**RISC-V RV32IM ISA Reference Sheet v1.5**

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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 31 | 25 | 24 | 20 | 19 | 15 | 14 | 12 | 11 | 7 | 6 | 0 |  |
| funct7 | | rs2 | | rs1 | | funct3 | | rd | | opcode | | R-type |
| imm[11:0] | | | | rs1 | | funct3 | | rd | | opcode | | I-type |
| imm[11:5] | | rs2 | | rs1 | | funct3 | | imm[4:0] | | opcode | | S-type |
| imm[12,10:5] | | rs2 | | rs1 | | funct3 | | imm[4:1,11] | | opcode | | B-type |
| imm[31:12] | | | | | | | | rd | | opcode | | U-type |
| imm[20,10:1,11,19:12] | | | | | | | | rd | | opcode | | J-type |

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| --- | --- | --- | --- |
| reg | alias | reg | alias |
| x0 | zero | x5-x7 | t0-t2 |
| x1 | ra | x8, x9 | s0/fp, s1 |
| x2 | sp | x10-x17 | a0-a7 |
| x3 | gp | x18-x27 | s2-s11 |
| x4 | tp | x28-x31 | t3-t6 |

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| --- | --- | --- | --- | --- | --- |
| instruction | fmt | opcode | fun3 | fun7 | semantics |
| lui rd,imm20 | U | **6’h**37 |  |  | rd = imm20 << 12 |
| auipc rd,imm20 | U | 17 |  |  | rd = pc + (imm20 << 12) |
| addi rd,rs1,imm12 | I | 13 | 000 |  | rd = rs1 + se(imm12) |
| slti rd,rs1,imm12 | I | 13 | 010 |  | rd = rs1 <signed se(imm12) ? 1 : 0 |
| sltiu rd,rs1,imm12 | I | 13 | 011 |  | rd = rs1 <unsign se(imm12) ? 1 : 0 |
| xori rd,rs1,imm12 | I | 13 | 100 |  | rd = rs1 ^ se(imm12) |
| ori rd,rs1,imm12 | I | 13 | 110 |  | rd = rs1 | se(imm12) |
| andi rd,rs1,imm12 | I | 13 | 111 |  | rd = rs1 & se(imm12) |
| slli rd,rs1,imm12 | I | 13 | 001 | 0x0 | rd = rs1 << imm12[4:0] |
| srli rd,rs1,imm12 | I | 13 | 101 | 0x0 | rd = rs1 >> imm12[4:0] |
| srai rd,rs1,imm12 | I | 13 | 101 | 0x20 | rd = rs1 >>> imm12[4:0] |
| add rd,rs1,rs2 | R | 33 | 000 | 0x0 | rd = rs1 + rs2 |
| sub rd,rs1,rs2 | R | 33 | 000 | 0x20 | rd = rs1 – rs2 |
| sll rd,rs1,rs2 | R | 33 | 001 | 0x0 | rd = rs1 << rs2[4:0] |
| slt rd,rs1,rs2 | R | 33 | 010 | 0x0 | rd = rs1 <signed rs2 ? 1 : 0 |
| sltu rd,rs1,rs2 | R | 33 | 011 | 0x0 | rd = rs1 <unsign rs2 ? 1 : 0 |
| xor rd,rs1,rs2 | R | 33 | 100 | 0x0 | rd = rs1 ^ rs2 |
| srl rd,rs1,rs2 | R | 33 | 101 | 0x0 | rd = rs1 >> rs2[4:0] |
| sra rd,rs1,rs2 | R | 33 | 101 | 0x20 | rd = rs1 >>> rs2[4:0] |
| or rd,rs1,rs2 | R | 33 | 110 | 0x0 | rd = rs1 | rs2 |
| and rd,rs1,rs2 | R | 33 | 111 | 0x0 | rd = rs1 & rs2 |
| lb rd,imm12(rs1) | I | 03 | 000 |  | rd = se(mem[rs1+se(imm12)][7:0]) |
| lh rd,imm12(rs1) | I | 03 | 001 |  | rd = se(mem[rs1+se(imm12)][15:0]) |
| lw rd,imm12(rs1) | I | 03 | 010 |  | rd = mem[rs1+se(imm12)][31:0] |
| lbu rd,imm12(rs1) | I | 03 | 100 |  | rd = ze(mem[rs1+se(imm12)][7:0]) |
| lhu rd,imm12(rs1) | I | 03 | 101 |  | rd = ze(mem[rs1+se(imm12)][15:0]) |
| sb rs2,imm12(rs1) | S | 23 | 000 |  | mem[rs1+se(imm12)][7:0] = rs2[7:0] |
| sh rs2,imm12(rs1) | S | 23 | 001 |  | mem[rs1+se(imm12)][15:0] = rs2[15:0] |
| sw rs2,imm12(rs1) | S | 23 | 010 |  | mem[rs1+se(imm12)][31:0] = rs2 |
| jal rd,targ20 | J | 6f |  |  | rd = pc+4; pc += se(targ20<<1) |
| jalr rd,imm12(rs1) | I | 67 | 000 |  | rd = pc+4; pc = (rs1+se(imm12)) & ~0x1 |
| beq rs1,rs2,targ12 | B | 63 | 000 |  | if (rs1 == rs2) pc += se(targ12<<1) |
| bne rs1,rs2,targ12 | B | 63 | 001 |  | if (rs1 != rs2) pc += se(targ12<<1) |
| blt rs1,rs2,targ12 | B | 63 | 100 |  | if (rs1 <signed rs2) pc += se(targ12<<1) |
| bge rs1,rs2,targ12 | B | 63 | 101 |  | if (rs1 ≥signed rs2) pc += se(targ12<<1) |
| bltu rs1,rs2,targ12 | B | 63 | 110 |  | if (rs1 <unsign rs2) pc += se(targ12<<1) |
| bgeu rs1,rs2,targ12 | B | 63 | 111 |  | if (rs1 ≥unsign rs2) pc += se(targ12<<1) |
| ecall | I | 73 | insn[31:7]==0 | | transfer control to OS |
| fence |  | 0f | 000 | varies | order data and I/O memory operations |
| fence.i |  | 0f | 001 | 0x0 | order data memory writes and instruction memory fetch |
| mul rd,rs1,rs2 | R | 33 | 000 | 0x01 | rd = (rs1 \* rs2)[31:0] |
| mulh rd,rs1,rs2 | R | 33 | 001 | 0x01 | rd = (signed(rs1) \* signed(rs2))[63:32] |
| mulhsu rd,rs1,rs2 | R | 33 | 010 | 0x01 | rd = (signed(rs1) \* unsign(rs2))[63:32] |
| mulhu rd,rs1,rs2 | R | 33 | 011 | 0x01 | rd = (unsign(rs1) \* unsign(rs2))[63:32] |
| div rd,rs1,rs2 | R | 33 | 100 | 0x01 | rd = rs1 /signed rs2 |
| divu rd,rs1,rs2 | R | 33 | 101 | 0x01 | rd = rs1 /unsign rs2 |
| rem rd,rs1,rs2 | R | 33 | 110 | 0x01 | rd = rs1 %signed rs2 |
| remu rd,rs1,rs2 | R | 33 | 111 | 0x01 | rd = rs1 %unsign rs2 |

