



OVP Guide to Using Processor Models

Model specific information for SiFive_E21

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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 E21 32-bit processor model

1.2 Licensing

This Model is released under the Open Source Apache 2.0

1.3 Extensions

1.3.1 Extensions Enabled by Default

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

misa bit 0: extension A (atomic instructions)

misa bit 1: extension B (bit manipulation extension)

misa bit 2: extension C (compressed instructions)

misa bit 8: RV32I/RV64I/RV128I base integer instruction set

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

misa bit 20: extension U (User mode)

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, if supported on this variant. Parameter “sub_Extensions_mask” can be used to disable dynamic update of features in the same way.

Legacy parameter “misa_Extensions_mask” can also be used. This Uns32-valued parameter specifies all writable bits in the misa Extensions field, replacing any permitted bits 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.

1.3.2 Enabling Other Extensions

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

misa bit 3: extension D (double-precision floating point)

misa bit 4: RV32E base integer instruction set (embedded)

misa bit 5: extension F (single-precision floating point)

To add features from this list to the visible set in the misa register, use parameter “add_Extensions”. This is a string containing identification letters of features to enable; for example, value “DV” indicates that double-precision floating point and the Vector Extension should be enabled, if they are currently absent and are available on this variant.

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

To add features from this list to the implicitly-enabled set (not visible in the misa register), use parameter “add_implicit_Extensions”. This is a string parameter in the same format as the “add_Extensions” parameter described above.

1.3.3 Disabling Extensions

The following extensions are enabled by default in the model and can be disabled:

misa bit 0: extension A (atomic instructions)

misa bit 1: extension B (bit manipulation extension)

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

misa bit 20: extension U (User mode)

To disable features that are enabled by default, use parameter “sub_Extensions”. This is a string containing identification letters of features to disable; for example, value “DF” indicates that double-precision and single-precision floating point extensions should be disabled, if they are enabled by default on this variant.

To remove features from this list from the implicitly-enabled set (not visible in the misa register), use parameter “sub_implicit_Extensions”. This is a string parameter in the same format as the “sub_Extensions” parameter described above.

1.4 General Features

1.4.1 mtvec CSR

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 0xffffffff. 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 64.

If parameter “mtvec_sext” is True, values written to “mtvec” are sign-extended from the most-significant writable bit. In this variant, “mtvec_sext” is False, indicating that “mtvec” is not sign-extended.

The initial value of “mtvec” is 0x0. A different value may be specified using parameter “mtvec” if required.

1.4.2 Reset

On reset, the model will restart at address 0x0. A different reset address may be specified using parameter “reset_address” or applied using optional input port “reset_addr” if required.

1.4.3 NMI

On an NMI, the model will restart at address 0x0; a different NMI address may be specified using parameter “nmi_address” or applied using optional input port “nmi_addr” if required. The

cause reported on an NMI is 0x2 by default; a different cause may be specified using parameter “`ecode_nmi`” or applied using optional input port “`nmi_cause`” if required.

If parameter “`rnmi_version`” is not “`none`”, resumable NMIs are supported, managed by additional CSRs “`mnscratch`”, “`mnepc`”, “`mncause`” and “`mnstatus`”, following the indicated version of the Resumable NMI extension proposal. In this variant, “`rnmi_version`” is “`0.2.1`”.

1.4.4 WFI

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`).

1.4.5 cycle CSR

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 cause Illegal Instruction traps.

1.4.6 time CSR

The “`time`” CSR is not implemented in this variant and reads of it will cause Illegal Instruction traps. Set parameter “`time_undefined`” to False to instead specify that “`time`” is implemented.

1.4.7 instret CSR

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 cause Illegal Instruction traps.

1.4.8 hpmcounter CSRs

“`hpmcounter`” CSRs are implemented in this variant. Set parameter “`hpmcounter_undefined`” to True to instead specify that “`hpmcounter`” CSRs are unimplemented and reads of them should cause Illegal Instruction traps.

1.4.9 Unaligned Accesses

Unaligned memory accesses are not supported by this variant. Set parameter “`unaligned`” to “`T`” to enable such accesses.

Unaligned memory accesses are not supported for AMO instructions by this variant. Set parameter “`unalignedAMO`” to “`T`” to enable such accesses.

1.4.10 PMP

8 PMP entries are implemented by this variant. Use parameter “PMP_registers” to specify a different number of PMP entries; set the parameter to 0 to disable the PMP unit. The PMP grain size (G) is 0, meaning that PMP regions as small as 4 bytes are implemented. Use parameter “PMP_grain” to specify a different grain size if required. Unaligned PMP accesses are not decomposed into separate aligned accesses; use parameter “PMP_decompose” to modify this behavior if required.

1.4.11 LR/SC Granule

LR/SC instructions are implemented with a 64-byte reservation granule. A different granule size may be specified using parameter “lr_sc_grain”.

1.5 Compressed Extension

Standard compressed instructions are present in this variant.

Parameter Zcea_version is used to specify the version of Zcea instructions present. By default, Zcea_version is set to “none” in this variant. Updates to this parameter require a commercial product license.

Parameter Zceb_version is used to specify the version of Zceb instructions present. By default, Zceb_version is set to “none” in this variant. Updates to this parameter require a commercial product license.

Parameter Zcee_version is used to specify the version of Zcee instructions present. By default, Zcee_version is set to “none” in this variant. Updates to this parameter require a commercial product license.

1.6 Privileged Architecture

This variant implements the Privileged Architecture with version specified in the References section of this document. Note that parameter “priv_version” can be used to select the required architecture version; see the following sections for detailed information about differences between each supported version.

1.6.1 Legacy Version 1.10

1.10 version of May 7 2017.

1.6.2 Version 20190608

Stable 1.11 version of June 8 2019, with these changes compared to version 1.10:

- mcountinhibit CSR defined;
- pages are never executable in Supervisor mode if page table entry U bit is 1;
- mstatus.TW is writable if any lower-level privilege mode is implemented (previously, it was just if Supervisor mode was implemented);

1.6.3 Version master

Unstable master version corresponding to evolving 1.12 specification, with these changes compared to version 20190608:

- mstatush, mseccfg, mseccfgh, menvcfg, menvcfgh, senvcfg, henvcfg, henvcfgh and mconfigptr CSRs defined;
- xret instructions clear mstatus.MPRV when leaving Machine mode if new mode is less privileged than M-mode;
- maximum number of PMP registers increased to 64;
- data endian is now configurable.

1.7 Unprivileged Architecture

This variant implements the Unprivileged Architecture with version specified in the References section of this document. Note that parameter “user_version” can be used to select the required architecture version; see the following sections for detailed information about differences between each supported version.

1.7.1 Legacy Version 2.2

2.2 version of May 7 2017.

