0	rw	Machine Performance Monitor Event Select 31
mscratch	32	0	rw	Machine Scratch
mepc	32	0	rw	Machine Exception Program Counter
mcause	32	0	rw	Machine Cause
mtval*	32	-	rw	Machine Trap Value
mip	32	0	rw	Machine Interrupt Pending
tselect	32	0	rw	Trigger Register Select
tdata1	32	28001040	rw	Trigger Data 1
tdata2	32	0	rw	Trigger Data 2
tdata3	32	0	rw	Trigger Data 3
tinfo	32	4	rw	Trigger Info
mcontext	32	0	rw	Trigger Machine Context
scontext	32	0	rw	Trigger Supervisor Context
dcsr	32	40000003	rw	Debug Control and Status



dpc	32	0	rw	Debug PC
dscratch0	32	0	rw	Debug Scratch 0
dscratch1	32	0	rw	Debug Scratch 1
mcycle*	32	-	rw	Machine Cycle Counter
minstret*	32	-	rw	Machine Instructions Retired
mhpmpcounter3	32	0	rw	Machine Performance Monitor Counter 3
mhpmpcounter4	32	0	rw	Machine Performance Monitor Counter 4
mhpmpcounter5	32	0	rw	Machine Performance Monitor Counter 5
mhpmpcounter6	32	0	rw	Machine Performance Monitor Counter 6
mhpmpcounter7	32	0	rw	Machine Performance Monitor Counter 7
mhpmpcounter8	32	0	rw	Machine Performance Monitor Counter 8
mhpmpcounter9	32	0	rw	Machine Performance Monitor Counter 9
mhpmpcounter10	32	0	rw	Machine Performance Monitor Counter 10
mhpmpcounter11	32	0	rw	Machine Performance Monitor Counter 11
mhpmpcounter12	32	0	rw	Machine Performance Monitor Counter 12
mhpmpcounter13	32	0	rw	Machine Performance Monitor Counter 13
mhpmpcounter14	32	0	rw	Machine Performance Monitor Counter 14
mhpmpcounter15	32	0	rw	Machine Performance Monitor Counter 15
mhpmpcounter16	32	0	rw	Machine Performance Monitor Counter 16
mhpmpcounter17	32	0	rw	Machine Performance Monitor Counter 17
mhpmpcounter18	32	0	rw	Machine Performance Monitor Counter 18
mhpmpcounter19	32	0	rw	Machine Performance Monitor Counter 19
mhpmpcounter20	32	0	rw	Machine Performance Monitor Counter 20
mhpmpcounter21	32	0	rw	Machine Performance Monitor Counter 21
mhpmpcounter22	32	0	rw	Machine Performance Monitor Counter 22
mhpmpcounter23	32	0	rw	Machine Performance Monitor Counter 23
mhpmpcounter24	32	0	rw	Machine Performance Monitor Counter 24
mhpmpcounter25	32	0	rw	Machine Performance Monitor Counter 25
mhpmpcounter26	32	0	rw	Machine Performance Monitor Counter 26
mhpmpcounter27	32	0	rw	Machine Performance Monitor Counter 27
mhpmpcounter28	32	0	rw	Machine Performance Monitor Counter 28
mhpmpcounter29	32	0	rw	Machine Performance Monitor Counter 29
mhpmpcounter30	32	0	rw	Machine Performance Monitor Counter 30
mhpmpcounter31	32	0	rw	Machine Performance Monitor Counter 31
mcycleh*	32	-	rw	Machine Cycle Counter High
minstreth*	32	-	rw	Machine Instructions Retired High
mhpmpcounterh3	32	0	rw	Machine Performance Monitor Counter High 3
mhpmpcounterh4	32	0	rw	Machine Performance Monitor Counter High 4
mhpmpcounterh5	32	0	rw	Machine Performance Monitor Counter High 5
mhpmpcounterh6	32	0	rw	Machine Performance Monitor Counter High 6
mhpmpcounterh7	32	0	rw	Machine Performance Monitor Counter High 7
mhpmpcounterh8	32	0	rw	Machine Performance Monitor Counter High 8
mhpmpcounterh9	32	0	rw	Machine Performance Monitor Counter High 9
mhpmpcounterh10	32	0	rw	Machine Performance Monitor Counter High 10
mhpmpcounterh11	32	0	rw	Machine Performance Monitor Counter High 11
mhpmpcounterh12	32	0	rw	Machine Performance Monitor Counter High 12
mhpmpcounterh13	32	0	rw	Machine Performance Monitor Counter High 13
mhpmpcounterh14	32	0	rw	Machine Performance Monitor Counter High 14
mhpmpcounterh15	32	0	rw	Machine Performance Monitor Counter High 15
mhpmpcounterh16	32	0	rw	Machine Performance Monitor Counter High 16
mhpmpcounterh17	32	0	rw	Machine Performance Monitor Counter High 17
mhpmpcounterh18	32	0	rw	Machine Performance Monitor Counter High 18
mhpmpcounterh19	32	0	rw	Machine Performance Monitor Counter High 19
mhpmpcounterh20	32	0	rw	Machine Performance Monitor Counter High 20
mhpmpcounterh21	32	0	rw	Machine Performance Monitor Counter High 21
mhpmpcounterh22	32	0	rw	Machine Performance Monitor Counter High 22