Register Map

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| reg | alias | description | saver | reg | alias | description | saver |
| x0 | zero | hard-wired zero |  | t7 | t2 | temporary | caller |
| x1 | ra | return address | caller | x8 | s0/fp | saved reg/frame pointer | callee |
| x2 | sp | stack pointer | callee | x9 | s1 | saved reg | callee |
| x3 | gp | global pointer |  | x10-x11 | a0-a1 | function args/return values | caller |
| x4 | tp | thread pointer |  | x12-x17 | a2-a7 | function args | caller |
| x5 | t0 | temporary/alt link reg | caller | x18-x27 | s2-s11 | saved regs | callee |
| x6 | t1 | temporary | caller | x28-x31 | t3-t6 | temporaries | caller |

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| --- | --- | --- |
| pseudoinstruction | base instruction(s) | meaning |
| la rd,symbol | auipc rd,symbol[31:12]  addi rd,rd,symbol[11:0] | load address |
| l{b|h|w|d} rd,symbol | auipc rd,symbol[31:12] l{b|h|w|d} rd,symbol[11:0](rd) | load global |
| s{b|h|w|d} rd,symbol,rt | auipc rt,symbol[31:12] s{b|h|w|d} rd,symbol[11:0](rt) | store global |
| nop | addi x0,x0,0 | no operation |
| li rd,immediate | lui and/or addi | load immediate |
| mv rd,rs | addi rd,rs,0 | copy register |
| not rd,rs | xori rd,rs,-1 | one’s complement |
| neg rd,rs | sub rd,x0,rs | two’s complement |
| seqz rd,rs | subw rd,x0,rs | set if = zero |
| snez rd,rs | addiw rd,rs,0 | set if ≠ zero |
| sltz rd,rs | sltiu rd,rs,1 | set if < zero |
| sgtz rd,rs | sltu rd,x0,rs | set if > zero |
| beqz rs,target | beq rs,x0,target | branch if = zero |
| bnez rs,target | bne rs,x0,target | branch if ≠ zero |
| blez rs,target | bge x0,rs,target | branch if ≤ zero |
| bgez rs,target | bge rs,x0,target | branch if ≥ zero |
| bltz rs,target | blt rs,x0,target | branch if < zero |
| bgtz rs,target | blt x0,rs,target | branch if > zero |
| bgt rs,rt,target | blt rt,rs,target | branch if > |
| ble rs,rt,target | bge rt,rs,target | branch if ≤ |
| bgtu rs,rt,target | bltu rt,rs,target | branch if >, unsigned |
| bleu rs,rt,target | bgeu rt,rs,target | branch if ≤, unsigned |
| j target | jal x0,target | jump |
| jal target | jal x1,target | jump and link |
| jr rs | jalr x0,rs,0 | jump register |
| jalr rs | jalr x1,rs,0 | jump and link register |
| ret | jalr x0,x1,0 | return from subroutine |
| call target | auipc x6,target[31:12] jalr x1,x6,target[11:0] | call far-away subroutine |
| tail target | auipc x6,target[31:12] jalr x0,x6,target[11:0] | tail call far-away subroutine |
| fence | fence iorw,iorw | fence on all memory and I/O |

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| AXI-Lite Signals  orange signals are **to**subordinate (from manager), others **from** subordinate (to manager) | | | | | |
| Clock/Reset | Address Read request | Read response | Address Write request | Write data request | Write response |
| ACLK | ARREADY | RREADY | AWREADY | WREADY | BREADY |
| ARESETn | ARVALID | RVALID | AWVALID | WVALID | BVALID |
|  | ARADDR | RDATA | AWADDR | WDATA | BRESP |
|  | ARPROT | RRESP | AWPROT | WSTRB |  |