1.7.2 Version 20191213

Stable 20191213-Base-Ratified version of December 13 2019, with these changes compared to version 2.2:

- floating point fmin/fmax instruction behavior modified to comply with IEEE 754-201x.
- numerous other optional behaviors can be separately enabled using Z-prefixed parameters.

1.8 Bit-Manipulation Extension

This variant implements the Bit-Manipulation extension with version specified in the References section of this document. Note that parameter “bitmanip_version” can be used to select the re-

quired version of this extension. See section “Bit-Manipulation Extension Versions” for detailed information about differences between each supported version.

1.8.1 Bit-Manipulation Extension Parameters

Parameter Zbb is used to specify that the base instructions are present. By default, Zbb is set to 1 in this variant. Updates to this parameter require a commercial product license.

Parameter Zba is used to specify that address calculation instructions are present. By default, Zba is set to 1 in this variant. Updates to this parameter require a commercial product license.

Parameter Zbc is used to specify that carryless operation instructions are present. By default, Zbc is set to 0 in this variant. Updates to this parameter require a commercial product license.

Parameter Zbe is used to specify that bit deposit/extract instructions are present. By default, Zbe is set to 0 in this variant. Updates to this parameter require a commercial product license. This parameter is ignored for version 1.0.0, which does not implement that subset.

Parameter Zbf is used to specify that bit field place instructions are present. By default, Zbf is set to 0 in this variant. Updates to this parameter require a commercial product license. This parameter is ignored for version 1.0.0, which does not implement that subset.

Parameter Zbm is used to specify that bit matrix operation instructions are present. By default, Zbm is set to 0 in this variant. Updates to this parameter require a commercial product license. This parameter is ignored for version 1.0.0, which does not implement that subset.

Parameter Zbp is used to specify that permutation instructions are present. By default, Zbp is set to 0 in this variant. Updates to this parameter require a commercial product license. This parameter is ignored for version 1.0.0, which does not implement that subset.

Parameter Zbr is used to specify that CRC32 instructions are present. By default, Zbr is set to 0 in this variant. Updates to this parameter require a commercial product license. This parameter is ignored for version 1.0.0, which does not implement that subset.

Parameter Zbs is used to specify that single bit instructions are present. By default, Zbs is set to 0 in this variant. Updates to this parameter require a commercial product license.

Parameter Zbt is used to specify that ternary instructions are present. By default, Zbt is set to 0 in this variant. Updates to this parameter require a commercial product license. This parameter is ignored for version 1.0.0, which does not implement that subset.

1.8.2 Bit-Manipulation Extension Versions

The Bit-Manipulation Extension specification has been under active development. To enable simulation of hardware that may be based on an older version of the specification, the model implements behavior for a number of previous versions of the specification. The differing features of these are listed below, in chronological order.

1.8.3 Version 0.90

Stable 0.90 version of June 10 2019.

1.8.4 Version 0.91

Stable 0.91 version of August 29 2019, with these changes compared to version 0.90:

- change encodings of bmatxor, grev, grevw, grevi and greviw;
- add gorc, gorcw, gorci, gorciw, bfp and bfpw instructions.

1.8.5 Version 0.92

Stable 0.92 version of November 8 2019, with these changes compared to version 0.91:

- add packh, packu and packuw instructions;
- add sext.b and sext.h instructions;
- change encoding and behavior of bfp and bfpw instructions;
- change encoding of bdep and bdepw instructions.

1.8.6 Version 0.93-draft

Draft 0.93 version of January 29 2020, with these changes compared to version 0.92:

- add sh1add, sh2add, sh3add, sh1addu, sh2addu and sh3addu instructions;
- move slo, sloi, sro and sroi to Zbp subset;
- add orc16 to Zbb subset.

1.8.7 Version 0.93

Stable 0.93 version of January 10 2021, with these changes compared to version 0.93-draft:

- assignments of instructions to Z extension groups changed;
- exchange encodings of max and minu instructions;
- add xperm.[nbhw] instructions;
- instructions named *u.w renamed to *.uw;
- instructions named sb* renamed to b*;
- instructions named pcnt* renamed to cpop*;
- instructions subu.w, addiwu, addwu, subwu, clmulw, clmulrw and clmulhw removed;

- instructions slo, sro, sloi, sroi, slow, srow, sloiw and sroiw removed from all Z extension groups and are therefore never implemented;
- instructions bext/bdep renamed to bcompress/bdecompress (this change is documented under the draft 0.94 version but is required to resolve an instruction name conflict introduced by instruction renames above);

1.8.8 Version 0.94

Stable 0.94 version of January 20 2021, with these changes compared to version 0.93:

- instructions bset[i]w, bclr[i]w, binv[i]w and bextw removed.

1.8.9 Version 1.0.0

Stable 1.0.0 version of June 6 2021, with these changes compared to version 0.94:

- instructions with immediate shift operands now follow base architecture semantics to determine operand legality instead of masking to XLEN-1;
- only subsets Zba, Zbb, Zbc and Zbs may be enabled;
- if the B extension is present, it is implicitly always enabled and not subject to control by misa.B, which is zero.

1.8.10 Version master

Unstable master version, with these changes compared to version 1.0.0:

- any subset may be enabled;
- xperm.n, xperm.b, xperm.h and xperm.w instructions renamed xperm4, xperm8, xperm16 and xperm32.

1.9 Other Extensions

Other extensions that can be configured are described in this section.

1.9.1 Zmmul

Parameter “Zmmul” is 0 on this variant, meaning that all multiply and divide instructions are implemented. if “Zmmul” is set to 1 then multiply instructions are implemented but divide and remainder instructions are not implemented.

1.9.2 Zicsr

Parameter “Zicsr” is 1 on this variant, meaning that standard CSRs and CSR access instructions are implemented. if “Zicsr” is set to 0 then standard CSRs and CSR access instructions are not implemented and an alternative scheme must be provided as a processor extension.

1.9.3 Zifencei

Parameter “Zifencei” is 1 on this variant, meaning that the fence.i instruction is implemented (but treated as a NOP by the model). if “Zifencei” is set to 0 then the fence.i instruction is not implemented.

1.9.4 Zicbom

Parameter “Zicbom” is 0 on this variant, meaning that code block management instructions are undefined. if “Zicbom” is set to 1 then code block management instructions cbo.clean, cbo.flush and cbo.inval are defined.

If Zicbom is present, the cache block size is given by parameter “cmomp_bytes”. The instructions may cause traps if used illegally but otherwise are NOPs in this model.

1.9.5 Zicbop

Parameter “Zicbop” is 0 on this variant, meaning that prefetch instructions are undefined. if “Zicbop” is set to 1 then prefetch instructions prefetch.i, prefetch.r and prefetch.w are defined (but behave as NOPs in this model).