mhpcounterh23	32	0	rw	Machine Performance Monitor Counter High 23
mhpcounterh24	32	0	rw	Machine Performance Monitor Counter High 24
mhpcounterh25	32	0	rw	Machine Performance Monitor Counter High 25
mhpcounterh26	32	0	rw	Machine Performance Monitor Counter High 26
mhpcounterh27	32	0	rw	Machine Performance Monitor Counter High 27
mhpcounterh28	32	0	rw	Machine Performance Monitor Counter High 28
mhpcounterh29	32	0	rw	Machine Performance Monitor Counter High 29
mhpcounterh30	32	0	rw	Machine Performance Monitor Counter High 30
mhpcounterh31	32	0	rw	Machine Performance Monitor Counter High 31
cycle*	32	0	rw	User Cycle Counter
instret*	32	0	rw	User Instructions Retired
hpmcounter3	32	0	r-	Performance Monitor Counter 3
hpmcounter4	32	0	r-	Performance Monitor Counter 4
hpmcounter5	32	0	r-	Performance Monitor Counter 5
hpmcounter6	32	0	r-	Performance Monitor Counter 6
hpmcounter7	32	0	r-	Performance Monitor Counter 7
hpmcounter8	32	0	r-	Performance Monitor Counter 8
hpmcounter9	32	0	r-	Performance Monitor Counter 9
hpmcounter10	32	0	r-	Performance Monitor Counter 10
hpmcounter11	32	0	r-	Performance Monitor Counter 11
hpmcounter12	32	0	r-	Performance Monitor Counter 12
hpmcounter13	32	0	r-	Performance Monitor Counter 13
hpmcounter14	32	0	r-	Performance Monitor Counter 14
hpmcounter15	32	0	r-	Performance Monitor Counter 15
hpmcounter16	32	0	r-	Performance Monitor Counter 16
hpmcounter17	32	0	r-	Performance Monitor Counter 17
hpmcounter18	32	0	r-	Performance Monitor Counter 18
hpmcounter19	32	0	r-	Performance Monitor Counter 19
hpmcounter20	32	0	r-	Performance Monitor Counter 20
hpmcounter21	32	0	r-	Performance Monitor Counter 21
hpmcounter22	32	0	r-	Performance Monitor Counter 22
hpmcounter23	32	0	r-	Performance Monitor Counter 23
hpmcounter24	32	0	r-	Performance Monitor Counter 24
hpmcounter25	32	0	r-	Performance Monitor Counter 25
hpmcounter26	32	0	r-	Performance Monitor Counter 26
hpmcounter27	32	0	r-	Performance Monitor Counter 27
hpmcounter28	32	0	r-	Performance Monitor Counter 28
hpmcounter29	32	0	r-	Performance Monitor Counter 29
hpmcounter30	32	0	r-	Performance Monitor Counter 30
hpmcounter31	32	0	r-	Performance Monitor Counter 31
cycleh*	32	0	rw	User Cycle Counter High
instreth*	32	0	rw	User Instructions Retired High
hpmcounterh3	32	0	r-	Performance Monitor High 3
hpmcounterh4	32	0	r-	Performance Monitor High 4
hpmcounterh5	32	0	r-	Performance Monitor High 5
hpmcounterh6	32	0	r-	Performance Monitor High 6
hpmcounterh7	32	0	r-	Performance Monitor High 7
hpmcounterh8	32	0	r-	Performance Monitor High 8
hpmcounterh9	32	0	r-	Performance Monitor High 9
hpmcounterh10	32	0	r-	Performance Monitor High 10
hpmcounterh11	32	0	r-	Performance Monitor High 11
hpmcounterh12	32	0	r-	Performance Monitor High 12
hpmcounterh13	32	0	r-	Performance Monitor High 13
hpmcounterh14	32	0	r-	Performance Monitor High 14
hpmcounterh15	32	0	r-	Performance Monitor High 15
hpmcounterh16	32	0	r-	Performance Monitor High 16

hpmcounterh17	32	0	r-	Performance Monitor High 17
hpmcounterh18	32	0	r-	Performance Monitor High 18
hpmcounterh19	32	0	r-	Performance Monitor High 19
hpmcounterh20	32	0	r-	Performance Monitor High 20
hpmcounterh21	32	0	r-	Performance Monitor High 21
hpmcounterh22	32	0	r-	Performance Monitor High 22
hpmcounterh23	32	0	r-	Performance Monitor High 23
hpmcounterh24	32	0	r-	Performance Monitor High 24
hpmcounterh25	32	0	r-	Performance Monitor High 25
hpmcounterh26	32	0	r-	Performance Monitor High 26
hpmcounterh27	32	0	r-	Performance Monitor High 27
hpmcounterh28	32	0	r-	Performance Monitor High 28
hpmcounterh29	32	0	r-	Performance Monitor High 29
hpmcounterh30	32	0	r-	Performance Monitor High 30
hpmcounterh31	32	0	r-	Performance Monitor High 31
mvendorid	32	602	r-	Vendor ID
marchid	32	4	r-	Architecture ID
mimpid	32	0	r-	Implementation ID
mhartid	32	0	r-	Hardware Thread ID

Table 13.2: Registers at level 1, type:Hart group:Machine\_Control\_and\_Status

\* Registers marked with an asterisk are part of the processor extension library.

### 13.1.3 Integration support

Registers at level:1, type:Hart group:Integration\_support

Name	Bits	Initial-Hex	RW	Description
DM	8	0	rw	Debug mode active
commercial	8	0	r-	Commercial feature in use

Table 13.3: Registers at level 1, type:Hart group:Integration\_support