1.9.6 Zicboz

Parameter “Zicboz” is 0 on this variant, meaning that the cbo.zero instruction is undefined. if “Zicboz” is set to 1 then the cbo.zero instruction is defined.

If Zicboz is present, the cache block size is given by parameter “cmoz_bytes”.

1.10 CLIC

This model implements a Core Local Interrupt Controller (CLIC) with 16 levels. Parameter “CLICLEVELS” can be used to specify a different number of interrupt levels (2-256), as described in the RISC-V Core-Local Interrupt Controller specification (see references). Set “CLICLEVELS” to zero to indicate the CLIC is not implemented.

The model can 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.

1.10.1 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). The default value in this variant is True.

“CLICXNXTI”: this Boolean parameter indicates whether xnxti CSRs are implemented (if True) or unimplemented (if False). The default value in this variant is True.

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

“mclicbase”: this parameter specifies the CLIC base address in physical memory. The default value in this variant is 0x2800000.

“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. The default value in this variant is False.

“intthresh_undefined”: this Boolean parameter indicates whether xintthresh CSRs registers are implemented (if True) or unimplemented (if False). The default value in this variant is True.

“mclicbase_undefined”: this Boolean parameter indicates whether the mclicbase CSR register is implemented (if True) or unimplemented (if False). The default value in this variant is True.

1.10.2 CLIC Internal-Implementation Parameters

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

“CLIC_version”: this defines the version of the CLIC specification that is implemented. See the References section of this document for more information.

“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). The default value in this variant is 0.

“CLICCFGLBITS”: this Uns32 parameter indicates the number of bits implemented in cliccfg.nlbits. The default value in this variant is 2.

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

“posedge_0.63”: this Uns64 parameter is a mask for interrupts 0 to 63 indicating whether an interrupt is fixed positive edge triggered. If the corresponding mask bit for interrupt N is 1 then the trig value for that interrupt is hard wired to 1. If the mask bit is zero, then the interrupt is either fixed level triggered (see below) or may be configured as either edge or level triggered. The default value in this variant is 0x100f.

“poslevel_0.63”: this Uns64 parameter is a mask for interrupts 0 to 63 indicating whether an interrupt is fixed positive level triggered. If the corresponding mask bit for interrupt N is 1 then the trig value for that interrupt is hard wired to 0. If the mask bit is zero, then the interrupt may be configured as either edge or level triggered. The default value in this variant is 0x0.

“posedge_other”: this Boolean parameter indicates whether interrupts 64 and above are fixed positive edge triggered. If True then the trig value for those interrupts is hard wired to 1. If False, then those interrupts are either fixed level triggered (see below) or may be configured as either edge or level triggered. The default value in this variant is False.

“poslevel_other”: this Boolean parameter indicates whether interrupts 64 and above are fixed positive level triggered. If True then the trig value for those interrupts is hard wired to 0. If False, then those interrupts may be configured as either edge or level triggered. The default value in this variant is False.

1.10.3 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 “tvt_undefined” parameter is False, vectored interrupts will use selective hardware vectoring, as described in the CLIC specification. If “tvt_undefined” is True, vectored interrupts will behave like basic mode vectored interrupts.

“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).

1.10.4 CLIC Versions

The CLIC specification has been under active development. To enable simulation of hardware that may be based on an older version of the specification, the model implements behavior for a number of previous versions of the specification. The differing features of these are listed below, in chronological order.

1.10.5 Version 20180831

Legacy version of August 31 2018, required for SiFive cores.

1.10.6 Version 0.9-draft-20191208

Stable 0.9 version of December 8 2019.

1.10.7 Version master

Unstable master version as of 11 May 2021 (commit dd15cd3), with these changes compared to version 0.9-draft-20191208:

- level-sensitive interrupts may no longer be set pending by software;
- if there is an access exception on table load when Selective Hardware Vectoring is enabled, both `xtval` and `xepc` hold the faulting address;
- if the `xinhv` bit is set, the target address for an `xret` instruction is obtained by a load from address `xepc`.

1.11 CLINT

This model implements a SiFive-compatible Core Local Interruptor (CLINT) block at address 0x2000000. Use parameter “CLINT_address” to specify a different address for this block, or set it to zero to disable the CLINT

The tick timer in the CLINT (`mtime`) will increment at 32768Hz. Use parameter “`mtime_Hz`” to specify a different timer frequency.

1.12 Load-Reserved/Store-Conditional Locking

By default, LR/SC locking is implemented automatically by the model and simulator, with a reservation granule defined by the “`lr_sc_grain`” parameter. It is also possible to implement locking externally to the model in a platform component, using the “`LR_address`”, “`SC_address`” and “`SC_valid`” net ports, as described below.

The “LR_address” output net port is written by the model with the address used by a load-reserved instruction as it executes. This port should be connected as an input to the external lock management component, which should record the address, and also that an LR/SC transaction is active.

The “SC_address” output net port is written by the model with the address used by a store-conditional instruction as it executes. This should be connected as an input to the external lock management component, which should compare the address with the previously-recorded load-reserved address, and determine from this (and other implementation-specific constraints) whether the store should succeed. It should then immediately write the Boolean success/fail code to the “SC_valid” input net port of the model. Finally, it should update state to indicate that an LR/SC transaction is no longer active.

It is also possible to write zero to the “SC_valid” input net port at any time outside the context of a store-conditional instruction, which will mark any active LR/SC transaction as invalid.

Irrespective of whether LR/SC locking is implemented internally or externally, taking any exception or interrupt or executing exception-return instructions (e.g. MRET) will always mark any active LR/SC transaction as invalid.

1.13 Active Atomic Operation Indication

The “AMO_active” output net port is written by the model with a code indicating any current atomic memory operation while the instruction is active. The written codes are:

0: no atomic instruction active

1: AMOMIN active

2: AMOMAX active

3: AMOMINU active

4: AMOMAXU active

5: AMOADD active

6: AMOXOR active

7: AMOOR active

8: AMOAND active

9: AMOSWAP active

10: LR active

11: SC active

1.14 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 or “reset_addr” port 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 or “nmi_addr” port 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.

1.15 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 simula-

tion 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.

1.15.1 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.

1.15.2 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.

1.15.3 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.

1.15.4 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.

1.15.5 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.

1.15.6 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).

1.16 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.

1.17 Integration Support

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

1.17.1 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.

1.17.2 LR/SC Active Address

Artifact register “LRSCAddress” shows the active LR/SC lock address. The register holds all-ones if there is no LR/SC operation active or if LR/SC locking is implemented externally as described above.

1.18 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.

1.19 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.

1.20 References

The Model details are based upon the following specifications:

RISC-V Instruction Set Manual, Volume I: User-Level ISA (User Architecture Version 20191213)

RISC-V Instruction Set Manual, Volume II: Privileged Architecture (Privileged Architecture Version Ratified-IMFDQC-and-Priv-v1.11)

RISC-V “B” Bit Manipulation Extension (Bit Manipulation Architecture Version v0.94-20210120)

RISC-V Core-Local Interrupt Controller (CLIC Version 20180831)

SiFive E21 Manual v19.05

Chapter 2

Configuration

2.1 Location

This model's VLVN is `sifive.ovpworld.org/processor/riscv/1.0`.

The model source is usually at:

`$IMPERAS_HOME/ImperasLib/source/sifive.ovpworld.org/processor/riscv/1.0`

The model binary is usually at:

`$IMPERAS_HOME/lib/$IMPERAS_ARCH/ImperasLib/sifive.ovpworld.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.ovpworld.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
E20	
E21	(described in this document)
E24	
E31	
E34	
E51	
E76	
S21	
S51	
S54	
S76	
U54	
U74	
X280	
P550	

Table 3.1: All Variants in this model

Chapter 4

Bus Master Ports

This model has these bus master ports.

Name	min	max	Connect?	Description
INSTRUCTION	32	34	mandatory	Instruction bus
DATA	32	34	optional	Data bus

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
reset_addr	input	optional	externally-applied reset address
nmi	input	optional	NMI
nmi_cause	input	optional	externally-applied NMI cause
nmi_addr	input	optional	externally-applied NMI address
nmiexc_addr	input	optional	externally-applied RNMI exception address
MSWInterrupt	input	optional	Machine software interrupt
MTimerInterrupt	input	optional	Machine timer interrupt
MExternalInterrupt	input	optional	Machine external interrupt
CSIP	input	optional	CLIC software 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
LocalInterrupt16	input	optional	Local interrupt 16
LocalInterrupt17	input	optional	Local interrupt 17
LocalInterrupt18	input	optional	Local interrupt 18
LocalInterrupt19	input	optional	Local interrupt 19

LocalInterrupt20	input	optional	Local interrupt 20
LocalInterrupt21	input	optional	Local interrupt 21
LocalInterrupt22	input	optional	Local interrupt 22
LocalInterrupt23	input	optional	Local interrupt 23
LocalInterrupt24	input	optional	Local interrupt 24
LocalInterrupt25	input	optional	Local interrupt 25
LocalInterrupt26	input	optional	Local interrupt 26
LocalInterrupt27	input	optional	Local interrupt 27
LocalInterrupt28	input	optional	Local interrupt 28
LocalInterrupt29	input	optional	Local interrupt 29
LocalInterrupt30	input	optional	Local interrupt 30
LocalInterrupt31	input	optional	Local interrupt 31
LocalInterrupt32	input	optional	Local interrupt 32
LocalInterrupt33	input	optional	Local interrupt 33
LocalInterrupt34	input	optional	Local interrupt 34
LocalInterrupt35	input	optional	Local interrupt 35
LocalInterrupt36	input	optional	Local interrupt 36
LocalInterrupt37	input	optional	Local interrupt 37
LocalInterrupt38	input	optional	Local interrupt 38
LocalInterrupt39	input	optional	Local interrupt 39
LocalInterrupt40	input	optional	Local interrupt 40
LocalInterrupt41	input	optional	Local interrupt 41
LocalInterrupt42	input	optional	Local interrupt 42
LocalInterrupt43	input	optional	Local interrupt 43
LocalInterrupt44	input	optional	Local interrupt 44
LocalInterrupt45	input	optional	Local interrupt 45
LocalInterrupt46	input	optional	Local interrupt 46
LocalInterrupt47	input	optional	Local interrupt 47
LocalInterrupt48	input	optional	Local interrupt 48
LocalInterrupt49	input	optional	Local interrupt 49
LocalInterrupt50	input	optional	Local interrupt 50
LocalInterrupt51	input	optional	Local interrupt 51
LocalInterrupt52	input	optional	Local interrupt 52
LocalInterrupt53	input	optional	Local interrupt 53
LocalInterrupt54	input	optional	Local interrupt 54
LocalInterrupt55	input	optional	Local interrupt 55
LocalInterrupt56	input	optional	Local interrupt 56
LocalInterrupt57	input	optional	Local interrupt 57
LocalInterrupt58	input	optional	Local interrupt 58
LocalInterrupt59	input	optional	Local interrupt 59
LocalInterrupt60	input	optional	Local interrupt 60
LocalInterrupt61	input	optional	Local interrupt 61
LocalInterrupt62	input	optional	Local interrupt 62
LocalInterrupt63	input	optional	Local interrupt 63
LocalInterrupt64	input	optional	Local interrupt 64

LocalInterrupt65	input	optional	Local interrupt 65
LocalInterrupt66	input	optional	Local interrupt 66
LocalInterrupt67	input	optional	Local interrupt 67
LocalInterrupt68	input	optional	Local interrupt 68
LocalInterrupt69	input	optional	Local interrupt 69
LocalInterrupt70	input	optional	Local interrupt 70
LocalInterrupt71	input	optional	Local interrupt 71
LocalInterrupt72	input	optional	Local interrupt 72
LocalInterrupt73	input	optional	Local interrupt 73
LocalInterrupt74	input	optional	Local interrupt 74
LocalInterrupt75	input	optional	Local interrupt 75
LocalInterrupt76	input	optional	Local interrupt 76
LocalInterrupt77	input	optional	Local interrupt 77
LocalInterrupt78	input	optional	Local interrupt 78
LocalInterrupt79	input	optional	Local interrupt 79
LocalInterrupt80	input	optional	Local interrupt 80
LocalInterrupt81	input	optional	Local interrupt 81
LocalInterrupt82	input	optional	Local interrupt 82
LocalInterrupt83	input	optional	Local interrupt 83
LocalInterrupt84	input	optional	Local interrupt 84
LocalInterrupt85	input	optional	Local interrupt 85
LocalInterrupt86	input	optional	Local interrupt 86
LocalInterrupt87	input	optional	Local interrupt 87
LocalInterrupt88	input	optional	Local interrupt 88
LocalInterrupt89	input	optional	Local interrupt 89
LocalInterrupt90	input	optional	Local interrupt 90
LocalInterrupt91	input	optional	Local interrupt 91
LocalInterrupt92	input	optional	Local interrupt 92
LocalInterrupt93	input	optional	Local interrupt 93
LocalInterrupt94	input	optional	Local interrupt 94
LocalInterrupt95	input	optional	Local interrupt 95
LocalInterrupt96	input	optional	Local interrupt 96
LocalInterrupt97	input	optional	Local interrupt 97
LocalInterrupt98	input	optional	Local interrupt 98
LocalInterrupt99	input	optional	Local interrupt 99
LocalInterrupt100	input	optional	Local interrupt 100
LocalInterrupt101	input	optional	Local interrupt 101
LocalInterrupt102	input	optional	Local interrupt 102
LocalInterrupt103	input	optional	Local interrupt 103
LocalInterrupt104	input	optional	Local interrupt 104
LocalInterrupt105	input	optional	Local interrupt 105
LocalInterrupt106	input	optional	Local interrupt 106
LocalInterrupt107	input	optional	Local interrupt 107
LocalInterrupt108	input	optional	Local interrupt 108
LocalInterrupt109	input	optional	Local interrupt 109

LocalInterrupt110	input	optional	Local interrupt 110
LocalInterrupt111	input	optional	Local interrupt 111
LocalInterrupt112	input	optional	Local interrupt 112
LocalInterrupt113	input	optional	Local interrupt 113
LocalInterrupt114	input	optional	Local interrupt 114
LocalInterrupt115	input	optional	Local interrupt 115
LocalInterrupt116	input	optional	Local interrupt 116
LocalInterrupt117	input	optional	Local interrupt 117
LocalInterrupt118	input	optional	Local interrupt 118
LocalInterrupt119	input	optional	Local interrupt 119
LocalInterrupt120	input	optional	Local interrupt 120
LocalInterrupt121	input	optional	Local interrupt 121
LocalInterrupt122	input	optional	Local interrupt 122
LocalInterrupt123	input	optional	Local interrupt 123
LocalInterrupt124	input	optional	Local interrupt 124
LocalInterrupt125	input	optional	Local interrupt 125
LocalInterrupt126	input	optional	Local interrupt 126
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
LR_address	output	optional	Port written with effective address for LR instruction
SC_address	output	optional	Port written with effective address for SC instruction
SC_valid	input	optional	SC_address valid input signal
AMO_active	output	optional	Port written with code indicating active AMO
deferint	input	optional	Artifact signal causing interrupts to be held off when high

Table 6.1: Net Ports

Chapter 7

FIFO Ports

This model has no FIFO ports.

Chapter 8

Formal Parameters

Name	Type	Description
Fundamental		
variant	Enumeration	Selects variant (either a generic UISA or a specific model)
user_version	Enumeration	Specify required User Architecture version (2.2, 2.3, 20190305 or 20191213)
priv_version	Enumeration	Specify required Privileged Architecture version (1.10, 1.11, 20190405, 20190608 or master)
endian	Endian	Model endian
enable_expanded	Boolean	Specify that 48-bit and 64-bit expanded instructions are supported
endianFixed	Boolean	Specify that data endianness is fixed (mstatus.{MBE,SBE,UBE} fields are read-only)
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)
sub_Extensions	String	Remove extensions specified by letters from misa.Extensions (for example, specify “VD” to remove 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)
sub_Extensions_mask	String	Remove extensions specified by letters from mask of writable bits in misa.Extensions (for example, specify “VD” to remove V and D features)
add_implicit_Extensions	String	Add extensions specified by letters to implicitly-present extensions not visible in misa.Extensions
sub_implicit_Extensions	String	Remove extensions specified by letters from implicitly-present extensions not visible in misa.Extensions
Zicsr	Boolean	Specify that Zicsr is implemented
Zifencei	Boolean	Specify that Zifencei is implemented
Zicbom	Boolean	Specify that Zicbom is implemented
Zicbop	Boolean	Specify that Zicbop is implemented
Zicboz	Boolean	Specify that Zicboz is implemented
Zmmul	Boolean	Specify that Zmmul is implemented
Bit Manipulation		
bitmanip_version	Enumeration	Specify required Bit Manipulation Architecture version (0.90, 0.91, 0.92, 0.93-draft, 0.93, 0.94, 1.0.0 or master)
Zba	Boolean	Specify that Zba is implemented (bit manipulation extension)
Zbb	Boolean	Specify that Zbb is implemented (bit manipulation extension)
Zbc	Boolean	Specify that Zbc is implemented (bit manipulation extension)
Zbe	Boolean	Specify that Zbe is implemented (bit manipulation extension; ignored if version 1.0.0)

Zbf	Boolean	Specify that Zbf is implemented (bit manipulation extension; ignored if version 1.0.0)
Zbm	Boolean	Specify that Zbm is implemented (bit manipulation extension; ignored if version 1.0.0)
Zbp	Boolean	Specify that Zbp is implemented (bit manipulation extension; ignored if version 1.0.0)
Zbr	Boolean	Specify that Zbr is implemented (bit manipulation extension; ignored if version 1.0.0)
Zbs	Boolean	Specify that Zbs is implemented (bit manipulation extension)
Zbt	Boolean	Specify that Zbt is implemented (bit manipulation extension; ignored if version 1.0.0)
Interrupts_Exceptions		
rnmi_version	Enumeration	Specify required RNMI Architecture version (none or 0.2.1)
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
ecode_mask	Uns64	Specify hardware-enforced mask of writable bits in xcause.ExceptionCode
ecode_nmi	Uns64	Specify xcause.ExceptionCode for NMI
ecode_nmi_mask	Uns64	Specify hardware-enforced mask of writable bits in mn-cause.ExceptionCode
tval_zero	Boolean	Specify whether mtval/stval/utval are hard wired to zero
tval_zero_ebreak	Boolean	Specify whether mtval/stval/utval are set to zero by an ebreak
tval_ii_code	Boolean	Specify whether mtval/stval contain faulting instruction bits on illegal instruction exception
trap_preserves_lr	Boolean	Whether a trap preserves active LR/SC state
xret_preserves_lr	Boolean	Whether an xret instruction preserves active LR/SC state
reset_address	Uns64	Override reset vector address
nmi_address	Uns64	Override NMI vector address
nmiexc_address	Uns64	Override RNMI exception vector address
CLINT_address	Uns64	Specify base address of internal CLINT model (or 0 for no CLINT)
mtime_Hz	Double	Specify clock frequency of CLINT mtime counter
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_e deleg	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
Fast Interrupt		
CLIC_version	Enumeration	Specify required CLIC version (20180831, 0.9-draft-20191208 or master)
mclicbase	Uns64	Override mclicbase register
CLICLEVELS	Uns32	Specify number of interrupt levels implemented by CLIC, or 0 if CLIC absent
CLICANDBASIC	Boolean	Whether original basic mode is also implemented
CLICVERSION	Uns32	Specify CLIC version
CLICINTCTLBITS	Uns32	Specify number of bits implemented in clicintctl[i]
CLICCFGLBITS	Uns32	Specify number of bits implemented for cliccfg.nlbts
CLICSELHVEC	Boolean	Whether selective hardware vectoring supported
CLICXNXTI	Boolean	Whether nxxti CSRs implemented
CLICXCSW	Boolean	Whether xscratchsw/xscratchswl CSRs implemented
externalCLIC	Boolean	Whether CLIC is implemented externally (if False, then use implementation in this model)
tv_t_undefined	Boolean	Specify that mtvt, stvt and utvt CSRs are undefined

intthresh_undefined	Boolean	Specify that mintthresh, sintthresh and uintthresh CSRs are undefined
mclicbase_undefined	Boolean	Specify that mclicbase CSR is undefined
posedge_0_63	Uns64	Mask of interrupts 0 to 63 that are fixed positive edge triggered
poslevel_0_63	Uns64	Mask of interrupts 0 to 63 that are fixed positive level triggered
posedge_other	Boolean	Whether interrupts 64 and above are fixed positive edge triggered
poslevel_other	Boolean	Whether interrupts 64 and above are fixed positive level triggered
Debug		
debug_mode	Enumeration	Specify how Debug mode is implemented (none, vector, interrupt or halt)
Simulation Artifact		
use_hw_reg_names	Boolean	Specify whether to use hardware register names x0-x31 and f0-f31 instead of ABI register names
verbose	Boolean	Specify verbose output messages
traceVolatile	Boolean	Specify whether volatile registers (e.g. minstret) should be shown in change trace
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>
Memory		
unaligned	Boolean	Specify whether the processor supports unaligned memory accesses
unalignedAMO	Boolean	Specify whether the processor supports unaligned memory accesses for AMO instructions
lr_sc_grain	Uns32	Specify byte granularity of ll/sc lock region (constrained to a power of two)
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)
PMP_decompose	Boolean	Whether unaligned PMP accesses are decomposed into separate aligned accesses
Instruction_CSR Behavior		
wfi_is_nop	Boolean	Specify whether WFI should be treated as a NOP (if not, halt while waiting for interrupts)
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
cycle_undefined	Boolean	Specify that the cycle CSR is undefined
time_undefined	Boolean	Specify that the time CSR is undefined
instret_undefined	Boolean	Specify that the instret CSR is undefined
hpmcounter_undefined	Boolean	Specify that the hpmcounter CSRs are undefined
CSR Masks		
mtvec_mask	Uns64	Specify hardware-enforced mask of writable bits in mtvec register
mtvt_mask	Uns64	Specify hardware-enforced mask of writable bits in CLIC mtvt register
mip_mask	Uns64	Specify hardware-enforced mask of writable bits in mip register
mtvec_sext	Boolean	Specify whether mtvec is sign-extended from most-significant bit
mtvt_sext	Boolean	Specify whether mtvt is sign-extended from most-significant bit
Trigger		
trigger_num	Uns32	Specify the number of implemented hardware triggers
CSR Defaults		
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

Compressed		
Zcea_version	Enumeration	Specify version of Zcea implemented (code-size reduction extension) (none or 0.50.1)
Zceb_version	Enumeration	Specify version of Zceb implemented (code-size reduction extension) (none or 0.50.1)
Zcee_version	Enumeration	Specify version of Zcee implemented (code-size reduction extension) (none or 1.0.0-rc)

Table 8.1: Parameters that can be set in: Hart

8.1 Extension Parameters

Name	Type	Description
FeatureDisable_Present	Boolean	Specify whether Feature Disable CSR present
BranchPredictionMode_Present	Boolean	Specify whether Branch Prediction Mode CSR present
PowerDial_Present	Boolean	Specify whether PowerDial CSR present
CFLUSH_Present	Boolean	Specify whether CFLUSH.D.L1 and CDISCARD.D.L1 instructions present
CEASE_Present	Boolean	Specify whether CEASE instruction present

Table 8.2: Parameters for sifiveExtensions

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 20191213
20190305	Deprecated and equivalent to 20191213
20191213	User Architecture Version 20191213

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 20190608
20190405	Deprecated and equivalent to 20190608
20190608	Privileged Architecture Version Ratified-IMFDQC-and-Priv-v1.11
master	Privileged Architecture Master Branch (1.12 draft)

Table 8.4: Values for Parameter priv_version

8.2.3 Parameter bitmanip_version

Set to this value	Description
0.90	Bit Manipulation Architecture Version v0.90-20190610
0.91	Bit Manipulation Architecture Version v0.91-20190829
0.92	Bit Manipulation Architecture Version v0.92-20191108

0.93-draft	Bit Manipulation Architecture Version 0.93-draft-20200129
0.93	Bit Manipulation Architecture Version v0.93-20210110
0.94	Bit Manipulation Architecture Version v0.94-20210120
1.0.0	Bit Manipulation Architecture Version 1.0.0
master	Bit Manipulation Master Branch as of commit 1f56afe (this is subject to change)

Table 8.5: Values for Parameter bitmanip_version

8.2.4 Parameter rnmi_version

Set to this value	Description
none	RNMI not implemented
0.2.1	RNMI version 0.2.1

Table 8.6: Values for Parameter rnmi_version

8.2.5 Parameter CLIC_version

Set to this value	Description
20180831	CLIC Version 20180831
0.9-draft-20191208	CLIC Version 0.9-draft-20191208
master	CLIC Master Branch as of commit dd15cd3 (this is subject to change)

Table 8.7: Values for Parameter CLIC_version

8.2.6 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 8.8: Values for Parameter debug_mode

8.2.7 Parameter Zcea_version

Set to this value	Description
none	Zcea not implemented
0.50.1	Zcea version 0.50.1

Table 8.9: Values for Parameter Zcea_version

8.2.8 Parameter Zceb_version

Set to this value	Description
none	Zceb not implemented
0.50.1	Zceb version 0.50.1

Table 8.10: Values for Parameter Zceb_version

8.2.9 Parameter Zcee_version

Set to this value	Description
none	Zcee not implemented
1.0.0-rc	Zcee version 1.0.0-rc

Table 8.11: Values for Parameter Zcee_version

8.3 Parameter values

These are the current parameter values.

Name	Value
Fundamental	
variant	E21
user_version	2.3
priv_version	1.11
endian	none
enable_expanded	F
endianFixed	F
misa_MXL	1
misa_Extensions	0x101107
add_Extensions	
sub_Extensions	
misa_Extensions_mask	0
add_Extensions_mask	
sub_Extensions_mask	
add_implicit_Extensions	
sub_implicit_Extensions	
Zicsr	T
Zifencei	T
Zicbom	F
Zicbop	F
Zicboz	F
Zmmul	F
Bit Manipulation	
bitmanip_version	0.94
Zba	T
Zbb	T
Zbc	F
Zbe	F
Zbf	F
Zbm	F
Zbp	F
Zbr	F
Zbs	F
Zbt	F

Interrupts_Exceptions	
rnmi_version	0.2.1
mtvec_is_ro	F
tvec_align	64
ecode_mask	31
ecode_nmi	2
ecode_nmi_mask	3
tval_zero	F
tval_zero_ebreak	F
tval_ii_code	T
trap_preserves_lr	F
xret_preserves_lr	F
reset_address	0
nmi_address	0
nmiexc_address	0
CLINT_address	0x2000000
mtime_Hz	3.276800e+04
local_int_num	127
unimp_int_mask	0
force_mideleg	0
no_ideleg	0
no_e deleg	0
external_int_id	F
Fast Interrupt	
CLIC_version	20180831
mclicbase	0x2800000
CLICLEVELS	16
CLICANDBASIC	T
CLICVERSION	17
CLICINTCTLBITS	5
CLICCFGLBITS	2
CLICSELHVEC	T
CLICXNXTI	T
CLICXCSW	F
externalCLIC	F
tvf_undefined	F
intthresh_undefined	T
mclicbase_undefined	T
posedge_0_63	0x100f
poslevel_0_63	0
posedge_other	F
poslevel_other	F
Debug	
debug_mode	none
Simulation Artifact	

use_hw_reg_names	F
verbose	F
traceVolatile	F
enable_CSR_bus	F
CSR_remap	
Memory	
unaligned	F
unalignedAMO	F
lr_sc_grain	64
PMP_grain	0
PMP_registers	8
PMP_max_page	0
PMP_decompose	F
Instruction_CSR_Behavior	
wfi_is_nop	F
counteren_mask	0xffffffff
noinhibit_mask	0
cycle_undefined	F
time_undefined	T
instret_undefined	F
hpmcounter_undefined	F
CSR_Masks	
mtvec_mask	0
mtvt_mask	0
mip_mask	0x337
mtvec_sext	F
mtvt_sext	F
Trigger	
trigger_num	0
CSR_Defaults	
mvendorid	0x489
marchid	0x80000002
mimpid	0x4210427
mhartid	0
mtvec	0
Compressed	
Zcea_version	none
Zceb_version	none
Zcee_version	none
sifiveExtensions	
FeatureDisable_Present*	F
BranchPredictionMode_Present*	F
PowerDial_Present*	F
CFLUSH_Present*	F
CEASE_Present*	F

Table 8.12: Parameter values

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

Chapter 9

Execution Modes

Mode	Code	Description
User	0	User mode
Machine	3	Machine 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
EnvironmentCallFromUMode	8	ECALL instruction executed in User mode
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
CSIP	76	CLIC software 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
LocalInterrupt16	96	Local interrupt 16
LocalInterrupt17	97	Local interrupt 17
LocalInterrupt18	98	Local interrupt 18
LocalInterrupt19	99	Local interrupt 19
LocalInterrupt20	100	Local interrupt 20
LocalInterrupt21	101	Local interrupt 21
LocalInterrupt22	102	Local interrupt 22
LocalInterrupt23	103	Local interrupt 23
LocalInterrupt24	104	Local interrupt 24
LocalInterrupt25	105	Local interrupt 25
LocalInterrupt26	106	Local interrupt 26
LocalInterrupt27	107	Local interrupt 27
LocalInterrupt28	108	Local interrupt 28
LocalInterrupt29	109	Local interrupt 29
LocalInterrupt30	110	Local interrupt 30
LocalInterrupt31	111	Local interrupt 31
LocalInterrupt32	112	Local interrupt 32
LocalInterrupt33	113	Local interrupt 33
LocalInterrupt34	114	Local interrupt 34
LocalInterrupt35	115	Local interrupt 35
LocalInterrupt36	116	Local interrupt 36
LocalInterrupt37	117	Local interrupt 37
LocalInterrupt38	118	Local interrupt 38
LocalInterrupt39	119	Local interrupt 39
LocalInterrupt40	120	Local interrupt 40
LocalInterrupt41	121	Local interrupt 41
LocalInterrupt42	122	Local interrupt 42
LocalInterrupt43	123	Local interrupt 43
LocalInterrupt44	124	Local interrupt 44
LocalInterrupt45	125	Local interrupt 45
LocalInterrupt46	126	Local interrupt 46
LocalInterrupt47	127	Local interrupt 47
LocalInterrupt48	128	Local interrupt 48
LocalInterrupt49	129	Local interrupt 49
LocalInterrupt50	130	Local interrupt 50
LocalInterrupt51	131	Local interrupt 51
LocalInterrupt52	132	Local interrupt 52
LocalInterrupt53	133	Local interrupt 53
LocalInterrupt54	134	Local interrupt 54
LocalInterrupt55	135	Local interrupt 55

LocalInterrupt56	136	Local interrupt 56
LocalInterrupt57	137	Local interrupt 57
LocalInterrupt58	138	Local interrupt 58
LocalInterrupt59	139	Local interrupt 59
LocalInterrupt60	140	Local interrupt 60
LocalInterrupt61	141	Local interrupt 61
LocalInterrupt62	142	Local interrupt 62
LocalInterrupt63	143	Local interrupt 63
LocalInterrupt64	144	Local interrupt 64
LocalInterrupt65	145	Local interrupt 65
LocalInterrupt66	146	Local interrupt 66
LocalInterrupt67	147	Local interrupt 67
LocalInterrupt68	148	Local interrupt 68
LocalInterrupt69	149	Local interrupt 69
LocalInterrupt70	150	Local interrupt 70
LocalInterrupt71	151	Local interrupt 71
LocalInterrupt72	152	Local interrupt 72
LocalInterrupt73	153	Local interrupt 73
LocalInterrupt74	154	Local interrupt 74
LocalInterrupt75	155	Local interrupt 75
LocalInterrupt76	156	Local interrupt 76
LocalInterrupt77	157	Local interrupt 77
LocalInterrupt78	158	Local interrupt 78
LocalInterrupt79	159	Local interrupt 79
LocalInterrupt80	160	Local interrupt 80
LocalInterrupt81	161	Local interrupt 81
LocalInterrupt82	162	Local interrupt 82
LocalInterrupt83	163	Local interrupt 83
LocalInterrupt84	164	Local interrupt 84
LocalInterrupt85	165	Local interrupt 85
LocalInterrupt86	166	Local interrupt 86
LocalInterrupt87	167	Local interrupt 87
LocalInterrupt88	168	Local interrupt 88
LocalInterrupt89	169	Local interrupt 89
LocalInterrupt90	170	Local interrupt 90
LocalInterrupt91	171	Local interrupt 91
LocalInterrupt92	172	Local interrupt 92
LocalInterrupt93	173	Local interrupt 93
LocalInterrupt94	174	Local interrupt 94
LocalInterrupt95	175	Local interrupt 95
LocalInterrupt96	176	Local interrupt 96
LocalInterrupt97	177	Local interrupt 97
LocalInterrupt98	178	Local interrupt 98
LocalInterrupt99	179	Local interrupt 99
LocalInterrupt100	180	Local interrupt 100

LocalInterrupt101	181	Local interrupt 101
LocalInterrupt102	182	Local interrupt 102
LocalInterrupt103	183	Local interrupt 103
LocalInterrupt104	184	Local interrupt 104
LocalInterrupt105	185	Local interrupt 105
LocalInterrupt106	186	Local interrupt 106
LocalInterrupt107	187	Local interrupt 107
LocalInterrupt108	188	Local interrupt 108
LocalInterrupt109	189	Local interrupt 109
LocalInterrupt110	190	Local interrupt 110
LocalInterrupt111	191	Local interrupt 111
LocalInterrupt112	192	Local interrupt 112
LocalInterrupt113	193	Local interrupt 113
LocalInterrupt114	194	Local interrupt 114
LocalInterrupt115	195	Local interrupt 115
LocalInterrupt116	196	Local interrupt 116
LocalInterrupt117	197	Local interrupt 117
LocalInterrupt118	198	Local interrupt 118
LocalInterrupt119	199	Local interrupt 119
LocalInterrupt120	200	Local interrupt 120
LocalInterrupt121	201	Local interrupt 121
LocalInterrupt122	202	Local interrupt 122
LocalInterrupt123	203	Local interrupt 123
LocalInterrupt124	204	Local interrupt 124
LocalInterrupt125	205	Local interrupt 125
LocalInterrupt126	206	Local interrupt 126

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 4 commands.

This level in the model hierarchy has 5 register groups:

Group name	Registers
Core	33
User_Control_and_Status	62
Machine_Control_and_Status	133
CLINT	3
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 getCSRIndex

Return index for a named CSR (or -1 if no matching CSR)

Argument	Type	Description
-name	String	CSR name

Table 12.1: getCSRIndex command arguments

12.1.2 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 12.2: isync command arguments

12.1.3 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
-memory	String	show memory accesses by this instruction. Argument can be any combination of X (execute), L (load or store access) and S (system)
-off	Boolean	disable instruction tracing

-on	Boolean	enable instruction tracing
-processorname	Boolean	Include processor name in all trace lines
-registerchange	Boolean	show registers changed by this instruction
-registers	Boolean	show registers after each trace

Table 12.3: itrace command arguments

12.1.4 listCSRs

12.1.4.1 Argument description

List all CSRs in index order

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 User_Control_and_Status

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

Name	Bits	Initial-Hex	RW	Description
cycle	32	0	r-	Cycle Counter
instret	32	0	r-	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	r-	Cycle Counter High
instreth	32	0	r-	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

Table 13.2: Registers at level 1, type:Hart group:User_Control_and_Status

13.1.3 Machine_Control_and_Status

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

Name	Bits	Initial-Hex	RW	Description
mstatus	32	0	rw	Machine Status
misa	32	40101107	rw	ISA and Extensions
mie	32	0	rw	Machine Interrupt Enable
mtvec	32	0	rw	Machine Trap-Vector Base-Address
mcounteren	32	0	rw	Machine Counter Enable
mtvt	32	0	rw	Machine CLIC Trap-Vector Base-Address
mcounthinhibit	32	0	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	0	rw	Machine Trap Value
mip	32	80	rw	Machine Interrupt Pending
mnxti	32	0	rw	Machine Interrupt Handler Address/Enable
mintstatus	32	0	rw	Machine Interrupt Status
mnscratch	32	0	rw	Machine RNMI Scratch
mnepc	32	0	rw	Machine RNMI Program Counter
mncause	32	0	rw	Machine RNMI Cause
mnstatus	32	8	rw	Machine RNMI Status
pmpcfg0	32	0	rw	Physical Memory Protection Configuration 0
pmpcfg1	32	0	rw	Physical Memory Protection Configuration 1
pmpcfg2	32	0	rw	Physical Memory Protection Configuration 2
pmpcfg3	32	0	rw	Physical Memory Protection Configuration 3
pmpaddr0	32	0	rw	Physical Memory Protection Address 0
pmpaddr1	32	0	rw	Physical Memory Protection Address 1
pmpaddr2	32	0	rw	Physical Memory Protection Address 2
pmpaddr3	32	0	rw	Physical Memory Protection Address 3
pmpaddr4	32	0	rw	Physical Memory Protection Address 4
pmpaddr5	32	0	rw	Physical Memory Protection Address 5
pmpaddr6	32	0	rw	Physical Memory Protection Address 6
pmpaddr7	32	0	rw	Physical Memory Protection Address 7
pmpaddr8	32	0	rw	Physical Memory Protection Address 8
pmpaddr9	32	0	rw	Physical Memory Protection Address 9
pmpaddr10	32	0	rw	Physical Memory Protection Address 10
pmpaddr11	32	0	rw	Physical Memory Protection Address 11
pmpaddr12	32	0	rw	Physical Memory Protection Address 12
pmpaddr13	32	0	rw	Physical Memory Protection Address 13
pmpaddr14	32	0	rw	Physical Memory Protection Address 14
pmpaddr15	32	0	rw	Physical Memory Protection Address 15
mcycle	32	0	rw	Machine Cycle Counter
minstret	32	0	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	0	rw	Machine Cycle Counter High
minstreth	32	0	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
mhpmpcounterh23	32	0	rw	Machine Performance Monitor Counter High 23
mhpmpcounterh24	32	0	rw	Machine Performance Monitor Counter High 24
mhpmpcounterh25	32	0	rw	Machine Performance Monitor Counter High 25
mhpmpcounterh26	32	0	rw	Machine Performance Monitor Counter High 26
mhpmpcounterh27	32	0	rw	Machine Performance Monitor Counter High 27
mhpmpcounterh28	32	0	rw	Machine Performance Monitor Counter High 28
mhpmpcounterh29	32	0	rw	Machine Performance Monitor Counter High 29
mhpmpcounterh30	32	0	rw	Machine Performance Monitor Counter High 30
mhpmpcounterh31	32	0	rw	Machine Performance Monitor Counter High 31
mvendorid	32	489	r-	Vendor ID
marchid	32	80000002	r-	Architecture ID
mimpid	32	4210427	r-	Implementation ID
mhartid	32	0	r-	Hardware Thread ID

Table 13.3: Registers at level 1, type:Hart group:Machine_Control_and_Status

13.1.4 CLINT

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

Name	Bits	Initial-Hex	RW	Description
msip	8	0	rw	CLINT msip
mtimecmp	64	0	rw	CLINT mtimecmp
mtime	64	0	rw	CLINT mtime

Table 13.4: Registers at level 1, type:Hart group:CLINT

13.1.5 Integration_support

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

Name	Bits	Initial-Hex	RW	Description
LRSCAddress	32	ffffff	rw	LR/SC active lock address
commercial	8	0	r-	Commercial feature in use

Table 13.5: Registers at level 1, type:Hart group:Integration_support